TI Designs: TIDA-01478
IO-Link With Digital Output and DC-DC Reference Design

Description

With an increase in industrial automation, the requirement for robust transceiver modules is more important. This high-density reference design demonstrates the ability to have an IO-Link transceiver module. With an IO-Link transceiver module, digital output channel, and a DC-DC buck converter, this reference design offers a wide range of flexibility for different applications. This robustly protected design can be used in industrial settings where there is potential for high amounts of electrostatic discharge (ESD). With the DC-DC buck converter, this module can power a wide array of external devices, such as microcontrollers (MCUs), sensors, displays, and more. This reference design only implements the physical layer of IO-Link.

Features

- IO-Link and Digital Output (M12 Type A)
- 10-Pin Header for MCU and External Devices
- Power Output of 500 mW
- Designed to Meet With: ±16-kV IEC 61000-4-2, ±4-kV IEC 61000-4-4, ±1.5-kV/40-Ω IEC 61000-4-5

Applications

- Factory Automation and Process Control
- Building Automation
- Sensors and Field Transmitters
- Other Industrial

Resources

TIDA-01478	Design Files
TIOL111	Product Folder
TIOS101	Product Folder
LM5165X	Product Folder

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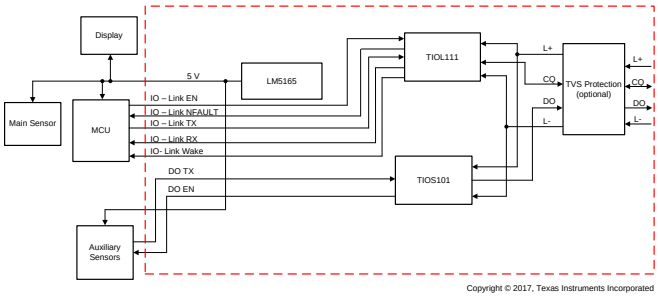

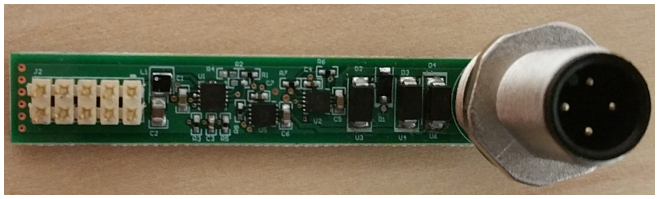

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1 System Description

This reference design demonstrates the ability to have a high-density, IO-Link transceiver module, digital output (DO) [1] channel, and a DC-DC buck converter. With the DC-DC this module can power a wide array of external devices, such as microcontrollers (MCUs), sensors, displays, and more. IO-Link and DO communication channels offer a wide range of flexibility for different applications. This reference design will fit applications that require a combination of sensors, such as a flow meters, level sensors, motion sensors, light sensors, or ultrasonic sensors. The TIOL111 and TIOS101 have high tolerances to ESD as outlined in IEC 61000-4-4 and IEC 61000-4-5 (500 Ω), allowing them to be used in industrial settings where there is a potential for high amounts of ESD. With the addition of transient voltage suppression (TVS) diodes, the level of ESD protection can be raised substantially. This reference design only implements the physical layer of IO-Link.

1.1 IO-Link Interface

This system includes an IO-Link physical layer interface (TIOL111), the standard M12, four-position, connector, and 10-pin header for an MCU to interface with the module. This interface has NFault and Wake function pins. Wake pins allow a master controller to initiate communication with the device. NFault pins indicate whether the device is in undervoltage lockout (UVLO), thermal shutdown, or overcurrent.

1.2 Power Supply

The TIOL111 and TIOS101 include a built-in, high-voltage, linear voltage regulator (LDO) that powers the IC from L+ with a range of 7V to 36V.

A wide-input voltage range DC-DC buck converter (LM5165X) can generate 5-V Vcc for the external system from the nominal 24V from the IO-Link L+ line. This device powers an external MCU and a variety of accessories that the end user can choose. This output is accessible using the 10-pin header.

1.3 Digital Output (DO)

Along with the IO-Link interface, this module implements DO (TIOS101) for a second line of communication for sensor data and other one-way data streams. [2] This second output channel can be used in applications that require different outputs for two different levels on a sensor. The DO is accessible using the 10-pin header.

(1) Digital output (DO) can be referred to as SIO, but this reference design will refer to digital output as DO.

(2) This DO output is the same as DI/DQ pin of IO-Link.

1.4 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS
IO-Link PHY	Meet the physical layer specifications of IO-Link
System level protection	±16-kV IEC 61000-4-2, ±4-kV IEC 61000-4-4, ±1.5-kV/40-Ω IEC 61000-4-5
Small board design	Easy to use in a wide variety of situations
Sensor front end	Digital output, Standard Input Output (SIO) using header pins
DC-DC power	100-mA output current

2 System Overview

2.1 Block Diagram

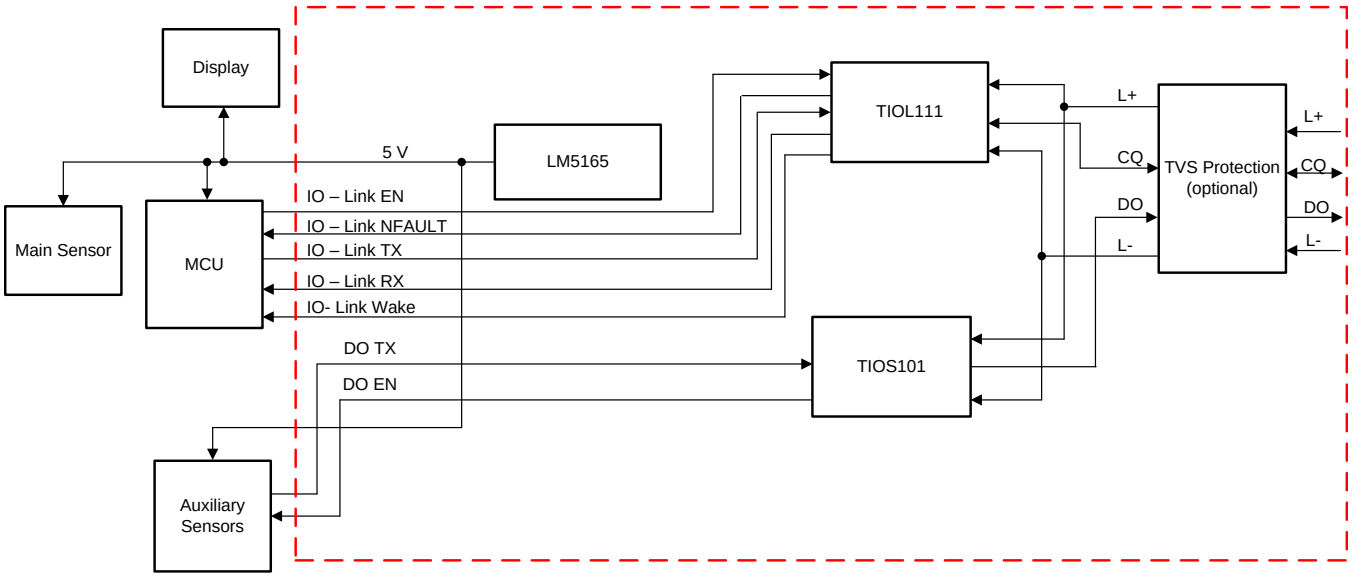

Figure 1. TIDA-01478 Block Diagram

2.2 Highlighted Products

2.2.1 TIOL111

The TIOL111 family of transceivers implements the IO-Link interface for industrial, bidirectional, point-to-point communication. When the device is connected to an IO-Link master through a three-wire interface, the master can initiate communication and exchange data with the remote node while the TIOL111 acts as a complete physical layer for the communication.

These devices are capable of withstanding up to 1.2 kV (500 Ω) of IEC 61000-4-5 surge and feature integrated reverse polarity protection.

A simple, pin-programmable interface allows easy interfacing to the controller circuits. An external resistor can configure the output-current limit.

Fault reporting and internal functions provide protection for undervoltage, overcurrent and overtemperature conditions.

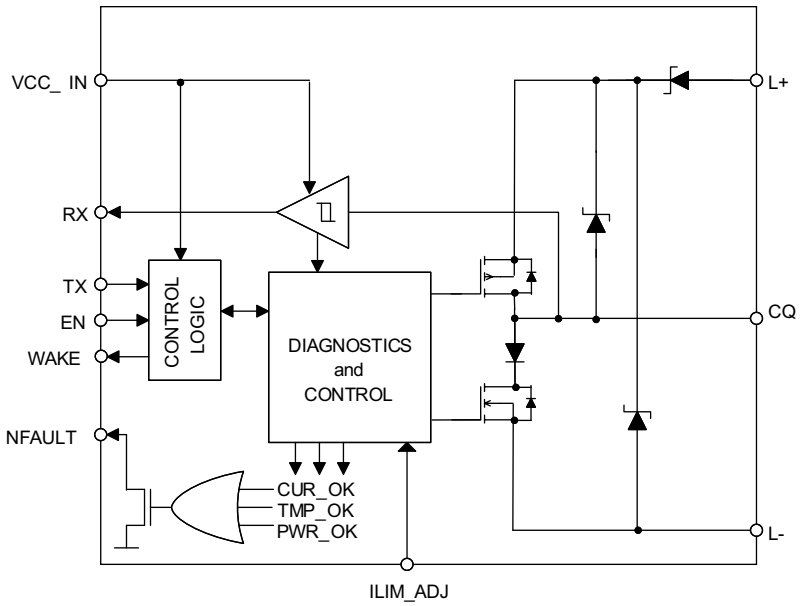

Figure 2. Block Diagram of TIOL111

- 7-V to 36-V supply voltage
- Tolerant to ±65-V transients < 100 µs
- Reverse polarity protection of up to 55 V on L+, CQ, and L–
- Integrated electromagnetic compatibility (EMC) protection on L+ and CQ
  - ±16-kV IEC 61000-4-2 ESD contact discharge
  - ±4-kV IEC 61000-4-4 electrical fast transient
  - ±1.2-kV or 500-Ω IEC 61000-4-5 surge (1.2/50 µs)
- Fast demagnetization of inductive loads up to 1.5 H
- Large capacitive load driving capability

2.2.2 TIOS101

The TIOS101 devices are configurable as high-side, low-side or push-pull drivers. These devices are capable of withstanding up to 1.2 kV (500 Ω) of IEC 61000-4-5 surge and feature integrated reverse polarity protection.

A simple pin-programmable interface allows easy interfacing to the controller circuits. The output current limit can be configured using an external resistor.

Fault reporting and internal protection functions are provided for undervoltage, over circuit current and overtemperature.

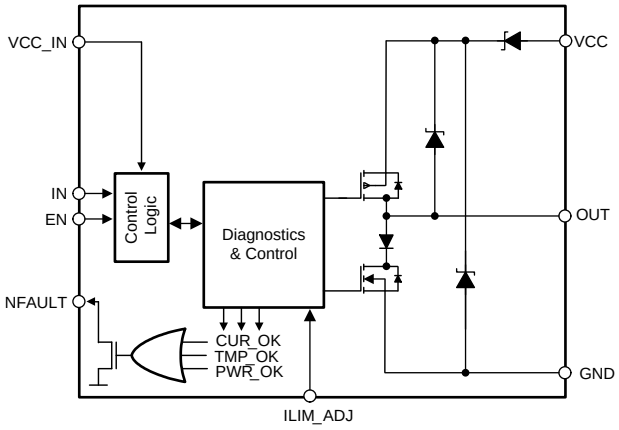

Figure 3. TIOS101 Functional Diagram

- 7-V to 36-V supply voltage
- Tolerant to ±65-V transients < 100 µs
- Reverse polarity protection of up to 55 V on VCC, OUT, and GND
- Integrated EMC protection on L+ and CQ
  - ±16-kV IEC 61000-4-2 ESD contact discharge
  - ±4-kV IEC 61000-4-4 electrical fast transient
  - ±1.2-kV/500-Ω IEC 61000-4-5 surge (1.2/50 µs)
- Fast demagnetization of inductive loads up to 1.5 H
- Large capacitive load driving capability

2.2.3 LM5165X

The LM5165X is a compact, easy-to-use, 3-V to 65-V, ultra-low IQ, synchronous buck converter with high efficiency over wide input voltage and load current ranges. With integrated high-side and low-side power MOSFETs, up to 150 mA of output current can be delivered at fixed output voltages of 3.3 V or 5 V or an adjustable output. The converter simplifies implementation while providing options to optimize the performance the target application. Pulse frequency modulation (PFM) mode is for optimal light-load efficiency, or constant on-time (COT) control is for nearly constant operating frequency. Both control schemes do not require loop compensation while providing excellent line and load transient response and short PWM on-time for large, step-down, conversion ratios.

The high-side, p-channel MOSFET can operate at 100% duty cycle for lowest dropout voltage and does not require a bootstrap capacitor for gate drive. Also, the current limit setpoint can adjust to optimize inductor selection for a particular output current requirement. Selectable and adjustable startup timing options include minimum delay (no soft start), internally fixed (900 µs), and externally-programmable soft start using an external capacitor. An open-drain PGOOD indicator can be used for sequencing and output voltage monitoring. The LM5165X is qualified to automotive AEC-Q100 grade 1 and is available in a VSON-10 package with 0.5-mm pin pitch.

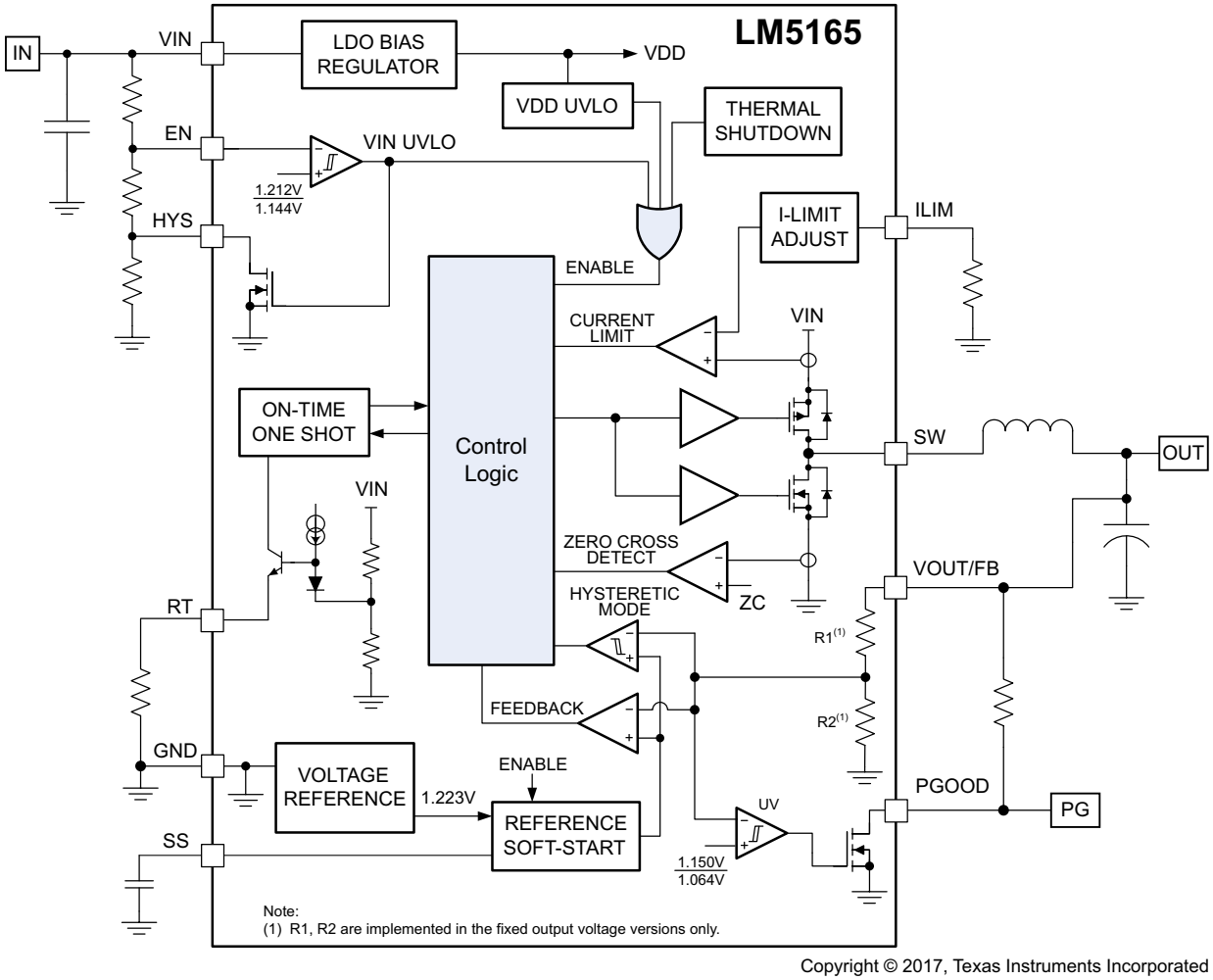

Figure 4. LM5165X Block Diagram

- Wide input voltage range of 3 V to 65 V
- Fixed (3.3 V, 5 V) or adjustable output voltages
- Maximum output current as high as 150 mA
- –40°C to 150°C junction temperature range

- Selectable PFM or COT mode operation
- Switching frequency as high as 600 kHz
- 10-lead, 3-mm × 3-mm VSON package

2.3 Design Considerations

The main design consideration is to have a high-density board with a lot of functionality with protection against ESD, EFT, and surge.

This reference design has two communication channels that use the TIOL111 and TIOS101: IO-Link and Digital Out. These two channels support a wide variety of applications on which these board can work. These parts were chosen of their integrated ESD, EFT, and surge protection and small size. TIOL111 and TIOS101 already have ±16-kV IEC 61000-4-2, ±4-kV IEC 61000-4-4, and ±1.2-kV/500-Ω IEC 61000-4-5.

The use of a DC-DC buck converter provides more power than what could be provided by the integrated LDOs in the TIOL111 and TIOS101. This switching DC-DC will help with thermal effects. The LDO in the TIOL111-5 could dissipate a high amount of heat if the device had to convert 24 V to 5 V. The efficiency (η) of an LDO is approximately Equation 1. Equation 1 implies that the efficiency is proportional to the ratio of the output to input voltage. In this case the reference design goes from 24 V to 5V, which gives an η of approximately 20%. All of this power is dissipated as heat.

$$\eta(\%) = I_0 V_0 \times 100 \tag{1}$$

Where:

- V_i is input voltage
- V_o is output voltage
- I_o is output current

Equation 2 shows a comparison to a DC-DC buck converter. As described in Section 3.2, this system has an efficiency of about 75%, which helps with thermal performance of this system.

$$\eta(\%) = \frac{P_0}{P_0 + P_D} \times 100 \tag{2}$$

Where:

- P_o is the output power
- P_D is the power dissipated in the buck converter
  - Based upon the switching frequency, duty cycle, and the R_{DSON} of the integrated MOSFETs in the converter.

2.4 System Design Theory

There are many design aspects to consider in this reference design. The one with most impact to the overall size would be the DC-DC LM5165X. This section will mostly discuss the design theory of the DC-DC buck converter.

2.4.1 TIOL111 and TIOS101

This reference design uses TIOL111 and TIOS101 for their high ESD, EFT, and surge protection. These parts come in a very small package (2.5-mm × 3-mm, 10-pin, VSON package), which makes them well suited for small designs. TIOL111 and TIOS101 can accept a wide range of supply voltages from 7 V to 36 V.

2.4.2 LM5165X

LM5165X provides a small package with a high range of input voltage and high switching frequency. This reference design uses this part for the current the device can supply, the wide range of supply voltages over which the device can work with, and the switching frequency the device can support. A more in-depth design theory for this part can be found in the datasheet for the LM5165X. The *LM5165 3-V to 65-V Input, 150-mA Synchronous Buck Converter With Ultra-Low I_Q* [1] datasheet will provide an overview of the design process taken for this board design.

2.4.2.1 Application Specific Assumptions and Choices

For this application size is the major concern, so the chosen switching frequency is to be around 350 kHz. Because this device is made to be powered off of the L+ line of IO-Link, efficiency is not as big of a concern as size. The output voltage is to be 5 V, and the output current is to be I_{out} = 100 mA.

2.4.2.2 Inductor Sizing

Inductor sizing is an important step in designing a DC-DC converter. In this reference design the DC-DC is operating in PFM [(1)]mode(Rt=0Ω to ground) with a target frequency of 350 kHz. In PFM mode the chosen filter inductance dictates the PFM pulse frequency. To choose the right size inductor Equation 3can be used to find the inductance required to operate at this frequency. $I_{L(peak)}$ is the peak-to-peak ripple current corresponding to R_{ILM} value. In this reference design, 240 mA (R_{ILIM} = 0 Ω) is the $I_{L(peak)}$; therefore using Equation 3, L_f = 47µH. On this board the F_{sw} ≈ 320 kHz. Make sure to choose an inductor with a current rating higher than the peak current limit; in this case, I_{peak} = 240 mA.

$$L_f = \frac{V_{out}}{F_{SW\,(PFM)} \times I_{PK\,(PFM)}} \times \left(1 - \frac{V_{out}}{V_{in}}\right) \tag{3}$$

Where:

- V_{in} = 24 V
- V_{out} = 5 V
- F_{sw} = 350 kHz
- $I_{pk(PFM)}$ = 240 mA

2.4.2.3 Output Capacitance Selection

The output capacitance must be large enough to accept the energy stored in the inductor without a large deviation in output voltage. The approximate output voltage ripple is given by Equation 4.

$$\Delta V_{out} = I_{out} \times \frac{\mu s}{C_{out}} + \frac{V_{out}}{123} \tag{4}$$

Setting this voltage change equal to 0.5% of the output voltage results in Equation 5.

$$C_{out} = 100 \times L_f \left(\frac{I_{pk\,(PFM)}}{V_{out}}\right)^2 \tag{5}$$

Where:

- L_f = 47 µH
- $I_{pk(PFM)}$ = 240 mA
- V_{out} = 5 V

This calculation results in a C_{out} = 10.8 µF. To add headroom and help with load transients, this design uses a 22-µF, 10-V ceramic output capacitor with X7R dielectric and 0805 footprint.

(1) Note that in PFM mode, the inductor current ramps from zero to the chosen peak threshold every switching cycle. Consequently, the maximum output current is equal to half the peak inductor current.

3 Hardware, Testing Requirements, and Test Results

3.1 Required Hardware

This design is meant to be used with an MCU and accessories in an IO-Link application.

For initial setup the following hardware is recommended

- M12 cable
- MCU
- Sensors, displays, and other peripherals

3.2 Testing and Results

3.2.1 Tests Results for LM5165X

In this system implementation, the LM5165X had an efficiency of 75%, an output voltage ripple of <2% during no load condition, and about 5% during full load.

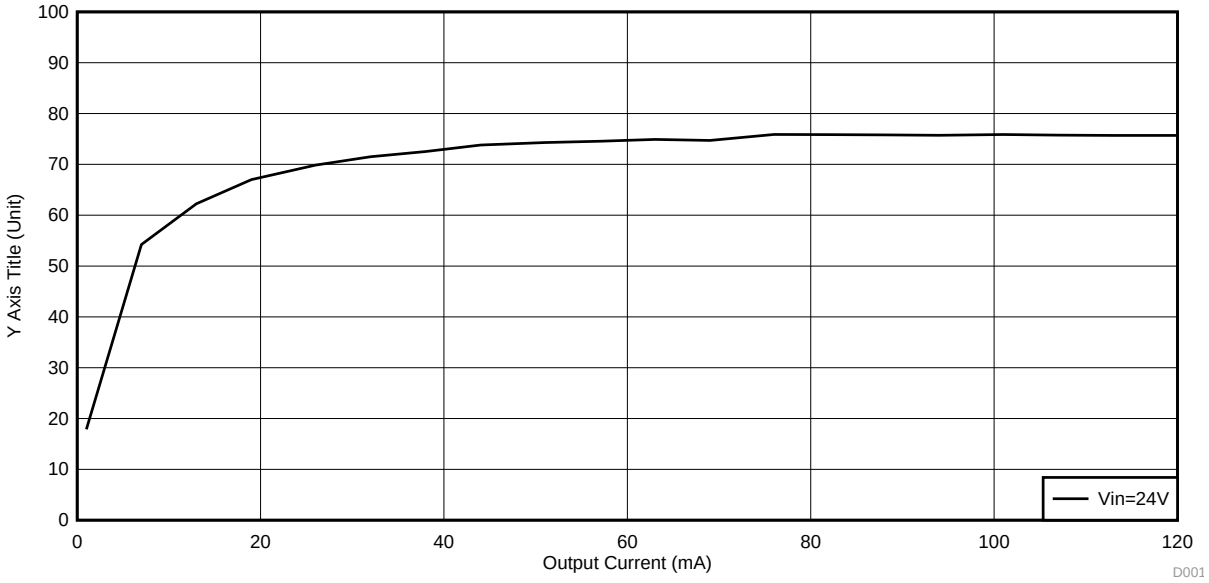

Figure 5. Efficiency

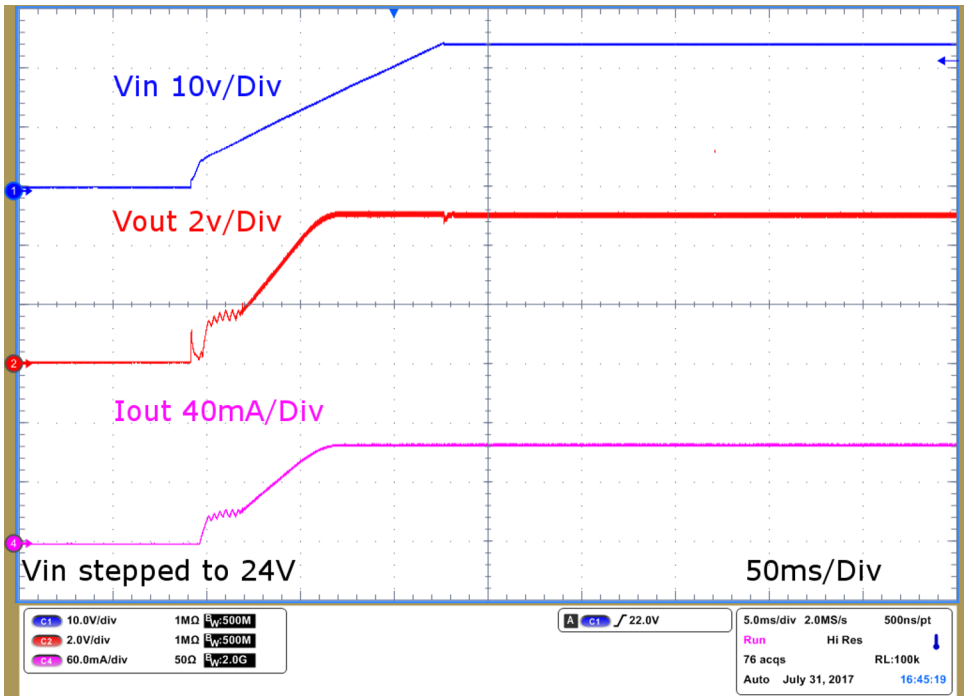

Figure 6. Start-Up, Full Load (100 mA)

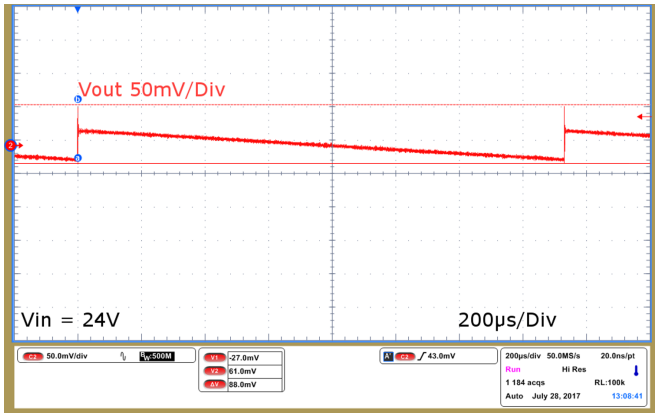

Figure 7. Output Ripple

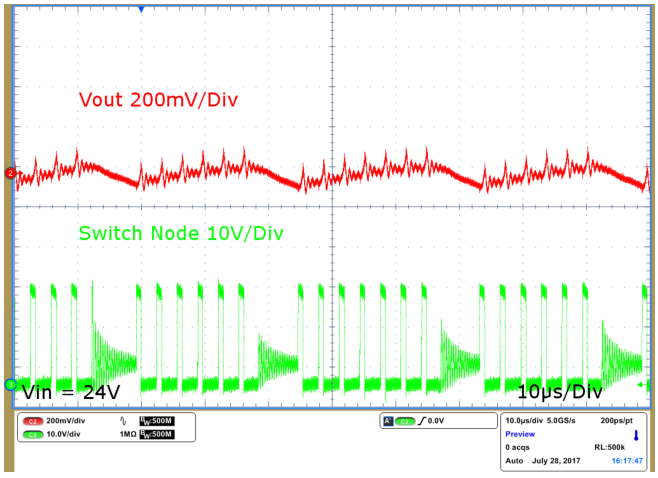

Figure 8. Switch Node, Full Load

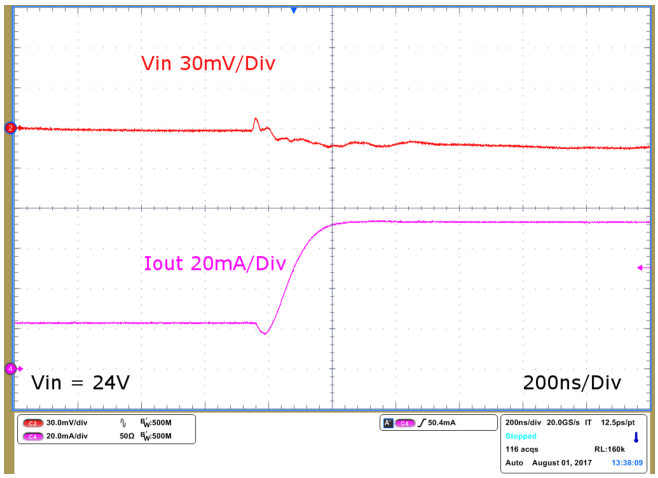

Figure 9. Load Transient, 25 mA to 75 mA

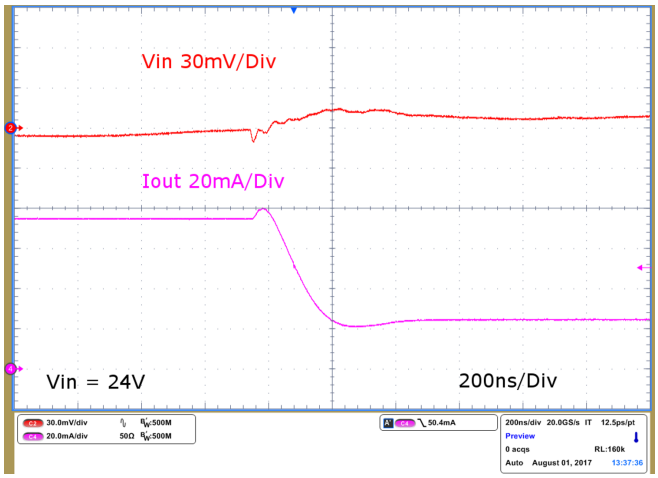

Figure 10. Load Transient, 75 mA to 25 mA

3.2.2 TIOL111 and TIOS101

3.2.2.1 Data Rates

The TIIOL111 and TIOS101 can support data rates up-to 230 kbps, as outlined in IO-Link specifications.

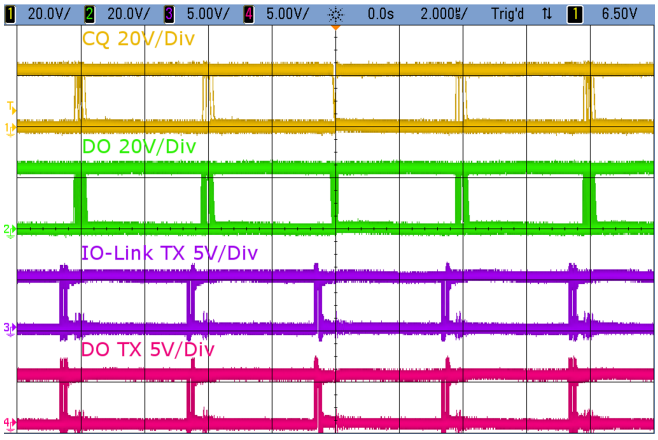

Figure 11. CQ and DO PRBS-7 230 kbps

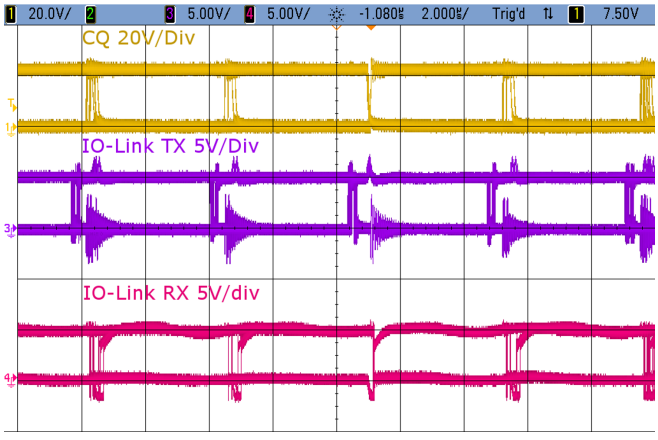

Figure 12. CQ, TX, and RX PRBS-7 230 kbps

3.2.2.2 Thermal Performance

Figure 13 and Figure 14 show the thermal performance. The ambient temperature of the room was 25ºC.

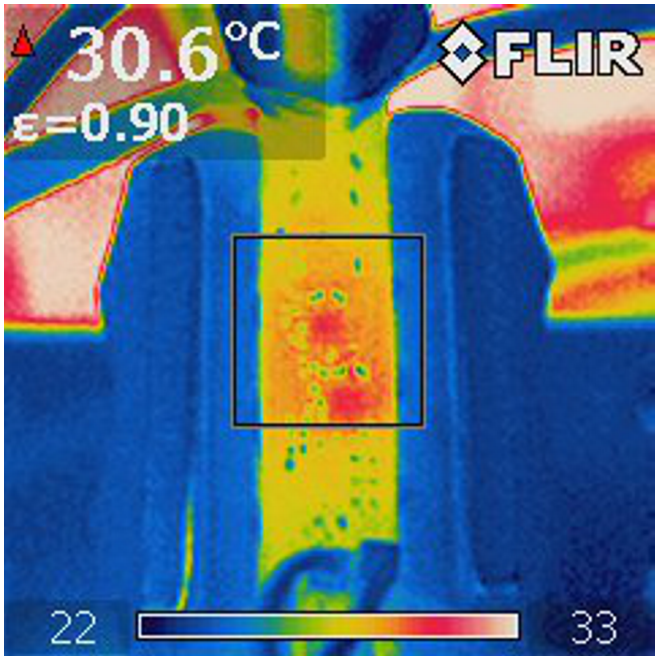

Figure 13. No Load

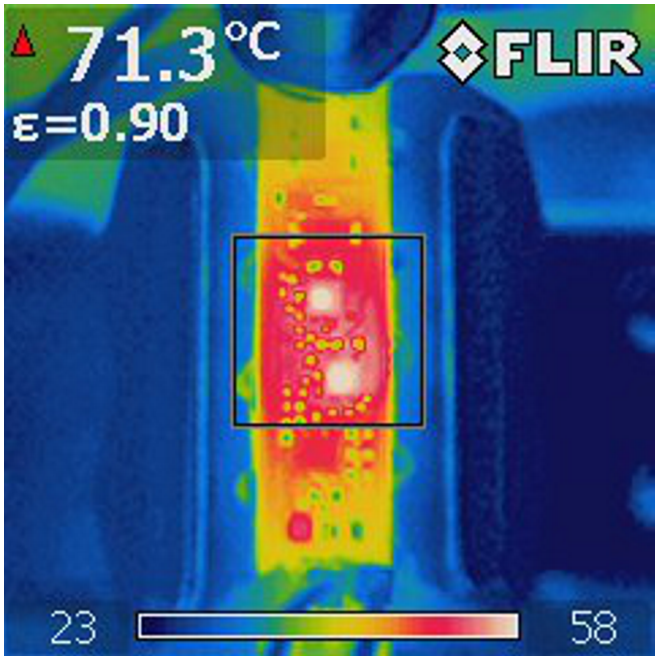

Figure 14. 100-mA Load on DC-DC, 240-mA Load on CQ and DO Each

3.2.2.3 Surge (IEC 61000-4-5)

For the TIOL111 and TIOS101 to have a higher level of surge protection per IEC 61000-4-5 (40 Ω), TVS diodes are required to accomplish this. In this application the SMJA30 was used. With the addition of the SMJA30, the system can withstand up to 1.5 kV in surge protection without compromising on size.

4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-01478.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01478.

4.3 PCB Layout Recommendations

The primary layout recommendation for this reference design is to have as small a current path for the DC-DC as possible, which will reduce the radiated EMI generated by high di/dt components relating to the pulsing currents in switching converters. The larger the area covered by the path of a pulsing current, the more electromagnetic emission is generated. The key to minimize radiated EMI is to identify the pulsing current path and minimize the area of that path.

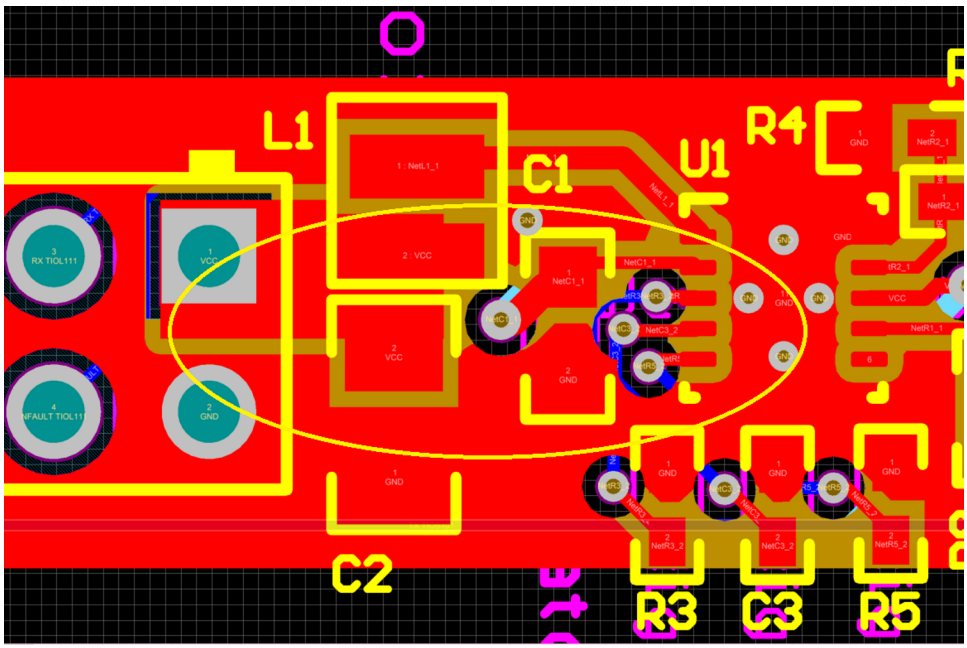

Figure 15. Small Current Loop

For detailed PCB layout recommendations, refer to the *LM5165 3-V to 65-V Input, 150-mA Synchronous Buck Converter With Ultra-Low I_Q* [1] datasheet.

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01478.

4.4 Altium Project

To download the Altium project files, see the design files at TIDA-01478.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01478.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01478.

5 Related Documentation

1. Texas Instruments, *LM5165 3-V to 65-V Input, 150-mA Synchronous Buck Converter With Ultra-Low I_Q* , LM5165 Datasheet (SNVSA47)

5.1 Trademarks

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