INDUSTRIAL
INTERFACE

SN65HVS88x

Interfacing High-Voltage Applications with Low-Voltage Controllers

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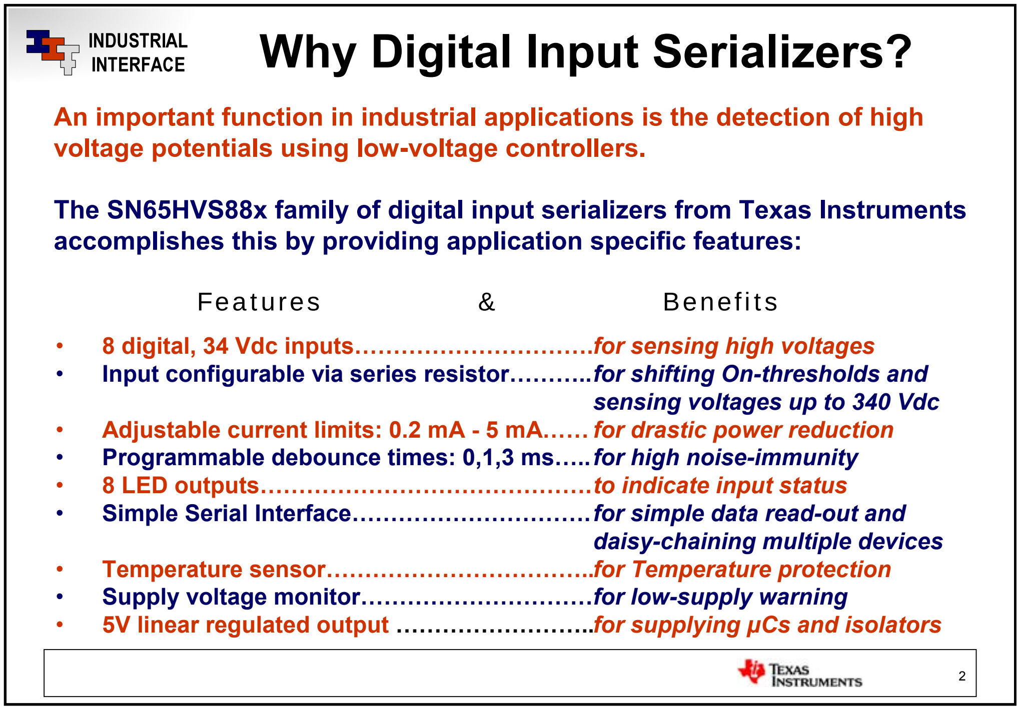

Many commercial and industrial applications face the challenge of interfacing low-voltage micro controllers and digital signal processors (DSP) to high-voltage sensor switches and other digital, high-voltage circuitry. In most cases the need for these interfaces is to gain feedback in form of binary (one / zero, or high / low) status information.

Initially designed for programmable logic controller (PLC) applications with nominal bus voltages of 24 Vdc, **Digital Input Serializers** (**DIS**) have found use in a multitude of different industrial and commercial applications since. Because of their capability to sense digital input voltages from as low as 6 Vdc up to some 300 Vdc in the most power-efficient way, DIS devices are considered as the most cost effective solution to interface low-power controllers to high-voltage signals.

Despite the high number of successful designs using DISs, such as digital input modules, system controllers of CNC machines, high-voltage monitor systems in electric trains, low-voltage token ring networks for safety applications, and mains-voltage supervision in commercial buildings, still many engineers new to the field of industrial design, pose the question on how to implement these devices into a wide variety of applications other than just PLC systems. To answer this question this training session explains the functional principle of a digital input serializer and provides examples on how to configure a DIS for low-, medium, and high-voltage input signals. The training also shows how to easily interface the 5 V serial interface of the DIS to micro controllers operating from a 3 V supply only.

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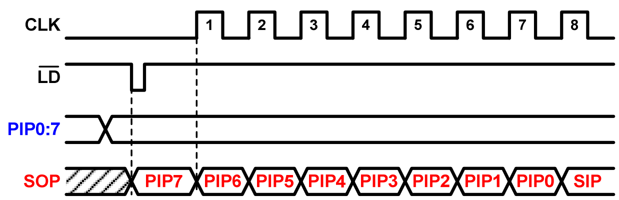
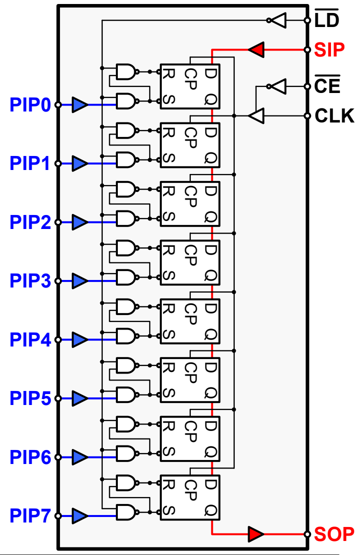
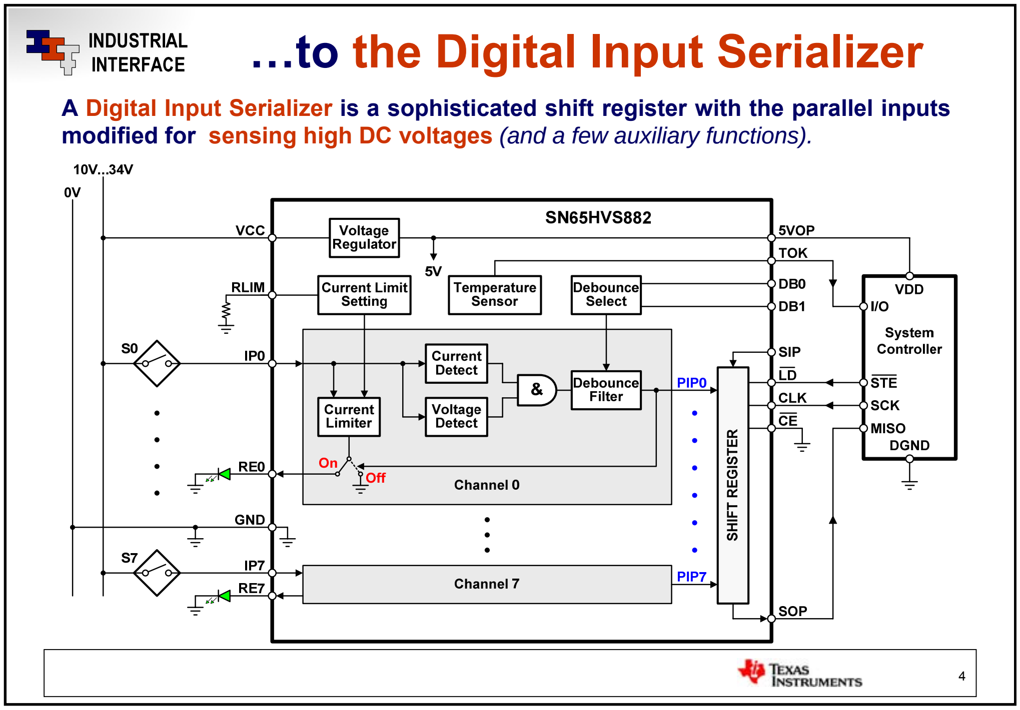
From a Standard Shift-Register…

Standard shift registers sense the status of digital low-volt sensors and switches.





1) Information changes at PIP0:7 is ignored.
2) Only a load pulse at /LD latches the information into the register.
3) Then a clock signal at CLK shifts the data out serially via the serial output SOP.



Illustrating the general function of the device, the slide above shows a simple, stand-alone digital input system of a micro controller sensing input voltages from 10V up to 34V. As shown in the drawing, these high voltages can be applied directly to the supply terminal and the eight input terminals without the need for protection resistors.

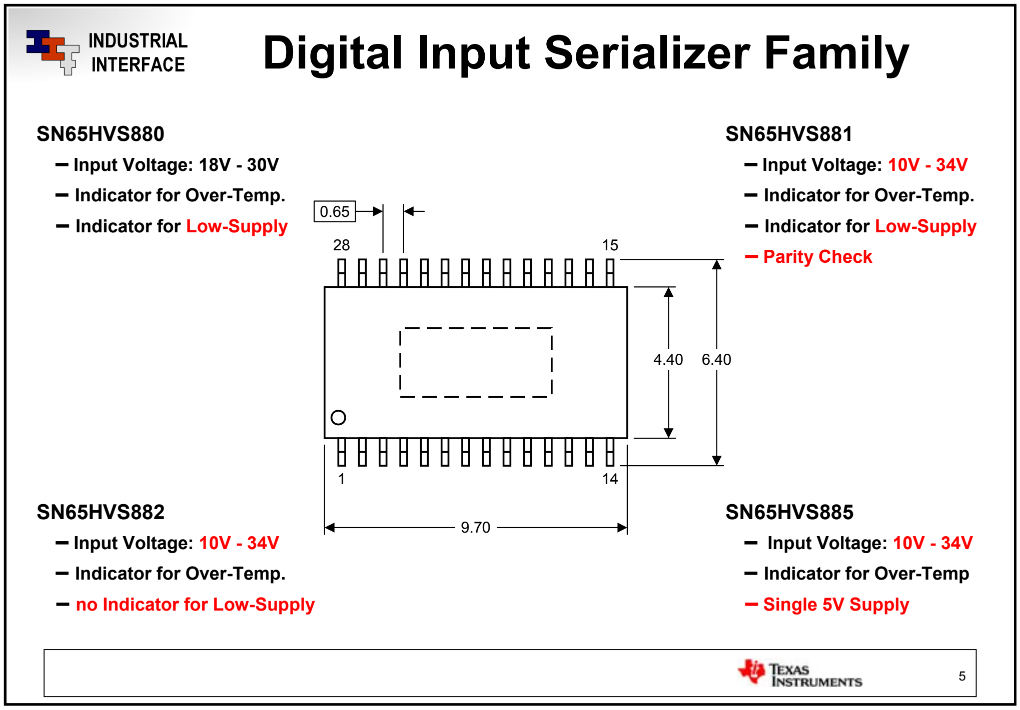
In the case of the supply voltage, an internal linear voltage regulator provides a smooth 5V output to supply the device internal circuitry as well as external isolators or micro controllers. Another auxiliary function is the on-chip temperature sensor, indicating an alarm condition to the controller should the junction temperature reach 150 oC.

The capability of tolerating the direct application of up to 34V at the device inputs is made possible through adjustable input current-limiting. In comparison to purely resistive inputs which drastically increase their power consumption with rising input voltage due to rising input current, the inputs of a DIS significantly reduce power consumption by limiting the input current to a constant level, which can be adjusted by the use of an external precision resistor, R_{LIM}.

In addition, each channel checks its input signal for strength and duration. The current- and voltage-detect functions possess internal signal thresholds to ensure that a channel is not triggered by any leakage current or residual voltage.

If signal strength is sufficient, the signal still has to be present for a certain length of debounce time, which is defined by an adjustable debounce filter. Debounce filtering prevents even strong noise transients from being interpreted as valid input data. Only input signals passing all three signal checks are accepted as true input data and as such are made available at the parallel inputs of the internal, parallel-in, serial-out shift register.

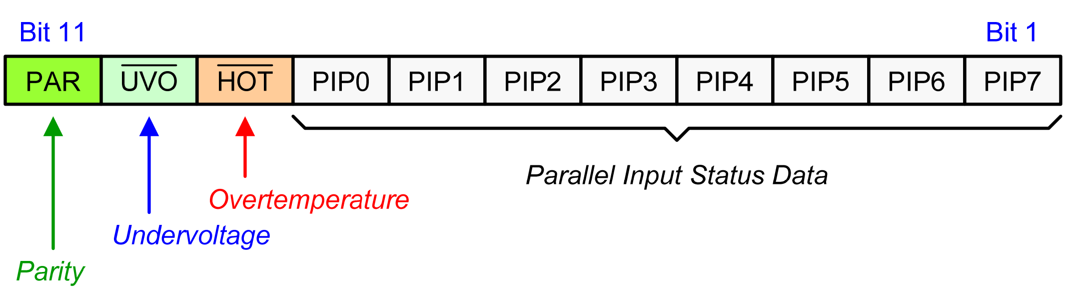
To read the status of the digital inputs, a controller simply applies a short load pulse to latch the parallel input data into the shift register. The subsequent application of a clock signal serially shifts the data out of the serializer into the controller memory. Because the timing of the serial interface is independent of the status changes at the digital field inputs, there exist no timely requirements for the controller on when and how often to load the shift register.



There are four, slightly different DIS devices available:

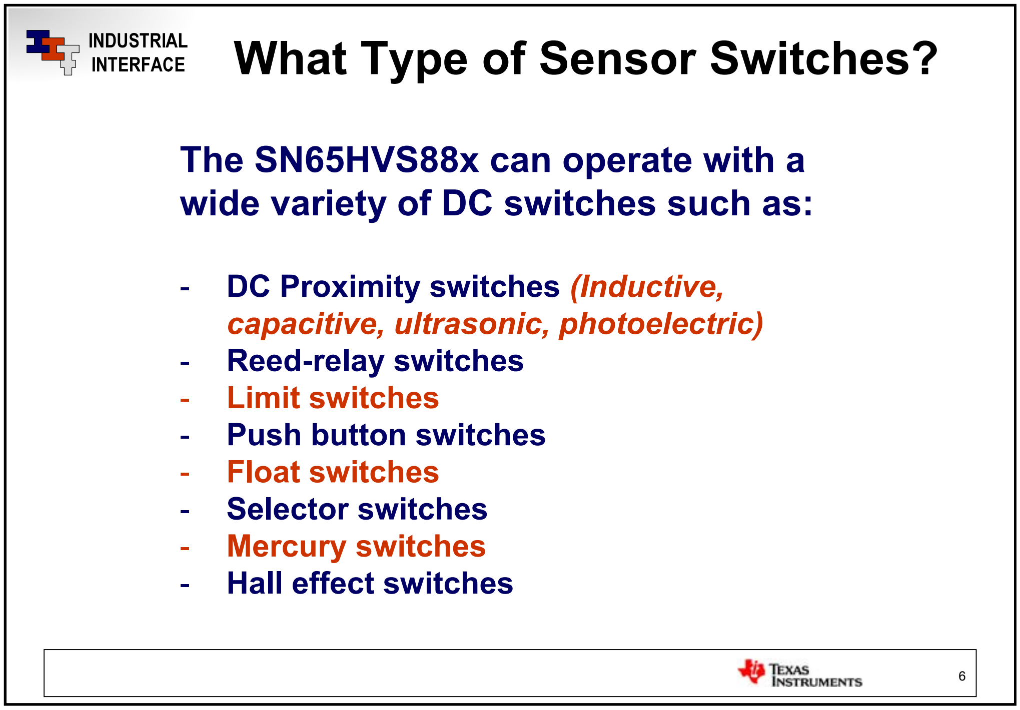
The HVS880 is primarily intended for PLC applications because it contains an undervoltage indicator that signals when the 24V nominal supply drops below 15V. Once the supply returns above 18V, the undervoltage indicator is reset. While the data sheet specifies a maximum input and supply voltage of 30V only, recent measurements have shown that the HVS880 can tolerate up to 35V maximum without problems.

The HVS881 is similar to the HVS880. But instead of bonding the undervoltage indicator out, it adds it as a status bit to the data word in the shift register. The overtemperature alarm is available as a pin and as a status bit in the data word. A third bit, the parity bit, checks for odd parity, and is also added to the data word. Thus the data word in the shift register consists of 11 bits as shown below.

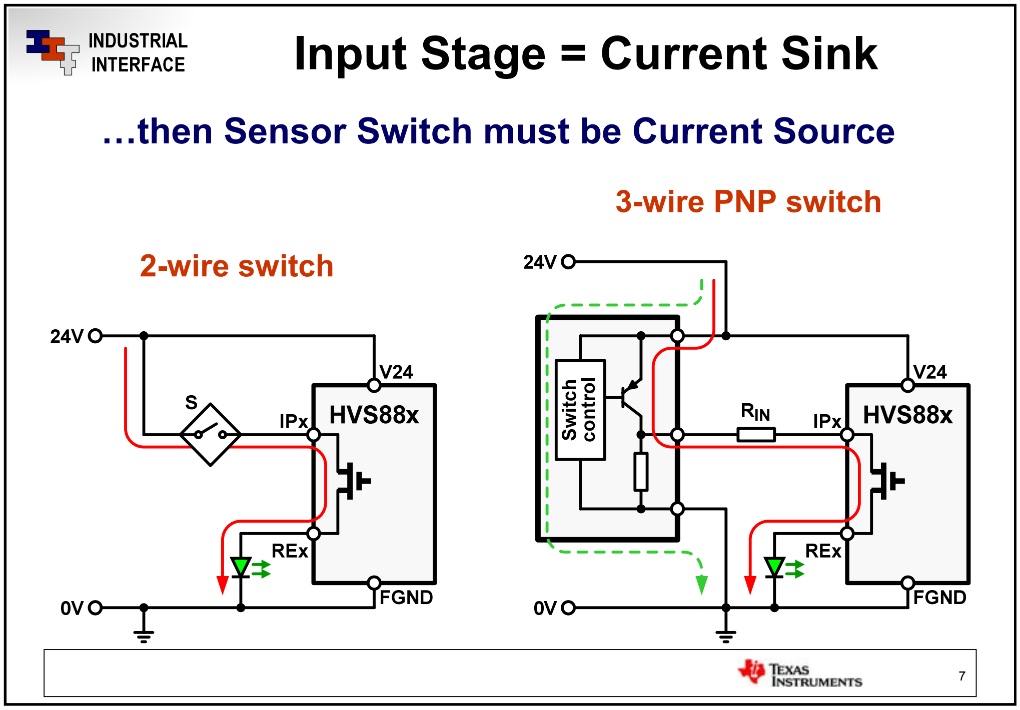


The HVS882 is primarily designed for generic micro-controller applications as it allows for operation from 34V down to 10V, thus making the undervoltage indicator redundant.

The HVS885 is similar to the HVS882 with the exception that it does not have a 24V nominal supply input and nor linear regulator on-chip. This device is only supplied by a 5V supply.

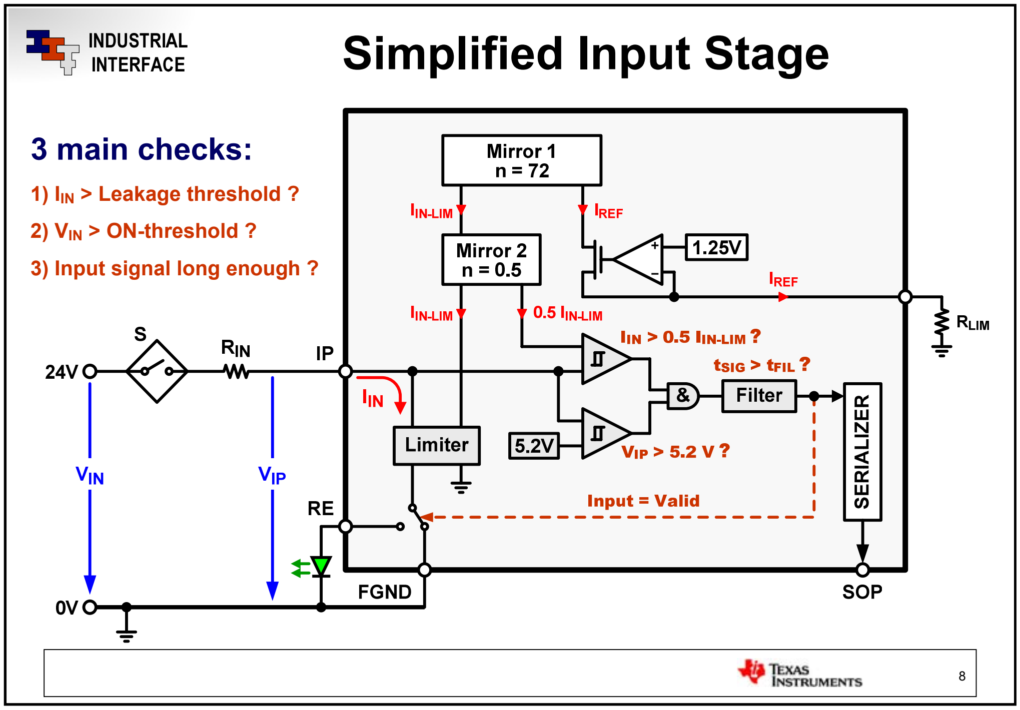


Any of the HVS88x devices can receive input signals from a wide variety of DC sensor switches, or DC voltage sources, which also include AC-rectified voltage sources.



Because the signal inputs of a HVS88x devices are current-sinking inputs, the sensor switch or voltage source applied must be current-sourcing.

3-wire sensor switches with current-sourcing capability are also know as PNP-switches.



In order to configure a DIS for various applications it is necessary to understand a channel's input stage in some more detail. Each of the 8 input stages performs multiple signal checks when an input changes its status. The following examples is given for a low-to-high transition of the input status:

Is the input voltage higher than 5.2V? If YES, the output of the voltage comparator goes high.

Is the input current higher than the leakage threshold (which is half the current limit)? If YES, the output of the current comparator goes high.

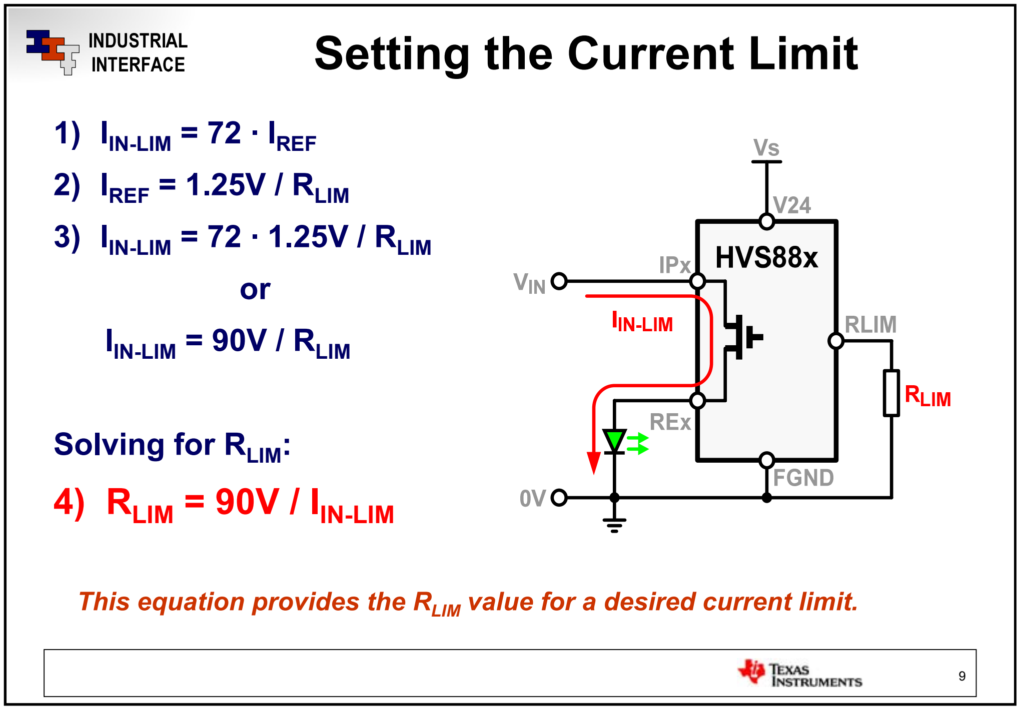
When both comparator outputs are high, is the signal duration longer than the debounce filter time? If YES, the filter output goes high.

When the filter output signal turns high, it is available at the parallel input of the shift register, waiting to be latched in. At the same time this signal switches the output of the current limiter from ground to the RE-output to turn on the LED.

Although the current comparator already switches at half the current limit (0.5 $I_{IN\text{-}LIM}$), when a sensor switch conducts, the low-to-high transition happens so fast, that by the time the filter output goes high, current limiting has set in.

Thus, when a sensor switch closes, the input voltage at the device inputs (IPx) is $V_{IP\text{-}ON}$ = 5.2V, and the input currents are limited to $I_{IN\text{-}LIM}$.

While $V_{IP\text{-}ON}$ is dictated through an internal voltage reference, $I_{IN\text{-}LIM}$ is derived from a reference current, I_{REF} , which in turn is determined via an external precision resistor, R_{LIM}.



The reference current I_{REF} is determined by the ratio of the internal bandgap reference of 1.25V to the external resistor R_{LIM} via:

$$I_{REF} = 1.25V / R_{LIM}. \qquad 1)$$

The current limit I_{IN-LIM} is mirrored from the reference current by a factor of 72:

$$I_{IN-LIM} = 72 \cdot I_{REF}. \qquad 2)$$

Inserting equation 1 into Equation 2 gives:

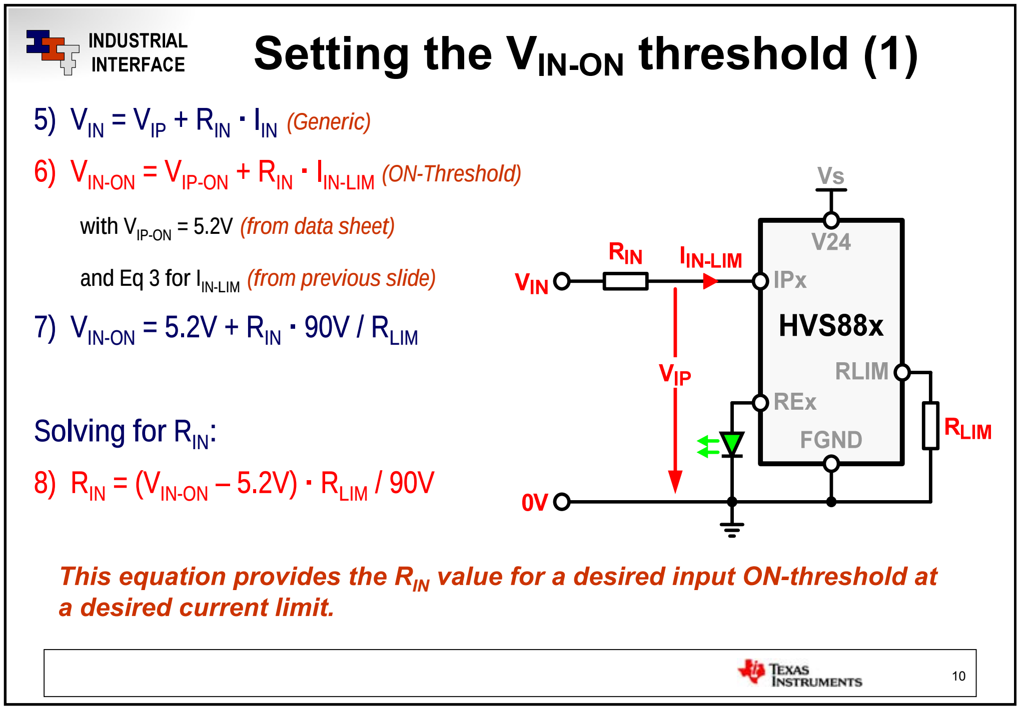
$$I_{IN-LIM} = 90V / R_{LIM}. \qquad 3)$$

Solving for R_{LIM} yields:

$$\mathbf{R_{LIM} = 90V / I_{IN-LIM}}. \qquad 4)$$

R_{LIM} presents the required resistor value for a desired input current limit.

Because the HVS88x devices are designed to preserve power consumption, the programmable current limit range is from 0.2mA to 5mA. The most common I_{IN-LIM} values are 2mA for low-volt applications and 0.5mA for high-volt applications.



Switching an input resistor, R_{IN}, in series to a device input, IPx, raises the input voltage at the field input, V_{IN}, by the voltage drop across R_{IN}:

$$V_{IN} = V_{IP} + R_{IN} \cdot I_{IN}. \qquad 5)$$

Notice, now we must distinguish between the device input voltage, V_{IP}, and the field input voltage, V_{IN}.

While Equation 5 expresses V_{IN} in generic terms, inserting the indices for the On-threshold yields the specific equation for the Off-to-On switching point:

$$V_{IN\text{-}ON} = V_{IP\text{-}ON} + R_{IN} \cdot I_{IN\text{-}LIM}. \qquad 6)$$

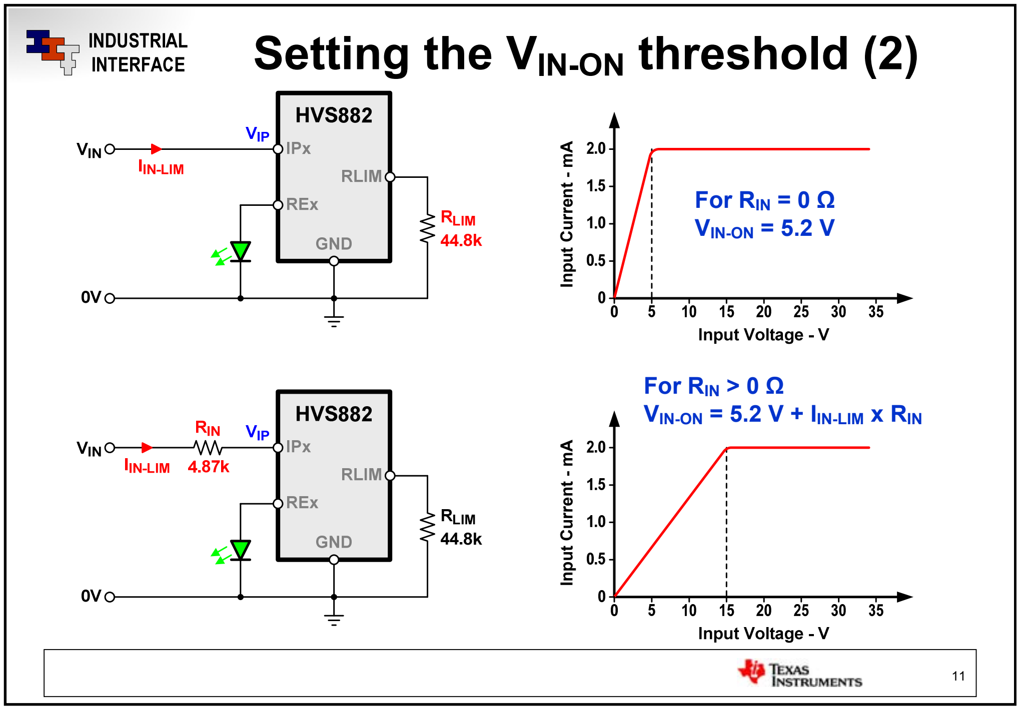
Inserting the data sheet value of 5.2V for $V_{IP\text{-}ON}$ and Equation 3 from the previous slide for $I_{IN\text{-}LIM}$ gives:

$$V_{IN\text{-}ON} = 5.2V + R_{IN} \cdot 90V / R_{LIM}. \qquad 7)$$

Solving for R_{IN} yields:

$$\mathbf{R_{IN} = (V_{IN\text{-}ON} - 5.2V) \cdot R_{LIM} / 90V} \qquad 8)$$

R_{IN} is the required resistor value for a desired field input On-threshold.



Example 1)

Assuming no R_{IN} ($R_{IN} = 0\Omega$), makes $V_{IN} = V_{IP} = 5.2V$.

For a desired current limit of $I_{IN\text{-}LIM} = 2mA$:

➔ **$R_{LIM} = 90V / I_{IN\text{-}LIM}$** $= 90V / 2mA = 44.8k\Omega$.

$R_{LIM} = 45k\Omega$ (*closest E-192 value*)

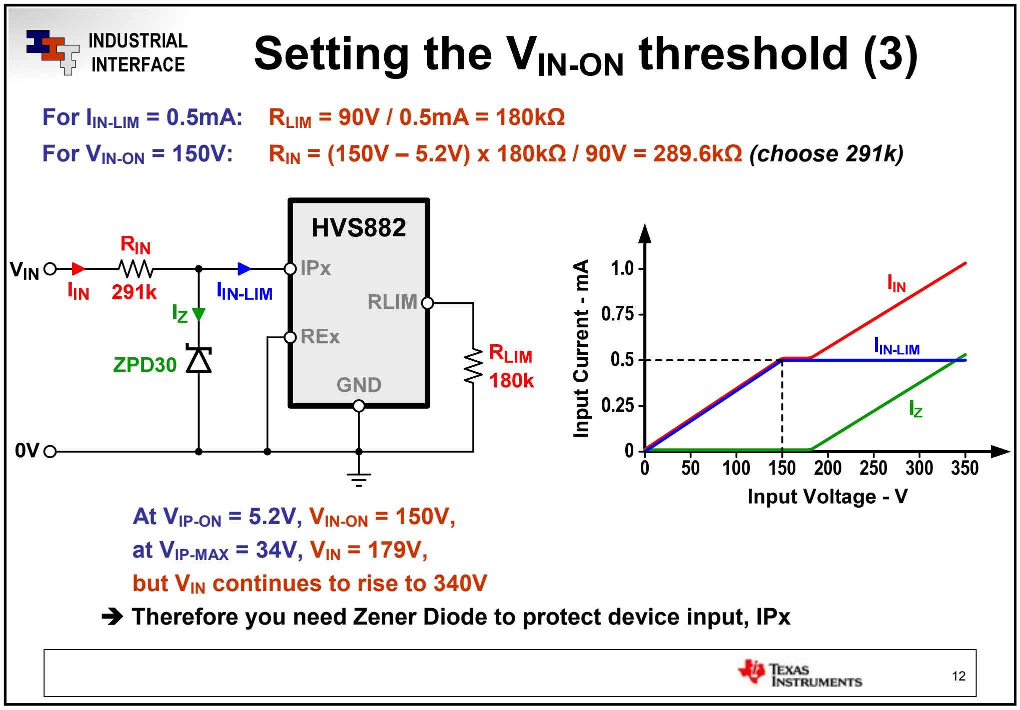
Example 2)

Assuming the current limit of the previous example ($R_{LIM} = 44.8k\Omega$), and a desired input threshold of $V_{IN} = 15V$:

➔ **$R_{IN} = (V_{IN\text{-}ON} - 5.2V) \cdot R_{LIM} / 90V$** $= (15V - 5.2V) \cdot 44.8k\Omega / 90V = 4.88k\Omega$

$R_{IN} = 4.87k\Omega$ (*closest E-192 value*)

Note, choosing current limits between 2mA and 3mA allows use of low-current LEDs.



Example 3)

In this example the on-off status of a 240V AC mains voltage is tested. First the AC voltage is rectified, yielding a peak DC level of 340V. *Note that the rectifier is not shown in the slide.*

In order to limit the I^2R losses within R_{IN} at high input voltages, the current limit is set to $I_{IN\text{-}LIM}$ = 0.5mA by making:

R_{LIM} = 90V / $I_{IN\text{-}LIM}$ = 90V / 0.5mA = 180 kΩ.

Assuming a switch-on threshold of $V_{IN\text{-}ON}$ = 150V, R_{IN} is determined via:

R_{IN} = ($V_{IN\text{-}ON}$ – 5.2V) · R_{LIM} / 90V = (150V – 5.2V) · 180kΩ / 90V = 289.6 kΩ.

R_{IN} = 291kΩ (*closest E-192 value*).

When V_{IN} rises while I_{IN} is in current-limit, ($I_{IN\text{-}LIM}$ = constant), V_{IP} rises too. At the maximum device input level of $V_{IP\text{-}MAX}$ = 34V, V_{IN} ~ 179V. However, because V_{IN} continues to rise to 340V, a 30V Zener diode connected to the IPx input clamps the input and prevents damage due to overvoltage.

Thus, when V_{IN} reaches 179V, the Zener diode conducts and draws additional current towards ground. This Zener current also flows through R_{IN}, and increases its voltage drop and I^2R losses.

Therefore when calculating the maximum power consumption within R_{IN}, the sum of $I_{IN\text{-}LIM}$ and I_Z must be considered.

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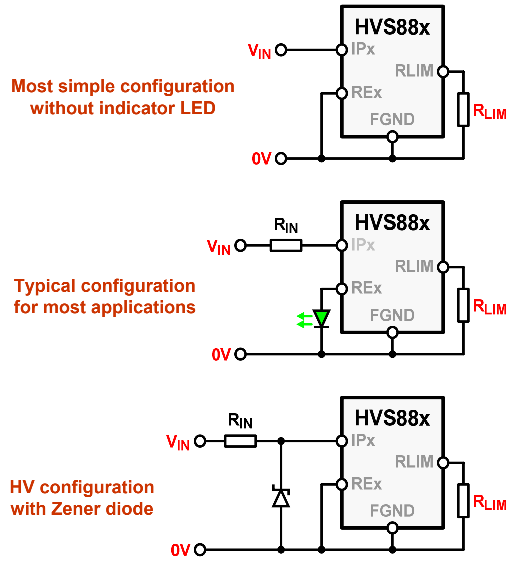
Various Input Configurations

V_{IN} [V]	V_{IN-ON} [V]	I_{IN-LIM} [mA]	R_{IN} [kΩ]	R_{LIM} [kΩ]
0-12	5.2	2	0	44.8
0-34	5.2	2	0	44.8
0-34	10	2	2.4	44.8
0-48	24	2	9.4	44.8
0-100	50*	0.5	89.6	180
0-350	150*	0.5	290	180

* Use 30V Zener diode for input protection



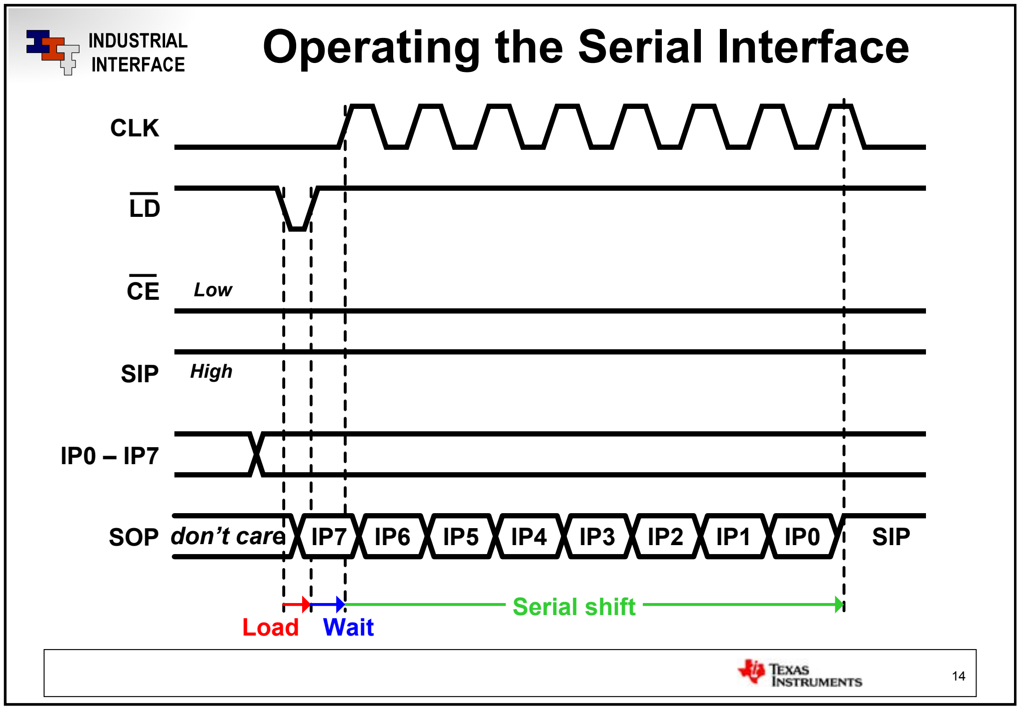
TEXAS INSTRUMENTS 13

The table above provides resistor values for R_{IN} and R_{LIM} for various input voltage ranges, input on-thresholds and input current limits.

The most simple input configuration without input resistors and indicator LEDs is often used in low-cost micro-controller applications, where status LEDs are connected to the general purpose outputs of the controller.

The typical input configuration with input resistors and LED indicators is primarily found in PLC applications and digital input modules of remote I/O of industrial automation systems. Here RIN serves two purposes: 1) it determines the input switching characteristics according the the PLC standard (IEC61131-2), and 2) it prevents a fire hazard in the case of a input short according to the UL standard.

The high-voltage (HV) configuration can be used to sense the presence of the 110V / 240V mains voltages in building automation applications. It is also found in 400V DC supply systems of electrical trains.



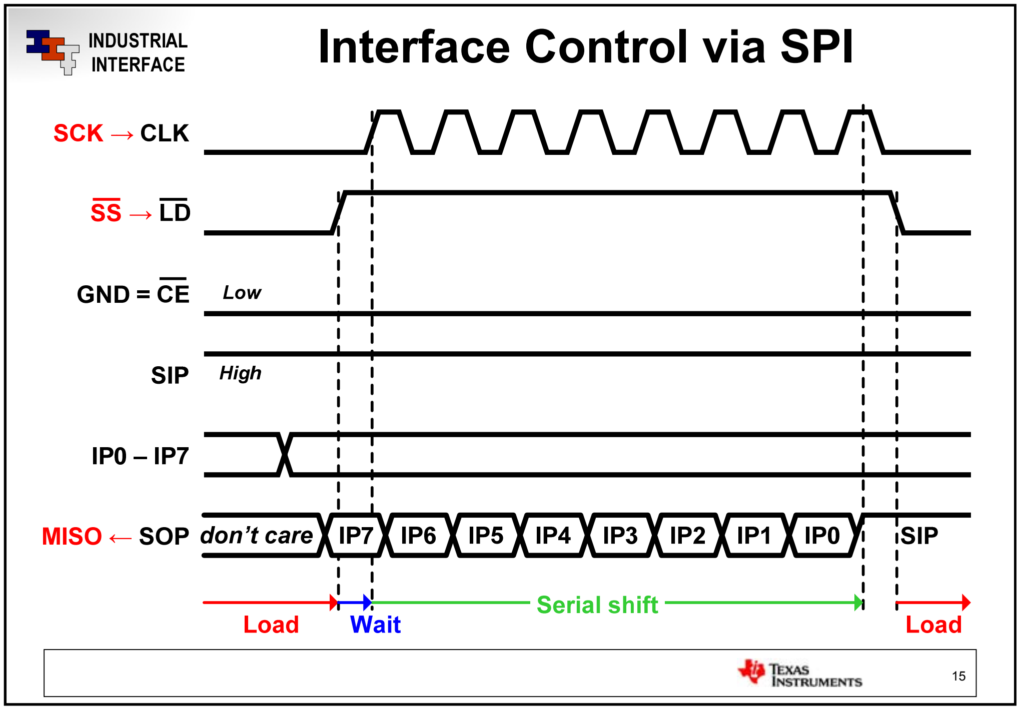
The serial interface of the HVS88x is that of a simple shift register interface.

It requires one low-active clock pulse to load the parallel input data into the shift register. When the low-active LOAD input is low, serial shifting is blocked.

After /LOAD is taken high, the application of a clock signal at CLK serially shifts the data word out of the register with each rising clock edge.

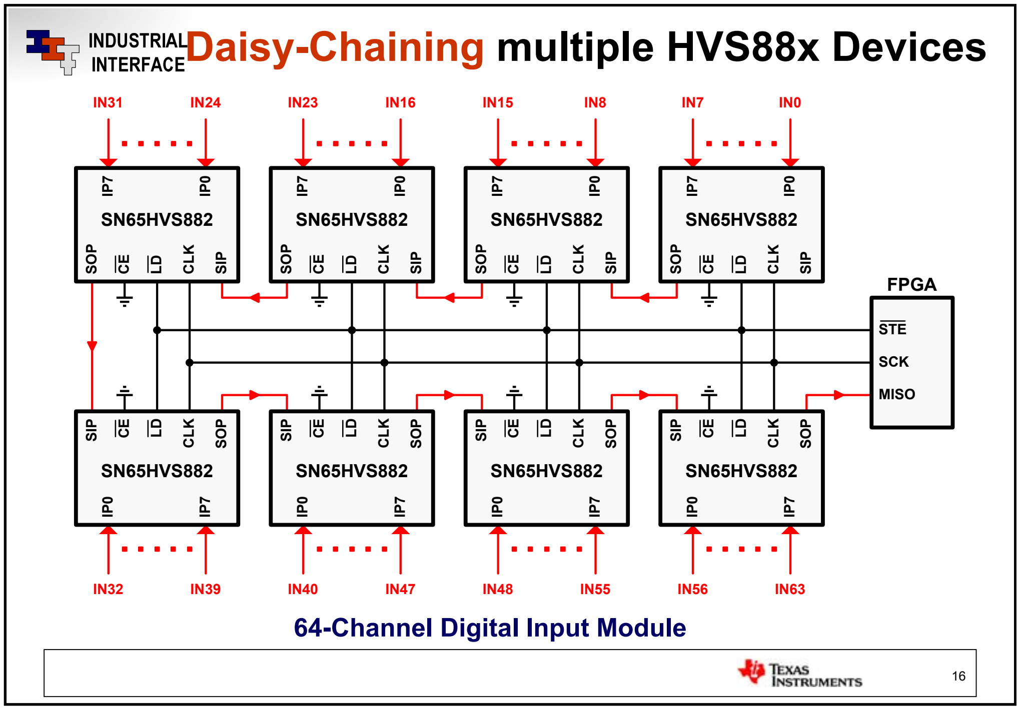
The low-active Clock Enable signal (/CE) can be connected to ground, or to CLK.

When /LOAD goes high, the serial output (SOP) assumes the input status of the 8th parallel input, IP7. Then the first rising edge of CLK will clock this bit into the controller data input register. Eight consecutive clock cycles are required to shift out the entire data word. At the 8th rising edge, the status of IP0 is clocked into the controller's input register and SOP assumes the status of the serial input (SIP).



When driving the serial interface of the HVS88x via a SPI interface, the SPI slave-select signal (SS) must be connected to the /LOAD input of the HVS88x.

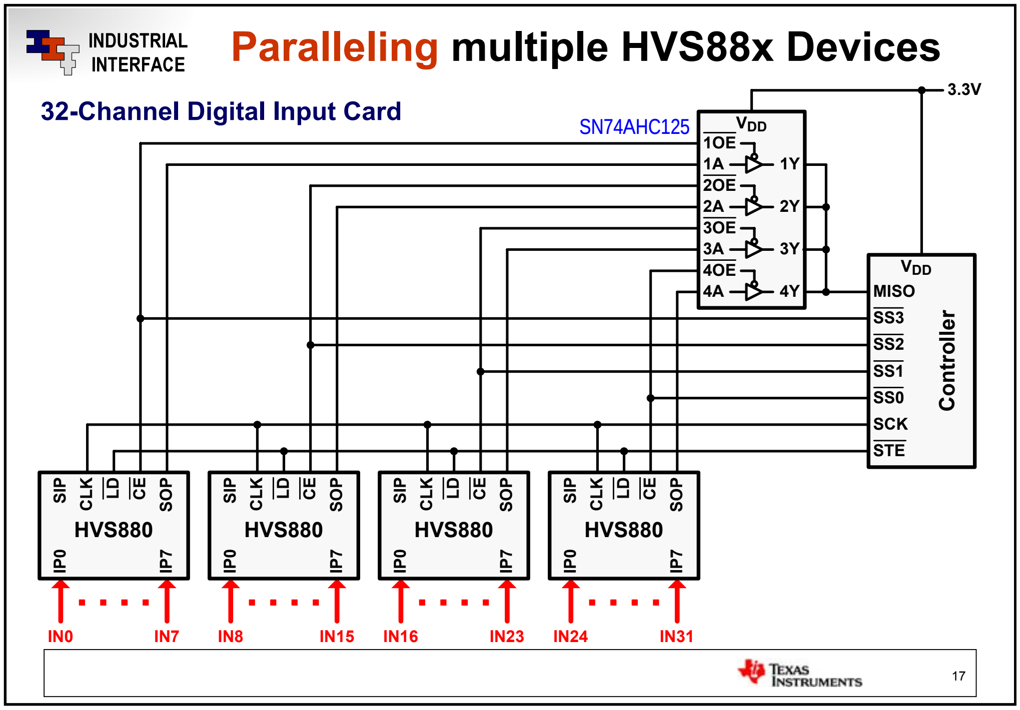
However, because SS is typically low-active (/SS) during the data transfer, its polarity must be inverted. Many state-of-the-art micro-controller provide this function through configuration registers.



Daisy-chaining up to four HVS88x devices can still be accomplished via SPI.

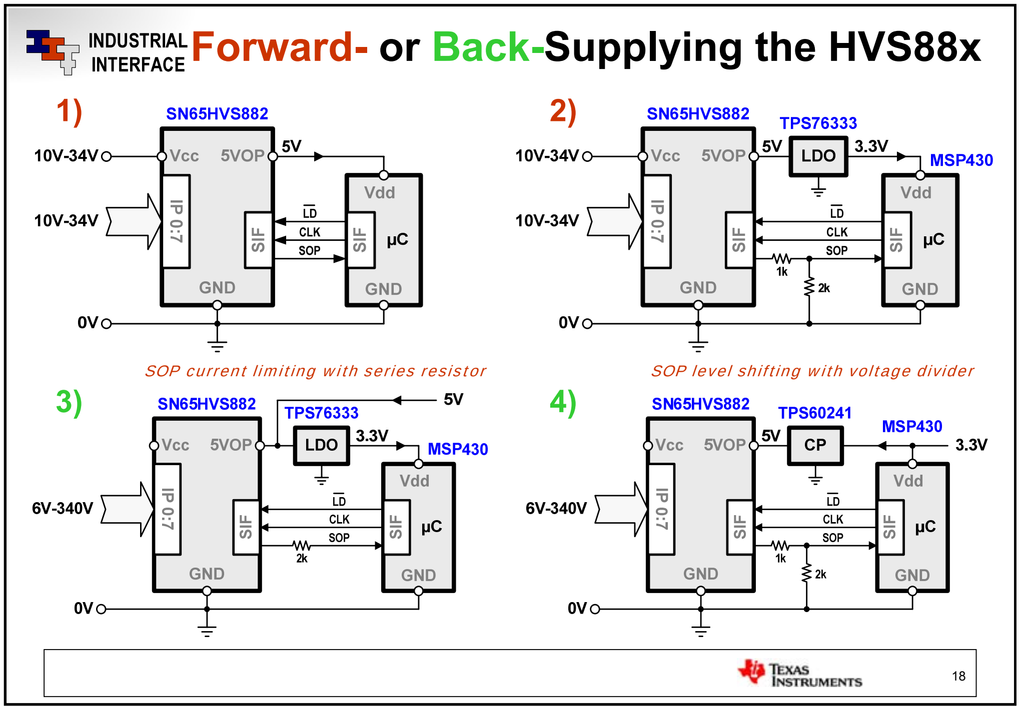
For longer chains involving higher channel numbers, FPGAs are used to provide longer input register depth for greater word lengths, and to allow for simple interface configuration.

Long daisy-chains of HVS88x devices are required in CNC controllers and 64-channel digital input modules of industrial automation systems.



Operating multiple HVS88x devices in parallel requires a simple tristate buffer, such as SN74AHC125, as the HVS88x serial outputs are push-pull outputs without tristate capability.

In this case, the clock and Load lines are controlled in parallel from two control lines, while the clock-enable inputs and serial outputs are controlled individually.



While isolated applications allow for the application of two different supplies, non-isolated designs might require the conversion and level shifting of supply and signal voltages.

The slide above shows various scenarios for interfacing the HVS88x to a system controller.

In the first example the HVS88x regulates a 24V input supply down to a 5V output supply and provides it to a 5V controller.

In the 2nd example the 5V output of the HVS88x is regulated down to a 3.3V supply for a low-volt controller.

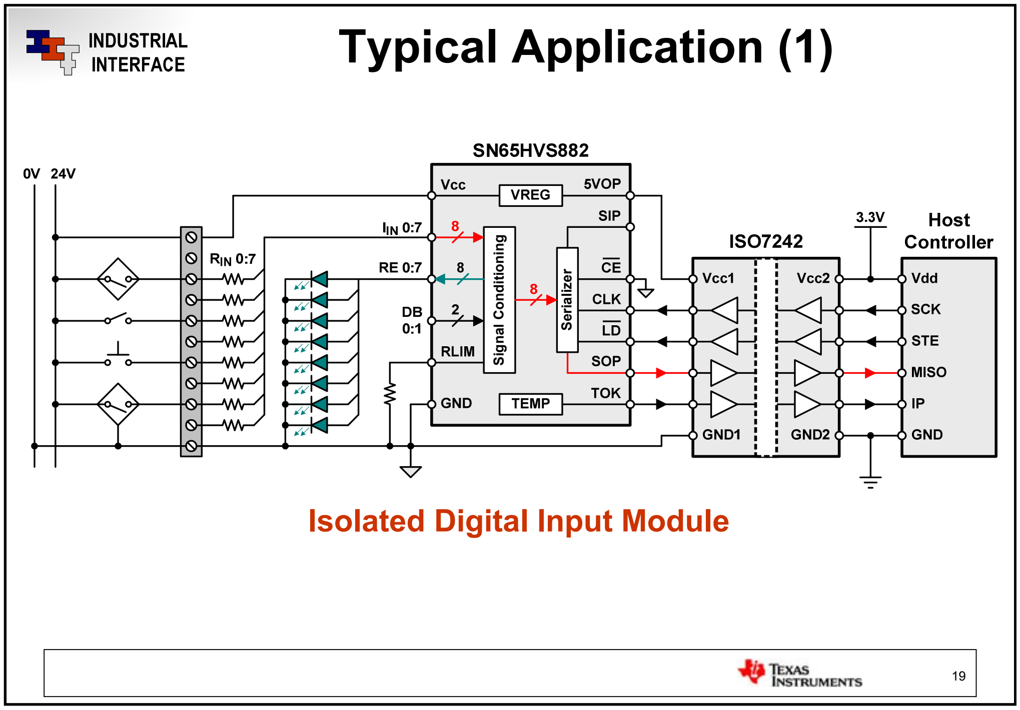
The 3rd example receives an external 5V supply, which is used to back supply the HVS88x and a low-volt micro via an additional LDO **(TPS76333).**

Note when back-supplying the HVS88x, the 24V input supply pin must be floating.

In the 4th example an external 3.3V supply directly supplies the controller, while for the HVS88x back-supply, a low-power charge-pump **(TPS60241)** is used to boost the 3.3V to the necessary 5V.

Interfacing the 5V SOP with the data input of a 3.3V controller requires level shifting. While the proper method is to use a resistor voltage divider, many designs rely on simple current limiting through a series resistor only.

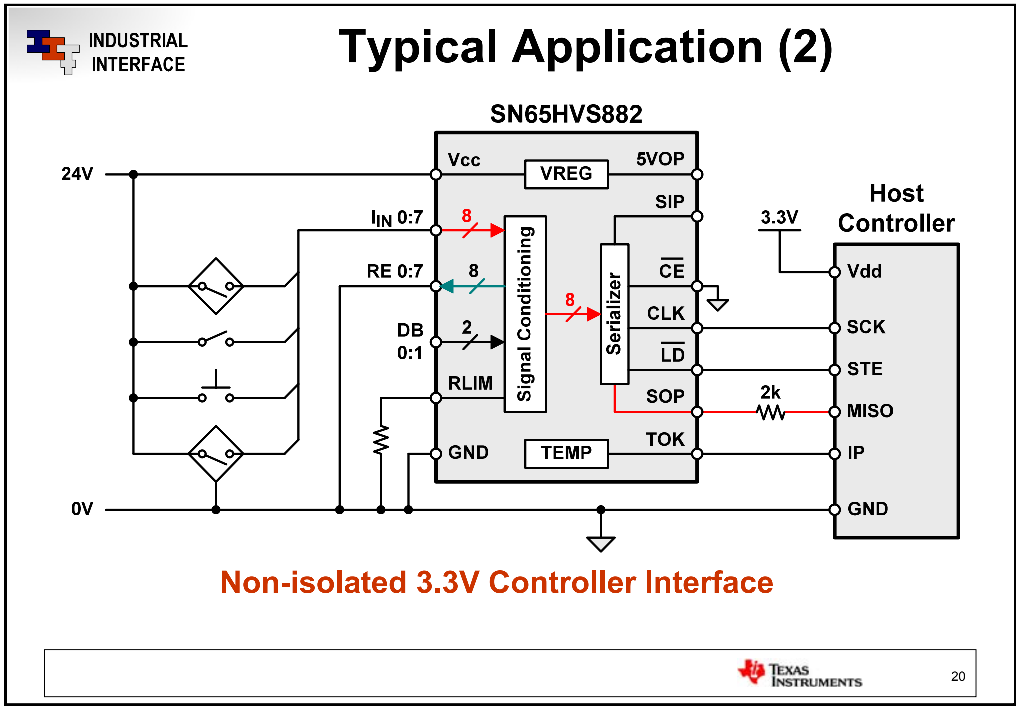
Although this type of interfacing has been observed to operate successfully over a couple of years, the long term reliability of such an interface might be reduced due to continued overstress of the controller I/Os internal protection cells.



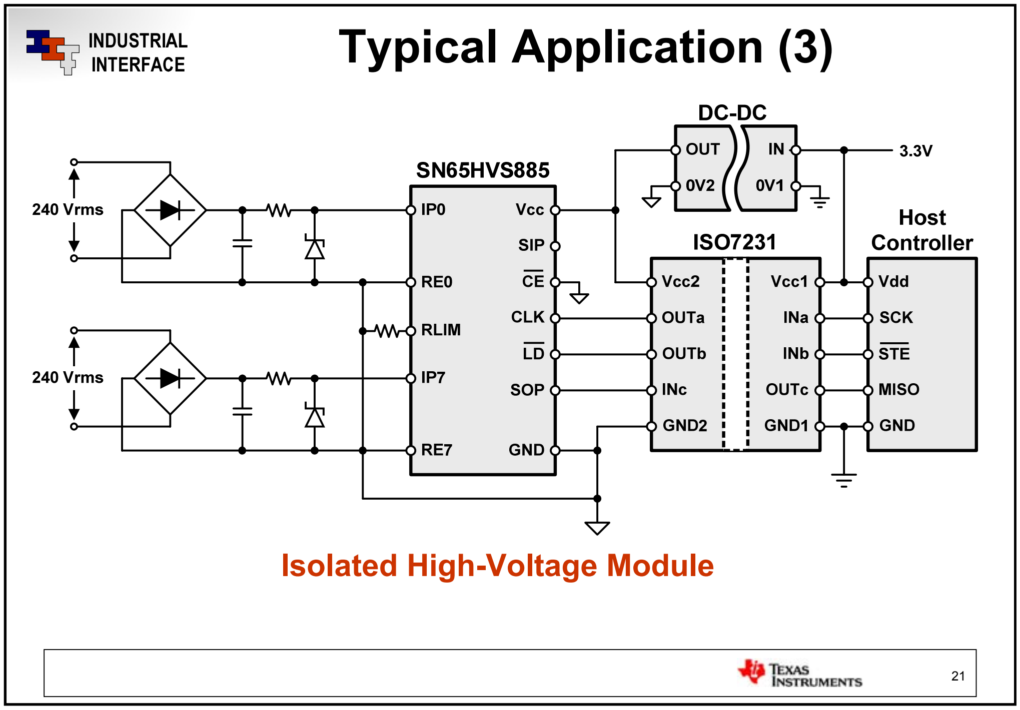
A typical digital input application must provide input resistors due to UL fire hazards prevention, and input status LEDs at the field input side according to IEC61131-2.

Designs for industrial automation and process control also must provide galvanic isolation between the field inputs and the system controller.

In this case the HVS88x provides the isolator supply on the field side, while the system supply feeds the controller and the isolator on the control side.

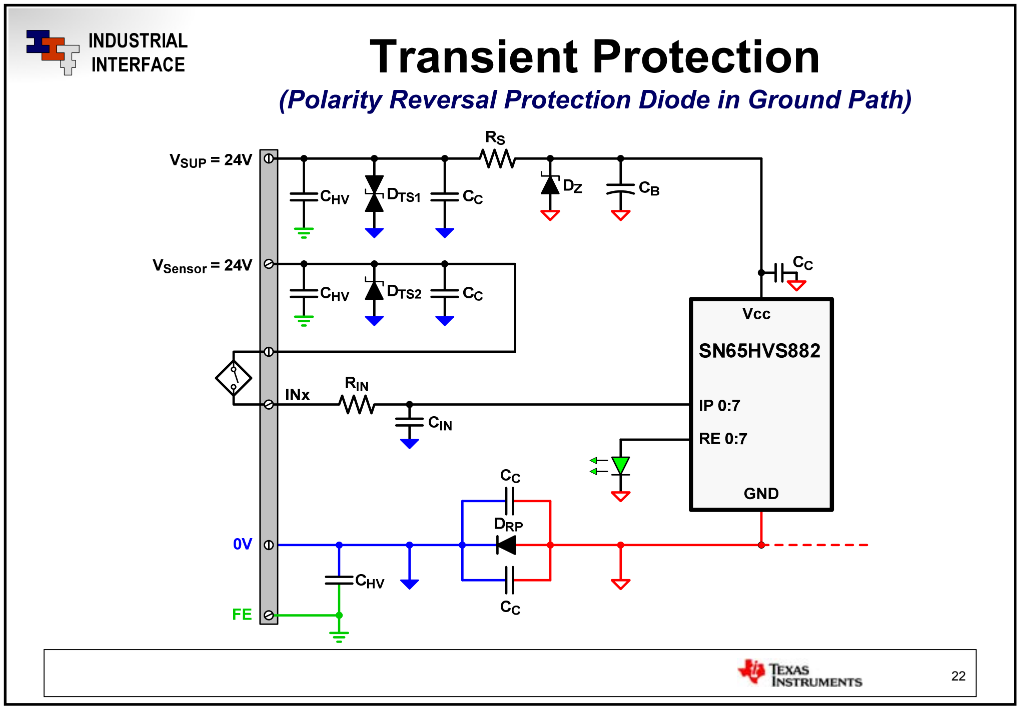


As mentioned earlier, low-cost designs providing status LEDs at the controller side, can connect their REx outputs directly to ground. This is only possible due to the internal current limiting function of the HVS88x.



This slide shows a simplified block diagram of a High-voltage interface using galvanic isolation. Here the 3.3V controller supply is boosted to a 5V supply via an isolated DC-DC converter.

In HV-designs, the boosting of the controller supply is often easier to realize, cost and space-wise, than deriving the 24V supply from the mains voltage.



The applied protection components such as high-voltage capacitors, transient suppressors, bypass capacitors and clamping diodes are NOT ONLY for the protection of the HVS882 devices but for the protection of the entire module. Many input modules also have isolators, voltage regulators, dc-dc converters and micro controllers located on the board. Therefore noise transients must be absorbed straight at the connector or terminal block (grey).

Many modules also have two separate supplies, one for the ICs, and another one for the sensor switches. Each supply has a high-voltage capacitor (CHV) connected to Functional Earth (FE).

The sensor supply has a unidirectional transient suppressor (DTS2) and a bypass capacitor (CC) connected to field ground (0V = black ground).

Note, that the reverse-polarity protection diode (DRP) separates field ground (black ground) from the device ground (white ground).

The IC supply path has a bidirectional transient suppressor (DTS1) and a bypass capacitor (CC) connected to field ground (0V = black ground). Because the clamping voltage of DTS1 can be up to 70V, a Zener diode (DZ) and a MELF series resistor (RS) are used to keep the board supply below 40V. A bulk capacitor (CB) is used to buffer the supply.

Good analog design technique requires bypass capacitors (CC) for each device on the board, not only the HVS882 ICs. The bypass capacitors also bypass any remaining transient energy to ground.

Note that DZ, CB, and the CC of each device connect to device ground (white ground).

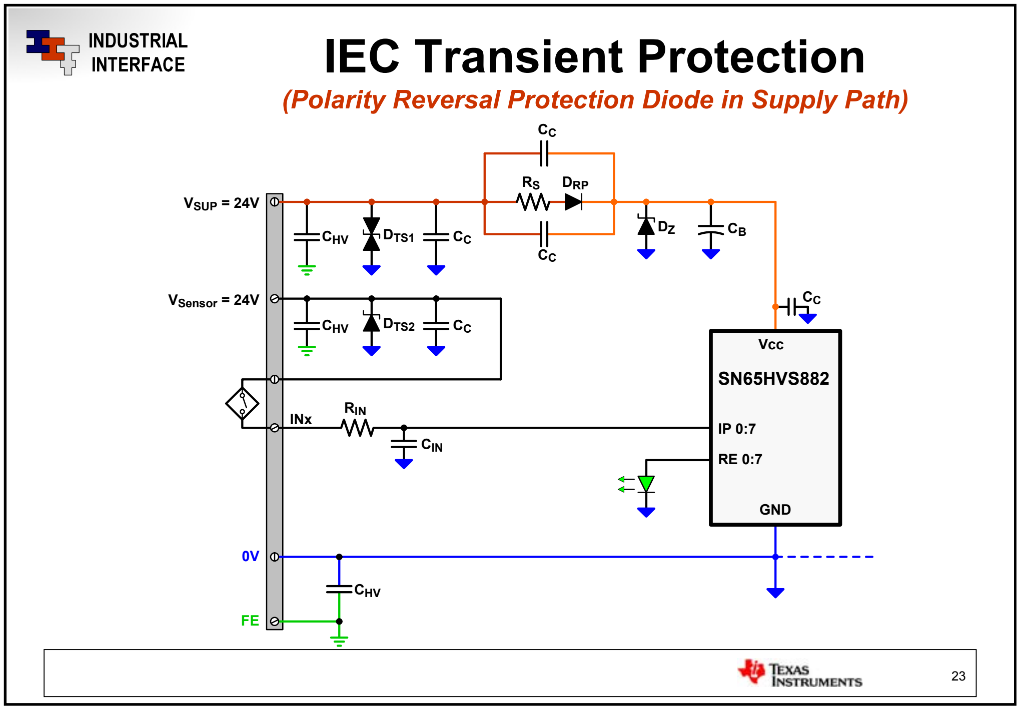
The digital inputs must have an input resistor according to UL standard to prevent fire hazard in the case of a short-circuit condition at the device input. They also determine the voltage switching threshold at the filed input (INx). An input capacitor (CIN= 22nF….220nF) is used for each input to reduce burst and surge transients.

While the HVS882 has strong internal protection diodes, external capacitors are a cheap solution to avoid huge internal protection diodes and keep the chip size and the chip cost low.

The input current into INx is returned at REx through an LED connect to device ground. If no LED is required, connect the REx output directly to device ground.

The reverse polarity diode separates the ground plane into two ground planes.

For low inductance, use multiple bypass capacitors parallel to DRP. Also connect the field ground (0V = black ground) to Functional Earth (FE) via a high-voltage capacitor, CHV.



Measurements have shown that implementing the reverse-polarity diode (DRP) into the Chip supply path provides one ground plane with excellent low-inductance and better Burst and Surge robustness.

When applying a 34V reverse polarity to the digital inputs for 2 hours, no destruction of the inputs occurred.

Table 2. Component List

D_{TS1}	Bidirectional Transient Voltage Suppressor: SMCJ33CA, or SM15T36CA
D_{TS2}	Unidirectional Transient Voltage Suppressor: SMCJ33A, or SM15T36A
D_{RP}	Super Rectifier: BYM10-1000, or General Purpose rectifier: 1N4007
D_Z	33 V – 36 V fast Zener Diode, Z2SMB36
R_S	56 Ω, 1/3 W MELF Resistor
R_{IN}	1.2 kΩ, 1/4 W MELF Resistor
C_{IN}	22 nF….220 nF, 60 V Ceramic Capacitor
C_{HV}	4.7 nF, 2 kV Ceramic Capacitor
C_C	n x 220 nF, 60 V Ceramic Capacitors
C_B	1 µF - 10 µF, 60 V Ceramic Capacitor

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Summary

Digital Input Serializers are the most versatile solution for interfacing low-volt controllers to high DC voltages because they:

- interface to a huge range of high voltages
- interface to a wide range of controllers
- drastically reduce power consumption
- possess high noise-immunity
- enable high channel-count designs
- safe massive board space
- are easy to use
- and low in price

Texas Instruments