

TI Designs: TIDA-01509

光学スイッチを使用する破損ワイヤ検出のリファレンス・デザイン



概要

このリファレンス・デザインでは、TIのISO121xデバイスを使用した16の絶縁デジタル入力チャンネルのコンパクトな実装を紹介します。このデザインは絶縁電源なしに動作し、チャンネルごとに最高100kHzの入力信号(200kbit)をサポートします。このデザインは、それぞれ8チャンネルの2グループに分割されます。破損ワイヤの検出は、チャンネルごとに1つの光学スイッチ、またはグループごとに2つの光学スイッチと1つの追加コンデンサを使用するだけで実行できます。この機能には追加の補助電源が必要ありません。通常のデジタル入力モジュールでは破損ワイヤを診断するために、現場入力側に追加の絶縁電源が必要なことと比べると、これはISO121xファミリを使用するデジタル入力モジュールに固有の利点となります。

リソース

TIDA-01509	デザイン・フォルダ
ISO1211	プロダクト・フォルダ
ISO1212	プロダクト・フォルダ
SN74LV165A	プロダクト・フォルダ
SN74LVC1GU04	プロダクト・フォルダ
TVS3300	プロダクト・フォルダ

特長

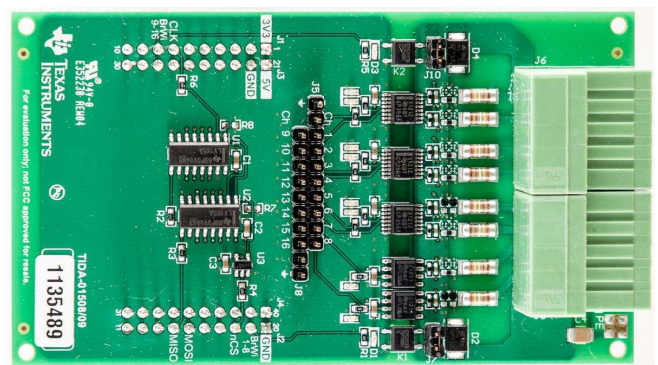
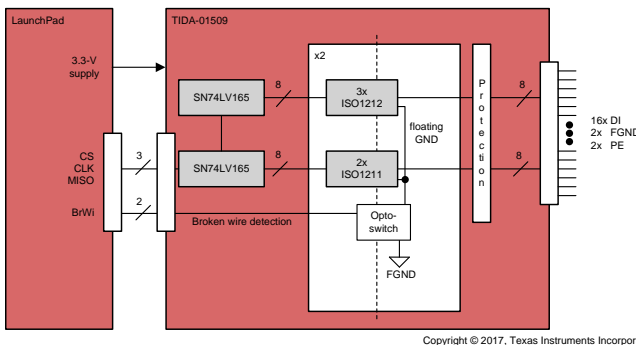
- 最高±60Vの入力電圧を許容する16のデジタル入力チャンネル
- 単一チャンネルについて、追加部品1つだけで破損ワイヤを検出
- スケーラブルなグループ・チャンネル構成について、追加部品3つだけで破損ワイヤを検出
- 主電源のみで動作し、絶縁電源が不要
- LaunchPad™ヘッダーによる迅速で簡単な評価

アプリケーション

- [デジタル入力モジュール](#)
- [産業用ロボットのIOモジュール](#)



[E2E™エキスパートに質問](#)



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1 System Description

This reference design shows a compact implementation of 16 isolated digital input channels using TI's new ISO121x devices, a single- (ISO1211) and dual- channel (ISO1212), isolated, 24-V digital input receiver. The design is split into two groups of eight channels each. Every group is built up out of three dual-channel ISO1212 and two single-channel ISO1211 devices.

A broken wire detection can be executed using only one additional optical switch for each channel. This design does not need any other adjustments to the circuitry.

The optical switch disconnects the field ground of the ISO121x devices for a short time and connects it again afterwards. This results in a pulse at the output pin of the ISO121x depending on the status of the wire—broken or connected. This pulse even works for logic '0' input signals if the input signal is coming from a high-side switch with a pullup resistor.

For this functionality, no secondary-side supply is needed, which gives a unique benefit to digital inputs built with the ISO121x compared to regular digital inputs that need an additional isolated power supply on the field input side for broken wire diagnostic.

For an easy and quick evaluation, this reference design can be plugged onto the MSP430FR5969 LaunchPad or any other TI LaunchPad with the same SPI pinout. The LaunchPad also supplies power to the system.

Furthermore, this reference design can be used as a regular 16-channel digital input module. The ISO121x device provides an accurate current limit for digital inputs, enabling a power dissipation of less than 1 W for 16 inputs channels for input signals of 24 V. For more information about this, see the [Sub 1-W, 16-Channel, Isolated Digital Input Module Reference Design](#).

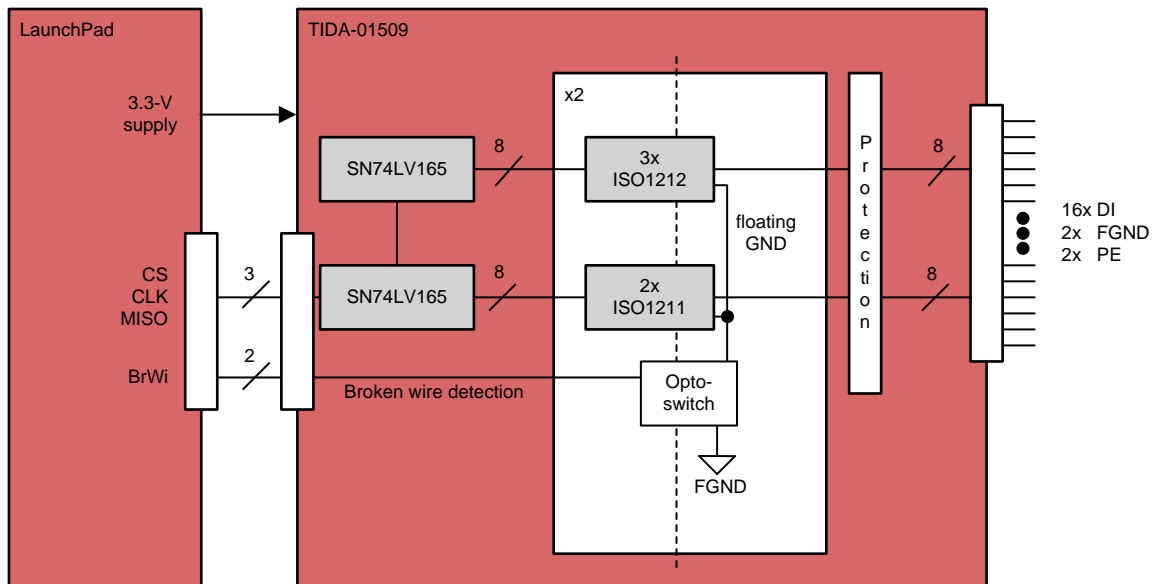
1.1 Key System Specifications

表 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Number of channels	16 (in groups of 8)	2.3.1
Supply voltage	3.3 V (provided by LaunchPad)	3.1
Maximum sampling speed, serial	100 kHz (200 kbps) / channel	2.3.1
Maximum sampling speed, parallel	2 MHz (4 Mbps) / channel	2.2.1
time needed for broken wire detection, single channel configuration	3 ms (100-k Ω pullup to a 24-V supply)	3.2.2.2
minimum supply voltage for broken wire detection to work	14.9 V (100-k Ω pullup, single-channel configuration)	3.2.2.2
time needed for broken wire detection, group configuration (eight channels)	24 ms (800-k Ω pullup to a 24-V supply per channel)	3.2.2.1
Additionally needed parts for broken wire detection, single channel configuration	1 optical switch	2.3.2

2 System Overview

2.1 Block Diagram



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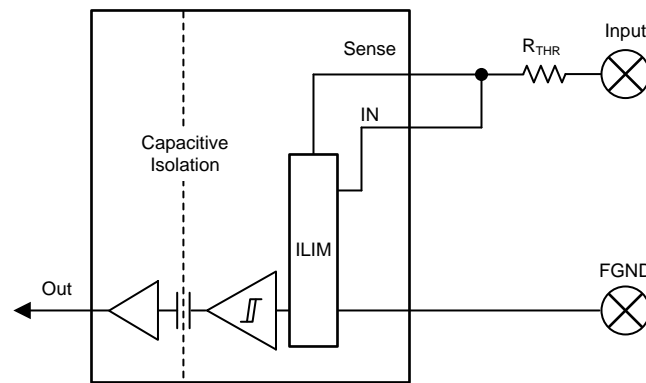
図 1. Block Diagram of TIDA-01509

2.2 Highlighted Products

2.2.1 ISO121x

The ISO1211 and ISO1212 devices are isolated 24-V digital input receivers, compliant to IEC 61131-2 Type 1, 2, and 3 characteristics, and suitable for programmable logic controllers (PLCs) and motor-control digital input modules. Unlike traditional optocoupler solutions with discrete, imprecise current limiting circuitry, the ISO121x devices provide a simple, low-power solution with an accurate current limit to enable the design of compact and high-density I/O modules. These devices do not require field-side power supply and are compatible with high-side or low-side switches. The ISO121x devices operate over the supply range of 2.25 V to 5.5 V, supporting 2.5-V, 3.3-V, and 5-V controllers. A ± 60 -V input tolerance with reverse polarity protection helps ensure the input pins are protected in case of faults with negligible reverse current. These devices support up to 4-Mbps data rates passing a minimum pulse width of 150 ns for high-speed operation. The ISO1211 device is ideal for designs that require channel-to-channel isolation and the ISO1212 device is ideal for multichannel space-constrained designs.

図 2 shows the functional block diagram of one channel of the ISO121x family.



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図 2. Functional Block Diagram of ISO121x

2.2.2 SN74LV165A

The SN74LV165A devices are parallel-load, 8-bit shift registers designed for 2-V to 5.5-V VCC operation.

When the devices are clocked, data is shifted toward the serial output QH. Parallel-in access to each stage is provided by eight individual direct data inputs that are enabled by a low level at the shift/load (SH/LD) input. The SN74LV165A devices feature a clock-inhibit function and a complemented serial output, QH.

図 3 shows a functional block diagram of the SN74LV165A.

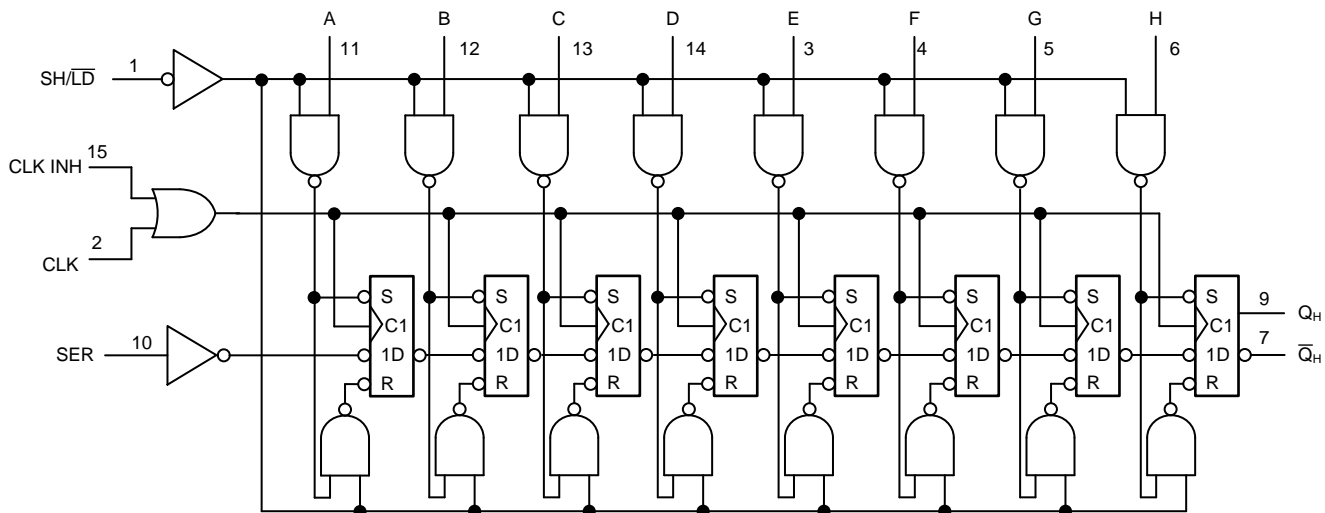


図 3. Functional Block Diagram of SN74LV165A

2.2.3 SN74LVC1GU04

This single inverter gate is designed for 1.65-V to 5.5-V VCC operation.

The SN74LVC1GU04 device contains one inverter with an unbuffered output and performs the boolean function $Y = \bar{A}$.

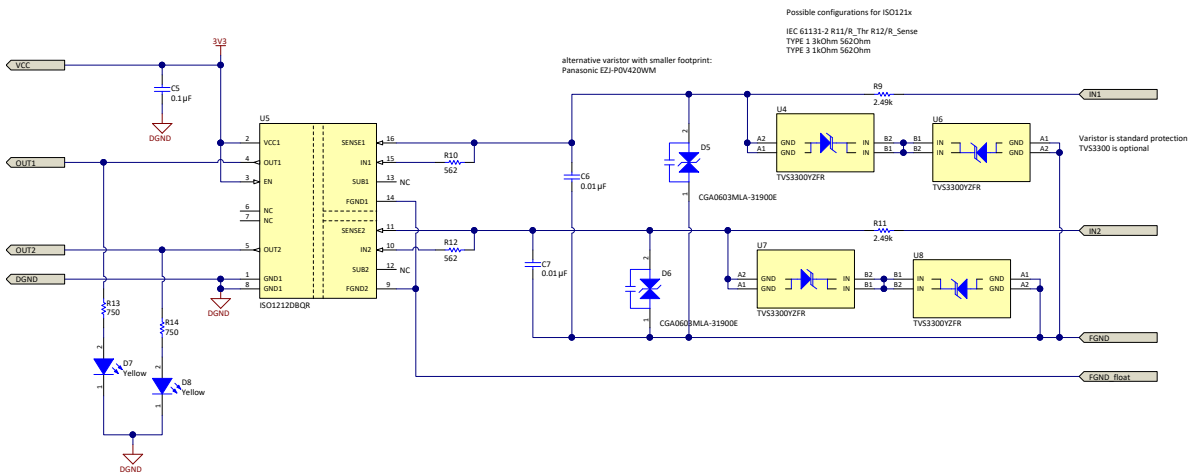


図 5. Schematic of Input Stage ISO1212

Pin FGND of the two ISO1211 as well as pins FGND1 and FGND2 of the three ISO1212 are connected to the field ground FGND through an optical switch with default state normally on. The optical switch can disconnect the two grounds by switching the control line high. In this reference design, the microcontroller on the LaunchPad is used to control the optical switch. 図 6 shows the connection of the FGND pins of the ISO121x devices to the field ground.

If the broken wire feature is not needed and the design is only used as a standard digital input, the optical switch can be short-circuited with a jumper. For this use case, see the [Sub 1-W, 16-Channel, Isolated Digital Input Module Reference Design](#).

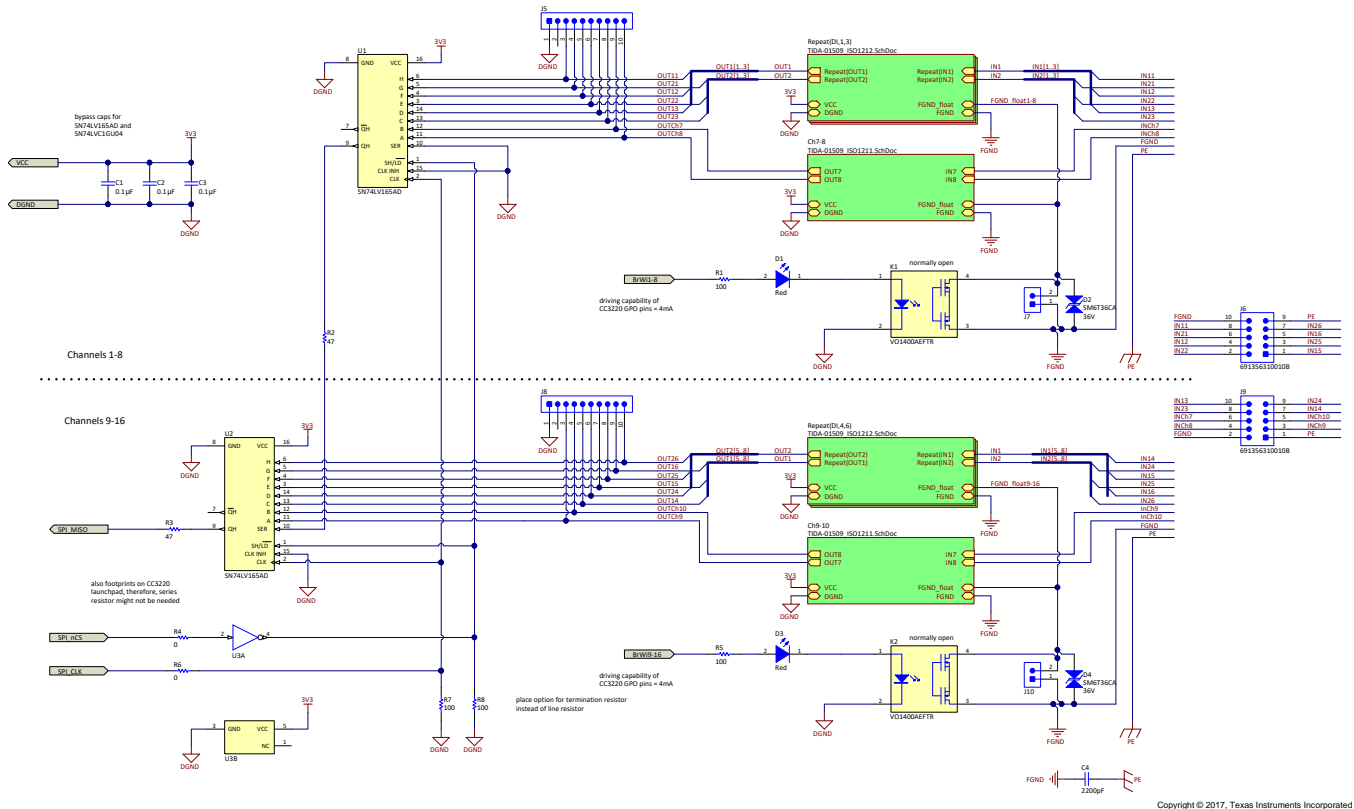


図 6. Schematic of Floating Ground to Field Ground (FGND) Connection With Optical Switch

Every input of the ISO1211 can be configured for Type 1, 2, 3 characteristics according to IEC 61131-2 with resistors R_{THR} and R_{SENSE} . In addition, an input capacitor C_{IN} is connected after R_{THR} to GND creating an RC filter with R_{THR} for further protection against ESD, EFT, and surge events. To withstand high pulse voltages, R_{THR} is selected as a pulse proof resistor. 表 2 shows the configuration for Type 1 and 3 digital inputs as well as the resulting voltage ratings according to IEC 61002-4-2, IEC 61002-4-4, and IEC 61002-4-5 for specific values of R_{THR} , R_{SENSE} , and C_{IN} , respectively.

表 2. Surge, ESD, and EFT

IEC 61131-2 TYPE	R_{SENSE}	R_{THR}	C_{IN}	SURGE			IEC ESD	IEC EFT
				LINE-TO-PE	LINE-TO-LINE	LINE-TO-FGND		
Type 1	562	3 k Ω	10 nF	± 1 kV	± 1 kV	± 1 kV	± 6 kV	± 4 kV
Type 3	562	1 k Ω	10 nF	± 1 kV	± 1 kV	± 500 kV	± 6 kV	± 4 kV
			330 nF	± 1 kV	± 1 kV	± 1 kV	± 6 kV	± 4 kV

To protect the inputs against surge events with even higher ratings, all inputs are as well protected with either a varistor or two TVS3300 TVS diodes. Those devices are placed in parallel to C_{IN} .

In this reference design, all channels as configured for Type 1 inputs with $R_{THR} = 2.4$ k Ω and $R_{SENSE} = 562$ Ω . The typical high-level threshold V_{IH} and minimum low-level threshold V_{IL} at the ISO121x input (include R_{THR}) for output high and low are given by 式 1 and 式 2.

$$V_{IH} (typ) = 8.25 V + R_{THR} \times \frac{2.25 mA \times 562 \Omega}{R_{SENSE}} = 13.65 V \tag{1}$$

$$V_{IL} (\text{min}) = 7.1 \text{ V} + R_{\text{THR}} \times \frac{2.25 \text{ mA} \times 562 \ \Omega}{R_{\text{SENSE}}} = 12.5 \text{ V} \tag{2}$$

2.3.2 Broken Wire Detection

Broken wire detection is explained for a single-channel configuration. This means that only one channel of a ISO121x device is used. Only one additional optical switch is needed. The rest of the circuit stays the same. As shown in [Figure 6](#), the optical switch must be placed in between the FGND pin of the respective ISO121x channel and the field ground input.

For the broken wire detection to work, when the wire is intact, a small current is available to charge C_{IN} even when the input state is '0'. This assumption is made because the IEC61131-2 allows for Type 1, 2, and 3 inputs in '0' state currents of up to a few mA (see [Figure 7](#)).

This is only valid for powered field devices and not passive inputs like a simple, standalone mechanical switch. Furthermore, the output of the sourcing device must have a pullup resistor to its supply.

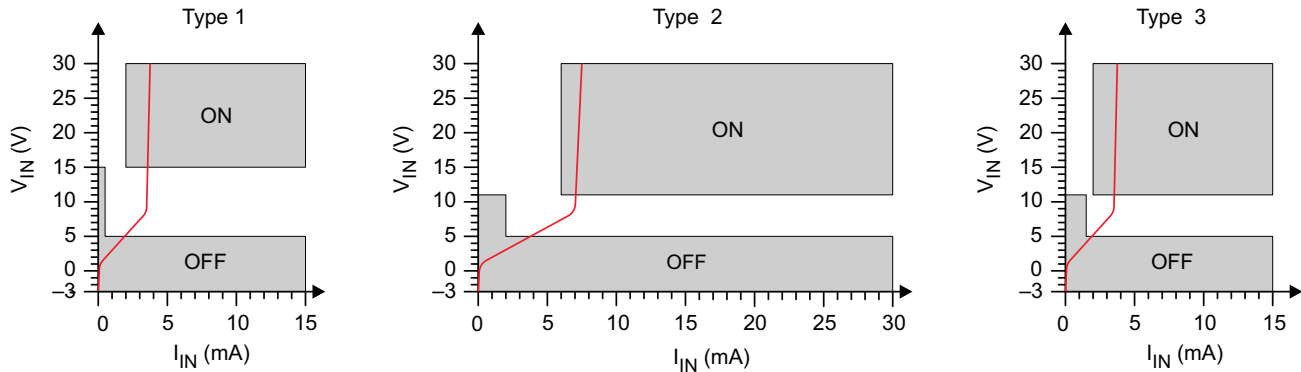


Figure 7. Switching Characteristics for IEC 61131-2 Type 1, 2, and 3 Proximity Switches

The broken wire detection sequence works as follows:

1. In normal operation, the field ground pin FGND of the input channel is connected to the actual field ground through the optical switch.
2. The optical switch is opened by switching its control line low.
3. The control line is switched high again to close the optical switch.
4. Afterwards, the output state of the ISO121x channel is read. If a wire is connected, the output state of the channel will be '1'. This is the case for input states '1' and '0'. However, if the wire is broken, the output state of the respective channel is '0' constantly.

For more information on these different cases, see 2.3.2.1 to 2.3.2.3. Therein, Break FGND is the control state of the optical switch (0 V means the switch is off, 3.3 V means the switch is turned on), IN is the input signal from the field device, C_{IN} is the voltage at the input capacitor, and OUT is the output state of the ISO121x. The respective times are given in brackets (t_x).

2.3.2.1 Case 1: Wire Intact and Input State '1'

In case the wire is intact and IN is '1', the output of OUT will be '1'. When Break FGND (t₁) switches low, the optical switch is disabled after the delay of the optical switch (t₂). Then, OUT switches to '0'. When Break FGND switches high again, OUT switches to '1' again plus the delay of the optical switch.

In general, this use case is the most uninteresting one because if OUT is '1' the user already knows that a wire is connected.

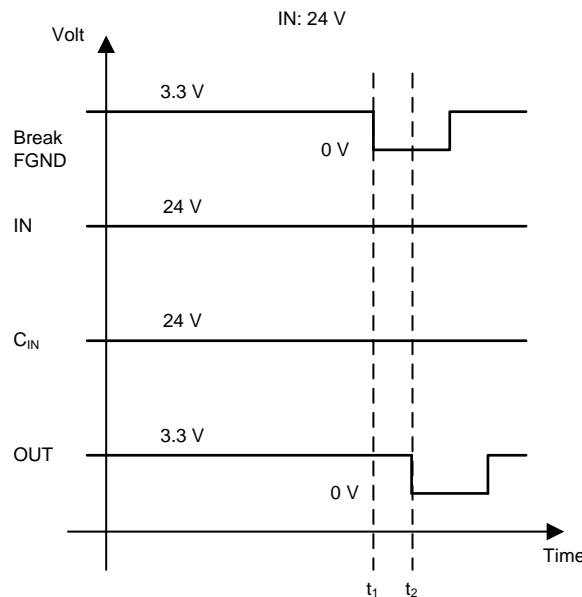


図 8. Broken Wire Detection With Intact Wire and IN = 24 V

2.3.2.2 Case 2: Wire Intact and Input State '0'

In case the wire is intact and IN is '0', OUT is '0' as long as Break FNGD is '1'. As soon as Break FNGD is '0' (t₃), the field ground of the ISO121x is disconnected. Now, C_{IN} is charged to the supply voltage of the field device. This result is because the field device has a pullup resistor to its supply and it is still connected to C_{IN} (t₄). Again, consider the delay of the optical switch.

Because the ISO121x has no ground connection, there is no voltage drop across the device. This result means that the voltage at C_{IN} is also present at the floating FGND pin of the ISO121x. Hence, the voltage drop across the optical switch (equal pin FGND and field ground) is also equal to the supply voltage of the field device.

Break FGND can switch to '1' again when C_{IN} is charged to the supply voltage of the field device (t_5). As soon as the ISO121x is connected to the field ground again, the device starts operating. The ISO121x is now supplied by the energy stored in C_{IN} . As soon as the current through the sense resistor R_{SENSE} is high enough ($I_{MIN} = 2.2 \text{ mA}$, taken from the [ISO121x data sheet](#)) and the voltage at the SENSE pin is above the voltage level threshold, OUT switches to '1' (t_6). As soon as the voltage level at C_{IN} drops below the voltage level threshold for a high state, OUT drops back to '0' (t_7).

The curves of IN and C_{IN} would be identical because they are connected to each other. However, to indicate that the digital output state of the field device is '0' continuously, IN is '0' in the diagram continuously as well.

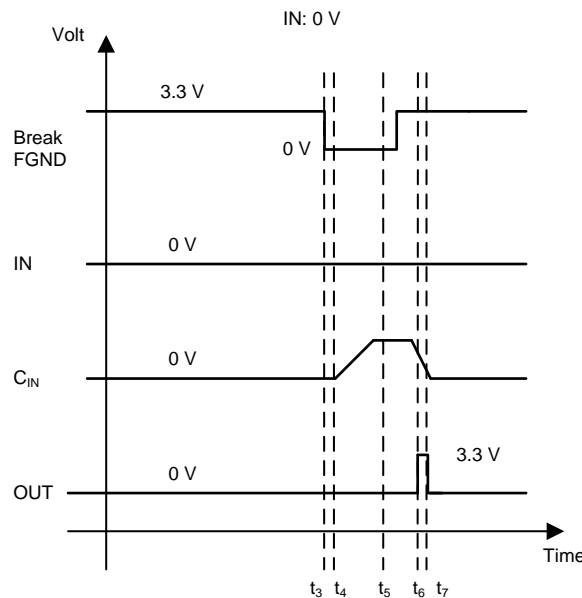


図 9. Broken Wire Detection With Intact Wire and $IN = 0 \text{ V}$

2.3.2.3 Case 3: Broken Wire

In case of a broken wire, OUT is always 0 V. This result is independent of the switching of Break FGND (t_8). C_{IN} can never be charged because it does not connect to a supply.

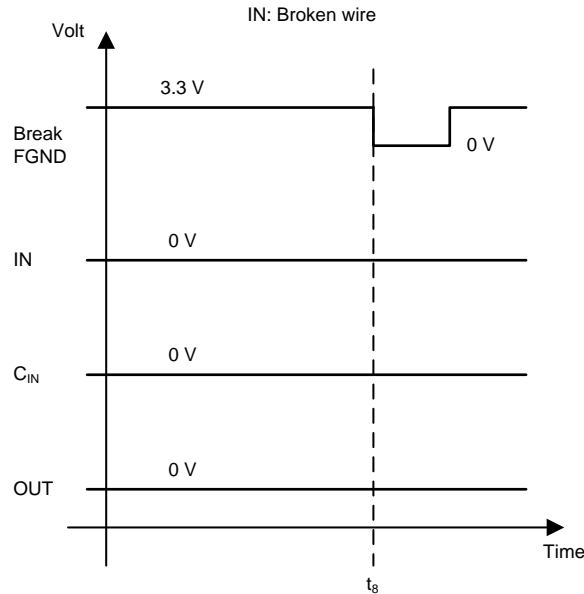
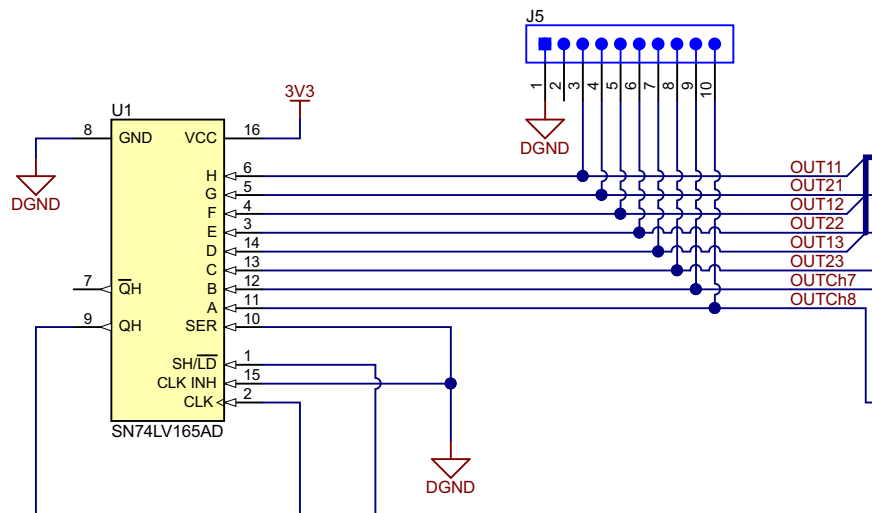


図 10. Broken Wire Detection With Broken Wire

2.3.3 Readout of Digital Outputs

To readout the 16 digital output signals, there are two options:

1. Parallel readout of output signals at connectors J5 (channels 1–8) and J8 (channels 9–16)
2. Serial readout of output signals from parallel-in serial-out registers U1 and U2



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図 11. Schematic of Parallel and Serial Readout Options for Output Signals

For serial readout, all eight output signals per group are connected to the parallel-in serial-out register SN74LV165A. The output QH of register U1 is connected to input pin SER of register U2. To readout the register, the SPI of the LaunchPad is used. For this, the LaunchPad SPI is connected to the SN74LV165A registers as follows:

- 注: The SPI_nCS signal of the LaunchPad is inverted using a logic gate SN74LVC1GU04 with function $Y = \bar{A}$.
- SPI_nCS logic '0' / low = logic '1' / high at SH/ \overline{LD} pin of SN74LV165A

表 3. Electrical Connections Between SPI and U1, U2

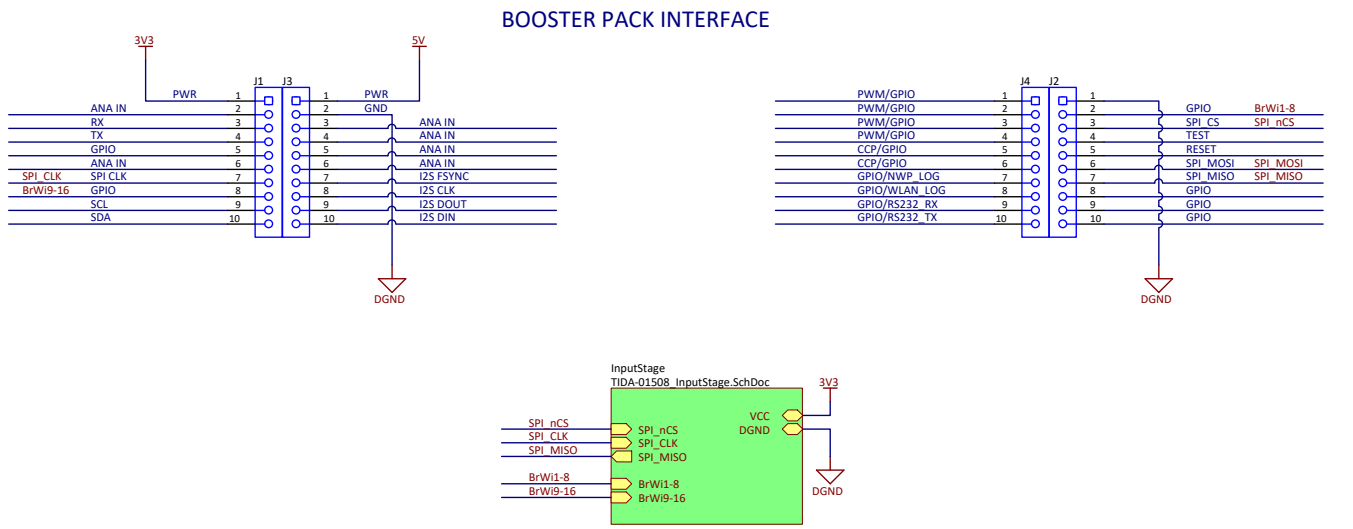
LAUNCHPAD	U1 (CHANNELS 1–8)	U2 (CHANNELS 9–16)
SPI_MOSI	Not used	Not used
SPI_MISO	Not connected	QH
SPI_nCS	SH/ \overline{LD}	SH/ \overline{LD}
SPI_CLK	CLK	CLK
	QH	SER

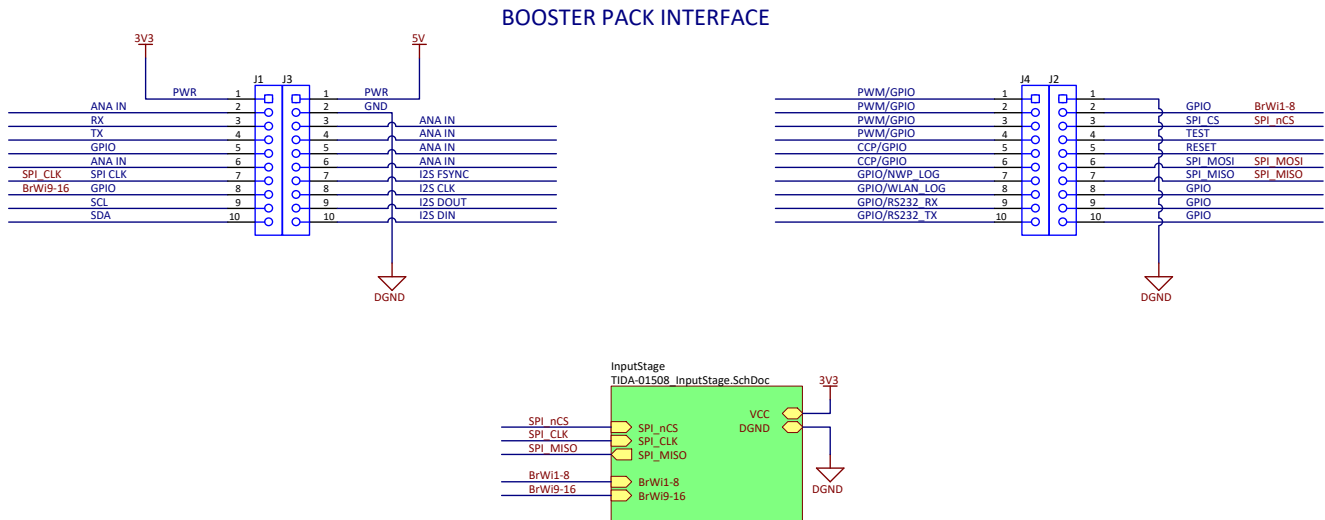
The readout of the 16 output states works as follows:

1. SPI_nCS is high → both SN74LV165A continuously load input states
2. SPI_nCS pulled low → both SN74LV165A store current status of their respective eight inputs
3. SPI_CLK is clocked 16 times → output QH of register U2 first gives out outputs states of inputs H–A (channel 9–16) of U2, second gives out output states H–A (channel 1–8) of U1.

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

The board can be powered and interfaced over connectors J1–J4. A snapshot of the interface is shown in  12. To evaluate easily, use an MSP430FR5969 LaunchPad or any other TI LaunchPad with the same pinout to power and interface the board.



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 12. Schematic of LaunchPad Interface

3.1.1 Hardware

- MSP430FR5969 LaunchPad
- Mechanical switch with a parallel pullup resistor
- Power source and scope: National Instruments Virtual Bench

3.1.2 Software

For a parallel readout of the output signals of the ISO121x devices, no special software is required.

To control the optical switch, the user needs to program a routine that toggles the control line of the optical switch. This runs on the microcontroller of the LaunchPad.

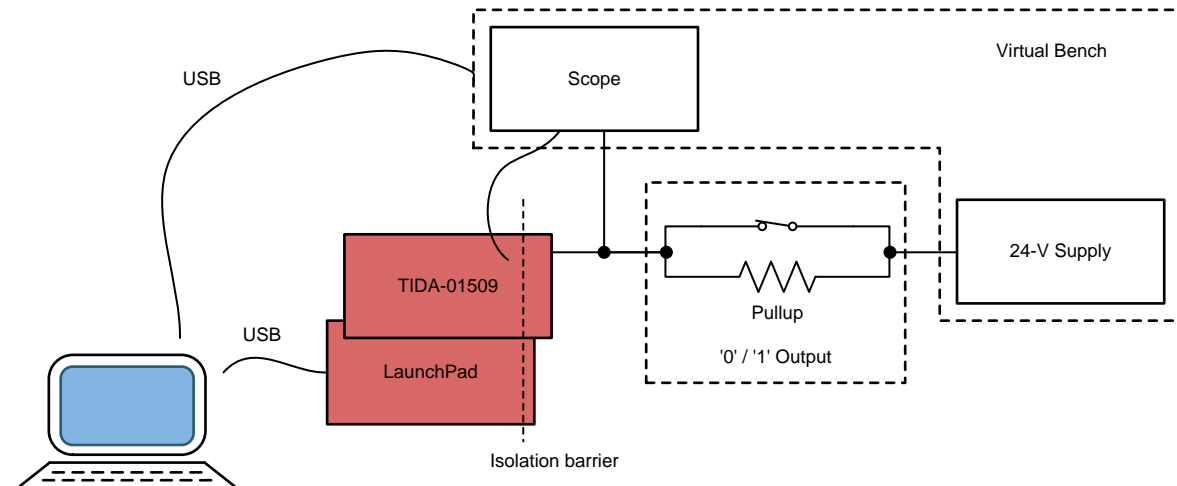
3.2 Testing and Results

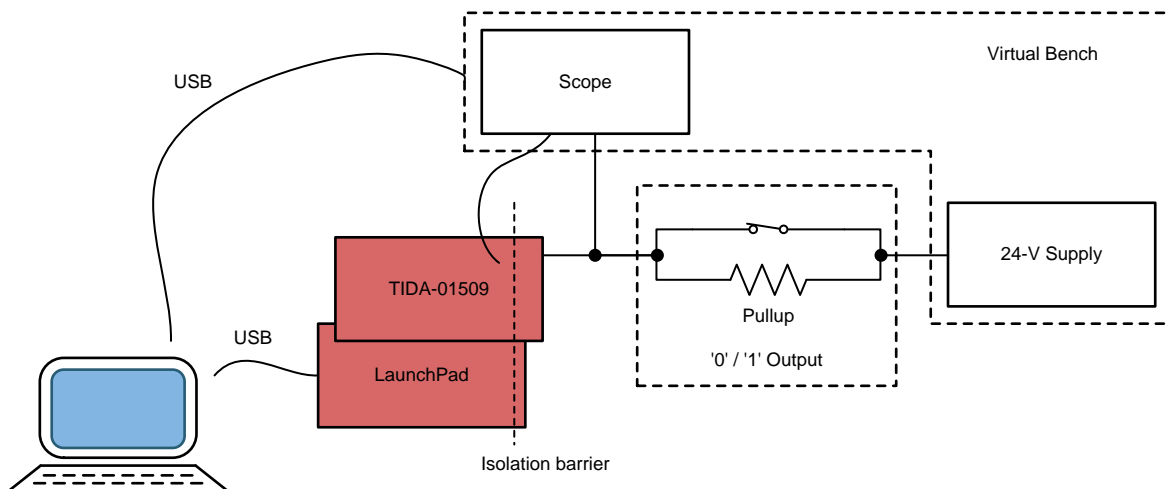
This section describes the test setup, documents the results and discusses how those results affects the circuitry of the broken wire detection.

3.2.1 Test Setup

The board is plugged onto an MSP430FR5969 LaunchPad, which is connected over USB to a laptop. The laptop is used to program the microcontroller on the LaunchPad. The microcontroller switches the control lines of the optical switches on the board. Furthermore, the MCU reads the output states of the different channels.

The input signal is coming from a mechanical switch. A 100-kΩ pullup resistor is placed in parallel.

The switch is connected to a 24-V supply of the virtual bench. The virtual bench is also connected to the laptop over USB to control the two-channel scope.  shows a block diagram of the test setup.



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 13. Test Setup of TIDA-01509

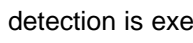
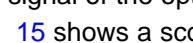
3.2.2 Test Results

To characterize the broken wire detection, the test is executed in a group-channel configuration and a single-channel configuration.

For the group-channel configuration, all eight channels are connected to the same mechanical switch. Therefore, the common 100-kΩ pullup resistor is equal to a separate 800-kΩ pullup resistor for every channel (see 式 3).

$$1 \text{ } 100 \text{ k} \Omega = 1 \text{ } R_p + 1 \text{ } R_p + 1 \text{ } R_p + 1 \text{ } R_p + 1 \text{ } R_p + 1 \text{ } R_p + 1 \text{ } R_p + 1 \text{ } R_p = 8 \text{ } R_p \rightarrow R_p = 8 \times 100 \text{ k} \Omega = 800 \text{ k} \Omega \quad (3)$$

3.2.2.1 Group-Channel Configuration

The mechanical switch is turned off. The common pullup resistor is 100 kΩ. Then, the broken wire detection is executed.  shows a scope shot where channel 2 of the scope is connected to the control signal of the optical switch (BrWi) and channel 1 is connected to the OUT pin of one ISO121x (ChOut).  shows a scope shot where channel 2 of the scope is connected to the input capacitor C_{IN} of one ISO121x channel (V_{cap}) and channel 1 is connected to the OUT pin of one ISO121x (ChOut).

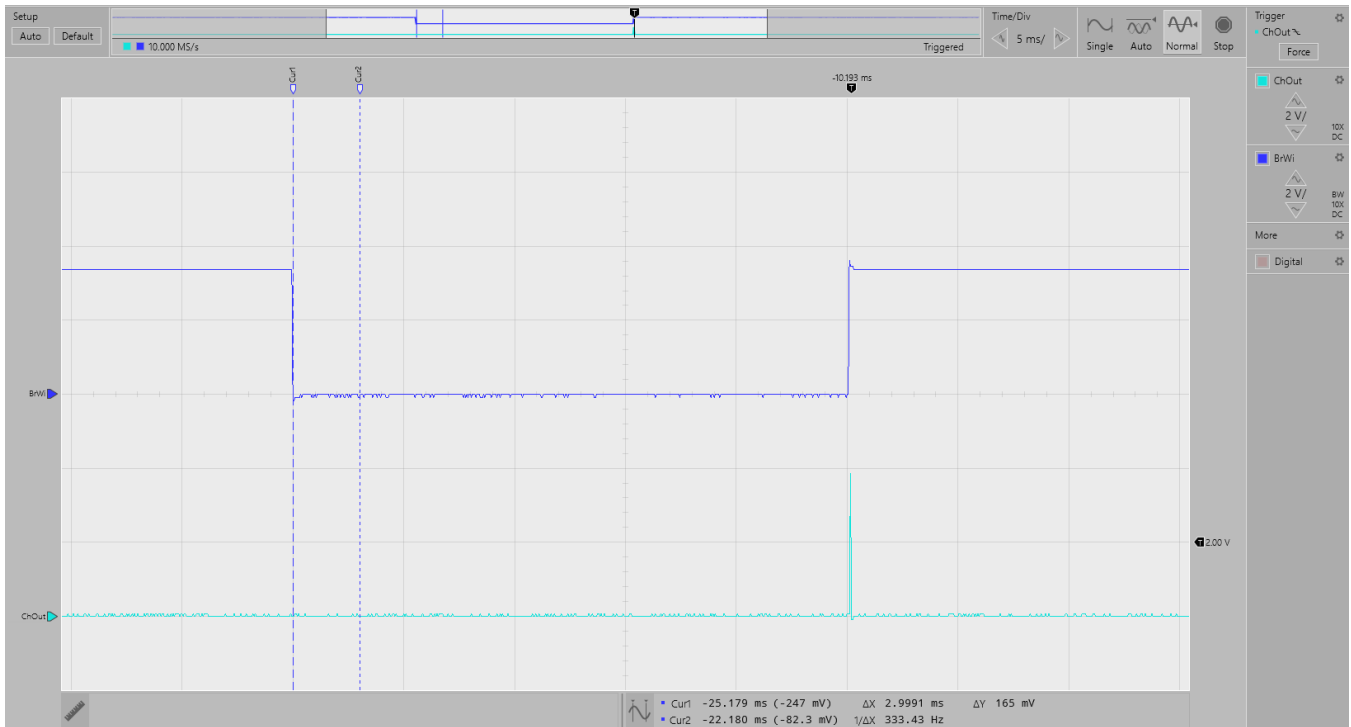


図 14. Group Broken Wire Detection, $R_{pullup} = 800 \text{ k}\Omega/\text{Channel}$ - ChOut (2), BrWi (1)

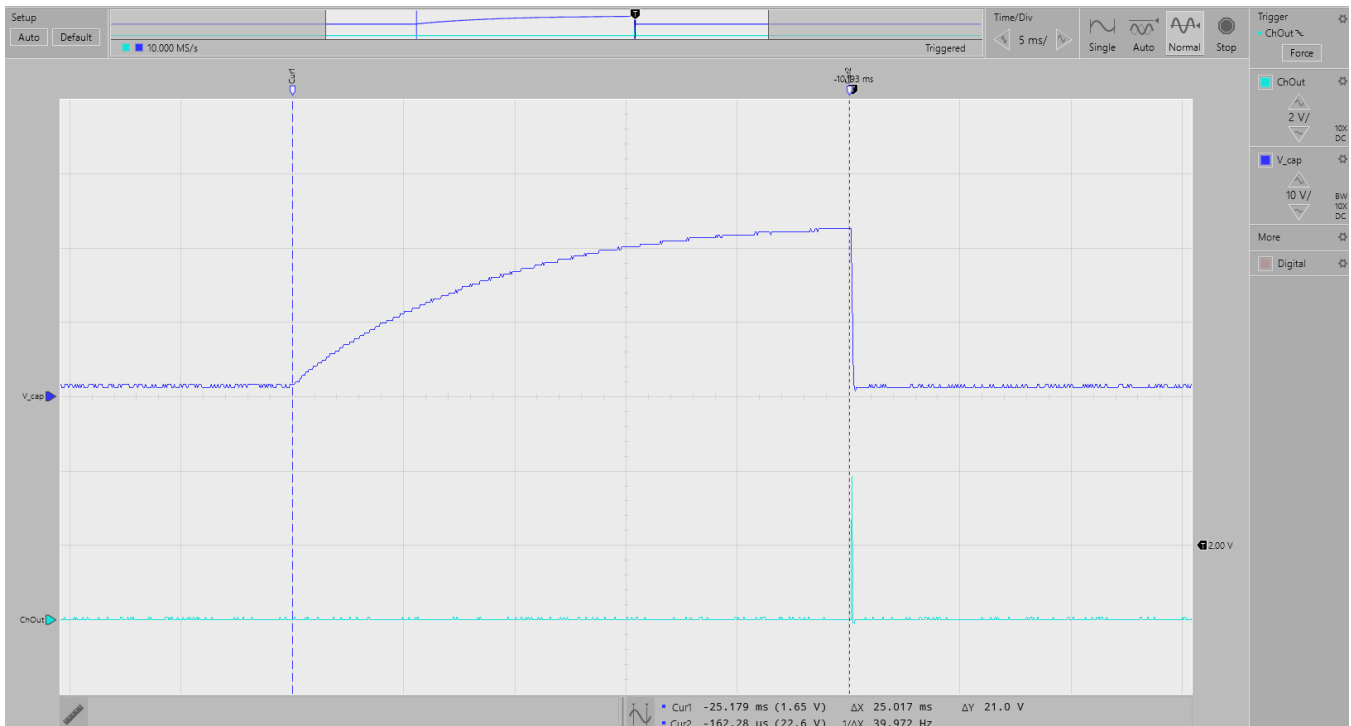


図 15. Group Broken Wire Detection, $R_{pullup} = 800 \text{ k}\Omega/\text{Channel}$ - V_cap (2), BrWi (1)

Figure 14 shows that as soon as the ground connection is enabled again, the ISO121x gives out a pulse. The device takes 24 ms until C_{IN} is charged. Figure 15 shows that C_{IN} is charged to a maximum value of 22.6 V. The 24 V is not reached because of the voltage drop across the pullup resistor, which equals to a current of $1.4 \text{ V} / 100 \text{ k}\Omega = 14 \mu\text{A}$.

Note that this current is not used by the ISO121x, but is leakage current caused by the different protection devices and leakage through the input capacitor. Also, the voltage drop across the pullup resistor is lower if the pullup resistor itself is lower. This result is also shown in the single-channel setup.

Figure 16 shows a zoom into Figure 15.

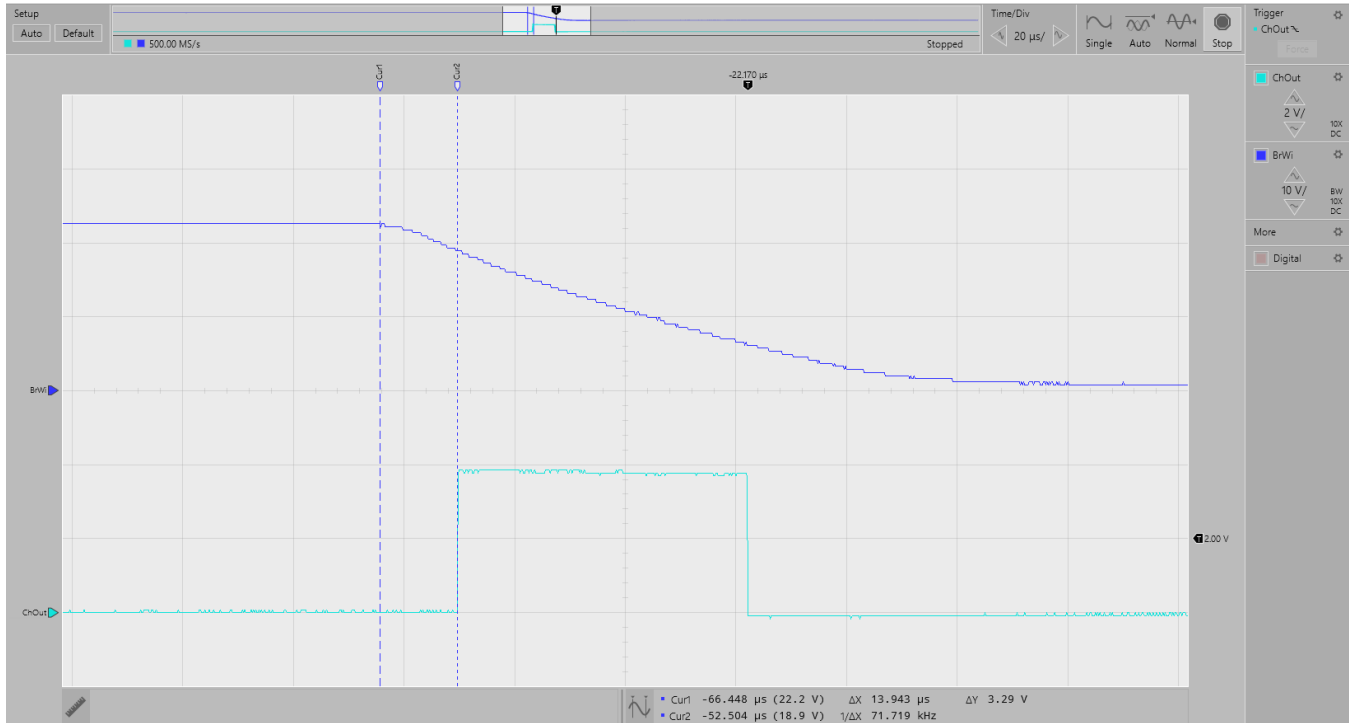


Figure 16. Zoom Into Figure 15 - V_cap (1), ChOut (2)

After the ISO1211 is enabled again, C_{IN} is discharged and the ISO1211 starts operating. It takes around 14 μs until first, there is a solid GND connection for the ISO1211 established, and second, enough current (2.2 mA, typical, taken from ISO121x data sheet) is flowing through R_{SENSE} while at the same time the voltage at the SENSE pin is still above the logic high level, so above $13.65 \text{ V} - 1.2 \text{ V}$ (hysteresis) = 12.45 V. Now, the output of the ISO1211 switches high. As soon as the energy stored in C_{IN} is not anymore high enough to supply 2.2 mA and keep the voltage at the SENSE pin in the high level range, the output of the ISO1211 switches low.

For this configuration, the resulting pulse lasts around 50.5 μs .

3.2.2.2 Single-Channel Configuration

For a 100-k Ω pullup resistor, a single-channel configuration where only one channel is connected is built up. The mechanical switch is turned off. The pullup resistor is 100 k Ω . Then, the broken wire detection is executed. Figure 17 shows a scope shot where channel 2 of the scope is connected to the input capacitor C_{IN} of one ISO1211 channel (V_cap) and channel 1 is connected to the OUT pin of the same ISO1211 (ChOut). Figure 18 shows a zoom into Figure 17.

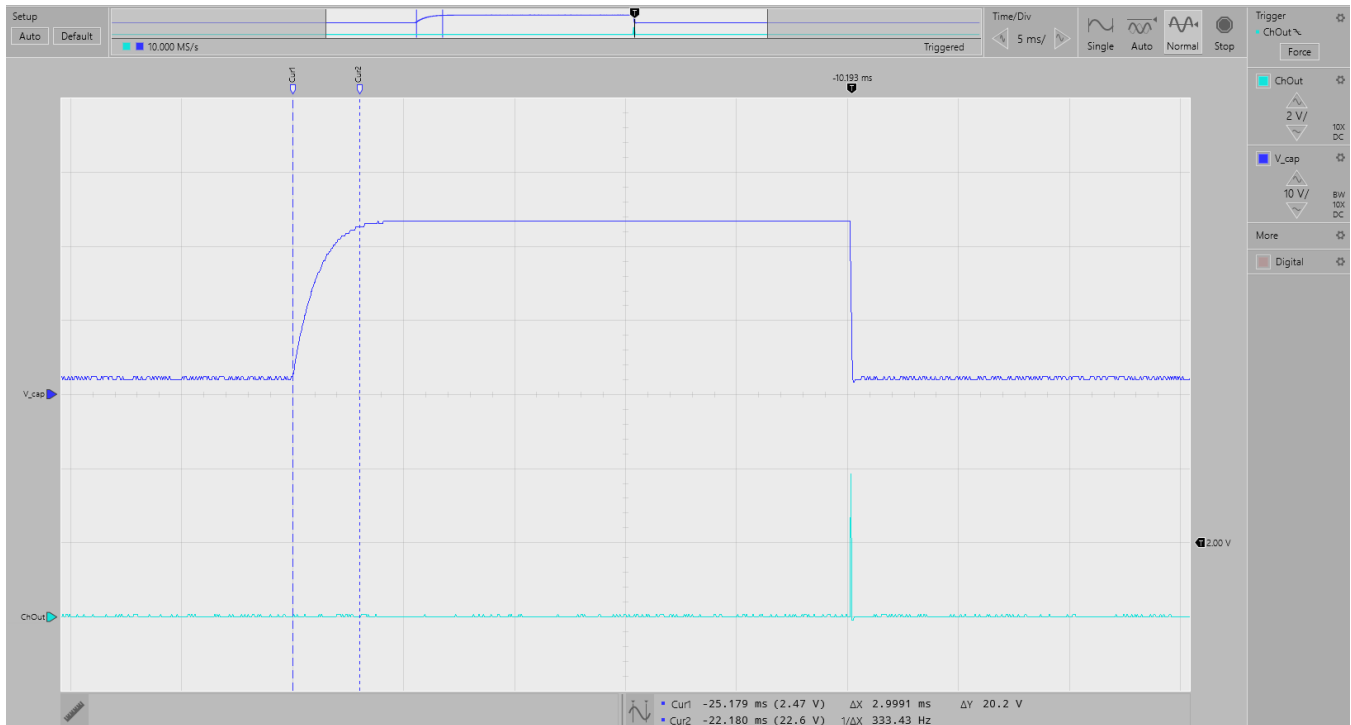


図 17. Single Broken Wire Detection, $R_{pullup} = 100 \text{ k}\Omega$ - V_cap (2), ChOut (1)

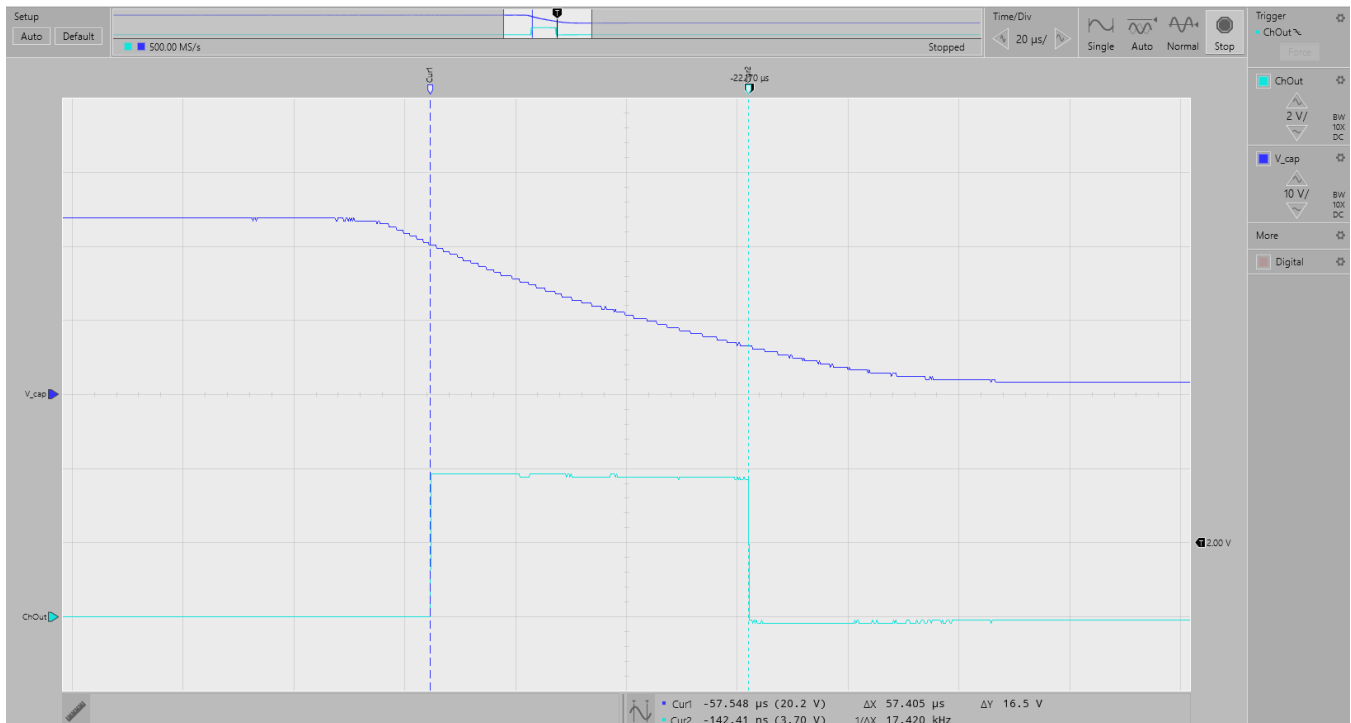


図 18. Zoom into 図 17 - V_cap (2), ChOut (1)

Now the charging of C_{IN} takes only around 3 ms. This amount of time is expected because now the pullup resistor is much smaller compared to before ($100 \text{ k}\Omega \Leftrightarrow 800 \text{ k}\Omega$). Furthermore, the maximum voltage at the input capacitor is now 23.6 V and the resulting pulse length is 57 μs .

Because fewer components are used, there is less leakage in the system and less current is flowing. Therefore, the voltage drop across the pullup resistor is smaller. In addition, more energy is stored on the capacitor ($E_C = 1/2 \times C \times U^2$), which makes the output pulse longer. Also, while the capacitor is discharged there is additional current flowing through the pullup resistor, which is recharging the capacitor at the same time. This current is again higher for a pullup resistor of only 100 k Ω compared to 800 k Ω .

Figure 19 shows a scope shot for the same single-channel configuration. However, now the supply voltage is only 14.9 V. There is still energy stored in the capacitor so that a pulse is generated at the output of the ISO1211. However, due to the lower input voltage, the output pulse is reduced to 15 μ s now.

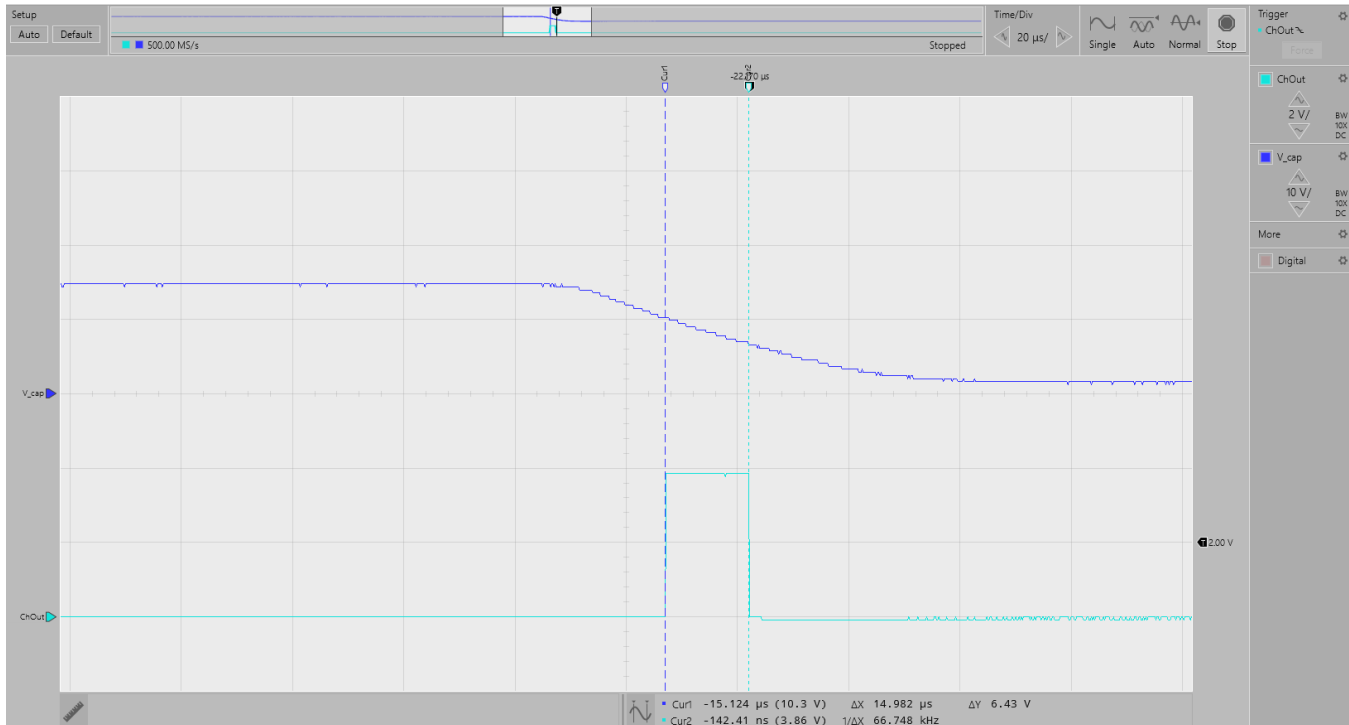


Figure 19. Single Broken Wire Detection, $V = 14.9$ V, $R_{\text{pullup}} = 100$ k Ω - V_{cap} (2), ChOut (1)

3.2.3 Conclusion

The broken wire detection works as expected. However, several observations need to be considered when implementing the broken wire detection.

The higher the pullup resistor to 24 V, the lower the maximum voltage at C_{IN} . Also, consider the leakage current through protection elements and the capacitor. For example:

1. 100-k Ω pullup, single-channel configuration $\rightarrow V(C_{\text{IN}})_{\text{max}} = 23.6$ V; 800-k Ω pullup, group-channel configuration $\rightarrow V(C_{\text{IN}})_{\text{max}} = 22.6$ V
2. The higher the pullup resistor is to 24 V, the shorter the resulting output pulse \rightarrow less energy stored in the input capacitor, less (recharging) current flowing through pullup resistor to the ISO121x during discharge
3. The lower the supply voltage of the switch, the shorter the resulting output pulse \rightarrow less energy stored on the input capacitor, low-level threshold is reached quicker
4. The higher the capacitance of the input capacitor, the longer the resulting output pulse \rightarrow more energy stored in the input capacitor

注: In general, it is important to choose an optical switch that turns on and off quickly. If the optical switches turns on too slow, C_{IN} will already be discharged too much before the ISO121x has a solid GND connection. Then, no output pulse is created.

4 Design Files

4.1 Schematics

To download the schematics, see the design files at [TIDA-01509](#).

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-01509](#).

4.3 PCB Layout Recommendations

For layout guidelines regarding the digital input stage, refer to the Layout section of [ISO121x Isolated 24-V to 60-V Digital Input Receivers for Digital Input Modules](#).

4.3.1 Layout Prints

To download the layer plots, see the design files at [TIDA-01509](#).

4.4 Altium Project

To download the Altium project files, see the design files at [TIDA-01509](#).

4.5 Gerber Files

To download the Gerber files, see the design files at [TIDA-01509](#).

4.6 Assembly Drawings

To download the assembly drawings, see the design files at [TIDA-01509](#).

5 Software Files

To download the software files, see the design files at [TIDA-01509](#).

6 Related Documentation

1. Texas Instruments, [ISO121x Isolated 24-V to 60-V Digital Input Receivers for Digital Input Modules Data Sheet](#)

6.1 商標

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7 About the Author

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