SYSTEM BOARD 7283

MAXREFDES177# IO-Link Universal Analog IO

The MAXREFDES177# is a complete, IO-Link® universal analog input-output (IO) reference design that has a MAX22515 IO-Link transceiver with integrated protection. It demonstrates a fully software-configurable analog IO module using the MAX22000 industrial configurable analog IO device. The analog (field) side is fully isolated from the IO-Link side with the MAX14483 digital data isolator and an isolated power supply derived from the L+ (24V) supply from the IO-Link master connection.

The MAXREFDES177#, built in an industrial form factor, uses an industry-standard M12 connector with a 4-wire IO-Link cable. The analog (field) side uses a 4-way PCB terminal block. The complete reference design fits on a 61mm x 25mm printed circuit board (PCB).

The configurable modes include analog voltage input (±10V), analog current input (±20mA), analog voltage output (±10V), and analog current output (±20mA) across the AIO and GND terminals. The MAXREFES177# sets the linear range at 105% and full-scale range at 125% of the nominal range. The accuracy is as good as 0.1% over a ±50°C temperature variation. The other two terminals can be configured to measure temperature using a standard device such as a PT100 or PT1000 RTD. These terminals interface to the integrated Programmable Gain Amplifier (PGA) in the MAX22000 at inputs AI5 and AI6.

An Atmel® ATSAM low-power microcontroller interfaces between the MAX22000 industrial configurable analog IO device and MAX22515 IO-Link device transceiver. The MAX22515 features integrated surge protection for robust communication in a very small PCB area without requiring external protection components such as TVS diodes. The MAX22515 is available in a tiny 20-bump wafer-level package (WLP), allowing the MAXREFDES177# to have a small footprint. The design is reverse-polarity protected using the integrated active reverse-polarity protection of the MAX22515. The MAX22515 has two integrated LDO regulators (3.3V and 5V). The 3.3V LDO generates the 3.3V supply for other circuitry, reducing the number of required external components and saving space. The MAX22515 also features low on-resistance drivers (C/Q and DO/DI) to reduce power dissipation, allowing this reference design to consume minimal power with very low thermal dissipation.

This IO-Link device utilizes the Technologie Management Gruppe Technologie und Engineering (TMG TE) IO-Link device stack to communicate to any IO-Link version 1.1-compliant master. The board contains a male M12 connector to connect to a compliant IO-Link master using a standard M12 cable. Connecting the MAXREFDES177# to a USB IO-link master, such as the MAXREFDES165#, with the associated software allows for easy evaluation.

The design files, firmware, and software are available in the Design Resources tab. The board is also available for purchase.

Features

- IEC 61131-9 Compliant
- TMG TE IO-Link Stack
- IO-Link Version 1.1 Compliant
- Universal Analog IO
- Integrated Galvanic Isolation

Applications

- Industrial Automation
- Analog Input Output Modules
- PLC and DCS Systems
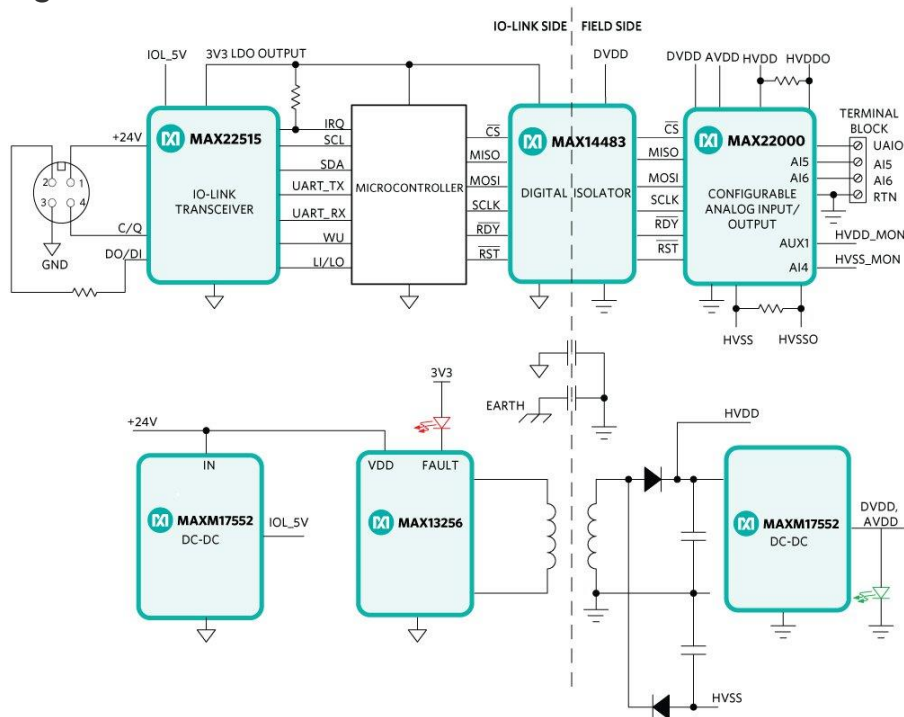- Smart Sensors and Actuators

System Diagram

Figure 2. MAXREFDES177# system block diagram.

Introduction

Advanced factory automation solutions (Industry 4.0) require an increasing number of smart sensors and smart actuators, which are typically controlled using IO-Link point-to-point serial communication between the sensor/actuator and controller (master). Maxim Integrated, as a leading provider of IO-Link sensor transceivers and master transceiver ICs, also provides complete reference design solutions to help its customers improve their time to market. These proven designs cover all the hardware and software requirements needed for compliance with the IO-Link standard.

IO-Link is the first open, field bus agnostic, low-cost, point-to-point serial communication protocol used for communicating with sensors and actuators that has been adopted as an international standard (IEC 61131-9). IO-Link standardizes the interoperability of industrial equipment worldwide. IO-Link can function directly from the PLC or be integrated into all standard field buses, making it the de-facto standard for universally communicating with smart devices like the MAXREFDES177#.

A true field-configurable, universal IO is realized when the field programmability of the IO-Link is combined with a software-configurable IO. Industrial sensor/actuator OEMs can thus provide end users total flexibility at the factory floor level to simplify equipment installation and commissioning, while reducing their number of SKUs and BOMs, and simplifying and streamlining their purchasing and manufacturing.

Maxim Integrated and TMG TE collaborated to design the MAXREFDES177# reference design compliant with the IO-Link version 1.1/1.0 standard. The MAXREFDES177# design has an industry-standard MAX22515 IO-Link device transceiver, an Atmel ATSAM low-power microcontroller that uses the TMG TE IO-Link device stack, and a MAX22000 industrial universal analog IO device that is fully software configurable for all common industrial analog input and output, voltage and current ranges. The complete reference design fits on a 61mm x 25mm printed circuit board (PCB).

Detailed Description of Hardware

The MAXREFDES177# IO-Link universal analog IO consumes minimal power, space, and cost, making it a complete solution for the many analog input sensors or analog output actuators found in various industrial control and automation applications.

The MAX22515 IO-Link device transceiver is compliant with the IO-Link version 1.1/1.0 physical-layer specification. It integrates the high-voltage functions commonly found in industrial sensors, including drivers, and two linear regulators, all in a tiny 2.5mm x 2.0mm WLP. The MAX22515 has extensive integrated protection to ensure robust communication in harsh industrial environments. All four I/O pins (V24, C/Q, DO/DI, and GND) are reverse-voltage, short-circuit protected, and have integrated ±1kV/500Ω surge protection. Thus, a very small PCB area is needed with no required external protection components such as TVS diodes. The low on-resistance driver (C/Q) further reduces power dissipation so that this reference design consumes minimal power with very low thermal dissipation. Operation is specified for normal 24V supply voltages up to 36V. Transient protection is simplified due to high voltage tolerance (i.e., 65V absolute maximum rating) in addition to the integrated surge protection.

The two integrated LDO regulators in the MAX22515 generate 3.3V and 5V, reducing the number of additional external components and required space.

The MAX22515 features a flexible control interface through either an SPI or I²C interface. The I²C interface is used in this reference design to reduce the number of pins required by the microcontroller. The I²C interface provides extensive diagnostics for the MAX22515. A 3-wire UART interface is provided for IO-Link communication.

The MAXREFDES177# does not require external protection devices such as varistors or TVS diodes due to the integrated surge protection in the MAX22515 at the IO-Link interface. This reference design meets both the IEC 61000-4-2 for electrostatic discharge (ESD) up to ±4kV and IEC 61000-4-4 for electrical fast transient (EFT) ±4kV standards. It is designed to meet a surge capability (2A at t = 1.2/50µs) up to ±1.0kV. Additional TVS protection circuitry is included as part of the analog IO (field side) circuit.

The MAXREFDES177# uses an industry-standard M12 connector with a 4-wire cable.

The MAX22000 is an industrial-grade configurable analog input/output device configurable on-the-fly in software as a voltage/current input or output. Additional inputs are available to measure other analog signals. The device offers an 18-bit DAC with fast settling time as well as a 24-bit delta-sigma ADC. The ADC and DAC can individually choose between an internal or an external reference. This design uses the internal voltage reference. The MAX22000 can meet an accuracy of 0.1% over a ±50°C temperature variation because of the very stable 5ppm/°C internal reference. The MAX22000 sets the linear range at 105% and full-scale range at 125% of the nominal range. For example, the MAX22000 provides a linear range of ±10.5V and a full-scale range of ±12.5V for a nominal range of ±10V.

The MAX22000 supports the ADC with a low-noise PGA with high-voltage and low-voltage input ranges to support RTD measurements. Additional auxiliary inputs are also present, and in this design, implement on-board diagnostic measurement for the HVDD supply.

The MAX22000 communicates through a high-speed SPI bus for all configuration and management information as well as conversion results. An optional 8-bit CRC enhances the reliability of the SPI interface, protecting against all 8-bit bursts as well as all double-bit errors. The MAX22000 operates from 2.7V to 3.6V analog and digital supplies, and up to ±24V high-voltage supplies. The device is available in a 64-pin LGA package and operates over the -40°C to +125°C industrial temperature range.

Galvanic isolation between the IO-Link side (microcontroller) and the analog IO (field side) is provided by the MAX14483 for data isolation. A switched DC-DC is based around the MAX13256 transformer driver for power isolation.

The MAX14483 is a 6-channel, low-power, 3.75kVRMS SPI digital isolator. The six signal channels are individually optimized for SPI applications, and include very low propagation delay on the SDI, SDO, and SCLK channels. Two extra channels are used in this design for RDY feedback from the MAX22000 and for RST to allow the MCU to

provide a software reset to the MAX22000. The MAX14483 is available in a 20-pin SSOP package with 5.5mm creepage and clearance.

The Atmel microcontroller limits the reference design operating temperature range from -40°C to +105°C. However, the MAX22515 IO-Link transceiver, MAX22000, and MAX14483 can all operate over the -40°C to +125°C temperature range.

Refer to the MAX22000 and MAX14483 data sheets for detailed information on the software-configurable analog IO device and digital isolator.

Power Supplies

Power solutions use Maxim Integrated ICs and modules to generate the various voltage rails on both the IO-Link and field sides of the isolation barrier (**Figure 2**). Power is supplied from the IO-Link cable on L+ and is nominally 24V on the IO-Link side. The MAX22515 has two internal LDOs, which can step down this 24V rail. However, a more efficient solution is realized by using a tiny MAXM17552 compact step-down power module to create a 5V input to the MAX22515, which then uses an integrated LDO to generate the 3.3V rail. The MAXM17522 is available in a low-profile, compact 10-pin 2.6mm x 3mm x 1.5mm µSLIC™ package.

The MAX13256 H-bridge transformer driver is a simple solution to make isolated power supplies up to 10W. The device drives a transformer's primary coil with up to 300mA of current from a wide 8V to 36V DC supply. The device is available in a small 10-pin (3mm x 3mm) TDFN package and is specified over the -40°C to +125°C temperature range.

The transformer's secondary-to-primary winding ratio defines the output voltage, allowing the selection of virtually any isolated output voltage. Two supplies, HVDD = +24V and HVSS = -24V, are generated in this design. For this design the same supplies are used for HVDDO and HVSSO respectively. On the analog or field side, a MAXM17522 is used to step down the HVDD rail to 3.3V for the DVDD and AVDD requirements of MAX22000.

The MAXREFDES177# consumes 30mA to 35mA (typ) under normal conditions, and more if the current input or output mode is selected. A red LED indicates a power fault on the transformer driver while an additional green LED indicates the presence of AVDD supply.

Detailed Description of Firmware

The MAXREFDES177# is shipped preprogrammed as a working IO-Link device ready to connect to an IO-Link master. The firmware targets an Atmel ATSAM microcontroller and follows the simple flowchart in **Figure 3**. The firmware utilizes the TMG TE IO-Link device stack. The MAXREFDES177# waits for a wake-up signal from the IO-Link master after plug-in. The MAXREFDES177# synchronizes to the IO-Link master using the 230.4kbps (COM3) baud rate on receiving the wake-up signal. The communication parameters are exchanged. The IO-Link master then starts a cyclic data exchange by

requesting the sensor process data. The IO-Link master detects a missing sensor if the MAXREFDES177# is removed.
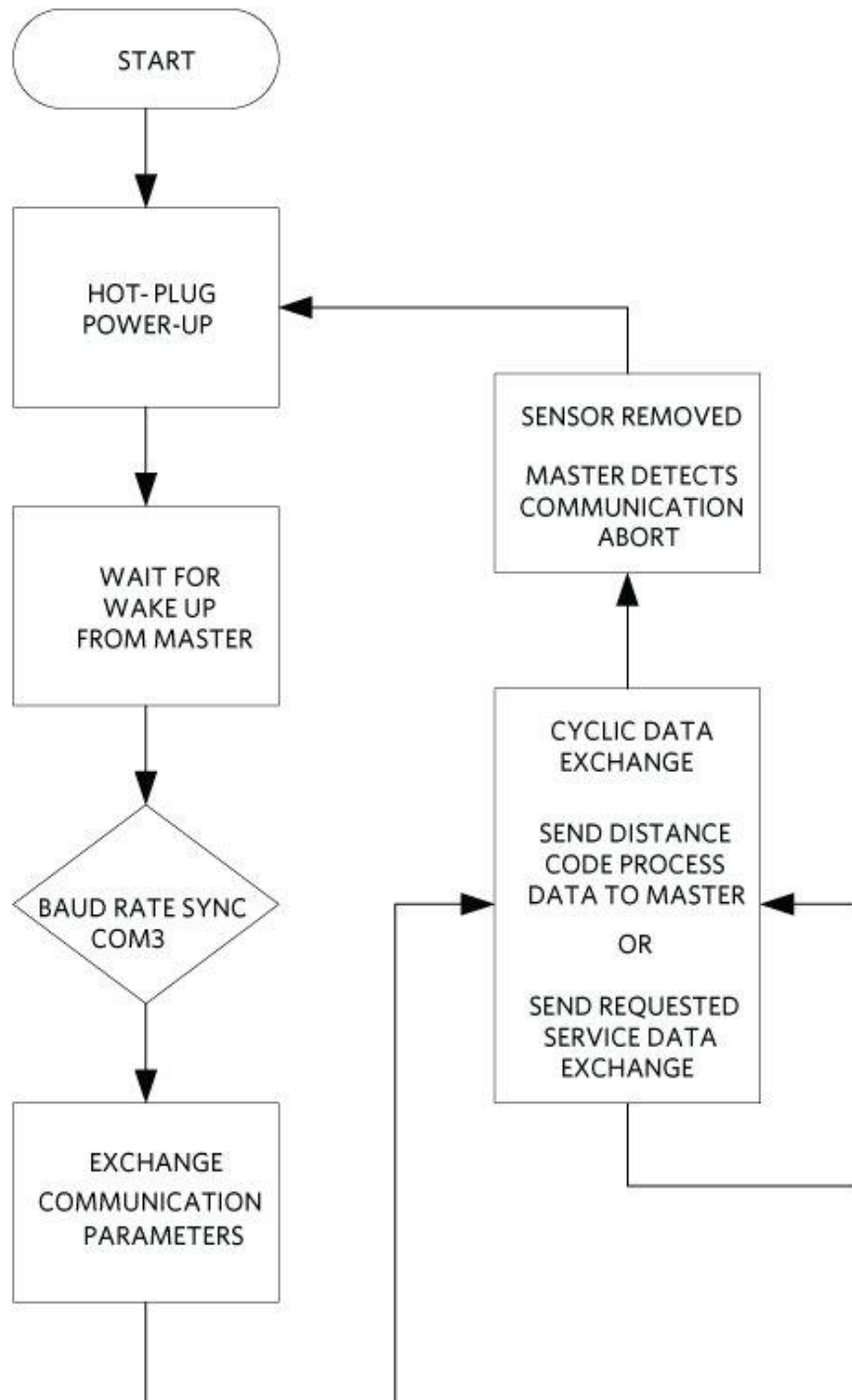

Figure 3. MAXREFDES177# firmware flowchart.

The TMG TE IO-Link Device Tool software is Windows®-compatible, features IODD file import capability, connects to a PC through USB, and is available to download from the TMG TE website.

The TMG TE IO-Link Device Tool software is shown in **Figure 4**. A complete guide is also downloadable from the TMG TE website.
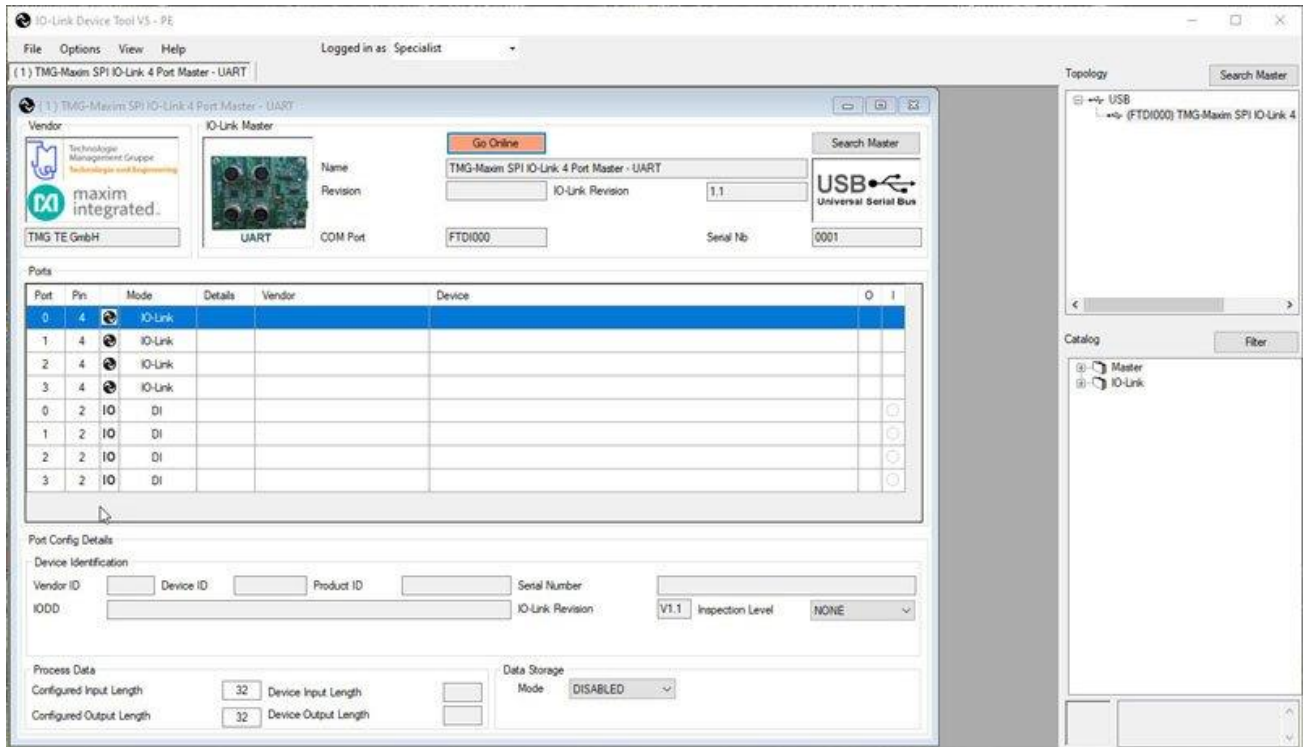

Figure 4. The TMG TE IO-Link device tool.

The source code for the MAXREFDES177# is not available. The TMG TE IO-Link stack is shipped preprogrammed inside the MAXREFDES177# hardware with a perpetual license.

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Detailed Description of Software

The MAXREFDES177# was verified using the MAXREFDES165# IO-Link Master, featuring the MAX14819 IO-Link master transceiver and IODD interpreter tool IO-Link Device Tool from the TMG TE website.

Download the IODD file (*.xml) located in the Design Resources tab. Follow the step-by-step instructions in the Quick Start Guide section to use the software. **Figure 4** is a screenshot of the TMG TE IO-Link Device Tool communicating with the master and sensor.

EMC Testing

The general rules for the test configuration of a device (such as the MAXREFDES177#) are as follows:

- The SDCI cable shall be unshielded, 20m long, coiled, and placed 10cm (4in) above the ground plane.
- The devices shall be placed 10cm (4in) above the ground plane.

The MAXREFDES177# was tested in a Maxim Integrated lab for the common industrial compliance standards, and the test methodology and results are presented in this document. Although the IO-Link Interface and System Specification does not require surge testing, Maxim did this test in addition to the ESD and EFT tests.

Equipment Used:

- MAXREFDES177# IO-Link Sensor
- MAXREFDES165# 4-Port IO-Link Master
- 20m M12 Cable
- Haefely® Technology ECOMPACT4 EFT/Surge Generator
- Teseq® CDN 117 Signal Line Coupling Network
- Teseq CDN 3425 EFT Data Line Coupling Clamp
- Teseg NSG438 ESD Generator

Surge Testing

The MAXREFDES177# module was tested to withstand up to ±1.0kV of 1.2/50µs IEC 61000-4-5 surge with a total source impedance of 500Ω. The surge testing was performed using the MAXREFDES165# IO-Link master. Ten surge pulses were applied for each test (**Table 1** and **Table 2**).

The MAXREFDES177# continued to operate normally (executed code and transferred data) and was not damaged by the tests. The MAX22515 registers were not corrupted while communicating with the master during the tests shown in Table 1. Maxim Integrated also tested the analog IO (field side) (Table 2) in addition to testing the IO-Link side.

Table 1. Surge test results for the IO-Link interface.

Test Condition	Surge Tests		
	L+ TO GND	C/Q TO GND	L+ TO CQ
+1kV	Pass	Pass	Pass
-1kV	Pass	Pass	Pass

Table 2. Surge test results for the analog IO interface.

Test Condition	Surge Tests		
	AIO TO AGND	AIO TO SNS+	AIO TO SNS-
+1.2kV	Pass	Pass	Pass
-1.2kV	Pass	Pass	Pass

EFT/Burst Testing

The MAXREFDES177# was tested to withstand electrical fast transient (EFT)/bursts up to ±4kV according to IEC 61000-4-4 with a 20m IO-Link cable with standard M12 connectors. The EFT testing was performed using the MAXREFDES165# IO-Link master. The EFT pulses were applied for one minute for each test (Table 3).

Table 3. EFT/Burst test results.

Test Condition	5kHz/15ms	100kHz/0.75ms
+4kV	Pass	Pass
-4kV	Pass	Pass

ESD Testing

The MAXREFDES177# was tested to withstand electrostatic discharge (ESD) for Contact and Air-Gap Discharge up to ±4kV according to IEC 61000-4-2. The ESD testing was performed on the MAXREFDES177# M12 connector pins after the test operation was verified using the MAXREFDES165# IO-Link master to transfer data (**Table 4**). The MAXREFDES177# was not damaged by any ESD tests and continued to operate normally.

Table 4. ESD test results.

Test Condition	L+ TO GND	C/Q TO GND
+4kV Contact Discharge	Pass	Pass
-4kV Contact Discharge	Pass	Pass
+4kV Air-Gap Discharge	Pass	Pass
-4kV Air-Gap Discharge	Pass	Pass

The IO-Link interface and system specification version 1.1.2 requires ESD testing with a 20m cable attached, and the ESD strike is applied to the sensor casing. Because this reference design is only a PCB with no metallic casing, the ESD strikes were applied to the male M12 connector pins. Maxim Integrated expects this design to meet the levels specified in Table 4 when testing with a casing and cable.

Restrictions and Warnings for Maxim Integrated Reference Design Use

The MAXREFDES177# is designed and tested to meet IO-Link operation and harsh industrial environments covered by the IEC 61000-4-x standards for transient immunity. This board and associated software are designed to be used to evaluate the performance of the MAX22515 and MAX22000 but are not intended to be deployed as-is into an end product in a factory automation system.

The MAXREFDES177# is not for use in functional safety or safety-critical systems.

Quick Start Guide

Connect the MAXREFDES177# universal analog IO to a port of an IO-Link master to test it. The following example uses a MAXREFDES165# IO-Link master and TMG software tool. However, any IO-Link compliant master and associated IO-Link device GUI should work.

Required Equipment
Supplied by Maxim

- MAXREFDES177#

Note: Download the IODD files from the Design Resources tab.

User Supplied

- IO-Link master (i.e., MAXREFDES165#) with a 24V AC-to-DC power adapter

- TMG TE IO-Link Device Tool software
- One IO-Link cable
- Windows 10 PC with a USB port
- Digital multimeter (at least 6.5 digit DMM is recommended)
- Adjustable DC power supply

▼ Master Setup Procedure

Master Setup Procedure

1. Connect the MAXREFDES177# sensor to the IO-Link master with an IO-Link M12 cable.
2. Connect the IO-Link master to the PC with a USB cable.
3. Download and install the latest IO-Link Device Tool software from the TMG TE website.
4. Download the IODD file for the MAXREFDES177# from the Design Resources tab or from the TMG TE website.
5. The MAXREFDES177# comes preprogrammed with firmware and the IO-Link device stack.

Sensor Testing Procedure

1. Connect the female end of the IO-Link cable to the MAXREFDES177#.
2. Connect the male end of the IO-Link cable to one of the ports on the IO-Link master.
3. Open the IO-Link Device Tool software and click **Search Master** (**Figure 4**). Select the 4-port master (MAXREFDES165#) found by the tool.
4. Import the IODD file for the MAXREFDES177#. This includes a picture of the PCB (**Figure 5**).
5. Click **Go Online** (Figure 4).
6. The IO-Link Device Tool software shows the IO-Link master connection if communication is established correctly. Select the port number the MAXREFDES177# is connected to and click **Check Devices** below the **Ports** section. The software shows the MAXREFDES177# is connected, Click **Takeover devices into engineering** in **Check Devices** (**Figure 6**).
7. The Go Offline button is green. The software tool shows that the device is MAXREFDES177# and the IODD vendor is TMG TE GmbH (**Figure 7**).
8. Double-click port **1** (for this example) to open the window with the MAXREFDES177# sensor details. Select the Process Data tab.
9. Select the mode (analog output voltage) (**Figure 8** and **Figure 9**). Enter a value between -10 and +10 and read the voltage with a DMM connected to the AIO and AGND terminals. The output voltage is 1V in this example.
10. Select the mode desired – in this case (analog input voltage). Apply a DC voltage (from an adjustable power supply for example) to terminals AIO and AGND. In this example we set the voltage to approximately 4V. Read the voltage (**Figure 10**). It reads 4.00414V in this example.

11. Due to the very high accuracy of the DAC and ADC in MAX22000, it is recommended to use a 6.5 digit or better DMM to measure the external voltages to experience the high precision of the MAX22000 and MAXREFDES177#.
12. It is recommended to perform a two-point calibration for the voltage/current input and output functions and to store the calibration coefficients in the on-board memory to utilize the full performance of MAXREFDES177#. Refer to the MAX22000 data sheet for the MAX22000 gain and offset calibration details, and the various registers used.
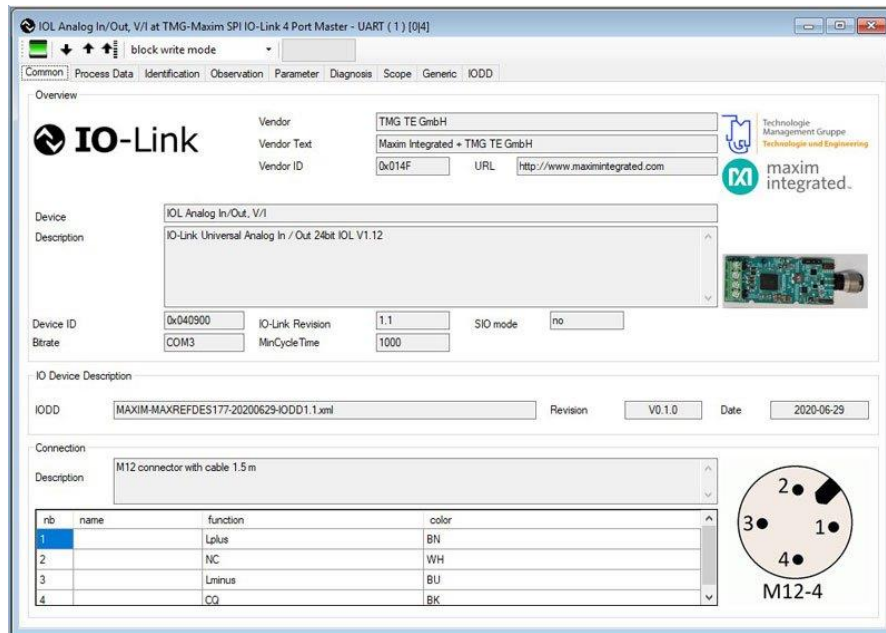
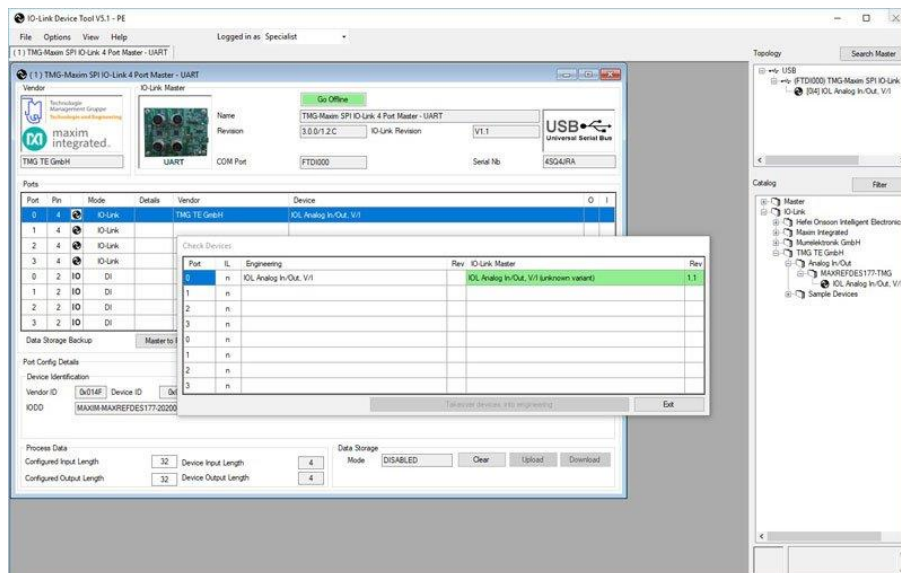

Figure 5. MAXREFDES177# IODD file.
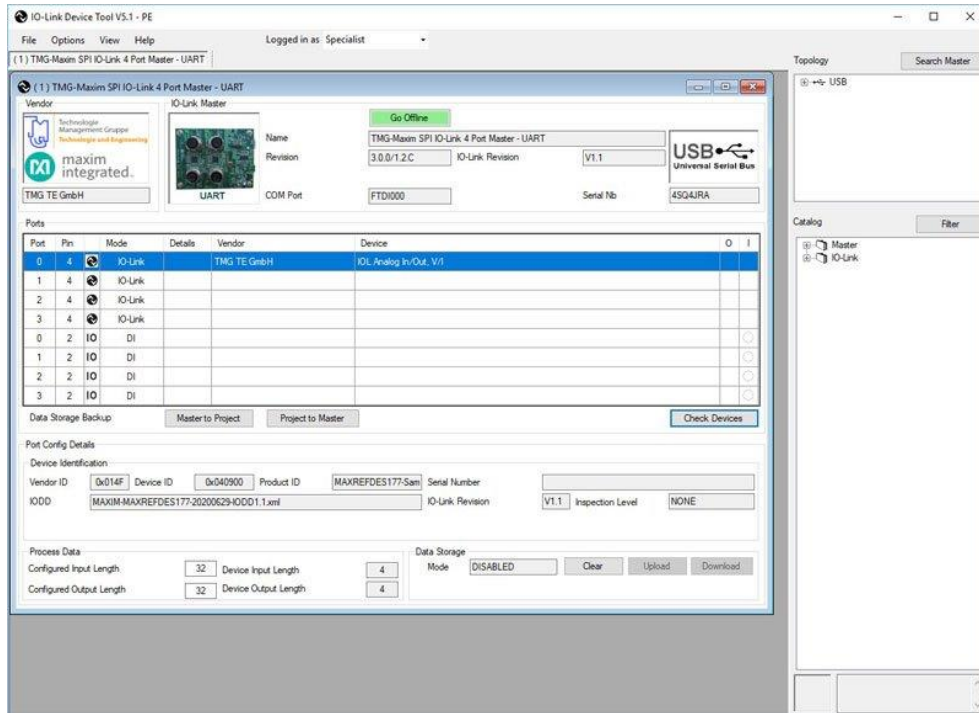

Figure 6. MAXREFDES177# sensor found.

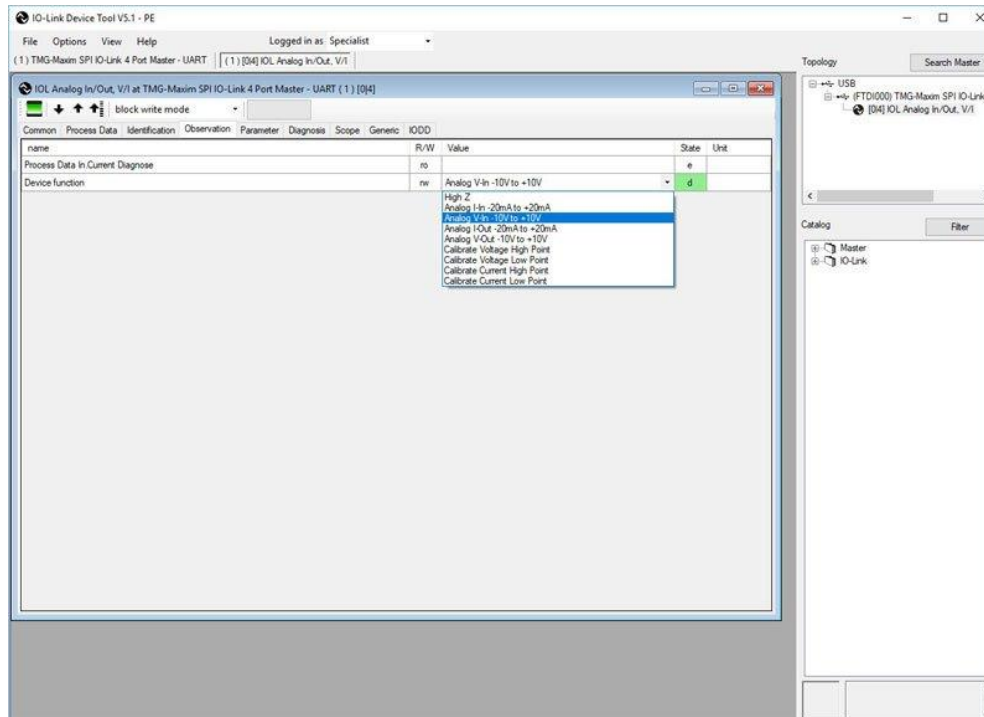*Figure 7. MAXREFDES177# sensor connected to the master.*

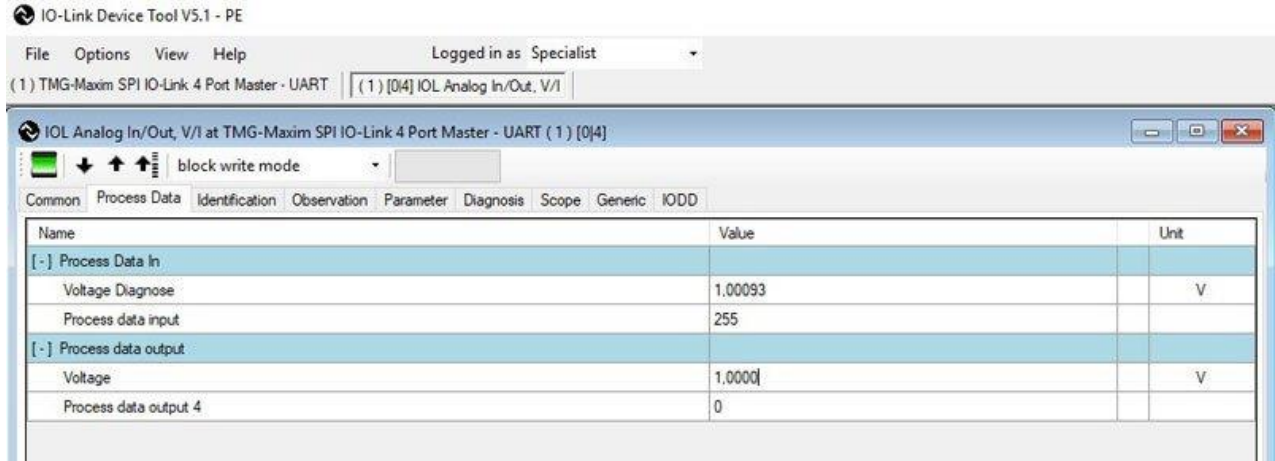*Figure 8. MAXREFDES177# analog output modes.*
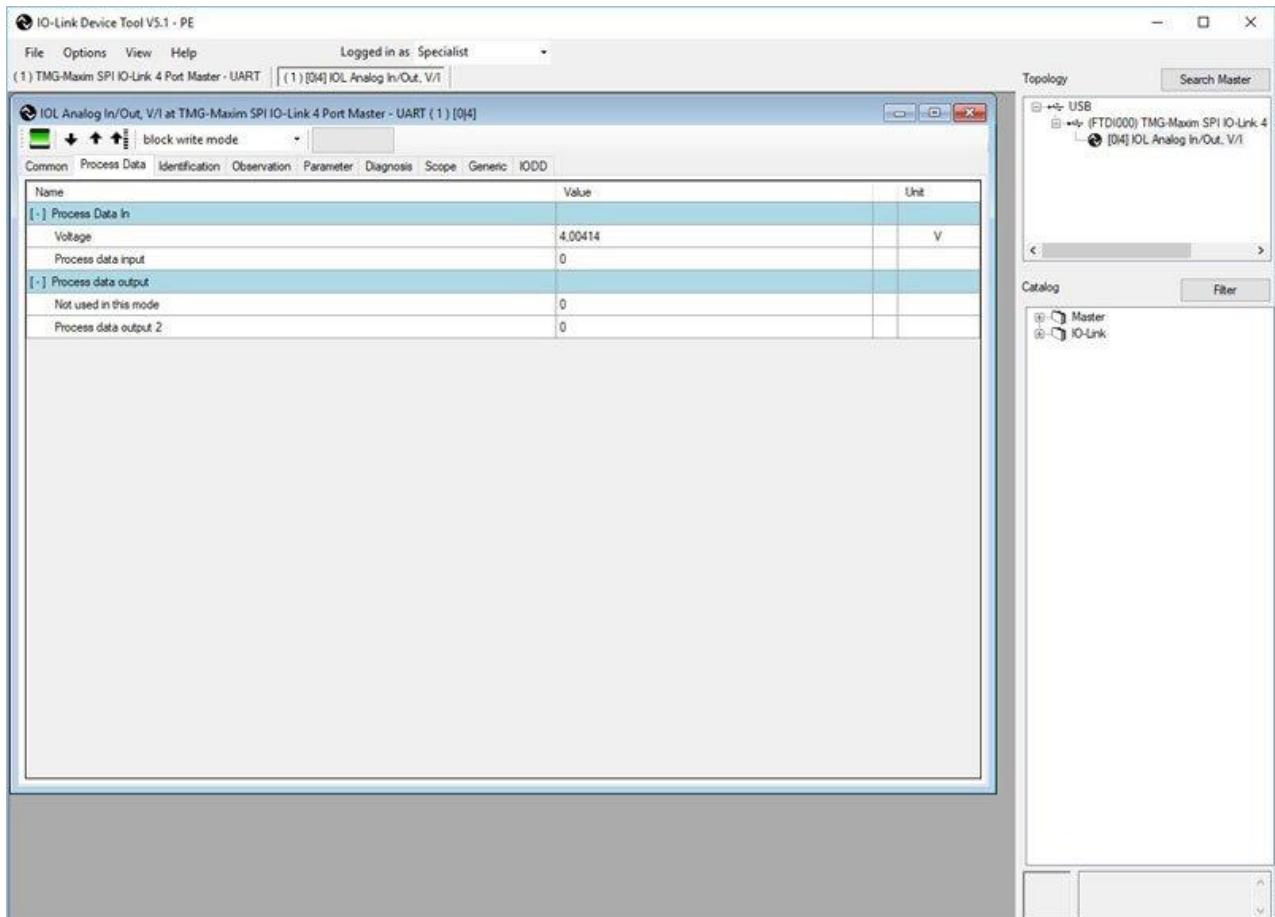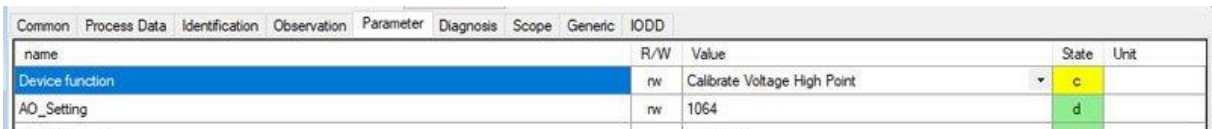
Figure 9. MAXREFDES177# analog data values.

Figure 10. MAXREFDES177# analog input modes.

Calibration Procedure for Voltage Input and Output

This calibration procedure takes care of the voltage input/output mode simultaneously. The DAC generates a voltage, which is measured back through the ADC. The voltage is measured with a precision voltmeter. The results are entered in the PDOut field. The MAXREFDES177# then calculates the calibration factors for the analog input/output. It stores these parameters in the non-volatile memory on the board. Follow the steps in the sequence or the calibration fails.
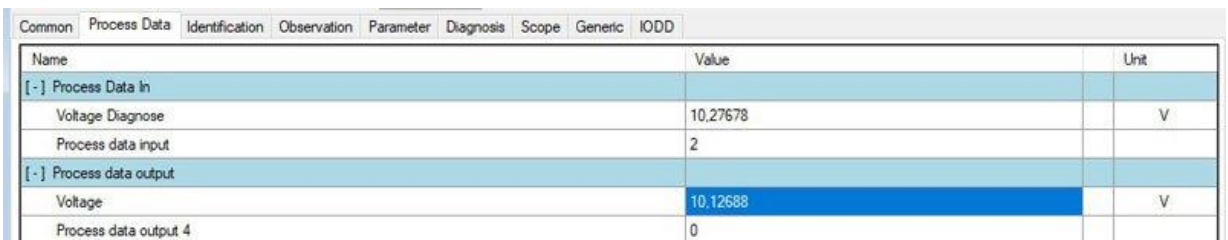
1. Select **Calibrate Voltage High Point** in the **Parameter** tab under **Device function** (**Function 11**).
2. Click a different text box to finish the selection.
3. Click the yellow arrow to **write all changed values to device**.

name	R/W	Value	State	Unit
Device function	rw	Calibrate Voltage High Point ▼	c	
AO_Setting	rw	1064	d	

Figure 11. Calibrating the voltage high point.

4. Measure the voltage on the connector X2 between the pins 1 and 4 using a precision voltmeter. The voltage must be approximately +10V.
5. Select the **Process Data** tab and enter the measured voltage into **Process data output** (Figure 12).

Name	Value	Unit
[-] Process Data In		
Voltage Diagnose	10,27678	V
Process data input	2	
[-] Process data output		
Voltage	10,12688	V
Process data output 4	0	

Figure 12. Calibrating the voltage output.

6. Select **Calibrate Voltage Low Point** in the **Parameter** tab under **Device function**.
7. Click a different text box to finish the selection.
8. Click the yellow arrow to **write all changed values to device**.
9. Measure the voltage on the connector X2 between pins 1 and 4 using a precision voltmeter. The voltage must be approximately -10V.
10. Select the **Process Data** tab and enter the measured voltage into **Process data output**.
11. Select **High Z** in the **Parameter** tab under **Device function**.
12. Click a different text box to finish the selection.
13. Click the yellow arrow to **write all changed values to device**.
14. The MAXREFDES177# calculates the calibration factors for the DAC and ADC voltage modes. It stores them in the non-volatile memory on the board. Each

time MAXREFDES177# powers up, the microcontroller copies these calibration factors to the MAX22000 to avoid the need to calibrate the design again.

Calibration Procedure for Current Input and Output

This calibration procedure takes care of the current input/output mode simultaneously. The DAC generates a current, which is measured back through the ADC. The current is measured with a precision ammeter. The results are entered in the PDOut field. The MAXREFDES177# then calculates the calibration factors for the analog input/output. It stores these parameters in the non-volatile memory on the board. Follow the steps in the sequence or the calibration fails.

1. Select **Calibrate Current High Point** in the **Parameter** tab under **Device function** (**Figure 13**).
2. Click a different text box to finish the selection.
3. Click the yellow arrow to **write all changed values to device**.

Common	Process Data	Identification	Observation	Parameter	Diagnosis	Scope	Generic	IODD				
name						R/W	Value			State	Unit
Device function						rw	Calibrate Current High Point	▼		d	
AO_Setting						rw	1064			d	

Figure 13. Calibrating the current high point.

4. Measure the current on the connector X2 between the pins 1 and 4 using a precision ammeter. The current must be approximately +20mA.
5. Select the **Process Data** tab and enter the measured current into **Process data output** (Figure 14).

Common	Process Data	Identification	Observation	Parameter	Diagnosis	Scope	Generic	IODD	
Name						Value			Unit
[-] Process Data In									
Current						20.56186			mA
Process data input						2			
[-] Process data output									
Current						20.24574			mA
Process data output 3						0			

Figure 14. Calibrating the current output.

6. Select Calibrate Current Low Point in the Parameter tab under Device function.
7. Click a different text box to finish the selection.
8. Click the yellow arrow to write all changed values to device.
9. Measure the current on the connector X2 between the pins 1 and 4 using a precision ammeter. The current must be approximately -20mA.
10. Select the Process Data tab and enter the measured current into Process data output.
11. Select High Z in the Parameter tab under Device function.
12. Click a different text box to finish the selection.

13. Click the yellow arrow to write all changed values to device.
14. The MAXREFDES177# calculates the calibration factors for the DAC and ADC (mA) current modes. It stores them in the non-volatile memory on the board.

All Design Files
Download All Design Files

Schematic
Bill of Materials (BOM)
PCB Layout
IODD

Order the reference design MAXREFDES177 from your local Maxim representative.

Trademarks List

- Atmel is a registered trademark and registered service mark of Atmel Corporation.
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