May 11, 1948. W. D. HOUGHTON 2,441,418

PULSE GENERATOR AND MODULATOR SYSTEM

Filed Sept. 20, 1945 2 Sheets-Sheet 1

Fig. 1.

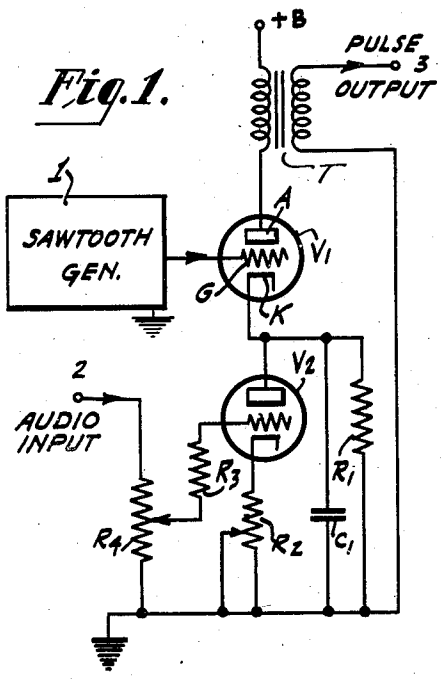



Fig. 2.

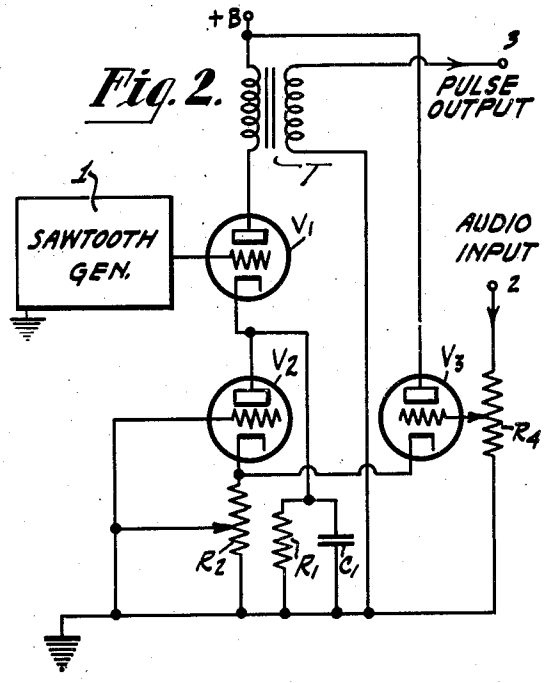
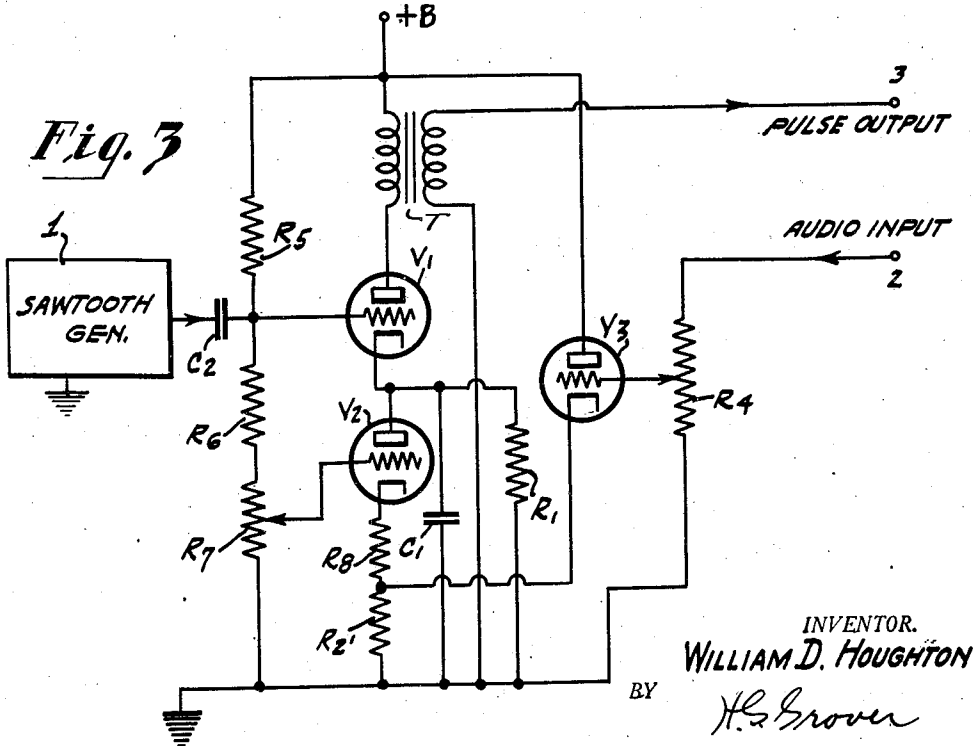



Fig. 3

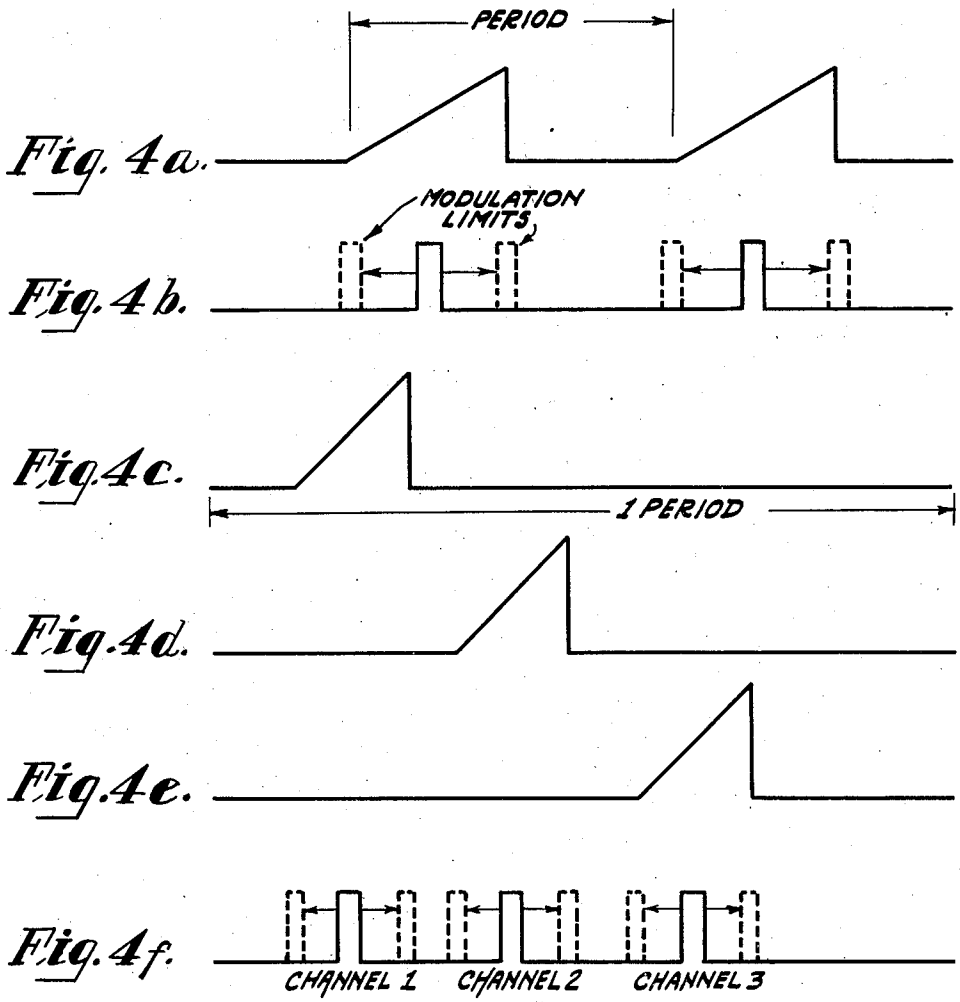



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PULSE GENERATOR AND MODULATOR SYSTEM

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# UNITED STATES PATENT OFFICE

2,441,418

## PULSE GENERATOR AND MODULATOR SYSTEM

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Application September 20, 1945, Serial No. 617,634

12 Claims. (Cl. 179—171.5)

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This invention relates to a pulse signaling system, and more particularly to a method of and apparatus for generating pulses of constant average frequency and varying their occurrence time within fixed limits.

An object of the present invention is to enable the phase or timing modulation of pulses of constant frequency at an audio rate within fixed limits regardless of the amplitude of the applied modulation.

Another object is to provide a pulse generator and pulse timing modulation system suitable for use in a multiplex system in which a pulse is produced for each assigned period regardless of the magnitude of modulation.

A further object is to provide an improved pulse generator which is synchronized and controlled by a triangular wave generator.

A more detailed description of the invention follows, accompanied by a drawing wherein:

Figs. 1, 2 and 3 illustrate three different embodiments of the invention, and

Figs. 4*a* to 4*f* are curves given in explanation of the operation of the invention.

Throughout the figures of the drawing, the same or like parts are represented by like reference characters.

Referring to Fig. 1 in more detail, there is shown a simplified form of pulse generator and modulator system of the invention comprising a triode vacuum tube $V_1$ normally biased to be non-conducting and having its anode connected to a source of positive polarizing potential +B through one winding of a differentiating transformer T, its grid G connected to the output of a saw-tooth voltage generator, and its cathode K connected to the anode of a modulator tube $V_2$ and also to ground via resistor $R_1$. Any appreciable flow of current through tube $V_1$ must be through tube $V_2$ since resistor $R_1$ is large in value. In shunt to resistor $R_1$ there is provided a capacitor $C_1$ which is large enough to maintain the bias required on tube $V_1$ but small enough so that it does not cause undue attenuation of the higher audio frequencies developed across tube $V_2$ from the audio modulation, as described later.

The modulator tube $V_2$ comprises a triode vacuum tube to whose grid there is applied the audio input modulation from terminal **2** over resistors $R_4$ and $R_3$. Resistor $R_3$ is a limiting resistor in the grid circuit of tube $V_2$ which prevents the grid from being driven positive above the zero voltage value. Resistor $R_4$ is a potentiometer which is used to control the amplitude of the audio modulation voltage applied to the grid

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of $V_2$. A resistor $R_2$ in the cathode circuit of tube $V_2$ enables a control of the anode resistance of tube $V_2$ and hence a control of the value at which tube $V_1$ conducts on the rise of the saw-tooth.

In the operation of the system of Fig. 1, tube $V_2$ acts as a resistance in the cathode circuit of tube $V_1$. The value of the resistance offered by tube $V_2$ is a function of its grid-to-cathode voltage and is determined by the setting of the tap on resistor $R_2$.

The saw-tooth voltage generator 1 supplies the grid of tube $V_1$ with a saw-tooth wave of positive polarity having a shape similar to that shown in the graph of Fig. 4*a*. Tube $V_1$ is normally biased to be non-conducting, and is arranged (due to the setting of $R_2$) to conduct at about the middle of the applied saw-tooth voltage wave with no audio voltage present on terminal **2**. Obviously, any variation in the resistance of tube $V_2$ will result in a variation of the point on the saw-tooth voltage wave at which tube $V_1$ will conduct, inasmuch as the grid-to-cathode voltage of $V_1$ is determined by the average current through $V_1$ and the value of the resistance offered by tube $V_2$.

When tube $V_1$ conducts, current flows through differentiation transformer T resulting in a pulse of voltage appearing at output terminal **3** in circuit with the secondary winding of the transformer. Also, when $V_1$ ceases conducting at the end of the saw-tooth wave, another pulse of opposite polarity is generated. This last pulse does not vary with modulation and is therefore not used in the following stages. Any suitable utilization circuit may be connected to output terminal **3**. It will thus be seen that the entire position of the pulse generated at terminal **3** varies in time with the modulation. There is generated at terminal **3** a positive pulse when tube $V_1$ starts to conduct and a negative pulse when tube $V_1$ ceases conducting. Since the starting time of $V_1$ is the variable, then the correspondingly produced pulse is the one which varies with the modulation. The solid line pulse in the curve of Fig. 4*b* shows the position of this output pulse relative to the applied saw-tooth wave, with no audio modulation on input terminal **2**. The current cut-off to current limiting region of tube $V_1$ is made to be small with respect to the amplitude of the applied saw-tooth wave because a sharp current change is desired in tube $V_1$, and this region is moved over the slope of the saw-tooth wave with modulation.

The audio modulation voltage applied to the

grid of tube $V_2$ varies the resistance of tube $V_2$ and the bias on tube $V_1$, hence varying the critical value or time at which tube $V_1$ starts to conduct over the range of the applied saw-tooth wave. When the starting point of current flow in tube $V_1$ is varied by the modulation, the occurrence time of the resulting output pulse in transformer T is also varied with respect to the leading and trailing edges of the applied saw-tooth wave. When audio voltages are applied to the grid of tube $V_2$ of sufficient magnitude to cut off the flow of current in tube $V_2$, then the resistance in the cathode circuit of tube $V_1$ becomes the resistance of $R_1$. The value of $R_1$ is such that with the flow of current in tube $V_2$ cut off, the tube $V_1$ will conduct at the peak of the applied saw-tooth wave. This feature is important because it assures an output pulse from the system for each applied saw-tooth wave in the event tube $V_2$ is cut off by excessive modulation.

As mentioned above, resistor $R_3$ is a grid limiting resistor. Hence the resistance of modulator tube $V_2$ cannot go below a minimum value regardless of the amplitude of the audio modulation voltage applied to the grid of this tube. This minimum value is such that tube $V_1$ will conduct at the leading edge of the saw-tooth wave. Consequently, regardless of the amplitude of the applied audio modulation, the position of the output pulse at output terminal **3** always falls within the time interval or duration of the applied saw-tooth wave. This is shown by the dotted line pulses in Fig. 4*b* which illustrate the limiting positions of the output pulses with extreme positive and negative modulation voltages.

A more detailed description is as follows: Tube $V_1$ is normally made to conduct at the middle of the linear rise time of the applied sawtooth wave. After $V_1$ starts to conduct, it continues to conduct for the remaining portion of the linear rise time.

When tube $V_1$ conducts, a charge is stored in condenser $C_1$. This charge leaks off through the impedance of tube $V_2$ and $R_1$ during the time interval during which $V_1$ is non-conducting. Since $R_1$ is large compared to the impedance offered by tube $V_2$, its effect may be neglected as long as tube $V_2$ is conducting. If the value of $C_1$ is very large it will be seen that it will require a number of cycles of the sawtooth wave to reach stability, that is, when the charge stored in $C_1$ during each sawtooth is exactly balanced by the decrease in charge during the time interval when $V_1$ is cut-off. Also, when the voltage on the grid of tube $V_2$ is changed it will require a number of cycles for a new equilibrium condition to be obtained. For example, when the bias on tube $V_1$ is zero and $C_1$ is large, it will require a number of cycles of the applied sawtooth wave before the charge stored in $C_1$ is balanced by the decrease in charge provided by tube $V_2$. If after this equilibrium condition is reached and the bias on tube $V_2$ is set at a value where tube $V_1$ is conducting at the middle of the linear rise portion of the applied sawtooth wave, the voltage on the grid of tube $V_2$ is made negative the charge leaked off by tube $V_2$ will not be as great as the charge stored when tube $V_1$ conducts; hence the voltage across $C_1$ will rise and tube $V_1$ will conduct for a smaller portion of the applied sawtooth. After a number of cycles, a new equilibrium will be established with tube $V_1$ starting to conduct at a higher or later point on the sawtooth, thus producing a pulse in the output winding of transformer T at a later time than when the bias on tube $V_2$ was zero. Likewise, if the bias on tube $V_2$ is made positive, the charge leaked off by tube $V_2$ will be greater than that stored when tube $V_1$ conducts and hence tube $V_1$ starts to conduct at a lower point on the sawtooth. After a number of cycles, a new equilibrium point is reached where tube $V_1$ is conducting for a greater portion of the applied sawtooth than when the bias on tube $V_2$ was zero.

It will thus be seen that if condenser $C_1$ were very large it would require a large number of cycles of the sawtooth wave before equilibrium would be reached. It is common practice to make the pulse carrier (the sawtooth frequency) two or three times the highest audio frequency and it is therefore necessary to make condenser $C_1$ of such a value that equilibrium may be established within this time. $C_1$ must have a minimum such that with the type of tube used for $V_2$, a bias will be developed sufficient to cause tube $V_1$ to conduct at the middle of the linear rise time.

Fig. 2 shows modification of the system of Fig. 1. In Fig. 2, audio modulation voltage from input terminal **2** is first applied to the grid of a cathode follower or cathode amplifier tube $V_3$ whose cathode is connected to the cathode of tube $V_2$. Both tubes $V_2$ and $V_3$ use the same common cathode resistor $R_2$. Any variation in current through vacuum tube $V_3$ in response to audio modulation from input terminal **2** causes a variation of the cathode voltage of tube $V_2$. Because the grid voltage of tube $V_2$ is fixed, this variation in cathode voltage changes the average anode resistance of tube $V_2$ and hence the cathode bias of tube $V_1$.

Fig. 3 illustrates a third modification of the invention in which a direct current voltage is impressed on the grids of tubes $V_1$ and $V_2$ by means of the bleeder circuit composed of resistors $R_5$, $R_6$ and $R_7$. Here again, the audio modulation is applied to the cathode follower tube $V_3$, but the modulation voltage is now inserted in the grid-to-cathode circuit of tube $V_2$ across resistor $R_2'$. A degeneration resistor $R_8$ in the cathode of $V_2$ makes the anode resistance of tube $V_2$ vary in a linear manner with applied audio voltage. The saw-tooth voltage from generator **1** is now applied to the grid of tube $V_1$ through a condenser $C_2$. The connections are such that there is a direct current voltage applied to the grid of tube $V_1$ together with the saw-tooth wave. This raises the average voltage on the grid of tube $V_1$ and as a result raises the direct current anode voltage of tube $V_2$. This allows tube $V_2$ to work at a more suitable value of anode voltage. The amplitude of the applied saw-tooth voltage, however, remains the same in both conditions.

The maximum advance position in time of an output pulse from the system of Fig. 3 due to negative modulating voltage is determined by the minimum anode resistance of tube $V_2$ (maximum conduction condition) which occurs when tube $V_3$ is cut off, and the actual value of this minimum anode resistance of tube $V_2$ is set by the values of resistors $R_8$ and $R_2'$. When a maximum positive modulating voltage is applied to tube $V_3$, its current will cut off tube $V_2$ and leave resistor $R_1$ as the biasing resistor for tube $V_1$. Thus the flow of current through resistor $R_1$ when tube $V_2$ is cut off, automatically biases tube $V_1$ so that it yields a useful pulse at the top position of any saw-tooth wave applied to the grid of tube $V_1$.

The system of the invention can be used in a pulse multiplex communication system wherein

different transmitting channels have individual pulse generator and modulator circuits, like those shown in Figs. 1, 2 or 3. When used in a multiplex system, the different pulse generator circuits are supplied with separate saw-tooth voltages, each displaced in time so that the start of one saw-tooth follows the decay of another saw-tooth by an interval of time called a "guard band." The saw-tooth waves as applied to three separate channels are shown in Figs. 4*c*, 4*d* and 4*e*. The resulting pulses (Fig. 4*f*) from the different channels are combined in a common circuit, amplified and used to 100% modulate or key a radio transmitter. The dotted pulses indicate the limits of the pulse range when a channel is fully modulated. Only three channels are represented in Figs. 4*c* through 4*f*, although more channels may be used. One such pulse multiplex system utilizing the present invention is described in my copending application Serial No. 608,957, filed August 4, 1945.

One advantage of using the invention in a pulse multiplex system lies in the assurance that a pulse will be generated in each channel for each assigned period regardless of the presence of excessive modulation. This prevents cross-modulation or cross-talk in the channels which may otherwise occur due to a change in power levels throughout the system if a pulse were not passed on the peaks of modulation by a channel.

The invention is not limited to the precise details shown in the drawing, since various changes can be made by the substitution of equivalent elements without departing from the spirit and scope of the invention. As an illustration, the transformer T can be replaced by a differentiating coil one terminal of which can be connected to the anode of $V_1$, and the other terminal connected to the positive terminal of a source of unidirectional potential. In this case, the output would be obtained from the anode of tube $V_1$ via a coupling condenser to remove the direct current from the output. With such an arrangement, the pulse which is varied with modulation would be negative, while the unmodulated pulse would be positive. Alternatively, the transformer T could be replaced by a center-tapped inductance coil one terminal of which can be connected to the anode of $V_1$ while the other terminal is connected to +B. In this last case, the output pulse (pulse which is varied with modulation) would be positive and would be coupled to utilization circuits via a coupling capacity to remove direct current from the output.

If a variable width output pulse is desired, the transformer T can be replaced by a resistor of suitable value to provide a desired build-up and decay of the pulse. The variable width pulse generated in this event would be negative in polarity.

The invention can be used wherever there is need for a pulse generator controlled by a saw-tooth wave, with or without the modulation feature. For example, the use of tubes $V_1$ and $V_2$ and associated circuit elements can be used in a radar system where the saw-tooth sweep wave for the cathode ray device is generated simultaneously with the outgoing wave. This saw-tooth sweep wave can be applied to the grid of tube $V_1$. By calibrating resistor $R_2$ in distance and adjusting $R_2$ manually, it is possible to produce a marker pulse which can be made to occur at the same instant as the echo wave is received. For this particular application of the invention, there is no modulation applied to tube $V_2$.

The term "ground" used in the appended claims is deemed to include any point or surface of zero potential for alternating current or direct current, and may be considered a point of reference potential.

What is claimed is:

1. A pulse generator comprising first and second vacuum tubes each having an anode, a cathode, and a control electrode, a source of triangular waves coupled to the control electrode of said first tube, a differentiating circuit connected between the anode of said first tube and the positive terminal of a source of unidirectional potential, a connection from the cathode of said first tube to the anode of said second tube, a resistor in the cathode circuit of said second tube, a connection between the grid of said second tube and said cathode resistor, and a resistor shunted by a capacitor connected between the anode of said second tube and that terminal of the cathode resistor farthest removed from the cathod of said second tube, said second tube functioning as a resistance in the cathode circuit of said first tube, the value of said capacitor being such that said first tube is normally biased to the anode current cut-off condition, the effective anode resistance of said second tube determining the point on the applied triangular wave at which said first tube conducts, and an output terminal coupled to said differentiating circuit.

2. A pulse generator comprising first and second vacuum tubes each having an anode, a cathode, and a control electrode, a source of triangular waves coupled to the control electrode of said first tube, a differentiating transformer connected between the anode of said first tube and the positive terminal of a source of unidirectional potential, a connection from the cathode of said first tube to the anode of said second tube, a variable resistor in the cathode circuit of said second tube, a connection between the grid of said second tube and said cathode resistor, and a resistor connected between the anode of said second tube and that terminal of the cathode resistor farthest removed from the cathode of said second tube, said second tube functioning as a resistance in the cathode circuit of said first tube, means normally biasing said first tube to the anode current cut-off condition, the effective anode resistance of said second tube determining the point on the applied triangular wave at which said first tube conducts, and an output terminal coupled to said differentiating transformer.

3. A pulse generator comprising first and second vacuum tubes each having an anode, a cathode, and a control electrode, a source of triangular waves coupled to the control electrode of said first tube, a differentiating circuit connected between the anode of said first tube and the positive terminal of a source of unidirectional potential, a connection from the cathode of said first tube to the anode of said second tube, a resistor connected between the cathode of said second tube and ground, a resistor connected between the control electrode of said second tube and ground, a resistor connected between the anode of said second tube and ground, the normal anode resistance of said second tube being such and the circuit components having such values and so arranged that said first tube is normally biased to the anode current cut-off condition in the absence of an applied triangular wave and said first tube conducts at a point intermediate the ends of the forward slope of the

applied triangular wave, and an output terminal coupled to said differentiating circuit.

4. A pulse generator comprising first and second vacuum tubes each having an anode, a cathode, and a control electrode, a source of triangular waves coupled to the control electrode of said first tube, a differentiating circuit connected between the anode of said first tube and the positive terminal of a source of unidirectional potential, a connection from the cathode of said first tube to the anode of said second tube, a resistor connected between the cathode of said second tube and ground, a connection from the control electrode of said second tube to a variable tap on said last resistor, a resistor shunted by a condenser connected between the anode of said second tube and ground, the anode resistance of said second tube being such and said condenser having such value that said first tube is normally biased to cut-off in the absence of an applied triangular wave, and an output terminal coupled to said differentiating circuit.

5. A pulse generator comprising first and second vacuum tubes each having an anode, a cathode, and a control electrode, a source of triangular waves coupled to the control electrode of said first tube, a differentiating circuit connected between the anode of said first tube and the positive terminal of a source of unidirectional potential, a connection from the cathode of said first tube to the anode of said second tube, a resistor connected between the cathode of said second tube and ground, a resistor connected between the control electrode of said second tube and ground, a resistor shunted by a condenser connected between the anode of said second tube and ground, the normal anode resistance of said second tube being such and said condenser having such value that said first tube is normally biased to the anode current cut-off condition in the absence of an applied triangular wave and said first tube conducts at a point intermediate the ends of the forward slope of the applied triangular wave, and means for varying the anode resistance of said second tube in accordance with a modulating voltage to thereby vary the current conducting point of said first tube.

6. A pulse generator comprising first and second vacuum tubes each having an anode, a cathode, and a control electrode, a source of triangular waves coupled to the control electrode of said first tube, a differentiating circuit connected between the anode of said first tube and the positive terminal of a source of unidirectional potential, a connection from the cathode of said first tube to the anode of said second tube, a resistor connected between the cathode of said second tube and ground, a potentiometer having one terminal connected to ground and another terminal connected to a source of modulating voltage, a connection including a grid limiting resistor from the grid of said second tube to a point on said potentiometer, a resistor connected between the anode of said second tube and ground, means normally biasing said first tube to cut-off such that said first tube conducts at about the middle of the forward slope of the applied triangular wave in the absence of modulating voltage applied to said potentiometer, and an output terminal coupled to said differentiating circuit.

7. A pulse generator comprising first and second vacuum tubes each having an anode, a cathode, and a control electrode, a source of triangular waves coupled to the control electrode of said first tube, a differentiating circuit connected between the anode of said first tube and the positive terminal of a source of unidirectional potential, a connection from the cathode of said first tube to the anode of said second tube, a resistor connected between the cathode of said second tube and ground, a resistor shunted by a condenser connected between the anode of said second tube and ground, a resistance network connected between said positive terminal and ground, and connections from different points on said resistance network to the control electrodes of said first and second tubes, the value of said condenser and the normal anode resistance of said second tube being such that said first tube is normally biased to the anode current cut-off condition in the absence of an applied triangular wave and said first tube conducts at a point intermediate the ends of the forward slope of the applied triangular wave, and an output terminal coupled to said differentiating circuit.

8. A pulse generator comprising first and second vacuum tubes each having an anode, a cathode, and a control electrode, a source of triangular waves coupled to the control electrode of said first tube, a differentiating circuit connected between the anode of said first tube and the positive terminal of a source of unidirectional potential, a connection from the cathode of said first tube to the anode of said second tube, a resistor connected between the cathode of said second tube and ground, a resistor connected between the control electrode of said second tube and ground, a resistor shunted by a condenser connected between the anode of said second tube and ground, the normal anode resistance of said second tube being such that said first tube is normally biased to the anode current cut-off condition in the absence of an applied triangular wave and said first tube conducts at a point intermediate the ends of the forward slope of the applied triangular wave, means for varying the anode resistance of said second tube in accordance with an audio modulating voltage to thereby vary the current conducting point of said first tube, said means including a third vacuum tube whose cathode is connected to the cathode of said second tube and whose control electrode is connected to a source of audio voltage, and an output terminal coupled to said differentiating circuit.

9. A pulse generator comprising first and second vacuum tubes each having an anode, a cathode, and a control electrode, a source of sawtooth waves coupled to the control electrode of said first tube, a differentiating circuit connected between the anode of said first tube and the positive terminal of a source of unidirectional potential, a connection from the cathode of said first tube to the anode of said second tube, a resistor in the cathode circuit of said second tube, a connection between the grid of said second tube and said cathode resistor, and a resistor connected between the anode of said second tube and that terminal of the cathode resistor farthest removed from the cathode of said second tube, said second tube functioning as a resistance in the cathode circuit of said first tube, means normally biasing said first tube to the anode current cut-off condition, the effective anode resistance of said second tube determining the point on the applied sawtooth wave at which said first tube conducts, means for varying the anode resistance of said second tube in accordance with an audio voltage to thereby vary the current conducting point of

said first tube, said means including a cathode follower tube whose cathode is connected to the cathode of said second tube and whose control electrode is connected to a source of audio voltage, and an output terminal coupled to said differentiating circuit.

10. A pulse generator comprising first and second vacuum tubes each having an anode, a cathode, and a control electrode, a source of triangular waves coupled to the control electrode of said first tube, a differentiating circuit connected between the anode of said first tube and the positive terminal of a source of unidirectional potential, a connection from the cathode of said first tube to the anode of said second tube, a resistor connected between the cathode of said second tube and ground, a connection from the control electrode of said second tube to a variable tap on said last resistor, a resistor shunted by a condenser connected between the anode of said second tube and ground, the value of said condenser and the anode resistance of said second tube being such that said first tube is normally biased to cut-off in the absence of an applied triangular wave, means for varying the anode resistance of said second tube in accordance with an audio voltage to thereby vary the current conducting point of said first tube, said means including a cathode follower tube whose cathode is connected to the cathode of said second tube and whose control electrode is connected to a source of audio voltage, and an output terminal coupled to said differentiating circuit.

11. A pulse generator comprising first and second vacuum tubes each having an anode, a cathode, and a control electrode, a source of triangular waves coupled to the control electrode of said first tube, an impedance network connected between the anode of said first tube and the positive terminal of a source of unidirectional potential, a connection from the cathode of said first tube



to the anode of said second tube, a resistor in the cathode circuit of said second tube, a connection between the grid of said second tube and said cathode resistor, and a resistor shunted by a condenser connected between the anode of said second tube and that terminal of the cathode resistor farthest removed from the cathode of said second tube, said second tube functioning as a resistance in the cathode circuit of said first tube, the value of said condenser being such that said first tube is normally biased to the anode current cut-off condition, the effective anode resistance of said second tube determining the point on the applied triangular wave at which said first tube conducts, and an output terminal coupled to said impedance network.

12. A pulse generator comprising first and second vacuum tubes each having an anode, a cathode, and a control electrode, a source of triangular waves coupled to the control electrode of said first tube, a differentiating circuit connected between the anode of said first tube and the positive terminal of a source of unidirectional potential, a connection from the negative terminal of said source of unidirectional potential to a point of reference potential, a direct connection from the cathode of said first tube to the anode of said second tube, a resistor between the cathode of said second tube and said point of reference potential, a connection between the grid of said second tube and said cathode resistor, a resistor connected between the anode of said second tube and said point of reference potential, said second tube functioning as a resistance in the cathode circuit of said first tube, means for normally biasing the first tube to the anode current cut-off condition, a source of audio modulating voltage cupled to said second tube, and an output terminal coupled to said differentiating circuit.

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