

CURRENT MIRROR USING
RESISTOR RATIOS IN CMOS PROCESS

The present invention relates generally to
5 current control devices, and particularly to a current
control device well adapted for consistent operation
even across low voltages.

Background of the Invention

A current control device maintains a given
10 magnitude of current along a particular current path,
e.g., a series combination of circuit components.
Conventional current control devices typically require
either a minimum potential across terminal leads, or
react undesirably to slight variation in circuit
15 parameters, e.g., deviation from expected power supply
voltage or expected component characteristics.

One use of a current control device is driving
a light emitting diode (LED), a common display device
for electronic products. The brightness of an LED is
20 a function of the amount of current passing through
the LED. To control the brightness of an LED then, it
is sufficient to control the magnitude of current
passing through the LED. To provide consistent LED
brightness, a consistent magnitude of current must
25 pass through the LED.

A number of LED display devices connected in
series have a desired level of brightness by
controlling the amount of current passing through the
series combination. As a diode, however, the voltage
30 drop across an LED is substantially independent of the
current it carries. Much of the potential across the
LED series combination, therefore, can be taken by
voltage drops across the LED display devices. As a
result, less voltage potential remains across the
35 current control device, and its operation may be
impaired if this remaining potential is insufficient.

This is particularly critical when, for example, a relatively small supply voltage is used to drive a series combination of LED display devices. A conventional current mirror placed in series with an LED provides current control substantially independent of the voltage drop, i.e., forward voltage, of the LED. However, a simple current mirror, for example, an n-channel MOS-G device, typically requires at least 2 volts across its drain and source terminals for proper operation. For a 5 volt supply voltage and a pair of series coupled LED display devices, each having a 2 volt forward biased voltage, only 1 volt remains across the current mirror for current control, and the device cannot operate as desired. It is, therefore, desirable that a current control device operate with a small potential across its terminal leads.

A second current control approach uses an output transistor in its linear mode with a resistor circuit for setting current flow through the transistor. While this approach is less sensitive to the potential across the transistor, it is quite sensitive to variation in the supply voltage, LED forward voltage, and absolute resistor values obtained. A slight variation in these circuit parameters can result in significant variation in LED brightness.

Some applications require an array of adjacent LED devices. Each LED of the array is desirably of substantially identical brightness when activated. For example, if the LED array is part of a seven segment display, it is desirable that each segment of the display appear with matching brightness. Also, some laser printers use an array of hundreds of LED light sources, and the quality of printed output obtained depends on consistency of LED brightness. To

accomplish consistent LED brightness, currents of substantially matching magnitude must pass through each LED.

Summary of the Invention

The present invention is defined in the claims.

5 It would be desirable to provide precise current control with small voltage potentials across the terminal leads of the current control device.

It would also be desirable to obtain current control as a function of resistor ratios. As an integrated circuit,
10 where such resistor ratios are precisely obtained, a current control device in accordance with the present invention can provide a number of separate current paths of substantially matching magnitude.

It would also be desirable to provide current control
15 in an LED light source substantially independent of LED forward voltage, but operational with very little potential across the leads of the current control device.

In a principal preferred embodiment of the present invention, the foregoing points are addressed by a current
20 control device providing a current path, including a series combination of a voltage controlled variation resistor and a current sense resistor. The current sense resistor and voltage controlled variation resistor lie in a series combination with a circuit component through which current
25 flow is to be controlled. The series combination couples a first voltage and a second voltage, e.g., a supply voltage and a reference voltage. The current control device further includes an operational amplifier providing its output to the gate of the voltage controlled variation resistor, and
30 having a first one of its inputs tied to the interconnection of the current sense resistor and the voltage controlled variation

resistor. The second input of the operational amplifier is tied to a substantially fixed voltage signal.

The resistance of the current sense resistor
5 is selected to provide a target voltage across its terminals when a desired magnitude of current passes therethrough. The constant voltage signal applied to the second input of the operational amplifier is maintained substantially at the target voltage. The
10 operational amplifier acts to vary the resistance of the variation resistor to maintain the target voltage across the current sense resistor and thereby establish the desired current flow.

The subject matter of the present invention is
15 particularly pointed out and distinctly claimed in the concluding portion of this specification. Both the organization and method of operation of the invention, together with further advantages and objects thereof, however, may best be understood by reference to the
20 following description and accompanying drawings wherein like reference characters refer to like elements.

Brief Description of the Drawings

FIG. 1 is a schematic illustration of an
25 integrated circuit current control device in accordance with the present invention as used for discrete LED current control;

FIG. 2 is a schematic illustration of a
current control device in accordance with the present
30 invention as used for providing a plurality of substantially identical or matching current outputs; and

FIG. 3 is a schematic illustration of a
current control device in accordance with the present
35 invention as used for current control in connection with a seven segment display device.

Detailed Description of a Preferred Embodiment

FIG. 1 is a schematic illustration of a current control device 10, according to the present invention, as used for discrete light emitting diode (LED) current control. Device 10 includes an integrated circuit 12 and an external resistor 26 for providing a predetermined magnitude of current through LED display element 14. The magnitude of current passing through LED display element 14 determines the brightness of element 14. Thus, by controlling current, device 10 controls the brightness of display element 14.

Integrated circuit 12 includes an operational amplifier 20, poly-silicon current set resistor 28, poly-silicon current sense resistor 48, and an n-channel MOS transistor 34. The operational amplifier 20 includes a non-inverting input terminal 22 and an inverting input terminal 24. Resistors 26 and 28 couple in series to provide a voltage divider 29 between supply voltage V_{sup} and a ground or reference voltage V_{ref} , with resistor 26 connected to voltage V_{sup} and resistor 28 connected to voltage V_{ref} . The point of interconnection between resistors 26 and 28 connects to non-inverting input terminal 22 of operational amplifier 20. Thus, non-inverting input terminal 22 of amplifier 20 receives a substantially constant voltage signal derived as a proportion of the potential of voltage V_{ref} relative to voltage V_{sup} .

Output terminal 30 of operational amplifier 20 drives gate 32 of transistor 34, acting as a voltage controlled variation resistor. Display element 14 comprises LED 40 and LED 42 connected in series, with the cathode of LED 40 coupled to the anode of LED 42. The anode of LED 40 connects to supply voltage V_{sup} , and the cathode of LED 42 connects to drain terminal

46 of transistor 34. Resistor 48 couples source terminal 50 of transistor 34 to voltage V_{ref} . Also, source terminal 50 of transistor 34 connects as feedback to inverting input terminal 24 of operational amplifier 20.

A current path 60 between supply voltage V_{sup} and reference voltage V_{ref} exists along the series combination of forward biased diodes 40 and 42, terminals 46 and 50 of transistor 34, and resistor 48. The resistance of current path 60 is a function of the resistance of resistor 48 plus the drain-to-source resistance of transistor 34. Because transistor 34 acts as a voltage controlled variation resistor, its resistance is determined by the voltage present at output terminal 30 of amplifier 20. The resistance of path 60, and particularly that of transistor 34, then varies in accordance with the output of amplifier 20.

The high gain of operational amplifier 20 keeps the voltage at input terminals 22 and 24 essentially equal. The current through resistor 28 is thereby mirrored proportionally into the resistor 48, each resistor coupling essentially the same potential to voltage V_{ref} . The ratio between the respective currents in resistors 28 and 48 is then a function of the relative resistance of resistors 28 and 48. It may be appreciated that the relative current in resistors 28 and 48 is independent of the absolute values of resistors 28 and 48. Thus, resistors 28 and 48 are advantageously implemented in integrated circuit 12, where the task of providing a given resistor ratio is more accurately achieved than providing particular absolute resistor values.

By making the value of external resistor 26 large relative to that of resistor 28, the current through resistor 28, and therefore the current along

path 60, is determined essentially by the value of an external component. By fabricating the relatively small resistor 28 as part of integrated circuit 12 and using the larger resistor 26 as an external resistor, 5 little material resources, i.e. chip fabrication resources, are required for implementation of voltage divider 29.

The value of resistor 48 is chosen to allow passage of a desired LED current I_{led} along path 60, 10 corresponding to a desired LED brightness, when a given potential V_1 exists across resistor 48. With reference to an assumed value for supply voltage V_{sup} , the values of resistors 26 and 28 are chosen to provide the same potential V_1 at input terminal 22 of 15 amplifier 20.

Transistor 34 provides, when fully turned on, a minimum on-resistance equal to a given potential V_2 divided by the desired current I_{led} . Thus, where transistor 34 is fully turned on and the actual 20 voltage V_3 across integrated circuit 12, i.e., across the series combination of transistor 34 and resistor 48, equals the sum of the given voltages V_1 and V_2 , the desired current I_{led} flows through diodes 40 and 42. As discussed more fully hereafter, where V_1 and 25 V_2 are each on the order of 0.2 volts, integrated circuit 12 operates with as little as 0.4 volts at the drain terminal 46 of transistor 34.

Generally, the actual voltage V_3 at drain terminal 46 of transistor 34 is a function of the 30 supply voltage V_{sup} minus the substantially fixed voltage drop across diodes 40 and 42. Thus, voltage V_3 is subject to variation depending on the actual value of supply voltage V_{sup} and actual forward voltage drop of LED 40 and LED 42. In accordance 35 with the present invention, the resistance of transistor 34 is compensated to adjust current flow in

path 60 to be substantially equal to the desired current I_{led} . More particularly, change in voltage V_3 at drain terminal 46 of transistor 34 results, by way of feedback through amplifier 20, in a change in resistance of transistor 34, such that transistor 34 carries a greater or lesser voltage drop. As the actual voltage V_3 increases, the voltage at source terminal 48 is urged toward an increase, and the inverting input terminal 24 of amplifier 20 receives a slightly greater input voltage. As a result, the potential of output terminal 30 drops in accordance with the high gain of amplifier 20. The resistance of transistor 34 then increases, and transistor 34 carries a larger proportion of the voltage V_3 . Similarly, if the voltage V_3 decreases, the voltage at output terminal 30 increases and transistor 34 carries a smaller portion of voltage V_3 .

In this manner, amplifier 20 keeps the voltage at its input terminals 22 and 24 substantially equal to voltage V_1 . The voltage across resistor 48 then remains substantially at the desired voltage V_1 . With the voltage V_1 across the resistor 48, the current along path 60 is substantially equal to the desired current I_{led} and the desired LED brightness is achieved.

The utility of the present invention is evident in an installation having a small supply voltage V_{sup} , e.g., 5 volts, and a substantial voltage drop across the series combination of LED 40 and LED 42, e.g., a voltage drop on the order of 4 volts. For a desired current I_{led} on the order of 0.011 amps, resistor 48 can be approximately 20 ohms, establishing voltage V_1 at approximately 0.2 volts. Transistor 34 is designed to provide approximately 20 ohm resistance when fully turned on, setting voltage V_2 also at approximately 0.2 volts. Accordingly, resistor 26

should be approximately 10k ohms, and resistor 28 approximately 460 ohms, to deliver approximately 0.2 volts to input terminal 22 of operational amplifier 20. In an actual implementation, supply voltage V_{sup} and the voltage drop across LED 40 and LED 42 can vary from their expected values. Despite such variation, current control device 10 as implemented with the above component values, compensates by providing an LED current along path 60 substantially equal to 0.011
10 amps.

Consider, for example, an actual supply voltage V_{sup} of 4.8 volts and a combined voltage drop across diodes 40 and 42 of 4.4 volts. The potential V_3 at drain terminal 46 is then 0.4 volts.
15 Operational amplifier 20 drives the voltage at its output terminal 30 toward supply voltage V_{sup} , in this case 4.8 volts, until the on-resistance of transistor 34 is low enough to keep the drain-to-source voltage of transistor 34 at about 0.2 volts, thereby leaving
20 the remaining 0.2 volts across resistor 48. The desired current I_{led} thereby passes through LED 40 and LED 42.

If, on the other hand, supply voltage V_{sup} is actually 5.25 volts and the combined voltage drop
25 across diodes 40 and 42 is 3.6 volts, then the potential V_3 at drain terminal 46 of transistor 34 is 1.65 volts. With the potential across resistor 48 urged toward 0.2 volts by terminal 24 of operational amplifier 20, the remaining 1.45 volts must be taken
30 by transistor 34. The voltage at the output terminal 30 of amplifier 20 moves in the required direction to adjust the resistance of transistor 34 to take the remaining potential. The circuit tends toward stabilization where the potential across resistor 48
35 equals the potential at non-inverting input terminal 22. Transistor 34 thereby changes in resistance in

order to carry the potential necessary to leave the potential across resistor 48 at the desired voltage V1.

Proper operation of device 10 is substantially independent of the voltage drop across LED 40 and LED 42, provided a minimum voltage V3 remains across integrated circuit 12, i.e., sufficient voltage at drain terminal 46 of transistor 34. In the embodiment of FIG. 1, a voltage V3 as low as approximately 0.4 volts is sufficient for the desired current control. Variation of transistor characteristics due to temperature and process variation is also substantially removed.

Remaining sources of error include mismatches between resistors 28 and 48, variation in power supply, the absolute value of resistor 28, offset voltage of operational amplifier 20, and the tolerance of external resistor 26. However, mismatch between resistors 28 and 48 is substantially less than the typical 30% absolute value variation due to process and is calculated to result in only approximately 5% variation in LED brightness. Absolute value of resistor 28 should have negligible effect where its resistance is much less than that of resistor 26. Accordingly, it is suggested that external resistor 26 have 1% variation relative to its specified value to minimize error. Offset voltage of operational amplifier 20 will cause a difference between voltages at input terminals 22 and 24. Amplifier 20 should be designed with no systematic offset, but random offset of approximately 0.005 volts can be expected. Overall current variation due to the above noted sources of error is calculated to be on the order +/- 20%. Such variation in current magnitude is considered small in light of the broad range of variables, such variation

in supply voltage V_{sup} and LED forward voltage, in which device 10 operates.

FIG. 2 illustrates a second current control arrangement, according to the present invention, where a number of similar current control devices 80 each provide substantially equal or matching current outputs I_o . In FIG. 2, each control device 80 includes an operational amplifier 20', a transistor 34', and a current sense resistor 48'. As with device 10, one terminal of current sense resistor 48' connects to source terminal 50' of transistor 34' and connects as feedback to inverting input terminal 24' of amplifier 20'. The remaining terminal of resistor 48' connects to reference voltage V_{ref} . A current path 60' between drain terminal 46' of transistor 34' and reference voltage V_{ref} provides each current output I_o . The interconnection of resistors 26 and 28 provides a voltage input for each of the non-inverting input terminals 22' of the amplifiers 20'. As previously described, the voltage across resistor 28 establishes a similar voltage across each resistor 48', whereby the magnitude of current through resistor 28 is mirrored proportionally through each resistor 48'. Again, this proportionate mirroring of current does not depend on the absolute values of resistors 28 and 48', rather it depends on the ratio of resistance of resistor 28 to that of resistors 48'. Because resistors 28 and 48' may be implemented in a single integrated circuit, or in integrated circuits of substantially identical composition, precise resistance ratios are possible. Therefore, precise current control is possible. More particularly, very close matching among current outputs I_o is achieved.

Error, or mismatch, in current output is calculated as the potential range of current I_o

variation for devices 80 (dI_o) divided by the desired current output (I_o). More particularly,

5
$$\frac{dI_o}{I} \approx \frac{dR_{48}}{R_{48}} + \frac{dV_x}{V_x} \approx \frac{dL}{L} + \frac{dV_y}{V_x}$$

where dL is the possible difference in poly-silicon resistor width for resistors 48, dV_x is the possible difference in voltage across resistor 28, and dV_y is
10 the possible difference in operational amplifier offset voltage. Typically dL equals approximately 0.1 μm , L equals approximately 20 μm , dV_y equals approximately 0.01 volts, and V_x equals approximately 1 volt. The expected mismatch in current outputs I_o
15 is calculated to be only approximately 1.5%.

FIG. 3 illustrates a current control device 100 allowing for matching brightness between discrete LED elements or segments of a seven segment display 101. Providing consistent LED current in a seven
20 segment display can be difficult because voltage across the display elements often varies, depending on which display elements are currently activated. A current control device in accordance with the present invention, however, maintains a substantially constant
25 LED current despite variations in voltage potential.

Seven segment display 101 includes light emitting diodes 102-108. In accordance with conventional multiplexing schemes for such seven segment displays, various ones of the light emitting
30 diodes 102-108 couple to reference voltage V_{ref} by way of certain digit switches. For example, the digit switch 110 couples the diodes 102, 103, 104 and 108 to voltage V_{ref} . When digit switch 110 is enabled, diodes 102, 103, 104 and 108 are illuminated to form a
35 particular digit or portion of a digit. Thus, by selectively enabling various digit switches, various digits are displayed on the seven segment display.

For purposes of illustration, only the single digit switch 110 and diodes 102, 103, 104 and 108 are shown. It will be understood, however, that additional digit switches, similar to digit switch 5 110, are necessary to provide the necessary combinations of diode illumination.

Each of diodes 102-108 in the seven segment display 101 is placed in a series combination with a separate current control device. In FIG. 3, a current 10 control device 112 for driving LED 102 is shown. However, it will be understood that an additional device similar to current control device 112 is required for each of diodes 103-108. The current device 112 includes an operational amplifier 114, a 15 current sense resistor 116, and a p-channel MOS transistor 118. The output terminal of amplifier 114 drives gate terminal 128 of transistor 118. Resistor 116 connects to supply voltage V_{sup} and to terminal 120 of transistor 118. The point of interconnection 20 between resistor 116 and terminal 120 is connected as feedback to the inverting input terminal 122 of operational amplifier 114. Terminal 124 of transistor 118 connects in series through diode 102 and digit switch 110 to reference voltage V_{ref} .

25 It may be appreciated that the current control device 112 operates in a substantially similar manner as that of the previously described current control devices 10 and 80. More particularly, and as will be described more fully hereafter, a substantially 30 constant voltage signal is applied to the non-inverting input 126 of operational amplifier 114. This substantially constant voltage signal corresponds to a voltage which would be present at the interconnection of resistor 116 and terminal 120 when 35 the desired magnitude of current flows through resistor 116. As the voltage present at the

interconnection of resistor 116 and transistor 118 varies, operational amplifier 114 drives the gate 128 of transistor 118 to vary the resistance of transistor 118 and thereby adjust current flow through the diode
5 102 to the desired magnitude.

Because transistor 118 is a p-channel device, a level shifting circuit 130 is used to apply the substantially constant voltage signal to the non-inverting input terminal 126 of operational amplifier
10 114. This level shifting circuit 130 operates in a manner substantially similar to that of the previously described current control devices.

Level shifting circuit 130 includes an operational amplifier 132 having its non-inverting
15 input terminal 134 tied to the output of a voltage divider 136. Voltage divider 136 includes a series combination of resistor 138 and resistor 140 connecting supply voltage V_{sup} and reference voltage V_{ref} .

20 Output terminal 142 of operational amplifier 132 drives gate 144 of an n-channel MOS transistor 146. Source terminal 148 of transistor 146 couples to voltage V_{ref} by way of resistor 150, while the drain terminal 152 of transistor 146 couples to supply
25 voltage V_{sup} by way of resistor 154. In this manner, a substantially constant voltage signal, shifted up toward voltage V_{sup} , is provided at drain terminal 152 of transistor 146. Drain terminal 152 of transistor 146 connects to non-inverting input terminal 126 of
30 operational amplifier 114.

By suitably selecting component values, as previously described, the substantially constant voltage signal present at the drain terminal 152 of transistor 146 corresponds to the target voltage
35 across the resistor 116, i.e. that voltage present at the interconnection of resistor 116 and terminal 120

of transistor 118 when the desired current magnitude passes through resistor 116. Because only one LED display segment is used for each segment of display 101, a larger voltage drop across each such device 112 is generally available. Accordingly, the voltage drop across the current sense resistor 116 is selected to be approximately 0.4 volts to minimize error due to operational amplifier offset voltage. Even with the additional stage of level shifting provided by circuit 130, the current control device 110 operates with as little as +/- 25% variation in LED current.

Thus, a precise current control device has been shown. The current control device is well suited for implementation in integrated circuits, and particularly in MOS circuitry. As used for driving LED displays, current control is substantially independent of LED forward voltage, but is operational with very little voltage across the integrated circuit. Furthermore, and more importantly, this approach to current control depends on matching of on-chip resistance instead of obtaining particular absolute resistance values.

While a preferred embodiment of the present invention has been shown and described, it will be apparent to those skilled in the art that many changes and modifications may be made without departing from the invention in its broader aspects. The appended claims are, therefore, intended to cover all such changes and modifications as fall within the true scope of the invention.

CLAIMS

1. A current control device (12) for establishing a controlled current through an LED (14) connected to a supply voltage terminal (V_{sup}), the current control device (12) being connectable between the LED (14) and a reference voltage terminal (V_{ref}) and comprising:

a series combination of a controlled current sense resistor (48) and a transistor (34) having gate (32), drain (46), and source (50) terminals, said transistor (34) being responsive to a control signal applied to said gate terminal (32), said transistor (34) having said source terminal (50) connected to one end of said controlled current sense resistor (48), the second end of the controlled current sense resistor (48) being connectable to said reference voltage terminal (V_{ref}) and said drain terminal (46) being connectable to the LED (14) opposite the LED connection to the supply voltage terminal (V_{sup});

operational amplifier means (20) having an output terminal (30) coupled to said gate terminal (32) for providing said control signal, an inverting input terminal (24) coupled to said connection of said controlled current sense resistor (48) and said source terminal (50) as a sense point in said series combination, and a noninverting input terminal (22) receiving a substantially constant voltage signal corresponding to a voltage present at said sense point when the desired magnitude of current passes through said controlled current sense resistor (48)

; and

a reference current sense resistor (28) connected at one end thereof to said operational amplifier noninverting input terminal (22) and at the second end thereof being connectable to the reference voltage terminal;

wherein the reference current sense resistor (28) and the controlled current sense resistor (48) are both fabricated in integrated circuit form so that a desired ratio of resistances therebetween may be accurately set.



2. A current control device according to claim 1 wherein said transistor comprises an n-channel MOS field effect transistor.

3. A display device (10) comprising:

5 a voltage supply terminal (V_{sup});

a voltage reference terminal (V_{ref});

a first light emitting diode (40) having an anode terminal and a cathode terminal;

10 a second light emitting diode (42) having an anode terminal and a cathode terminal;

a voltage controlled transistor (34) having drain (46) and source (50) current path terminals and a gate control terminal (32) wherein voltage present at the gate control terminal (32) determines resistance between the current path
15 terminals (46, 50);

a first resistor (48) having first and second terminals and a substantially fixed resistance therebetween;

20 wherein said first resistor (48) is coupled at said first terminal to said voltage reference terminal (V_{ref}), and coupled at said second terminal to said source (50) current path terminal, said voltage controlled

transistor (34) is coupled at said drain current path terminal (46) to said cathode terminal of said second light emitting diode (42), said anode terminal of said second light
25 emitting diode (42) is coupled to said cathode terminal of said first light emitting diode (40), and said anode terminal of said first light emitting diode (40) is coupled to said voltage supply terminal (V_{sup});

an operational amplifier (20) having an inverting
30 input terminal (24), a non-inverting input terminal (22), and an output terminal (30), the output terminal (30) being coupled to the gate control terminal (32) of said voltage controlled transistor (34), the inverting input terminal (24) being coupled to the source current path terminal (50)
35 of said voltage controlled transistor (34); and

a voltage divider (29) comprising a reference current sense resistor (28) and a second (26) resistor connected in series between said voltage supply terminal (V_{sup}) and said



voltage reference terminal (Vref), the interconnection of said reference sense (28) and second (26) resistors being coupled to the non-inverting input terminal (24) of said operational amplifier (20).

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4. A method of providing a desired ratio of a current magnitude I through an LED (14) connected to a supply voltage terminal (Vsup) to a reference current magnitude, the method comprising the steps of:

placing the LED (14) in a series combination across a voltage potential established between the supply voltage terminal (Vsup) and said reference voltage terminal (Vref), the series combination including the steps of connecting a substantially fixed resistor (48) to said reference voltage terminal (Vref), connecting a source terminal (50) of a voltage variable transistor (34) having a gate terminal (32) responsive to a control signal for varying the resistance of said voltage variable transistor (34) to said substantially fixed resistor (48) at a sense point along said series combination, and connecting a drain terminal (46) of said voltage variable transistor (34) to the LED (14);

applying the reference current magnitude to a reference current sense resistor (28) whose resistance is proportional to the resistance of said fixed resistor (48) according to the desired ratio of current magnitude I to the reference current magnitude; and

adjusting, by control means (20) responsive to voltage at said sense point, the resistance of said voltage variable transistor (34) such that voltage across said fixed resistor (48) corresponds to a voltage established across said reference current sense resistor (28) by the application of the reference current.



5. A method according to claim 4 wherein said adjusting step includes:

5 applying the output of an operational amplifier (20) as the control signal to the gate of said voltage variable transistor (34), and

10 applying a voltage signal taken from said sense point of said series combination to an inverting input terminal of said operational amplifier (20).

6. A current control device substantially as herein described with reference to any of Figures 1 to 3 of the accompanying drawings.
