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54 Precision switched current source.

57 A precision switched current source uses two transistors, preferably bipolar devices, with one transistor (Q1) establishing a reference current and the second transistor (Q2) connected to provide an output current which proportionately mirrors the reference current. A voltage controlled switch, preferably a field effect transistor (FET) (T1), is connected between the bases of the two bipolar transistors (Q1, Q2), and is switched to open and close that connection. The mirrored output current is thus switched on and off, under the control of the FET switch (T1). A second switch (T2) may be provided and operated inverse to the first FET switch (T1) to discharge the base of the output bipolar transistor (Q2) when that transistor is off.

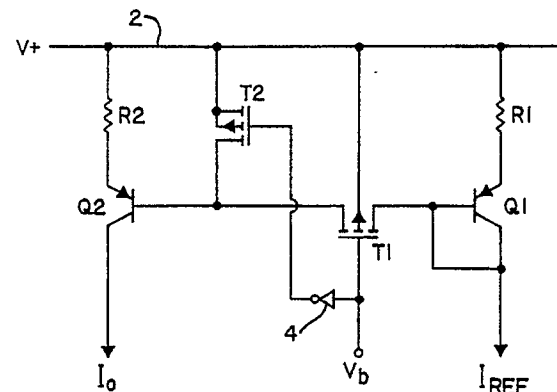


Fig. 1

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to electronic circuitry, and more particularly to a current source capable of being rapidly switched on and off.

Description of the Related Art

Switched current sources have been implemented in both bipolar and complementary metal oxide semiconductor (CMOS) formats. With the bipolar approach, a pair of bipolar transistors are connected as a differential switch, with the output of one of the transistors taken as the current source output. There is a constant current flow through the circuit, with bias signals applied to the bases of the two bipolar transistors to steer the current to one transistor or the other. The current source is switched "on" by biasing the output transistor to conduct the applied current, while it is switched "off" by biasing the transistors to steer the current away from the output transistor and through the other transistor.

One of the problems with the bipolar current source is that it is difficult to switch the device cleanly. Rather than immediately producing a constant current output, the emitter voltage of the output transistor exhibits a transient oscillation when switched, which causes the output current to similarly vary from the desired nominal value. This switching transient can be reduced, but to do so requires the addition of more complicated circuitry and a higher voltage source. Also, since current is flowing and the circuit is consuming power regardless of whether it is switched on or off, it is not highly efficient in terms of power consumption.

The CMOS approach to a switched current source uses a single CMOS transistor which is turned on or off by a voltage control signal applied to its gate. For an enhancement device, the output current is turned off by applying a large voltage signal to its gate and then switched on with a low voltage signal; the opposite pattern would be used for a depletion device. While this type of current source consumes less power than the bipolar approach, CMOS transistors are subject to large processing variations; their threshold voltages are difficult to predict, making the ultimate current value obtained from the source similarly difficult to predict. CMOS transistors also have an inherently low output resistance, which is an undesirable characteristic for a current source.

SUMMARY OF THE INVENTION

The present invention seeks to provide a cur-

rent source that can be switched on and off under a voltage control, which has a very high compliance when switched on, which consumes little or no power when switched off, exhibits a high output resistance, allows for large swings in the control voltage, and produces an accurate and predictable current output.

To achieve these goals, the invention uses a master-slave circuit in which a first transistor establishes a reference current, and a second transistor is slaved to the first transistor to produce an output current which is proportionate to the reference current. The two transistors are preferably proportionately matched bipolar devices having their bases connected together by an interruptable circuit connection in a current mirror configuration. A current control switch interposed in the base circuit connection connects the transistor bases in one switching state to enable the second transistor to proportionately mirror the first transistor's reference current, and thereby provide a controlled current output. When in the opposite switching state, the switch disconnects the bases of the two transistors, thereby terminating current flow through the second transistor and turning the current source "off".

The switch is preferably a field effect transistor (FET), although it may be implemented in other ways such as a diode bridge circuit or a ring of three amplifier. A discharge switch, preferably in the form of a second FET, is connected to discharge the base of the current source transistor when that transistor is off. For this purpose the discharge transistor is switched in a manner inverse to the current control switch transistor.

These and other features and advantages of the invention will be apparent to those skilled in the art from the following detailed description of preferred embodiments, taken together with the accompanying drawings, in which:

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of one embodiment of the invention employing pnp bipolar transistors;

FIGs. 2 and 3 are schematic diagrams of alternate implementations of the switch device shown in FIG. 1; and

FIG. 4 is a schematic diagram of another embodiment of the invention employing npn bipolar transistors.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. 1 is a schematic diagram of one embodiment of the invention. A pair of pnp bipolar transistors Q1 and Q2 have their bases connected together through the source-drain circuit of a metal oxide semiconductor field effect transistor

(MOSFET) T1. While Q1 and Q2 might also be implemented as CMOS FETs, bipolar transistors are preferable because their current outputs are more predictable; FETs are subject to threshold voltage variations because of processing differences, which make their current levels somewhat unpredictable.

The emitters of Q1 and Q2 are connected through current limiting resistors R1 and R2, respectively, to a positive voltage bus 2. The base and collector of Q1 are tied together in a diode configuration so that Q1 draws a constant reference current. The collector of Q1 is connected to ground or to a suitable negative voltage bus.

Q2 is proportionately matched with Q1 so that when the MOSFET switch T1 is closed, the base of Q2 is connected to the base of Q1 and Q2 proportionately mirrors the reference current flowing through the collector-emitter circuit of Q1. In this respect the Q1/Q2 circuit operates as a conventional current mirror, with Q2 slaved to Q1.

The gate of T1 is controlled by a bias voltage V_b , which provides the switching control element for the current source. When V_b is at a voltage level that biases T1 into conduction, the bases of Q1 and Q2 are effectively tied together, causing Q2 to carry an output current I_o which proportionately mirrors the known current through Q1, and provides the output current from the current source circuit. Since the current through Q1 can be accurately established and the matching between Q2 and Q1 can also be done accurately when the two transistors are fabricated in the same process, I_o can be made very precise. The switching of Q2 by the T1 interconnection is accomplished cleanly, without significant oscillations in the Q2 current output. Q2 carries zero current when T1 is switched off, thus conserving power when the current source is off.

Although illustrated as a MOSFET, T1 can preferably be implemented as any kind of FET, such as a junction FET (JFET). Several "biCMOS" fabrication processes are currently available and known in the art which are compatible with both bipolar and FET devices. While a bipolar transistor might be used for T1, this would not be desirable because a bipolar device has a significant collector-emitter voltage drop, typically on the order of 100mV or greater. By contrast, the typical leakage source current for an FET in an "off" state is on the order of tens or hundreds of microamps, so the FET appears as a low value resistor with a resistance of less than 1 kohm. This results in a very small drain-source voltage drop, typically less than 1mV.

Other possible alternatives to the use of an FET for the switch between the bases of Q1 and Q2 are a diode bridge switch and a "ring of three"

amplifier, illustrated respectively in FIGs. 2 and 3. These are conventional circuits and need not be described in detail. They are switched by controlling the biasing voltages V_b so that their associated switched transistors are turned on and off in tandem. These switched circuits would be connected in the current source circuit of FIG. 1 with their input terminal connected to the base of Q1 and their output terminal to the base of Q2. Although they could provide functional substitutes for a simple FET switch, they are considerably more complex, consume more power, and occupy more space.

Referring back to FIG. 1, a second FET T2 has its source-drain circuit connected between the base of Q2 and the positive voltage bus 2. The purpose of T2 is to discharge the base of Q2 when the latter transistor is off. Otherwise, a charge could accumulate at the base of Q2 while it is off, making the circuit more susceptible to noise and radiation, including light.

The switching control for T2 is opposite to T1, so that T2 is closed only when T1 is open and Q2 is off. This can conveniently be accomplished with an inverter 4 that inverts V_b , the control voltage for T1, and applies the inverted V_b to the gate of T2. While T2 is not absolutely required for a functional circuit, it is preferable to have this base discharge function because of the attendant improvement in noise and radiation resistance.

FIG. 1 illustrates a circuit with pnp bipolar transistors that provides a controlled current output I_o from a positive voltage bus 2. An equivalent circuit can be implemented with npn transistors to provide a controlled current to a negative voltage bus. Such a circuit is illustrated in FIG. 4, in which elements which are functionally equivalent to those in FIG. 1 are identified by the same reference numerals, and the negative voltage bus is indicated by numeral 6.

The described current source has many different applications, and in general can be used whenever a precise switched current source is required. One such application, not to be taken as limiting, is a slow oscillator using two of the current sources.

Various embodiments of an improved switched current source which can be switched on and off cleanly, has a low level of power consumption, and can be made very precise, have thus been shown and described. The circuit has a high output resistance typical of bipolar transistors, on the order of many megohms, and can support large control voltage swings extending close to the limits of the positive and negative voltage busses. As numerous variations and alternate embodiments will occur to those skilled in the art, it is intended that the invention be limited only in terms of the appended

claims.

Claims

1. A precision switched current source, comprising:
 - a first transistor (Q1) having input, output and control electrodes, and connected to provide a reference current source,
 - a second transistor (Q2) having input, output and control electrodes, the second transistor (Q2) being proportionately matched with said first transistor (Q1) and having its control electrode connected in circuit with the first transistor's control electrode to enable an output current through said second transistor (Q2) which proportionately mirrors the first transistor's reference current, and
 - a current control switch means (T1) connected in said circuit between the first (Q1) and second (Q2) transistor control electrodes for closing and opening said circuit, said switch means (T1) when in one switching state connecting said first (Q1) and second (Q2) transistor control electrodes together to enable said output current, and when in the opposite switching state disconnecting said first (Q1) and second (Q2) transistor control electrodes to terminate said output current.
2. The precision switched current source of claim 1, said current control switch means comprising a field effect transistor (T1) having its source-drain circuit connected between the control electrodes of said first (Q1) and second (Q2) transistors, and its gate electrode connected to receive a control signal for opening and closing the connection between the first (Q1) and second (Q2) transistor control electrodes.
3. The precision switched current source of claim 1, said current control switch means comprising a diode bridge circuit.
4. The precision switched current source of claim 1, said current control switch means comprising a ring of three amplifier.
5. The precision switched current source of claim 1, said first (Q1) and second (Q2) transistors comprising bipolar transistors.
6. The precision switched current source of claim 5, further comprising a discharge switch means (T2) connected to discharge the base of said second bipolar transistor (Q2) when said current control switch means (T1) dis-

connects said first (Q1) and second (Q2) transistor control electrodes.

7. A precision switched current source, comprising:
 - a voltage bus (V+),
 - a diode-connected master bipolar transistor (Q1) connected in circuit with said bus (V+) to conduct a predetermined collector-emitter reference current,
 - a slave bipolar transistor (Q2) proportionately matched with said master transistor (Q1) and connected in circuit with said bus (V+) to conduct a predetermined collector-emitter source current which is proportionately slaved to said reference current when said slave transistor (Q2) is biased by said master transistor (Q1), and
 - a controllable switch means (T1) connecting the bases of said master (Q1) and slave (Q2) transistors to slave the source current to the reference current when said switch means (T1) is in one switching state, and disconnecting the bases of said master (Q1) and slave (Q2) transistors to disable the slave transistor (Q2) from conducting source current when said switch means (T1) is in the opposite switching state.
8. The precision switched current source of claim 7, wherein said switch means comprises a field effect transistor (T1) having its source-drain circuit connected between the bases of said master (Q1) and slave (Q2) transistors, and its gate connected to receive a switching control voltage (V_b).
9. The precision switched current source of claim 7, further comprising a discharge switch means (T2) connected to discharge the base of said slave transistor (Q2) when said switch means (T1) disconnects the bases of said master (Q1) and slave (Q2) transistors.
10. The precision switched current source of claim 9, said discharge switch means comprising a field effect transistor (T2) having its source-drain circuit connected between said voltage bus (V+) and the base of said slave transistor (Q2), and its gate connected to receive a control voltage (-V_b).

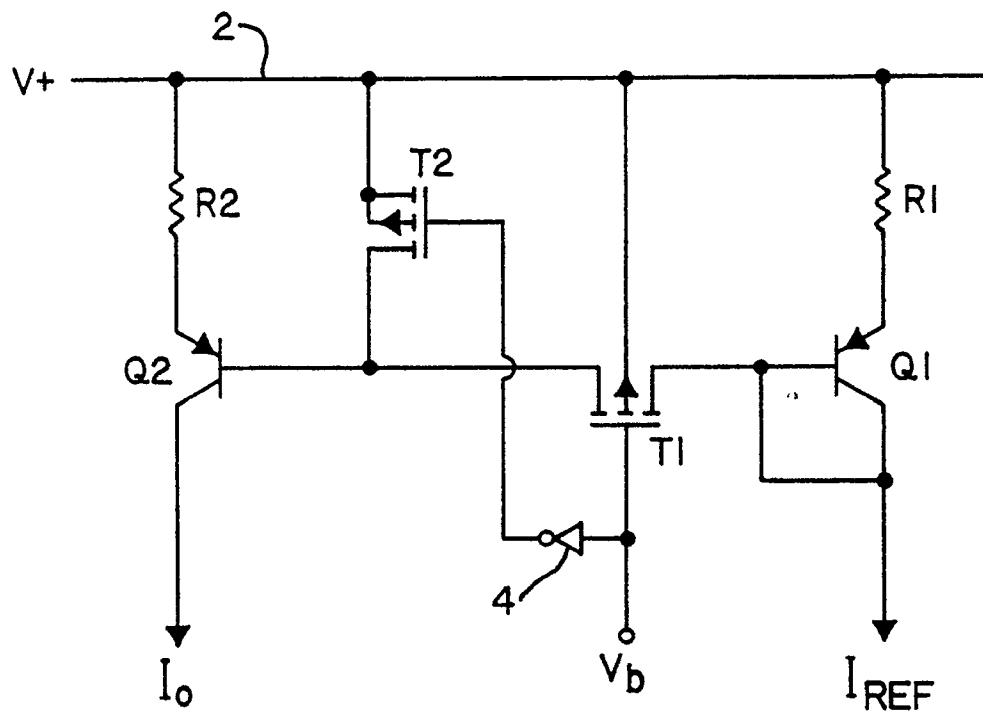


Fig. 1

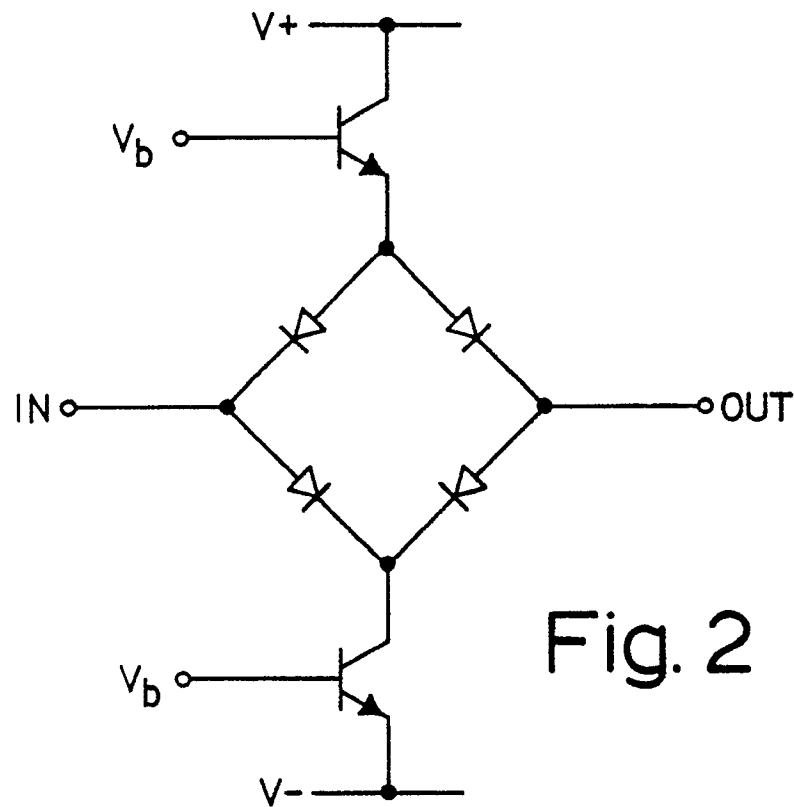


Fig. 2

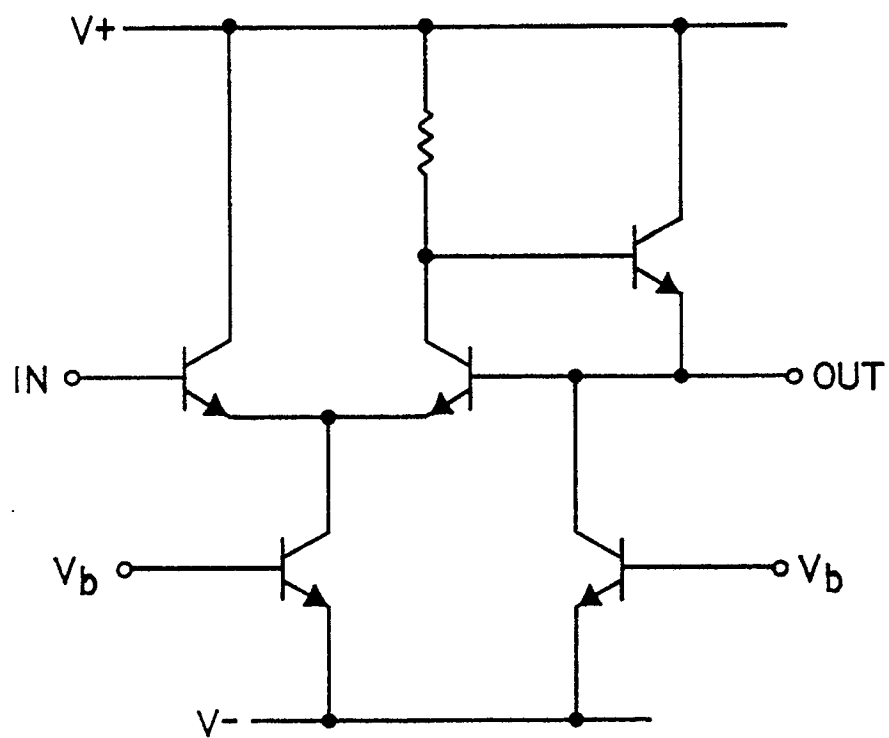


Fig. 3

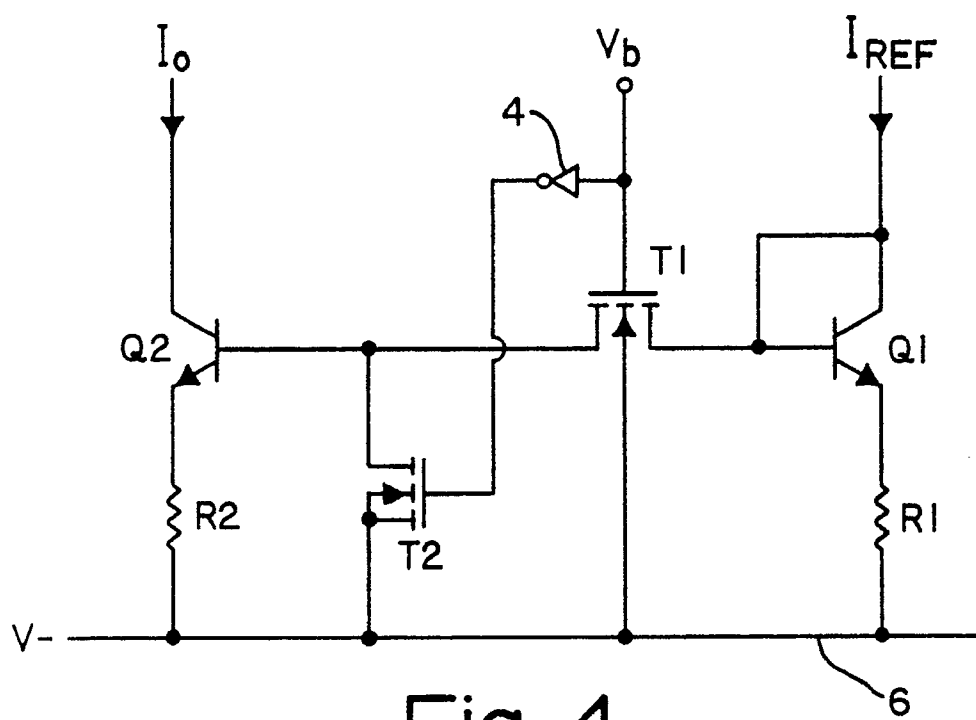


Fig. 4