TI Designs: TIDA-01335
Ultra-Small IO-Link Sensor Transmitter With RTD Front-End Reference Design

Description

This reference design demonstrates the IO-Link communication in a small form factor of a 6-mm PCB width with integrated protection and an RTD sensor front end. The highly integrated and tiny IO-Link PHY offers ESD, EFT, and surge protection as well as reverse polarity protection. The built-in LDO and configurable output current provide easy and flexible system implementation and offers at the same time low power dissipation due to the ultra-low residual voltage. The 24-bit sigma-delta analog-to-digital converter (ADC) captures the RTD value (PT100 temperature sensor), which is converted in the MCU and sent through IO-Link to the IO-Link master.

Resources

TIDA-01335	Design Folder
TIOL111	Product Folder
MSP430FR5738	Product Folder
ADS1220	Product Folder

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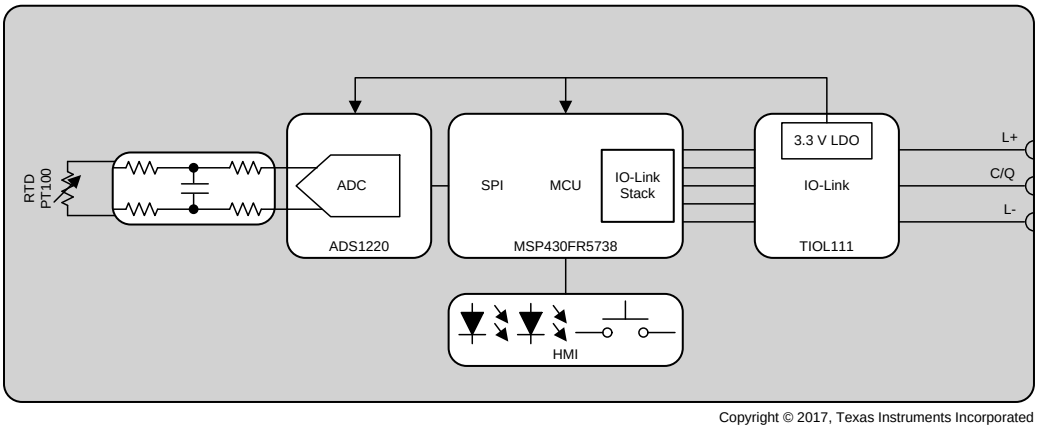
Features

- IO-Link PHY With Integrated:
  - 3.3- or 5-V LDO
  - Reverse Polarity Protection
  - ESD, EFT, and Surge Protection According to IEC 61000-4
- 50- to 350-mA Configurable Output Current Limit
- IO-Link V1.1 and V1.0 (TMG Stack)
- Small PCB Board Width of 6 mm
- RTD Performance: 0.17°C

Applications

- Factory Automation and Control
- Displacement Transmitter
- Temperature Transmitter
- Flow Transmitter
- Level Transmitter
- Pressure Transmitter



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1 System Description

In Factory Automation and Control systems, the IO-Link interface is becoming more and more popular. Applications that usually have a switching output, either NPN or PNP, are upgraded with the IO-Link standard. With this upgrade, two possible scenarios can be addressed:

1. Extend the switching output with the capability to program and configure the field transmitter with IO-Link.
2. Completely communicate with the IO-Link protocol between the field transmitter and PLC.

For the IO-Link communication, a stack is implemented in the MCU, which is also part of this system design. To easily showcase the functionality, a resistance temperature detector (RTD) sensor (in particular, a PT100 element) is connected to the 24-bit ADC, so the sensor data is sent through the IO-Link interface. When the system is connected to an IO-Link master system, the temperature information is shown in the master software.

In addition, this reference design allows one to set a temperature threshold level either with the switch button or configured using IO-Link through the IO-Link master. Two LEDs indicating the status of the system, whether the IO-Link communication is established or in case an error occurs.

The highly integrated IO-Link PHY with a size of only 2.5 mm × 3 mm provides reverse polarity protection and helps designers meet system compliance with the International Electrotechnical Commission (IEC) 61000-4 standard. The built-in EMC protection allows for:

- ±16-kV IEC 61000-4-2 ESD Contact Discharge
- ±4-kV IEC 61000-4-4 Electrical Fast Transient (EFT)
- ±1.2-kV/500-Ω IEC 61000-4-5 Surge

With the capability of using the onboard LDO with either a 3.3-V or 5-V output, the remaining system can be supplied with up to 20 mA. In this reference design, the integrated 3.3-V LDO supplies the MCU and the 24-bit ADC with power from the volatge input, which covers a range from 7 to 36 V with a ±65-V tolerant transient.

This feature set is key for very small field transmitters, like the 6-mm wide PCB in this reference design, which easily fits in a M12-sized tube.

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1.1 Key System Specifications

PARAMETER	SPECIFICATIONS / COMMENTS
ANALOG FRONT-END	
PT100	3-wire mode
Current excitation	Programmable (10, 50, 100, 250, 500, 1000, 1500 µA)
Reference resistor	3.24 kΩ, Tol = 0.1 %, TC = 10 ppm/C
Resolution	24-bit ADC
DIGITAL PROCESSING	
Temperature calculation	Look up table, based on the Callendar-Van Dusen equation
IO-Link stack	TMG
	V1.1 and V1.0
	Supports COM3
INTERFACE	
Communication	IO-Link
SIO	NPN, PNP
	50- to 350-mA configurable current limit
ALARM	
Fault indicator (open drain)	Overcurrent
	Temperature
	Power supply
POWER SUPPLY	
Operating voltage	7- to 36-V DC
	±65-V transients < 100 µs
LDO	3.3-V output voltage
	20-mA output current

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2 System Overview

2.1 Block Diagram

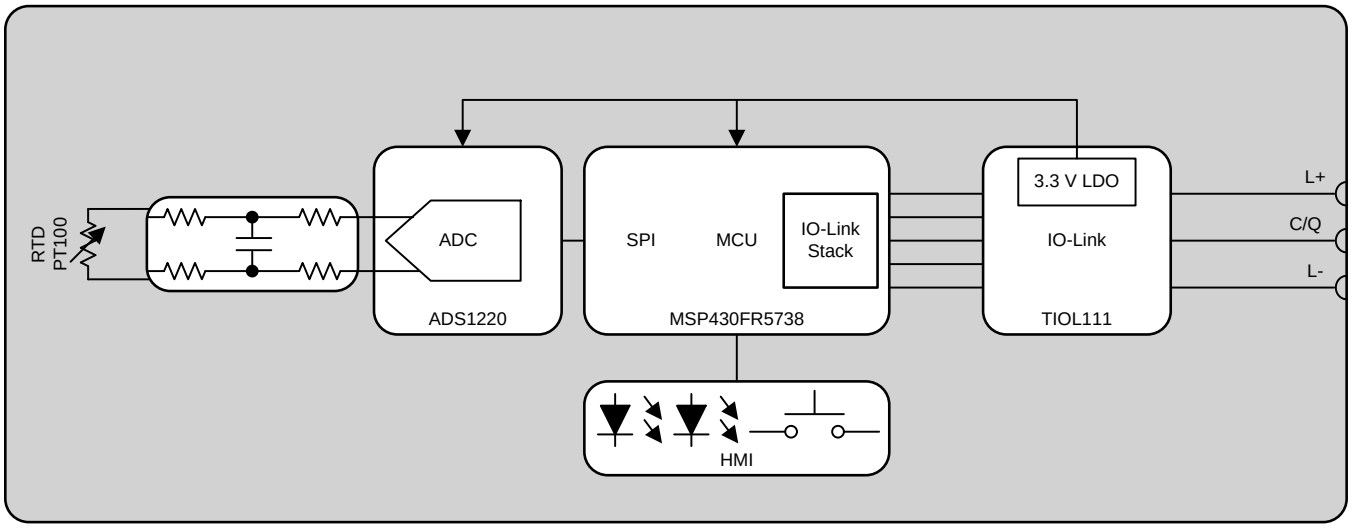

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Figure 1. TIDA-01335 Block Diagram

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2.2 Design Considerations

2.2.1 IO-Link Interface

The highly integrated IO-Link PHY TIOL111 requires only a small amount of external components. In this reference design, C10, C11, and C13 are placed at the inputs. C9 is the output capacitor of the integrated LDO, and R16 is the resistor setting the maximum output current. The two output signals WAKE and FAULT are open-drain outputs. The needed pullup resistors are inside the MSP430™.

Figure 2 shows the schematic of the IO-Link interface. J2 is the M12 connector.

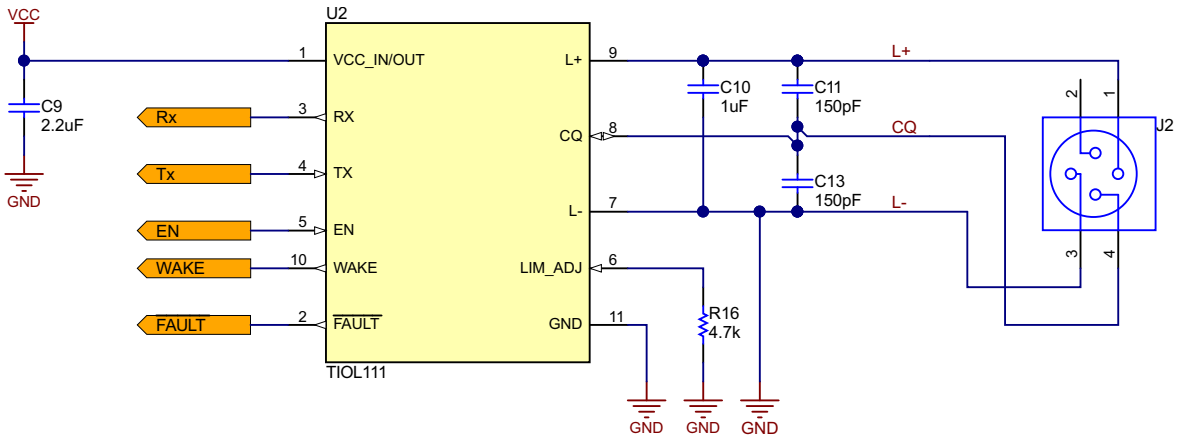

Figure 2. IO-Link Interface and 3.3-V Output

The TIOL111 device comes in three different versions:

- TIOL111-3: IO-Link PHY with an integrated LDO, providing 3.3 V
- TIOL111-5: IO-Link PHY with an integrated LDO, providing 5 V
- TIOL111: IO-Link PHY without an integrated LDO

This reference design uses the 3.3-V LDO version, which is capable of providing up to a 20-mA output current. This current is sufficient to power the MCU and ADC as well as to supply the LEDs.

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2.2.2 RTD Front End

The main focus of this reference design is the realization of the IO-Link interface including the IO-Link stack. To have real world sensor data to transmit using the IO-Link interface, a temperature sensor is also part of this design. The board contains a PT100 element as the temperature sensor.

For the excitation current and to measure the RTD resistance value, this references design uses the ADS1220. With two integrated, programable excitation current sources and a programmable PGA, the 24-bit ADC is a perfect fit in this application.

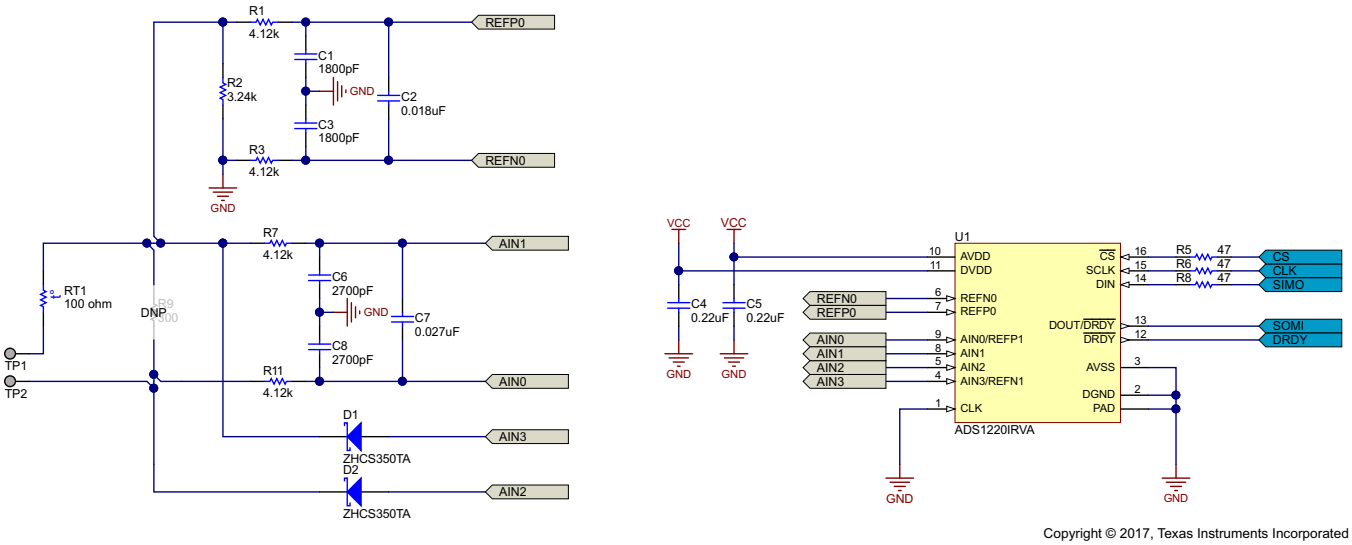

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Figure 3. Analog Front-End Circuitry

Figure 3 shows the circuitry of the analog front end. Resistor R9 is only needed for calibration purposes. With R9 = 300 Ω, it is used to run a gain calibration. For this purpose, the PT100 element has to be disconnected. This can be realized by removing the short between TP1 and TP2 once calibration is done or not needed. R9 has to be removed and TP1 shorted with TP2.

The excitation current from the ADS1220 is provided through the two diodes D1 and D2, developing a reference voltage across R2. This 3.24-kΩ precision resistor has a 0.1% tolerance with a temperature coefficient of 10 ppm/C and generates the reference volatge for the ADC, enabling a ratiometric measurement.

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2.2.3 Digital Processing

For calculating the temperature, based on the measured RTD resistance, the MSP430FR5738 is part of the design. A look-up table (LUT) translates the measured voltage levels into the respective temperature values according to Calendar-Van Dusen equations. For this, the MCU gets a data set once the ADC provides the data ready (DRDY) information. Once calculated, the temperature data is transmitted through the IO-Link interface.

Also in the MSP430FR5738, the IO-Link stack is running. Once an IO-Link connection is established between the TIDA-01335 reference design and an IO-Link master, the green LED D5 is blinking. With the pushbutton S1, it is possible to set a temperature threshold. Once this threshold is reached, the information is also sent through IO-Link to the master. With the IO-Link master GUI, it is possible to read out this temperature threshold and overwrite the temperature threshold with the GUI. Figure 4 shows the schematic of the digital processing section.

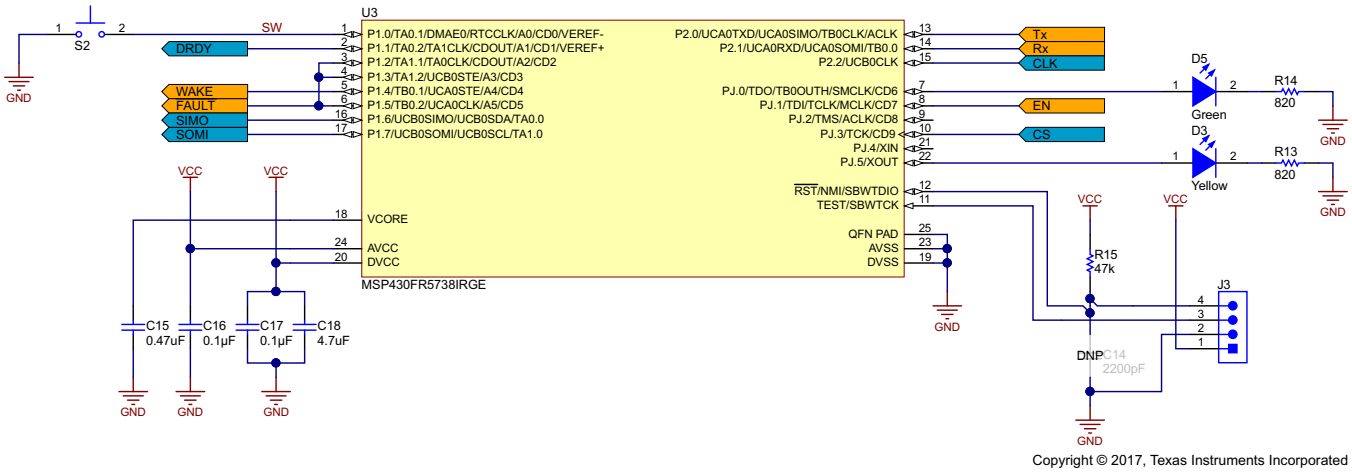

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Figure 4. Digital Processing Section

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2.3 Highlighted Products

The following subsections detail each circuit block in the TIDA-00559 block diagram. For more information on each of these devices, see their respective product folders at TI.com.

2.3.1 TIOL111: IO-Link Device Transceiver With Integrated Surge Protection

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. The output current limit can be configured using an external resistor. Fault reporting and internal protection functions are provided for undervoltage, overcurrent, and overtemperature conditions.

Key features of this device include:

- 7- to 36-V supply voltage
- PNP, NPN, or IO-Link configurable output
  - IEC 61131-9 COM1, COM2, and COM3 data rate support
- Low residual voltage of 1.75 V at 250 mA
- 50- to 350-mA configurable current limit
- Tolerant to ±65-V transients < 100 µs
- Reverse polarity protection of up to 55 V on L+, CQ, and L–
- Integrated EMC protection on L+ and CQ:
  - ±16-kV IEC 61000-4-2 ESD Contact Discharge
  - ±4-kV IEC 61000-4-4 EFT
  - ±1.2-kV/500-Ω IEC 61000-4-5 Surge
- Fast demagnetization of inductive loads up to 1.5 H
- Large capacitive load driving capability
- < 2-µA CQ leakage current
- < 1.5-mA quiescent supply current
- Integrated LDO options for up to 20-mA current:
  - TIOL111: No LDO
  - TIOL111-3: 3.3-V LDO
  - TIOL111-5: 5-V LDO
- Overtemperature warning and thermal protection
- Remote wake-up indicator
- Fault indicator
- Extended ambient temperature: –40°C to 125°C
- 2.5-mm×3-mm 10-pin VSON package

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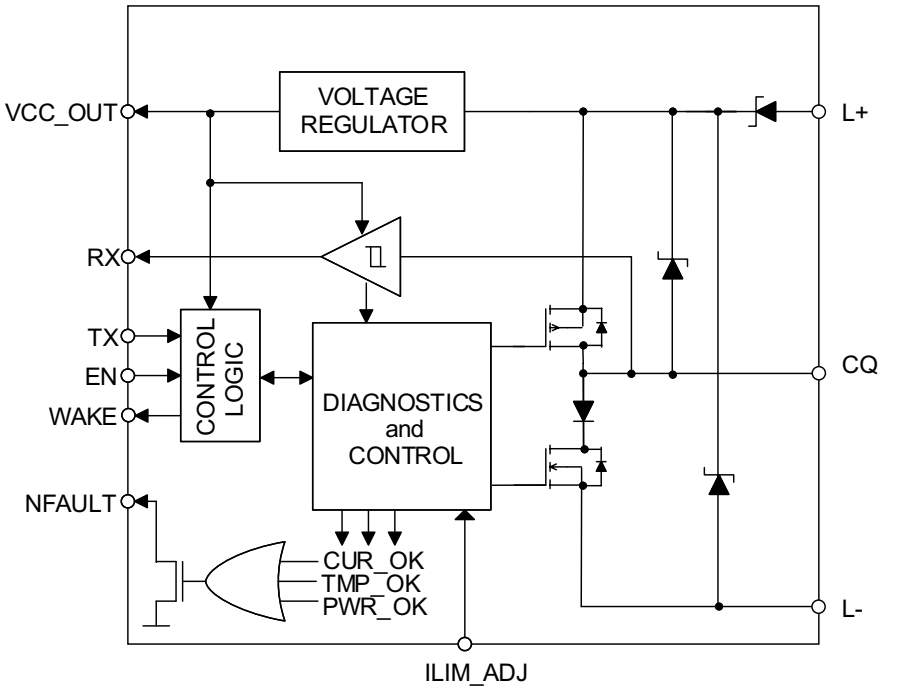

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Figure 5. TIOL111-3 With 3.3-V Voltage Regulator

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2.3.2 MSP430FR5738

The TI MSP430FR573x family of ultra-low-power microcontrollers consists of multiple devices that feature embedded FRAM nonvolatile memory, an ultra-low-power 16-bit MSP430 CPU, and different peripherals targeted for various applications. The architecture, FRAM, and peripherals, combined with seven low-power modes, are optimized to achieve extended battery life in portable and wireless sensing applications. FRAM is a new nonvolatile memory that combines the speed, flexibility, and endurance of SRAM with the stability and reliability of flash, all at lower total power consumption. Peripherals include a 10-bit ADC, a 16-channel comparator with voltage reference generation and hysteresis capabilities, three enhanced serial channels capable of I^2C, SPI, or UART protocols, an internal DMA, a hardware multiplier, an RTC, five 16-bit timers, and digital I/Os.

Key features of this device include:

- Embedded MCU 16-bit RISC architecture up to 24-MHz clock:
  - Wide supply voltage range (2 to 3.6 V)
  - Optimized ultra-low-power modes (81.4 µA/MHz in active and 320 nA in shutdown (LPM4.5))
  - Ultra-low-power ferroelectric RAM
  - 16-KB nonvolatile memory
  - Ultra-low-power writes
  - Fast write at 125 ns per word (16kB in 1 ms)
  - Built-in error coding and correction (ECC) and MPU
  - Universal memory = program + data + storage
  - 10^{15} write cycle endurance
- Intelligent digital peripherals:
  - 32-bit hardware multiplier (MPY)
  - Three-channel internal DMA
  - RTC with calendar and alarm functions
  - 16-bit Cyclic redundancy checker (CRC)
  - High-performance analog
  - Enhanced serial communication

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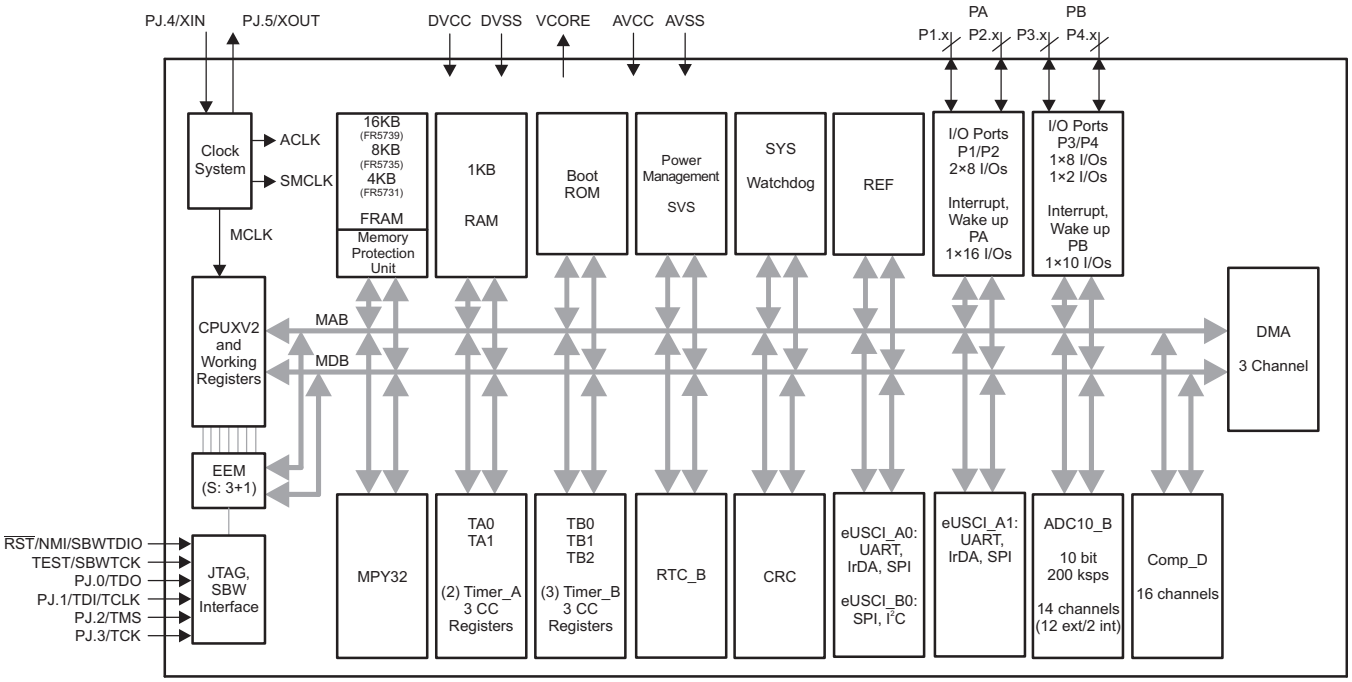

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Figure 6. Functional Block Diagram MSP430FR5738

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2.3.3 ADS1220: 24-Bit, 2kSPS, Four-Channel, Low-Power Delta-Sigma ADC With PGA and V_{REF} for Small Signal Sensors

The ADS1220 is a precision, 24-bit, ADC that offers many integrated features to reduce system cost and component count in applications measuring small sensor signals. The device features two differential or four single-ended inputs through a flexible input multiplexer (MUX), a low-noise, programmable gain amplifier (PGA), two programmable excitation current sources, a voltage reference, an oscillator, a low-side switch, and a precision temperature sensor.

The device can perform conversions at data rates up to 2000 samples-per-second (SPS) with single-cycle settling. At 20 SPS, the digital filter offers simultaneous 50-Hz and 60-Hz rejection for noisy industrial applications. The internal PGA offers gains up to 128 V/V. This PGA makes the ADS1220 ideally-suited for applications measuring small sensor signals, such as RTDs, thermocouples, thermistors, and resistive bridge sensors. The device supports measurements of pseudo- or fully-differential signals when using the PGA. Alternatively, the device can be configured to bypass the internal PGA while still providing high input impedance and gains up to 4 V/V, allowing for single-ended measurements.

Power consumption is as low as 120 µA when operating in duty-cycle mode with the PGA disabled. The ADS1220 is offered in a leadless VQFN-16 or a TSSOP-16 package and is specified over a temperature range of –40°C to 125°C.

Key features of this device include:

- Low current consumption:
  - Duty-cycle mode: 120 µA
  - Normal mode: 415 µA
- Wide supply range: 2.3 to 5.5 V
- Programmable gain: 1 to 128 V/V
- Programmable data rates: up to 2 kSPS
- Simultaneous 50-Hz and 60-Hz rejection at 20 SPS with a single-cycle settling digital filter
- Low-noise PGA: 90 nV_{RMS} at 20 SPS
- Dual-matched programmable current-sources: 10 to 1500 µA
- Internal 2.048-V reference: 5 ppm/°C (typical) drift
- Internal oscillator: 2% (maximum) accuracy
- Internal temperature sensor
- Two differential or four single-ended inputs
- SPI-compatible interface
- Package: 3.5 mm × 3.5 mm × 0.9 mm QFN

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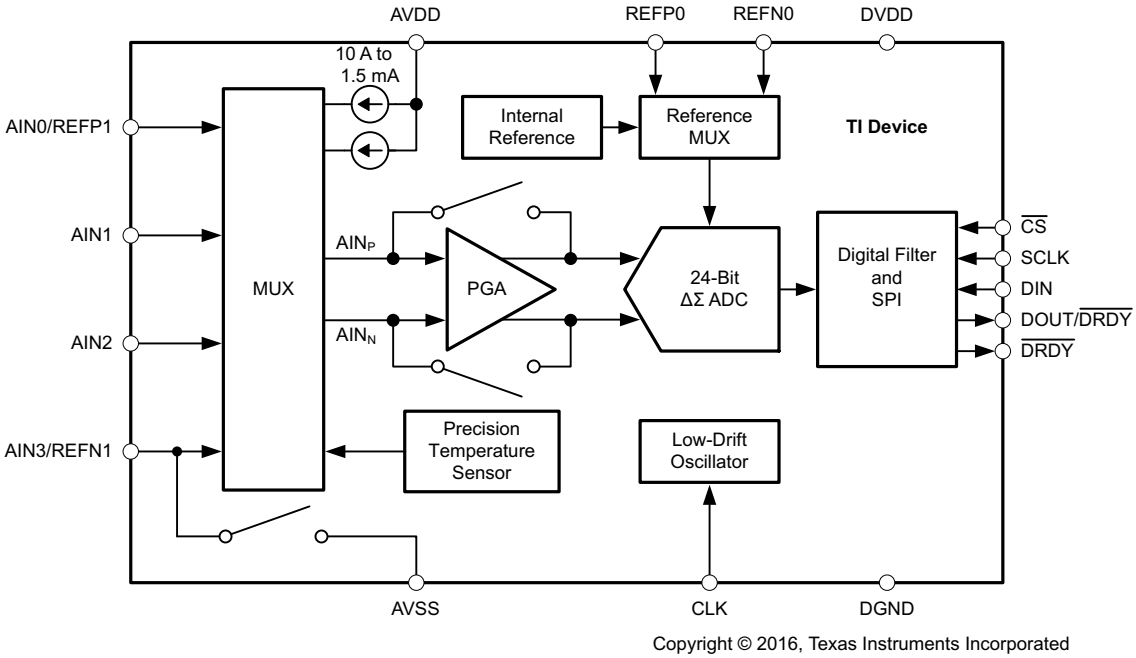

Figure 7. Functional Block Diagram of ADS1220

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3 Hardware, Software, Testing Requirements, and Test Results

In Figure 8, the different building blocks of TIDA-01335 are highlighted.

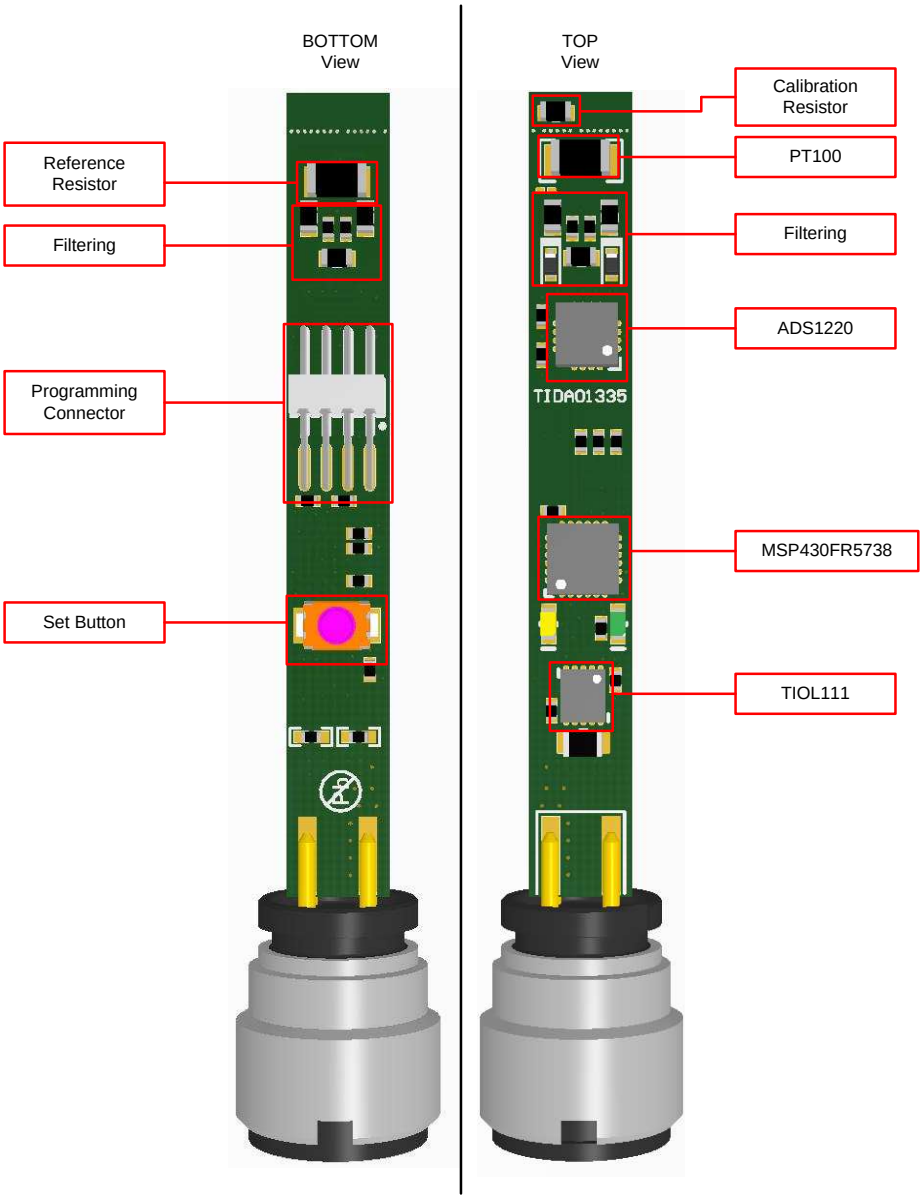

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Figure 8. TIDA-01335 Board Description

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In the bottom view:

- Reference resistor (see Figure 9): The resistor R2 is a precise reference resistor. The excitation current develops a voltage across R2, which is used as a reference volatge for the ADC. This approach allows for a ratiometric measurement. It is important to have a stable resistor because the resistor value of the RTD is a ratio to R2. In this reference design, R2 has a tolerance of 0.1% with a temperature coefficient of 10ppm/C.
- Filtering (see Figure 9)
- Programming connector (see Figure 10)
- Set button: When pressing this button, the current temperature is used as a temperature threshold. The value can also be read out using IO-Link.

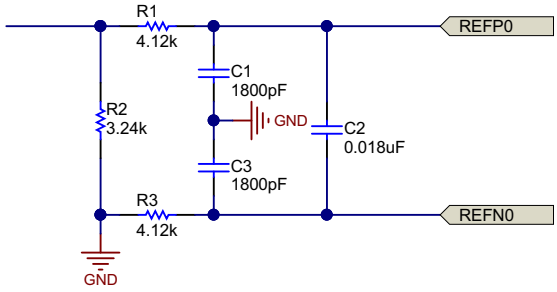

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Figure 9. Reference Resistor and Filtering

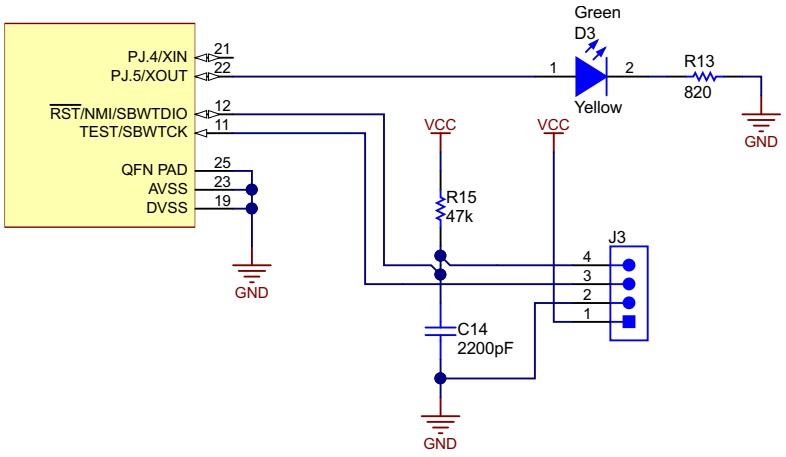

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Figure 10. Programming Connector

In the top view:

- Calibration resistor: Resistor R9 is not populated per default. The resistor can be used for gain calibration of the ADC.
- PT100: The PT100 is the temperature sensing element.
- ADS1220: ADC to capture the voltage across the RTD
- MSP430FR5738: The MCU calculates the temperature based on the voltage across the RTD and the look-up table. The MSP430 also has the IO-Link stack for the IO-Link communication.
- TIOL111: This is the IO-Link PHY

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3.1 Required Hardware and Software

To get the TIDA-01335 reference design up and running, the following hardware and software is needed:

- TIDA-01335 reference design
- IO-Link master:
  - Example: TMG USB IO-Link Master V2
  - Software for IO-Link master
- M12 cable to connect the reference design and IO-Link master
- MSP430 programmer
  - Example: MSP-FET
- PC
- IO-Link stack
- IO-Link IODD files
- Optional:
  - Precision reference resistor for calibrating the analog front end
  - Precision digital multimeter (DMM)

3.2 Testing and Results

3.2.1 Test Setup

Figure 11 shows how to connect the reference design. The MSP-FET is only required for programming or debugging the MSP430. The M12 cable connects the reference design with the IO-Link master, which is also connected through USB to the PC. The PC has the IO-Link master software installed. For details on the installation of the GUI, see the user manual of the IO-Link master software.

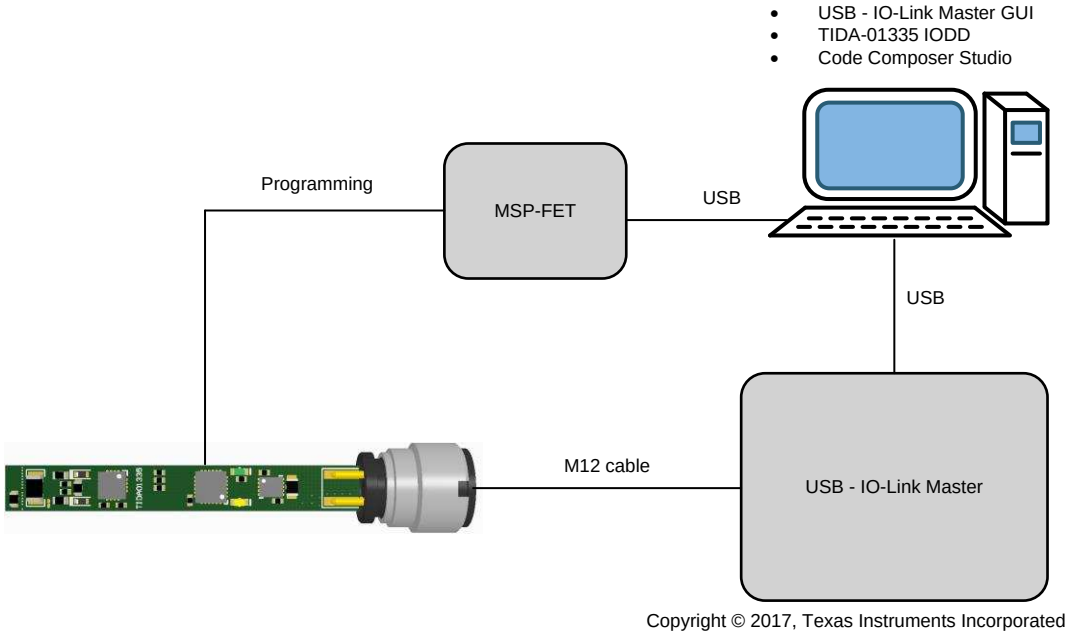

Figure 11. Test Setup of Reference Design

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3.2.2 Test Results

Figure 12 through Figure 18 show the different steps to configure the IO-Link master GUI. Note that these steps are only valid for the IO-Link master used here. When the reference design is connected as per Figure 11, launch the GUI and follow these steps:

1. Click the "Search Master" button (see Figure 12).
2. Double-click in the pop-up window on the IO-Link master, which is connected to the system. Typically, this is only one entry as long as only one IO-Link master is connected to the PC (see Figure 13).
3. Drag the "TIDA-01335" IODD file and drop it in the "IO-Link" row. See the manual on how to load the specific IODD files (see Figure 14).
4. Go to the Vendor and Device information in the IO-Link row. Click on the "Go Online" button to establish a connection between the PC and the IO-Link master. If successful, the color of the button turns green (see Figure 15).
5. Double-click in the "Topology" window on "TI Design TIDA-01335" to open the details of this reference design (see Figure 16).
6. The green button in the upper left corner indicates a proper connection between the IO-Link master and IO-Link device (see Figure 17).
7. By clicking on the "Process Data" tab, the information of the reference design are shown. For this design, the temperature of the RTD sensor is shown, as well as the threshold of the low and high temperature limits (see Figure 18).

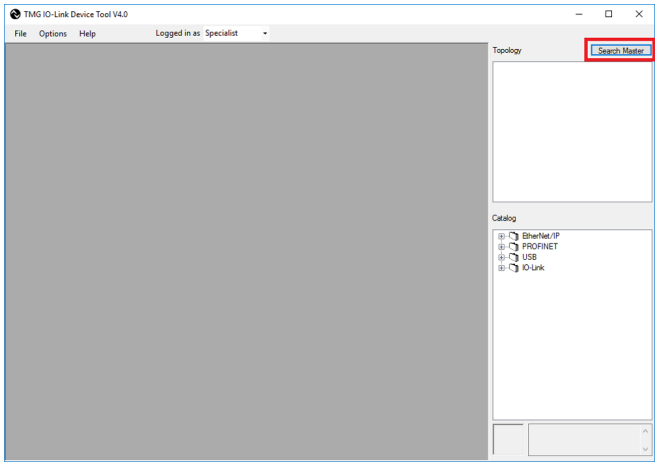

Figure 12. IO-Link Master GUI 1

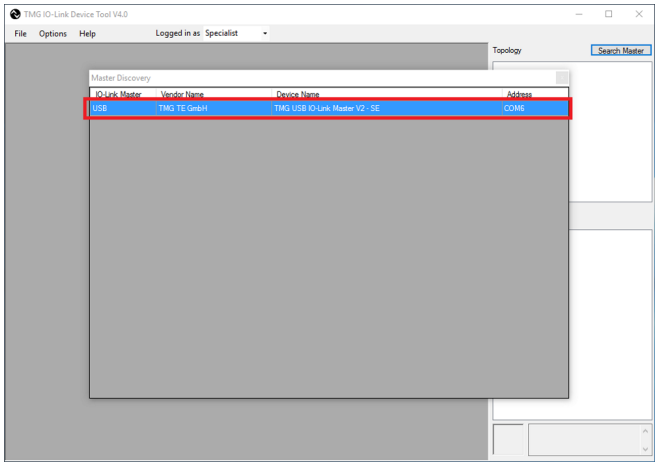

Figure 13. IO-Link Master GUI 2

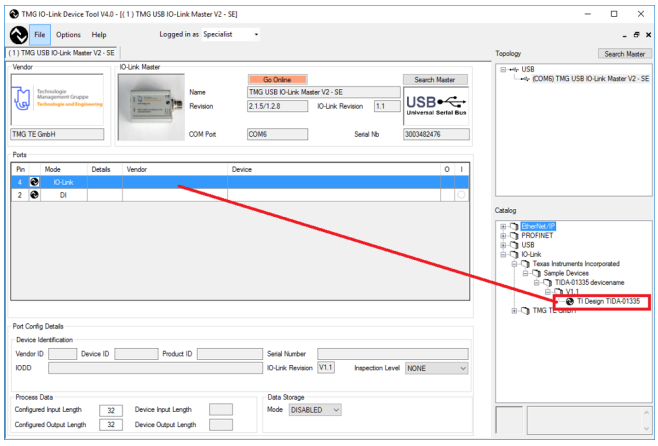

Figure 14. IO-Link Master GUI 3

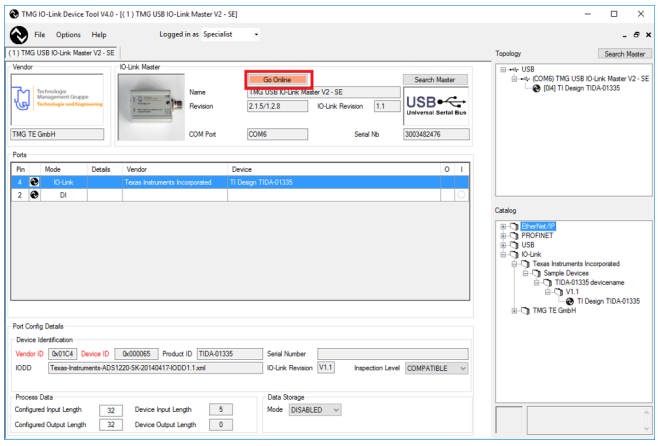

Figure 15. IO-Link Master GUI 4

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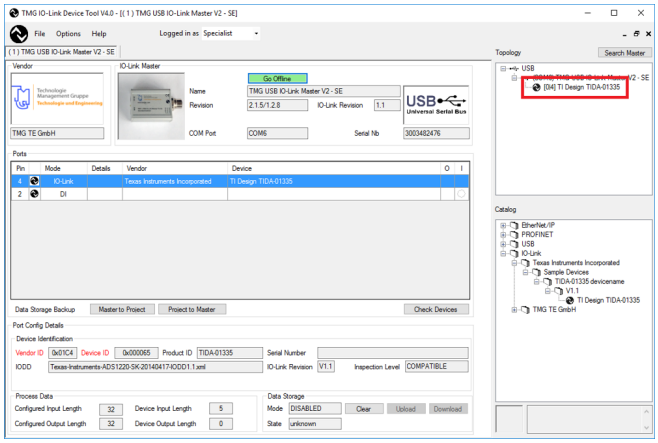

Figure 16. IO-Link Master GUI 5

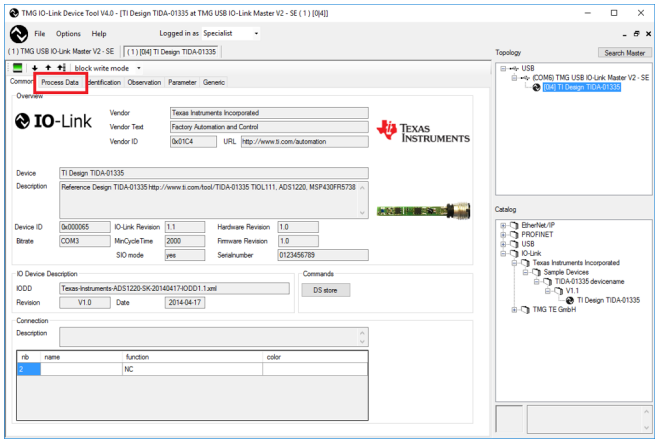

Figure 17. IO-Link Master GUI 6

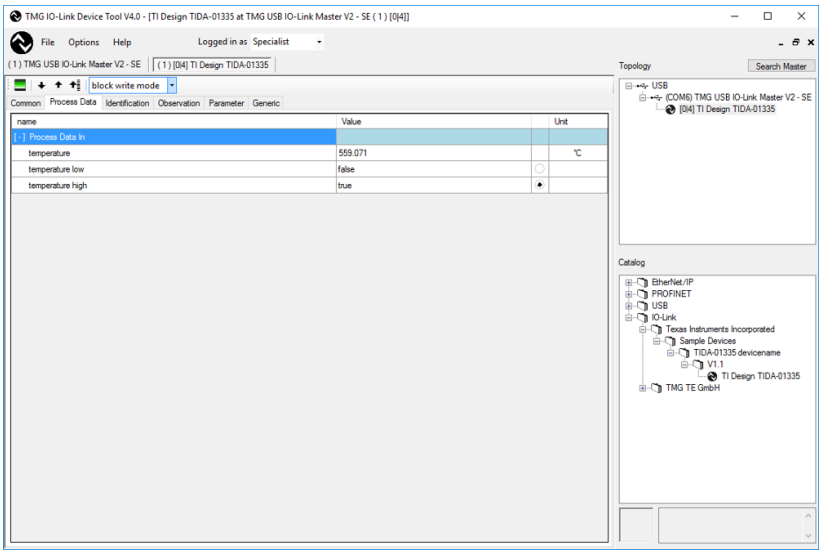

Figure 18. IO-Link Master GUI 7

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4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-01335.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01335.

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01335.

4.4 Altium Project

To download the Altium project files, see the design files at TIDA-01335.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01335.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01335.

5 Software Files

To download the software files, see the design files at TIDA-01335.

6 Related Documentation

This design did not use any documentation.

6.1 Trademarks

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All other trademarks are the property of their respective owners.

7 About the Author

ALEXANDER WEILER is a systems engineer at Texas Instruments, where he is responsible for developing reference design solutions for the industrial segment. Alexander brings to this role his extensive experience in high-speed digital, low-noise analog, and RF system-level design expertise. Alexander earned his diploma in electrical engineering (Dipl.-Ing.(FH)) from the University of Applied Science in Karlsruhe, Germany.

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