Nov. 28, 1944. S. DOBA, JR 2,363,659

ELECTRIC CIRCUIT

Filed Jan. 31, 1942 2 Sheets-Sheet 1

FIG. 1

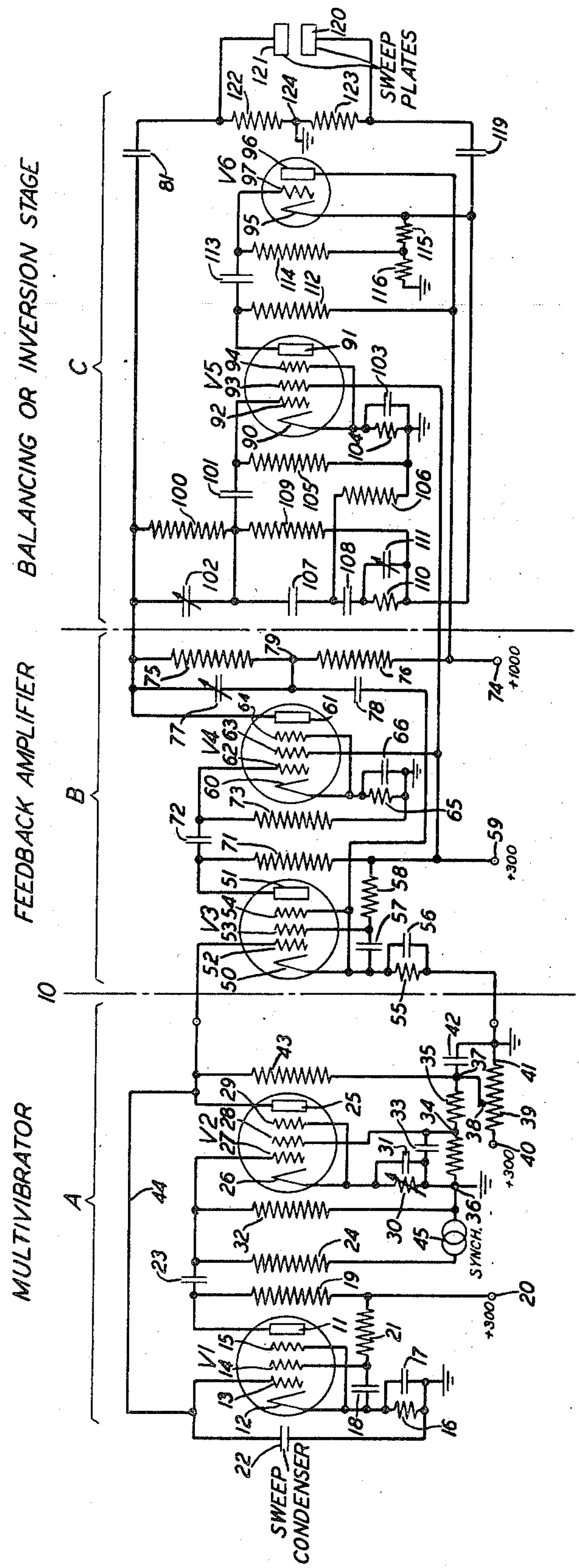
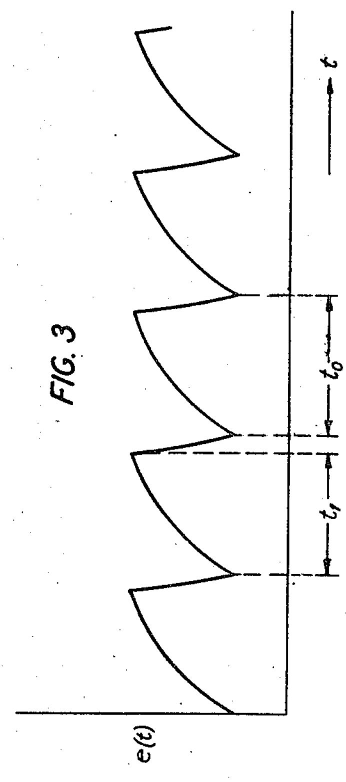


FIG. 3



INVENTOR
S. DOBA, JR.
BY
O. A. Sprague
ATTORNEY

Nov. 28, 1944. S. DOBA, JR 2,363,659

ELECTRIC CIRCUIT

Filed Jan. 31, 1942 2 Sheets-Sheet 2

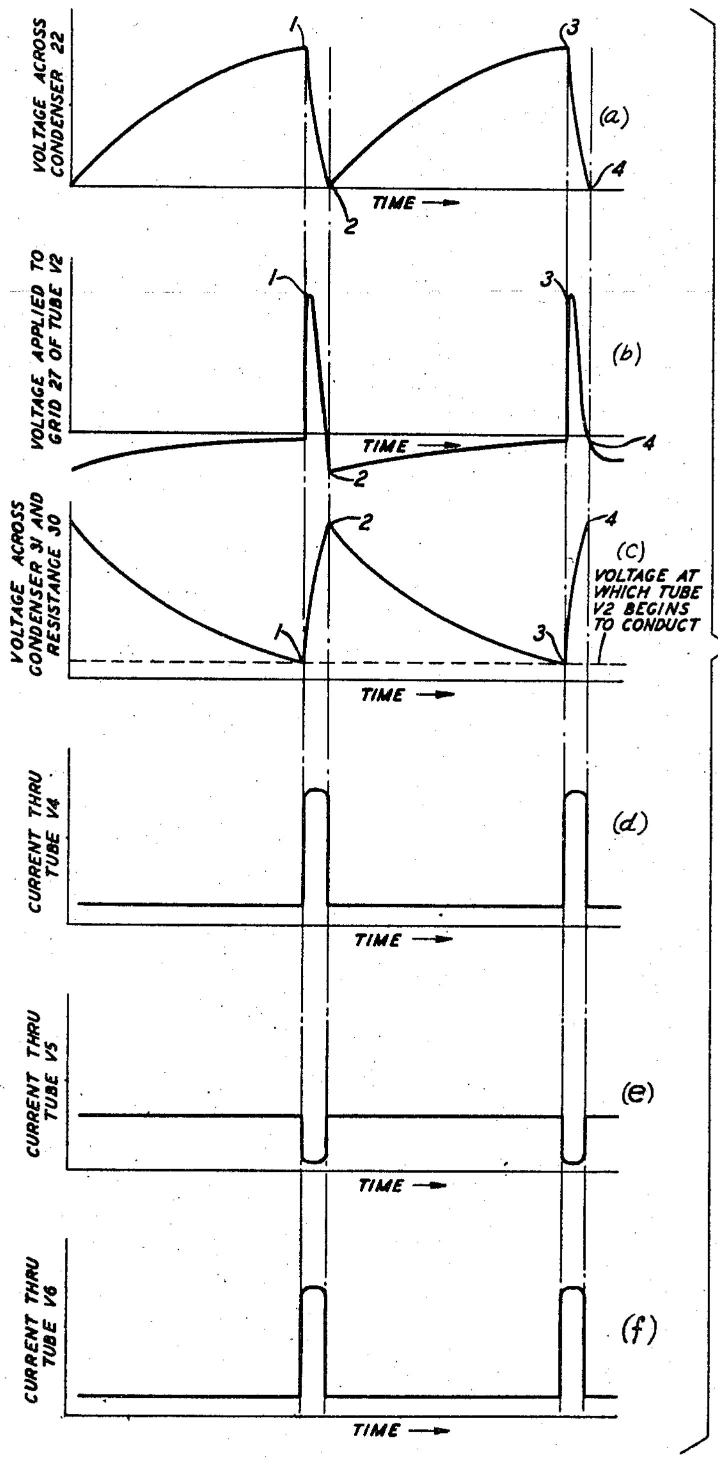


FIG. 2

INVENTOR
S. DOBA, JR.
BY O. E. Sprague
ATTORNEY

Patented Nov. 28, 1944 2,363,659

UNITED STATES PATENT OFFICE

2,363,659

ELECTRIC CIRCUIT

Stephen Doba, Jr., Long Island City, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application January 31, 1942, Serial No. 429,067

17 Claims. (Cl. 315—15)

This application relates to electric circuits and more particularly to circuits for deflecting a beam in a cathode ray tube.

It is an object of this invention to provide a novel circuit suitable for producing deflection of the beam in a cathode ray tube or for similar use.

Another object is to provide a novel form of generator of recurrent waves of saw-tooth wave form.

In a sweep circuit suitable for use with high quality cathode ray tubes, particularly of the type used as television receivers, it is desired that the sweep voltage be linear with time and have small distortion, that the sweep have a small return time and that a relatively high output voltage which is balanced with respect to ground be obtained. It is also desirable that only high vacuum tubes be used. The sweep circuit of this invention, the novel features of which will be pointed out below, meets these specifications.

In many known sweep circuits, so-called constant current devices are used to enable the charging or discharging of the sweep condenser to be substantially linear with respect to time. Even with such devices the characteristic curve of current versus time is not exactly linear and it is frequently difficult to adjust the devices properly. In accordance with the present invention in an important aspect this disadvantage is overcome by doing away with a constant current device and employing instead a non-linear saw-toothed wave generated by a self-oscillating "multivibrator" arrangement in which correctness in wave form is purposely made subordinate to simplicity and cost of the apparatus and compensation for the non-linearity of the wave is subsequently made, preferably in an amplifier stage through which the wave is passed, to produce a saw-toothed wave the slowly changing portion of which varies linearly with time. It has been found that compensation may be effected by properly choosing the time constant of a capacity-resistance combination in the feedback of a feedback amplifier.

A feature of this aspect of the invention is the amplifier, which has a special form of feedback circuit. This amplifier not only passes a wide band of frequencies in proper amplitude relations to avoid the rounding off of the corners of the saw-toothed wave which occurs when the very high frequency components of the wave are reduced or suppressed, but it does this in a manner to introduce the desired compensation for the rather wide departure from linearity in the wave generated by the multivibrator.

In order to produce a balanced output to be applied to the deflecting plates of the cathode ray tube (so that distortions of the television image and of the shape of the field caused by the use of unbalanced sweep voltages are prevented) an inverting stage comprising a single high-vacuum tube has been used in the prior art, the input circuit of the inverting tube being connected to one plate of a pair of sweep plates and the output circuit of this inverting tube being connected to the other of the pair of plates. With a gain equal to unity and a 180-degree phase shift in the inverting tube, the saw-toothed voltage wave applied to one plate of the pair is equal to and 180 degrees out of phase with the voltage wave applied to the other plate of the pair. This arrangement has been found to have the disadvantage, however, that power dissipation is high. Although the plate current in the last tube of the amplifier is low except during the flyback time, when it is high, just the reverse of this is true in the inverter tube because of the phase reversal; that is, the plate current is high during most of the time and low during the flyback interval (which is of the order of a few per cent of the total sweep interval). This plate current in the inverter tube, being high most of the time, causes a high power dissipation. An additional feature of the sweep generating means of this invention is an arrangement, hereinafter described in greater detail, in which this disadvantage is overcome by adding a second tube in the phase inverting stage, the cathode of this second tube being connected to one of the pair of deflecting plates and the output circuit of the amplifying stage being connected to the other of the pair. This added tube has a low current during the sweep time, thus not dissipating much power. While the first tube in the inverting stage draws a relatively high current during the sweep time, this current is much lower than that which would be present if the first tube in the phase inverting stage were connected directly to one of the deflector plates (the second tube being, of course, omitted) due to the fact that the parasitic capacities existing across the anode circuit of the first tube of the inverting stage are much lower than those existing across the deflector plate circuit. Thus the total power consumption in the output tubes is reduced.

In accordance with a preferred embodiment of the invention, chosen by way of example to illustrate the features of novelty thereof, there is provided a sweep circuit comprising six electron discharge devices which may be considered for convenience in description as being divided into three stages of two tubes each, the first stage comprising a self-oscillating multivibrator generating a saw-toothed wave of low amplitude having a slowly changing portion which varies nonlinearly with time, the second stage comprising a two-tube feedback amplifier, and the third stage consisting of two tubes which together constitute an inverting stage. The amplifier stage consists of a two-stage feedback amplifier with a voltage amplification of approximately twenty. Due to the particular feedback arrangement used, the amplifier stage compensates for the non-linearity of the sweep voltage waves generated by the multivibrator. At the same time the flat transmission of the feedback amplifier allows a wide band of frequencies to be amplified. The phase inverting stage consists of one tube the input of which is connected to the output of the feedback amplifier stage, and a second tube the input of which is connected to the output of the first tube. A connection to one sweep plate of a pair is made from the output of the feedback amplifier while a connection to the other sweep plate of the pair is made from the cathode of the second tube in the inverting stage. Thus only one phase reversal is obtained by the two tubes in the phase inverting stage. Amplification without distortion can be obtained by this arrangement and at the same time the power dissipation is low.

The invention will be more readily understood by referring to the following description of an illustrative arrangement taken in connection with the accompanying drawings forming a part thereof in which:

Fig. 1 is a diagrammatic showing of a sweep circuit embodying the principles of this invention; and

Figs. 2 and 3 are graphical representations to aid in explaining the invention.

Referring more particularly to the drawings, Fig. 1 shows a sweep circuit 10 suitable for use with a cathode ray tube, particularly for a tube used as a television receiver. The circuit 10 comprises six high vacuum tubes designated V_1, V_2, V_3, V_4, V_5 and V_6 with appropriate circuit elements and connections therefor.

Tubes V_1 and V_2 together constitute a multivibrator, that is, an arrangement wherein the control grid of each tube is connected in circuit with the anode of the other, the two tubes cooperating to produce oscillations. The tube V_1 preferably comprises an anode 11, a cathode 12, a control grid 13, a screen grid 14, and a suppressor grid 15. A resistance 16 and a condenser 17 connected thereacross are provided in the circuit between the control grid 13 and the cathode 12 and in the circuit between the cathode 12 and the anode 11 to provide, as will be explained below, grid voltage between the cathode 12 and the control grid 13. A by-pass condenser 18 is connected between the cathode 12 and the screen grid 14. Appropriate potential for the screen grid is obtained by means of the resistor 21 which is connected to the positive terminal 20 of a source of B supply, the terminal 20 having a positive potential of, for example 300 volts with respect to ground. The suppressor grid 15 is connected to the cathode 12 and appropriate potential is obtained for the anode 11 by means of the resistor 19 which is connected to the point of positive potential 20. The sweep condenser 22 is connected between ground and the control grid 13.

The anode 11 of the tube V_1 is connected by means of a coupling condenser 23 to the control grid 27 of the tube V_2. The coupling circuit comprising the resistors 19 and 32 and the condenser 23 attenuates the low frequencies in the wave applied to the control grid of the tube V_2. The tube V_2 preferably comprises an anode 25, a cathode 26, the control grid 27, a screen grid 28, and a suppressor grid 29. The suppressor grid 29 is connected directly to the cathode 26. A resistor 30 and a condenser 31 shunted thereacross are connected in a circuit between the cathode 26 and the anode 25 and also in a circuit between the cathode 26 and the control grid 27 to provide grid voltage between the latter two elements. A by-pass condenser 33 is connected between ground and the screen grid 28. Potential for the screen grid 28 is obtained by means of a connection to an inner terminal 34 of a potentiometer 35, the terminal 36 of which is connected to ground and the terminal 37 of which is connected to an inner terminal 38 of a potentiometer resistor 39, one terminal 40 of which is connected to a source of direct current having a positive potential of, for example, 300 volts, and the other terminal 41 of which is connected to ground. The terminal 37 of potentiometer resistor 35 is connected to ground through the by-pass condenser 42. Potential for the anode 25 is obtained by connecting one end of the anode resistor 43 to the terminal 37, the other end of the resistor being connected to the anode. The anode 25 of the tube V_2 is also connected by the feedback connection 44 to the control grid 13 of the tube V_1. A source 45 of synchronizing signals may, if desired, be connected between ground and one terminal of a resistor 24, the other terminal of which is connected to the control grid 27 to control the frequency of the charging and discharging of the sweep condenser 22.

The operation of the multivibrator comprising the tubes V_1 and V_2 over a cycle is as follows: Assume that the condenser 22 is charged to a maximum value (point 1 of Fig. 2a). The charging circuit may be traced from the positive terminal 38 of the source of B potential (represented by potentiometer 39) through the anode resistor 43, connection 44, the sweep condenser 22, and ground to the terminal 41 of the source of B potential. During the charging period, the tube V_2 has been inoperative as the potential drop across the resistor 30 (due to the charge on the condenser 31 which has been previously charged during the last discharge of the sweep condenser 22) supplies a negative grid voltage between the control grid 27 and the cathode 26 which blocks the tube V_2. This negative grid voltage has been decreasing during the charging period of the sweep condenser 22 due to the discharge of the condenser 31 through the resistance 30 and when the sweep condenser 22 is charged to its maximum value, this negative grid voltage has decreased to a minimum value. At this point the tube V_2 becomes unblocked (because the potential of the grid has been raised—negative grid voltage lowered) to a value at which current will begin to flow and the sweep condenser 22 then discharges relatively quickly through a path including the anode-cathode path of the tube V_2 and elements 30 and 31 in parallel. The flow of sweep condenser discharging current through the condenser 31 charges the latter. As the discharge path for the sweep condenser 22 is of low impedance compared to the impedance of the charging path including anode resistor 43, the portion of the sweep wave produced by this discharge is steep (see line 1—2 of Fig. 2a). This low impedance of the discharge path through V_2 results from a positive pulse from V_1. This pulse exists long enough for condenser 31 to recharge to a substantial value. Without this pulse the condenser 31 would charge only to a small value before the potential drop across resistance 30 would cause the potential of the grid V_2 to reach it blocking value. That is, when the discharging action of the sweep condenser starts, the discharge current begins to recharge condenser 31, thus causing the potential of the grid 27 to fall relatively to that of cathode 26. This action is seen to be in a direction to tend to decrease the rate of discharge of condenser 22. The discharging action of condenser 22 ceases abruptly when the pulse from V_1 ceases. The sweep condenser 22 will then immediately begin to be charged again to initiate another cycle. As the sweep condenser 22 is connected in the circuit between the control grid 13 and the cathode 12 of the tube V_1, the potential variations due to the charging and discharging of this condenser constitute the input wave for the tube V_1, which tube would amplify said wave as such, were it not for elements now to be discussed. The parallel connected resistance 16 and condenser 17, which are included in both the cathode-control grid and the cathode-anode circuits of the tube V_1, acquire (when current flows) a feedback voltage across their terminals which is in opposition to that across the sweep condenser 22 and of such amplitude that the grid 13 of the tube V_1 does not at any time become positive with respect to the cathode 12. Distortions of such nature as to produce sharp pulses in the wave shown in Fig. 2b (that is, the input wave applied between the control grid 27 and the cathode 26 of the tube V_2) are caused by this feedback voltage and by the attenuation of the low frequencies caused by the coupling circuit between the tubes V_1 and V_2 comprising resistors 18 and 32 and the condenser 23. The voltage (see Fig. 2b) applied to the input circuit of the tube V_2 is essentially the time derivative of the voltage (Fig. 2a) applied to the control grid 13 of the tube V_1. The pulses in the wave shown in Fig. 2b drive the control grid 27 of the tube V_2 sharply in a positive direction, thus permitting a discharge of the condenser, and then abruptly cease so that tube V_2 blocks again.

The period of free oscillations may be changed by varying the resistance 30. If the resistance 30 is made large the charge on the condenser 31 decays slowly, thus increasing the period of the saw-tooth wave. This period is normally set slightly longer than that between the synchronizing pulses when these are used, so that the latter have control. The adjustment is not critical and with sufficient amplitude of the synchronizing pulses the free period may be increased one hundred per cent with no ill effects. The amplitude may be adjusted by means of the potiometer 39, which controls the rate of charge of the sweep condenser 22. If the resistor 63 is varied, the shape of the wave is changed.

The output voltage is available across the sweep condenser 22 and, assuming that the plate impedance of the tube V_2 is practically infinite, this voltage has a slowly changing portion which is an exponential and not a linear function of time. The output voltage is applied directly to the control grid of the first tube in the feedback amplifier B which preferably comprises two tubes V_3 and V_4. It can be shown by mathematical analysis and verified experimentally that the difference between these two functions is similar to that due to a series capacitance in a constant resistance line. This conception leads to the introduction of means in the amplifier feedback path which gives good compensation.

Given the saw-tooth wave shown in Fig. 3

$$\left.\begin{aligned} e(t)&=A(1-\epsilon^{-t/T})+B\epsilon^{-t/T} & 0<t<t_1 \\ &=C\epsilon^{-t/T}-D(1-\epsilon^{-t/T}) & t_1<t<t_0 \end{aligned}\right\} \quad (1)$$

where T is the time constant and is equal to the product CR, t_0 is the period for one complete cycle, and t_1 is the period for the slowly changing portion of the cycle.

Let

$$f_0=\frac{1}{t_0},\ \omega_0=2\pi f_0,\ x=\omega_0 t,\ m=\frac{1}{\omega_0 T},\ \text{and}\ \phi=\frac{t_0-t_1}{t_0}2\pi$$

Then Equation 1 may be written in terms of $e(x)$ where x varies between 0 and 2π.

$$\left.\begin{aligned} e(x)&=A(1-\epsilon^{-mx})+B\epsilon^{-mx} & 0<x<2\pi-\phi \\ &=B\epsilon^{-mx}-D(1-\epsilon^{-mx}) & 2\pi-\phi<x<2\pi \end{aligned}\right\} \quad (2)$$

With no loss of generality the maximum amplitude of $e(x)$ may be taken as unity and by discarding a direct current term, the minimum may be taken as zero. Also letting $e(x)=e_1(x)+e_2(x)$, there is obtained

$$e_1(x)=\frac{1-\epsilon^{-mx}}{1-\epsilon^{-m(2\pi-\phi)}} \qquad 0<x<2\pi-\phi \qquad (3)$$

$$e_2(x)=\frac{\epsilon^{m(2\pi-x)}-1}{\epsilon^{m\phi}-1} \qquad 2\pi-\phi<x<2\pi \qquad (4)$$

The value of any harmonic component, n, at a time t will then be given by:

$$H_n=\frac{1}{\pi}\int_0^{2\pi-\phi}e_1(x)(\sin nx \sin n\omega_0 t+\cos nx \cos n\omega_0 t)\,dx$$

$$+\frac{1}{\pi}\int_{2\pi-\phi}^{2\pi}e_2(x)(\sin nx \sin n\omega_0 t+\cos nx \cos n\omega_0 t)\,dx$$

Using the notation in accordance with circuit theory that $\cos n\omega_0 t=j \sin n\omega_0 t$, we have

$$H_n=\frac{\sin n\omega_0 t}{\pi}\left[\int_0^{2\pi-\phi}e_1(x)(\sin nx+j\cos nx)\,dx\right.$$

$$\left.+\int_{2\pi-\phi}^{2\pi}e_2(x)(\sin nx+j\cos nx)\,dx\right]$$

Since $\sin nx+j\cos nx=j\epsilon^{-jnx}$, and letting

$$H_n=A_n \sin n\omega_0 t$$

where A_n is the complex amplitude,

$$A_n=\frac{j}{\pi}\int_0^{2\pi-\phi}e_1(x)\epsilon^{-jnx}dx+\frac{j}{\pi}\int_{2\pi-\phi}^{2\pi}e_2(x)\epsilon^{-jnx}dx \qquad (5)$$

Inserting the values of $e_1(x)$ and $e_2(x)$, and integrating, upon the collection of terms, there is obtained

$$A_n=\left[-j2\frac{(1-\epsilon^{jn\phi})}{n^2\phi(2\pi-\phi)}\right]\cdot$$

$$\left[\frac{\phi(2\pi-\phi)m\epsilon^{m\phi}(1-\epsilon^{-2m\pi})}{(\epsilon^{m\phi}-1)(1-\epsilon^{-m(2\pi-\phi)})}\right]\cdot\left[\frac{1}{1+\frac{m}{jn}}\right] \qquad (6)$$

Of these terms the first is independent of m, the second is independent of n, and the last is a function of both. As m approaches zero, the second and third factors above approach unity and Equation 6 becomes

$$A_n=\frac{-j2(1-\epsilon^{jn\phi})}{n^2\phi(2\pi-\phi)} \qquad (7)$$

Also, Equations 3 and 4 will reduce to:

$$e_1(x)=\frac{x}{2\pi-\phi} \qquad 0<x<2\pi-\phi \tag{8}$$

$$e_2(x)=\frac{2\pi-x}{\phi} \qquad 2\pi-\phi<x<2\pi \tag{9}$$

Equations 8 and 9 may be defined as the expressions for an "ideal" wave, i. e., linear functions of x and hence of time. Hence, Equation 7 represents the complex amplitude of such an ideal wave. Equation 6 may then be seen to represent this wave multiplied by a pure amplitude factor affecting all harmonics equally and multiplied by a distortion factor which affects the various harmonics differently. Since

$$m=\frac{1}{\omega_0 T}$$

where T is a time constant or RC product this distortion factor may be represented as a continuous function of frequency. Or

$$\frac{1}{1+\frac{m}{jn}}=\frac{1}{1+\frac{1}{jn\omega_0 T}}=\frac{1}{1+\frac{1}{j\omega CR}} \tag{10}$$

where $T=CR$, $n\omega_0=\omega$.

To correct for this factor a correcting network, the transmission characteristic of which varies directly as

$$1+\frac{1}{j\omega CR}$$

is supplied. This connecting network which comprises a two-stage amplifier having a feedback circuit between the output circuit of the second stage and the input circuit of the first stage will now be described.

Referring now to the amplifier B, tube V_3 comprises a cathode 50, an anode 51, a control grid 52, a screen grid 53, and a suppressor grid 54 while the tube V_4 comprises a cathode 60, an anode 61, a control grid 62, a screen grid 63 and a suppressor grid 64. The cathode 50 is connected through the parallel-connected resistance 55 and condenser 56 to ground. The screen grid 53 is connected through condenser 57 to the cathode 50 and through resistance 58 to a point 59 having a direct potential of about 300 volts positive. The suppressor grid 54 is connected directly to the cathode 50 while the anode 51 is connected through an anode resistor 71 to the point 59 of positive direct potential. A coupling condenser 72 is provided between the output circuit of the tube V_3 and the input circuit of the tube V_4. The resistance 65 and the condenser 66 are used to apply grid voltage between the cathode 60 and the control grid 62 thereof and resistor 73 is used as a grid leak. The suppressor grid 64 is connected directly to the cathode 60 while the screen grid 63 is connected directly to the point 59 of positive direct potential. The anode 61 of the tube V_4 is connected to a point 74 having a direct potential of about 1,000 volts positive through resistances 75 and 76, a variable condenser 77 being shunted across the resistance 75. A condenser 78 is connected from the common terminal 79 of the resistances 75 and 76 back to the cathode 50 of the tube V_3.

The low frequency response of the amplifier, with which we are here concerned, can be determined from the following well-known equation for the effective amplification μ' of a feedback amplifier:

$$\mu'=\frac{\mu}{1+\mu\beta} \tag{11}$$

where μ represents the amplification without feed back and β is the feed back ratio. Since the reactance effects of the condensers 56 and 81 (leading to one of the plates of a pair of deflecting plates) will be small at the frequencies involved, β is approximately:

$$\beta=\frac{\beta_0}{1+\frac{1}{j\omega CR'}} \tag{12}$$

where β_0 is the feedback ratio existing if the capacity C of condenser 78 were infinite, and R′ is the effective resistance facing condenser 78 (R′=the resistor 55 plus the resistor 76). The effective amplification is then:

$$\mu'=\frac{\mu}{1+\frac{\mu\beta_0}{1+\frac{1}{j\omega CR'}}} \tag{13}$$

$$\doteq\frac{1}{\beta_0}\left(1+\frac{1}{j\omega CR'}\right)$$

the approximation holding when

$$\omega CR'>>1<<\mu\beta_0$$

which is effectively fulfilled in practice. Equation 13 is of the form required (see Equation 10) in order to compensate for the non-linearity of the input sweep voltage. For substantially exact compensation, the product of the capacity of condenser 78 and the resistance R′ (that is, $R_{76}+R_{55}$) facing this condenser should be equal to the product of the capacity of the sweep condenser 22 and the resistance of the resistor element 43. The effect of condenser 56 may here be neglected because the capacity of condenser 56 is small compared with that of the condenser 78.

The amplifier comprising the tubes V_3 and V_4 thus compensates for the non-linear voltage wave produced by the multivibrator arrangement A comprising tubes V_1 and V_2. The feedback is less at low frequencies and greater at high frequencies. The output of the tube V_4 is connected to the balancing and inverter stage C comprising the tubes V_5 and V_6, these two tubes being used to obtain a balanced output. Shunt type feedback is incorporated in the inverter to obtain unity amplification.

The tube V_5 preferably comprises a cathode 90, an anode 91, a control grid 92, a screen grid 93 and a suppressor grid 94, while the tube V_6 preferably comprises a triode having a cathode 95, an anode 96, and a control grid 97. The anode 61 of the tube V_4 is connected to the control grid 92 of the tube V_5 through the resistance 100 and the condenser 101, a variable condenser 102 being shunted across the resistance 100. The condenser 102 is made variable to adjust the gain to zero. Bias for the control grid 92 is supplied by means of the feedback circuit comprising the condenser 103 and the resistance 104, each of which is connected between the cathode 90 and ground and hence is in both the input and output circuits of the tube V_5. A resistor 105 serving as a grid leak is also connected in circuit between the grid 92 and the cathode 90 of the tube V_5, one terminal of the resistance 105 being connected to ground and also, through resistor 106, to the common terminal of condensers 107 and 108. Connected between the common terminal of the condensers 102 and 107 and the cathode 95 of the tube V_6 is a resistor 109, this resistor shunting the condensers 107, 108 and 111 in series. A resistor 110 is shunted across the condenser 111.

The voltage applied between the control grid and the cathode of the tube V_5 is determined by the current flowing through the resistance 100 and the condenser 102 in parallel, and also by the voltage due to the feedback from the cathode of the tube V_6 through resistance 110 and condenser 111 in parallel and condensers 108, 107 and 101 to the control grid 92 of the tube V_5. The condensers 107, 108 and 111 form a series condenser which determines to a large extent the high frequency response. This series condenser is split up as shown in the drawing so as to allow for the connections at inner points thereof to the resistance 110 and the resistance 106. The resistance 106 is used to introduce a low frequency phase shift in the feedback path which compensates for any phase shift caused by the circuit of the tubes V_5 and V_6. The larger the value of the capacity 111, the more high frequency energy is fed back and the lower the gain at these frequencies, since the effect of increased feedback is to reduce the gain. The anode 91 of the tube V_5 is connected through a resistance 112 to the terminal 74 having a positive direct potential of 1,000 volts and is also connected by means of the coupling condenser 113 and to the control grid 97 of the tube V_6, the grid leak resistor 114 being connected to the common terminal of a resistor 115 and a resistor 116. The other terminal of the resistor 116 is connected to ground while the other terminal of the resistor 115 is connected to the cathode 95 of the tube V_6. The cathode 95 is connected through a coupling condenser 119 (similar to the coupling condenser 81) to a deflecting plate 120, the opposite plate 121 of the pair of plates in a cathode ray tube (not shown) being connected to the condenser 81. Thus there is applied to these plates 120 and 121, by the circuit shown in Fig. 1, a saw-toothed voltage wave of horizontal or line scanning frequency. Connected across the plates 120 and 121 are high resistors 122 and 123, the common terminal 124 of which is preferably connected to ground in accordance with well-known practice. Any suitable cathode ray tube may be used with the sweep circuit of this invention, as for example, the tube described in Patent 2,217,198 issued October 8, 1940, to C. J. Davisson.

In the usual sweep circuit, the plate current of the output tube (or the inverter tube) is high most of the time and is reduced to substantially zero only during the flyback time. With this situation much power is dissipated. In the circuit arrangement of this invention the plate current in the inverter tube V_5 (as shown in Fig. 2f) is low except during the flyback when it is high. The plate current in the last amplifier tube V_4 (shown in Fig. 2d) is low except during the flyback time when it is high and just the reverse of this obtained in the tube V_5. The inverter tube V_5 as shown in Fig. 2e draws a relatively high current during the sweep time and a low current during the flyback time. But since the parasitic capacities existing across the anode-cathode circuit of the tube V_6 are lower than those existing across the deflector plate circuit, this relatively high current may be much lower than if the tube V_5 were connected directly to one of the deflector plates. By the use of the two tubes V_5 and V_6, the latter of which is of low impedance and which is a cathode follower, the power input is not as large as with the use of a single tube.

In a circuit actually constructed the tubes V_1, V_2 and V_3 were 6J7 tubes, the tubes V_4 and V_5 were 802 tubes, while the tube V_6 was a 1608 tube. The condenser 22 had a value of 300 microfarads; condenser 17, 500 micromicrofarads; condenser 23, 100 micromicrofarads; condenser 31, 0.001 microfarad; condenser 33, .1 microfarad; condenser 42, 1 microfarad; condenser 56, 175 micromicrofarads; condenser 57, 0.1 microfarad; condenser 72, .01 microfarad; condenser 66, .1 microfarad; condenser 77, 25 micromicrofarads; condenser 78, .02 microfarad; condenser 81, 0.1 microfarad; condenser 119, 0.1 microfarad; condenser 102, 25 micromicrofarads; condenser 101, 0.001 microfarad; condenser 103, 0.1 microfarad; condenser 107, 20 micromicrofarads; condenser 108, 20 micromicrofarads; and condenser 111, 150 micromicrofarads. The resistance 43 had a value of 1.5 megohms; resistance 16, 17,000 ohms; resistance 19, 20,000 ohms; resistance 32, 20,000 ohms; resistance 30, 0.1 megohm; resistance 24, 0.1 megohm; resistance 35, 0.1 megohm per section; resistance 39, 0.1 megohm; resistance 55, 10,000 ohms; resistance 58, 0.1 megohm; resistance 71, 20,000 ohms; resistance 73, 0.1 megohm; resistance 65, 4,500 ohms; resistance 75, 0.1 megohm; resistance 76, 10,000 ohms; resistance 122, 1 megohm; resistance 123, 1 megohm; resistance 100, 10 megohms; resistance 105, 10 megohms; resistance 104, 2,500 ohms; resistance 109, 10 megohms; resistance 106, 1.43 megohms; resistance 110, 0.1 megohm; resistance 112, 50,000 ohms; resistance 114, 1 megohm; resistance 115, 5,000 ohms and resistance 116, 0.1 megohm.

The circuit described above produces a linear sweep voltage with maximum variation of velocity of 20 per cent at the edges of the sweep, a return time of 2.25 microseconds for a sweep time of 75 microseconds, and a maximum output voltage of 1600 volts peak to peak, balanced to ground.

Various modifications may be made in the embodiment above described without departing from the spirit of the invention, the scope of which is indicated in the appended claims.

What is claimed is:

1. In combination, means for generating a potential wave in which for the major part of each cycle there is a relatively slow change in one direction and for the rest of the cycle a relatively rapid change in the opposite direction, said wave being non-linear in the slowly changing portion, a multistage arrangement for amplifying said potential wave without changing the shape of the wave produced by said generating means, said arrangement comprising a negative feedback circuit from a later stage to an earlier stage for compensating for the non-linearity of the slowly changing portion of said potential wave, whereby the output potential wave of said amplifier has a slowly changing portion which is substantially linear, and means for utilizing said output potential wave.

2. A generator of saw-tooth waves of the form having one side at least somewhat curved, comprising a condenser, means for varying the charge on said condenser to generate said curved part of each wave comprising a resistance means of constant value connected in circuit with said condenser, the rate of varying said charge being predominantly dependent upon the resistance of said resistance means and the capacity of said

condenser, means associated with said condenser for varying the voltage thereacross to set up the other side of each of said sawtooth waves, means upon which the voltage across said condenser is at all times impressed, and means cooperating with said last-mentioned means for compensating for the curvature in said curved side of each wave comprising a circuit consisting of capacity means and linear resistance means together having a time constant substantially equal to that of said first-mentioned condenser and resistance means.

3. A generator of saw-tooth waves of the form having one side at least somewhat curved comprising a condenser, means for varying the charge on said condenser to generate said curved part of each wave comprising a resistance means connected in circuit with said condenser, the rate of varying said charge being predominantly dependent upon the resistance of said resistance means and the capacity of said condenser, means associated with said condenser for varying the voltage thereacross to set up the other side of each of said saw-tooth waves, means upon which the voltage across said condenser is at all times impressed, and means cooperating with said last-mentioned means for compensating for the curvature in said curved side of each wave comprising a multistage amplifier having a negative feedback circuit between a later stage and an earlier stage consisting of capacity means and resistance means together having a time constant substantially equal to that of said first-mentioned condenser and resistance means.

4. A generator of saw-tooth waves of the form having one side at least somewhat curved comprising a condenser, means for varying the charge on said condenser to generate said curved part of each wave comprising a resistance means of constant value connected in circuit with said condenser, the rate of varying said charge being predominantly dependent upon the resistance of said resistance means and the capacity of said condenser, means associated with said condenser for varying the voltage thereacross to set up the other side of each of said saw-tooth waves, means upon which the voltage across said condenser is at all times impressed, and means cooperating with said last-mentioned means for compensating for the curvature in said curved side of each wave comprising a two-stage amplifier having a negative feedback circuit between the output circuit of the second stage and the input circuit of the first stage consisting of capacity means and resistance means of constant value together having a time constant substantially equal to that of said first-mentioned condenser and resistance means.

5. In combination, an impedance means one terminal of which is maintained at a fixed potential, means for generating a periodically varying potential at the other terminal of said impedance means, a pair of like impedance elements having a common terminal maintained at a fixed potential, one of said pair having its outside terminal effectively connected to the terminal of said first-mentioned impedance means having a varying potential so that the potentials of these two connected terminals vary in fixed phase relationship with each other, and means controlled by the potential difference across said first impedance means for giving the outside terminal of the second of said pair of like impedance elements a varying potential such that it is always opposite in sign to that of the outside terminal of the first of said pair of impedance elements with respect to said fixed potential of said common terminal and equally different from said fixed potential of said common terminal, said last-mentioned means comprising phase inverting means connected to said first impedance means, single stage means for repeating the output of said phase inverting means without phase inversion, and means for impressing the output of said repeating means upon the second of said pair of impedance elements.

6. In combination, an impedance means one terminal of which is maintained at a fixed potention, means for generating a periodically varying potential at the other terminal of said impedance means, a pair of like impedance elements having a common terminal maintained at a fixed potential, one of said pair having its outside terminal effectively connected to the terminal of said first-mentioned impedance means having a varying potential so that the potentials of these two connected terminals vary in fixed phase relationship with each other, and means controlled by the potential difference across said first impedance means for giving the outside terminal of the second of said pair of like impedance elements a varying potential such that it is always opposite in sign to that of the outside terminal of the first of said pair of impedance elements with respect to said fixed potential of said common terminal and equally different from said fixed potential of said common terminal, said last-mentioned means comprising phase inverting means connected to said first impedance means, means for repeating the output of said phase inverting means without phase inversion, and means for impressing the output of said repeating means upon the second of said pair of impedance elements, said repeating means comprising a cathode, an anode and a control element, said cathode being connected to the second of said pair of impedances.

7. In combination, an impedance means one terminal of which is maintained at a fixed potential, means for generating a periodically varying potential at the other terminal of said impedance means, a pair of like impedance elements having a common terminal maintained at a fixed potential, one of said pair having its outside terminal effectively connected to the terminal of said first-mentioned impedance means having a varying potential so that the potentials of these two connected terminals vary in fixed phase relationship with each other, and means controlled by the potential difference across said first impedance means for giving the outside terminal of the second of said pair of like impedance elements a varying potential such that it is always opposite in sign to that of the outside terminal of the first of said pair of impedance elements with respect to said fixed potential of said common terminal and equally different from said fixed potential of said common terminal, said last-mentioned means comprising phase inverting means connected to said first impedance, means for repeating the output of said phase inverting means without phase inversion, and means for impressing the output of said repeating means upon the second of said pair of impedance elements, said phase inverting means having a high internal impedance compared with that of said repeating means.

8. The combination of elements as in claim 5 in further combination with a pair of deflecting plates in a cathode ray tube, and means for con-

necting the output terminals of said pair of like impedance means respectively to the plates of the pair.

9. A sweep circuit comprising means for generating a saw-tooth potential wave in which for the major part of each cycle there is a relatively slow change in one direction and for the rest of each cycle a relatively rapid change in the opposite direction, said wave being non-linear in the slowly changing portion, means for amplifying said potential wave, said means comprising means for compensating for said non-linearity of said potential wave without changing the shape of the wave produced by said generating means, whereby the output potential wave of said amplifier has a slowly changing portion which is substantially linear, a pair of deflecting plates in a cathode ray tube, means for connecting one terminal of said amplifying means to one of said pair of deflecting plates, a phase inverting circuit, and means for connecting the output wave of said amplifying means through said phase inverting circuit to the other of said pair of deflecting plates.

10. A sweep circuit comprising means for generating a saw-tooth potential wave in which for the major part of each cycle there is a relatively slow change in one direction and for the rest of each cycle a relatively rapid change in the opposite direction, said wave being non-linear in the slowly changing portion, means for amplifying said potential wave, said means comprising means for compensating for the non-linearity of said potential wave whereby the output potential wave of said amplifier has a slowly changing portion which is substantially linear, a pair of deflecting plates in a cathode ray tube, means for connecting one terminal of said amplifying means to one of said pair of deflecting plates, a phase inverting circuit, means for connecting the output wave of said amplifying means through said phase inverting circuit to the other of said pair of deflecting plates, said phase inverting circuit comprising a high impedance tube followed by a low impedance tube, the connection to the second of said pair of deflecting plates being made from the cathode of said low impedance tube.

11. An oscillator comprising a first tube having an anode, a cathode and a control element, a second tube having an anode, a cathode and a control element, means for coupling the anode of the first tube to the control element of the second tube, said coupling means being such as to pass high frequencies and greatly attenuate or suppress low frequencies, means for coupling the anode of the second tube to the control element of the first tube, a first condenser, means for connecting said first condenser between the anode of said second tube and the cathode thereof through a circuit which includes a second condenser with a resistor shunted thereacross, means including a source of potential for relatively slowly varying the potential across said first condenser, and means including the anode-cathode path of said second tube for relatively quickly varying the potenial across said first condenser by allowing the condenser to discharge therethrough, said discharge causing the second condenser to be charged.

12. The combination of elements as in claim 11 in which said resistor is variable to change the period of oscillations.

13. The combination of elements as in claim 11 in further combination with means to apply synchronizing signals to the control means of one of said tubes.

14. An oscillator comprising an electron discharge device having an anode, a cathode and a control element, a sweep condenser, a second condenser, a first resistor shunted across said second condenser to discharge said condenser relatively slowly during the charging of said sweep condenser, means for connecting the sweep condenser and the second condenser in a series circuit including the anode-cathode path of said discharge device, means for connecting the second condenser and said first resistor shunted thereacross in a circuit between the cathode and the control element of said discharge device to vary the potential of said control element with respect to said cathode, a second resistor, a source of potential for relatively slowly charging said sweep condenser through said second resistor, said discharge device being blocked during at least the major portion of the charging time by the voltage between the terminals of said first resistor which voltage decreases with respect to time during the charging interval to swing the potential of said control element with respect to said cathode in a positive direction thus tending to unblock said discharge device, and means including the anode-cathode path of said discharge device for relatively quickly discharging said sweep condenser when the device becomes unblocked and thereby charge said second condenser whereby the voltage across the terminals of said first resistor is raised by an amount sufficient to block said tube.

15. The combination of elements as in claim 14 in further combination with means including a second electron discharge device for amplifying and distorting the wave produced across the sweep condenser, and means for applying the resultant wave between the control element and the cathode of said first electron discharge device.

16. A saw-tooth wave generator comprising an electron discharge device having an anode, a cathode and a discharge control element, a source of direct potential in series with said anode and cathode, a resistance, a second resistance shunted by a condenser, both said resistances being in series with said source and said anode and cathode, said second resistance being also in the input circuit of said discharge device, a second condenser having one terminal connected to said anode and the other to that terminal of said second resistance remote from said cathode, means for applying a steep sided pulse of voltage to said input circuit to cause said discharge device to pass current and charge said first condenser to a potential difference such that when said voltage pulse ceases said discharge device is blocked, whereby said first condenser then discharges through said second resistance.

17. In combination, means for generating a potential wave in which for the major part of each cycle there is a relatively slow change in one direction and for the rest of the cycle, a relatively rapid change in the opposite direction, said wave being non-linear in the slowly changing portion, electric circuit means, including a negative feedback amplifier, independent of said wave generating means, for producing from said wave an amplified and distorted version thereof in which the slowly changing portion is substantially linear, and means for utilizing said output potential wave.

STEPHEN DOBA, Jr.