Application Report
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Driving High-Current LEDs

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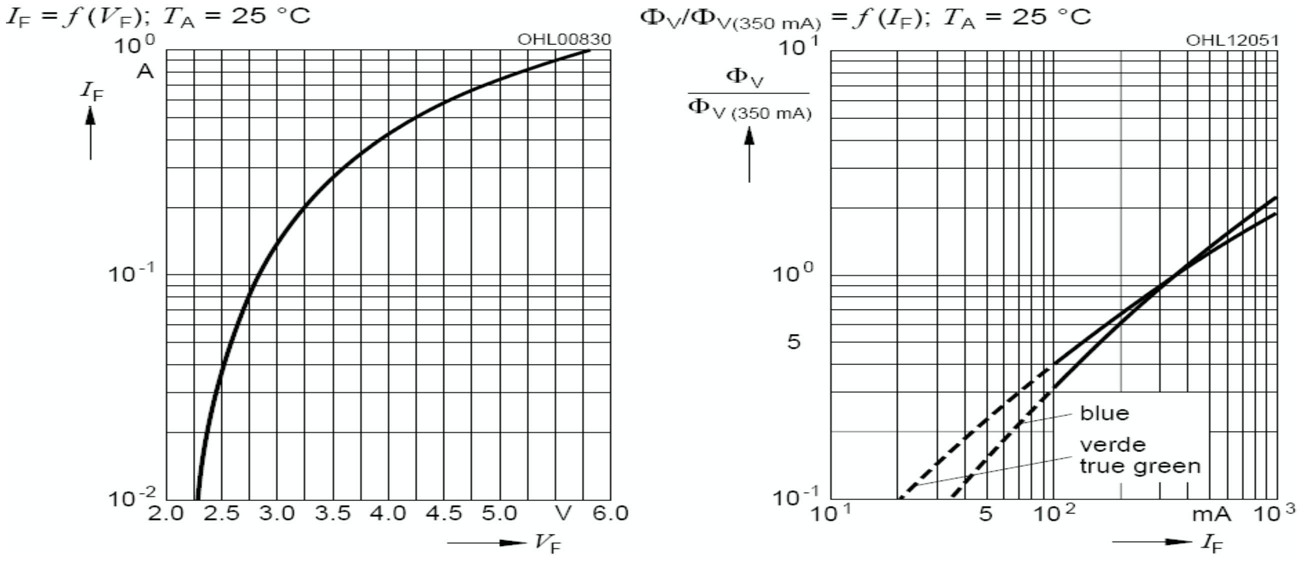
ABSTRACT

This application report presents high-current LED driving requirements and implementations that use the TI integrated boost converter IC TPS6106x and integrated buck converter IC bqSWITCHER™ (bq2410x/11x/12x). Step-by-step design procedures, measurement results, and two dimming methods are provided and discussed.

Today, many applications such as cellular phones, PDAs, pocket PCs, and LCD TVs require LED-driver solutions. To achieve high brightness, today's LEDs handle much higher current and have a higher voltage drop compared to traditional small-current LEDs. Figure 1(a) shows a typical V-I curve and Figure 1(b) shows a relative luminous flux of 350-mA, 3.8-V true green LED LT W5SG from OSRAM [1].

LEDs are current–driven devices whose brightness is proportional to their forward current. A constant-current source is preferred because it eliminates changes in current due to variations in forward voltage and temperature [2].



(a) Forward Current vs Voltage **(b) Relative Luminous Flux vs Current**

Figure 1. Typical Characteristics of LEDs.

For portable applications, battery life is critical. A high-efficiency converter not only alleviates thermal stress and simplifies thermal design, but it also significantly extends battery life. Many portable LED applications also require a dimming function to provide brightness and contrast adjustment.

In addition to direct control of current, high efficiency, and dimming function, other requirements for power LED drivers include short-circuit protection, overvoltage protection, small size, and ease of use [2].

bqSWITCHER is a trademark of Texas Instruments.

In many applications, one LED is not enough to get the desired luminous flux. Several LEDs have to be used together in series and/or in parallel. The LED driver's input voltage may be lower or higher than the output voltage. Depending on the input and output voltage range, a boost or buck converter can be selected to get the step-up or step-down voltage.

Texas Instruments provides many choices for LED driver applications. The TPS61060/61/62 is a high-frequency, synchronous boost converter with constant-current output to drive up to five white LEDs. For maximum safety, the device features integrated overvoltage and an advanced short-circuit protection when the output is shorted to ground. The device operates with 1-MHz, fixed switching frequency to allow for the use of small external components and to simplify possible EMI problems. A typical application circuit diagram is shown in Figure 2 [3].

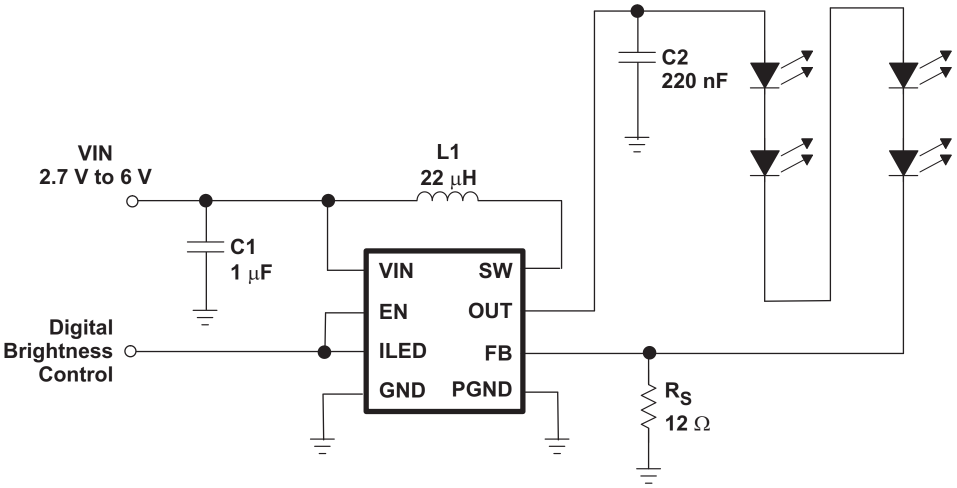


Figure 2. Typical Application Circuit Diagram of TPS6106x

If the input voltage is always higher than the output voltage, a synchronous buck converter is attractive for LED driver applications due to its high efficiency. The Texas Instruments bqSWITCHER™ series (bq2410X/11X/12X) are highly integrated synchronous buck converters targeted at Li-ion and Li-polymer charger applications. However, they also can be used for driving LED applications. The bqSWITCHER™ series have CC (constant current) and CV (constant voltage), two regulation phases of the typical charging profile. As long as the LED voltage drop is lower than the user-programmable, maximum output voltage, the bqSWITCHER™ converter stays in CC mode, which is the desired work mode for LEDs.

The bqSWITCHER™ series can achieve 10% current regulation accuracy for 100-mV to 200-mV sensing resistor voltage. It can provide constant current up to 2 A and can achieve up to 95% efficiency with a fixed frequency of 1.1 MHz. In addition, it provides a built-in overvoltage protection to protect the device and other components against damages if the output voltage becomes too high. When the output voltage becomes too low, a programmable precharge current is applied to the output. Further decrease of output voltage makes it enter into short-circuit mode which limits the output current to 50 mA. The temperature sense pin gives thermal protection for power LEDs against thermal damage in high ambient temperature cases. The device itself has a thermal shutdown function at 165°C to prevent thermal damage. All these features make it attractive for high-current power LED applications.

Among the bqSWITCHER™ series, the output voltage range of bq24105 is externally programmable which gives flexibility for LED applications. Figure 3 shows the circuit schematic of the bq24105EVM [4].

One EVM was modified to demonstrate the bq24105 capability for high-current LED applications. The design target is a 2s4p (two LEDs in series and four in parallel) configuration of eight LT W5SG LEDs from OSRAM as shown in Figure 3. It supplies 1.4-A output current and 6-V to 8.2-V output voltage. The input voltage range can be from 9 V to 16 V. Four resistor values, including the sensing-resistor R4, voltage-feedback resistor R5, current-setting resistors R8 and R9, should be changed for this application design. The following gives the details of how to select these resistor values [5].

1. Sensing resistor R4

   To achieve good current regulation, the sensing resistor should have 100- to 200-mV voltage for full-load current. Therefore, the R4 should between

$$\frac{0.1\ \text{V}}{1.4\ \text{A}} = 0.0714\ \Omega \text{ and } \frac{0.2\ \text{V}}{1.4\ \text{A}} = 0.143\ \Omega \tag{1}$$

Select R4 = 0.1 Ω.

2. Feedback resistor R5

   The feedback resistor divider R5 and R7 set the maximum output voltage. The internal reference is 2.1 V. The LED maximum voltage is set to 4.1 V. As a result, the total output voltage for the two LEDs in series is 8.2 V.

   $$\text{R5} = \frac{200\ \text{k}\Omega \times (8.2\ \text{V} - 2.1\ \text{V})}{2.1\ \text{V}} = 581\ \text{k}\Omega \tag{2}$$

   Select R5 = 590 kΩ. For LED-driving applications, the designer must ensure that the bqSWITCHER™ series converter remains in constant-current mode by setting the output voltage to be always higher than the maximum LED voltage drop.

3. Charge current setting resistor R8

   For charge current setting resistor R8, Equation 3 is used to set the full-load current to 1.4 A according to the data sheet.

$$\text{R8} = \frac{K_{\text{ISET1}} \times V_{\text{ISET1}}}{R_{\text{SNS}} \times I_{\text{OCHARGE}}} = \frac{1000\frac{\text{V}}{\text{A}} \times 1\ \text{V}}{0.1\ \Omega \times 1.4\ \text{A}} = 7.14\ \text{k}\Omega \tag{3}$$

   Select R8 = 7.32 kΩ.

4. Precharge current setting resistor R9

   The precharge current for an LED application must be set sufficiently high; otherwise, the small precharge current results in a low forward voltage drop of LEDs, and the bqSWITCHER™ device may stay in this condition permanently. This is different from the battery charge case where the battery voltage can be charged over the precharge to fast-charge transition voltage threshold V_{LOWV}. Here the precharge current is selected to be 0.64 A (0.16 A each branch) to ensure that the voltage drop at this current is higher than the voltage threshold V_{LOWV}. For charge current setting resistor R9, the following equation is used to set the precharge load current to 0.64 A according to the data sheet.

   $$\text{R9} = \frac{K_{\text{ISET2}} \times V_{\text{ISET2}}}{R_{\text{SNS}} \times I_{\text{OPRECHRG}}} = \frac{1000\frac{\text{V}}{\text{A}} \times 0.1\ \text{V}}{0.1\ \Omega \times 0.64\ \text{A}} = 1.56\ \text{k}\Omega \tag{4}$$

   Select R9 = 1.54 kΩ.

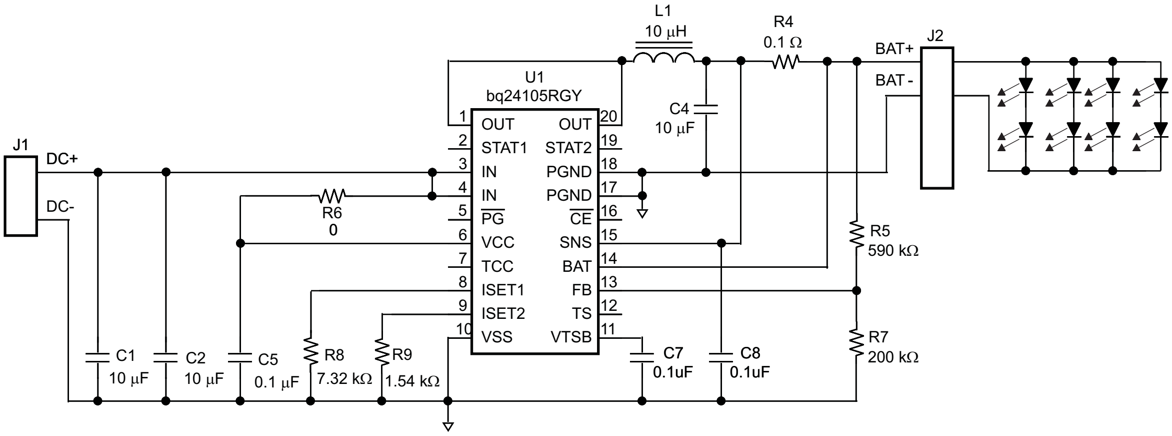


Figure 3. Circuit Schematic of bq24105 EVM

The steady-state switching waveform of a 9-V input is shown in Figure 4.

If a dimming function is required, it is easy for a bqSWITCHER$^{\text{TM}}$ device to implement this by adding one more resistor Rdim and a small switch Qdim, which is shown in Figure 5. When Qdim is off, the R8 determines that the regulated current goes through the LEDs. When Qdim is on, the parallel resistor value of Rdim and R8 determines that the regulated current goes through the LEDs. By changing the duty cycle of the dimming PWM signal at Qdim gate, the dimming function is achieved. The frequency of the PWM dimming signal has to be above 100 Hz to ensure that there is no flicker. The maximum PWM dimming frequency depends on the current-loop response time. Here a 200-Hz dimming PWM signal is selected.

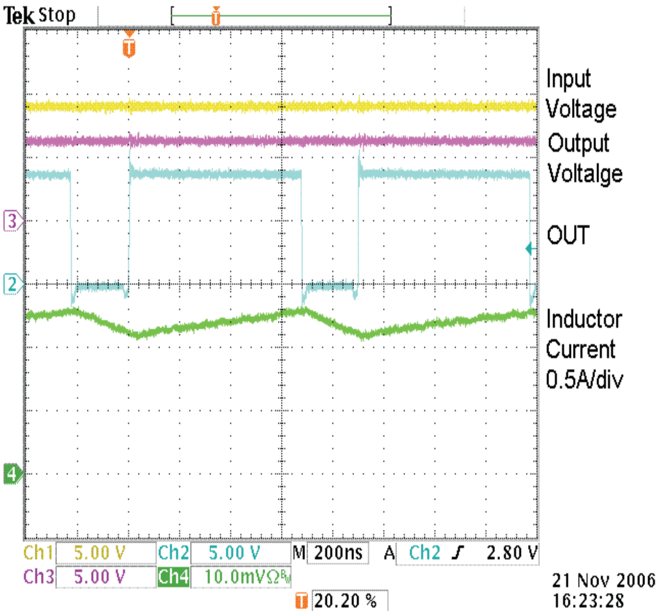


Figure 4. Steady-State Switching Waveform of bq24105 EVM for LED Applications

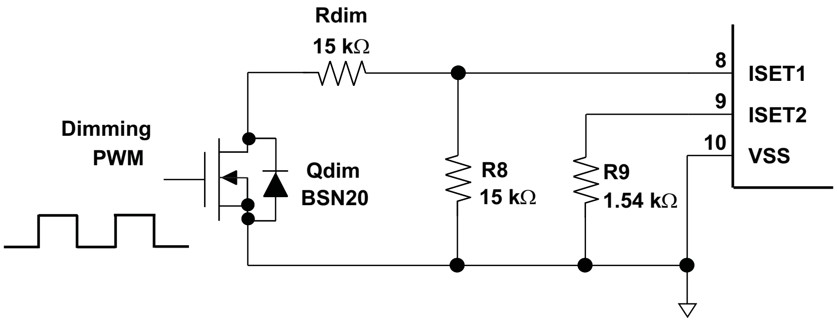
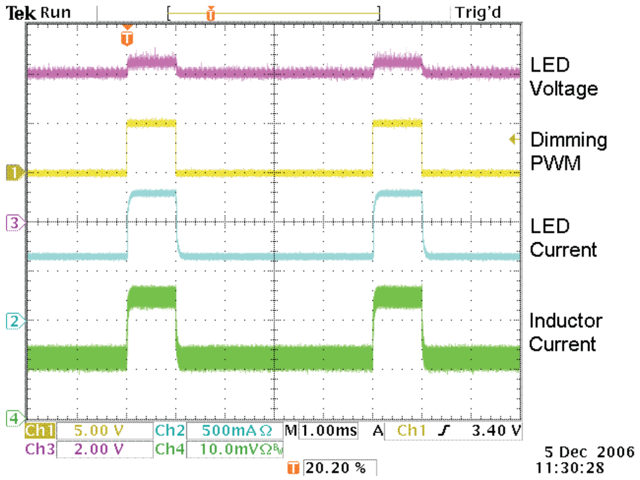


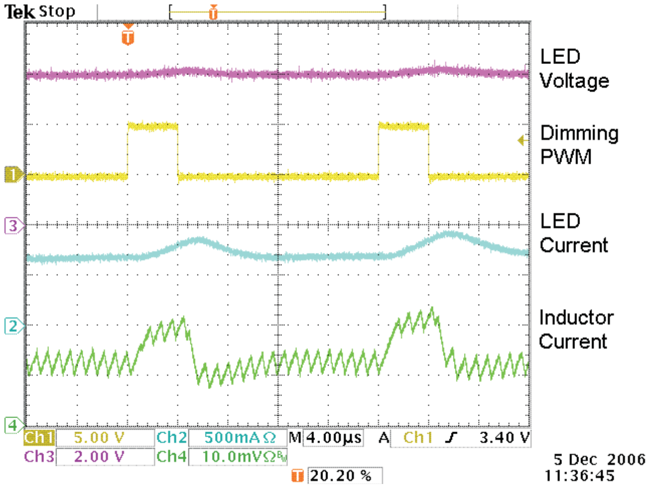
Figure 5. Modified EVM Schematic to Add Dimming Function

Twenty-percent duty-dimming and 80% duty-dimming waveforms are shown in Figure 6 (a) and (b), respectively. It is clear that the current loop is fast enough to follow the dimming PWM control signal. The dimming PWM frequency can be set up to 50 kHz to provide the most flexibility and ease of integration. At a 50-kHz dimming PWM frequency, a 20% duty-dimming and a 80% duty-dimming waveforms are shown in Figure 7 (a) and (b), respectively.



(a) 20% Duty Dimming (b) 80% Duty Dimming

Figure 6. Waveforms of Digital PWM Dimming Control



(a) 20% Duty Dimming (b) 80% Duty Dimming

Figure 7. Waveforms of Digital PWM Dimming Control at 50kHz Frequency

The pulse current that goes through the LEDs is proportional to the dimming duty cycle. The linearity is good for a wide, dimming duty cycle range at low frequency. At high frequency such as 50 kHz, due to the output capacitor filter function, the current is no longer a pulse shape. In this case, a smooth LED current is preferred; the Figure 5 schematic can be changed by just adding one more resistor and capacitor as shown in Figure 8 [6]. The Rdim resistor is replaced by two resistors Rdim1 and Rdim2. The midpoint of two resistors, Rdim1 and Rdim2, is connected to ground by a capacitor Cdim. The midpoint voltage Vx can hold a relatively smooth voltage due to the RC filter function. As a result, the current that goes through the LEDs is smooth.

At steady state, the charge and discharge currents that go through Cdim must be balanced; so, the following equation for voltage level Vx for the midpoint is

$$\text{Vx} = \frac{\text{Rdim2}}{\text{Rdim1} \times \text{D} + \text{Rdim2}} \tag{5}$$

where D is the dimming duty cycle, and the current goes through Rdim1 Ix is

$$\text{Ix} = \frac{\text{D}}{\text{Rdim1} \times \text{D} + \text{Rdim2}} \tag{6}$$

The nonlinear current Ix plus the constant current go through R8, and this is the total current on the ISET1 pin; because this is what determines the inductor current, it is clear that current control linearity is lost. However, if Rdim2 is larger or equal to Rdim1, then the nonlinearity is small. An easy solution is to let Rdim1 equal Rdim2; as a result, Rdim1 and Rdim2 are selected to be 7.5 kΩ.

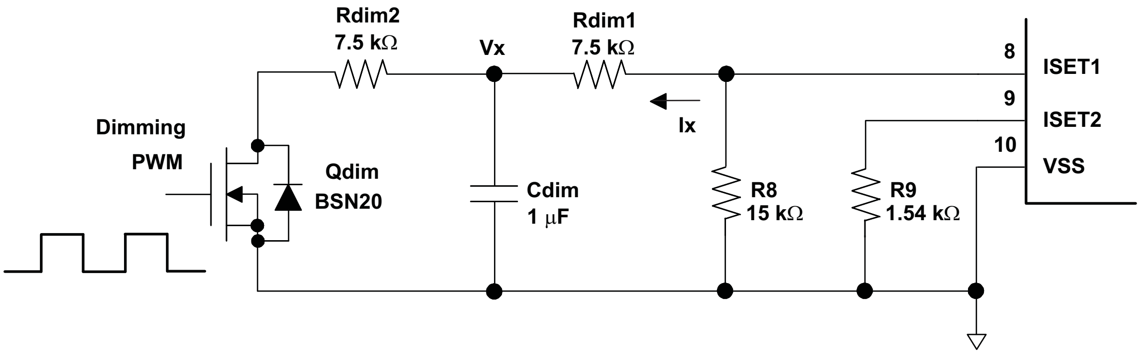


Figure 8. Smooth Dimming Current Schematic

A dimming frequency voltage ripple at midpoint causes a dimming frequency current ripple of the inductor. The Cdim capacitor value should be select based on the current ripple requirement. The voltage ripple at midpoint is

$$\mathrm{Vpk} = \frac{\mathrm{Ipk} \times R_{\mathrm{SNS}}}{K_{\mathrm{SET1}}} \times \mathrm{Rdim1}, \tag{7}$$

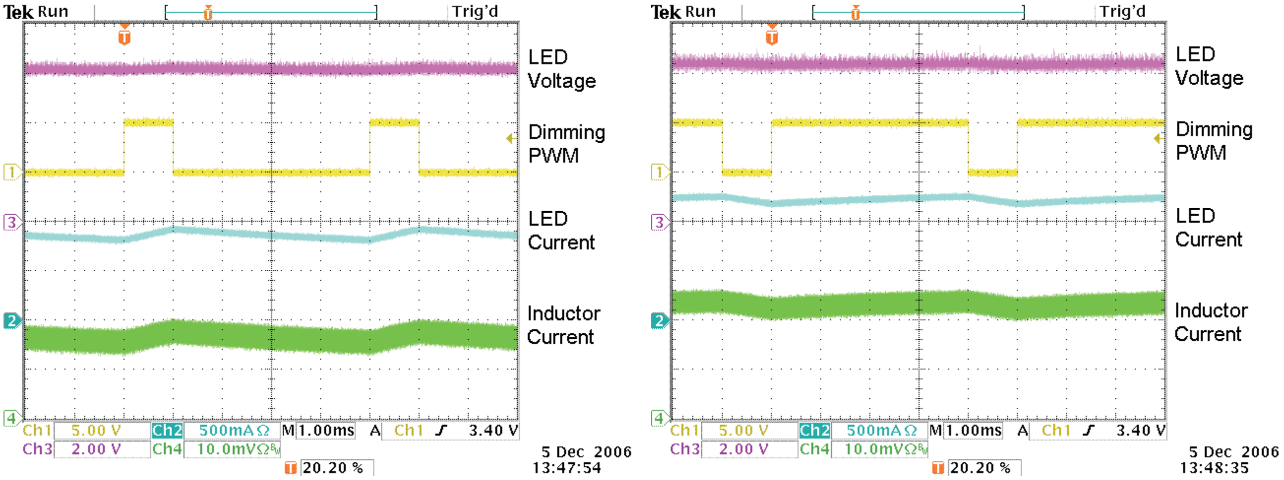
where the Ipk is the allowed peak-to-peak dimming frequency current ripple. Here, 0.14 A is selected for Ipk and Vpk is 0.105 V.

The Cdim equation is

$$\mathrm{C\,dim} = \frac{(1 - \mathrm{D}) \times \mathrm{D}}{(\mathrm{Rdim1} \times \mathrm{D} + \mathrm{Rdim2}) \times \mathrm{Fdim} \times \mathrm{Vpk}}, \tag{8}$$

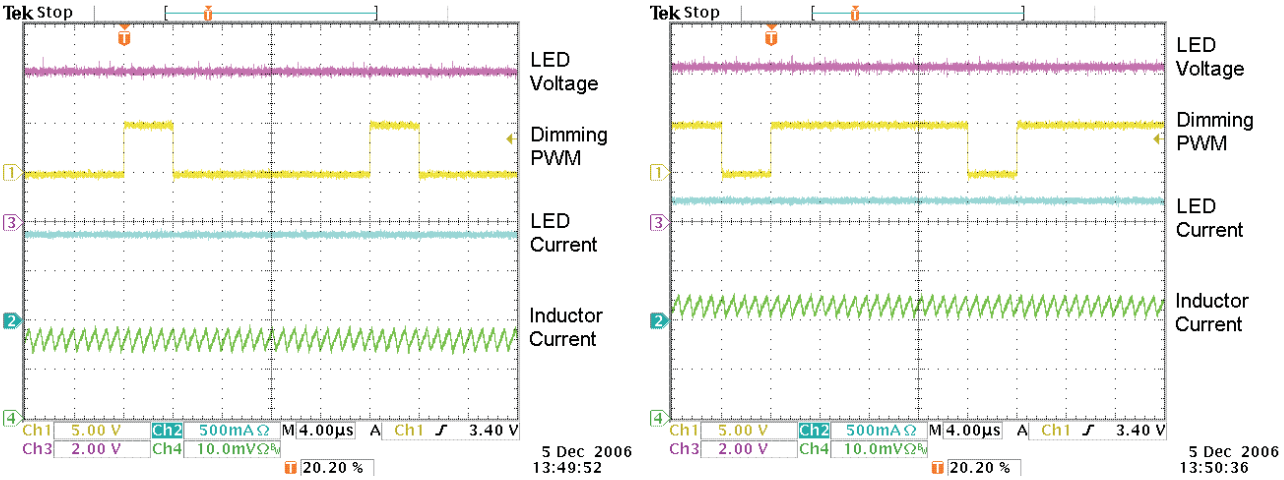
where Fdim is the lowest dimming frequency. Here, Fdim is selected as 200 Hz. As a result, the worst case Cdim is 1.1 µF when D is 0.41. So, select Cdim = 1 µF.

Twenty-percent duty dimming and 80% duty-dimming waveforms are shown in Figure 9 (a) and (b), respectively. The measured peak-to-peak dimming current ripple is about 0.16 A which matches the calculation well. At 50 kHz, the PWM frequency 20% duty dimming and 80% duty dimming waveforms are shown in Figure 10 (a) and (b), respectively. It is clear that at a high dimming frequency, the dimming frequency current ripple is negligible.



(a) 20% Duty Dimming (b) 80% Duty Dimming

Figure 9. Waveforms of Digital PWM Smooth Current Dimming Control



(a) 20% Duty Dimming (b) 80% Duty Dimming

Figure 10. Waveforms of Digital PWM Smooth Current Dimming Control at 50-kHz Frequency

References:

1. OSRAM LT W5SG data sheet
2. *LED-Driver Considerations*, Analog Applications Journal, Texas Instruments, 1Q 2004.
3. *TPS6106x, Constant Current LED Driver with Digital and PWM Brightness Control* data sheet (SLVS538)
4. *Using the bq241xx (bqSWITCHER™) User's Guide* (SLUU200).
5. *bq2410x/11x Synchronous Switchmode Li-Ion and Li-Polymer Charge-Management IC with Integrated Power FETs (bqSWITCHER™)* data sheet (SLUS606)
6. *Duty Cycle Modulation of Fast Charge Current using bqSWITCHER*, Internal Report, Texas Instruments, 4Q 2003.

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