Easing digital input integration and functional safety challenges in process and industrial automation applications

THE TRANSFORMATION OF MANUFACTURING

Across the manufacturing world, the overall equipment effectiveness (OEE), a measure of how efficiently a factory uses its production assets, is on the up. Government and manufacturing transformation initiatives such as Industry 4.0 and the Industrial Internet of Things (IIoT) are responsible for transforming the industrial landscape. The connected world of industrial process automation links together production machinery, sensors, and actuators with control and performance management systems.

As industrial processes become more advanced and sophisticated, factory floor space is typically at a premium. Often, industrial equipment control cabinets are limited to only one per item of machinery. This constraint requires process automation engineers to carefully architect control systems using programmable logic controllers (PLC), distributed I/O modules, power supplies, and motor drives that are compact and energy efficient.

Energy efficiency is paramount for any equipment today. However, within the confines of an industrial control cabinet, any controller generating unwanted heat creates thermal management issues for the whole cabinet. Engineers can install forced-air cooling fans, but these occupy precious equipment space, consume energy, and increase ambient noise levels.

With higher levels of automation, the potential for harm and injury increases. Industrial robots typically feature high torque motor drives and could cause serious injury. Also, the deployment of collaborative robots "cobots" means that human workers are now close to them. In the event that an electrical fault occurs in a system, the safety of operators using related machinery control panels and user interfaces may also be at risk. Internationally recognised functional safety standards for industrial equipment stipulate levels of protection. Any item of control equipment must comply with these standards.

This whitepaper focuses on how engineers working on a wide range of process, industrial, and building automation applications can better protect their equipment and ensure the safety of their personnel through the use of a robust, low-power approach based on self-powered digital input current limiters.

INTERFACING TO THE REAL WORLD

An industrial automation control system needs data; lots of it. See Figure 1 for an example of the architecture of an industrial automation deployment. Digital inputs from an army of sensors, actuators, and switches feed the control system, typically via a programmable logic controller (PLC).

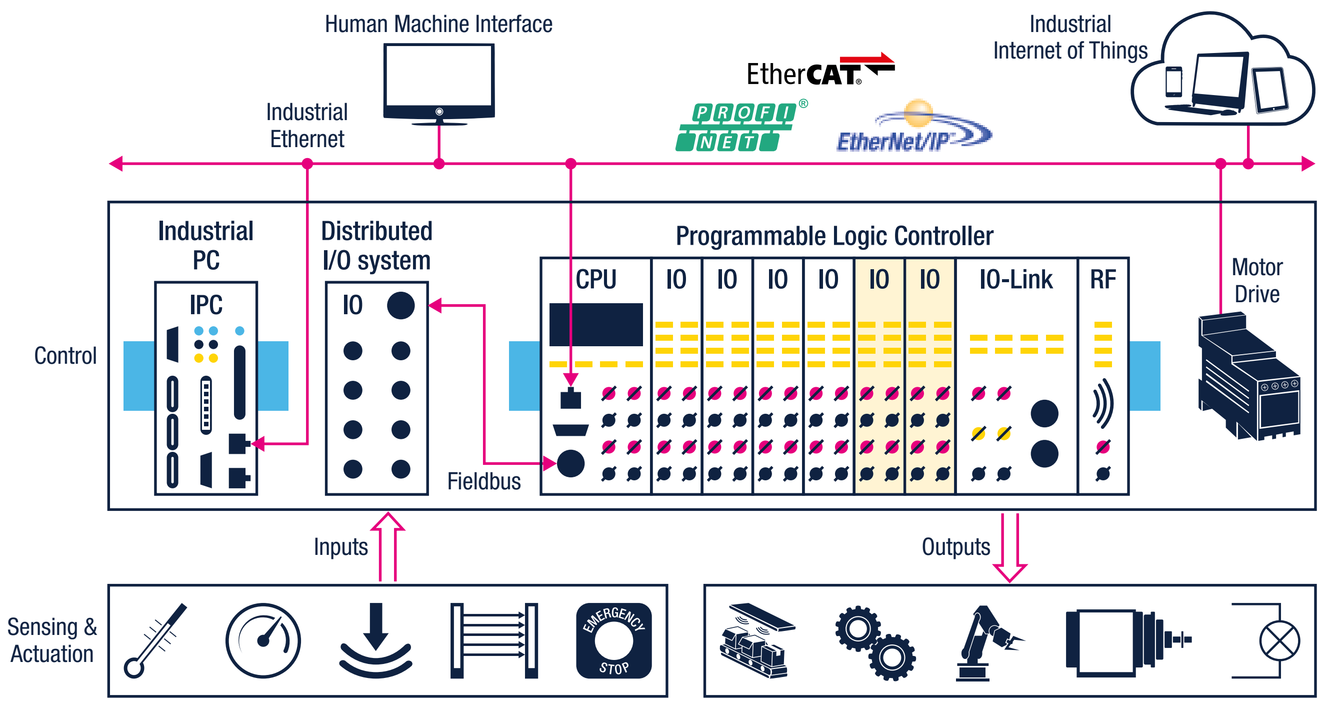

Figure 1 - Example architecture of an industrial automation implementation (source ST)

Typically, binary digital input signals operate with a logic high DC voltage of greater than 11 V, up to 24 V. A logic low is from less than 5 V down to 0 V.

Digital input modules convert these field-side signals from these relatively high voltages down to lower voltage levels usually used by the logic circuits of embedded systems, 3.3 V or 5.0 V being the norm (Figure 2).

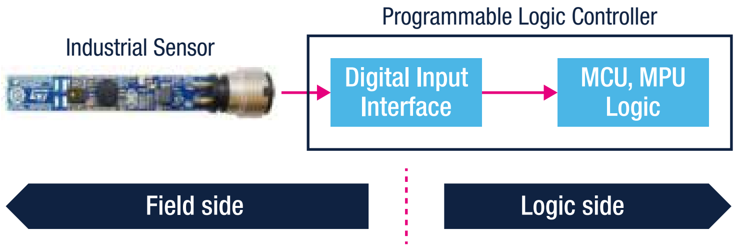

Figure 2 - Digital input interface and the conversion to logic side signal levels (source ST)

One significant challenge presented in the industrial domain is that it is electrically a noisy environment. Despite using shielded cables and EMI/EMC filtering, it is inevitable that digital input cables will pick up some unwanted transients.

To ensure the compatibility of safe digital signals across a broad range of industrial control systems and sensors, the IEC 61131-2 standard stipulates three different digital input types: Types 1, 2 and 3. Type 1 is for electromechanical switching devices such as push buttons and relays. Type 2 is for legacy solid-state two-wire sensors such as proximity switches. Type 3 is now widely adopted for modern low power solid-state sensors and the standard states that ideally, the digital input should draw close to 2 mA in the high state. It also sets a transitional threshold voltage range, moving from a high to a low, or a low to a high, of between 5 and 11 V (Figure 3).

Different digital input types according to IEC 61131-2 standard

Type 1

- Sensing electromechanical switching devices such as relays, pushbuttons, switches etc.
- Not suitable for two-wire solid state sensors due to low OFF-state current

Type 2

- Early solid state two-wire sensors with increased consumption (proximity switches).
- Standard two-wire proximity switches (IEC 61947-5-2)

Type 3

- Electromechanical switching devices as well as today's solid state sensors with low consumption

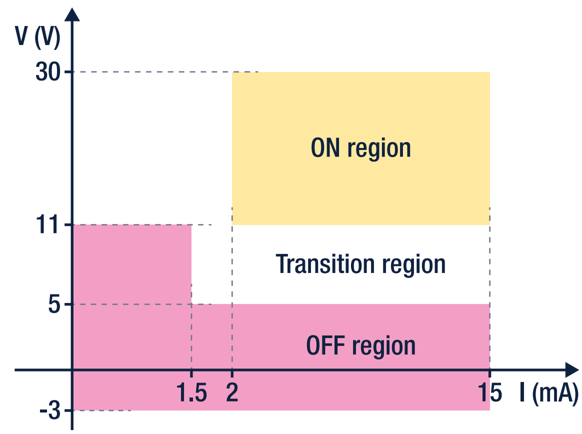

Figure 3 - Digital input characteristics as defined by IEC 61131-2 (source ST)

FUNCTIONAL SAFETY CONSIDERATIONS

The top-level functional safety standard for electronics-based systems is IEC 61508. This standard also forms the basis of certain industry- and application-specific iterations, for example, IEC 62061 for machinery safety. A core element of functional safety standards is the safety integrity level (SIL). There are four SIL levels, SIL 1, SIL 2, SIL 3, and SIL 4. A SIL indicates the frequency and severity of a hazard occurring. As the SIL level increases, the more dependable the application must be, and the greater the need for stricter safety measures.

The end-product must incorporate components and functions that ensure it meets the required SIL to comply with applicable safety standards. Safety functions may involve status monitoring and detecting critical component failure, indicating to a user that fault conditions compromised the system's safety integrity.

MANAGING AND INTEGRATING INDUSTRIAL DIGITAL INPUTS SAFELY

The design of a digital input module highlights a specific set of requirements. With multiple interfaces packed into a space-constrained control cabinet, each input module needs to exhibit a low power profile and not generate heat. It also needs to efficiently limit the input current per IEC 61132-2, and help ensure the end application complies with the relevant safety standards.

The simplest method of limiting the input current is using a passive resistor divider circuit (Figure 4). The divider has a linear voltage-to-current relationship, so as the input voltage rises, the current through the resistors also increases. An opto-coupler provides galvanic isolation of the digital input signal from the associated controller circuitry.

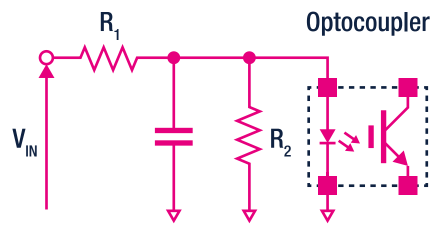

Figure 4 - A simple passive voltage divider circuit using series resistors (source ST)

While this divider approach is compact and straightforward, unfortunately, it presents a thermal management challenge. With a 24 V ON voltage, the power dissipation is substantial and may range from 120 to 290 mW. Using this divider method, a single 20 digital input module would generate upwards of 6 W of heat dissipation.

WHAT ARE DIGITAL INPUT MODULES AND WHY ARE THEY IMPORTANT?

Digital input modules are an important part of any industrial application. They provide several key functions:

- To protect and isolate the sensitive inputs of logic-side programmable logic controllers from the high-voltage signals coming from the electrically noisy and harsh field-side environment.
- Converting the high-voltage input signals, typically of 24 V_{DC}, to the 3.3 or 5 V_{DC} digital logic levels required by process logic controllers and microcontrollers.
- Providing input compatibility across a wide range of industrial sensors, and switches against the IEC 61131-2 industry standard. This includes limiting the input current within stipulated limits.

Key features to look for when selecting a digital input module:

- Complies with relevant industry standards
- Conforms to functional safety requirements and safety integrity levels
- Consumes very low or zero power to assist low power consumption attributes
- Has compact and space-saving dimensions for use in space-constrained control cabinets
- Is electrically resilient and robust to filter out transient voltage spikes – ‘deglitching’ input signals to the programmable logic controller.

IMPLEMENTING A SELF-POWERED AND NON-LINEAR METHOD OF DIGITAL INPUT INTEGRATION

A more viable, compact and low power approach to digital input current integration uses the **CLT03 series of current limiter termination ICs** from ST.

The CLT03 series is entirely self-powered from the digital input signal, and the semiconductor-based approach creates a non-linear voltage to current characteristic. It also accurately limits the current across the whole input voltage range to comply with the, typically, 3 mA specification of Type 1 and Type 3 definitions of IEC 61131-2.

Figure 5 compares the voltage and current characteristic curves for the passive resistor divider circuit and the CLT03 series.

The colored sections of Figure 5 highlight the ON, OFF, and transition regions as defined by IEC 61131-2. As highlighted, using the CLT03 solution significantly reduces the input current and represents a 40% reduction of input losses, and consequently, heat dissipation, during an ON signal. Most importantly, since the CLT03 devices are entirely self-powered from the energy on the digital input, there is no requirement for a field-side external power supply, and no power is consumed during the OFF state. From the perspective of heat dissipation, using the CLT03 solution results in an 80% reduction compared to a discrete component approach.

Figure 6 illustrates the main functional blocks of one-half of a dual-channel CLT03 IC in an example application.

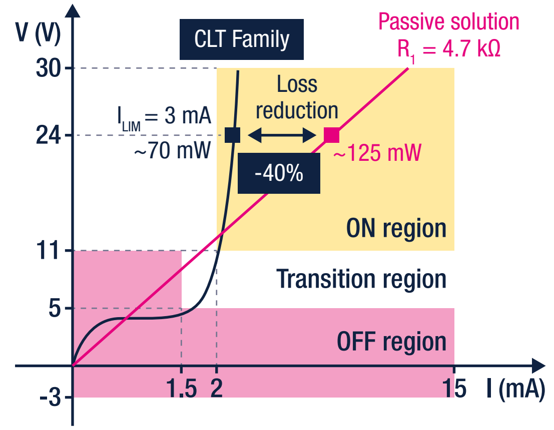

Figure 5 - Power dissipation comparison between a passive divider circuit and the non-linear self-powered CLT03 family of current limited termination ICs (source ST)

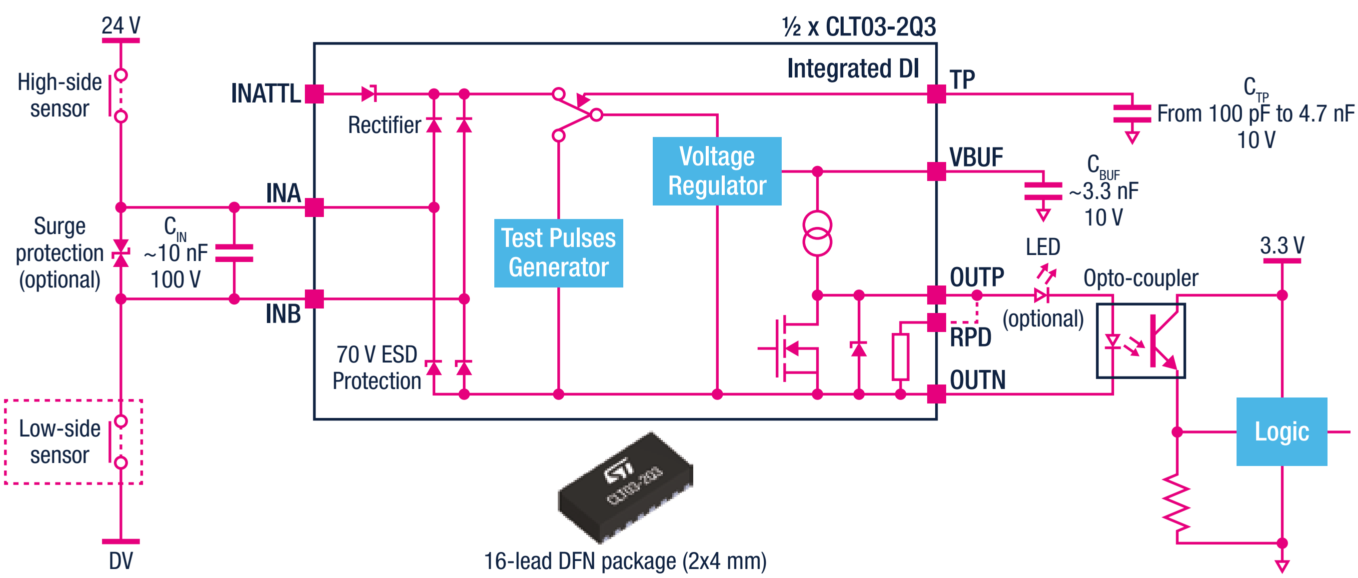

Figure 6 - Primary functional blocks of the CLT03 IC in an example application (source ST)

With its low power dissipation characteristics, the CLT03 series is ideal for increasing the number of input channels in a digital input module.

FUNCTIONAL SAFETY FEATURES OF THE CLT03 SERIES

The CLT03 incorporates several features that assist customers in achieving SIL certification and IEC 61508 compliance of their end products.

As 24 V input pins are prone to failure due to early ageing, the CLT03 offers better reliability than other typical integrated solutions as it is high voltage tolerant up to a maximum of 60 V. (The maximum digital input voltage industry norm is 45 V.)

Moreover, in the event that the input voltage exceeds a specified VFAULT threshold level, the CLT03 enters a fault mode to reduce power dissipation. It remains in the fault mode until the input voltage falls below the VFAULT threshold. During a fault, the output is set to OFF to prevent compromising worker safety or equipment damage. The CLT03 series is safe-by-design, for example, to prevent accidental damage during wiring, the inputs are reverse plugin compatible.

Another safety feature is the inclusion of a test pulse generator. System design engineers can implement a cyclic hardware connection test to the host microcontroller using the pulse generator. With this approach, the host application can instigate regular diagnostic checks during the input's ON state to determine if the digital input channel is working reliably. An external capacitor is connected to the CLT03 to enable this function, with the pulse period adjustable from 1.2 to 62 ms. Figure 7 shows the test pulses on the output signal during the output ON state.

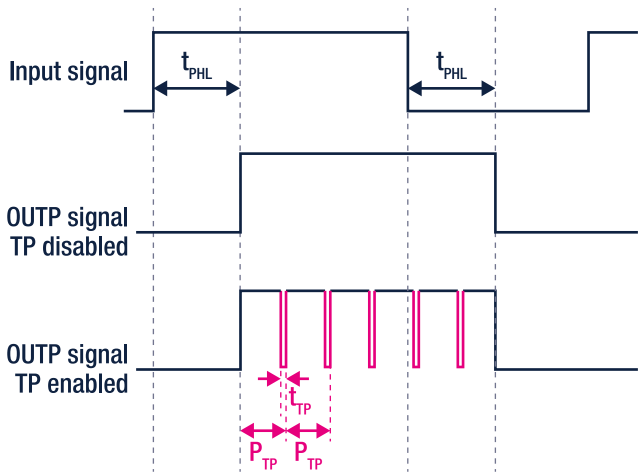

Figure 7 - The embedded test pulses on the output signal (source ST)

THE CLT03 SERIES OFFERS EASE OF DESIGN INTEGRATION

The IEC 61132-2 standard stipulates that each field-side input channel be equipped with a visual indication of the ON state. The CLT03's internal current generator can deliver between 2 to 4 mA, sufficient to drive a status indicator LED in series with the isolation opto-coupler. Figure 6 illustrates this implemented in an example application.

The space-saving CLT03 series is available in single- and dual-channel versions, providing board layout flexibility compared to more complex single-IC solutions. Also, with an embedded rectification block, high-side sinking and low-side sourcing inputs are accommodated in addition to AC signals. Most industrial applications require an isolated configuration, typically using an opto-coupler, but the CLT03 is also suitable for directly driving either CMOS or LVTTL logic in non-isolated designs without requiring any additional components.

For extra safety during operation, the dual-channel CLT03 devices feature galvanic isolation between channels, ensuring that a fault condition on one input channel will not impact the operation of the other channel.

RELIABLE OPERATION IN ELECTRICALLY NOISY INDUSTRIAL ENVIRONMENTS

All industrial applications need to operate reliably despite high-voltage transients generated by electrical switchgear, motor drives and control equipment. These transients can cause glitches to occur in sensors, upsetting their performance and consequently impacting overall system operation. To prevent these problems, the CLT03 series incorporates a deglitch filter to suppress overvoltage inputs based around a non-resettable monostable circuit (Figure 8).

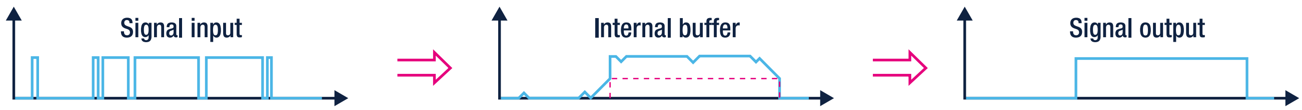

Figure 8 - Operation of the CLT03 series deglitch filter (source ST)

The CLT03 series includes protection against electromagnetic interference (EMI), surges, electrical fast transients (EFT), and electrostatic discharges (ESD). The series of devices comply with IEC 61000-4-5 (surges), IEC 61000-4-2 (ESD) up to ± 4 kV air discharge, and IEC 61000-4-4 up to ± 4 kV (EFT). For certification against the highest surge levels, as specified in IEC 61000-4-5, the addition of an external transient voltage suppressor (TVS) at the input stage is recommended (Figure 5). This solution is suitable with a high-speed data rate with limited impact on signals in normal operating conditions.

THE ST CLT03 SERIES OF SELF-POWERED DIGITAL INPUT CURRENT LIMITER ICs

The CLT03 series includes the **single line CLT03-1SC3** in a SOT23-8L package and the **dual line CLT03-2Q3** available in a QFN-16L format. The series suits both high-and low-side digital inputs with isolated opto-coupler systems or non-isolated applications.

To ease the design of factory automation systems using the CLT03 current limiter series, the **STEVAL-IFP035V1** evaluation board provides an ideal prototyping platform (Figure 9).

Equipped with two CTLT03-2Q3 devices for evaluating both dual input isolated and non-isolated digital inputs, the board only requires power for the isolated opto-coupler output.

Figure 9 - The STEVAL-IFP035V1 evaluation board for the CLT03-2Q3 series of self-powered current limited termination devices (source ST)

DESIGNING SAFE, EMI ROBUST, SELF-POWERED DIGITAL CURRENT LIMITED INPUTS

This whitepaper has highlighted the power and dissipation limitations of using a passive discrete component current limiter input for industrial programmable logic controllers.

A more robust, low-power approach uses the CLT03 series of digital input current limiters yields much less heat generation, enabling greater input module density in space-constrained industrial control cabinets. With its integrated features easing SIL certification of final applications, the CLT03 series suits a broad range of process, industrial, and building automation applications.

ADDITIONAL RESOURCES

Self-powered CLT03 digital input current limiter portfolio [Web page]

CLT03-1SC3 and CLT03-2Q3 or How to Make Smaller Digital Input Modules [Blog post]

ST solutions for self-powered digital input applications for use in efficient, compact industrial control systems [Video]

Self-powered CLT03-2Q3 current limiter evaluation board (STEVAL-IFP035V1) [Product page]

ST Protection Finder mobile app. Easily identify the device that best fits your application using the parametric or series search engine [Product page]

APPLICATION NOTES

- [AN1608] Evaluating the robustness of the CLT3-4 quadruple input digital termination device against electromagnetic disturbances.
- [AN2846] Guidelines for using the SCLT3 8-line protected digital input termination devices with serialized state transfer in industrial automation applications
- [AN2482] Recommendations for robust PCLT designs regarding EMI and thermal behavior and other application design tips
- [AN3031] Guidelines for using the SCLT3-8 input termination demonstration board (STEVAL-IFP007V1)
- [AN4625] Guidelines for using the CLT01-38S4 input termination evaluation board (STEVAL-IFP023V1)

Order code: **BRWP2204CLT03S**

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