

How to Use Analog Dimming With the TPS6116x

Matt Guibord

Battery Power Applications

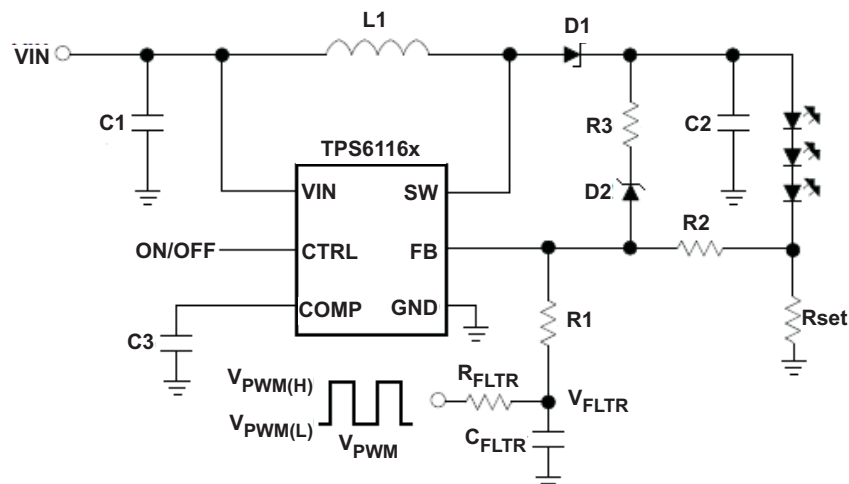
ABSTRACT

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 Ω and a desired rise time of 500 ms requires a corner frequency of 0.7 Hz and a capacitor of 47 μ 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.

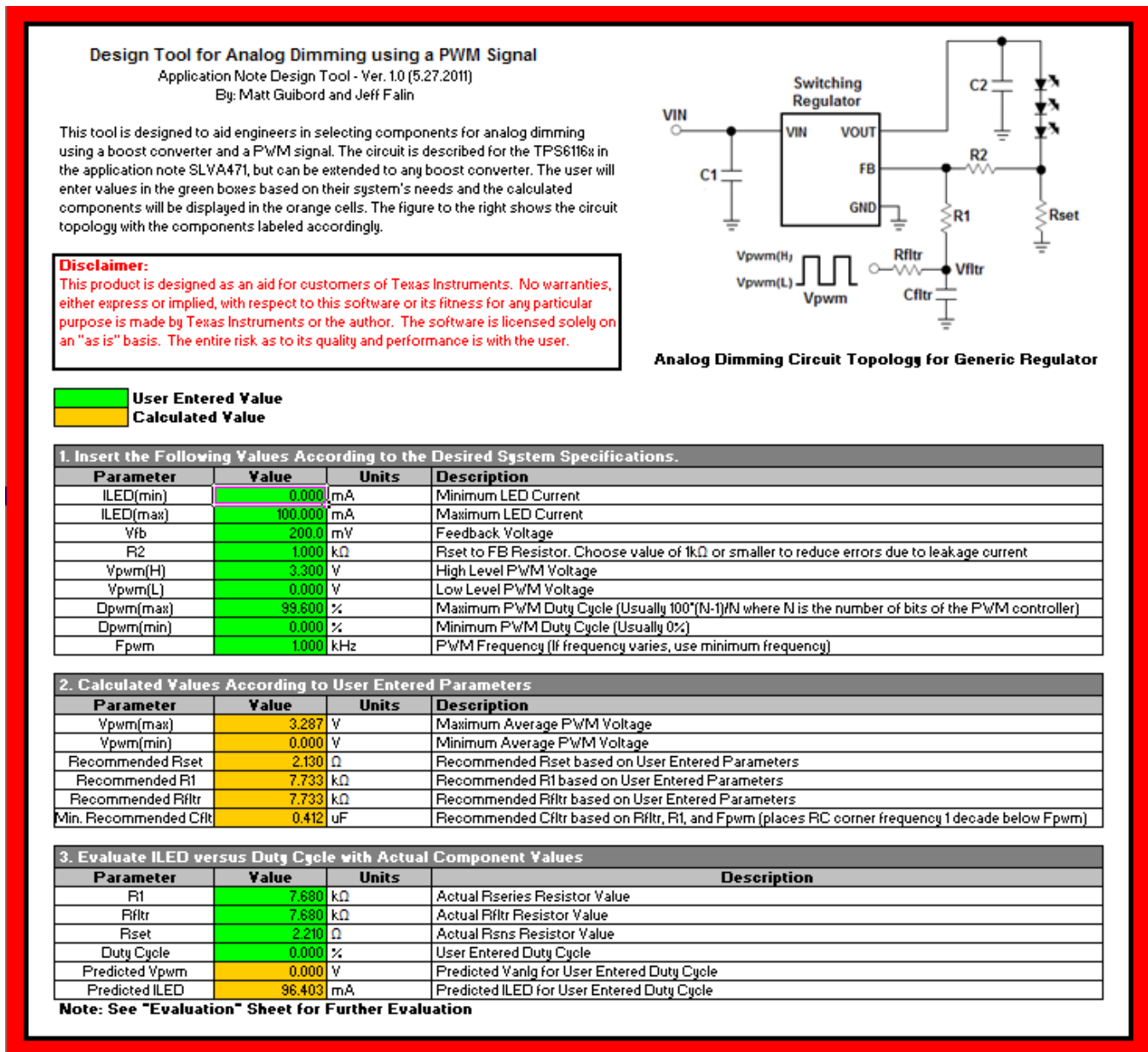


Figure 2. Design Tool for Analog Dimming Using a PWM Signal Screen Shot

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 μA 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 Ω 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_{FLTR} and C_{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_{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](#))

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

Audio	www.ti.com/audio
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

Communications and Telecom	www.ti.com/communications
Computers and Peripherals	www.ti.com/computers
Consumer Electronics	www.ti.com/consumer-apps
Energy and Lighting	www.ti.com/energy
Industrial	www.ti.com/industrial
Medical	www.ti.com/medical
Security	www.ti.com/security
Space, Avionics and Defense	www.ti.com/space-avionics-defense
Transportation and Automotive	www.ti.com/automotive
Video and Imaging	www.ti.com/video
Wireless	www.ti.com/wireless-apps

TI E2E Community Home Page

e2e.ti.com

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2011, Texas Instruments Incorporated