

TI Designs: TIDA-010044

具有故障保护和诊断功能的 NAMUR PLC 数字输入参考设计



说明

在工业控制中，广泛使用 NAMUR 接近传感器来满足最大功耗方面的特殊要求。这方面的要求进而决定了对于连接到此类传感器的 PLC 数字输入在精度和可靠性方面的特殊要求。此参考设计是与 NAMUR 传感器兼容的数字输入模块的完整前端。此设计展示了在紧凑的外形中通过冗余性、故障保护和全面诊断功能实现可靠性。

资源

TIDA-010044	设计文件夹
LM2901AV-Q1	产品文件夹
TL431LI	产品文件夹
TVS3301	产品文件夹
LM25019	产品文件夹
TLV760	产品文件夹
ISO7340FC	产品文件夹

特性

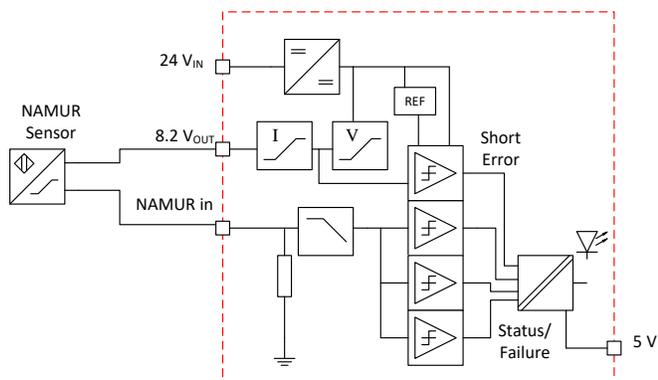
- 1.6mA 阈值电流，0.4mA 迟滞电流
- 0.2mA 开路电流，6mA 短路阈值电流
- 8.2V 开路电压，8.2mA 短路电流
- 全面诊断功能
- 故障保护
- 电源和数据隔离
- 通过冗余组件提高可靠性

应用

- [PLC NAMUR 数字输入模块](#)
- [NAMUR 隔离栅](#)



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1 System Description

The NAMUR proximity sensor is widely used in industrial control when a special requirement on maximum energy is to be fulfilled by the sensor. This in turn dictates special requirements on the PLC digital input designed to interface with such sensor with regard to accuracy, and reliability.

NAMUR sensors and their interfaces (digital input or amplifiers) have to comply with the NAMUR standard(EN 60947-5-6:2000 or IEC 60947-5-6).

NAMUR abbreviation stands for the German term "**N**ormen**a**rbeits**g**emeinschaft für **M**eiß- und **R**egelungstechnik in der Chemischen Industrie" which translates to "Association for Standardization of Measurement and Control Engineering in the Chemical Industry"

TIDA-010044 is a NAMUR PLC digital input module reference design illustrating the common performance requirements and shows how to enhance reliability of the module by adding diagnostics and protection features.

1.1 Key System Specifications

The TIDA-010044 system specifications in 表 1 represent the common set of parameters required by a NAMUR PLC digital input module. On top comes the extensive diagnostic features required to implement a high-reliability module.

表 1. Key System Specifications

PARAMETER	SPECIFICATIONS
Number of Inputs	1
Input type	NAMUR compatible
ON-state current	2.1 mA
OFF-state current	1.2 mA
Hysteresis	0.4 mA
Output impedance	1 kΩ
Maximum input voltage	24 V, -24 V
Short-circuit current	8.2 mA
Short-circuit threshold	6 mA
Broken wire threshold	0.4 mA
Short-to-supply+ threshold	8.5 V
Short-to-supply- threshold	-6 V
Isolated 12-V supply fault threshold	7 V
24-V supply range	18 V to 36 V
Operating temperature range	-40 °C to 80°C
Diagnostic functions	Sensor failure: wire break and short circuit Short to supply: forward or reverse short to supply Isolated supply failure

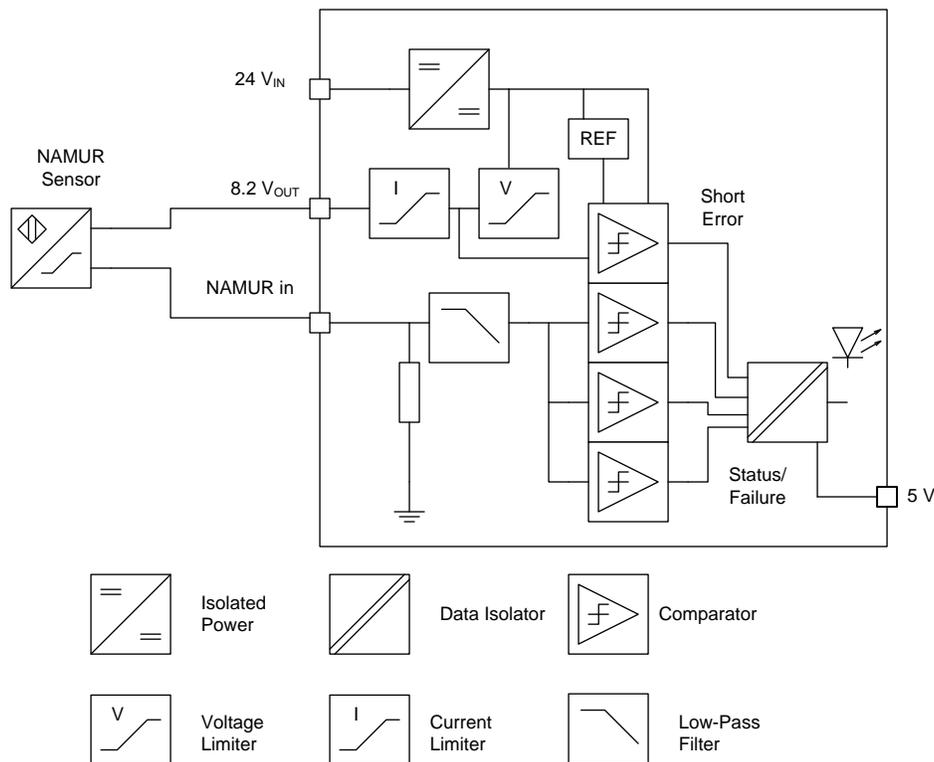
2 System Overview

The NAMUR standard (EN 60947-5-6:2000) defines characteristics of proximity sensors and their interfaces and digital inputs. Those sensors are acting as very low current switch representing the binary states ON and OFF.

TIDA-010044 is a NAMUR PLC digital input module reference design showing one simple implementation of such module. 图 1 shows the block diagram of the reference design.

2.1 Block Diagram

图 1. TIDA-010044 Block Diagram



Refer to 节 2.4.3 for a detailed explanation of different parts of the block diagram.

2.2 Design Considerations

NAMUR digital input modules is basically a PLC digital input module that resolves low level current input and fulfills the NAMUR standard as detailed in 节 2.4.2. In addition to fulfilling the I-V characteristics of the standard, diagnostic features are essential for modern input modules. Sensor failures including open and short-circuit conditions are detected by sensing the sensor current exceeding certain limits. Short-to-supply errors are detected to prevent module damage due to miss-wiring. Isolated power supply is also monitored to prevent wrong readings due to failed supply. It is important to have high reliability module that fulfills the NAMUR standard even if one component failed, this might dictate selecting certain components that fail in a certain way short or open, or adding redundant devices. Industrial temperature range is essential for all components to achieve the specified operating temperature range.

2.3 Highlighted Products

2.3.1 TVS3301

The TVS3301 device shunts up to 27 A of IEC 61000-4-5 fault current to protect systems from high-power transients or lightning strikes. The device survives the common industrial signal line EMC requirement of 1-kV IEC 61000-4-5 open circuit voltage coupled through a 42- Ω impedance. The TVS3301 uses a feedback mechanism to ensure precise flat clamping during a fault, keeping system exposure lower than traditional TVS diodes. The tight voltage regulation allows designers to confidently select system components with a lower voltage tolerance, lowering system costs and complexity without sacrificing robustness. The TVS3301 has a ± 33 -V operating range to enable operation in systems that require protection against reverse wiring conditions.

In addition, the TVS3301 is available in a small SON footprint designed for space constrained applications, offering a significant size reduction compared to standard SMA and SMB packages. Low device leakage and capacitance ensure a minimal effect on the protected line. To ensure robust protection over the lifetime of the product, TI tests the TVS3301 against 5000 repetitive surge strikes at 125°C with no shift in device performance.

The TVS3301 is part of TI's Flat-Clamp family of surge devices. For a deeper look at the Flat-Clamp family, refer to the [Flat-Clamp Surge Protection Technology for Efficient System Protection](#) white paper.

2.3.2 LM2901AV

The LM2901xx devices consist of four independent voltage comparators that are designed to operate from a single power supply over a wide range of voltages. Operation from dual supplies also is possible, as long as the difference between the two supplies is 2 V to 36 V, and VCC is at least 1.5 V more positive than the input common-mode voltage. Current drain is independent of the supply voltage. The outputs can be connected to other open-collector outputs to achieve wired-AND relationships. The LM2901AV device is characterized for operation from -40°C to 125°C .

2.3.3 TL431LI

The TL431LI device is a three-terminal adjustable shunt regulator, with specified thermal stability over applicable automotive, commercial, and military temperature ranges. The output voltage can be set to any value from Vref (approximately 2.495 V) and 36 V, with two external resistors. These devices have a typical output impedance of 0.3 Ω . Active output circuitry provides a very sharp turn-on characteristic, making these devices excellent replacements for Zener diodes in many applications, such as onboard regulation, adjustable power supplies, and switching power supplies. This device is a pin-to-pin alternative to the industry standard TL431, with optimized Iref and Idev performance. The lower Iref and Idev values enable designers to achieve higher system accuracy and lower leakage current.

The TL431LI device is offered in two grades, with initial tolerances (at 25°C) of 0.5% and 1%, for the B and A grade, respectively. In addition, low output drift versus temperature ensures good stability over the entire temperature range. The TL431LIAQ device is characterized for operation from -40°C to 125°C .

2.3.4 LM25019

The LM25019 is a 48-V, 100-mA synchronous step-down regulator with integrated high-side and low-side MOSFETs. The constant on-time (COT) control scheme employed in the LM25019 requires no loop compensation, provides excellent transient response, and enables very high step-down ratios. The on-time varies inversely with the input voltage resulting in nearly constant frequency over the input voltage range. A high-voltage start-up regulator provides bias power for internal operation of the IC and for integrated gate drivers.

A peak current limit circuit protects against overload conditions. The undervoltage lockout (UVLO) circuit allows the input undervoltage threshold and hysteresis to be independently programmed. Other protection features include thermal shutdown and bias supply undervoltage lockout.

2.3.5 TLV76050

The TLV760 is an integrated linear-voltage regulator featuring operation from an input as high as 30 V. The TLV760 has a maximum dropout of 1.2 V at the full 100-mA load across operating temperature. Standard packaging for the TLV760 is the 3-pin SOT-23 package.

The TLV760 is available in 3.3 V, 5 V, 12 V and 15 V. The SOT-23 packaging of the TLV760 series allows the device to be used in space-constrained applications.

The TLV760 is designed to bias digital and analog circuits in applications that are subject to voltage transients and spikes up to 30 V — for example, appliances and automation applications. The device has robust internal thermal protection, which protects itself from potential damage caused by conditions like short to ground, increases in ambient temperature, high load, or high dropout events.

2.3.6 ISO7340

The ISO734x family of devices provides galvanic isolation up to 3000 V_{RMS} for 1 minute per UL 1577 and 4242 V_{PK} per VDE V 0884-10. These devices have four isolated channels comprised of logic input and output buffers separated by a silicon dioxide (SiO₂) insulation barrier. The ISO7340x device has four channels in forward direction. In case of input power or signal loss, the default output is 0.

Used in conjunction with isolated power supplies, these devices help prevent noise currents on a data bus or other circuits from entering the local ground and interfering with or damaging sensitive circuitry. The ISO734x device has integrated noise filter for harsh industrial environment where short noise pulses may be present at the device input pins. The ISO734x device has TTL input thresholds and operates from 3-V to 5.5-V supply levels. Through innovative chip design and layout techniques, electromagnetic compatibility of the ISO734x family of devices has been significantly enhanced to enable system-level ESD, EFT, surge, and emissions compliance.

2.4 System Design Theory

Details of the design flow of the NAMUR digital input reference design is explained in the following sections. Starting from the NAMUR sensor and standard, we derive the required functions for the digital input.

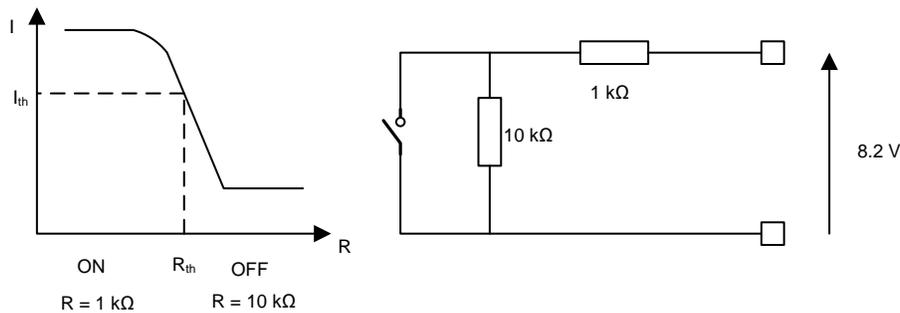
2.4.1 NAMUR Sensor

A field supply typically powers digital switches and proximity switches for industrial control systems. The possibility of electrical arcs forming at the switch contacts, or the possibility of capacitive energy accumulation in the sensors, make these types of switches unsuitable for hazardous areas with flammable atmospheres.

a NAMUR output sensor is a type of sensor that is trying to circumvent this issue by representing the switch states (ON and OFF) with two levels of resistance. The sensor is operated with a nominal operating voltage of 8.2 V.

图 2 is a simple model of a NAMUR sensor.

图 2. NAMUR Sensor Model



This resistive change results in a low-level current change (a few mAs), which a NAMUR input module needs to detect. Common values of the threshold currents are below 1.2 mA for the off state and above 2.1 mA for the on state.

2.4.2 NAMUR Standard

The NAMUR standard (EN 60947-5-6:2000) defines characteristics of proximity sensors and their interfaces and digital inputs. Those sensors are acting as very low current switches as described in the previous section.

The NAMUR standard (EN 60947-5-6:2000) defines the valid operating regions of the NAMUR sensor as 图 3 shows. On top of the I-V curve, different impedance levels of the sensor are overlaid. The valid ON-state operating region extends up to the load line equal to the ON-state resistance (for example up to 1 kΩ as a common case)

图 3. NAMUR Sensor Valid Operating Regions

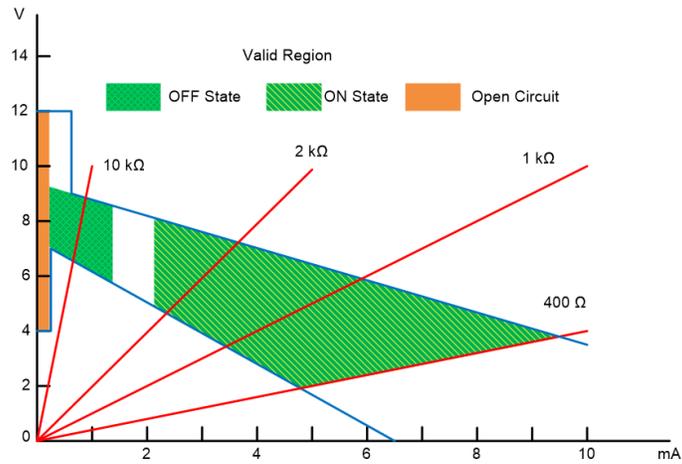
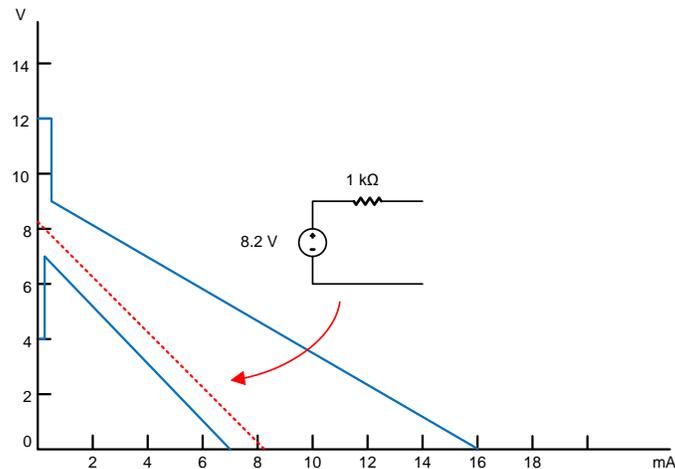


图 4 代表了 NAMUR 传感器接口（信号放大器或数字输入）的有效操作区域掩码。任何操作曲线被限制在掩码内应满足 NAMUR 标准。图中显示的一个有效数字输入模型是 8.2-V 电压源与 1-kΩ 电阻串联的戴维南等效电路。该模型具有从 8.2 V 垂直轴延伸到 8.2 mA 水平轴的虚线负载线。TIDA-010044 设计为与此模型等效。

图 4. NAMUR Digital Input Valid Operating Region



2.4.3 NAMUR Digital Input

The NAMUR input module is a special PLC digital input module that acts like a barrier and amplifier for a NAMUR sensor. It delivers limited power (limited voltage and limited current) to the NAMUR sensor, and is able to interpret the low-level output signal of the sensor to detect its state.

图 1 shows a simplified NAMUR digital input block diagram. A stable 8.2 V is derived from the 24-V field supply, with a current limiter in place in case of a short circuit to supply. Analog comparators powered from the 24-V supply convert the return current into voltage and filter for detection. Isolating the comparator array outputs from the backplane protects the outputs in case of a surge or other harmful event.

The NAMUR input module has to implement the following functions:

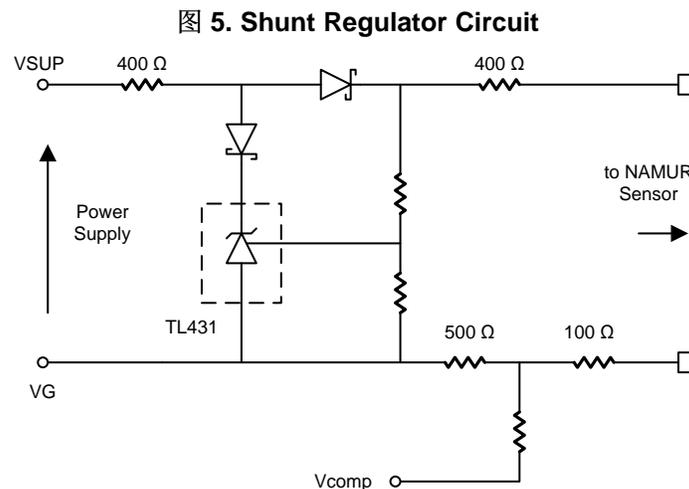
- Deliver a regulated 8.2-V output voltage at no load with a 1-k Ω source impedance.
- Limit the current in case of a short-circuit load to a current below 10 mA.
- Detect the off (below 1.2 mA of input current) and on (above 2.1 mA) state of the sensor.
- Detect sensor failure: short-circuit (close to current limit) and open-circuit (close to zero current) states.
- Detect short-to-supply error (forward and reverse)
- Protect against miswiring (short circuit to field supply, forward and reverse).
- Protect against surge events.

Many of these functions (detection and protection) are related to reliability. 节 2.4.4 will go into details of how those functions are achieved.

2.4.4 Circuit Design

2.4.4.1 Shunt Regulator

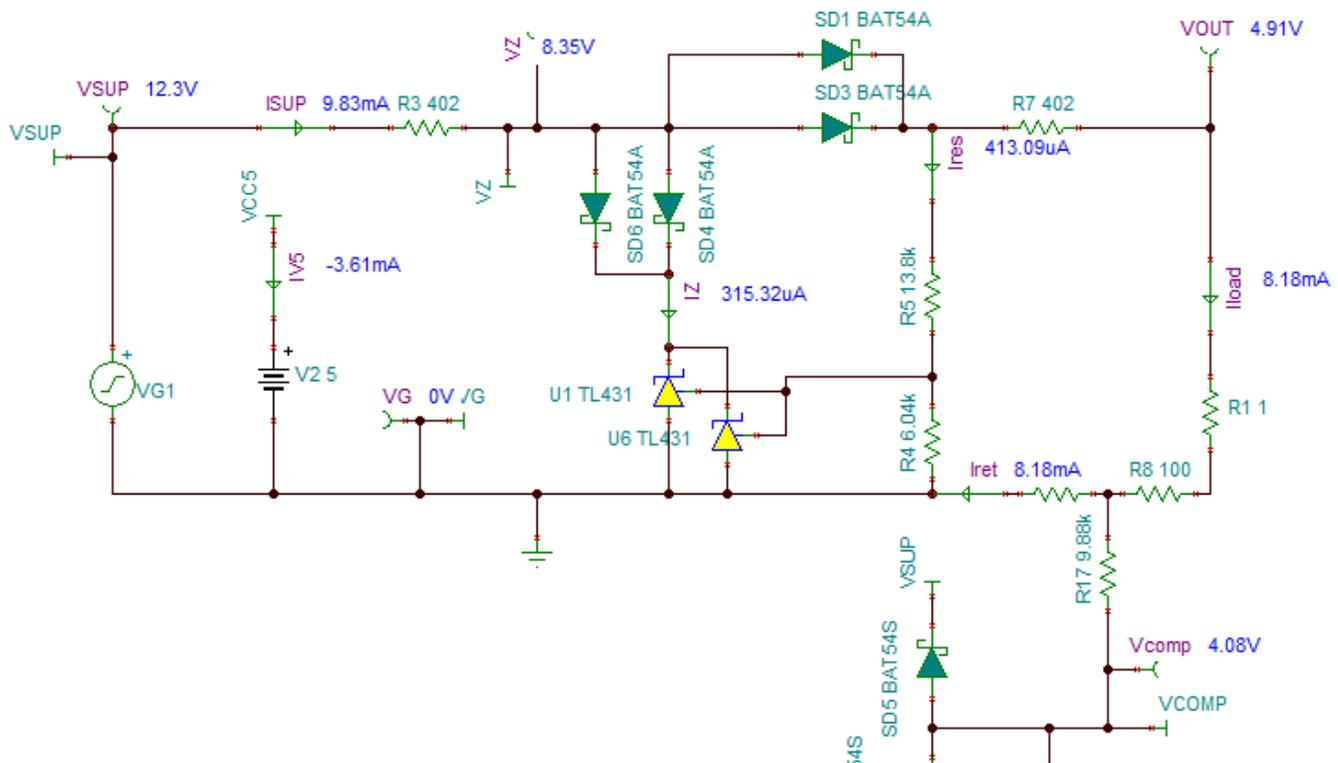
The TL431 is used as shunt regulator to provide 8.2-V open circuit, it offers more flexibility compared to a simple Zener diode. The TL431 is protected by two back-to-back diodes to prevent overcurrent in case of short to positive or negative supply and to isolate the 12-V supply from the external terminals. 图 5 shows a simplified shunt regulator circuit.



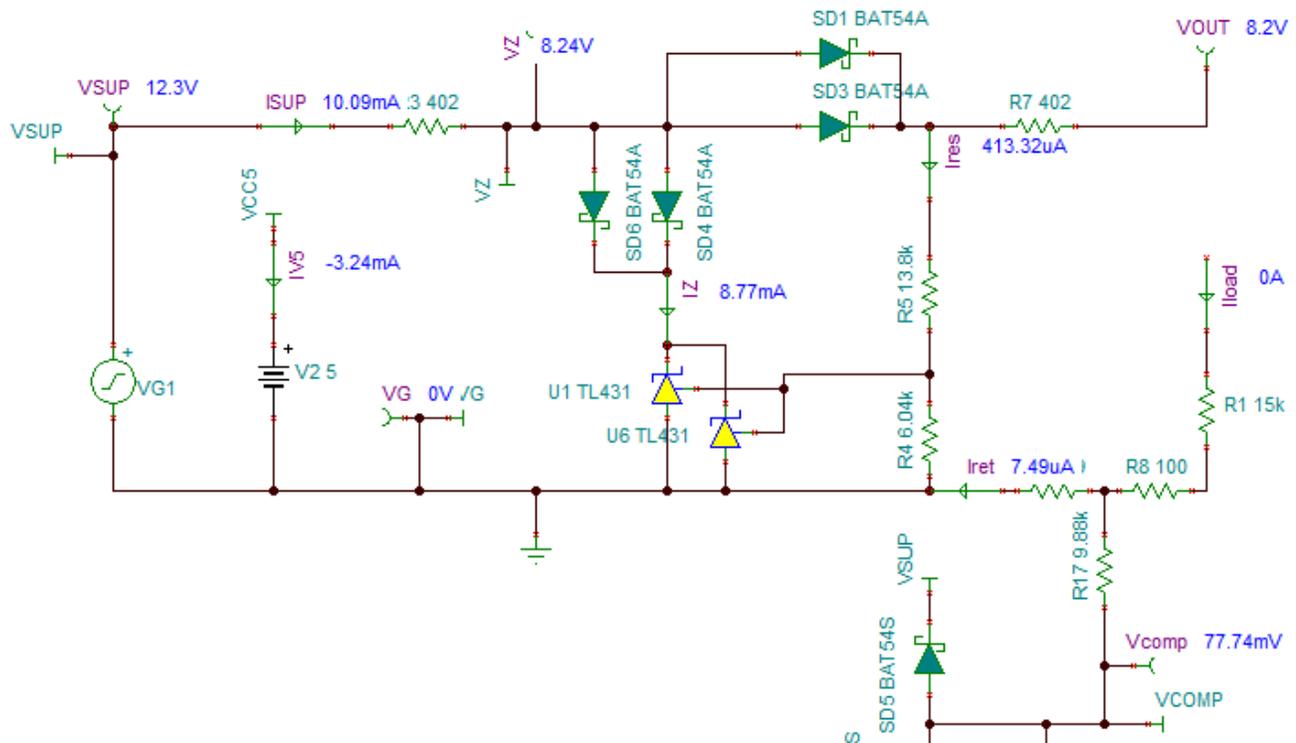
The 1-kΩ input impedance is split into 400 and 600 so that both pins have current limiter resistors. Regulator is set to 8.5 V to account for the protection diode drop. This shows one benefit of using the TL431 device as the regulated voltage can be set accurately to meet protection requirements.

The current from the supply is almost constant 10 mA over load range (0 to open circuit) as the simulation results in 图 6 show, the current is split between the load and the Zener.

图 6. DC Operating Point Of Short-Circuit Case



The open load voltage is 8.2 V, as 图 7 shows, and decreases with load. Note that open load voltage is not equal to the Zener voltage.

图 7. DC Operating Point Of Open Circuit Case


In the actual schematic, two TL431 devices are used to ensure the voltage limit is maintained in case one of the devices fails open. The same applies for the protection back-to-back diodes which are duplicated. The redundancy is increasing the level of reliability of the module and ensures output voltage is not exceeded even in case of component failure.

2.4.4.2 Protection Against Short to Supply

As previously mentioned, the back-to-back diodes are preventing overcurrent in the TL431 device and preventing overvoltage to reach the supply transformer. Apart from that maximum current in any component (resistor or diode) should be maintained within the power rating of that component.

Simulation results in 图 8 and 图 9 show that maximum current occurs in case of short to supply 24 V or -24 V and does not exceed 27 mA. This is well below 0.5 W for the associated resistors. Rating resistors of 1-W are selected, preferably carbon film resistors as they fail open.

图 8. DC Operating Point of Short to 24-V Supply Case

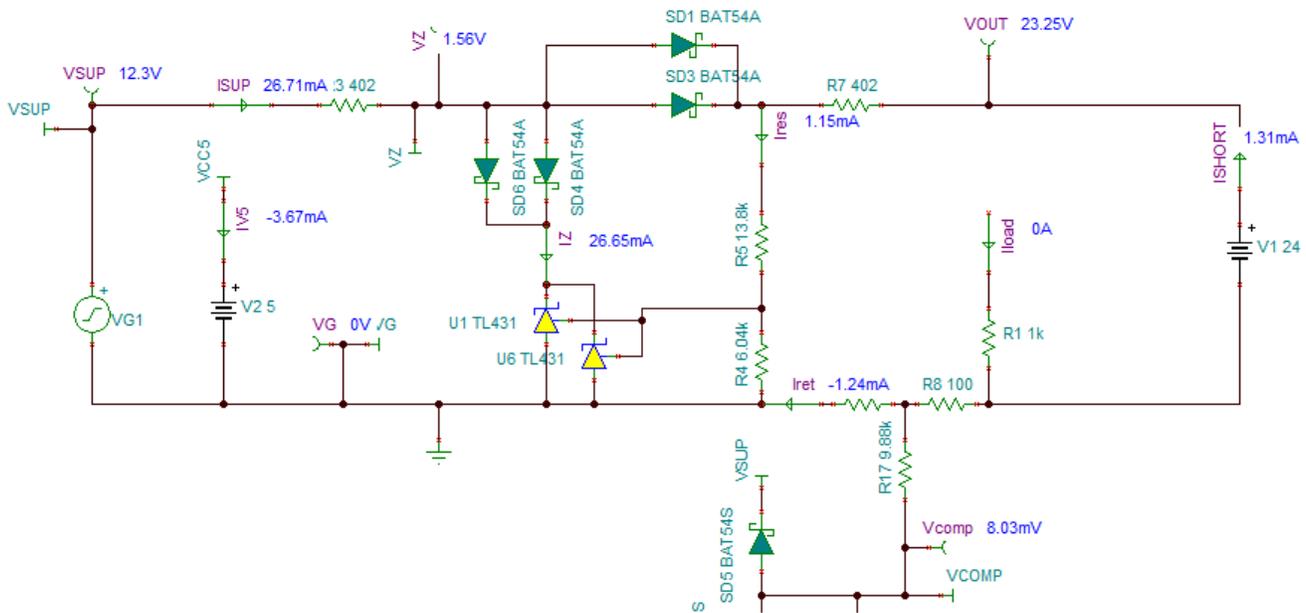
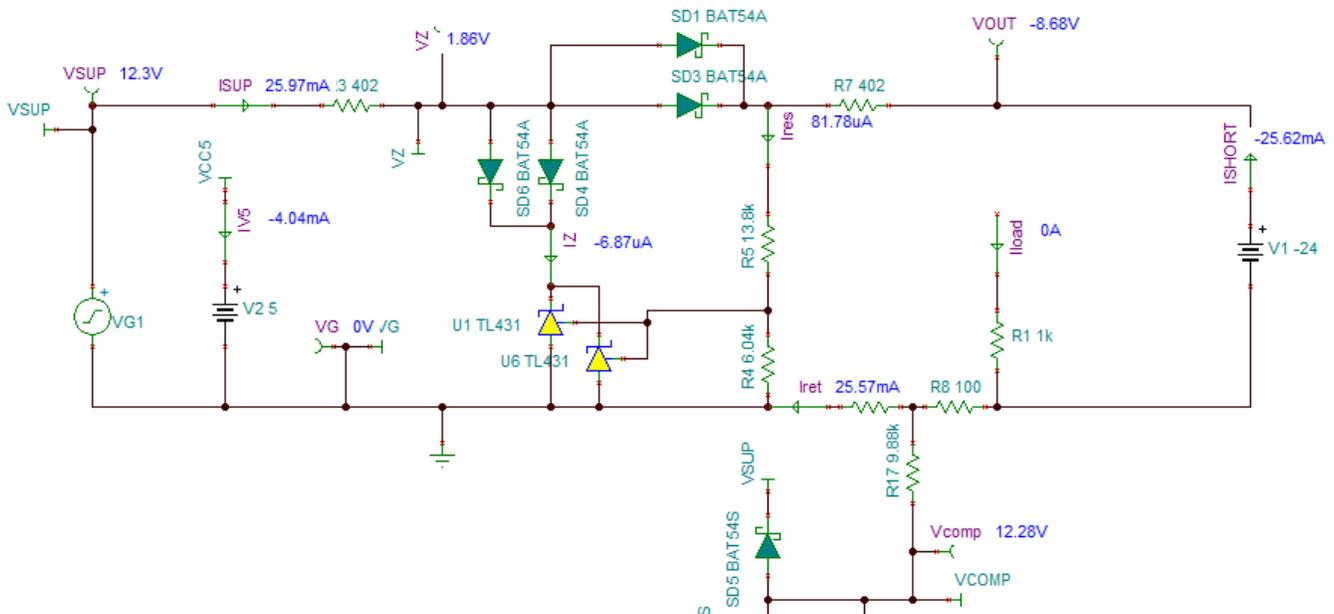


图 9. DC Operating Point of Short to -24-V Supply Case

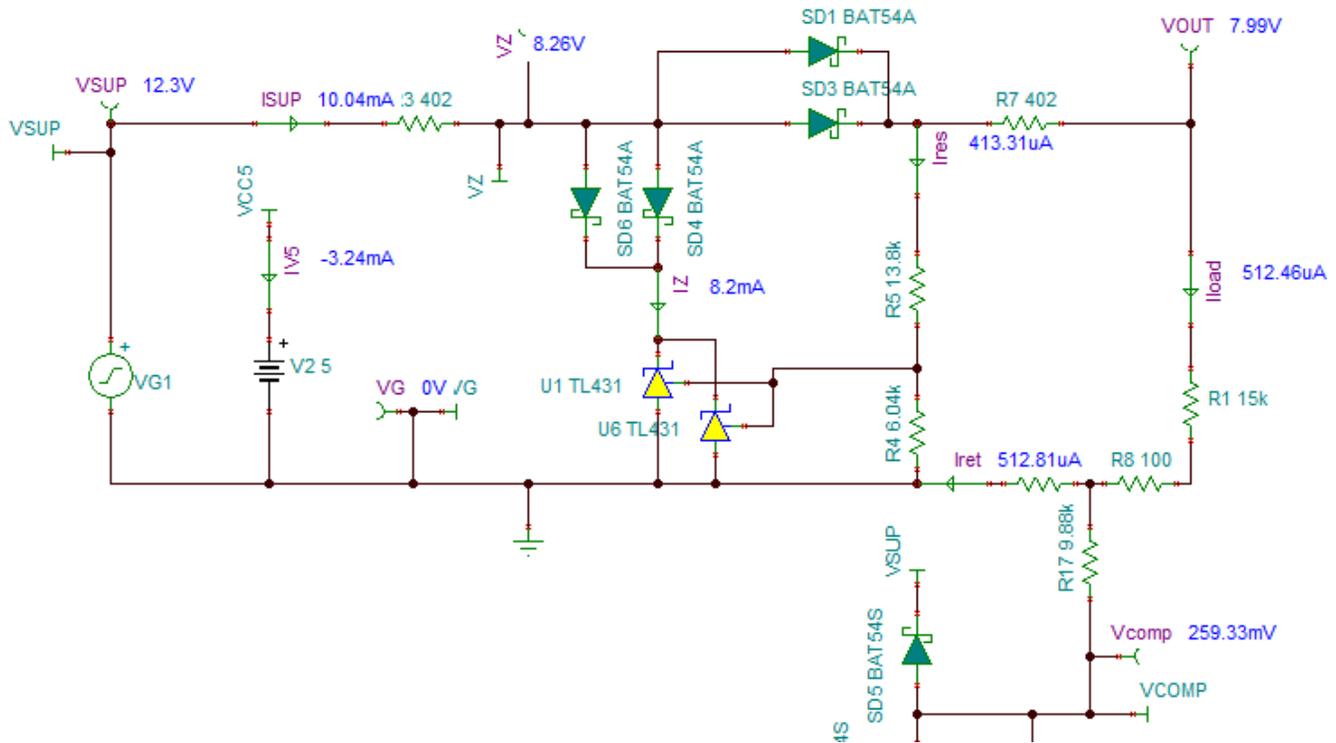


2.4.4.3 Isolated Supply

First choice of the isolated power supply is the secondary voltage level. From one side, a lower power-supply level (close to 8.2 V) will reduce power dissipation in the limiting resistor. However, maintaining a stable voltage over temperature range and various loading conditions will require a higher power-supply level. A value of 12 V is optimal because it enables headroom with a low power requirement.

Based on the maximum current required from the 12 V source, less than 0.5 W source power is needed. The chosen buck converter LM26019 is capable of delivering 100 mA on the primary side.

图 11. DC Operating Point for OFF State

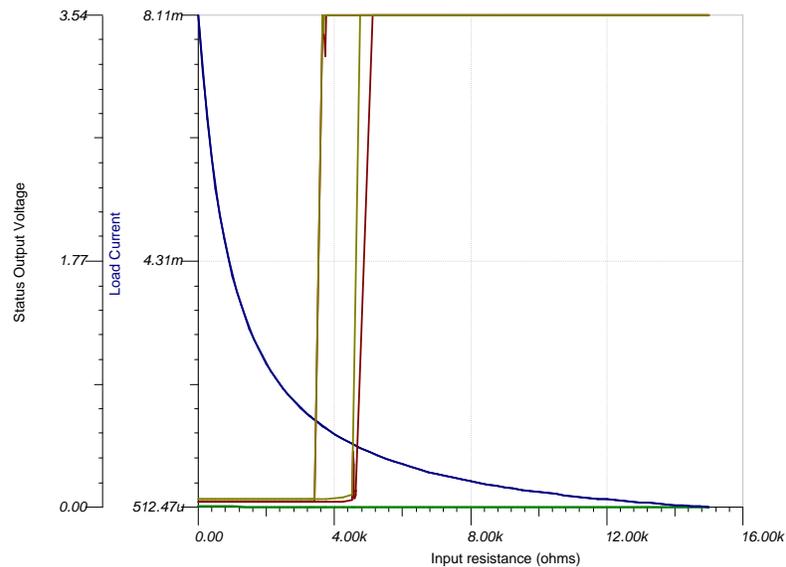


High power-supply voltage comparators make protection easier as 12 V appears at the input in case of short to reverse 24-V supply. An open collector should ease the interface with the subsequent digital stage. Lower offset comparator is required to achieve higher accuracy threshold levels, and rail-to-rail input range is required to resolve the low threshold below 1 V. The LM2901AVQ device is chosen for the comparator circuit as cost-effective low offset, 36-V comparator with near rail-to-rail input range.

The 12-V supply is only used to power the comparator, while the LDO generated 5 V is used as a reference, and a supply for the pullup resistors of the comparator output stage.

As the input can reach high voltages in case of short to reverse supply, protection diodes are placed at the comparator input to clamp input at the 12-V supply level. A 10-kΩ input impedance will keep the input current in that case within few mAs, and hence protecting the input stage of the comparator.

图 12 shows the simulated transfer function of the status detection comparator circuit including the hysteresis over temperature range -40°C to 80°C. The OFF state threshold is from 1.39 mA to 1.46 mA, while the ON state threshold is well at 1.8 mA.

图 12. Status Output Simulation Curve


Note that NAMUR ON state is interpreted as logic '1' at Status output, However, the logic '1' is represented as off LED after the isolator, and logic '0' is indicated as lit green LED.

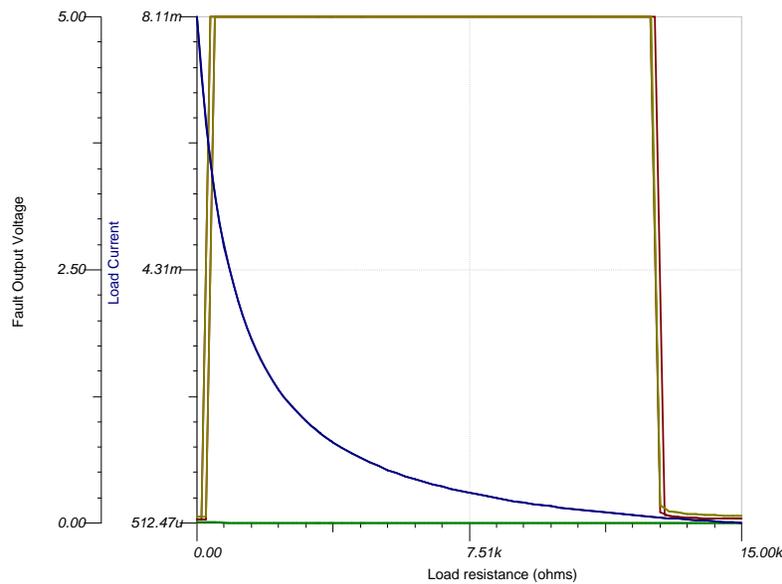
For the basics of comparator design, view the [Effective Application of Analog Comparators](#) training, and [TI Precision Labs - Op Amps: Comparator Applications 1](#). For the details of designing an inverting amplifier with hysteresis, see the [Inverting Comparator With Hysteresis Circuit](#) application note, and the [Comparator with Hysteresis Reference Design](#).

2.4.4.5 Fault Window Comparator

Apart from the input status (logic level), the circuit should detect sensor failures caused by short circuit and open circuit (broken wire) conditions using a window comparator. The window comparator indicates failure in case the input voltage is above or below certain thresholds. Failure is indicated as logic '0' at the failure output. The failure LED is attached to the supply so LED is lit when fault is detected.

图 13 shows the simulated transfer function of the fault detection window comparator circuit over temperature range -40°C to 80°C . The short state threshold is from 6.1 mA to 6.8 mA, while open circuit or broken-wire state threshold is very close to 0.6 mA.

图 13. Fault Output Simulation Curve

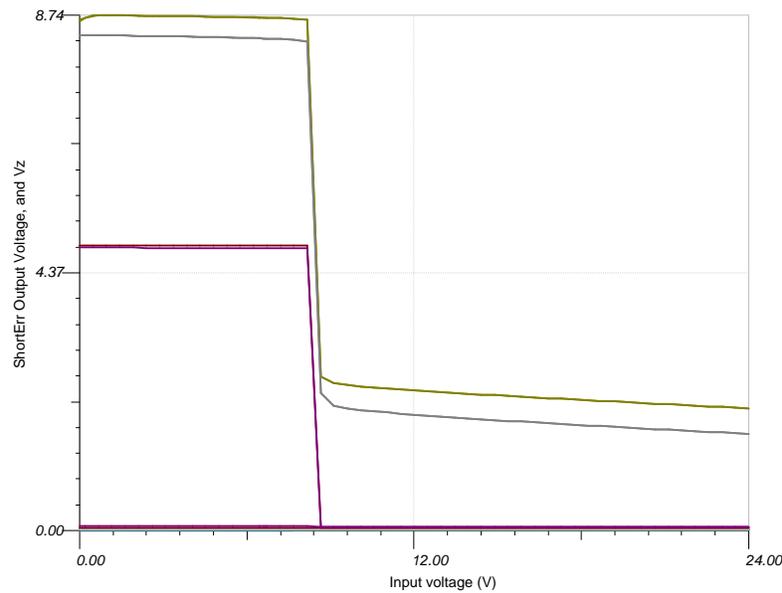
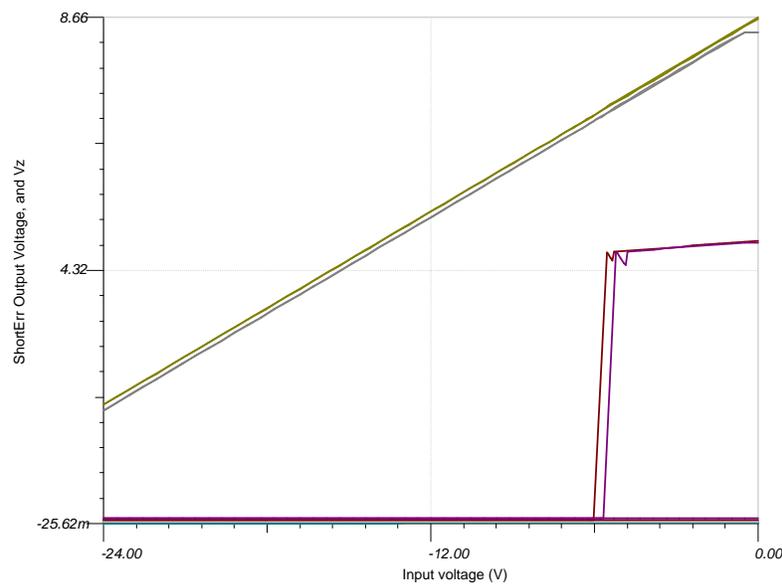


For designing window comparators, check [window comparator circuit](#) application note, and [window comparator reference design](#).

2.4.4.6 Short-to-Supply Comparator

Whenever a short to supply or reverse supply occurs, the TL431 device turns on and the regulated voltage VZ drops to about 2 V. This is used to detect the short to supply using a hysteresis comparator circuit. VZ is scaled down and reference threshold is driven from the 5-V supply. The short to supply is indicated as logic '0'. The short error LED is attached to the supply so LED is lit when short error is detected.

图 14 和 图 15 显示电压扫频的模拟，当电源短路到数字输入端时。如图显示，当正电源短路时，在 8.4 V 处检测到电源短路，而负电源在 -5 V 到 -5.5 V 处检测到电源短路。

图 14. Short to Positive Supply Sweep Simulation Curve

图 15. Short to Negative Supply Sweep Simulation Curve


For designing a non-inverting comparator with hysteresis, see the [Non-Inverting Comparator With Hysteresis Circuit](#) application note. Feedback resistors can be adjusted to change the hysteresis window to change the ShortErr circuit, it can work as the fault error, or make that error sticky so that power reset is required to clear the error when it occurs, according to need.

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

3.1.1 Hardware

The TIDA-010044 printed-circuit board (PCB) is two-layer, single-sided compact (7 × 3 cm²) board. 图 16 shows the component side with all connectors and jumpers annotated.

图 16. TIDA-010044 PCB Hardware - Top View

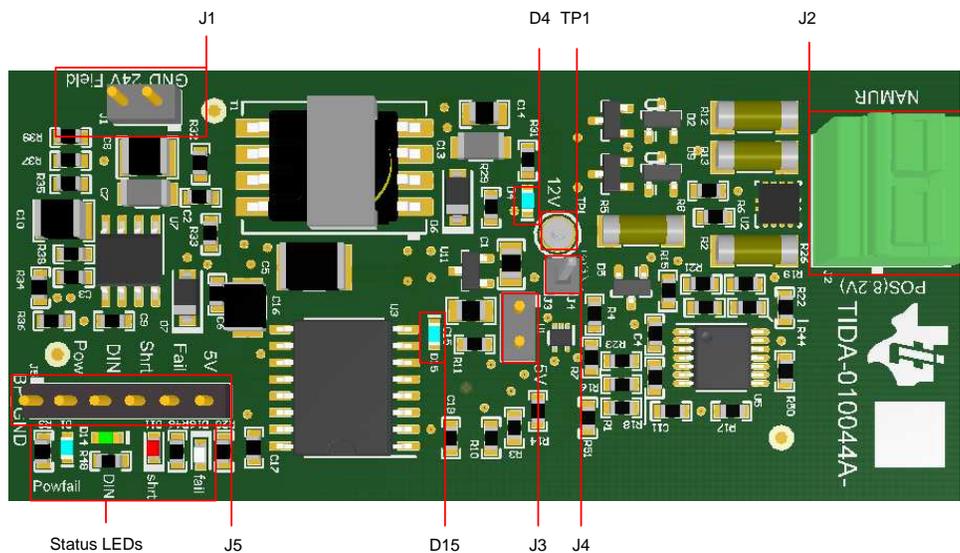


表 2 provides description of the board jumpers and connectors relevant to board testing.

表 2. TIDA-10044 Jumpers and Connectors

COMPONENT	DESCRIPTION
J1	24-V field supply connector. Note the polarity.
J2	NAMUR sensor connector. Note the polarity, positive terminal indicated by "POS(8.2 V)"
J3	5-V supply disconnect header: Short with jumper for normal operation where 5 V LDO output is powering the circuit. Disconnect to allow external 5-V supply, positive terminal is connected to the "5V" pin, and ground is connected to J4.
J4	Ground connector. Used as ground terminal when external 12-V or 5-V supply are connected. Note the requirements in 节 3.2.1.
J5	6-pin digital output header: 5 V, and BP_GND pins must be connected to a 5-V supply for the isolator to work and status LEDs to operate. Fail, Shrt, DIN (Status), Powfail are the status and diagnostics signals available for connection to back-end processor.
TP1	12-V supply test point. Use to prove the 12-V supply level. If external 12-V supply is to be enforced, disconnect 24-V supply from J1, and connect the 12-V supply through TP1 and J4 (GND)
D4	12-V supply ON LED indicator
D15	5-V supply ON LED indicator
Status LEDs	Status and diagnostics LEDs, requires 5-V supply connected through J5 to operate: Green: Status LED Orange: Sensor failure LED Red: Short-to-supply LED Blue: 12-V supply ON LED

3.1.2 Software

There is no software required to test TIDA-010044, all functionality can be tested by monitoring the status LEDs. Some performance parameters like threshold currents and voltages needs external multimeter in addition to monitoring the LEDs.

3.2 Testing and Results

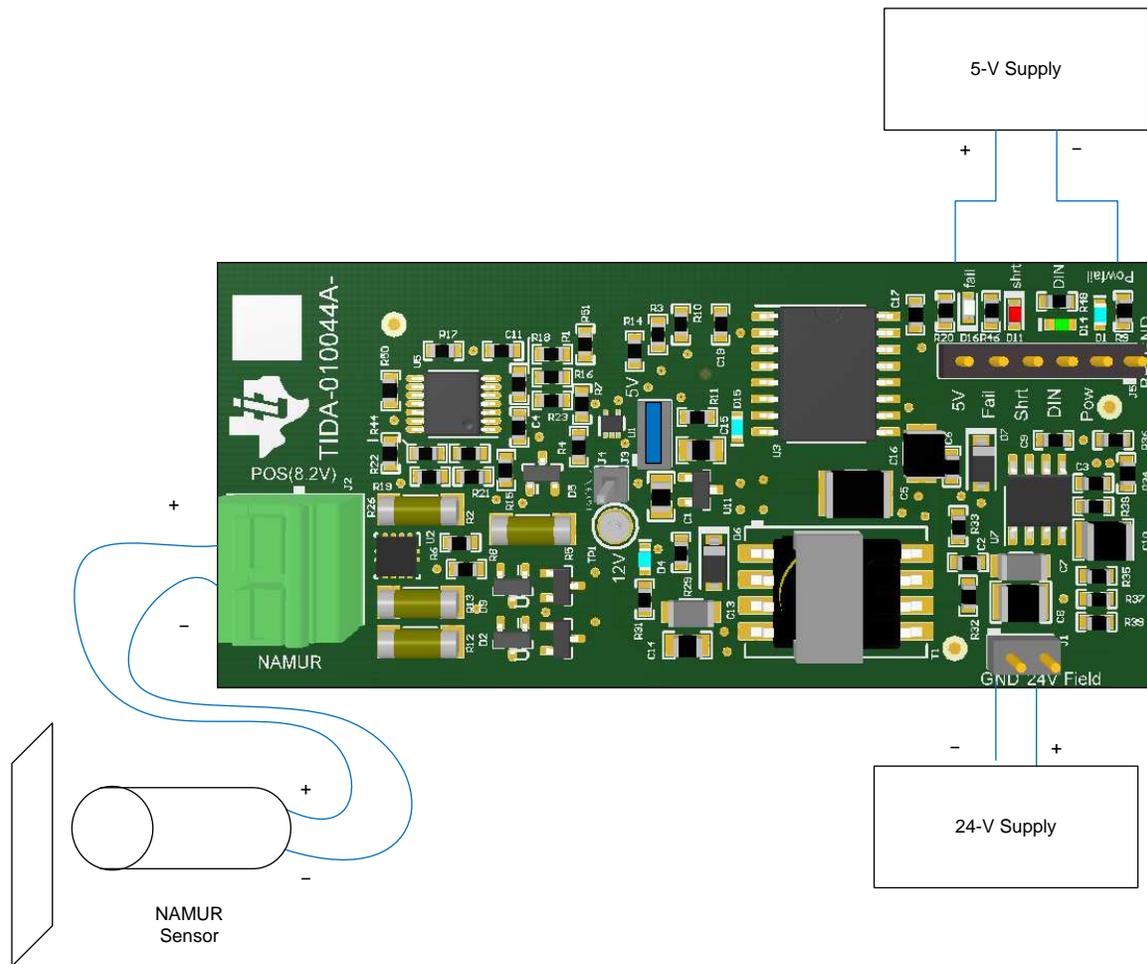
This section describes the test setups used for testing TIDA-010044 functionality. Different tests requires different powering schemes. Almost all tests can be carried out by only monitoring the status LEDs.

3.2.1 Normal Operation Test Setup

图 17 shows the test setup for normal operation. The 24-V supply is connected to J1, the 5-V backplane supply is connected to J5, and a NAMUR proximity sensor is connected to J2, and J3 is shorted with a jumper.

Pepperl+Fuchs NJ8-18GM-N, (106470) Induktiver Sensor (8 mm, 8 VDC, M18x1,5) is used for testing.

图 17. Normal Operation Test Setup



To test status operation, the metal plate is moved closer and away from the sensor. This is changing the status green LED.

To test sensor failure operation, sensor is replaced by short circuit (Orange and Green LEDs on), or left open (Orange LED on).

In all cases, the previously-mentioned current thresholds can be measured by adding an ammeter in series with a potentiometer, and gradually changing the potentiometer from a high resistive value (like 15 k Ω), down to a low value (like 100 Ω) and record the current level when LED lights (Green and Orange) change states. This is done in the reverse direction (low impedance to high impedance) to measure the hysteresis.

3.2.2 Power Fail Test Setup

图 18 shows the test setup for power failure test cases.

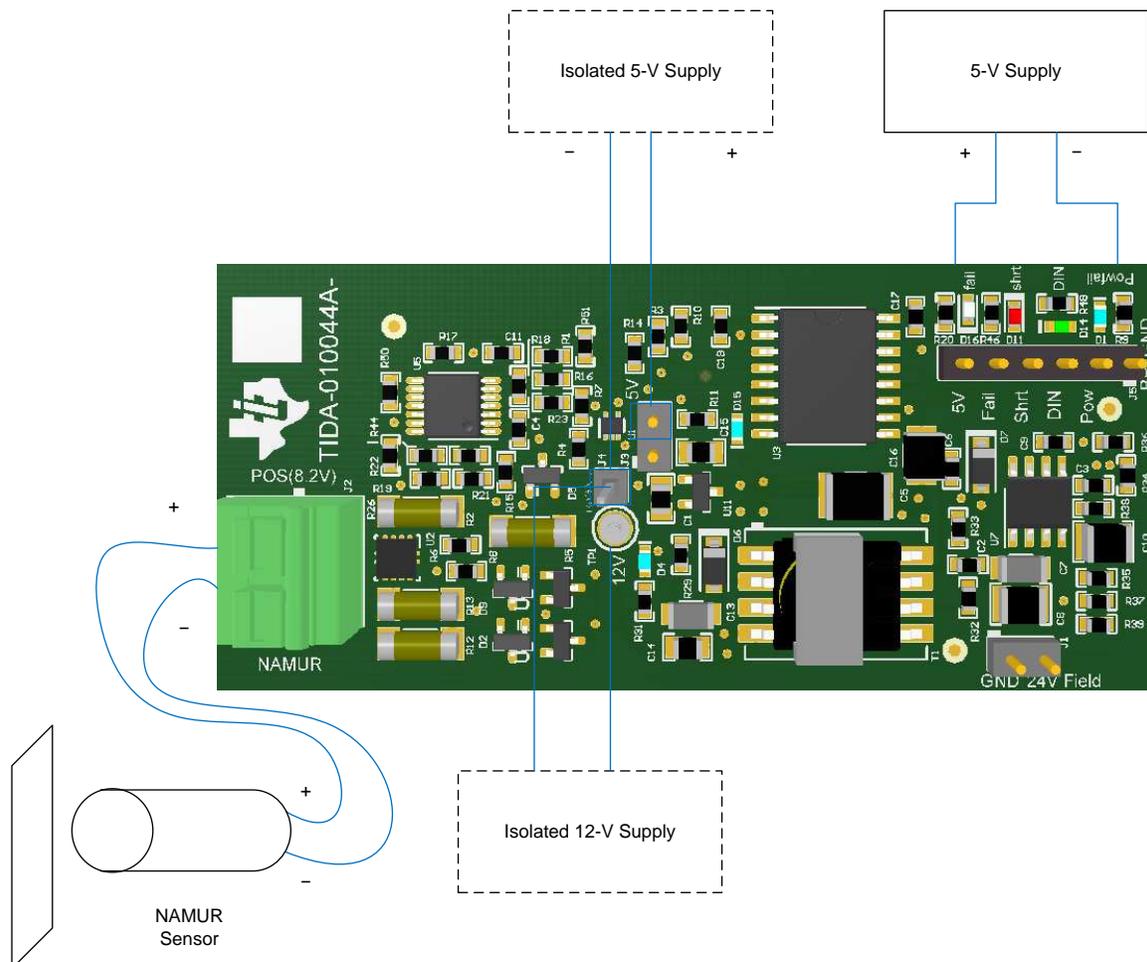
- For the 12-V failure test, the backplane 5-V supply is connected to J5, J1 is left unconnected, J3 is shorted with a jumper, and the external 12-V supply is connected to TP1 and J4.

In this case, the external 12-V supply is swept from 12 V down to 5 V and the blue LED light is monitored, the supply level at which LED turns off is the threshold for supply detection. The normal operation of sensor input works as long as the blue LED light is ON.

- For the 5-V failure test, the backplane 5-V supply is connected to J5, 24-V supply is connected to J1, J3 is not shorted, instead external 5-V supply is connected to 5V pin of J3 and J4.

In this case, the external 5-V supply is swept from 5 V down to 0 V, and output status LEDs are monitored, when 5-V supply goes below failure level, all the LEDs turn off, and the sensor input operation stops working. This indicates a 5-V supply failure.

图 18. Power Fail Test Setup



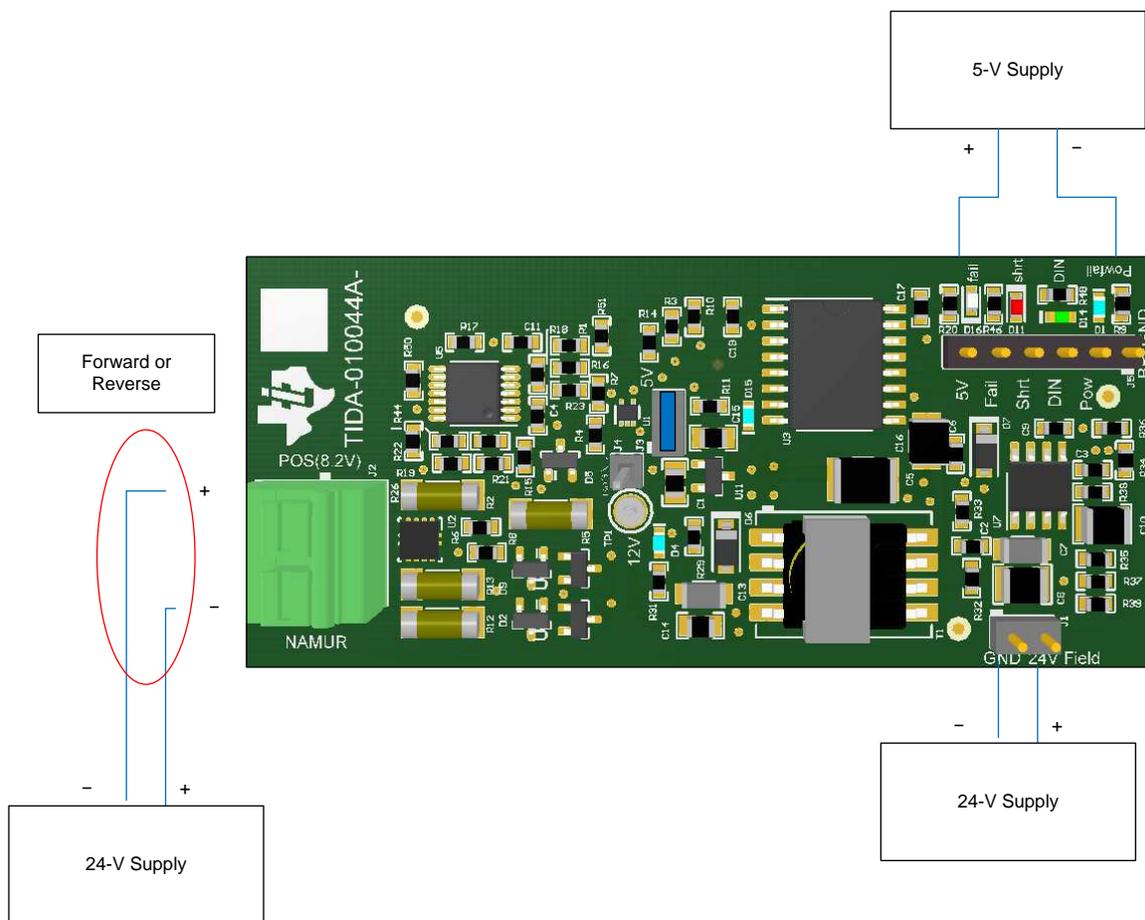
3.2.3 Short-to-Supply Test Setup

图 19 显示了用于短到场电源错误测试用例的测试设置。24-V 电源连接到 J1，5-V 背板电源连接到 J5，J3 用跳线短路。代替 NAMUR 传感器，可调电源连接到 J2 正向或反向。

在正向方向，电源电压水平从 0 到 24 扫描，此时 ShortErr LED 点亮所代表的短接至正电源的阈值水平。此时绿色状态 LED 点亮。

在反向方向，电源电压水平从 0 到 24 扫描，此时 ShortErr LED 点亮所代表的短接至负电源的阈值水平。此时绿色状态 LED 熄灭。

图 19. Short-to-Supply Test Setup



3.2.4 Test Results

The TIDA-010044 implements extensive diagnostic functions, allowing identification of most of the failures expected in the field for the NAMUR digital input module. As 表 3 shows, the 4 output signals are able to specify the exact state of the module, either normal or failure state. This greatly reduces the time and effort used to debug any of those failure states when they occur.

Looking at 表 3, TI recommends reversing the connection of the Powfail Blue LED, so that it is pulled-up to the supply. This arrangement signals the power good as the blue LED, and the short to supply –24 V and 5-V supply fail can be distinguished.

表 3. Diagnostic Outputs for Different Operating Conditions

CONDITION		Status (DIN) 0 = Green	Fault 0 = Orange	ShortErr 0 = Red	Powfail 1= Blue
Normal operation	SW ON	0	1	1	0
	SW OFF	1	1	1	0
Sensor failure	Short	0	0	1	0
	Open	1	0	1	0
Supply short	–24-V supply	0	0	0	0
	24-V supply	1	0	0	0
Power failure	12-V fail	followsDIN	followsDIN	0	1
	5-V fail	0	0	0	0

表 4 lists the measured values of the different tests for the normal case and failure conditions. Measured values pretty much matches those of the target specification values in 表 1.

表 4. Measured Voltage Thresholds for Operating Conditions

CONDITION	MEASUREMENT	
Normal operation	SW ON threshold	1.77 mA
	SW OFF threshold	1.48 mA
Sensor failure	Short threshold	5.7 mA
	Open threshold	0.59 mA
Supply short	Negative supply short threshold	-5-V (11.14 mA), -1-V (up)
	Positive supply short threshold	8.6-V (0.4 mA)
Power failure	12-V iso supply fail threshold	6-V (down), 9-V (up)
	5-V iso supply fail threshold	2.3-V (down), 3.8-V (up)
Open Circuit	Voltage	8.18 V
Short Circuit	Current	7.45 mA
Supply Current	5-V supply	6-7 mA, 8 mA (short)
	24-V supply	12-13 mA, 15 mA (short)

4 Design Files

4.1 Schematics

To download the schematics, see the design files at [TIDA-010044](#).

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-010044](#).

4.3 Layout Prints

To download the layer plots, see the design files at [TIDA-010044](#).

4.4 Altium Project

To download the Altium Designer® project files, see the design files at [TIDA-010044](#).

4.5 Gerber Files

To download the Gerber files, see the design files at [TIDA-010044](#).

4.6 Assembly Drawings

To download the assembly drawings, see the design files at [TIDA-010044](#).

4.7 Simulation Files

To download the simulation files, see the design files at [TIDA-010044](#).

5 Related Documentation

1. Texas Instruments, [TVS3301 33-V Bidirectional Flat-Clamp Surge Protection Device](#)
2. Texas Instruments, [LM339, LM239, LM139, LM2901 Quad Differential Comparators](#)
3. Texas Instruments, [TL43xLlx Programmable Shunt Regulator with Optimized Reference Current](#)
4. Texas Instruments, [LM25019 48V, 100mA Constant On-Time Synchronous Buck Regulator](#)
5. Texas Instruments, [TLV760 100-mA, 30-V, Fixed-Output, Linear-Voltage Regulator](#)
6. Texas Instruments, [ISO734x Robust EMC, Low Power, Quad-Channel Digital Isolators](#)

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6 About the Author

AHMED NOEMAN is a system engineer at Texas Instruments Germany currently developing design solutions for factory automation applications. Ahmed has many years of experience in analog and RF design, AMS modeling, and verification, as well as application and system engineering in a wide range of fields including RF transceivers, clocks and PLLs, memory systems. Ahmed received his BSC and MSEE from Ain Shams University, Egypt.

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