regulator device having improved thermal performance together with accurate current setting capabilities and which is preferably operable over a wide range of programmable current values. Furthermore, in view of the price sensitivity of many of these applications, LED drivers aimed at addressing these needs should ideally be cost-effective. In circuit design terms, this means realising solutions that use simple current topologies and simple components. For example, a cost-effective solution would be one that keeps transistor count low. This would have the added benefit of maximizing the MTBF of the current regulator and therefore of an LED driver incorporating it. It is also desirable to provide a current regulator device which exhibits a lower sensitivity to the manufacturing tolerance of current determining circuit elements than previously considered solutions.

~~According to a first aspect of the present invention~~ there is provided a current regulator for providing a regulated current from an input voltage, the current regulator comprising:

a driver circuit comprising a resistor and a transistor; and

a voltage regulator circuit operable to provide a regulated voltage to said driver circuit, wherein said voltage regulator circuit comprises a plurality of Zener diodes connected in parallel.

According to a first aspect of the present invention, there is provided a current regulator comprising a current regulator circuit for providing a regulated current from an input voltage, the current regulator circuit comprising:

a driver circuit comprising a resistor and a transistor; and

a voltage regulator circuit operable to provide a regulated voltage to said driver circuit, characterised in that said voltage regulator circuit comprises a plurality of Zener diodes connected in parallel, each Zener diode having a Zener voltage of less than 5.5V and wherein the Zener diodes are selected such that a variation of between 0.1V and 0.3V exists between the Zener voltages of the Zener diodes comprised in the plurality of Zener diodes.

Preferably, the driver circuit and the voltage regulator circuit form a first current regulator circuit. Preferably, the first current regulator circuit is cross-coupled to a second current regulator circuit. Preferably, in this case, the second current regulator circuit may comprise:

a second driver circuit comprising a resistor and a transistor; and

a second voltage regulator circuit operable to provide a regulated voltage to said second driver circuit, wherein said voltage regulator circuit comprises a plurality of Zener diodes connected in parallel.

Alternatively, the driver circuit and the voltage regulator circuit form a first current regulator circuit which is connected to a resistive summing circuit.

TAccording to a second aspect of the present invention there is provided a current regulator for providing a regulated current from an input voltage, the current regulator comprising:

a first current regulator circuit and a second current regulator circuit, wherein the output of the first current regulator circuit is cross-coupled to said second current regulator circuit, each of the first and second current regulator circuits comprising:

a driver circuit comprising a resistor and a transistor; and

a voltage regulator circuit operable to provide a regulated voltage to the respective driver circuit, wherein said voltage regulator circuit comprises a plurality of Zener diodes connected in parallel.

According to embodiments of the second aspect of the present invention the output of the first current regulator circuit is cross-coupled to said second current regulator circuit such that the collector of the transistor of the first current regulator circuit is connected to the positive terminal of the voltage regulator circuit of the second current regulator circuit.

Preferably, the Zener diodes of the/each voltage regulator

circuit comprise silicon Zener diodes. The transistors used in a cross-coupled current regulator circuit of this type preferably form a "complimentary pair" wherein one transistor is a Silicon bipolar transistor of the PNP type and the other is a Silicon bipolar transistor of the NPN type.

~~According to a third aspect of the present invention~~ there is also provided a voltage regulator circuit for use in a current regulator circuit comprising a plurality of Zener diodes connected in parallel.

Embodiments of the present invention advantageously exploit the well-defined breakdown voltage of Zener diodes as a means to regulate the voltage applied to the driver circuit of a current regulator device in order to generate a stabilised current for supply to a given load.

The provision of a plurality of Zener diodes which are connected in parallel to form the voltage regulator circuit according to embodiments of the present invention is advantageous in that it readily facilitates the generation of a wide range of regulated current values (I_T). Specifically, the current programming range of a current regulator embodying the present invention can advantageously be selected according to the number of Zener diodes used in each voltage regulator circuit, or voltage regulator device (VRD). As such, according to embodiments of the present invention, it is not necessary to parallelise, or replicate, the whole circuit in order to achieve a range of constant current values. Thus, the parts that are replicated according to the present invention (i.e. the Zener diodes) are simple, relatively inexpensive circuit elements. This advantageously provides a very cost-effective solution to the problem of providing a range of regulated current values,

invention find particular application in LED lighting, LCD backlights, including those for large public displays, as well as LED displays, architectural lighting and channel lettering applications, without recourse to additional means for correcting for thermal drift in regulator current.

In summary, preferred embodiments of the present invention advantageously provide a cost-effective regulation circuit, with improved thermal performance (i.e. temperature coefficient values which are less than those associated with the previously considered solutions), which is operable over a range of programmable current values, and which is accurately set.

According to a second~~fourth~~ aspect of the present invention there is provided an illumination apparatus comprising one or more LEDs, the illumination apparatus comprising a current regulator according to an embodiment of the first ~~or second~~ aspect.

The illumination apparatus may, for example, comprise a lighting fixture, containing LEDs, together with one or more LED drivers, where each of the said LED drivers contains one or more current regulators.

For a better understanding of the present invention, and to show how the same may be carried into effect, reference will now be made, by way of example to the accompanying drawings in which:

Figure 1 shows generalized current regulator circuit topologies according to the prior art;

Figure 2 shows the generalized topology of a three-terminal current regulator circuit according to the prior art;

CLAIMS

1. A current regulator circuit for providing a regulated current from an input voltage comprising:

a driver circuit comprising a resistor and a transistor; and

a voltage regulator circuit operable to provide a regulated voltage to said driver circuit, wherein said voltage regulator circuit comprises a plurality of Zener diodes connected in parallel, each Zener diode having a Zener voltage of less than 5.5V and wherein a variation of between 0.1V and 0.3V exists between the Zener voltages of the Zener diodes comprised in the plurality of Zener diodes.

2. A current regulator circuit as claimed in claim 1, wherein said driver circuit and said voltage regulator circuit form a first current regulator circuit, and wherein said first current regulator circuit is cross-coupled to a second current regulator circuit.

3. A current regulator circuit as claimed in claim 2, wherein said second current regulator circuit comprises:

a second driver circuit comprising a resistor and a transistor; and

a second voltage regulator circuit operable to provide a stabilised reference voltage to said second driver circuit, wherein said second voltage regulator circuit comprises a plurality of Zener diodes connected in parallel each Zener diode having a Zener voltage of less than 5.5V and wherein a variation of between 0.1V and 0.3V exists between the Zener voltages of the Zener diodes comprised in the plurality of Zener diodes.

4. A current regulator circuit as claimed in claim 1, wherein said driver circuit and said voltage regulator circuit form a first current regulator circuit, and wherein said first current regulator circuit is connected to a resistive summing circuit.

5. A current regulator for providing a regulated current from an input voltage comprising:

a first current regulator circuit and a second current regulator circuit, wherein the output of the first current regulator circuit is cross-coupled to said second current regulator circuit, each of the first and second current regulator circuits comprising:

a driver circuit comprising a resistor and a transistor;

a voltage regulator circuit operable to provide a regulated voltage to the respective driver circuit, wherein said voltage regulator circuit comprises a plurality of Zener diodes connected in parallel each Zener diode having a Zener voltage of less than 5.5V and wherein a variation of between 0.1V and 0.3V exists between the Zener voltages of the Zener diodes comprised in the plurality of Zener diodes.

6. A current regulator as claimed in any preceding claim, wherein the current regulator comprises a two-terminal circuit.

7. A current regulator as claimed in any preceding claim, wherein the Zener diodes of the/each voltage regulator circuit comprise silicon Zener diodes.

8. A current regulator as claimed in any preceding claim, wherein the Zener diodes of the/each voltage regulator circuit exhibit a Zener voltage of between 2.0V and 3.0V.

9. A current regulator as claimed in any preceding claim, wherein the circuit is operable for providing a programmed regulated current of between 25mA to 220mA.

10. A current regulator as claimed in any preceding claim, wherein the Zener voltage of the Zener diodes comprised in the voltage regulator circuit of the/each current regulator circuit are selected such that:

$Iz,opt = I_{spec}/2.N$

where Iz,opt is the current at which the rate of change of the Zener voltage with temperature substantially equals the rate of change of the base-emitter voltage vbe of the transistor of the current regulator circuit, N is an integer number of Zener diodes per voltage regulator circuit and I_{spec} is a current regulator current at which the temperature coefficient is substantially zero.

11. A current regulator, as claimed in any preceding claim, wherein the transistor of the/each driver circuit comprises a silicon bipolar transistor.

12. A current regulator as claimed in claim 11, wherein the silicon bipolar transistor is of the NPN or PNP type.

13. A current regulator as claimed in claim 12, when appended to either claim 3 or claim 5, wherein the transistor of the first or second current regulator circuit is of the PNP type whilst the transistor of other current regulator circuit is of the NPN type such that the transistors form a complimentary pair.

14. A current regulator as claimed in any one of claims 5 to 13, wherein the resistor of the first and/or second diver circuit is operable to vary in order to serve as a current programming resistor.

15. A voltage regulator circuit for use in a current regulator circuit comprising a plurality of Zener diodes connected in parallel each Zener diode having a Zener voltage of less than 5.5V and wherein a variation of between 0.1V and 0.3V exists between the Zener voltages of the Zener diodes comprised in the plurality of Zener diodes.

16. An illumination apparatus comprising one or more LEDs and a current regulator as claimed in any one of claims 1 to 14.

CLAIMS

1. A current regulator comprising a current regulator circuit for providing a regulated current from an input voltage, the current regulator circuit comprising:

a driver circuit comprising a resistor and a transistor; and

a voltage regulator circuit operable to provide a regulated voltage to said driver circuit, characterised in that said voltage regulator circuit comprises a plurality of Zener diodes connected in parallel, each Zener diode having a Zener voltage of less than 5.5V and wherein the Zener diodes are selected such that a variation of between 0.1V and 0.3V exists between the Zener voltages of the Zener diodes comprised in the plurality of Zener diodes.

2. A current regulator as claimed in claim 1, wherein said current regulator circuit forms a first current regulator circuit, and wherein said first current regulator circuit is cross-coupled to a second current regulator circuit.

3. A current regulator circuit as claimed in claim 2, wherein said second current regulator circuit comprises:

a second driver circuit comprising a resistor and a transistor; and

a second voltage regulator circuit operable to provide a stabilised reference voltage to said second driver circuit, wherein said second voltage regulator circuit comprises a plurality of Zener diodesconnected in parallel each Zener diode having a Zener voltage of less than 5.5V and wherein the Zener diodes are selected such that a variation of between 0.1V and 0.3V exists between the Zener voltages of the Zener diodes comprised in the plurality of Zener diodes.

4. A current regulator circuit as claimed in claim 1, wherein said current regulator circuit forms a first current regulator

circuit, and wherein said first current regulator circuit is connected to a resistive summing circuit.

5. A current regulator as claimed in any preceding claim, wherein the current regulator comprises a two-terminal circuit.

6. A current regulator as claimed in any preceding claim, wherein the Zener diodes of the/each voltage regulator circuit comprise silicon Zener diodes.

7. A current regulator as claimed in any preceding claim, wherein the Zener diodes of the/each voltage regulator circuit exhibit a Zener voltage of between 2.0V and 3.0V.

8. A current regulator as claimed in any preceding claim, wherein the circuit is operable for providing a programmed regulated current of between 25mA to 220mA.

9. A current regulator as claimed in any preceding claim, wherein the Zener voltage of the Zener diodes comprised in the voltage regulator circuit of the/each current regulator circuit are selected such that:

$$Iz,opt = I_{spec}/2.N$$

where Iz,opt is the current at which the rate of change of the Zener voltage with temperature substantially equals the rate of change of the base-emitter voltage vbe of the transistor of the current regulator circuit, N is an integer number of Zener diodes per voltage regulator circuit and I_{spec} is a current regulator current at which the temperature coefficient is substantially zero.

10. A current regulator, as claimed in any preceding claim, wherein the transistor of the/each driver circuit comprises a silicon bipolar transistor.

11. A current regulator as claimed in claim 10, wherein the silicon bipolar transistor is of the NPN or PNP type.

12. A current regulator as claimed in claim 11, when appended to claim 3, wherein the transistor of the first or second current regulator circuit is of the PNP type whilst the transistor of other current regulator circuit is of the NPN type such that the transistors form a complimentary pair.

13. A current regulator as claimed in claim 3 any one of claims 5 to 12 when appended to claim 3, wherein the resistor of the first and/or second diver circuit is operable to vary in order to serve as a current programming resistor.

14. An illumination apparatus comprising one or more LEDs and a current regulator as claimed in any one of claims 1 to 13.