

Feb. 23, 1943.

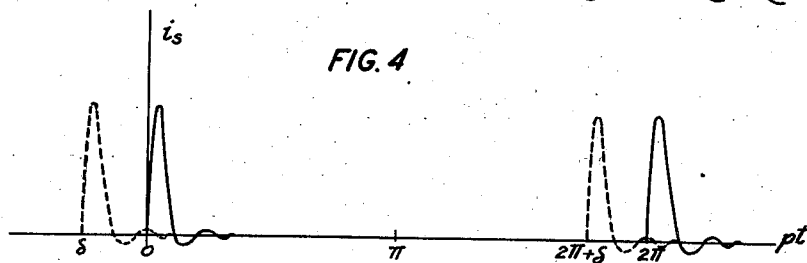
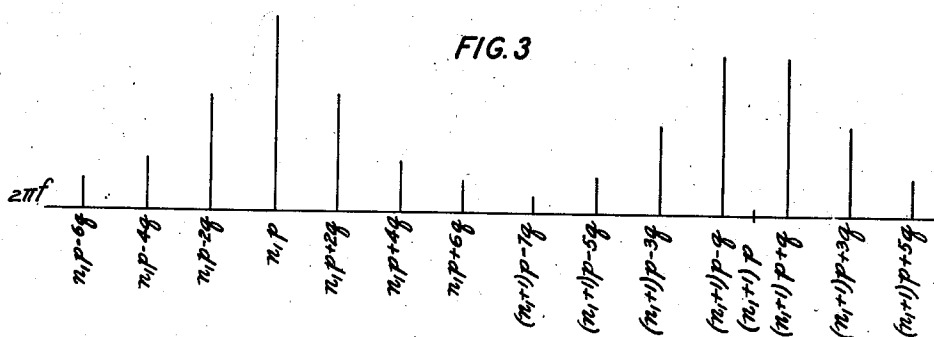
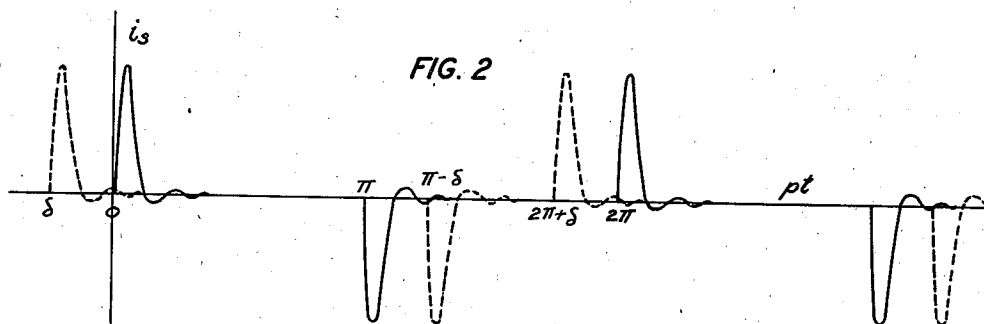
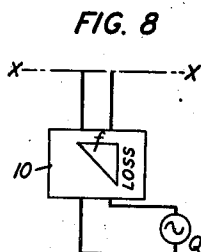
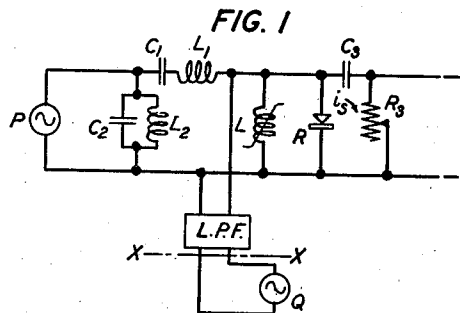
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2,311,796

MODULATION OF CARRIER FREQUENCIES

Filed Aug. 27, 1940

2 Sheets-Sheet 1



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MODULATION OF CARRIER FREQUENCIES

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2 Sheets-Sheet 2

FIG. 5

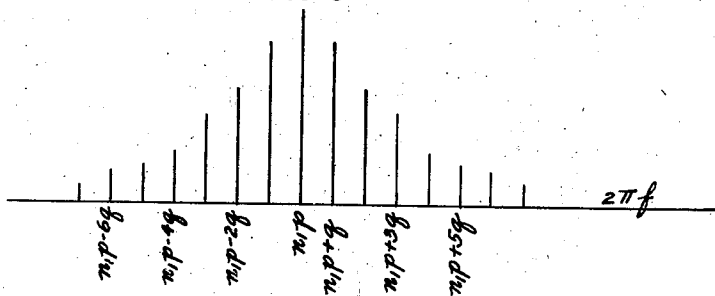


FIG. 6

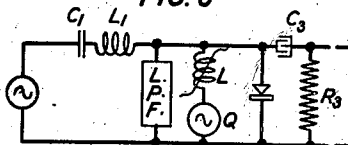


FIG. 7

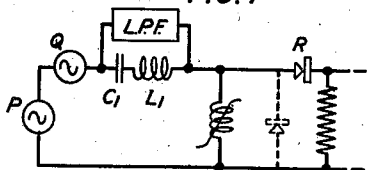
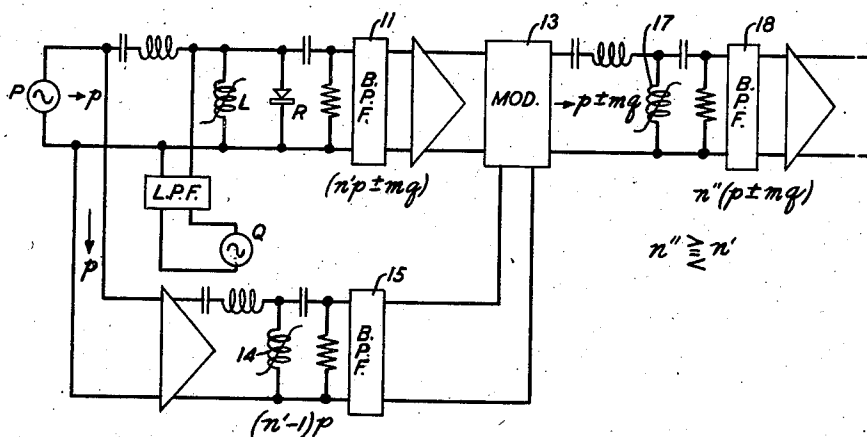


FIG. 9



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MODULATION OF CARRIER FREQUENCIES

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14 Claims. (Cl. 179—171.5)

This invention relates to signal modulation of carrier frequency oscillations. More specifically, it relates to phase modulation of a carrier frequency source in which use is made of the so-called magnetic harmonic generator.

In my United States Patent 2,117,752, May 17, 1938, the circuits and the characteristics of a magnetic harmonic generator are described. One of the characteristics of the generator there described is the generation of sharp peaks containing a large number of harmonics of nearly constant amplitude. In accordance with the present invention, a variable bias, such as from a signal current, is impressed on the non-linear magnetic coil of this generator, and as a result the timing of the peaks is shifted forward or backward from normal position by an amount approximately proportional to the instantaneous value of the biasing current. The resultant output takes on somewhat the characteristic of a phase modulated wave but the departure therefrom is substantial and important. I find, however, that by the introduction in the circuit of a rectifier which will suppress or eliminate certain of the products of the magnetic generator, I then obtain a true phase modulated wave. Such a phase modulated wave is adapted for transmission as a signal wave directly or may be converted into other forms of signal waves, such as a frequency modulated wave, as will be set forth hereinafter.

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

Fig. 1 shows one form of circuit arrangement for carrying out my invention;

Figs. 2 to 5 are figures explanatory of the operation of the circuit;

Figs. 6 and 7 show modifications of Fig. 1;

Fig. 8 is a modification of one part of the circuit of Fig. 1; and

Fig. 9 is a schematic drawing of a circuit for embodying my invention in an extended and particular form of modulation circuit.

Referring more particularly to Fig. 1, there is shown a source of oscillations P which is impressed on a non-linear magnetic coil L, the excitation of the coil being over a wide range so that the coil is carried well beyond its saturation point. In series with P and L are condenser C₁ and inductance L₁, the inductance of L₁ in general being large compared with that of L. Also, the values of C₁ and L₁ are preferably so adjusted that, combined with the inductance L, the circuit is tuned for the frequency of the gen-

erator P. Such tuning serves, among other things, the purpose of purifying the current wave from the source P. Further assistance in this direction may be obtained by the introduction of the shunt anti-resonant circuit C₂L₂.

Bridged across the inductance L is the series circuit C₃R₃ serving as a load circuit. With such a circuit it is found that corresponding to each half cycle of the source P there is a sharp voltage peak generated in the coil L when such coil is operated well into its saturation region. There will be a positive impulse and a negative impulse for each complete cycle of the wave from P, these occurring quite near to the time when the magnetizing force on the coil passes through zero, i. e., when the current in the winding of the coil passes through zero. The spacing of the impulses will be highly uniform and they give rise to a large number of harmonics of nearly the same amplitude, the frequencies of which will be represented by np where p corresponds to the frequency of the source and n takes on integral values. Thus this harmonic generator serves as a frequency multiplier.

The size of the coil of the harmonic generator or frequency multiplier will depend to a considerable extent on the frequency used. For example, in one particular case a toroidal coil was used with a permalloy core. The coil had a mean diameter of 0.3 inch and a weight of 10 milligrams. Such a coil is suitable for use with a base frequency of 200 kilocycles and from it one may readily pick off the twentieth harmonic. In another case the mean diameter of the coil was 0.05 inch, its length approximately the same, and the core contained but 0.6 milligram of permalloy, the total volume being about that of the head of a pin. This coil is suitable for use with a base frequency of 3 megacycles and it is possible then to pick off harmonics in the 40-megacycle range.

If a source of variable bias, such as a signaling current from a source Q, is impressed on the non-linear inductance then the timing of the impulses is altered, the instant of the peak being shifted by an amount corresponding to the shift of the new zero value of the two currents now flowing through the coil. This shift is indicated in Fig. 2 in which it will be observed that for the positive loops the peaks are advanced in time and for the negative loops they are retarded, as indicated by the dotted curves of Fig. 2. The full curves, then, represent the idealized wave form of the current i_s in the load circuit when the biasing voltage is zero and the dotted curves

give the corresponding wave form with a bias.

The curve as shown suggests that a phase modulation or something equivalent to a phase modulation has taken place. Analysis, however, shows that this is not quite true. Analysis shows that in the first place there will be present in the output circuit harmonics of the source P and that each one of these harmonics will have associated with it a family of side-bands corresponding to the signal frequency. This is indicated in Fig. 3 which, in accordance with analysis, discloses that a harmonic carrier $n_1 p$, where n_1 is odd, will have associated side-bands represented by $n_1 p \pm m q$ where m is even. Also associated with the harmonic frequency $(n_1 + 1)p$, which harmonic itself will be absent, there will be associated a family of modulation frequencies represented by $(n_1 + 1)p \pm m q$ where m is odd. In general, one may state that there will be present all frequencies represented by $n p \pm m q$ with the restriction that $n + m$ shall be odd.

It can be shown, however, that a carrier with a group of side-bands such as represented in Fig. 3 is not a true phase modulated wave. A true phase modulated wave calls for the presence of all the side-band frequencies $\pm m q$, both odd and even, with carrier harmonic $n p$. Such a group of carrier and side-bands is, for example, shown in Fig. 5.

It becomes apparent that this combination could be obtained by introducing around the carrier $n p$ of Fig. 3 odd harmonics of q and it is evident that this could be done by taking the group of odd harmonics associated with the carrier $(n_1 + 1)p$ of Fig. 3, modulating this against a carrier p to give the difference carrier frequency $n p$ with the odd side-bands which then could be combined in a suitable circuit with the group shown in the left-hand portion of Fig. 3. It will be recognized, however, that while this is possible it would represent the setting up of complicated circuit arrangements and I find that the desired result can be obtained in a much simpler manner. In particular, if the peaks of the one sign be suppressed, such as the lower peaks of Fig. 2, yielding a set of peaks such as shown in Fig. 4, then analysis shows that the output circuit will contain the even as well as the odd harmonics and there will be present a large number of carrier frequencies, each modulated with the family of side-bands of both even and odd order. I obtain this suppression of the peaks of the one sign by the introduction of a rectifier such as that shown at R in Fig. 1.

The rectifier R may obviously take on any of a large number of forms, such as a vacuum tube diode or a copper-oxide rectifier, the only requirement being that for transmission in the one direction the impedance shall be quite low and that it shall be able to withstand the back voltage during the period of no substantial transmission through the rectifier.

In Fig. 6 there is a modification in the manner of introducing the signal voltage. Here the source Q is shown as being in the bridge containing the non-linear inductance L. In such event, however, if the tuning circuit $C_1 L_1$ is present, then it will be necessary to provide a low impedance path for the signal current. This is shown in Fig. 6 by the low-pass filter which is one offering high impedance to the carrier frequency p and its harmonics.

Fig. 7 shows a further modified method of introducing the signal frequency. Here the

source Q is placed in series with the source P and a low-pass filter is shunted around the condenser C_1 and inductance L_1 , being of a form to offer low impedance to the signal current but high impedance to the frequency p and its harmonics.

In the operation of the non-linear coil it has been understood that while the coil is operating on the steep part of the B-H curve, the condenser C_1 , which is relatively small, is charging and reaches practically the full voltage developed across the coil. In going into the saturation region where the inductance of L falls to a low value and the voltage thereover becomes small, there occurs a sudden discharge of the condenser representing the peak heretofore referred to. In this mode of operation the voltage across R_3 will be somewhat less than the full voltage generated. I find, however, that the circuit may be operated in a somewhat different manner by making C_3 and R_3 both quite large. In this case the current flowing through the load circuit is small. The voltage drop over C_3 never becomes large and that across R_3 is at every instant substantially the same as that across L, the peak occurring during what in the other case is the charging period of C_3 and C_3 serves essentially as a direct current blocking condenser. Such a modification is indicated by the character of the elements shown in Fig. 6. I find this mode of operation, which I will call open circuit operation, is advantageous if the generator is feeding into a high impedance circuit such as the input of an amplifier, whereas the former mode of operation, which I will call load circuit operation, is generally to be preferred if the circuit feeds into a relatively low impedance load. One of the advantages of open circuit operation is that the ratio of Q/P may be appreciably increased without increase in distortion. An advantage of load circuit operation is that usually the higher order harmonics do not fall off so rapidly.

Furthermore, in the case of operating on a virtually open circuit load and combining with this the feature of suppressing the peaks in one direction, the circuit may be further modified by omitting the condenser C_3 , replacing it by the rectifier R as shown in Fig. 7. It is apparent that for the peaks in one direction the rectifier offers substantially no impedance and the full voltage across the coil appears across the high resistance R_3 whereas the peaks in the opposite direction are suppressed. One may also, if desired, place a second rectifier in shunt to the coil to by-pass the unwanted peaks although this will not ordinarily be necessary.

In Fig. 8 there is shown a simple circuit arrangement by which the phase modulated wave obtained as above described may be transformed into a frequency modulated wave. This is accomplished by replacing the source Q of Fig. 1 by the circuit of Fig. 8 which includes a circuit giving a loss to the signal proportional to its frequency. It will be recognized that a component of the current flowing in the output circuit $C_3 R_3$ would be represented by $i = A \cos(pt + \theta)$ where θ is a phase angle which may or may not be constant. In the case of a phase modulated wave in which the phase displacement is proportional to the instantaneous value of the signal amplitude, the phase angle will be represented by $\theta = Q \cos qt$, where Q is the maximum angular displacement. Upon introduction into the first equation, this gives $i = A \cos(pt + Q \cos qt) = A \cos \phi$, the

instantaneous value of the angle being represented by $\phi = pt + Q \cos qt$. The instantaneous value of the frequency of this wave is equal to the time derivative of ϕ and is given by

$$p = \frac{d}{dt} \phi = p - qQ \sin qt$$

If now the coefficient qQ can be made constant, then there results a true frequency modulated wave and this is accomplished by the introduction of the loss device 10 of Fig. 8. Thus, if Q_1 is the amplitude from the signal source and the loss is of the character described, then the amplitude on the output side of the loss device is given by

$$Q = \frac{Q'}{q}$$

whereupon the current for the component in question is given by $i = A \cos (pt - Q_1 \sin qt)$ and this will be recognized as the formal expression for a frequency modulated wave. In the above, as well as in the following, the terms frequency and angular frequency ($2\pi \times$ frequency) have been used interchangeably, no ambiguity arising therefrom.

Fig. 9 shows a more extended circuit arrangement in which by the use of saturated core inductances the frequency swing for the modulated signal is increased. In this figure, the source of base frequency P and the source of signal frequency Q are impressed on a saturating core inductance L with a rectifier R in the manner described in connection with Fig. 1. By means of the band-pass filter 11 there is selected a harmonic frequency carrier with its side-bands lying in the frequency range $n'p \pm mq$, where n' is a constant and m takes on integral values from zero up. After suitable amplification the output of the filter is impressed on a modulator 13.

From the source of base frequency there is also impressed a wave on the saturating core inductance 14 serving as a multiplier and by means of the band-pass filter 15 a suitable harmonic is selected and impressed upon the modulator 13. For illustrative purposes the harmonic selected is indicated as $(n'-1)p$. The output of the modulator will contain among other terms a difference frequency $p \pm mq$, which is then impressed on the coil 17 and from the output of this multiplier there is selected by the band-pass filter 18 a modulated carrier, the frequency of which is represented by $n''(p \pm mq)$ corresponding to a suitable high frequency carrier of value $n''p$, the modulation components of which are represented by $n''mq$. With the great flexibility of choice inherent in this system it is evident that the carrier frequency may be chosen of any desired high value and the swing of frequencies in the modulation components may also be made as large as is desired. In a particular case one may take $n'' = n'$, whereupon it is noted that the final carrier frequency is the same as that coming from the band-pass filter 11 but the frequency swing of the modulating components is increased by the factor n' . Obviously this process may be repeated in as many stages as desired.

It will be noted that in this circuit the first saturating core is used primarily as a modulating device whereas the other saturating cores serve as frequency multipliers. The output of the band-pass filter 18 thus yields a phase modulated wave with a wide swing of frequencies. If one desires a frequency modulated wave, this may obviously be obtained by introducing in the cir-

cuit of the source q a loss device of the character described in connection with Fig. 8.

It is to be emphasized that with any or all of the non-linear magnetic coils of Fig. 9, the output condenser and resistance will be given values which are appropriate to the input impedance of the succeeding elements. Thus, if the output circuit looks into a low impedance it will be desirable to give the resistance R_3 a relatively small value whereas if the input impedance of the subsequent circuit is high, then it will be advantageous to make the resistance shunting the non-linear coil quite high, whereupon substantially the whole harmonic voltage is available across the resistance element and the value of C_3 and the coil dimensions are so chosen as to give maximum output.

What is claimed is:

1. A circuit for obtaining a frequency modulated wave comprising a source of base frequency, a magnetic harmonic generator associated therewith to produce high harmonics of the base frequency, a rectifier associated with the output of the harmonic generator to suppress all peaks in one direction, a source of signal frequency associated with the harmonic generator to bias the said peaks in time phase and adapted thereby to produce in the output of the harmonic generator a phase modulated wave, a modifying network inserted between the signal source and the harmonic generator, said network introducing a loss proportional to signal frequency whereby the output of the circuit becomes a frequency modulated wave.

2. A circuit for obtaining a modulated wave comprising a source of base frequency and a source of signal frequency, a peak producing device associated therewith to produce harmonics of the base frequency, a rectifier associated with the output of the peak producing device to suppress the peaks in one direction, the remaining peaks comprising a series of harmonics of the base frequency with phase modulating side-bands and a selective circuit for selecting one harmonic of the base frequency with its modulating side-bands.

3. A circuit for obtaining a phase modulated wave comprising a source of base frequency and a source of signal frequency, a peak producing device associated therewith, the peaks corresponding to the summation of components of the carrier frequency and even and odd harmonics thereof, the source of signal frequency being so associated with the peak producing device as to displace the timing of the peaks in accordance with the signal amplitude to produce phase modulating side-bands for the base frequency harmonics and a selective circuit for selecting one harmonic of the base frequency with its modulating side-bands.

4. A circuit for obtaining a phase modulated wave comprising a source of base frequency and a source of signal frequency, a peak producing device associated therewith to produce harmonics of the base frequency, a rectifier associated with the output of the peak producing device to suppress the peaks in one direction, the remaining peaks comprising a series of harmonics of the base frequency, with phase modulating side-bands, a selective circuit for selecting one harmonic of the base frequency with its modulating side-bands, a modulator on which the output of the selective circuit is impressed, a second circuit derived from the base source for generating harmonics of the base frequency, and means for

impressing a chosen harmonic on the modulator to obtain in the output of the modulator a relatively low carrier harmonic frequency with its side-bands, and a harmonic multiplier on which said last-named carrier frequency and side-bands are impressed to yield a phase modulated higher carrier frequency harmonic with side-bands covering a wider signal frequency swing.

5. A circuit for obtaining a phase modulated wave comprising a source of base frequency, a magnetic harmonic generator associated therewith to produce high harmonics of the base frequency, a rectifier associated with the output of the harmonic generator to suppress all peaks in one direction, and a source of signal frequency associated with the harmonic generator to bias the said peaks in time phase to produce in the output of said harmonic generator a plurality of phase modulated waves.

6. In a circuit for obtaining a phase modulated wave of high carrier frequency and wide frequency swing comprising a source of base frequency, a peak producing device associated therewith to produce harmonics of the base frequency, a source of signal frequency associated also with the device to bias said peaks in time phase to yield a phase modulated harmonic carrier frequency, a second circuit derived from the base frequency source to generate a selected harmonic of the carrier frequency, and a modulation circuit for obtaining from the phase modulated harmonic and the selected harmonic a phase modulated carrier of lower frequency without decrease of the frequency swing.

7. A circuit for obtaining a phase modulated wave comprising a source of base frequency, a device for producing a train of peaks of one sign at the base frequency, a source of signal frequency associated with said device to bias said peaks in time phase in accordance with the instantaneous amplitude of the signal frequency to produce a complex wave containing harmonics of said base frequency together with side-band components and means for selecting from said complex wave a harmonic of the base frequency with its modulating side-bands.

8. The combination of claim 7, characterized by this that there is a modifying network associated with the signal source, said network introducing a loss proportional to the signaling frequency whereby the selected harmonic of the base frequency is frequency modulated.

9. In a system for producing modulation of the wave-length of high frequency waves, a source of base frequency waves, a peak producing circuit for distorting the wave form of said waves to produce sharp peaks all having the same sign, means associated with said peak producing circuit for shifting the phase angle of said peaks in accordance with signals, whereby a plurality of series of frequency components are produced representing wave-length modulation by said signals, the successive series being centered about said base frequency and its successive harmonics, and means to select for use one such series of components to the exclusion of the others.

10. In combination, a source of high frequency waves, a saturable core inductance, means to impress waves from said source in circuit with said inductance in sufficient amplitude to saturate the core thereof in each alternation of the impressed wave whereby non-sinusoidal impulses of peaked form are produced, a source of signal waves, means to utilize said signal waves to bias said core in proportion to the signal amplitude to vary the phase angle of said impulses, a unidirectionally conducting device on the output side of said inductance for suppressing the impulses of one sign only, and means to select from the unsuppressed pulses a wave-length modulated sinusoidal wave for transmission.

11. The method of producing a carrier wave modulated by a signal wave comprising distorting a base frequency wave to produce sharply peaked pulses of similar shape and equal amplitude and duration, all of one sign, shifting the phase of said pulses in accordance with the instantaneous amplitude of the signal wave and directly selecting from such phase-shifted pulses a sinusoidal wave whose wavelength is modulated by the signal.

12. In a modulating system, a source of base frequency waves, means for producing therefrom a series of sharply peaked pulses all of one sign, said pulses being equal to one another in amplitude and duration and similar in shape, means for shifting the phase of said pulses in accordance with the instantaneous amplitude of a signal, the resulting pulses comprising a multiplicity of wave-length modulated waves at harmonic intervals in the frequency scale, and means for directly selecting from said pulses a particular one of such wave-length modulated waves for transmission.

13. The method of producing a carrier wave modulated by a signal wave comprising distorting a base frequency wave to produce sharply peaked waves of equal amplitude and duration rich in harmonics, displacing the phase of the wave peaks in accordance with the instantaneous amplitude of the signal wave, retaining portions of the phase-displaced wave peaks in one sign only whereby waves of harmonic frequencies each carrying signal modulations are produced, and directly selecting from said retained wave peaks one of said harmonic frequency waves for use as transmitting carrier together with its signal modulations.

14. A phase modulating device comprising a saturable-core magnetic harmonic producer, a source of base frequency waves connected thereto, said harmonic producer producing sharply peaked pulses of respectively positive and negative sign per respective half period of the base frequency wave, means to variably bias said device in accordance with a signal wave to shift the phase of said pulses, means for suppressing the pulses of one sign and means to select a wave-length modulated harmonic frequency wave from such phase-shifted pulses.

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