

Ballast Resistor Calculation – Current Matching in Parallel LEDs

Mudassar Khatib

PMP - DC/DC Controllers

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.

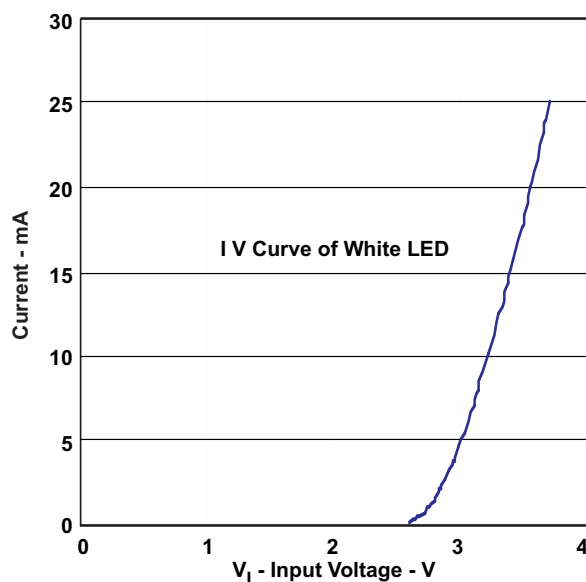


Figure 1. Typical LED I-V Curve

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.

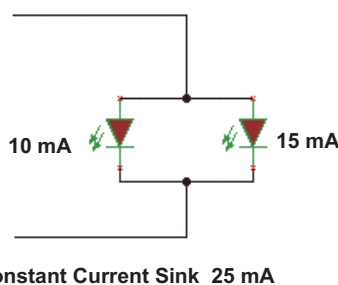


Figure 2. Parallel LED Connection Without Ballast Resistors

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.

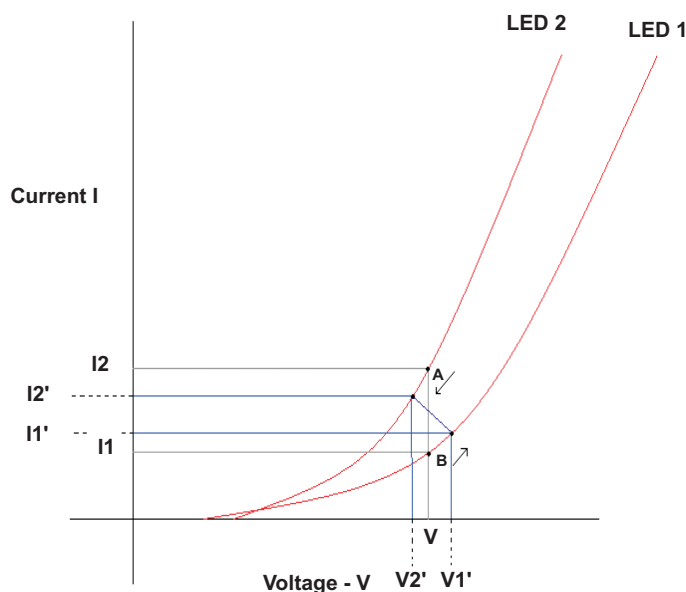


Figure 3. I-V Curves of Two Different LEDs

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.

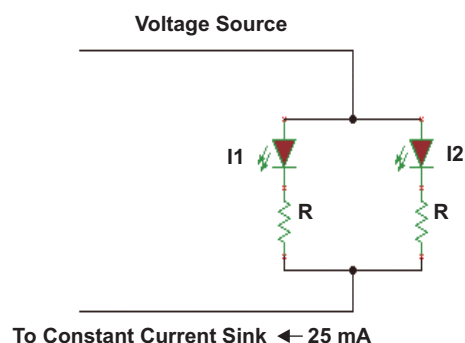


Figure 4. Paralleled LEDs With Ballast Resistors

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., $I_1 + I_2 = 25 \text{ mA}$. Figure 5 shows that point A moves to the left as V and I_2 decrease to V_2' and I_2' , whereas point B moves to the right as V and I_1 increase to V_1' and I_1' .

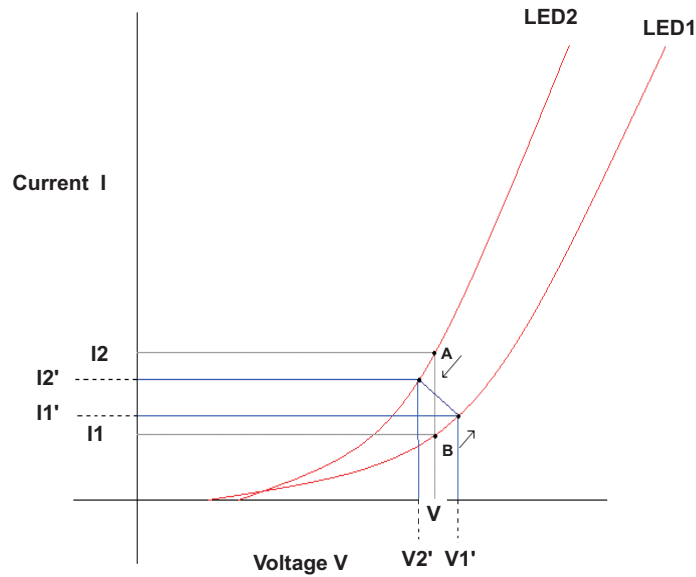


Figure 5. LED I-V Curve With Ballast Resistors

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:

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

$$\text{Solving for } R \text{ gives: } R = (V_1 - V_2)/(I_2 - I_1)$$

$$R = \Delta V / \Delta I$$

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.

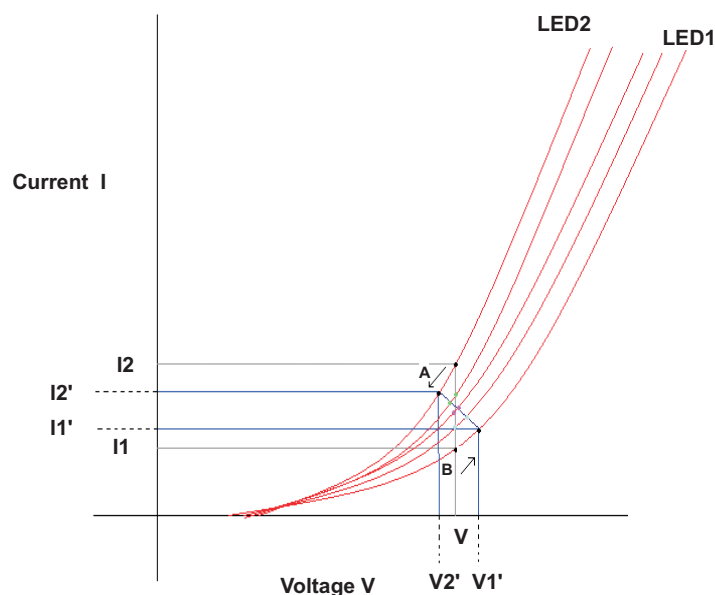


Figure 6. Multiple LED I-V Curves With Ballast Resistors

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:

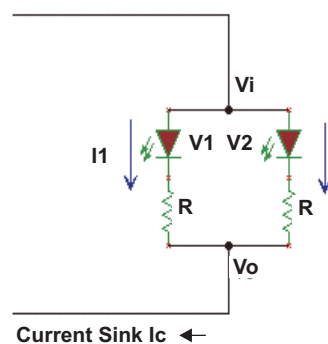


Figure 7. Similar LEDs Connected to Common Current Sink

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 ΔI 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:

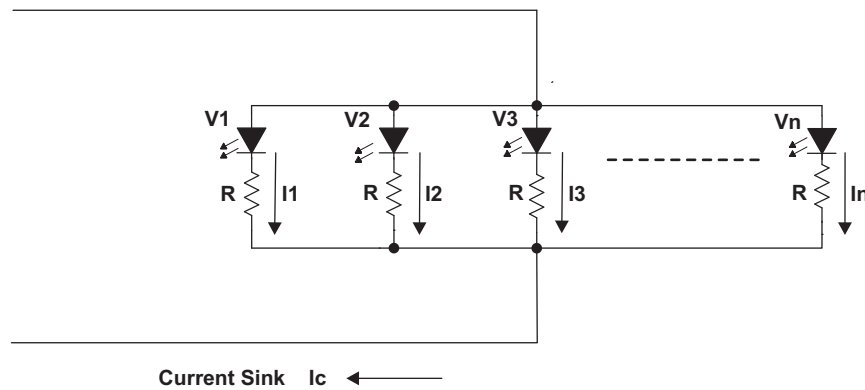


Figure 8. 'n' LEDs Connected in Parallel

From Figure 8, it can be seen that, for 'n' LEDs:

$$I_c = I_1 + I_2 + I_3 + \dots + I_n$$

Also,

$$V_1 + R \times I_1 = V_2 + R \times I_2 = V_3 + R \times I_3 = \dots = V_n + R \times I_n$$

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:

$$V_x + R \times I_x = V_y + R \times I_y$$

$$\text{Hence, } R \times I_x - R \times I_y = V_y - V_x$$

$$R \times (I_x - I_y) = V_y - V_x$$

$$R = (V_y - V_x) / (I_x - I_y)$$

$$R = \Delta V / \Delta I$$

Where ΔI can be the maximum current variation required and ΔV be the corresponding voltage variation.

EXAMPLE:

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

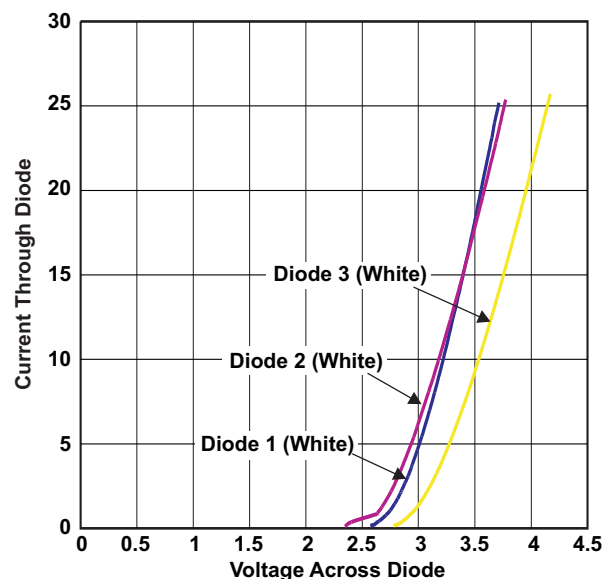


Figure 9. I-V Curves of Three White LEDs

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.

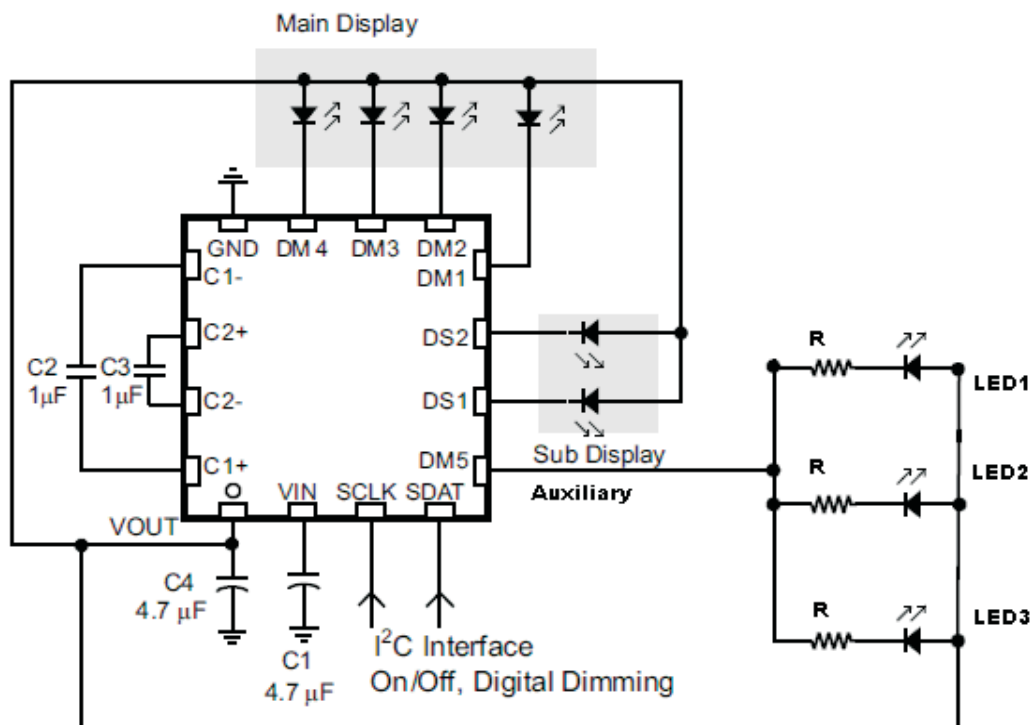


Figure 10. Three LEDs Connected to Auxiliary Pin of TPS60250

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

$$I_{LED1} = 22.58 \text{ mA}$$

$$I_{LED2} = 21.42 \text{ mA}$$

$$I_{LED3} = 12.25 \text{ mA}$$

This is about 30% variation from their mean. If the LED current matching requirement is $17 \text{ mA} \pm 2 \text{ mA}$, $\Delta I = 4 \text{ mA}$. 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 $R = 240 \text{ mV} / 4 \text{ mA} = 60 \Omega$. Resistors $R_1 = R_2 = R_3 = 61.9 \Omega$ were connected as ballast resistors.

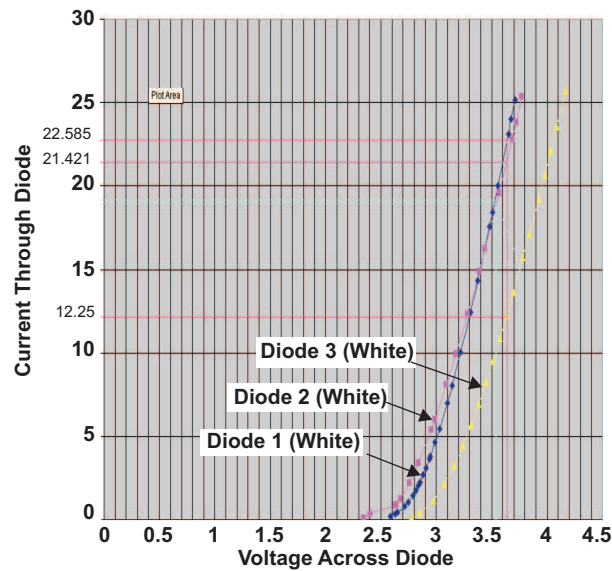
The resulting LED currents are:

$$I_{LED1} = 19.143 \text{ mA}$$

$$I_{LED2} = 18.943 \text{ mA}$$

$$I_{LED3} = 15.234 \text{ mA}$$

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.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products

Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
RF/IF and ZigBee® Solutions	www.ti.com/lprf

Applications

Audio	www.ti.com/audio
Automotive	www.ti.com/automotive
Broadband	www.ti.com/broadband
Digital Control	www.ti.com/digitalcontrol
Medical	www.ti.com/medical
Military	www.ti.com/military
Optical Networking	www.ti.com/opticalnetwork
Security	www.ti.com/security
Telephony	www.ti.com/telephony
Video & Imaging	www.ti.com/video
Wireless	www.ti.com/wireless

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2009, Texas Instruments Incorporated