

## How to Use Analog Dimming With the TPS6116x

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Battery Power Applications

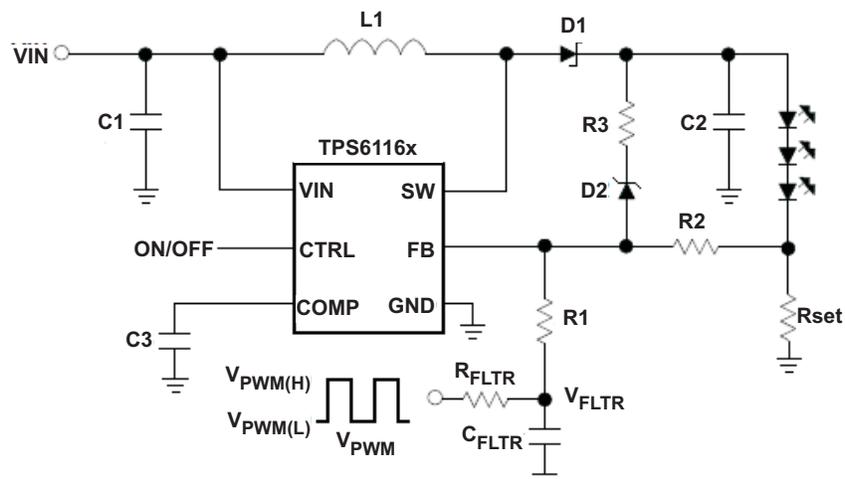
### ABSTRACT

The TPS6116x family of devices are simple, white LED drivers that can drive up to 10 LEDs in series. The CTRL pin on these devices is the input for the integrated analog dimming circuitry but can only be used for PWM signals switching higher than 5 kHz. This application report shows a simple, external circuit that can be used to perform analog dimming from PWM signals that are below 5 kHz as well as from other analog sources. The method discussed in this document can also be applied to other voltage-controlled switching regulators. An Excel™ spreadsheet design tool is discussed that can aid designers in choosing proper components.

### 1 Analog Dimming by Injecting Voltage Onto Feedback Pin

The TPS6116x family of devices allows dimming through the CTRL pin using two methods. The first is accomplished by applying a PWM signal to the CTRL pin which varies the reference voltage based on the duty cycle. This method is considered analog dimming because it applies a constant current through the LEDs rather than pulsing the full current. The main disadvantage with this method is that the frequency of the PWM signal has to be within the range of 5 kHz to 100 kHz. The second method of dimming through the CTRL pin is the one-wire digital interface which also changes the feedback voltage, but the device must be disabled between each write which may cause a perceptible flicker. The method discussed in this application is similar to the method of applying a PWM signal to the CTRL pin, but without the frequency limitation. Additionally, an analog signal from some other source, such as a DAC, can be used.

Figure 1 shows the general topology of this technique. A PWM signal is applied at  $R_{FLTR}$ , which is averaged by the simple RC filter of  $R_{FLTR}$  and  $C_{FLTR}$ . The FB voltage is a combination of the voltage injected through R2 from the voltage across  $R_{SET}$  and the voltage injected through R1 from  $V_{ANLG}$ . Because the feedback voltage is fixed, if  $V_{FLTR}$  increases, then the voltage across  $R_{SET}$  must decrease and vice versa. The current through the LEDs is set by the voltage across  $R_{SET}$ , and therefore the LED current is inversely proportional to the PWM duty cycle. The Zener diode, D2, added between the output voltage and the feedback pin, provides overvoltage protection, and R3 prevents high-frequency current spikes from coupling through the capacitance of the diode. The IC's integrated overvoltage protection circuitry, which normally protects against overvoltage conditions due to disconnection or burn-out of one of the LEDs, does not function properly due to the FB pin being artificially held high by the injected voltage. The individual components are discussed in the following sections.


**Figure 1. Schematic of Analog Dimming Through External Filter**

## 2 Choosing Component Values

The values of  $R_{FLTR}$ ,  $C_{FLTR}$ ,  $R_1$ ,  $R_2$ , and  $R_{SET}$  are determined by the system parameters and error tolerance. The main source of LED current error is leakage current from the FB pin. The error gets worse as the LED current decreases. The error due to leakage current is given by Equation 1, where the impedance seen by the FB pin has a major impact. To reduce error due to the leakage current, the impedance seen by the FB pin needs to be small. Because  $R_2$  is much smaller than  $R_1 + R_{FLTR}$ ,  $R_2$  must be chosen to be small to minimize the impedance seen by the FB pin. In general,  $R_2$  must be chosen to be 1 kΩ or less. If greater accuracy at smaller currents is needed, then  $R_2$  must be chosen to be even smaller.

$$\%error = \frac{I_{FB}}{\frac{V_{FB}}{(R_1 + R_{FLTR}) // R_2} - \frac{D \times V_{PWM(H)} + (1 - D)V_{PWM(L)}}{R_1 + R_{FLTR}}} \quad (1)$$

Once  $R_2$  has been chosen, the value of  $R_{SET}$  and  $R_1 + R_{FLTR}$  can be calculated using Equation 2 through Equation 5. The individual values of  $R_1$  and  $R_{FLTR}$  can be any combination that sums up to  $R_1 + R_{FLTR}$ . In general, choosing  $R_1$  and  $R_{FLTR}$  to be the same value gives a minimum requirement for  $C_{FLTR}$ .

$$V_{PWM(min)} = D_{(min)}V_{PWM(H)} + (1 - D_{(min)})V_{PWM(L)} \quad (2)$$

$$V_{PWM(max)} = D_{(max)}V_{PWM(H)} + (1 - D_{(max)})V_{PWM(L)} \quad (3)$$

$$R_{SET} = \frac{V_{FB} (V_{PWM(max)} - V_{PWM(min)})}{V_{PWM(max)}I_{LED(max)} - V_{FB}I_{LED(max)} + V_{FB}I_{LED(min)} - V_{PWM(min)}I_{LED(min)} \quad (4)$$

$$R_1 + R_{FLTR} = \frac{R_2 (I_{LED(max)}(V_{PWM(max)} - V_{FB}) - I_{LED(min)}(V_{PWM(min)} - V_{FB}))}{V_{FB} (I_{LED(max)} - I_{LED(min)})} + \frac{V_{PWM(max)} - V_{PWM(min)}}{I_{LED(max)} - I_{LED(min)}} \quad (5)$$

Finally,  $C_{FLTR}$  can be chosen based on the amount of filtering desired or to provide a gradual dimming effect that is popular in many lighting products. At a minimum,  $C_{FLTR}$  must be chosen to provide at least 20 dB of attenuation at the PWM frequency. Equation 6 can be used to calculate the minimum capacitor value to provide this attenuation.

$$C_{FLTR} = \frac{1}{2\pi (R_{FLTR} // R_1) \frac{f_{pwm}}{10}} \quad (6)$$

To provide gradual dimming, a large capacitor must be chosen to provide a long transient time when changing the PWM duty cycle. Equation 7 shows how to calculate the recommended corner frequency of the RC filter based on the 10% to 90% rise time. Once the corner frequency is known, it can be used to calculate the required capacitor using Equation 8.

$$f_{RC} = \frac{0.35}{t_r} \quad (7)$$

$$C_{FLTR} = \frac{1}{2\pi (R_{FLTR} // R_1) f_{RC}} \quad (8)$$

For example, a design with  $R_{FLTR}$  and  $R_1$  equal to 10 k $\Omega$  and a desired rise time of 500 ms requires a corner frequency of 0.7 Hz and a capacitor of 47  $\mu$ F.

### 3 Using the Analog Dimming Design Tool

To simplify the design, a tool was developed in an Excel spreadsheet ([SLVC366](#)) to aid designers in choosing components based on system parameters. Figure 2 shows a screen shot of the tool. In the first section, the user inserts the appropriate system parameters. Parameters  $I_{LED(min)}$  and  $I_{LED(max)}$  are the desired currents when fully dimmed and fully on, respectively. The feedback voltage,  $V_{FB}$ , depends on the device used, which is 200 mV for the TPS6116x family. Parameters  $V_{PWM(H)}$ ,  $V_{PWM(L)}$ ,  $D_{PWM(max)}$ ,  $D_{PWM(min)}$ , and  $F_{PWM}$  are based on the specifications of the PWM driver. Choose  $R_2$  as described in the previous section.

At this point, the second table is filled in with the calculated values of  $R_{SET}$ ,  $R_1$ ,  $R_{FLTR}$ , and  $C_{FLTR}$ . The  $C_{FLTR}$  value is the minimum recommended value to guarantee at least 20 dB of attenuation at  $f_{pwm}$ . The other resistor values are calculated using the equations described in the previous section.

Once the final component values have been selected, the third table can be used to find the LED current at different duty cycles. If further evaluation is desired, switch to the *Evaluation* sheet. This sheet allows graphing of the values versus duty cycle. Measured results can also be entered into the spreadsheet to see how the actual currents compare to the calculated currents.

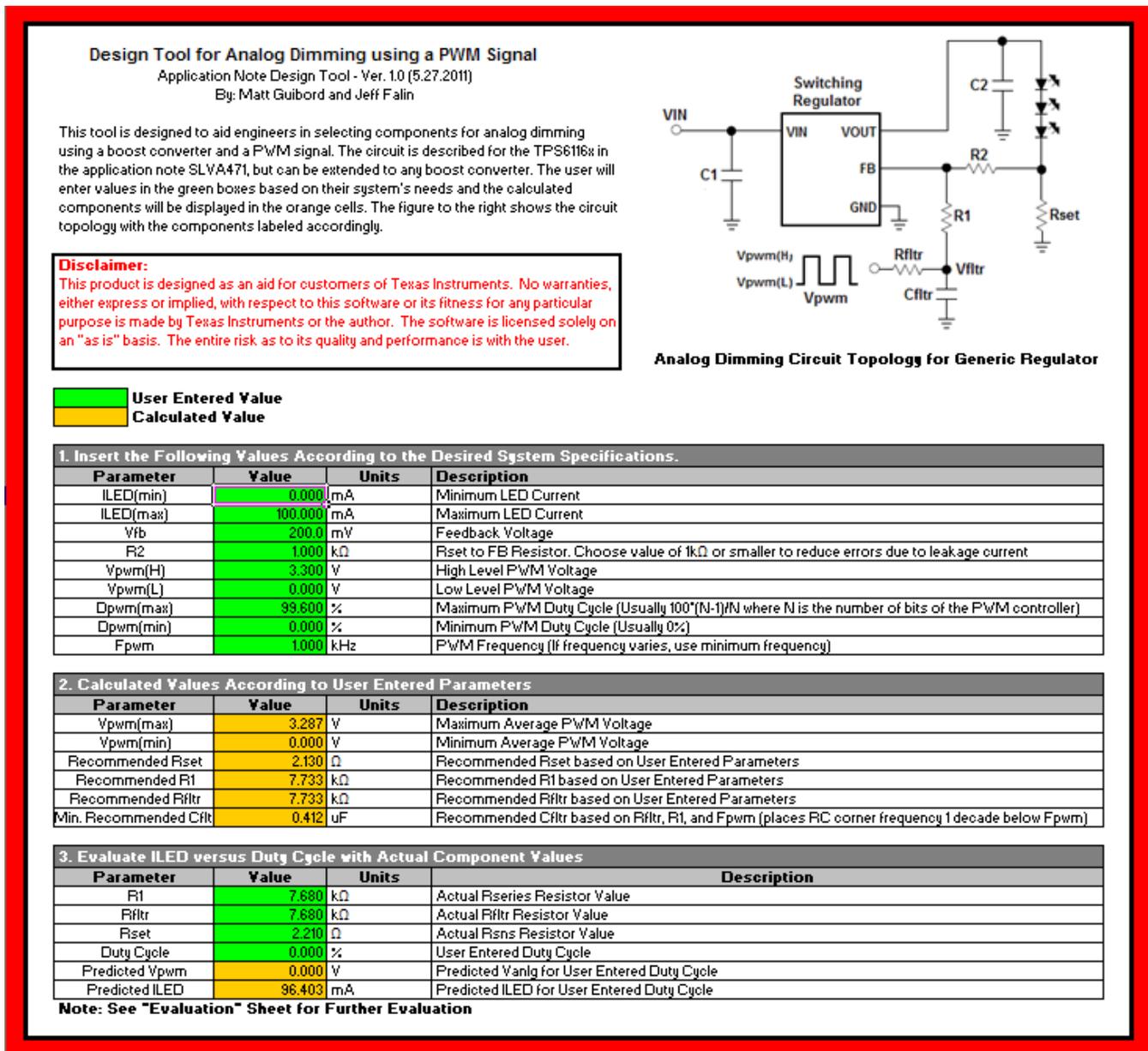


Figure 2. Design Tool for Analog Dimming Using a PWM Signal Screen Shot

#### 4 Using a Zener Diode to Protect Against Open LED Condition

One disadvantage of the described method is that the IC's open LED protection is ineffective at high PWM duty cycles because it does not allow the feedback voltage to drop to half the internal reference. To restore protection from an open LED condition, a Zener diode and series resistor must be placed from the output to the FB pin as shown in Figure 1 as D2 and R3. The Zener voltage must be greater than the summation of the forward-voltage drops of all the LEDs such that it does not conduct during normal operation. In addition, the reverse current of the Zener diode at the normal operating output voltage must be sufficiently small to prevent errors in the LED current. As an example, if four LEDs are used that each have a forward-voltage drop of 3 V, then a 16-V Zener diode must be chosen. The summation of the

forward voltage drops equals 12 V. The MMSZ4703 16-V Zener diode has a reverse leakage current of 0.05  $\mu\text{A}$  at 12 V, which is sufficiently small to reduce LED current errors. In general, the Zener diode reverse leakage current at the normal operating voltage must be much smaller than the leakage current of the FB pin of the device in order to have a negligible effect on the LED current. R3 must be chosen to be approximately 100  $\Omega$  to prevent high-frequency current spikes from reaching the FB pin at start-up.

## 5 Using Analog Voltage to Control LED Brightness

The preceding method can be modified slightly to use a DAC, or another source, in place of the PWM signal to control the brightness of the LEDs. Because filtering of the signal is no longer needed,  $R_{\text{FLTR}}$  and  $C_{\text{FLTR}}$  can be removed from the circuit. The Analog Dimming Design Tool can still be used to choose the proper components. Choose R2 as mentioned previously, and enter it into the tool. Choose the value of R1 as the summation of the R1 and  $R_{\text{FLTR}}$  as provided by the tool.

## 6 Conclusion

This application report describes an alternative method of LED dimming for the TPS6116x family of devices. This design method allows designers to achieve desired performance based on their system's needs. Additionally, the *Design Tool for Analog Dimming Using a PWM Signal* can aid designers in choosing the proper components and allowing for evaluation of the circuit. Lastly, this application report discusses the addition of a Zener diode to protect against an open LED condition as well as modifications to the circuit to control the LED brightness with a DAC or other voltage source.

## 7 References

1. *TPS61165, High Brightness White LED Driver in 2mm x 2mm QFN and SOT-23 Packages* data sheet ([SLVS790](#))
2. *Design Tool for Analog Dimming Using a PWM Signal* ([SLVC366](#))

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