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L. A. MEACHAM
TRIANGULAR WAVE GENERATOR

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FIG. 1

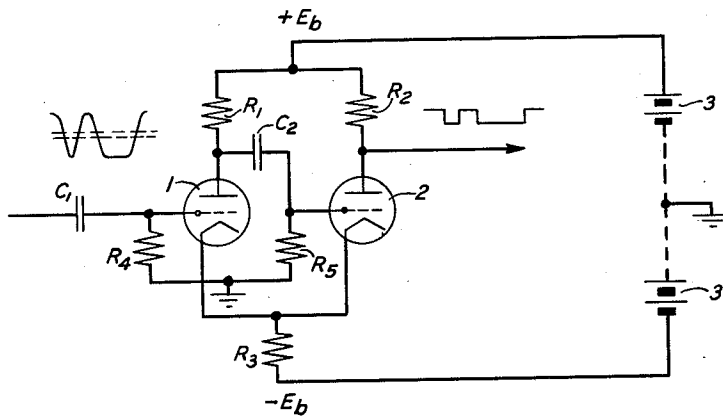
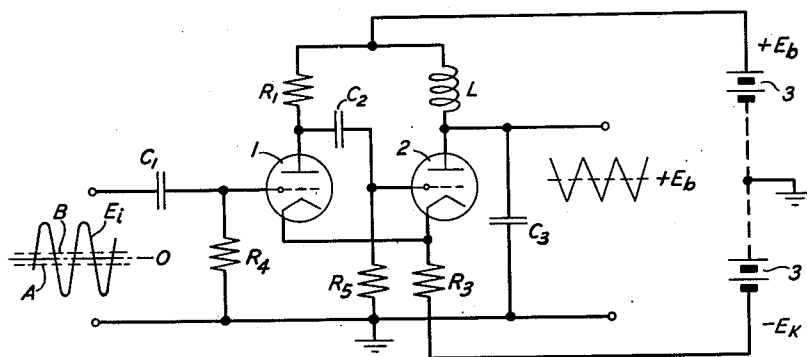


FIG. 2



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TRIANGULAR WAVE GENERATOR

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10 Claims. (Cl. 250—27)

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This invention relates to the generation of triangular electric waves and its principal object is to generate a triangular wave in a novel manner. A related object is to generate a triangular wave whose rising and falling portions are controlled as to their slopes.

It is well known to generate a triangular wave indirectly by first generating a rectangular wave, as with a conventional multivibrator, and thereupon applying this rectangular wave to an integrating circuit. As distinguished from this indirect approach the present invention generates a triangular wave of controlled slopes simply and directly. In brief, a two-tube slicer circuit, having plate-to-grid cross-coupling in one direction and coupling by way of a common cathode resistor in the other direction is modified as compared with the conventional circuit by the replacement of the usual anode resistor of one tube by a constant current device such as a choke coil. A storage condenser is connected from the anode of this tube to a point of fixed potential such as ground. A signal whose frequency is that of the desired wave is applied to the grid of the other tube of the pair and operates to trip the slicer from a first condition, in which one tube conducts while the other is cut off, to the opposite condition in which the first tube is cut off while the other conducts. With appropriate selection of the magnitudes of the circuit elements, the tripping action takes place each time the input signal passes through its zero value.

While the tube whose anode contains the choke coil in series with it is non-conducting the constant choke coil current flows into the condenser and charges it at a constant rate until the slicer is tripped. Thereupon the constant choke coil current flows through this tube and through the common cathode resistor. In addition the condenser, now charged, proceeds to discharge through this tube and through the common cathode resistor. Constancy of the discharge current is secured by virtue of cathode feedback, in that any possible reduction of the tube current tends to reduce the voltage drop across the common cathode resistor. This in turn reduces the potential of the cathode of the discharge tube with respect to its grid so that the resistance of its discharge path is reduced, thus providing a compensating increase of the discharge current. In this sense the condenser discharge circuit is self-stabilizing, and since the choke coil current is also constant the condenser discharge rate is constant. Since the tripping action takes place each time the input signal passes through its zero

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value, then, with an input signal of symmetrical wave form, the constant discharge rate becomes equal to the charge rate so that the output wave, namely the voltage across the storage condenser is of symmetrical triangular form.

The invention will be fully apprehended from the following detailed description of a preferred embodiment thereof taken in connection with the appended drawings, in which:

Fig. 1 is a schematic circuit diagram showing a slicer circuit of well-known construction; and

Fig. 2 is a schematic circuit diagram showing apparatus embodying the invention.

Referring now to the drawings, Fig. 1 shows a slicer circuit which comprises a pair of similar triodes 1, 2 whose cathodes are connected together by way of a common resistor R_3 of relatively large magnitude to the negative terminal of a battery 3. The positive terminal of this battery is connected by way of comparatively small resistors R_1 and R_2 to the anodes of the tubes. The grids of the tubes are connected by way of individual comparatively large resistors R_4 , R_5 of like magnitude to ground. The anode of the left-hand tube 1 is coupled to the grid of the right-hand tube 2 by way of a condenser C_2 of relatively large capacitance; i. e., of low impedance to transient or surge currents. An input signal such as a pulse train is applied to the grid of the left-hand tube by way of condenser C_1 . The circuit of Fig. 1 resembles a conventional single-trip multivibrator in configuration but it operates in a different fashion because of the choice of the values of the various circuit elements. In particular, the capacitance of the coupling condenser C_2 is sufficiently large that the potential drop across it does not vary appreciably during normal operation and the anode resistor R_1 of the left-hand tube is given a small value so that the gain around the feedback path of the circuit as a whole is approximately unity in the intermediate unstable state in which both triodes are in their active conditions. The grids of both tubes are returned to ground. When the input signal is of small magnitude, the grids of the two tubes are maintained at nearly the same potential. Unlike the single trip multivibrator which, when tripped, remains tripped until the charge on the coupling condenser has had time to relax, this slicer circuit trips whenever the input signal rises through a narrow potential range near the value zero and trips back again whenever the input signal falls through the same potential range. Such a slicer therefore generates a square wave of constant amplitude representing an accurate narrow slice

of the input signal, which is made available at the anode of the right-hand tube. Such a circuit and its operation are described in detail in an article entitled "An Experimental Multichannel Pulse Code Modulating System of Toll Quality" by L. A. Meacham and E. Peterson, published in the Bell System Technical Journal for January 1948, vol. 27, page 1, especially page 29.

Fig. 2 shows a circuit which is modified as compared with the circuit of Fig. 1 by the substitution of a constant current device such as a choke coil L for the anode resistor R₂ of the right-hand tube and by the addition of a storage condenser C₃ which is connected from the anode of the right-hand tube to ground. The output terminals of the apparatus are the same as the terminals of the storage condenser C₃.

In the operation of the circuit of Fig. 2, as the input voltage E_i, applied to the grid of the left-hand tube rises through a value such as A, near zero or ground potential, the left-hand tube commences to conduct. The flow of current from the battery 3 to the left-hand anode through the resistor R₁ depresses the voltage of this anode and the resultant negative surge is transmitted to the grid of the right-hand tube by way of the condenser C₂, thus tending to drive the right-hand tube into its non-conducting condition. This reduces current flow through the right-hand tube and therefore the voltage drop across the common cathode resistor R₃ and so tends further to increase the current through the left-hand tube, the voltage drop across the resistor R₁ and the negative surge of voltage applied to the right-hand grid. This action is thus regenerative so that the cut-off of the right-hand tube takes place quite sharply.

The current through the choke coil L or other constant current device now flows only into the condenser C₃, provided that the impedance of the load be high compared to that of the condenser. The condenser C₃ is then charged by this constant current and its voltage rises linearly with time. Meanwhile the signal has increased to and through its positive peak and is returning to its zero value. During this time the left-hand tube behaves as a cathode follower; that is to say, its cathode rises in potential to remain always above that of the grid, and thus avoids the passage of grid current, which, if it were to occur, would be objectionable because of charging condenser C₁ and thus disturbing the proper biasing of the input signal. As the signal falls through a potential such as B, near zero, the potential of the cathode of the right-hand tube, which has also been falling, reaches a value for which the right-hand tube commences to conduct. This in turn tends to prevent any further decrease in the potential of the cathode of the left-hand tube, and thus the plate current of the left-hand tube is reduced. The corresponding decrease in the voltage drop across resistor R₁ produces a positive surge on the grid of the right-hand tube, and thus the transfer of conduction from tube 1 to tube 2 is complete and abrupt.

There are now available to the right-hand tube two sources of anode current. The first is the constant current flowing through the choke coil L and the second is the charge stored in the condenser C₃. The storage condenser C₃ therefore commences to discharge through the anode-to-cathode path of the right-hand tube and the discharge current flows through the common cathode resistor. By virtue of the cathode feed-

back action thus provided, the second component of the right-hand tube current is held substantially constant throughout the condenser discharge portion of the cycle. That is to say, if the resistance of the condenser discharge path as a whole were constant the discharge rate of the condenser C₃ would diminish exponentially. But with the arrangement shown, as the condenser charge is reduced, any tendency of the discharge current to diminish reduces the voltage drop across the common cathode resistor R₃ and so the potential of the right-hand cathode with respect to its grid. This is equivalent to an increase in the grid potential of the right-hand tube with respect to its cathode which results in an increase of its anode-to-cathode current; and this effect offsets the tendency of the right-hand tube current to be reduced as the storage condenser is discharged. Thus the storage condenser discharge current remains sensibly constant throughout the discharge portion of the cycle.

As the discharge of the storage condenser proceeds, the input signal reaches and passes through its negative maximum and returns toward its zero axis. When it next passes through its zero value in the positive direction the cycle as above described repeats.

As a result of these operations the wave form of the condenser voltage rises linearly with time until an instant determined by the negative axis crossing of the input signal, whereupon it immediately commences to fall, and falls linearly with time until an instant determined by the next positive axis crossing of the input signal.

With an input wave whose positive and negative portions are of equal durations the slicer trips from one of its two conduction conditions to the other and back again at equal intervals, so that each tube conducts during just one-half of the full cycle. Since the choke coil current flows continuously its magnitude is one-half that of the On value of the anode-to-cathode current of the right-hand tube or, in other words, the current which the right-hand tube draws while it is conducting is twice the choke coil current. As above explained, this conduction current is composed of two components, first the choke coil current and second the condenser discharge current. It follows that these two components are alike in magnitude and that the condenser discharge current, the second of the two components, is equal to the condenser charge current which, as above explained, is identical with the choke coil current.

Therefore, provided the positive and negative portions of the input wave are of equal durations, the positive and negative slopes of the output voltage wave are equal in magnitude as well as linear with time.

On the other hand, if the input wave form is such that its negative portions differ in length from its positive portions, then the intervals during which the right-hand tube conducts become unequal to the intervals during which this tube is cut off. In this event, the output wave form adjusts itself so that the slopes of the rising and falling portions are inversely proportional to their respective durations and so that, apart from unavoidable series resistance in the choke coil L the areas of the output wave form above and below its axis, namely the battery potential, are equal.

Still further constancy of the discharge current of the storage condenser may be attained by employing in place of the common cathode

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resistor R₃ the combination of the discharge path of an additional thermionic discharge device and a resistor interconnected in cathode follower fashion. Such a circuit, one form of which is described, for example, in an application of L. A. Meacham Serial No. 21,651 filed April 17, 1948, now Patent 2,607,030, issued August 12, 1952, operates with high precision as a current stabilizer.

What is claimed is:

1. Apparatus for generating a voltage of triangular wave form which comprises a pair of discharge devices intercoupled for operation in one or other of two stable states in one of which the first device conducts while the second is cut off and in the other of which the first device is cut off while the second conducts, a storage condenser connected in shunt with the discharge path of the second device, a constant current element connected in series with a discharge electrode of the second device, and means for applying a signal to trip said pair of devices from either of said stable states to the other of said stable states.

2. Apparatus as defined in claim 1 wherein said constant current element is connected in series with the anode of said second discharge device.

3. Apparatus as defined in claim 2 wherein said constant current element is a choke coil.

4. In combination with apparatus as defined in claim 2, means for stabilizing the discharge current of said second device, throughout each of the periods in which it conducts, at a fixed magnitude.

5. Apparatus as defined in claim 4 wherein the current-stabilizing device comprises a resistor connected in series with the cathode of said second discharge device.

6. In combination with apparatus as defined in claim 1 wherein the cathodes of said two devices are connected together, a point of fixed potential, and a resistor, said cathodes being connected by way of said resistor to said fixed potential point.

7. In combination with apparatus as defined in claim 2 a point of fixed potential, a resistor, the cathode of said second discharge device being connected by way of said resistor to said fixed potential point whereby the current of said second discharge device is stabilized by cathode feedback.

8. Apparatus as defined in claim 1 wherein said

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pair of discharge devices have, in addition to said two stable states, an intermediate state which is, by a small margin, unstable.

9. Apparatus for generating a voltage of symmetrical triangular wave form which comprises a trigger circuit including a pair of discharge devices each of which has a cathode, an anode, and a control electrode, the electrodes of said devices being cross-coupled to provide two stable conditions in one of which the first device conducts while the second is cut off and in the second of which the second device conducts while the first is cut off, a resistor connected to the anode of the first device by way of which its anode-cathode current is supplied, a constant current element connected to the anode of the second device by way of which its anode-cathode current is supplied, a fixed potential point to which the cathodes of both devices are connected, a condenser interconnecting the anode of the second device with said fixed potential point, and means for applying a periodic signal to the control electrode of the first device.

10. Apparatus for generating a voltage of symmetrical triangular wave form which comprises a trigger circuit including a pair of discharge devices each of which has a cathode, an anode, and a control electrode, a resistor which is common to the two cathodes, the anode of one of said devices being cross-coupled to the grid of the other device to provide two stable conditions in one of which the first device conducts while the second is cut off and in the second of which the second device conducts while the first is cut off, a resistor connected to the anode of the first device by way of which its anode-cathode current is supplied, a constant current element connected to the anode of the second device by way of which its anode-cathode current is supplied, a fixed potential point to which the common cathode resistor is connected, a condenser interconnecting the anode of the second device with said fixed potential point, and means for applying a periodic signal to the control electrode of the first device.

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