

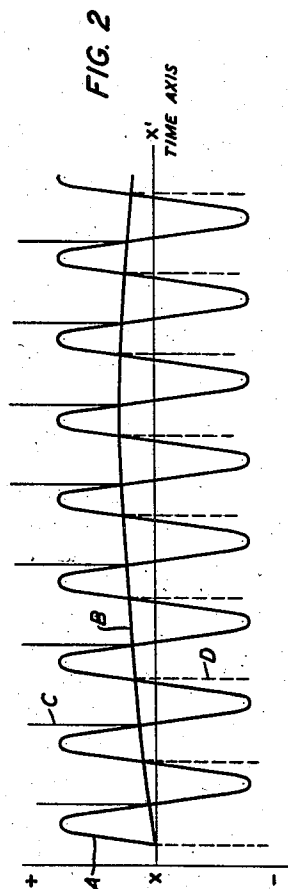
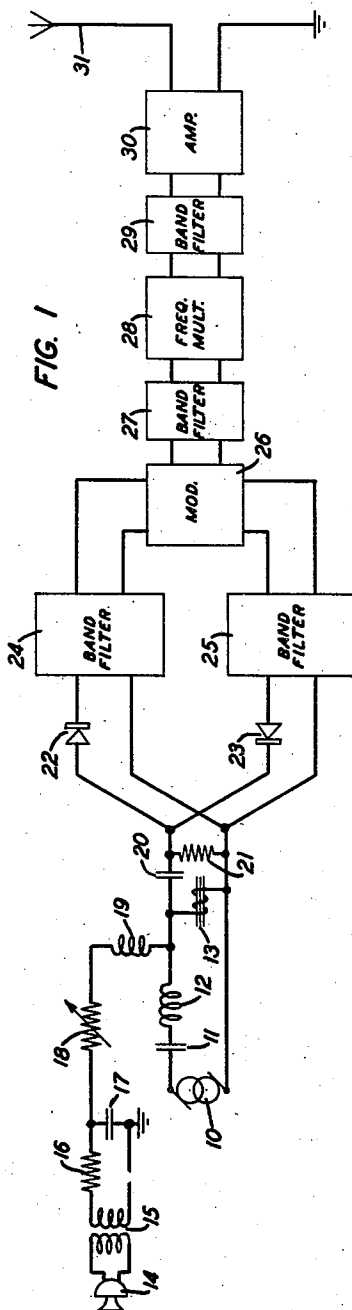
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PHASE MODULATION

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PHASE MODULATION

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This invention relates to frequency or phase modulation systems and more particularly to systems for the production of modulated waves having wide frequency deviations.

An object of the invention is to facilitate the production of wide frequency swings of a modulated carrier wave while at the same time maintaining a high degree of stability of the mean frequency. Another object is to improve the linearity of the modulation characteristic in wide swing modulation systems. Additional objects are to facilitate the production of wide frequency deviations at relatively low carrier frequencies and to simplify the equipment necessary for the production of large frequency deviations.

The modulation method of the invention is in some respects similar to the well-known method according to which a low frequency carrier derived from a stable frequency source is modulated in phase by the signaling current and is then increased in frequency by steps of frequency multiplication sufficiently to bring the phase swing or the frequency deviation to the desired amplitude. In accordance with the invention, however, a large part of the multiplication of the phase deviation is made to take place in the modulator itself thereby reducing the amount of frequency multiplication subsequent to the modulation process. It has in common with the earlier systems the advantage that the stability of the mean frequency of the transmitted wave is the same as that of the original carrier source and is not affected by the modulation process.

The extent of the modulation imparted to the low frequency carrier in systems of the type described above is ordinarily restricted to a phase deviation of less than 30 degrees in order that a high degree of linearity of the modulation characteristic may be maintained. To increase this limited modulation to an extent sufficient to provide a frequency deviation of 75 kilocycles or more requires multiplication by a factor which may be as high as 2,000 and this may entail the use of as many as ten or even more frequency doubling stages following the modulator. To provide a wide frequency deviation at an assigned carrier wave length may therefore require the use of an initial carrier of very low frequency, in which case the multiplication process may give rise to difficulties because of the close spacing of the harmonics of the original carrier wave. The method of the invention provides large multiplications of the phase modulation within the modulator itself

and thereby permits the use of higher initial frequencies with the consequent simplification of the later frequency multiplication steps.

The nature of the invention and its mode of operation will be understood from the detailed description which follows and by reference to the accompanying drawing of which:

Fig. 1 illustrates the embodiment of the invention in a frequency modulation ratio transmitter; and

Fig. 2 is a diagram explanatory of the operation of the system.

Referring to Fig. 1, 10 is a carrier wave generator which may, for example, be a quartz crystal-controlled vacuum tube oscillator or which may be any other source having an equally high degree of frequency stability. The generator supplies current to a circuit comprising condenser 11, inductance 12, and an impulse generating coil 13. This impulse coil may comprise a very small closed magnetic core made of fine laminations of a nickel-iron alloy containing 78.5 per cent nickel, known as "Permalloy," and wound with a few turns of wire. The speech current circuit comprising a microphone 14, transformer 15, predistorting network 16, 17 and adjustable resistance 18 is coupled to the impulse coil through a high frequency choke 19 in such a way that the speech currents are superimposed upon the carrier currents in the coil windings. Across the terminals of the impulse coil is connected a circuit comprising condenser 20 and resistance 21 in series. Two branching paths lead from the terminals of resistance 21 through oppositely poled rectifiers 22 and 23 to band-pass filters 24 and 25, respectively, and from thence to the input circuits of a modulator 26. The band-pass filters are designed to transmit different harmonics of the carrier frequency; for example, the filter 24 may be tuned to the twentieth harmonic and the filter 25 to the fifteenth harmonic. The oscillations selected by the two filters are impressed upon modulator 26 and from the output of this the modulation products corresponding to the difference of the two frequencies are selected by band-pass filter 27. The remaining parts of the system comprise a multiplier 28 in which the frequency of the carrier is raised to the value desired for radiation, a band-pass filter 29, power amplifier 30 and an antenna 31. The multiplier 28 may contain as many individual stages as are necessary, together with suitable filters for selecting the desired frequency in the output of each stage. The final

filter 29 selects the harmonic that is to be utilized.

The output circuit of the carrier generator 10 is tuned by means of condenser 11 and inductance 12 to the frequency of the generated wave and these elements constitute substantially the whole impedance of the circuit. The inductance of coil 13, as will be explained later, is of very low value during the greater part of the carrier wave cycle, so that it has substantially no effect on the tuning of the circuit. If need be, its inductance may be taken into account by an appropriate adjustment of the inductance coil 12. By virtue of the tuning of the circuit the carrier current traversing the windings of coil 13 is kept substantially free from harmonics and may be regarded as having a simple sinusoidal wave form. In the operation of the device it is desirable that the amplitude of the carrier wave should be maintained substantially greater than that of the signal wave. Resistance 18 in the speech circuit is provided for the purpose of adjusting the amplitudes of the two currents to their proper relative values.

The predistorting network 16, 17 is such as to attenuate the several components of the speech current in degrees proportional to their respective frequencies, in accordance with the well-known principle that such predistortion of the signal wave before phase modulation gives the final modulated wave the characteristics of frequency modulation. The rectifiers 22 and 23 are indicated conventionally and may be diode or triode vacuum tubes, or copper-oxide rectifiers.

The operation of the system will now be explained. When the windings of a magnetic coil are traversed by a sinusoidal alternating current of sufficient amplitude to produce strong saturation of the magnetic core, the voltage across the coil terminals develops a sharply peaked wave form with the alternate positive and negative peaks centered close to the instants that the current passes through zero value. By the use of core materials which are easily saturated magnetically and which are relatively free from hysteresis, and by increasing the amplitude of the impressed current to a value, many times that necessary for saturation, the voltage wave can be made to take the form of a train of very short and very sharp impulses alternately positive and negative. These impulses will be practically coincident with the instants of zero current and can be made to last substantially less than one per cent of the period of the current.

If the impressed current consist of a sinusoidal frequency saturating current upon which is superimposed a relatively weak low frequency signaling current, the instants of zero value of the resulting complex current will be displaced in time from the zeroes of the high frequency component taken by itself and the timing of the impulses will be correspondingly altered. The manner in which the instants of zero current and the timing of the voltage impulses are affected is shown clearly in Fig. 2. Here the horizontal line X—X' represents the time axis, sinusoidal curve A represents the instantaneous values of the high frequency saturating current, and curve B represents a portion of a cycle of the low frequency signaling current plotted with its phase reversed. The superposition of the two components is equivalent to the substitution of the curve B as a new time axis, the zero values of the complex current occurring at the times corresponding to the intersections of the two curves. The polarity of an impulse depends upon the sign of the time derivative

of the current at the instant of zero value. In the figure, the vertical solid lines C represent positive voltage impulses occurring as the current changes from positive to negative and the dotted lines B represent negative impulses induced as the current reverses in the opposite direction. It is evident from an inspection of the diagram that the negative impulses are retarded in time with respect to the zero instants of the high frequency current alone, while the positive impulses are symmetrically advanced in time.

The above action takes place in the coil 13 when the windings are traversed by the superimposed currents from sources 10 and 14 and the voltage impulses are developed across the coil terminals. To develop the shortest and sharpest possible impulses it is desirable that the core material of the coil should be such that it is very readily saturated by a weak magnetic force and also should be substantially free from hysteresis. Materials such as the 78.5 per cent nickel-iron alloy already mentioned are well adapted to meet these requirements and permit very large impulse voltages to be developed in a coil having only a few turns of wire in the windings. For operation at high frequencies, of the order of 1,000,000 cycles or more, it is desirable that the total energy loss in the coils be kept as small as possible and to this end the core should be of small volume and very finely laminated. The carrier current should be so adjusted that the magnetic core becomes saturated at a very small fraction of its amplitude. In that case the induced electromotive force in the coil is substantially zero except at the instants of current reversal and the effective inductance of the coil over substantially the whole high frequency cycle is negligibly small.

During the existence of the induced voltage pulse, condenser 20 becomes charged and immediately upon the termination of the pulse it discharges at a very rapid rate, the discharge current producing an impulse voltage drop across the resistance 21. The effect of the condenser and resistance is to provide a substantial sharpening of the pulse and to make its duration substantially independent of the other portions of the circuit. The rate of discharge of the condenser depends principally upon the value of the resistance but may be modified to a slight extent by the inductance of the impulse coil during its saturated interval. It is not necessary for purposes of the invention that the condenser and resistance be used, and in many cases it may be preferable to employ directly the impulses representing the induced voltage across the coil terminals. For this purpose the condenser and resistance may be entirely omitted or, if desired, the condenser may be made of such large capacity that its effect is negligible.

The two trains of impulses, positive and negative, are modulated in opposite senses with respect to the times of their occurrence. It may be shown that each train is equivalent to a multiplicity of harmonically related carrier waves, all modulated in phase by the superimposed low frequency current in degrees proportional to their respective frequencies. The fundamental frequency of the train is the same as that of the carrier current from source 10 and the amplitude, θ , of its phase modulation has substantially the value

$$\theta = \sin^{-1} S/C \quad (1)$$

where S and C denote the amplitudes of the signal and carrier waves, respectively. As already

pointed out, this value should not be permitted to exceed about 30 degrees in order that linearity of modulation may be maintained. The amplitude of the phase modulation of any chosen harmonic component is substantially equal to the above value multiplied by the number denoting the order of the harmonic.

The rectifiers 22 and 23 provide for the separation of the two trains of modulated impulses. For example, the positive impulses may be selected by rectifier 22 and passed to band-pass filter 24 and the negative impulses may be selected by rectifier 23 and passed on to filter 25. The harmonic components selected by filters 24 and 25 will therefore be phase modulated in opposite senses and the frequency deviations corresponding to the phase modulations will likewise take place simultaneously in opposite senses. Since the selected waves are modulated in opposite senses the modulation of the difference frequency component will exhibit an increased modulation equal to the sum of the modulations of the two waves. The net result is the production of a wave in which the phase and frequency modulation is greatly multiplied without a corresponding increase in its mean frequency. If the m th and n th harmonics be selected by the filters, it may be shown that the mean frequency of the wave selected by band-pass filter 27 has the value

$$(m-n)f_c$$

and its phase deviation has the amplitude

$$(m+n)\theta$$

where f_c denotes the frequency of the original carrier current and θ is the phase modulation of the fundamental component of the impulse trains. The fact that the two quantities m and n can be independently chosen, results in a great degree of flexibility in the system with respect to its capability for producing any desired degree of modulation at any assigned frequency. The choice of the initial value of the carrier wave is therefore not restricted by the amount of multiplication that must be applied to the original small phase modulation and, accordingly, relatively high values for this frequency may be chosen. For example, if we assume that it is desired to provide a modulation swing of about 75 kilocycles at a final carrier frequency of 40 megacycles it will be found that a multiplication of the phase modulation of about 1,000 would be required. This would normally entail the use of an original carrier having a frequency of about 40 kilocycles per second. By the use of the invention, however, an original carrier of 1,000,000 cycles might be chosen and the fifteenth and fourteenth harmonics of the resulting impulse trains selected. The selected output of modulator 26 will then be a wave of 1,000,000 cycles with twenty-nine times the modulation of the fundamental. With a frequency multiplication of 40 in the subsequent multiplier stages, the total multiplication of the modulation becomes 1160, which is substantially the value desired. The use of an original carrier frequency of the order indicated ensures a great enough separation of the harmonics so that no difficulty is met in selecting any harmonic up to at least the twentieth.

In the systems of the invention the initial phase modulation of something less than 30 degrees, which is commonly used to ensure a satisfactorily linear modulation characteristic, is not increased, consequently the large modulation

swings are achieved without sacrifice of signal quality. On the other hand, the facility with which the large modulation swings are developed makes it possible to start with substantially reduced initial modulation and thereby to achieve an increased degree of linearity of the final modulation characteristic.

The invention is also effective in preventing or diminishing distortion of the modulation characteristic due to hysteresis and eddy currents in the impulse coil cores. The presence of hysteresis in the core material results in a time lag between the induced voltage impulses and the instants of zero current in the coil windings. Since the positive and the negative impulses are modulated in opposite senses by the signal, the time lag, which is equivalent to a more or less constant phase bias, affects the modulations of the two impulse trains oppositely. Its effect in each train is to introduce a distortion of the modulation characteristic corresponding to the introduction of a second harmonic of the signal current and if one of the trains, positive or negative, is used alone for the production of the final modulated wave, the distortion may become noticeable. By utilizing the two trains in the manner described for the production of the final modulated wave, their respective distortions tend to neutralize each other thus preserving the linearity of the modulation characteristic. The effect of eddy currents in the core material is like that of hysteresis, the presence of eddy currents tending to widen the hysteresis loop and to produce the same kind of distortion of the modulation characteristic. It is compensated in the system of the invention in the same way as is the hysteresis effect.

What is claimed is:

1. The method of phase modulation which comprises superimposing a signal oscillation on a sinusoidal carrier oscillation of relatively greater amplitude, deriving from the resulting complex oscillation a train of impulses, alternately positive and negative, occurring at the instants of zero value of the said complex oscillation, separating the positive and the negative impulses, selecting from the separated impulses two oscillations of different frequencies corresponding to different harmonics of the carrier oscillation, modulating the amplitude of one of said selected oscillations by the other selected oscillation, and selecting from the resulting amplitude modulated wave the component oscillation of frequency corresponding to the frequency difference of the said selected harmonic oscillations.

2. The method of modulation which comprises superimposing a signal oscillation on a sinusoidal carrier oscillation of relatively greater amplitude, deriving from the resulting complex oscillation a train of impulses, alternately positive and negative, occurring at the instants of zero value of the said complex oscillation, selecting a harmonic component of the positive impulses, selecting a different harmonic component of the negative impulses, said selected harmonic components being phase modulated in opposite senses and in degrees proportional to their respective frequencies, beating the selected harmonics together to produce an oscillation of the differential frequency and selecting the differential frequency oscillation so produced.

3. In a phase modulating system comprising a magnetic impulse coil, a source of high frequency currents, a source of signal current, and circuit means for superimposing the currents

from said sources in the windings of said impulse coil to induce therein alternate positive and negative voltage impulses, the method which comprises separating the positive and the negative impulses, selecting a harmonic component of the separated positive impulses, selecting a different harmonic component of the negative impulses, beating the selected components together to produce an oscillation of the differential frequency, and selecting and transmitting said differential frequency oscillation.

4. A phase modulating system comprising a source of carrier currents, a source of signal currents, a magnetic impulse coil, circuit means for superimposing the currents from said sources in the windings of said coil, means for separating according to their polarity voltage impulses generated in said coil by the superimposed currents, selective circuits for selecting from the separated impulses two oscillations of different frequencies corresponding to different harmonics of the carrier current, a modulating device, circuits for impressing said selected harmonics thereon, and a filter in the output circuit of said device for selecting oscillations corresponding to the differential beat between the impressed harmonic oscillations.

5. A phase modulating system comprising a magnetic impulse coil, a source of carrier cur-

rents, a source of signal currents, circuit means for superimposing the currents from said sources in the windings of said coil, a pair of transmission paths coupled to said coil to receive and transmit impulses generated therein, a rectifier in each of said paths, said rectifiers being respectively poled to transmit impulses of opposite signs, a selective circuit in one of said paths tuned to select one harmonic of the carrier current, the selective circuit in the other of said paths tuned to select a different harmonic of the carrier current, a modulating device having input and output circuits, circuit means coupling the output terminals of said paths to the input of said modulator, and a filter included in the modulator output circuit selective to currents of the difference frequency of the impressed harmonics.

6. The method of phase modulation which comprises deriving from a single carrier wave two trains of impulses recurring at the carrier frequency rate and modulated in their timing in opposite senses in accordance with a common signal oscillation, selecting single harmonic components of different frequencies from the two trains, beating the selected harmonics together to produce an oscillation of the difference frequency and selecting the difference frequency oscillation so produced.

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