Engineers often need to connect LEDs in parallel. Ideally, the LEDs share current equally. In reality, even LEDs from the same production lot have poorly matched I-V characteristics. This mismatch causes the LEDs to not share the current equally. The engineer can add a ballast resistor in series with each LED to minimize current differences. This application report explains how to size the ballast resistor to minimize differences in the LED currents of paralleled LEDs connected to a current sink.

**Background**

Figure 1 shows the I-V Curve of a typical LED.

![I-V Curve of White LED](image)

**Figure 1. Typical LED I-V Curve**

If two LEDs have identical I-V curves and are connected in parallel, their currents are equal. However, the problem arises when their I-V curves are different, as shown in Figure 2.

![Parallel LED Connection Without Ballast Resistors](image)

**Figure 2. Parallel LED Connection Without Ballast Resistors**

When two LEDs are connected to a constant current sink of 25 mA, due to the difference in the I-V curves of the LEDs, 10 mA flows through one of the LEDs and 15 mA through another.
Figure 3. I-V Curves of Two Different LEDs

Figure 3 illustrates why the currents are different. Because the voltage (V) across both LEDs is the same, the 25 mA of current demanded by the current sink splits per each LED’s I-V curve, as highlighted by segment AB. If the variation in forward current needs to be reduced, the engineer can add a ballast resistor in series with each LED.

As an example, connect a resistor of $R \Omega$ in series with each LED.

The voltage drop across each LED decreases. The sum of the currents must remain the same, i.e., $I_1 + I_2 = 25$ mA. Figure 5 shows that point A moves to the left as V and I2 decrease to $V_2'$ and $I_2'$, whereas point B moves to the right as V and I1 increase to $V_1'$ and $I_1'$. 
The end result is that the values $I_1$ and $I_2$ move closer together, whereas the voltage drops across the LEDs move farther apart. The goal is to set the resistor to such a value that $I_1$ and $I_2$ are within the specified limits. The total voltage drop across both LEDs plus resistors must be equal:

$$V_1 + R \times I_1 = V_2 + R \times I_2$$

Solving for $R$ gives: $R = (V_1 - V_2)/(I_2 - I_1)$

$$R = \frac{\Delta V}{\Delta I}$$

The goal is to set the resistor to such a value that $I_{1'}$ and $I_{2'}$ are within the specified limits. So, setting $\Delta I = I_{2'} - I_{1'}$ to the maximum allowable LED current variation and knowing that $\Delta V = V_{1'} - V_{2'}$ is the maximum forward voltage drop variation among the LEDs at the split current level per the LED data sheet gives $R$ as the optimum value. This resistor value is also given by the reciprocal of the magnitude of the slope of segment AB in Figure 5.

The higher the resistor value, the closer are the current values. The same formula is valid for more than two LEDs connected in parallel as illustrated in Figure 6.
Here, $\Delta I' = I2' - I1'$ is the maximum allowable current variation specified by the user and $\Delta V' = V2' - V1'$ is the maximum voltage variation. $\Delta V'$ is a function of the LED I-V curves and $\Delta I'$. The tilted segment AB confirms that the current is now within the tolerance limits. Also, it passes through all the I-V curves and hence is valid for all the LEDs.

This can be mathematically proved as follows:

$$R = \frac{V2 - V1}{I2 - I1},$$

where $R$ is the ballast resistor, $V2$ and $V1$ are the voltage drops across the corresponding LEDs, and $I2$ and $I1$ are the currents through the LEDs.

**Figure 7. Similar LEDs Connected to Common Current Sink**

Suppose two similar LEDs are connected to a common current sink as shown in Figure 7. Due to variations in the I-V curves, $I1 \neq I2$. $V1$ and $V2$ are the voltage drops across the corresponding LEDs. If $\Delta I$ is the maximum allowable current variation, then $R$ must be chosen such that $I1 - I2 = \Delta I$.

From Figure 7, $V1 + R \times I1 = V2 + R \times I2$

This simplifies to, $R = (V2 - V1)/(I2 - I1)$, i.e., $R = \Delta V/\Delta I$
The same thing can be proved for ‘n’ number of LEDs as follows:

\[ I_c = I_1 + I_2 + I_3 + \ldots + I_n \]

Also,

\[ V_1 + R \times I_1 = V_2 + R \times I_2 = V_3 + R \times I_3 = \ldots = V_n + R \times I_n \]

For any LED number x and LED number y, if \( I_x \) and \( I_y \) are such that \( I_x - I_y \) is the maximum variation in current through the LEDs and \( V_x \) and \( V_y \) being the corresponding voltage drops, then:

\[ V_x + R \times I_x = V_y + R \times I_y \]
\[ \text{Hence, } R \times (I_x - I_y) = V_y - V_x \]
\[ R = \frac{(V_y - V_x)}{(I_x - I_y)} \]

Where \( \Delta I \) can be the maximum current variation required and \( \Delta V \) be the corresponding voltage variation.

**EXAMPLE:**

Here is an actual example. Figure 9 shows the I-V Curves of three white LEDs.

![Figure 8. ‘n’ LEDs Connected in Parallel](image)

![Figure 9. I-V Curves of Three White LEDs](image)
These three LEDs were connected to the auxiliary pin of the TPS60250 current sink as shown in Figure 10. On the TPS60250 software (GUI), only the auxiliary pin is enabled. It is programmed to sink 56 mA.

With ballast resistors $R_1 = R_2 = R_3 = 0 \, \Omega$, the LED currents are:

- $I_{LED1} = 22.58 \, mA$
- $I_{LED2} = 21.42 \, mA$
- $I_{LED3} = 12.25 \, mA$

This is about 30% variation from their mean. If the LED current matching requirement is $17 \, mA \pm 2 \, mA$, $\Delta I = 4 \, mA$. Using Figure 9, draw a line, AB, that crosses the I-V curves between 17 mA and 21 mA. The voltage variation between point A and point B is 240 mV. The required ballast resistors value is $R = 240 \, mV/4 \, mA = 60 \, \Omega$. Resistors $R_1 = R_2 = R_3 = 61.9 \, \Omega$ were connected as ballast resistors.

The resulting LED currents are:

- $I_{LED1} = 19.143 \, mA$
- $I_{LED2} = 18.943 \, mA$
- $I_{LED3} = 15.234 \, mA$

Which are within the specified tolerance limits.
NOTE: The blue lines show the operating conditions after connecting the ballast resistors and the red lines show the condition before the ballast resistors are connected.

**Figure 11. I-V Characteristics of Different LEDs**

Note that the higher the ballast resistor value, the more closely matched the LED currents. However, larger resistor values increase the power dissipation in the circuit. The increased power dissipation is defined by

\[ P_d = (I_{led})^2 \times R_{ballast} \times n \]

Where:
- \( I_{led} \) is the current through each LED
- \( R_{ballast} \) is the ballast resistor value
- \( n \) is the total number of LEDs in parallel

The user must make a tradeoff between LED current tolerance and power dissipation through the resistors.
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