

June 23, 1936.

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2,045,107

PHASE MODULATION

Original Filed Dec. 2, 1932

4 Sheets-Sheet 1

Fig. 1

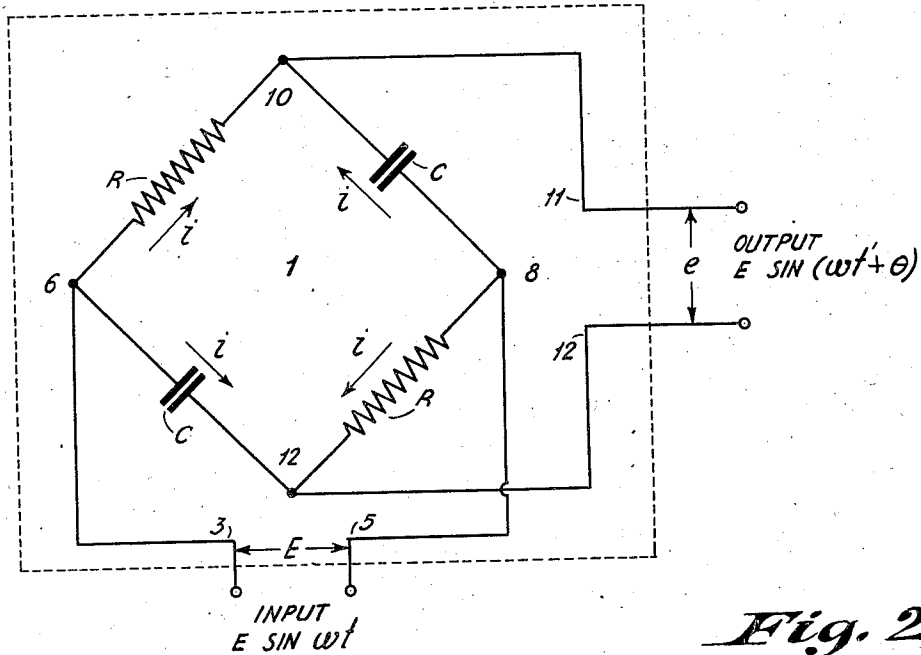
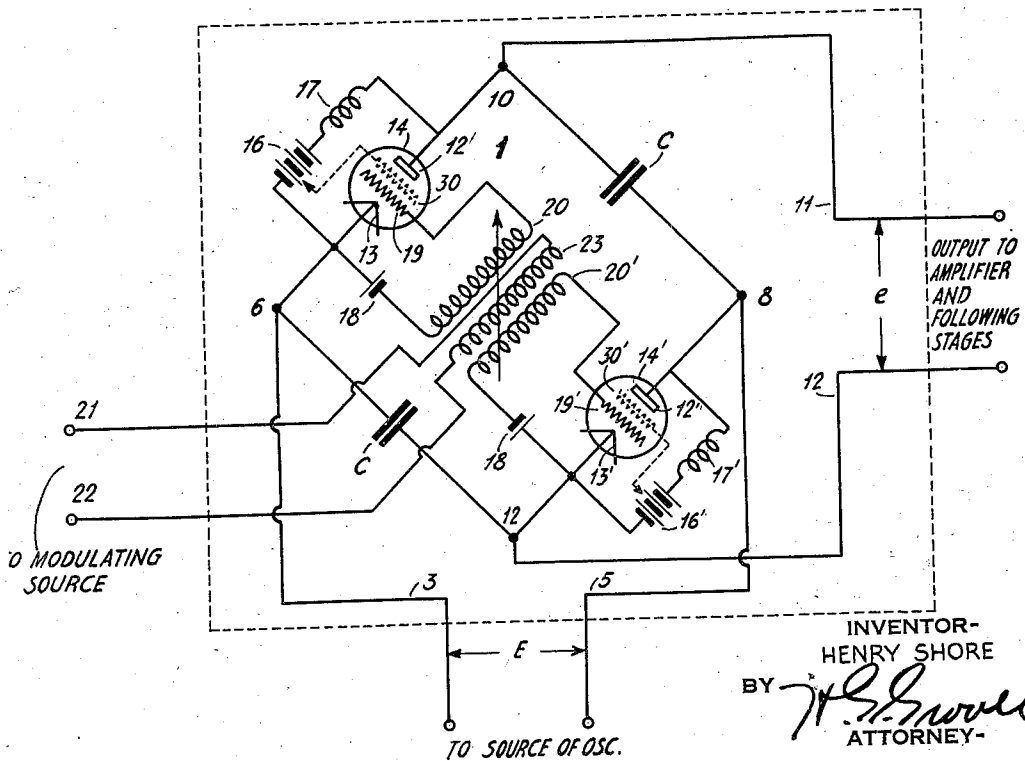


Fig. 2



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Original Filed Dec. 2, 1932

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Fig. 3.

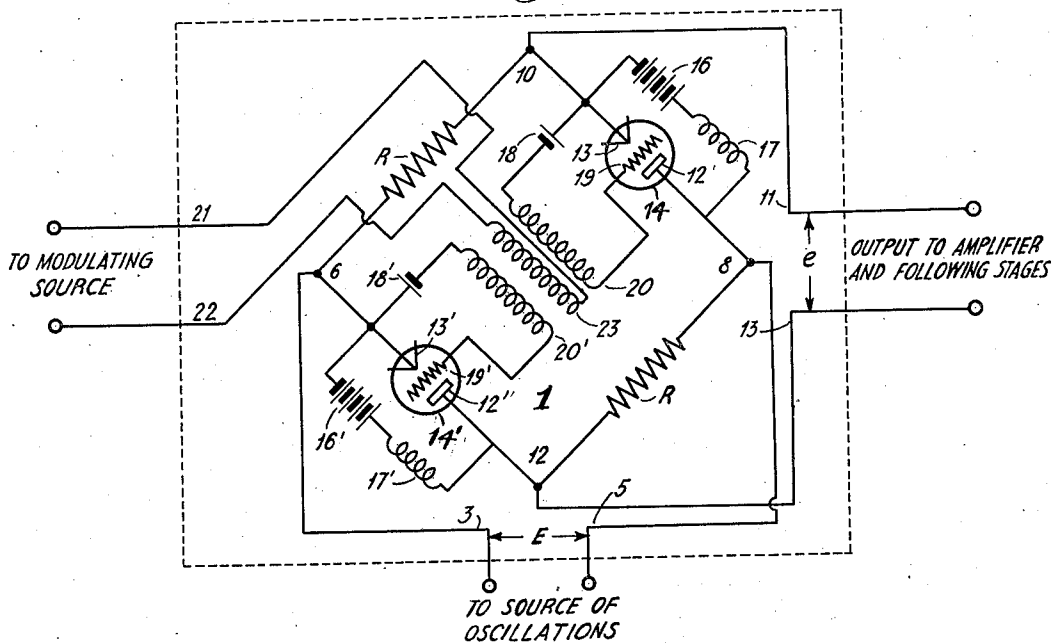
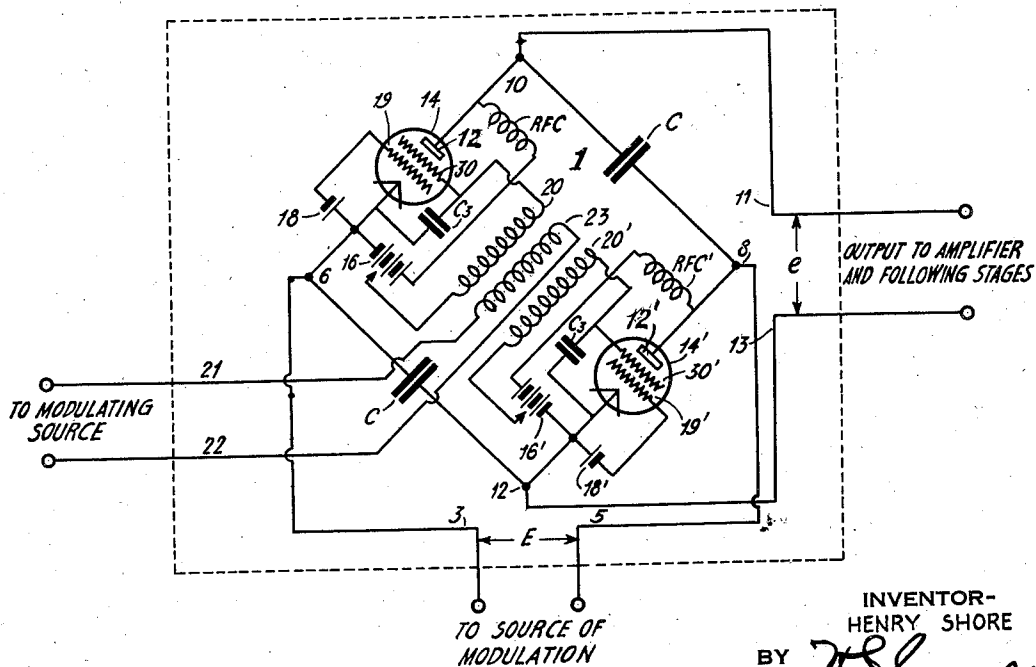


Fig. 4.



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Original Filed Dec. 2, 1932

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Fig. 5

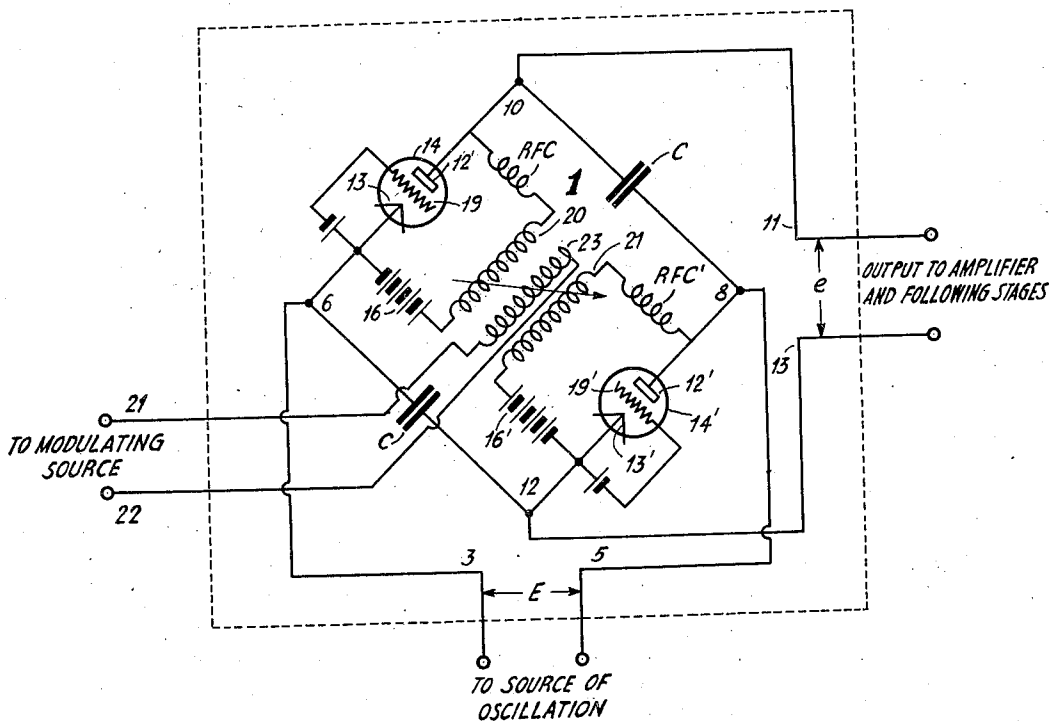
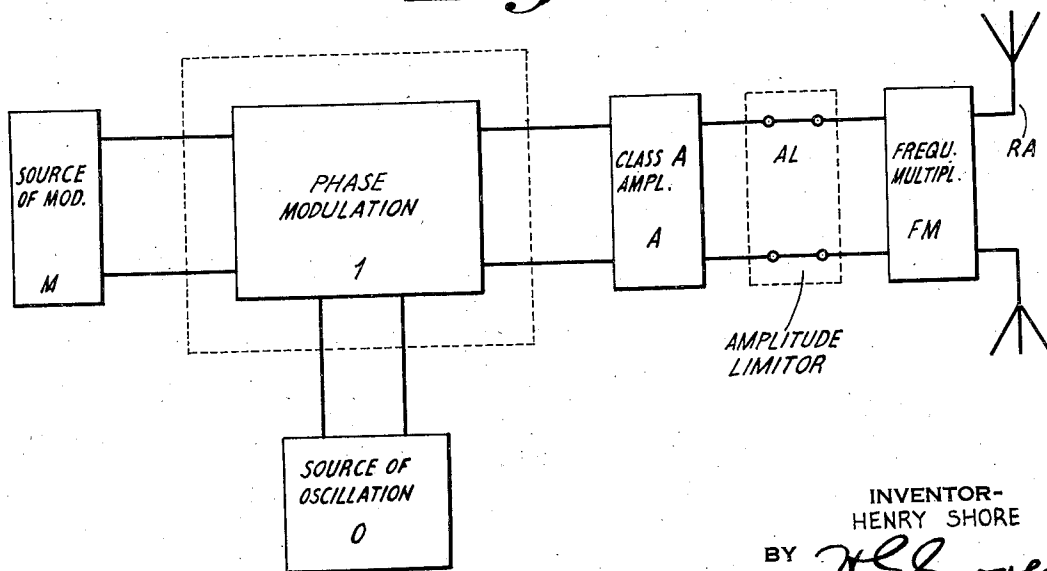


Fig. 6



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2,045,107

PHASE MODULATION

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Application December 2, 1932, Serial No. 645,436
Renewed May 3, 1934

20 Claims. (Cl. 179—171)

This invention relates to signalling and in particular to means for varying in phase the frequency of carrier oscillations at signal frequency. The phase modulating means may be applied to radio transmitters in which the modulated and amplified oscillations are radiated into a natural medium or in transmission systems wherein the modulated oscillations may be impressed for transmission on conductors or other artificial channels.

Phase modulator systems have been known heretofore. In general the phase modulating schemes known heretofore have required that either completely new installations be made including the modulating schemes, or considerable modifications be made to the existing circuits in the transmitters.

An object of the present invention is to provide a new and improved phase modulator scheme which may be applied to completely new installations or may, without modification of existing transmitters, be inserted bodily into transmission circuits now in use to adapt the same to phase modulation signalling. All that is required in modifying a transmitter now in use, as, for example, an amplitude modulated transmitter, is to remove the amplitude modulating unit and substitute in place thereof the phase modulator circuit of the present invention.

Moreover, the phase modulator of the present invention may be used simultaneously with amplitude modulation in new installations and in amplitude modulators now in use. This is an extremely important feature since it permits multiplexing of signals on the same carrier frequency. Furthermore, the resulting apparatus is simple in nature and efficient in operation.

The phase modulator circuit of the present invention may be introduced or inserted in the excitation leads in any of the stages of the transmitter. For example, it may be inserted between the high frequency oscillator, the modulating potential source, and the amplifier. The only essential is that the phase modulating circuit of the present invention be followed by an amplifier of the class A type. The reason why this requirement must be met will appear more in detail hereinafter.

In its broadest aspect my phase modulating scheme comprises a bridge circuit having four arms, each arm being composed of impedances, the impedances of an opposed pair of arms being variable, and means for varying at the signal frequency the impedances of said arms. Now,

if a source of high frequency oscillations is connected with one pair of diagonal points of said bridge, the potentials appearing across the other pair of diagonal points of said bridge, when the impedances of said variable arms are varied at signal frequency, will be phase modulated in accordance with the said signal.

One apparent advantage to be obtained by the use of my invention is that it permits rapid interchange or simultaneous use of different types of modulation and so results in a considerable saving of time and maintenance work. For example, an amplitude or frequency modulated transmitter may be readily, and with little effort, changed into a phase modulation transmitter by merely inserting therein my phase modulating bridge circuit. Subsequently the transmitter may be reconverted into an amplitude or frequency modulated transmitter by removing the bridge circuit of the present invention and restoring the original connections. Of course, both types of modulation may be used simultaneously.

Another advantage to be gained by the use of the bridge circuit phase modulating scheme of the present invention is that, since it may be substituted or inserted in transmitters now in existence, the use of phase modulated signals with all the advantages to be gained thereby does not necessitate a complete transmitting apparatus since all that is necessary is the simplified phase modulating bridge circuit of the present invention. This results in economy since a limited amount of apparatus is necessary to signal with several types of modulation.

The novel features of my invention have been pointed out with particularity in the claims appended hereto.

The nature of the circuit of the present invention and the mode of operation thereof will be better understood from the following detailed description thereof and therefrom when read in connection with the drawings, throughout which like reference characters indicate like parts, and in which:

Figure 1 is a bridge circuit used to illustrate the principle of the present invention;

Figures 2, 3, 4 and 5 are circuit arrangements similar to Figure 1, which may be used in the practical application of the invention;

Figures 6 and 7 show the application of the present phase modulating scheme to a transmitter which may be an installation now in use or a new installation; while,

Figures 8 and 9 are graphs which, with Figure 1, assist in clearly disclosing the principles of my invention.

Referring to the drawings, and in particular to Figure 1 thereof, the phase modulator circuit 1 comprises a bridge circuit having four connected arms. The impedances of the arms are substantially equal numerically in their unenergized state. Two of the opposed arms may, as shown, comprise substantially equal resistances R and R , while the opposite arms may be composed of substantially equal capacities C and C . If oscillations are impressed by way of leads 3 and 5 on to opposed points 6 and 8 of the bridge circuit, potentials of amplitude equal to the amplitude of the impressed oscillations will appear across the opposed points 10 and 12 of this bridge circuit. Due to the action of resistances R and R and the capacities C and C , these oscillation potentials appearing on the opposed points 10 and 12 will be shifted in phase with respect to the oscillating potentials applied on the opposed junction points 6 and 8. The circuit is not a balanced or null bridge in which there is no output when the bridge is balanced, but is a phase angle bridge in which, as indicated, the output voltage e is equal in magnitude to the input voltage E , and in which, as indicated, in Figure 1, $e = E \sin(\omega t + \theta)$. The relationship of phase shift between the input and output oscillations may be determined by the equation:

$$1. \quad \theta = \cos^{-1} \frac{(R^2 - X_C^2)}{(R^2 + X_C^2)}$$

35 That the relationship of phase shift between the input voltage E and the output voltage e is represented by Equation No. 1, given above, will be clear by reference to Figure 1 and to the graph of Figure 8.

40 In Figure 8 the voltage E , applied across the opposed points 6 and 8 of Figure 1, has been plotted along the X axis. The resistances R are assumed to be larger in impedance than the capacities C . The potential drop in R is represented in the graph by iR , which lags the voltage E . The potential drop through C has been represented by iX_C and leads the voltage E . The resultant e represents the voltage appearing across the opposed points 10, 12. The resultant voltage e is shifted with respect to the voltage E by an angle θ . Now if the angle θ is bisected we have the following relations:

$$2. \quad \tan \frac{\theta}{2} = \frac{iX_C + 2}{iR + 2} = \frac{X}{R}$$

from which

$$3. \quad \theta = 2 \tan^{-1} \frac{X}{R}$$

60 Now $i_1 = i_2$ because $X_C = X_C$ and $R = R$. (X_C = the reactance of the condensers).

Also

$$4. \quad e = i_1 R - (-j i_2 X_C) = i_1 R + j i_2 X_C$$

65 and

$$5. \quad i_1 = \frac{E}{R - j X_C} = i_2$$

Substituting Equation No. 5 in Equation No. 4 we get

$$6. \quad e = \frac{(R + j X_C)}{(R - j X_C)} E$$

$$75. \quad = \left[\frac{R^2 - X_C^2}{R^2 + X_C^2} + \frac{j 2 R X_C}{R^2 + X_C^2} \right] E$$

From the real part of this equation we get the cosine of the phase angle, or,

$$7. \quad \theta = \cos^{-1} \frac{(R^2 - X_C^2)}{(R^2 + X_C^2)}$$

In other words, $E = e$ in absolute values but the respective voltages are of different phase. This is because the bridge is not a null bridge but is a phase angle bridge, the voltage output of which is equal in magnitude to the voltage input. The voltages are out of phase except when the bridge is in a balanced state. If the impedances in either pair of opposed arms, that is, the resistances R , R or the capacities C , C , are varied in value in phase at signal frequency, it is obvious that the phase of the oscillations appearing at the output points, that is, the opposed points 10 and 12, will be shifted in variable degrees at signal frequency with respect to the phase of the oscillations impressed by leads 3 and 5 on to the other points 6 and 8 of the bridge circuit. That a change in the values of the resistances R or in the capacities C of the bridge arms results in a phase shift between the input voltage E and the output voltages e has been proven graphically in Figure 9, in which the values of the applied voltage E , the potential drop iR through the resistance R , and the potential drop iX_C through the capacities are the vectors of a vector system.

First, assume that the resistance R is large as compared to the capacity C . In this case the potential drop through R is represented by the vector $i_1 R$ lagging the vector E . The potential drop through C is represented by $i_2 X_C$. The resultant e_1 lags the vector E by the angle θ_1 .

Now assume that the value of the resistance R has been decreased substantially (say, by modulating means) and is small as compared to C . The potential drop through resistance R still lags E but is smaller and is represented by the vector $i_2 R$. The potential drop through C is larger and again leads the voltage E . The resultant e_2 now lags the vector E by an angle θ_2 which is considerably larger than the angle θ_1 . This increase in phase shift between E and e is due to the modulation of the value of R and the phase shift $\Delta\theta$ resulting from said modulation $= \theta_2 - \theta_1$.

In a similar manner it can be shown that modulation of the value of C will result in a phase shift between E and e . The phase shift may not be as large when C is modulated as when R is modulated.

The phase shifted oscillations may be impressed from the leads 11, 13 connected with points 10, 12 to any utilization circuit.

In practice either the resistances R , R or the capacities C , C may be varied by the modulating potentials. The practical applications of my phase modulating bridge circuit will now be described.

Referring to Figure 2 of the drawings, the bridge circuit 1 comprises four arms, as in Figure 1. Furthermore, an opposed pair of arms includes, as shown, capacities C and C . Here, however, the resistances R , R in the other pair of arms are replaced by the impedances between the anode 12 and cathode 13 and anode 12' and cathode 13' of thermionic tubes 14 and 14' respectively. Space current is supplied to the tube 14 by way of source 16 connected, as shown, between the cathode 13 and anode 12 by way of choking inductance 17. In a similar manner space charge current for the tube 14' is supplied from source 16' by way of choking inductance 17'. The control grid cathode circuits

of tubes 14 and 14' include biasing batteries 18 and 18' which maintain the control grids 19 and 19' at negative potential with respect to the cathodes and also inductances 20 and 20'. In order to vary the anode to cathode impedances of each of tubes 14 and 14' in phase at signal frequency, modulating potentials are applied by way of leads 21 and 22 to an inductance 23 symmetrically coupled with inductances 20 and 20'. The oscillations at signal frequency flowing in the inductance 23 are impressed in like phase on to inductances 20 and 20' and from said inductances in phase on to the control electrodes 19 and 19' of tubes 14 and 14'. These in-phase potentials are superimposed upon the direct current potentials applied to the control grids 19 and 19' respectively from sources 18 and 18' respectively and vary the conductivity of the tubes in phase. Now if, as in Figure 1, the carrier frequency oscillations to be modulated are applied by leads 3 and 5 to the junction points 6 and 8, potentials equal in amplitude to the applied potentials will appear at the junction points 10 and 12. The potentials at 10 and 12 will be shifted in phase with respect to the applied potentials. The amount of phase shift between these potentials will be determined by the amplitude of the modulating potentials acting on the conductivity of the tubes 14 and 12, and the rate at which the phase shifts between the applied oscillations and the oscillations appearing at 10 and 12 take place will be determined by the frequency of the modulating potentials. The phase modulated oscillations may be utilized by connecting any utilization circuit to the leads 11 and 12. In order to insure efficient operation of the modulating circuit, and to insure that the phase modulations on the carrier be truly representative of the signal, it is desirable that the load, that is, the current flowing in the several arms of the bridge circuit, is maintained at minimum. This requirement is satisfied in accordance with the present invention by connecting the output leads 11, 13 of the bridge circuit to an amplifier of what is known as the class A type. In this type of amplifier the thermionic tube is biased to such a point that little or no grid current flows in the input circuit and, therefore, little or no load is applied on the bridge circuit which is to be connected with the grid-electrode or with the input circuit of the amplifier.

Since change in the potential applied to the control grid electrode of a thermionic tube results in change in capacity of the tube, and since change in the value of the capacities C, C in the arms of the present bridge circuit results in phase modulation of the oscillations applied, as indicated hereinbefore, the arms C, C of the bridge circuit may be replaced by the impedances of the thermionic tubes, as shown in Figure 3. In this figure, 3, the other two arms of the bridge circuit include the two resistances R and R. The bridge circuit is otherwise the same as the bridge circuit of Figure 2. Furthermore, the oscillations to be modulated and the modulating oscillations are applied in a manner similar to which they are applied to the bridge circuit of Figure 2. Moreover, the phase modulated oscillations are derived from the points 10 and 12, as in Figure 2, and may be applied to any work circuit by way of a class A amplifier.

The arrangement of Figure 3 and the operation thereof will be obvious to the reader of the prior specification, and a description thereof and

a statement of the operation thereof is thought unnecessary at this point. It will be noted, however, that, since changes in capacity of the tubes due to variations in the applied modulating potentials are slight, the phase shift resulting at the junction points 10 and 12 will be less than in the arrangement of Figure 2. Where apparatus is limited the arrangement of Figure 3 may not be as desirable as the arrangement of Figure 2. However, if the class A amplifier, connected with the leads 11 and 13, can be followed by a frequency multiplier, the bridge circuit of Figure 3 may be more desirable than the bridge circuit of Figure 2 since frequency multiplication of the modulated carrier will increase the phase modulation sufficiently to insure satisfactory detection of the modulated wave at the receiving point.

Although in illustrating the present invention thermionic tubes of the triode type have been used, it will be understood that tubes of any other type may be used, and in particular tubes of the screen grid type in which the screening electrode is maintained at a positive potential to eliminate coupling between the input and output electrodes. The use of such tubes in the bridge circuit of the present invention has been illustrated in Figure 2 wherein the screening grid electrodes 30 and 30' are shown in dotted lines connected with a point on the potential sources 30, 16 and 16'.

Moreover, the impedance of the tubes 14 and 14' may be varied by applying the modulating potentials to other electrodes therein. For example, the modulating potentials may be applied to the screen grid electrodes 30 and 31, as indicated in Figure 4, or plate modulating may be utilized, as shown in Figure 5. Since the operation of the arrangements of Figures 4 and 5 will be obvious to one who has read the foregoing specification, a description of the operation thereof will not be given at this point.

Where the modulating potentials are applied to the screen grid electrodes, as in Figure 4, or to the plate electrodes, as in Figure 5, the anode leads include radio frequency choke coils RFC and RFC', as shown.

In practice the bridge circuits of Figures 2, 3, 4 and 5 may in new installations be connected with a source of modulating potentials M and a source of oscillations O and with a class A amplifying means A and radiating means RA, as shown in Figure 6. The phase modulator here and the rest of the apparatus may comprise a new installation. If phase modulation only is used the class A amplifier may be followed by an amplitude limiter AL, shown in dotted lines between the class A amplifier and the utilization circuit. The class A amplifier amplitude limiter, when the latter is also used may be followed by frequency multiplying means FM and additional amplifying means, if necessary. The amplified frequency multiplied or limited and frequency multiplied energy may be radiated from the aerial RA. The use of the frequency multiplier may be desirable in many cases and is particularly desirable if a phase modulating bridge circuit, as disclosed in Figure 3, is used.

When the phase modulating bridge circuit of the present invention is to be utilized with installations now in use of practically any type, as, for example, an installation including a source of modulating potentials M, an oscillator O, an amplifier A, and a utilization circuit FM and RA, as shown in Figure 6, the modulator therein, en-

closed in the dotted line rectangle and interposed between M and O and A, may be removed and replaced by a phase modulator bridge circuit, as disclosed in Figures 2, 3, 4 or 5. In this case, if the transmitter does not already include an amplifier of the class A type, such an amplifier may be interposed between the modulator I and the utilization circuits FM and RA, as shown.

When multiplex signalling is desired by new installation the arrangement as shown in Figure 7 may be used. Where multiplex operation is desired by transmitters now in use, as, for example, amplitude modulated transmitters, said transmitters may be modified as indicated in Figure 7. In Figure 7 the source of modulating potentials M is connected with a phase modulator I which is also energized by carrier frequencies from source O. The phase modulated oscillations are fed from I to a class A amplifier A and from thence to an amplitude modulator AM, from which the phase modulated and amplitude modulated signals may be fed to frequency multipliers and amplifiers and radiating means and to one or more of such devices. If an installation, as for example, an amplitude modulated transmitter, is to be modified for multiplexing by adding a phase modulator thereto, the leads L, shown in dotted lines between the amplitude modulator AM and the source of oscillations O, may be disconnected. The leads between the source of modulating potentials M and the amplitude modulator AM may be opened and phase modulator I may be connected between the modulation source M and the amplitude modulator AM. The source of oscillations O may now be connected to the phase modulator I, as shown. The oscillations from O are phase modulated in I by the signal potentials from M and the phase modulated carrier is fed from I to the amplitude modulator AM, which may be supplied with other modulating potentials from a source M'. The carrier frequency oscillations, which have already been modulated in phase by the signal potentials from the source M, will in the stage AM be modulated in amplitude in accordance with the signal oscillations from M'. The carrier frequency oscillations modulated in phase and in amplitude may be multiplied in frequency and amplified and radiated.

In order that the current in the arms of the phase modulating bridge circuit I of the present invention be maintained at minimum, a class A amplifier may be interposed between the amplitude modulator AM and the phase modulator I, as shown.

Having thus described my invention and the operation thereof, what I claim is:

1. A phase modulator circuit comprising, a pair of thermionic tubes having their cathodes connected together by way of an impedance and their anodes connected together by way of a second impedance equal in value to the value of the first impedance, means for applying high frequency oscillations to the cathode of one of said tubes and to the anode of another of said tubes, means for varying the impedances of said tubes in phase, and a utilization circuit connected with the cathode of the other of said tubes and the anode of said first named tube.

2. The combination with a bridge circuit having four arms and two pairs of opposed points of, a source of modulating potentials connected in phase to a pair of opposed arms, a source of high frequency oscillations connected across one of said pairs of said opposed points, and a work

circuit connected across the other pair of said opposed points.

3. Signalling means comprising, in combination, a bridge circuit having pairs of opposed impedances which are normally substantially numerically equal, one pair of which impedances are variable, and pairs of opposed points, a source of high frequency oscillations connected across one of said pairs of opposed points, a class A amplifier having its input electrodes connected across another pair of said opposed points, and means for phase modulating said high frequency oscillations comprising a source of modulating potentials connected with said opposed pair of variable impedances.

4. A combination as claimed in claim 3 including, a frequency multiplier connected with the output electrodes of said class A amplifier.

5. In a phase modulator, a bridge circuit having four balanced arms, each including an impedance, the impedances in an opposed pair of said arms being variable, a circuit for applying carrier oscillations to a pair of opposed junction points on said bridge, a circuit for varying said variable impedances in phase at signal frequency, and a relaying circuit connected with another pair of opposed junction points on said bridge.

6. A phase modulator circuit comprising, a pair of thermionic tubes having their cathodes connected together by way of a capacity and their anodes connected together by way of a second capacity substantially equal in value to the value of the first capacity, a circuit for applying high frequency oscillations to the cathode of one of said tubes and to the anode of another of said tubes, an inductance connected between the control grid and cathode of each of said tubes, a source of low frequency oscillations coupled to said inductances, and a utilization circuit connected with the cathode of the other of said tubes and the anode of said first named tube.

7. A phase modulator circuit comprising, a pair of thermionic tubes having their cathodes connected together by way of a capacity and their anodes connected together by way of a second capacity substantially equal in value to the value of the first capacity, a circuit for applying high frequency oscillations to the cathode of one of said tubes and to the anode of the other of said tubes, a circuit for applying low frequency oscillations to the control electrodes of each of said tubes, an auxiliary electrode interposed between the anode and control electrode in each tube, and a utilization circuit connected with the cathode of the other of said tubes and the anode of said first named tube.

8. A phase modulator circuit comprising, a pair of thermionic tubes of the screen grid type having their cathodes connected together by way of a capacity and their anodes connected together by way of a second capacity equal in value to the value of the first capacity, a circuit for applying high frequency oscillations in phase opposition to the anode of one of said tubes and to the cathode of the other of said tubes, a circuit for applying oscillations of a different frequency in phase to the screen grid electrodes of said tubes, means for maintaining the control grid electrodes of said tube at a potential different with respect to the cathodes of said tubes, and a utilization circuit connected between the cathode of the other of said tubes and the anode of said first named tube.

9. A phase modulator circuit comprising, a pair of thermionic tubes having their cathodes con-

connected together by way of a capacity and their anodes connected together by way of a second capacity equal in value to the value of the first capacity, a circuit for applying oscillations to the anode of one of said tubes and to the cathode of the other of said tubes in phase opposition, a circuit for applying oscillations of a different frequency in phase to the anodes of each of said tubes, means for maintaining the control grid electrodes of said tubes at a potential different than the potential of the cathodes, and a utilization circuit connected with the cathode of said first named tube and the anode of said other tube.

10. The combination, with a bridge circuit having four arms and two pairs of opposed junction points between said arms, of a source of modulating potentials coupled in phase to a pair of opposed arms, a source of high frequency oscillations connected across one of said pairs of opposed junction points, an amplifier connected across the other pair of said opposed junction points, a frequency multiplier connected with said amplifier, and radiating means connected with said frequency multiplier.

11. The combination, with a bridge circuit having four arms, each including an impedance and two pairs of opposed junction points, of a source of modulating potentials coupled in phase to a pair of opposed arms, a source of high frequency oscillations connected across one of said pairs of said opposed junction points, an amplifier connected across the other pair of said opposed junction points, an amplitude modulator including a source of modulating potentials connected with said amplifier, and a utilization circuit coupled to said amplitude modulator.

12. The combination, with a bridge circuit having four arms and two pairs of spaced points, of a source of modulating potentials connected in phase to a pair of opposed arms, a source of high frequency oscillations connected with one of said pairs of said spaced points, and a class A amplifier connected across the other pair of said spaced points of said bridge.

13. Signalling means comprising, in combination, a bridge circuit having pairs of opposed impedances, one pair of which impedances is variable, and pairs of spaced points, a circuit for applying constant frequency oscillations to one of said pairs of spaced points, an amplifier having its input electrodes connected across another pair of said spaced points, and a circuit for applying modulating potentials in phase to said opposed pair of variable impedances.

14. A combination as set forth in claim 13 including, a frequency multiplier connected with the output electrodes of said amplifier.

15. In a phase modulator, a bridge circuit having four arms, each including an impedance, the impedances in an opposed pair of said arms being variable, a circuit for applying carrier oscillations to a pair of opposed points on said bridge, and a circuit for varying said variable impedances in phase at signal frequency whereby carrier wave energy modulated in phase at signal frequency is produced at another pair of opposed points on said bridge.

16. The combination of a device for phase modulating carrier waves including a bridge circuit

having a plurality of arms, opposed pairs of said arms being substantially balanced, a circuit for applying carrier frequency oscillations to a pair of opposed junction points on said bridge circuit, means for phase modulating said carrier frequency oscillations comprising a circuit for applying modulating potentials to a pair of said opposed arms, an amplifier connected across another pair of opposed junction points on said bridge circuit, and an amplitude modulator connected with said amplifier.

17. The combination of a phase modulator including a bridge circuit having a plurality of pairs of arms, opposed pairs of said arms being substantially balanced, a circuit for applying carrier frequency oscillations to a pair of opposed points on said bridge circuit, means for phase modulating said carrier frequency oscillations comprising a circuit for applying modulating potentials to a pair of opposed arms, an amplifier of the type in which small grid current flows during operation connected across another pair of opposed points on said bridge circuit, and an amplitude modulator including a circuit energized by modulating potentials connected with said amplifier.

18. A phase modulator comprising, a pair of thermionic tubes having their cathodes connected together by way of a reactance and their anodes connected together by way of a second reactance, a circuit for applying high frequency oscillations to the cathode of one of said tubes and to the anode of another of said tubes, a reactance connected between the control grid and cathode of each of said tubes, a source of low frequency potentials coupled in phase to said last named reactances, and a utilization circuit connected with the cathode of the other of said tubes and the anode of said first named tube.

19. A phase modulator comprising, a pair of thermionic tubes of the screen grid type having their cathodes connected together by way of a reactance and their anodes connected together by way of a second reactance, a circuit for applying high frequency oscillations in phase opposition to the anode of one of said tubes and to the cathode of the other of said tubes, a reactance connected between the screen grid and cathode of each of said tubes, a circuit for applying oscillations of a different frequency to said last named reactances, and a utilization circuit connected between the cathode of the other of said tubes and the anode of said first named tube.

20. A phase modulator circuit including, a pair of thermionic tubes having their cathodes connected together by way of reactance and their anodes connected together by way of a second reactance substantially equal in value to the value of the first reactance, a circuit for applying oscillations to the anode of one of said tubes and to the cathode of the other of said tubes in phase opposition, a reactance connected between the anode of each of said tubes and the cathode of each of said tubes, a circuit for applying controlling potentials in phase to said last named reactances, and a utilization circuit connected with the cathode of said first named tube and the anode of said other tube.

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