

March 2, 1948.

L. RUBIN

2,437,047

PHASE MODULATION

Filed Dec. 23, 1943

3 Sheets-Sheet 1

Fig. 1.

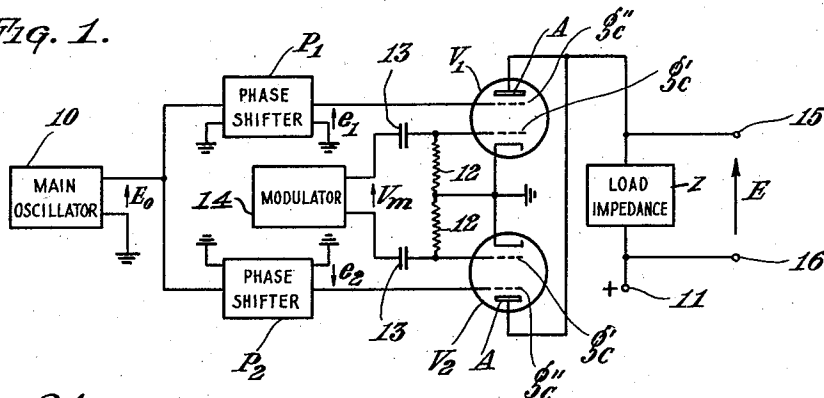


Fig. 2A

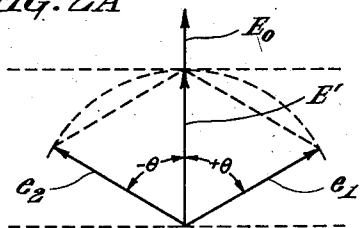


Fig. 2B.

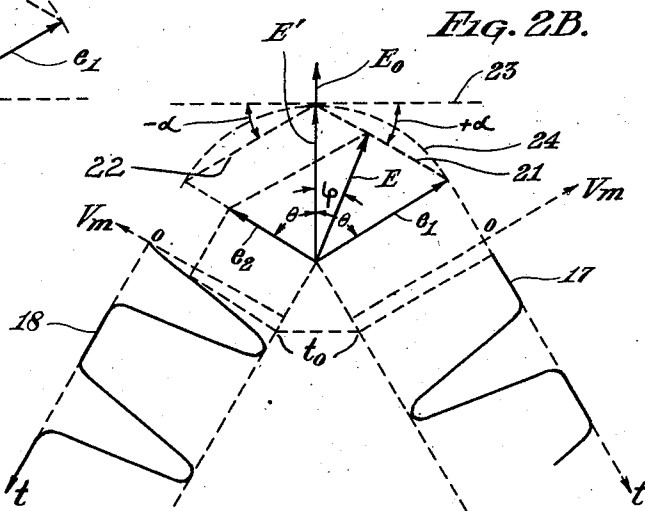
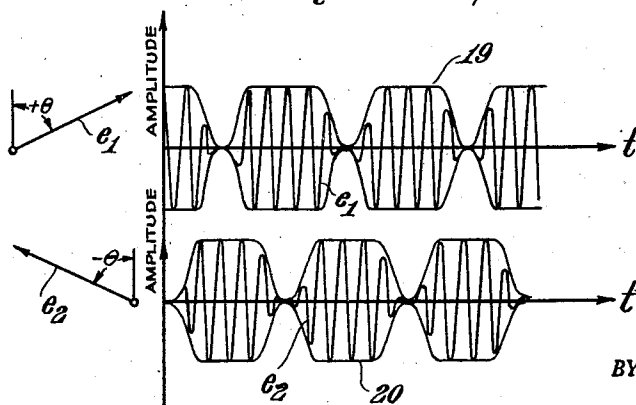


Fig. 3.



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Fig. 4.

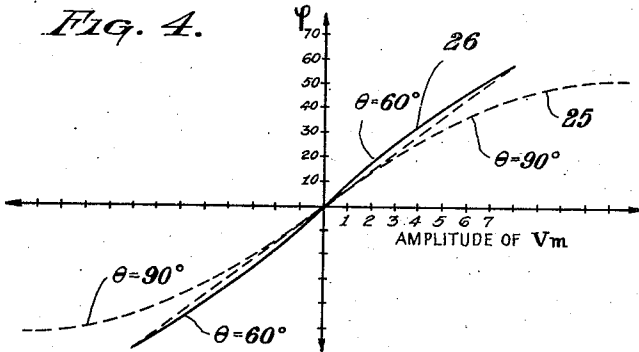


Fig. 5.

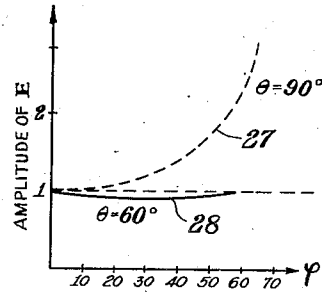


Fig. 6.

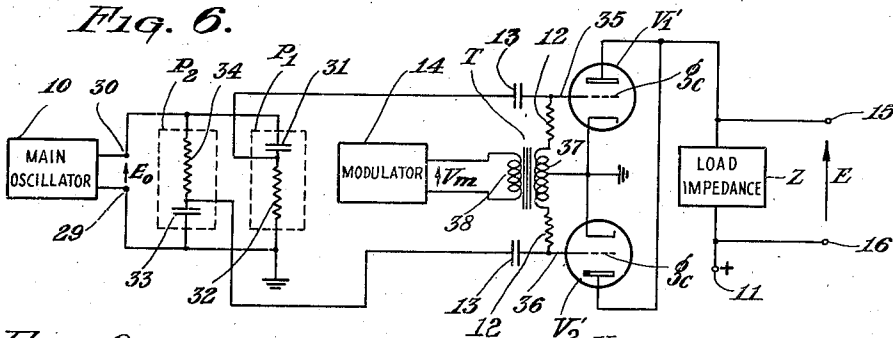


Fig. 8.

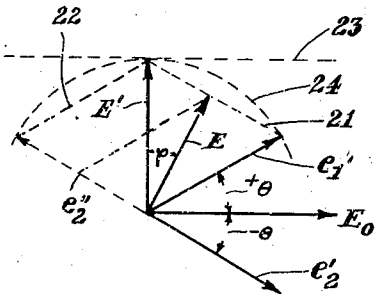
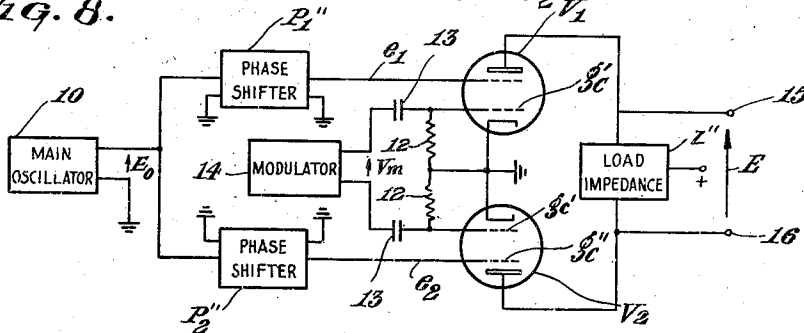


Fig. 7.

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Fig. 9.

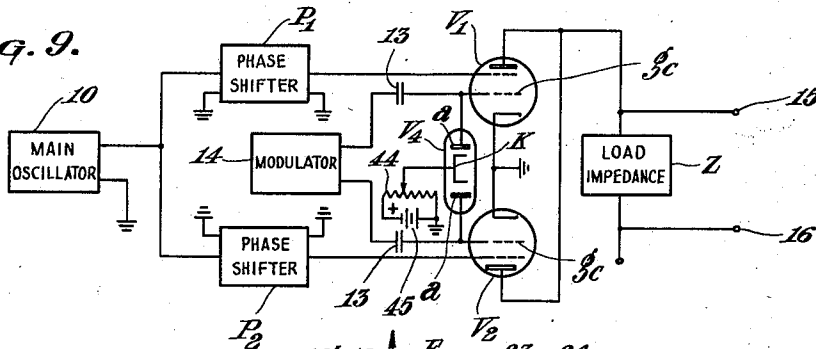


Fig. 10.

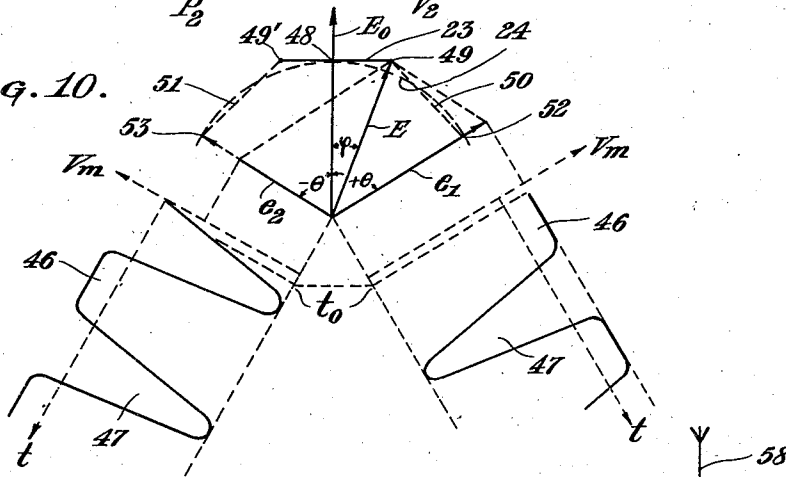
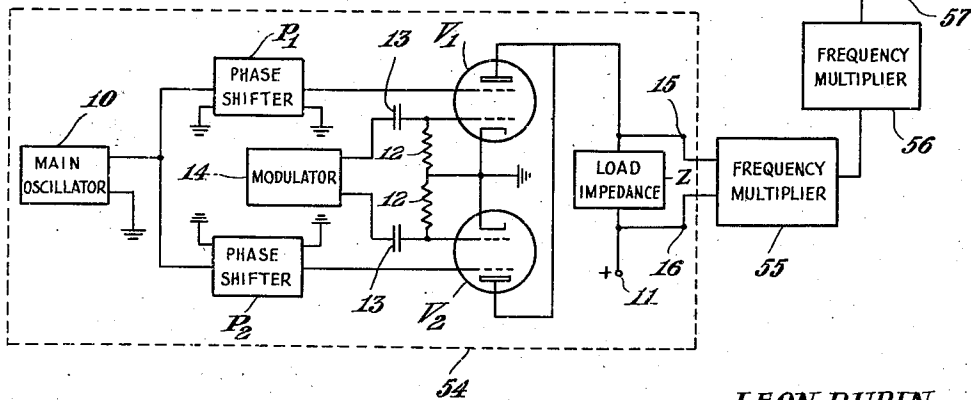


Fig. 11.



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PHASE MODULATION

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Application December 23, 1943, Serial No. 515,446

9 Claims. (Cl. 179—171.5)

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This invention relates to phase modulation and more particularly to an improved phase modulation circuit especially useful for frequency modulation transmitters.

It is known that a phase modulated oscillation can be obtained by either combining the carrier wave in quadrature with the side bands or by linearly modulating in phase opposition the amplitudes of two oscillations having a given phase difference and by combining these amplitude modulated oscillations. In both systems, one extreme of the vector representing the resulting phase modulated oscillation in the corresponding vector diagram, slides along a straight line perpendicular to the vector representing the unmodulated oscillation during a complete modulation cycle, while in an ideal phase modulating circuit this phase modulated vector slides along an arc of a circle, drawn with said vector as radius.

Consequently, in these systems, the relation between phase angle and amplitude of the modulating potential cannot be linear, the admissible tolerance in distortion usually limiting the phase angle to a maximum value of approximately $\pm 30^\circ$.

I have now found that if the amplitude of two oscillations having a phase difference smaller than π radians is non-linearly modulated in phase opposition in accordance with the amplitude variations of an intelligence oscillation, the vector sum of these oscillations will represent a phase modulated oscillation which, for some optimum value of phase angle between these amplitude modulated oscillations, will closely approach the characteristics of an ideal phase modulating circuit. In fact, the vector representing the phase modulated oscillation obtained will alternatively slide with its end along two lines which, forming some angle with a straight line perpendicular to the vector representing the resulting oscillation in the absence of modulation, constitute the complementary lines of the corresponding vector diagram, so that these two lines in view of their inclination, may be regarded to represent the corresponding arc of the ideal phase modulating circuit in first approximation.

It is therefore one of the main objects of the present invention to provide a phase modulating system wherein the relation between the amplitude of the modulating potential and phase angle of the modulated high-frequency oscillation will be linear over a wide range of phase angle variations.

A further object of the present invention is to

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provide a phase modulating system which, while being of simple circuit layout and including a minimum of circuit elements allows of a maximum variation in the phase angle.

Another object of the present invention is to provide a transmitter in which the number of frequency multiplier stages necessary to obtain the modulation index required, will be less as compared with the known frequency modulation systems.

The above and further objects and advantages of the present invention will become more apparent from the following detailed description taken with reference to the accompanying drawings forming part of this specification and wherein:

Fig. 1 is a block diagram, schematically showing one embodiment of the present invention.

Figs. 2A to 5 are explanatory diagrams relating to the operation of the phase modulation system shown in Fig. 1.

Fig. 6 is a circuit diagram of the phase modulation system according to Fig. 1.

Fig. 7 illustrates a modification of the circuit shown in Figs. 1 and 6.

Fig. 8 is an explanatory vector diagram relating to the operation of the phase modulation system shown in Fig. 7.

Fig. 9 shows still another modification of the phase modulation system shown in Figs. 1 and 6.

Fig. 10 is an explanatory vector diagram relating to the operation of the system shown in Fig. 9, and finally

Fig. 11 schematically illustrates a transmitter using the phase modulating circuit according to one embodiment of the present invention.

The same reference characters are used to indicate like or corresponding parts or elements throughout the drawings.

Referring now to Fig. 1, it may be seen that oscillator 10, generating a main oscillation E_0 , is coupled through phase shifters P_1 and P_2 to control grids g'_c of thermionic tubes V_1 and V_2 , respectively, the anode circuits of which are connected in parallel to a common load impedance Z , connected to the positive pole 11 of a direct current supply not shown in the drawing. Control grids g'_c of these tubes, provided with grid leak resistances 12, are coupled in push-pull by means of coupling condensers 13 to a modulator 14 constituting a source of modulating potential V_m .

As can be observed in the vector diagram shown in Fig. 2A, phase shifters P_1 and P_2 are designed so that partial oscillations e_1 and e_2 derived from

main oscillation E_0 and amplified by tubes V_1 and V_2 have their phase shifted $+\theta$ and $-\theta$ degrees, respectively, from the phase of said main oscillation E_0 , the sum of these angles θ being always smaller than π radians. Consequently, in the absence of modulation the output oscillation E' , appearing at the output terminals 15 and 16 of the phase modulation system and developed across common load impedance Z , will represent the vectorial sum of partial oscillations e_1 and e_2 and will be in phase with main oscillation E_0 .

The control circuits of tubes V_1 and V_2 including grids g'_c and g''_c are designed to operate with grid current saturation during the positive half periods of the modulating potential V_m by utilizing very large resistances as grid leaks 12, the time constants of the combination of coupling condensers 13 and grid leak resistances 11 being however, smaller than the periods of the highest modulation frequency. Hence assuming that the positive half wave of modulating oscillation V_m is present on control grid g'_c of tube V_1 , the amplitude of partial oscillation e_1 generated by this tube across load impedance Z , will be maintained constant, while the amplitude of partial oscillation e_2 , generated by tube V_2 across the same load impedance Z , will first decrease to a minimum value or to zero and then again increase to its maximum value in synchronism with the amplitude variations of the negative half wave of said modulating oscillation or potential V_m , as can be observed in the vector diagram shown in Fig. 2B, where curves 17 and 18 illustrate the biasing potentials present at control grids g'_c of tubes V_1 and V_2 , respectively, while curves 19 and 20 shown in Fig. 3 represent the high frequency current generated by these tubes across common load impedance Z . It is therefore evident that vector E in the diagram shown in Fig. 2B, corresponding to the output oscillation appearing between terminals 15 and 16 of the phase modulation system according to the present invention, is equal to the vector sum of partial oscillation e_1 which is maintained on its maximum amplitude and partial oscillation e_2 the amplitude of which is determined by the amplitude of modulating oscillation V_m which, in the vector diagram shown in Fig. 2B, is illustrated at some arbitrary time t_0 . Output oscillation E thus has its phase shifted $+\varphi$ from the phase of oscillation E_0 which is in phase with vector E' representing the unmodulated output oscillation. Since the amplitude modulation of partial oscillations e_1 and e_2 is carried out in phase opposition or push-pull, it will be obvious that during a complete cycle of the modulating oscillation V_m , phase angle φ of output oscillation E will vary from zero to $\pm\theta$ and that the extreme of vector E will slide along straight lines 21 and 22 which complete the vector diagram and which form the angles $+\alpha$ and $-\alpha$, respectively, with straight line 23 perpendicular to vector E' representing the unmodulated output oscillation E .

Lines 21 and 22, each forming part of the vector diagram, intersect circumference 24 of a circle drawn with E' as a radius at two points and may be regarded as the first approximation of the arc included between these intersection points, so that the phase modulation characteristics of the system according to the present invention, reproduce more closely the operating conditions in the ideal phase modulation circuit as the known phase modulation system wherein the extreme of vector E would slide along straight line 23. Therefore, it will be evident for those skilled in the art that the range over which the relation between the

amplitude of modulating oscillation or potential V_m and phase angle φ will be wider in the phase modulation system according to the present invention, than in the known phase modulation systems, and that for some optimum value of θ this relation will be perfectly linear for all practical purposes.

The advantages of the novel phase modulation system can be fully appreciated in the graphs shown in Figures 4 and 5, the first showing curves 25 and 26, representing the relation between phase angle φ and amplitude of modulating potential V_m .

Curve 25 has been drawn for a phase difference $\theta=90^\circ$, i. e. illustrating the operating conditions of the known phase modulation systems, while curve 26 has been drawn with $\theta=60^\circ$ as a parameter, this value representing the optimum phase difference between main oscillation E_0 and partial oscillations e_1 and e_2 . As can be observed in Fig. 4, curves 25 and 26 illustrate in a drastic manner the limitations inherent to the known phase modulation systems in which a linear relation between the amplitude of modulating potential V_m and phase angle φ can be obtained over a range of $\pm 30^\circ$ only, while in the phase modulation system according to the present invention this relation is practically perfectly linear over a range of $\pm 60^\circ$. Hence, frequency modulation systems, utilizing the phase modulation circuit according to the present invention, will require fewer frequency multiplier stages to obtain a given modulation index and consequently will represent not only a better technical but also a more economic solution of the problem to produce phase or frequency modulated oscillations.

In Fig. 5 curves 27 and 28 illustrate the relation between the amplitude of the phase modulated oscillation E and phase angle φ , the curves being drawn with $\theta=90^\circ$ and $\theta=60^\circ$ as parameters. It is well known in the art that owing to the particular organization of the known phase modulation systems, the phase modulation of the output oscillation is inevitably accompanied by an amplitude modulation and that this amplitude modulation constitutes one of the main drawbacks of the known systems in which amplitude limiter stages have to be used in order to obtain an output oscillation modulated in phase only. Curve 27 quite clearly illustrates these unfavourable operating conditions of the known phase modulation systems which in fact can be regarded as a phase modulation system wherein phase difference θ between partial oscillation e_1 and e_2 is equal to zero, and it can be seen that for a phase angle of 70° the amplitude of the phase modulated oscillation E has increased to three times its original amplitude.

In contradistinction to the known phase modulation systems, the amplitude of phase modulated oscillation E remains practically constant over a range of phase angles from zero to 70° when the phase difference θ between E' and partial oscillations e_1 and e_2 is equal to the optimum value of 60° , as illustrated by curve 28 shown in Fig. 5.

It will be understood that the advantages and improvements inherent to the phase modulation system according to the present invention are obtained in view of the fact that phase modulated output oscillation E is obtained as the vectorial sum of two partial oscillations e_1 and e_2 having a phase difference smaller than π radians and the amplitudes of which are non-linearly modulated or varied in phase opposition in accordance with the amplitude variations of modulating potential

V_m , so that the end of vector E representing this output phase modulated oscillation in the corresponding vector diagram will slide along two straight lines 21 and 22 forming an angle equal to the phase difference between partial oscillations e_1 and e_2 .

In the schematic block diagram shown in Fig. 1 as well as in the circuit diagram in Fig. 6, representing one of the embodiments of the phase modulation system according to the present invention, the non-linearity of the amplitude modulation of partial oscillations e_1 and e_2 is obtained by grid current saturation of thermionic tubes V_1 and V_2 . However, this represents one of the many possible arrangements for non-linearly modulating partial oscillations e_1 and e_2 and a somewhat different circuit for this purpose will be described hereinafter.

As can be seen in the circuit diagram shown in Fig. 6, output terminals 29 and 30 of main oscillator 10 are connected to phase shifters P_1 and P_2 formed by the series connected condenser 31, resistance 32 and condenser 33 and resistance 34, respectively. As can be seen in the drawing, resistance 32 and condenser 33 are connected to output terminal 29 of main oscillator 10, while condenser 32 and resistance 34 are connected to the opposite terminal 30, the junction points between the condensers and resistances of phase shifters P_1 and P_2 being coupled by means of coupling condensers 13 and conductors 35 and 36, respectively, to the control grids g_c of thermionic tubes V_1 and V_2 . Control grids g_c of these tubes are connected, as already explained hereinabove, through grid leak resistances 12 to the ends of the secondary winding 37 of a modulation transformer T , the primary winding 38 of which is connected to modulator 14. The electrical mid-point of secondary winding 37 is connected together with the cathodes of said thermionic tubes V_1 and V_2 to ground potential.

The circuit elements of phase shifters P_1 and P_2 are designed so that partial oscillations e_1 and e_2 applied to control grids g_c of tubes V_1 and V_2 have their phase shifted $\pm\theta^\circ$ from the phase of main oscillation E_0 and, although in the circuit diagram shown in Fig. 6 these partial oscillations are applied to control grid g_c together with modulating potential V_m , the operation of this circuit is similar to that shown in Fig. 1.

Thus the phase modulated oscillation E is obtained in the phase modulation system according to Figures 1 and 6 by combining two partial oscillations e_1 and e_2 having a phase difference smaller than 180° and by alternatively maintaining one of these partial oscillations at its maximum value, while decreasing the amplitude of the other partial oscillation to a minimum value and back to said maximum amplitude, so that vector E , representing the phase modulated oscillation in the corresponding vector diagram, will slide along two straight lines 21 and 22 forming an angle equal to the phase difference between said partial oscillations.

However, the same results may be obtained by vectorially combining an oscillation of constant amplitude and phase with two partial oscillations having their phase shifted $\pm\theta^\circ$ from the phase of this oscillation and by varying the amplitude of one of these partial oscillations from zero to a maximum value and back to zero, while substantially completely suppressing the other partial oscillation, and vice-versa.

In the circuits representing the embodiments of the phase modulation system according to the

present invention, the phase difference between partial oscillations e_1 and e_2 , i. e. the sum of phase angles θ , has been always smaller than π but larger than $\pi/2$. However, for some applications it may be convenient to operate with partial oscillations having an original phase difference smaller than $\pi/2$, and the schematic block diagram shown in Fig. 7 illustrates a phase modulation system incorporating the abovementioned condition. The only difference between the circuit layout shown in Fig. 7 and that of Fig. 1 consists in that the anode circuits of thermionic tubes V_1 and V_2 are connected in push-pull to load impedance Z'' , so as to compensate the smaller value of the original phase difference between partial oscillations e'_1 and e'_2 derived from main oscillation E_0 by means of phase shifters P''_1 and P''_2 , respectively.

As already explained hereinbefore, in the system according to Fig. 1 the phase modulated output oscillation E is obtained by vectorially combining two partial oscillations e_1 and e_2 which are derived from main oscillation E by means of phase shifters P_1 and P_2 and which have a phase difference $+\theta$ and $-\theta$ respectively with reference to said main oscillation, the amplitudes of these partial oscillations being non-linearly modulated in accordance with the amplitude variations of modulating potential V_m .

Now let us assume that phase shifters P''_1 and P''_2 are designed so that partial oscillations e'_1 and e'_2 have their phases shifted $+\theta'$ and $-\theta'$ degrees respectively, from the phase of main oscillation E_0 , as can be observed in the vector diagram shown in Fig. 8. In the phase modulation system according to Fig. 1, the phase relationship between partial oscillations e_1 and e_2 applied to the control grids of tubes V_1 and V_2 and the amplitude modulated partial oscillations developed across common load impedance Z is not altered, since the anode circuits of both tubes are connected in parallel, so that the phase inversion of 180° , taking place in each tube, does not affect the phase difference between the partial oscillations.

However, in the circuit shown in Fig. 7 the anode circuits of tubes V_1 and V_2 are connected in push-pull. Hence, tube V_1 may be regarded as operating in a way similar to that of the circuit shown in Fig. 1, while tube V_2 will generate across load impedance Z a partial oscillation e''_2 which will be 180° out of phase with respect to partial oscillation e'_2 applied to control grid g_c of this tube. Consequently, the phase modulated output oscillation E will be now formed as the vector sum of partial oscillation e'_1 generated by tube V_1 and partial oscillation e''_2 generated by tube V_2 , and the vector diagram of Fig. 8 clearly shows that there is no difference between the results obtained with the circuit shown in Figs. 1 and 2.

Consequently, in the phase modulation system according to Fig. 11, thermionic tube V_2 operates not only as an amplitude modulator for partial oscillation e'_2 but also constitutes part of the phase shifter P''_2 , so that the vectorially combined partial oscillations e'_1 and e''_2 have a phase difference smaller than π but larger than $\pi/2$.

It has been already explained hereinbefore that the basic idea of my invention consists therein that during modulation the end of the vector representing the phase modulated output oscillation is made to slide along two straight lines 21 and 22 representing the first approximation of an arc of the ideal phase modulation

circuit, this result being obtained by non-linearly modulating the amplitudes of partial oscillations e_1 and e_2 having a phase difference smaller than π .

In the circuits described hereinbefore, the non-linear modulation has been achieved by varying the amplitude of partial oscillations e_1 and e_2 or e'_1 and e'_2 , during one half-period only of modulating oscillation V_m , the amplitude of these partial oscillations remaining unchanged during the other half-periods of V_m . However, I have found that if the amplitude of said partial oscillations is also varied during a portion of the half-period usually not utilized for modulation, a phase modulation system will be obtained which will reproduce still better the operating conditions of the ideal phase modulation circuit, provided that the amplitude variation of e_1 and e_2 or e'_1 and e'_2 will be maintained within certain limits during these half-periods.

The schematical block diagram shown in Fig. 9 illustrates a phase modulation system incorporating the aforementioned improvement, the circuit differing from the circuit shown in Fig. 1 in that control grids g_c of thermionic tubes V_1 and V_2 are connected to anodes a of a double diode V_4 , the common cathode k of which is connected to the movable arm of a potentiometer 44 connected in shunt across a direct current supply 45, the negative pole of which is coupled together with the cathode of tubes V_1 and V_2 to ground potential.

When cathodes k of diode tube V_4 are connected to ground potential, the positive half-periods of modulating oscillation V_m will not affect the operation of tubes V_1 and V_2 which will remain conductive over the whole duration of these half-periods. The operation of the circuit shown in Fig. 9 will be similar to that of the circuit shown in Fig. 1. If, however, cathodes k of diode tube V_4 are made positive by conveniently adjusting the movable arm of potentiometer 45, then the amplitude of partial oscillation e_1 and e_2 will also be varied during portions of the positive half-period of modulating oscillation V_m and will remain substantially constant during the remaining portion of these half-periods, the relationship between these portions being determined by the positive bias of cathode K of double diode V_4 .

As can be observed in the vector diagram shown in Fig. 10, vector E representing the phase modulated output oscillation obtained between the output terminals 15 and 16 of the circuit will first slide with its end along straight line 23 during the positive half-period 46 of modulating oscillation V_m , the distance between intersection point 48 of line 23 and vector E' (representing output oscillation E in the absence of modulation) and points 49 and 49' on the same line, being determined by the amplitude of positive half periods 46 of V_m . During the negative half-waves 47 of V_m the end of vector E will slide along straight lines 50 and 51 interconnecting points 49 and 49' with points 52 and 53 respectively, the latter points corresponding to the ends of vector e_1 and e_2 in the absence of modulation.

It will be understood that the combination of line 50, portion 49-49' of straight line 23 and line 51 constitutes a better approximation of arc 24 of the ideal phase modulation circuit than the combination of straight lines 21 and 22 obtained in the vector diagrams of the circuits described hereinbefore. It will be also understood that by conveniently adjusting the amplitude of positive half-periods 46 of modulating oscillation V_m , 75

lines 50 and 51 can be made to cross the corresponding portions of arc 24 at two points (as shown), thus obtaining a phase modulation system the output characteristics of which will practically be equal to those of the ideal phase modulation circuit.

Fig. 11 illustrates the schematic block diagram of a transmitter incorporating a phase modulation system according to the present invention. As can be seen in the drawing, the novel phase modulator, designated by the general reference number 54, is coupled by means of two frequency multiplier stages 55 and 56 to power amplifier 57 provided with antenna 58. Since the amplitude of the phase modulated output oscillation E present at the input of frequency multiplier stage 55 remains substantially constant throughout the whole range of phase variations, it is not necessary to use amplitude limiter stages between the phase modulator 54 and the other stages of the transmitter. Furthermore, the number of frequency multiplier stages can be kept at a minimum due to the wide range of phase angle variations which can be obtained in the phase modulation system according to the present invention.

While I have shown my phase modulation system as utilizing phase shifters of the resistance capacitance type, it will be understood that the present invention is not limited to the use of such phase shifters. Obviously, other types of phase shifters can be used, since the primary object of these circuit elements is to derive from main oscillation E_0 the partial oscillations e_1 and e_2 having some predetermined phase difference. Similarly, it will be apparent to one skilled in the art that my invention is by no means limited to the particular arrangements shown and described, but that many modifications may be made without departing from the scope of the invention.

I claim:

1. The method of varying the phase of an electrical oscillation in accordance with the amplitude variations of a modulating potential, which comprises the steps of generating a main oscillation, deriving from said main oscillation two partial oscillations having a phase difference smaller than π radians, antiphasally varying the amplitudes of said partial oscillations in accordance with the amplitude variations of a predetermined portion of the period of said modulating potential, antiphasally maintaining the amplitudes of said partial oscillations substantially constant during the remaining portion of the period of said modulating potential, and vectorially adding said non-linearly amplitude modulated partial oscillations to produce an electrical oscillation having a phase angle substantially proportional to the amplitude of said modulating potential.

2. The method of varying the phase of an electrical oscillation in accordance with the amplitude variations of a modulating potential, which comprises the steps of generating a main electrical oscillation, deriving from said main oscillation two partial oscillations having a phase difference smaller than π radians, antiphasally varying the amplitudes of said partial oscillations in accordance with the amplitude variations of the half-periods of one polarity of said modulating potential, antiphasally maintaining the amplitudes of said partial oscillations substantially constant during the half-periods of the other polarity of said modulating potential, and vectorially adding said non-linearly amplitude modulated partial oscillations to produce an electrical oscillation

having a phase angle substantially proportional to the amplitude of said modulating potential.

3. The method of varying the phase angle of an electrical oscillation in accordance with the amplitude variations of a modulating potential, which comprises the steps of generating a main electrical oscillation, deriving from said main oscillation two partial oscillations of substantially equal amplitude and having a phase difference smaller than π radians, antiphasally varying the amplitudes of said partial oscillations from a maximum to a minimum and back to said maximum value in accordance with the negative half-periods of said modulating potential, antiphasally maintaining the amplitudes of said partial oscillations substantially constant during the positive half-periods of said modulating potential, and vectorially adding said non-linearly amplitude modulated partial oscillations to produce an electrical oscillation having a phase angle substantially proportional to the amplitude of said modulating potential.

4. A phase modulation system comprising, means for generating a main electrical oscillation, means for deriving from said main oscillation two partial oscillations having a phase difference smaller than π radians, a source of a modulating potential, an amplitude modulator having a non-linear modulation characteristic connected to said partial oscillation deriving means and coupled to said source of modulating potential generating means to antiphasally vary the amplitudes of said partial oscillations in accordance with the amplitude variations of a predetermined portion of the period of said modulating potential and to antiphasally maintain the amplitudes of said partial oscillations substantially constant during the remaining portion of the period of said modulating potential, and means connected to said amplitude modulation means to vectorially add the amplitude modulated partial oscillations to produce an electrical oscillation having a phase angle substantially proportional to the amplitude of said modulating potential.

5. A phase modulation system comprising, means for generating a main electrical oscillation, phase shifting means coupled to said main oscillation generating means to derive two partial oscillations of substantially equal amplitude and having a phase difference smaller than π radians, a source of a modulating potential, two thermionic tubes each having a cathode, at least one control electrode and an anode, each of said control electrodes being coupled to one of said phase shifting means in an oscillation amplification arrangement, said control electrodes being also coupled to said source of modulating potential in a push-pull arrangement, means to operate said control electrodes under grid current saturation circuit condition thereby to vary the amplitudes of said partial oscillations in phase opposition from a maximum value to a minimum and back to a maximum value in accordance with the negative half-periods of said modulating potential and to maintain the amplitudes of said partial oscillations substantially constant in phase opposition during the positive half-periods of said modulating potential, and a load impedance element connected in parallel with the anodes of said tubes for vectorially adding the amplitude modulated partial oscillations to produce an electrical oscillation having a phase angle substantially proportional to the amplitude of said modulating potential.

6. A phase modulation system comprising, an oscillator for generating a main oscillation, two phase shifters connected after said oscillator to derive from said main oscillation two partial oscillations of substantially equal amplitude and having a phase difference substantially equal to $\frac{2}{3}\pi$ radians, a source of a modulating potential, two thermionic tubes each having a cathode, a control electrode and an anode, the control grids of said thermionic tubes being coupled each to one of said phase shifters, a modulating transformer having a primary winding coupled to said modulating source and a secondary winding having its electrical midpoint connected to the cathodes of said tubes, grid leak resistors interconnecting the ends of said secondary winding to the said control grids in a push-pull grid-current saturation circuit arrangement, and a load impedance element connected in parallel to the anodes of said tubes for vectorially adding the amplitude modulated partial oscillations to produce an electrical oscillation having a phase angle substantially proportional to the amplitude of said modulating potential.

7. A phase modulation system comprising, an oscillator for generating a main oscillation, two phase shifters coupled to said oscillator to derive from said main oscillation a first and a second partial oscillations of substantially equal amplitude and having a phase difference smaller than π radians, a source of a modulating potential, two thermionic tubes each having a cathode, a first and a second control electrode and an anode, each of said first control electrodes being coupled to one of said phase shifters, while said second control electrodes are connected in push-pull to said source of modulating potential, each of said second control electrodes being returned to the cathode of the corresponding tube through a half-wave rectifier circuit and a source of direct voltage, to antiphasally vary the amplitudes of said partial oscillations during a portion greater than half of the period of said modulating potential, and to antiphasally maintain the amplitudes of said partial oscillations substantially constant during the remaining portion of the period of said modulating potential, and vectorial addition means constituted by a load impedance connected in parallel to the anodes of said tubes to produce an electrical oscillation having a phase angle substantially proportional to the amplitude of said modulating potential.

8. A phase modulation system comprising, an oscillator for generating a main oscillation, two phase shifters coupled to said oscillator to derive from said main oscillation two partial oscillations of substantially equal amplitude and having a phase difference smaller than π radians, a source of modulating potential, two thermionic tubes each having a cathode, a first and a second control electrode, and an anode, each of said first control electrodes being coupled to one of said phase shifters, means to antiphasally vary the amplitudes of said partial oscillations in accordance with the amplitude variations of the negative half-period and a variable part of the positive half-period of said modulating potential and to antiphasally maintain the amplitudes of said partial oscillations substantially constant during the remaining portion of the positive half-periods of said modulating potential, comprising means to couple said second control electrodes in push-pull to said source of modulating potential, two rectifier tubes having their anodes each connected to one of said second control electrodes,

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a source of direct voltage having its negative pole connected to the cathodes of said thermionic tubes, a potentiometer shunted across said source and having the arm thereof connected to the cathodes of said rectifier tubes, and vectorial addition means constituted by a load impedance connected in parallel to said anodes to produce an electrical oscillation having a phase angle substantially proportional to the amplitude of said modulating potential.

9. A phase modulation system comprising, means for generating a main electrical oscillation, phase shifting means coupled to said main oscillation generating means to derive from said main oscillation two partial oscillations of substantially equal amplitude and having a phase difference smaller than $\pi/2$ radians, a source of a modulating potential, two thermionic tubes each having a cathode, a first and a second control electrode and an anode, each of said first control electrodes being connected to one of said phase shifting means, said second control electrodes being connected in push-pull to said source of modulating potential in a grid-current saturation-circuit ar-

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angement, and vectorial addition means constituted by a load impedance connected in push-pull to the anodes of said tubes to vectorially combine the non-linearly amplitude modulated potential oscillations and to produce an electrical oscillation having a phase angle substantially proportional to the amplitude of said modulating potential.

L. RUBIN.

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2,347,458	Brown -----	Apr. 25, 1944