

Oct. 17, 1944.

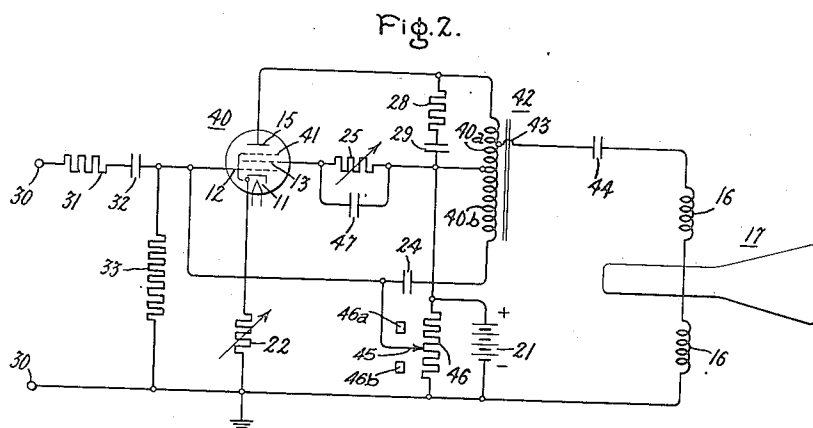
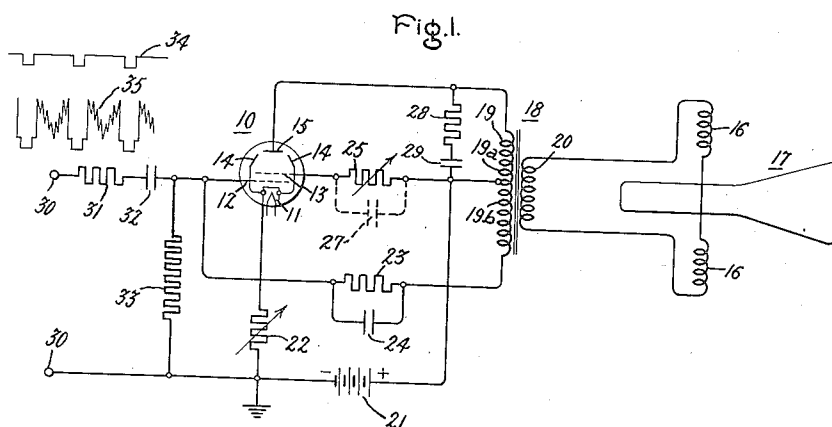
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2,360,697

SAWTOOTH WAVE GENERATION

Filed Jan. 27, 1942

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

Fig. 3.

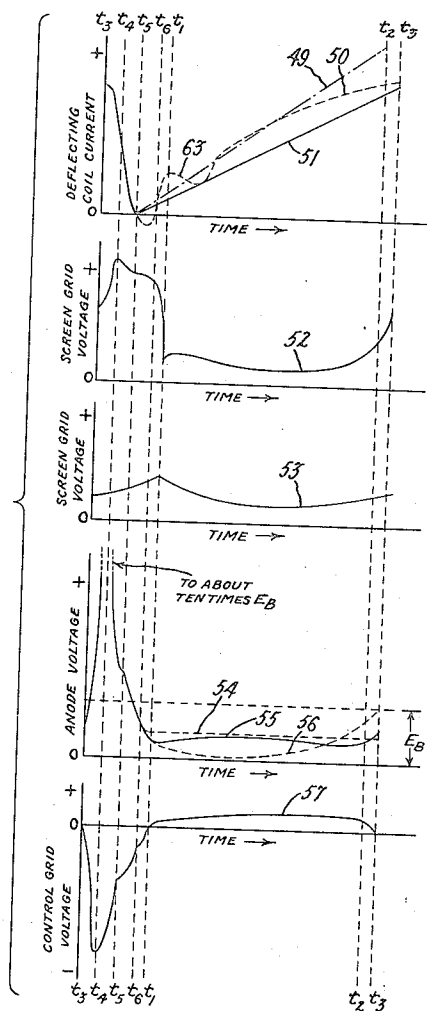


Fig. 4.

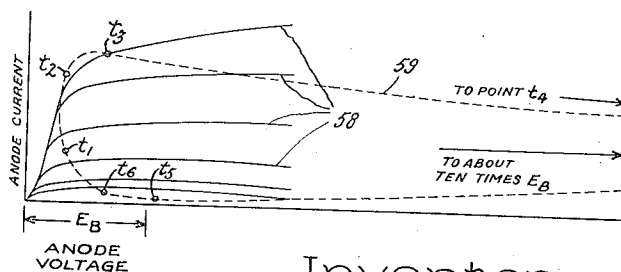
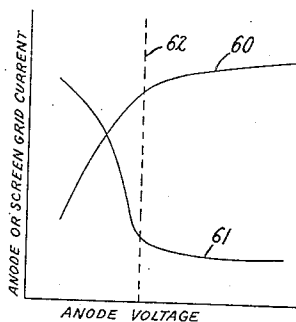


Fig. 5.



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UNITED STATES PATENT OFFICE

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SAW-TOOTH WAVE GENERATION

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Application January 27, 1942, Serial No. 428,395

11 Claims. (Cl. 175-335)

My invention relates to sawtooth wave generation and particularly to oscillator circuits adapted to supply deflecting currents of linear sawtooth wave form to cathode ray devices and the like.

It is an object of my invention to provide improved means for generating sawtooth sweep waves, for oscillographic wave form analysis, television picture scanning, and similar applications, having a high degree of linearity during the useful portion of the sweep cycle.

It is also an object of my invention to provide an improved power oscillator circuit which requires only one thermionic tube and which is adapted to supply substantially sawtooth sweep waves to a magnetic deflecting coil circuit.

Still another object of my invention is to provide an improved sweep power oscillator which is simple and inexpensive, which requires a minimum number of component parts, and which nevertheless gives good electrical performance.

In preferred embodiments of my invention a beam power amplifier or pentode amplifier is utilized to generate the scanning waves supplied to the inductive sweep coils of a cathode ray device. In these preferred embodiments an inner control grid is utilized as the oscillator triggering element in the generation of the sweep waves and an outer screen grid is utilized primarily as a wave shaping element. In accordance with the principles of my invention, fully set forth in the following specification, the organization and adjustment of the circuit elements are such that the output current wave form is substantially linear over the entire active trace interval.

The features of my invention which I believe to be novel are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings, in which Fig. 1 is a circuit diagram of one embodiment of the invention; Fig. 2 is a circuit diagram of a modified form of the invention; Figs. 3, 4 and 5 are graphs illustrating certain operating characteristics of the circuits of Figs. 1 and 2 for particular operating conditions and adjustments described in the accompanying specification.

In the circuit of Fig. 1 the tube 10 is represented as a well-known form of beam power

amplifier having an indirectly heated cathode 11, inner control grid 12, outer screen grid 13, a pair of beam-forming plates 14, and an anode 15.

The sweep waves, generated in the circuits associated with the device 10, in a manner to be described shortly in detail, are supplied to the deflecting coils 16 of a cathode ray device 17 through an output coupling transformer 18 having a tapped primary winding 19 and a secondary winding 20. The cathode ray device 17 is represented only in outline form, since it may comprise any well-known form of tube having magnetic ray-deflecting coils associated therewith. For example, it may be an image producing tube such as is used in oscillographic or television receiving apparatus; or it may be a camera tube such as is used in television transmitting apparatus. Furthermore, the cathode ray tube will in general have other coordinate ray-deflecting means although only one pair of coils is represented to simplify the drawings.

An anode-to-cathode circuit for the device 10 extends from the anode 15, through the upper portion 19a of the tapped primary winding 19, a suitable source of anode supply potential, represented conventionally by a battery 21, and a variable resistor 22 to the cathode 11. A control grid-to-cathode circuit extends from the control grid 12, through a grid resistor 23 and grid capacitor 24 in parallel, the lower portion 19b of the tapped primary winding 19, potential source 21, and through variable resistor 22 to the cathode 11. A screen grid-to-cathode circuit extends from the screen grid 13, through a variable resistor 25, potential source 21 and variable resistor 22 to the cathode 11.

The two portions 19a and 19b of the primary winding 19 are magnetically coupled in such sense that anode voltage variations are impressed regeneratively upon the control grid 12. It will also be observed that a fixed bias of relatively high positive value is impressed upon the control grid 12 from the source 21. The transformer ratio and other circuit constants are proportioned to provide feedback voltages of sufficient amplitude for the production of sawtooth oscillations, as will be described in a later paragraph where circuit constants of a typical oscillator are given. The circuit therefore operates essentially as an over-coupled or blocking oscillator, as will shortly be explained in greater detail.

Resistor 23 and capacitor 24 together limit the maximum swing of control grid voltage in the

positive direction and maintain an average bias within the dissipation rating of the tube. Their time constant, i. e., product of resistance and capacitance, should be of the same order of magnitude as, or longer than, the period of oscillation. The oscillations developed in the anode circuit are supplied to the deflecting coils 16 from the secondary winding 20 with which they are serially connected.

For reasons that will shortly become apparent, the resistor 25 in the screen grid circuit is represented in Fig. 1 as being unbypassed or, more accurately, bypassed only by its inherent distributed capacity, indicated schematically by the dotted lines 27. The winding 19a is bypassed by a filter network comprising a resistor 28 and capacitor 29 in series for the purpose of damping or suppressing high-frequency parasitic oscillations which would otherwise distort the output wave form.

In television systems it is generally necessary to synchronize the sweep oscillator with other circuit components. This is readily accomplished by injecting synchronizing pulses upon the control grid 12 from any suitable source, not shown, connected to the terminals 30. The input coupling network for the synchronizing signal comprises the series resistor 31 and capacitor 32; and in some cases it may be desirable to employ a coupling resistor 33 between the control grid 12 and ground.

In television receiving systems the synchronizing pulses are usually separated from the complete television signal and supplied to the terminals 30. Synchronizing pulses of such form are represented schematically by the wave 34. The individual pulses in the wave are applied with such polarity as to drive the control grid 12 more negative with respect to the cathode 11. However, in some cases it may be preferable to impress the complete television picture signal upon the grid 12. One well-known form of picture signal is generally represented by the wave 35. By proper adjustment of the oscillator circuit constants, particularly the positive bias on control grid 12, only the most negative portions of the wave 35—corresponding to the synchronizing pulses of the wave 34—can be made effective to trigger the oscillator.

In accordance with common practice the oscillator is adjusted to have a free-running frequency slightly lower than the frequency of the received synchronizing pulses. The variable resistor 22 provides a speed control for adjusting this free-running frequency within limits. It will be observed that this resistor is common to the control grid and anode circuits of the amplifier 10. It provides a small amount of degenerative feedback, in opposition to the regenerative feedback from winding 19b, so that the net regenerative feedback may be adjusted to the proper value to maintain oscillations at the desired frequency.

The circuit of Fig. 2 represents a modified form of the invention. Since it is similar in many respects to that of Fig. 1 and fundamentally operates in the same manner, it is believed unnecessary to describe all of its features in detail. Therefore attention is particularly directed only to those points wherein it differs from the embodiment of Fig. 1. Corresponding elements have been designated by corresponding reference numerals wherever possible.

In the Fig. 2 modification, the oscillator-amplifier 40 is represented as being of the pentode type having a suppressor grid 41 in place of the beam-

forming electrodes 14. It will of course be understood that my invention is not limited to the use of any particular type of amplifying device. Various known types of tubes having at least two control electrodes may be employed. The tubes shown in the drawings are merely representative of two alternative types which I have found to be satisfactory.

In the embodiment of Fig. 2, the deflecting coils 16 are energized from an autotransformer 42 having sections 40a and 40b corresponding generally to sections 19a and 19b of the transformer 18 of Fig. 1. The deflecting coils 16 in this case are connected between a tap 43 on the section 40a and ground. A blocking capacitor 44 is also included in the deflecting coil circuit to isolate the deflecting coils from the voltage of the source 21.

In this modification the bias on the control grid 12 is made adjustable by a connection to a tap 45 on a voltage divider 46 connected across the anode supply source 21. A pair of mechanical stops 46a and 46b limit the movement of tap 45 to an intermediate portion of divider 46. This permits adjustment of the linearity of sweep to a limited extent, by permitting adjustment of the total damping of the circuit. The main control of linearity in either of the illustrated forms of the invention is effected by the screen grid resistor 25, as will shortly be explained in greater detail. It has also been found by test that adjustment of the position of the variable tap 45 provides adjustment of the mean potential on control grid 12 for most favorable synchronization in the presence of a combined picture signal including both video signals and synchronizing pulses, as indicated schematically by the wave 35 in Fig. 1. This follows from the fact that this adjustment changes the level at which portions of the picture signals become effective to drive the control grid 12 negative.

In the modification of my invention illustrated in Fig. 2 the screen grid resistor 25 is represented as being bypassed by a physical capacitor 47. For reasons that will be explained later, this capacitor is relatively small, being only large enough to bypass some of the higher frequency components present in the screen grid current waves. It must have an appreciable impedance at the fundamental sweep frequency, as compared to the impedance of resistor 25, if the improved results obtainable in accordance with my invention are to be realized.

The electrical characteristics of the circuits of Figs. 1 and 2 for certain operating conditions shortly to be described, are represented graphically by the curves of Figs. 3, 4 and 5. The solid line curves in Fig. 3 are drawn from actual oscillographic observations made during tests on one particular form of apparatus embodying the invention. The dashed curves are derived from theoretical considerations. The curves 49, 50 and 51 represent current variations in the deflecting coil circuit; the curves 52 and 53 represent screen grid voltage variations; the curves 54, 55 and 56 represent anode voltage variations; and the curve 57 represents control grid voltage variations. The ordinates of the voltage variation curves are not to the same scale. Their wave shapes only are to be compared. All of these curves are positioned one above another with reference to a common time axis. Each of the six vertical dashed lines marked t_1 , t_2 , t_3 , t_4 , t_5 , and t_6 , respectively, intersects all curves at 75 points representative of their values at a corre-

sponding instant of time within one complete cycle of operation. Reference will be made to these instants of time in the analysis of operation presented below.

The curves of Fig. 4 are theoretical curves illustrating the tube and load characteristics for the operating conditions represented by the curves of Fig. 3. The curves 58 are conventional static characteristic curves. The dashed curve 59 is a derived load characteristic curve. This curve 59 takes into account only the currents flowing in the inductive portions of the circuits, capacity current effects being neglected. The various points t_1 , t_2 , t_3 , t_4 , t_5 , and t_6 on the load curve 59 illustrate the load characteristics during one cycle at the instants of time correspondingly indicated in Fig. 3.

Fig. 5 graphically represents the manner in which the anode and screen grid currents vary in a typical pentode or beam power amplifier, as the anode voltage is varied, for one value of control grid voltage. Curve 60 represents the static anode characteristic and curve 61 represents the corresponding static screen grid characteristic.

The adjustment and operation of the circuits of Figs. 1 and 2 will become apparent from a consideration of the curves of Figs. 3, 4, and 5 in conjunction with the following description, in which one complete cycle of operation is analyzed.

To simplify the analysis, let it be assumed for the present that the screen grid voltage is maintained at some constant value over the entire cycle. Now consider the various voltages and currents at the instant of time t_1 . At this instant the control grid voltage is nearly zero and is rising in the direction of positive grid voltage as a result of feedback from the anode circuit. The anode resistance of the amplifier is now relatively low and the anode voltage is also low.

During the time interval t_1-t_2 the anode current and the deflecting coil current rise at a rate determined primarily by the effective transformer inductance and the reflected inductance of the sweep coils. If the load circuit contained only pure inductance, the deflecting coil current would rise at a uniform rate, for example, as shown by the dashed line 49, and the anode voltage would correspondingly remain constant, for example as shown by the horizontal dashed line 54. However, the circuit is unavoidably loaded by various resistive and capacitive components which tend to decrease the rate of rise of the anode current and deflecting coil current, particularly toward the end of the trace interval. Consequently, under the assumed conditions the deflecting coil current tends to vary in the manner represented approximately by the dashed curve 50, and the anode voltage tends to vary in the manner represented approximately by the dashed curve 56.

The resistive components mentioned in the preceding paragraph primarily include the transformer core loss, the resistance reflected into the transformer primary from the sweep coil circuit and the internal resistance of the tube itself. The capacitive components are largely comprised by the distributed capacity of the transformer windings, referred to the primary side, and the interelectrode capacity of the tube.

It will be seen from Fig. 4 that conditions of anode current saturation are approached at the instant t_2 . The limitation in the rate of rise of the anode current causes the anode voltage to rise, as is evident from the curve 56. This in turn causes the voltage of the control grid to

decrease due to the regenerative feedback from the anode circuit. The curve 57 also shows that the control grid, which is maintained positive by the rising anode current throughout this interval, has its most positive value just prior to the instant t_2 . Due to the continuing loss of charge on the grid blocking capacitor 24, caused by flow of grid current during the interval just prior to instant t_2 , an increasingly negative component of grid voltage is developed. The net grid voltage therefore starts to fall at instant t_2 .

Since all of these effects are highly cumulative, the anode current starts to fall and begins to decrease very rapidly near the instant of time t_3 . When this occurs the control grid is rapidly driven to high negative potential values in the interval t_3-t_4 by the inductive voltage surge in the transformer primary winding. The internal resistance of the tube consequently rises to a very high value and the anode current decreases at a rate determined largely by the circuit and tube capacities. If the circuit elements are carefully designed, these capacities can be made low enough to provide a retrace interval t_3-t_5 which is a small fraction of the time period of a complete cycle.

During the time interval t_3-t_1 the anode voltage goes through approximately a half-cycle of oscillation at a high frequency. This frequency is determined primarily by the circuit and tube capacities and by the reflected load inductance, and it may be of the order of ten times the operating frequency in the ordinary case. The anode voltage increases until the instant t_4 at which time the anode resistance of the tube and the circuit capacities become effective in absorbing the anode voltage surge. It will be observed from Fig. 3 that this surge may reach the value of the order of about ten times the anode supply potential E_b . The control grid and anode voltage surges then decrease until, at the instant t_5 , the anode current again begins to increase in the positive direction. If the transformer and coils have low distributed capacity the coil current will also start its forward trace at instant t_5 . Otherwise, the start of the forward trace will be slightly delayed.

During the time interval t_3-t_1 the tube operates in the region of negative control grid voltages. Therefore during the fraction t_5-t_1 of the active trace interval the control grid exercises some control over the wave form of the anode and deflecting coil currents; that is, the linearity of sweep within this interval may be slightly affected by adjustment of the values of the grid resistor 23 and grid capacitor 24 in the modification of Fig. 1, or by adjustment of the tap 45 on the resistor 46 in the modification of Fig. 2. However, during the entire interval of trace t_5-t_2 the principal quantities influencing the linearity of rise in deflecting coil current under the assumed condition of fixed screen voltage are the transformer and sweep coil inductances, referred to the primary side of the transformer.

The function of the series resistor 28 and capacitor 29 connected across the anode circuit is to suppress high frequency transient or parasitic oscillations which would otherwise be caused by the anode voltage surge in the vicinity of the point t_5 . The manner in which the deflecting coil current curve would otherwise be distorted by these parasitic oscillations is approximately indicated by the dotted oscillatory curve portion 63 in Fig. 3. An alternative method of damping such parasitic oscillations is to replace capacitor

29 with an inductance of the same order of magnitude as the deflecting coil inductance reflected into that portion of the transformer primary winding included in the anode circuit. As a further modification, such a damping circuit may be connected across the deflecting coils providing a suitably corrected value of damping inductance is employed.

The operation of the system has now been traced through one complete cycle under the assumed conditions of fixed screen grid potential. It has been shown that the sweep current tends to be distorted from its desired linear sawtooth wave form, particularly toward the end of the active trace interval t_1-t_2 , as shown by the curve 50 due to circuit damping effects. It now remains to investigate the circuit operation in somewhat greater detail to show how the screen grid is utilized to control the deflecting coil current wave shape during the interval t_1-t_2 and how the linearity of sweep during this interval is thereby materially improved in accordance with the principles of my invention.

As previously mentioned, the static characteristic curves 60 and 61 of Fig. 5 illustrate respectively the manner in which the anode and screen grid currents vary as a function of anode voltage, for one fixed value of control grid voltage, in a typical pentode or beam power amplifier. It is a familiar fact that so long as the anode voltage exceeds a certain value, indicated approximately by the vertical line 62, the division of total space current between anode and screen grid is substantially independent of anode voltage.

It is also well known that for values of anode voltage so low that an effective virtual cathode is formed between the anode and screen grid, the currents to these respective electrodes vary in a manner shown by the portions of the curves 59 and 60 to the left of the vertical dashed line 62. In this operating region it will be seen that the screen grid takes a greater proportion of the total space current and the anode takes a correspondingly smaller proportion as the anode voltage decreases. It is further important to note that this relation is distinctly non-linear, i. e., the screen grid current curve has a pronounced curvature in this region, as shown. So long as space charge conditions limit the space current, the control grid voltage determines the magnitude of the space current but does not affect the manner in which space current flowing to the anode and to the screen grid is divided between them.

Referring again to Figs. 3 and 4 of the drawings, the voltage E_s may be regarded as representing a typical value of anode supply potential. It will be apparent that during the time interval t_1-t_2 the instantaneous anode voltage is very low as compared to this value. Consequently, the anode and screen grid currents in this region are dependent upon the anode voltage, for the reasons outlined in the preceding paragraph.

In accordance with my invention this interdependence between screen grid current and anode voltage is utilized to improve the linearity of trace. In the interval t_1-t_2 the linearity of trace is regulated primarily by the impedance in the screen grid circuit, which causes the screen grid voltage to vary degeneratively in response to variations in the anode voltage. For example, the curve 52 in Fig. 3 shows how the screen grid voltage varied in a particular case when the screen grid resistor had a value of the order of 2500 ohms and was unbypassed by any external capacity. It will be observed that the screen

grid voltage curve 52 is concave upward over most of the interval t_1-t_2 . It is also important to note that this curvature is greatest during the latter portion of this interval when the tendency for the deflecting coil current curve 50 to become concave downward, due to the circuit damping effects previously described, is also greatest.

It has been found that, by proper adjustment of the screen grid resistor 25, the resultant variation in deflecting coil current can be made almost perfectly linear, as the experimental curve 51 clearly shows. It is not easy to analyze this phenomenon mathematically, since the wave form of the deflecting coil current depends upon a number of variables which are related in a complex manner. However, observations and experiments indicate that the form of the screen grid voltage curve 52 is primarily due to the previously described non-linear relationship between screen grid current and anode voltage within the interval t_1-t_2 . As the anode voltage decreases with increasing anode current in the interval t_1-t_2 , the screen grid current increases, but at a constantly decreasing rate due to this non-linear relationship. Consequently, through the action of the screen grid resistor 25, the screen grid voltage curve 52 is caused to have the concave upward curvature observed in actual practice. Additional upward swing of screen grid voltage occurs in the interval t_2-t_3 because of the slight increase of anode voltage and increase of anode current during this interval.

It is well known that a variation in screen grid voltage causes a variation in the transconductance of the amplifier in the same sense; or expressed in another way, the internal anode-to-cathode impedance of the amplifier varies inversely with variations in the screen grid voltage. Consequently, the screen grid voltage variations cause the anode voltage to follow the curve 55, as actually observed, instead of the dashed curve 56.

Now consider very briefly a complete cycle of operation taking into account the effect of the screen grid variations during the cycle. It will be observed from the actual test curve 55 in Fig. 3 that the anode voltage variations closely approach the theoretical curve 54 and that the curve 55 has an opposite curvature over most of the interval t_1-t_2 from the curvature of the uncompensated anode voltage variation curve 56. (The small remaining curvature in the curve 55 is apparently necessary to correct for capacity effects and for losses in the anode, control grid, and deflecting coil circuits which have been neglected in order to simplify the analysis.)

During the interval t_2-t_3 the deflecting coil current and the control grid voltage reverse in direction, as previously explained. In the uncompensated circuit this time interval may be an appreciable fraction of the active trace period t_3-t_4 , as is indicated by the relatively gradual change in curvature in the curve 56 near the end of the trace interval. However, by suitable choice of the control grid and screen grid circuit constants, it is possible to increase the speed of reversal of control grid potential, in accordance with the principles of my invention, so that the interval t_2-t_3 becomes practically negligible. This will be evident from the pronounced upward curvature of the voltage curves 52 and 55 and the pronounced downward curvature of the voltage curve 57 in the immediate vicinity of time t_3 . It will also be apparent to those skilled in

the art without detailed explanation that the current and voltage reversals may be accelerated by negative synchronizing pulses applied to the control grid just prior to the time t_3 . The free-running frequency of the oscillator can be adjusted within limits by variation of the resistor 22 so that synchronization is readily obtained at frequencies reasonably close to the free-running frequency of the system.

During the interval t_3-t_4 these current and voltage reversals continue at an increasing rate, causing the anode voltage to reach a high positive peak which may, for example, be of the order of ten times the anode supply potential in the case of a system adjusted to have a retrace interval t_3-t_4 approximately equal to one-tenth of the total period of a cycle.

At the instant t_4 the internal anode-to-cathode resistance of the tube reaches a very high value and the control grid simultaneously reaches its most negative value. The circuit losses and the decrease of charge on grid blocking capacitor 24 caused by current flow through resistor 23 in Fig. 1 and through voltage divider 46 in Fig. 2 limit the anode potential rise at this instant, and therefore the rate of decrease in anode current becomes less, and the induced negative control grid voltage becomes less. As a result, a second reversal of anode and control grid voltages occurs cumulatively, as previously explained.

The deflecting coil current continues to decrease beyond the instant t_4 and up to the instant t_5 , due to the effect of various circuit capacities which cause the natural period of oscillation of the deflecting coil circuit to be longer than the interval t_3-t_4 . Just after the instant t_5 the screen grid current begins to rise very rapidly because the anode voltage is now appreciably lower than the screen grid voltage. At the point t_5 the anode current begins to rise because the control grid voltage is approaching zero potential. The cycle then repeats.

The points of discontinuity in the control grid voltage curve 57 at instants of time t_5 and t_6 have been found to have negligible effect upon the rate of rise of deflecting coil current, providing that the correct values of circuit constants are employed. Capacity currents in the anode circuit also occur at each sharp discontinuity in the cycle, but these do not appreciably affect the current in the deflecting coils and hence have been neglected in the foregoing analysis.

In some cases it may be desirable to provide a small external bypass capacitor in shunt to the degeneration resistor 25 in order to modify the effective impedance in the screen grid circuit. The Fig. 2 modification shows the capacitance 47, in full lines, to represent such capacitor. The curve 53 in Fig. 3 shows the effect upon the screen grid voltage wave form produced by the addition of a small capacitor of the order of .01 mfd., at a sweep frequency of 13,230 cycles per second. It will be observed that this wave is generally of "cusp" form. It will be evident from a comparison with the wave 52 that the higher frequency components in the screen grid current are bypassed around the screen grid resistor and that the concave upward curvature during the time interval t_1-t_2 particularly near the beginning of the interval, is accentuated. Whether any appreciable improvement in linearity of sweep is effected by addition of this external shunt capacity depends upon the damping characteristics of the particular transformer and deflecting coils employed and upon the other constants of the

circuit. The parallel impedance of resistor 25 and any shunt capacity must be large enough to cause the screen grid voltage to follow screen current variations at the fundamental sweep frequency. In other words, the time constant of the screen grid degeneration network must be shorter than the period of the sweep frequency.

Prior art circuits of the blocking oscillator type for generating sawtooth waves have heretofore relied upon a high value of primary inductance in the output transformer circuit to insure reasonable linearity of sweep. Such constructions are not only expensive but fall considerably short of realizing the desired linearity. My improved circuits, on the other hand, require only an inexpensive output transformer of relatively low primary inductance, such as is readily available on the commercial market, and utilize the wave shaping action of the screen grid circuit to compensate for the distortion which would otherwise be caused by the damping characteristics of the transformer and load. Not only is the cost of the apparatus thereby reduced but the wave form of the deflecting currents is more nearly a perfect sawtooth than is obtainable with these more expensive prior art arrangements. The proper value for the screen grid resistor 25 can be readily determined in any particular case by varying its value, or by substituting fixed resistors of different values, and observing oscillographically the effect upon the linearity of the output wave form.

As another advantage of my invention, only a single power tube is required for generating the sweep waves and energizing the deflecting coils. No additional stages of amplification for the sawtooth waves are required. This further contributes to the economy of construction and reduces the possible causes of wave form distortion to a minimum. The high positive bias upon the control grid also contributes to efficient operation by insuring a large swing in grid voltage over the cycle.

It appears to be a fundamental theorem in power oscillators of this general type that the more efficiently the oscillator grid performs its triggering action in sustaining the sawtooth oscillations, the less useful it is for controlling the output current wave form. Consequently, the apparatus embodying my invention has the further advantage that these two functions are largely separated, the control grid 12 being utilized primarily for triggering the beginning of the retrace interval and the screen grid 13 being utilized primarily for wave shaping. It is thus possible to adjust the oscillator frequency and wave form characteristics substantially independently of each other and to proportion the circuit constants so that each control element performs its primary function with the greatest possible efficiency. The inner control grid 12 is best suited for triggering because the mutual conductance between control grid and anode is much higher than the screen-grid-to-anode mutual conductance. Therefore a large swing in grid voltage, which contributes to the attainment of a short retrace time and to efficient oscillator operation, is readily secured with a minimum of grid excitation. Similarly, the screen grid 13 is best suited for wave shaping because of the non-linear relation of the division of anode and screen grid current with variation of anode voltage and control grid bias.

Merely for completeness of illustration, and not by way of limitation, the following circuit constants are given for a particular apparatus

embodying the circuits of Fig. 1. These values were found to give satisfactory results in actual practice in a television line scanning oscillator operating at a synchronized sweep frequency of 13,230 cycles per second. These constants are as follows:

Tube 10: Type 25C6G beam power amplifier.
Sweep coils 16: Effective inductance at 13,230 cycles per second=about one millihenry.

Transformer 18:

Winding 19a: 500 turns.

Winding 19b: 1000 turns.

Winding 20: 100 turns.

Open circuit inductance of winding 19a (with .05 amp. D. C.)=0.6 H.

Inductance of winding 19a with winding 20 short-circuited=18 millihenries.

Source 21=115 volts.

Resistor 22=0-150 ohms (variable).

Resistor 23=30,000 ohms.

Capacitor 24=.003 mfd.

Resistor 25=3,000 ohms (variable—set at about 2,500 ohms).

Capacitor 27=.01 mfd. (external bypass capacitor).

Resistor 28=20,000 ohms.

Capacitor 29=50 mmf.

Resistor 31=50,000 ohms.

Capacitor 32=470 mmf.

Resistor 33=infinite (omitted).

While I have shown particular embodiments of my invention, it will of course be understood that I do not wish to be limited thereto since various modifications may be made, and I contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An oscillation generator for developing a linear sawtooth current wave having a relatively long trace interval and a relatively short retrace interval during each cycle comprising, in combination, an electron discharge device having a pair of control electrodes and an output electrode, means coupling said output electrode to an inductive load, feedback means for regeneratively impressing a voltage wave upon one of said control electrodes in response to current in said output electrode, said voltage wave having sufficient amplitude to cause said device to operate as a blocking oscillator for supplying a sawtooth current wave to said load, said current wave tending to have an undesired curvature in one sense within said trace interval due to circuit damping effects, and means to compensate for said tendency comprising means for simultaneously impressing a voltage wave on the other of said control electrodes having a curvature in the opposite sense within said trace interval.

2. A sweep wave generator for developing current waves of linear sawtooth wave form with relatively long trace intervals and relatively short retrace intervals comprising, in combination, an electron discharge amplifier having inner and outer control electrodes and an output electrode, means coupling said output electrode to an inductive load, means for impressing a regenerative feedback voltage wave upon said inner control electrode in response to current in said output electrode, said voltage wave having sufficient amplitude to cause said device to operate as a blocking oscillator for supplying sawtooth current waves to said load, said waves tending

to have an undesired decreasing rate of rise within said trace interval due to circuit damping effects, and means for causing the voltage of said outer control electrode to rise in response to voltage variations of said output electrode at an increasing rate within said interval and in an amount sufficient to maintain said rate of rise in load current substantially constant.

3. A sawtooth current wave generator comprising, in combination, a thermionic amplifier having at least a cathode, an inner control grid, an outer screen grid and an anode, means for maintaining both said grids and said anode at positive average operating potentials with respect to said cathode, means coupling said anode to an inductive output circuit including a magnetic deflecting coil, means for regeneratively impressing a voltage wave on said control grid in response to output current variations, said device thereby being rendered effective to develop a sustained oscillatory sawtooth current wave in said coil, said current wave tending to have a progressively increasing departure from a constant slope during the rising current portion of each cycle due to undesired damping effects in said amplifier and output circuit, and means for degeneratively impressing a voltage wave on said screen grid which is responsive to anode voltage variations and which has a progressively increasing departure from a constant slope in the opposite sense during said portion of each cycle, thereby to render said slope more nearly constant.

4. An oscillation generator for developing a linear sawtooth current wave having a relatively long trace interval and a relatively short retrace interval comprising, in combination, a thermionic amplifying device having at least a cathode, an inner grid, an outer grid and an anode, a highly inductive output circuit connected between said anode and cathode and including a current coil, an oscillation control circuit connected between said inner grid and cathode, said circuits being regeneratively over-coupled in an amount sufficient to cause development of a sawtooth current wave in said coil, said wave tending to have an undesired curvature during said trace interval due to damping effects in said device and output circuit, a wave form control circuit connected between said outer grid and cathode, and means in said last-mentioned circuit for causing the voltage of said outer grid to follow a voltage-time characteristic having an opposite curvature during said interval, whereby the transconductance of said device is caused to vary in a manner to offset said tendency.

5. In a sweep wave generator, the combination of an amplifying device having a cathode, a control grid, a screen grid and an anode, an inductive load circuit connected from said anode to said cathode, a first control circuit connected from said control grid to said cathode through a source of positive bias potential, said circuits being regeneratively over-coupled to cause said device to generate sustained oscillations of sawtooth form, and a second control circuit connected from said screen grid to said cathode through a non-inductive impedance network, said network having a time constant shorter than the fundamental period of said oscillations.

6. A sweep wave generator for developing current waves of linear sawtooth wave form with relatively long trace intervals and relatively short retrace intervals comprising, in combination, an electron discharge device having inner and outer

control electrodes and an output electrode, means coupling said output electrode to a highly inductive load circuit including a magnetic sweep coil, means responsive to current in said load circuit for impressing regenerative voltages on said inner control electrode sufficient in magnitude to cause said device to supply sawtooth current waves to said coil, said waves tending to have an undesired decreasing rate of rise during at least a portion of said trace interval due to damping effects in said device and output circuit, and means for causing the voltage of said outer control electrode to rise in response to voltage variations of said output electrode at an increasing rate within said interval and in an amount sufficient to maintain said rate of rise in load current substantially constant, said last means comprising a non-inductive degeneration network included in circuit with said outer control electrode and having substantial impedance at the fundamental sweep frequency.

7. A sawtooth wave generator comprising, in combination, a thermionic device having a cathode, a control grid, a screen grid and an anode, a highly inductive load circuit connected between said anode and cathode and including an output transformer and a magnetic deflecting coil, an oscillation control circuit connected between said control grid and cathode including a source of positive bias potential and a non-inductive current-limiting impedance network and a regenerative feedback coil on said transformer, said control circuit being over-coupled to said load circuit for the production of a sawtooth current wave in said coil and having a time constant at least as great as the fundamental period of said wave, and a wave form control circuit connected between said screen grid and cathode and including a non-inductive impedance network, said network having a predetermined impedance at said frequency and a time constant short as compared to said fundamental period.

8. A sweep wave generator for developing a linear sawtooth current wave having a relatively long trace interval and a relatively short retrace interval comprising, in combination, a thermionic amplifying device including a cathode, an inner grid, an outer grid and an anode, a highly inductive output circuit connected between said anode and cathode and including an output coupling transformer and a magnetic sweep coil, a first control circuit connected between said inner grid and cathode and including a source of positive bias potential and a regenerative feedback winding on said transformer, said winding providing sufficient feedback voltage to cause said device to operate as a blocking oscillator for supplying a sawtooth current wave to said coil, said wave tending to have an undesired curvature within said trace interval due to damping effects in said device and output circuit, a second control circuit connected between said outer grid and cathode, and means in said last-mentioned circuit for causing the voltage of said outer grid to follow a voltage-time characteristic having an opposite curvature during the same portion of said trace interval, said means comprising a non-inductive element in said second circuit having substantial impedance at the fundamental sweep frequency.

9. An oscillation generator for developing a

linear sawtooth current wave comprising, in combination, an amplifying device having a cathode, a control grid, a screen grid and an anode, an inductive load circuit connected from said anode to said cathode, a first control circuit connected from said control grid to said cathode through a source of positive bias potential and a grid current limiting impedance, means for regeneratively feeding back voltages from said load circuit to said control circuit sufficient in magnitude to cause said device to generate sustained oscillations of sawtooth wave form, frequency control means comprising a variable resistor common to said circuits for providing a relatively small, adjustable degenerative feedback therebetween, a second control circuit connected from said screen grid to said cathode, and means comprising a non-inductive impedance in said second control circuit for causing the voltage of said screen grid to vary in response to variations in screen grid current at the fundamental frequency of said oscillations.

10. An oscillation generator for developing a linear sawtooth current wave comprising, in combination, an amplifying device having a cathode, a control grid, a screen grid and an anode, an inductive load circuit connected from said anode to said cathode, a first control circuit connected from said control grid to said cathode through a source of positive bias potential and a grid current limiting impedance, means for regeneratively feeding back voltages from said load circuit to said control circuit sufficient in magnitude to cause said device to generate sustained oscillations of sawtooth wave form, a second control circuit connected from said screen grid to said cathode, means comprising a resistance element in said second control circuit for causing the voltage of said screen grid to vary in response to variations in screen grid current at the fundamental frequency of said oscillations, and means to impress negative synchronizing signals on said control grid having a fundamental frequency slightly higher than said oscillation frequency.

11. An oscillation generator for developing a linear sawtooth current wave comprising, in combination, an amplifying device having a cathode, a control grid, a screen grid and an anode, an inductive load circuit connected from said anode to said cathode, a first control circuit connected from said control grid to said cathode through a source of positive bias potential, means for regeneratively feeding back voltages from said load circuit to said control circuit sufficient in magnitude to cause said device to generate sustained oscillations of sawtooth wave form, a second control circuit connected from said screen grid to said cathode, means comprising a non-inductive impedance in said second control circuit for causing the voltage of said screen grid to vary in response to variations in screen grid current at the fundamental frequency of said oscillations, means to impress synchronizing signals on said control grid having portions tending to drive said control grid negative at regularly recurring intervals slightly shorter than the natural period of oscillation, and means to adjust said bias potential so that said grid is driven negative only by said portions.

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