Application Note

Designing an LED Driver for Medical Systems

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ABSTRACT

Light-emitting diode (LED) applications are spreading in consumer and automotive markets worldwide as a replacement for fluorescent lighting. This trend has penetrated the medical field and LEDs are now widely used for medical equipment such as *in vitro diagnostic* (IVD) systems, endoscopes, surgical operating rooms and so forth. In consumer and automotive applications, dimming LEDs generally use pulse width modulation (PWM) mode to save energy and make lighting comfortable for human eyes. There are countless LED drivers in the market with the PWM dimming function to meet market requirements. However, unlike consumer and automotive applications, medical applications often require an analog dimming design to avoid the banding effect and stroboscopic effect. The second issue is that medical applications can require high output current (about 40A) to drive large capacity LEDs but most LED drivers in the market cannot output large currents. This application note introduces several ways to use TI products to drive LEDs to meet the requirements of medical applications.

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1 Introduction

LED applications are spreading in consumer and automotive markets worldwide as a replacement for fluorescent lighting. There always has dimming requirement in LED lighting to save energy and to provide comfortable for human eyes and so on. Currently, there are two methods to dim LEDs: one is called analog dimming and the other is called PWM dimming. In analog dimming methods, the current going through the LED is adjusted by an input controlling voltage. PWM dimming leverages the slow response of human eyes by quickly turning the LED on and off (at a frequency above 100Hz) without changing the LED current flowing through during turn-on time. Since human eyes are not responsive to any frequency above 30Hz, brightness seems to change linearly according to the duty cycle of the PWM signal.

The drawbacks of PWM dimming are in the quality of light and the effect on different objects. PWM dimming involves frequency. Low-frequency dimming is in the 100Hz to 2kH range, a range that is perceptible to humans (subtly) and this dimming introduces eye strain or fatigue. A banding effect can occur when taking photos or recording videos if the dimming frequency is in such a range. PWM dimming can also create the stroboscopic effect, which is when moving objects or rotational objects look stationary. In short, to use PWM dimming and avoid any drawbacks, set the PWM dimming frequency higher than 2kHz.

To achieve high-frequency dimming, most LED drivers have a PWM dimming input. However, the bandwidth of the LED driver limits the dimming frequency and contrast ratio. For a fixed-frequency switched mode power supply type LED driver using a DC-to-DC conversion architecture, the loop bandwidth is typically designed at or below 50kHz. That imposes a limit on the contrast ratio to about 25-to-1 with a 2kHz PWM dimming frequency. To achieve a better contrast ratio, either use a lower PWM dimming frequency or try to further increase the loop bandwidth.

1.1 LED Lighting in Medical Systems

As previously stated, LED lighting is now widely used in medical systems. In an IVD system, LEDs are used to shine the samples and then convert the received optical information to voltage signals to do optical spectral analysis on the receive side. In an endoscope system, LEDs are used to internally light the human body with fiber to provide light for a camera, and thus to get clear images for doctors. In an operating room, LEDs are used for lighting without creating shadows. In an SpO2 system, LEDs are used to illuminate a human’s finger for oxygen analysis. In most cases, all these applications use analog dimming for appropriate lighting.

1.2 Key Challenges of LED Drivers in Medical Applications

The first key challenge for LED lighting in medical applications is the large LED forward current and the limited number of LED drivers that can output the large current needed to meet requirements in market. For example, in an endoscope application, a design can potentially require an LED driver to output high current (up to 40A) to compensate optical attenuation by fiber. The second challenge is high linearity for LED current and no ripple current, especially in small LED current situations. This is especially true for IVD applications. The third challenge is a high PWM frequency (potential higher than 10kHz) to dim LEDs without the banding effect, as required in operating rooms.

2 Proposed LED Drive Designs With Analog Dimming

Section 2.1 through Section 2.3 shows three scenarios that TI currently proposes for driving an LED with the analog dimming function. Each design has benefits and drawbacks. Designer can select the best design from proposals to meet specific application according performance, cost, and package .

2.1 Drive LED With Linear Constant-Current Source

The first method to drive an LED with the analog dimming function is to use an adjustable constant-current source. Figure 2-1 shows the schematic. The MOSFET (CSD19536KTT), amplifier (OPA863A), and digital-to-analog converter (DAC) (DAC60501) comprise an adjustable constant-current sink. The LED current equals the D-pole current of the CSD19536 since the sum of R_1 and R_2 is much larger than the sensing resistor (R_S). Equation 1 shows the function between the output voltage of DAC60501 and current flow of the LED.

$$I_{LED} = \frac{V_{DAC} \times (R_1 + R_2)}{R_2 \times R_S} \tag{1}$$

where

- R_S is sensing resistor
- V_{DAC} is output voltage of DAC
- R_1 and R_2 are divider resistors

The MOSFET runs in linear range and can potentially consume lots of power, resulting in low system efficiency. To solve this issue, the designer needs to use another DAC60501 to adjust the output voltage of the buck regulator (TLVM13610) and keep the MOSFET running in linear mode but close the switch-on mode (about 100mV–200mV higher than the switch-on drop voltage). Under these conditions, the designer can keep the system at a high efficiency consuming low power; thus, a low rise in temperature. Equation 2 shows the function between the output voltage of the buck regulator with the output voltage of DAC60501.

$$V_{Buck\_regulator\_output} = \left(1 + \frac{R_T}{R_B} + \frac{R_T}{R_C}\right) \times V_{REF} - \frac{R_T}{R_C} \times V_{DAC} \tag{2}$$

where

- R_T is the top resistor
- R_B is the bottom resistor
- R_C is the serial resistor with DAC
- V_{REF} is the reference voltage of the buck regulator
- V_{DAC} is DAC output voltage

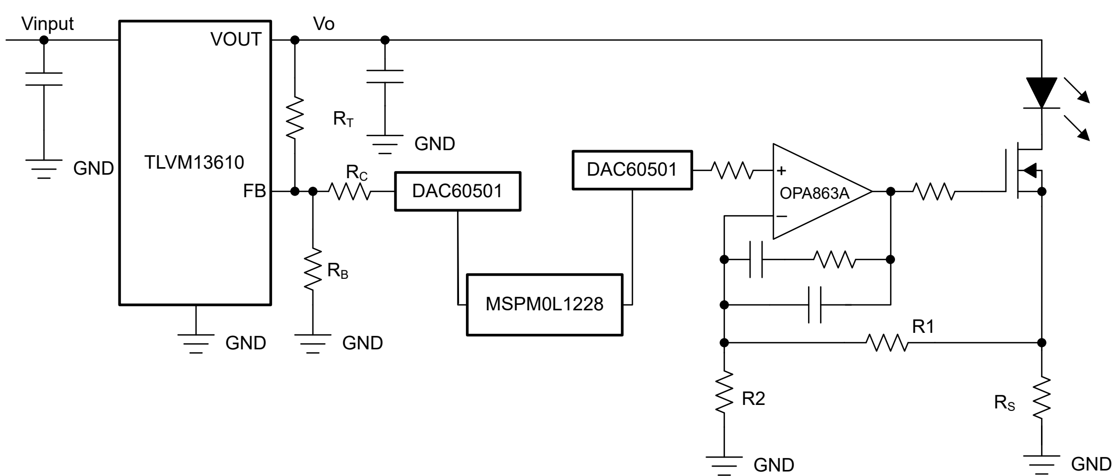

Figure 2-1. LED Analog Dimming With Adjustable Constant-Current Sink

Sometimes, the LED current is very large and the DAC cannot use all the range. For example, assume the maximum LED current is 20A and the sensing resistor is 20mΩ. The sensing voltage is then 0.4V and the designer needs to use an 8W sensing resistor. This causes the maximum output of the DAC to be 0.4V; therefore, the DAC cannot use the full range resulting in low resolution. The second issue is the large power consumption of the sensing resistor and the large package size.

To solve these two issues in large-current LED applications, consider the following changes:

- Use a smaller sensing resistor (for example, with a smaller value to 2mΩ), now the power consumed is 0.8W and the maximum sensing voltage is 0.04V.
- To extend the DAC output range, insert a current-sensing amplifier (for example, the INA241A) with a gain of 100 (see Figure 2-2). This expands the DAC output to 4V from 0.04V and improves system resolution since INA241A is a precise current-sensing amplifier with 10µV offset and is an excellent choice for this application.
- Use MSPM0L1228 as the controller to configure two DAC60501 devices with an SPI or IIC interface
- Use the TPS548D26 buck regulator with a maximum 40A output current.

Using the previously mentioned options, the designer can easily get LED current with DAC output voltage as Equation 3 shows.

$$I_{LED} = \frac{V_{DAC} \times (R_1 + R_2)}{R_2 \times R_S \times G_{INA241A}} \quad (3)$$

where

- $G_{INA241A}$ is the gain of INA241
- R_S is the sensing resistor
- R_1 and R_2 are the divider resistors

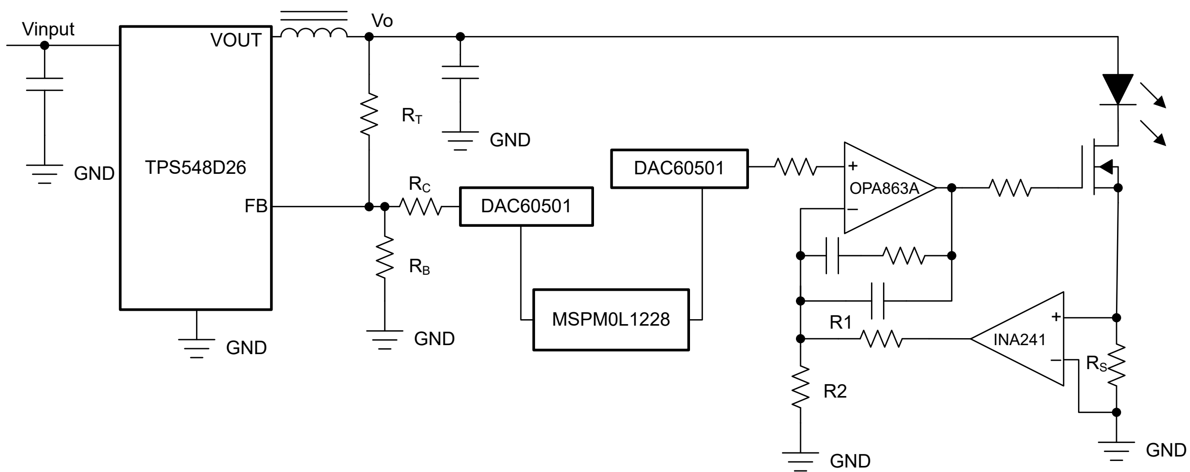

Figure 2-2. Large Current LED Analog Dimming

This design benefits from the fact that the design can dim the LED with either the analog method or in PWM mode. In analog dimming mode, this design has premium linearity. In PWM dimming mode, the design can dim with high PWM frequency to several MHz if the designer replaces OPA863A with a high-speed amplifier and high-speed DAC. In fact, this scheme can generate any desired LED drive current waveform. The drawbacks include increased cost and a larger PCB footprint.

2.2 Drive LED With a DC-DC Regulator

Figure 2-3 shows how designers can also use a buck regulator or buck module to build an LED driver with analog dimming. The Zener diode is used to clamp the output voltage to $V_z + V_{REF}$ if the LED is opened. The Zener diode is removable since the maximum output voltage is equal to the input voltage in the worst case for a buck regulator; therefore, there is no danger to humans in most cases. Assume the output of the DAC is V_{DAC} and the reference voltage of the buck regulator is V_{REF}. Then the designer can determine the function between LED and DAC, as Equation 4 shows.

$$I_{LED} = \left(1 + \frac{R_T}{R_B} + \frac{R_T}{R_C}\right) \times \frac{V_{REF}}{R_S \times G} - \frac{R_T \times V_{DAC}}{R_C \times R_S \times G} \quad (4)$$

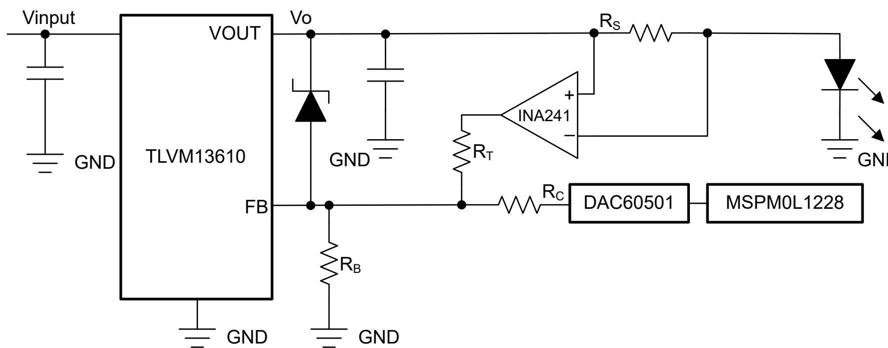

Figure 2-3. Drive LED Using Buck Regulator With Dimming

Equation 4 is complicated and the current of the LED is inversely proportional with the DAC voltage. To simplify the function between the DAC voltage and the LED current, the designer can use an external error amplifier (for example, OPA863A) as Figure 2-4 shows. The LED current and DAC voltage can now follow Equation 5 which is quite simple. The function of the diode in this design is to block current from the Zener diode and removable.

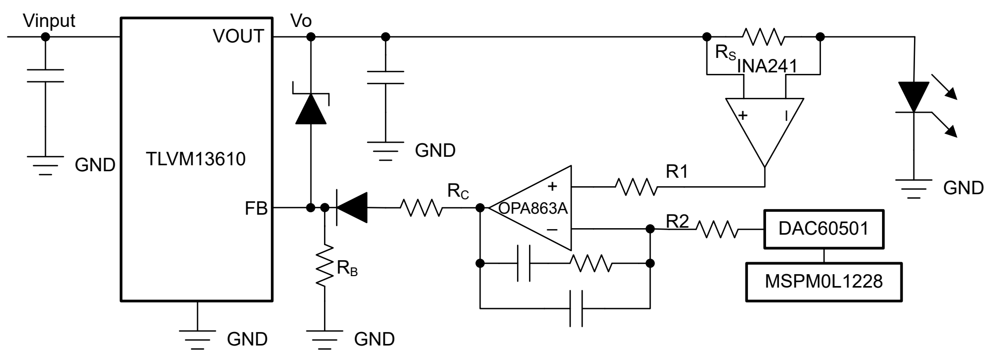

Figure 2-4. Dimming LED With a Simple Function

$$I_{LED} = \frac{V_{DAC}}{R_S \times G_{INA241}} \quad (5)$$

This design has a higher cost than the design in Section 2.3. Also, this design cannot to do fast PWM dimming. The transient response is not faster than the design in Section 2.3 since the buck regulator has a low bandwidth in most cases. The designer also must keep the minimum output voltage of buck regulator in worst case less than the LED forward voltage under LED lighting off mode. In this condition, the LED has no current and the buck regulator outputs the minimum voltage since most buck regulators have a minimum turn on time. The designer needs to keep output voltage in this condition smaller than the LED forward voltage. Otherwise, the LED has forward current and is out of control.

2.3 Drive LED With TPS92640 or TPS92641

TI also has the single-chip, TPS92640 and TPS92641 LED drivers with analog and PWM dimming capacity. The difference between TPS92640 and TPS92641 is that TPS92641 devices include a shunt FET dimming input and MOSFET driver for high-resolution PWM dimming. Both parts have 500:1 analog dimming capacity. With the integrated 2Ω, $1A_{peak}$ MOSFET gate drivers, the designer can drive LEDs with the expected current capacity by selecting a good external MOSFET in theory. The external DAC60501 can be connected to an analog dimming terminal I_{ADJ} to adjust the LED current as Equation 6 shows. I_{ADJ} can be set to any value up to 2.54V.

$$I_{LED} = \frac{V_{DAC}}{10 \times R_{CS}} \tag{6}$$

This single-chip design provides the lowest cost, but the resolution is lower than the previously mentioned scheme.

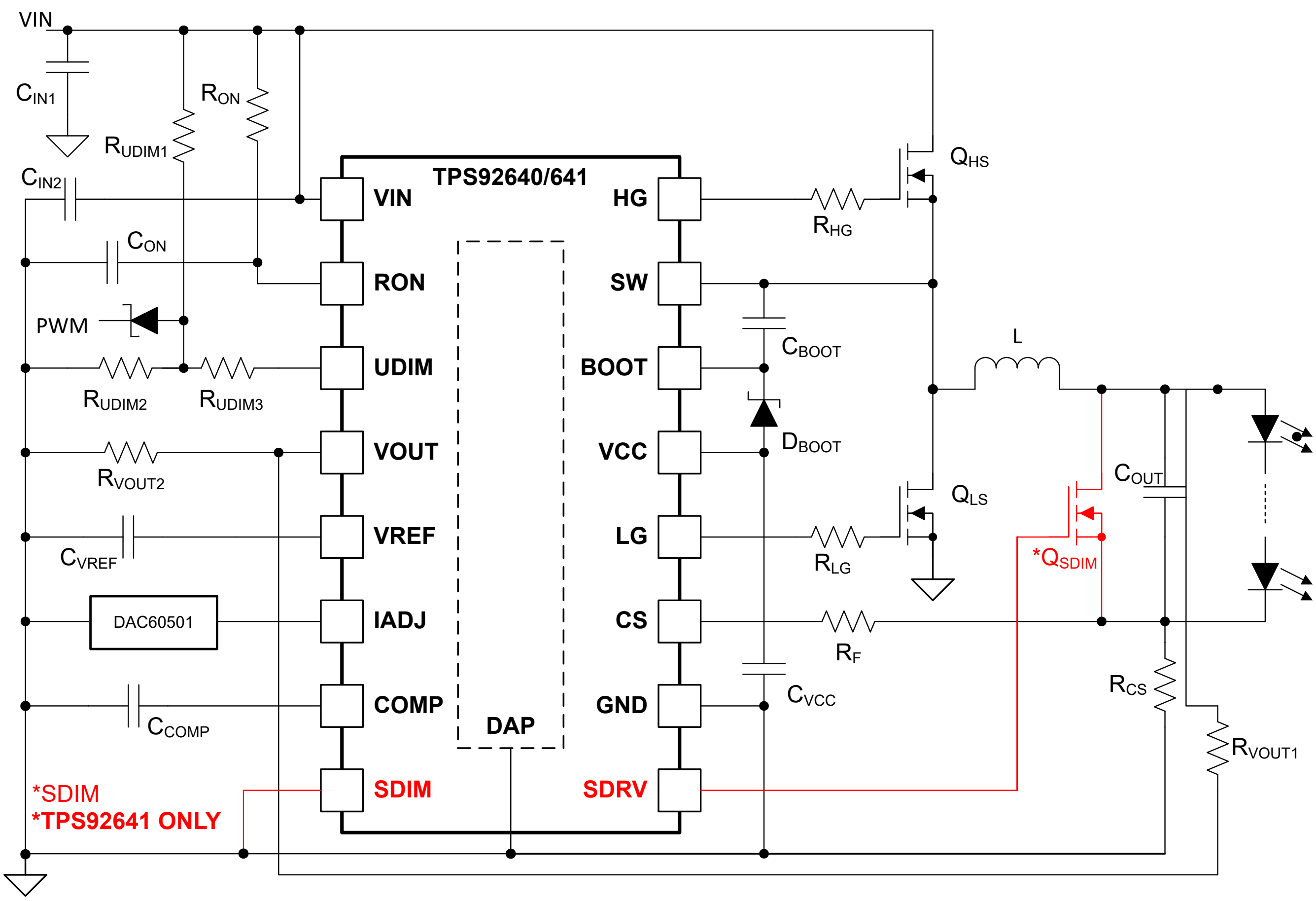

Figure 2-5. Driving LED With TPS92640 or TPS92641 With Analog Dimming

3 Summary

The previously discussed LED drive designs can meet most medical application requirements. In an actual design, the designer can select one of the previously mentioned designs to meet all the specific requirements and make tradeoffs between performance, cost, packaging, and so forth.

4 References

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