Interfacing high-voltage applications to low-power controllers

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A common requirement of industrial applications is to interface high-voltage potentials, such as signal outputs of sensor switches and AC rectifiers, to the peripheral input ports of low-voltage microcontrollers (MCUs) and digital signal processors. A new generation of interface circuits providing this function are digital-input serializer (DIS) devices. They can sense digital input voltages ranging from as low as 6 VDC up to 300 VDC and convert them into 5-V serial data streams while consuming almost 80% less power than a discrete design. This capability makes DIS devices the most power- and cost-efficient solution in industrial interface applications.

This article explains the functional principle of a DIS and its configuration in a typical industrial interface design.

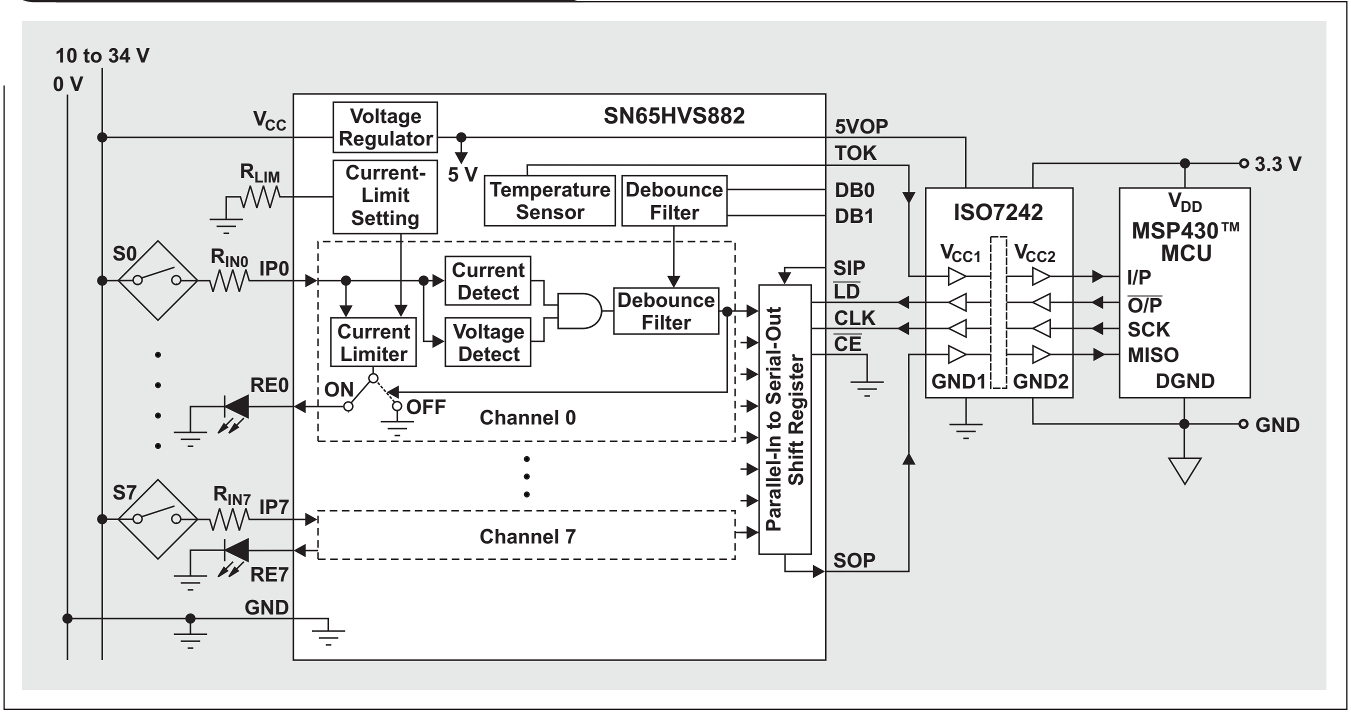
Functional principle

Understanding the operational principle of a DIS is faster accomplished by seeing the device in the context of an entire interface design as shown in Figure 1. A high-voltage supply in the range of 10 to 34 V supplies the sensor switches, S0 to S7, and the DIS. The ON/OFF status of each sensor switch is detected by the eight parallel field inputs of the device, then internally processed and made available to the low-voltage inputs of a parallel-in, serial-out shift register. An MCU provides the necessary control signal to the serial interface of the DIS via a digital isolator. Firstly, a load pulse at the $\overline{\text{LD}}$ input latches the switch's status information into the shift. Then a clock signal applied to the CLK input serially shifts the register content out of the DIS into a controller register via the isolator.

S0 to S7 comprise a wide range of sensor switches, such as proximity switches, relay contacts, limit switches, push buttons, and many more. While the input resistors, R_{IN0} to R_{IN7}, are optional, they can serve two purposes when implemented. One is that in high-voltage applications, some industrial standards might require input resistors as a safety precaution to prevent fire hazards in the event of an input short circuit. The other purpose is to raise the ON/OFF threshold voltage of a sensor switch.

Internally, each input signal is checked for signal strength and stability. A current comparator detects whether the input current is higher than a predefined leakage threshold, and a voltage comparator checks whether the input voltage is higher than an internally

Figure 1. Stand-alone digital-input system



fixed reference voltage. If both comparator outputs are logic high, a programmable debounce filter checks whether the new input status is caused by a short but strong noise transient, or whether the signal presence outlasts the debounce time and thus presents a true input signal.

For a true input signal, the filter output presents the corresponding logic level to the parallel inputs of the shift register and also switches the output of the internal current limiter accordingly. For an OFF condition (when the switch is open), the filter output is low, and the output of the current limiter is switched to ground. For an ON condition, the filter output is high, and the output of the current limiter is connected to a signal-return output (RE). Connecting a light-emitting diode (LED) to an RE output allows for the visible indication of a switch's status.

Input configuration

To configure a DIS for various applications, the current and voltage capability of its input, IPx, must be known, as well as its switching thresholds. For that purpose, Figure 2 shows a more detailed block diagram of a channel's input stage. During a sensor switch's OFF-to-ON transition, the two parameters of interest are the positive-going voltage threshold at a device input, $V_{IP\text{-}ON}$, and its selected current limit, $I_{IN\text{-}LIM}$.

While $V_{IP\text{-}ON}$ is internally fixed at 5.2 V, $I_{IN\text{-}LIM}$ can be adjusted via an external precision resistor, R_{LIM}. Note that setting the current limit affects all device inputs equally. $I_{IN\text{-}LIM}$ is derived from a reference current, I_{REF}, via a current mirror, making $I_{IN\text{-}LIM} = 72 \times I_{REF}$. I_{REF} is determined by the ratio of an internal bandgap reference to the resistor value, R_{LIM} ($I_{REF} = V_{REF}/R_{LIM}$). The current limit can therefore be expressed as a function of R_{LIM}:

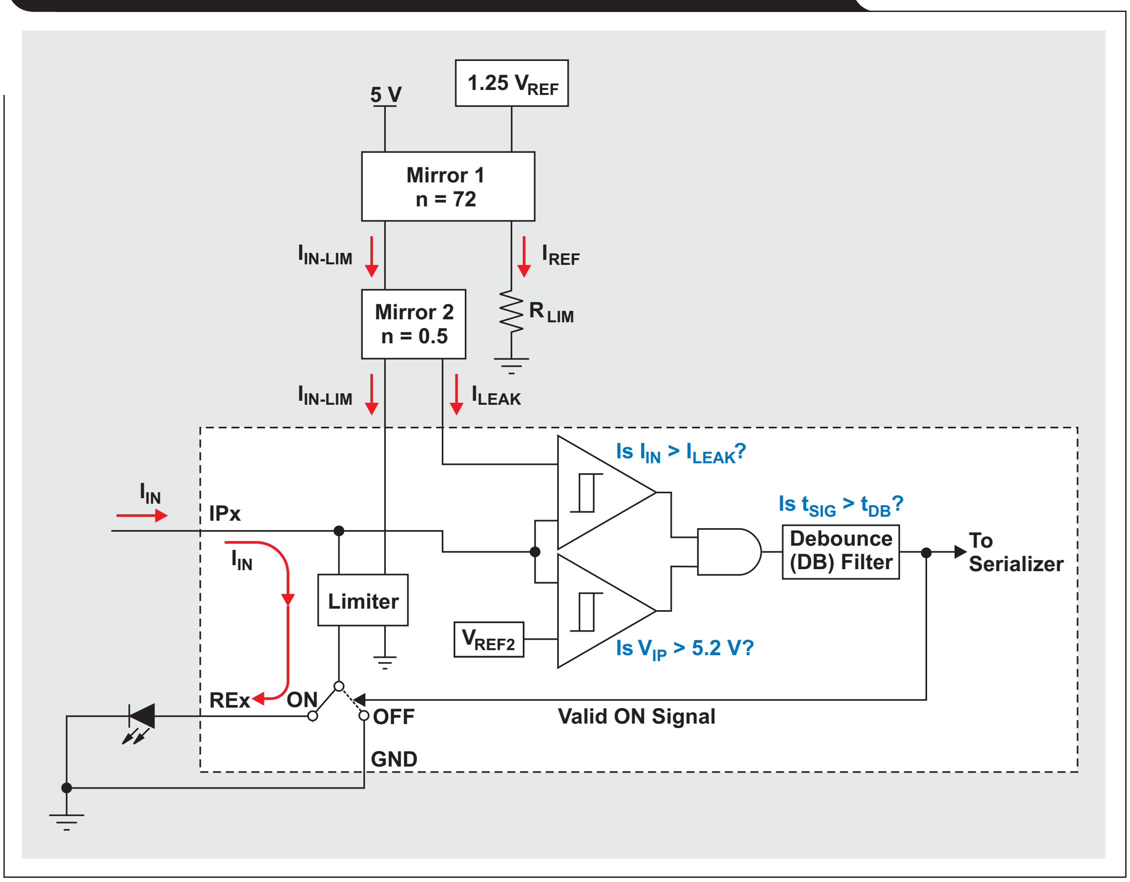
$$I_{IN\text{-}LIM} = 72 \times \frac{1.25\ \text{V}}{R_{LIM}} = \frac{90\ \text{V}}{R_{LIM}} \qquad (1)$$

Solving for R_{LIM} then provides the required resistor value for a desired current limit:

$$R_{LIM} = \frac{90\ \text{V}}{I_{IN\text{-}LIM}} \qquad (2)$$

For low-voltage applications using a 12-V supply, setting the current limit via R_{LIM} might be the only calculation required. Because the device inputs can tolerate voltages of up to 34 V, switching the 12-V supply directly to a digital

Figure 2. Simplified block diagram of a single-channel input stage



input causes no damage to the device. With $V_{IP\text{-}ON}$ = 5.2 V, the ON threshold lies almost in the middle of the 12-V input-voltage range. Figure 3 shows the schematic of this simple circuit design. With the low-current LED indicator requiring a forward current of $I_{IN\text{-}LIM}$ = 2 mA, R_{LIM} is determined via Equation 2 to be 45 kΩ, with the closest 1% value being 44.8 kΩ.

However, for high-voltage designs using a supply of 24 V or more, an input resistor is needed to raise the ON threshold into the middle of the input-voltage range. Figure 4 presents this case, with the input-current limit assumed to be 2 mA. The input resistor now separates the device's input voltage, V_{IP}, from the field input voltage, V_{IN}, thus raising the actual ON threshold to $V_{IN\text{-}ON} = V_{IP\text{-}ON} + R_{IN} \times I_{IN\text{-}LIM}$. Inserting the specified 5.2-V threshold for $V_{IP\text{-}ON}$ and expressing $I_{IN\text{-}LIM}$ through Equation 1 yields $V_{IN\text{-}ON}$ = 5.2 V + R_{IN} × 90 V/R_{LIM}. Solving for R_{IN} then provides the required input-resistor value for a desired ON threshold:

$$R_{IN} = (V_{IN\text{-}ON} - 5.2\ \text{V}) \times \frac{R_{LIM}}{90\ \text{V}} \qquad (3)$$

In order to set the ON threshold in the circuit in Figure 4 to $V_{IN\text{-}ON}$ = 12 V, the input resistor is determined via Equation 3:

$$R_{IN} = (12\ \text{V} - 5.2\ \text{V}) \times \frac{44.8\ \text{k}\Omega}{90\ \text{V}} = 3.385\ \text{k}\Omega,$$

with the closest 1% value being 3.4 kΩ.

This simple design methodology can be applied to input voltages of up to 60 V. Higher voltages, however, will increase V_{IP} above its specified maximum of 34 V, so a

Figure 3. Switch ON condition: $V_{IP\text{-}ON}$ = 5.2 V, $I_{IN\text{-}LIM}$ = 90 V/R_{LIM}

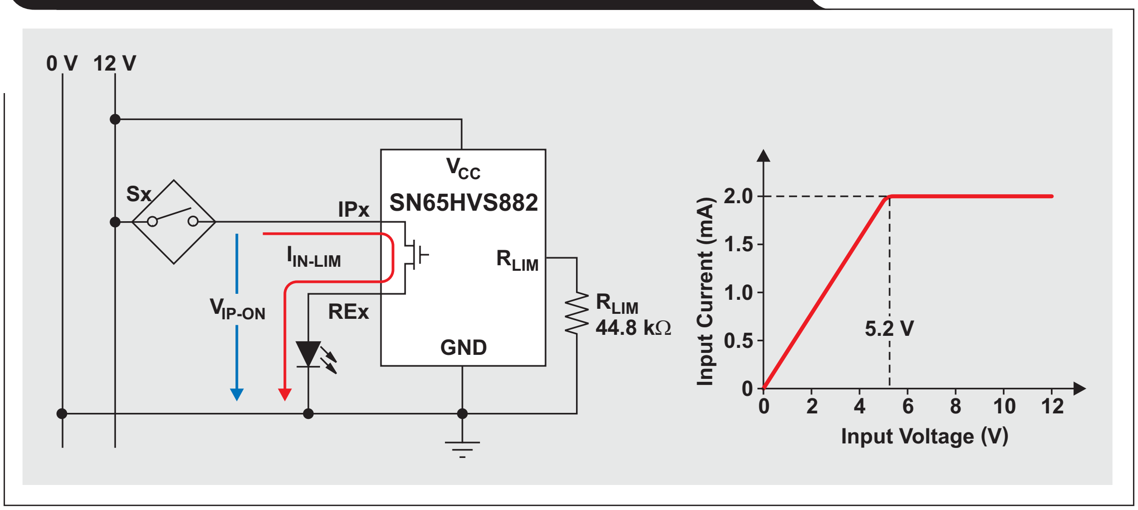
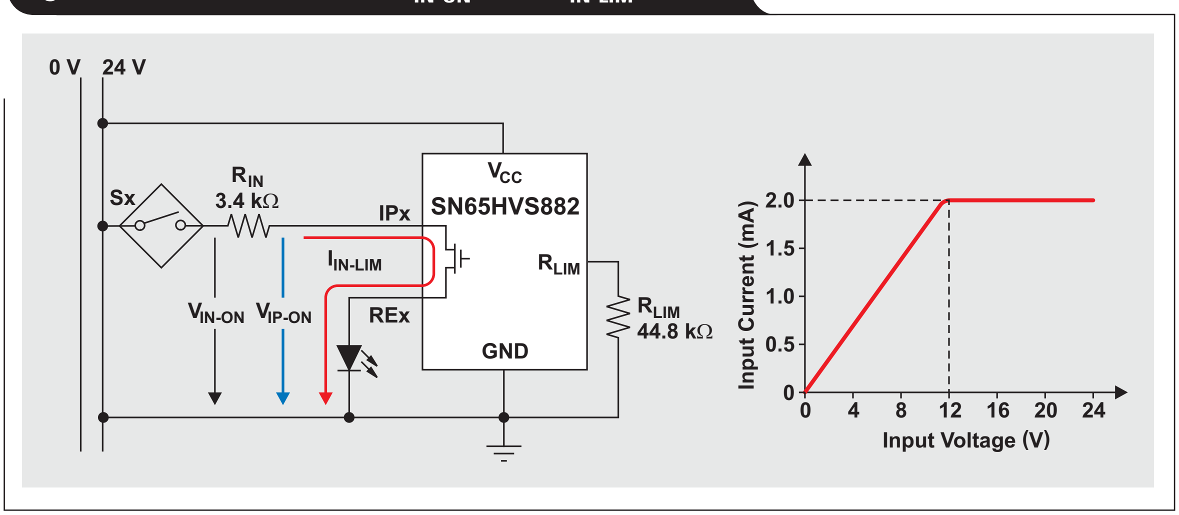


Figure 4. Switch ON condition: $V_{IN\text{-}ON}$ = 12 V, $I_{IN\text{-}LIM}$ = 2 mA



clamping element in the form of a Zener diode is required to prevent the device input from overvoltage stress. Figure 5 gives an example of a mains voltage detector, often used in building automation systems. Here the AC mains voltage of 240 V_{rms} is rectified, thus yielding a peak input of 340 VDC. At such high voltages it is necessary to minimize the I^2R losses within the input resistor. Therefore, the current limit is simply set to 0.5 mA by making R_{LIM} = 90 V/0.5 mA = 180 kΩ.

The ON threshold is set to 150 V by making R_{IN} = (150 V – 5.2 V) × 180 kΩ/90 V = 289.6 kΩ, with 291 kΩ as the closest 1% value. At $V_{IN\text{-}ON}$ = 150 V, $V_{IP\text{-}ON}$ = 5.2 V, and current limiting sets in. Beyond the ON threshold, V_{IP} increases linearly until the Zener voltage of approximately 30 V is reached. At that moment, the Zener diode starts clamping; and the Zener current, I_Z, adds to the current limit ($I_{IN\text{-}LIM}$) to make up the total input current, I_{IN}.

Serial interface

Reading the status information of the digital field inputs is easy and can be performed by using either shift register timing or serial peripheral interface timing.

When shift register timing is used, a short low-active pulse applied to the load input ($\overline{LD}$) latches the status information of the digital inputs into the shift register. A subsequent clock signal at CLK, consisting of eight consecutive clock cycles, serially shifts the data out of the DIS register into the input register of an MCU. Each data shift occurs at the rising edge of the clock signal (Figure 6).

Figure 5. Switch ON condition: $V_{IN\text{-}ON}$ = 150 V, $I_{IN\text{-}LIM}$ = 0.5 mA

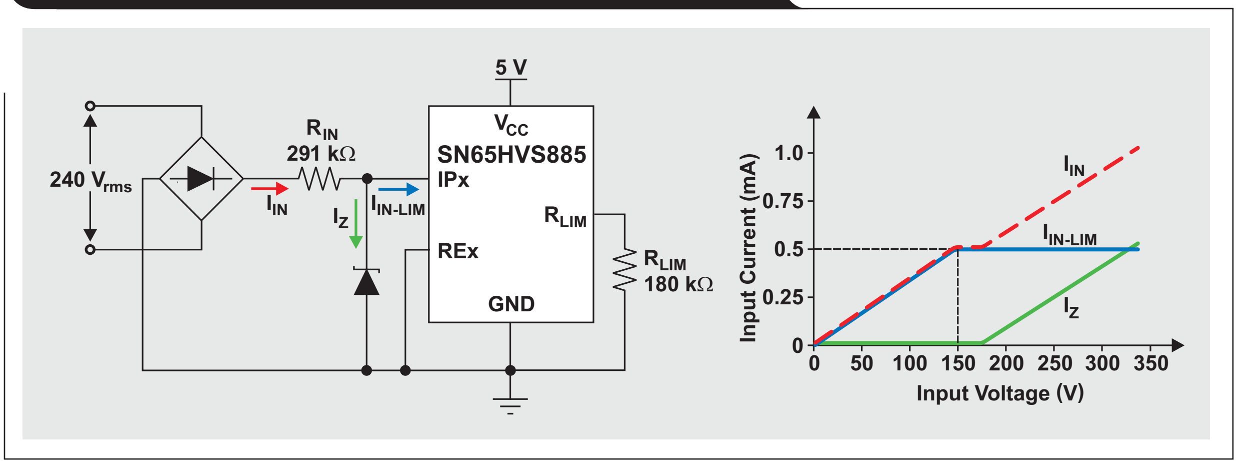
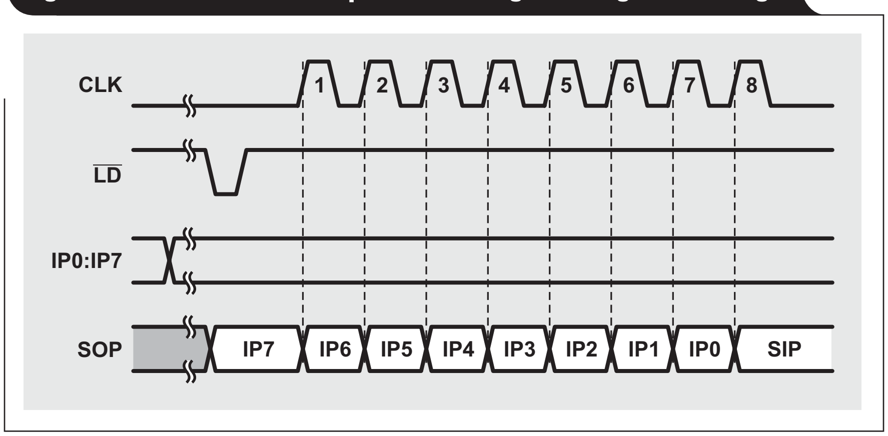


Figure 6. Serial-interface operation using shift register timing



Designing input modules with a high channel count is possible by daisy-chaining multiple DIS devices. In this case the serial output of a leading device is connected with the serial input of a following device. Figure 7 shows the simplicity of a daisy-chained, 64-channel digital-input module requiring only three interface lines.

Powering the interface

DIS devices allow for a variety of power-supply configurations. When powered from an industrial 24-V bus, the DIS can supply 5-V regulated output to digital isolators and MCUs. For 5-V controllers (Figure 8a), the direct connection of supply and serial interface (SIF) lines is straightforward. However, 3.3-V controllers require a low-dropout regulator (LDO) for the supply line and a voltage divider in the serial output (SOP) line (Figure 8b). Control signals from a 3.3-V controller towards the DIS are correctly interpreted.

In applications without a bus supply, it is possible to back-supply a DIS by driving the 5-V output as a supply

Figure 7. Daisy-chained, 64-channel digital-input module

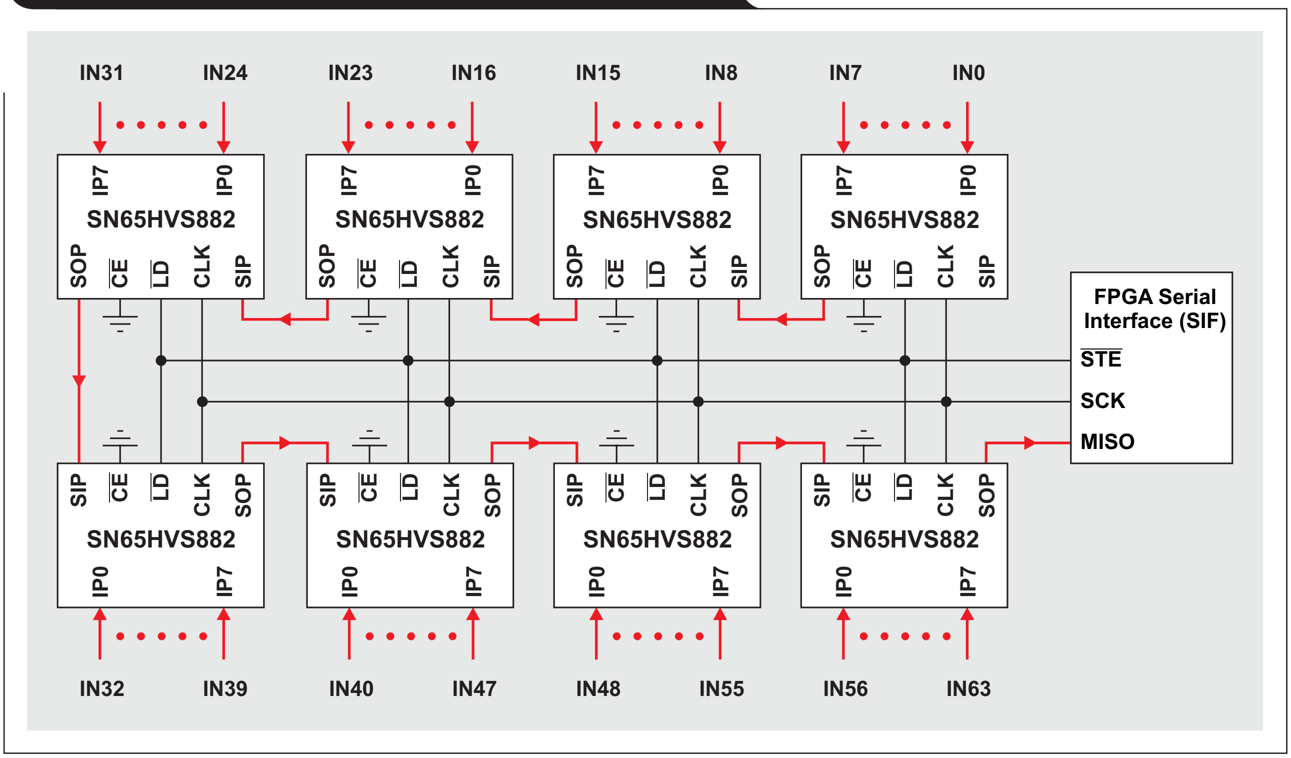


Figure 8. Bus-powered digital-input system

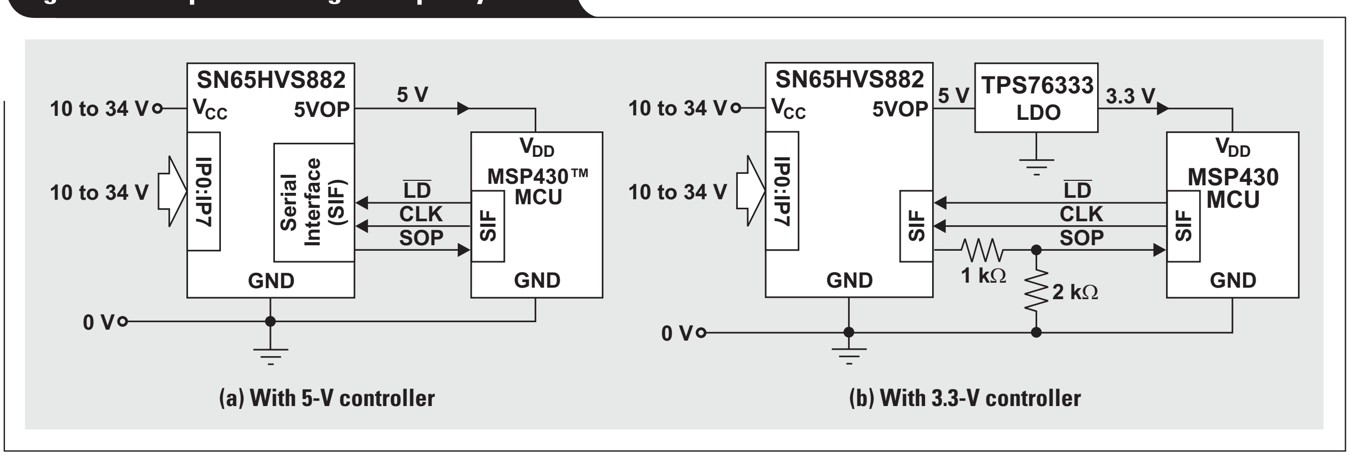
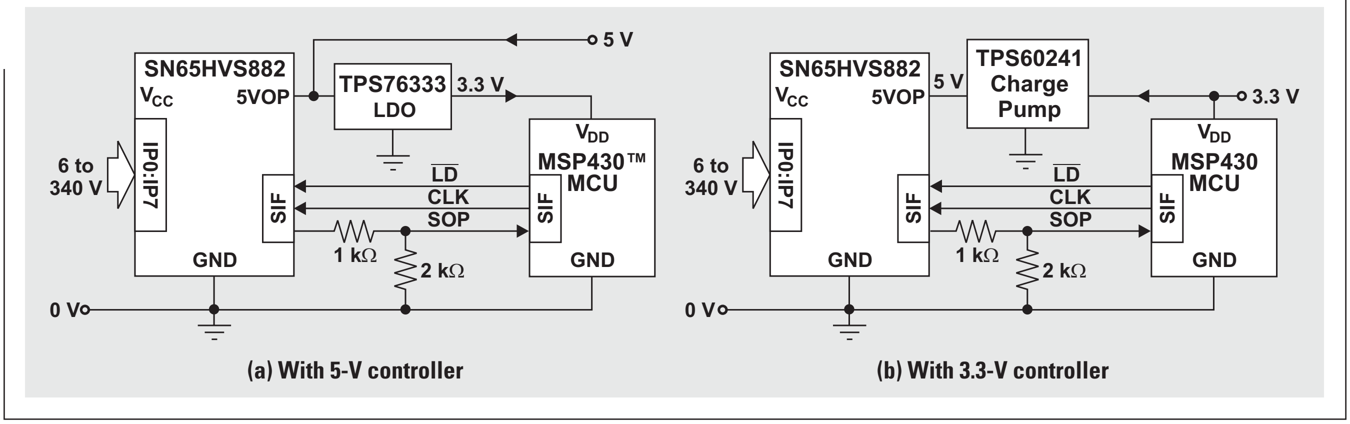


Figure 9. Back-supplied digital-input system



input while leaving the normal V_{CC} supply pin floating. Figure 9 shows two back-supply options for interfacing to a 3.3-V controller. In Figure 9a, the 5-V system supply powers the DIS directly but requires an LDO to supply the controller. In Figure 9b, a 3.3-V supply powers the controller directly but requires a charge pump to boost the supply voltage to the required 5-V level of the DIS.

Conclusion

DIS devices represent the most versatile solution for interfacing a low-power controller to high DC voltages. Supporting the interface design between low-voltage controllers and high-voltage applications, the SN65HVS88x family of DIS devices provides a wide variety of features, such as undervoltage detection, current limiting, debounce filtering, thermal protection, parity generation, and a single 5-V supply.

References

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