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PHASE MODULATION SYSTEM

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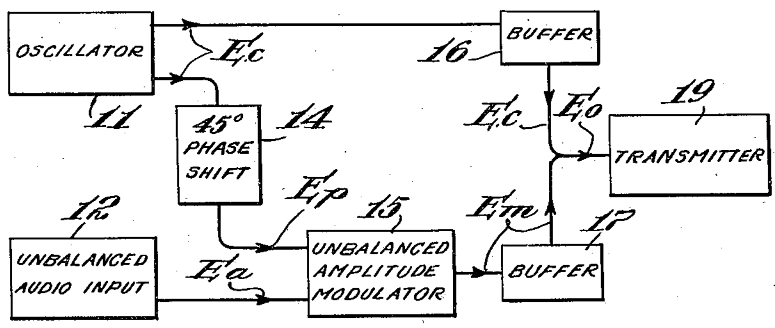

Fig. 1

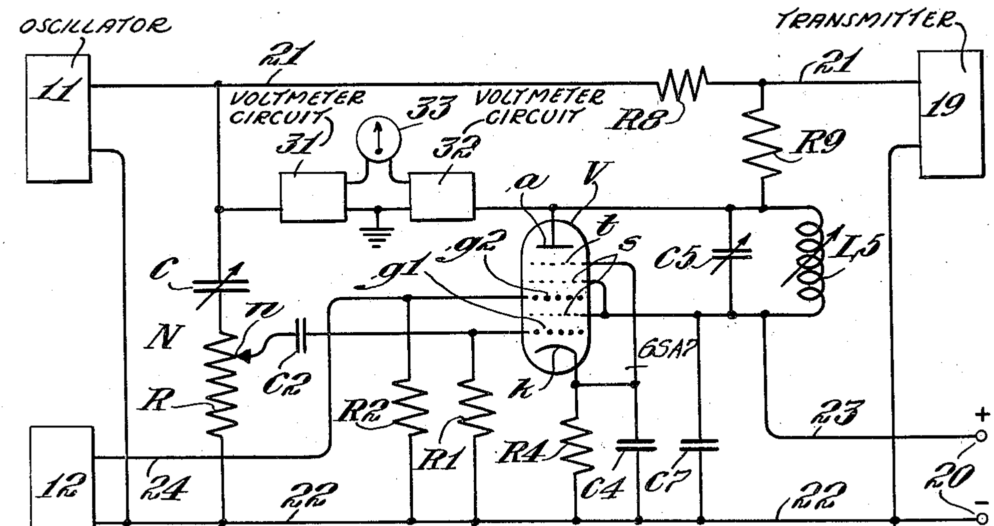

Fig. 3

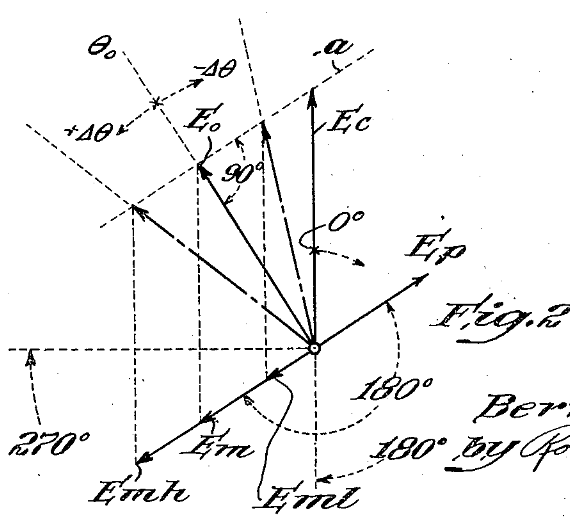

Fig. 2

Inventor
Bernard J. Cosman
by Roberts, Cushman & Grover
attys.

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PHASE MODULATION SYSTEM

Bernard J. Cosman, Arlington, Mass., assignor to Harvey Radio Laboratories, Inc., Cambridge, Mass., a corporation of Massachusetts

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The present invention relates to a system of transmitting signals by modulating a high frequency carrier wave in accordance with signal impulses, and more particularly to angular modulation through varying the instantaneous phase angle of the carrier wave, this variation being proportionate to the instantaneous value of the modulating signal impulse.

It has heretofore been proposed to modulate the phase of a carrier wave train by modulating the amplitude of one or both of two components thereof, these components having the same frequency but being so displaced as to phase that they always subtend a phase angle of 90° when the phase is not shifted in one sense or the other. Either system involves balanced operation of pairs of tubes as elements of a balanced amplitude modulation circuit or of a symmetric audio imput network. The first of the above mentioned systems, namely that with a single amplitude modulated component, uses balanced amplitude modulation of that component, whereas the other system employs amplitude modulation of both components; both require balanced audio imput. In systems of this type, any unbalance in the above mentioned circuit elements gives rise to asymetric phase modulation, and since it is practically impossible to prevent such unbalance, the phase swing has to be limited to very small angles, unless considerable distortion is tolerated. Further, each of these systems calls, in addition to two or more tubes working in balance, for a device providing fairly exact 90° phase shift, which requires comparatively complex circuits which are not absolutely reliable.

It is the principal object of the present invention to provide a method of phase modulation and apparatus for carrying out that method, wherein one of two out-of-phase carrier components of the same frequency is amplitude modulated, but which is independent of balanced operation and does not require complex and exactly operating phase shifting devices, and which is, in spite of extreme simplicity, independent of variations of circuit components and permits easy monitoring of the conditions for maintaining symmetric phase swing.

In one of its aspects, the invention contemplates the vectorial summation of a single-ended amplitude modulated vector with an unmodulated vector of the same frequency at such phase angle that the zero phase modulated resultant and the amplitude modulated component are normal to each other. At the same time, the phase angle of the two components, namely the unmodulated

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component and the amplitude modulated component, has such a value that the resultant vector remains fully phase modulated at the lowest amplitude of the single ended amplitude modulated component vector. In another aspect, the invention provides a phase modulation system wherein unmodulated and amplitude modulated component vectors form a reflex angle (that is an angle greater than 180°), with the zero modulation vector of the resultant, phase modulated wave being at right angles to the amplitude modulated component vector. In a further aspect, the invention utilizes two carrier components at a phase angle of approximately 45°, one of the components being amplified and in that stage of the transmission shifted a further 180° so that the two components are combined while forming an angle of approximately 225°, with the zero phase modulating amplitude of the amplitude modulated component providing a resultant vector which is normal to the amplitude modulated vector.

These characteristics permit, as an important feature of the invention, the use of circuit elements which combine simple construction with exact functioning, namely a network for shifting a vector 45°, and an amplification and modulation arrangement which inherently carries out a 180° phase shift between input and output waves.

In still another aspect of the invention, a phase modulated resultant wave is obtained by combining two phase displaced vectors of the same frequency, one of which is single-end amplitude modulated, such that the phase displacement includes substantially 45° introduced by a phase shifting network, and a further shift of 180° introduced by the function of an electronic tube. The invention thus provides a phase modulation system with a minimum number of the simplest possible parts, and which is inherently insensitive to incidental changes in element characteristics.

An additional feature of the invention is the possibility of maintaining symmetric phase swing by monitoring the output of the amplitude modulator, before it is combined with the unmodulated component vector.

These and other objects, aspects and features will be apparent from the following description of a practical embodiment illustrating the novel characteristics of my invention. This description refers to a drawing in which

Fig. 1 is a block diagram which explains the phase modulation method according to the invention;

Fig. 2 is a vector diagram further explaining the method carried out with circuits according to Fig. 1; and

Fig. 3 is a detailed circuit diagram of a transmitter incorporating the invention.

The principle of the phase modulation system according to the invention will first be generally explained with reference to Figs. 1 and 2.

In the block diagram of Fig. 1, numeral 11 indicates an oscillator which furnishes the carrier voltage Ec, vectorially indicated in Fig. 2. The carrier voltage Ec is directly applied, if desired through a buffer network 16, to the output utilizing instrumentality, herein indicated by transmitter 19. The voltage Ec is also applied to a network 14 which shifts its phase an acute angle, for example 45° and applies the phase shifted voltage E*p* to an unbalanced amplitude modulator device 15. In this device 15, voltage E*p* is by way of amplification shifted a further 180° and also amplitude modulated, under the control of voltage E*a* supplied by an unbalanced audio signal imput device indicated at 12.

Fig. 2 indicates the phase relation of voltages Ec and E*p*. As likewise indicated in Fig. 2, the amplified and modulated voltage E*p* appears as modulated voltage E*m* which is shifted 180° relatively to E*p* and varies, as controlled by the signal voltage E*d*, between values E*ml* and E*mh*. Voltage E*m* is then combined, if desirable through a buffer circuit 17, with the original carrier voltage Ec, these two components furnishing the resultant voltage Eo. As will be evident from Fig. 2, the vector Eo which corresponds to the intermediate or unmodulated value of E*m* forms an angle of 90° with the vectorial direction of voltage E*p* and E*m*, the locus of the phase modulated voltage vectors Eo being a line *a* parallel to the direction of E*p* and E*m*. As clearly indicated in Fig. 2, the total phase shift is an acute angle from Ec to E*p*, and 180° from E*p* to E*m*, so that E*m* and E*p* form a reflex angle.

In this system, the criterion for symmetrical phase modulation is that Eo be normal to the originally phase shifted and amplitude modulated values E*p*, E*m*. This condition for maintaining symmetrical phase swing $\pm\Delta\theta$, as indicated in Fig. 2, can be readily maintained by monitoring the voltage E*m* at its proper value. It will now be evident that the present system requires only a phase shifting circuit which is of the condenser-resistor type wherein $\omega RC=1$, instead of the complicated and critical L.-C. circuits which are required for providing the 90° shift upon which previously suggested phase modulation systems are based. The amplitude modulator is single-ended, therefore requiring only one tube instead of the two tubes required in previously suggested systems which are based on balanced modulation. Similarly, the audio frequency input effecting the modulation of vector E*m*, may be unbalanced in the present system instead of the balanced type required in previous circuits.

A practical phase modulation circuit according to the present invention will now be described with reference to Fig. 3.

In Fig. 3, numeral 11 again indicates an oscillator circuit furnishing the carrier voltage Ec which is supplied to the output device, herein indicated as transmitter 19, if desirable through a buffer herein indicated as resistor R8.

The oscillator 11 also feeds into a phase shifting network N consisting of variable capacitor C and resistor R, connected between wire 21 and wire 22, wire 22 representing the negative side of the energy input which is indicated at 20 and whose positive side is represented by wire 23.

At adjustable tap *n* of network N, voltage E*p* is derived and applied, through a blocking capacitor C2, to grid *g1* of a suitable multi-grid tube V, for example of type 6SA7.

The second control grid *g2* of tube V is connected to the audio input circuit 12, through wire 24. Grids *g1* and *g2* are connected to wire 22 through grid resistors R1 and R2 respectively. The cathode *k* of tube V is connected to wire 22 through the usual bias resistor R4 which is bridged by a bypass capacitor C4. The plate *a* of tube V is supplied from wire 23 through a filter network consisting of adjustable capacitor C5 and inductor L5, which may also be adjustable. The amplified and phase modulated voltage E*m* is fed, if desired through a buffer, herein indicated as buffer resistor R9, into wire 21 and transmitter 19.

The suppressor *t* is as usual connected to cathode *k*, and the screens *s* are connected to wire 23 and bypassed by capacitor C7.

When buffer amplifiers are used instead of resistors R8, R9, the phase shift characteristics of these buffers must be substantially identical, so that the phase relation of the combining vectors is not altered.

For the purpose of monitoring the phase relation of unmodulated and amplitude modulated components, respectively, substantially identical vacuum tube voltmeter circuits 31 and 32 are connected to wire 21, carrying unmodulated wave train Ec, and the output circuit of tube V, carrying amplitude modulated wave train E*m*. These voltmeter circuits are of the conventional type suited for measuring the linear average voltage, and are counter-connected into a zero reading instrument 33 of any type suitable for indicating the difference between the voltage values furnished by circuits 31 and 32.

Recapitulating the above explanation of the operation of a phase modulation system according to the present invention with reference to Fig. 3, the circuit according to that figure functions as follows:

Oscillator 11 feeds voltage Ec through buffer resistor R8 into transmitter 19. The approximately 45° phase shifted voltage E*p*, derived at tap *n* of phase shifting network N is applied through blocking capacitor C2 to grid *g1*, plate *a* thus furnishing vector E*m*, compare Fig. 2. The audio frequency supplied by network 12 is applied through wire 24 to grid *g2*, and effects the amplitude modulation of vector E*m*, between the values of E*mh* and E*ml*.

The amplitude modulated voltage E*m* is fed, if desired through buffer resistor R9 into wire 21, where it is combined with the carrier voltage Ec to provide the resultant phase modulated voltage Eo, which varies through angles $\pm\Delta\theta$. The transmitter 19 is thus furnished with a phase modulated input wave train which, if desired, may first be passed through a buffer amplifier, and thereupon further utilized, for example for wireless broadcasting purposes.

If the phase difference between Ec and E*p* is kept at substantially 45°, which can be easily accomplished by adjusting capacitor C and tap *n* of resistor R, the condition of perpendicularity between vectors Eo and E*m* can be maintained by monitoring these voltages for zero reading at indicator 33. For phase differences other than 45°, the indicator has to be calibrated for zero reading at symmetrical phase modulation, as detected from the phase modulated output.

The dimensions and characteristics of the various circuit elements are selected according to conventional rules, depending upon the energy rating of the device and the tolerated deviations from the theoretically determined values as indicated in Fig. 2, care being taken that the impedance looking into the modulator circuit is fairly high as compared to the input impedance.

It will now be evident that the above mentioned value of 45° for the phase shift between vectors E_c and E_p is not critical, and that the present system will operate satisfactorily, so long as the locus a of the ends of vectors E_o is parallel to the direction of the vector E_m, and so long as the minimum value E_{ml} of modulated vector E_m does not altogether disappear, that is, so long as angle $-\Delta\theta$ is not greater than the angle between E_o and E_c.

It will further be evident, that the circuit elements shown in Fig. 3 need not necessarily be used, but that any combination of elements performing the function indicated in Fig. 2 may be employed, so long as they conform to the basic concept of the invention, namely the combination of two voltage vectors at an angle of substantially more than 180°, one of these vectors being single-end amplitude modulated, and the resultant unmodulated vector being normal to the amplitude modulated component vector.

I claim:

1. In the art of signal transmission by modulated high frequency waves, the method of phase modulating a carrier wave train under control of signal impulses, which method comprises the steps of generating a wave train, deriving from said wave train a second wave train of substantially equal frequency but having a phase which differs from that of said first train by an angle greater than 180° but less than 270°, modulating the amplitude of said second train under the control of signal impulses while maintaining it on one side of its zero value and while maintaining said frequency, and vectorially adding said second train to the unmodified first train to form a phase modulated resultant wave, the phase and amplitude values of said two trains being so selected that said phase modulation of said resultant wave remains substantially symmetrical.

2. In the art of signal transmission by angularly modulated high frequency waves, the method of phase modulating a carrier wave train under control of signal impulses, which method comprises the steps of generating a wave train of substantially constant frequency, deriving from said wave train a second wave train of substantially the same frequency but having a phase displacement of more than 180° but less than 270° relatively thereto, unidirectionally modulating the amplitude of said second train proportionate to a signal while maintaining its polarity and frequency, and vectorially adding said second train to the unmodified first train to form a phase modulated resultant wave, the values of said two trains being so selected that the direction of the unmodulated vector of said resultant wave is substantially normal to the direction of the vector of said second train.

3. In the art of signal transmission by modulated high frequency waves, the method of phase modulating a carrier wave train under control of signal impulses, which method comprises the steps of generating a wave train of substantially constant frequency, deriving from said wave train a second wave train of substantially the same frequency but having a phase displacement of approximately 45° relatively thereto, amplifying said second wave train while shifting its phase a further 180° to obtain a third wave train at approximately 225° to said first wave train, unidirectionally modulating the amplitude of said third train proportionate to said signal impulses while maintaining said frequency, and vectorially adding said unmodified first train and said third train to form a phase modulated resultant wave, the values of said trains being so selected that the direction of the vector of the unmodulated resulting wave is substantially normal to the direction of said third train.

4. In the art of signal transmission by modulated high frequency waves, the method of phase modulating a carrier wave train under control of signal impulses, which method comprises the steps of generating a wave train of substantially constant frequency, deriving from said wave train a second wave train of substantially the same frequency but having an acute angle phase displacement relatively thereto, amplifying said second wave train while substantially reversing its phase to obtain a third wave train at a phase angle relatively to said first train which is greater than 180° but less than 270°, unidirectionally modulating the amplitude of said third train proportionate to said signal impulses while maintaining said frequency, vectorially adding said unmodified first train and said third train to form a phase modulated resultant wave, and regulating the values of said trains such that the direction of the vector of the unmodulated resultant wave is substantially normal to the direction of said third train.

5. In the art of signal transmission by modulated high frequency waves, apparatus for phase modulating a carrier wave train under control of signal impulses, comprising means for generating a wave train, means for deriving from said wave train a second wave train of substantially equal frequency but having a phase which differs from that of said first train by an angle greater than 180° but less than 270°, means for unidirectionally modulating the amplitude of said second train under control of said signal impulses while maintaining said frequency, and means for vectorially adding said second train to the unmodified first train to form a phase modulated resultant wave whose unmodulated vector is substantially normal to the vector of said second train.

6. In the art of signal transmission by modulated high frequency waves, apparatus for phase modulating a carrier wave train under control of signal impulses, comprising means supplying a signal wave to be transmitted, means for generating a wave train, means for deriving from said wave train a second wave train of substantially the same frequency but having phase displacement greater than 180° but less than 270° relatively thereto, means for unidirectionally modulating the amplitude of said second train proportionate to said signal wave while maintaining said frequency, means for vectorially adding said unmodified first train and said second train to form a phase modulated resultant wave, and means for maintaining the unmodulated vector of said resultant wave substantially normal to the vector of said second train.

7. In the art of signal transmission by modulated high frequency waves, apparatus for phase modulating a carrier wave train under control of signal impulses, comprising means for generating a wave train of substantially constant frequency, means for deriving from said wave

train a second wave train of substantially the same frequency but having a phase displacement greater than 180° but less than 270° relatively thereto, means for unidirectionally modulating the amplitude of said second train proportionate to said signal impulses while maintaining said frequency, and means for vectorially adding said unmodified first train and said third train to form a phase modulated resultant wave whose unmodulated vector is substantially normal to the vector of said second train.

8. In the art of signal transmission by modulated high frequency waves, apparatus for phase modulating a carrier wave train under control of signal impulses, comprising means for generating a wave train, means for deriving from said wave train a second wave train of substantially the same frequency but having an acute angle phase displacement relatively thereto, means for amplifying said second wave train while substantially reversing its phase to obtain a third wave train, means for unidirectionally modulating the amplitude of said third train under control of said signal impulses while maintaining said frequency, means for vectorially adding said unmodified first train and said third train to form a phase modulated resultant wave, and means for maintaining the unmodulated vector of said resultant wave substantially normal to the vector of said third train.

9. Phase modulation apparatus comprising a transmission line with two conductors, an oscillator of substantially fixed frequency feeding into said line, a phase shifting network including a capacitor and a resistor connected in series across said first and said second conductors, a high vacuum tube having anode, cathode and two control electrodes, a connection from a tap between said capacitor and said resistor to one of said electrodes, signal impulse supply means having two terminals, one of which is connected to said

second conductor, a connection from said second electrode to the other terminal of said signal supply means, means for connecting said anode to said first conductor, a transmitter, and a substantially purely ohmic resistance connection from said transmitter through said first conductor to said oscillator.

10. Phase modulation apparatus comprising a transmission line with two conductors, an oscillator of substantially fixed frequency feeding into said line, a phase shifting network including a capacitor and a resistor connected in series across said first and said second conductors, a high vacuum tube having anode, cathode and two control electrodes, a connection from a tap between said capacitor and said resistor to one of said electrodes, signal impulse supply means having two terminals, one of which is connected to said second conductor, a connection from said second electrode to the other terminal of said signal supply means, means for connecting said anode to said first conductor, means for adjusting the amplitude of the output current of said tube, a transmitter, and a substantially purely ohmic resistance connection from said transmitter through said first conductor to said oscillator.

BERNARD J. COSMAN.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,687,225	Peterson	Oct. 9, 1928
1,892,383	Chiveix	Dec. 27, 1932
1,964,522	Lewis	June 26, 1934
1,994,048	Runington	Mar. 12, 1935
2,027,044	Hofer et al.	Jan. 7, 1936
2,238,249	Crosby	Apr. 15, 1941