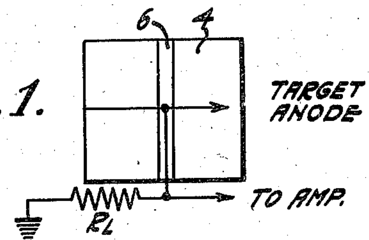
June 22, 1948. C. N. KIMBALL 2,443,958

MODULATION

Filed Sept. 23, 1944 2 Sheets-Sheet 1

Fig. 1.



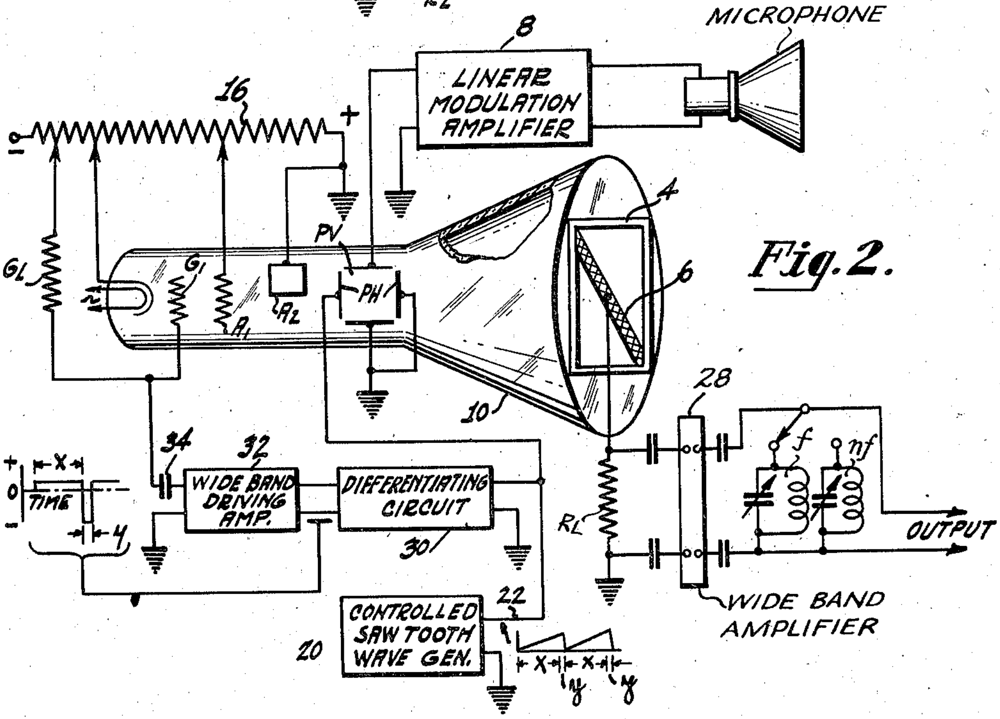


Fig. 2.

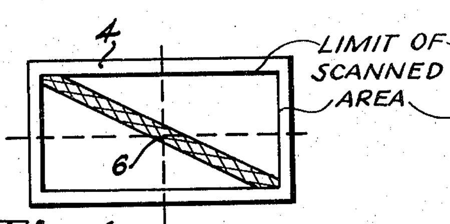


Fig. 4.

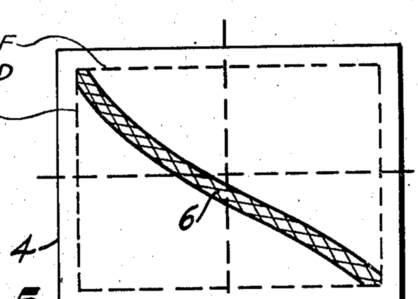


Fig. 5.

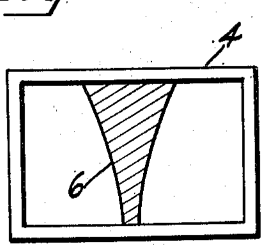


Fig. 6.

INVENTOR.
CHARLES N. KIMBALL
BY H. S. Grover
ATTORNEY.

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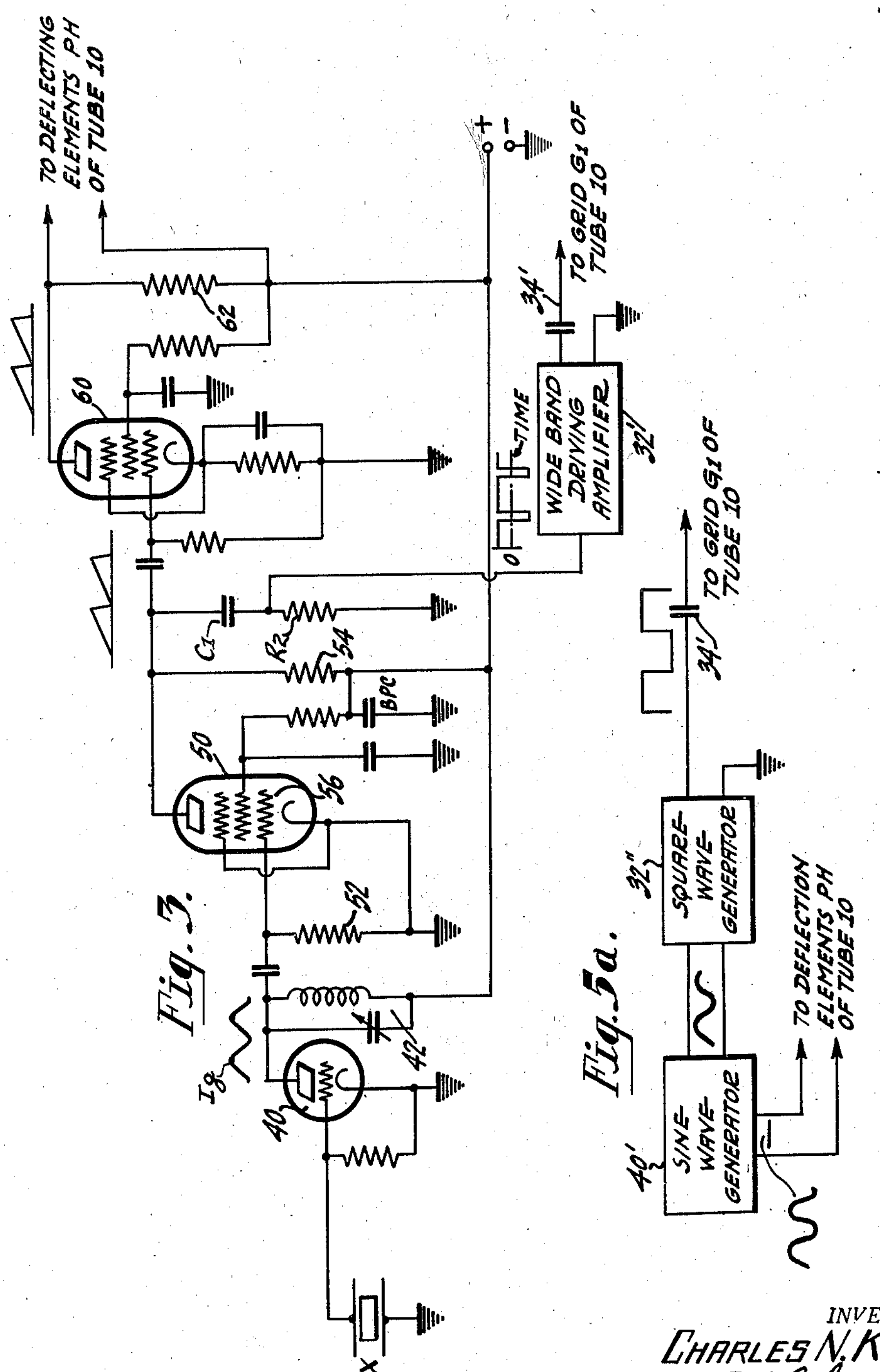

INVENTOR.
CHARLES N. KIMBALL
BY H. S. Grover

ATTORNEY

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2,443,958

MODULATION

Charles N. Kimball, Kansas City, Mo., assignor to Radio Corporation of America, a corporation of Delaware

Application September 23, 1944, Serial No. 555,465

6 Claims. (Cl. 179—171.5)

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This application pertains to angle modulation of carrier wave energy in accordance with signals. In an embodiment amplitude modulation is accomplished.

In this specification the term phase modulation is used throughout the description. It will be understood that the modulation may be more generally designated as angle modulation since the same may have characteristics of what is termed in the art phase modulation or frequency modulation or characteristics of phase and frequency modulation.

The particular nature of the angle modulation will depend on the treatment of the modulating signal before it is used for angle displacement of the wave energy in accordance with my invention. In any event, in my improved system the angular displacement of the wave energy is linear with respect to the amplitude of the modulation.

An object of my invention is to increase the amount of angular or phase deviation of carrier wave energy in accordance with modulation currents.

Another object of my invention is to produce increased angular or phase deviation of carrier wave energy, which deviation is linear with respect to the amplitude of the modulation currents.

My improved method and means produces a phase modulated signal, in which the phase deviation can be made to vary linearly with the amplitude of the modulating voltage over approximately 360° at the carrier source frequency. In other systems known heretofore, not employing this principle, the amount of phase deviation is generally limited to angles for which the tangent and the angle are substantially equal in radians. If a harmonic of the output is taken the phase deviation is multiplied an amount equal to the harmonic number.

The principle involved is also applicable to amplitude modulation and in an embodiment of my improved system amplitude modulation is accomplished. A further object of my invention is an improved amplitude modulation system wherein the carrier is modulated linearly in accordance with control or modulation currents or potentials.

In describing my invention in detail, reference will be made to the attached drawings wherein Figs. 1, 2, 4, 5 and 6, illustrate targets of an electron beam tube used in my improved modulation system. These figures are used in explaining the principle of operation of my invention;

Fig. 2 also illustrates by circuit and block diagram the essential features of an arrangement for carrying out my invention;

Fig. 3 illustrates a preferred arrangement for generating a wave of saw-tooth form and applying the same to the deflecting elements of the tube. This figure also illustrates preferred means for generating a blanking voltage or potential and applying the same to the control grid of the electron ray tube.

The target illustrated in Fig. 6 is used when amplitude modulation is accomplished; while

Fig. 5*a* illustrates by block diagram the means for producing and applying the control voltages to the electron beam tube when a target as shown in Fig. 5 is used.

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To illustrate the principle involved consider an electron device similar to the "monoscope" or also to the "iconoscope," in which the usual mosaic surface of the target electrode is replaced by a plate of insulating material illustrated schematically at 4, Figs. 1, 2, 4, 5 and 6, to which is fastened a conductive member such as a metallic bar 6 lying in the plane of the surface of the target or insulating plate and connected to an external load resistance RL (Fig. 2). Either static or magnetic reflection (preferably static by plates PH) is used to deflect the electron beam horizontally at the carrier frequency rate, say 100 kc. This is accomplished by generating and applying to the horizontal deflecting elements HP a saw-tooth wave entrained or keyed in with the unmodulated carrier frequency of said 100 kc. The vertical deflection of the electron beam is obtained electrostatically (electro-magnetic deflection may be used) by applying modulating voltages through a linear amplifier 8 to the vertical plates VP.

Assume first that the bar 6 is placed in a vertical plane, i. e., as illustrated in Fig. 1. Each time the beam sweeps horizontally across the contact bar 6 a pulse of current is generated and appears through the load resistance RL. If the return sweep (scan) is blanked out at the carrier frequency rate, the pulse repetition rate is equal to the carrier sweep frequency, i. e., the repetition rate is in the example given 100 kc. per second. If the conducting member 6 is perfectly vertical the application of modulating potentials to the vertical plates PV will produce no effect on the output signal which will be pulses of a repetition rate of 100 kilocycles per second.

However, if the conducting member or bar 6 is inclined at an angle to the vertical, as shown in Fig. 2, while still lying in the plane of the insulating plate 4, the time elapsed between the start of a horizontal sweep and the point of time where the beam hits the bar 6 will be a function of the vertical displacement of the bar, and/or of the instantaneous value of the modulating voltage from amplifier 8 which controls the vertical deflection. Thus, in the ideal case, with zero return time in the horizontal saw-tooth sweep frequency wave characteristic and with blanking applied to the electron gun's grid G1 to prevent the generation of a spurious pulse during the flyback interval, i. e., the blanking time, a possible change in pulse phase of ±180° at the applied carrier frequency exists. With a longer return time of the horizontal sweep frequency, say 10°, this range is reduced proportionally.

The wave shape of the output pulse appearing across RL will be essentially square neglecting the finite rise time due to output circuit capacitance limitations and to the aperture effect due to the finite spot size in the cathode ray tube 10. Hence the output wave will contain harmonics of the applied source carrier frequency such that they may be picked off and employed to increase the phase deviation. That is, if $\pm\phi$ degrees are obtained at the carrier source frequency, $\pm n\phi$ degree shift will be available, if say a parallel tuned circuit tuned to the nth harmonic of the pulse is coupled to RL and the nth harmonic picked off in a resonant fashion to be used as the output voltage of the beam tube 10. The output appearing across RL may be coupled into a resonant circuit tuned to the fundamental frequency f, or into a resonant circuit tuned to a harmonic nf, or a resonant circuit tunable to the fundamental or a harmonic, directly or through a wide band amplifier 30.

A means for producing and applying a saw-tooth wave of the desired carrier frequency and applying the same to the beam deflectors PH of the tube 10 as the sweep frequency and the means for producing and applying the control energy for blanking on the return sweep is shown in Fig. 2.

The tube 10 has a cathode, a stream intensity control grid G1, a focusing anode A1, and a second anode A2 which is connected to the positive end of a potentiometer resistance 16, usually grounded at the positive end. The cathode is tapped up from the negative end of potentiometer 16 with respect to the point at which the control grid G1 is tapped, so that G1 operates at the desired negative bias.

There is a target anode comprising an insulating plate 4 and a conducting member 6. The conducting member 6 is connected with an output load resistance RL across which the phase shifted pulses and harmonics thereof appear.

The cathode ray tube 10 also has a pair of horizontal deflecting plates PH connected with the output of an arrangement in unit 20 for generating waves of saw-toothed form and of a periodicity equal to the frequency of a control source in 20 by means of which the saw-toothed wave is synchronized. Saw-toothed wave generators are known in the art and may take various forms. Several preferred generators are described hereinafter. The unit 20 has an output of a wave form as illustrated along lead 22.

Although the return sweep time is only about 14% of the saw-tooth wave cycle, the tube 10 stream should be stopped during the return time. In other words, the system should be blanked during the return sweep in order to prevent distortion from occurring in the output, particularly at the reversals in direction of flow of the current producing the saw-tooth wave. In accordance with my invention a pulse for blanking the system is developed by differentiating the saw-tooth wave applied as the horizontal sweep control. I have shown at 30 a unit representing a differentiating circuit by means of which the first derivative of the saw-tooth wave form may be obtained. This differentiating network may take various forms, some of which will be described in detail hereinafter. It includes means, however, for deriving a wave form as illustrated at the leads between the rectangle 30 and the wide band driving amplifier 32. Note that the output of this differentiating network has a wave form in which the voltage is constant during the time the saw-tooth wave form is rising at a constant rate, and then drops suddenly in value as the saw-tooth wave falls off rapidly at a constant rate to its original point. The cycle is then repeated. The peaks in the wave at the output of the differentiating circuit occur during the return sweep of the tube beam, and this wave is supplied to a wide band driving amplifier in 32, and impressed from 32 by a coupling condenser 34 on the grid G1.

During operation the cathode ray tube electrodes are biased as shown by connections to a potentiometer 16. The grid G1 is adjustably connected through a grid leak resistance GL to a movable point on 16, and this grid runs negative with respect to the cathode by an adjustable amount such as to provide during the sweep period an electron beam from the cathode through the fields of the various electrodes and to the target 6 by way of the horizontal and vertical deflecting elements. A potential is developed in GL by the grid current and when the sweep frequency voltage has finished rising during the sweep portion of the cycle, to fall suddenly on the return sweep, an amplified potential which is negative is impressed from 32 through the coupling condenser 34 on to the grid G1 to bias the same negative with respect to the cathode by a biasing value such that the electron stream in tube 10 is cut off. The condenser 34 may be considered a short circuit for the high frequency output of the wide band amplifier 32 so that when the amplifier side of the condenser 34 becomes highly negative the other side does also, and this negative potential biases the grid G1 to cut-off.

The differentiating circuit in 30 is a means for deriving the first derivative of the saw-tooth wave. In its simplest form this may be a condenser and a small resistance in series with voltage of the saw-tooth wave form applied across the combination. The current through this resistance then will be the first derivative of the voltage across the combination and therefore the differential of the saw-tooth wave form, the voltage of which is applied across the combination. The condenser C1 and resistance R1 of Fig. 3 serves this purpose as will appear in detail hereinafter. When this simplified differentiating means is used in 30 the amplifier 32 comprises two stages, so that at its output the peaks are in the same direction as at its input, i. e., in a negative direction. Of course a single cathode driven stage wherein the input wave and output wave are in phase may be used at 32.

A preferred means for producing the saw-tooth wave form voltage for the horizontal deflecting plates PH and the blanking control potential for grid G1 is shown in Fig. 3. This means comprises a conventional crystal oscillator including tube 40 having a tuned tank circuit 42 and a crystal element X so arranged and operated that oscillations of sine wave form and fixed frequency are developed in the tank circuit 42. As an example, the generated oscillations could be of 100,000 cycles and have an amplitude of 200 volts alternating current. The oscillations are impressed on a pentode tube 50 having its control grid self-biased highly negative by a biasing resistance 52. The anode potential supplied through resistance 54 and the bias on the control grid, etc., of this tube 50 is such that it is biased to cutoff, except for small portions of the peaks of the alternating voltage impressed on the grid 56.

On application of the sine wave voltage generated in 40 to the grid 56, the grid leak 52 develops a bias nearly equal to the peak signal applied to the grid and peaks of this sine wave voltage barely reach grid current through the tube. This is shown schematically by the graph above the circuit 42. The plate current as a consequence flows a small part of the time at the peaks of the applied sine wave. The tube 2 therefore may be considered to operate as a class C amplifier with a capacitive plate load.

A condenser C1 is connected between the anode and cathode of the tube 50, thereby being effectively connected in shunt to the output impedance of tube 50 (due to condenser BPC) and in shunt to resistance 54. When the tube 50 is cut off the condenser C1 is charged through resistance 54 by current and voltage from the source connected to the anodes of the tubes.

The voltage on the condenser C1 starts rising and rises at a constant rate until the voltage of sine wave form on the grid 56 reaches the point at which cutoff bias is overcome. The plate circuit of the tube 50 now draws current to discharge the condenser of C1 rapidly. Thus across the condenser C1 is produced a voltage of saw-tooth wave form.

The stage including tube 60 is a resistance coupled class A pentode amplifier, feeding the amplified wave of saw-tooth form to the horizontal deflecting elements PH of the tube 10. The amplifier stage tube 60 is believed to be well known in the art and will not be described in detail herein. The purpose of this tube is to provide at its output across the resistance 62 amplified voltage of a wave form corresponding to the voltage applied at the input of this tube.

The differentiating network for supplying the blanking control potential comprises the condenser C1 and a resistance R2 in series therewith. This resistance R2 is small relative to the impedance of the condenser C1. As stated above, the current through the circuit including R2 is the first derivative of the voltage across the condenser C1 and consequently, the differential of the saw-tooth wave form voltage across C1. Therefore I derive from R2 a voltage which is of constant intensity during the time the condenser C1 is charging and the saw-tooth wave is rising at a constant rate and this voltage then drops abruptly to a negative value while the condenser C1 is discharging at a constant but faster rate, and the saw-tooth wave is on the blanking part of the cycle. The potential across R2 is supplied to a wide band driving amplifier 32′, and thence by a coupling condenser 34′ to the grid of the tube 10.

Of course, saw-tooth wave generators of other types such as, for example, shown in Hoover U. S. Patent #1,978,461, filed November 25, 1933, and issued October 30, 1934, may be used. When this patent is used the arrangement of Fig. 1 of the patent is then included with the carrier frequency control source in the rectangle 20. The carrier frequency source may then comprise a crystal controlled generator such as, for example, the generator 40 of Fig. 3 of this application, the generator tube 40 anode is then coupled to the condenser 51 of the said Hoover patent.

A differentiating circuit C1, R2, as described in connection with Figs. 2 and 3 may then be connected to the high potential one of the two leads marked "0" of the Hoover et al. Fig. 1. Alternatively, the voltage represented in Fig. 4 of the Hoover patent appearing at the grid of tubes 15 and 16 may be picked off at an appropriate point in the circuit of Fig. 1 of Hoover et al., and fed to a wide band driving amplifier and thence applied by the coupling condenser 34 to the grid G1. Note that in this embodiment the voltage as illustrated in Fig. 4 has positive peaks which occur at the return sweep part of the cycle, and the wide band amplifier then includes an odd number of stages in order to reverse the wave form of this voltage to apply the peaks in a negative direction to bias the grid G1 to cutoff during the blanking period.

Maximum utilization of the effectiveness of the system is attained by making the inclined bar or target electrode 6 span both the maximum horizontal and vertical dimensions covered by the beam in its sweep across the target as indicated in Figs. 4 to 6. In Fig. 2 it will be noted that the bar 6 is assumed to be so arranged. The bar width may be 10 to 20% of the distance covered by the horizontal sweep.

The linearity of the system depends only upon obtaining a saw-tooth wave of linear horizontal form and a linear bar as the target 6. The linearity of the system is independent of vertical and horizontal centering of the beam as long as the sweeps do not extend beyond the extremity of the target 6.

The device may be made to operate directly off a sinusoidal carrier sweep by properly shaping the metallic bar 6, plus the use of blanking, as described above, to eliminate the horizontal return sweep generated signal. The target 6 is then as illustrated in Fig. 5, having a shape like a section of a sine wave. In this embodiment then, the control frequency of sine wave form included in the unit 20 of Fig. 2, or the amplified output of the crystal generator 40 of Fig. 3, or the control source to be used with the saw-tooth wave generator of the above identified Hoover patent, may be fed directly to the horizontal deflecting elements PH, and then the blanking control voltage is derived by other means, such as, for example, any of the numerous circuits known as square wave generators which derive a square wave from a sine wave by means of clipping, limiting, etc. (all of which are known in the art). The resultant square wave, in proper polarity, is applied to the grid G1. For example, as illustrated in Fig. 5*a*, a sine wave source 40′ such as, for example, the crystal generator 40 of Fig. 3, feeds output directly to plates PH and to a unit 32″. The unit 32″ may include one or more tube stages operating as amplifiers and clippers to produce an output, as shown at the lead going to G′, of square wave form, and of a polarity such as to bias tube 10 to cutoff on the return sweeps. Centering of the sine wave section-like target relative to the position of the beam spot thereon, at rest position, should be accurate.

The invention may be used independently as a generator of amplitude modulation by using a vertical wedge shaped bar as the target 6. The target would then be as illustrated in Fig. 6. Now it will be noted, as the beam is swept back and forth across the target the peak amplitude of the current developed through RL will depend upon the magnitude of the beam. This will be considered to be constant. However, when modulation is applied, the width of the pulse changes as the vertical deflecting elements VP are energized, and it may be shown by Fourier analysis, or actual measurement, that while the peak amplitude of the pulse remains constant, the relative amplitudes of the various constituent harmonics change with variations in pulse width. The pulse width will vary with vertical deflection in accordance with the modulating wave form.

When amplitude modulation is to be carried out the arrangement may be as illustrated in Fig. 2, except that now the target **6** is as illustrated in Fig. 6. The sweep voltage may be generated and applied as described in connection with Figs. 2 and 3. The same remarks apply to the blanking potential.

I have shown the deflecting means as comprising plates PV and PH. It will be understood that electro-magnetic deflecting means in the form of windings excited by the sweep and modulation voltages may be used if desired.

I claim:

1. In a timing modulating system, an electron beam tube having electrodes including an electron beam source, a control grid, horizontal and vertical deflecting elements, and a target, having a shape like a section of a sine wave, positioned in the beam axis with its surface in a plane substantially at right angles to the beam axis and angularly related to the effective field of a deflecting element, a generator for producing a voltage of sine wave form and of carrier wave frequency and applying the same to deflecting elements to deflect the beam across the target, a wave forming circuit excited by voltages derived from said generator for applying a potential to said grid such as to cut off the beam during the time at which the return excursions of the beam would take place except for said cutoff potential, connections for applying modulating potentials to another deflecting element, an output impedance coupled to said target and a circuit, parallel resonant at a frequency integrally related to said carrier wave frequency, coupled to said output impedance.

2. In a modulation system, a cathode ray tube having electrodes including an electron beam source, a control grid, horizontal and vertical deflecting elements, and a target including an elongated conducting member in the path of the beam and substantially at right angles thereto, said elongated member being angularly related to the main or effective field of the deflecting elements and having a shape like a section of a sine wave, a sine wave generator for producing a voltage of carrier wave frequency and applying the same to one deflecting element, means for applying a potential to said grid to cut off the beam during alternate half cycles of the carrier wave, means for applying controlling potentials to the other deflecting element, an impedance coupled to said conducting member and a circuit, parallel resonant at a frequency integrally related to said carrier frequency, coupled to said impedance.

3. In a timing modulation system, an electron beam tube having electrodes including an electron beam source, a control grid, horizontal and vertical deflecting elements, and a target including a conducting member in the path of the beam and angularly related to the main or effective fields of the deflecting elements, said conducting member having a contour like a sine wave, means for producing a voltage of carrier wave frequency and applying the same to one deflecting element, means for applying a potential to said grid to cut off the beam on one excursion of the carrier wave, means for applying controlling potentials to the other deflecting element, an impedance coupled to said conducting member and a circuit, parallel resonant at a frequency integrally related to said carrier frequency, coupled to said impedance.

4. In a timing modulation system, an electron beam tube having electrodes including an electron beam source, a control grid, horizontal and vertical deflecting elements and a target including a conducting member in the path of the beam and angularly related to the main or effective fields of the deflecting elements, a generator for producing a voltage of carrier wave frequency and sine wave form and means for applying the same to one deflecting element, apparatus for producing negative potentials of a time duration about equal to one half of a cycle of said sine wave and applying the same to said control grid to cut off the beam on half cycles of the carrier wave excursions, means for applying controlling potentials to the other deflecting element, an impedance coupled to said conducting member and a circuit, parallel resonant at a frequency integrally related to said carrier frequency, coupled to said impedance.

5. In a modulation system, a cathode ray tube having electrodes including an electron beam source, a control grid, horizontal and vertical deflecting elements, and a target including an elongated conducting member in the path of the beam and substantially at right angles thereto, said elongated member being angularly related to the main or effective field of the deflecting elements and having a shape like a section of a sine wave, a sine wave generator for producing a voltage of carrier wave frequency and means for applying the same to one deflecting element, means for applying a potential to said grid to cut off the beam during alternate half cycles of the carrier wave, means for applying controlling potentials to the other deflecting element, and an impedance coupled to said conducting member.

6. In a timing modulation system, an electron beam tube having electrodes including an electron beam source, a control grid, horizontal and vertical deflecting elements, and a target including a conducting member in the path of the beam and angularly related to the main or effective fields of the deflecting elements, said conducting member having a contour like a sine wave, means for producing a voltage of carrier wave frequency and applying the same to one deflecting element, means for applying a potential to said grid to cut off the beam on one excursion of the carrier wave, means for applying controlling potentials to the other deflecting element, and an impedance coupled to said conducting member.

CHARLES N. KIMBALL.

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