Dec. 21, 1948. G. C. SZIKLAI 2,456,754

ELECTRONIC SAW TOOTH PULSE GENERATOR

Filed March 20, 1945

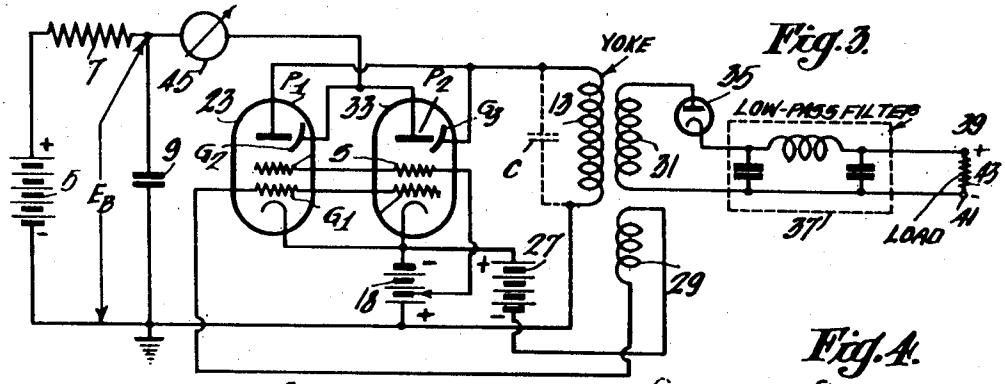


Fig. 3.

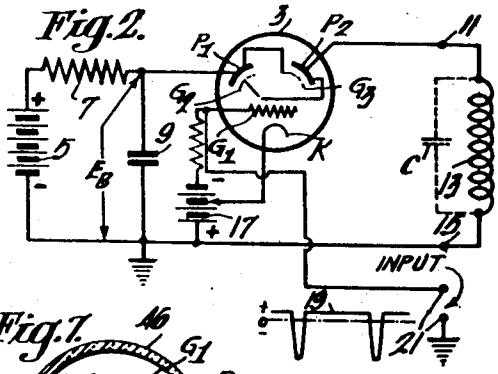


Fig. 2.

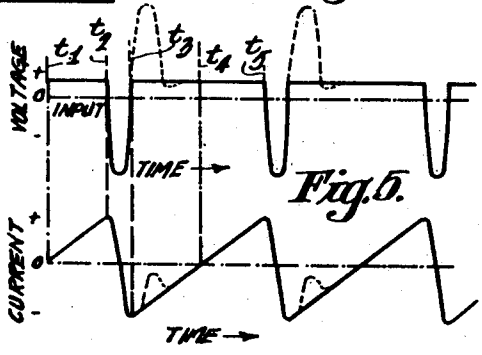


Fig. 4.

Fig. 5.

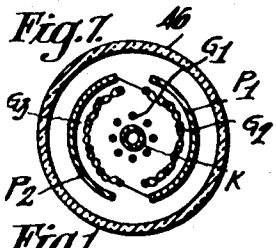


Fig. 7.

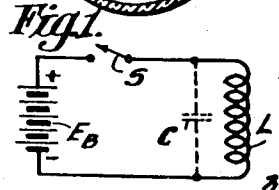


Fig. 1.

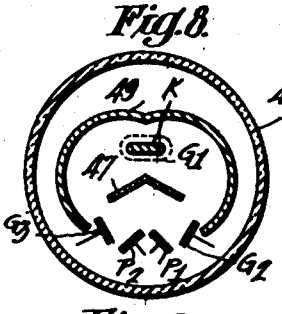


Fig. 8.

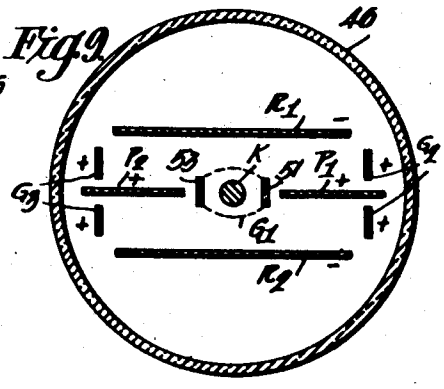


Fig. 9.

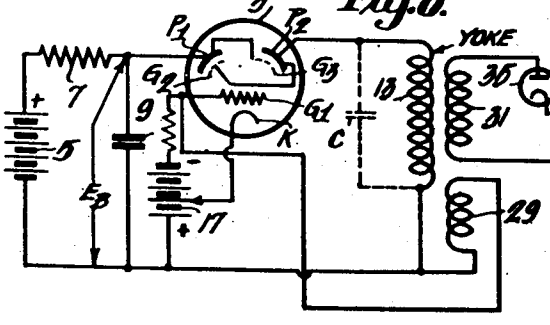


Fig. 6.

INVENTOR.
George C. Szikłai
BY
ATTORNEY

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ELECTRONIC SAW-TOOTH PULSE GENERATOR

George C. Sziklai, Princeton, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application March 20, 1945, Serial No. 583,801

9 Claims. (Cl. 171—97)

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This invention relates generally to electronic apparatus and more particularly to improved saw-tooth pulse generators and electronic switching tube apparatus employed therewith.

The invention relates specifically to saw-tooth pulse generating circuits utilizing novel non-polarized low impedance electronic switches which are controllable by weak high frequency electrical keying signals. Such apparatus has particular applications to cathode ray oscillographic and television cathode ray deflection systems.

Conventional saw-tooth pulse generators employing thermionic vacuum tubes require special wave damping circuits since the high resistance of the thormionic vacuum tubes employed as switching devices permit oscillatory currents to circulate throughout the circuit. Such oscillatory currents must be effectively suppressed to provide a substantially linear saw-tooth output voltage wave-form. Also such suppressor circuits and high resistance switching tubes dissipate considerable energy, thereby requiring the use of relatively high power apparatus for providing the required high voltage saw-tooth deflecting pulses.

The instant invention employs novel bidirectional thermionic tubes of the orbital-beam type. Due to the relatively high operating efficiency inherent in such secondary emission tubes, the switching resistance is relatively low, and the bidirectional characteristics of the device eliminate the necessity for oscillatory current suppressor circuits. The measured efficiency of the instant system is of the order of 5 times that of other known systems, thereby permitting the use of apparatus having relatively low power ratings.

Among the objects of the invention are to provide an improved method of and means for generating saw-tooth pulse electrical currents. Another object is to provide an improved saw-tooth pulse generator employing a novel bidirectional electronic switch. An additional object is to provide a novel pulse generator employing a bidirectional orbital-beam electronic switching device. A further object of the invention is to provide a saw-tooth pulse generator having high operating efficiency characteristics. Another object of the invention is to provide a continuously operating saw-tooth generator utilizing a novel bidirectional electronic switch which eliminates the necessity for oscillatory current suppressor networks.

Other objects of the invention are to provide an improved high voltage undirectional power source. Another object is to provide an improved deflection voltage generator for oscillographic apparatus. An additional object is to provide a novel bidirectional electronic switch. A further object is to provide a novel electronic bidirectional switch utilizing secondary electronic emission for obtaining high operating efficiency. A still further object is to provide an improved bidirectional electronic switch of orbital-beam type. Another object is to provide an improved bidirectional electronic switch of cycloidal beam type.

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The invention will be described theoretically and with reference to specific circuits and structure by reference to the accompanying drawing of which Figure 1 is a schematic circuit diagram for explaining the basic theory of the system, Figure 2 is a schematic circuit diagram of a first embodiment of the invention adaptable, for example, to television kinescope deflection circuits, Figure 3 is a schematic circuit diagram of a second embodiment of the invention adapted to simultaneous operation for deflection of a television cathode ray beam and for supplying high unidirectional operating voltages for external circuits, Figure 4 is a graph illustrating voltage characteristics in the circuit, Figure 5 is a graph illustrating current characteristics in the circuit, Figure 6 is a schematic circuit diagram of a third embodiment of the invention having similar applications to the circuit of Figure 3 and employing a novel bidirectional electronic switch, Figure 7 is a cross-sectional plan view of a first novel type of bidirectional electronic switch, Figure 8 is a cross-sectional plan view of a second novel bidirectional electronic switch of orbital-beam type, and Figure 9 is a cross-sectional plan view of a third novel bidrectional switch of cycloidal beam type. Similar reference characters are applied to similar elements throughout the drawing.

Referring to the drawing, the circuit of Fig. 1 shows the basic circuit of many conventional types of saw-tooth pulse generators. The battery E_B represents a power source (which in more detailed circuits may comprise a charged storage capacitor), S represents an ideal bidirectional switch capable of high speed operation and designed to withstand high voltages in its open position and having perfect bidirectional conduction in its closed position; L represents an inductive load such, for example, as a deflecting yoke for a television kinescope tube, and C is the distributed capacitance of said yoke. The circuit may be assumed to include no resistance.

When the switch S is first closed at time t_1, the

current (see Figure 5), will increase linearly with time:

$$\frac{di}{dt}=\frac{E_B}{L} \quad (1)$$

until at time t_2 the switch is opened. Then the current stored in the inductance L will be discharged through the capacitance C in an oscillatory manner, (the solution for the equilibrium equation being

$$L\frac{di}{dt}+\frac{i}{C}\int idt=0 \quad (2)$$

$$i=-\frac{E_B}{\sqrt{\frac{L}{C}}}\sin\frac{t}{\sqrt{LC}} \quad (3)$$

If the switch is closed at time t_3 corresponding to the end of a half period of the self resonance of the inductor, the inductance returns its energy to the battery E_B with the current changing linearly with time until the instant t_4, at which time current equilibrium occurs. Then the battery will deliver current in a linear manner to the inductance, and the cycle will be repeated.

It will be seen from the foregoing simple analysis that if there is no resistance in the circuit, and the switch system is perfectly bidirectional, no external energy would be required to provide a continuous saw-tooth current (which would be wattless) and the purely reactive load would behave in the same manner as zero power factor loads behave with sinusoidal currents. This condition is true from the fact that deflection of a cathode ray electron beam, by periodic deflecting voltages or currents, requires no work, the reactance of the reflecting yoke acting merely as a fly-wheel for moving the cathode ray beam bidirectionally.

Figure 4 represents the voltage which would appear across the inductance L,

$$\left(E_L=L\frac{di}{dt}\right) \quad (4)$$

and it will be observed that the waveform of this voltage is substantially the derivative of the current waveform since the voltage is responsive to the rate of change of current through the inductance L. However, the voltage E_L is much greater than the input voltage E_B, the value being

$$E_L=1.41E_B\frac{t_3-t_2}{t_2-t_1} \quad (5)$$

Since the yoke comprising the inductance necessarily includes resistance, the current into the inductance must satisfy the following:

$$iR+L\frac{di}{dt}=E_B \quad (6)$$

or in the exponential form,

$$i=\frac{E_B}{R}\left(1-\epsilon^{-\frac{R}{L}t}\right) \quad (7)$$

wherein the saw-tooth waveform is not linear.

However, resistance in the switch causes greater difficulty than resistance in the inductance load. With conventional grid-controlled electron tubes employed as electronic switches, the resistance is many times that of the resistance of the inductive yoke. Although impedance transformation may be employed between the electronic switch and the associated circuit, a transformation limit is encountered by the fact that the return time of the saw-tooth wave is determined by the inductance and distributed capacity of the transformer ($t_3-t_2=\pi\sqrt{LC}$). Another difficulty is met by

the fact that conventional electron tubes are not bidirectional, and do not actually conduct until the yoke voltage is discharged to a value below the tube anode supply potential. In the interim, the yoke circuit retains its oscillatory characteristics, thereby providing yoke voltages which are distorted, as indicated by the dashed-line portions of the graph of Fig. 4. The yoke current also is distorted as indicated by the dashed-line portions of the graph of Fig. 5.

Some prior systems have employed diode or triode thermionic tubes connected across the inductive load in order to suppress such undesired oscillatory currents, the suppressor tubes operating as switching devices during the time interval when the thermionic switching tube is not conducting due to reversed potentials on its anode. The instant invention, by employing a truly bidirectional electronic switching device, eliminates the necessity for such oscillatory current suppressor circuits since it approximates the operating characteristics of a perfect bidirectional switch.

Referring to Fig. 2, a bidirectional electronic switch 3 comprises an evacuated envelope containing a thermionic cathode K, a control electrode G_1, a pair of secondary-electron-emissive anodes P_1 and P_2, and a pair of secondary-electron collector electrodes G_2 and G_3, wherein collector electrode G_2 is responsive to secondary electrons from anode P_1, and collector electrode G_3 is responsive to secondary electrons from the anode P_2.

A voltage source such as, for example, a battery 5 is connected through a high resistor 7 to charge a storage capacitor 9, one terminal of which is grounded. The charge on the storage capacitor 9 is indicated as E_B. The ungrounded terminal of the storage capacitor 9 is connected to the first anode P_1 and to the second collector electrode G_3 of the bidirectional electronic switch 3. The first collector electrode G_2 and the second anode P_2 are connected to one terminal 11 of a reactive load 13 such as, for example, an inductive yoke for deflecting the beam of a cathode ray oscillograph tube. The remaining terminal 15 of the inductive load 13 is grounded. The distributed capacitance of the inductive load 13 is indicated by the capacitance C, shown in dash lines, connected in shunt with the inductive load. A bias battery 17 is connected through a suitable grid resistor between the control electrode G_1 and ground to provide fixed operating bias voltages for the control grid, cathode and the second anode. The cathode K is connected to an intermediate point on the bias battery 17. Input signals, having a waveform 19, are applied to the circuit through input terminals 21 connected between the control electrode G_1 and ground.

In operation the supply voltage E_B charges the storage capacitor 9 and applies high potential to the first anode P_1 and to second collector electrode G_3. Positive potential from the bias battery 17 also is applied to the second anode P_2 and the first collector electrode G_2. The initial positive pulse portion of the input signal 19 at the time t_1 applied to the control electrode G_1, causes primary electrons to pass from the cathode K to both of the secondary-electron-emissive anodes P_1 and P_2, which each emit relatively large numbers of secondary electrons.

Since the first anode P_1 and the second collector electrode G_3 are more positive than the second anode P_2 and the first collector electrode G_2, the secondary electrons emitted from the second anode P_2 are collected by the second col-

lector electrode G_3, and those emitted from the first anode P_1 are returned thereto. This establishes an effective electrical connection between the anodes P_1 and P_2 causing current to build up in the inductive load **13** according to the law

$$I = \frac{E}{L}t$$

(by assuming no losses in the circuit). This current continues to build up until the time t_2, when a relatively high negative pulse is applied to the control electrode G_1, thus interrupting the primary electrons passing from the cathodes to the anodes P_1 and P_2. Since no primary electrons reach the anodes, no secondary electrons are emitted therefrom, and the effective circuit between the anodes is opened.

Then the energy stored-up in the inductive load **13** will be discharged by its distributed capacitance C in an oscillatory fashion, as shown in the graph of Fig. 5, between the times t_2 and t_3. At the time t_3 the control electrode G_1 again becomes positive, and primary electrons from the cathode reach the anodes P_1 and P_2, and again produce secondary-electron-emission therefrom. At this time, the inductive load **13** discharges its energy through the effective connection between the anodes P_1 and P_2 to the storage capacitor **9**, thus returning part of the energy to the power supply during the period between t_3 and t_4. At the time t_4, both anodes P_1 and P_2 are at the same potential. At this time, the saw-tooth cycle commences to repeat, since the first anode P_1 becomes more positive than the second anode P_2.

Since the potential generated across the inductive load **13** is similar in waveform to that indicated in graph **19** (see Fig. 4), because

$$E = L\frac{di}{dt}$$

the input control voltage applied to the input terminals **21** may be derived from a secondary winding coupled to the inductive load **13**, as shown and described hereinafter by reference to the circuits of Figs. 3 and 6. Thus, the circuit may be used as a keyed generator or as a continuous generator, depending upon the source of control pulses applied to the control electrode G_1.

The bidirectional switching circuit thus described has low series impedance, bidirectional operating characteristics, and because of its high efficiency requires relatively low cathode emission. The secondary-electron-emissive anodes P_1 and P_2 may be coated with silver magnesium or other materials which emit secondary electrons of the order of 4 or more times the number of primary electrons impinging thereon. Such surfaces may be operated at high current densities for several thousand hours. Voltage source **5** should preferably be of the order of 200 volts in order to provide ample primary electron emission. Although the anode-to-anode impedance is measurable, the efficiency of the system will be at least 5 times that obtainable when using conventional thermionic switching tubes, since no energy dissipative oscillatory current suppressors are required, and the switch series impedance is substantially reduced.

The circuit of Fig. 3 is similar to the circuit of Fig. 2 except that two conventional orbital beam tubes **23** and **33**, each having a control electrode G_1, a screen S, a secondary-electron-emissive anode and a secondary-electron collector electrode are substituted for the bidirectional

electronic switch **3**. Orbital beam tubes of this type are described in an article by H. M. Wagner and W. R. Ferris in the Proceedings of the Institute of Radio Engineers for November 1941, at pages 598 to 602. Screen voltage for the screen electrodes S is provided by an intermediate connection on a bias battery **18** which is connected between the cathode and the grounded terminal of the reactive load **13**. Grid potential for the control electrodes G_1 of the orbital beam tubes **23** and **33** is provided by a second bias battery **27** connected between the cathodes of the tubes and one terminal of a voltage pickup winding **29** which is inductively coupled to the reactive load **13**. The remaining terminal of the voltage pickup winding **29** is connected to the control electrodes G_1 of the tubes. Thus, keying voltages of the type shown in the solid line graph of Fig. 4 are applied to key the control electrodes G_1 of the two single orbital beam tubes in the manner described heretofore by reference to the circuit of Fig. 2.

The circuit also may be employed to provide high unidirectional operating voltages for external circuits. A second voltage pickup winding **31**, inductively coupled to the reactive load **13**, and having suitable voltage step-up characteristics, is connected, through a rectifier tube **35** and a conventional low-pass filter **37**, to D.-C. output terminals **39**, **41** which may be connected to any desired load **43**. Thus, rectified and filtered unidirectional voltage may be applied to the load **43** simultaneously with the application of saw-tooth deflecting currents to the inductive yoke **13**.

A current meter **45** serially connected between the ungrounded terminal of the storage capacitor **9** and the anode and collector electrodes of the orbital beam tubes shows that the current load on the battery source **5** is reduced by a factor of 4 when both orbital beam tubes **23** and **33** are operated simultaneously, as compared with the operation of the circuit when either one of the tubes is operated alone. Thus, the bidirectional operation of the circuit materially improves the circuit efficiency as well as the linearity of the saw-tooth deflecting currents applied to the reactive yoke **13**.

The circuit of Figure 6 is similar to the circuit of Fig. 3 with the exception that applicant's novel bidirectional orbital beam tube is substituted for the pair of unidirectional orbital beam tubes **23**, **33**. The operation of the saw-tooth voltage generator portion of the circuit is identical to that described heretofore by reference to the circuit of Figure 2, except that the control-grid voltage pulses are derived from a voltage pickup winding **29** coupled to the reactive yoke **13**, in the same manner as described by reference to the circuit of Figure 3. The high voltage pickup winding **31** also coupled to the reactive yoke **13** provides rectified and filtered unidirectional potential for an external load **43** in the manner previously described.

Figure 7 shows a first embodiment of a bidirectional orbital beam electronic tube which may be employed in the circuits of Figures 2 and 6. An evacuated envelope **46** contains a centrally-disposed cathode K which is surrounded by successive concentrically disposed control electrodes G_1, semi-circular secondary-electron-collector electrodes G_2 and G_3 disposed on diametrically opposite sides of the cathode K, and diametrically disposed, semi-circular secondary-electron-emissive anodes P_1 and P_2. Internal or external connections may be provided between the anode P_1

and collector electrode G_3 and between the anode P_2 and the collector electrode G_2. The operation of the device is as described heretofore by reference to the circuit of Figure 2. One disadvantage of the structure disclosed is that foreign matter emitted by the cathode K directly impinges upon the anodes P_1 and P_2, thereby causing contamination of the secondary-electron-emissive coatings thereon. Also the collector electrodes G_2 and G_3 are subjected to undesirable primary-electron emission.

The structure illustrated in Figure 8 is superior to that shown in Figure 7 since primary electrons, emitted by the cathode K and controlled by the surrounding control electrode G_1, traverse orbital paths between the cathode and the anodes P_1 and P_2 due to the lens action of a pair of reflector electrodes 47, 49, which are biased negatively with respect to the cathode potential. Primary electrons traversing the orbital paths to the two secondary-electron emissive anodes P_1 and P_2 do not impinge upon the collector electrodes G_2 and G_3 located adjacent to the anodes P_1 and P_2, respectively.

Also foreign matter emitted by the cathode is shielded from the anodes by means of the reflector electrode 47 interposed therebetween. Secondary electrons emitted by the anodes P_1 and P_2, in response to primary electrons impinging thereon, are collected by the adjacently disposed collector electrodes G_2 and G_3, respectively. Thus, the dual orbital paths provided by the unique reflector electrode construction shown in Figure 8 provides an exceedingly efficient and stable bidirectional electronic device when the tube is employed in circuits such as those shown in Figures 2 and 6.

A third type of tube construction illustrated in Figure 9 includes a centrally disposed cathode surrounded by a control grid G_1 having shielding portions 51 and 53 for preventing direct emission from the cathode to the flat, edgewise-disposed anodes P_1 and P_2. A pair of flat reflector electrodes R_1 and R_2, disposed parallel to and on opposite sides of the anodes P_1 and P_2, cause the primary electrons emitted by the cathode K to traverse cycloidal paths to the secondary-electron-emissive anodes P_1 and P_2, both of which emit secondary electrons from both sides faces. The secondary electrons emitted by the anodes P_1 and P_2 are collected by the collector electrodes G_2 and G_3, respectively adjacent thereto, while the primary electron emission is effectively shielded from the collector electrodes by the cycloidal electron paths provided by the reflector electrodes. Appropriate operating potential polarities are indicated on the anode, collector, and reflector electrodes.

Thus, the invention described comprises several embodiments of novel saw-tooth generator circuits including provisions for obtaining high unilateral operating potential for external circuits. Also three proposed types of bidirectional electronic switching tubes are disclosed and the operation thereof is explained by reference to their use in the disclosed circuits.

I claim as my invention:

1. A saw-tooth pulse generator including a storage capacitor, a source of unilateral potential, means connecting said source to said capacitor to charge said capacitor, selectively bidirectional thermionic tube means, a reactive load, means connecting said capacitor to said tube means for selectively discharging said capacitor through said tube means and said load, means connecting said load to said tube means for alternately discharging said load through said tube means and said capacitor, and means for keying said tube means to effect alternate discharges of energy from said capacitor and said load.

2. A saw-tooth pulse generator including a storage capacitor, a source of unilateral potential, means connecting said source to said capacitor to charge said capacitor, bidirectional thermionic tube means comprising at least a cathode, a control electrode, a pair of secondary-electron-emissive anodes and a pair of secondary-electron-collector electrodes, each of said collector electrodes being responsive to secondary electrons derived substantially only from an adjacent one of said anodes, a reactive load, means connecting said capacitor to said tube means for selectively discharging said capacitor through said tube means and said load, means connecting said load to said tube means for alternately discharging said load through said tube means and said capacitor, a source of keying pulses, and means for applying said keying pulses to said control electrode to effect alternate discharges of energy from said capacitor and said load.

3. A saw-tooth pulse generator including a storage capacitor, a unipotential source, means connecting said source to said capacitor to charge said capacitor, thermionic tube means comprising at least a cathode, a control electrode, a pair of secondary-electron-emissive anodes and a pair of secondary-electron-collector electrodes, each of said collector electrodes being responsive to secondary electrons derived substantially only from an adjacent one of said anodes, a reactive load, means connecting said capacitor to one of said anodes and to the one of said collectors adjacent to the other of said anodes for selectively discharging said capacitor through said one collector, said anodes and said load, means connecting said load to the other of said anodes and the other of said collectors adjacent said one of said anodes for alternately discharging said load through said other collector, said anodes and said storage capacitor, a source of keying pulses, and means for applying said keying pulses to said control electrode to effect alternate discharges of energy from said capacitor and said load.

4. A saw-tooth pulse generator including a storage capacitor, a source of unilateral potential, resistive means connecting said source to said capacitor to charge said capacitor, thermionic tube means comprising at least a cathode, a control electrode, a pair of secondary-electron-emissive anodes and a pair of secondary-electron-collector electrodes, each of said collector electrodes being responsive to secondary electrons derived substantially only from an adjacent one of said anodes, a reactive load, means connecting said capacitor to one of said anodes and to the one of said collectors adjacent to the other of said anodes for discharging said capacitor through said one collector, said anodes and said load, means connecting said load to the other of said anodes and the other of said collectors adjacent said one of said anodes for discharging said load through said other collector, said anodes and said storage capacitor, a source of keying pulses responsive to the rate of change of energy in said load, and means for applying said keying pulses to said control electrode to effect alternate discharges of energy from said capacitor and said load.

5. A saw-tooth pulse generator including a storage capacitor, a source of unilateral potential, re-

sistive means connecting said source to said capacitor to charge said capacitor, thermionic tube means comprising at least a cathode, a control electrode, a pair of secondary-electron-emissive anodes and a pair of secondary-electron-collector electrodes, each of said collector electrodes being responsive to secondary electrons derived substantially only from an adjacent one of said anodes, a reactive load, means connecting said capacitor to one of said anodes and to the one of said collectors adjacent to the other of said anodes for discharging said capacitor through said tube means and said load, means connecting said load to the other of said anodes and the other of said collectors adjacent said one of said anodes for discharging said load through said tube means and said storage capacitor, a source of keying pulses comprising means reactively coupled to said load, and means for applying said keying pulses to said control electrode to effect alternate discharges of energy from said capacitor and said load.

6. A saw-tooth pulse generator including a storage capacitor, a source of unilateral potential, resistive means connecting said source to said capacitor to charge said capacitor, thermionic tube means comprising at least a cathode, a control electrode, a pair of secondary-electron-emissive anodes and a pair of secondary-electron-collector electrodes, each of said collector electrodes being responsive to secondary electrons derived substantially only from an adjacent one of said anodes, a reactive load, means connecting said capacitor to one of said anodes and to the one of said collectors adjacent to the other of said anodes for discharging said capacitor through said tube means to said load, means connecting said load to the other of said anodes and the other of said collectors adjacent said one of said anodes for discharging said load through said tube means to said storage capacitor, means reactively coupled to said load providing a source of keying pulses responsive to the rate of change of energy in said load, and means for applying said keying pulses to said control electrode to effect alternate discharges of energy from said capacitor and said load.

7. A high voltage system including a storage capacitor, a relatively low voltage source, means connecting said source to said capacitor to charge said capacitor, thermionic tube means comprising at least a cathode, a control electrode, a pair of secondary-electron-emissive anodes and a pair of secondary-electron-collector electrodes, each of said collector electrodes being responsive to secondary electrons derived substantially only from an adjacent one of said anodes, a step-up transformer having primary and secondary windings, said primary winding having substantial distributed capacitance, a discharge path for said capacitor including means connecting said capacitor to one of said anodes and to the one of said collectors adjacent to the other of said anodes for discharging said capacitor through said tube means and said transformer primary winding, a second discharge path for the capacitance of said transformer primary winding including means connecting said primary winding to the other of said anodes and the other of said collectors adjacent said one of said anodes for discharging said transformer primary winding capacitance through said tube means and said capacitor, a source of keying pulses, means for applying said keying pulses to said control electrode to effect alternate discharges of energy from said capacitor and said transformer primary winding capacitance, and means for deriving high alternating potentials from said transformer.

8. A high voltage unipotential system including a storage capacitor, a relatively low voltage unipotential source, means connecting said low voltage source to said capacitor to charge said capacitor, thermionic tube means comprising at least a cathode, a control electrode, a pair of secondary-electron-emissive anodes and a pair of secondary-electron-collector electrodes, each of said collector electrodes being responsive to secondary electrons derived substantially only from an adjacent one of said anodes, a transformer having primary and secondary windings, a discharge path for said capacitor including means connecting said capacitor to one of said anodes and to the one of said collectors adjacent to the other of said anodes for discharging said capacitor through said tube means and said transformer primary winding, a second discharge path for the capacitance of said transformer primary winding including means connecting said transformer primary winding to the other of said anodes and the other of said collectors adjacent said one of said anodes for discharging said transformer primary winding through said tube means and said capacitor, means including said transformer comprising a source of keying pulses, means for applying said keying pulses to said control electrode to effect alternate discharges of energy from said capacitor and said transformer, a rectifier responsive to high alternating potentials derived from said transformer, and means for deriving a high D. C. voltage for said rectifier.

9. A saw-tooth pulse generator including a storage capacitor, a source of unilateral potential, means connecting said source to said capacitor to charge said capacitor, selectively bidirectional thermionic tube means including at least one secondary-electron-emissive anode and at least one secondary-electron-collector electrode, a reactive load, means connecting said capacitor to said tube means for selectively discharging said capacitor through said tube means and said load, means connecting said load to said tube means for alternately discharging said load through said tube means and said capacitor, and means for keying said tube means to effect alternate discharges of energy from said capacitor and said load, at least alternate ones of said energy discharges being between said secondary-electron-emissive anode and collector electrodes.

GEORGE C. SZIKLAI.

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