

June 3, 1941.

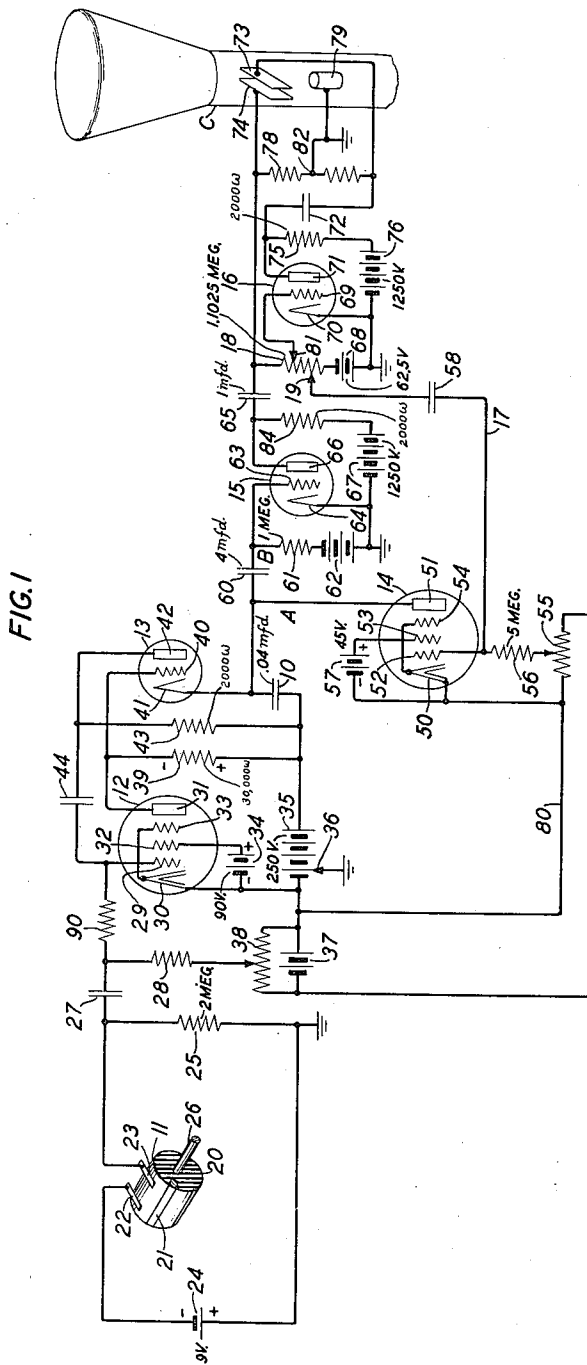
W. A. KNOOP

2,244,013

ELECTRIC CIRCUIT

Filed Feb. 11, 1939

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 2

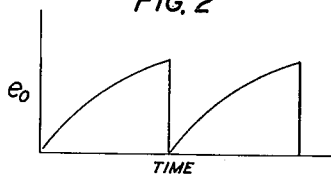


FIG. 3

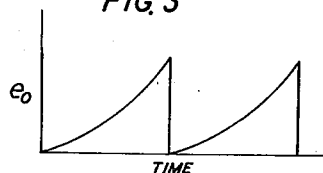


FIG. 4

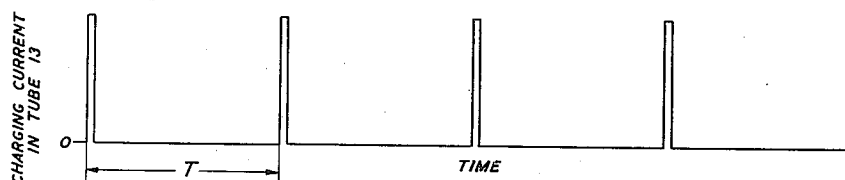


FIG. 5

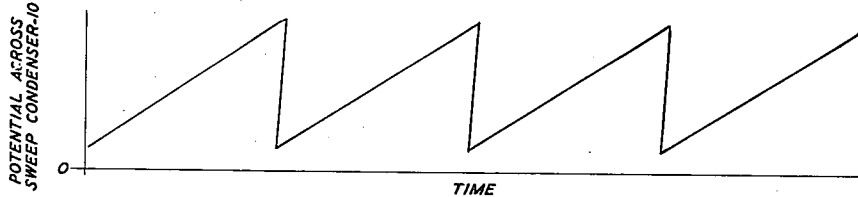


FIG. 6

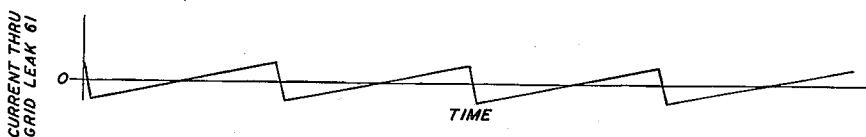


FIG. 7

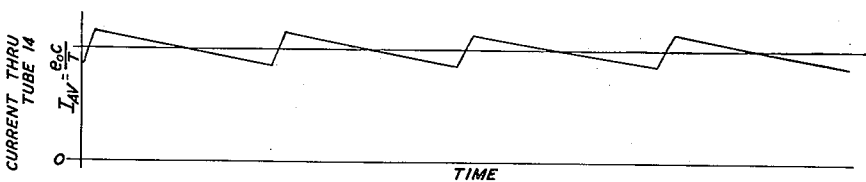
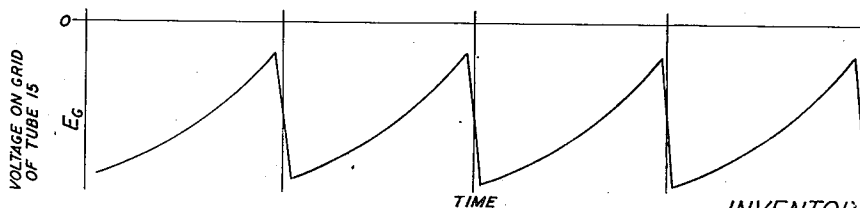


FIG. 8



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## UNITED STATES PATENT OFFICE

2,244,013

## ELECTRIC CIRCUIT

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Application February 11, 1939, Serial No. 255,903

13 Claims. (Cl. 178-7.7)

This invention relates to electric wave form circuits and more specifically to sweep circuits suitable for television scanning.

It is an object of this invention to provide a novel wave generating circuit.

In the operation of cathode ray tubes suitable for television scanning and employing electrostatic deflection, the sweep circuits used have been customarily of a type in which one or more condensers are charged and discharged in such a manner that a saw-toothed wave form is produced, which voltage wave form may be applied between a pair of electrostatic deflecting plates in the cathode ray tube. It has been found in practice that it is frequently desirable to amplify these saw-tooth wave form voltage waves before applying them to the deflecting plates. During the amplifying process it has been discovered that the resistance-capacity coupling between the sweep condenser and the amplifying tube introduces distortions in the resultant amplified wave.

Another object of this invention is to provide a sweep circuit making use of amplifying means in which the amplified wave applied to the deflecting plates is of substantially pure saw-toothed wave form.

It is a further object of this invention to provide an improved balanced sweep circuit utilizing high vacuum tubes.

In accordance with the invention, in the single embodiment thereof shown by way of example, a sweep circuit is provided which comprises a sweep condenser, two high vacuum tubes which are connected in such a manner that upon the appearance of a pulse in the input circuit of one of these tubes the sweep condenser in the output circuit of the other is almost instantaneously discharged, a pentode tube for slowly charging the sweep condenser, an amplifying tube resistance-capacity coupled to the sweep condenser, a phase inverting tube coupled to the amplifying tube for producing a voltage which is reversed in phase with respect to the output of the amplifying tube to thus produce with the output voltage of the amplifying tube a sweep voltage balanced with respect to the anode voltage of the cathode ray tube, to which anode is connected the mid-point of a high resistance connected between the deflecting plates of the cathode ray tube, and a feedback connection from the output circuit of the first amplifying tube to the control electrode of the pentode tube to compensate for the non-linearity of the sweep condenser charging current produced by the resistance-capacity coupling of the amplifying

tube. By the feedback arrangement the space current through the pentode tube is made to vary in the opposite direction from the current in the resistance-capacity coupling, thus insuring a linear drop in voltage in the output circuit of the amplifying tube to thereby produce a linear sweep voltage.

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

Fig. 1 shows a balanced sweep circuit involving the principles of this invention; and

Figs. 2 to 8, inclusive, are graphic representations used to explain the principles of this invention.

Referring more particularly to the drawings, Fig. 1 shows a balanced sweep circuit, which may be used, for example, as a suitable source to generate a saw-tooth voltage wave to be applied between a pair of deflecting plates in a cathode ray tube C used, for example, for television transmitting or receiving to cause deflection of the cathode ray beam in one direction, as, for example, in a vertical direction. A similar circuit, differing only in the value of its circuit constants, may be used to produce horizontal deflection, if desired. This circuit comprises a sweep condenser 10, a discharging means comprising impulse generator 11 and two interconnected high vacuum tubes 12 and 13, a charging means comprising the pentode tube 14, and amplifying and phase reversing means comprising the vacuum tubes 15 and 16, and a feedback connection 17 from the input resistance 18 of the vacuum tube 16 to one of the grids of the pentode tube 14.

Considering first the discharging circuit for the condenser 10, the pulse generator 11 generates a sharp negative pulse (with the battery 24 poled as shown in the drawings once per revolution which is peaked by means of the interconnected vacuum tubes 12 and 13 to discharge substantially instantaneously the condenser 10 which has been previously charged. The pulse generator 11 preferably comprises a cylindrical element 20 of insulating material having a metallic element 21 which electrically connects once per revolution contact elements 22 and 23 thus completing a circuit including the source of direct potential 24 and the resistance 25. The negative terminal of the source 24 is preferably connected to the contact element 22 and the positive terminal of the source 24 is con-

nected to ground. The cylindrical member 20 is mounted on an axis 26 which is rotated by suitable means (not shown) at such a speed that the contact elements 22 and 23 are connected together once for every complete scanning of the object or field of view at the television transmitting station. In practice, the scanning may be at the rate of 20, 24, 30 or 60 frames per second. Of course, it is obvious that any other suitable means such as vacuum tube arrangements, peaking transformers, etc., may be used to produce these negative pulses, if desired.

The negative pulse produced once per revolution by means of the rotating device 11 is applied through the coupling condenser 27 to the input resistor 28. The potential drop across this resistor is applied to the control grid 29 of the vacuum tube 12 through the resistor 30. The tube 12 also includes a cathode 30, an anode 31, a screen grid 32 and a suppressor grid 33. The screen grid 32 is placed at a positive potential with respect to that of the cathode 30 by means of the source 34. The suppressor grid 33 is directly connected to the cathode 30, the cathode being also connected to the negative terminal of the source of potential 35 of approximately 250 volts, an inner terminal 36 of which is connected to ground. A source of potential 37 shunted by a potentiometer resistor 38 provides bias for the control grid 29. The positive terminal of the source 35 is connected through an anode resistance 39 to the anode 31.

Directly coupled to the anode 31 of the tube 12 is the grid 40 of the tube 13. The cathode 41 of this tube is connected to one terminal of the sweep condenser 10, the other terminal of which is connected to the positive terminal of the source 35. The anode 42 of the tube 13 is connected through the anode resistance 43 to the terminal of the capacity 10 which is remote from the cathode 41. The anode 42 is also coupled back to the grid 29 of the tube 12 through coupling condenser 44. The purpose of this feedback connection will be explained hereinafter. When the tube 13 conducts current, the condenser 10 is quickly discharged.

Shunted across the condenser 10 is a circuit including the pentode tube 14 ordinarily used as a constant current device and the source of potential 35, the purpose of this arrangement being to relatively slowly place a charge on the condenser 10 after it has been discharged by a pulse generated by the device 11.

The pentode tube 14 preferably comprises a cathode 50, an anode 51, a control grid 52, a screen grid 53 and a suppressor grid 54. The cathode 50 is connected to the positive terminal of the source 37, the negative terminal of which is connected through a portion of the potentiometer resistance 55 (which is connected across the source 37) and the resistance 56 to the control grid 52 to supply bias therefor.

Positive bias for the screen grid 53 is supplied by means of the source 57 which is connected between the cathode 50 and the screen grid 53. The suppressor grid 54 is preferably connected directly to the cathode 50. The control grid 52 is connected through the feedback connection 17 which includes the coupling condenser 58 to an inner terminal 19 of the input resistance 18 of the phase reversing tube 16 for a purpose which will be described more fully hereinafter. The anode 51 is connected to one terminal of the con-

denser 10 while the cathode 50 is connected to the other terminal of the condenser 10 through the source 35.

A large class of vacuum tubes, most of them pentodes, have characteristics making them useful as constant current leaks. For instance, the R. C. A. 58 whose characteristics are shown on page 144 of the R. C. A. Receiving Tube Manual (RC-13 of R. C. A. technical series) is quite suitable. As will be seen from these curves the plate current is independent of the plate voltage over a considerable range from about 300 volts to 30 volts with approximately 10 volts on the control grid. The R. C. A. 57 may also be used for this purpose. Its characteristics may be found in the R. C. A. Handbook series HB-3 under R-57. If the plate current depended upon the plate potential as it does in the triode tubes the current therethrough would not be constant.

Due to the fact that pentode tubes of the type described above (and other similar tubes) have relatively constant current characteristics for a rather large voltage range, the charging current of the condenser 10 will tend to remain substantially constant in the absence of other factors. This constancy, however, is disturbed by the fact that also connected across the condenser 10 is the input circuit of the tube 15 including the coupling condenser 60, input resistance 61 and biasing source 62. In a low frequency sweep circuit (and to a less noticeable extent in a high frequency sweep) this input circuit, principally the input resistance 61, distorts the saw-toothed wave into a logarithmic type of wave because the current through the grid leak resistance 61 varies with the applied potential.

If the tube 14 has its circuit so arranged, however, that the space current therethrough varies in the opposite direction from the variation in current through the circuit including the grid leak resistor 61, the wave between the grid 63 and cathode 64 of the tube 15 is linear. This change in the variation of the space current in the tube 14 is obtained by tapping off a small part of the output of the amplifier tube 15. Thus, the inner tap 19 of the resistor 18 in the input circuit of the phase reversing tube 16, which resistor is connected to the output resistor 84 of the tube 15 through a coupling condenser 65, is connected through condenser 53 to the control grid 52 of the tube 14.

The anode circuit of the tube 15 also includes the resistance 84 connected between the anode 66 and the anode source of potential 67, the negative side of which is connected to the cathode 64. A source 68 serves to bias the grid 69 of the phase reversing tube 16 negative with respect to the cathode 70. The anode 71 of the tube 16 is connected through a coupling condenser 72 to deflecting plate 73 of the cathode ray tube, the opposite deflecting plate 74 being connected directly to the condenser 65 which couples it to the anode 66 of the tube 15. The anode circuit of the tube 16 is completed by means of the anode resistance 75 and the source 76.

Let the total charging current of the condenser 10 be called  $I$  and assume it to be constant. Then  $I = I_T + I_R$  where  $I_T$  is the current through tube 14 and  $I_R$  is the current through resistor 61. (The impedance of the condenser 60 can be neglected as its capacity is so large as to have no effect except to block direct voltages).

If  $I$  is constant and  $q_0$  is the initial quantity

of electricity in condenser 10 at the beginning of each cycle and

$$\frac{q_0}{C} = e_0$$

which is the initial potential across condenser 10 whose capacity is C, then

$$\left[ \frac{q_0 - I \cdot t}{C} \right]_0^T$$

will be the potential at any instant  $t$  across condenser 10 between zero time and  $T$ .  $T$  is the period of one scanning cycle. This is a wave whose amplitude is linear with respect to time. At any time  $t$  the current  $I_R$  through the resistor 61 will be

$$\frac{I \cdot t}{CR} - \frac{I \cdot T}{2CR} \text{ or } \frac{I}{RC} \left[ t - \frac{T}{2} \right]$$

(Thus when

$$t = \frac{T}{2}, I_R = 0)$$

This expression is also linear with respect to time. The current through tube 14 is  $I_T$  and as  $I_T = I - I_R$ ,

$$I_T = I - \frac{I}{RC} \left[ t - \frac{T}{2} \right]$$

which is also linear with respect to time but varies in the opposite direction from the current  $I_R$  in the resistor 61. To effect this requires making the control grid of the pentode 14 more negative with increase in time. This grid potential must also vary linearly with time. Thus the grid potential  $E_g$  should have the following value:  $E_g = E_c - Kt$  where  $E_c$  is the biasing potential of the control grid of tube 14 and  $K$  is a proportionality constant.

This potential wave is secured from the output of tube 15. As it has been assumed that a time linear wave is applied to the grid of the tube 15, a similar wave (inverted) will be produced. The potentiometer tap 19 is used to get the proper value of  $K$ .

In order to fix the average potential of the plates 73 and 74 with respect to the potential of the anode 79 of the cathode ray tube C most closely adjacent the deflector plates 73 and 74, the high resistance 78 is connected between these plates and the mid-point 82 of this resistance is connected to the anode 79. Inasmuch as the potentials applied by means of the coupling condensers 65 and 72 to the deflecting plates are balanced with respect to ground (the tube 16 serves only to reverse the phase of the potential in its input circuit without amplification thereof) the potentials applied to the deflecting plates 73 and 74 are balanced with respect to the potential of the anode 79 thus preventing the defocussing of the beam which would otherwise occur if these deflecting potentials were not thus balanced. For a fuller discussion of the advantages of balanced sweep circuits, reference may be made to Patent 2,209,109 issued July 23, 1940 to Frank Gray. For a description of a circuit utilizing a phase inverting tube to obtain balanced sweep voltages, reference may be made to British Patent 423,427 to Schlesinger, January 28, 1935.

The operation of the circuit shown in Fig. 1 of the drawings will now be described. Assume that there is a charge on the sweep condenser 10. The cylindrical insulating element 20 of the pulse generator 11 is turned by suitable means at the proper speed, which speed is predetermined by the frequency desired for the sweep circuit, until

the metal contact bar 21 comes under the contacts 22 and 23. Instantly a pulse is generated which flows through the resistance 25. The potential drop thus generated in the resistance 25 is applied to the control grid 29 of the tube 12 and as the pulse is in the negative direction the space current in the tube 12 is decreased, thus decreasing the potential drop across the resistance 39 and increasing the potential of the anode 31 with respect to the cathode 30 and ground. This raises the potential of the grid 40 which is directly connected to the anode 31. This causes the tube 13 to become conducting or "unblocked," it being previously "blocked," or, in other words, non-conducting. While the tube 13 is "unblocked," the condenser 10 is discharged through a circuit including condenser 10, anode resistor 43 and the space current path of the tube 13. The space current flowing in the tube 13 produces a potential drop in the resistor 43 and this is applied through the condenser 44 to the control grid 29 of the tube 12 and as this change is also in the negative direction, the process is accelerated. As the condenser 10 discharges, the voltage across the tube 13 decreases and it finally "blocks" again.

The purpose of the resistance 90 in the input circuit of the tube 12 is to prevent the pulse from anode 42 from being dissipated or short-circuited by the contacts 21, 22 and 23. If the resistance 90 is reduced to zero and the commutator makes contact, a negative pulse is applied to the grid 29 of tube 12. This cuts down the space current and "unblocks" tube 13 whose plate potential starts to face toward zero. This is a negative pulse on the other side of blocking condenser 44 and if the resistance 90 is zero, this pulse cannot exceed the battery voltage but if the resistance 90 is fairly high the pulse from the commutator is swamped on the grid and tube 12 is blocked until the sweep condenser is nearly discharged. At that time no further current can flow through tube 12 so its plate returns to full positive potential and the negative pulse is over. In this way the contact of the commutator merely initiates the cycle and any subsequent chatter of the brushes has no effect. If the resistance 90 were omitted, the discharge of the condenser would depend on the length of time the brushes were in contact.

Connected across the sweep condenser is the pentode tube 14 which, under ordinary circumstances, would permit the charging of the condenser 10 at a substantially constant rate if it were not for the amplifying tube 15. Assuming that the tube 14 is acting as a constant current tube, and that only the tube 15 is across the condenser 10, the voltage change across the condenser 10 would, for practical purposes, make a perfect saw-tooth wave. The circuit for charging the sweep condenser comprises the anode-cathode path of the tube 14, the conductor 80, and the source 35 which is connected to the other side of the condenser 10. The resistance 61, however, complicates the situation.

Reference will now be made to Figs. 4 to 7, inclusive, in order to present a graphic picture of the voltage and current versus time relationship in various portions of the circuit. Fig. 4 represents the discharging current flowing through tube 13 at intervals  $T$  seconds apart,  $T$  being the scanning interval. The current is in the form of sharp pulses. Fig. 5 shows the change in potential across the sweep condenser 10 with respect to time. This figure is not drawn

to scale. It will be clear from this figure that this potential in the preferred arrangement varies according to a saw-toothed pattern, each cycle comprising a sharp, almost vertical, discharging and a relatively slow, linear charging. Fig. 6 shows the current through the grid leak 61 and it will be noted that the average value of the current is zero. The blocking condenser 60 is the cause of this, and this is the only purpose of the condenser 60. The current through 61 actually reverses but the shape of the wave still follows that of the driving potential shown in Fig. 5. Fig. 7 shows the current through the tube 14. This is opposite in phase to the current shown in Fig. 6. If no grid leak were used the curve in Fig. 7 would be a straight line equal to its average as shown. It will be noted that if the curves of Figs. 6 and 7 are combined, giving the total current charge through the sweep condenser 10, a straight line parallel to the horizontal or time axis will be produced. This means that the total current remains constant during the time the sweep condenser is being charged so that the ideal curve shown in Fig. 5 may be realized even though there is the grid leak resistor 61 across the sweep condenser 10 in addition to the tube 14.

The value of the condensers 60 and 10 and the resistance 61 should be chosen with care having in mind the particular circuit required, although a certain range of values is suitable. If the condenser 60 has too small a capacity, a curve such as that shown in Fig. 8 would represent the voltage on the grid of tube 15. This may be partly compensated for by increasing the feedback to tube 14. If the capacity of condenser 10 is too large, too long a time will be consumed in discharging it by a tube of a practical size. If the condenser 10 has too small a capacity the average current,

$$I_{AV} = \frac{e_0 C}{T}$$

will be so small as to be swamped by leakage. If the grid leak resistance 61 has too low a value, it will be impossible to compensate for its effect and if this resistance is too high the leakage currents in the tube may set the grid potential too close to zero. This will cause the grid to draw current at that part of the cycle where the grid should be approaching zero.

The output of the tube 15 is connected to the input of the tube 16, the resistance 18 serving as the input resistor. The tap 81 on this resistor 18 is so arranged that the tube 16 does not amplify the voltage produced in the output of the tube 15 but only reverses the phase thereof. The tap 19 on this resistor is connected through the coupling condenser 53 to the input resistor 52 of the tube 14 so that as the voltage across the resistor 61 decreases and the current therethrough gets smaller, the current through resistance 18 increases by virtue of the phase reversing action of the tube 15, and in turn raises the potential of the grid 52 with respect to the cathode and increases the current through the tube 14. With the proper positioning of the tap 19, the current in the tube 14 can be made to increase by the same amount as the current through the path B decreases so the total current input to the sweep condenser 10 is constant. Thus it is possible for linearity (of the sweep voltage change with respect to time) to be achieved.

The varying voltage output of the tube 15 is applied between the deflecting plate 74 and the anode 79 by means of the coupling condenser 55,

while this voltage is reversed in phase without amplification by means of the tube 16 and the resultant voltage applied between the plate 73 and the anode 79 by means of the coupling condenser 72. The tube 16 is thus in "paraphase" connection with the tube 15 or, stated differently, in push-pull cascade connection therewith.

If desired, it is possible to over-compensate or under-compensate by means of the feedback arrangement as the tap 19 is an adjustable one. If too great an amplitude is applied to the control grid of tube 14, it is possible to produce an output wave like that shown in Fig. 2, but if not enough amplitude is applied to the control grid, it is possible to produce an output wave like that shown in Fig. 3. Thus it is possible by this means to compensate, at least in part, for possible distortions between the grid leak 61 and the sweep plates 73 and 74.

It is possible to directly couple the grid of the tube 15 to the condenser 10 but this involves careful adjustment of the average control grid potential and also grounding the battery 35 near its positive end which would have disadvantages.

While batteries have been shown in the drawings as sources of potential for biasing the grids and for supplying plate or anode voltage to the various tubes, it is clearly obvious that other appropriate means, such as one or more rectifiers, may be used to supply all or any desired portion of these potentials. Inasmuch as these rectifiers sometimes produce 60-cycle and 120-cycle components, by suitably connecting the extreme end of the anode resistance, as for example, the resistance 84, most remote from the source of anode potential to the following tube in the circuit, the amplitude of the 60-cycle and 120-cycle components with respect to ground is made as small as possible.

If desired, a gas-filled tube or tubes can be used to discharge the sweep condenser 10 instead of the high vacuum tubes 12 and 13. The circuit constants for an operative embodiment of this invention have been shown on the drawings. These constants are given for a sweep circuit of 24 cycles having a linear output of about 1400 volts. It is obvious, however, that the invention is not limited to the specific constants or frequencies shown and described.

Various other modifications of the invention may obviously be made without departing from the spirit thereof, the scope of which is defined by the appended claims.

What is claimed is:

1. A circuit comprising a condenser, means comprising an electron discharge device having an anode, a cathode and a control member for slowly varying the charge on said condenser, means for amplifying the variations of charge on said condenser, said amplifying means having an output circuit, and a feedback connection from said output circuit to the control member of said electron discharge device to modify the rate at which the charge on said condenser is varied.

2. A circuit comprising a condenser, means comprising an electron discharge device having an anode, a cathode and a control member for slowly varying the charge on said condenser, means including a second electron discharge device for amplifying the potential variations across said condenser, and means feeding back a portion of the output voltage of said second electron discharge device to the control member of said first

electron discharge device to control the rate of varying the charge on said condenser.

3. A circuit comprising a condenser, means for periodically and quickly varying the charge on said condenser in one direction, means comprising an electron discharge device having an anode, a cathode, and a control member for relatively slowly varying the charge on said condenser in the opposite direction, means including a second electron discharge device for amplifying the potential variations across said condenser, and means for feeding back a portion of the output voltage of said second electron discharge device to the control member of said first electron discharge device so that the rate of variation of charge on said condenser is controlled in such a way that the output voltage of said second electron discharge device is of a substantially sawtoothed pattern.

4. In combination, a condenser, an amplifying device, a circuit including a resistance shunted across said condenser, said resistance being a part of the input circuit of said amplifying device, a second circuit including an electron discharge device also shunted across said condenser, means for varying the charge on said condenser in one direction, means including said two circuits for varying the charge on said condenser in the opposite direction, and means responsive to the flow of current in said resistance due to said variation in charge on said condenser for controlling the flow of current through said electron discharge device.

5. In combination, a condenser, an amplifying device, a circuit including a resistance shunted across said condenser, said resistance being a part of the input circuit of said amplifying device, a second circuit including an electron discharge device also shunted across said condenser, high vacuum electron discharge means for varying the charge on said condenser in one direction relatively quickly, means including said two circuits for varying the charge on said condenser in the opposite direction relatively slowly, and means responsive to the flow of current in said resistance due to said variation in charge on said condenser for controlling the flow of current through the electron discharge device in said second circuit.

6. In combination, a condenser, a circuit including a resistance shunted across said condenser, a second circuit including an electron discharge device also shunted across said condenser, means for periodically generating a pulse, a pair of high vacuum electron discharge devices each having an input circuit and an output circuit, means for interconnecting the input and output circuits of the two electron discharge devices, means for connecting said condenser in the output circuit of the second electron discharge device of the pair of electron discharge devices, means for connecting the input circuit of the first of said pair of electron discharge devices to the pulse generator so that said pulse generator and the two interconnected electron discharge devices vary the charge on said condenser in one direction periodically and relatively quickly, means including said shunted circuit including a resistance and said shunted circuit including an electron discharge device for varying the charge on said condenser in the opposite direction relatively slowly, and means responsive to the flow of current in said resistance due to said variation in charge on said condenser for controlling the flow of current through said electron discharge device in said second circuit.

7. In combination, a cathode ray tube having at least one anode, and a pair of deflecting plates adjacent said anode, a condenser, a circuit including a resistance shunted across said condenser, a second circuit including a first electron discharge device also shunted across said condenser, means for varying the charge on said condenser in one direction, means including said two circuits for varying the charge on said condenser in the opposite direction, a second electron discharge device having input and output circuits, means for connecting said resistance in said input circuit, a third electron discharge device having input and output circuits, means for connecting the output circuit of said second electron discharge device to the input circuit of said third electron discharge device, said input circuit of the third electron discharge device including a resistance, means for connecting an inner point of said resistance to the control member of said first electron discharge device, a high resistance connected across said deflecting plates, means for connecting the mid-point of said high resistance to the anode of said cathode ray device, means for connecting the output circuit of said second electron discharge device to one of said pair of deflecting plates and means for connecting the output circuit of said third electron discharge device to the other of said pair of deflecting plates, the input circuit of said third electron discharge device being so arranged that the third electron discharge device serves only as a phase inverter.

8. An electron discharge device having input and output circuits, there being no signals normally applied to the input circuit of said device, a second electron discharge device having input and output circuits, a condenser coupling the output circuit of said first electron discharge device to the input circuit of said second electron discharge device, said condenser having a capacity so low that signals produced in the output circuit of said first electron discharge device are distorted, and means including a circuit between the output circuit of said second electron discharge device and the input circuit of said first electron discharge device to reduce said distortion.

9. In a sweep circuit arrangement wherein the output circuit of an electron discharge device serving as the tube for slowly varying the charge on the sweep condenser in one direction is coupled to the input circuit of a second electron discharge device which serves to amplify the voltage changes across said sweep condenser through a coupling condenser having a capacity so low that distortions in the input wave of the second electron discharge device are produced, the method of compensating, at least in part, for said distortions which comprises feeding back a portion of the energy in the output circuit of said second electron discharge device to the input circuit of said first electron discharge device whereby the waves reaching said coupling condenser are pre-distorted in the reverse direction from said distortions.

10. In combination, a condenser, a charging circuit for said condenser, a second charging circuit for said condenser, and means responsive to the flow of condenser charging current in said first charging circuit for controlling the impedance of said second charging circuit and hence the flow of current through said second charging circuit.

11. In combination, a condenser, a first circuit

for varying the charge on said condenser, a second circuit for varying the charge on said condenser in the same direction as in said first circuit, and means responsive to the flow of condenser variation current in said first circuit for varying the impedance of said second circuit.

12. In combination, a condenser, a first circuit of substantially constant impedance for varying the charge on said condenser, a second circuit for varying the charge on said condenser in the same direction as in said first circuit, and means responsive to the change in condenser variation current in said first circuit for varying the impedance of said second circuit in such a direction that the condenser variation current in said second circuit changes inversely to that in said first circuit.

13. In apparatus for producing saw-tooth voltage waves, the combination with a condenser of means for periodically alternately charging and discharging said condenser comprising two circuits which are effectively in parallel with respect to said condenser, one being a charging and the other a discharging circuit, a unidirectional

electron discharge device having a cathode, an anode and a control member with its cathode and anode serially related to said condenser in one of said circuits, an amplifier comprising a cathode, an anode and a control member, a resistance element serially connected with said cathode and control member of said amplifier, a third circuit effectively in shunt to each of said first two circuits with respect to said condenser, said third circuit including said resistance element, whereby when current is caused to flow through said resistance element due to its connection to said condenser the variations in said current set up a varying voltage difference across said resistance which is impressed on the cathode and control member of said amplifier, and a voltage feedback circuit for impressing across the cathode and control member of said electron discharge device a voltage varying in accordance with said voltage impressed on said amplifier and in a direction which tends to make constant the sum of the currents through said electron discharge device and said resistance element.

WILLIAM A. KNOOP.