

## New Digital Input Serializers Catapult Channel Count of Digital Input Modules

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The trend towards increased monitoring in industrial automation and process control requires input modules with higher channel densities. In these applications, 24V DC digital inputs (DI) make up the lion's share of the overall industrial I/O market, as they capture the two-state signals from a wide variety of mechanical contact and solid-state switching devices and convert them into a single-bit binary number.

Modern digital input module designs require high-channel count, small form factor, low-power consumption and high data rates. Conventional input designs using discrete resistor-diode networks are unable to match these requirements due to high-power consumption and extensive component count. Instead, new innovative circuit designs such as digital input serializers (DIS) exceed the expectations on the above requirements and, therefore, lay the groundwork for future digital input designs.

This article gives a brief overview on conventional digital input designs and compares their performance with the innovative functions integrated into a digital input serializer. This article then describes the functional principle of a DIS and shows how its features enable input module designs with true high-channel densities.

### Digital Input Switching Characteristics

While DIs may conform to a variety of input characteristics, the most commonly applied ones are IEC61131-2 Type 1, 2 and 3 (see **Figure 1**).

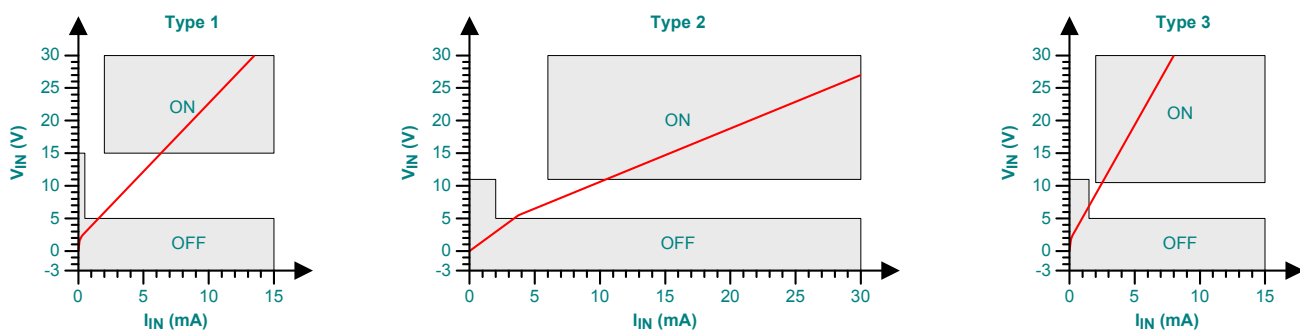


Figure 1: Digital Input characteristics according to IEC61131-2

Type 1 senses signals from mechanical contact switching devices such as relay switches, push-buttons and switches. Type 1 may not be suitable for use with solid-state devices such as sensors and proximity switches.

Type 2 senses signals from high-power, solid-state switching devices such as older two-wire proximity switches, which are designed to IEC60497-2. This characteristic also can be used for Types 1 and 3 applications.

Type 3 inputs are applied with low-power, solid-state switching devices such as state-of-the-art two-wire proximity switches, but also can be used in Type 1 applications. These inputs have lower power characteristics than Type 2; thus, allowing higher input channel densities per module.

### Conventional Input Channel Designs

While there are various input designs using diverse R-D networks, all have the following requirements in common:

- input switching characteristics conforming to IEC61131-2, Type 1, 2, or 3
- input status indication at the field side (required by IEC61131-2)
- debounce circuitry for noise suppression (although not standardized, the two most common values are 1ms and 3ms)
- galvanic isolation of the 24V field inputs from the low-voltage PLC or I/O electronics

Figure 2 shows two input channel designs:

- the input characteristic is determined by the resistor values of  $R_{IN}$  and  $R_P$
- the switch status is indicated via an LED located at the field side
- noise suppression is achieved via an R-C time constant
- and galvanic isolation is provided through an opto-coupler

All together there are too many discrete components to allow for high-channel density in the case of a 32-channel input module, for example.

A further drawback is the high-power consumption during an On-condition. While the input's On/Off thresholds typically are designed to occur somewhere in the middle of the transition region (the white area between the grey-shaded On- and Off-regions), the input current continues to rise until the field input voltage has reached its nominal level of 24V. Furthermore, the IEC standard allows the field supply of 24V nominal to vary between – 15% and + 20%, so that the maximum input power consumption actually occurs at 30V.

In the case of the Type-1 switch in **Figure 1**, input currents of 11mA at 24V and 13.5mA at 30V cause power consumptions of 260mW and 400mW respectively. This power is converted into heat. Due to the inefficient power dissipation capabilities of discrete components, “hot-spots” can occur on the printed circuit board, if input channels are placed too close to each other. This is another fact counteracting high-channel density design.

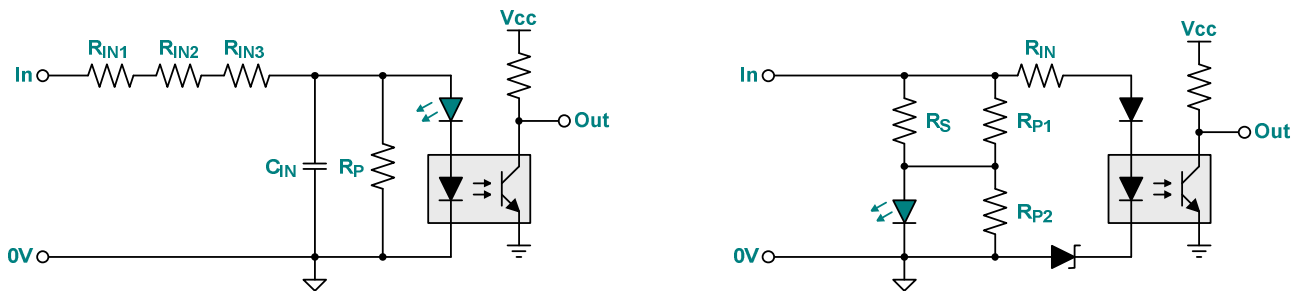


Figure 2: Conventional input designs use many discrete components while consuming enormous power

A first step towards power reduction and a reduced number in isolators presents the circuit in **Figure 3**. Here a constant current source around Q1 provides a well defined current limit determined by the value of  $R_{LIM}$ . Each stage includes a debounce filter through  $R_F$  and  $C_F$ , which, when using low-tolerance components, yields precise debounce times.

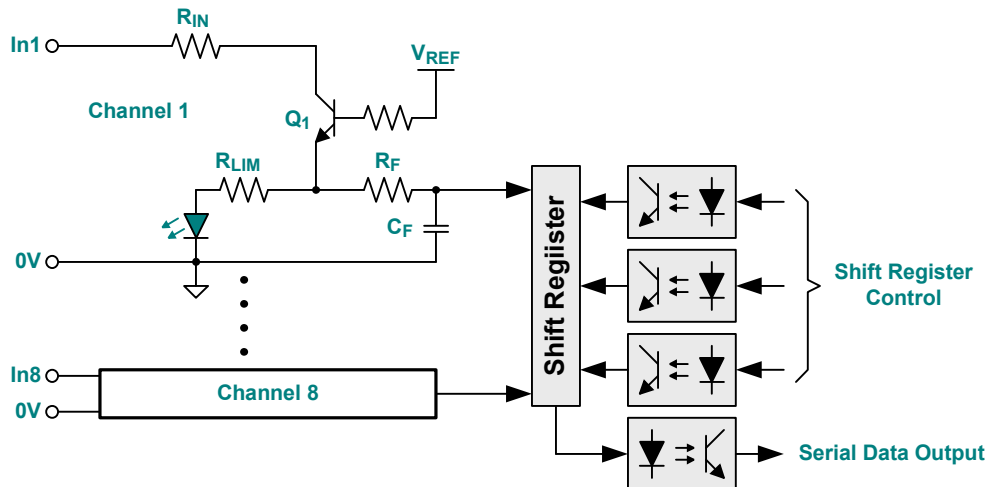


Figure 3: Legend 8-channel input module with current limiter and shift register

Another benefit this circuit provides is the level shift from the 24V field inputs down to a 5V logic level. This allows the status of the debounce filter outputs to be latched into the parallel inputs of a shift register. Converting the information of the parallel field input into a serial data stream drastically reduces the numbers of isolators required and makes the isolator count independent from the channel count of the input module.

## Digital Input Serializer

Digital input serializers (DIS) are tailored for commercial and industrial input applications using input voltages of 12V to 24V DC nominal with maximum ratings of up to 34V. A DIS provides eight parallel inputs that connect to two- or three-wire DC proximity switches, relay-switches, push buttons, limit-switches, float-switches, selector-switches and photoelectric sensors (**Figure 4**).

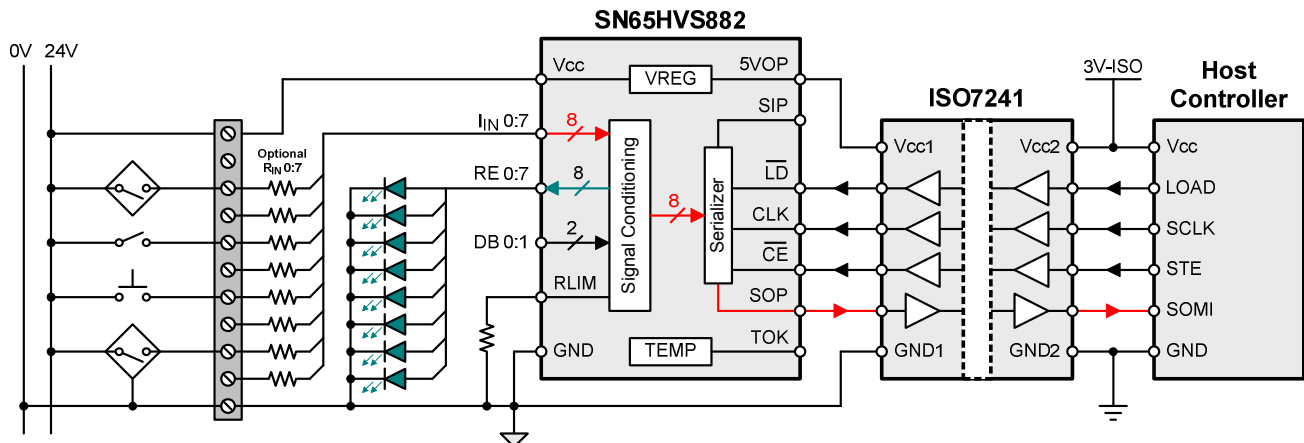


Figure 4: Basic System Level Diagram of an isolated 8-Channel Digital Input Module

Information on the switches' On-Off status is level-shifted and filtered by a signal conditioning stage whose eight parallel outputs are latched into a serializer. Under the supervision of an external controller, the serializer content is clocked out serially. Digital isolators can provide an isolated interface for the control and data lines between the DIS on the field side, and the system controller of a PLC- or PC-based system on the control side. Cascading multiple DIS devices is possible by connecting the serial output of the leading device with the serial input of a following device, thus allowing for the design of digital input modules with high-channel density. Note that the input resistors,  $R_{IN\ 0:7}$ , are optional for non-IEC compliant designs. Zero input resistance allows for low-volt switching with On- and Off- threshold voltages in the range of 5V and 4.5V respectively.

Industrial input designs, however, require input resistors for several reasons. For a given current limit, the resistors level-shift the field input threshold voltages right into the middle of the transition regions of the IEC61131-2 Type 1, 2, and 3 characteristics. They also serve as part of the burst and surge protection during electromagnetic compatibility tests (EMC) according to IEC61000-4-4 and -4-5. Finally, they serve as current limiting resistors preventing fire hazards in case of a device short, which is a U.L. certification requirement.

**Figure 5** now shows the inner structure of the digital input serializer in **Figure 4**.

An integrated linear voltage regulator converts the 24V supply into a regulated 5V output to supply the device internally as well as external digital isolators.

The on-chip temperature sensor indicates a fault condition, should the device internal temperature exceed 150°C. The output of the temperature sensor can be made visible via an external LED, or can be transmitted via an isolated channel to the Interrupt input of the system controller.

Each input channel comprises a current-sense and a voltage-sense circuit, which compare the input signal with their respective reference thresholds. Additionally, the current sense function contains a current limiter circuit with an adjustable current limit range from 0.2mA up to 5mA. The current limits for all channels are determined by the resistor value of the external precision resistor,  $R_{LIM}$ .

The outputs of the current-sense and the voltage-sense stages are gated by an AND function and applied to a debounce filter, which ensures that the input signal is sufficiently stable. That is, its duration must surpass the filter debounce time to be accepted as a valid input. In the case of a valid input signal, the output of the debounce filter appears at the parallel input of the serializer, ready to be latched in with the next load pulse. At the same time, the debounce filter output controls a switch within the current limiter (red dotted line), and switches it towards the return output, REx. Thus, most of the input current is redirected through an external LED (red bold line), indicating a valid On-condition.

The debounce-select logic determines the debounce times for all channels. Three typical selections are possible: 3ms, 1ms and 0ms. In the case of 0ms, the debounce filters are bypassed internally and external provisions can be made to modify the debounce times.

The On-chip serializer converts the parallel information from the debounce filter outputs into a serial data stream, ready to be transmitted across the isolated data channel. Serializer control is maintained by the controller through standard control channels such as Load, Clock, and Clock-Enable. Clock rates of up to 100MHz are possible, thus, allowing 32 inputs to be scanned (from four cascaded DIS devices) in less than 500ns. This can significantly improve data throughput, data latency and power savings at the system level.

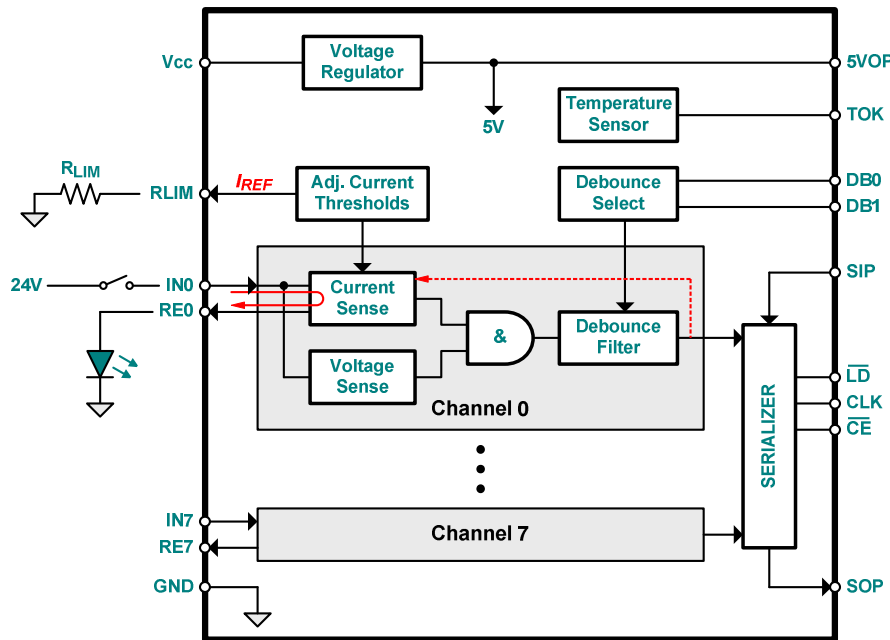


Figure 5: Simplified Block Diagram of a Digital Input Serializer

## Power Savings

While the input current of conventional R-D structures continues to rise proportionally with the input voltage, the current limiters in DIS devices ensure constant input currents during an On-condition. With the input currents being independent after the Off-to-On transition point, drastic reductions in power consumption are achieved.

**Table 1** lists the power savings of current limited inputs versus R-D inputs for the three IEC input characteristics, which have been derived from the input current plots in **Figure 6**.

|               | Input Voltage | Type 1 | Type 2 | Type 3 |
|---------------|---------------|--------|--------|--------|
| Power Savings | 24 V          | 76%    | 75%    | 61%    |
|               | 30 V          | 80%    | 80%    | 65%    |

Table 15: Power Savings of an DIS versus a Conventional Input Design

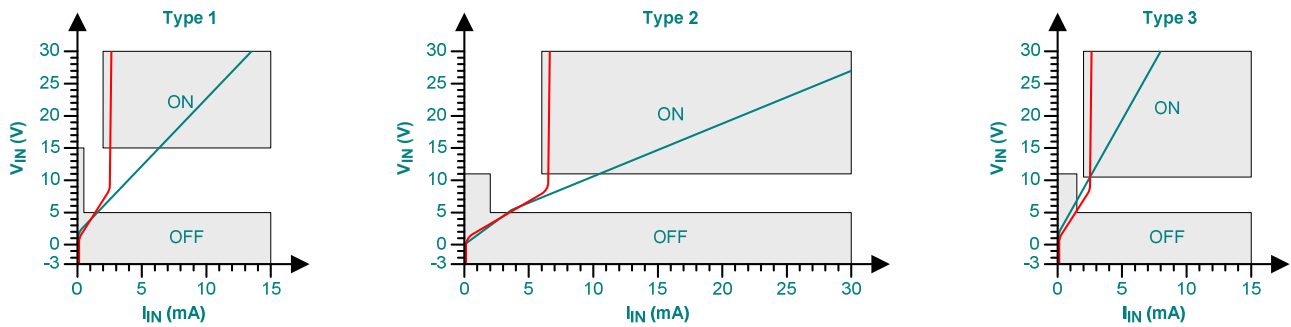


Figure 6: Comparing Power Consumptions of a DIS (red) versus Conventional Input Designs (green)

## Heat Dissipation

Current limiting requires a drastic increase in input resistance. Thus the  $I^2R$ -losses of the input field-effect transistors rise sharply after the transition point. This power is converted into heat and must be dissipated effectively. For that purpose, thermally enhanced packages are used that provide a thermal pad at the bottom of the package. Additionally, PCB designs must provide a sufficient large copper area that, when making contact with the thermal pad, ensures efficient heat dissipation.

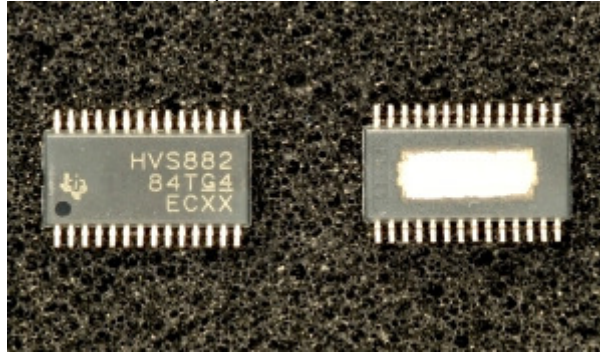


Figure 7: Thermal Enhanced Package dissipates heat more efficiently

This effective heat dissipation enables eight input channels to be integrated into one chip, thus, laying the foundation for a high-channel density design.

To familiarize yourself with the application of thermally enhanced packages and the associated PCB layout, refer to the application note SLMA002B in the reference section of this article.

## Space Savings

Whilst the above sounds awfully complex and space consuming, actually it is not. The digital input serializer in **Figure 4**, for example, uses a 28-pin Power-Pad package of 6.4mm x 9.4mm dimensions, which is almost negligibly small compared to the real estate of a conventional eight-channel R-D input module with 16 resistors and eight diodes.

The space savings achieved on an eight-channel port become even more pronounced in modules with higher channel counts, i.e., when cascading four DIS devices to a 32-channel input module, as shown in **Figure 8**.

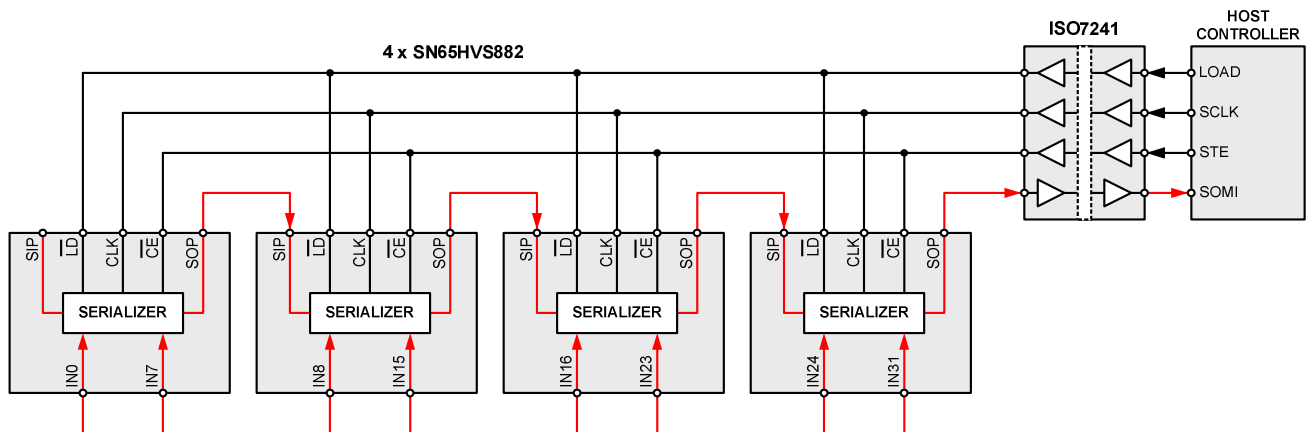


Figure 8: Cascading 4 DIS to a 32-Channel Digital Input Module

Now, in addition to the four serializers consuming significantly less space than 64 resistors and 32 diodes, the conversion of 32 parallel inputs into a serial data stream enables the use of only one quad isolator, thus, further replacing 32 opto-couplers.

**Figure 9** shows an actual test board of a 32-channel input module with the field inputs located at the bottom of and the IEC protection circuitry at the top of the PCB image.

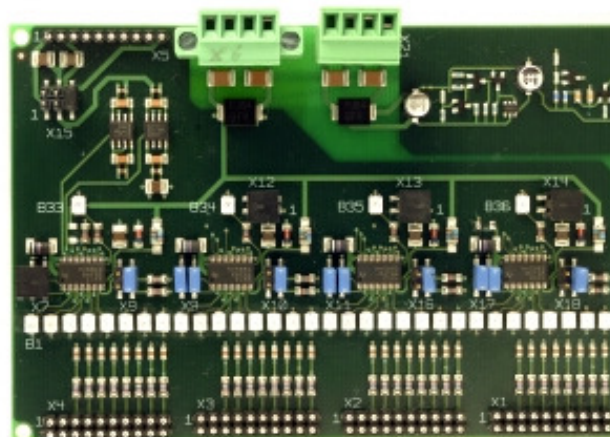


Figure 9: Actual 32-Channel Digital Input Module PCB

## Conclusion

Digital Input Serializers are innovative, highly integrated system solutions, tailored for digital input modules with high-channel density. The three main features allowing for high-channel density are:

- 1) internal current limiting, which saves power of between 60 to 80 percent versus conventional resistor-diode structures,
- 2) a thermally enhanced package that provides far more effective heat dissipation of the input design than discrete components,
- 3) the ability to cascade multiple serializers while requiring one isolator circuit only.

Supporting the trend of new digital input designs, Texas Instruments is introducing its SN65HVS88x family of digital input serializers for commercial and industrial applications.

## References

Further information is available at [www.ti.com/interface](http://www.ti.com/interface) by entering the literature numbers provided below in parenthesis into the Keyword Search field.

- SN65HVS882 data sheet (SLAS601)
- SN65HVS882 EVM Manual (SLAU249)
- SN65HVS880 data sheet (SLAS592A)
- SN65HVS880 EVM Manual (SLAU245)
- PowerPAD Thermally Enhanced Package (SLMA002B)

## About the Author

Thomas Kugelstadt is a Senior Applications Engineer at Texas Instruments where he is responsible for defining new, high-performance analog products and developing complete system solutions that detect and condition low-level analog signals in industrial systems. During his 20 years with TI, he has been assigned to various international application positions in Europe, Asia and the U.S. Thomas is a Graduate Engineer from the Frankfurt University of Applied Science.