TI Designs

RGB LED Signal Tower for Industrial Automation Reference Design

TI Designs

This TI Design details a multisegment RGB signal tower for industrial-process automation. The design enables flexible control of the LED color and brightness and allows users to change the amount of LED segments. With this smart-process condition and safety indicator, any type of industrial stack light can be detected and configured with software.

Design Resources

TIDA-00979	Design Folder
TLC5971	Product Folder
LMZ35003	Product Folder
MSP430F5528	Product Folder
HDC1080	Product Folder
TPD2E001	Product Folder

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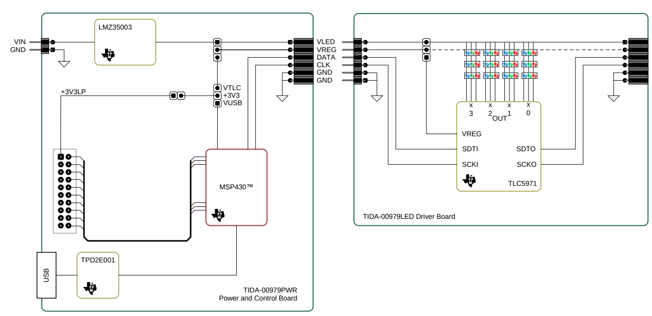
Design Features

- Flexible and Easy to Control RGB LED Tower Light Design
- Different Configurable Modes: Stack Light, Level Indication, Flash Light
- Controllable RGB Color, Brightness, and Blinking Speed
- One to Five RGB LED Segments With Four Individual Channels Each
- Adjustable Maximum LED Current up to 60 mA for Each Channel

Featured Applications

- Factory Automation and Control
- Building Automation



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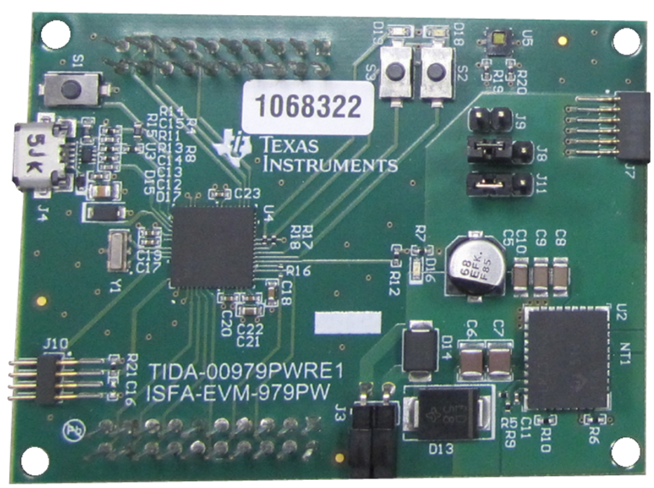

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1 Key System Specifications

Table 1 shows the key system specifications.

Table 1. Key System Specifications

PARAMETER	SPECIFICATION
Power Supply	V_{IN_MIN} = 18 V
	V_{IN_MAX} = 36 V
	V_{OUT} = 12 V (5 V)
Interfaces	GPIO
	SPI, I^2C, UART
	USB
	LaunchPad Development Kit, BoosterPack
LED	RGB
	Max 60 mA for each channel
	Brightness control
	Daisy-chainable

2 System Description

Industrial signal lights indicate the status of manufacturing equipment or the status of processes in industrial environments. These lights are often called stack lights, tower lights, or indicator lights, and contain one to five difference colors. The IEC 60073 standard shows how the colors correspond to different states (see Table 2).

Table 2. IEC 60073 International Color Usage

COLOR	SAFETY MEANING	CONDITION OF A PROCESS
RED	Danger	Emergency or fault
AMBER	Warning	Abnormal
GREEN	Safe	Normal
BLUE	Mandatory significance	
WHITE	No specific meaning assigned	

This TI Design provides a flexible solution based on RGB light-emitting diodes (LEDs) and a modular approach. The solution has two printed circuit boards (PCBs) (see Figure 1):

- Power and control board (TIDA-00979PW)
- LED driver with RGB LEDs (TIDA-00979LD)

Because of the modular design, it is possible to daisy chain up to five LED boards to one power and control board. More LEDs can be used by using a higher power-management solution.

Depending on the LED configuration, an input voltage (V_{IN}) supply from 7 V to 50 V is feasible. Controlling the different modes is highly flexible and could be:

- GPIO
  - GPIOs can be used for a typical control of stack lights with wires.
- SPI, I^2C, and UART
  - Any type of interface, such as wireless or I/O link, with a SPI, I^2C, or UART interface is controllable by the system.
- USB
  - The microcontroller (MCU) in this TI Design has a USB port that can be connected to a USB host system.

This design can be configured to be:

- A simple one-color stack light
- A multicolor stack light
- A tower light with single or multicolor

3 Block Diagram

Figure 1 shows the block diagram of this design.

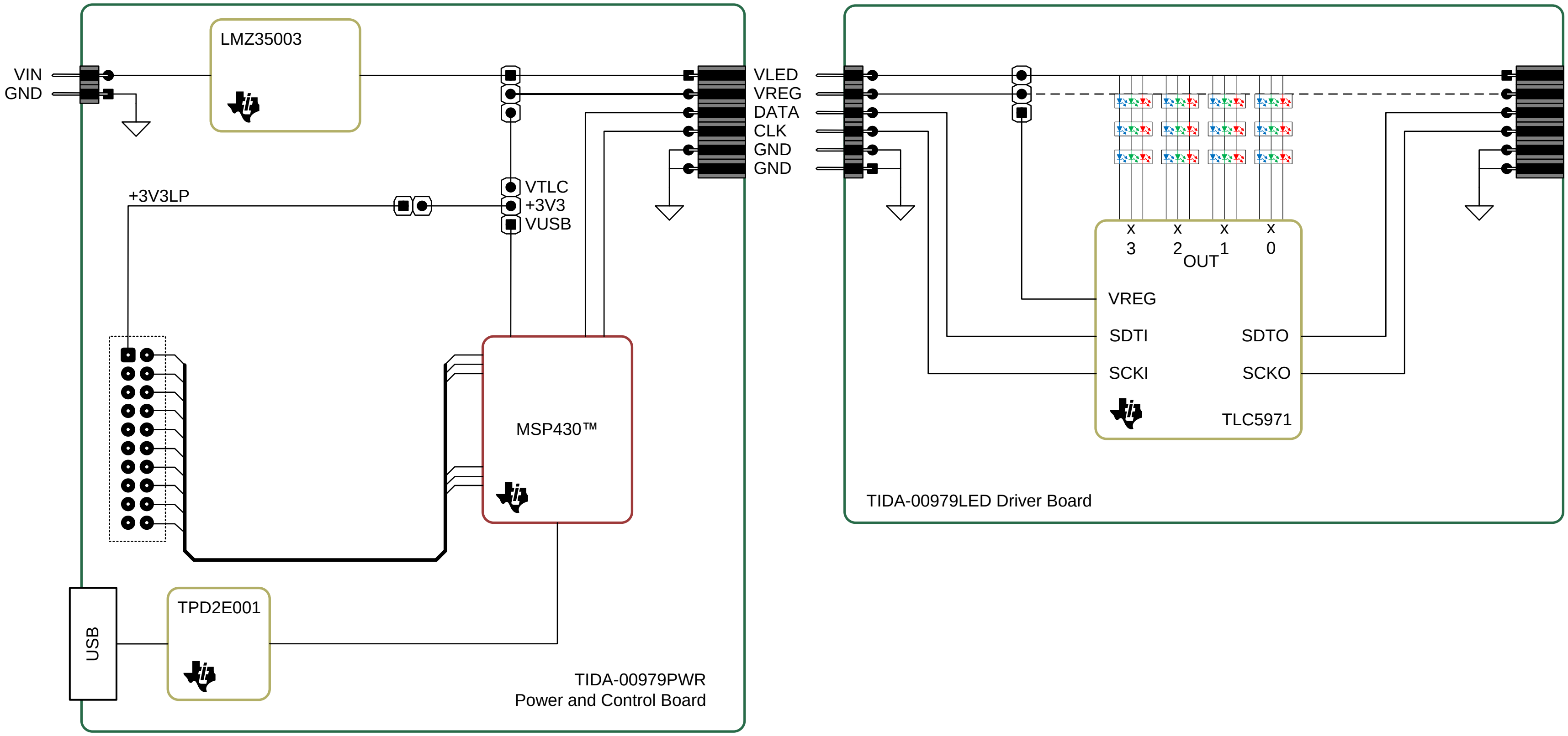

Figure 1. Block Diagram

3.1 Highlighted Products

The Reference Design features the TLC5971, LMZ35003, MSP430F5528, HDC1080, and TIPD2E001.

For more information on each of these devices, see their respective product folders at www.ti.com.

3.1.1 TLC5971

The TLC5971 device is a 12-channel, constant-current sink driver. Each output channel has individually adjustable currents with 65536 pulse-width modulation (PWM) greyscale (GS) steps. Each color group can be controlled by 128 constant-current sink steps with the global brightness control (BC) function. GS control and BC are accessible through a two-wire signal interface. The maximum current value for each channel is set by a single external resistor. All constant-current outputs are turned off when the IC is in an overtemperature condition. Figure 2 shows the functional block diagram of the TLC5971 device.

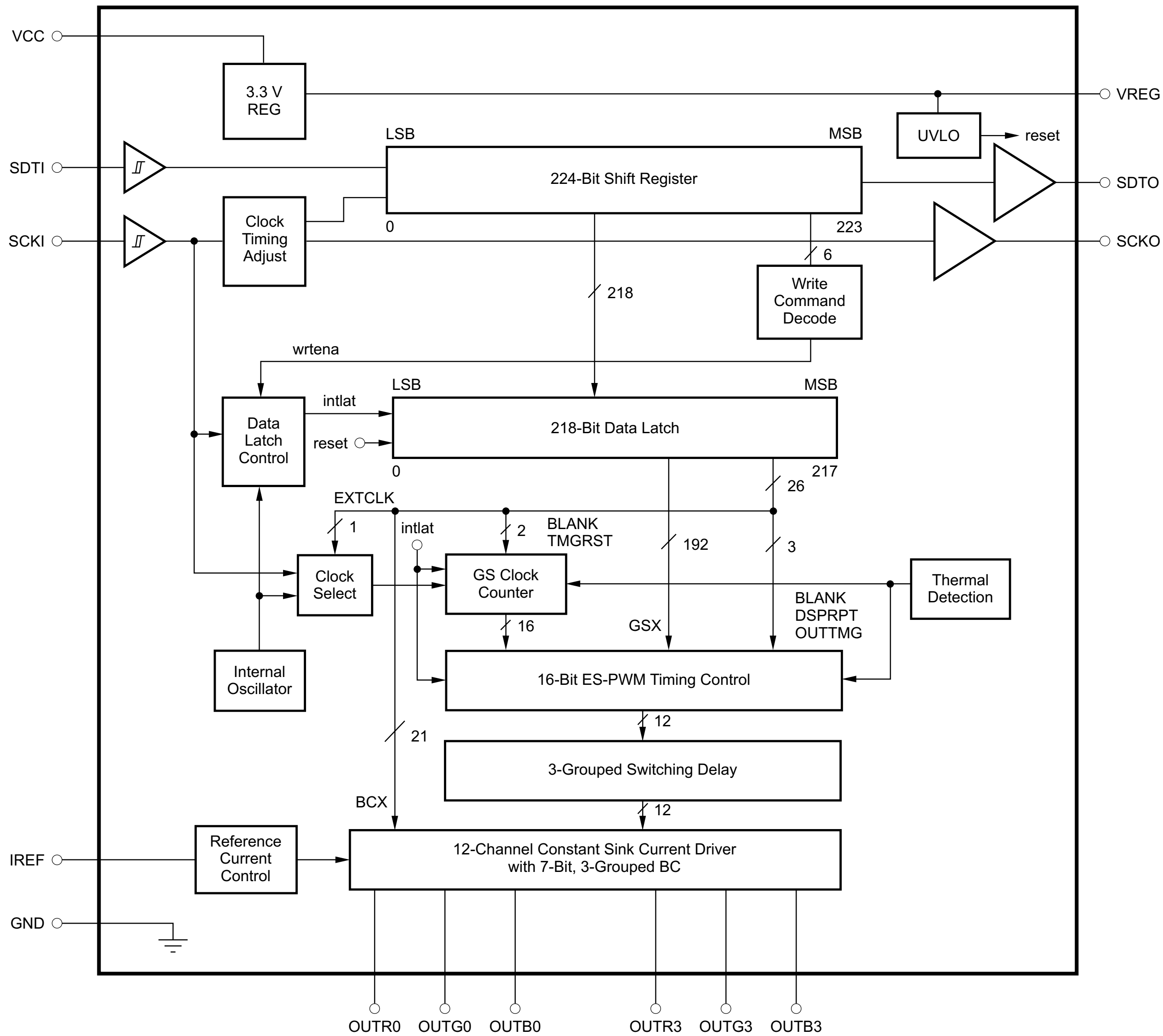

Figure 2. TLC5971 Functional Block Diagram

3.1.2 LMZ35003 SIMPLE SWITCHER®

The LMZ35003 SIMPLE SWITCHER® power module is an easy-to-use integrated power solution that combines a 2.5-A DC-DC converter with a shielded inductor and passives into a low-profile QFN package. This total power solution allows as few as five external components and eliminates the loop compensation and magnetics part-selection process.

The small 9-mm × 11-mm × 2.8-mm QFN package is easy to solder onto a PCB and allows a compact point-of-load design with greater than 90% efficiency and excellent power dissipation capability. The LMZ35003 offers the flexibility and the feature-set of a discrete point-of-load design and is ideal for powering a wide range of ICs and systems. Advanced packaging technology affords a robust and reliable power solution that is compatible with standard QFN mounting and testing techniques. Figure 3 shows the functional block diagram of the LMZ35003 device.

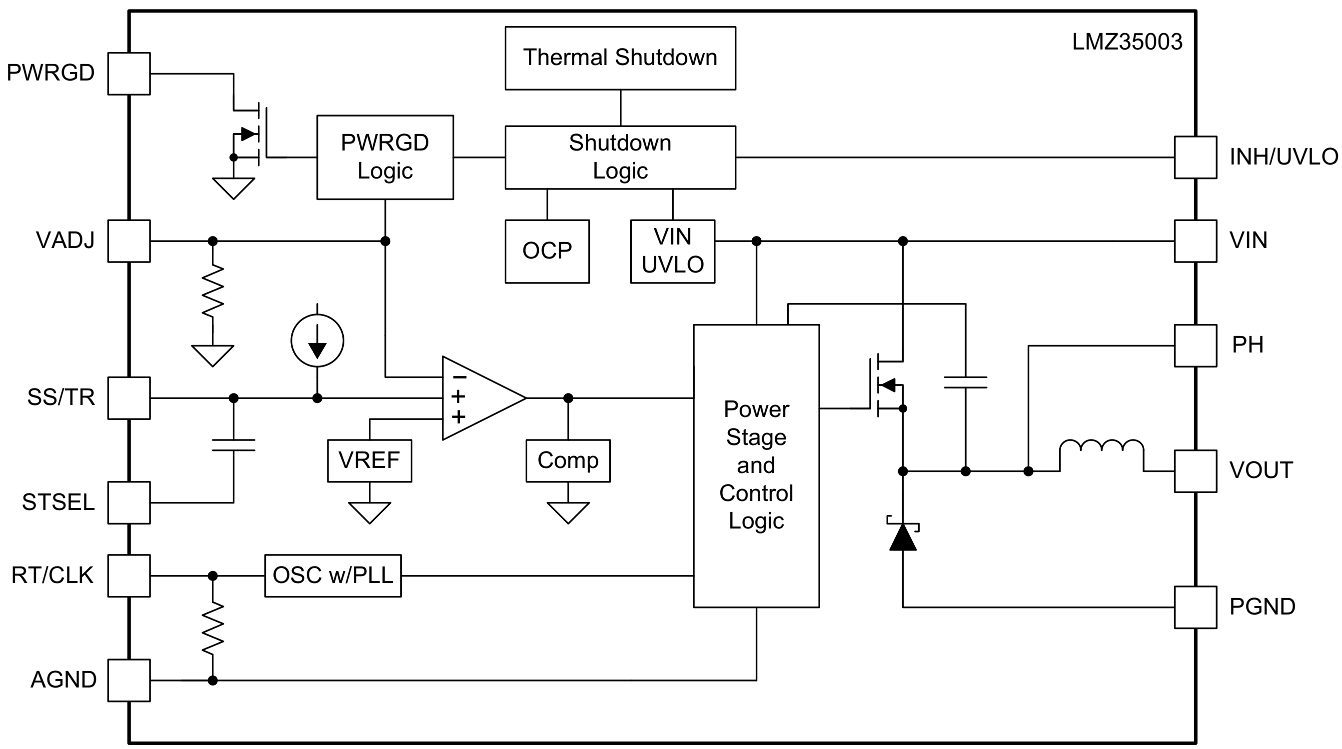

Figure 3. LMZ35003 Functional Block Diagram

3.1.3 MSP430F5528

The TI MSP430™ family of ultra-low-power MCUs consists of several devices featuring peripheral sets targeted for a variety of applications. The architecture, combined with low-power modes, is optimized to achieve extended battery life in portable measurement applications. The MCU features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally controlled oscillator (DCO) allows the devices to wake up from low-power modes to activate in 3.5 µs (typical).

The MSP430F5529, MSP430F5517, MSP430F5525, and MSP420F5521 MCUs have integrated USB and PHY, supporting USB 2.0, four 16-bit timers, a high-performance 12-bit analog-to-digital converter (ADC), two universal serial communication interfaces (USCI), a hardware multiplier, DMA, a real-time clock (RTC) module with alarm capabilities, and 63 I/O pins. The MSP430F5528, MSP420F5526, MSP430F5524, and MSP430F5522 MCUs have all of these peripherals, but have 47 I/O pins.

The MSP420F5519, MSP430F5517, and MSP430F5515 MCUs have integrated USB and PHY supporting USB 2.0, four 16-bit timers, two USCIs, a hardware multiplier, DMA, an RTM module with alarm capabilities, and 63 I/O pins. The MSP430F5514 and MSP430F5513 MCUs include all of these peripherals but have 47 I/O pins.

Typical applications include analog and digital sensor systems, data loggers, and others that require connectivity to various USB hosts. Figure 4 shows the functional block diagram of the MSP430F5528 device.

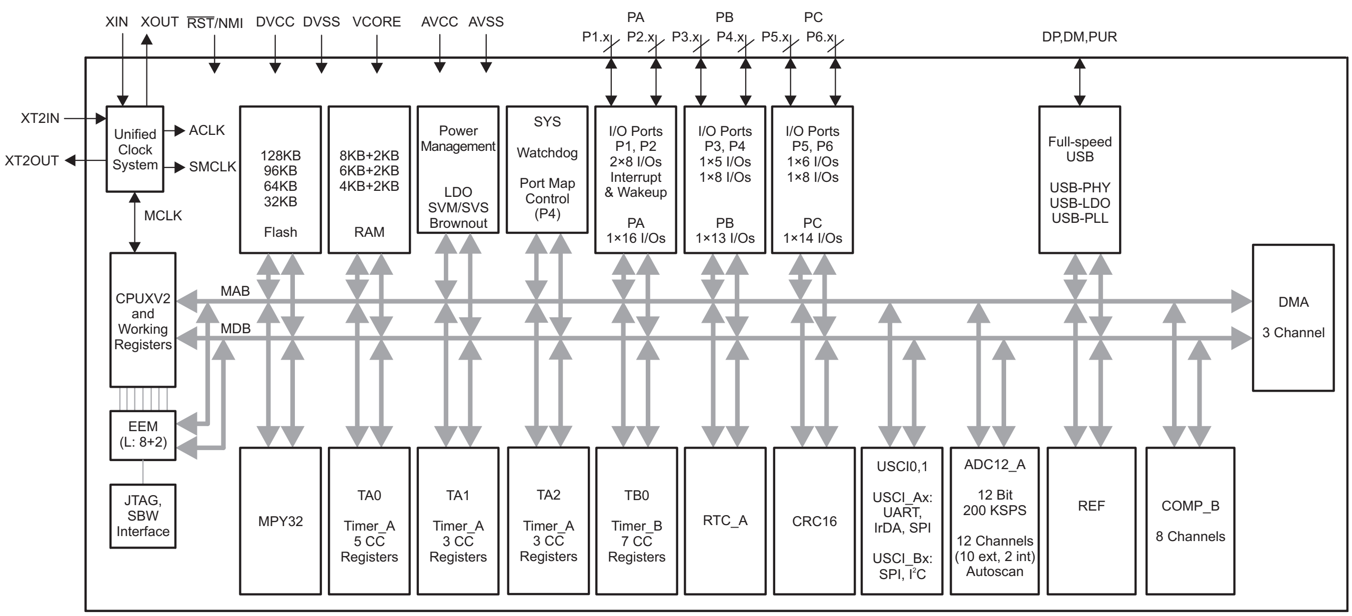

Figure 4. MSP430F5528 Functional Block Diagram

3.1.4 HDC1080

The HDC1080 is a digital humidity sensor with an integrated temperature sensor that provides excellent measurement accuracy at low power. The HDC1080 operates over a wide supply range, and is a low-cost, low-power alternative to competitive solutions in a wide range of common applications. The humidity and temperature sensors are factory calibrated.

Figure 5 shows the functional block diagram of the HDC1080 device.

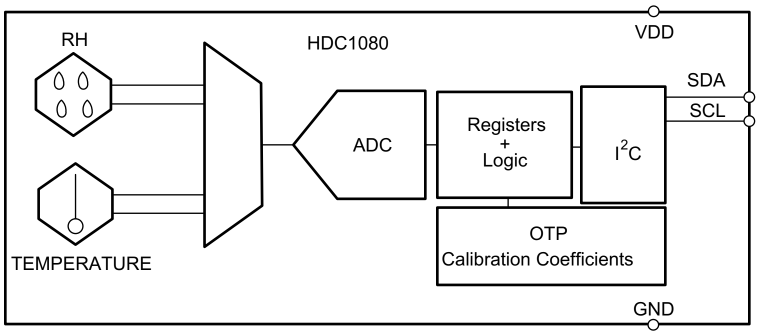

Figure 5. HDC1080 Functional Block Diagram

3.1.5 TPD2E001

The TPD2E001 is a 2-channel, transient voltage suppressor (TVS) based, electrostatic discharge (ESD) protection diode array (see Figure 6). The TPD2E001 is rated to dissipate ESD strikes at the maximum level that is specified in the IEC 6100-42 Level 4 international standard.

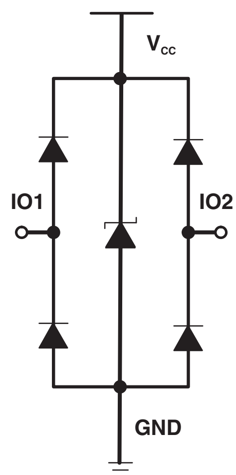

Figure 6. TPD2E001 Diagram

4 System Design Theory

This TI Design is flexible, enabling many different versions and variants to be achieved. This TI Design details one version (see Section 4.1). Some comparisons to other use cases are also listed in this section.

4.1 System Overview

Figure 7 shows the LED driver and RGB LED board description.

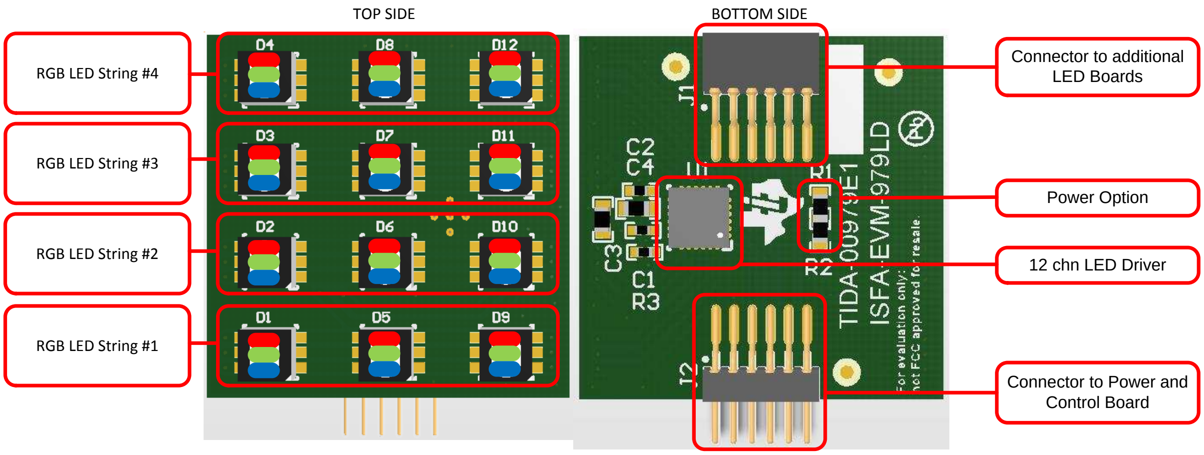

Figure 7. LED Driver and RGB LED Boards

Figure 8 shows the power and control board description.

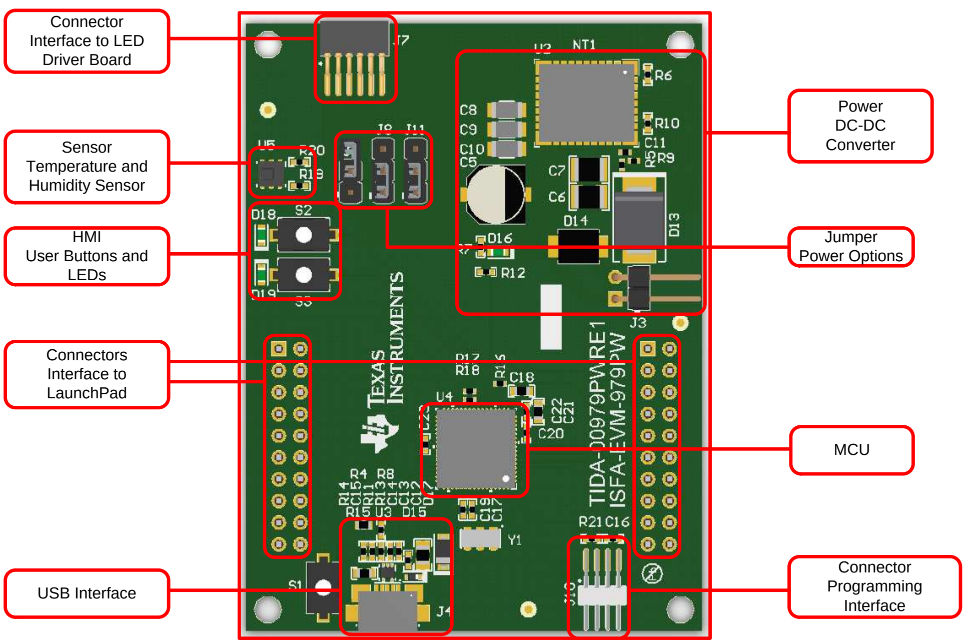

Figure 8. Power and Control Board

4.2 LED Control

There are many solutions for controlling LEDs. The LED requires a constant current. The variety of available LEDs is large, and the brightness is usually dependent on the current that is going through the LED.

In this TI Design, the 12-channel RGB LED driver (TLC5971) controls the LEDs and provides the following advantages.

- Dedicated RGB LED controller
- Twelve independent constant-current sinks to adjust to the current for each channel
- Ability to use the driver with different types of LEDs with up to 60 mA for each channel
- Simple two-wire interface to control the TLC5971 from an MCU
- Several devices are can be daisy-chained

Figure 9 shows the schematic of the TLC5971 and the RGB LED matrix. Each channel of the LED driver has a string of three LEDs in series. The amount of LEDs for each string depends on the application and which LEDs are used. The more LEDs that are in series, the higher VLED (sum of the forward voltages) has to be.

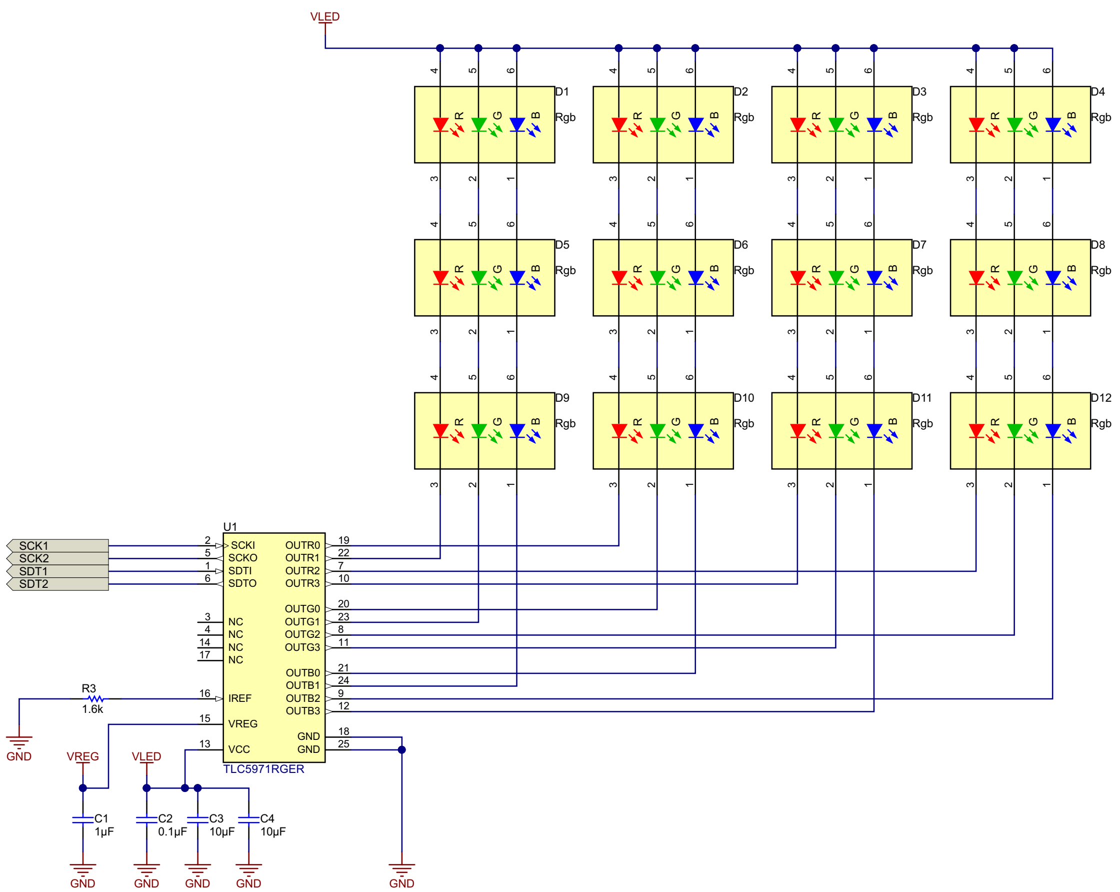

Figure 9. Schematic of LED Control

This setup results in a 4 × 3 RGB LED matrix where the four strings can be controlled independently in terms of color and brightness (see Figure 10).

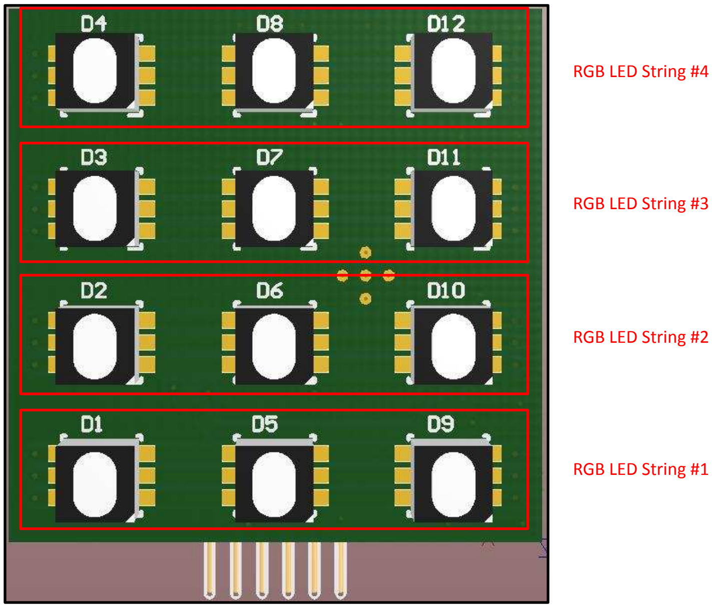

Figure 10. RGB LED Matrix PCB

4.2.1 RGB LED

In this TI Design, the RGB LED CLX6C-FKB that comes in a PLCC6 package is used (see [1]). This package is common for LEDs, allowing users to easily switch to different LEDs. Table 3 shows a summary of important data sheet parameters for further calculations.

Table 3. RGB LED Data Sheet Parameters

PARAMETER	RED	GREEN	BLUE
MAximum forward current I_F [mA]	50	35	35
Maximum power dissipation P_D [mW]	125	130	130
Average forward voltage V_F at I_F = 8 mA [V]	1.9	3.0	3.0
Maximum forward voltage V_F at I_F = 8 mA [V]	2.5	3.7	3.7

4.2.2 Requirement for LED Supply Voltage (V_{LED})

The TLC5971 can be configured in different ways. Figure 11 shows the implementation used for this design. The system in this TI Design uses the built-in linear regulator to provide 3.3 V from V_{LED}. The maximum (V_{LED_MAX}) is given by the TLC5971 of 17 V. Calculate the maximum number of LEDs for each string by using V_{LED_MAX} = 17 V and Equation 1.

$$\frac{V_{LED\_MAX}}{V_{F\_MAX}} = \frac{17\ V}{3.7\ V} = 4.6\ V \tag{1}$$

In this design, the maximum number of LEDs for each string that can be used is four (assuming that V_{F_MAX} = 3.7 V at I_F = 8 mA).

If more LEDs are required for an application, a different architecture can be designed. Please refer to the TLC5971 data sheet for further information.

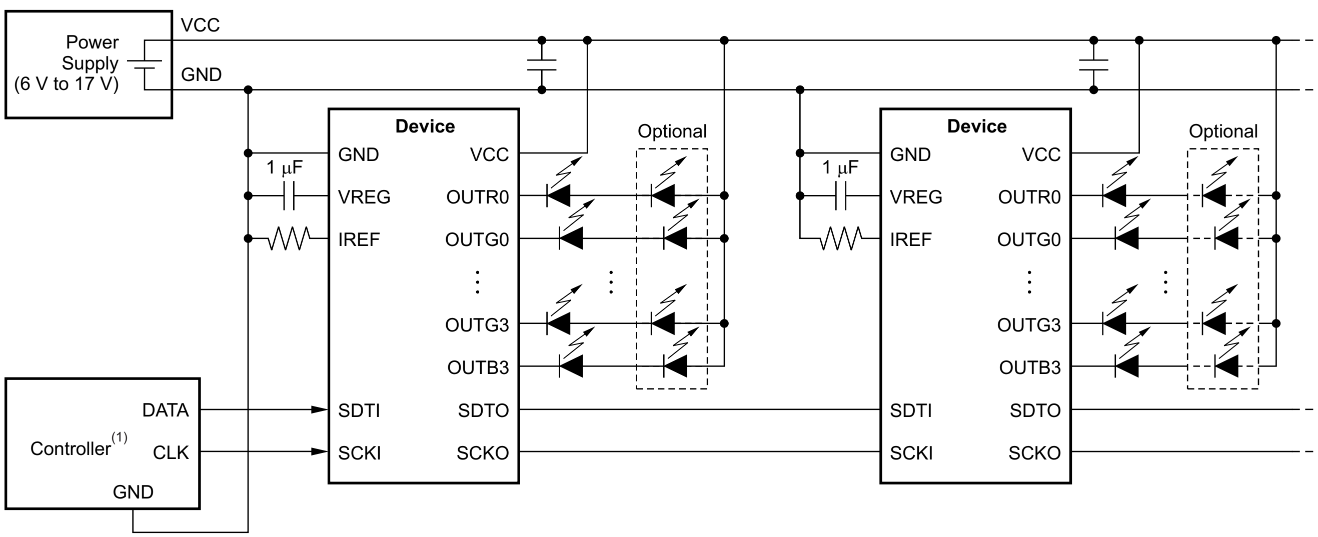

Figure 11. Example of Typical Application Circuit of TLC5971

This TI Design has three LEDs for each channel. Calculate V_{LED} by using Equation 2.

$$V_{LED} \geq nLED \times V_{F\_MAX} = 3 \times 3.7\ V = 11.1\ V \tag{2}$$

Where:

- nLED is the amount of LEDs for each string

NOTE: The forward voltages in Table 3 are valid for a forward current of 8 mA.

Different LED colors have different forward voltages. The red LED has an average forward voltage of 1.9 V, and the green and blue LED have an average forward voltage of 3 V (forward current of 8 mA). The data sheets shows graphs of forward current versus forward voltage to better dimension the circuitry.

The difference in voltage between V_{LED} and nLED × V_F will be dropped in the TLC5971. There is also a voltage required within the TLC5971 for proper operation. Figure 12 and Figure 13 are from the TLC5971 data sheet and show the needed output voltage that is available at the device for a given output current.

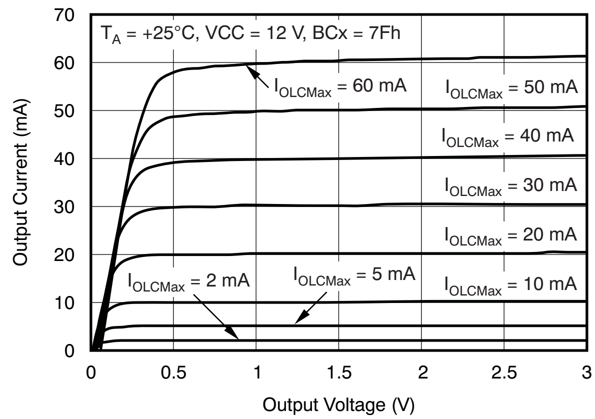

Figure 12. Output Current Versus Output Voltage

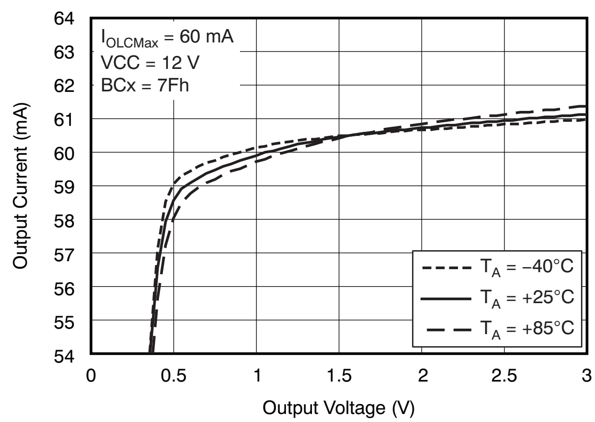

Figure 13. Output Current Versus Output Voltage: 2

Table 4 is an overview of the voltage drop inside of the TLC5971 and the power dissipation for a current of 10 mA and the given forward voltages of the LED.

Table 4. TLC5971 Voltage Drop and Power Dissipation

	V_F [V]	3 × V_F [V]	V_{LED} [V]	V_{OUT} [V]	I_{LED} [mA]	P_{DISS} [mW]
RED_average	1.9	5.7	12	6.3	10	63
GREEN_average	3	9	12	3	10	30
BLUE_average	3	9	12	3	10	30
TOTAL_average						**123**
RED_max	2.5	7.5	12	4.5	10	45
GREEN_max	3.7	11.1	12	0.9	10	9
BLUE_max	3.7	11.1	12	0.9	10	9
TOTAL_max						**63**

Figure 14 shows the voltage drop behavior across the LED current for different topologies. The blue lines indicate the power dissipation for the setup in this TI Design. The green lines show the power dissipation if only one LED for each string (at 12 V) is used. The orange lines show the power dissipation with one LED for each string when V_{LED} is set to 5 V.

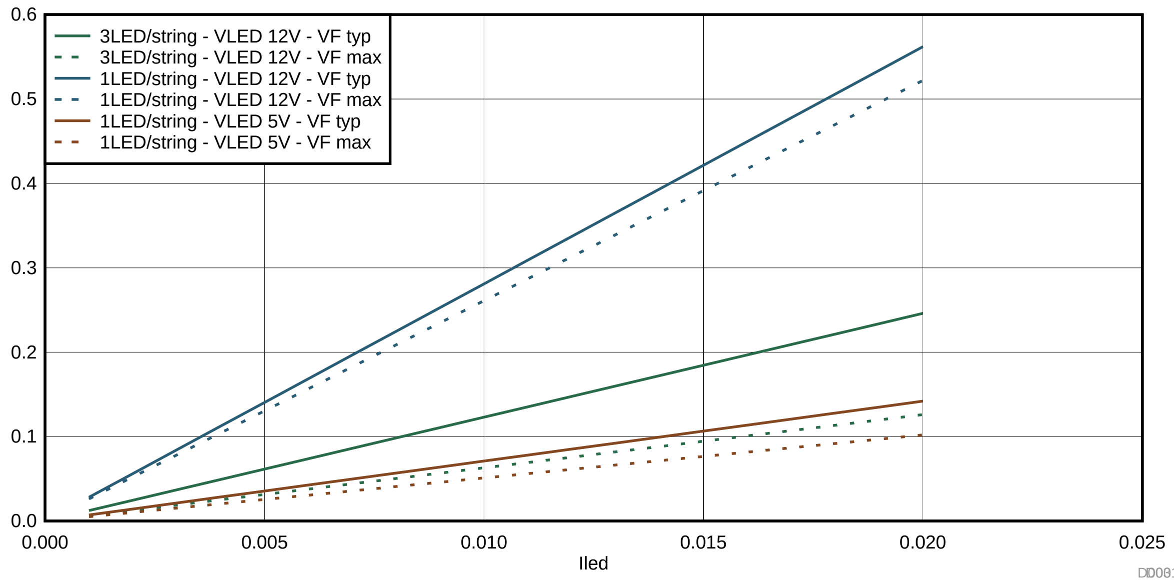

Figure 14. Power Dissipation in TLC5971 Versus LED current for Different Topolgies

For different applications and different LEDs it is possible to optimize the solution for the highest efficiency.

4.2.3 Constant-Current Settings of TLC5971

The TLC5971 can provide up to 60 mA for each channel, but the maximum constant current set with resistor R3 at PIN 16 (IREF) is 20 mA. When using different LEDs, the maximum current can be set to higher values.

4.2.4 Connector and Power Option Settings

The LED driver PCB has two connectors: J1 and J2. Use these two connectors to daisy chain up to five LED PCBs (see Table 5).

Table 5. Connections of LED Driver Board

CONNECTOR - PIN	DESCRIPTION
J1 - 1	GND
J1 - 2	GND
J1 - 3	SDT2
J1 - 4	SCK2
J1 - 5	VLED or VREG
J1 - 6	VLED
J2 - 1	GND
J2 - 2	GND
J2 - 3	SDT1
J2 - 4	SCK1
J2 - 5	VLED or VREG
J2 - 6	VLED

The TLC5971 has an internal regulator that outputs 3.3 V at PIN VREG. The 3.3 V at VREG can supply the 3.3-V rail of the LED control board. In this case, R1 has to be DNP and R2 = 0R. In the default configuration, R1 is 0R and R2 is DNP, and J2 pin 5 has the voltage level (VLED).

NOTE: Verify the correct jumper settings of both boards (TIDA-00979PW and TIDA-00979LD) to avoid damage (see Table 6).

Table 6. Power Options

TIDA-00979PW		TIDA-00979LD	
J11: 1 to 2 J8: 1 to 2	3.3 V from MSP is provided	R1 = 0R R2 = DNP	J1 to J5 and J2 to J5: VLED
J11: 2 to 3 J8: 2 to 3	3.3 V from TLC is provided	R1 = DNP R2 = 0R	J1 to J5 and J2 to J5: VREG

Figure 15 shows the connector and power options of the LED control board.

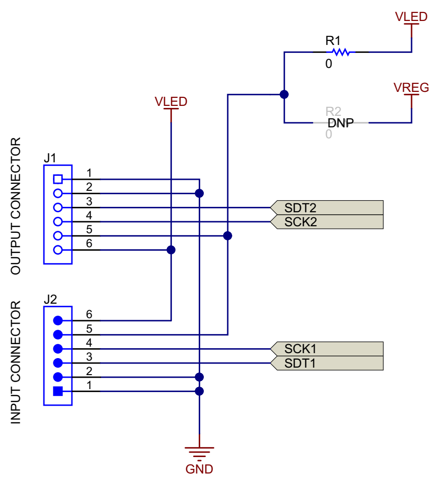

Figure 15. Connector and Power Options of LED Control Board

4.3 Power Supply

4.3.1 Power Supply Requirements

Input Voltage

The power supply in this design must be able to work within the common industrial voltage range of 24 V. The power supply must work with the common IO_Link range from 18 V to 36 V.

Output Voltage

Three RGB LEDs are used for each channel of the TLC5971. Table 4 shows the maximum forward voltage of the LEDs at 11.1 V. Use an output voltage of 12 V to have a margin. The output voltage of a single LED string can be set to 5 V.

Output Current

The maximum channel current of the TLC5971 is 20 mA in this design. The power supply must be able to support five LED PCBs that are daisy chained. See Equation 3 to calculate the required amps.

$$I_{OUT\_MAX} = 12 \times 20\text{ mA} \times 5 = 1.2\text{ A} \quad (3)$$

4.3.2 SIMPLE SWITCHER® Power Module

The LMZ35003 SIMPLE SWITCHER power module is an easy-to-use integrated power solution that requires few external components. Table 7 shows a summary of the power supply requirements.

Table 7. Power Supply Requirements

PARAMETER	VALUE	LMZ35003
V_{IN_MIN} [V]	18	7
V_{IN_MAX} [V]	36	50
V_{OUT} [V]	12	2.5 to 15
I_{OUT_MAX} [A]	1.2	2.5

4.3.3 Power Supply Schematics

The power supply schematic for the DC-DC converter is shown in Figure 16, and can be found in at TIDA-00979.

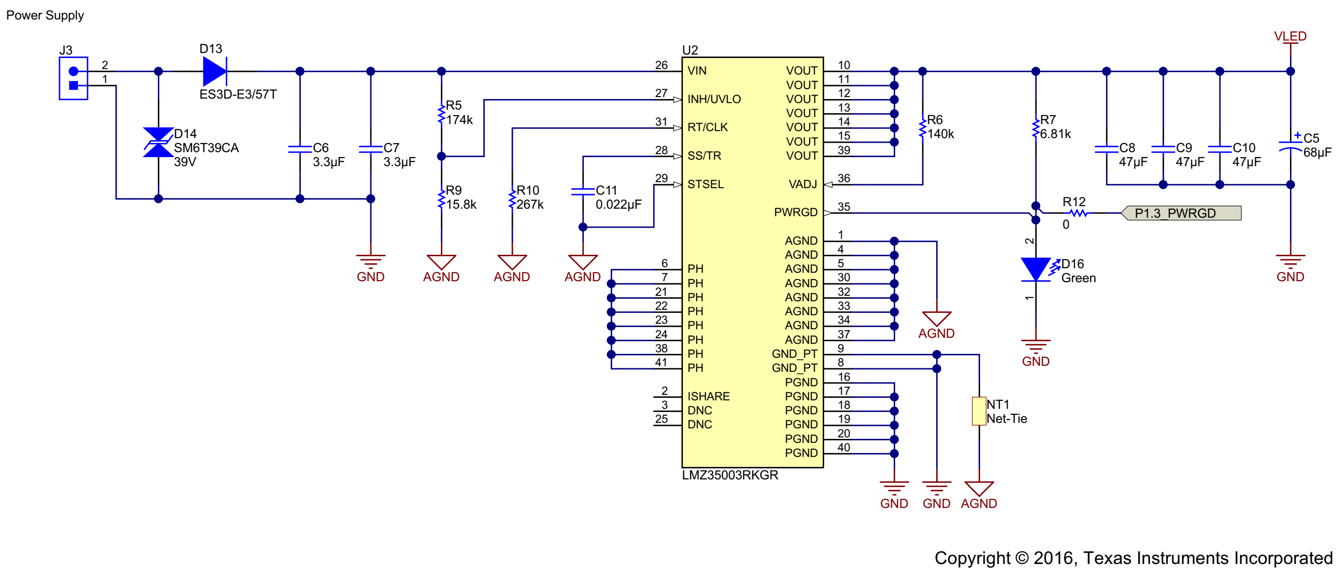

Figure 16. Power Supply Schematic

4.4 Microcontroller

An SPI interface is required to control the LED driver (TLC5971). The MSP430F5528 is used as for this requirement for the following reasons:

- The MSP430 can control the LEDs through a USB connection.
- The MSP430 has enough SPI, I²C, and UART interfaces to use the LaunchPad™ Development Kit ports (for example, CC3200, TIDA-00339, and more).
- The MSP430 has available GPIOs to use with the LaunchPad Development Kit GPIOs.

The test firmware has a set of different LED modes. These modes can be adjusted to control the LEDs through a USB, GPIO, SPI, push buttons, and more.

5 Getting Started Hardware

To begin, use the following instructions.

1. Verify the jumper settings (see Table 6).
2. Connect five TIDA-00979LD boards together (J2 to J11).
3. Connect J2 of the TIDA-00979LD board to J7 of the TIDA-00979PW board.
4. Connect J4 with a USB cable to a PC.
5. Provide 24 V to J3.

The TIDA-00979 will run in demo mode after the previous five steps are complete. Connect the programming tool to J10 to change the firmware.

6 Test Setup

The following list shows instruments and equipment required for a basic test setup.

- 1x TIDA-00979PW
- 1x TIDA-00979LD
- A PC with:
  – A USB interface
  – A GPIB interface
  – A MSP430 programmer
  – Code Composer Studio™
  – Python®
- Power supply of 18 V to 36 V
- 4x DMM

With the four DMMs, it is possible to measure input and output voltages and to measure the input and output current of the DC-DC converter to calculate the efficiency. The test firmware has the following features:

- Users can set the color for all LED clusters to be the same.
  – RED
  – AMBER
  – GREEN
  – BLUE
  – WHITE
- Users can set the brightness to zero.
- When the terminal programs sends the RETURN command, the brightness increases in increments until it reaches the 127 maximum value.
- After each brightness increase, the four DMMs take a measurement.

NOTE: The LEDs in this design are capable of handling forward currents of 35 mA (RED) and 50 mA (GREEN and BLUE). However, the data sheet specifies most parameters at 8 mA. The change in brightness above 10 mA is not visible to the human eye. Some parameters are subjective and cannot be tested.

Figure 17 shows the test setup.

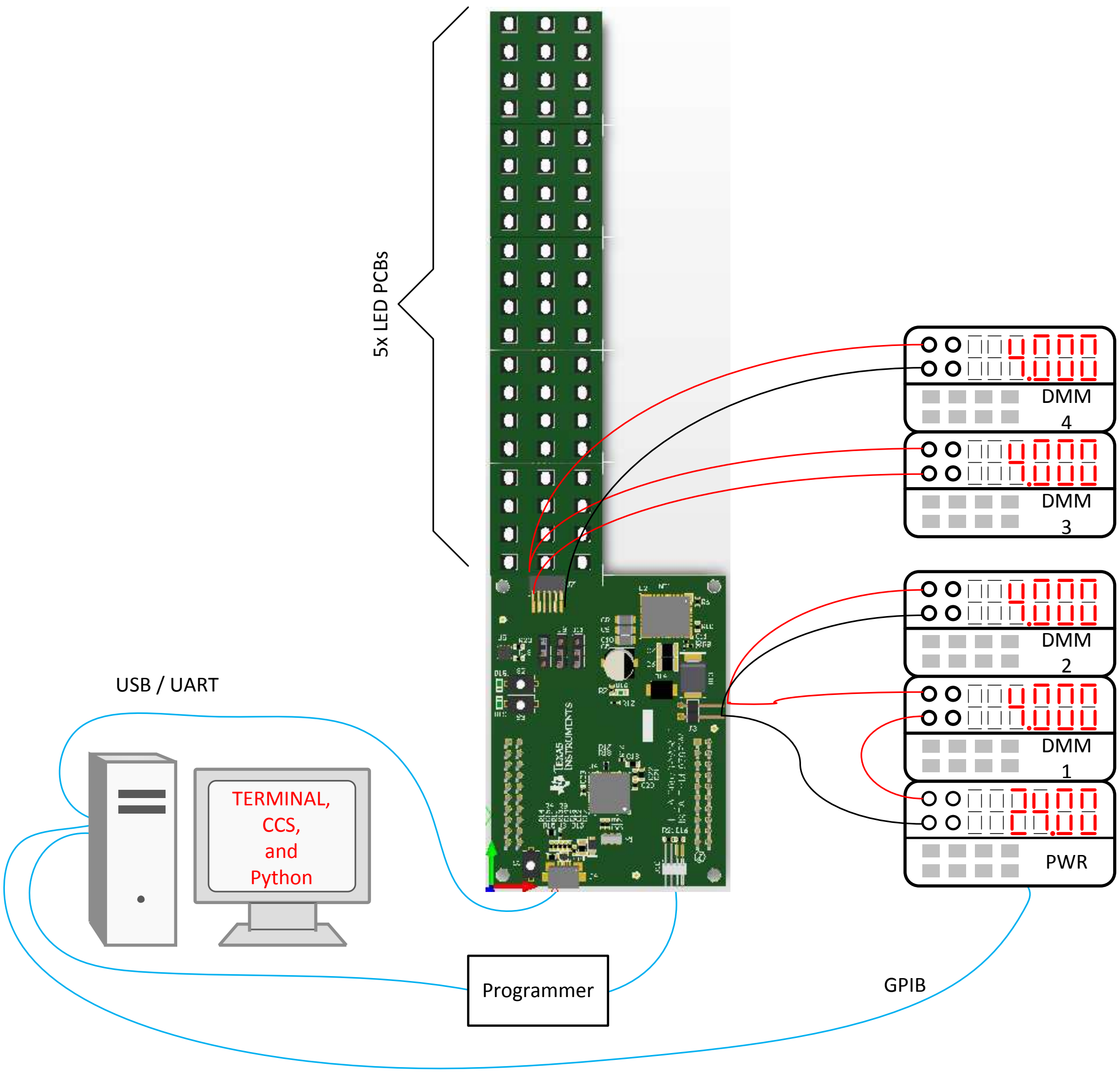

Figure 17. Test Setup

7 Test Data

7.1 DC-DC Input Current Versus LED Current

Depending on the application and the interface, there might be limits of the current rating. Figure 18 and Figure 19 show the input current for different conditions (input voltage and LED color).

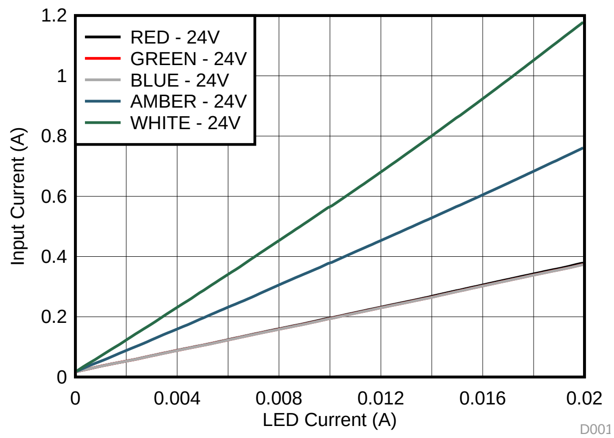

Figure 18. Input Current for Different LED Currents and LED Color

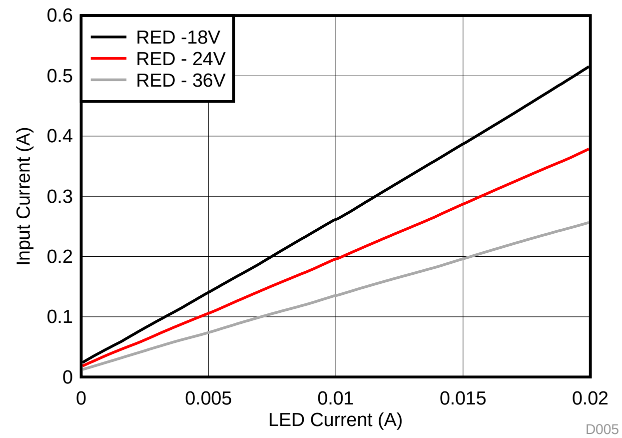

Figure 19. Input Current for Different LED Currents and Input Voltages

7.2 Efficiency

Figure 20 shows the DC-DC converter efficiency versus the LED current.

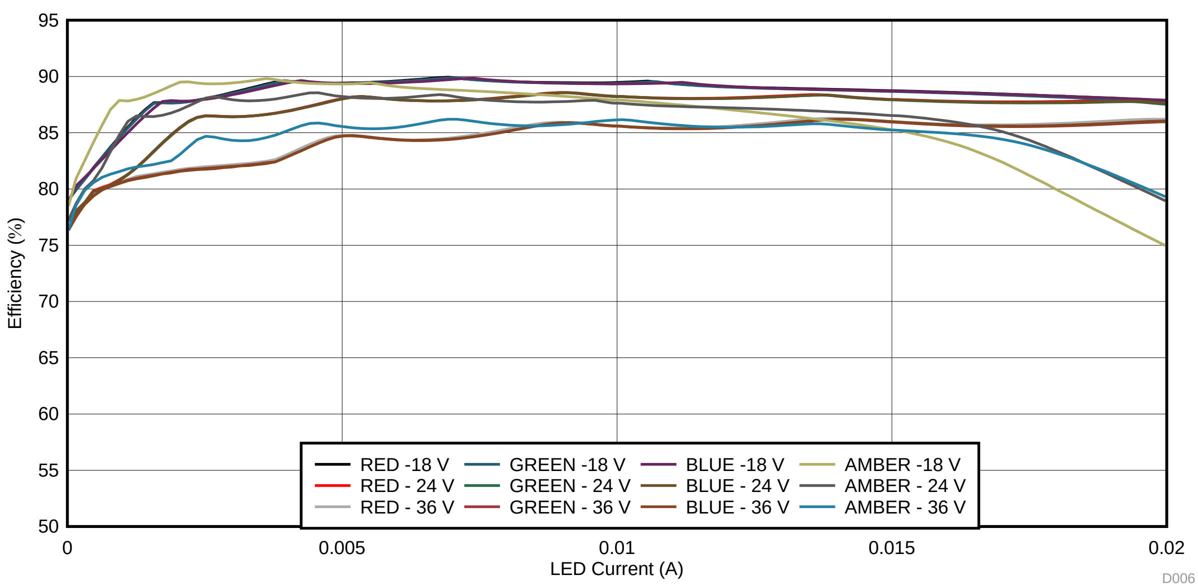

Figure 20. DC-DC Converter Efficiency Versus LED Current

8 Design Files

8.1 Schematics

To download the schematics, see the design files at TIDA-00979.

8.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00979.

8.3 PCB Layout Recommendations

8.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-00979.

8.4 Altium Project

To download the Altium project files, see the design files at TIDA-00979.

8.5 Layout Guidelines

The layout of the TIDA-00979LD and TIDA-00979LW boards are based on the layout guidelines from their data sheets. Depending on the LEDs and the forward current, a dedicated PCB layout has to be made for proper heat dissipation.

8.6 Gerber Files

To download the Gerber files, see the design files at TIDA-00979.

8.7 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-00979.

9 Software Files

To download the software files, see the design files at TIDA-00979.

10 References

1. Cree, Inc., *Cree® PLCC6 3 in 1 SMD LED CLX6C-FKB*, 2014, Data Sheet (CLX6C-FKB)
2. Texas Instruments, *Noise Analysis in Operational Amplifier Circuits*, Application Report (SLVA043)
3. Texas Instruments, *WEBENCH® Design Center*, (WEBENCH®)

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (June 2016) to A Revision	Page
• Changed from preview draft	1

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