Design Guide: TIDA-080008
Display LED Driver Reference Design

👋 **TEXAS INSTRUMENTS**

Description

This reference design describes the characteristics, operation, and use of the LED/Laser Driver. This driver contains Texas Instruments TPS92641 IC configured as a solid-state driver solution providing a 3-channel regulated current output to drive 3 solid-state devices. A high-efficiency single inductor synchronous step-down (buck) converter topology is used. This reference design includes the driver specifications, a schematic diagram, PCB layout artworks, recommended test setup, and bill of materials to help the end user to implement the driver in their specific application.

Resources

TIDA-080008	Design Folder
DLPC4422 Controller	Product Folder
TPS92641	Product Folder
DLPA100	Product Folder

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Features

- High Brightness
- Low Cost BOM
- Top Side Pump Architecture
- Small Form Factor

Applications

- Classroom Projectors
- Enterprise Projectors
- Home Theater Projectors
- Industrial Display Projectors
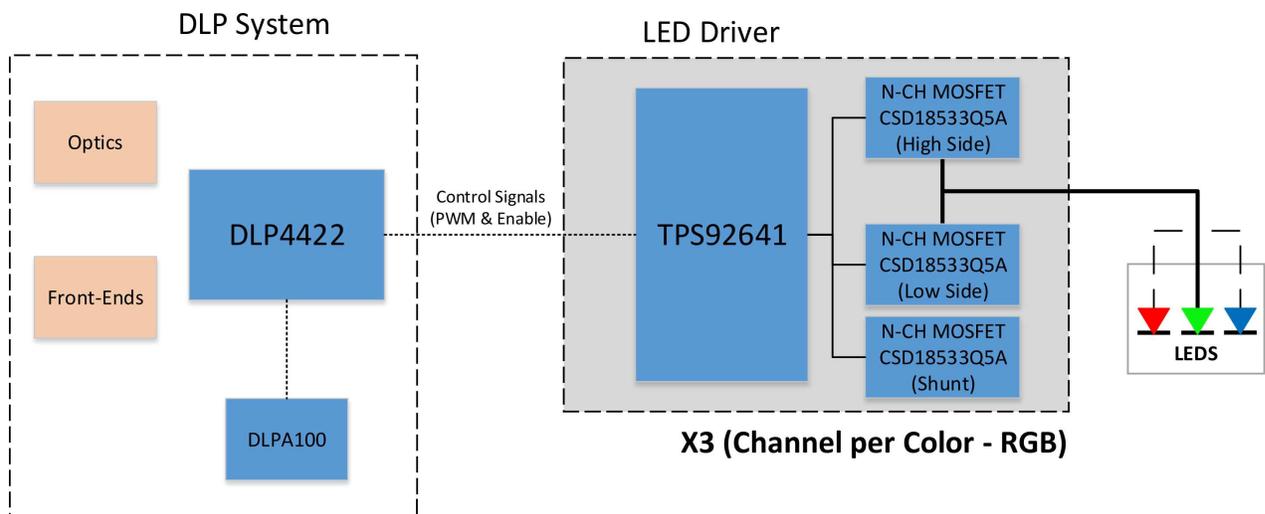
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1 System Overview

The TPS92641 is a high-voltage and synchronous NFET controller for buck-current regulators. Output current regulation is based on valley current-mode operation using on-time control architecture. This control method eases the loop compensation design and faster transient response. The PWM controller supports both analog and PWM input signals resulting in exceptional dimming control range. A linear dimmer between input command and LED current is achieved with true zero current using a low off-set error amplifier and proprietary PWM dimming logic. Protection features include cycle-by-cycle current protection, overvoltage protection, and thermal shutdown. LED driver has 3 separate driver blocks which allows for flexible color overlap schemes. As shown in Figure 1 the LED driver has 3 separate driver blocks, allowing for flexible color overlap schemes.

**Figure 1. TPS92641**
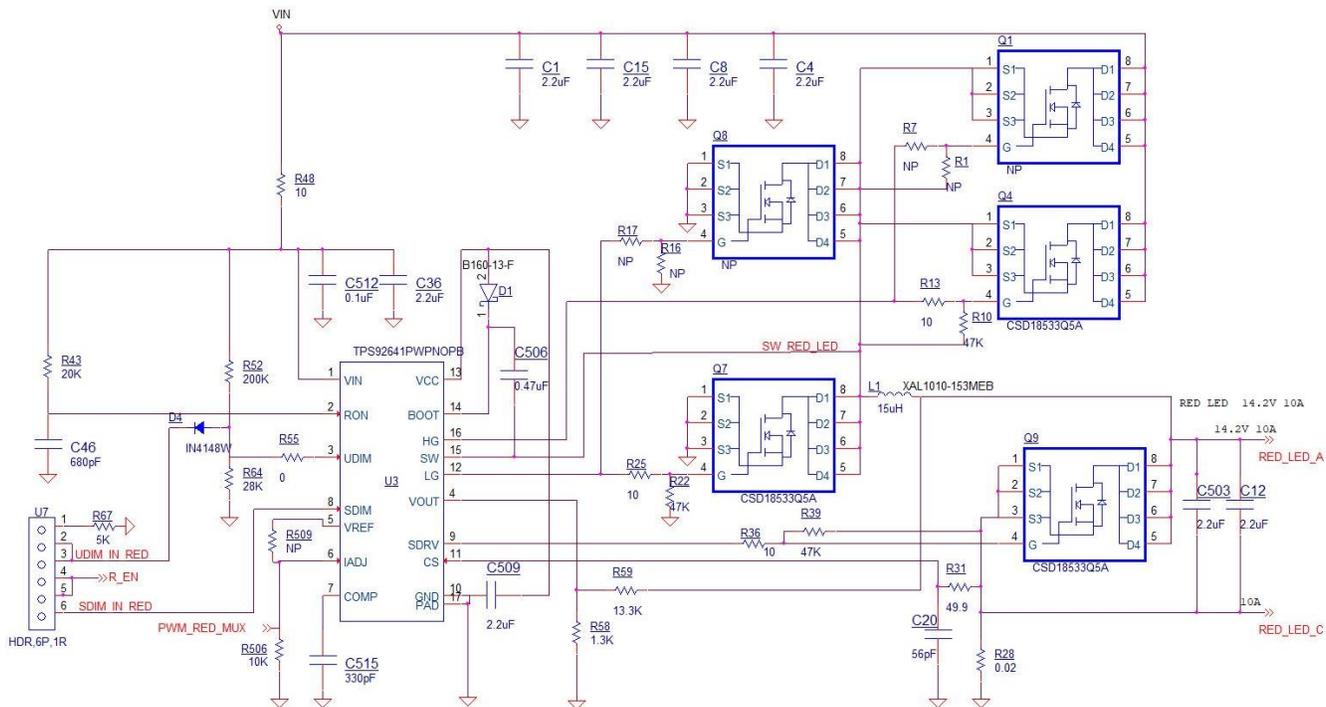
1.1 Key System Specifications

Table 1 provides a summary of the TPS92641EVM performance specifications. All specifications are given for an ambient temperature of 25°C.

Table 1. Driver Electrical Performance Specifications

PARAMETER	NOTES AND CONDITIONS	MIN	TYP	MAX	UNIT
VIN	Input Voltage		40	48	V
VOUT	Top Side Pump Configuration for Green Channel	14.2	15.6 V	31.6 V	V
ILED		1.5		10	A
Buck Regulator Fsw			766		KHz
Dimming			50:1		
Enable Delay		7		60	uS
LED Rise Time	Based on load Capacitors value		4		uS
LED Fall Time	Based on load Capacitors value		0.3		uS

1.2   Block Diagram

Figure 2. TIDA-080008 System Block Diagram
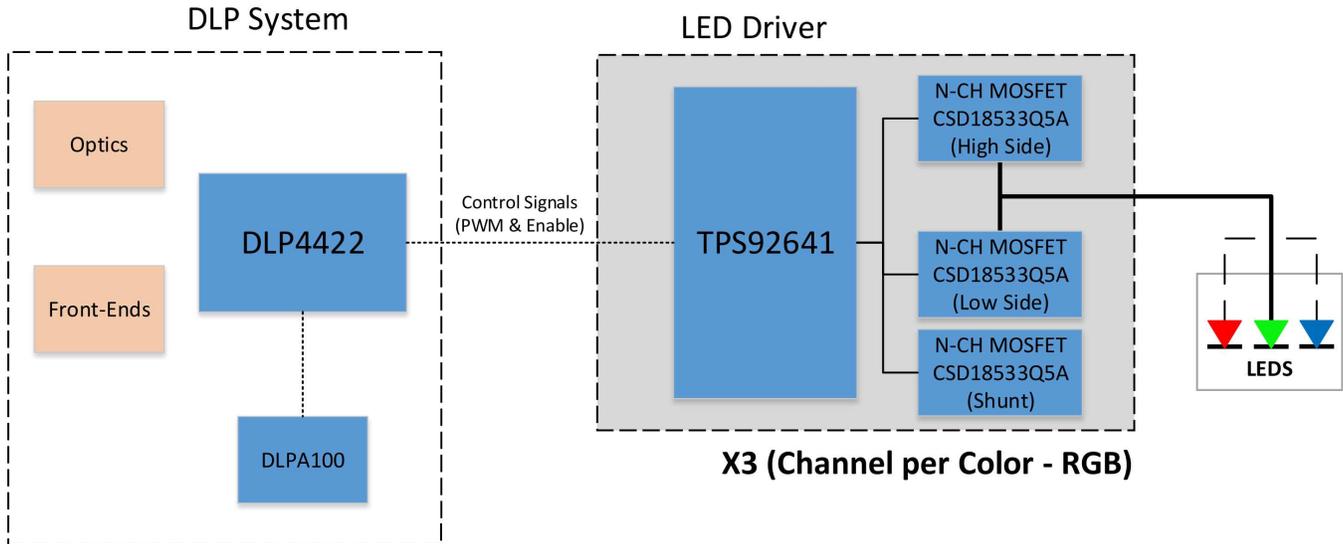
Section 1.2 shows the LED Driver and the 3 independently controller channels, one for each color. Each channel has been configured and designed with existing series LEDS that operated at different voltage & current levels.

Table 2 describes the max LED voltage and current levels that this board is configured to support.

Table 2. LED Operating Specs

| COLOR	CURRENT (A)	VOLTAGE (V)
RED	8	14.2
GREEN	10	15.8
BLUE	10	15.8

1.3   Top Side Pump

Currently LED systems are designed for a lumens level below 2000 when using the standard three channel architecture where one color (Red, green or blue) would be used per channel. As shown in Figure 3, there exists a limitation from the system étendue, meaning that it is not possible increase the lumens by simply making the light emitter larger while maintaining the size of the imager (DMD) constant. This is where a new innovative concept called Top Side Pump (TSP) comes in, allowing for higher lumens with the use of a 4th LED in the system.

Figure 3. Three Channel Configuration
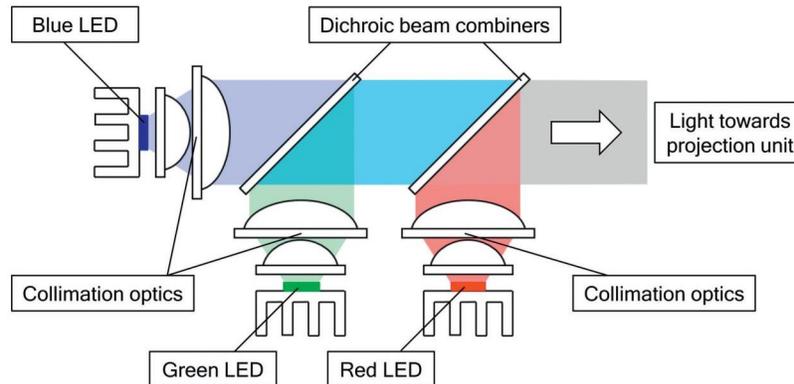
To produce a green light, manufactures take a blue LED and use a green phosphor layer to convert the blue spectrum light into green. As shown in Figure 4, TSP takes advantage of this concept by adding an additional blue LED to further excite the top side of the green phosphor to have a greater green output. The result is about an enhancement of 40%, but to maintain the white point, this translates to approximately a 15% boost in lumens. The limiting factor for TSP is the red channel LED, if more red was produced, then more of the available green output could be used.

Figure 4. Top Side Pump Configuration
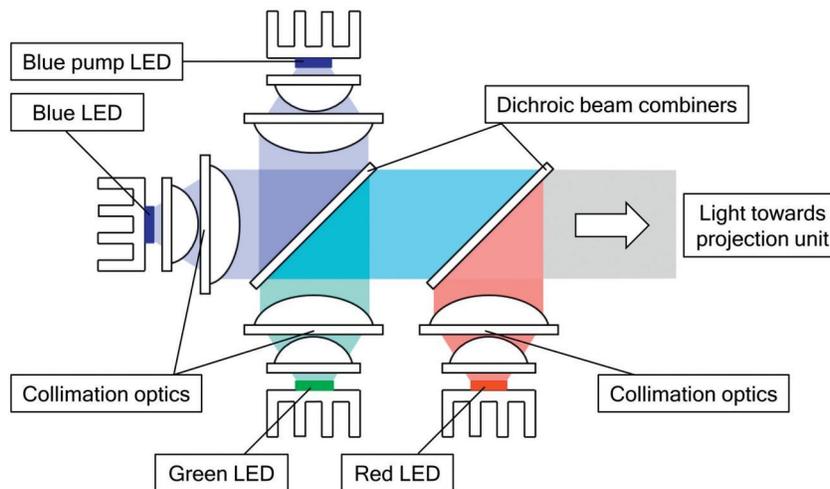
Green LED requires driving 2 diodes: Green LED and Blue pump LED together. With that in mind, here are the real voltages that are supplied for the driver to accommodate Green and Blue pump LED now requires 31.6 V to driver both diodes in series.

Table 3. LED Operating Specs

COLOR	CURRENT (A)	VOLTAGE (V)
Red	8	14.2
GREEN	10	31.6
BLUE	10	15.8

1.4   LED Driver Input Signals

Each color receives 2 control signals ENABLE to turn LED on and off, and PWM signal which controls LED current level. Connector J1 shows all digital inputs into LED driver board including EN and PWM signals, as well as SSI_SUBFRAME, SENSE_PLS and PWM_CAL signals which are used for calibration purposes.

Figure 5. Driver Input Signals
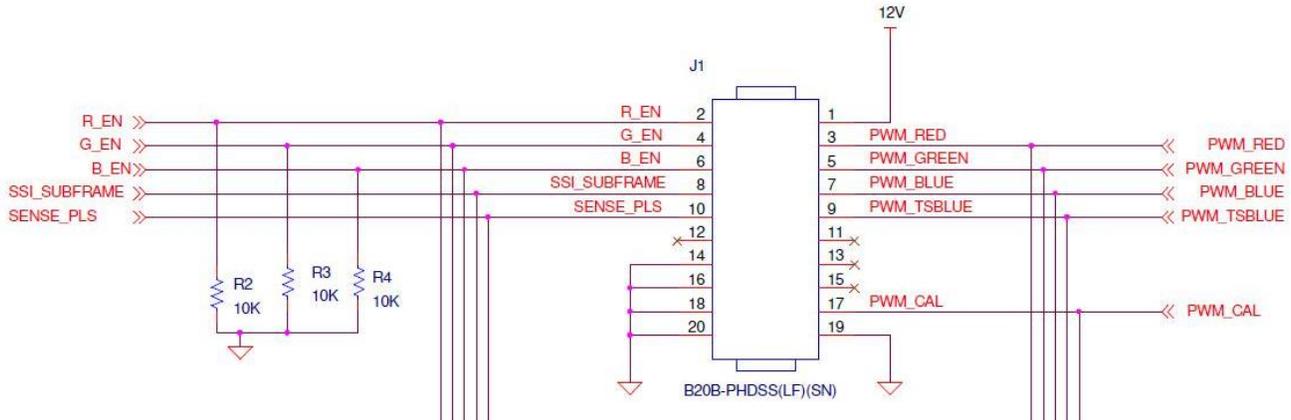
1.5   LED Driver SDIM/UDIM Settings

There are 2 control signals that can be options to turn LEDs on and off – UDIM and SDIM. UDIM controls the synchronous NFET operation of the buck regulator and provides for a slower turn on of the LEDs. SDIM turns off/on shunt NFET that quickly shunts current from and to the LED providing for faster rise time. SDIM rise time is x5 faster than UDIM. SDIM fall time is x20 times faster than UDIM. LED load, as well as capacitor that is placed in parallel with the load, can influence rise/fall time of the current (current rise/fall time vs. capacitor is addressed in Section 2.5)

Each LED driver block has a connector that allows for flexibility of design in testing UDIM and SDIM operation. Current board is set up for SDIM operation.
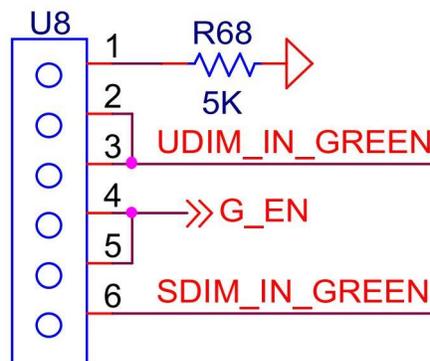
**Figure 6. UDIM/SDIM Header**

Table 4. Default Jumpers

OPTIONS	CONNECTOR SETTING	OTHER REQUIREMENTS
SDIM (Default)	Jumper together pin 5 and 6	Shunt NFET must be populated
UDIM	Jumper together pin 4 and 3	Shunt NFET must be depopulated

> NOTE: **Warning:** Make sure UDIM is driven to 0 V during power up, especially when main supply that drives LEDs is on. If UDIM is left floating, it will apply constant VLED voltage/current and might damage the LED, if LED is meant to be pulsed.

1.6 TPS92641 Board Description

This reference design contains the TPS92641 IC configured as an RGB LED power solution providing three-channel regulated current output to drive red, green and blue colors with max 20 A. This application note includes a schematic diagram, PCB layouts, and a bill of materials to help the end user implement the device in their specific application.

Figure 7. Driver Block Diagram
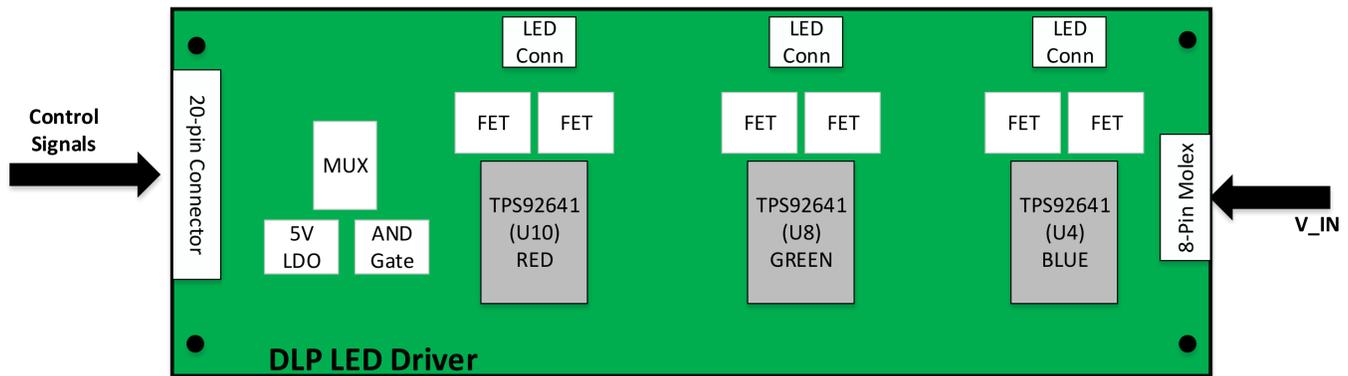
1.7 Setting the LED Current and Analog Dimming

Average LED current regulation is set by using a sense resistor in-series with the LEDs. The internal error amplifier regulates the voltage across the sense resistor (VCS) to the IADJ voltage divided by 10. IADJ can be set to any value up to 2.54 V by connecting it to VREF through a resistor divider for static output current settings. IADJ can also be used to change the regulation point if connected to a controlled voltage source or potentiometer to provide analog dimming. The ILED setting is based on the equations in Equation 1.

$$I_{LED} = \frac{V_{CS}}{R_{CS}}$$

$$V_{CS} = \frac{V_{IADJ}}{10}$$

(1)

1.8 PWM Dimming

The PWM dimming can be achieved through the UDIM pin and SDIM pin. The UDIM pin can be driven with a PWM signal which controls the synchronous NFET operation. The brightness of the LEDs can be varied by modulating the duty cycle (DDIM) of the signal using a Schottky diode with anode connected to UDIM pin. The SDIM pin is controlled with an external shunt FET PWM dimming. Extremely high dimming range and linearly is achieved by shunt FET dimming operation with the SDIM and SDRV pin. When higher frequency and time resolution PWM dimming signal is applied to the SDIM pin, the SDRV pin provides an inverted signal of the same frequency and duty cycle that can be used to drive the gate of a shunt NFET directly across the LED load.

2 LED Driver Key Parameters

Figure 8 shows the specific characteristics of a waveform that detail the performance of any LED driver. A LED driver should be both consistent and repeatable, meaning that the light output should reach the same no matter the driver level. Referring back to the figure, we can divide a LED driver waveform to 5 main areas. The five (5) Key Parameters include the following:

- Enable Delay [A]
- Rise Time [B]
- Disable Delay [C]
- Fall Time [D]
- Ripple [E]

Figure 8. 5 Key Parameters
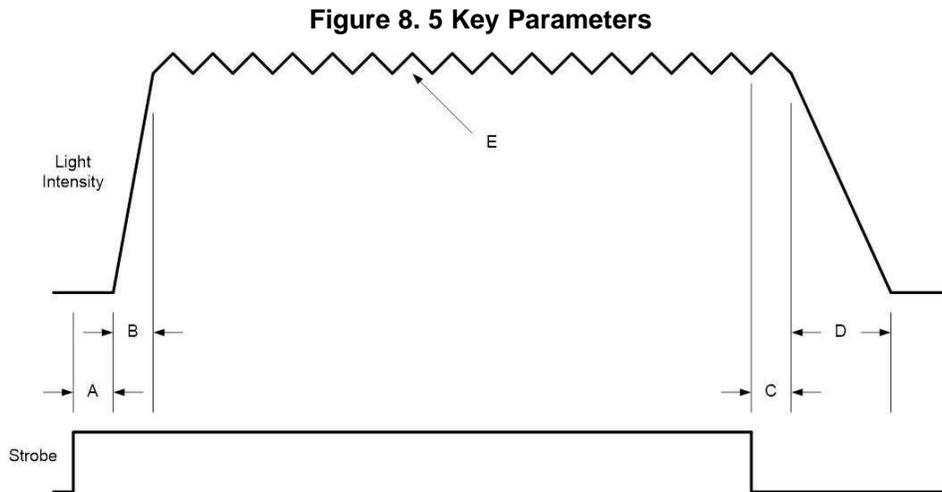
2.1 Enable and Disable Delay

Enable delay and Disable delay are the times when the driver is told to turn the light on/off and when the light actually turns on/off (typically measured with a sensor). A potential artifact from not meeting the specs is color bleed. Color bleed is when the incorrect color is being illuminated, either because the driver is too slow or too fast. An additional artifact also includes ramp smoothness issues.

2.2 Rise and Fall Time

Rise and fall times are how long it takes the light output to go from 10% to 90% and vice versa. The desired waveform should closely resemble a square wave as much as possible. The faster the time, the better the driver will perform. Keep in mind that the higher the rise time, the less margin one will have for the enable/delay. The fall time should be the same or better than the rise time. Potential issues from not having a fast rise times are ramp smoothness, PWM artifacts, CCA accuracy and dither performance.

2.3 Ripple

Lastly, the ripple is the variation of the light output. The requirements here are a little more straight forward with the max ripple equal to +/-10% and the frequency must be greater than 250 KHz. Similar artifacts as mentioned before are also possible consequences of poor ripple performance.

2.4 Performance Parameters

Table 5. LED Driver Parameters

PARAMETER	MIN	MAX	IDEAL
Enable Delay	1 µS	--	1 µS
Rise Time	0 µS	19 µS for LED	1 µS
Enable Delay + Rise Time	1 µS	20 µS for LED	<17 µS
Disable Delay	1 µS	--	1 µS
Fall Time	0 µS	19 µS for LED	1 µS
Disable Delay + Fall Time	1 µS	20 µS for LED	<17 µS
Ripple	>250 KHz	10 %	--

2.5 LED Load Capacitor for Rise/Fall Time

Choosing LED capacitor is very important when it comes to rise times, delay times, and current ripple. Here is a table what capacitor measurements that we made to help choose proper capacitor based on rise time and current ripple requirements. Capacitor choice might be different for Blue vs. Green LEDs. Green and top side pump are placed in parallel and are a larger load to the driver compared to just a Blue LED by itself.

Table 6. Load Capacitor effect on performance

COLOR	CAP (UF)	ENABLE DELAY (US)	RISE TIME (US)	ENABLE DELAY + RISE TIME	RIPPLE PEAK TO PEAK (A)
Green	6.60	16.70	4.30	21.00	0.60
Green	4.40	12.40	4.40	16.80	0.80
Green	3.30	7.00	3.00	10.00	1.00
Green	2.20	6.50	2.70	9.20	0.60
Blue	10.0	11.20	3.60	14.80	0.64
Blue	6.60	11.50	4.80	16.30	0.56
Blue	4.40	8.70	3.40	12.10	0.72
Blue	3.30	5.50	3.30	8.80	0.60
Blue	2.20	4.00	1.90	5.90	0.56

2.6 LED Load Capacitor And Audible Noise

Ceramic capacitor are great when it comes to size and price, however, they can create audible noise in LED driver applications. As voltage across LED is turned on and off, capacitor flexes and vibrates the PCB, creating audible noise. There are two options to reducing this audible noise: layout considerations, as well as using an electrolytic capacitor.

2.6.1 Layout Considerations

The two layout consideration options include:

- Place two identical capacitors directly opposite each other on the top and bottom side of the PCB. If there is only a single capacitor, it bends its middle towards the PCB and back. In doing this, the PCB is stimulated like the membrane of a loud speaker and emits acoustic waves. If two capacitors are placed opposite one another, both bend towards and away from the PCB at the same time. Thus, the PCB cannot resonate anymore.

- The second action to reduce the residual noise further is to minimize the mechanical coupling of the ceramic capacitors and the PCB. By milling holes into the PCB besides the solder points, the stimulated PCB area is reduced significantly. Figure 4 shows the read marked holes in the PCB around the ceramic capacitors Top view.

Figure 9. LED Capacitor Layout
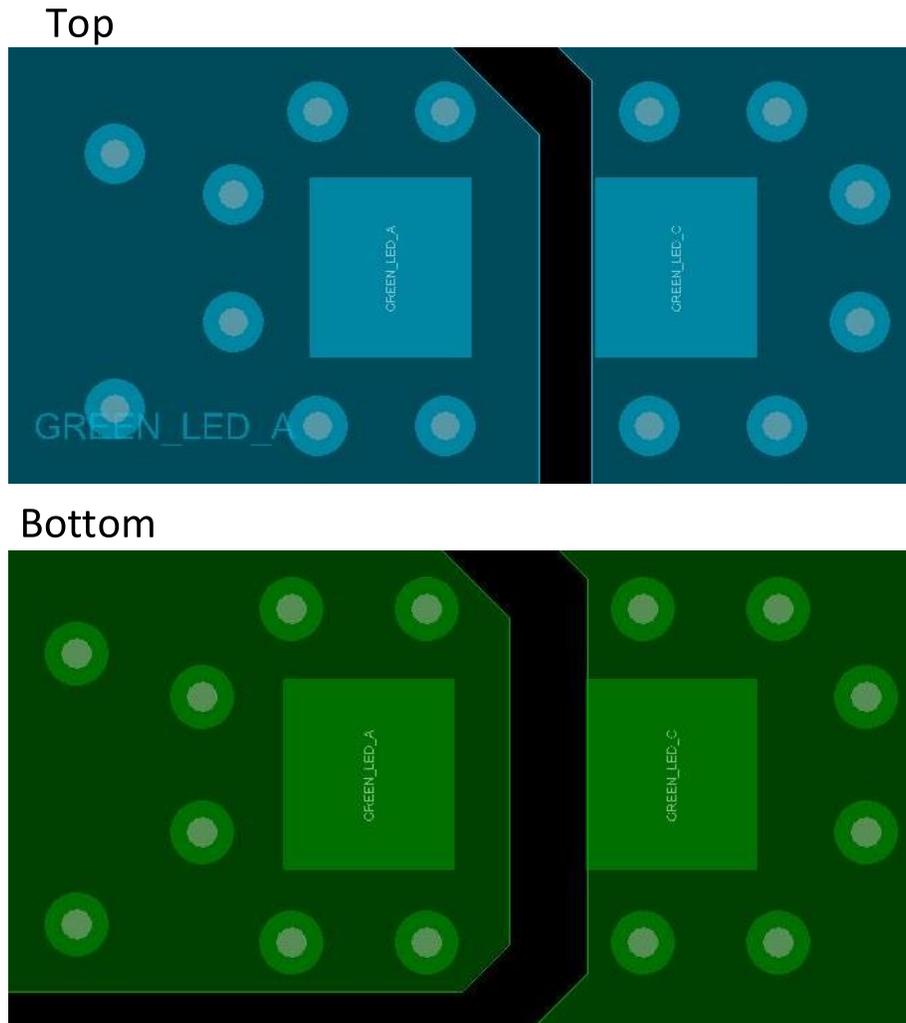
2.6.2 Electrolytic capacitor considerations

Electrolytic capacitors is less noisy because they don't vibrate the PCB due to their structure and packaging, however, they have higher resistance and inductance components, and can slow down LED current rise time and enable delay. Figure 10 is an example of Green LED with 4.7μF ceramic load in parallel, 10A.
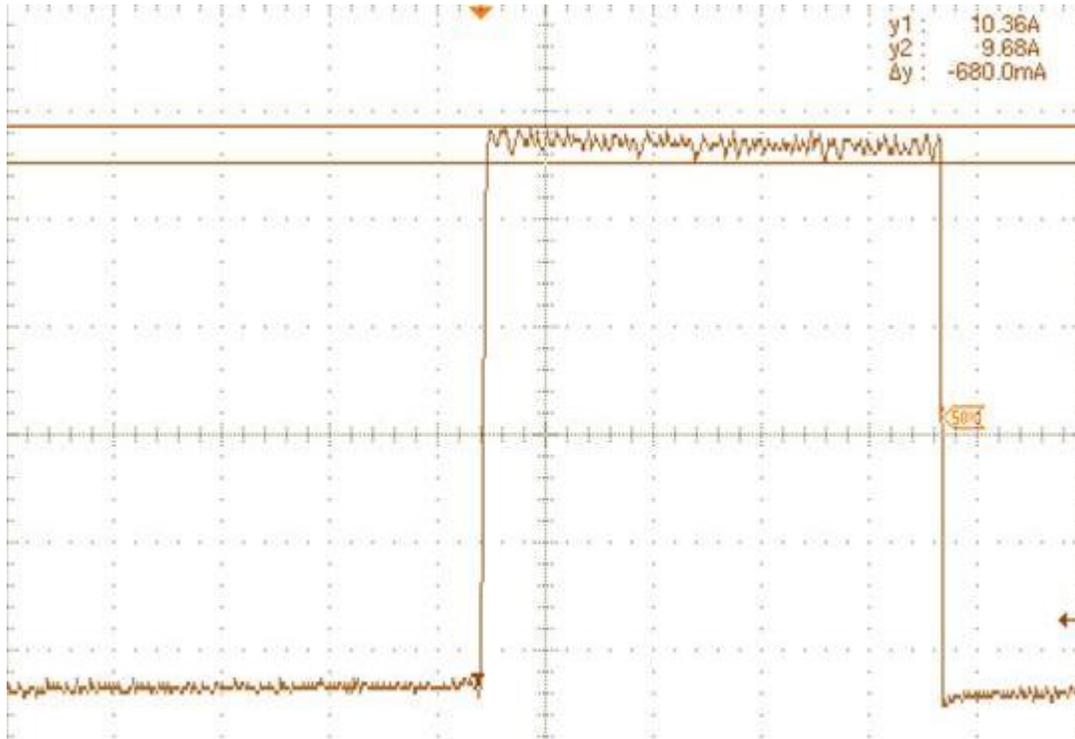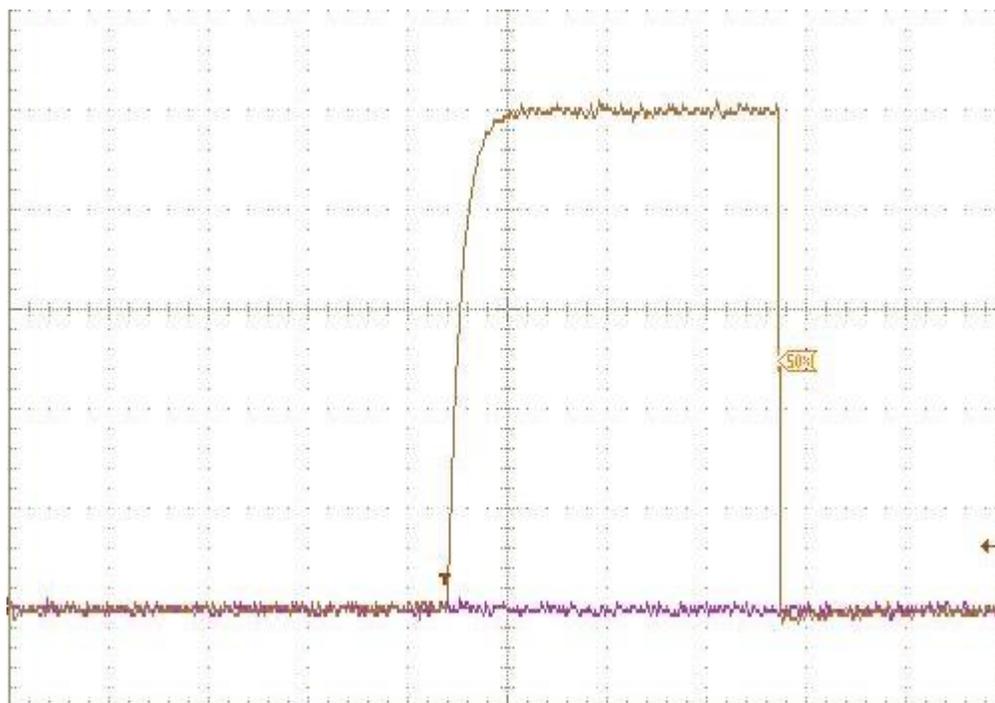
Figure 10. LED Waveform with 4.7 µF Ceramic Capacitors

Figure 11 is an example of GREEN LED with 4.7µF electrolytic load in parallel, 10A.

Figure 11. LED Waveform with 4.7 µF Electrolytic Capacitors

Table 7 is an example of timing differences between Ceramic and Electrolytic Cap.

Table 7. Driver Performance between Ceramic and Electrolytic Capacitors

COLOR	CAP VALUE (μF)	CAPACITOR TYPE	ENABLE DELAY (μS)	RISE TIME (μS)	ENABLE DELAY + RISE TIME (μS)	RIPPLE PEAK TO PEAK (A)
Green	4.70	Ceramic	9.20	3.00	12.20	1.20
Green	4.70	Electrolytic	28.00	28.50	56.50	0.40
Green	3.30	Ceramic	7.00	3.00	10.00	1.00
Green	3.30	Electrolytic	7.80	12.00	19.80	0.40
Green	2.20	Ceramic	2.70	2.70	9.20	0.60
Green	2.20	Electrolytic	10/80	10.80	15.20	0.60

2.6.3   Standoff Capacitors

For applications that have more stringent noise requirements, different capacitors can be used to mitigate any capacitor ringing that may occur at the output of the switching node. This ringing may be attributed to a piezo-electric resonant behavior with the PCB board. One solution is to use ceramic capacitors with metal terminals that physically lift the capacitor off the board.

Figure 12. Standoff Capacitors

2.7   LED Driver Calculator Tool

If LED driver has changes based on different LED specifications or even Lasers, you can use LED Driver Components Calculator. LED driver components calculator is an excel-based calculator that allows customers to calculate various components values based on led driver specifications in tab Component Values. You can enter values in blue such as LED voltage signal, LED current and others, and the calculator will calculate the rest of the values needed for the driver to work as shown in Figure 13.

Figure 13. Driver Component Calculator Tool

Second tab ComponentRatings tab shown in Figure 14 calculates various component ratings based on selected specs from ComponentValues tab. This should help customers choose appropriate power and voltage ratings.

Figure 14. Component Ratings Tool

| Component	Value	Unit	Rating Name	Rating Value	Rating Unit
CIN1	407.91	uF	VIN	40	V
CIN2	10	uF	VIN	40	V
RON	20	kOhm	POWER	0.002	W
CON	680	uF	VIN	40	V
RUDIM1	200	kOhm	POWER	0.0057	W
RUDIM2	37.95359905	kOhm	POWER	0.0011	W
RVOUT1	1	kOhm	POWER	0.8468	W
RVOUT2	0.085910653	kOhm	POWER	0.0728	W
RADJ1	10	kOhm	POWER	0.0002	W
RADJ2	15.38461538	kOhm	POWER	0.0001	W
CCOMP	0.1 - 0.47	uF	VOLTAGE	25	V
RHG/RLG	4-10	Ohm	POWER	0.1	W
CBOOT	0.47	uF	VOLTAGE	48.5	V
DBOOT			VOLTAGE	48.5	V
COUT	0.04	uF	VOUT	31.6	V
RCS	0.02	Ohm	POWER	2	W
CVCC	2.2uF	uF	VCC	8.5	V
L	7.93	uH	ILpeak	25.5	A
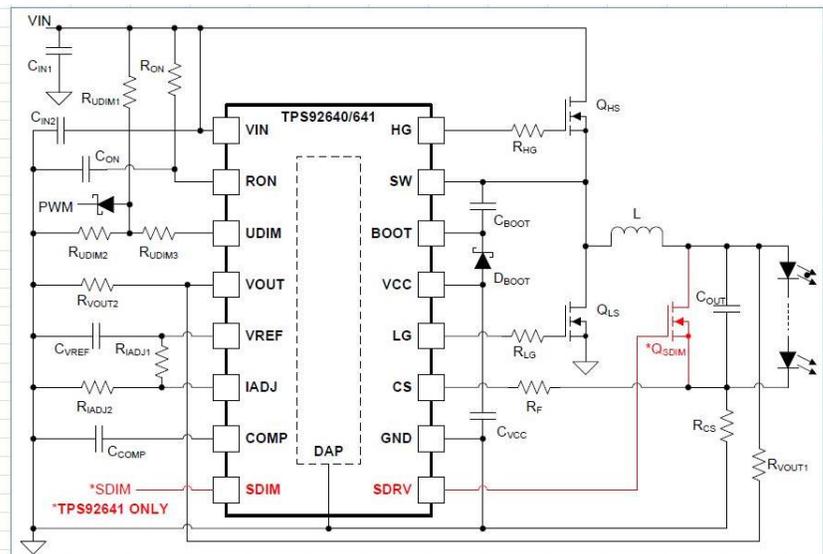
3   Layout

Figure 15 shows the layout guidelines taken from the TPS92641 Synchronous Buck Controllers for Precision Dimming LED Drivers data sheet.

Discontinuous currents are the most likely to generate EMI, therefore take care when routing these paths. The main path for discontinuous current in the TPS92640 and TPS92641 buck converters contain the input capacitor (CIN), the low side MOSFET (QLS), and the high side MOSFET (QHS). This loop should be kept as small as possible and the connections between all three components should be short and thick to minimize parasitic inductance. In particular, the switch node (where L, QLS, and QHS connect) should be just large enough to connect the components without excessive heating from the current it carries. The current sense trace (CS pin) should be run along with a ground plane or have differential traces run for CS and ground.

In some applications, the LED or LED array can be far away (several inches or more) from the circuit, or on a separate PCB connected by a wiring harness. When an output capacitor is used and the LED array is large or separated from the rest of the converter, the output capacitor should be placed close to the LEDs to reduce the effects of parasitic inductance on the AC impedance of the capacitor.

Figure 15. TPS92641 Layout Guidelines
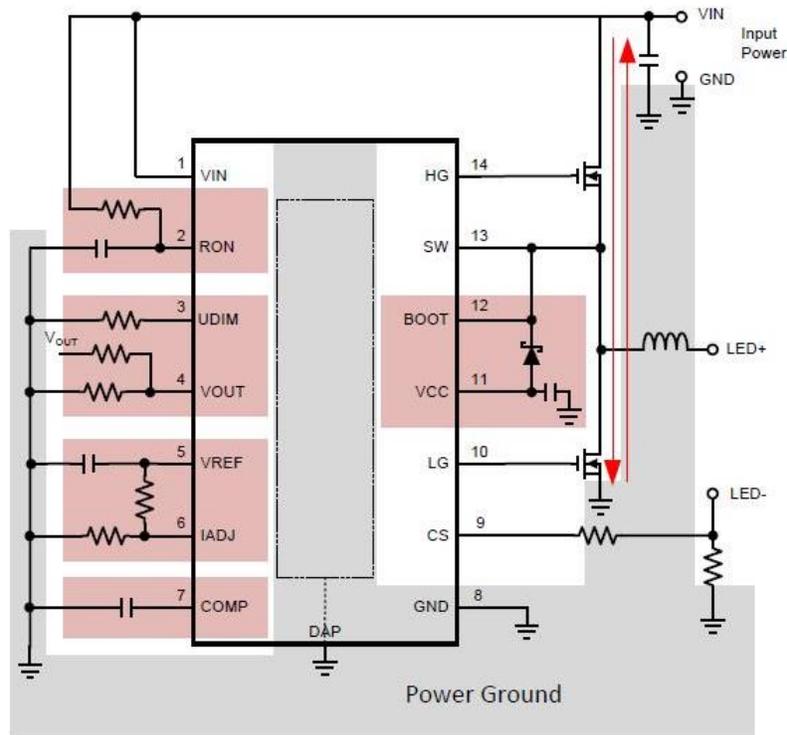
4   Related Documentation

1. Texas Instruments, *Getting Started With TI DLP® Display Technology Application Report*
2. Texas Instruments, *TI DLP® Display & Projection Chipset Selection Guide*
3. Texas Instruments, *TI DLP® System Design: Brightness Requirements and Tradeoffs Application Report*
4. Texas Instruments, *Low-Latency, High-Speed TI DLP® Digital Projection Reference Design*
5. Texas Instruments, *4K UHD display chip sub-system Reference Design featuring DLP660TE and DLPC4422*

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