Application Report

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Analog Dimming with the TPS61181

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ABSTRACT

The TPS61181 LED driver supports PWM dimming; however, it also has the ability to support analog dimming with some simple modifications. Analog dimming causes less EMI noise and achieves better efficiency than PWM dimming. Analog dimming can be achieved by using an analog voltage to control the current sourced by the ISET pin. This application note explores this alternative dimming method for the TPS61181.

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1 Introduction

The TPS61181 is an ideal LED driver for medium sized LCD panel backlighting. For the cost advantage and ease of use, this chip is well suited for use in small-sized handheld equipment. Popular applications include the displays for MP3 players, GPS, etc. This device supports six current sinks of 25mA each and, although designed to operate with PWM dimming, can be modified to operate with analog dimming.

The benefits of analog dimming over PWM dimming include lower EMI and slightly higher efficiency. When PWM dimming, EMI noise is generated from pulsing the maximum current through the LEDs at the applied duty cycle. When analog dimming, a DC current directly proportional to brightness and LED forward voltage flows through the LEDs. At lower DC currents, the LED forward voltages drop, resulting in slightly lower output power for the same brightness level. The only drawback to analog dimming is a slight shift in hue at very low dimming levels. Either an external analog voltage (V_x) or a PWM signal can drive the analog dimming. In order to use this type of dimming a few extra circuit components are required, regardless of which type of signal will drive the circuit.

2 Theory

Analog dimming is achieved by controlling the current sourced from the ISET pin. This current is directly proportional to the current limit of each current sink input used to drive the LEDs. The DCTRL pin, where the PWM signal is normally applied, should be tied to a logic high signal, effectively a 100% duty cycle PWM signal. With this set-up, the current through the IFB pins will now be controlled by the current limit.

A simple way of controlling the current sourced by the ISET pin is to use an analog voltage as the input to the circuit shown in Figure 1. The voltage at the ISET pin is constant, so changing V_x will control the current through R_{s2}. The current through R_{s1} is constant, so V_x determines how much current the ISET pin needs to source.

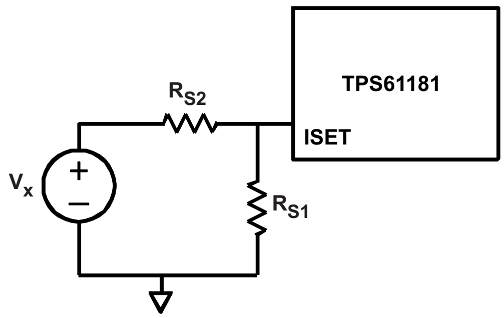

Figure 1. TPS61181 Analog Dimming Configuration

By adjusting V_x, the current being sourced by ISET will change. By modifying equation 1 of the TPS61181 datasheet, the current through the LEDs will be determined by Equation 1.

$$I_{LED} = K_{ISET} \times \left(\frac{V_{ISET}}{R_{s1}} - \frac{V_x - V_{ISET}}{R_{s2}} \right) \quad (1)$$

Where:

K_{ISET} = Current multiple (1000 typical);
V_{ISET} = ISET pin voltage (1.229 V typical);
V_x = External voltage

For a given input voltage range, the optimum resistor values can be found if the maximum and minimum LED currents are known. The equations for R_{s1} and R_{s2} are shown in Equation 2 and Equation 3.

$$R_{s2} = K_{ISET} \times \frac{V_{x(max)} - V_{x(min)}}{I_{LED(max)} - I_{LED(min)}} \quad (2)$$

$$R_{s1} = \frac{K_{ISET} \times R_{s2} \times V_{ISET}}{I_{LED(min)} \times R_{s2} + K_{ISET} \times \left(V_{x(max)} - V_{ISET}\right)} \quad (3)$$

There are multiple methods of generating the analog signal. One method is to filter a PWM signal to create a smooth analog signal. Even though a PWM signal is used, the current through the LEDs will be at a constant level set by the ISET pin. Figure 2 shows an example of a circuit that uses a PWM signal to generate an analog voltage.

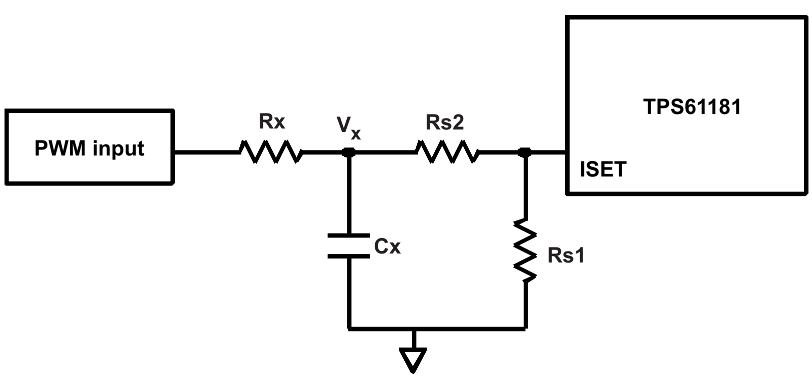

Figure 2. RC Filter to get the Average Value of PWM Signal

In this case, the duty cycle of the PWM input controls the current through the LEDs. The RC filter made up of R_x and C_x filters the PWM input so that the voltage at V_x will be the average value of the PWM signal. Increasing the duty cycle of the PWM input increases the voltage at V_x. Assuming that the PWM signal is switching from 0V to V_{PWM}, the average value of the PWM signal can be represented as:

$$V_{avg} = V_{PWM} \times D \tag{4}$$

Where:

D = Duty cycle of the PWM signal

Equation 1 can be modified to account for this new circuit configuration. From there, if the minimum and maximum duty cycle of the PWM signal and the minimum and maximum desired LED currents are known, then R_{s1} and R_{s2} can be calculated. Equation 5 and Equation 6 show the design equations for R_{s2} and R_{s1} respectively.

$$R_{s2} = K_{ISET} \times \frac{D_{max} \times V_{PWM} - D_{min} \times V_{PWM}}{I_{LED(max)} - I_{LED(min)}} \tag{5}$$

$$R_{s1} = \frac{K_{ISET} \times R_{s2} \times V_{ISET}}{I_{LED(min)} \times R_{s2} + K_{ISET} \times (D_{max} \times V_{PWM} - V_{ISET})} \tag{6}$$

The RC filter requires at least 20dB of attenuation at the frequency of the PWM signal. More attenuation can be added to create a smoother signal, or to cause a gradual dimming effect. The minimum capacitor value is given by Equation 7. To minimize the capacitor size, choose R_x to be equal to R_{s2}.

$$C_{X(min)} = \frac{1}{2 \times \pi \times (R_X \parallel R_{S2}) \times \frac{f_{pwm}}{10}} \tag{7}$$

Where:

f_{PWM} = frequency of PWM signal

It is recommended that the minimum and maximum duty cycles be chosen as 0% and 100% respectively. Exceeding the maximum duty cycle causes the maximum voltage at V_x to be exceeded, possibly causing current to be sinked through the ISET pin instead of sourced. This causes an unstable state and could damage the LEDs. Going below the minimum duty cycle increases the LED current above the chosen $I_{LED(max)}$. This could damage the LEDs if their maximum current rating is exceeded. Since a DC signal is essentially a 100% duty cycle and a grounded signal is a 0% duty cycle, choosing the proposed duty cycle limits prevents accidental damage to the LEDs during start-up or any other time when the PWM signal may be inactive.

In actual practice, the current matching between all six LED strings gets worse as the current decreases. As long as I_{min} is chosen to be 5mA or greater, the current matching will be very good. If it is necessary to dim below this level, then a combination of analog and PWM dimming should be used. Consider, if the analog dimming method lowers the LED current to 5mA, then a PWM signal on the DCTRL pin will cause the LED current to jump between 0mA and 5mA. PWM dimming with a lower peak output current helps reduce EMI, and provides better current matching between the strings.

3 Design Example

Consider a system that wishes to use an input dimming control voltage that ranges from 0 to 2V, and wishes the LED driving current to range from 5 to 20mA. From this situation, the following variables can be filled out:

$V_{x(max)}$ = 2 V
$V_{x(min)}$ = 0 V
$I_{LED(max)}$ = 20 mA
$I_{LED(min)}$ = 5 mA

Using Equation 2 and Equation 3 to determine R_{s2} and R_{s1} respectively yield:

R_{s2} = 133 kΩ
R_{s1} = 113 kΩ

The theoretical relationship between the voltage at V_x and the LED current is linear. Figure 3 shows this theoretical curve.

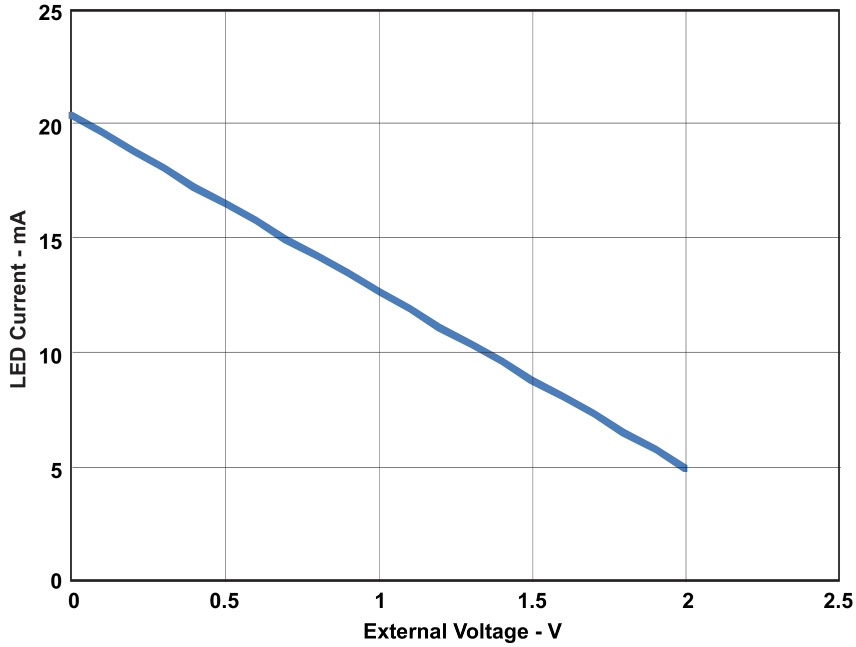

Figure 3. Theoretical Led Current and External Voltage

All six strings of LEDs should match this curve; however, at lower LED current levels, the current matching can be unreliable. As long as I_{min} is chosen to be 5mA or greater, then K_m should stay below 2.5%, as specified in the data sheet. K_m is a measure of the current variation between the six LED current sinks. Equation 8 shows how to calculate K_m.

$$K_m = \frac{I_{max} - I_{min}}{I_{AVG}} \; x \; 100\% \tag{8}$$

The data shown in Figure 4 was collected from the system shown in Figure 1, with 130kΩ resistors for R_{s1} and R_{s2}. The graph shows the currents of each LED output versus the external voltage applied. Notice that there is a linear relationship up until the LED currents drop below about 5 mA. Below about 5 mA, the current limit matching between the six current sinks suffers.

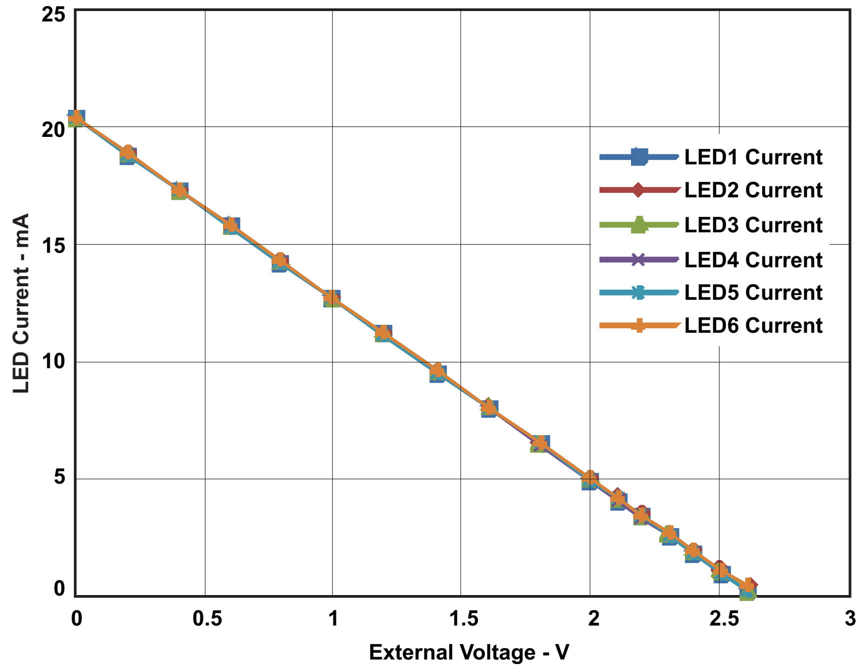

Figure 4. Actual LED Current vs External Voltage

Figure 5 shows how the error increases as the current through the LEDs gets smaller.

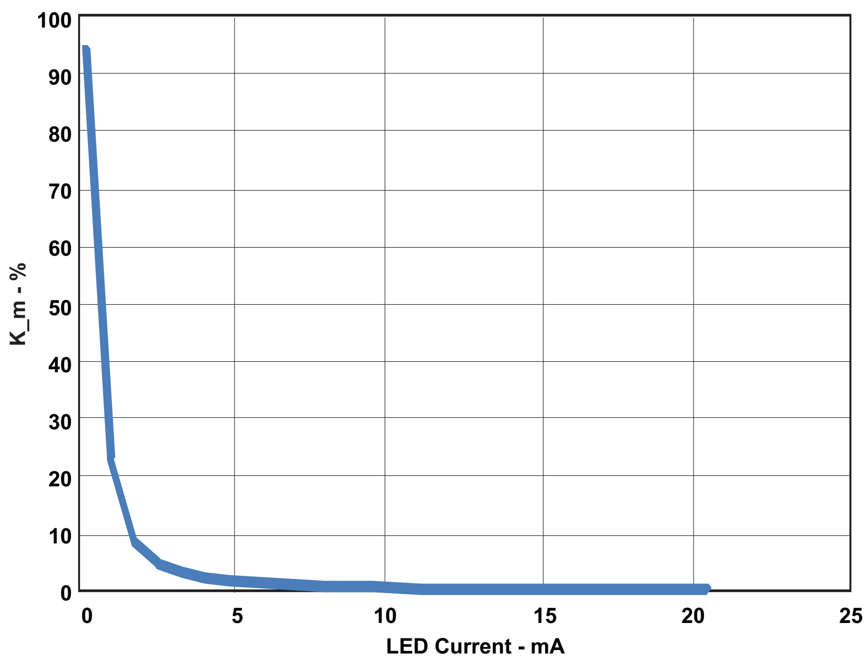

Figure 5. K_m vs LED Current

If it is necessary to operate at these low current levels it is advisable to use the traditional built-in PWM dimming scheme, either in conjunction with analog dimming or by itself. If PWM dimming causes the LED current to switch between 0 and 5 mA, instead of between 0 and $I_{LED(max)}$ (20 mA in this example), the EMI noise disruption would be significantly less than if the PWM dimming scheme was used for the entire current range.

4 Conclusion

The TPS61181 is a versatile LED driver, offering two different approaches to control the dimming level of the LEDs. PWM dimming and analog dimming are both inherently built into the part. PWM dimming is effective at very low power ranges, but causes much more EMI noise than analog dimming. It also can be less efficient than analog dimming in certain current ranges. Analog dimming is a viable alternative where the current through the LEDs is controlled by adjusting an analog voltage. For the TPS61181, this analog voltage controls the current limit for each LED string. Analog dimming can also be implemented by using a PWM signal to generate the analog signal. This causes much less noise than if PWM dimming was used to directly drive the LEDs because the PWM signal used in analog dimming needs about three orders of magnitude less power than the PWM signal in PWM dimming. Using PWM dimming and analog dimming together reduces the EMI noise while still maintaining precise control over the LED currents during low power operation. Depending on the application and the range of dimming needed, PWM dimming or analog dimming can fulfill the dimming needs of the TPS61181.

5 References

1. TPS61181, *WLED Driver for Notebook Display* (SLVS801C)
2. Guibord, Matt; *How to Use Analog Dimming With the TPS6116x* (SLVA471)