

May 19, 1959

L. W. HUSSEY ET AL

2,887,619

CURRENT LIMITING GATING CIRCUIT

Filed Oct. 4, 1957

2 Sheets-Sheet 1

FIG. 1

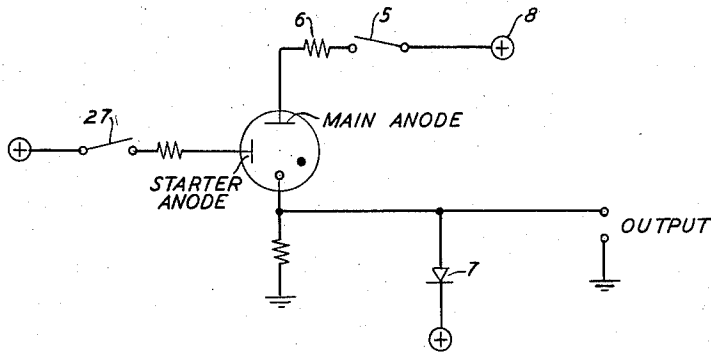
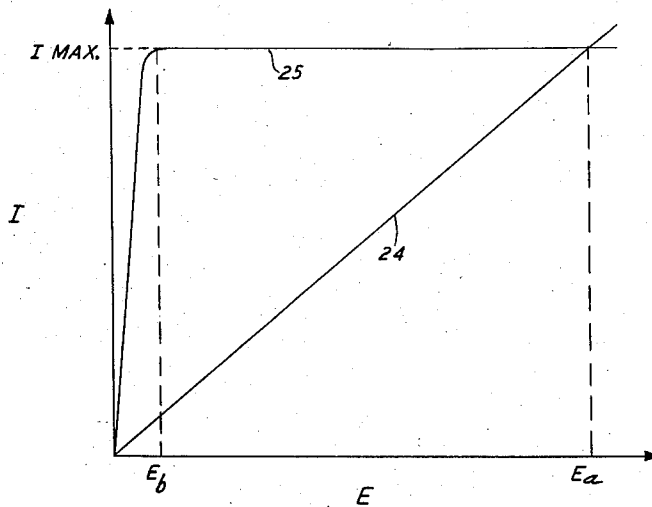


FIG. 2



INVENTORS **L. W. HUSSEY**
W. PEIL
BY **S.E. Hollander**
ATTORNEY

May 19, 1959

L. W. HUSSEY ET AL
CURRENT LIMITING GATING CIRCUIT

2,887,619

Filed Oct. 4, 1957

2 Sheets-Sheet 2

FIG. 3

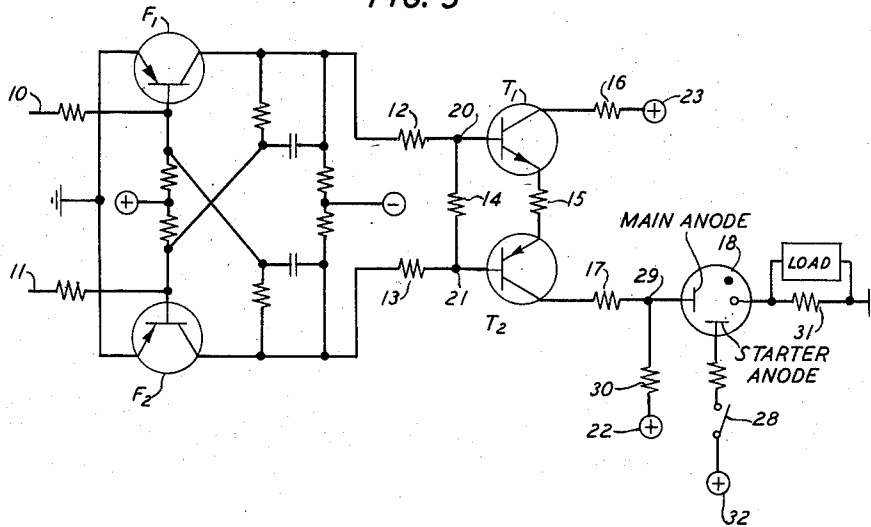
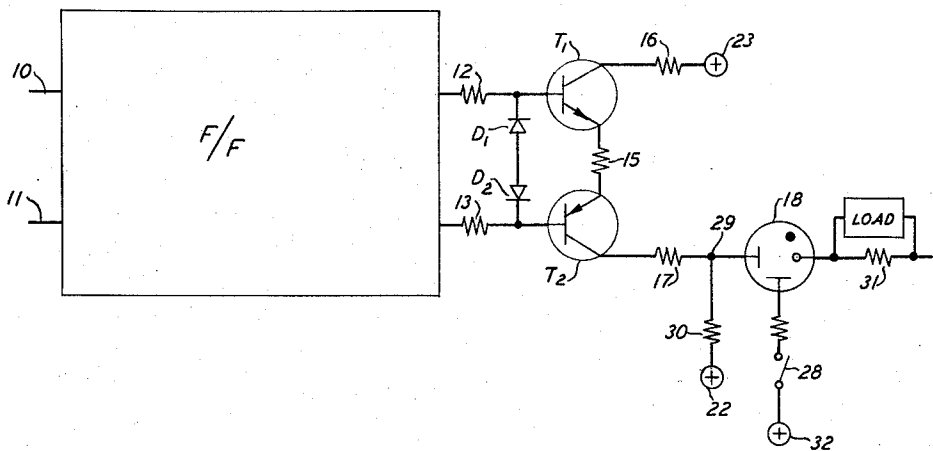


FIG. 4



INVENTORS **L. W. HUSSEY**
W. PEIL
BY **S. E. Hollander**
ATTORNEY

1

2,887,619

CURRENT LIMITING GATING CIRCUIT

Luther W. Hussey, Sparta, and William Peil, Budd Lake, N.J., assignors to Bell Telephone Laboratories, Incorporated, New York, N.Y., a corporation of New York

Application October 4, 1957, Serial No. 688,179

13 Claims. (Cl. 315-168)

This invention relates to switching devices and more particularly to means for switching a current of predetermined magnitude into a load.

In general practice, gas tubes are employed as low impedance devices. Consequently, changes in the potential applied to a conducting gas tube, although relatively slight, may produce a sufficient alteration in current flow to injure tubes which are operated at or near their safe limit. A factor tending to aggravate the situation is that different gas tubes of the same designation, manufactured under similar conditions, may exhibit variations in the order of 5 percent in essential characteristics, such as main gap sustain potential and breakdown potential.

It is desirable, therefore, to provide a supply source to gas tubes which incorporates automatic regulating means for limiting current flow through the tube.

In the past, the means adopted for limiting the current flow through a gas tube have included the introduction of a series impedance in the main discharge circuit of the tube. A disadvantage in the use of an impedance protective or limiting arrangement, however, is the fact that the output pulse available from the tube is diminished to the extent of the voltage drop across the impedance. Thus, in order to provide an output pulse of given magnitude, the applied voltage to the circuit is generally increased to compensate for the voltage drop across the series impedance.

However, the magnitude of the applied voltage is limited by the breakdown potential of the tube, since operation at or in excess of the latter potential will cause the tube to be constantly in the firing or conductive condition.

Ideally, to obtain the highest level output pulse from the tube, the protective device employed should exhibit an impedance characteristic which causes minimal voltage drop across the device until a predetermined maximum current level is achieved. At this level, the voltage drop should be permitted to increase to the value required to prevent any increase of current beyond the predetermined level.

It is therefore an object of this invention to improve the protective devices used in conjunction with gas tube circuits.

Another object of this invention is to provide for the constant current operation of low impedance devices.

An additional object of the invention is to improve the level of the voltage pulse available from a gas tube circuit.

A further object of this invention is to improve switching of gas tube circuits and devices.

Still another object of this invention is to provide for the switching of gas tube circuits from the output of symmetrical flip-flop circuits.

A feature of this invention is the use of serially-connected n-p-n and p-n-p transistors, the bases of which are supplied from opposite outputs of a conventional flip-flop.

A further feature of this invention is a switch having current limiting features incorporated therein.

2

A further feature of this invention is a switching device designed to experience a variable voltage drop thereacross.

There are other objects and features of the invention 5 may be realized in one embodiment by the utilization of n-p-n and p-n-p switching transistors in series with a gas tube. The emitters are series connected through a resistive impedance and the bases are connected to opposite outputs of a transistor flip-flop. A pair of diodes, 10 one of which is a breakdown or Zener semiconductor diode, are connected in series opposition between the two bases of the switching transistors.

When the flip-flop is in the "on" condition, both of the switching transistors are driven into saturation. The 15 magnitude of the base current in the switching or gating transistors is controlled by the difference in voltage between the flip-flop outputs and by the base resistances. The base-to-base voltage is kept at a uniform level by the diodes. When the emitter-to-emitter voltage ap- 20 proaches the level of the base-to-base voltage, as a result of the drop across the series external emitter resistance, the transistors tend to fall out of saturation and thus clamp the current at a fixed maximum value.

The above and other objects and features of the in- 25 vention may be more fully comprehended by an examination of the following specification, appended claims and attached drawings in which:

Fig. 1 shows a known typical current limiting device for a gas tube circuit employing an anode resistor;

30 Fig. 2 is a graphical representation of the characteristic of a type of protective device most suited for producing high level output pulses and also the characteristic of the resistive limiter of Fig. 1;

Fig. 3 shows an embodiment of the invention utilizing 35 two transistors in series with the load, a resistance interconnecting the emitters and a resistive shunt between the bases; and

Fig. 4 shows another embodiment of applicants' invention in which oppositely poled serially-connected diodes 40 are used in lieu of the resistive shunt of Fig. 3.

In all of the figures where a voltage source is shown by a plus or a minus sign, it is to be assumed that the opposite pole of the source is grounded unless otherwise indicated.

45 Referring now to Fig. 1, illustrative of the prior art, a gas tube circuit employing a resistive limiter to protect the gas tube against current overloads, is shown. A separate switch 5 is used in series with the protective resistance 6 to deenergize the gas tube. The diode clamp 7 50 in the cathode circuit fixes the highest level of the voltage pulse obtainable.

In operation, when switch 5 is closed, a voltage 8 higher than the main gap sustain potential, but lower than the breakdown potential, is applied.

55 To fire the tube, switch 27 is closed to the starter anode and the gas tube ionizes and transfers to the main gap in the usual way, drawing a current which is limited by anode resistance 6. The voltage output pulse is determined by the difference between the applied 60 voltage from source 8 and the sum of the sustain voltage of the tube and the drop across the resistance 6 in the anode circuit. It is apparent that if there were no resistance in the anode circuit, or if it were lower, the obtainable output pulse would be higher. This condition, however, may jeopardize the life of the tube due 65 to attendant permissive high currents.

Fig. 2 shows the voltage-current characteristic 24 of the limiting resistance 6 of Fig. 1 and also the characteristic 25 of the type of protective device most 70 suited for producing high voltage output pulses. As a practical matter, some voltage drop across a protective circuit is inevitable. However, Fig. 2 illustrates that

3

the voltage drop across the desired type of protective device is much smaller than that across a resistive protector. Thus, the output pulse obtainable from a gas tube using a protective device having the characteristic 25 shown in Fig. 2 is much higher than that available when resistive protection is used.

For example, referring to Fig. 2, it is seen that for a particular value of current I_{Max} the voltage drop (line 24) across the resistive protection device, such as resistance 6 of Fig. 1, is E_a while the corresponding voltage drop across the preferred type of arrangement is E_b , a considerably lower voltage. Since, as explained above, the available output pulse is decreased by the drop across the protection circuit, the voltage of the signal obtainable with a device having the current-voltage characteristic 25 is an improvement voltage-wise over the resistive protector in an amount equal to the difference between E_a and E_b .

An embodiment of an arrangement which will manifest an $E-I$ relationship similar to that of curve 25 in Fig. 2 is shown in Fig. 3.

Referring now to Fig. 3, an illustrative two-transistor bistable or flip-flop circuit including transistors F1 and F2 is shown. The flip-flop circuit is operable in the usual way in response to pulses over leads 10 and 11. The output of the flip-flop circuit includes resistors 12 and 13 which are respectively connected to the bases of transistors T1 and T2. Resistor 14 is connected in shunt between the bases of transistors T1 and T2. The latter are respectively n-p-n and p-n-p transistors, the emitters of which are connected serially by resistor 15. The collector circuit of transistor T2 is connected through collector external resistance 17 to the main anode of gas tube 18 and to a potential source 22 over resistance 30. The cathode of gas tube 18 is connected to ground over resistance 31. A load device, shown symbolically, is connected in parallel with resistance 31. A switch 28 connects potential source 32 to the starter anode of tube 18.

In operation, assuming that transistor F1 is in the nonconducting condition and F2 in the conducting condition, the output potential at terminal 20 will be somewhat more negative than the output potential at terminal 21. As a result, transistor T1 will be in the "off" condition due to the negative potential on the base of transistor T1 with reference to the emitter of T1 and transistor T2 will be in the "off" condition in consequence of the somewhat higher potential on the base electrode of transistor T2 with respect to its emitter.

The impedance presented by transistors T1 and T2 is very high in the "off" condition and is, in effect, a virtual open-circuit in series with the gas tube. Since no current flows through resistance 31, the potential at the cathode of the gas tube approaches ground potential.

In order to energize transistors T1 and T2, a negative pulse may be applied to conductor 10 thereby causing transistor F1 to conduct and shifting transistor F2 to the quiescent state in a well-known manner. When transistor F1 is in the "on" condition, its collector potential increases in the positive direction and the collector potential of F2 which is now "off" increases in the negative direction. Terminal 20 is now more positive than terminal 21, thereby driving the base of transistor T1 positive with respect to its emitter and the base of transistor T2 negative with reference to the emitter thereof. Transistors T1 and T2 are thus shifted to the low impedance state or "on."

When transistors T1 and T2 are in their low impedance state, the voltage at terminal 29 and at the main anode of tube 18 is shifted from the potential of source 22 which may, for example, be 95 volts to a voltage approximating that of potential source 23 which may illustratively be 150 volts. In practice, the voltage of source 22 is chosen to be somewhat lower than the sustain potential of the tube while source 23 is

4

higher than the sustain potential but lower than the breakdown potential.

Since the voltage of source 23 is lower than the breakdown potential of tube 18, the tube does not fire although the voltage thereacross has been raised above the sustain potential.

Where switch 28 is closed, however, a potential is applied to the starter anode from source 32 sufficient to ionize the starter gap. Transfer to the main gap takes place in a well-known manner and tube 18 continues to conduct in consequence of the increased potential at the main anode from source 23.

When tube 18 conducts through its main gap the voltage at the cathode of the tube rises from near ground potential to a voltage approaching that of source 23 less the sum of the drops through transistors T1 and T2, resistance 15 and gas tube 18, thereby applying a sharp pulse to the load device in parallel with resistance 31. The value of resistors 16 and 17 is designed to be sufficiently low to exhibit an insignificant voltage drop thereacross.

The current flow through gas tube 18 is limited by the maximum possible collector current which in turn is governed by the base current flow and the current gain of the transistors. Thus, as the current through the gas tube increases, the voltage drop across resistance 15 increases. When the emitter-to-emitter voltage (which is the voltage drop across resistance 15) approaches the base-to-base voltage, or the drop across resistance 14, the emitters will no longer be forward biased and the transistors will tend to fall out of saturation thereby sharply limiting the current flow. In effect, therefore, the gas tube current flow is limited to the voltage drop across the resistance 14 divided by the value of resistor 15. Moreover, the shunting of control current between the bases degrades the effective gain or alpha of the transistors. Since the collector current is proportional to the base current divided by $1-\alpha$, the percent variation of the critical parameter $1-\alpha$ among different transistors can be controlled within acceptable limits.

To extinguish tube 18, a negative pulse may be applied to lead 11 thereby re-establishing the original flip-flop condition and shifting transistors T1 and T2 to the "off" condition.

Another embodiment of the invention is shown in Fig. 4. In this embodiment, diodes D1 and D2 are used in lieu of resistor 14 of Fig. 1. Diode D1 is a breakdown or Zener diode having a substantially low impedance in the forward conduction direction and a relatively high impedance in the reverse conduction direction until a predetermined breakdown voltage is achieved, at which time the impedance of the diode falls sharply thereby maintaining a relatively constant voltage drop thereacross. For a further discussion of this type of device, reference may be made to an article entitled "Silicon p-n Junction Alloy Diodes," Proceedings of the I.R.E., November 1952, page 1348.

Diode D2 has a characteristic which exhibits a low impedance in the forward conduction direction and a relatively high impedance in the reverse conduction direction throughout the range of voltages to which the circuit is subjected.

Assuming, for example, that diode D1 has a 5-volt breakdown potential and that 10 milliamperes output current through the gas tube is required, resistance 15 should be designed as

$$\frac{5}{.01} = 500 \text{ ohms}$$

Consequently, when the current in the gas tube builds up to 10 milliamperes the drop through resistance 15 is 10 milliamperes times 500 ohms or 5 volts. Thus the emitter-to-emitter voltage substantially equals the base-to-base voltage and the transistors tend to fall out of saturation. As a result, the current through resistor 15 cannot

exceed 10 milliamperes. For higher current outputs a breakdown diode of larger voltage may be utilized, or a smaller resistance 15, or both.

The operation of the circuit of Fig. 4 is similar to that of Fig. 3 in that the transistors T1 and T2 are controlled by the outputs of the transistor flip-flop F1 and F2 which is shown in outline form in Fig. 4 as F/F, the details being similar to those of Fig. 3. When transistors T1 and T2 are in the "on" state or low impedance condition, the gas tube device may be energized by closing switch 28, thus applying a pulse to the load circuit. When transistors T1 and T2 are in the "off" state the voltage across the gas tube is decreased and the impedance in series therewith is increased thereby deenergizing the tube.

As an alternative to the operating procedure described above, switch 28 to the starter anode may be closed in advance of the operation of the switching transistors T1 and T2. In this event, with transistors T1 and T2 in the "off" condition, actuating switch 28 will ionize the starter gap, but no main gap discharge will take place since the voltage of source 22 is lower than the sustain potential of tube 18.

When transistors T1 and T2 are subsequently changed to the "on" condition, however, by the means described above, a voltage will be applied to the main anode sufficient to cause transfer of the starter gap discharge to a main gap discharge.

To extinguish the main gap discharge, transistors T1 and T2 are switched to the "off" condition as described above.

It is understood that the arrangements and values shown are merely exemplary and that various modifications may be made by those skilled in the art without departing from the spirit or scope of the present invention.

What is claimed is:

1. A current regulating gating circuit including at least two transistors, each of said transistors having emitter, base and collector electrodes, impedance means for joining said emitter electrodes in series relationship, a utilization device connected to one of said collector electrodes, means for supplying operating potentials to said collector electrodes, and switching means operable to supply control potentials to said base electrodes to transfer said transistors between low and high impedance conditions.

2. A current regulating switch including at least two transistors of opposite conductivity types, each having base, emitter and collector electrodes, impedance means joining said emitters in series relationship, triggering means operable to supply control potentials to said base electrodes, means for supplying operating potentials to said collector electrodes, and a utilization device connected to one of said collector electrodes, whereby a regulated current is driven through said utilization device in response to the operation of said triggering means.

3. A current limiting device including at least two transistors, each having base, emitter and collector electrodes, impedance means joining said emitters in series relationship, a two-state device having opposed potential output means connected to said base electrodes, an operating potential source connected to said collector electrodes, and a utilization device connected to one of said collector electrodes, whereby a current of predetermined maximum amplitude is supplied to said utilization device when said two-state device is in a particular state and whereby substantially no current is supplied to said utilization device when said two-state device is in the other state.

4. A gate circuit including at least two transistors of opposite conductivity types, each having base, emitter and collector electrodes, a first impedance means connected across said base electrodes, a second impedance means joining said emitter electrodes in series relationship, triggering means operable to supply control potentials to said base electrodes to transfer said transistors between a substantially low impedance condition and a substantially high impedance condition and vice versa, a potential source

for supplying operating potentials to said collector electrodes, and a utilization device connected to one of said collector electrodes, whereby the transfer of said transistors to said substantially low impedance condition in response to the operation of said triggering means permits a regulated current to flow through said utilization device.

5. A current limiting gating device including at least two transistors of opposite conductivity types, each having base, emitter and collector electrodes, impedance means joining said emitters in series relationship, a resistance connected across said base electrodes, triggering means operable to supply a predetermined potential difference across said resistance, a potential source for supplying operating potentials to said collector electrodes, and a utilization device connected to one of said collector electrodes, whereby the operation of said triggering means to produce a potential difference across said resistance of a given polarity allows a regulated current of predetermined maximum amplitude to flow through said utilization device and whereby the operation of said triggering means to produce a potential difference across said resistance of the opposite polarity allows substantially no current to flow through said utilization device.

6. A regulated current gating circuit including two transistors of opposite conductivity types, each having base, emitter and collector electrodes, impedance means joining said emitters in series relationship, a pair of oppositely poled p-n junction semiconductor diodes connected across said base electrodes, one of said diodes having a low resistance in the forward direction and a substantially constant voltage region in the reverse conduction characteristic for applied voltages equal to or in excess of a critical value, triggering means operable to develop a potential difference across said pair of diodes, means for supplying operating potentials to said collector electrodes, and a utilization device connected to one of said collector electrodes, whereby a regulated current is allowed to flow through said utilization device in response to the development of a potential difference of a particular polarity equal to said critical value across said diodes and whereby substantially no current flows through said utilization device in response to the operation of said triggering means to develop a potential of the opposite polarity across said diodes.

7. A current limiting gating device including two transistors of opposite conductivity types, each having base, emitter and collector electrodes, a first resistance connected across said base electrodes, a second resistance joining said emitters in series relationship, switching means operable to produce a potential difference across said first resistance, means for supplying operating potentials to said collector electrodes, and a utilization device connected in series with one of said collector electrodes, whereby a current of predetermined magnitude is permitted to flow through said utilization device in response to the operation of said triggering means, said current being limited by the approach of the potential difference across said second resistance to the potential difference across said first resistance as the current through said utilization device increases.

8. A current regulating switch including at least two transistors of opposite conductivity types, each having base, emitter and collector electrodes, a resistance serially connecting said emitter electrodes, a pair of serially connected p-n junction semiconductor diodes connected in bridge with said base electrodes, one of said diodes having a low resistance in the forward direction and a substantially constant voltage region in the reverse conduction direction for applied voltages equal to or in excess of a critical value, triggering means operable to develop a potential difference across said pair of diodes, means for supplying operating potentials to said collector electrodes, and a utilization device connected to one of said collector electrodes, whereby a regulated current is driven

through said utilization device in response to the development of a potential difference of a particular polarity equal to said critical value across said diodes and whereby substantially no current flows through said utilization device in response to the operation of said triggering means to develop a potential difference of the opposite polarity across said diodes.

9. A current limiting gating circuit including two transistors of opposite conductivity types, each having base, emitter and collector electrodes, a first resistance connected across said base electrodes, a second resistance joining said emitter electrodes in series relationship, a bistable triggering device operable to supply a potential difference across said first resistance, means for supplying operating potentials to said collector electrodes, and a utilization device connected to one of said collector electrodes, whereby the operation of said triggering means to one state produces a potential of given polarity across said first resistance permitting a regulated current flow of predetermined maximum amplitude through said utilization device and whereby the operation of said triggering device to the other state produces a potential difference of opposite polarity across said first resistance causing substantially no current to flow through said utilization device.

10. A current limiting gating device including at least two transistors of opposite conductivity, type, each having base, emitter and collector electrodes, a resistance joining said emitters in series relationship, a pair of oppositely poled diodes connected across said base electrodes, one of said diodes having a substantially low resistance in the forward direction and a reverse conduction characteristic including a region of substantially constant voltage for applied voltages equal to or in excess of a critical value, a bistable triggering device operable to produce a potential difference across said pair of diodes, means for supplying operating potentials to said collector electrodes, and a utilization device connected to one of said collector electrodes, whereby a regulated current of predetermined amplitude is drawn through said utilization device by the production of a voltage of particular polarity across said diodes in response to the operation of said triggering means to one state and whereby substantially no current is drawn through said utilization device by the production across said diodes of a voltage of the opposite polarity in response to the operation of said triggering device to the other state.

11. A current limiting gating device including at least two transistors of opposite conductivity types, each transistor having a base, emitter and collector electrode, a first resistance connected across said base electrodes, a second resistance joining said emitters in series relationship, switching means operable to apply a potential difference to said base electrodes, means for supplying operating potentials to said collector electrodes, and a gas tube connected in series with one of said collectors, whereby a regulated current is supplied to said gas tube in response to the operation of said triggering means.

12. A current limiting gating device including two transistors of opposite conductivity types, each having base, emitter and collector electrodes, a resistance joining said emitters in series relationship, a pair of serially-connected oppositely poled diodes connected across said bases, at least one of said diodes having a low resistance in the forward conduction direction and a reverse conduction characteristic having a region of substantially constant voltage for voltages equal to or exceeding a critical value, triggering means operable to supply a potential difference across said base electrodes equal to said critical voltage, means for supplying operating potential to said collector electrodes, and a gas tube having its main electrodes connected in series with one of said collector electrodes, whereby a current of predetermined maximum amplitude is driven through said gas tube in response to the operation of said triggering means.

13. A current limiting supply source including two transistors of opposite conductivity types, each having base, emitter and collector electrodes, first impedance means connected across said base electrodes, second impedance means joining said emitters in series relationship, means including said transistors for producing a predetermined potential difference across said first impedance means of a given polarity and a potential difference across said second impedance of the opposite polarity, means for supplying operating potentials to said collector electrodes, and a utilization device connected to one of said collector electrodes, whereby a limited current of predetermined amplitude is driven through said utilization device, said current being limited by the development of a voltage across said second impedance in opposition to the voltage across said first impedance.

No references cited.