May 26, 1942. J. M. MANLEY ET AL 2,284,402

MODULATION CIRCUIT

Filed Aug. 27, 1940

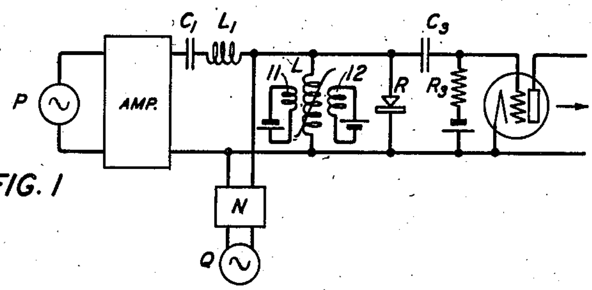


FIG. 1

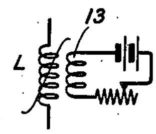


FIG. 6

FIG. 2

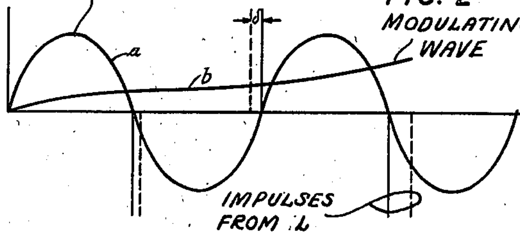


FIG. 4

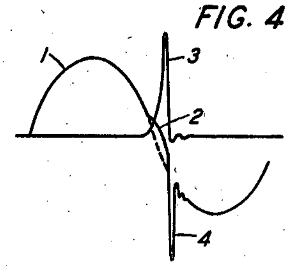


FIG. 3

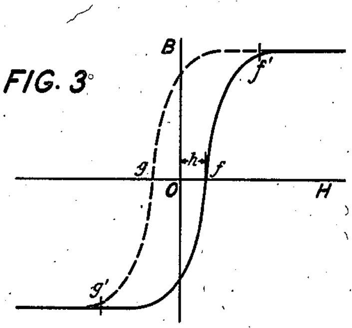


FIG. 5

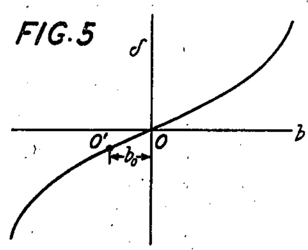


FIG. 7

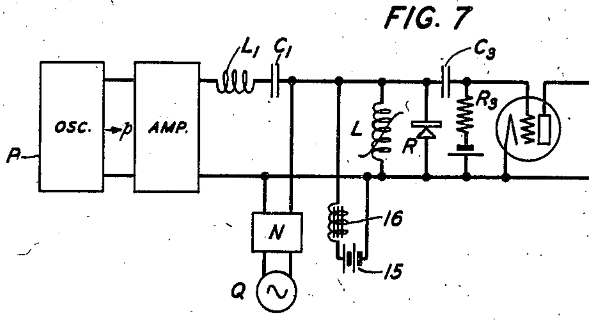


FIG. 8

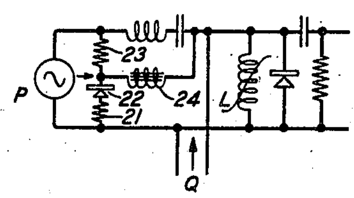
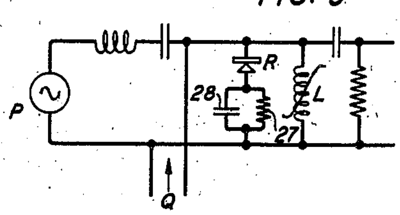


FIG. 9



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MODULATION CIRCUIT

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Application August 27, 1940, Serial No. 354,373

9 Claims. (Cl. 179—171.5)

This invention relates to modulation of carrier frequencies for radio or other signal transmission purposes and, more particularly, to phase modulation of a carrier frequency. The invention is applicable to such phase modulation circuits as are shown in the copending application of Wrathall, Serial No. 354,357, filed August 27, 1940, and its purpose is to improve phase modulation by providing means to neutralize certain distortion effects present in some forms of such modulation circuits. The invention will be better understood by reference to the following specification and the accompanying drawing, in which:

Fig. 1 shows a circuit adapted to operate in accordance with our invention;

Figs. 2 to 5 are curves explanatory of our invention;

Fig. 6 shows a modification of a portion of the circuit of Fig. 1; and

Figs. 7 to 9 show further modifications of Fig. 1.

Referring more particularly to Fig. 1, there is shown a source P of carrier frequency which is associated with a circuit containing condenser C_1, linear inductance L_1 and non-linear inductance L. Across the non-linear inductance L are connected in series the condenser C_3 and resistance R_3 and as thus described the circuit constitutes the circuit for the magnetic harmonic generator described in the copending application referred to.

When the magnetizing force of the input wave is $P \cos (pt+\theta)$, as in curve *a* of Fig. 2, the output of the coil consists of a periodic succession of pulses, as indicated by the vertical solid lines. Analysis shows that this group of sharp impulses consists of a large number of harmonic terms, the frequency of which can be represented by $np/2\pi$ where $p/2\pi$ is the frequency of the source P and n takes on successive integral values. If now a biasing magnetizing force of magnitude b, such as curve b of Fig. 2, is added to the non-linear coil L, analysis shows that the forms of these pulses are unchanged and that to a reasonable approximation the heights of the pulses are unchanged. The principal effect of the bias is to shift the phase of each pulse by an amount δ from the solid line positions to the dotted line positions shown in Fig. 2. Calculation further shows that this phase shift is nearly proportional to b/P, provided that b is small compared to P. Within a relatively narrow region of phase displacements the relation is expressed by $\delta=-b/P$.

If the bias is now varied sinusoidally at a signal frequency, then it is found that

$$\delta=-\frac{Q}{P}\sin qt$$

where Q is the amplitude of the signal and $q/2\pi$ is its frequency. The extent of the shift of pulses in Fig. 2 is approximately proportional to the instantaneous value of the modulating signal wave so long as this value is kept small compared with P. Analysis of this succession of variably displaced pulses shows that it consists of harmonics of q and p and side-band frequencies $(np\pm mq)/2\pi$ but only those frequencies are present for which $(m+n)$ is odd, this being so because of the odd function property of the magnetic characteristic.

As pointed out in the copending application referred to above, any one of the carrier frequencies, corresponding to different values of n, with its side-bands takes on some of the characteristics of a phase modulated wave but is defective because of the absence of certain side-bands. Also as pointed out in the copending application, this defect can be overcome by suppressing one set of peaks, such as the lower peaks of Fig. 2, which suppression serves the purpose of introducing the otherwise absent side-bands. One method of suppression of the undesired peaks is by the insertion of a rectifier R across the load circuit, as shown in Fig. 1.

In our investigations we have found that certain distortion effects appear in the output of the modulating device. One of these is due to the hysteresis which is characteristic of the iron forming the core of the coil L. The hysteresis loop of such a core is illustrated in the B—H curve of Fig. 3. We find that, whereas it is desirable that the peaks should occur at times corresponding to the zero value of H, actually they are displaced due to hysteresis by an amount so that they would occur at points f and g of Fig. 3, that is, at the points corresponding to zero value of the magnetic induction, and thus the phase displacement of the pulses is not quite in accordance with the simple relationships given above. The phase displacement would, as a matter of fact, be given by

$$\delta=-\frac{b-(of)}{P}$$

for the pulse occurring at f. In this Fig. 3 one branch of the hysteresis loop is shown as a full line and the other branch as a dotted line. The interest is confined to one of these, say the full line, inasmuch as the peaks due to the other branch are to be suppressed by the rectifier R.

We have found that we can correct for the distortion due to this time displacement of the pulse in a number of ways. For example, an additional winding 11 on the coil L may be used, this winding being supplied with a small direct current to shift the timing of the pulse from that corresponding to f to that corresponding to zero magnetizing force at o. The direction of this current will depend primarily on the poling of the rectifier which suppresses the unwanted peaks. Such a direct current will also, of course, shift the time of the pulse corresponding to the point g in the same direction but this has no deleterious effect for the reason that the rectifier R suppresses the peaks corresponding to that point.

There is a second distortion effect which we find present, due to the timing of the pulses with respect to the exciting current. This will be better understood by reference to Fig. 4, which is for somewhat idealized conditions but is qualitatively descriptive of what occurs. If, in this figure, the full line **1** represents the current from the exciting source flowing through the coil L, then the period of maximum reactance of the coil is in the region **2** where the current is near its zero value but has its maximum rate of change. The induced electromotive force in the coil may at that time be represented by the pulse wave **3** and it is for the duration of this voltage peak that the condenser C_3 is charged. At the close of this period, as the core reaches its saturation condition and its reactance falls to a very low value, the condenser C_3 discharges in a manner indicated qualitatively by the peak **4**. In other words, this condenser discharge tends to take place at the knee of the magnetization curve, that is at f' or g' of Fig. 3. It will be noted that this delay in timing of the peak, resulting from the discharge of the condenser, is in the same direction as the delay due to the hysteresis. Thus the accompanying distortion may be corrected by an additional direct current biasing effect such as might be provided by an additional winding **12** on the coil L. Again it will be observed that the shift of one of the pulses to g' is of no significance inasmuch as the pulse corresponding to this point is suppressed by the rectifier R.

A further explanation of the invention will be apparent by reference to Fig. 5 in which the curve gives the relationship between the phase displacement δ and the signal biasing voltage b, this being for ideal conditions where the distortions referred to above are not present. Since it is desirable in the operation of this modulator that δ shall be linearly proportional to b, it is evident that operation should be limited to the linear portion of the curve of Fig. 5. In view of the distortions referred to above, the timing of the pulses is so delayed that one effectively operates about the point o' instead of the point o on the curve of Fig. 5. Thus the range over which δ is proportional to b is decreased on the one side and increased on the other, so limiting the permissible amplitude of signal wave which can be used without producing further distortion. In order to operate over as wide a linear range as possible, it is evident that one should shift the origin about which operation takes place to the mid-point of the linear portion of the curve of Fig. 5, that is, to the point o, and this can be accomplished by a biasing current corresponding to b_0. It is this shift which is contemplated by the biasing currents of Fig. 1.

While in Fig. 1 the coils **11** and **12** have been shown as separate, for a better understanding of the invention, actually in practice one would use but one coil such as coil **13** of Fig. 6, the magnitude of the current flowing through that coil being adjusted to give the desired bias.

Still other expedients for obtaining this bias may be desirable, such as shown in Figs. 7 to 9. For example, in the circuits of Figs. 1 and 6 and with the high frequencies contemplated, the additional coils would in themselves introduce various losses due to parasitic capacitances, etc. In Fig. 7 the biasing current flows through the main winding itself of coil L, the biasing current coming from a battery **15**. A choke coil **16** is included in the circuit of sufficient magnitude to prevent appreciable flow therethrough of the signal current, the carrier frequency and its harmonics.

Fig. 8 shows a further modification of Fig. 1, the biasing current in this case being obtained by rectifying a small portion of the carrier frequency. To this end a rectifier **21** in series with resistances **22** and **23** is bridged across the terminals of the generator. A choke coil **24** is connected from one side of the rectifier in one terminal of the coil L. This will give rise to a small direct current through the coil L in the proper direction to correct distortions of the wanted peaks.

Fig. 9 shows a further modification of Fig. 1 in which the bias is obtained from the direct current due to the rectifier which is inserted for removing the one set of pulses. In Fig. 9 there is shown in series with the suppressing rectifier R a resistance **27** and condenser **28** in parallel. The condenser **28** is of sufficient capacity to offer low impedance to the carrier frequency and its harmonics which make up one of the peaks. It is noteworthy that with this circuit connection the direct current component will flow in the right direction through L to give the desired biasing effect.

It should be mentioned that we find the amount of distortion increases as the amplitude of the exciting base frequency increases. Accordingly, the correcting biasing current should also increase. The circuits of Fig. 8 and Fig. 9 automatically make this provision in that as the amplitude of the source P increases, the rectified current also increases.

In the description above, reference has been made to correction for two distortion effects. One of these is due to the tendency of the pulses to be moved towards the point f' of Fig. 3, as explained in connection with Fig. 4. This condition exists in one form of the modulating circuit described in the copending application to Wrathall, referred to above, where the peak arises essentially from the discharge of the condenser C_3. In another form of operation described in the Wrathall application, C_3 is made very large and R_3 is also made large. In this case the current flowing through R_3 is very small and the voltage across it is substantially the same as that across the coil L corresponding to the curve **3** of Fig. 4. At no time is there any appreciable voltage present in the condenser C_3. In this mode of operation, which we have called open circuit operation, the distortion arising from the shift from f to f' is not present and the correction is then mainly confined to that due to hysteresis.

What is claimed is:

1. In a phase modulating frequency multiplying system, a source of base frequency waves, a harmonic generator excited thereby, a source of signal waves, means to impress the signal waves upon said generator to produce phase modulated waves of high frequencies relative to said base frequency, said generator possessing inherent tendency toward unsymmetrical operation with consequent tendency toward production of distortion in the modulated waves, direct current biasing means for applying a bias to said gen-

erator that is small in comparison with the maximum amplitude of the signal wave and of a magnitude and polarity such as to compensate said distortion, and means to utilize the phase modulated waves for signal transmission.

2. In a phase modulating system, a source of base frequency waves, a magnetic harmonic generator comprising a non-linear coil excited thereby, a source of signal waves, means to impress the signal waves upon the generator to produce phase modulated waves of carrier frequencies, said generator tending to produce distortion in the modulated waves, a direct current biasing winding associated with the coil for biasing said generator by an amount that is small in comparison with the peak amplitude of the signal waves and of such magnitude and polarity as to neutralize distortion effects in the harmonic generator and a circuit for utilizing the phase modulated waves.

3. In a phase modulating system, a source of base frequency waves, a magnetic harmonic generator comprising a non-linear coil excited thereby, a source of signal waves associated with the generator to produce phase modulated waves of carrier frequencies, said generator tending to produce distortion in the modulated waves due to hysteresis effects, and means for applying a relatively small magnetic bias to said generator, sufficient to shift the operating point within the total range of magnetization covered by the amplitude range of the signal by such amount and in such direction as to compensate said distortion.

4. In a phase modulating system, a source of base frequency waves, a magnetic harmonic generator comprising a non-linear coil excited thereby, a source of signal waves, means to apply said base frequency waves and said signal waves to said generator to produce output impulses, means to derive from said output impulses carrier frequency waves whose phase is modulated in accordance with said signal waves, said base frequency waves being of sufficient amplitude to swing past the knee of the magnetization curve of said generator, whereby the system tends to shift the timing of the output impulses and cause distortion of the modulated waves, and means to apply a relatively small unidirectional bias in said coil of such magnitude and direction as to compensate said distortion.

5. In a phase modulating system, a source of base frequency, a magnetic harmonic generator comprising a non-linear coil excited thereby, a source of signal waves, means to impress said signal waves upon the generator to produce phase modulated waves of carrier frequencies, a load circuit coupled to said coil and including a resistance and a capacity of such magnitudes that the capacity has appreciable charging time, a unilateral impedance element shunted across the coil to suppress impulses of one polarity, and means for applying a magnetic bias to the core of the coil to neutralize distortion due to hysteresis of the coil core and due to the delay of the condenser discharge in the load circuit of the harmonic generator because of its charging time.

6. In a system for obtaining phase modulated carrier frequency waves comprising a source of base frequency, a magnetic harmonic generator comprising a non-linear coil excited thereby, a load circuit associated with the coil including a series condenser and resistance, a source of signal waves associated with the coil in parallel to the source of base frequency whereby there are generated positive and negative pulses of a frequency corresponding to the base frequency and displaced in phase in accordance with the amplitude of the signal wave, means associated with the coil for suppressing peaks of one sign whereby there is produced in the circuit a plurality of harmonic carrier frequencies each of which is phase modulated in accordance with the signal wave, and means associated with the circuit to neutralize distortion effects in the coil arising from the hysteresis of the coil core and the delay of the condenser discharge in the output circuit associated with the non-linear coil because of its charging time.

7. The combination of claim 6, characterized in this that the means for neutralizing the distortion comprises a rectifier circuit associated with the source of base frequency, the magnitude of the direct current through the non-linear coil being adjusted to compensate for the said distortions.

8. In a phase modulating system, a source of base frequency waves, a source of signal waves, a saturable core inductance, means to impress both said base frequency waves and said signal waves across said coil to effect phase modulation, a rectifier effectively across said coil for suppressing impulses of one sign, a load circuit connected to said rectifier and coil for utilizing the resulting phase modulated waves, means producing a steady biasing magnetism in the core of said coil to compensate distortion arising from hysteresis of said core.

9. A system according to claim 8 comprising means deriving said bias magnetism from a direct current and connections for supplying said direct current from said rectifier.

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