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J. M. MANLEY ET AL

2,284,401

MODULATION CIRCUIT

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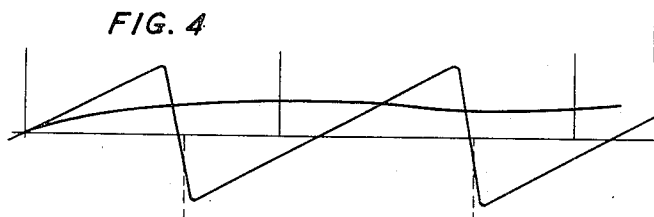
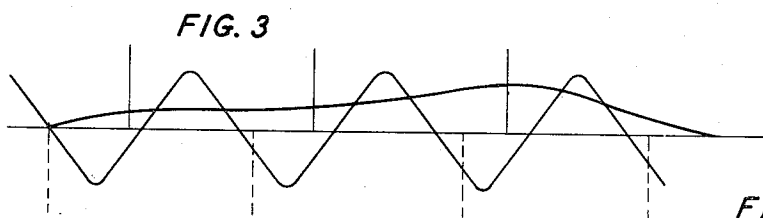
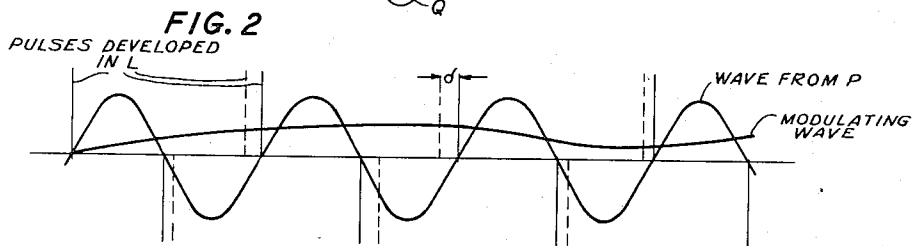
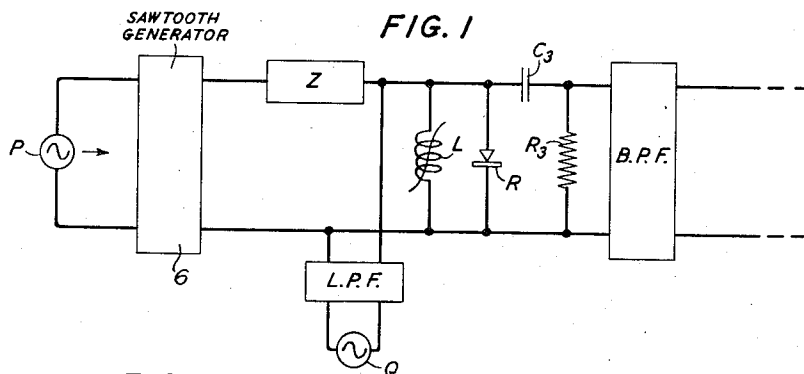


FIG. 5

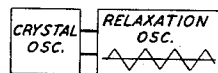
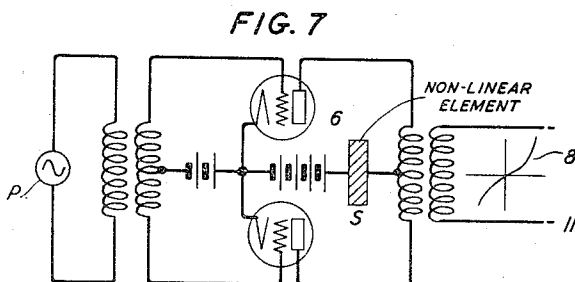
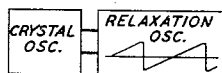


FIG. 6



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MODULATION CIRCUIT

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Application August 27, 1940, Serial No. 354,372

6 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 wave. 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 for rendering the phase displacement of any component more nearly proportional to the instantaneous amplitude of the modulating signal.

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 and 3 are curves explanatory of our invention;

Fig. 4 is an alternative curve for that of Fig. 3; Figs. 5 and 6 illustrate two forms of wave generators for carrying out our invention; and

Fig. 7 is another form of wave generator, shown in greater detail.

In our invention, referring more particularly to Fig. 1, there is shown a source P of base frequency, which is associated with a circuit containing an impedance Z and a non-linear inductance L . Across the non-linear inductance L is connected 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 $P \cos(pt + \theta)$ the output consists of a periodic succession of pulses as indicated by the solid lines in Fig. 2. 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 is added to the non-linear coil, 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 displacement 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 and $q/2\pi$ is the frequency of the signal wave. The extent of the shift of the 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 p and q and the 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 pulses, such as the lower pulses of Fig. 2, which suppression serves the purpose of introducing the otherwise absent side-bands. One method of suppression of the undesired pulses is by the introduction of a rectifier R across the coil L .

Mention has been made of the fact that the phase shift δ will be approximately proportional to $\frac{Q}{P} \sin qt$ and that this approximation becomes closer and closer as Q/P becomes smaller. For effective modulation, however, it is desirable that the phase displacement shall be relatively large and any provision for increasing δ is of importance. Obviously this could be done by increasing Q but as this is done departure of proportionality rapidly increases. Our analysis shows that the departure from proportionality is dependent on the extent to which $\sin pt$ departs from pt , that is to the extent of which the sine of an angle is not equal to the angle itself.

In accordance with our invention, then, we find that we can increase the region of linearity by changing the shape of the wave arriving from the source P so that the instantaneous value of the current resulting therefrom shall be proportional to the angle over an increased range. This we do by generating a wave for impression on the non-linear coil L of such saw-toothed form as is indicated by Fig. 3. In Fig. 3 the pulses in the one direction are shown in full lines and the pulses in the other direction, which are to be suppressed by the rectifier R or its equivalent, are shown in dotted lines. The time displacement of pulses and, therefore, the phase shift in the side-bands associated with any harmonic carrier is proportional to the quantity Q so long as one keeps within the range over which the carrier frequency wave current is linear with time.

Various means for obtaining such a saw-toothed wave form, as indicated in Fig. 3, may be used. Ordinarily, one would initiate a sine wave from some oscillator such as a crystal con-

trolled oscillator, indicated in Fig. 5, which oscillator would then operate upon and control a relaxation oscillator, the output of which will be a substantial departure from a sine wave and, by suitable selection of circuits may be of the form indicated in Fig. 3. The presence of such means to produce a saw-toothed wave is indicated at 6 in Fig. 1.

It now becomes apparent that further depth of phase modulation through the increase in amplitude of the signal frequency Q would be permissible were it possible to still further increase the interval of time of the high frequency wave over which the current therefrom is proportional to the time. The most favorable condition for this would be obtained from a wave of the form shown in Fig. 4. A close approximation to such a wave form as that of Fig. 4 can also be obtained from a relaxation circuit, which latter is itself subject to a crystal controlled oscillator, as indicated in Fig. 6. While it would not be possible physically to obtain the ideal curve, it is practicable to approach it quite closely and so long as the phase displacement is kept within the limits over which the wave form of Fig. 4 is itself linear, the phase displacement will be proportional to the instantaneous value of the signal wave.

It will be observed that there will be impulses shown by the dotted lines of Fig. 4 and that the phase displacement for these will be very small. These impulses, however, are of no particular interest because they are suppressed by the rectifier R .

Fig. 7 shows a circuit which is particularly adapted for obtaining and delivering to the coil L a saw-toothed current wave approximating a form shown in Fig. 3. It makes use of the non-linear characteristics usually present in vacuum tube circuits. In Fig. 7 the sine wave generator P is associated with the input of a push-pull circuit 6. The characteristic of one of these tubes may be broadly expressed as being of the form

$$ip = a_1e + a_2e^2 + a_3e^3 + \dots$$

As is well known in the art, the characteristic of the push-pull circuit is that the even power terms in the expression above cancel out and in many cases terms of powers higher than the second may be neglected. In many other cases, however, either because of the characteristics of the tube or because of the circuit arrangements, the third power term may be appreciable and in that case the over-all characteristic of the push-pull circuit will be as shown at 8 in Fig. 7. If with such a characteristic a sine wave is impressed on the input circuit, then it will be apparent that the output takes on to a greater or lesser degree of approximation the form of wave shown in Fig. 3. Furthermore, if the particular tubes and circuit used do not give a sufficient degree of curvature, such curvature may be emphasized or increased by the introduction of some non-linear element S which may be a thyrite resistor or a non-linear diode, or any other desirable device in which the current increases faster than the voltage.

While the invention has been described particularly in connection with a magnetic harmonic generator of the kind shown in the co-pending application referred to, it is to be understood that the invention is not so limited but is equally applicable to any phase modulation circuit in which pulses are generated from the base frequency source, the time phase of the

pulses being controlled by a signal wave. In some of these pulse generators, such as in certain vacuum tube generators, the pulses are in one direction only so that there is no need for the suppressing rectifier heretofore mentioned. The advantage of having a saw-toothed wave delivered from the base frequency source still holds.

What is claimed is:

1. In a phase modulating circuit for modulating a carrier frequency wave with a signal, a source of base frequency waves, a peak producing device excited by said source to give sharp impulses, a source of signal wave associated with the device to produce therein phase modulation waves of a carrier frequency harmonically related to said base frequency, the base frequency source delivering waves of saw-toothed form and means to select said modulated carrier waves for transmission.

2. In a phase modulating circuit for modulating a carrier frequency wave with a signal, a source of base frequency waves, a peak producing device excited by said source to give sharp impulses, a source of signal wave associated with the device to produce therein phase modulation waves of a carrier frequency harmonically related to said base frequency, the base frequency source delivering waves of a form linear with respect to time for a longer interval than in a sine wave and means to select said modulated carrier wave for transmission.

3. In a phase modulating circuit for modulating a carrier frequency wave with a signal, a source of base frequency waves, a peak producing device excited by said source to give sharp impulses, a source of signal wave associated with the device to produce therein simultaneously phase modulation of a plurality of carrier frequency waves harmonically related in frequency, the base frequency source delivering waves of saw-toothed form, and means for selecting one carrier frequency with its modulation side-bands.

4. In a phase modulated wave circuit, a source of base frequency waves, a magnetic modulator peak producing device excited by said source giving positive and negative impulses of short duration compared with the period of the waves from said source and containing frequency components representing a series of harmonics of the base frequency, a source of signal waves associated with the device to produce phase modulation of said harmonics of the base frequency, the base frequency source being of a form to deliver waves of saw-toothed form and means to select for use one of said phase modulated harmonic frequency waves.

5. In a phase modulating system, a source of base frequency waves of saw-toothed form, a non-linear device for producing therefrom a series of sharp unidirectional current pulses containing frequency components representing a series of harmonics of the base frequency, a source of signal waves connected to said device for producing phase modulation of said waves of harmonic frequencies simultaneously, and means for selecting for use one of said phase modulated harmonic frequency waves.

6. A system according to claim 5 in which said non-linear device is an inductance having a saturable magnetic core for producing sharp pulses in combination with a unidirectionally conducting element for pulses of one polarity.

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