Texas Instruments

Application Report
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DLP® Pico™ Brightness Turbo and TPS92641 Design Guide

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ABSTRACT

This application note presents *Brightness Turbo*, a method to boost the system brightness on LED-based projectors. Brightness Turbo is able to raise the system brightness further. A hardware logic is introduced to support Brightness Turbo, the projector running in either high-brightness mode or saturated-color mode. The Brightness Turbo logic is built with the TI TPS92641 LED driver. The second half of the application note introduces the TPS92641 as the discrete LED driver in DLP® products and includes the schematic, O-scope performance measurement, and design guidelines for mainstream LED products.

The application note is recommended on the DPP6401 DLP® Pico™ product with PWM driver control interface.

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1 Brightness Turbo Introduction

A single DMD chip, DLP® LED projector is known as using a color-sequential method to produce colors that turn Red, Green, or Blue LED on at a time within the whole frame time. In pure LED illumination systems, Red, Green, and Blue LEDs have to use the dichroic mirrors with appropriate optical layout and form the same incident light cone to the DMD as shown in Figure 1. The conventional LED driving scheme either drives LED at full power or completely off as the example in Figure 2.

In order to boost the system brightness, Brightness Turbo is a new LED driving concept that slightly turns on the other two LEDs while they are originally completely off. For example, a given red LED time, green and blue LEDs are turned on with 15% of their full power, and the same rule applies to green and blue LED sequence time as shown in Figure 3. Therefore, all three LEDs are turned on while Brightness Turbo is enabled. Because all LEDs are turned on at all times, the price of gaining the extra brightness is the color gamut. The amount the color desaturation depends on how much brightness boost created by Brightness Turbo.

There are two significant advantages when Brightness Turbo is implemented in an LED-based DPP6401 projector:

- The projector can claim higher brightness specification and still keep the original color gamut specification in the other display mode. The control logic is introduced in Section 2.
- Typically, LED has higher efficiency when operating at a lower forward current. Brightness Turbo takes the LED nature to boost brightness with better power versus brightness trade.

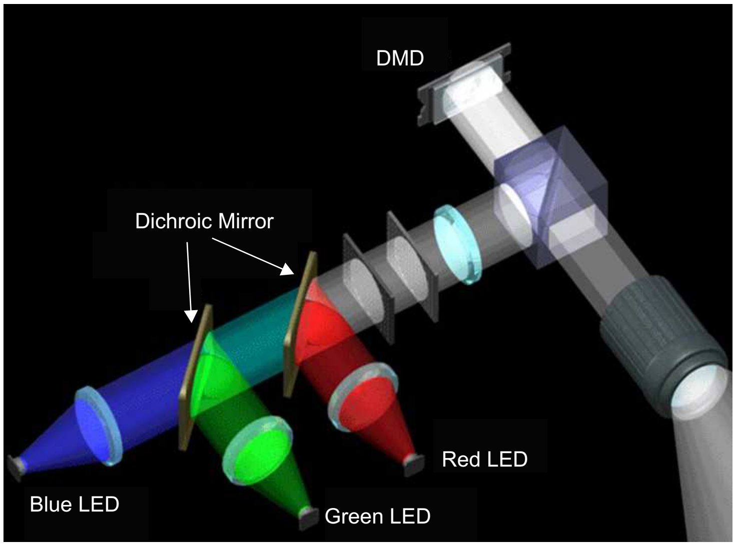


Figure 1. Optical Layout of DLP® LED Projector

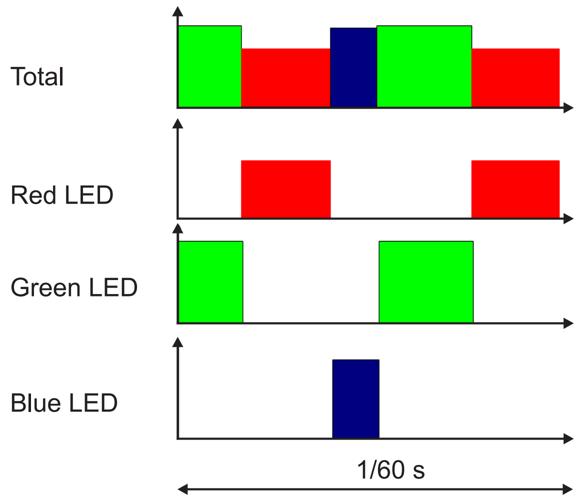


Figure 2. Conventional LED Driving Scheme in 60 Hz Video

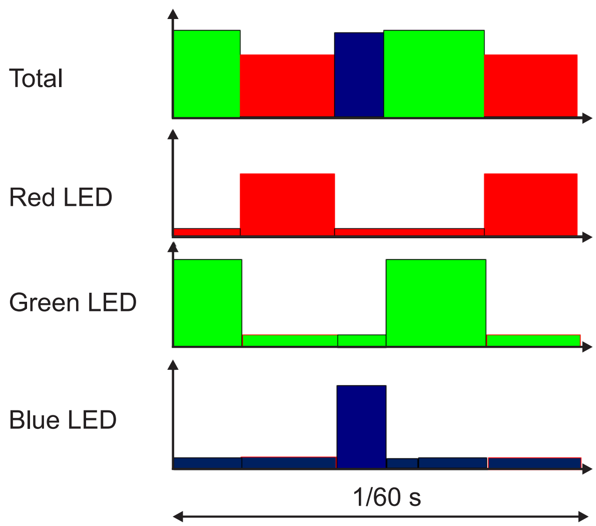


Figure 3. Brightness Turbo Slightly Turned on all LEDs at all Times

2 Brightness Turbo Design

2.1 Hardware Logic

Brightness Turbo logic is realized on the TI TPS92641 LED driver and the logic circuit was made and proven effectively on TPS92641+ Brightness Turbo EVM. The logic supports the features to control Brightness Turbo enabled/disabled, and the brightness boost ratio.

The TPS92641 provides two input control signals to manipulate LED current level and on/off sequence. IADJ (pin 6) is an analog input that controls LED current level. High-level input voltage with higher LED current. UDIM (pin 3) is a fast switch of LED on and off. High indicates LED on, low indicates LED off.

Figure 4 shows the logic of Brightness Turbo over IADJ. The *Brightness Turbo SW* is the switch that turn on or off Brightness Turbo. Two analog multiplexers (MUX) are used with normal open and normal close input ports. The MUX at TPS92641 end is controlled by LED strobe which is sent from DPP6401. The Strobe at the status of high switches the MUX output to PWM which is the LED current setting for this particular color sequence time. While Strobe is at low status, the MUX outputs the signal from the other MUX which is controlled by *Brightness Turbo SW*. If Brightness Turbo SW is off, then convey the low signal to LED driver that indicate no brightness boost. On the other hand, convey the voltage which is decided by two cascaded resisters to determine how much LED current is used to boost the brightness when Brightness Turbo SW is on. Figure 5 is the logic chart of the control signal over IADJ. Two steps of LED current levels when Brightness Turbo is turned on. In design implementation, the same logic is applied for red, green, and blue TPS92641 LED drivers.

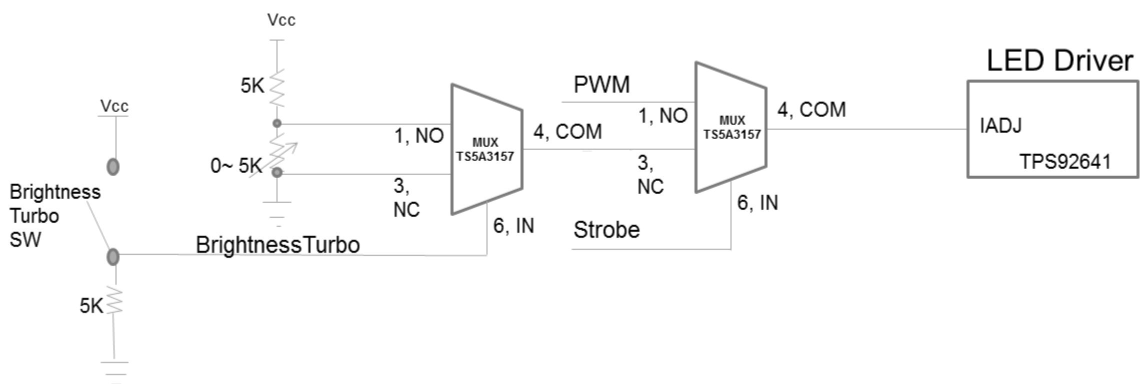


Figure 4. IADJ Control of Brightness Turbo

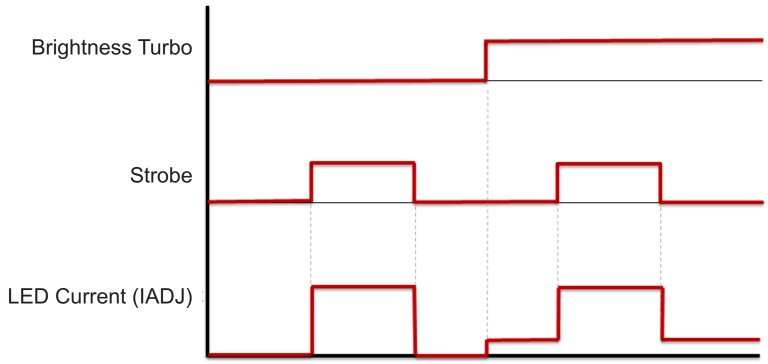


Figure 5. Logic Chart of Control over IADJ

Since IADJ is an analog control signal, the LED occasionally may not completely turn off due to analog noise when Brightness Turbo is off. Figure 6 shows the additional logic circuit on green channel to reinforce and provides faster response time over UDIM. When Brightness Turbo is on, the green LED is turned on as long as red, green, or blue Strobe is high. UDIM follows green Strobe that fast switch the LED on/off while Brightness Turbo is off. The same logic circuit applies to red and blue UDIM.

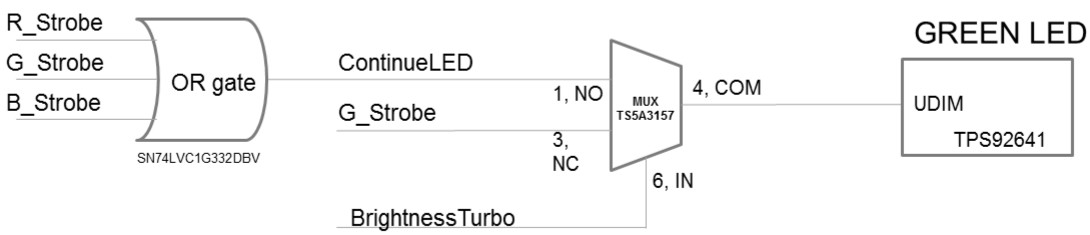


Figure 6. UDIM Control on Green LED

The detail logic chart and the interaction of Brightness Turbo control signals are shown in Figure 7. Input signals are Brightness Turbo, R Strobe, G Strobe, and B Strobe.

Output signals are Red IADJ, Red UDIM, Green IADJ, Green UDIM, Blue IADJ, and Blue UDIM. The complete circuit of Brightness Turbo for R, G, and B channels is shown in Figure 8.

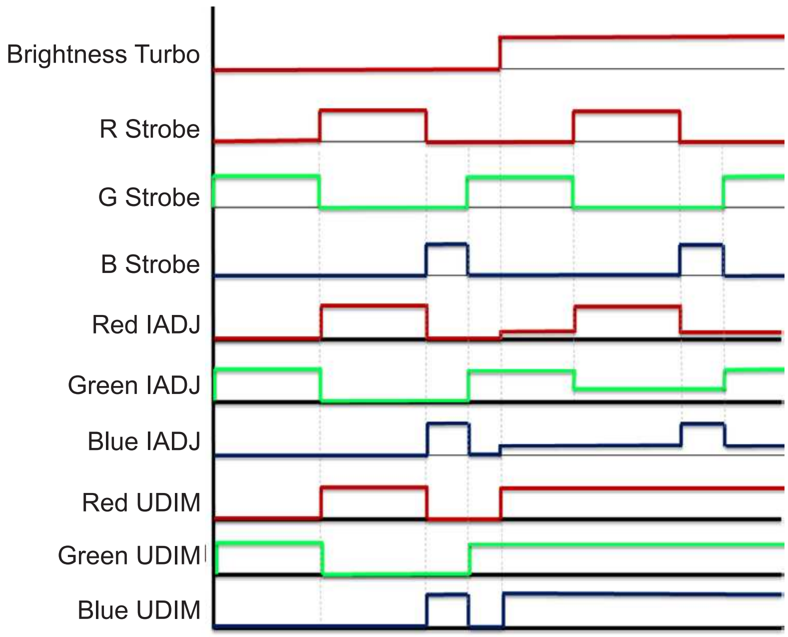


Figure 7. Logic Chart of Brightness Turbo Inputs/Outputs

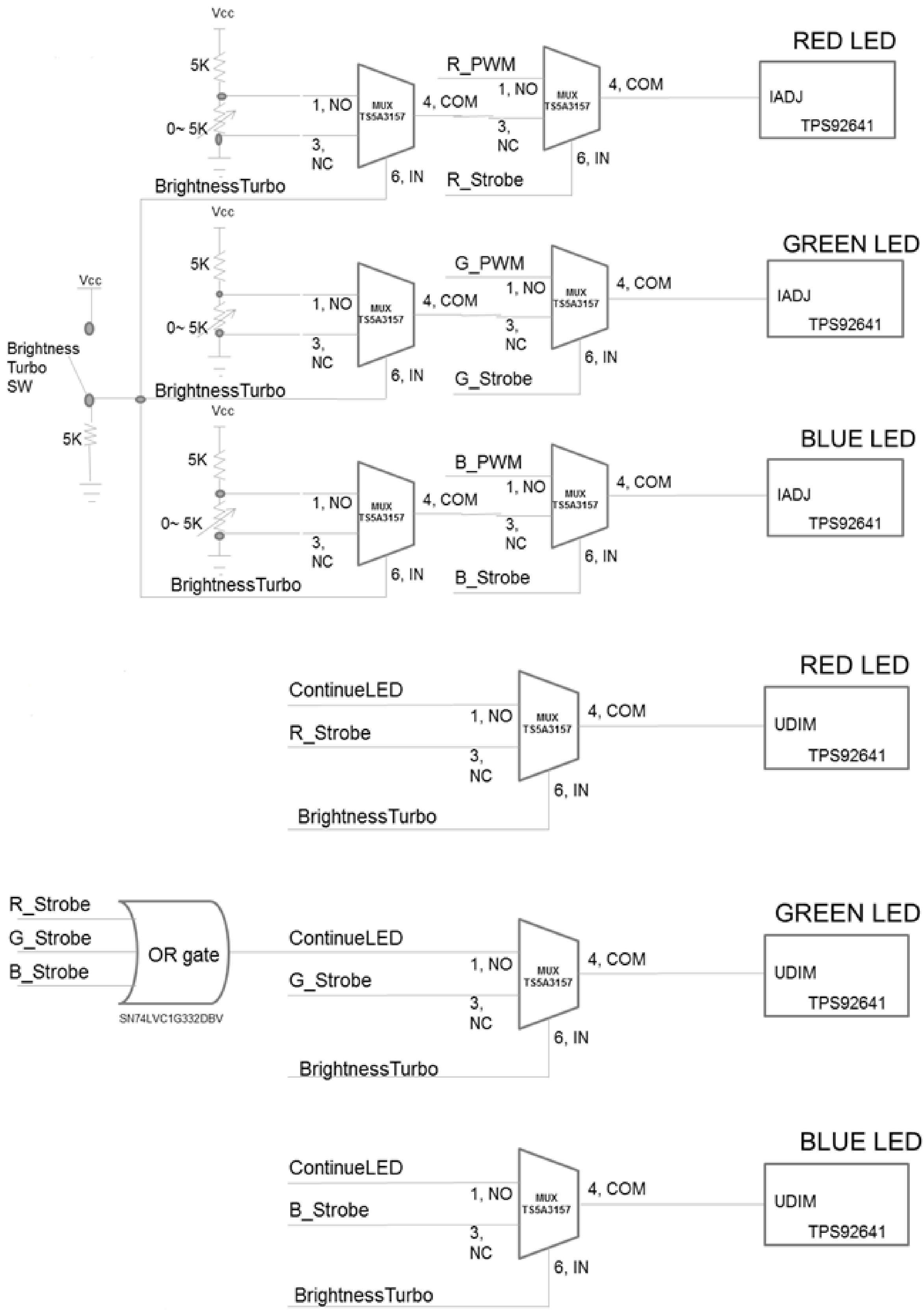


Figure 8. Brightness Turbo Circuit for R, G, B Channels

2.2 *The DLP® Composer Settings*

The Brightness Turbo implementation not only requires the hardware circuit modification, but also software setting. As Brightness Turbo shrinks the color gamut in different display modes, the Composer project supports the different color gamut in different sequence groups. The user has to update the R, G, and B color points depending on the boost level. Using incorrect color points Composer may result in non-smooth gray ramp, and contour.

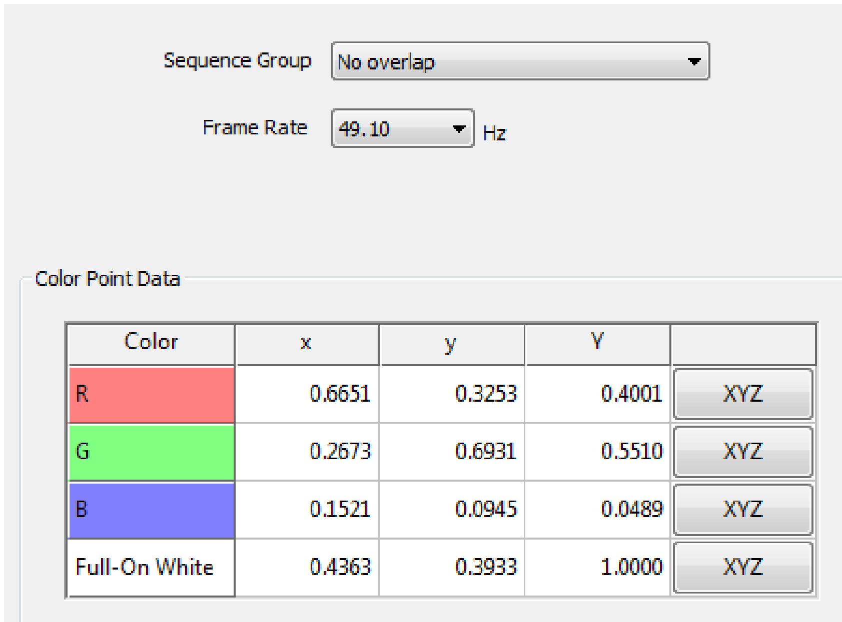


Figure 9. Original Color Gamut When Brightness Turbo Disabled

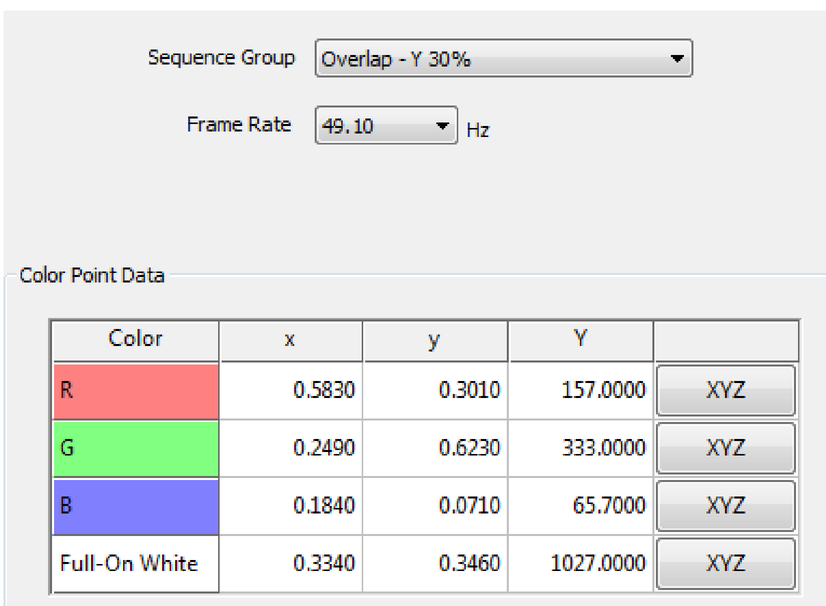


Figure 10. Smaller Color Gamut When Brightness Turbo Enabled

3 TPS92641 on DLP® Pico™ Products

3.1 Introduction

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 is operating at up to 1.0 MHz and 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.

3.2 TPS92641 Board Description

This EVM 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. The TS5A3157 IC is configured as an analog switch for logic of Brightness Turbo functions, and the SN74LVC1G332 IC is configured as an OR gate while Brightness Turbo is disabled. 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.

3.3 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 (V_{CS}) 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 I_{LED} setting is based on Equation 1:

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

$$V_{CS} = \frac{V_{IADJ}}{10} \tag{1}$$

For this application, ADJ has optional functions, the first one is tied to VREF through a resistor divider to fix the LED current, the second one is tied to TS5A3157 logics for the Brightness Turbo function.

3.4 PWM Dimming

The PWM dimming can be achieved via 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 (D_{DIM}) 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.

For this application, the UDIM pin is tied to TS5A3157 and SN74LVC1G322 logics for faster response and truly turns off while Brightness Turbo is disabled; UDIM will follow strobe signal to turns on and off the LED current. SDIM is tied to strobe signal while both Brightness Turbo and UDIM pin functions are disabled.

3.5 Schematic

Figure 11, Figure 12, and Figure 13 illustrate the TPS92641 Red, Green, and Blue LED Driver schematics. Figure 14 illustrates the Brightness Turbo logics schematic.

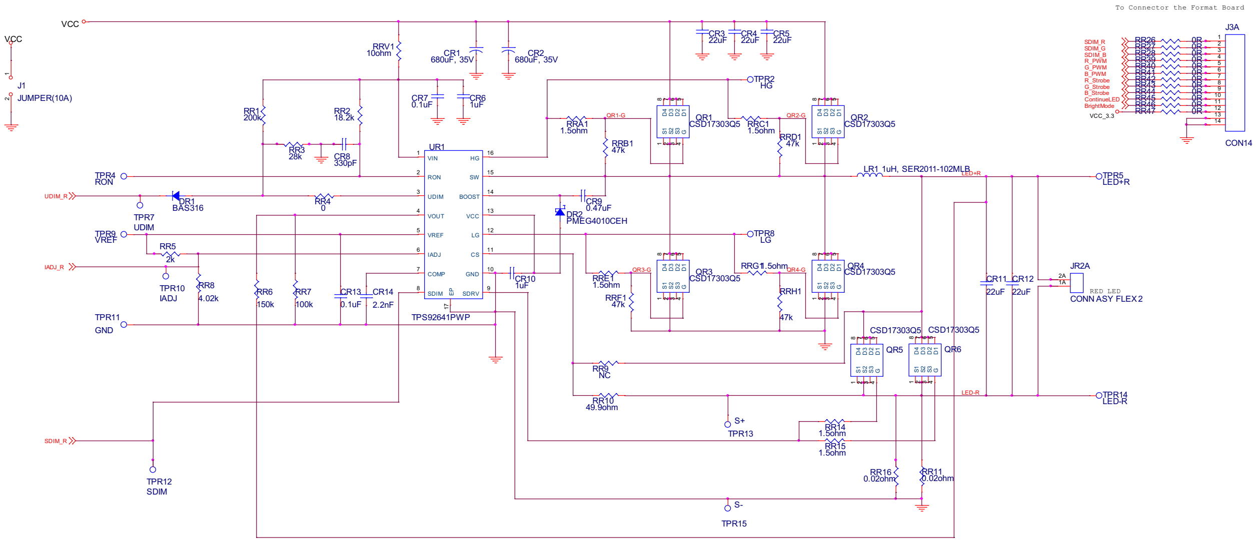


Figure 11. TPS92641 Red LED Driver Schematic

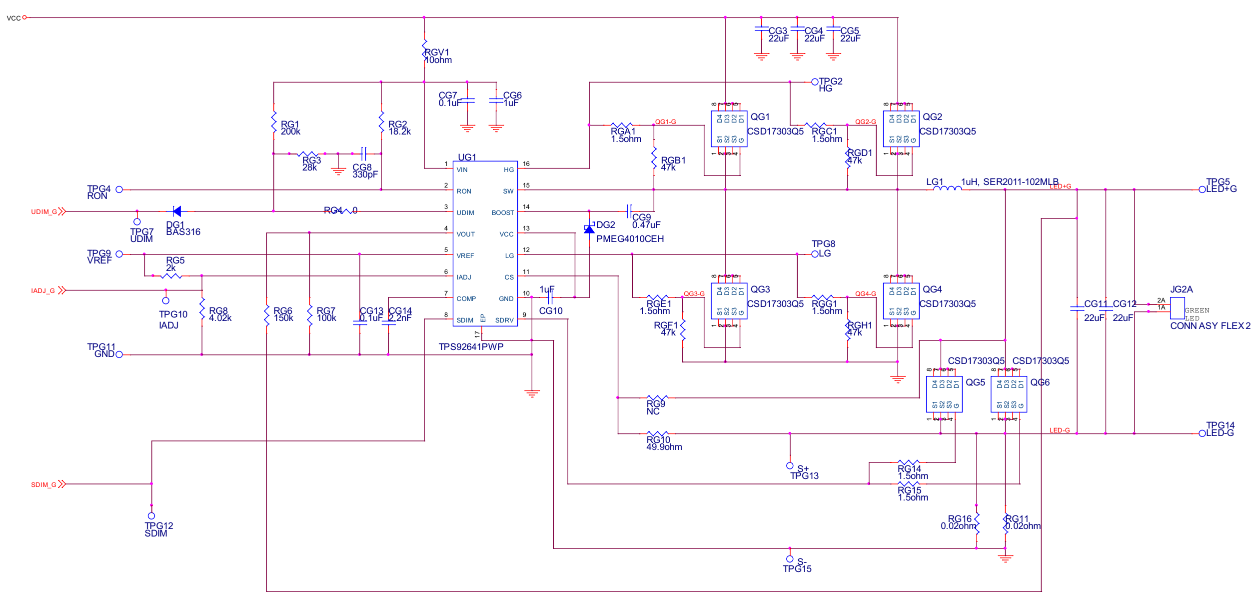


Figure 12. TPS92641 Green LED Driver Schematic

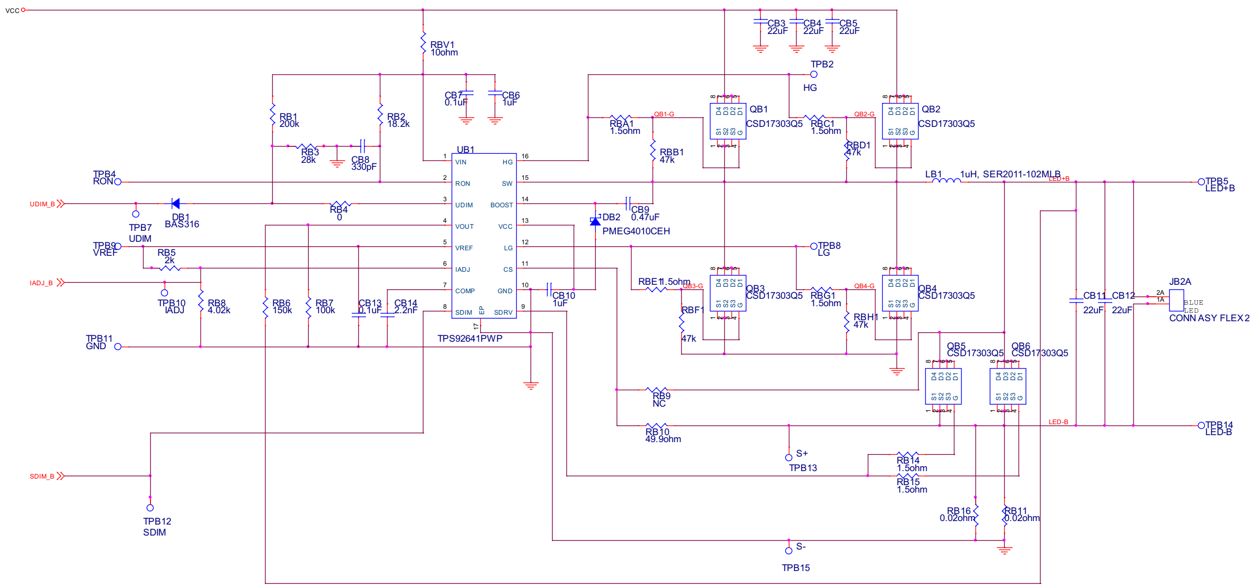


Figure 13. TPS92641 Blue LED Driver Schematic

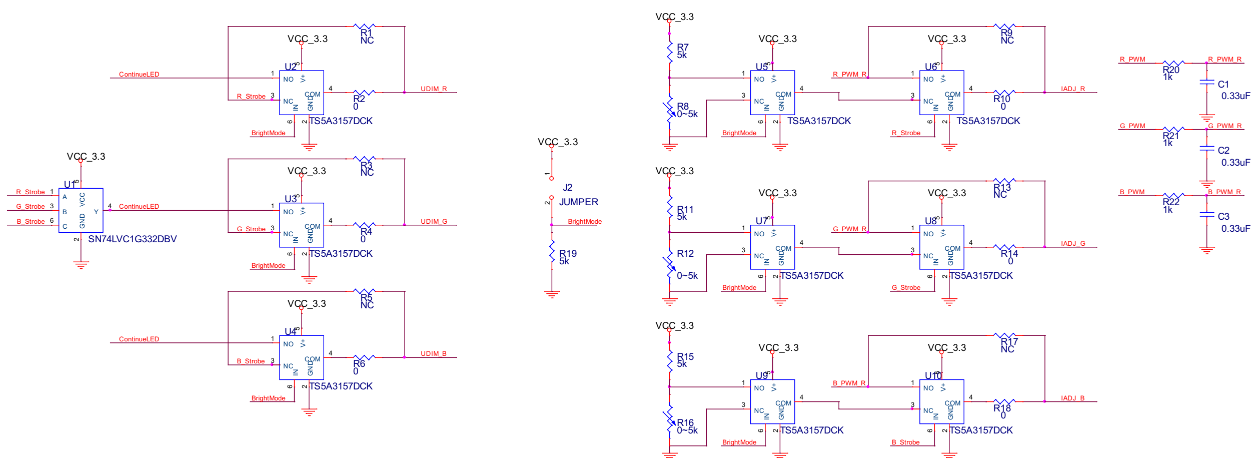


Figure 14. Brightness Turbo Logics Schematic

3.6 Layout

Figure 15, Figure 16, and Figure 17 illustrate the PCB layouts.

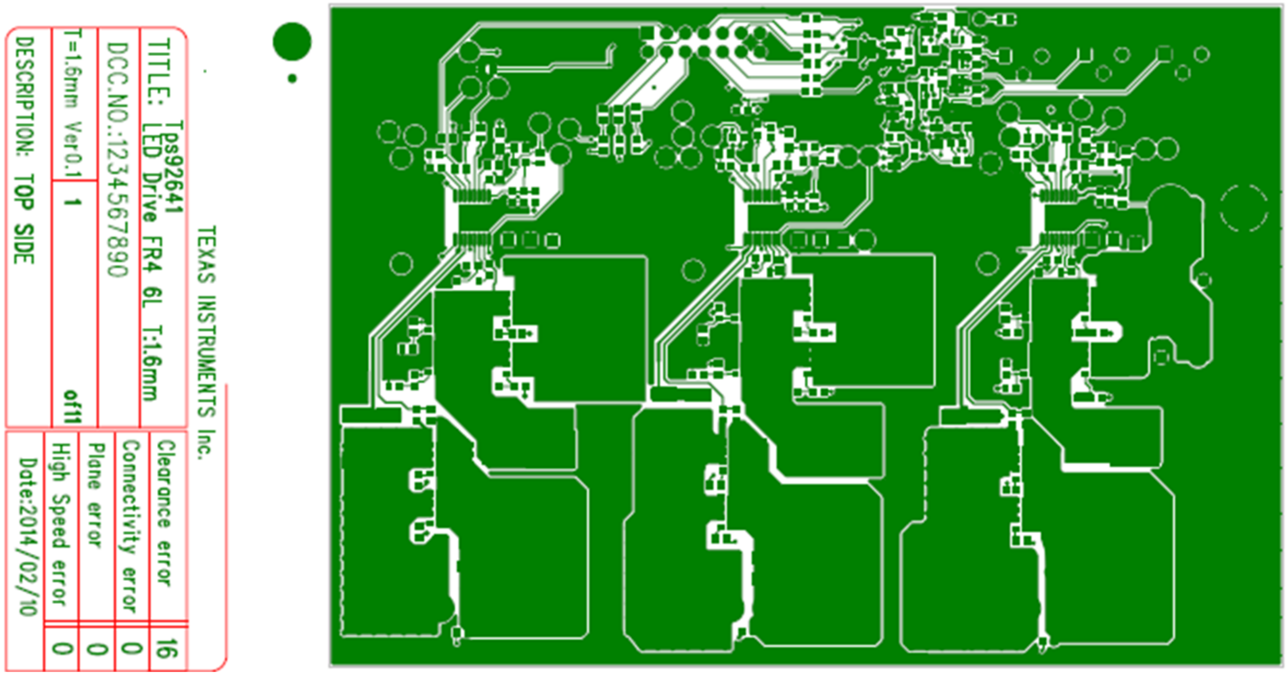


Figure 15. Top View

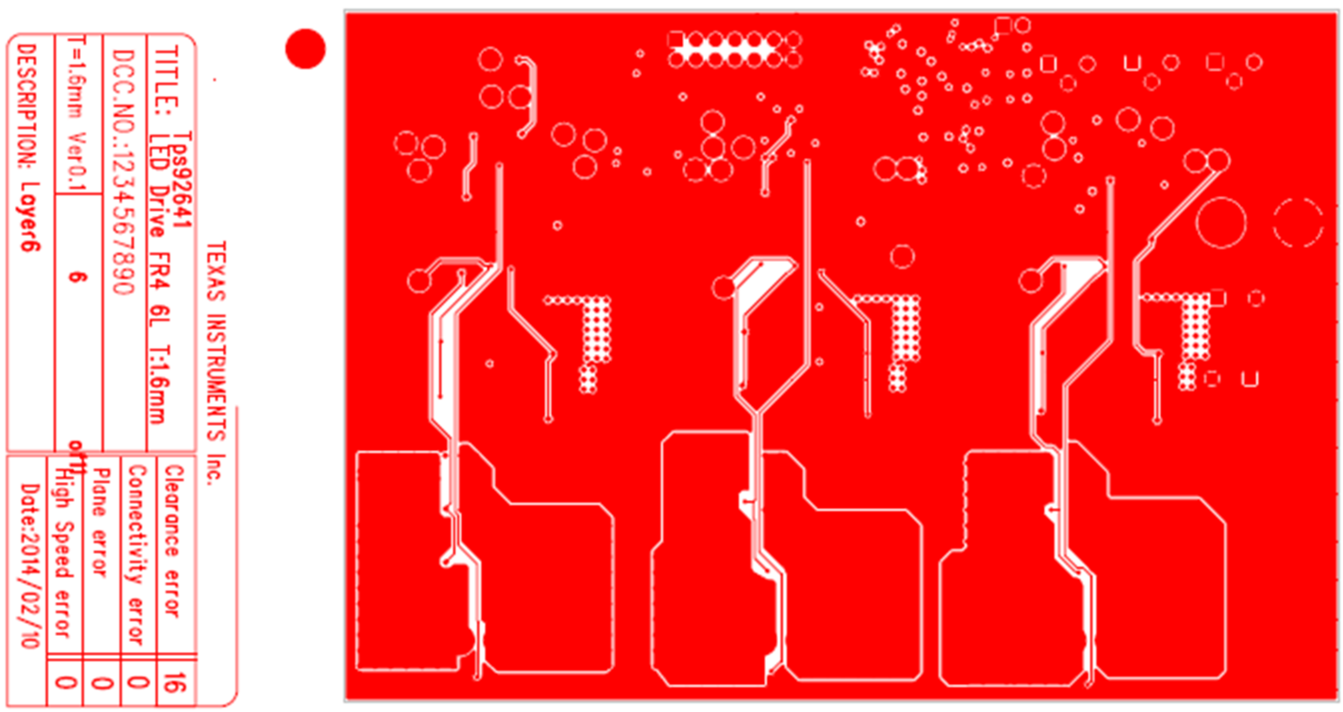


Figure 16. Bottom View

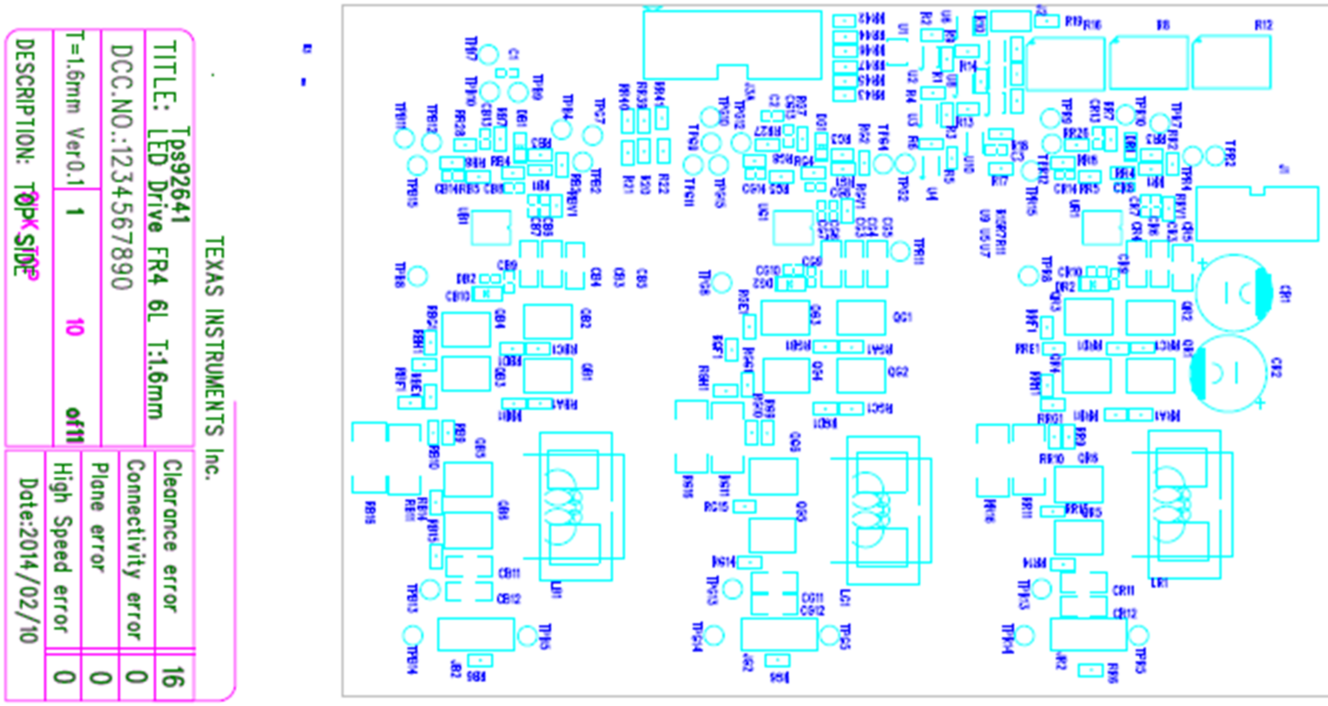


Figure 17. PCB Top View With Component

3.7 Bill of Materials (BOM)

Table 1 lists the bill of materials.

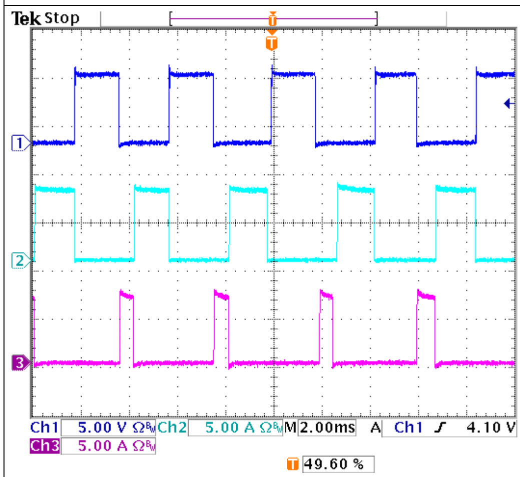
Table 1. Bill of Materials

Qty	ID	Part Number	Value	Description	Size	Vender
15	CR3, CG3, CB3, CR4, CG4, CB4, CR5, CG5, CB5 ,CR11, CG11, CB11,CR12, CG12, CB12	STD	22μF	Capacitor, Ceramic	805	STD
6	CR6, CG6, CB6, CR10, CG10, CB10	STD	1μF	Capacitor, Ceramic	603	STD
6	CR7, CG7, CB7, CR13, CG13, CB13	STD	0.1μF	Capacitor, Ceramic	603	STD
3	CR8, CG8, CB8	STD	330pF	Capacitor, Ceramic	603	STD
3	CR9, CG9, CB9	STD	0.47μF	Capacitor, Ceramic	603	STD
3	CR14, CG14, CB14	STD	2.2nF	Capacitor, Ceramic	603	STD
2	CR1, CR2	STD	680μF, 35V	CAP SMD ELECT	SMD	STD
3	C1, C2, C3	STD	0.33μF	Capacitor, Ceramic	603	STD
3	DR1, DG1, DB1	BAS316	VR<100V	Diodes	SC-90	NXP
3	DR2, DG2, DB2	PMEG4010CEH	VR=40V, IF=1A	Schottky	SC-90	NXP
3	JR2, JG2, JB2	STD	CONN ASY FLEX 2	30A Connector		STD
1	J1	JUMPER	10A	10A Jumper		STD
1	J2	JUMPER	2.54 mm Jumper	2.54mm Jumper		STD
1	J3A	CON14	2.54mm connector	14pin 2.54mm connector		STD
3	LR1,LG1,LB1	TMPC1265HP-1R0MG-D	1μH, INDUCTORS	1μH 30A		TAI Tech
18	QR1, QG1, QB1, QR2, QG2, QB2, QR3, QG3, QB3, QR4, QG4, QB4, QR5, QG5, QB5, QR6, QG6, QB6	CSD17303Q5	30V N Channel	30V N Channel NexFET	SON	TI
18	RRG1, RRE1, RRC1, RRA1, RGG1, RGE1, RGC1, RGA1, RBG1, RBE1, RBC1, RBA1, RR14, RG14, RB14, RR15, RG15, RB15	STD	1.5Ω	Resistor, Chip, 1/16-W, 1%	603	STD
12	RRH1, RRF1, RRD1, RRB1, RGH1, RGF1, RGD1, RGB1, RBH1, RBF1, RBD1, RBB1	STD	47kΩ	Resistor, Chip, 1/16-W, 1%	603	STD
3	RRV1,RGV1,RBV1	STD	10Ω	Resistor, Chip, 1/16-W, 1%	603	STD
3	RR1,RG1,RB1	STD	200kΩ	Resistor, Chip, 1/16-W, 1%	603	STD
3	RR2,RG2,RB2	STD	18.2kΩ	Resistor, Chip, 1/16-W, 1%	603	STD
3	RR3,RG3,RB3	STD	28kΩ	Resistor, Chip, 1/16-W, 1%	603	STD
9	R2, RR4, RG4, RB4, R4, R6, R10, R14, R18	STD	0Ω	Resistor, Chip, 1/16-W, 1%	603	STD
3	RR5, RG5, RB5	STD	2kΩ	Resistor, Chip, 1/16-W, 1%	603	STD
3	RR6, RG6, RB6	STD	150kΩ	Resistor, Chip, 1/16-W, 1%	603	STD
3	RR7, RG7, RB7	STD	100kΩ	Resistor, Chip, 1/16-W, 1%	603	STD
3	RR8, RG8, RB8	STD	4.02kΩ	Resistor, Chip, 1/16-W, 1%	603	STD
3	RR9, RG9, RB9	STD	NC	Resistor, Chip, 1/16-W, 1%	603	STD
3	RR10, RG10, RB10	STD	49.9Ω	Resistor, Chip, 1/16-W, 1%	603	STD
6	RR11, RG11, RB11, RR16, RG16, RB16	WSR5R0100FEA	0.02Ω	Res, Power Metal Strip, 2W, ±x%	4527	VISHAY
12	RR26, RR27, RR28, RR39, RR40, RR41, RR42, RR43, RR44, RR45, RR46, RR47	STD	0 Ω	Resistor, Chip, 1/16-W, 1%	603	STD
6	R1, R3, R5, R9, R13, R17	STD	NC	Resistor, Chip, 1/16-W, 1%	603	STD
4	R7, R11, R15, R19	STD	5kΩ	Resistor, Chip, 1/16-W, 1%	603	STD
3	R8, R12, R16	STD	0~5kΩ	Variable resistor		STD
3	R20, R21, R22	STD	1kΩ	Resistor, Chip, 1/16-W, 1%	603	STD
3	UR1, UG1, UB1	TPS92641PWP	Synchronous buck controller for LED driver	LED Drivers	TSSOP	TI
1	U1	SN74LVC1G332DBV	5.5V	OR Gate	SOT-23	TI
9	U2, U3, U4, U5, U6, U7, U8, U9, U10	TS5A3157DCK	10Ω	10 Ω Analog switch	SOT-23	TI

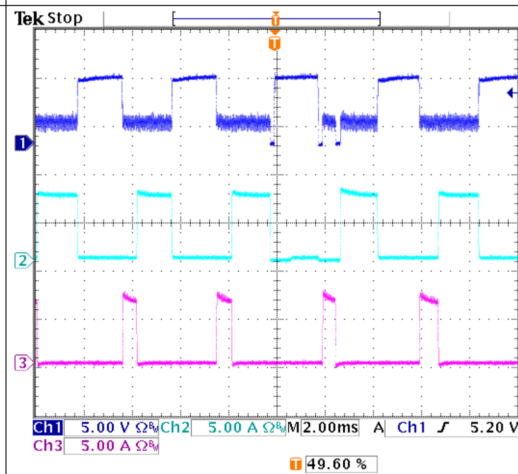
4 Brightness Turbo + TPS92641 Measurement Data

Table 2. Test Waveforms

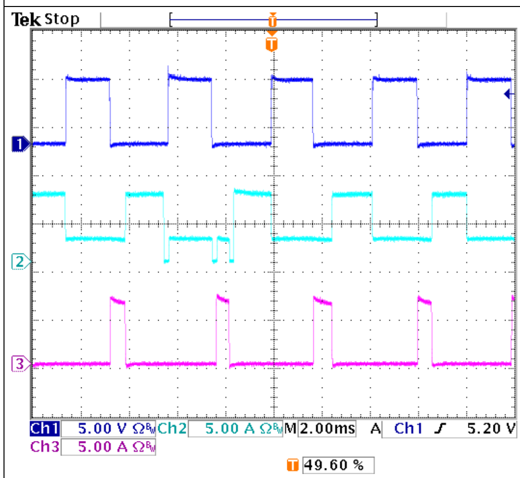
Without Brightness Turbo
Ch1: Red current
Ch2: Green current
Ch3: Blue current



Red Brightness Turbo
Ch1: Red current
Ch2: Green current
Ch3: Blue current



Green Brightness Turbo
Ch1: Red current
Ch2: Green current
Ch3: Blue current



Blue Brightness Turbo
Ch1: Red current
Ch2: Green current
Ch3: Blue current

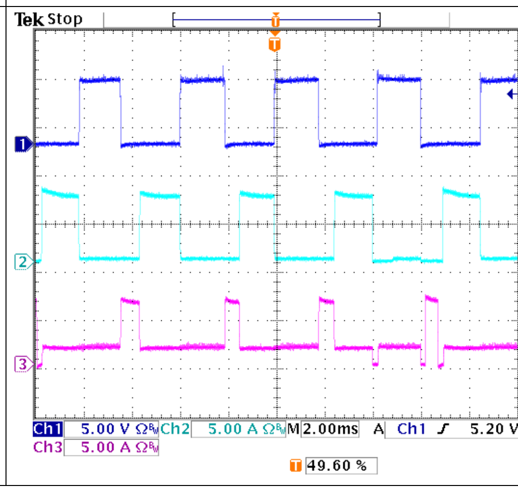


Table 3. Power vs Brightness Measurement

Brightness Turbo	On	Off
VIN	11.932 V	11.986 V
IIN	3.15 A	2.70 A
P Input (Watt)	37.59 W	32.36 W
Brightness (Lux)	3861	3082
ColorTemp (°K)	6468°K	6293°k
Power Increase (%)	16%	
Brightness Increase (%)	25%	