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2,591,914

SELF-SUSTAINING SAWTOOTH CURRENT GENERATOR

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Fig. 1

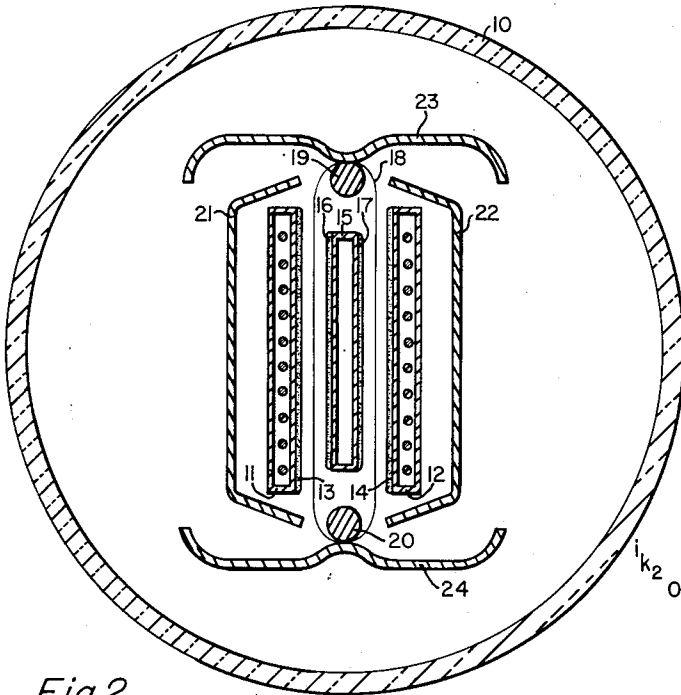


Fig. 2

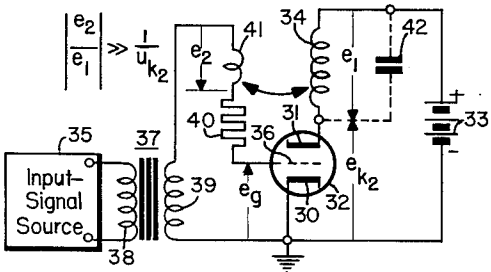


Fig. 4

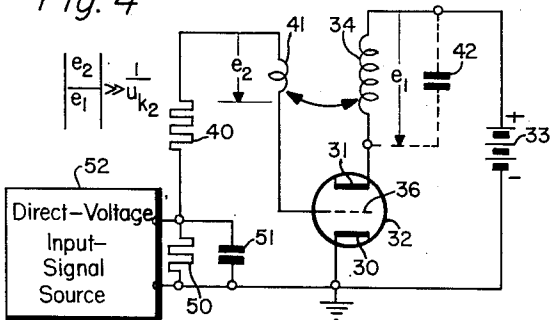
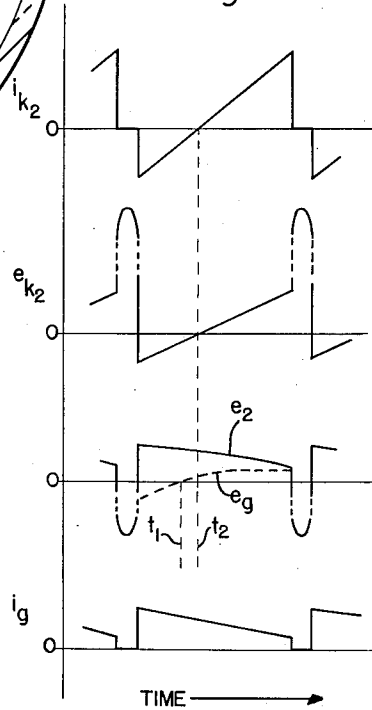


Fig. 3



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2,591,914

SELF-SUSTAINING SAWTOOTH CURRENT GENERATOR

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Application November 26, 1949, Serial No. 129,671

7 Claims. (Cl. 250—36)

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This invention relates to signal-generating apparatus and more particularly to apparatus for generating an output current of sawtooth waveform. It is a primary object of the present invention to provide novel and improved apparatus of this type.

In the copending application of Robert Adler, Serial No. 129,554, filed concurrently herewith for Electron Discharge Device and Circuits and assigned to the present assignee, there is disclosed and claimed a novel type of electron-discharge device having an electron-discharge path capable of passing current of either positive or negative polarity through an associated load circuit. Briefly, such a device comprises a pair of thermionic cathodes spaced from one another along an electron-discharge path and a control grid disposed across the path intermediate the cathodes for controlling electron space current flow therebetween. A device of this type is a versatile new tool in the art and is particularly, although not exclusively, useful in signal-generating apparatus for generating an output current of sawtooth waveform.

Signal-generating apparatus for this purpose, as disclosed and claimed in the Adler application, comprises a bidirectional electron-discharge device between the cathodes of which is coupled the series combination of a source of unidirectional operating potential and a load circuit including an inductor. A control signal, preferably comprising negative-polarity pulses, is applied between the control grid and one of the cathodes periodically to render the device non-conductive. The apparatus also comprises means effectively providing across the load circuit inductor a capacity of magnitude to resonate with the inductor at a predetermined frequency having a period substantially equal to twice the predetermined time duration of the individual control pulses.

In accordance with one particular feature of the invention disclosed and claimed in the Adler application, the input circuit comprises a feedback coil inductively coupled to the output circuit, and the voltage ratio of the feedback coil with respect to the output inductor is preferably made substantially equal to the reciprocal of the effective amplification factor of the bidirectional electron-discharge device as measured from the control grid to the ungrounded cathode. In this manner, the feedback arrangement provides negative pulses in the input circuit so that the amplitude of the required input-signal pulses is reduced.

This arrangement, while providing an output current of substantially sawtooth waveform with a simple circuit comprising a minimum number of components and with a relatively low supply voltage, must in practice be actuated periodically by input pulses. For example, in the event that

one of the input pulses should fail to be applied to the control grid, the output current continues to build-up until the next input pulse arrives. Thus, in some applications, it is possible that the electron space current may become excessive, even to the point of causing failure of the control tube. Such a difficulty may particularly be encountered in the application of the circuit to provide a sawtooth output current for the line-frequency scanning system of a television receiver, in which the line-frequency synchronizing signal pulses are utilized periodically to render the tube non-conductive; it is quite possible in such an application, particularly when the receiver does not provide for automatic frequency control, that a certain number of synchronizing-signal pulses may not be transmitted to the control grid.

It is, therefore, an important object of the invention to provide improved apparatus for generating an output current of sawtooth waveform.

It is a further object of the present invention to provide signal-generating apparatus similar to that disclosed and claimed in the aforementioned copending Adler application, but which is not dependent for successful operation upon regular application of a control pulse.

Still another object of the invention is to provide improved signal-generating apparatus for generating an output current of sawtooth waveform which may be synchronized by input signal pulses of substantially shorter duration than that required for synchronizing the apparatus disclosed and claimed in the above identified copending Adler application.

In accordance with the present invention, apparatus for generating an output current of sawtooth waveform comprises a bidirectional electron-discharge device having a pair of thermionic cathodes spaced from one another along an electron-discharge path and a control electrode disposed along the electron-discharge path intermediate the cathodes, and having an effective amplification factor as measured from the control grid to one of the cathodes. An output circuit including an inductor is coupled between the cathodes, and means are provided for impressing a unidirectional operating potential difference between the cathodes and in series with the output circuit. The apparatus also comprises means effectively providing across the output circuit inductor a capacity of magnitude to resonate with that inductor at a predetermined frequency. An input circuit is coupled to the control grid and to the other cathode and comprises a feedback coil inductively coupled to the output circuit by a voltage ratio substantially greater than the reciprocal of the effective amplification factor for periodically exciting the output circuit into substantially one-half cycle of self-oscillation at the

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frequency determined by the output inductor and the effective capacity thereacross. An input-signal source is coupled to the input circuit to apply an input signal between the control grid and the other cathode to control the times of initiation of the self-oscillation in the output circuit.

Throughout the specification and the appended claims, the term "cathode" is used as definitive of an electrode which is capable of thermionic emission and is not intended to be restricted to an electrode which is connected to the negative terminal of the external circuit. Furthermore, the term "bidirectional," as applied to an electron-discharge device, is to be interpreted to mean that the device is capable of passing current in either direction, as contrasted with prior art devices which are unilaterally conductive only. A "bidirectional" electron-discharge path is thus construed as one which is defined by terminating electrodes each of which is capable of supplying space electrons, so that space current flow may be established in either direction by providing appropriate operating potentials.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may best be understood, however, by reference to the following description taken in connection with the accompanying drawing, in the several figures of which like reference numerals indicate like elements, and in which:

Figure 1 is a cross-sectional view of a bidirectional electron-discharge device which may be used in the apparatus of the present invention;

Figure 2 is a schematic diagram of signal-generating apparatus constructed in accordance with the invention and embodying the device of Figure 1;

Figure 3 is an idealized graphical representation useful in understanding the operation of the present invention, and

Figure 4 is a schematic circuit diagram of another embodiment of the invention.

In Figure 1, which is a cross-sectional view of an electron-discharge device of the type disclosed and claimed in the above-identified Adler application, a pair of thermionic cathodes and a control grid intermediate the cathodes are provided within an evacuated envelope 10. Preferably, the first cathode comprises a pair of members 11 and 12 having thermionically emissive surfaces 13 and 14 respectively. The second cathode 15 is disposed between members 11 and 12 and is provided with a pair of thermionically emissive surfaces 16 and 17 opposite surfaces 13 and 14 respectively. Suitable means are provided for heating members 11 and 12 of the first cathode; for example individual heater elements may be provided for each of these members. A control grid 18, which may be of the parallel-wire type, is arranged to surround second cathode 15, and the conductive grid elements are disposed between second cathode 15 and members 11 and 12. Control grid 18 may be conveniently supported by means of side-rods 19 and 20. Members 11 and 12 are connected together for operation at a common potential by circuit means (not shown) which may be either internal or external of evacuated envelope 10. Heat-shield members 21 and 22 are arranged substantially to surround the cathodes, so that heat developed in the first cathode members is directed inwardly to second cathode 15 to raise the temperature of that cathode

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to a sufficient extent to establish thermionic emission. Since the envelope 10 is evacuated, the only substantial heat loss is by radiation so that heating by radiation, direct as well as reflected, is relatively efficient, and second cathode 15 may be raised to its emission temperature within a relatively short period of time.

In order to prevent overheating of control grid 18, radiating fins 23 and 24 may be welded or otherwise secured to supporting posts 19 and 20 respectively.

The device of Figure 1 is capable of passing electron space current in either direction between the first cathode, comprising members 11 and 12, and the second cathode 15, depending on the relative operating potentials applied to the two cathodes. Thus, at a particular instant of time, second cathode 15 may be maintained at a potential higher than that of first cathode members 11 and 12. In this event, second cathode 15 instantaneously operates as an anode or collector for electrons originating at emissive surfaces 13 and 14. Electrons emanating from emissive surfaces 16 and 17 encounter a retarding field, due to the lower operating potential of first cathode members 11 and 12, and cannot reach the first cathode.

When operated in this manner, additional heat is provided at second cathode 15 by virtue of its plate dissipation in the role of anode with respect to first cathode members 11 and 12.

Conversely, if at another instant of time the first cathode members 11 and 12 are operated at a potential higher than that of second cathode 15, the first cathode members function instantaneously as an anode or collector for electrons originating at emissive surfaces 16 and 17, and electrons emanating from surfaces 13 and 14 are suppressed.

Control grid 18 serves as a convenient means for controlling the electron space current flow between the cathodes constituting the terminating electrodes for the electron-discharge path. At any instant of time, the control grid has an effective amplification factor or mu relative to the terminating electrode acting as anode at that instant, since the device operates instantaneously as a conventional triode. However, the device differs from conventional electron-discharge amplifiers in the bidirectional nature of the discharge path.

As disclosed in the above-identified Adler application, it is also possible to construct a bidirectional electron discharge device generally similar to that shown in Figure 1 but comprising a pair of thermionic cathodes each having a separate heater element. When such a tube having separate heater elements is used, special precautions must be employed to prevent any detrimental effects from the high potential pulses between one of the cathodes and ground. These effects can be prevented by the use of a separate filament transformer for each heater or by the use of sufficient insulation between the ungrounded cathode and its heater.

Figure 2 is a schematic diagram of signal-generating apparatus embodying the device of Figure 1 and constructed in accordance with the present invention. In Figure 2, the cathodes 30 and 31 of a bidirectional electron-discharge device 32 are connected in series with a source of unidirectional operating potential, here shown as a battery 33, and an output circuit including an inductor 34. Inductor 34 may, in some applications, conveniently comprise the primary winding of an output transformer. An input signal

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source 35, which may be a source of negative-polarity pulses, is coupled between the control grid 36 of device 32 and first cathode 30 by means of an input transformer 37 having primary and secondary windings 38 and 39 respectively; the input signal from source 35 may also be applied to the input circuit by other means known to the art, as for example by means of a coupling condenser and a grid resistor. A current-limiting resistor 40 is included in series with secondary winding 39 and control grid 36. First cathode 30 is directly connected to ground.

A feedback coil 41, which is inductively coupled to inductor 34, is coupled in series in the input circuit between resistor 40 and secondary winding 39. In accordance with the invention, the voltage ratio of feedback coil 41 relative to inductor 34 is made materially greater than the reciprocal of the effective amplification factor of control grid 36 with respect to second cathode 31. In other words, the absolute value of the ratio of the voltage e_2 developed across coil 41 to the voltage e_1 across load inductor 34 is made materially greater than the reciprocal of the effective amplification factor μ_{k_2} measured from control grid 36 to second cathode 32, in accordance with the equation

$$\left| \frac{e_2}{e_1} \right| > \frac{1}{\mu_{k_2}} \quad (1)$$

A capacity 42 is provided across output inductor 34; capacity 42 may comprise either a separate circuit element, or the capacity reflected from circuits (not shown) coupled to output inductor 34. This capacity is of suitable magnitude to resonate with inductor 34 at a predetermined natural frequency.

In operation, the device 32 is maintained in a conductive state except for a short interval during each cycle. During the first portion of each conductive period, inductor 34 delivers power to battery 33; during the second half of the conductive cycle, power is delivered from battery 33 to load inductor 34. Since the time rate of change of current from a constant unidirectional voltage source through a constant inductor is constant and dependent only on the ratio of the voltage of the source to the inductance of the load, the output current during the conductive period is of constant slope, and this slope may be adjusted to any desired value by suitable selection of operating potential and load inductance. If there were no losses in the circuit, the net direct-current component would be zero, due to the bidirectional character of the current in the series circuit comprising device 32, inductor 34, and battery 33.

Particular reference is now made to Figure 3, comprising idealized graphical waveform representations of the second-cathode current i_{k_2} , second-cathode voltage e_{k_2} , feedback voltage e_2 across coil 41, control grid voltage e_g , and control grid current i_g plotted as functions of time. The apparatus of Figure 2 constitutes a self-sustaining sawtooth current generator. For purposes of explanation, let it be assumed that the circuit is operating in a self-sustaining manner without application of an input signal from source 35. As the output current i_{k_2} builds up at a rate determined by the voltage of source 33 and the inductance of inductor 34, the voltage e_{k_2} of the second cathode 31 with respect to ground also increases. Coil 41 is arranged to provide 180° phase reversal, so that the feedback voltage e_2 appearing across coil 41 falls from a maximum positive value at the beginning of the conductive period

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to a somewhat smaller positive value at the end of the conductive period. During this period, grid current is drawn first from cathode 31 and later from cathode 30. The voltage e_g applied to control grid 36 is represented by the dotted curve, building up from a slightly negative value at the beginning of the sweep cycle to a maximum positive value at the end of the conductive period; the difference between the voltage e_2 fed back by way of coil 41 and the control grid voltage e_g is determined by the value of limiting resistor 40. Consequently, the control grid voltage e_g is limited and cannot exceed the instantaneous voltage fed back by way of coil 41. However, the second cathode voltage e_{k_2} is not limited as is the control grid voltage, but rises with increasing output current i_{k_2} at a rate determined by the voltage drop across device 32. Consequently, the effective transconductance of control grid 36 with respect to second cathode 31 rises sharply toward the end of the conductive period as the control grid voltage e_g approaches its limited maximum. When this effective transconductance has built up to a predetermined critical value, substantially one-half cycle of self-oscillation is induced in the output circuit comprising inductor 34 and capacity 42 at a frequency determined by these elements. The initial sharp rise in second cathode voltage e_{k_2} at the commencement of the free oscillation in the output circuit induces a large negative pulse across feedback coil 41 which operates to render device 32 non-conductive. When substantially one-half cycle of free oscillation has been completed, the second cathode voltage e_{k_2} has returned to its negative value with respect to ground, and the potential of control grid 36 again becomes positive, thereby rendering device 32 once again conductive. The cycle is then repeated.

Since the control grid voltage is always positive with respect to one of the cathodes 30 and 31 except during flyback, grid current i_g flows during the entire conductive period. While the grid current i_g may be of considerable magnitude, the voltages required are small so that the power dissipation in the input circuit is not excessive. Most of the required driving power is derived from the output circuit by feedback to the input circuit through coil 41, so that little power is required from source 35 to synchronize the output current.

The output current i_{k_2} is of substantially sawtooth waveform, modified to the extent that the output current is zero during the flyback period. During the first portion of the conductive period, electrode 30 serves as anode and electrode 31 as cathode; during the latter portion of the conductive period, the functions of these electrodes are reversed. Ideally, the current would reverse direction exactly in the middle of the conductive period, so that the peak positive and negative currents would be equal; in such a case, no direct-current component would appear in the output. In practice, however, the load is not purely inductive and some voltage drop is required between the cathodes to obtain the required flow of current, so that there is an energy loss during each cycle, and the negative current after flyback is of smaller magnitude than the positive current at the end of the conductive period. Consequently there is a small net direct-current component in the output.

In order to maintain the impedance of device 32 low at all times during the conductive period, thereby to avoid further energy loss and non-

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linearity in the output current waveform, it is desirable to select the values of the several circuit components so that the voltage e_g of control grid 36 with respect to ground changes sign somewhat before voltage e_{k_2} of the second cathode with respect to ground swings from negative to positive. This operation has been illustrated in the graphical representation of Figure 3, in which the grid voltage e_g swings through zero at a time t_1 slightly before the time t_2 when the voltage e_{k_2} changes sign.

It is noted that the waveforms of Figure 3 are drawn to different scales, the pulses appearing at the second cathode during flyback being in fact many times larger in peak value than the negative control pulses applied to grid 36.

Thus, the apparatus schematically illustrated in Figure 2 constitutes a self-sustaining sawtooth current generator. To provide increased stability to adapt the system of Figure 2, for example, to drive the deflection coils associated with the image reproducing device of a television receiver, it may be desirable to impress on the input circuit negative-polarity pulses from source 35 for controlling the times of initiation of self-oscillation in the output circuit, thereby to synchronize the output current. However, these pulses may be of small magnitude and duration, since the voltage fed back by way of coil 41 serves to maintain device 32 in a non-conductive state once cut-off has been established until the potential of second cathode 31 again becomes negative. Furthermore, in the event that one of the negative-polarity input pulses should be absent, overloading of device 32 by excessive current build-up is prevented by the inherent self-sustaining characteristic of the circuit when the effective transconductance of the control grid 36 with respect to second cathode 31 exceeds a predetermined critical value.

It is also possible, in accordance with the invention, to utilize a varying direct-voltage input signal to control the times of initiation of the self-oscillation in the output circuit. In Figure 4, a resistor 50 is included in the series input circuit, and a bypass condenser 51 is connected in parallel with resistor 50. A source 52 of direct-voltage input signals, as for example, an automatic - frequency - control potential source, is coupled across resistor 50. Current-limiting resistor 40 is connected between feedback coil 41 and resistor 50. In all other respects, the circuit of Figure 4 is identical with that of Figure 2.

With the arrangement of Figure 4, the initiation time of the self-oscillation in the output circuit comprising inductor 34 and capacity 42 is controlled by varying the bias potential of control grid 36. The time of initiation of self-oscillation is determined by the length of time, from the beginning of the sweep cycle, required to build-up an effective transconductance of control grid 36 with respect to second cathode 31 which exceeds the predetermined critical value required to produce oscillation. When no unidirectional bias potential is supplied from source 52, self-oscillation is induced at a predetermined time t_0 after the beginning of the sweep cycle. If, now, a negative bias potential is applied from source 52 to the input circuit, the effective transconductance of control grid 36 with respect to second cathode 31 builds up to the required critical value for oscillation more rapidly, and self-oscillation is initiated at a time $t_0 - \Delta t$ after the beginning of the sweep cycle, which is less than

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that required when no bias potential is supplied. Conversely, if a positive bias potential is applied in the input circuit from source 52, self-oscillation is initiated only after a longer time $t_0 + \Delta t$. Thus, control of the frequency of the output current may conveniently be effected by merely varying the bias applied to the control grid.

As a further alternative, the frequency of the output current may be controlled by varying the self-bias of the control grid by means of a variable element in the input circuit. For example, resistor 50 may be of variable size for this purpose.

Thus, the present invention provides novel apparatus for generating an output current of sawtooth waveform. In particular, the invention provides a self-sustaining sawtooth current generator which may be controlled either by short pulses of small magnitude and duration or by a varying direct-voltage input signal. Because the apparatus is self-sustaining, current build-up is limited to a predetermined maximum, so that none of the circuit components can be subjected to overloading.

While particular embodiments of the present invention have been shown and described, it is apparent that various changes and modifications may be made, and it is therefore contemplated in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

I claim:

1. A self-sustaining sawtooth current generator comprising: a bidirectional electron-discharge device having a pair of thermionic cathodes spaced along an electron-discharge path and a control electrode disposed across said path intermediate said cathodes, and having an effective amplification factor as measured from said control electrode to one of said cathodes; an output circuit, including an inductor and having a predetermined natural resonant frequency, coupled between said cathodes; means for impressing a unidirectional operating potential difference between said cathodes and in series with said inductor; and an input circuit coupled to said control grid and to the other of said cathodes and comprising means inductively coupled to said output circuit by a voltage ratio materially greater than the reciprocal of said amplification factor for periodically exciting said output circuit into substantially one-half cycle of self-oscillation at said predetermined frequency.

2. A self-sustaining sawtooth current generator comprising: a bidirectional electron-discharge device having a pair of thermionic cathodes spaced along an electron-discharge path and a control electrode disposed across said path intermediate said cathodes, and having an effective amplification factor as measured from said control electrode to one of said cathodes; a source of unidirectional operating potential and an output circuit including an inductor coupled in series between said cathodes; means effectively providing across said inductor a capacity of magnitude to resonate with said inductor at a predetermined frequency; an input circuit coupled to said control grid and to the other of said cathodes and comprising a feedback coil inductively coupled to said inductor by a voltage ratio materially greater than the reciprocal of said amplification factor for periodically exciting said output circuit into substantially one-half cycle of self-oscillation at said predetermined frequency; and an input-signal source for applying an input signal between

said grid and said other cathode to control the times of initiation of said self-oscillation.

3. A self-sustaining sawtooth current generator comprising: a bidirectional electron-discharge device having a pair of thermionic cathodes spaced along an electron-discharge path and a control grid disposed across said path intermediate said cathodes, and having an effective amplification factor as measured from said grid to one of said cathodes; an output circuit including an inductor coupled between said cathodes; means for impressing a unidirectional operating potential difference between said cathodes and in series with said output circuit; means effectively providing across said inductor a capacity of magnitude to resonate with said inductor at a predetermined frequency; an input circuit coupled to said control grid and to the other of said cathodes and comprising a feedback coil inductively coupled to said inductor by a voltage ratio materially greater than the reciprocal of said amplification factor for periodically exciting said output circuit into substantially one-half cycle of self-oscillation at said predetermined frequency; and an input-signal source for applying an input signal between said grid and said other cathode to control the times of initiation of said self-oscillation.

4. A self-sustaining sawtooth current generator comprising: a bidirectional electron-discharge device having a pair of thermionic cathodes spaced along an electron-discharge path and a control grid disposed across said path intermediate said cathodes, and having an effective amplification factor as measured from said grid to one of said cathodes; an output circuit including an inductor coupled between said cathodes; means for impressing a unidirectional operating potential difference between said cathodes and in series with said output circuit; means effectively providing across said inductor a capacity of magnitude to resonate with said inductor at a predetermined frequency; an input circuit including an inductor coupled to said control grid and to the other of said cathodes and comprising a feedback coil inductively coupled to said output circuit by a voltage ratio materially greater than the reciprocal of said amplification factor for periodically exciting said output circuit into substantially one-half cycle of self-oscillation at said predetermined frequency; and a source of control pulses individually of time duration no greater than one-half period of said predetermined frequency coupled to said input circuit inductor for applying an input signal between said grid and said other cathode to control the times of initiation of said self-oscillation.

5. A self-sustaining sawtooth current generator comprising: a bidirectional electron-discharge device having a pair of thermionic cathodes spaced along an electron-discharge path and a control grid disposed across said path intermediate said cathodes, and having an effective amplification factor as measured from said grid to one of said cathodes; an output circuit including an inductor coupled between said cathodes; means for impressing a unidirectional operating potential difference between said cathodes and in series with said output circuit; means effectively providing across said inductor a capacity of magnitude to resonate with said inductor at a predetermined frequency; an input circuit including an inductor coupled to said control grid and to the other of said cathodes and comprising a feedback coil inductively coupled to said out-

put circuit by a voltage ratio materially greater than the reciprocal of said amplification factor for periodically exciting said output circuit into substantially one-half cycle of self-oscillation at said predetermined frequency; and a source of negative-polarity control pulses individually of time duration less than one-half period of said predetermined frequency coupled to said input circuit inductor for applying an input signal between said grid and said other cathode to control the times of initiation of said self-oscillation.

6. A self-sustaining sawtooth current generator comprising: a bidirectional electron-discharge device having a pair of thermionic cathodes spaced along an electron-discharge path and a control grid disposed across said path intermediate said cathodes, and having an effective amplification factor as measured from said grid to one of said cathodes; an output circuit including an inductor coupled between said cathodes; means for impressing a positive unidirectional operating potential on said one cathode through said output circuit; means effectively providing across said inductor a capacity of magnitude to resonate with said inductor at a predetermined frequency; an input circuit coupled to said control grid and to the other of said cathodes and comprising a feedback coil inductively coupled to said inductor by a voltage ratio materially greater than the reciprocal of said amplification factor for periodically exciting said output circuit into substantially one-half cycle of self-oscillation at said predetermined frequency; and means for varying the bias of said control grid to control the times of initiation of said self-oscillation.

7. A self-sustaining sawtooth current generator comprising: a bidirectional electron-discharge device having a pair of thermionic cathodes spaced along an electron-discharge path and a control grid disposed across said path intermediate said cathodes, and having an effective amplification factor as measured from said grid to one of said cathodes; an output circuit including an inductor coupled between said cathodes; means for impressing a unidirectional operating potential difference between said cathodes and in series with said output circuit; means effectively providing across said inductor a capacity of magnitude to resonate with said inductor at a predetermined frequency; an input circuit coupled to said control grid and to the other of said cathodes and comprising a feedback coil inductively coupled to said inductor by a voltage ratio materially greater than the reciprocal of said amplification factor for periodically exciting said output circuit into substantially one-half cycle of self-oscillation at said predetermined frequency; a resistor and a condenser connected in parallel in said input circuit; and a direct-voltage input-signal source coupled to said resistor for varying the bias of said control grid to control the times of initiation of said self-oscillation.

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