How to implement wire-break detection and diagnostics in isolated digital inputs

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Introduction

Modern factories are becoming increasingly sophisticated and complex. As a result, owners are increasing emphasis on preventing accidents that could harm the environment or pose a threat to nearby residents. Programmable logic controllers (PLCs) used for automation in industries such as oil and gas, petrochemicals, or power distribution may need to implement diagnostics in their input/output (I/O) modules to minimize the chances of malfunction or functional failure. Diagnostics include detecting breakage in a wire connecting a sensor to the PLC or stuck-at faults in the I/O module.

This article presents a simple scheme to implement wire-break detection and diagnostics in isolated digital input modules.

Figure 1. Isolated digital inputs implemented with optocouplers

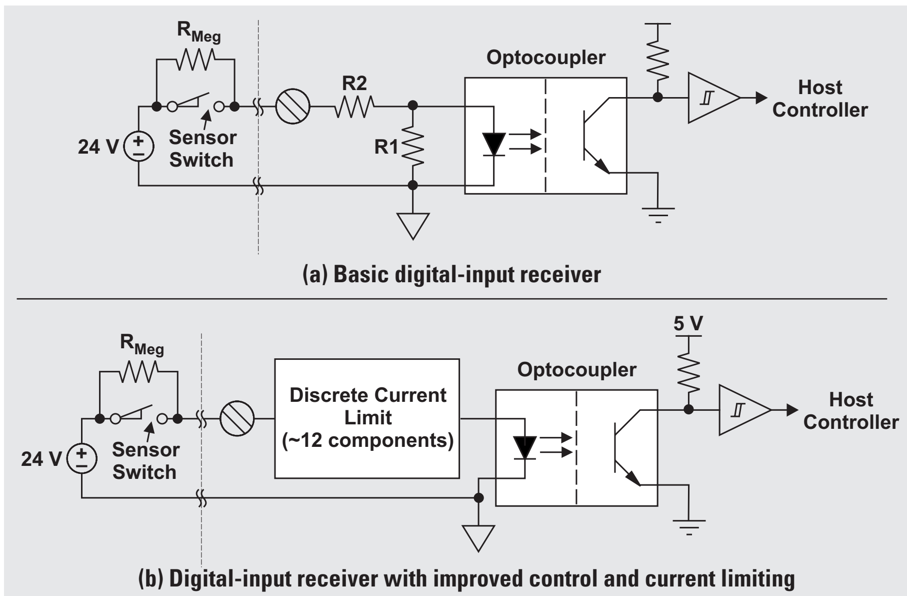
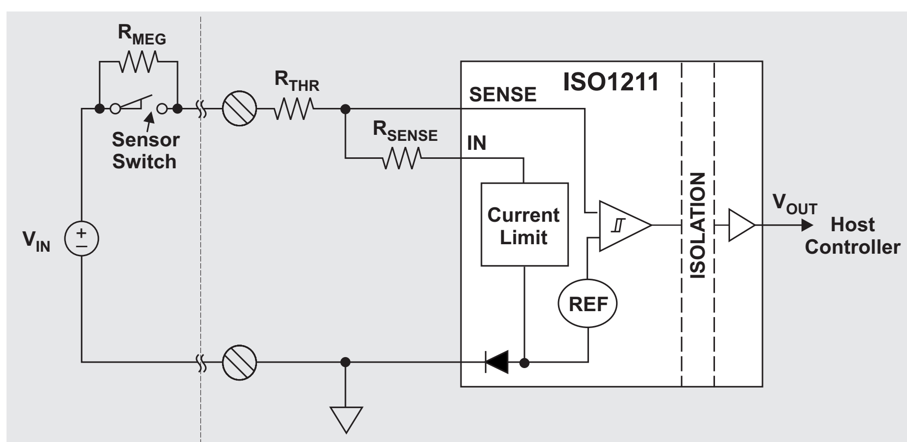


Figure 2. Isolated digital input with the ISO1211



Isolated digital inputs

In PLCs and motor drives, digital-input modules receive 24-V digital inputs from field sensors and switches. Isolation between the digital-input receiver and the host controller accounts for differences in ground potentials. A typical digital-input receiver implements a voltage comparator with hysteresis to interpret the input as logic high or low. Also, some form of current limit avoids excess current draw from the 24-V inputs to limit the power dissipation.

Figure 1 shows the two most common implementations of digital-input receivers in use today. In Figure 1a, the ratio of R1 and R2 sets the voltage thresholds, and resistor R2 implements a crude current limit. Figure 1b shows the addition of several discrete components to implement better current-limit and controlled-voltage thresholds.

The ISO1211 and ISO1212 digital-input receivers from Texas Instruments are high-speed isolated devices with an integrated current limit, a built-in precise voltage comparator, and a reverse-polarity current block. Figure 2 shows the implementation of one channel of a digital-input module with the ISO1211. The R_{SENSE} resistor controls the current limit and R_{THR} controls the voltage transition thresholds. Note that the ISO1211 and ISO1212 devices can both emulate an optocoupler in drawing power from the voltage being sensed, without the need for a separate “field-side” supply.

Challenges with wire-break detection and diagnostics in digital-input modules

In the traditional approaches shown in Figure 1, there is no separate field-side power supply. The optocoupler uses the current from the input being sensed, and the circuit provides a logic-high output when the sensor or switch is in the ON state.

When the sensor or switch is in the OFF state, the input current drops to a very low value (in the range of ten to hundreds of microamperes). For proximity sensors, this OFF state corresponds to the minimum bias current required by the sensor to remain active. For push-button switches, the inclusion of a high-value resistor across the switch creates a small off state current explicitly for the purpose of wire-break detection. A few hundred microamperes are not sufficient to energize the optocoupler, so the output of the digital-input module is logic low.

If the wire connecting the sensor to the digital-input module is broken due to fault conditions, the input current to the optocoupler is zero. In this case, the output of the digital-input module is also a logic low. It is clear that the wire-break fault is indistinguishable from the sensor's off state. Hence, this circuit cannot detect a wire break.

Similarly, if the output of the digital-input module is stuck high or low due to a fault or defect in the internal circuitry of the optocoupler, the fault goes undetected.

Proposed solution for wire-break detection and diagnostics

Figure 3 shows an application circuit for detecting wire breaks and introducing diagnostics in isolated digital-input modules. The solution is shown for a multichannel digital-input module, but also holds true for single-channel applications.

The assumption is that a certain small current, I_{OFF} (ten to hundreds of microamperes), is present at the the IN_X channel inputs when the corresponding sensor is in the off state. This is true for all proximity sensors. For push-button switches, including a high-value resistor (100 kΩ to 1 MΩ) in parallel (for example, R_{Meg} in Figures 1 and 2) can create this off-state current.

The key challenge is to use this low-current I_{OFF} to signal logic high to the host controller so that it knows that the wire is intact. To achieve this, disconnect the ground return path of all ISO1212 devices in the multichannel module using one common phototransistor, OPT1. With no conductive return path through the ISO1212 devices, the I_{OFF} in every off channel charges the corresponding capacitor C_{HOLD} to the system voltage (24 V). The ground is disconnected for a duration, t_{TEST}, whose chosen value gives enough time for capacitors C_{HOLD} to charge fairly close to the system voltage.

At the end of t_{TEST}, the ground connection is re-established, enabling the current path through the ISO1212. The ISO1212 uses the charge stored in C_{HOLD} to create a pulse at its output. Thus, even with only a very small current available from the sensor in its OFF state, a signal pulse provided to the microcontroller can still indicate that the wire is intact.

Figure 3. Application circuit for wire-break detection and diagnostics with the ISO1212

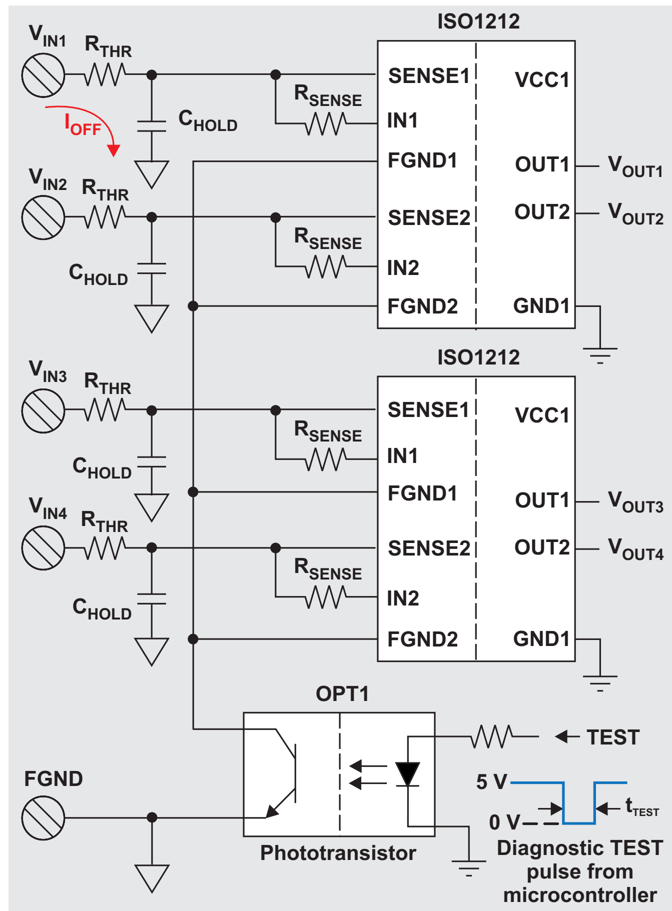


Figure 4 shows the input and output of ISO1212 devices, and the charge on C_{HOLD}, in relation to the test signal from the microcontroller. The following descriptions cover each sensor condition shown in Figure 4.

Case No. 1: The sensor is in the ON state (Input High)

In this case, the input voltage (V_{INx}) is close to 24 V and the corresponding output (V_{OUTx}) is at logic high. When the test signal goes to zero, the ground connection to ISO1212 disconnects and the outputs read a low value. Once the test signal returns to 5 V, the ground connection is re-established and OUTx goes to a logic high again. This high-low-high transition confirms that the wire is intact and that there are no stuck-at faults in the receiver. The capacitor, C_{HOLD}, remains at 24 V throughout, since the sensor switch is on with low impedance.

Case No. 2: The sensor is in the off state (Input Low).

In this case, a low current (I_{OFF} is between 10 and 100 µA) is flowing into the INx terminal. This current is not enough to energize the ISO1212, and V_{OUTx} is normally zero. When the test signal becomes zero, the ground connection of all ISO1212 devices is broken and no current flows through them. The current into the INx terminal now starts to charge the corresponding C_{HOLD} capacitor toward the 24-V system voltage. When the test signal returns to 5 V, the ground connection is re-established, enabling the ISO1212 devices to draw current from C_{HOLD} and generate a high output voltage, V_{OUTx}. The integrated current limit in the ISO1212 discharges C_{HOLD} at a constant rate. Eventually, C_{HOLD} discharges to below the input voltage threshold of the ISO1212 and V_{OUTx} returns to 0 V. This low-high-low transition of V_{OUTx} indicates that the connection between the sensor and the digital input module is intact; in other words, there is no wire break.

Equation 1 gives the time taken for C_{HOLD} to charge to the 24-V input.

$$t_{CHARGE} = \frac{C_{HOLD}\quad 24}{I_{OFF}} \tag{1}$$

where I_{OFF} is the OFF-state current of the sensor. The duration of t_{TEST} must be greater than t_{CHARGE} to allow C_{HOLD} to charge to the maximum voltage.

Equation 2 gives the time taken for C_{HOLD} to discharge.

$$t_{DISCHARGE} = \frac{C_{HOLD}\quad 24}{I_{ILIM}} \tag{2}$$

where I_{LIM} is the current limit of the ISO1212. The width t_{OUT} of the output pulse on OUTx during the off state is greater than $t_{DISCHARGE}$.

Case No. 3: The wire between the sensor and digital-input module is broken.

In this case, there is absolutely no current going into the digital input module. V_{OUTx} remains low throughout; thus, the microcontroller can identify this case uniquely as a wire break.

Table 1 lists some example numbers that show the relationships between I_{OFF}, C_{HOLD}, t_{TEST} and t_{OUT}. The values of C_{HOLD} and t_{TEST} depend on system requirements and can be chosen as needed.

Figure 4. Timing diagram for wire-break detection and diagnostics

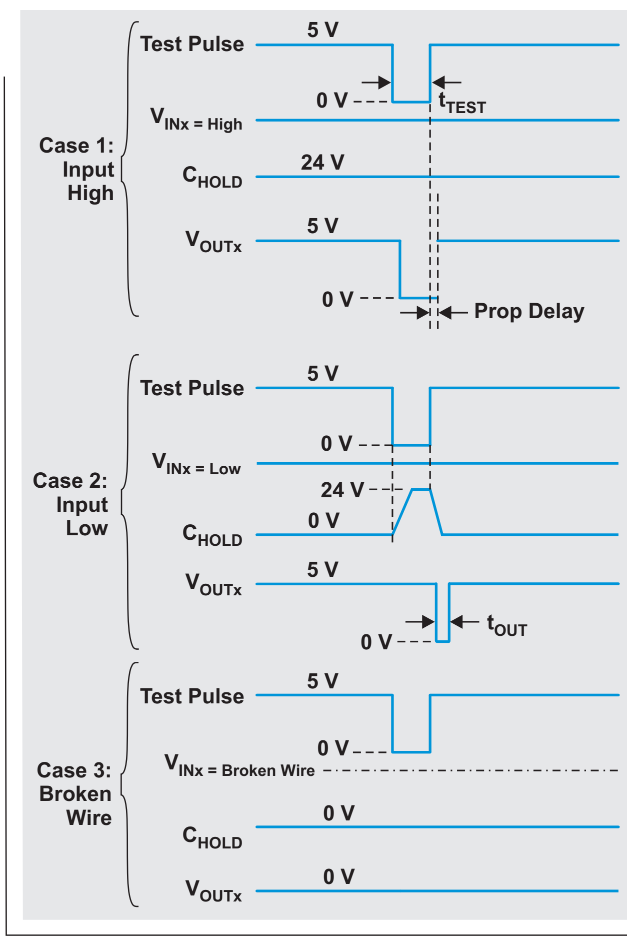


Table 1. Example calculations for C_{HOLD}, t_{TEST} and t_{OUT} depending on sensor OFF-state current

I_{OFF}	C_{HOLD}	t_{TEST}	t_{OUT}
10 µA	10 nF	24 ms	63 µs
10 µA	100 pF	240 µs	630 ns
100 µA	10 nF	2.4 ms	63 µs
100 µA	100 pF	24 µs	630 ns
500 µA	10 nF	0.48 ms	63 µs
500 µA	100 pF	4.8 µs	630 ns

For simplicity of analysis, and to understand the essence of the proposed solution, the current from the sensor is modeled as a current source in the earlier discussion. In reality, I_{OFF} is more likely to behave like a resistor in certain voltage ranges. It may be necessary to make some adjustments to the parameters for a practical implementation. Reference 1 provides further design considerations, test results and component choices.

Unique features of the ISO1211 and ISO1212 to enable wire-break detection

The integrated current limit, high bandwidth and reverse-polarity blocking features of ISO1211 and ISO1212 devices make them a good fit for the application circuit described in this article. The current-limit feature prevents a rapid discharge of the C_{HOLD} capacitor upon reconnection of the ground and the high bandwidth allows the generation of an output pulse in this duration.

The reverse-polarity blocking prevents an ON-state on one channel from charging the C_{HOLD} capacitor on a different channel that may have a broken wire. Without reverse-polarity blocking, each digital-input channel will need a separate phototransistor to provide the test pulse because sharing one phototransistor across multiple channels is not possible.

Conclusion

Increasing complexity in industrial automation systems has led to the need for diagnostics in PLC I/O modules. This article presented a simple scheme to implement wire-break and stuck-at fault detection in PLC digital input modules. The integrated current limit, high bandwidth and reverse-polarity blocking features of TI's ISO1211 and ISO1212 devices help support the implementation of wire-break detection and diagnostics for isolated digital inputs.

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