May 21, 1940. R. E. SHELBY 2,201,323

ELECTRONIC MODULATOR AND METHOD OF MODULATION

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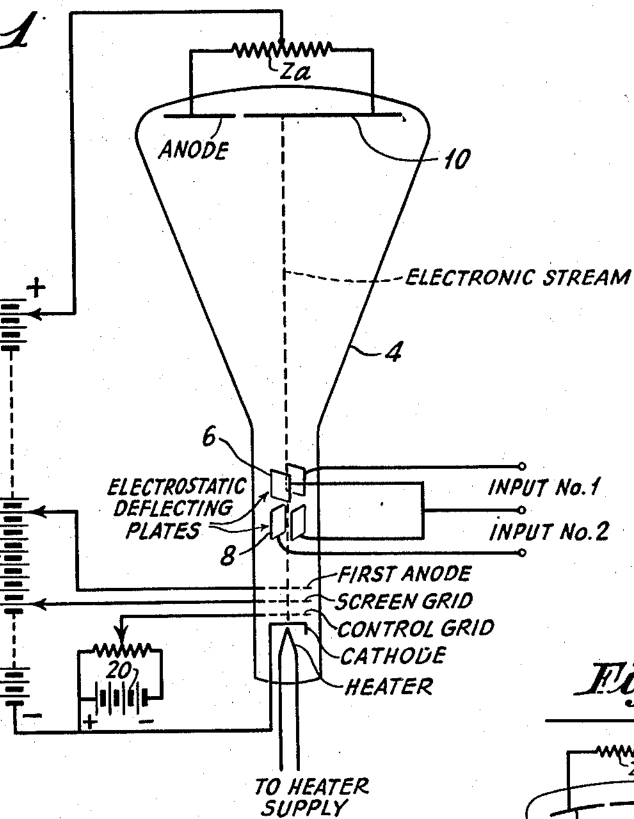
Fig.1



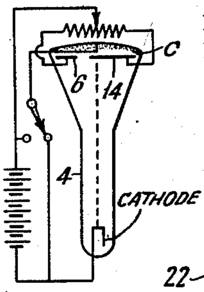


Fig.1b.

Fig.1a

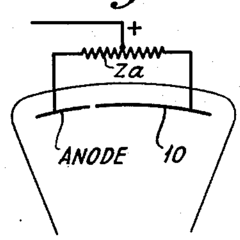
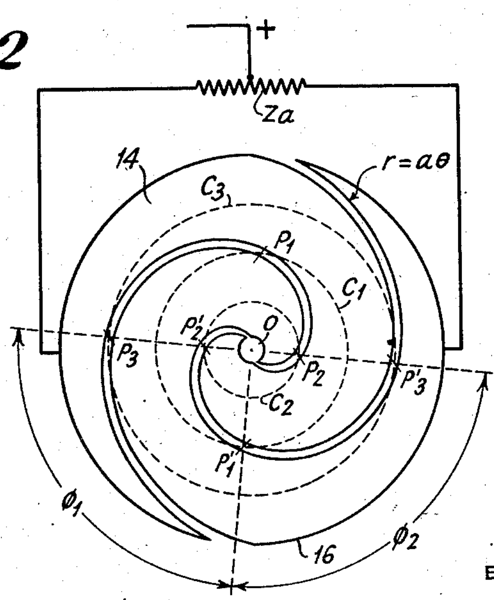


Fig.2



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ELECTRONIC MODULATOR AND METHOD OF MODULATION

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Fig. 3

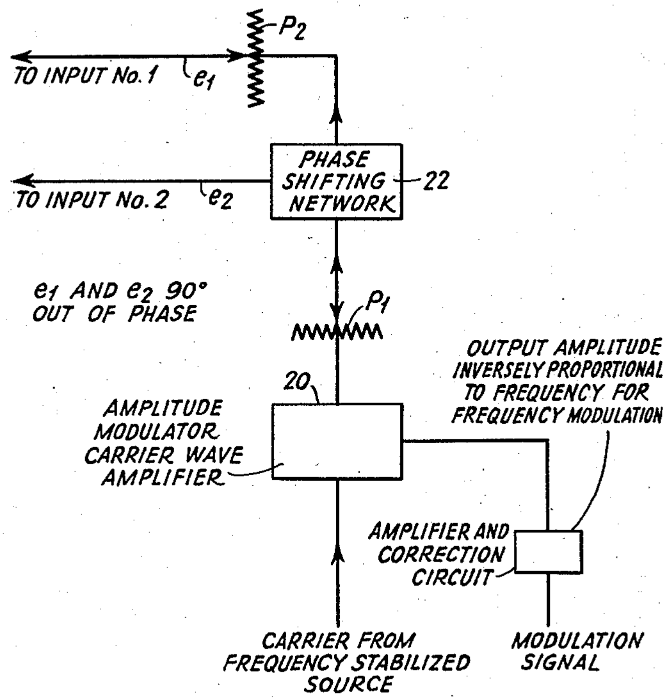


Fig. 3a

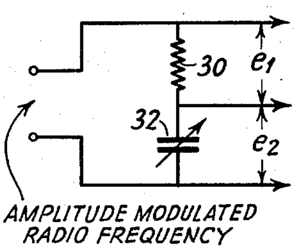


Fig. 4

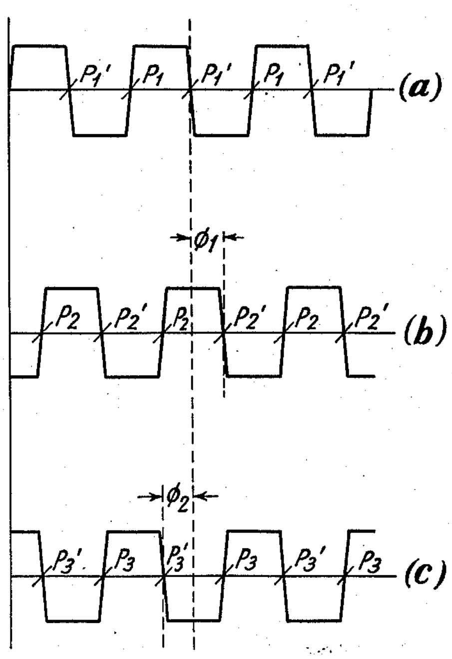
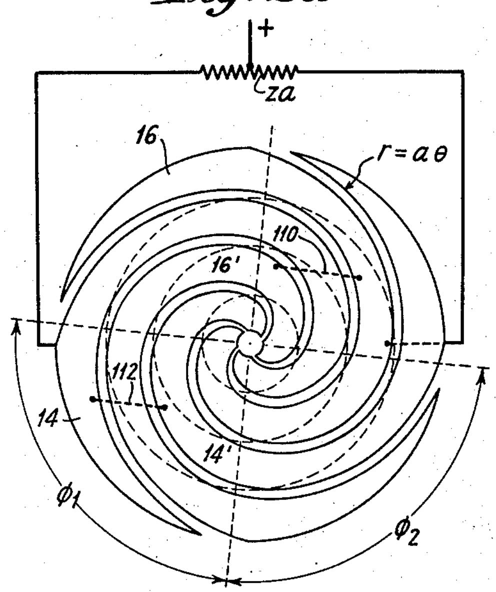


Fig. 2a



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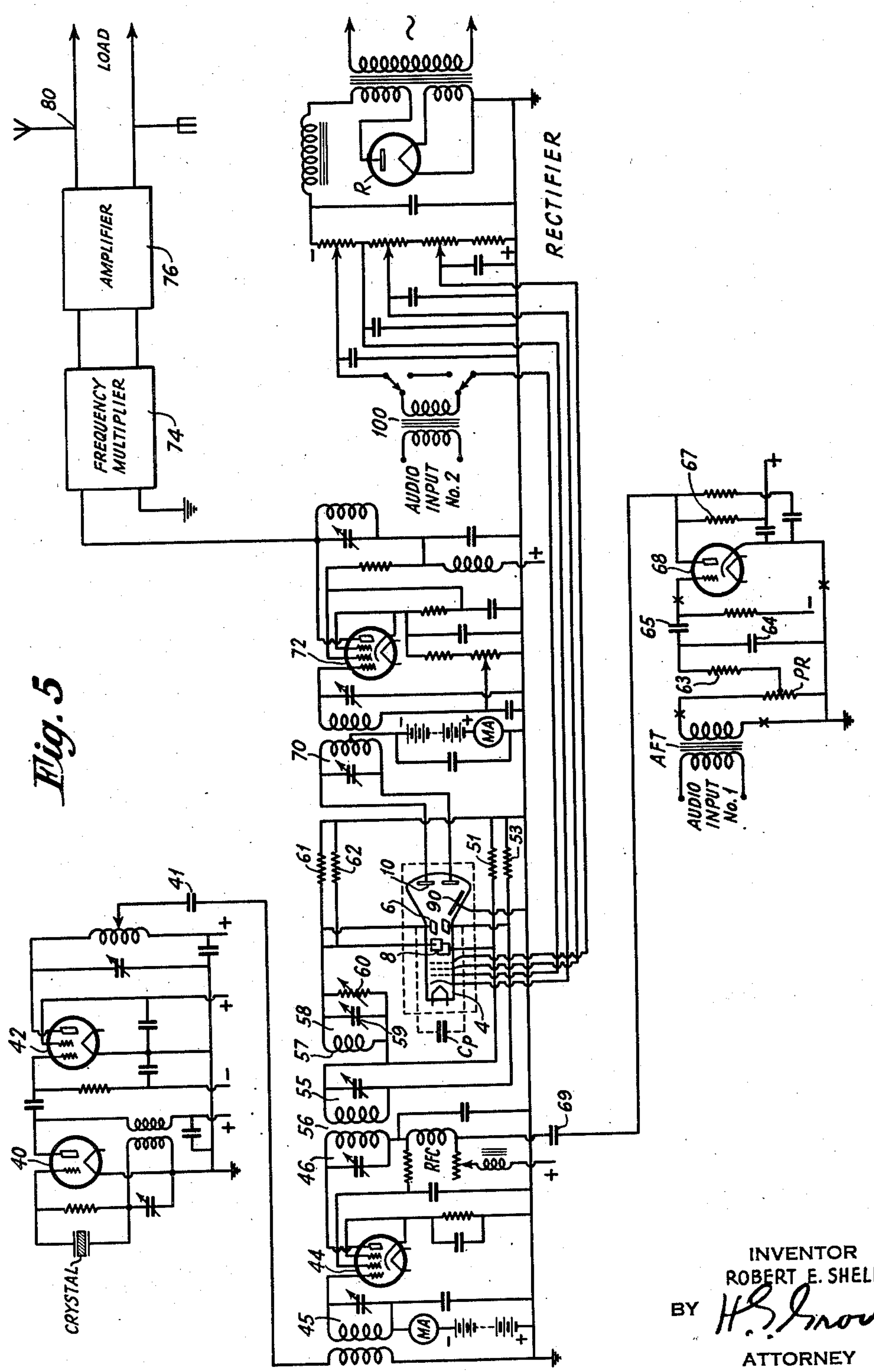

Fig. 5

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UNITED STATES PATENT OFFICE

2,201,323

ELECTRONIC MODULATOR AND METHOD OF MODULATION

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Application April 6, 1936, Serial No. 72,916

30 Claims. (Cl. 179—171.5)

The method and means of the present invention is proposed mainly as a method and means for frequency or phase modulating a carrier signal obtained from an oscillator of constant frequency and phase. The oscillations may be obtained from a crystal controlled oscillator. However, various embodiments of the underlying principle may be used for other purposes such as amplitude modulation, current limiting, frequency conversion, rectification, etc. This application has features in common with my United States application #100,627, filed September 14, 1936, now Patent #2,171,150, dated August 29, 1939.

In one system of frequency modulation known in the art, modulation is achieved by adding two voltages of the same frequency which have a phase difference of 90°, one voltage having constant amplitude and the other varying in amplitude with the modulation signal. This method has the disadvantage of serious distortion unless the maximum phase shift is limited to small angles, say of the order of 30°. The reason that distortion is produced is that the amplitude of the modulation signal (of any given frequency) is proportional to the tangent of the angle of phase shift and not proportional to the angle itself as it should be for distortionless modulation. For angles less than about 30° the tangent approximates the angle closely enough to prevent serious distortion but above about 30° the distortion increases rapidly. In order to obtain a worthwhile shift at the final carrier frequency when the shift in the modulated stage is 30° or less it is necessary to modulate a relatively low frequency carrier and employ frequency multiplication of large ratio.

The method proposed here does not have this limitation. Theoretically it will give distortionless phase shift of many times 360°, though actually this may be limited by structural difficulties to a few complete cycles.

In this specification the term "phase modulation" unless otherwise specifically stated, refers to modulation of the kind in which the form of the modulated current wave may be represented by the equation:

$$i_p = A_p \sin (w_o t + k_p \phi_o \sin \mu t) \qquad (1)$$

if the unmodulated carrier wave has the form $\sin w_o t$ and the modulation signal has the form $\sin \mu t$; and the term "frequency modulation" employed herein, refers to modulation of the kind in which the form of the modulated current wave may be represented by the equation:

$$i_f = A_f \sin \left(w_o t + \frac{k_f}{\mu} \sin \mu t\right) \qquad (2)$$

if the unmodulated carrier wave has the form $\sin w_o t$ and the modulation signal has the form $\sin \mu t$.

The symbols of equations 1 and 2 have the following meanings:

- i_p=instantaneous value of phase modulated current.
- i_f=instantaneous value of frequency modulated current.
- $w_o = 2\pi$ times carrier wave frequency in cycles per second.
- $\mu = 2\pi$ times modulation signal frequency in cycles per second.
- t=time in seconds.
- A_p, A_f, k_p, k_f, and ϕ_o are arbitrary constants.

The term "electron gun" used in this specification has the meaning given to it in the paper, "Theory of Electron Gun" by I. G. Maloff and D. W. Epstein, Proceedings Institute of Radio Engineers, December, 1934, page 1386.

In describing my invention reference will be made to the attached drawings wherein:

Figures 1 and 2 show an electron device, or gun or cathode ray tube arranged in accordance with the present invention and having a novel anode or target or plate. The discharge device is shown connected in my novel modulation circuit;

Figure 1*a* shows a modified form of the target. In Figure 1*a* the target is saucer shaped so that the points on the useful surface are equi-distance from the electron stream origin;

Figure 1*b* illustrates a modified electron tube or gun wherein the surface of the tube envelope is coated with a conducting material to collect electrons which pass the target anode or are of a secondary nature;

Figure 2*a* is an additional modification of the target. The target of 2*a* includes pairs of elements similar to the pairs of elements of Figure 2. A target as shown in Figure 2*a* may be used when multiplication of frequency, or the same with modulation, is desired;

Figure 3 illustrates by line diagram my novel circuit for producing and applying deflecting potentials to the electrodes of the novel electron discharge device of Figures 1 and 2;

Figure 3*a* shows in detail, one form of phase shifting network used in the circuit of Figure 3;

Figure 4 shows graphs or curves illustrating the principle of operation of the electron discharge device and circuits of the prior figures; and finally,

Figure 5 illustrates the principle circuit elements of a complete modulation system arranged in accordance with my novel concept.

Structurally the device consists, as will be seen by reference to Figures 1 and 2, essentially of an electron gun **4**, two sets of electrostatic deflecting plates **6** and **8** and a target anode **10** of special design, enclosed in an evacuated container of suitable size and shape. One typical arrangement has been shown schematically in Figure 1 for purposes of illustration. It will be seen at once that the device illustrated is similar in some respects to a conventional cathode ray oscillograph tube. One of the fundamental differences between the present device and known devices, is the novel design of the target anode 10. Figure 2 illustrates one form which the target anode may take. It consists of two (or more) metallic electrodes 14 and 16 with curved boundaries, upon which electrodes the electrons from the electron gun impinge. The electrodes 14 and 16 may consist of metallic plates or meshes or metallic deposits on the tube envelope or on a support in said tube. Where the elements 14 and 16 are of mesh, a collecting electrode may be located back of these targets and properly charged relative to the other electrodes as shown in Figure 1*b*. In order to obtain frequency or phase modulation of a carrier wave in which the angular phase shift of the wave is a linear function of the amplitude of the modulation potentials the inner edges of the plates 14 and 16 have a curvature defined by the polar equation

$$r = a\theta \qquad (3)$$

which defines an Archimedean spiral. In this equation r is the radial distance from the origin 0 to any point on the curved edge of the plates, θ is the angular displacement of the same point from a selected datum line, and a is a design constant related to the number of turns of the plates 14 and 16. In other words, r and θ are the usual parameters used in polar coordinates. In the preferred form, the periphery of any plate adjacent the edge of the adjacent plate defined by $r = a\theta$ may be defined by the same equation with reference to other properly selected datum lines.

In operation the electron stream is deflected by plates 6 and 8 in such a way that it traces out a circle on the target, or anode plates 14 and 16, the diameter of the circle being a variable which is directly proportional to the instantaneous value of the modulating signal potentials. When controlled in this way the electron stream may be made to produce a phase or frequency modulated carrier wave in the impedance Z_a upon striking a target having the special design just described, provided the deflecting plates 6 and 8 are properly energized. Operation of the system will now be described more fully.

The electron gun is controlled and focused by adjusting the direct current potentials applied from any suitable source or sources to the cathode, control grid, screen grid and first anode, just as in the case of oscillograph tubes and kinescopes. Sources 20 and 22 have been shown for purposes of illustration. The electron stream is focused on the target anode comprising sections 14 and 16, and when there is no voltage applied to the electrostatic deflecting plates 6 and 8 it strikes the exact geometrical center of the target anode. In a preferred form the deflecting plates 6 and 8 are substantially displaced by 90°. In this case the carrier waves applied to the sets of plates should be displaced by 90°. Of course other angular relations between the sets of deflecting plates 6 and 8 may be used, in which case the phase relation between the applied waves may be changed. The essential requirement is that the electron stream be caused to describe a circle on the target anode, with the plates shown, if linear modulation is desired. The inputs, which consist of two carrier waves of equal frequency and almost equal amplitude but differing in phase and having the same percentage amplitude modulation, are applied to the two sets of electrostatic deflecting plates.

Figure 3 illustrates by line diagram one means of supplying the inputs to the deflecting plates 6 and 8. In Figure 3 carrier wave oscillations from any source are supplied to the input of an amplitude modulator 20 which is also connected to any source of modulating potentials. The output of the modulator is connected to an amplitude regulating potentiometer P_1 which is connected to a phase shifting system or network 22. This network may take any form, the essential feature being that the output thereof supplies two voltages e_1 and e_2 characteristic of the amplitude modulated wave in phase displaced relation. The phase displacement is 90° when the deflecting plates 6 and 8 are at right angles and linear modulation is desired. One output goes directly to one set of deflecting plates. The other output is fed to an additional potentiometer P_2 which is connected to the other set of deflecting plates. A preferred form of phase shifter has been shown in Figure 3*a*. In this phase shifting circuit the amplitude modulated radio frequency or carrier frequency waves are applied to input terminals and from said terminals to a resistance 30 in series with a condenser 32. By adjusting the condenser 32 and selecting the valve of 30 the desired phase relation between e_1 and e_2 can be produced. The oscillations may be modulated by keying, by voice frequencies, by television or facsimile signals or by constant frequency variable dot characters.

If phase modulated output is desired the modulating potentials are applied in their characteristic form to the stage 20 where amplitude modulations takes place. If frequency modulated output is desired the modulating potentials are distorted or corrected in such a manner that the potentials applied to the stage 20 are attenuated in proportion to their frequency.

The produced phase or frequency modulated output appears in the circuit including one or both of the target electrodes 14 and 16, across the impedance Z_a or any portion of Z_a. If Z_a is a pure resistance the output voltage appearing across it will be a flat-topped wave of constant amplitude having frequency or phase modulation proportional to the amplitude modulation of the input, and a fundamental frequency equal to that of the input carrier. By use of suitable reactance elements instead of a resistance, Z_a may be tuned to the fundamental or any one of its harmonics. By using a target anode composed of a larger number of curved sections the fundamental frequency of the flat-topped output wave may be made any desired multiple of the input frequency. Thus, it is seen that, if desired, frequency multiplication may be obtained during the process of converting amplitude modulation into frequency or phase modulation.

For a more detailed explanation of the way in which amplitude modulation is translated into frequency or phase modulation refer to Figures 2, 3, and 4. First with no modulation applied to 20 the phase shifting network 22 and potentiometer P_2 of Figure 3 are adjusted so that the electron beam from the cathode of 4 describes a circle on the final anode target and in particular, on plates 14 and 16, the center of said circle coinciding with the point 0. If the potentiometer P_1 is adjusted so that this circle is of the size designated by C_1 in Figure 2 then the voltage appearing across Z_a will be shown in curve *a* of Figure 4. Note that the electron stream passes from one segment of the target anode to the other segment at points p_1 and p_1'. If now, the two deflecting voltages are decreased say, for example, roughly 50 percent by changing potentiometer P_1, all other controls being left the same, the locus or path of the electron stream on the target anode will be C_2 of Figure 2, and the voltage across Z_a will be as shown by curve *b* in Figure 4. The electron stream now passes from one segment of the target anode to the other at points p_2 and p_2'. Likewise, if the potentiometer P_1 is adjusted to give higher voltages, say, for example, voltages 50 percent greater than those which gave the locus C_1, then C_3 will be the new path or locus of the electron stream on the target, and the electron stream will pass from one target anode segment to the other at points p_3 and p_3' and the voltage appearing across Z_a will be as shown by curve *c* in Figure 4. Now if P_1 is reset so that the electron stream path falls on C_1 and, for example, a fifty percent amplitude modulation is then applied to the carrier in the manner indicated by Figure 3 the locus or path of the end-point of the electron stream will vary between the limits C_2 and C_3 and the output wave will shift in phase between the limits indicated by curves *b* and *c* of Figure 4. In this system adjustment of circuit constants and monitoring of the system is facilitated by coating the target anodes or plates with willemite or other substance which fluoresces under the bombardment of the electron stream.

Although as pointed out above, frequency or phase modulation accompanied by frequency multiplication may be accomplished when the target is as shown in Figure 2 if Z_a is reactive I provide other means for accomplishing these results. By providing a target as illustrated in Figure 2*a* having a plurality of pairs of elements **14**, **14'** and **16**, **16'** with boundaries similar to the boundaries of the corresponding plates of Figure 2, the phase or frequency modulation and frequency multiplication is accomplished simultaneously in the tube. The number of elements may be increased indefinitely within practical limits. When two pairs of elements are used as shown in Figure 2*a*, alternate ones are joined as shown at **110** and **112**. For simplicity the reference characters for circles C_1 C_2 and C_3, etc., have been omitted in Figure 2*a*.

Although my invention will be clear to those skilled in the art from the preceding description thereof, for completeness of description I have shown in Figure 5 a circuit arrangement including the essential elements of a modulation system arranged in accordance with the present invention. In the circuits of Figure 5 potential sources have in certain instances been omitted in order that the circuit diagrams do not become too involved. Likewise, cathode heating and filament heating circuits have been omitted for the same reason.

Referring more in particular to Figure 5, **40** is an oscillation generator having its electrodes connected as shown to produce oscillations of the desired frequency of constant frequency. Although I have shown the oscillator as being of the crystal control type it will be clearly understood that any means, such as a long line control frequency oscillator or an electron coupled oscillator may be utilized in place of the crystal oscillator shown. The output electrodes of the crystal oscillator are connected with a buffer amplifier stage comprising an electron discharge device **42** and are supplied by way of a blocking condenser **41** and transformer from the output electrodes of said buffer amplifier stage to the control grid electrode of a further amplifier **44**. Electron discharge device **42** may be of the screen grid type as shown, wherein the screen grid serves to shield the output electrodes and circuit from the input electrodes and driving stage or this tube may be of the three electrode type and may be connected in a neutralized circuit. The amplifier **44** may also multiply the frequency of the impressed oscillations while amplifying the same. In this case the input circuit **45** of **44** is tuned to the frequency at which **42** operates while the output circuit **46** is tuned to a harmonic of said frequency. This tube **44** has been shown as being of the pentode type although it will be realized that any other appropriate tube may be used in place of the one shown. The anode electrode of the tube **44** is coupled to a tuned circuit **46** the winding of which forms the primary winding of a transformer **56**. The secondary winding of this transformer **56** is connected in parallel with a tuning condenser to provide a tuned circuit **55**, one terminal of which is connected to ground by way of a resistance **53** and directly to one plate of one of the sets of deflecting plates **6** and **8**, say of plates **6**. The other terminal of the tuned circuit **55** is connected with a phase shifting circuit **58** comprising an inductance **57** shunted by a variable condenser **59** and a variable resistance **60**. One end of this phase shifting circuit **58** is connected as shown to ground by way of a resistance **51** and directly to one of the plates of the other set of deflecting plates, say plates **8**. The other terminal of the phase shifting circuit **58** is connected to the remaining deflecting plates of the pairs of plates **6** and **8**. These remaining deflecting plates are also connected to ground by way of resistances **61** and **62**. Thus, we have a series circuit including the capacity between the plates **6**, indicated by the dotted capacity C_p, the tunable resonant circuit **58** and the driver circuit **55**. This arrangement may be made the equivalent of a pure resistance in series with a capacity-bridged across the driver circuit since the circuit **58** and the capacity of the other set of deflecting plates **8** may be tuned to resonance at the frequency of the oscillations applied to **55** and thereby made to represent a pure resistance at this frequency. The variable resistance **60** is used to control the amplitude of the potentials applied to the deflecting plates **8**. When adjusted in such a manner this phase shifting circuit is the equivalent of that shown in Figure 3*a*. Any other appropriate phase shifting means may be used.

Operating potentials for the tubes **40**, **42**, **44** and **72** may be supplied from any suitable source. Likewise, operating potentials for the cathode ray tube **4** may be supplied from any source. I prefer, however, to use a rectifier such as illustrated at R with its positive side grounded and its output connected to the electrodes of **4** as shown. This circuit, it is believed, needs no explanation.

Up to this point, I have described means for applying high frequency or carrier frequency oscillations in phase displaced relation between the plates **8** and **6** of the electron discharge device of the present invention. I will now describe the means for amplitude modulating the oscillations before they are phase displaced and applied to said deflecting plates.

Modulating potential may be applied from any source to the primary winding of an audio frequency transformer AFT, the secondary winding of which is coupled as shown to a potentiometer resistance PR. A point on the potentiometer resistance PR is connected as shown by way of the resistance 63 and condenser 65 to the control grid of a modulation frequency amplifier 68. The resistance 63 and a portion of the potentiometer resistance PR is shunted by a condenser 64. The output of the modulation potential amplifier 68 is connected as shown to a direct current plate circuit comprising resistance 67 and to an audio frequency circuit comprising a coupling condenser 69 connected to a radio frequency choke RFC which is in turn connected to the anode of the amplifier or multiplier 44 to accomplish in said tube anode modulation of the amplitude of the carrier wave being applied to the phase shifting circuit.

The phase modulated or frequency modulated oscillations produced on the target anode 10 appear in the circuit 70 and are impressed from the circuit 70 on to an additional amplifier 72. The circuit 70 may be tuned to the fundamental frequency, that is, the frequency applied to the deflecting electrodes of the tube 4 or to a harmonic thereof. The circuit 70 is coupled to the input electrodes of amplifier 72, the output electrodes of which may be connected to a utilization circuit 80 directly or by way of a frequency multiplier 74 and a further amplifier shown diagrammatically in a rectangle 76. If desired, the circuit 70 and its coupling to the tube 72 may be replaced by a resistance as in Figure 1 in which case the phase or frequency modulated wave energy from the target anode 10 will be impressed on tube 72 with no appreciable filtering. This energy then may be frequency multiplied and amplified for use by any one of several means well known to the art. The output or utilization circuit 80 may comprise radiating means or lines over which the phase or frequency modulated waves may be transmitted.

When the waves are to be frequency modulated the resistance 63 connected in the input circuit of amplifier 68 may be of high impedance to the modulating frequencies and in particular to the higher modulating frequencies, while the condenser 64 may be of low impedance to the modulating frequencies and in particular, of low impedance to the higher modulating frequency potentials. By properly adjusting the values of this resistance 63 and condenser 64 the potentials applied to the input electrodes of 68 may be caused to vary inversely as the frequency of the said modulating potentials. When this condition is obtained a pure frequency modulated wave is produced in the tube 4 and appears in the circuit 70.

When phase modulated oscillations are to be produced the values of 63 and 64 are selected such that the modulating potentials appearing between the control grid and cathode of 68 are directly proportional to the applied modulating potentials and are independent of the frequency of the applied modulating potentials. In this case the circuit transformer AFT may be connected directly by way of its secondary winding to the control grid and cathode of the tube 68. This may be accomplished by breaking the circuits at the points marked X and removing those portions of the circuit between said points.

In the electron tube 4 of Figure 5, I increase the power output of the electron tube by providing a second anode 90 located adjacent the two target anodes. In practice, 90 may be a conducting element located in the tube or may consist of a deposit or coating on the tube envelope as shown at C in Figure 1*b*. The electrode 90 is maintained at a potential more positive than that applied to electrodes 10. This anode or coating or collecting, or return electrode 90 collects the electrons emitted from the target anode 10 by the phenomenon of secondary emission occurring when the primary electrons of the beam strike the target. The electrode 90 also collects any electrons free in the tube and there may be considerable in the case electrodes 10 are grids or meshes. The electrode 90 is in this particular embodiment in the current path of both electrodes 10 and the circuit 70 and since the secondary emission may be made greater than the primary emission, the current output may obviously be increased. When this is accomplished to the desired extent the number of stages between the output circuit 70 and the utilization circuit may be materially reduced. The stages remaining may operate to multiply the frequency of the phase or frequency modulated oscillations produced to a greater extent when a high frequency output is desired. The manner in which this phenomenon is used to enhance the power output has been disclosed more in detail in Headrick, United States application #673,570 filed May 30, 1933, now Patent #2,069,441, dated February 2, 1937.

It will be understood that many variations of the above described apparatus are possible. The fundamental principle involves the use of an electron gun, or other source of electrons, and an anode of such configuration that the voltage fluctuations applied to one or more elements of the tube are translated into phase, frequency or amplitude modulation in the anode circuit, the type of translation being dependent upon the configuration of the anode as well as upon the nature of the input voltages and the method of applying them.

The amount of maximum phase shift in the device described above will be determined by the curvature of the anode plates, that is, it will depend upon the value of a in Equation 3. For the anode illustrated in Figure 2 the phase shift is plus and minus approximately 90° when the input is amplitude modulated 50 percent. Under the same conditions, amplitude modulation of 75 percent on the input will give phase shift of approximately plus and minus 135°, etc.

Electromagnetic deflection of the electron stream may be utilized instead of electrostatic deflection as described above.

Instead of amplitude modulating the voltages used to deflect the electron stream, these voltages may have constant amplitude and the modulation voltage may be introduced (in proper ratio) into the accelerating electrode circuits of the electron gun. Variation of the accelerating electrode voltages will cause the sensitivity or stiffness of the electron stream to vary, so that for voltages of constant amplitudes on the deflecting plates the size of the circle described on the target anode by the electron stream will vary in some inverse relation to the anode voltages. Variation of voltages on two or more of the electrodes of the electron gun (in proper ratio) is necessary to preserve sharp focus of the electron stream throughout the modulation cycle.

In Figure 1, the target anode 10 is indicated as having a plane surface. In one type of this modulator tube the target anode 10 has been constructed with a curved surface (saucer-shaped) as shown in Figure 1a, so that the electrons from the electron gun always travel very nearly the same distance before striking the target, regardless of the amount of deflection of the electron stream from its undeflected path. In this case the curvature of the boundaries of the target electrodes is not completely represented by the simple Equation 3. In this particular tube the curvature of the boundaries was made such that the phase shift in the output wave is directly proportional to the change in deflecting potentials causing the phase shift.

Auxiliary electrodes may be added to the device described for control or monitoring purposes. For example, a willemite screen such as that used in cathode ray oscillograph tubes might be provided beyond the target anode, so that the electron stream would produce a pattern upon it when it passed between segments of the target or beyond the outer edges of the target plates. Additional electrodes, located in the same plane as the target anode, but electrically separate from it, might be used for adjusting the modulator and also for indicating over-modulation. Such an electrode, of small area, located at the geometrical center of the anode (where the anode plates are cut away) would be useful in centering the electron stream. A narrow annular ring around the outside of the main anode could be used in connection with adjustment of the phase shifting network to obtain circular deflection of the electron stream. Other auxiliaries will undoubtedly suggest themselves.

The description so far has related to the production of modulation in which the phase shift is proportional to the modulating voltage, but the principle is quite flexible in this respect. By use of a properly shaped target, the phase shift may be made almost any function of the modulating voltage, this being determined by the curvature of the boundaries of the target plates and/or the nature of the curve described on the anode by the electron stream.

The amplitude of the output voltage wave may be varied independently of the frequency (or phase) modulation by varying the direct current potential applied to the control grid of the electron gun. If it is desired to amplitude modulate the output wave in addition to or instead of frequency (or phase) modulating it in the manner described this may be done readily by applying the amplitude modulation signal to the control grid, provided the electron gun is so constructed, adjusted and operated that the rate of electron emission from the gun is a linear function of control grid voltage over the operating range. One manner in which the output wave may be modulated in amplitude has been illustrated in Figure 5. Other means will be obvious to those skilled in the art who have read this specification. In Figure 5 a second source of modulating potentials may be connected with the primary winding of a transformer 100 and the secondary winding of this transformer may be switched into the direct current circuit between the cathode and number 1 grid of the gun 4. The wave may now be amplitude modulated only by potentials from 100 or may be phase or frequency modulated only by potentials from AFT, or a phase modulated wave carrying signals from AFT may be amplitude modulated by other signals from 100 so that multiplexing of signals on a single carrier is feasible. The wave may also be frequency modulated by one signal from AFT and amplitude modulated by a second signal from 100.

Of course I contemplate amplitude modulating by additional signals the frequency multiplied phase or frequency multiplied wave in 72, or 74 or 76 or at the output of 76 when multiplexing of signals is desired.

I claim:

1. The method of modulation by means of a tube device comprising at least one target electrode in the form of a conductor lying substantially in a plane and spiralling outwardly from a selected point which includes the steps of, producing an electron stream of constant intensity which falls on said selected point, deflecting and rotating the path of said produced electron stream in accordance with phase displaced modulated wave energy, collecting energy produced by the stream falling on the target, and producing currents characteristic of the collected energy for signalling purposes.

2. The method of modulation by means of a tube device comprising a plurality of target electrodes each in the form of a conductor lying substantially in a plane and spiralling outwardly with adjacent correspondingly curved peripheries in a direction normal to a selected path, which includes the steps of, producing an electron stream of constant intensity which follows said selected path, deflecting and rotating the path of said electron stream in accordance with phase displaced modulated wave energy, collecting energy produced by the stream falling on the target electrodes and producing currents characteristic of the collected energy for signalling purposes.

3. The method of phase or frequency modulation by means of a tube device comprising at least one target electrode in the form of an anode lying substantially in a plane and spiralling outwardly from a selected point, which includes the steps of, producing in said tube an electron stream of constant intensity along a selected path through said point, deflecting and rotating the path of said stream in accordance with phase displaced modulating potentials to control its path on the target, and producing currents characteristic of the electrons collected by said target for signalling purposes.

4. The method of producing phase modulation by means of a tube device comprising at least one target electrode in the form of an anode lying substantially in a plane and spiralling outwardly from a selected point, which includes the steps of, amplitude modulating oscillations of carrier wave frequency, deriving from said modulated oscillations two phase displaced voltages, producing an electron stream which falls along a path through said selected point, producing forces, characteristic of said phase displaced voltages on said stream to deflect said stream from its normal path in accordance with the relative phases and amplitudes of the derived voltages to control the path of the stream on the target and producing current flow characteristic of the electrons collected by said target.

5. The method of producing phase or frequency modulation of carrier wave energy by means of an electron discharge tube having a target electrode including a pair of surfaces spiraling outwardly substantially in a plane from a selected point in said plane, which includes the steps of, producing an electron stream which normally falls on said selected point, amplitude modulating oscillations of carrier wave frequency, deriving from said modulated oscilla-

tions two phase displaced voltages, producing force adjacent the path of said stream, characteristic of said phase displaced voltages, to control the path which said stream follows and thereby control the path followed by said stream on said target, and collecting energy characteristic of the energy produced in said surfaces by said stream.

6. The method of modulation and frequency multiplication by means of an electron discharge tube having a target electrode including a pair of surfaces spiralling outwardly substantially in a plane from a selected point in said plane which includes the steps of, producing an electron stream of constant intensity which normally falls on said selected point, deflecting the path of said stream in accordance with phase displaced modulating potentials to control its path on said target electrode, and producing currents characteristic of the current impulses caused by electrons falling on said target and of a frequency greater than the frequency of the modulating potentials for signalling purposes.

7. The method of multiplexing signals by means of an electron discharge tube having a target electrode including a pair of surfaces spiralling outwardly substantially in a plane from a selected point in said plane, which includes the steps of, producing an electron stream which normally falls on said selected point, varying the intensity of said stream in accordance with signal potentials, deflecting the path of said stream in accordance with other phase displaced signal potentials to control its path on said target, and producing currents characteristic of the intensity of said stream and the radial and angular displacement of said stream on said surfaces for signalling purposes.

8. The method of multiplexing signals by amplitude modulation and phase or frequency modulation by means of an electron discharge tube having a target electrode including a pair of surfaces spiralling outwardly substantially in a plane from a selected point in said plane, which includes the steps of, producing an electron stream which normally falls on said selected point, varying the intensity of said stream in accordance with signal potentials, deflecting the path of said stream in accordance with other phase displaced signal potentials to control its path on said target and producing currents the intensity of which is characteristic of the intensity of said stream and the phase of which is characteristic of electrons collected by said surfaces.

9. In a modulation system, a discharge device having an electron stream emitting system, a target electrode comprising a conducting surface spiralling outward substantially in a plane substantially normal to the path of said stream, means for modulating carrier wave oscillations in accordance with signalling potentials, means for deflecting said stream relative to its normal path in accordance with said modulated carrier wave oscillations, and a load connected in a path including said target electrode.

10. In a modulation system, a discharge device having an electron emitting electrode, a target electrode comprising a plurality of surfaces spiralling outwardly in a surface substantially normal to the path between said emitting electrode and said target electrode, and pairs of deflecting electrodes adjacent the path between said emitting electrode and said target electrode, means for producing phase displaced amplitude modulated waves and means for applying said phase displaced waves to said deflecting electrodes.

11. In a modulation system, a discharge device having an electron emitting electrode, a target electrode comprising a plate, a portion of the boundaries of which is defined by $r = a\theta$ (where r = radius from the electron stream focal point, a is a constant, and θ is angular deviation from a straight datum line through said focal point along which $r = 0$), and pairs of deflecting electrodes adjacent the path between said emitting electrode and said target electrode, means for producing phase displaced amplitude modulated waves and means for applying said phase displaced waves to said deflecting electrodes.

12. In a modulation system an electron discharge device, an electron emission element, pairs of deflecting electrodes and a target electrode in the path of said emission from said element, said target electrode comprising plates or surfaces, a portion of the periphery of each of which is defined by $r = a\theta$ where r = radial distance from normal focal point of said emission under the condition of zero potential on all deflecting electrodes, a is a constant; and θ is angular displacement relative to the line through said normal focal point along which r = zero, means for applying phase displaced modulated waves to said deflecting electrodes, and a load circuit connected with said target.

13. A system as recited in claim 11 wherein said target comprises a pair of plates the datum lines of which are 180° apart.

14. In a modulation system an electron discharge device including, an electron emission element, pairs of deflecting electrodes, a target electrode in the path of said emission from said elements said target electrode comprising similar conductors of considerable surface area having adjacent correspondingly curved boundaries and an anode located adjacent said target electrode to collect secondary emission therefrom when said element, deflecting electrodes, target and anode are energized, means for applying phase displaced modulated waves to said deflecting electrodes, and a load circuit connected with said target.

15. A system as recited in claim 14 wherein said load circuit comprises a non-reactive impedance.

16. A system as recited in claim 14 wherein said load circuit comprises a reactance.

17. A system as recited in claim 14 wherein said load comprises a reactance tuned to a harmonic of the mean frequency of said waves.

18. In a phase modulation system, a discharge device having an electron emitting electrode, a target electrode in the form of a substantially planar conducting surface spiralling from and substantially normal to the normal path of emission from said emitting electrode, and pairs of deflecting electrodes adjacent a path between said emitting electrode and said target electrode, means for producing potentials characteristic of signal waves, means for amplitude modulating carrier wave oscillations in accordance wtih said produced potentials means for applying the modulated oscillations in phase displaced relation to said deflecting electrodes and a utilization circuit operatively associated with said target electrode.

19. A system as recited in claim 10 wherein the angular displacement of said pairs of deflecting electrodes adjacent the path between said emitting electrode and said target electrode

is substantially 90° as is the phase displacement of said modulated wave.

20. A system as recited in claim 18 wherein the angular displacement of said pairs of deflecting electrodes adjacent the path between said emitting electrode and said target electrode is substantially 90° as is the phase displacement of said modulated oscillations.

21. In a frequency modulation system, a discharge device having an electron emitting electrode, a target electrode comprising a pair of conducting members having complementary curved boundaries, and pairs of deflecting electrodes adjacent the path between said emitting electrode and said target electrode, means for producing potentials which vary in accordance with the frequency of modulating waves, means for amplitude modulating carrier wave oscillations in accordance with said produced potentials and means for applying the modulated oscillations in phase displaced relation to said deflecting electrodes.

22. In a multiplexing system, an electron discharge device including an electron ray emitting electrode, a target electrode comprising a pair of conducting members having complementary curved boundaries, deflecting electrodes adjacent the path between said emitting electrode and said target electrode and a control electrode between said deflecting electrodes and said emitting electrodes, circuits for applying phase displaced oscillations modulated in amplitude by a first signal to said deflecting plates, circuits for applying other signal potentials between said control electrode and emitting electrode, and an output circuit connected with said target electrode.

23. A system as recited in claim 22 wherein said target electrode comprises a plurality of pairs of members alternate ones of which are connected together and connected to said output circuit.

24. A system as recited in claim 22 wherein said output circuit is tuned to a harmonic of the frequency of the displaced potentials applied to said deflecting electrodes.

25. In a two-channel modulation system an electron discharge device including, an electron emission element, an emission control element, pairs of deflecting plates and a target electrode in the path of said emission from said element said target electrode comprising electrodes having complementary curved boundaries, means for applying phase displaced modulated waves to said deflecting plates, means for applying modulating potentials to said electrode which controls the electron emission and an output circuit connected with said target electrode.

26. In a signalling system, an electron discharge device having an electron emitting electrode, a control electrode, an electron collecting electrode, a pair of deflecting electrodes interposed between said electron emitting electrode and said collecting electrode, a pair of target electrodes interposed between said deflecting electrodes and said collecting electrode, circuits for applying modulated wave energy to said deflecting electrodes, and signal potentials to said control electrode, a utilization circuit coupled to said target electrodes and a connection between said collecting electrode and another electrode in said device.

27. The method of modulating the phase of alternating potentials in accordance with signalling potentials by means of an electron discharge system comprising an electron stream producing element which includes the steps of, producing amplitude modulated wave energies of like frequency and unlike phase, setting up deflecting forces characteristic of said energies adjacent said stream to control the angular and radial position of said stream relative to its normal path in accordance with the modulations on said waves of like frequency and unlike phase, producing currents characteristic of said electron stream and changing the flow of said currents as a function of the radial distance of said stream from its normal path and the phase displacement of said stream from a selected datum line through the normal path of said stream.

28. The method of phase modulating alternating currents in accordance with signalling potentials by means of an electron pencil or ray producing means and a target comprising electrodes located in a surface normal to the path of said stream which includes the steps of producing wave energies modulated in accordance with signalling potentials of like frequency and displaced phase, producing forces adjacent the path of said ray to control the movement of said ray relative to its normal path in accordance with the modulating potentials on said wave energies, producing currents characteristic of the intensity of said electron ray, reversing the flow of said currents and controlling the phase of reversal of said currents as a function of the distance said ray has been displaced from its normal path and of the angular displacement of said ray from a selected datum line through the normal path of said ray.

29. In a phase or frequency modulation system, an electron discharge device having an electron emitting electrode, a target electrode comprising a plurality of conductive surfaces spiralling outwardly substantially in a plane substantially normal to the path between said electron emitting electrode and said target electrode, and pairs of deflecting elements adjacent the path between said electron emitting electrode and said target electrode, means cooperating with the electrodes of said tube and said deflecting elements for angularly rotating and radially displacing the path of emission from said electron emitting electrode as a function of phase displaced wave voltages and modulating potentials to thereby control the path of said emission on said target electrode, and an output circuit coupled between the conductive surfaces of said target electrode and said electron emitting electrode.

30. In a phase modulation system, an electron discharge device having an electron emission element, and a target electrode comprising a plurality of conducting surfaces having adjacent correspondingly curved boundaries spiralling outwardly substantially in a plane from a point in said plane on which the electron ray emitted from said emission element normally falls, means responsive to amplitude modulated wave energy for causing said ray to follow a rotary path on said target whose dimensions are proportional to the amplitude of the modulated wave, whereby the time phase of the point at which the ray crosses the boundaries of the conducting surfaces of said target varies with changes in the amplitude of the modulated wave, and a circuit connected with said conducting surfaces to utilize the constant amplitude variable phase current pulses flowing through said target.

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