

Description

Background of the invention

The present invention relates to a method for regulating current and, more particularly, to a circuit and method for limiting the current flow in a semiconductor device.

There are many applications in which it is desirable to protect a transistor by limiting the maximum current flow in the collector-emitter path of the transistor. For instance, when a transistor is operating in its active region, a large voltage drop across the collector-emitter junction of the device could cause the transistor to be damaged or even destroyed because the power dissipation characteristics of the transistor may be exceeded. One way to prevent this occurrence is to limit the current through the transistor to a maximum value which is well within the power handling capabilities of the device.

One prior art technique for protecting high gain transistors from conducting high currents simultaneously with large voltage potentials applied across the collector-emitter junctions thereof is to utilize a sense resistor between the emitter and ground reference in conjunction with a feedback circuit coupled between the emitter and base of the transistor. In a typical application, the feedback circuit may be an additional transistor having its base and emitter coupled across the sense resistor and its collector connected to the base of the transistor to be protected. Hence, whenever the current through the high gain transistor produces a voltage across the sense resistor sufficient to turn on the feedback transistor, base current to the high gain transistor is stolen through the collector-emitter of the feedback transistor thereby limiting the current in the output transistor.

However, the above described prior art circuit suffers from two disadvantages that may not be acceptable in some applications requiring protection of output transistors commonly found in operational amplifiers, comparators, automotive circuits, etc. First, the voltage drop across the sense resistor is at least equal to the base-to-emitter voltage, V_{BE} , of the feedback transistor which reduces the V_{SAT} characteristics of the circuit comprising the protected transistor. Thus, the maximum output voltage swing of this prior art circuit is limited which may not be tolerable. Secondly, the addition of the sense resistor causes a loss in the gm of the transistor amplifier which is not desirable in many cases.

Another prior art method for limiting current in an output transistor is illustrated in Fig. 1 herein. This prior art circuit comprises an output transistor 10 and diode 12 and is commonly referred to as a current mirror. The anode and cathode of diode 12 is connected to the base and emitter respectively of transistor 10. Transistor 10 is illustrated as having an emitter area N times the area of the anode region of diode 12 as understood. A preceding or intermediate amplifier stage comprising transistor 14, which is adapted

to receive an input signal at base 16, is coupled at its collector to the base and anode of transistor 10 and diode 12 respectively. A current source 18, supplying a current I , is connected between power supply V_{CC} and the collector of transistor 14.

In operation, the output current flowing in transistor 10 is at all times equal to NI , where I is the current flow in diode 12. Thus, the maximum current flow at the collector of transistor 10 is limited to NI . Hence, it is seen that this circuit suffers from a severe loss of beta, the forward current gain factor of the transistor.

Document US—A—3845405 discloses a monolithic integrated circuit including first and second transistors of like conductivity type, the bases and emitters of which are respectively interconnected, the emitter area of the first transistor being a multiple (N) of that of the second transistor; a current source for supplying current to the collector of the second transistor, base current drive being supplied to the interconnected bases.

This circuit has the disadvantage that additional transistors are required in order to clamp the current through the first transistor to a desired value.

Therefore a need exists for a circuit and method for limiting the current in a semiconductor device which circuit exhibits good VSAT characteristics and which does not suffer severe loss in the gain thereof.

Summary of the invention

The above problems are mitigated in the monolithic integrated circuit of one aspect of the invention in which the current source supplies a current having a predetermined value (I') such that at a current threshold value of the base current drive the second transistor becomes saturated as the value (I') of the current supplied to the collector of the second transistor from the current source is less than the current required by the second transistor whereby the collector current of the first transistor is limited to a value of N times the magnitude of the current I' while the second transistor is saturated.

Brief description of the drawings

Fig. 1 is a schematic illustrating a prior art current limiter circuit;

Fig. 2 is a schematic illustrating the current limiter circuit of the preferred embodiment; and

Fig. 3 is a more detailed schematic illustrating the circuit of Fig. 2.

Detailed description of the preferred embodiment

Turning now to Fig. 2 there is illustrated the novel method and structure for limiting the collector current of transistor 10 to a predetermined value. It is to be understood that the components of Fig. 2 corresponding to like components illustrated in Fig. 1 have the same reference numerals. As described previously, transistor 10 may be an output amplifier stage which is driven by a pre-driver transistor amplifier or intermediate ampli-

fier stage 14. Current limiting is accomplished by addition of transistor 20. The base and emitter electrodes of transistor 20 are coupled to the base and emitter respectively of transistor 10: the transistor whose collector current is to be limited. The collector of transistor 20 is coupled to current source 22 which sources a constant current of value I' thereto. As indicated, the emitter area of transistor 10 is made N times the emitter area of transistor 20. The output of the circuit is taken at node 24, the collector of transistor 10.

Under normal operating conditions the input drive signal to base input 16 of transistor 14 is such that transistors 10 and 20 are either operated in their active or cut off regions. If operated in their active region, the overall gain of the output stage comprising the two transistors 10 and 20 is proportional to the forward current gain, beta, of the matched transistors times the base current drive supplied thereto from current source 18. There is some slight loss of gain in the circuit of Fig. 2 when compared to the gain thereof without transistor 20 because of the base current flowing in this transistor. However, the gain of the circuit remains substantially the same being reduced by a factor of $1/N+1$.

When the input signal to transistor 14 is such as to cause a decrease in conduction of this transistor to a threshold limiting value wherein excess base current drive is available from current source 18 to transistor 20, the circuit is operated in a current limiting mode. Hence, at the limiting threshold value the magnitude of the portion of the current, I , supplied to the base of transistor 20 causes this transistor to want to source a larger current at its collector than can be supplied by current source 22. Thus, there is insufficient collector current available to transistor 20 to satisfy its requirement, the transistor is therefore caused to become saturated. In this state, the current in the collector of transistor 10 is limited to a value of NI' as no additional base drive current can be supplied thereto. The excess base current drive available to transistors 10 and 20 when transistor 20 is saturated is sunk to the substrate of the IC circuit through a parasitic PNP device formed by the base-collector junction of transistor 20 being forward biased. Thus, protection is provided to transistor 10 by limiting the current therethrough although the gain of this transistor stage has been only slightly decreased. In addition, the V_{SAT} characteristics of the circuit have not been affected by addition of current limiting transistor 20.

Hence, the circuit and method described above for current limiting allows the transistor whose collector current is to be limited to operate unhindered up to the limiting threshold value. Thereafter, the current through the transistor is limited to a predetermined maximum value.

Fig. 3 illustrates the circuit described and shown in Fig. 2 which has been fabricated in monolithic integrated circuit form. The collector of transistor 14 is coupled through series resistor 28 to the base of a multi-collector PNP transistor

30. Current source 22 is realized by resistor 26. The collector of output transistor 10 is coupled to VCC through multi-collector PNP transistor 30 via collector 30a. Collector 30b coupled with the base of transistor 30 to resistor 28.

In operation the collector current of transistor 10 is limited to N times the current flowing through resistor 26. If for example N is equal to the integer 4 (the emitter region of transistor 10 being four times the emitter region of transistor 20) the approximate value of current in transistor 10 at limiting is equal to:

$$I_{MAX} = 4 \frac{V_{CC}}{R_{26}}$$

Thus, by varying the value of resistor 26 the maximum value of current in transistor 10 can be programmed.

Claims

1. In a monolithic integrated circuit including a first transistor (10) and a second transistor (20) of like conductivity, the base and emitter of the second transistor being connected to the base and emitter of the first transistor respectively, the emitter area of the first transistor being ratioed with respect to the emitter area of the second transistor and a current source (22) which supplies a current (I') to the collector of the second transistor, a method for limiting the collector current of the first transistor (10) characterized by the step of limiting the value of the current (I') to a predetermined magnitude such that the second transistor (20) becomes saturated as the base current drive thereto exceeds a value at which the second transistor (20) requires greater collector current than the current (I') supplied thereto by the current source (22) whereby the collector current of the first transistor (10) is limited to a value equal to the ratio of the emitter areas of the two transistors times the current magnitude (I') supplied by the current source (22).

2. A monolithic integrated circuit including first (10) and second (20) transistors of like conductivity type, the bases and emitters of which are respectively interconnected, the emitter area of the first transistor (10) being a multiple (N) of that of the second transistor (20), a current source (22) for supplying current to the collector of the second transistor (20), base current drive being supplied to the interconnected bases, characterized in that the current source (22) supplies a current having a predetermined value (I') such that at a current threshold value of the base current drive the second transistor (20) becomes saturated as said value (I') of the current supplied to the collector of the second transistor (20) from the current source (22) is less than the current required by the second transistor (20) whereby the collector current of the first transistor is limited to a value of N times the

fier stage 14. Current limiting is accomplished by addition of transistor 20. The base and emitter electrodes of transistor 20 are coupled to the base and emitter respectively of transistor 10: the transistor whose collector current is to be limited. The collector of transistor 20 is coupled to current source 22 which sources a constant current of value I' thereto. As indicated, the emitter area of transistor 10 is made N times the emitter area of transistor 20. The output of the circuit is taken at node 24, the collector of transistor 10.

Under normal operating conditions the input drive signal to base input 16 of transistor 14 is such that transistors 10 and 20 are either operated in their active or cut off regions. If operated in their active region, the overall gain of the output stage comprising the two transistors 10 and 20 is proportional to the forward current gain, beta, of the matched transistors times the base current drive supplied thereto from current source 18. There is some slight loss of gain in the circuit of Fig. 2 when compared to the gain thereof without transistor 20 because of the base current flowing in this transistor. However, the gain of the circuit remains substantially the same being reduced by a factor of $1/N+1$.

When the input signal to transistor 14 is such as to cause a decrease in conduction of this transistor to a threshold limiting value wherein excess base current drive is available from current source 18 to transistor 20, the circuit is operated in a current limiting mode. Hence, at the limiting threshold value the magnitude of the portion of the current, I , supplied to the base of transistor 20 causes this transistor to want to source a larger current at its collector than can be supplied by current source 22. Thus, there is insufficient collector current available to transistor 20 to satisfy its requirement, the transistor is therefore caused to become saturated. In this state, the current in the collector of transistor 10 is limited to a value of NI' as no additional base drive current can be supplied thereto. The excess base current drive available to transistors 10 and 20 when transistor 20 is saturated is sunk to the substrate of the IC circuit through a parasitic PNP device formed by the base-collector junction of transistor 20 being forward biased. Thus, protection is provided to transistor 10 by limiting the current therethrough although the gain of this transistor stage has been only slightly decreased. In addition, the V_{SAT} characteristics of the circuit have not been affected by addition of current limiting transistor 20.

Hence, the circuit and method described above for current limiting allows the transistor whose collector current is to be limited to operate unhindered up to the limiting threshold value. Thereafter, the current through the transistor is limited to a predetermined maximum value.

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Thus, by varying the value of resistor 26 the maximum value of current in transistor 10 can be programmed.

Claims

1. In a monolithic integrated circuit including a first transistor (10) and a second transistor (20) of like conductivity, the base and emitter of the second transistor being connected to the base and emitter of the first transistor respectively, the emitter area of the first transistor being ratioed with respect to the emitter area of the second transistor and a current source (22) which supplies a current (I') to the collector of the second transistor, a method for limiting the collector current of the first transistor (10) characterized by the step of limiting the value of the current (I') to a predetermined magnitude such that the second transistor (20) becomes saturated as the base current drive thereto exceeds a value at which the second transistor (20) requires greater collector current than the current (I') supplied thereto by the current source (22) whereby the collector current of the first transistor (10) is limited to a value equal to the ratio of the emitter areas of the two transistors times the current magnitude (I') supplied by the current source (22).

2. A monolithic integrated circuit including first (10) and second (20) transistors of like conductivity type, the bases and emitters of which are respectively interconnected, the emitter area of the first transistor (10) being a multiple (N) of that of the second transistor (20), a current source (22) for supplying current to the collector of the second transistor (20), base current drive being supplied to the interconnected bases, characterized in that the current source (22) supplies a current having a predetermined value (I') such that at a current threshold value of the base current drive the second transistor (20) becomes saturated as said value (I') of the current supplied to the collector of the second transistor (20) from the current source (22) is less than the current required by the second transistor (20) whereby the collector current of the first transistor is limited to a value of N times the



magnitude of the current I' while the second transistor (20) is saturated.

3. The monolithic circuit of claim 2 wherein the current source (22) is a resistor (26) having a value R which is connected between a power supply V_{cc} and the collector of the second transistor wherein the maximum value of collector current sourced by the first transistor is equal to the value NV_{cc}/R during the time that the second transistor (20) is in a saturated condition.

Patentansprüche

1. Verfahren zum Begrenzen des Kollektorstromes des ersten Transistors (10) in einer monolithischen integrierten Schaltung mit einem ersten Transistor (10) und einem zweiten Transistor (20) gleicher Leitfähigkeit, bei der die Basis und der Emitter des zweiten Transistors mit der Basis bzw. dem Emitter des ersten Transistors verbunden sind, die Emitterfläche des ersten Transistors in bezug auf die Emitterfläche des zweiten Transistors abgestimmt ist und eine Stromquelle (22) einen Strom (I') dem Kollektor des zweiten Transistors zuführt, dadurch gekennzeichnet, daß die Stärke des Stromes (I') auf eine solche vorbestimmte Stärke begrenzt wird, daß der zweite Transistor (20) gesättigt wird, wenn der zugeführte Basistreiberstrom einen Wert übersteigt, bei welchem der zweite Transistor einen größeren Kollektorstrom als den durch die Stromquelle (20) zugeführten Strom (I') benötigt, wodurch der Kollektorstrom des ersten Transistors (10) auf einen Wert begrenzt wird, der gleich dem Verhältnis der Emitterflächen der zwei Transistoren mal der von der Stromquelle (22) zugeführten Stromstärke (I') ist.

2. Monolithische integrierte Schaltung mit einem ersten (10) und einem zweiten (20) Transistor gleicher Leitfähigkeit, deren Basen und Emitter jeweils miteinander verbunden sind, wobei die Emitterfläche des ersten Transistors (10) ein Vielfaches (N) der des zweiten Transistors (20) ist, eine Stromquelle (22) dem Kollektor des zweiten Transistors (20) einen Strom zuführt, ein Basistreiberstrom den miteinander verbundenen Basen zugeführt ist, dadurch gekennzeichnet, daß die Stromquelle (22) einen Strom zuführt, der einen solchen vorbestimmten Wert (I') hat, daß ein Stromgrenzwert des Basistreiberstromes des zweiten Transistors (20) gesättigt wird, wenn der genannte Wert (I') des dem Kollektor des zweiten Transistors (20) von der Stromquelle (22) zugeführten Stroms kleiner als der Strom ist, der von dem zweiten Transistor (20) benötigt wird, wodurch der Kollektorstrom des ersten Transistors auf einen Wert begrenzt wird, der das N -fache der Stärke des Stromes (I') ist, während der zweite Transistor (20) gesättigt ist.

3. Monolithische Schaltung nach Anspruch 2, bei der die Stromquelle (22) ein Widerstand (26) ist, der einen Wert (R) hat, der zwischen eine Stromquelle V_{cc} und den Kollektor des zweiten

Transistors geschaltet ist, wobei der Maximalwert des Kollektorstroms, der von dem ersten Transistor durchgelassen wird, gleich dem Wert NV_{cc}/R während der Zeit ist, in der der zweite Transistor (20) sich in einem gesättigten Zustand befindet.

Revendications

1. Procédé de limitation du courant de collecteur du premier transistor (10) dans un circuit intégré monolithique comprenant un premier transistor (10) et un second transistor (20) de même conductivité, la base et l'émetteur du second transistor étant connectés respectivement à la base et à l'émetteur du premier transistor, la surface d'émetteur du premier transistor étant dans un certain rapport avec la surface d'émetteur du second transistor, et une source de courant (22) fournissant un courant (I') au collecteur du second transistor, caractérisé en ce qu'il consiste à limiter la valeur du courant (I') à une intensité prédéterminée du manière que le second transistor (20) soit saturé quand son courant d'attaque de base dépasse une valeur pour laquelle le second transistor (20) nécessite plus de courant de collecteur que le courant (I') qui lui est fourni par la source de courant (22) de manière que le courant de collecteur du premier transistor (10) soit limité à une valeur égale au rapport des surfaces d'émetteur des deux transistors multiplié par l'intensité du courant (I') fourni par la source de courant (22).

2. Circuit intégré monolithique comprenant un premier (10) et un second (20) transistor de même type de conductivité, dont les bases et les émetteurs sont respectivement interconnectés, la surface d'émetteur du premier transistor (10) étant un multiple (N) de celle du second transistor (20), une source de courant (22) fournissant un courant au collecteur du second transistor (20), l'attaque de courant de base étant fournie aux bases interconnectées, caractérisé en ce que la source de courant (22) fournit un courant ayant une valeur prédéterminée (I') de manière qu'à une valeur seuil de courant de l'attaque de courant de base, le second transistor (20) soit saturé quand ladite valeur (I') du courant fourni au collecteur du second transistor (20) par la source de courant (22) est inférieure au courant nécessité par le second transistor (20), de manière que le courant de collecteur du premier transistor soit limité à une valeur de N fois l'intensité (I') pendant que le second transistor (20) est saturé.

3. Circuit monolithique selon la revendication 2, dans lequel la source de courant (22) est une résistance (26) ayant une valeur R qui est connectée entre une source d'alimentation V_{cc} et le collecteur du second transistor, la valeur maximale du courant de collecteur prélevé par le premier transistor étant égale à la valeur NV_{cc}/R pendant le temps où le second transistor (20) est à l'état sature.

