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PERIODIC WAVE GENERATOR

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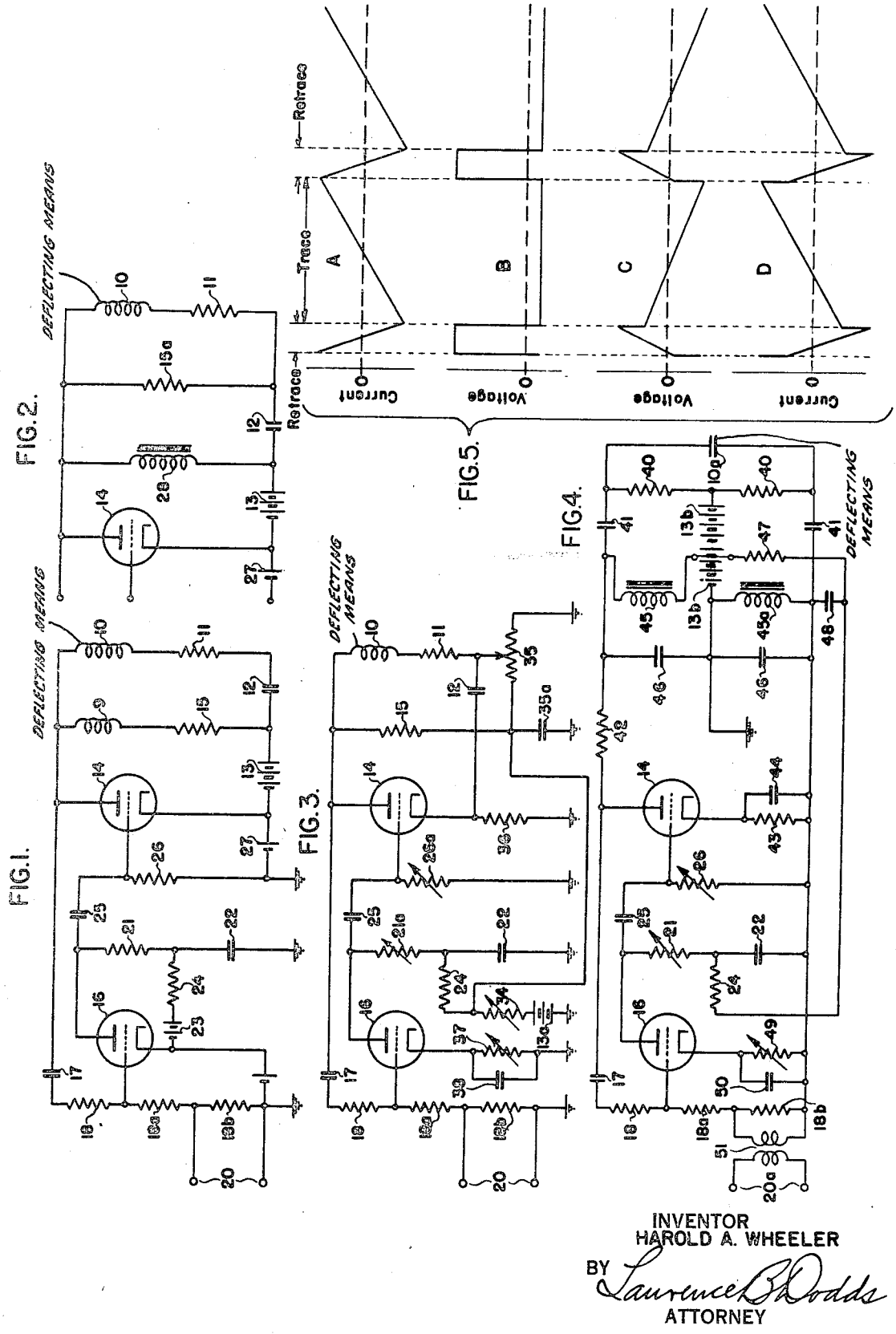

INVENTOR
HAROLD A. WHEELER

BY Laurence B. Dodds

ATTORNEY

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PERIODIC WAVE GENERATOR

Harold A. Wheeler, Great Neck, N. Y., assignor to Hazeltine Corporation, a corporation of Delaware

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This invention relates to periodic wave generators and, while of general application, it is especially useful in the development of scanning fields of saw-tooth wave form for use in television systems.

Periodic waves having complex wave forms, such as saw-tooth and related forms, are useful for various purposes. In television systems, for example, at both the transmitter and the receiver, electrostatic or electromagnetic fields of saw-tooth wave form are utilized in scanning systems to deflect a beam focused on a target, such as the cathode ray in a cathode-ray tube system, so as to cause the beam to scan successive fields or series of parallel lines on the target. These fields are produced by applying periodic current or voltage waves of the desired wave form to field-producing elements.

In general, it is required that periodic wave generators of the type described be capable of developing waves of precisely the desired wave form; in a television system, of a form suitable to effect accurately uniform velocity of trace and rapid retrace of the scanning beam, that is, a saw-tooth wave comprising a linear trace stroke and a retrace stroke of only a fraction of the duration of trace stroke. Further characteristics essential to such generators are simplicity of construction and dependability in operation.

It is an object of the present invention, therefore, to provide an improved generator for developing a periodic wave of complex wave form, such as a saw-tooth or related form, which may be either a current wave for electromagnetic scanning or a voltage wave for electrostatic scanning.

It is a further object of the invention to provide a periodic wave generator having one or more of the desirable characteristics and features referred to above.

In accordance with the present invention, a generator of periodic saw-tooth waves having substantially linear trace and relatively short retrace periods comprises an output circuit including capacitance means and means including a voltage supply circuit and a vacuum tube for effecting periodic charging of the capacitance means from the supply circuit by substantially constant current in one direction during the trace periods and discharging of the capacitance means by current in the opposite direction during retrace periods. The vacuum tube has a grid voltage-conductance characteristic free from excessive curvature over a part of its operating range between limiting regions thereof. The generator includes a feed-back circuit for the tube responsive to operating conditions in the output circuit for effecting operation of the tube over the aforesaid part of its operating range and one of the limiting regions and for causing the tube to develop in the output circuit a current wave including both saw-tooth and pulse components. The generator additionally includes means connected in circuit and cooperating with the capacitance means for dividing the aforesaid current in two paths, one of the paths including the capacitance means. The impedances of the aforesaid paths are relatively so proportioned that there flows through the capacitance means only the one of the aforesaid current components required to produce the desired saw-tooth wave therein with the tube operating only over the aforesaid part of its operating range during trace periods.

For a better understanding of the invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing and its scope will be pointed out in the appended claims.

In the accompanying drawing, Fig. 1 is a circuit diagram of a periodic wave generator embodying the present invention; Fig. 2 is a circuit diagram of a modified form of the output circuit of the generator of Fig. 1; Figs. 3 and 4 are circuit diagrams of modified forms of periodic wave generators embodying the invention; while Fig. 5 is a group of curves illustrating the wave forms of various currents and voltages developed in the generator of Fig. 1.

Referring now more particularly to Fig. 1 of the drawing, the generator illustrated comprises an energy-storage means, such as an inductance element 10, which may be a magnetic scanning element of a television scanning system, through which it is desired to produce a current of saw-tooth wave form. The inductance element 10 is included in the output circuit of the generator in series with a resistor 11, which may comprise, in whole or in part, the inherent resistance of the inductance element, a blocking condenser 12, a source of operating voltage, such as a battery 13, and a repeater device, preferably a vacuum tube 14 which may be a triode, as shown, or a multi-grid tube. For the purpose of controlling certain operating conditions of the system in accordance with the present invention and for applying the operating potential from battery 13 to the anode of the tube 14, a resistor 15 is connected in parallel with the series-connected in-

ductance element 10, resistor 11, and condenser 12. Since the resistor 15 carries the space current of tube 14, it must be limited to a fairly small resistance value and an inductance element 9 may be included in series therewith, as shown, although, in some cases, this element may be omitted.

For the purpose of controlling the tube 14, there is provided a feed-back system responsive to operating conditions in the output circuit of the generator and comprising a reversing and limiting vacuum tube 16 which may be a triode, as shown, or a multigrid tube. The input circuit of the tube 16 is coupled to the load circuit of tube 14 by way of a coupling impedance including a series-connected condenser 17 and voltage-divider resistors 18, 18*a*, and 18*b*, the control grid of tube 16 being connected at the junction of resistors 18 and 18*a* so that only a portion of the available feed-back voltage is applied to the tube 16. The condenser 17 serves to absorb saw-tooth wave-form components from the feed-back voltage so that only pulse components thereof are applied to the tube 16. Tube 16 is arranged to operate beyond both its upper and lower cutoff limits so as to derive in its load circuit, presently to be described, a voltage of the required wave form and amplitude properly to stabilize the operation of the system. Positive synchronizing pulses for the generator may be applied to the input circuit of the tube 16, from input terminals 20, across the resistor 18*b*, which resistor is of a relatively low value so that the impedance of the synchronizing circuit does not interfere with the operation of the generator.

A complex load impedance is provided for the tube 16 including a series resistor 21 and condenser 22 which cooperate to develop a control voltage of the required wave form. Operating potential may be supplied from a suitable source, for example, a battery 23, by way of a resistor 24 and the load resistor 21. The load circuit 21, 22 is coupled to the control grid of the tube 14 by way of a suitable condenser 25 and grid-leak resistor 26. A negative-bias potential is applied to the control grid of the tube 14 by way of the resistor 26 from a suitable source, for example, battery 27. While, for simplification, batteries have been illustrated as sources of direct current and bias-voltage supply, it will be understood that, in practice, conventional power supply circuits will ordinarily be utilized.

The operation of the generator of Fig. 1 may best be understood by first neglecting the resistor 15 and the major part of the resistor 21, which comprise essential parts of the present invention, and assuming the former to be replaced by a large choke to carry the space current of tube 14. During the trace period of each cycle, the tube 16 is biased below grid-bias cutoff and the condenser 22 is charged through the resistor 24 causing the potential of the upper terminal of the condenser 22, which potential is applied to the control grid of the tube 14, to become increasingly positive so that current builds up through the series circuit including the tube 14 and inductance element 10. This current continues to rise until the operating conditions are disturbed, for example, by the application of a positive synchronizing pulse to the tube 16, which initiates the retrace portion of the cycle. Such pulse causes the potential of the control grid of the tube 14 to increase negatively, reducing its output current. This reduction in current is regenerated by means of the feed-back circuit including tube 16.

As long as the current in the tube 14 continues to fall, a positive voltage is fed back to the tube 16. The tube 14 is thus regenerated to cutoff. As soon as the current in the tube 14 is interrupted, the positive feed-back voltage is removed from the tube 16 and it returns to cutoff. The trace period described above is then repeated to initiate the next cycle.

While the grid voltage-conductance characteristic of a repeater, such as the vacuum tube 14, is substantially linear over the intermediate portion of its range, or at least does not have excessive curvature, the "limiting" or upper and lower cutoff regions of the range are sharply curved. The synchronizing signal determines the termination of the trace periods and, hence, the upper limit of the operating range. The circuit constants are preferably so related to the period of the synchronizing signal that this upper limit is just within the linear portion of the tube characteristic. However, with the system operating, as just described, so that the current through the tube 14 is reduced to zero at the end of the retrace period, it will be seen that the tube operates not only over the useful intermediate portion of its characteristic but also over the lower sharply curved limiting region in the early part of the trace period.

In accordance with the present invention, however, there are provided means for shifting the operation of the device substantially away from this lower limiting region during the entire trace period. This is accomplished by causing a pulse-current component to be superimposed on the desired saw-tooth current component in the generator output circuit. For this purpose the resistor 21, included in the load circuit of the tube 16, is given a substantial value so that there is developed across this circuit and applied to the control grid of the tube 14 a composite control voltage wave including not only the saw-tooth wave component developed across condenser 22 but also a pulse component developed across the resistor 21 which is of a value greater than needed for the development of saw-tooth current in the tube 14. Since it is necessary that only the saw-tooth current component passes through the inductance element 10, the resistor 15 is connected in parallel therewith and so proportioned relative thereto that it effectively by-passes all of the pulse-current component and, incidentally, part of the saw-tooth current component.

The actual operation of the system, therefore, is modified with respect to that described above. In Fig. 5 curves A—D, inclusive, illustrate voltages and currents developed at various points in the system during the actual operation thereof. Thus, curve A illustrates the desired saw-tooth wave form of the current through the inductance element 10, and curve B the corresponding pulse voltage developed thereacross. A saw-tooth voltage is developed across the resistor 11 by the saw-tooth current therethrough so that the total voltage developed across the load circuit of tube 14 by the saw-tooth load current is of the combined saw-tooth and pulse wave form illustrated by curve C. The current through the resistor 15, therefore, and inductance 9, where such is included in the circuit, is also of saw-tooth and pulse wave form. The total current which must be passed by the tube 14, therefore, is of the wave form illustrated by curve D, having both pulse and saw-tooth components. Current of this re-

quired wave form, as explained above, is caused to flow through the tube by properly proportioning the input circuit 21, 22 so that a voltage of the required pulse and saw-tooth wave form is developed thereby and applied to the control grid of the tube 14. The end of the trace period, as explained above, is determined below the upper limiting region by the application of the synchronizing pulse to the generator. During the retrace period the combined pulse and saw-tooth retrace components carry the tube through the lower limiting region of its repeating characteristic to cutoff and the tube thereupon swings away from this lower limiting region so that the trace period begins in and extends over the intermediate part of the range of the characteristic which is free from excessive curvature.

In certain cases it may be necessary for the resistor 15 to be of a relatively low value in order properly to carry the direct current. In such a case, in the absence of the inductance 9, the path including resistor 15 would take an excessive amount of the pulse current. The inductance 9, however, may be included, as shown, for the purpose of providing greater impedance to the pulse current when the resistor is of such low value.

It will be appreciated that the grid voltage-conductance characteristic of the tube 14 tends to cause curvature of the saw-tooth wave form of the current developed by the system during the trace period. Likewise, certain impedance elements in the system tend to cause such a curvature; for example, the condenser 12, together with the other load circuit elements connected therewith, the resistor 26 and condenser 25, and the resistor 24 anl condenser 22. The curvature which these impedance elements tend to cause, however, is opposite to that due to the tube 14 and the circuit constants are so proportioned that these opposite curvature effects compensate each other. Thus, while the condenser 12 has so large a capacitance that it does not greatly affect the wave form of the wave developed by the system, any curvature effected thereby is balanced against the characteristic of the tube 14.

While a voltage of both pulse and saw-tooth wave-form components is impressed upon the feed-back circuit, the saw-tooth components are absorbed, as explained above, by the condenser 17 and only the pulse components are applied to the input circuit of tube 16. Tube 16 being operated beyond both its upper and lower cutoff limits, a pure pulse current is developed thereby and the control voltage of the required complex wave form is developed across its load circuit comprising resistor 21 and condenser 22. Not only does the limiting action of the tube 16 properly limit the amplitude of the control wave but it serves also to avoid cumulative wave-form distortion and thus stabilizes the wave form and amplitude of the wave developed by the system.

In order that the tube 14 may simultaneously supply pure saw-tooth current to the load inductance 10 and a pulse and saw-tooth current in resistor 15, the time constant of the coupling impedance 21, 22 is made equal to that of the output circuit as follows:

$$C_{22}R_{21}=\frac{L_{10}(R_{15}+R_{14})}{R_{11}R_{15}+R_{11}R_{14}+R_{15}R_{14}} \quad (1)$$

in which C, R, and L are the capacitance, resistance, and inductance, respectively, of the particular elements indicated by the appended numerals. This relation is based on the assumption of a linear grid voltage-conductance characteristic in the tube 14 which is approximately realized over the major portion of its operating range.

In order to procure a pure pulse voltage across the resistors 18a and 18b, the condenser 17 is proportioned, as explained, to absorb the saw-tooth voltage developed across the resistor 11 in the output circuit as follows:

$$C_{17}R_{18}=\frac{L_{10}}{R_{10}}$$

in which, as in Equation 1, C, R, and L are the capacitance, resistance, and inductance, respectively, of the elements indicated by the numerals appended thereto.

Briefly, then, the system comprises an arrangement whereby a current of pure pulse wave form is produced by the tube 16 and a current of combined saw-tooth and pulse wave form is produced by the tube 14. Tube 16 operates to stabilize the amplitude of the current pulses; the synchronizing pulses determine the end of the trace period and beginning of the retrace period; the remaining characteristic of the wave, the duration of the retrace period, is determined by the tube 14 reaching cutoff, whereupon the tube 14 is instantaneously swung away from the cutoff region to begin the trace period.

It will be seen that, in accordance with one aspect of the present invention, impedance means, in the system of Fig. 1 the resistor 15, effectively is connected in parallel and cooperates with the energy-storage means to divide the current through the output circuit into two paths. One of the paths includes the energy-storage means, the inductance element 10 in Fig. 1, while the other path includes the impedance means 9, 15. The paths are so proportioned that there flows through the energy-storage means only the current components required to produce the desired saw-tooth wave which, in the generator of Fig. 1, is the current of saw-tooth wave form.

In Figs. 2, 3, and 4, there are illustrated modifications of the invention. Like reference numerals indicate corresponding parts in Figs. 1–4, inclusive.

In Fig. 2 there is illustrated a modified form of output circuit which may be substituted for the corresponding circuit in the generator of Fig. 1. In the circuit of Fig. 2, a resistor 15a is connected directly across the inductance element 10 and resistor 11 and an inductance element or choke 28, of the iron-core type, is connected in parallel with the circuit with its lower terminal at the inner side of condenser 12, providing a separate direct-current path for the space current of the tube 14. Since, with this arrangement, the shunt resistor 15a does not carry the space current of the tube 14, with resultant voltage drop, as in the case of the resistor 15 of Fig. 1, the resistor 15a may be made any size desired without affecting the space current or anode voltage of tube 14 and required battery voltage is less.

In Fig. 3 a modified form of the generator of Fig. 1 is shown which includes certain additional advantageous features whereby various operating characteristics of the system may be readily adjusted. Except, as explained below, the generator of Fig. 3 is of the same construction as that of Fig. 1. In the generator of Fig. 3 a single battery 13a is provided for supplying the operating potentials of both of the tubes 14 and 16, these potentials being applied by way of an adjustable

resistor 34 which is connected to the anode of tube 16 by way of resistors 24 and 21a, the latter preferably being adjustable, as shown. Resistor 34 is connected to the anode of tube 14 by way of resistor 15. A voltage-divider resistor 35 is connected across battery 13a and resistor 34 and has an adjustable tap to which the resistor 11 is connected. The condenser 12 in this case is connected directly between the lower end of resistor 11 and the cathode of tube 14. A biasing resistor 36 is included in the cathode circuit of tube 14 and an adjustable biasing resistor 37, by-passed by a condenser 38, is included in the cathode circuit of tube 16. Condenser 22 may be alternatively connected directly to the cathode of tube 16, instead of to ground. This alternative connection has the advantage of returning the pulse of output current of tube 16 directly to the cathode and thereby reducing the requirements of the by-pass condenser 38. The grid-leak resistor 26a of tube 14 is also adjustable.

The operation of this generator is substantially the same as that of the generator of Fig. 1. Here, however, the various adjustable resistors provide means whereby the various operating characteristics of the generator may be readily adjusted. By adjustment of the resistor 34, the amplitude of the wave developed by the system may be readily controlled. When increased voltage is applied to the tube 14 for developing a wave of greater amplitude, an increased control voltage is required to be developed by the tube 16 so that its operating voltage should also be increased. The resistor 34 thus provides a single means which may be adjusted simultaneously to effect the proper adjustments of the operating voltages of both tubes.

By adjustment of the tap on the voltage-divider resistor 35, the value of the direct-current component which flows through the inductance 10 may be readily controlled. Where the element 10 constitutes a scanning element of a cathode-ray tube, therefore, this adjustment is useful for the purpose of centering the scanning pattern on the target of the tube. Adjustment of the resistor 21a serves to control the amplitude of the pulse component of the control wave developed by the feed-back system. This provides a means for accurately controlling the curvature of the wave developed by the generator at the beginning of its trace period. A further control of the linearity or curvature of the wave developed by the generator is provided by the adjustable resistor 26a. Thus, the adjustable resistor 34 comprises means for adjusting the amplitude of the wave developed by the generator, the amplitude adjustment being independent of the linearity and frequency of the developed wave, and the adjustable resistors 21a and 26a comprise means for adjusting the linearity of the wave developed by the generator, the linearity adjustment being independent of the amplitude and frequency of the developed wave.

The free oscillating frequency of the generator of Fig. 3 is regulated by the time constant of resistor 37 and condenser 38, which determines the end of the trace period in the absence of a synchronizing pulse. As stated above, the end of the trace period is determined by the starting of current in tube 16. The operation of tube 16 in Fig. 3 is determined partly by resistor 37; that is, each pulse of current develops a bias across the condenser 38 which is applied positively to the cathode of tube 16, and this bias partially leaks off through the resistor 37 during the trace period. As it leaks off, it reaches a point where current starts to flow in tube 16, even in the absence of a synchronizing pulse, whereupon the trace period is ended and retrace begins; that is, a saw-tooth control voltage is developed across the circuit 37, 38. The time constant of resistor 37 and condenser 38 is adjusted so that the free oscillation period is slightly longer than the synchronizing period, so that the failure of a single synchronizing pulse will not result in too great a disturbance of the normal periodicity of the generator. Thus, the resistor 37 and condenser 38 comprise means for adjusting the free oscillating frequency of the generator, the frequency adjustment being independent of the amplitude and linearity of the developed wave.

The circuit constants of a generator such as illustrated in Fig. 3 which have proved highly satisfactory in actual practice are as follows:

Resistor 18=1 megohm
Resistor 18a=0.25 megohm
Resistor 18b=10,000 ohms
Resistor 37=35,000 ohms
Resistor 34=3,000 ohms
Resistor 24=1 megohm
Resistor 21=1,000 ohms
Resistor 26a=2 megohms
Resistor 36=1,100 ohms
Resistor 15=25,000 ohms
Resistor 35=0.25 megohm
Resistor 11=5,000 ohms (inherent in inductance 10)
Condenser 17=.001 microfarad
Condenser 38=0.5 microfarad
Condenser 22=0.25 microfarad
Condenser 25=0.1 microfarad
Condenser 35a=1 microfarad
Condenser 12=4 microfarads
Inductance 10=5 henries

For improved linearity of trace, the following values may be used in place of those above:

Resistor 37=>2,700 ohms
Resistor 21=7,000 ohms
Resistor 36=800 ohms
Resistor 15=1,500 ohms
Condenser 38=1 microfarad
Condenser 25=0.25 microfarad
Condenser 12=8 microfarads

The generator, constructed with the above circuit constants, developed a 60-cycle saw-tooth current wave through the inductance 10 which served as the scanning coils of a television cathode-ray tube system and provided field-scanning deflections for interlaced scanning at 60 deflections or fields per second. Only the inductance of the scanning coils being required in the generator, an important advantage is obtained, since at such low frequencies effective inductance coils are generally large and expensive.

In Fig. 4 there is illustrated still another modified form of the generator of the present invention which is designed to develop a saw-tooth voltage wave across capacitance means. The generator of Fig. 4 is similar to that of Fig. 1 except for the output circuit and certain details of the circuits of tubes 14 and 16. Here the energy-storage means comprises capacitance means including series-connected condensers 46, 46, grounded at their junction, and a condenser 10a in parallel therewith which may be the deflecting plates of a television cathode-ray tube, providing a balanced output circuit. For building up a saw-tooth voltage from a saw-tooth current,

resistors 40, 40 are connected across the condensers 46, 46 and 10a and their junction is grounded by way of a battery 13b. The uncommon terminals of resistors 40 are connected across the tube 14 by way of coupling condensers 41, 41, anode resistor 42, a biasing resistor 43, and by-pass condenser 44 included in the cathode circuit of the tube. Anode potential is supplied to the tube 14 from a suitable tap on the battery 13b by way of a choke 45 and the resistor 42, and the direct-current path of the battery is completed by a similar choke 45a connected between the negative or grounded terminal of the battery and the cathode resistor 43. Chokes 45 and 45a are preferably of the same inductance and may be wound on the same core.

Balancing condensers 46 are effective to by-pass pulse-current components in the output circuit to supplement the capacitance 10a.

Anode potential for the tube 16 is supplied from the battery 13b by way of a series resistor 47, by-pass condenser 48, and the resistors 24 and 21. A self-biasing resistor 49 and by-pass condenser 50 are included in the cathode circuit of the tube 16 and the lower terminals of these elements and the input circuit resistor 18b are grounded, by way of the common low potential lead of the system and the choke 45a. For the purpose of applying synchronizing pulses to the tube 16, there is provided an input transformer 51 having its secondary winding connected across the resistor 18b, the terminals 20a, 20a of its primary winding being suitable for receiving the synchronizing wave.

In the generator of Fig. 4, as in Fig. 1, the various circuit elements are proportioned, so that the characteristic curvature of the tube 14 and that of the circuit elements, which tend to cause curvature of the saw-tooth wave developed by the system, effectively counteract each other during the trace period. Here the condensers 41 and inductance elements 45 and 45a are included in the group of elements whose values are proportioned for this purpose.

The operation of the generator of Fig. 4 is similar to that of Fig. 1 except that here a balanced voltage of saw-tooth wave form is required to be developed across the capacitance means instead of a current of saw-tooth wave form through an inductance element. A pulse voltage component is also required for the feed-back circuit, as in the circuit of Fig. 1. Therefore, a resultant voltage of saw-tooth and pulse wave form must be developed across the output circuit of the generator. The desired saw-tooth voltage appears across the capacitance means 10a and current of pulse wave form only flows in condensers 10a and 46, 46. The saw-tooth current component flows through the resistors 40, 40. The total required current through the output tube 14, therefore, is again of saw-tooth and pulse wave form and is obtained, as in the circuit of Fig. 1, by properly proportioning the circuit elements in the output circuit 21, 22 of the tube 16. The resistor 42 is included in the circuit for developing, due to the flow of current therethrough, the required feedback pulse voltage component, since otherwise there would be only the desired saw-tooth voltage across the output circuit.

Thus, in the generator of Fig. 4, it will be apparent that means are provided whereby the output current is divided between two paths, first, the capacitive path including condensers 10a and 46, 46, through which the pulse component of the current flows, and second, the path provided by resistors 40 through which the saw-tooth current flows. That is, the battery 13b and the tube 14 comprise means including a voltage supply circuit and a vacuum tube for effecting periodic charging of the capacitance means from the supply circuit by substantially constant current in one direction during the trace periods and discharging of the capacitance means by current flow in the opposite direction during the retrace periods. Negligible current flows through the coils 45, 45a and the resistor 47, except for the direct-current components. Negligible voltage is developed across condensers 41, 41. This division of current is inevitable since a saw-tooth voltage is produced across the condenser 10a, and, therefore, across resistors 40 and condensers 46. In this case, the energy-storage means is not only the condenser 10a of the useful load circuit but also the condensers 46, 46, which are added for the practical reason of reducing the impedance of the output circuit, which would otherwise be excessive at low frequencies. In summary, it will be seen that the arrangement of Fig. 4 comprises a generator of periodic saw-tooth waves having substantially linear trace and relatively short retrace periods. The vacuum tube 14 of the Fig. 4 arrangement has, like the corresponding vacuum tube 14 of the Fig. 1 arrangement, a grid voltage-conductance characteristic free from excessive curvature over a part of its operating range between limiting regions thereof. Reversing vacuum tube 16 and the circuit elements 17, 18, 18a, 18b, 21, 22 and 24 comprise a feed-back circuit for the vacuum tube 14 responsive to operating conditions in the output circuit of the latter tube for effecting operation of the vacuum tube 14 over the curvature-free portion of its operating range and one of the limiting regions thereof and for causing this vacuum tube to develop in its output circuit a current wave including both saw-tooth and pulse components. Stated in other words, the vacuum tube 16 and the circuit elements 17, 18, 18a, 18b, 21, 22 and 24 comprise a reversing tube and a complex impedance proportioned to derive from the output voltage of vacuum tube 14 a feed-back voltage having saw-tooth and pulse wave-form components of relative amplitudes independent of those of the aforesaid output voltage. The resistors 40, 40 comprise means connected in circuit and cooperating with the capacitance means 10a for dividing the current in the output of vacuum tube 14 into two paths, one of which paths includes the capacitance means 10a, and the impedance of the paths are relatively so proportioned that there flows through the capacitance means 10a only the one of the current components required to produce the desired saw-tooth wave therein with the vacuum tube 14 operating only over the curvature-free portion of its operating range during trace periods.

While there has been described what is at present considered to be the preferred embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A generator of periodic saw-tooth waves having substantially linear trace and relatively

short retrace periods comprising, an output circuit including capacitance means, means including a voltage supply circuit and a vacuum tube for effecting periodic charging of said capacitance means from said supply circuit by substantially constant current in one direction during said trace periods and discharging of said capacitance means by current in the opposite direction during said retrace periods, said vacuum tube having a grid voltage-conductance characteristic free from excessive curvature over a part of its operating range between limiting regions thereof, a feed-back circuit for said tube responsive to operating conditions in said output circuit for effecting operation of said tube over said part of said range and one of said limiting regions and for causing said tube to develop in said output circuit a current wave including both saw-tooth and pulse components, and means connected in circuit and cooperating with said capacitance means for dividing said current in two paths, one of said paths including said capacitance means, and the impedances of said paths being relatively so proportioned that there flows through said capacitance means only the one of said current components required to produce the desired saw-tooth wave therein with said tube operating only over said part of said range during trace periods.

2. A generator of periodic saw-tooth waves having substantially linear trace and relatively short retrace periods comprising, an output circuit including capacitance means, means including a voltage supply circuit and a vacuum tube for effecting periodic charging of said capacitance means from said supply circuit by substantially constant current in one direction during said trace periods and discharging of said capacitance means by current flow in the opposite direction during said retrace periods, said vacuum tube having a desired grid voltage-conductance characteristic free from excessive curvature over a part of its operating range between relatively sharply curved limiting regions thereof, a feed-back circuit for said tube responsive to operating conditions in said output circuit for controlling said tube to cause operation thereof over said part of said range and at least one of said limiting regions, and means including resistance means effectively coupled to said capacitance means and so proportioned with respect thereto as to shift the operation of said tube substantially away from said limiting region during trace periods.

3. A generator of periodic saw-tooth waves having substantially linear trace and relatively short retrace periods comprising, an output circuit including capacitance means, means including a current supply circuit and a vacuum tube for effecting periodic flow of substantially constant current in one direction through said capacitance means from said supply circuit during said trace periods, said vacuum tube having a grid voltage-conductance characteristic free from excessive curvature over a part of its operating range between limiting regions thereof, a feed-back circuit for said tube responsive to operating conditions in said output circuit for effecting operation of said tube over said part of said range and one of said limiting regions to cause in said output circuit a current wave including both saw-tooth and pulse components, and means connected in circuit and cooperating with said capacitance means for dividing said current in two paths, one of said paths including said capacitance means and the other of said paths including resistance means and said paths being so proportioned that there flows through said one path only said current components of pulse wave form with said tube operating over said part of its range during trace periods.

4. A generator of periodic saw-tooth waves having substantially linear trace and relatively short retrace periods comprising, an output circuit including capacitance means, means including an energy supply circuit and a vacuum-tube repeater having a control electrode for effecting periodic flow of substantially constant current through said capacitance means during said trace periods, said vacuum-tube repeater having a grid voltage-conductance characteristic free from excessive curvature over a part of its operating range within upper and lower limiting regions, a feed-back circuit for said tube comprising a reversing tube having an input circuit and impedance means coupling said input circuit to said output circuit and proportioned to derive therefrom a feed-back voltage of pulse wave form, and a load circuit for said reversing tube coupled to said vacuum-tube control electrode comprising a series-connected resistor and condenser proportioned to develop a control voltage wave having saw-tooth and pulse wave form components for causing operation of said repeater tube over said part of said range and said lower limiting region, and means cooperating with said capacitance means for shifting the operation of said tube substantially away from said lower limiting region substantially simultaneously with the initiation of said trace periods.

5. A generator of periodic saw-tooth current waves having substantially linear trace and relatively short retrace periods comprising, an output circuit including an impedance element, a current supply circuit and a repeater vacuum tube for effecting periodic flow of current through said output circuit and developing voltage thereacross, said tube having a grid voltage-conductance characteristic free from excessive curvature over a part of its operating range within relatively sharply curved upper and lower limiting regions, a feed-back circuit for said repeater tube comprising a reversing tube and a complex impedance proportioned to derive from said output voltage a feed-back voltage having saw-tooth and pulse wave-form components of relative amplitudes independent of those of said output voltage for effecting operation of said repeater tube over said part of said range and said lower limiting region during retrace periods of operation, means for determining the duration of trace periods of operation of said repeater tube and limiting said operation below said upper limiting region, and impedance means in parallel with said impedance element for by-passing the pulse components of the current from said impedance element thereof to shift the operation of said repeater tube substantially above said lower limiting range substantially simultaneously with the initiations of said trace periods.

6. A generator of periodic saw-tooth waves having substantially linear trace and relatively short retrace periods comprising, an output circuit including capacitance means, a voltage supply circuit and a vacuum-tube repeater for effecting periodic charging and discharging of said capacitance means and developing a voltage across said output circuit from said supply circuit during said trace and retrace periods, said tube having a grid voltage-conductance characteristic free from excessive curvature over a

part of its operating range within upper and lower limiting regions, a feed-back circuit for said repeater tube comprising a reversing tube and a complex impedance proportioned to derive from said output voltage a feed-back voltage having saw-tooth and pulse wave-form components of relative amplitudes independent of those of said output voltage for effecting operation of said repeater tube over said part of said range and said lower limiting region during retrace periods of operation, means for determining the duration of trace periods of operation of said repeater tube and limiting said operation below said upper limiting region, and resistance means in parallel with said first-mentioned capacitance means for by-passing said saw-tooth wave-form current components from said capacitance means to shift the operation of said repeater tube substantially away from said lower limiting region substantially simultaneously with the initiation of said trace periods, whereby the operation of said tube is held above and below said lower and upper limiting regions, respectively, during said trace periods.

7. A generator of periodic saw-tooth waves having substantially linear trace and relatively short retrace periods comprising, an output circuit including capacitance means, means including a voltage supply circuit and a vacuum-tube repeater having a control electrode for effecting periodic charging of said capacitance means from said supply circuit by substantially constant current in one direction during said trace periods and discharging of said capacitance means by current flow in the opposite direction during said retrace periods, said vacuum tube having a grid voltage-conductance characteristic free from excessive curvature over a part of its operating range within upper and lower limiting regions, a feed-back circuit for said repeater tube comprising a reversing tube having an input circuit and impedance means coupling said input circuit to said output circuit and proportioned to derive therefrom a feed-back voltage of pulse wave form and a load circuit for said reversing tube coupled to said repeater tube control electrode and comprising a series resistor and condenser for developing a control voltage wave having saw-tooth wave-form components and pulse wave-form components determining the duration of retrace periods of operation and to effect operation of said repeater tube within one of said limiting regions during said retrace periods, means for applying synchronizing pulses to said input circuit for determining the duration of trace periods of operation of said repeater tube within said part of said range, and resistance means in parallel with said first-mentioned capacitance means for by-passing said saw-tooth wave-form current components from said capacitance means to shift the operation of said repeater tube substantially away from said last-mentioned limiting region substantially simultaneously with the initiation of said trace periods, whereby the operation of said tube is held above and below said lower and upper limiting regions, respectively, during said trace periods.

8. A generator of periodic saw-tooth waves having substantially linear trace and relatively short retrace periods comprising, an output circuit including energy-storage means, an energy supply circuit, and a repeater device for effecting periodic charging and discharging of said storage means from said supply circuit, said device having a repeating characteristic free from excessive curvature over a part of its operating range between relatively sharply curved limiting regions thereof, a feed-back circuit for said device responsive to operating conditions in said output circuit for controlling said device to cause operation thereof over said part of said range and at least one of said limiting regions, impedance means effectively coupled to said storage means and so proportioned with respect to the impedance thereof as to shift the operation of said device substantially away from said limiting region during trace periods, means for adjusting the amplitude of the wave developed by said generator, said amplitude adjustment being independent of the linearity of said developed wave, and means for adjusting the linearity of the wave developed by said generator, said linearity adjustment being independent of the amplitude of said developed wave.

9. A generator of periodic saw-tooth waves having substantially linear trace and relatively short retrace periods comprising, an output circuit including energy-storage means, an energy supply circuit, and a repeater device for effecting periodic charging and discharging of said storage means from said supply circuit, said device having a repeating characteristic free from excessive curvature over a part of its operating range between relatively sharply curved limiting regions thereof, a feed-back circuit for said device responsive to operating conditions in said output circuit for controlling said device to cause operation thereof over said part of said range and at least one of said limiting regions, impedance means effectively coupled to said storage means and so proportioned with respect to the impedance thereof as to shift the operation of said device substantially away from said limiting region during trace periods, means for adjusting the amplitude of the wave developed by said generator, said amplitude adjustment being independent of the frequency of said developed wave, and means for adjusting the free oscillating frequency of said generator, said frequency adjustment being independent of the amplitude of said developed wave.

10. A generator of periodic saw-tooth waves having substantially linear trace and relatively short retrace periods comprising, an output circuit including energy-storage means, an energy supply circuit, and a repeater device for effecting periodic charging and discharging of said storage means from said supply circuit, said device having a repeating characteristic free from excessive curvature over a part of its operating range between relatively sharply curved limiting regions thereof, a feed-back circuit for said device responsive to operating conditions in said output circuit for controlling said device to cause operation thereof over said part of said range and at least one of said limiting regions, impedance means effectively coupled to said storage means and so proportioned with respect to the impedance thereof as to shift the operation of said device substantially away from said limiting region during trace periods, means for adjusting the linearity of the wave developed by said generator, said linearity adjustment being independent of the frequency of the developed wave, and means for adjusting the free oscillating frequency of said generator, said frequency adjustment being independent of the linearity of said developed wave.

HAROLD A. WHEELER.