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to constitute a regulated current supply circuit

the invention relates to a circuit arrangement

for supplying a regulated current to a

current injector of an integrated injection

logic circuit element to be powered, said circuit

arrangement comprising a current repeater

circuit (as herein defined), a first current

path extending between the input terminal

of said current repeater circuit and a

supply terminal and a second current repeater

circuit and said supply terminal so that a

pair of current paths exists between the sum

terminal of said current repeater circuit and

said supply terminal and a coupling circuit

connected to provide current dependent

coupling between the current paths of said

pair so as to stabilize at a specific value the

currents occurring in the current paths of said

pair when a potential difference is applied

between said sum terminal and said supply

terminal.

A "current injector" is to be understood

to mean a multilayer structure comprising at

least three successive layers, which are sepa-

rated from each other by rectifying junctions,

including a first (injecting) layer,

which is provided with a bias current input

and is separated from the circuit element to

be supplied with current by at least one recti-

fying junction, an adjoining (intermediate)

second layer of semiconductor material

which is also provided with a bias current

input so that connection of a bias current

source between the bias current inputs in

such a sense as to forward bias the junction

between the injecting and intermediate

layers will cause charge carriers to be in-

jected into the intermediate layer by the in-

jecting layer, so causing the collection of

charge carriers by a subsequent (collecting)

layer of said successive layers of the current

injector via a rectifying junction which said

collecting layer forms with an adjacent layer

of the current injector, a zone of the circuit

element to be supplied with current belong-

ing to said collecting layer.

throughout the circuit, a collector terminal

provided with a bias current input

guidance a bias current line in common with

the injecting layer, a zone of the circuit

element to be supplied with current belong-

ing to said collecting layer.

A "current repeater circuit" is to be

understood to be a circuit which has an in-

put terminal, an output terminal and a sum

terminal and which is constructed to realise,

in response to the passage of an input cur-

rent through an input current path thereof

which extends between said input terminal

and said sum terminal, an output current in

an output current path thereof which ex-

tends between said output terminal and said

sum terminal, said output current being in a

linear relation to said input current and hav-

ing the same sense with respect to said sum

terminal as has said input current, and the

proportionality factor between the input and

output currents being substantially indepen-

dent of temperature and supply voltage.

Such a current repeater circuit may, for ex-

ample be constituted by two transistors hav-

ing a similar structure, the emitters of said

transistors being connected to a common

terminal, their bases being interconnected,

and one transistor being operated as a diode

by inter-connecting its base and collector. If

the collector current of one transistor is I_1 ,

the current carried by the diode-connected

transistor is I_2 , and the current fed to the

common terminal is I , then $I = I_1 + I_2$ and

$I = KI_1$, where K is a factor which depends

on the ratio of the effective emitter areas of

the two transistors.

Some integrated injection logic (I²L) cir-

cuits as described, for example, in Patent

Specification 1486907, have their current in-

jectors connected in series. The current in-

jectors should be fed with a constant cur-

rent to ensure that the current in the in-

jectors is constant and the current in the

collecting layer is constant and the current

in the injecting layer is constant.

rent, which may be derived from a variable voltage supply via a current regulator. However, integrable constant current sources normally have a rather high power consumption, and their current stabilization action is liable to result in an appreciable voltage drop. Several types of circuits for supplying a regulated current are known. Those described for example in Patent Specification No. 1,373,133 comprise: two current paths which are included between two common terminals, a first current repeater circuit which defines a fixed ratio between the currents in said paths, and a coupling circuit which provides a current-dependent coupling between said paths, which coupling circuit includes an impedance in one of the two current paths the value of which determines the output current independently of the input voltage. In these circuits said coupling circuit is constituted by the series combination of a semiconductor junction and the said impedance, which series combination shunts the base-emitter function of a transistor. A current-dependent coupling results because the voltage across the impedance must equal the difference between the voltage across said base-emitter junction and the voltage across said semiconductor junction.

The present invention provides a circuit arrangement for supplying a regulated current to a current injector (as herein defined) of an integrated injection logic circuit element to be powered, said circuit arrangement comprising a current repeater circuit (as herein defined), a first current path extending between the input terminal of said current repeater circuit and a supply terminal and a second current path extending between the output terminal of said current repeater circuit and said supply terminal so that a pair of current paths exists between the sum terminal of said current repeater circuit and said supply terminal, and a coupling circuit connected to provide current-dependent coupling between the current paths of said pair so as to stabilize at a specific value the currents occurring in the current paths of said pair when a potential difference is applied between said sum terminal and said supply terminal, said current injector being included either in series in one of the current paths of said pair or in parallel with a portion thereof in such manner that it forms part of the coupling circuit or the current repeater circuit.

A current injector may normally be regarded as at least one semiconductor junction. It is thus possible to replace a semiconductor junction already in a current regulator circuit, preferably that junction which has the largest area, by a current injector. This can enable the overall dissipation of, and voltage drop across, the circuit to be re-

duced compared with that which would occur if the current injector were separate from the regulator circuit.

Embodiments of the invention will be described in more detail, by way of example, with reference to the accompanying diagrammatic drawings in which:

Figure 1 is a diagram of a first embodiment,

Figure 2 is a diagram of a second embodiment,

Figure 3 is a diagram of a modification of the embodiment of Figure 2.

The circuit for supplying a regulated current output shown in Figure 1 comprises a first current repeater circuit which is constituted by a forward biased diode D_1 which is included in a first current path B_1 and which shunts the base-emitter junction of an npn transistor T_2 . The emitter of transistor T_2 is connected to the negative supply line L_2 and its collector-emitter path is included in a second current path B_2 . The collector of T_2 is connected to a positive supply line L_1 via the collector-emitter path of a pnp transistor T_1 whose emitter circuit includes a resistor R_1 . The transistor T_1 has its collector connected to its base and therefore operates as a diode. The base of transistor T_1 is connected to the base of a pnp transistor T_3 , whose emitter is connected to the positive supply line L_1 and whose collector is connected to the base of transistor T_2 .

The current injector of an I²L type circuit elements to be powered may be represented by a diode. In figure 1 an I²L type circuit element to be powered is the fact represented by the diode D_1 . The diode D_1 can be assumed to be equivalent to a diode-connected transistor the base-emitter junction of which has an effective area which is n times as large as the effective base-emitter area of the transistor T_2 which transistor is of the same type as T_2 . With such an assumption, and assuming moreover that the current in the current path B_1 is I_1 , and that the current in the current path B_2 is I_2 , it follows that $I_1 = nI_2$ owing to the current mirror action of the circuit D_1 , T_2 . If moreover T_2 is identical to T_1 , the coupling circuit T_1 , T_2 , R_1 imposes the additional requirement that $I_1 R = \frac{kT}{q} \ln n$, in which k is Boltzmann's constant, T is the absolute temperature, and q is the elementary charge.

The currents I_1 and I_2 are therefore given by:

$$I_2 = \frac{kT}{qR} \ln n \text{ and } I_1 = n \frac{kT}{qR} \ln n.$$

The current I_1 is the current which flows through the current injector D_1 of the circuit element to be powered, i.e. the useful load current. The lowest voltage which can be supplied across the circuit of Figure 1 if the circuit is to operate correctly corresponds to the situation when transistor T_2 is substantially bottomed ($V_{ce} = 0$ V) and is substan-

tially equal to one junction voltage (≈ 0.7 V with silicon junctions).

It should be noted that if the circuit of Figure 1 were instead included in series with the current injector of the circuit element to be powered, an additional diode equivalent to a diode-connected transistor the base-emitter junction of which has an effective area which is n times as large as the effective base-emitter area of transistor T_2 would effectively be connected in series with the circuit. This diode together with diode D_1 would have a larger dissipation than the diode D_1 alone and would double the minimum supply voltage which it is possible to use.

The circuit for supplying a regulated current shown in Figure 2 comprises a first current repeater circuit which is constituted by two transistors T_1 and T_2 of the same type, whose base-emitter junctions are connected in parallel. The transistor T_2 operates as a diode, its base and collector being interconnected. The emitters of the transistors T_1 and T_2 are connected to a common terminal which is represented by a conductor L_1 which has a positive potential $+V$. The current mirror action of the two pnp type transistors T_1 and T_2 (which may have a lateral structure) determines the ratio between the currents in the two current paths B_1 and B_2 of the circuit, which ratio is substantially the same as the ratio between the emitter areas of said transistors T_1 and T_2 .

A second current repeater circuit is constituted by two npn transistors T_3 and T_4 whose base-emitter junctions are also connected in parallel. The transistor T_3 is connected as a diode, its collector being connected to its base. The emitters of the transistors T_3 and T_4 are connected to a common terminal which is represented by a conductor L_2 which has a negative potential $-V$. The npn-type transistors T_3 and T_4 (which may have a vertical structure) conduct currents to the common terminal L_2 whose values are in substantially the same ratio as the emitter areas of the transistors T_3 and T_4 .

The current path B_1 includes a resistor R_1 in series between the transistors T_1 and T_2 .

In Figure 2 current injectors of I²L circuit elements to be powered are represented by two forward-biased diodes D_1 and D_2 which are connected in series. The maximum overall voltage drop across these diodes is greater than that across the diode-connected transistor T_2 . The series combination of the diodes D_1 and D_2 is connected between the terminal A of the resistor R_1 nearest the first current repeater circuit and the second common terminal represented by the conductor L_2 .

A transistor T_5 whose base is connected to L_1 via a capacitor C_1 is included between the common terminal L_2 and the bases of the

transistors T_3 and T_4 . This capacitor, and the transistor T_5 which amplifies the charge and discharge current of the capacitor, together constitute a turn-on circuit which may be required to ensure that the various transistors draw current when the circuit is switched on.

If the voltage applied to the circuit is initially zero and then increases rapidly, T_5 is turned on by the charging current of the capacitor C_1 . The result is that point F becomes positive, forward-biasing T_3 and T_4 . (If the value C_1 is large enough it may be possible to connect it directly between L_1 and point F, omitting T_5 altogether). Conduction in transistor T_3 in turn causes the base of transistor T_1 to become forward biased, turning transistor T_1 on. The current which flows in the feedback loop constituted by the transistors T_1 , T_2 , T_3 , T_4 and the resistor R_1 then increases, the loop gain being greater than unity and the voltage across the diodes D_1 and D_2 being greater than unity and the voltage across the diodes D_1 and D_2 being initially insufficient to produce a significant current in them. (The current in T_2 should not be so large that it materially affects the circuit operation after turn-on). When the voltage at point A becomes sufficient to turn the diodes D_1 and D_2 on, part of the current supplied by the transistor T_1 passes through them and the gain of the feedback loop is reduced to unity. The current in the loop can then no longer increase and becomes stabilised at the value which it has reached. This value is determined by the value of the resistor R_1 , the current I_1 in this resistor being given by:

$$I_1 = \frac{V_{D1} + V_{D2} - V_{BE12}}{R_1}$$

where V_{D1} and V_{D2} are the voltages at the terminals of the diodes D_1 , D_2 and V_{BE12} is the base-emitter voltage of the transistor T_2 . Thus, the current I_1 in the current path B_2 is also defined, being given by $I_1 = KI_2$, in which K is the ratio between the emitter areas of the transistors T_1 and T_2 . The current I_2 in the current path B_1 is also defined, being given by $I_2 = K'I_1$, in which K' is the ratio between the emitter areas of the transistors T_3 and T_4 . As the currents I_1 , I_2 and I_3 are defined irrespective of the voltage between the terminals L_1 and L_2 , the current I which flows in the diodes D_1 and D_2 is also defined: the lowest voltage V which it is possible to provide between L_1 and L_2 if the circuit is to operate correctly is given by $V > V_{D1} + V_{D2} + V_{CE1}$, where V_{CE1} is the voltage between the emitter and the collector of the transistor T_1 in the bottomed or substantially bottomed state.

The circuit for supplying a regulated current shown in Figure 3 is substantially the same as that shown in Figure 2.

A first current repeater circuit is constituted by a transistor T_1 having two collectors, one of which is connected to its base. T_1 and T_2 may have lateral and vertical structures respectively. A resistor R_2 is connected in series with the current path which includes the collector-emitter path of the transistor T_1 and the emitter-base junction of transistor T_2 . The current injectors of I^2L circuit elements to be powered are represented by the two diodes D_3 and D_4 which are included between the terminal G of the resistor R_2 and a conductor L_1 . A turn-on transistor T_3 whose base is open circuit, is included between a conductor L_2 and the terminal G. The operation of the circuit shown in Figure 3 is similar to that of the circuit described with reference to Figure 2.

If desired one of the two current injectors shown in Figure 2 or Figure 3 may be replaced by a simple diode.

The transistor T_1 of Figure 2 may be replaced by an open circuit-base transistor similar to transistor T_2 of Figure 3, or the transistor T_2 of Figure 3 may be replaced by a transistor having a capacitor connected to its base, similar to T_1 in Figure 2.

The circuit of Figures 1, 2 and 3 may each be integrated on a single semiconductor chip if desired.

WHAT WE CLAIM IS:-

1. A circuit arrangement for supplying a regulated current to a current injector (as herein described) of an integrated injection logic circuit element to be powered, said circuit arrangement comprising a current repeater circuit (as herein defined), a first current path extending between the input terminal of said current repeater circuit and a supply terminal and a second current path extending between the output terminal so that a pair of current paths exists between the sum terminal of said current repeater circuit and said supply terminal, and a coupling circuit connected to provide current-dependent coupling between the current paths of said pair so as to stabilize at a specific value the currents occurring in the current paths of said pair when a potential difference is applied between said sum terminal and said supply terminal, said current injector being included either in series in one of the current paths of said pair or in parallel with a portion thereof in such manner that it forms part of the coupling circuit or the current repeater circuit.

2. A circuit arrangement as claimed in Claim 1, wherein the coupling circuit includes a second current repeater circuit (as herein defined), the input terminal of the second current repeater circuit being connected to the output terminal of the current repeater circuit of Claim 1 via a resistance, the input terminal of the current repeater circuit of Claim 1 being connected to the

output terminal of the second current repeater circuit, and the sum terminal of the second current repeater circuit constituting said supply terminal, the two current repeater circuits providing a coupling between the current paths of said pair such that in operation the loop gain from the input terminal of the current repeater circuit of Claim 1 to the output terminal of the second current repeater circuit will be greater than unity, said current injector being included in a current shunt path which is connected in parallel with the series combination of said resistance and the input current path of the second current repeater circuit.

3. A circuit arrangement as claimed in Claim 2, wherein each of the two current repeater circuits is constituted by a pair of transistors of the same conductivity type constructed from the same materials, one of the transistors of each pair of transistors having its collector connected to its base, the emitters of the transistors of each pair of transistors being interconnected as are their bases.

4. A circuit arrangement as claimed in Claim 2 or Claim 3, including means for introducing a turn-on current into the feedback loop constituted by the two current repeater circuits and the resistance.

5. A circuit arrangement as claimed in any of Claims 2 to 4, including a further current injector (as herein defined) of an integrated injection logic circuit element to be powered, said further current injector being included in said current shunt path in series with the current injector of Claim 1.

6. A circuit arrangement as claimed in any of Claims 2 to 4, including a diode in said current shunt path in series with said current injector and with the same polarity.

7. A circuit arrangement as claimed in Claim 3, or in any of Claims 4 to 6 when appended to Claim 3, wherein the transistors of the first current repeater circuit of the pnp conductivity type and the transistors of the second current repeater circuit are of the npn conductivity type.

8. A circuit arrangement as claimed in Claim 7, wherein the transistors of the first current repeater circuit have a lateral structure and the transistors of the second current repeater circuit have a vertical structure.

9. A modification of a circuit arrangement as claimed in Claim 3, or in any of Claims 4 to 8 when appended to Claim 3, wherein the pair of transistors of each current repeater circuit are replaced by a single transistor having first and second collectors.

10. A circuit arrangement as claimed in Claim 4, or in any of Claims 5 to 9 when appended to Claim 4, wherein the turn-on means is constituted by a transistor whose base is open circuit and whose main current

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A first current repeater circuit is constituted by a transistor T_1 having two collectors, one of which is connected to its base. T_1 and T_2 may have lateral and vertical structures respectively. A resistor R_2 is connected in series with the current path which includes the collector-emitter path of the transistor T_1 and the emitter-base junction of transistor T_2 . The current injectors of I²L circuit elements to be powered are represented by the two diodes D_1 and D_2 which are included between the terminal G of the resistor R_2 and a conductor L_1 . A turn-on transistor T_3 whose base is open circuit, is included between a conductor L_2 and the terminal G. The operation of the circuit shown in Figure 3 is similar to that of the circuit described with reference to Figure 2.

If desired one of the two current injectors shown in Figure 2 or Figure 3 may be replaced by a simple diode.

The transistor T_1 of Figure 2 may be replaced by an open circuit-base transistor similar to transistor T_4 of Figure 3, or the transistor T_2 of Figure 3 may be replaced by a transistor having a capacitor connected to its base, similar to T_5 in Figure 2.

The circuit of Figures 1, 2 and 3 may each be integrated on a single semiconductor chip if desired.

WHAT WE CLAIM IS:-

1. A circuit arrangement for supplying a regulated current to a current injector (as herein described) of an integrated injection logic circuit element to be powered, said circuit arrangement comprising a current repeater circuit (as herein defined), a first current path extending between the input terminal of said current repeater circuit and a supply terminal and a second current path extending between the output terminal so that a pair of current paths exists between the sum terminal of said current repeater circuit and said supply terminal, and a coupling circuit connected to provide current-dependent coupling between the current paths of said pair so as to stabilize at a specific value the currents occurring in the current paths of said pair when a potential difference is applied between said sum terminal and said supply terminal, said current injector being included either in series in one of the current paths of said pair or in parallel with a portion thereof in such manner that it forms part of the coupling circuit or the current repeater circuit.

2. A circuit arrangement as claimed in Claim 1, wherein the coupling circuit includes a second current repeater circuit (as herein defined), the input terminal of the second current repeater circuit being connected to the output terminal of the current repeater circuit of Claim 1 via a resistance, the input terminal of the current repeater circuit of Claim 1 being connected to the

output terminal of the second current repeater circuit, and the sum terminal of the second current repeater circuit constituting said supply terminal, the two current repeater circuits providing a coupling between the current paths of said pair such that in operation the loop gain from the input terminal of the current repeater circuit of Claim 1 to the output terminal of the second current repeater circuit will be greater than unity, said current injector being included in a current shunt path which is connected in parallel with the series combination of said resistance and the input current path of the second current repeater circuit.

3. A circuit arrangement as claimed in Claim 2, wherein each of the two current repeater circuits is constituted by a pair of transistors of the same conductivity type constructed from the same materials, one of the transistors of each pair of transistors having its collector connected to its base, the emitters of the transistors of each pair of transistors being interconnected as are their bases.

4. A circuit arrangement as claimed in Claim 2 or Claim 3, including means for introducing a turn-on current into the feedback loop constituted by the two current repeater circuits and the resistance.

5. A circuit arrangement as claimed in any of Claims 2 to 4, including a further current injector (as herein defined) of an integrated injection logic circuit element to be powered, said further current injector being included in said current shunt path in series with the current injector of Claim 1.

6. A circuit arrangement as claimed in any of Claims 2 to 4, including a diode in said current shunt path in series with said current injector and with the same polarity.

7. A circuit arrangement as claimed in Claim 3, or in any of Claims 4 to 6 when appended to Claim 3, wherein the transistors of the first current repeater circuit of the pnp conductivity type and the transistors of the second current repeater circuit are of the npn conductivity type.

8. A circuit arrangement as claimed in Claim 7, wherein the transistors of the first current repeater circuit have a lateral structure and the transistors of the second current repeater circuit have a vertical structure.

9. A modification of a circuit arrangement as claimed in Claim 3, or in any of Claims 4 to 8 when appended to Claim 3, wherein the pair of transistors of each current repeater circuit are replaced by a single transistor having first and second collectors.

10. A circuit arrangement as claimed in Claim 4, or in any of Claims 5 to 9 when appended to Claim 4, wherein the turn-on means is constituted by a transistor whose base is open circuit and whose main current



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path is connected between the feedback loop and a said sum terminal.

5. 11. A circuit arrangement as claimed in Claim 4, or in any of Claims 5 to 9 when appended to Claim 4, wherein the turn-on means is constituted by a transistor whose main current path is connected between a said sum terminal and said feedback loop and whose base is connected to a said sum terminal via a capacitor.
- 10 12. A circuit arrangement for supplying

a regulated current to a current injector of an integrated injection logic circuit element to be powered, substantially as described herein with reference to Figures 1, 2 or 3 of the drawings. 15

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