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2,858,434

PRECISION STEP VOLTAGE GENERATOR

Filed Sept. 25, 1956

3 Sheets-Sheet 1

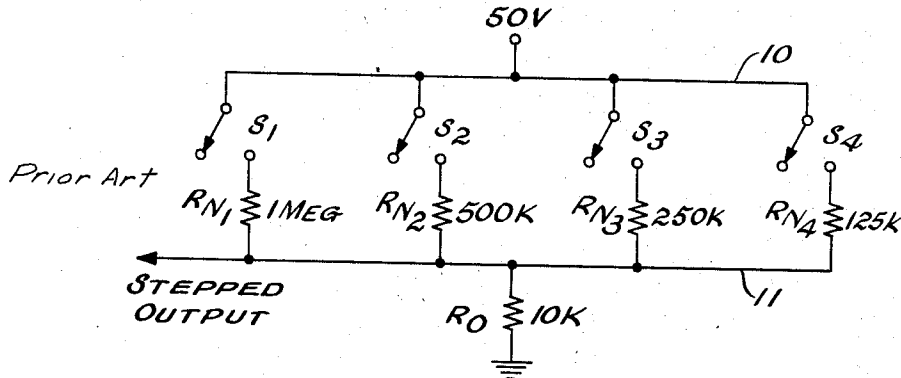


FIG 1

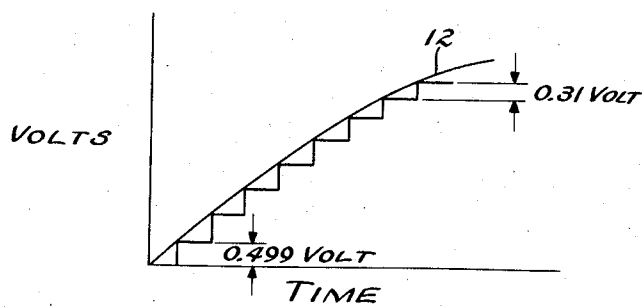
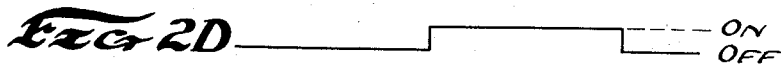
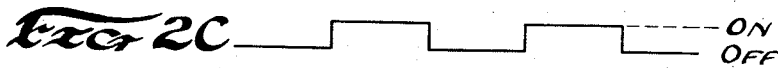
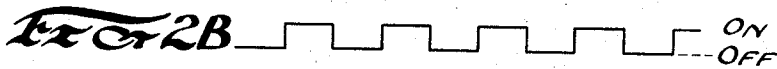


FIG 3

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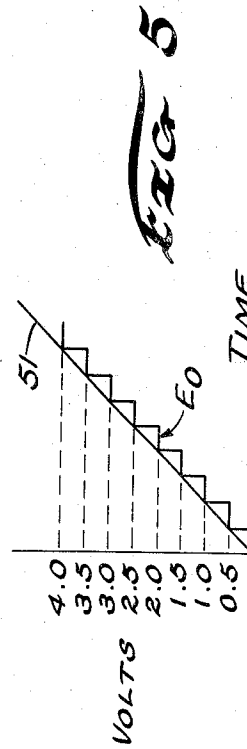
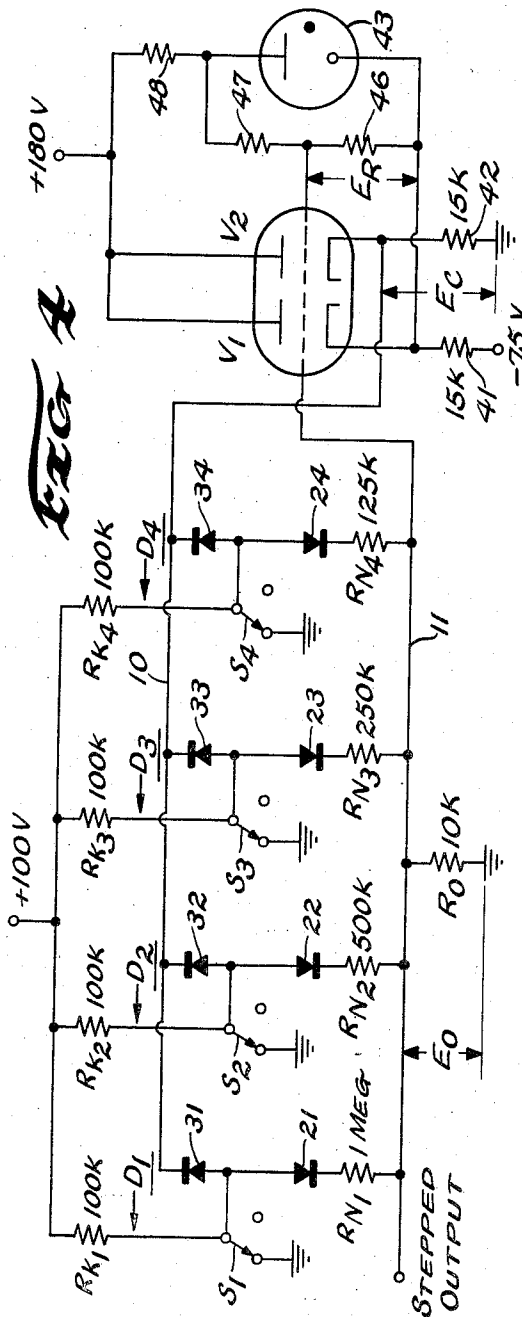
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3 Sheets-Sheet 2



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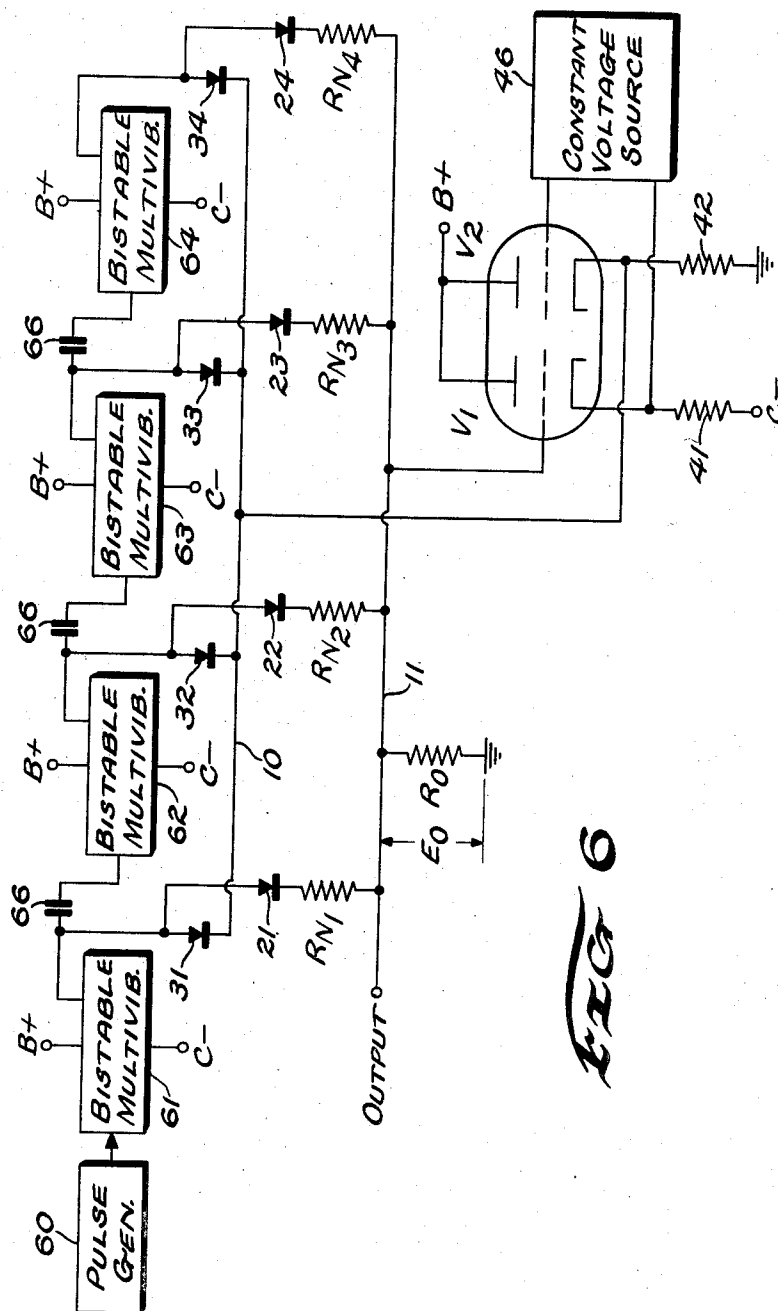
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PRECISION STEP VOLTAGE GENERATOR

Filed Sept. 25, 1956

3 Sheets-Sheet 3



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PRECISION STEP VOLTAGE GENERATOR

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7 Claims. (Cl. 250—27)

This invention relates to means for obtaining substantial equality of steps in a stepped-voltage wave.

Prior stepped-voltage generating means do not generally maintain substantial equality among the incremental voltage amplitudes in their stepped-output. Often, their stepped increments decrease in value as the steps increase in absolute amplitude.

Therefore, the principal object of this invention is to teach how a precision stepped-voltage generator may be constructed.

It is another object of this invention to provide means for maintaining equality of amplitude among the incremental amplitudes of a stepped-voltage wave.

It is still another object of this invention to provide a precise stepped-voltage generator that may be switched in a binary manner, wherein the number of output steps is large for a given number of components used in constructing the invention.

The invention includes floating-clamping means, comprising a pair of cathode followers, which maintain a given-reference potential between a pair of leads that float potential-wise with the stepped-voltage output. Current-controlling resistors are connected between the floating leads; and a common resistor is connected serially to one of the leads. A precisely stepped-output voltage may be taken from either lead.

The type of switching scheme used in a particular case of the invention determines the resistance values of the current-controlling resistors. Where a simple switching scheme is used which provides for each output step a respective switch and a respective current-controlling resistor, the resistors vary consecutively by inverse integer values and are switched in the same order. For example, the current-controlling resistors may be: 1 megohm, 500, 333, 250, etc. kilo-ohms.

However, the invention can be utilized more efficiently with a binary switching scheme. This arrangement permits a relatively small number of current-controlling resistors and switches, wherein N number of current-controlling resistors and switches can provide $(2^N - 1)$ number of output-voltage steps in each sequence of a repetitive wave. Furthermore, the binary switching scheme is easily provided electronically by a series of tandem-connected bistable circuits.

Further objects, features and advantages of the invention will be apparent to a person skilled in the art upon further study of the specification and drawings, in which:

Figure 1 illustrates a conventional stepped-voltage generating circuit utilizing a binary switching scheme;

Figure 2A, 2B, 2C and 2D illustrate a binary-switching scheme used with the respective switches in Figure 1;

Figure 3 illustrates the lack of equality in the output-voltage steps provided by conventional circuits;

Figure 4 is an illustrative form of the invention;

Figure 5 illustrates the output-voltage step sequence provided from the inventive circuit in Figure 4; and,

Figure 6 illustrates a form of the invention utilizing electronic switches.

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In order to better understand the invention, a conventional circuit is illustrated in Figure 1, utilizing a binary-switching scheme to provide a stepped-output voltage. Illustrative values of components are given in order to assist the understanding. A pair of leads 10 and 11 are provided, with lead 10 being connected to a 50-volt low-impedance direct-current power source having its other side (not shown) connected to ground. Four single-pole double-throw switches S_1 through S_4 have their poles respectively connected to lead 10. Four current-controlling resistors R_{N1} , R_{N2} , R_{N3} and R_{N4} are connected between the other lead 11 and a respective contact of each of the switches. They have respective values of one megohm, 500, 200, and 125 kilo-ohms. An output resistor R_0 is connected between ground and lead 11 and has a value of 10 kilo-ohms in Figure 1. The stepped-output voltage is taken across resistor R_0 .

Figure 2A through 2D illustrate the time-repetitive switching sequence for the four switches in Figure 1. Hence, switch S_1 opens and closes according to Figure 2A, switch S_2 according to Figure 2B, switch S_3 according to Figure 2C, and switch S_4 according to Figure 2D.

The four switches in Figure 1 permit a maximum of fifteen voltage steps in each stepping sequence. The stepping sequence is, of course, repetitious as long as the switches are operated continuously according to Figures 2A through 2D.

As a result of this sequence of opening and closing the switches, the stepped-output voltage in Figure 1 varies approximately as illustrated in Figure 3, where it can be seen that the voltage steps vary in a non-linear manner to follow approximately a non-linear defining curve 12.

It is therefore noted in Figure 3 (which only shows eight of the fifteen step sequence) that much incremental variation is obtained among the voltage steps provided by the circuit of Figure 1. For example, the first step is 0.499 volt, while the eighth step is 0.31 volt.

The invention teaches how such voltage steps may be made equal, and Figure 4 illustratively applies the invention to the circuit of Figure 1 to provide substantially equal output voltage steps.

In Figure 4 a first plurality of diodes 21 through 24 are respectively connected in series with resistors R_{N1} through R_{N4} and have their anodes respectively connected to the poles of switches S_1 through S_4 .

Another plurality of resistors R_{K1} through R_{K4} are each illustrated as 100 kilo-ohm resistors in Figure 4. They are respectively connected between the poles of switches S_1 through S_4 and a 100-volt direct-current power source, which has its other side (not shown) connected to ground.

A second plurality of diodes 31 through 34 also have their anodes respectively connected to the poles of switches S_1 through S_4 but have their cathodes connected to lead 10.

Switches S_1 through S_4 act as shunting devices in Figure 4 rather than as the series devices of Figure 1. Thus, in Figure 4 each switch has one of its contacts connected to ground and its other contact unconnected. The ground connection of the respective switches S_1 through S_4 may instead be connected to a negative-potential source which can in some cases improve the cutoff bias on the diodes.

The illustrated positions of the switches in Figure 4 connect the anodes of all of the diodes to ground to maintain them in a non-conducting state. Moving the pole of any switch to its other contact will bias its respective diodes into a conducting condition, because their anodes are then raised to a positive value by a voltage divider D provided between the 100-volt power source and ground by the respective series resistors R_K , R_N and R_0 .

A pair of electron-control means V_1 and V_2 are con-

nected as cathode followers, and are illustrated as triodes. Triodes V_1 and V_2 have their plates directly connected to the positive direct-current power source which is +180 volts in Figure 4. Both cathode followers operate in their substantially linear region between cutoff and grid-current limiting. Thus, a cathode resistor 41 is connected between the cathode of tube V_1 and a negative direct-current power source illustrated to provide -75 volts. The negative cathode supply is required for cathode follower V_1 to maintain it in its region between cutoff and grid-current limiting. The grid of tube V_1 is connected to lead 11.

Cathode follower V_2 is operated at a higher grid-voltage level than follower V_1 which permits follower V_2 to have its cathode resistor 42 connected between the ground-potential level and the cathode of tube V_2 . Lead 10 connects to the cathode of follower V_2 to receive its output.

A fixed-reference voltage E_R is provided between the grid of follower V_2 and the cathode of follower V_1 . A voltage-regulator tube 43 maintains voltage E_R at a fixed value. A pair of resistors 46 and 47, comprising a voltage divider, are connected across regulator tube 43, and a resistor 48 is connected between the anode of tube 43 and the +180 volt supply. Resistor 46 has one end connected to the grid of tube V_2 , and its other end connected to the cathode of tube V_1 . This example assumes that reference voltage E_R is +50 volts.

The electron-control means V_1 and V_2 are chosen to have as high an amplification factor as possible, in order to provide the cathode followers with substantially unity voltage gain. Thus, the voltages on the cathode and grid of tube V_1 will be substantially equal; and similarly, the voltages on the cathode and grid of tube V_2 will be substantially equal. A high amplification factor also provides a low output impedance for cathode follower V_2 that for example may be of the order of two-hundred ohms.

The switching scheme for switches S_1 through S_4 in Figure 4 is the same as described for Figure 1, and is illustrated similarly by Figures 2A through 2D. Consequently, the binary switching scheme provides up to a maximum of fifteen output steps since N is four in the limiting formula ($2^N - 1$).

The output voltage E_O in Figure 4 across resistor R_O varies with substantially equal steps as illustrated in Figure 5, wherein each step is substantially one-half volt. Thus, a linear defining line 51 may be drawn in Figure 5.

In operation, the invention maintains a constant voltage, equal to the reference voltage E_R , between leads 10 and 11 throughout the stepping sequence. Thus, in Figure 4, lead 10 is always maintained at +50 volts above lead 11, and provides the same stepping sequence as lead 11, but at a 50-volt higher level.

The voltages on leads 10 and 11 float with the varying output voltage E_O due to the following operation of cathode followers V_1 and V_2 : Output voltage E_O is applied directly to the grid of tube V_1 because it is connected to lead 11. Hence, the voltage on the cathode of tube V_1 will be very nearly equal to output voltage E_O because of the unity voltage gain of cathode follower V_1 .

Accordingly, the instantaneous voltage on the grid of tube V_2 is ($E_O + E_R$), because reference voltage E_R is there added to output voltage E_O of tube V_1 by the connection of the reference-voltage source.

Since the voltage on the cathode of tube V_2 is substantially equal to the voltage on its grid because of the unity voltage gain, its output voltage E_C is defined by the following formula:

$$E_C = E_R + E_O \quad (1)$$

Therefore, the instantaneous voltage on lead 10 is ($E_R + E_O$), while the instantaneous voltage on lead 11 is E_O .

While switches S_1 through S_4 are in the grounded positions shown in Figure 4, output voltage E_O is zero, because

both ends of resistor R_O are connected either directly or indirectly to the ground potential level. Thus, there will be no current output provided from cathode follower V_2 because diodes 31 through 34 are biased below cutoff by having their anodes grounded while their cathodes are at the positive potential of the cathode of tube V_2 .

The respective voltage dividers D_1 through D_4 are provided by ungrounding the respective switches. Whenever any switch is moved to its ungrounded position, its diode of 31 through 34 is thus biased to a conducting state by its respective voltage divider D , since the positive voltage provided at its switch pole is at all times more positive than the output voltage of cathode follower V_2 . Furthermore, it is more positive than voltage E_O provided on the other side of its diode of 21 through 24 to maintain it conducting. Therefore, the voltage-divider values of resistors R_K and R_N are chosen so that when all switches are ungrounded, the positive potential provided by the respective voltage dividers to their diodes always exceeds voltage E_C from tube V_2 . This insures that the diodes are always in a conducting state whenever their respective switches are ungrounded.

In the simplest of the binary switching situations, only one of the switches S_1 through S_4 is ungrounded. This provides a circuit between ground and the 100-volt source through the respective voltage divider and connects cathode-follower voltage E_C through the low forward impedances of the respective diodes to its resistor R_N which is in series with output resistor R_O . A current I flows through the series-connected resistors R_N and R_O and is caused by the cathode-follower output voltage E_C being maintained across them. Current I may therefore be defined by the expression:

$$I = \frac{E_C}{R_N + R_O} \quad (2)$$

Also, in this case, output voltage E_O may be defined by the expression:

$$E_O = IR_O = \frac{E_C R_O}{R_N + R_O} \quad (3)$$

Expressions 1, 2 and 3 above may be solved algebraically for output voltage E_O to provide:

$$E_O = \frac{R_O E_R}{R_N} \quad (4)$$

In Expression 4, both R_O and E_R are constants. As a result, the system of Figure 4 allows the output-voltage E_O provided across resistor R_O to be controlled by a single set of parameters, which are the values of resistors R_N .

In order to theoretically obtain equal-voltage steps across a common resistor that has currents switched through it in a binary fashion, it is necessary for the respective currents to have amplitudes that are binary related, wherein the adjacent amplitudes double in value as the adjacent switching rates decrease by one-half. Thus, to provide the proper current relationships through resistor R_O for the binary switching scheme, there must be a binary selection of resistors R_N ; wherein any two resistors in the sequence have values with 2-to-1 ratio.

The general case for a stepped-output voltage using a switching scheme, such as the binary one, where simultaneous conduction of plural resistors R_N is required during parts of the sequence, is given by the expression:

$$E_O = E_R R_O \left[\frac{R_{N_a} \cdots R_{N_k}}{R_{N_a} \cdots R_{N_k}} \right] \quad (5)$$

where the values of R_N in Expression 5 represent only those resistors which are conducting current for the particular output-voltage step E_O . This is a function of the switching scheme.

The binary sequence need not provide its maximum number of steps, but can be modified in a conventional manner to obtain a lesser number. For example, a

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decade number of steps can be obtained with four resistors R_N by causing the switching scheme to reset to zero after the ninth step.

Other switching sequences than binary may be used in the invention, and the above Expressions 1 through 5 apply. For example, the simplest sequence provides one output-voltage step for each resistor R_N . This straightforward switching scheme is, however, not usually the most efficient. It has its output defined completely by Expression 4. In this case, the values in a sequence of resistors R_N vary consecutively in inverted-integer fractions of the first resistor, in the order $1, \frac{1}{2}, \frac{1}{3}, \frac{1}{4}$, etc.

A slight source of error can exist in the invention due to the output impedance of the cathode follower. However, this error can be made a small fraction of one percent by having the cathode-follower output impedance very small compared to resistors R_N and having resistors R_K approximately the same order as resistors R_N .

The binary switching scheme explained above is also particularly useful because it can conveniently utilize electronically-controlled bistable circuits, such as multivibrators, in the well-known fashion of binary counters.

Figure 6 shows such a switching system and comprises a plurality of conventional bistable multivibrators 61 through 64 which are driven by a pulse generator 60 connected to the input of first multivibrator 61. The multivibrators are conventionally coupled by capacitors 66.

Each multivibrator is connected between a positive direct-voltage supply B+ and a negative direct-voltage supply C- to provide an output voltage that switches between a low level that is the ground-potential level (or slightly below) and a high level that might for example be 100 volts. With multivibrators, it is preferable that the potential level be slightly below the ground potential level. If the multivibrators also provide an output impedance of 100 kilo-ohms, they switch analogously to switches S_1 through S_4 with their respective resistors R_K in Figure 4.

Although the bistable multivibrators may each have two opposite outputs, the output is selected which correlates with the switching sequence described in Figure 2; wherein at the beginning of a sequence of steps, all of the multivibrator outputs simultaneously begin a period at their lower-voltage level.

Except for the replacement of switches S_1 through S_4 and their resistors R_{K_1} through R_{K_4} by respective bistable and their resistors R_{K_1} through R_{K_4} by respective bistable multivibrators 61 through 64, Figure 6 is otherwise identical in construction to Figure 4, and its operation is explainable in the same manner.

Although this invention has been described with respect to particular embodiments thereof, it is not to be so limited as changes and modifications may be made therein which are within the full intended scope of the invention as defined by the appended claims.

I claim:

1. Means for generating a sequence of incrementally-varying voltages comprising a plurality of switching means, ground-potential means, each of said switching means providing a pair of voltage states, with one voltage state being at or below ground potential, and the other voltage state being at positive potential, a positive source of direct voltage, output-resistance means having one end connected to said ground-potential means, a plurality of current-controlling resistance means, a first plurality of asymmetric conductors, each being connected in series with one of said current-controlling resistance means between the other end of said output-resistance means and one of said switching means respectively, a pair of cathode followers, each operating linearly over the range of its input voltages, the input of the first cathode follower being connected to said other end of said output-resistance means, a reference-voltage source being connected between the input of the second cathode follower and the

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cathode of the first cathode follower, and a second plurality of asymmetric conductors connected between the cathode of said second cathode follower and said switches respectively, with the asymmetric conductors being biased above cutoff only by the positive-potential state of its respective switching means.

2. Means for generating a sequence of incrementally-varying voltages comprising a plurality of switching means, each of said switching means alternately providing a low potential output and a high potential output, a common lead, an output resistor connected between ground and said common lead, a plurality of current-controlling resistance means having resistances related by a geometric progression, said resistance means being individually connected in series between said common lead and the respective individual switching means, a first plurality of diodes connected between said common lead and said switching means respectively, first and second cathode followers operating in their linear regions, a negative-voltage source providing the cathode current return of said first cathode follower, and said second cathode follower having its cathode-current returned to ground potential, the control grid of said first cathode follower being connected to said common lead, a second plurality of diodes connected between the cathode of said second cathode follower and said switching means respectively, a fixed-potential source connected between the control grid of said second cathode follower and the cathode of said first cathode follower, said fixed source being independent of ground potential, the diodes respectively connected to each of said switching means being alternately maintained in conducting and non-conducting conditions by its opposite switching states, and said current-controlling resistors having their values selected according to the switching of said switching means.

3. A circuit as defined in claim 2 in which a voltage-regulating tube comprises said fixed-potential source.

4. A circuit as defined in claim 3 in which a binary switching scheme is utilized, wherein said switching means are switched on and off with binary time-division relationships, and said current-controlling resistors having binary values, wherein each is related to its adjacent resistor by a two-to-one resistance ratio.

5. A precision step-voltage generator comprising a plurality of bistable circuits connected in tandem, with each bistable circuit providing an output having alternately a high potential state and a low potential state, first and second leads, a first plurality of diodes connected between said first lead and the respective outputs of said bistable circuits; a plurality of series circuits, each comprising a diode and a current-controlling resistor, said series circuits connected between said second lead and the respective outputs of said bistable circuits, with the resistors in said series circuits having their resistances proportioned in a binary decreasing fashion, output resistance means connected between said second lead and ground, first and second cathode followers operating linearly, the cathode of said second cathode follower being connected to said first lead, the grid of said first cathode follower being connected to said second lead, and a constant voltage source being connected between the grid of said second cathode follower and the cathode of said first cathode follower.

6. Precision step-voltage generating means comprising a pulse generator, a plurality of multivibrators connected in tandem with said pulse generator, with the outputs of said multivibrators being switched in binary-division relationship; a C-minus source, and a B-plus source being connected to each multivibrator to establish its opposite direct-current levels; each multivibrator having an output that switches between a high potential level approximately equal to the B-plus source and a low potential level equal or below the ground-potential level of the system, a first cathode follower having its plate connected to said B-plus supply and its cathode current returned to said C-minus supply, an output resistor connected between the grid of

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said first cathode follower and ground, a second cathode follower having its plate connected to said B-plus supply and having its cathode current returned to the ground-potential level, a first plurality of diodes, a plurality of current-controlling resistors, each connected in series with said output resistor and one of said first plurality of diodes and the output of one of said plurality of multivibrators, a second plurality of diodes respectively connected between the outputs of said multivibrators and the cathode of said second cathode follower, a constant-voltage source connected between the grid of said second cathode follower and the cathode of said first cathode follower, and the diodes connected to any of said multivibrator outputs being biased to a conducting state by its high-potential output and being biased to substantial non-conduction by its low-potential output state.

7. Means for stabilizing step voltages comprising a plurality of bistable circuits connected in tandem, each of said bistable circuits having an output alternately being at a high-voltage state and a low-voltage state, said low-voltage state being at or below ground potential, first and second common leads, output resistance means having one end connected to ground and its other end connected to said first common lead, a plurality of current-controlling resistors, a first plurality of diodes connected in series with said output resistor and said current-controlling resistors

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respectively and the outputs of said bistable circuits respectively, a second plurality of diodes being connected between said second common lead and the outputs of said bistable circuits respectively, with any of said second plurality of diodes being biased to a non-conducting state by receiving said low-voltage output and being biased to a conducting state by receiving said high-voltage output, a first cathode follower having its grid connected to said first common lead, a negative-potential source providing the cathode current return for said first cathode follower to permit linear operation, a second cathode follower, a B-plus source connected to the plates of said first and second cathode followers, said second cathode follower having its cathode current returned to ground potential, with its cathode being connected to said second common lead, and a constant-voltage source connected between the grid of said second cathode follower and the cathode of said first cathode follower.

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