TI Designs

RGB LED Signal Tower With IO-Link Interface Reference Design

Description

The objective of the TIDA-00980 reference design is to develop an embedded firmware to interface and control the functions of a multi-segment RGB signal tower used in factory floor and industrial process automation of greater complexity. This design helps to give more flexible usage along with a sequence of terminal commands.

External actions or controls of hardware activate the embedded firmware functions. This embedded firmware specifically has communication links to other devices such as the *RGB LED Signal Tower for Industrial Automation Reference Design* (TIDA-00979) [1] and the *IO-Link Sensor Transmitter BoosterPack* (TIDA-00339) [2] stacked on the MSP-EXP430FR4133 LaunchPad™ Development Kit for functionality or to address a requirement to adjust the application device.

The embedded firmware enables fully flexible control of color, speed, brightness, and rows of TLC5971 LED drivers considered as segments.

Resources

TIDA-00980	Design Folder
TIDA-00979	Design Folder
TIDA-00339	Design Folder
TLC5971	Product Folder
LMZ35003	Product Folder
MSP430F5528	Product Folder
HDC1080	Product Folder
TPD2E001	Product Folder
MSP430FR4133	Product Folder
SN65HVD102	Product Folder
MSP-EXP430FR4133	Tool Folder

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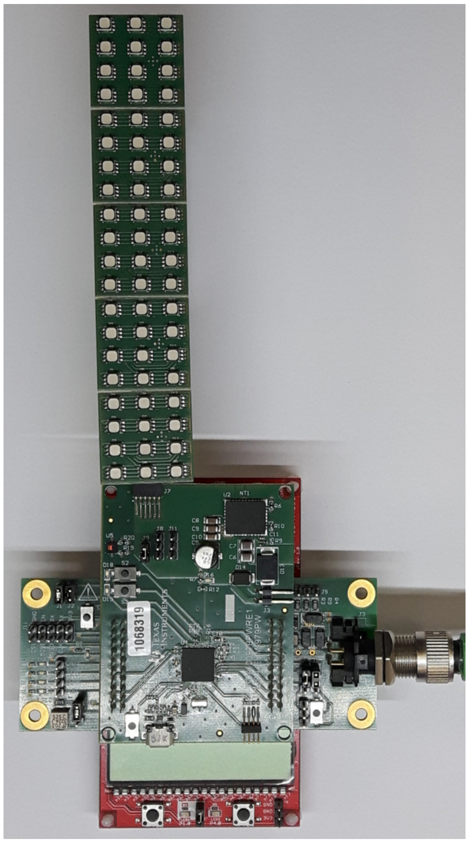
Features

- Flexible and Easy-to-Control RGB LED Tower Light Design
- Different Switchable Modes: Demo, Temperature, Humidity, and IO-Link
- Controllable RGB Color, Brightness, Row, and Blinking Speed
- One to Five RGB LED Segments With Four Individual Channels Each
- Adjustable Maximum LED Current up to 60 mA per Channel

Applications

- Factory Automation and Control
- Building Automation



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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_TYP} = 24 V
	V_{IN_MAX} = 36 V
Interfaces	IO-Link
	USB (CDC)
LED	60 RGB LEDs at 20 mA
	Max 60 mA for each channel
	Brightness control
	Configured as 3×20 array

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 four printed-circuit boards (PCBs) as Figure 1 shows:

- Power and control board (TIDA-00979PW)
- LED driver with RGB LEDs (TIDA-00979LD)
- IO-Link BoosterPack™ Plug-in Module (TIDA-00339)
- MSP430FR4133 LaunchPad™ Development Kit

Five of the mentioned LED boards are daisy chained and connected to one control board. This control board runs a stack light control software and communicates through a serial peripheral interface (SPI) with the MSP430FR4133 LaunchPad.

The LED driver requires an external power supply of 18 V to 36 V. The microcontroller (MCU) is externally powered through the IO-Link interface or USB. Two different interfaces can be used for controlling the function:

- IO-Link through IO-Link Booster Pack
- USB CDC Device

Different demo functions are implemented:

- Single color stack light with configurable color and brightness
- Blinking in configurable color and brightness
- Multicolor stack light
- Temperature visualization
- Humidity visualization
- Run light
- Level light

3 Block Diagram

Figure 1 shows the block diagram of this design.

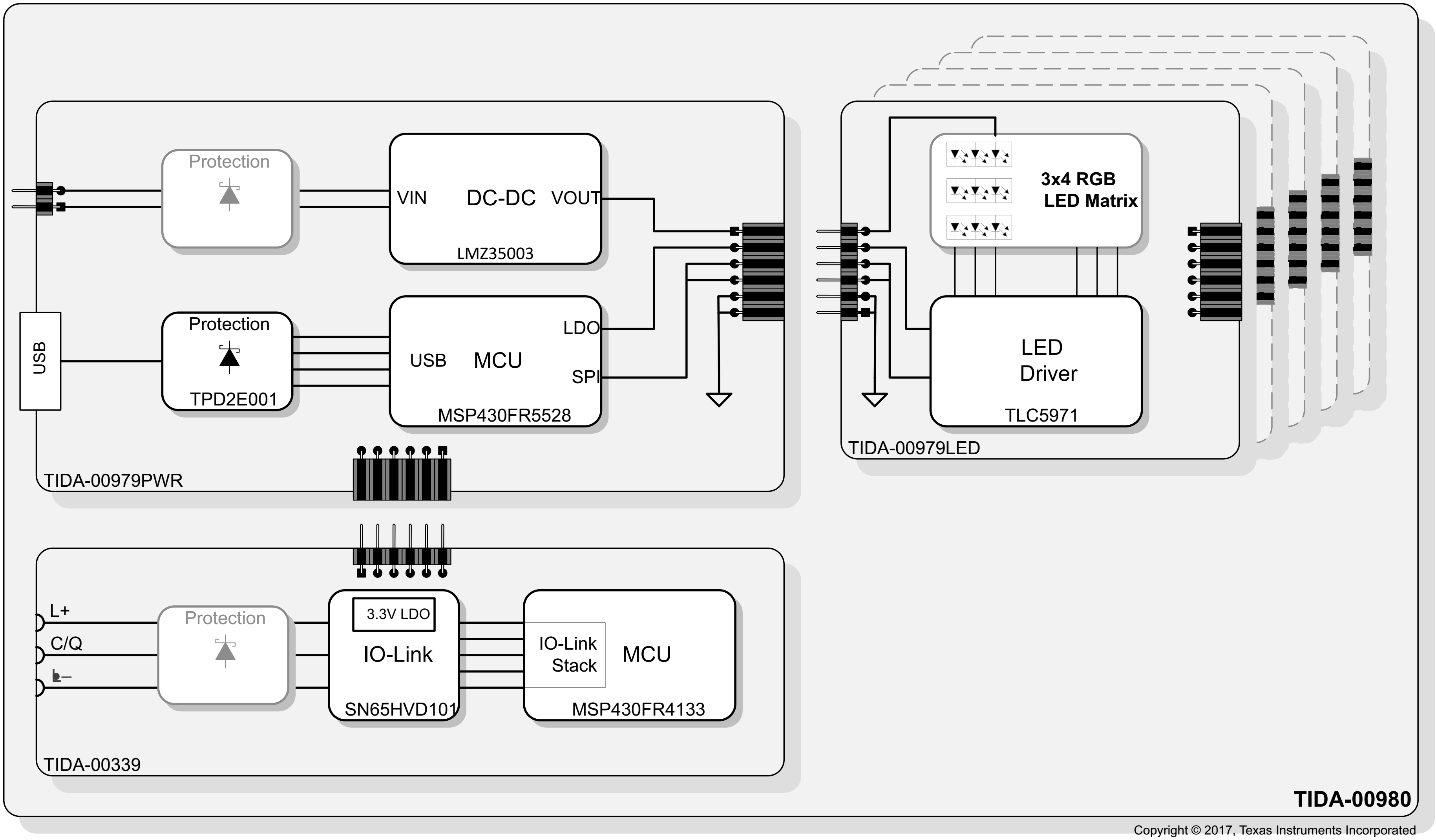

Figure 1. TIDA-00980 Block Diagram

3.1 Highlighted Products

The TIDA-00980 reference design features the TIDA-00979, TIDA-00339, as well as the MSP430FR4133 LaunchPad.

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

3.1.1 TIDA-00979

The TIDA-00979 provides a flexible solution based on RGB light-emitting diodes (LEDs) and a modular approach. The solution has two-printed circuit boards (PCBs) as Figure 2 shows.

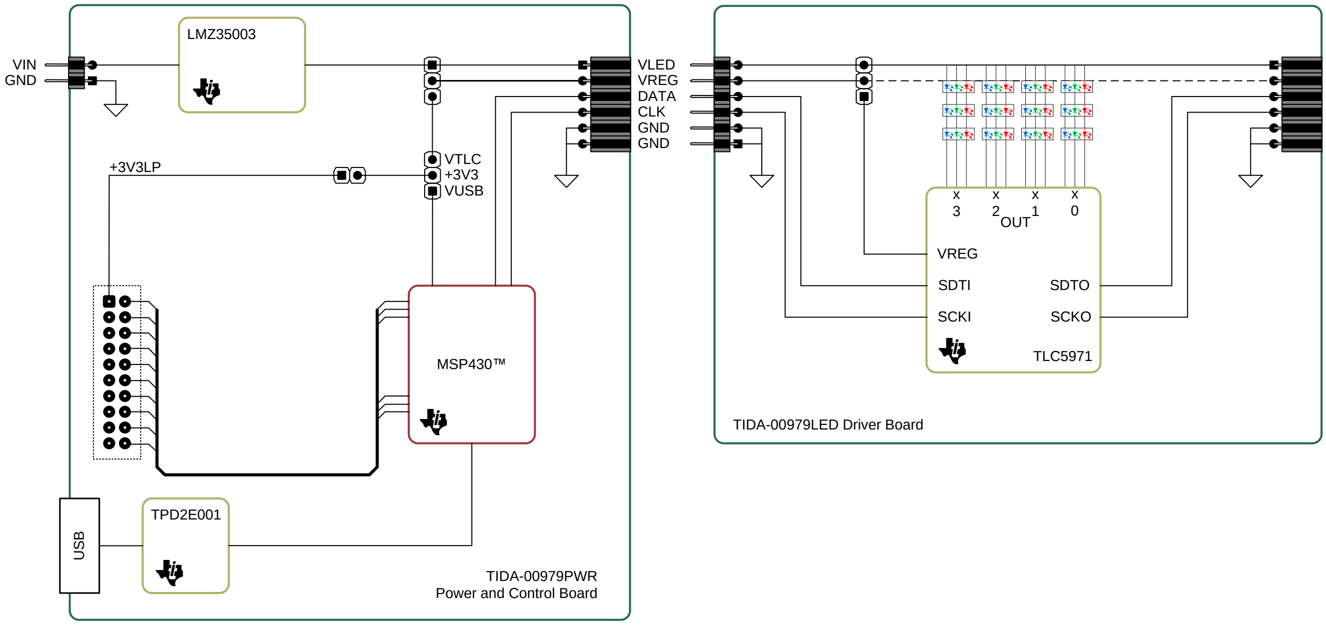

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Figure 2. TIDA-00979 Block Diagram

This design is used for driving a stack light consisting of 60 RGB LEDs organized in an 3×20 array. A software is built to communicate through SPI with TIDA-00339 with a host PC connected through USB or to display a different demo pattern.

The MCU on this design (MSP430F5528) has an integrated USB 2.0 PHY that is used to implement a USB CDC device, enabling control of the design without the requirement of an IO-Link master.

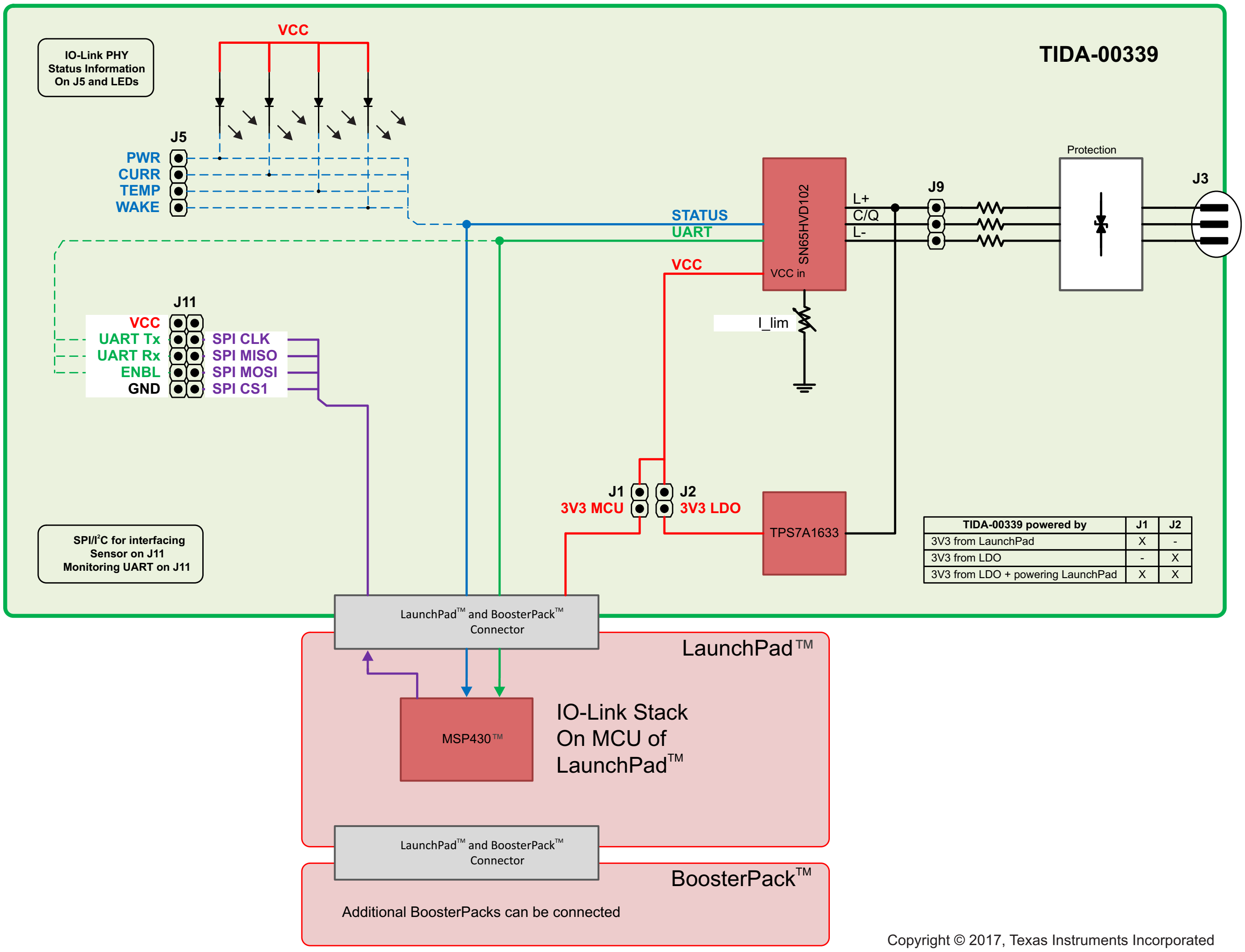
The TIDA-00339 is used through an SPI connection to communicate with an IO-Link master.

For further detail on this design, refer to the product folder.

3.1.2 TIDA-00339 and MSP430FR4133 LaunchPad™

The TIDA-00339 TI Design is a fully IO-Link compliant design enabling the user to easily evaluate the IO-Link communication. The modular approach is capable of use with different MCUs based on the LaunchPad and BoosterPack ecosystem and also allows the user to test their own sensor front end.

Figure 3 shows the block diagram of TIDA-00339 with the connection to the MSP430FR4133 LaunchPad. This setup is used for handling the IO-Link communication and has a SPI connection with the MCU on the TIDA-00979 board.



TIDA-00339 powered by	J1	J2
3V3 from LaunchPad	X	-
3V3 from LDO	-	X
3V3 from LDO + powering LaunchPad	X	X

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Figure 3. TIDA-00339 Block Diagram

4 System Design Theory

This TI Design consists of two different designs which are used together. This section describes the connection between them and the software design.

4.1 System Overview

Figure 4 shows the connection between the two designs and provides a short board description.

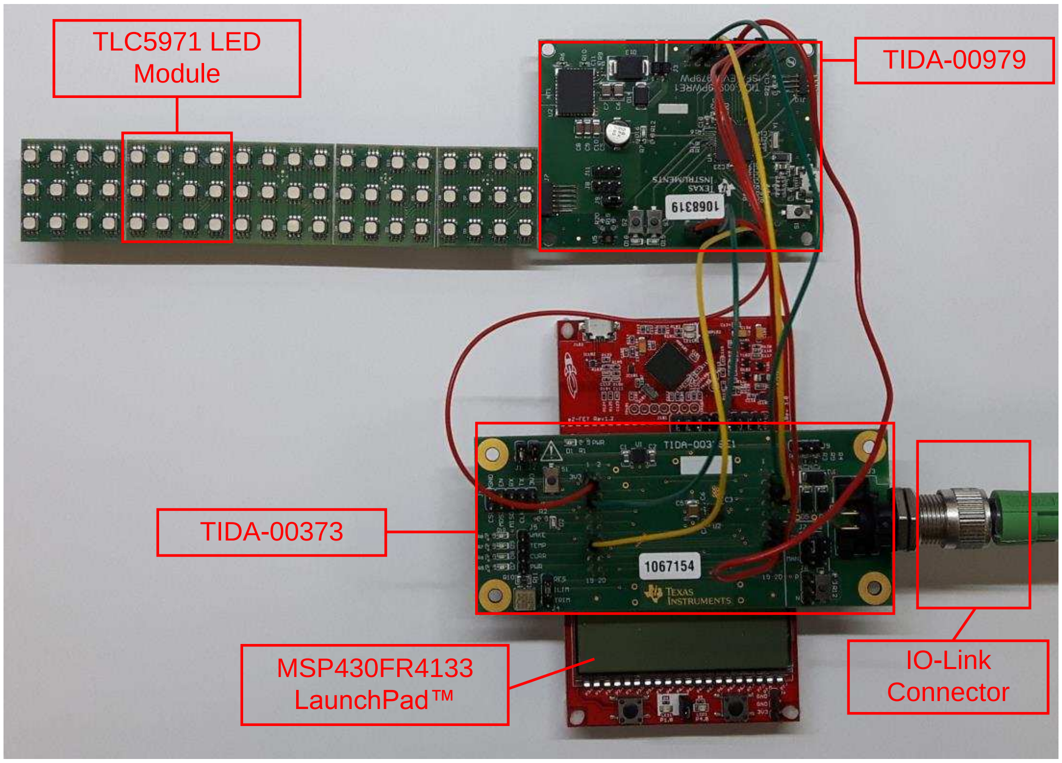


Figure 4. TIDA-00980 Setup

Table 3 provides details on the connection wiring between the boards. An IO-Link stack runs on the MSP430FR4133, which also implements a SPI master for communicating with other devices. Therefore, a SPI slave is implemented on the MSP430F5528 on the TIDA-00979 board. The SPI connection consists of the usual signal (CS, CLK, SIMO, SOMI) as well as some additional wires for issuing a reset and an acknowledge line.

Furthermore, the power for the MSP430F5528 is delivered from the IO-Link board. Check the correct jumper setting for the power supply shown in Table 4 and Table 5 to avoid damage to the boards.

Table 3. Connection Between TIDA-00979 and TIDA-00339

SIGNAL	TIDA-00979	TIDA-00339
3.3 V	J3 - 1	J12 - 1
P1.0 ACK	J3 - 3	J12 - 3
P2.7 UCA0_CLK	J3 - 13	J12 - 13
GND	J4 - 2	J10 - 2
P1.1 /CS	J4 - 6	J10 - 6
P3.3 UCA0_SIMO	J4 - 12	J10 - 12
P3.4 UCA0_SOMI	J4 - 14	J10 - 14
P6.5 GPIO5	J4 - 15	J10 - 10

Table 4. Jumper Setting on TIDA-00979

JUMPER	SETTING
J8	Open
J9	Short 1 - 2
J11	Short 1 - 2

Table 5. Jumper Settings of TIDA-00339

JUMPER	SETTING
J1	Short 1 - 2
J2	Short 1 - 2
J4	Short 2 - 3
J6	Short 1 - 2
J7	Short 1 - 2
Other	Open

4.2 Software

The software running on the MSP430FR4133 is supplied by TMG (Technologie Management Gruppe), whereas the software running on the MSP430F5528 has been adapted to implement different stack light features such as:

- Single-color stack light
- Blinking stack light
- Multicolor stack light
- Temperature visualization
- Humidity visualization
- Run light
- Level light

Two different interfaces are implemented for controlling the function: IO-Link (through the TIDA-00339) and USB (as a CDC device, so it is enumerated as a serial port). Different modes are additionally implemented, which can be switched by pressing S2:

- Demo mode: Switching between different patterns
- Temperature visualization mode: Displaying the current temperature
- Humidity mode: Displaying the measured humidity
- IO-Link mode: The desired pattern and configuration is set through IO-Link or USB

The following Section 4.2.1 explains the implementation of the different features in detail.

4.2.1 Demo Mode

The application starts up in a default demo mode that cycles between different patterns and is implemented in the file *Mode.c* in the MODE_DEMO() function . The main loop has to run without blocking statements, such as delays, otherwise the USB stack may cause problems.

Six patterns are implemented in total:

- All on: In this mode all LEDs are set to the same color and brightness. The function pattern1() anticipates the number of LEDs, the RGB color as eight-bit values, as well as the brightness up to a value of 128. This function is non-blocking and can be called once to set a new color, brightness, or number of LEDs that are turned ON.
- Blink: The blink mode is implemented in function pattern2(). The number of LEDs, the blink interval (the time depends on the timer ISR configuration), as well as the color and brightness must be passed. This function is non-blocking and must be called every iteration of the main loop. Controlling the state of the LEDs is done in the ISR; this function just configures this state and turns the LEDs

corresponding with the state that is set in the ISR ON or OFF.

- Stack light: This mode is implemented in function pattern3(). The segment, as well as the brightness, must be given as arguments for the function call. This function is non-blocking and must be called whenever something changes.
- Temperature visualization: This mode is implemented in pattern4(). The number of LEDs as well as the brightness must be given. This function is non-blocking and must be called whenever something changes.
- Run light: A run light pattern is implemented in function pattern5(). The parameters are the range as well as the RGB color and the brightness. This function is non-blocking and has an internal state, so it must be called within the main loop to work properly.
- Level light: A level is displayed using the LEDs in this mode. Function pattern6() handles this action and the parameters are the same as for the temperature visualization.

Table 6 provides an overview of the implemented pattern and the parameters. R (red), G (green), and B (blue) represents an eight-bit value for the corresponding color. BC is a global brightness value that corresponds with the current of the LEDs. A seven-bit value can be passed here.

Table 6. Implemented Pattern

FUNCTION NAME	DISPLAY	ARGUMENTS	COMMENTS
Pattern1	All LEDs ON	Number of LEDs, R, G, B, BC	Call once
Pattern2	Blinking LEDs	Number of LEDs, Interval, R, G, B, BC	Call regularly
Pattern3	Stack light (red, amber, green, blue, white)	Segment , BC	Call once
Pattern4	Temperature visualization	Value, BC	Call once
Pattern5	Run light	Number of LEDs, R, G, B, BC	Call regularly
Pattern6	Level light	Value, BC	Call once

4.2.2 Temperature and Humidity Mode

By pressing S2, the application switches in temperature mode and the D19 LED lights up. In this mode, the current ambient temperature is measured by an HDC1080 device on the PCB of TIDA-00979 and is visualized using the temperature pattern. The default range is configured to display a range from 15°C to 30°C. This range is configured with temp_min and temp_max in the source code and can either be changed in the source code or through IO-Link or USB.

By pressing S2 a second time, D18 lights up and humidity is visualized the same way using the level pattern. The default range here is from 0% to 100% and can be configured by setting level_min and level_max either in the source code or through IO-Link or USB.

The function handling both modes is implemented in MODE_I2C() and is non-blocking.

4.2.2.1 HDC1080 Sensor Data

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.

The HDC1080 sensor has an I^{2}C interface with a seven-bit address of 0x40. The device is a low-speed, multi-slave serial bus with a typical frequency of 100 kHz to 400 kHz. Figure 5 shows a typical bus connection with one master and two slaves. Pullup resistors are necessary due to the open drain design.

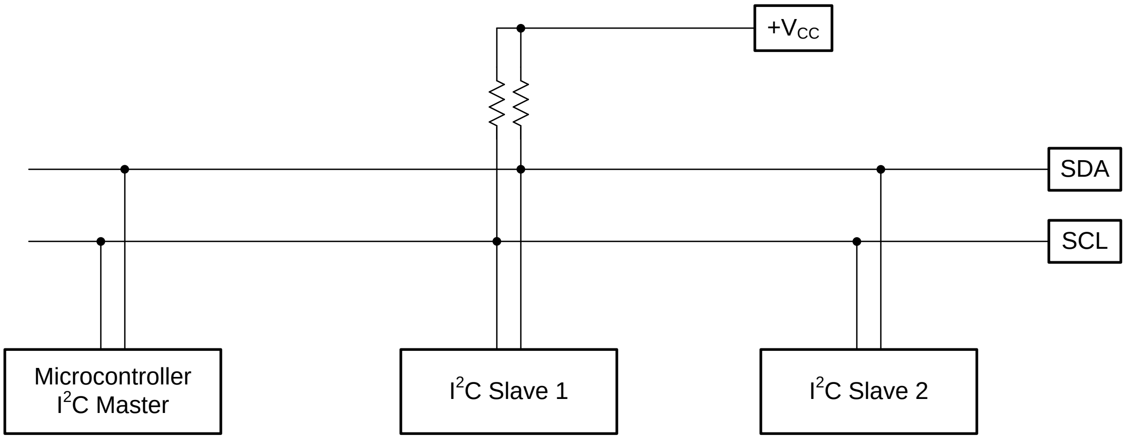


Figure 5. Typical I²C Bus System

The scope shot in Figure 6 shows a typical transmission for the HDC1080 sensor. This example shows the transmission for configuring the sensor and starting a measurement. A start is sent to address 0x40 with the write bit set, followed by the register (0x02) that should be written and the 16-bit data (0x1000).

The next transmission starts a conversation by issuing a write to register 0x0 without data. After a certain time for the conversation, the results can be read from register 0x0.

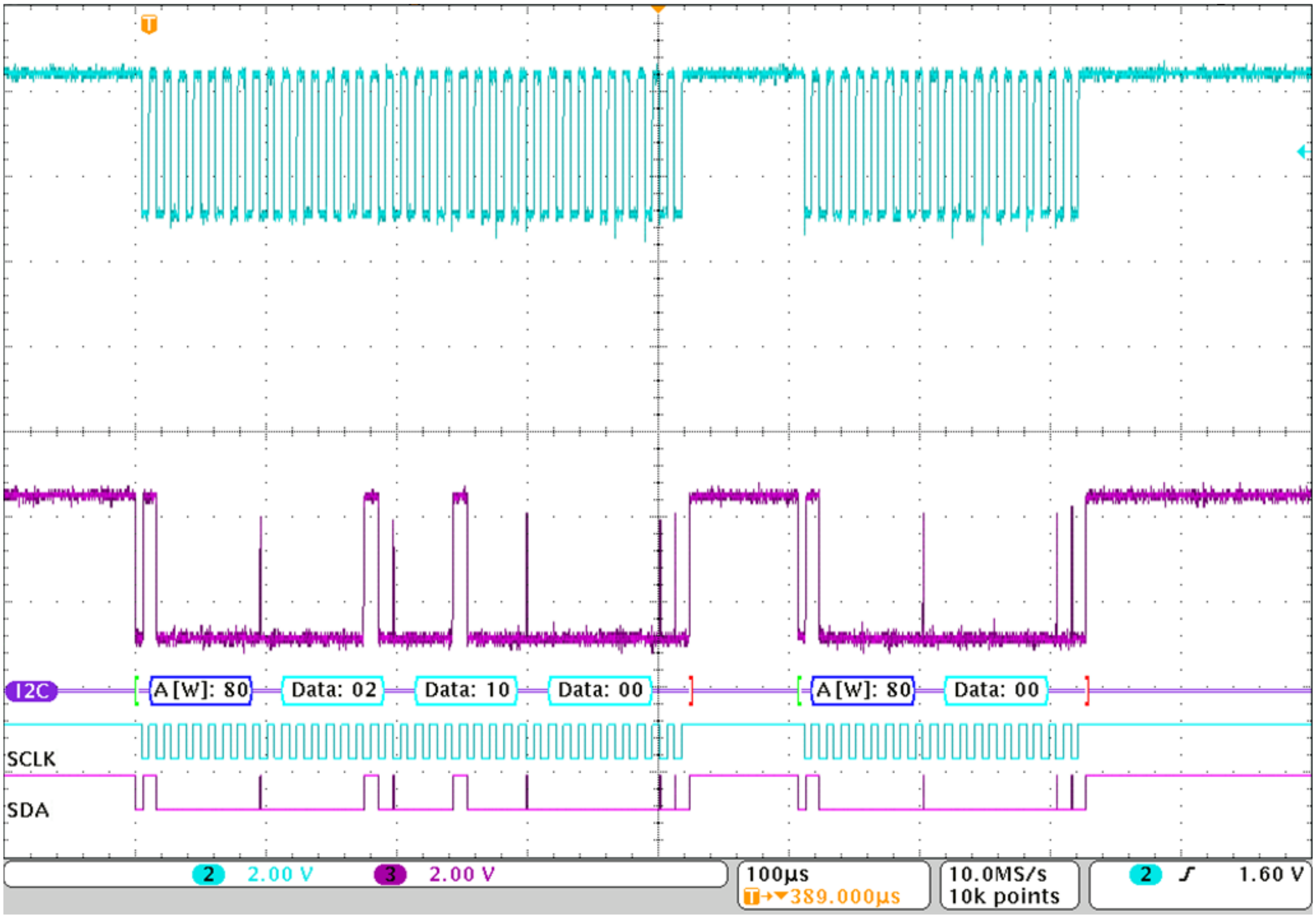


Figure 6. Start Sequence of HDC1080

The temperature value is a 16-bit value with the least significant bit (LSB) set to 0 because the resolution is 14 bit. The formula from the datasheet is simplified to avoid floating point operations.

The following code shows how this simplification is done: First copy the relevant data to a temporary 32-bit variable. Then the value is multiplied and the division is replaced by a bit-shift operation. The last line calls the function displaying the pattern with the scaled measurement. The variable temp contains the temperature in °C.

```
long temp;
temp = (reg_data[0]<<8)|reg_data[1] & 0xffff;
temp *= 165;
temp >>= 16;
temp -= 40;
pattern4(20*(temp-temp_min)/(temp_max - temp_min), DEFAULT_BC);
```

The same procedure can be done for the humidity value:

```
temp = ((reg_data[2]<<8)|reg_data[3]) & 0xffff;
temp *= 100;
temp >>= 16;
pattern6(20*(temp-level_min)/(level_max - level_min), DEFAULT_BC);
```

4.2.3 IO-Link and USB Mode

After pressing S2 a third time, the IO-Link or USB mode is entered and the D18 and D19 LEDs light up. In this mode, commands can be sent to control the different modes either through IO-Link or through USB.

The function MODE_SPI() handles the SPI communication and sets the pattern depending on the received process data.

4.2.3.1 IO-Link

After entering SPI mode, the IO-Link stack is initialized by calling IOLSPISAPI_Init() and must be polled regularly by calling IOLSPISAPI_Task(). For details about the SPI communication, refer to the TIDA-00339 product folder for a referenced example.

The stack then calls the IOLSPISAPI_CbfNewOutputs() function and the new 7-byte process data is copied to the pdOut variable whenever it changes.

These seven bytes are presented as three variables in software: an 8-bit wide pdOut.PDout8 that defines the operation mode as shown in Table 7, a 16-bit wide variable pdOut.PDOut16 that contains process data, and a 32-bit wide variable that contains configuration data. Whenever a pattern is displayed, the necessary parameters are set through pdOut16 as Table 8 shows. These bits are only relevant when PDOut8[5:4] is set to 0. The meaning of the 32 bits depends on the mode that is selected, see Table 9 for details.

Table 7. Process Data 1st Byte (pdOut.PDOut8)

BITS	FUNCTIONS
Bit 0 (On/Off)	0: Off
	1: Pattern On
Bit 3 - 1 (Pattern)	000: Pattern1 - All LEDs on
	001: Pattern2 - Blinking
	010: Pattern3 - Stack Light (fixed color)
	011: Pattern4 - Temperature (fixed color)
	100: Pattern5 - Run Light
	101: Pattern6 - Level Light (fixed color)
Bit 5 - 4 (Mode)	00: Normal Mode
	01: Configure Temperature Range
	10: Configure Level Range

Table 8. pdOut.PDOut16

PATTERN	BITS 15 TO 8	BITS 7 TO 0
Pattern1	—	Number of LEDs
Pattern2	Interval	Number of LEDs
Pattern3	—	Segment number
Pattern4	Temperature MSB	Temperature LSB
Pattern5	—	Number of LEDs
Pattern6	Level MSB	Level LSB

Table 9. pdOut.PDOut32

MODE	BITS 31 TO 24	BITS 23 TO 16	BITS 15 TO 8	BITS 7 TO 0
Normal	Red value	Green value	Blue value	Brightness
Configure temperature	temp_max[15:8]	temp_max[7:0]	temp_min[15:8]	temp_min[7:0]
Configure level	level_max[15:8]	level_max[7:0]	level_min[7:0]	level_min[7:0]

A range of 15°C to 30°C is predefined for the temperature. In level mode, the default range is from 0 to 100.

When pattern3 (temperature) or pattern6 (level) has been selected, the range of the input value can be set in the corresponding configuration mode and is scaled for display.

Table 10 shows some examples.

Table 10. Example Commands

PROCESS DATA	MEANING
01 00 14 FF FF FF 01	Pattern1 | LEDs on | 0x14 = 20 LEDs | Red = 0xff | Green = 0xff | Blue = 0xff | Brightness = 0x01
07 00 14 00 00 00 01	Pattern4 | Temperature on | Temperature = 20 | Brightness = 0x01
20 00 00 01 00 00 00	Set Level Range | level_max = 0x100 = 256 | level_min = 0

4.2.3.2 USB

USB is also an option in addition to sending data through IO-Link. This feature enables the possibility to test the application without requiring an IO-Link master. A USB CDC stack is implemented, so the device enumerates as a serial port. A connection can be established with any serial terminal program at any baudrate.

The commands that can be sent are similar to the IO-Link commands. Before sending a block of data, a 'd' must be sent, followed by the process data in 8-bit blocks with a space in between and a line break ('\r') at the end. One example of a command is:

```
d 01 00 14 ff ff ff 01
```

This command turns ON all LEDs in white with minimal brightness.

Independent from where the process data pdOut has been sent, the command is parsed in Pattern_call() and the configured pattern is displayed or a configuration value is changed.

5 Getting Started

To begin, use the following instructions.

1. Verify the jumper settings (see Table 4 and Table 5).
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 TIDA-00979PW to TIDA-00339 as described in Table 3.
5. Connect J3 of TIDA-00339 to an IO-Link master.
6. Provide 24 V to J3 of TIDA-00979PW.

The TIDA-00979 runs in demo mode after the previous five steps have been complete. Connect the programming tool to J10 of TIDA-00979PW to change the firmware.

5.1 Necessary Equipment

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

- 1x TIDA-00979PW
- 5x TIDA-00979LD
- 1x TIDA-00339
- 1x MSP430FR4133 LaunchPad
- IO-Link Master (this design uses the TMG – USB IO-Link Master V2 SE)
- A PC with:
  - A USB interface
  - An MSP430™ MCU programmer
  - Code Composer Studio™ software
  - Serial terminal software, such as PuTTY or TeraTerm
- Power supply of 18 V to 36 V

5.2 Software Installation

Refer to the user manual of the USB IO-Link master in use for further details on its software installation.

The IO-Link stack for TIDA-00339 can be found in the corresponding product folder.

The source files for the TIDA-00979 can be found in the product folder of this design. Import the files into Code Composer Studio, compile them, and then flash them to the MSP430F5528 device. After programming, the demo mode starts automatically.

5.3 Software Usage

The application starts in demo mode, switching between the different patterns described in Table 6.

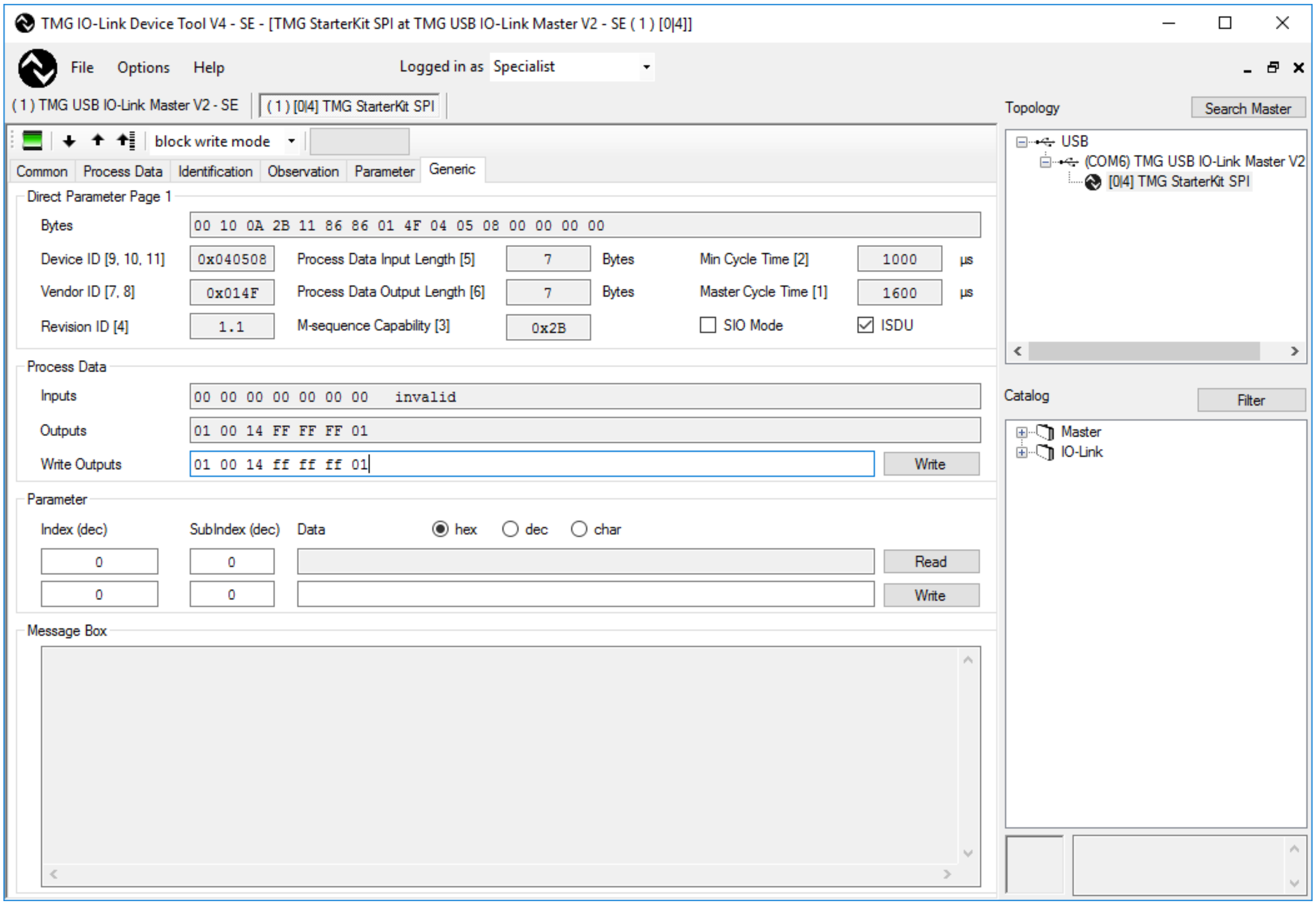
By pressing S2, the demo mode can be switched to temperature mode, after which the D19 LED lights up. The ambient temperature displays in a range of 15°C to 30°C.

Pressing S2 a second time switches to humidity mode and lights up D18.

Pressing S2 a third time causes both LEDs to light up and the design waits for data through IO-Link or USB.

5.3.1 IO-Link Data

In this example, the TMG IO-Link Master V2 - SE tool is used to send process data to the design. Figure 7 shows this example. The used sequence (01 00 14 ff ff ff 01) turns ON all LEDs in color and with minimal brightness as Figure 8 shows.



TMG IO-Link Device Tool V4 - SE - [TMG StarterKit SPI at TMG USB IO-Link Master V2 - SE (1) [0|4]]

Logged in as Specialist

(1) TMG USB IO-Link Master V2 - SE | (1) [0|4] TMG StarterKit SPI

Direct Parameter Page 1

Bytes: 00 10 0A 2B 11 86 86 01 4F 04 05 08 00 00 00 00

Device ID [9, 10, 11]: 0x040508 — Process Data Input Length [5]: 7 Bytes — Min Cycle Time [2]: 1000 µs

Vendor ID [7, 8]: 0x014F — Process Data Output Length [6]: 7 Bytes — Master Cycle Time [1]: 1600 µs

Revision ID [4]: 1.1 — M-sequence Capability [3]: 0x2B — □ SIO Mode ☑ ISDU

Process Data

Inputs: 00 00 00 00 00 00 00 invalid

Outputs: 01 00 14 FF FF FF 01

Write Outputs: 01 00 14 ff ff ff 01

Parameter

Index (dec) SubIndex (dec) Data ● hex ○ dec ○ char

0 0

0 0

Figure 7. TMG IO-Link Tool Example Sequence

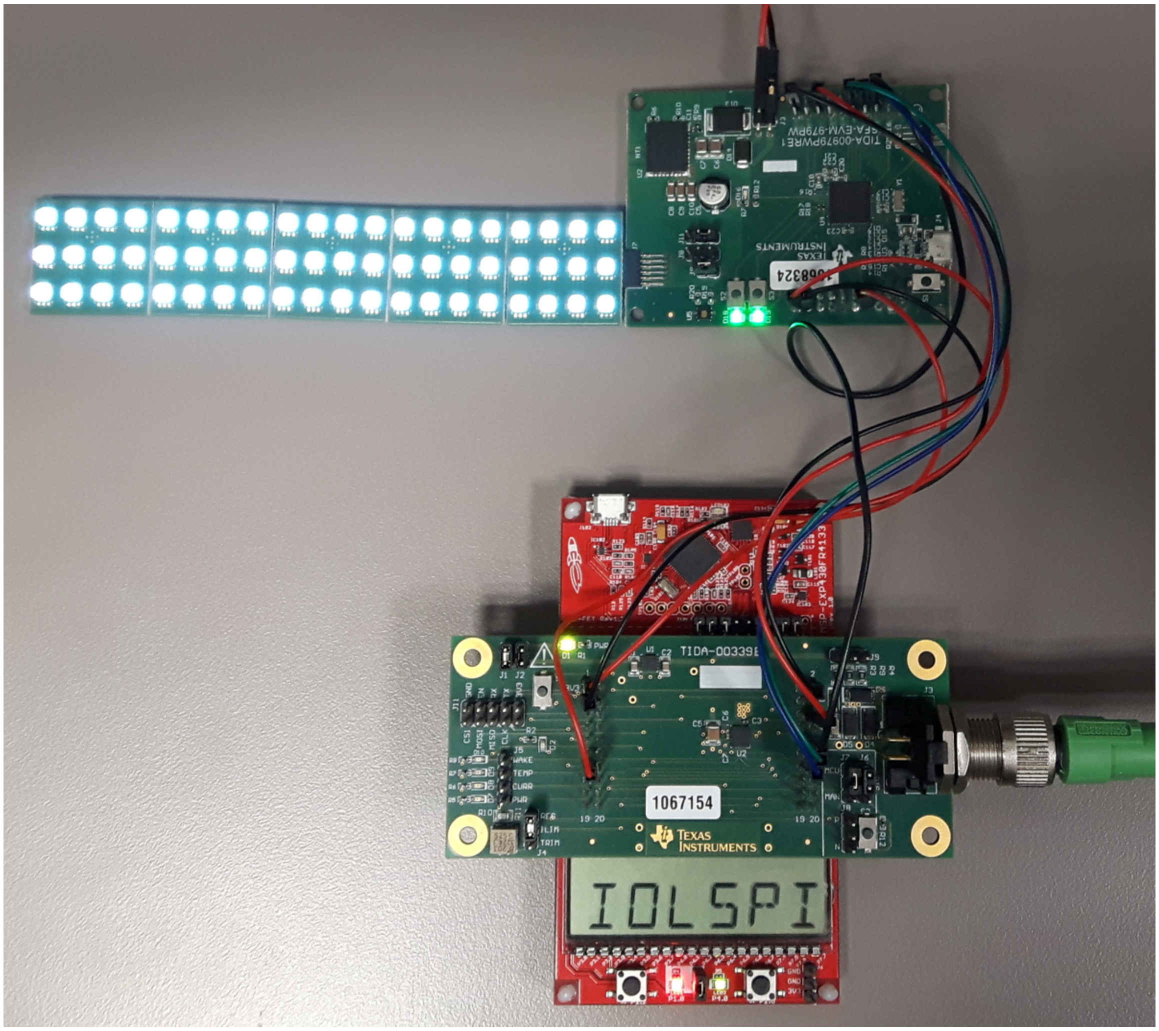
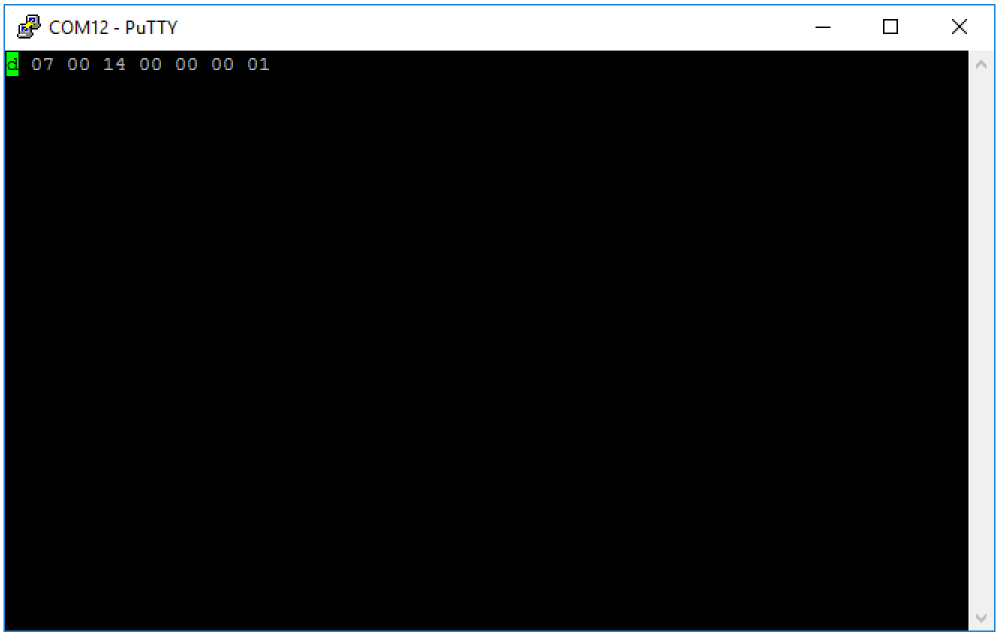


Figure 8. Showing Pattern 1 With All LEDs ON

5.3.2 USB Data

A USB can be used in the same way as an IO-Link. The device enumerates as a serial port; in this case, it is COM12. Connect to the device (using the PuTTY software, for example) at any baudrate. When connected, type a set of process data with a 'd' placed in front and hit the ENTER key. Figure 9 shows an example input for temperature display with a value of 20°C and minimal brightness.



```
d 07 00 14 00 00 00 01
```

Figure 9. USB Connection to TIDA-00980

After sending this set of data, six rows of LEDs light up, as Figure 10 shows.

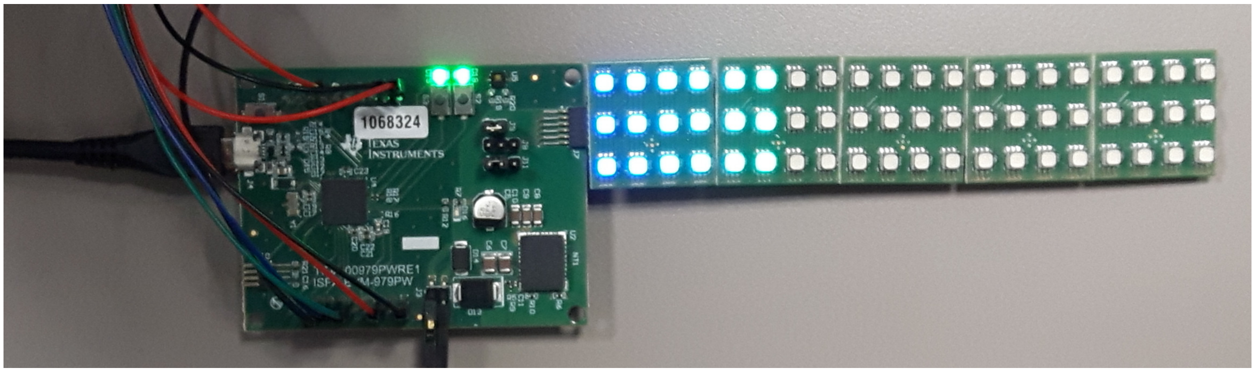


Figure 10. Temperature Displaying 20°C

6 Design Files

6.1 Schematics

To download the schematics, see the design files at TIDA-00980.

6.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00980.

6.3 PCB Layout Recommendations

6.3.1 Layout Prints

To download the layout prints, see the design files at TIDA-00980.

6.4 Altium Project

To download the Altium project files, see the design files at TIDA-00980.

6.5 Gerber Files

To download the Gerber files, see the design files at TIDA-00980.

6.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-00980.

7 Software Files

To download the software files, see the design files at TIDA-00980.

8 Related Documentation

1. Texas Instruments, *RGB LED Signal Tower for Industrial Automation Reference Design*, TIDA-00979 Reference Design (TIDUBV8)
2. Texas Instruments, *IO-Link PHY BoosterPack*, TIDA-00339 Reference Design (TIDU681)
3. Texas Instruments, *HDC1080 Low Power, High Accuracy Digital Humidity Sensor with Temperature Sensor*, HDC1080 Datasheet (SNAS672)

8.1 Trademarks

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