

May 30, 1939.

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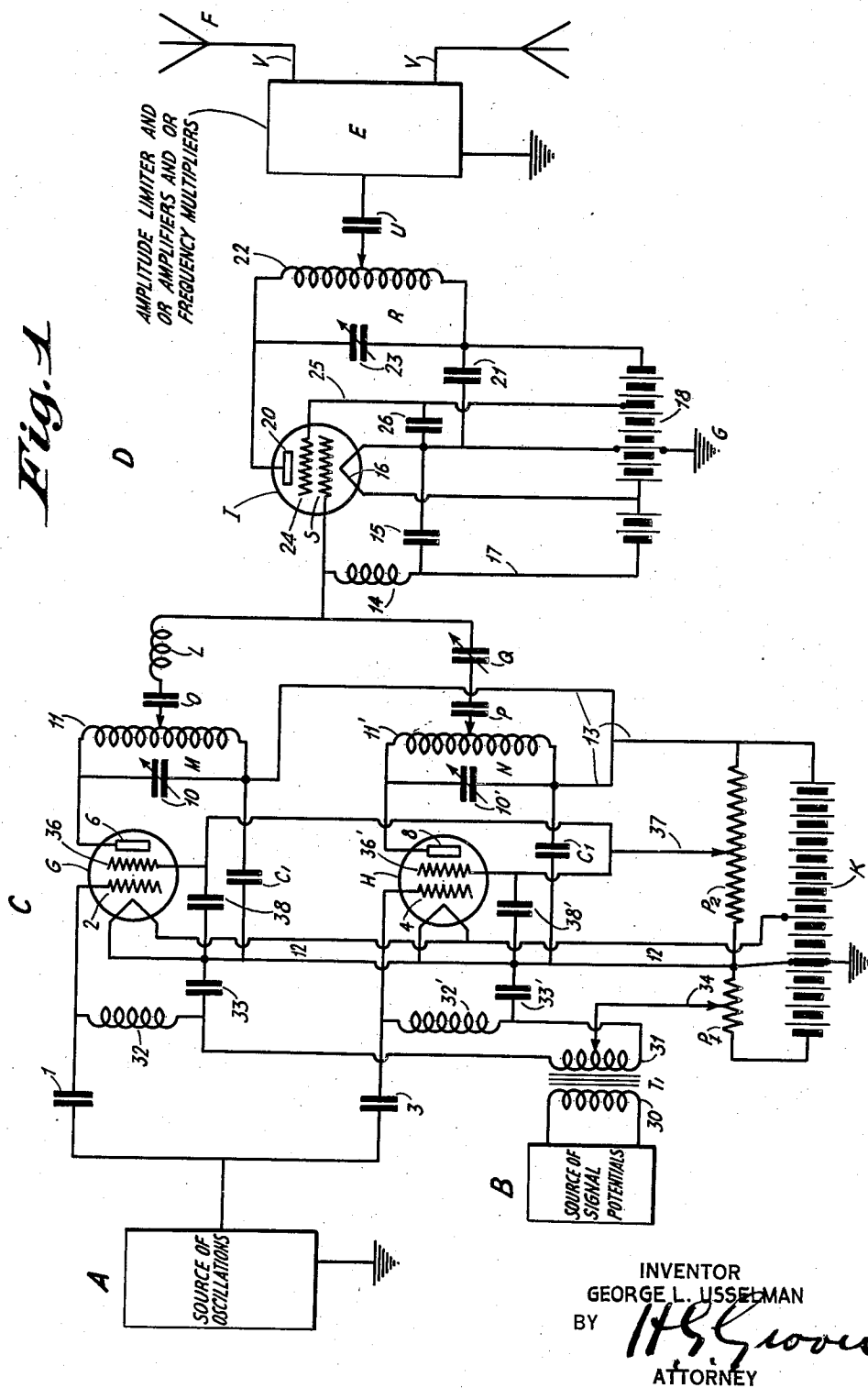
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PHASE MODULATION

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Fig. 1



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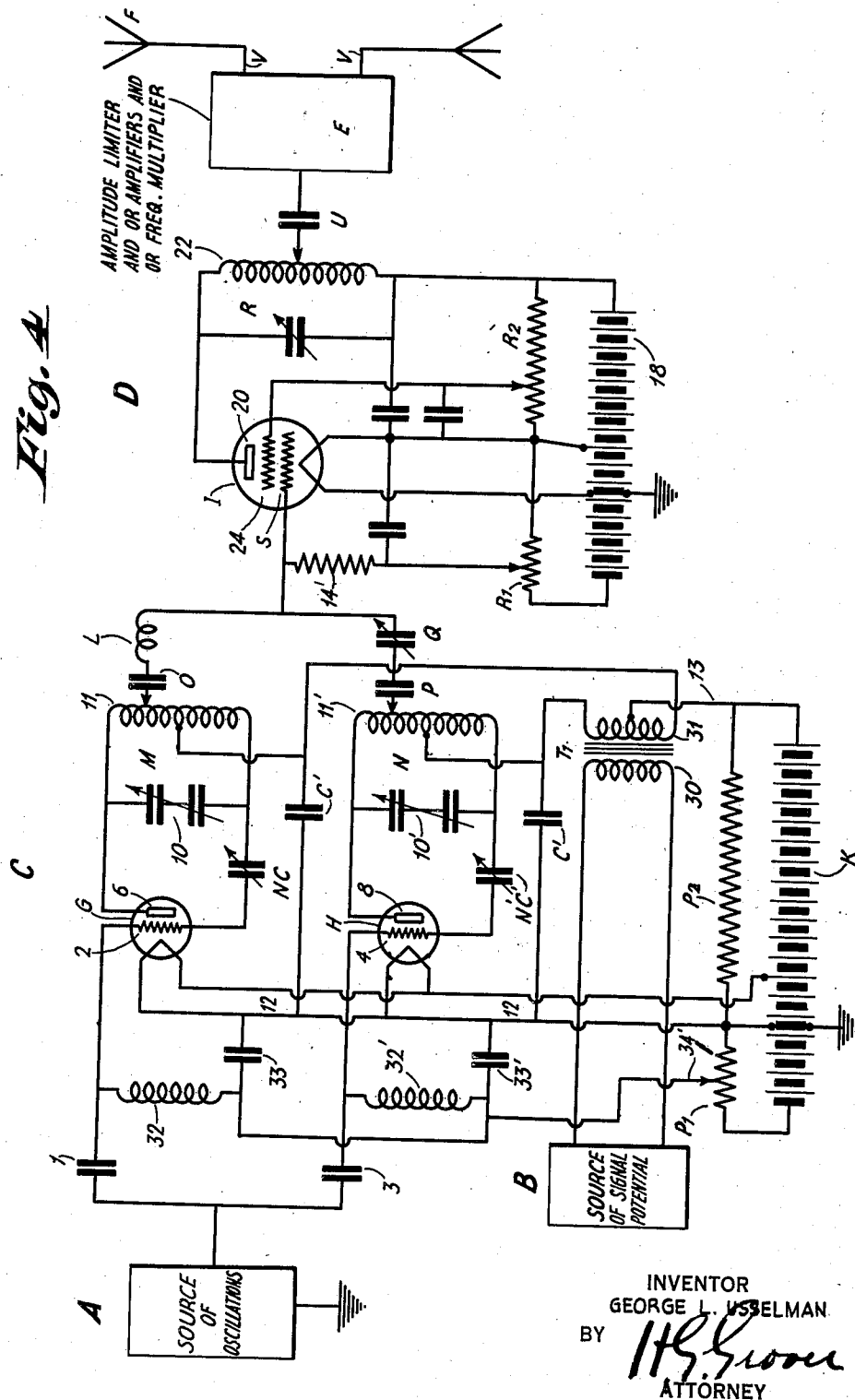
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PHASE MODULATION

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Fig. 4



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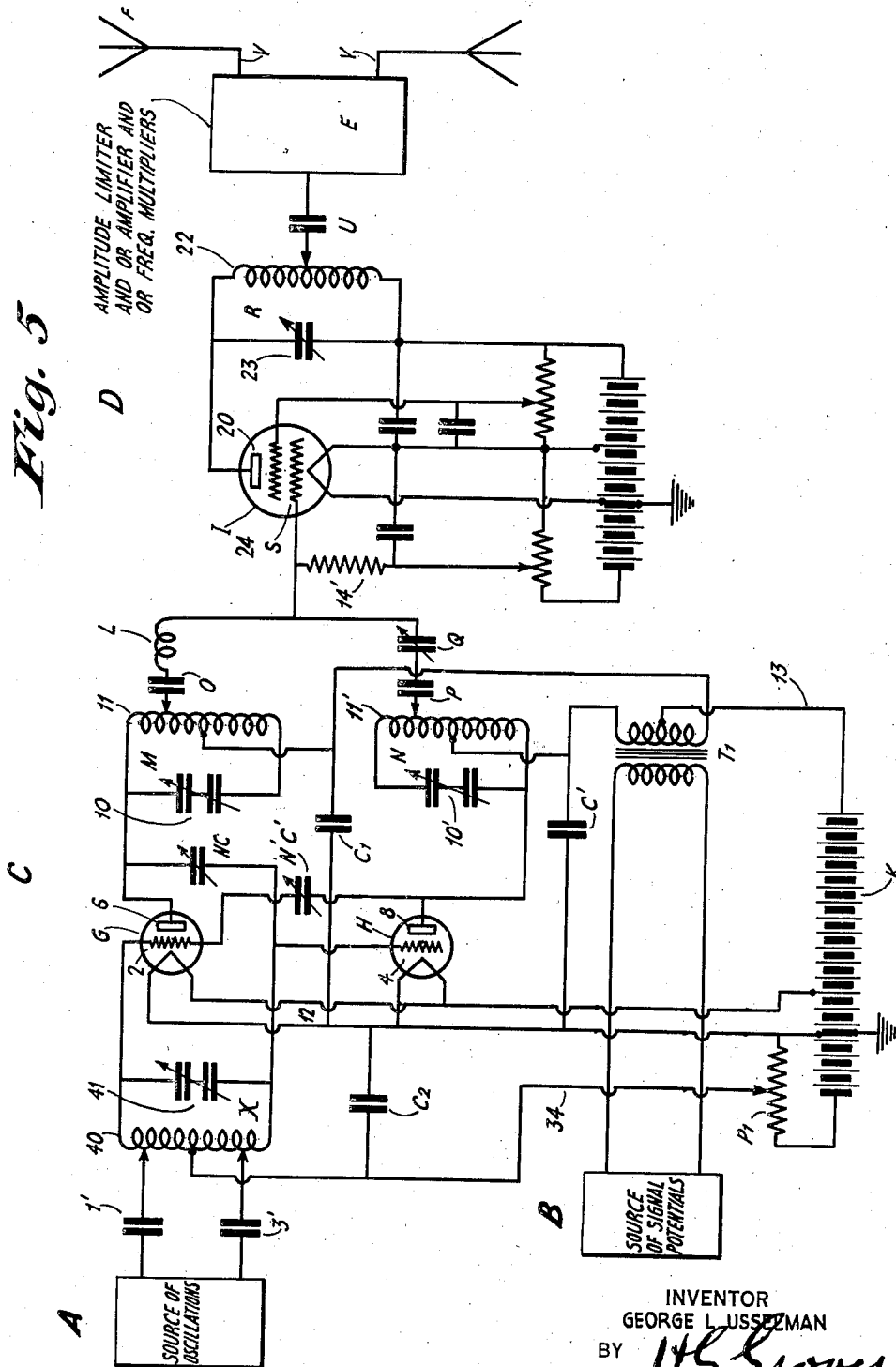
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PHASE MODULATION

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Fig. 5



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PHASE MODULATION

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41 Claims. (Cl. 179—171)

This invention relates to signalling means and in particular to means whereby the characteristics of high frequency oscillations other than amplitude are varied in accordance with signals to be transmitted.

It has been found that ordinary amplitude modulated high frequency oscillations in transmission from the sending station to the receiving station are subject to what is known as fading effects. This is a decided disadvantage since it introduces drop-outs and errors in the signal. Even where diversity receivers are used to receive the amplitude modulated signals the effect of fading is of serious disadvantage.

I have found that if the high frequency oscillations are modulated in phase or in frequency in accordance with the signal to be transmitted they are somewhat less subject to the effect of fading than amplitude modulated waves, assuming like amounts of power are utilized in the transmission. Phase or frequency modulation is advantageous because it allows the transmitter to operate at full output power, whereas in amplitude modulation it is necessary to reduce the power and operate the transmitter at about one fourth of the full transmitter power output. The increased signal strength gained by phase or frequency modulation is a great advantage for reducing fading and for increasing the reliability of the service.

In each of my United States applications, Serial No. 623,558, filed July 20, 1932, Patent #2,048,900 dated July 28, 1936; Serial No. 616,026, filed June 8, 1932, Patent #2,036,165 dated March 31, 1936; Serial No. 602,487, filed April 1, 1932, Patent #2,049,143 dated July 28, 1936; Serial No. 607,932, filed April 28, 1932, Patent #2,036,164 dated March 31, 1936, I have shown means for varying at signal frequency the characteristics other than the amplitude of a carrier frequency wave. In each of these arrangements the carrier frequency is impressed through phase shifting means onto the control grids of a pair of thermionic tubes which have their anodes connected in parallel to a common tank circuit and their internal impedances varied in phase opposition by the signal wave. In each of these arrangements the phase modulator stage comprises two tubes having their input electrodes symmetrically connected and energized as indicated above, and a common tank circuit connected in parallel to the anodes of said pair of tubes.

The present invention relates to an improved modulating means broadly of the type referred to above.

More in detail, this invention relates to an improved modulating means wherein a single phase modulator stage is preceded by an amplitude modulator stage which comprises a pair of tubes having control grids connected in circuits and energized at carrier frequency in phase. In accordance with the present invention each tube is equipped with its own separate tank circuit. Moreover, in the present invention, instead of phase modulating the energy reaching the grids of these two tubes, the phase shifting means is interposed between the separate tank circuits and the control electrode of the single tube in the following stage. Here, as in the prior applications, the internal impedances of the pair of tubes are varied in opposite senses by the modulating frequencies. In the present case this results in amplitude modulation of the carrier. This modulated energy is then fed by way of phase shifting elements to the control grid of the single phase modulator tube.

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

The nature of my invention and the operation thereof will be best understood from the following detailed description thereof and therefrom when read in connection with the drawings, throughout which like reference numerals indicate like parts, and in which:

Figure 1 illustrates a specific embodiment of the invention; while,

Figures 2, 3, 4 and 5 illustrate modifications of the arrangement of Figure 1.

A specific embodiment of my invention is shown in Figure 1. In this figure A is a source of constant frequency oscillations, such as a crystal controlled oscillator or a long line frequency controlled oscillator. The oscillator A is connected in parallel by way of blocking condensers 1 and 3 to the control grids 2 and 4 of tubes G and H respectively of stage C. The tubes G and H are shown as the screen grid type, although three element tubes may be used. In the latter case neutralizing circuits may be necessary. The anode electrodes 6 and 8 of tubes G and H respectively are connected to tank circuits M and N respectively. Tank circuit M includes a variable capacity 10 and an inductance 11. The tank circuit N includes a variable capacity 10' and inductance 11'. The alternating current circuits for tubes G and H are completed by connecting the lower terminals of tank circuits M and N by way of by-passing condensers C₁ to the grounded side of the circuit 12 supplying heating current

from the source K to the cathodes of the tubes. The energizing circuits for anodes 6 and 8 are completed by way of a lead 13 connecting the terminals of inductances 11 and 11' to the source K. Tank circuit M is connected through a blocking condenser O to one end of the phase retarding element L. Tank circuit N is connected through a blocking condenser P to one end of the phase advancing element Q. The other ends of both phase shifting elements are connected together as shown and to the grid S of tube I in stage D.

The alternating current input circuit of tube I is completed by way of radio frequency choking inductance 14 and by-pass condenser 15 connected between the grid S and cathode 16 of tube I. The cathode 16 is maintained at stable potential by connecting one side thereof to ground G as shown. The desired negative potential may be supplied to the grid S by way of choke coil 14 and lead 17 connected with source 18. The alternating current anode cathode circuit of tube I comprises the anode 20, tank circuit R, by-pass condenser 21, and the grounded side of cathode 16. The direct current anode cathode circuit of tube I comprises the anode 20, the inductance 22 of tank circuit R, a portion of the source 18, and the cathode 16. Tank circuit R may be tuned to the desired frequency by a variable capacity 23 connected in parallel with inductance 22. The tube I is of the screen grid type and charging potential is supplied to the screen grid electrode 24 by a lead 25 connected to a point on source 18. Any radio frequency potentials appearing on 24 are shunted around source 18 by a by-pass condenser 26. It will be understood that the screen grid tube I may be replaced by a three-electrode tube provided proper precautions are taken to obtain stable operation thereof. It should be understood that sources K and 18 may be of any desirable type, such as, storage batteries, motor generator sets, or vacuum tube rectifiers.

The tank circuit R of stage D is connected, by way of a line including blocking condenser U, to the stage E. Stage E may consist of limiting devices and either frequency multipliers or amplifiers or both. The last stage is connected by transmission lines V—V to the antenna F.

B represents a source of signal frequency of any nature. The source of modulating potentials, B, is connected with the primary winding 30 of a signal frequency transformer T₁. The secondary winding 31 of this transformer is connected as shown by way of radio frequency inductances 32 and 32' to the control grids 2 and 4 of tubes G and H respectively, as shown. The inductances 32 and 32' may be replaced by resistances if desired. In order that radio frequencies appearing in inductances 32 and 32' do not reach the modulation frequency transformer T₁ and source B connected therewith, the lower ends of inductances 32 and 32' are connected by way of by-passing condensers 33 and 33' to the grounded lead of the cathode heating circuit 12. The proper biasing potentials are applied to the control electrodes 2 and 4 by way of the secondary winding 31 and a lead 34 connecting the midpoint thereof to a potentiometer P₁ connected in shunt with a portion of direct current source K. Charging potentials for the screen grid electrodes 36 and 36' of tubes G and H are supplied by way of lead 37 connected to a point on potentiometer resistance P₂ shunted across source K. Alternating current appearing on the grid electrodes

36, 36' is shunted around source K by by-pass condensers 38 and 38' connected as shown.

In operation the oscillator A supplies equal amounts of high frequency excitation voltage to each of the control grids 2 and 4 of tubes G and H in stage C. If there is no signal frequency being supplied to the control grids 2 and 4 from B by way of T₁, this high frequency energy will be amplified equally and, if desired, multiplied in frequency in tubes G and H and tank circuits M and N respectively. This follows from the fact that like potentials are applied to the electrodes of these two tubes and also to the fact that tank circuits M and N are made to be of similar characteristics. Furthermore (still assuming no potentials are supplied from B), since in practice the impedances of phase retarding element L and phase advancing element Q are of equal magnitude, the high frequency energy reaching the grid S of tube I in stage D, from tank circuit M and from tank circuit N, will be of equal intensity. The energies will have equal phase angles, that is, one leading and the other lagging, about the average phase position. The resultant phase of the excitation energy supplied to S from M and N will in this case lie midway between the phase angles of the separate energies supplied from M and N. Stage D amplifies, or, if it is desired, may be adjusted to multiply the carrier frequency before it is transmitted to stage E. As I have said before, the carrier energy may be limited and multiplied in frequency or amplified, or both, in stage E. From the last stage, the carrier energy is transmitted through the transmission line V—V to antenna F, where it is radiated into space.

If we now assume that signal frequency is being sent out from source B, the potentials on the grids 2 and 4 of tubes G and H will be varied at signal frequency in phase opposition or, in other words, differentially. Steady negative bias is supplied equally to the control grids 2 and 4 of tubes G and H from the battery or source K by way of the midtap of the secondary winding 31 of transformer T₁. The end terminals of this winding carry the bias potential to the control grids 2 and 4. Now take some instant in the signal when the grid 2 of tube G will be swung, say, in a positive direction, while the grid 4 of tube H will be swung an equal amount in a negative direction.

The carrier energy produced in oscillator A is delivered in two equal parts to the grids 2 and 4 of tubes G and H respectively in stage C. One portion is amplified in amplifier G and appears in tank circuit M, while the other portion is amplified in amplifier H and appears in tank circuit N. This amplification is not constant because the amplified energies in the two amplifiers G and H are differentially modulated in amplitude so that the carrier energies delivered by the two amplifiers are of the same phase angle, but of an amplitude which varies at signal frequency and which is proportional to the signal intensity. Due to the action of the modulating transformer T₁ this variation in amplitude is made opposite for each amplifier about an average value. This differential action will increase the power output of tube G and tank circuit M, while the power output of tube H and tank circuit N will be decreased a like amount, or vice versa. The phase deviation or shift caused by L and Q in the two high frequency energies supplied to the grid S of tube I will be equal but the energies will be of unlike sense, and in this case the power supplied from

tank circuit M through phase retarding element L will be greater than the power supplied from tank circuit N through phase advancing element Q.

5 The carrier energy from the tank circuit M connected with amplifier G passes through the phase retarding element L, while the carrier energy delivered by the amplifier H to the tank circuit N passes through the phase advancing element Q. These two differentially modulated carrier energies are impressed on the grid electrode S of tube I at different phase angles because of the action of phase shifting elements L and Q. The impedance of L and Q should be made equal so that they have equal effect on the amplitude of the carrier energies delivered thereby from tank circuits M and N to control grid electrode S. It can be seen that we now have two carrier energies of the same frequency present on the grid S of tube I and that these two carrier energies have a constant phase difference but are of an amplitude which varies differentially about a constant total amplitude or average. In other words, the total energy delivered to the grid S of tube I is constant and the phase angle between the two parts of this energy is also constant. Each of these two parts of the total carrier energy is amplified or multiplied in frequency, or both, in tube I and delivered to the tank circuit R of the stage D. Tank circuit R has only one degree of freedom, that is, the carrier frequency or a desired harmonic of the carrier frequency to which the tank circuit may be tuned so that there can be but one oscillating current in the tank circuit R. Because of the phase difference of the two energies fed into the tank circuit the phase of the oscillating current in the tank circuit will be determined or controlled to a greater extent or made to shift toward that of the carrier energy having the greater amplitude. The amount of the shift will be proportional to the excess energy of one part of the carrier energy over the other part of the carrier energy. The amount of shift in phase of the carrier energy is limited by the value of the reactances of the phase shifting elements L and Q, as has been explained before. This results in carrier energy in the tank circuit R of stage D, which will be of substantially constant amplitude but of varying phase angle. The frequency of the variation of this phase angle is the signal frequency and the degree or amount of phase swing or phase deviation is substantially proportional to the amplitude of the signal. The amount of phase modulation is also controlled by the values of the phase shifting elements L and Q. If the energy in tank circuits M and N are linearly amplitude modulated in phase opposition, the phase of the energy appearing in tank circuit R of stage D will be linearly phase modulated.

60 The energy delivered from stage D may be utilized in any desired manner. The energy may be amplified or multiplied in frequency and it may be radiated from the antenna F. When the frequency of the phase modulated carrier is multiplied the angle of phase modulation is increased in the same ratio.

In some cases it may be desirable to impress the modulating potentials on the internal impedances of tubes G and H in a different manner than that in which they are impressed on said impedances in Figure 1. For example, it may be desirable to apply the signal oscillations from B by way of the secondary winding of transformer T₁ to the screen grid electrodes 36, 36' of tubes

G and H respectively in phase opposition, as shown in Figure 2 of the drawings. When the modulating potentials are applied in phase opposition to the screen grid electrodes of tubes G and H steady positive charging potential for said electrodes is supplied by way of a lead 37' connected to a point on the resistance of potentiometer P₂ as shown. In this novel modulating scheme the desired negative bias is applied to the control electrodes 2 and 4 of tubes G and H by way of a lead 34' connecting said electrodes to a point on the resistance of potentiometer P₁. The modulated transmitter of Figure 2 is otherwise the same as the transmitter of Figure 1.

The operation of the arrangement of Figure 2 is similar to the operation of the arrangement of Figure 1. The only difference between the two arrangements is that in Figure 1 the impedances of the tubes G and H are varied in opposition at signal frequency by varying the effective potential on the control grid electrodes, whereas in the arrangement of Figure 2 the impedances of tubes G and H are varied in phase opposition at signal frequency by varying the effective charging potential applied to the screen grid electrodes. In each case the carrier frequency relayed in tubes G and H is differentially modulated in amplitude at signal frequency.

In yet other cases it may be desirable to accomplish the amplitude modulation of the carrier in the stage C by means of modulating the anode potentials. When this method of modulating is desired the arrangement of Figure 3 may be used. In Figure 3 the proper negative biasing potentials are supplied to the control grids of tubes G and H by a lead 34' as in Figure 2. Direct current potentials for the screen grid electrodes of tubes G and H are supplied by way of a lead 37, as in Figure 1. In this arrangement, however, the modulating potentials from the source B are supplied by way of transformer T₁ in phase opposition to the anodes 6 and 8 of tubes G and H respectively. In this manner anode modulation in amplitude of the carrier waves passed by tubes G and H is accomplished in the stage C. In other respects the arrangement shown in Figure 3 operates the same as the arrangement of Figure 1. A repetition of the operation of these novel modulating arrangements in connection with Figure 3 is thought unnecessary.

When plate modulation of the amplitude of the carrier in the unit C by a more efficient method is desired, the arrangement of Figure 4 may be used. In this arrangement the tubes G and H are of the three-electrode type. Three-electrode tubes are used in this arrangement because, when the amplitude modulation of the carrier is accomplished by varying the anode potential, the three-electrode tubes give much greater response than that obtainable with the four-electrode tubes of Figure 3. When three-electrode tubes are used the capacity between the anode electrodes and grid electrodes of the tubes G and H may be neutralized by "plate circuit neutralization". This is accomplished by connecting the lower terminal of the tapped plate inductances 11 and 11' to the control electrodes 2 and 4 of the tubes G and H respectively by way of variable neutralizing capacities NC and N'C' respectively. The charging potential for the anode electrodes 6 and 8 is supplied from the lead 13 connected to the midpoint of the secondary winding 31 of transformer T₁ and by leads connecting the ends of the secondary winding 31 of transformer T₁ to the points tapped to the inductances 11 and 11'.

The arrangement of Figure 4 is otherwise similar to the arrangement of Figure 3.

The phase modulator of Figure 4 operates the same as the phase modulator of Figure 1. The high frequency oscillations from A are impressed cophasally in equal amounts onto the control electrodes of G and H respectively. These oscillations may be amplified or frequency multiplied, or both, in the tubes G and H, and in particular in the output circuits thereof. The high frequency oscillations, whether amplified, frequency multiplied, or both, are differentially modulated in amplitude in stage C in accordance with the signal impressed from source B in phase opposition on the anode electrodes of tubes G and H. The carrier energies from M and N, which are of the same phase but of amplitude which varies at signal frequency, are fed through the phase shifting means L and Q to the control electrode S of tube I. The action of the phase shifted energies from M and N on the control electrode S of tube I results in the production in tank circuit R of energy, the phase of which varies at signal frequency, but the amplitude of which is constant, as has been described in detail hereinbefore in connection with Figure 1. The frequency of the phase modulation of this energy is directly proportional to the signal frequency and the degree of phase shift is proportional to the amplitude of the signal, except as otherwise modified by the phase shifting elements L and Q of stage C. The energy from tank circuit R is fed by way of coupling unit U to the unit E, from which it may be radiated. The unit E may include amplitude limiters or amplitude amplifiers and/or frequency multipliers.

If, for some reason, grid neutralization of the amplitude modulator tubes G and H of stage C is preferable, the circuit arrangement of Figure 5 may be used.

In Figure 5 the source of oscillations A is coupled by way of blocking condensers 1' and 3' to points on the inductance 40 of the grid tank circuit X. This tank circuit X is tuned to the desired frequency by variable capacity 41, and the natural impedance of this tuned circuit X to the oscillations from A is such as to match the low impedance output of A to the high impedance of the input electrodes of tubes G and H. The high frequency oscillations from tank circuit X are applied in phase opposition to the control electrodes 2 and 4 of tubes G and H. The high frequency oscillations repeated or multiplied in tubes G and H are fed to tank circuits M and N, as in the prior arrangement. However, in this arrangement, since the high frequency oscillations are applied in phase opposition to the control electrodes and not cophasally, as in the prior arrangement, reversal of the energy in one of the amplitude modulators G and H must be accomplished in order to properly combine the energies led through the phase shifting means L and Q to the grid electrode S of tube V. This is accomplished by reversing the coupling of one of the tank circuits M and N with its tube G or H.

In Figure 5 the coupling between the tank circuit N and tube H is reversed. In other words, the output circuits of these tubes are, in a manner, connected in push-pull so that the energies therein are alike in phase. The phase shifting circuits L and Q are tapped to points on the inductances 11 and 11' such that the energy drawn from the tank circuits M and N is in phase and is fed to the control grid S in phase except for the phase shift accomplished by the phase shift-

ing elements L and Q. In this arrangement the grid to anode capacity of the tubes G and H is neutralized or compensated by connecting the anode 6 of tube G to the control electrode 4 of tube H and the anode 8 of tube H to the control electrode 2 of tube G by way of neutralizing condensers NC and N'C', as shown. Biasing potential for the control electrodes 2 and 4 of tubes G and H is supplied by way of a lead 34' connecting a point on potentiometer P₁ to the midpoint of inductance 40, which has its terminals conductively connected to the control electrodes 2 and 4. The arrangement of Figure 5 is otherwise the same as the arrangement of Figure 4.

It will be noted, however, that in Figures 4 and 5 the inductance 14 of stage D has been replaced by a resistance 14'. It will be understood that either an inductance or a resistance may be used, but it is preferable to use resistance at this point.

In operation the arrangement of Figure 5 operates substantially the same as the arrangement of Figure 4. However, since there has been a shift in phase of the high frequency oscillations applied to the control electrode 4 with respect to the phase of the high frequency oscillations applied to the same control electrode in Figure 4, there must be a second reversal in phase of the energy accomplished before the energy is applied to the phase shifting elements L and Q and from said elements to the control grid S of modulator tube V. This is accomplished, as indicated above, by reversing the connection between the anode electrode 8 of tube H and the tank circuit N, as shown. This brings amplified and amplitude modulated energies in the tank circuit in phase. The amplified and amplitude modulated and/or frequency multiplied energies in the tank circuits M and N are fed by way of phase shifting elements L and Q to the modulator tube, as in the prior arrangements. This modulation is accomplished in the tube V in the arrangement of Figure 5 and the phase modulated and amplitude modulated energy in the tank circuit R is fed by way of unit E, which may include all of the elements included in the like unit in the prior figures, to the load circuit F.

In the operation of the arrangements shown in Figures 1 to 5 inclusive the tank circuits M and N should be tuned alike, that is, to the same frequency, whether they are tuned to a fundamental or to a harmonic. In some cases it is suggested that a slight amount of mutual inductive coupling between the two circuits M and N be maintained in the proper direction to aid in keeping the two modulator tubes G and H in step. In some cases this should improve the operation of the transmitter. Moreover, it will be understood that the phase shifting elements L and Q may take the form of inductances and capacities, or any combination thereof, or may be replaced by transmission lines of the proper length. These lines may be artificial lines and may include tuning means. All that is necessary is that the desired amount of phase shift is introduced into the amplitude modulator carrier energy reaching the tube V.

Moreover, it will be understood that tubes of any type known may be used to replace the tubes used in the circuits included above, which are intended to be illustrative of the invention and are not intended to limit the invention in any manner except as limited in the claims appended hereto.

When the tubes G and H are used as frequency

multipliers as well as amplitude modulators, feed back coupling in these circuits may be resorted to to enhance the frequency multiplying effect. This may be accomplished in the arrangements illustrated in Figures 4 and 5 by over-neutralizing the circuits by means of the neutralizing condensers NC and N'C'. That is, the coupling between the input and output circuits of tubes G and H may be increased by these condensers sufficiently to insure the desired amount of regeneration.

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

1. Signalling means comprising, a source of oscillations, a modulator tube, a pair of electron discharge tubes having parallel input circuits connected to said source of oscillations means for varying the impedances of said pair of tubes in phase opposition at signal frequency, and output circuits connected through separate phase shifting means of different character to the input electrode of said modulator tube.

2. Signalling means comprising, a source of substantially constant frequency oscillations, a thermionic modulator tube, a pair of thermionic relay tubes having symmetrical input circuits and separate anode circuits, means for applying energy from said source to the input circuits of said pair of tubes in phase, and phase shifting means having different characteristics connecting each of said anode circuits to the control electrode of said modulator tube.

3. Modulating means comprising, a pair of electron discharge repeater tubes each having input and output electrodes, carrier frequency energizing circuits connected with the input electrodes of said repeater tubes, a separate tuned tank circuit connected to the output electrodes of each of said tubes, means connected with said tubes for varying the internal impedance of said tubes in phase opposition at signal frequency, a modulator tube having an input electrode, and reactive circuits of different character connecting the input electrode of said modulator tube to each of said tank circuits.

4. A phase modulating means comprising, a pair of thermionic tubes having input circuits energized by a carrier frequency wave and separate anode tank circuits, a modulator tube, phase changing means for connecting a point on each of said tank circuits to the control electrode of said modulator tube to excite the same by energy in phase displaced relation from said tank circuits, and a source of modulating voltages connecting the control electrodes of said pair of tubes in phase opposition.

5. Phase modulation means comprising, a pair of thermionic tubes of the screen grid type having input circuits energized by a carrier frequency wave and separate anode tank circuits, a modulator tube, phase changing means for connecting a point on each of said tank circuits to the control electrode of said modulator tube to excite the same by energy in phase displaced relation from said tank circuits, and a source of modulating voltages connecting the screen grid electrodes of said pair of tubes in phase opposition.

6. Phase modulating means comprising, a pair of thermionic tubes having input circuits energized by a carrier frequency wave and separate anode tank circuits, a modulator tube, phase changing means for connecting a point on each of said tank circuits to the control electrode of said modulator tube to excite the same by en-

ergy in phase displaced relation from said tank circuits, and a source of modulating voltages connected to the anode electrodes of said pair of tubes to vary the potential of said anodes in phase opposition.

7. Transmitting means comprising a source of oscillations, a pair of thermionic tubes, means for connecting said source in phase to the control electrodes of said tubes, a separate tank circuit connected to the anode of each of said tubes, a source of modulating potentials, means for impressing the modulating potentials in phase opposition on the impedances of said tubes, a modulator tube, and separate phase shifting means connecting the control electrode of said modulator tube to each tank circuit.

8. Means for relaying and phase modulating high frequency energy comprising, a pair of electron discharge tubes having their input electrodes energized in phase by wave energy of carrier frequency, a modulator tube, phase retarding means for applying energy from the anode of one of said pair of tubes to the control electrode of said modulator tube, phase advancing means for applying energy from the anode of the other of said pair of tubes to the same control electrode of said modulator tube, and means for impressing modulating potentials in phase opposition on the internal impedances of said pair of tubes.

9. In a phase modulator, a pair of electron discharge tubes, means for energizing the control electrodes of said tubes substantially cophasally by wave energy of carrier frequency, separate tank circuits connected with the anodes of said tubes, means for impressing modulating potentials on the internal impedances of said tubes, a modulator tube, and separate phase shifting reactances of different character for impressing energy from said tank circuits in phase displaced relation on the control electrode of said modulator tube.

10. Signalling means comprising, a source of high frequency oscillations, a pair of thermionic tubes, means for connecting the control electrodes of said tubes to said source so that oscillations therefrom appear on said control electrodes in phase, a separate tank circuit comprising a capacity and a tuned inductance connected with the output electrodes of each of said tubes, a work circuit, a modulator tube having its output electrodes coupled to said work circuit, phase advancing means connecting one of said tank circuits to the input electrodes of said modulator tube, phase retarding means connecting the other of said tank circuits to the input electrode of said modulator tube, a source of signal voltages, and means connected between said source of signal voltages and said pair of tubes for varying the conductivity of said tubes in phase opposition at signal frequency.

11. The method of signalling which comprises the steps of, generating a constant frequency carrier wave, producing potentials of modulating frequency, varying the amplitude of the carrier oscillations in accordance with variations in amplitude of the modulating potentials, shifting the phase of the amplitude modulated carrier wave before transmission into a utilizing circuit at a rate dependent upon the variation in amplitude of the carrier, the shift in phase producing a carrier energy, an undesired and desired side band energy, and controlling the amount of undesired side band energy by controlling the am-

plitude of the modulating potentials used to cause the amplitude modulation of the carrier wave.

12. In a phase modulation system the combination with a constant frequency generator of a pair of tubes having input electrodes symmetrically connected to said generator, a source of modulating potentials connected to said input electrodes, and a combining tube connected through separate phase shifting elements one of which is capacitive, the other of which is inductive to the anodes of said tubes.

13. In a signalling system, a source of oscillations, a combining tube, a pair of like electron discharge tubes having input circuits symmetrically connected to said source of oscillations and output circuits one of which is connected through an inductance and the other through a condenser to said combining tube, means associated with said pair of tubes for preventing reaction between the input and output circuits thereof, and means for applying modulating potentials to like electrodes of said pair of tubes.

14. A phase modulator comprising, a pair of like electron discharge tubes, means for energizing the control electrodes of said tubes cophasally by wave energy, a separate tank circuit connected with the anodes of each of said tubes, means for impressing modulating potentials on the internal impedance of said tubes, a combining tube, a phase shifting inductance and a phase shifting condenser for separately impressing energy from said tank circuits on the control electrode of said combining tube, and means for preventing the wave energy appearing in the tank circuits of said pair of tubes from reacting on the wave energy applied to the control electrodes of said pair of tubes.

15. The combination of a source of high frequency oscillations, and a source of signalling potentials of means for modulating the amplitude of the high frequency oscillations in accordance with signals, said means having an input and an output, a circuit connecting said means to said source of signaling potentials, a second circuit connecting said input with said source of high frequency oscillations, additional means coupled to the output of said amplitude modulating means for changing the amplitude modulated oscillations into phase modulated oscillations, and means connected with said amplitude modulating means for preventing the oscillations applied therefrom to said additional means from affecting the oscillations applied from said source of high frequency oscillations to the input of said amplitude modulating means.

16. In a signalling system comprising, a source of oscillations, a combining tube having input electrodes, a pair of electron discharge devices operating as frequency multipliers having input circuits symmetrically connected to said source of oscillations, said pair of discharge devices each having a separate output circuit, a reactance connecting one of said output circuits to the input electrodes of said combining tube, and a second reactance of different character connecting the other of said output circuits to said input electrodes.

17. Signaling means comprising, a pair of thermionic tubes each having an anode, a cathode and a control electrode, a source of carrier waves, circuits connecting said carrier wave source to the control electrodes and cathodes of each of said tubes, a separate tank circuit connected between the anode and cathode of each of said tubes, reactances in each of said tank circuits

for tuning the same, each to a frequency which is a multiple of the frequency of said source of carrier waves, a source of modulating potentials, a circuit connecting said source of modulating potentials in phase opposition to like electrodes in said tubes, a combining tube having a cathode and a control grid, an impedance connected between the cathode and control grid of said combining tube and phase shifting reactances of different character connecting each of said tank circuits to the control grid of said combining tube.

18. The combination with a constant frequency generator of a pair of thermionic tubes having input electrodes connected to said generator, said tubes also having output electrodes, a thermionic modulator tube having an input electrode connected through separate phase shifting elements to the output electrodes of said first named tubes and a source of modulating potentials connected with like electrodes in said pair of tubes for varying the internal impedance of said tubes in phase opposition at signal frequency.

19. Transmitting means comprising, a source of oscillations, a pair of thermionic tubes, means for connecting said source of oscillations in phase opposition to the control electrodes of said tubes, a separate tank circuit connected to the anode of each of said tubes, a source of modulating potentials, means for impressing the modulating potentials in phase opposition on the internal impedance of each of said tubes, a combining tube, a positive phase shifting reactance connecting the control electrode of said combining tube to one of said tank circuits, and a negative phase shifting reactance connecting the control electrode of said combining tube to the other of said tank circuits.

20. Means for relaying and phase modulating carrier frequency energy comprising, a pair of thermionic tubes having their input electrodes energized in phase opposition by a carrier frequency wave, a thermionic modulator tube, reactive means for applying energy from the anode of one of said tubes to a control electrode in said modulator tube, means for applying energy from the anode of the other of said tubes to a control electrode in said modulator tube, means for reversing the phase of the energy applied by one of said means, and means for impressing modulating potentials in phase opposition on the internal impedances of said pair of tubes.

21. Transmitting means comprising, a source of oscillations, a pair of thermionic tubes, circuits connecting said source of oscillations in phase opposition to the control electrodes of said tubes, a separate tank circuit connected to the anode of each of said tubes, there being appreciable coupling between said tank circuits, means for tuning said tank circuits to a frequency which is a harmonic of the frequency of said source, a source of modulating potentials, means for impressing the modulating potentials in phase opposition on the anode electrodes of said tubes, a modulator tube, and separate phase shifting means connecting the control electrode of said modulator tube to each tank circuit.

22. Signaling means comprising, a pair of electron discharge tubes having symmetrical input circuits and symmetrical grid neutralization circuits, a separate tank circuit connected with the anode of each of said tubes, one of said tank circuits being reversed as to its voltage characteristics with respect to the other tank circuit, means for applying high frequency oscillations in phase opposition to said input cir-

cuits, means for varying oppositely the impedances of said tubes at signal frequency, a utilization circuit, and separate reactances of different character connecting said tank circuits to said utilization circuit.

23. Signaling means comprising, a source of constant frequency oscillations, a thermionic modulator tube, a pair of thermionic frequency multiplier and amplifier tubes having a tuned input circuit, a separate anode circuit connected to each tube of said pair, a circuit for applying energy from said source of constant frequency oscillations to said input circuit and to said pair of tubes in phase opposition, means coupling the input circuit and anode circuits of said pair of tubes, means for tuning the anode circuits of said tubes to a frequency which is a multiple of the frequency of said oscillations, means for varying the internal impedances of said pair of tubes oppositely at signal frequency, phase shifting means of different character connecting each of said anode circuits to the control electrode of said modulator tube, and a resistance connected between the control electrode and cathode of said modulator tube.

24. Phase modulating means comprising, a pair of thermionic amplifiers and frequency multipliers of the triode type, a tuned tank circuit connected with the input electrodes of said amplifiers and frequency multipliers, means for energizing said tank circuit by wave energy of carrier frequency, an output circuit connected to each amplifier and frequency multiplier, means for tuning the output circuit of each of said amplifiers and frequency multipliers to a harmonic of the energizing frequency, means for insuring controlled regeneration in each of said tubes including a variable capacity connecting an output electrode of each of said tubes to an input electrode of the other of said tubes, means for varying the internal impedance of said tubes in phase opposition at signal frequency, a thermionic modulator tube having a resistance connected between its input electrodes, and phase shifting means for connecting the input electrodes of said modulator tube to each of said output circuits.

25. Modulating means comprising, a pair of thermionic tubes having input electrodes and output electrodes, a tuned tank circuit connected to the input electrodes of said tubes, separate tank circuits connected to the output electrodes of said tubes, capacitive means for tuning said separate tank circuits to a harmonic of the frequency to which the input circuit is tuned, means for applying high frequency oscillations to said input circuit, a capacity connected between the output electrode of each of said tubes and the input electrode of the other of said tubes to insure regeneration in said tubes, a circuit for varying the impedances of said tubes at signal frequency, and a phase modulator tube having its input electrode connected through phase shifting elements to said tank circuits.

26. In a phase modulation system, a source of oscillations of carrier wave frequency, an electron discharge tube, a pair of similar tubes having input circuits connected to said source of carrier frequency oscillations, output circuits connected with each of the tubes of said pair of similar tubes, a phase shifting coil connecting one of said output circuits to the input electrode of said first named tube, a phase shifting condenser connecting the other of said output circuits to the input electrode of said first named tube, and circuits for applying modulating potentials in phase

opposition to like electrodes in each of the tubes of said pair of similar tubes.

27. The combination of a constant frequency oscillation generator and a source of signal potentials, means for modulating the amplitude of the oscillations generated in accordance with said signal potentials comprising a pair of differential amplitude modulator tubes connected at their inputs with the output of said generator, said modulator tubes also acting as frequency multipliers and being connected to said source of potentials, and means for converting the resultant energy into phase modulated oscillations comprising an additional tube having its input electrodes connected through phase shifting elements to the output of said amplitude modulator and frequency multiplier tubes, and an amplifier connected at its input with the output of said additional tube.

28. The combination with a master oscillator, a pair of tank circuits, a source of signal potentials, means for modulating the amplitude of the oscillations produced by said oscillator in accordance with signals from said source comprising a pair of amplitude modulator tubes connected at their inputs to said oscillator and at their outputs to said tank circuits, circuits connecting said source of signal potentials to like electrodes in said modulator tubes, and means for converting the energy in the output of said tubes into phase modulated oscillations comprising an additional combining tube having a control electrode connected to each of said tank circuits, and phase shifting means of different character in the connections between said control electrode and said tank circuits.

29. In a signaling means the combination of a source of high frequency oscillations, a source of signal potentials, a radiating circuit, means for modulating the amplitude of the oscillations of said high frequency source in accordance with signals from said source of signal potentials comprising an amplitude modulator and frequency multiplier connected at its input to said source of high frequency oscillations, circuits connecting said amplitude modulator and frequency multiplier to said source of signal potentials, and means for converting the resultant energy into phase modulations, said means having an input and an output and being connected at its input through phase shifting elements to said amplitude modulator and at its output to said radiating circuit.

30. The combination of a constant frequency oscillation generator, a source of modulating potentials, means for modulating the oscillations generated in accordance with potentials from said source of modulating potentials comprising a pair of amplitude modulator tubes, said tubes also acting as frequency multipliers, circuits connecting the input electrodes of said tubes to the output of said generator and connecting electrodes in said tubes to said source of signal potentials, and means for converting the resultant energy into phase modulated oscillations comprising an additional tube, phase shifting reactances of different character connecting the input electrodes of said additional tube to the outputs of each of said pair of tubes, an amplifier and frequency multiplier connected at its input with the output of said additional tube, and means for neutralizing the internal capacity between electrodes in the amplitude modulator tubes.

31. The method of signalling by means of high

frequency oscillations and signal potentials which includes the steps of dividing the high frequency oscillatory energy into two portions, multiplying the frequency of the high frequency oscillations in each portion and simultaneously varying the amplitude of said portions in phase opposition in accordance with the signal potentials, shifting the phase of the oscillatory energy in each portion, and combining the resultant energies.

32. The method of signaling by means of carrier frequency oscillatory energy and signal potentials which includes the steps of separating said oscillatory energy of carrier frequency into two portions, the phases of the oscillatory energies of said portions being displaced substantially 180°, differentially amplitude modulating the oscillatory energy in said portions at signal frequency, relatively shifting the phase of the differentially amplitude modulated oscillatory energy in said portions, and combining the energies in the portions to produce a resultant the phase of which is determined by the relative amounts of said portions combined.

33. Transmitting means comprising a source of oscillations, a pair of thermionic tubes, circuits connecting said source of oscillations to the control electrodes of said tubes, separate tank circuits connected to the anode of each of said tubes, there being an appreciable coupling between said tank circuits, a source of modulating potentials, means for impressing the modulating potentials in phase opposition on like electrodes of said tubes, an additional tube, and separate reactive means of different character connecting the control electrode of said additional tube to each tank circuit.

34. In a phase modulation system, a pair of electron discharge tubes each having input and output electrodes, carrier wave frequency energizing circuits connected with the input electrodes of said tubes, a separate tuned tank circuit connected to the output electrodes of each of said tubes, means connected with said tubes for varying the internal impedance of said tube in phase opposition at signal frequency, a combining tube having an input electrode, a phase shifting inductance connecting the input electrode of said combining tube to one of said tank circuits, and a phase shifting condenser connecting the input electrode of said combining tube to the other of said tank circuits.

35. In a signalling system, means for differentially amplitude modulating two portions of oscillatory energy of like frequency in accordance with signals, means for simultaneously increasing the frequency of the oscillatory energy of each portion like amounts, means for relatively phase shifting the energy of said two differentially amplitude modulated portions, and means for combining the resultants to produce a component the phase of which varies at signal frequency.

36. A method of impressing phase changes at signal frequency or wave energy comprising, dividing the energy from a source of wave energy into two branches, differentially modifying the amplitudes of the energy in the branches in accordance with signals, then subjecting the energy in one branch to a leading power factor and subjecting the energy in the other branch to a lagging power factor, then combining the energy from the two branches so that the combined wave

is of substantially constant amplitude with a varying phase.

37. In an amplifier for modulating high frequency waves, a radio transmitter, two parallel branch circuits to which high frequency wave energy is fed by the transmitter, means for introducing a signal component on the high frequency energy in each branch, a capacitive reactance in the output of one branch and an inductive reactance in the output of the other branch, and means for coupling said capacitive and inductive reactances whereby there is generated an output wave of substantially constant amplitude whose longitudinal dimensions vary about a medial point in accordance with the signal component.

38. Means for impressing phase modulations at signal frequency on carrier frequency oscillations including, a pair of thermionic tubes having their input electrodes connected in circuits for impressing the oscillations to be modulated on the control grids of said tubes, the impressed oscillations being of like phase, means for varying the impedances of said tubes in phase opposition at signal frequency, and separate circuits connected with the output electrodes of said tubes for relatively shifting the phase of the oscillations repeated in said tubes.

39. The method of producing carrier wave energy modulated in phase at signal frequency which includes the steps of, separately modulating the amplitude of a plurality of carrier wave oscillations, of like phase and frequency, in opposite sense at signal frequency, relatively shifting the phases of the amplitude modulated carrier wave oscillations of like frequency, and combining the resultant energy to produce wave energy modulated in phase at signal frequency.

40. In a system for producing oscillatory energy modulated in phase in accordance with signals, a source of oscillatory energy of carrier wave frequency, an output circuit, two parallel branches each having an input to which oscillatory energy is fed from said source of oscillatory energy, means for modulating the amplitude of the oscillatory energy in each branch at signal frequency, a capacitive reactance coupling one branch to said output circuit, an inductive reactance coupling the other branch to said other output circuit and means associated with said branches for preventing oscillatory energy therein and in said output circuit from reacting on said source of oscillatory energy.

41. In a phase modulating system, an output circuit, a source of modulating potentials, a source of high frequency oscillations, a pair of thermionic tubes having separate anode circuits coupled to said output circuit, and circuits connecting the electrodes of said tubes to said sources to apply carrier frequency waves to said tubes and phase opposed modulating potentials to the impedances between like electrodes of said tubes, whereby the carrier frequency waves in said tubes are differentially modulated in amplitude and phase shifting means in the anode circuits of said tubes for producing relative phase shifts of the differentially amplitude modulated waves in said anode circuits.

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