LED balancing circuit with power limit

Introduction

Light Emitting Diodes (LEDs) are often used with an output voltage source from a power supply. The output voltage increases until the current through the LEDs reaches the value of the constant current source from the power supply. Maximum output voltage is limited by the power supply.

LEDs are used individually and when more light is required, LEDs are stacked in series with the same current passing through each one. The voltage across the string increases with each LED added. After a number of LEDs are added in series, the power supply may not be able to handle the higher output voltage required. Also, a change of output voltage could be a problem for the power supply if the range of LEDs required is high enough to increase the range of the output voltage and auxiliary circuits.

Various circuits can be used to balance the current in parallel strings of series loads where the individual loads vary in voltage, because LEDs have been shorted or opened. Without a circuit, the variation of the parallel loads could cause most, or all of the current to pass through the path of the load with the lowest voltage and a small amount of current to pass through the path of the load with the highest voltage. The result would be a variation in light output and could cause LED failure from excessive current. The objective is to achieve the same current through each parallel string of series loads even though the voltage across each load is not the same.

The following technical note is a description of a circuit which can be used to balance the current through two or more strings of LEDs. The power supply output voltage (LED circuit input voltage V_{in}) varies, up to a limit, while providing a constant current to the LED circuit. The circuit will balance the current in the LED strings and protect for a shorted or open LED.

A power limit circuit is described which limits the power of the LED balancing circuit when there is a large voltage variation for parallel strings of LEDs.
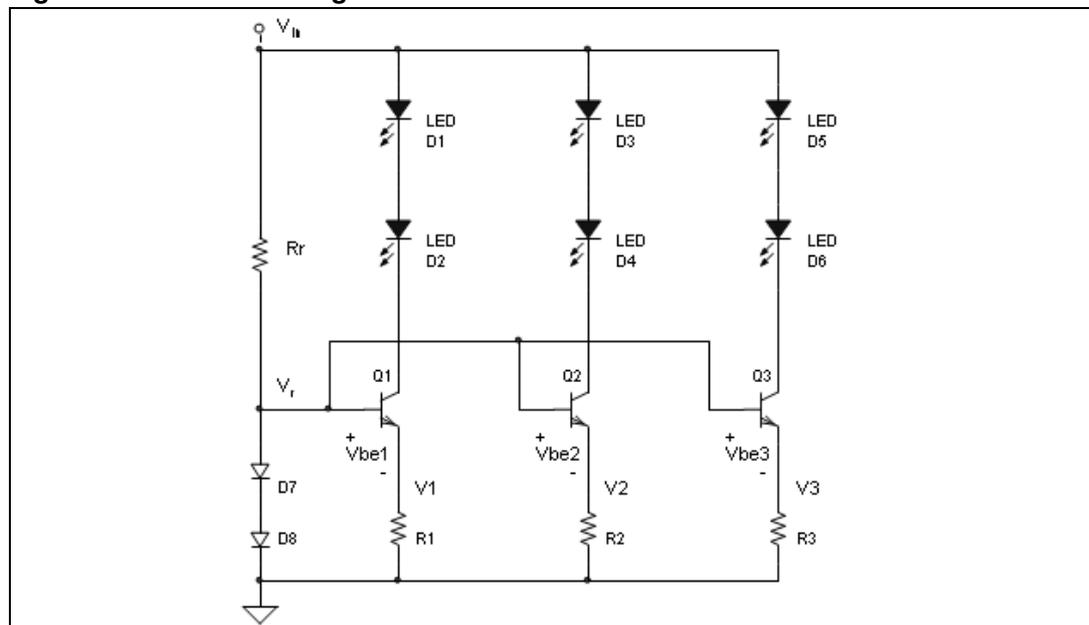
1   LED balancing circuit

This circuit is used to balance the current in two or more parallel strings of series loads where the individual loads vary in voltage, because loads have been opened or shortened. The circuit contains one bipolar transistor and one resistor per string, a voltage reference (two diodes shown in *Figure 1*) and a resistor for the reference. The current passing through each load (Note: a 'load' is one string of LEDs. See *Figure 1* which shows LED loads D1 and D2, D3 and D4, and D5 and D6 in series) is also the current through one transistor.

Figure 1 also shows the power supply for an example using LED loads D1 plus D2, D3 plus D4, D5 plus D6 and a power supply output voltage, with a constant output current, providing the circuit input voltage, V_{in}. With each string containing the same number of LEDs, any number of LEDs can be used.

The voltage at V1 is the reference voltage, V_r, minus the base to emitter voltage V_{be1}. The current through R1 is the voltage V1 divided by the resistor R1. The total LED current is approximately the sum of the current through the emitter resistors R1, R2 and R3.

The current through each string remains approximately equal, even if the LED voltage varies or if one is shorted. This is due to the relatively constant voltage of two reference diodes (D7 and D8, in series) will determine the current through the emitter resistors. For example if LED (D1) in one string is open, the current through the string (D1 and D2) is zero. The base to emitter junction of Q1 behaves like a diode and a small amount of current passes through R1. The reference voltage V_r drops, as to the other base to emitter junction voltages, and less current flows through the other strings (see *Equation 10*)

Figure 1.   LED balancing circuit

●   Operation of the LED balancing circuit, with an emitter resistor (R_e) is as follows:

Equation 1

$$I_{Re} = \frac{V_R - V_{be}}{Re}$$

Equation 2

$$Re = \frac{(V_r - V_{be})}{I_{Re}}$$

● For one open LED:

Equation 3

$$I_{Rr} = \frac{(V_{in} - V_r)}{R_r}$$

Equation 4

$$I_{Re} = \frac{(V_r - V_{be_{min}})}{Re}$$

Equation 5

$$V_r = V_{be_{max}} + I_{Rr} \bullet Re$$

Equation 6

$$V_r = V_{be_{max}} + (V_{in} - V_r) \bullet \frac{Re}{Rr}$$

Equation 7

$$V_r = V_{be_{max}} + V_{in} \bullet \frac{Re}{Rr} - V_r \bullet \frac{Re}{Rr}$$

Equation 8

$$V_r + V_r \bullet \frac{Re}{Rr} = V_{be_{max}} + V_{in} \bullet \frac{Re}{Rr}$$

Equation 9

$$V_r = \left(\frac{V_{be_{max}} + V_{in} \bullet \frac{Re}{Rr}}{1 + \frac{Re}{Rr}} \right)$$

Equation 10

$$I_{Re} = \frac{\dfrac{\left(V_{be_{max}} + V_{in} \bullet \frac{Re}{Rr} \right)}{\left(1 + \frac{Re}{Rr} \right)} - V_{be_{min}}}{Re}$$
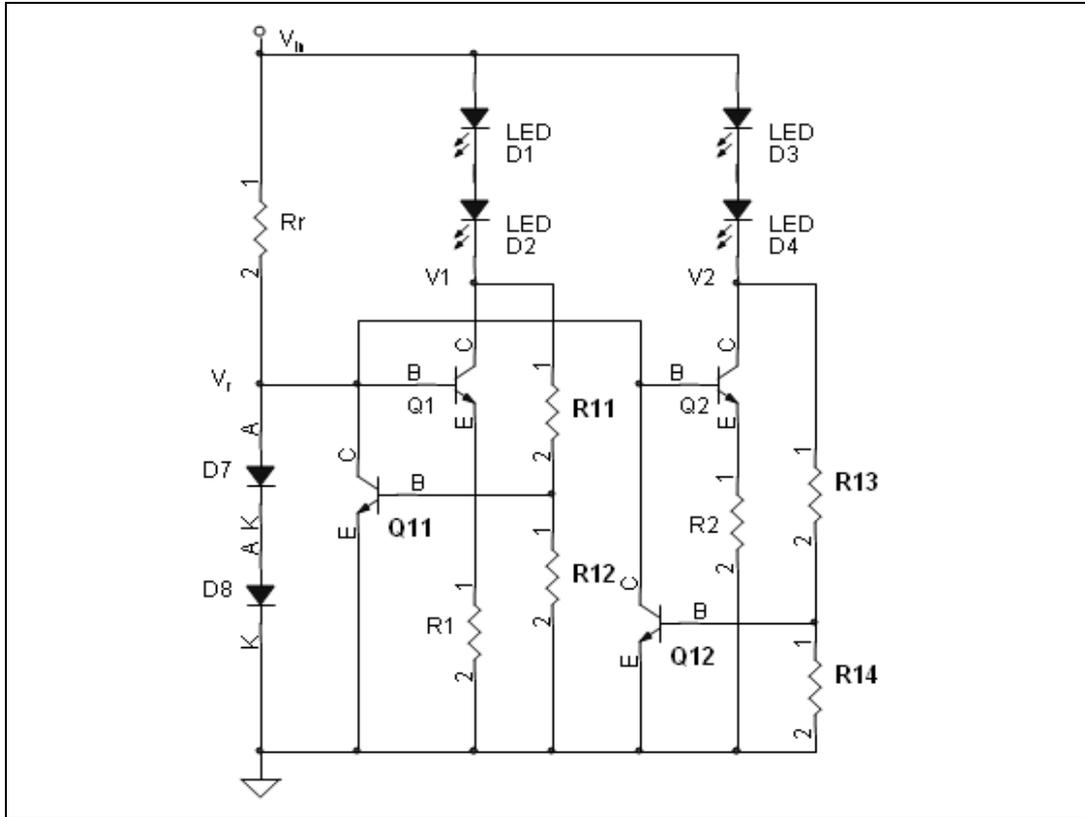
1.1 Power limit circuit

A power limit circuit can be added to the circuit in *Figure 1* to limit the overall power when there is a large voltage variation for parallel strings of LEDs. *Figure 2*, *Figure 3*, and *Figure 4* have two LED strings and the power limit circuit has bold references. The voltage variation can be from one string with low voltage drop LEDs and another string with a high voltage drop or if there is a shorted LED in one string.

In *Figure 2* shows the power limit circuits R11, R12, R13, R14, Q11 and Q12. If there is a low drop in the LED string D1 and D2, the voltage at V1 (Q1 collector) is high and Q11 is

switched on through R11 and R12. The voltage at V_r drop the current in both LED strings. The power supply source, which is constant, tries to supply the required current, and in doing so raises the output voltage up to the power supply output voltage limit. V_{in} and, V1 increase and, Q11 latches on and disables the LED balancing circuit until V_{in} is removed.

Figure 2. LED balancing circuit - two transistor power limit, latch

The following two circuits are variations of the power limit circuit in *Figure 2* which will disable the LED balancing circuit but will not latch it off.

Figure 3 and *Figure 4* show two variations of power limit circuits, which disable the LED balancing circuit but do not latch it off.

The circuit in *Figure 3* (R11, R12, R13 and Q11) has fewer parts but has a narrower fault tolerance detection range. Q11 is switched on through either R11 or R13. In the circuit (R11, R12, D9, D10 and Q11) in *Figure 4*, Q11 is switched on through diodes D9 or D10.

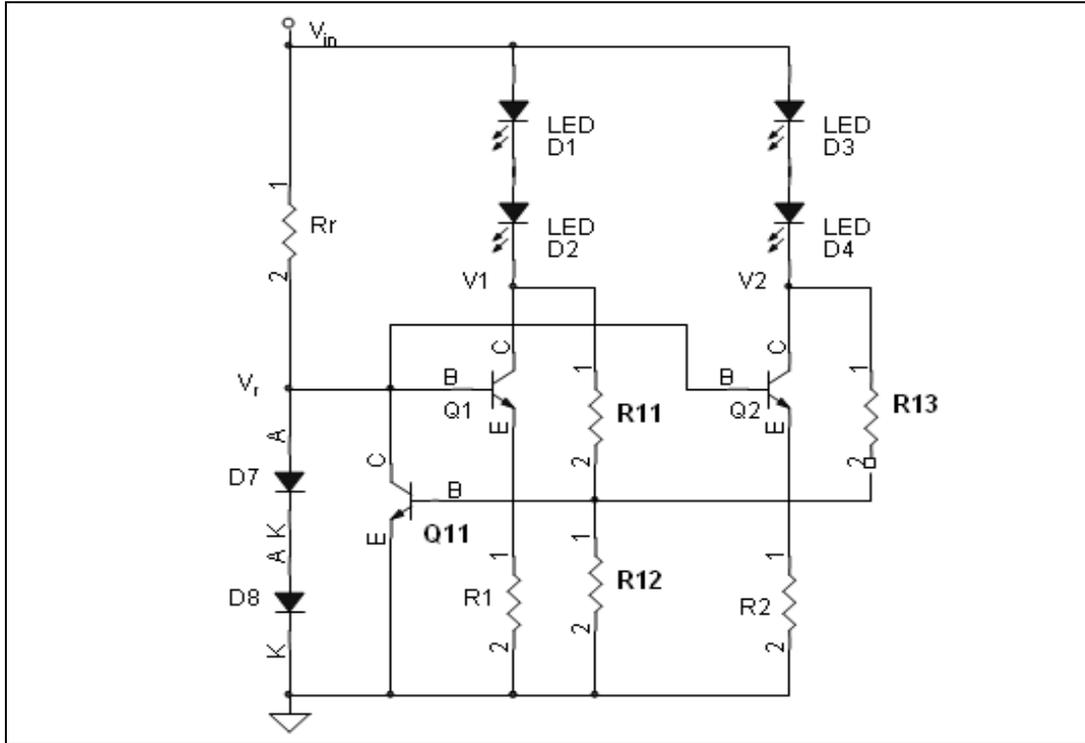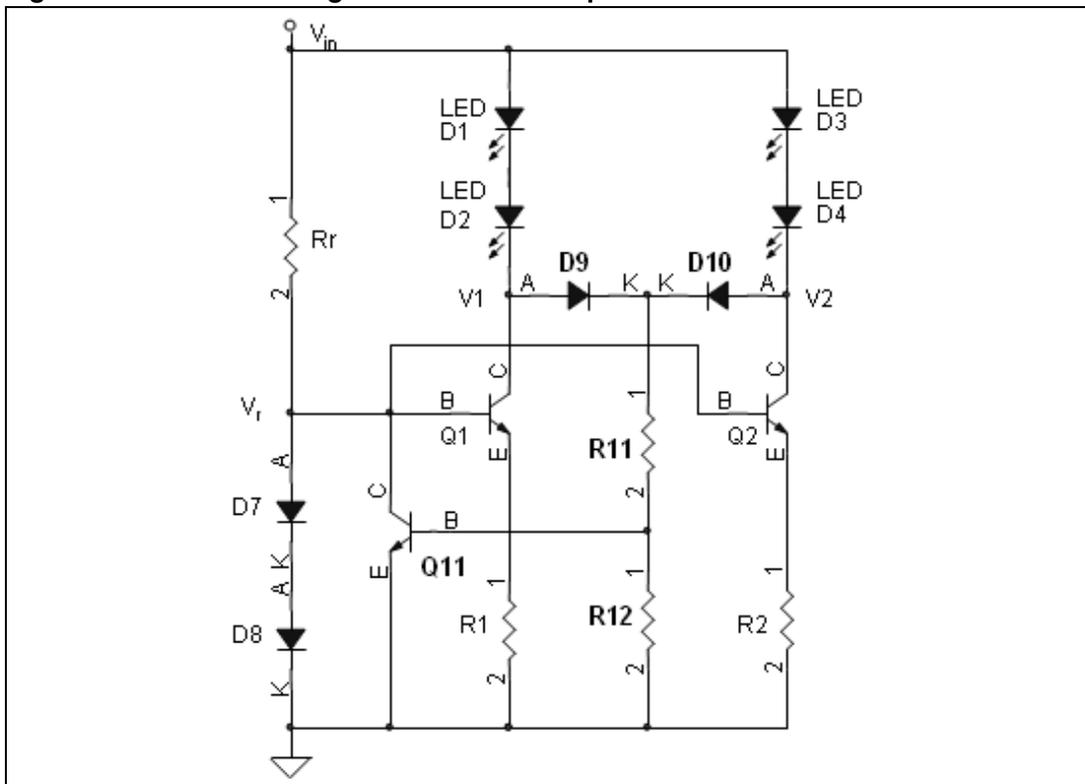**Figure 3.   LED balancing circuit - one transistor power limit**

Figure 4.   LED balancing circuit - two diode power limit

2 Revision history

Table 1.   Revision history

Date	Revision	Changes
25-Jan-2007	1	First issue
05-Apr-2007	2	Cross references updated

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