Improving the Ins and Outs of the Digital Factory

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Executive Summary

Designs of digital input and output modules for automated industrial controllers have, historically, been discrete in nature. Industry 4.0, the next revolution in the way factories run, will demand not only cloud control, but also faster throughput to maximize efficiency and profits. Throw in more diagnostic features to increase uptime, all in a significantly smaller form factor with lower power, and it sounds like we’ve got a tall task on our hands.

The first step in the journey: for designers to become educated on the available integrated devices in the market, so that DI and DO modules can, ultimately, realize their performance potential.

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In the digital age, performance expectations for the latest devices just keep getting higher. We hear about wafer process geometries getting smaller: nanometers are now a common measurement, and products that years ago were as big as a loaf of bread are now the size of a deck of cards. In many markets, this semiconductor-driven trend is apparent. Not so obvious, but no less important, is the way it’s affecting factory automation.

Industry 4.0, a term that originated in Europe but is catching on globally, has become the official name for this next revolution in production and manufacturing capabilities. It is characterized by decentralized, intelligent control systems. In addition to Internet connectivity and control, industrial controllers are getting overhauled with the latest in semiconductor technology and design methodology. And, in this overhaul, the age-old adage still applies: make it faster, cheaper, smaller, and cooler.

Programmable Logic Controllers (PLC) are the primary equipment on the factory floor to help ensure high efficiency, fast throughput and maximum profits. Today’s PLCs are located throughout the factory floor, close to the key processes they control. Both digital and analog inputs and outputs help feed necessary information in and out of each PLC; this article will focus on the digital I/O of PLC-like equipment.

Historically, digital input and output modules are designed using discrete components. As a matter of fact, it is common practice to pass down the same designs from one generation to another, with slight changes to a few building block devices here and there. Once a design becomes proven, with customers and longevity in the field, major changes are often difficult to carry out. But, once a large OEM or even a small manufacturer releases a smaller PLC, with more features like lower latency and heat dissipation, the rest of the market will follow.

The most common card of an industrial controller is the digital input (DI) module. This module takes in signals from industrial binary sensors or switches, which are spread throughout the factory floor, monitoring for parameters such as liquid levels and proximity of objects to name a couple. An input signal of 0V is defined as “OFF”; 24V, which exceeds a predefined threshold, is “ON.” The job sounds fairly straightforward; accept two different voltage levels, translate them to a lower logic level, and pass that on to a microcontroller or central processing unit to make a decision and take action.

Unfortunately, it’s not as straightforward as one might think. If designers are not aware of integrated devices in the market, a discrete approach might well be taken, with a path leading to a simple resistor divider. Such dividers need to accommodate the voltage range of poorly-regulated 24V supplies on the factory floor, which could lead to wide swings between sub-20V and 30V+ levels. Designers also need to keep in mind type 1, 2, and 3 digital inputs, per IEC 61131-2. For example, if the supply voltage is 32V, and you have a resistor of, say, 3 kΩ, then applying Ohm’s law, current flow would be 10.7mA. That may not sound like much, but for a card with 16 digital inputs, wattage could potentially add up to skywards of 5.5W, and that’s not taking into account the other components. Adding a current limiter is a good idea to minimize heat dissipation, but doing this with discrete components is not the most cost-effective way and will take up additional board space.

Isolation is also needed for the individual lines, via either single-channel optocouplers for each line or multi-channel isolators. To minimize the number of isolation lines, a serializer could be used; but those will be difficult to find as well, since they’re mostly designed for Gigabit
Ethernet equipment, which would be expensive and overkill for DI modules. But, if one could find all of the necessary components, the result might look something like Figure 1.

![Figure 1 - Proposed Discrete Digital Input Design](image)

Fortunately, there are integrated devices that incorporate all of the aforementioned features. The MAX31910-MAX31915 family, for example, is a family of octal channel digital input serializer/translators which incorporate a 5-bit CRC, including a few that offer a patent-pending ultra-low power mode. As a test, one of these Maxim devices and a competing part were mounted on a socket so as to emulate a worst-case scenario where the center heat slug is not soldered to the board ground plane (and therefore there is no heat-sinking effect provided by the PCB), while all eight inputs were tied to 24V and limit set to 2.4mA. As shown below, the difference is significant; competitor A rose +41°C from a room temperature of 25°C while Maxim rose only +23°C, as shown in Figure 2.

![Figure 2: Thermal Image of Maxim vs. Competitor A](image)
CRC’s error detection methodology ensures reliable communication in noisy industrial environments, and is more robust than other DI serializers with parity error detection. By incorporating the latest advancements in integrated digital input serializer/translators, manufacturers can reduce solution size by 50% and power/heat dissipation by up to 80%, compared to discrete designs. The result might look something like Figure 3.

Digital Output: Boosting Performance and Broadening Options

As for the digital output module, a similar line of thinking can be expected barring awareness of the integrated options available. Discrete designs for DO cards are common, and there are a variety of design approaches; a parallel drive directly from the local micro, or a deserializer connected to individual or multichannel FET drivers. The result may look similar to Figure 4. The actual FETs could be integrated into the driver, or external. There are advantages to both scenarios; integrated FETs save space, and external FETs provide flexibility in terms of the wide range of performance based on blocking voltage and current capabilities.

Many of the FET drivers in the market have UVLO to make sure voltage levels are sufficient before proper operation. Some also have a temperature shutdown mode in case there’s either an abnormal rise in temperature or possibly a short or high current occurrence. This feature is helpful in preventing damage to the die/part itself, and alerts the system of such a condition.

Moreover, DO designers want to make sure the driver in the DO module is capable of handling all kinds of loads; predominately inductive and resistive loads, and a few capacitive loads as well. For resistive loads, many legacy systems on factory floors still use filament lamps for indication instead of LEDs. This kind of lamp is one of the most difficult to drive because when the lamp hasn’t been driven in a while and the filament is cool, the filament resistance is around 20 or so ohms. Initial turn-on will demand high current, in the several amps range, which could cause the driver to trip because of a short circuit. After the filament heats up and settles, the resistance goes up to a few hundred ohms, and the current required is in the tens of milliamps range, less taxing for the outputs. Drivers for resistive loads need to keep this in mind.

For inductive loads, there are typically motors, solenoids, and electromechanical relays on the factory floor. Inductive kickback (surge) occurs when an electrically generated field collapses. A voltage spike occurs over the load in the opposite direction (polarity) to maintain the current flow. This fast and large voltage potential is
also imposed over the FET or transistor, where it is high enough to cause electrons to jump across the junction and either cause irreparable damage, or at the very least shorten the life of the device. A common solution to combat inductive kickback is to use a flyback diode to prevent and redirect the current from going across the FET. As a rule of thumb, the voltage rating of the diode should be 10 times the normal operating applied voltage, and its current rating should be at least as high as the current flowing through the load. Figure 5 shows a simple implementation of a flyback diode for a motor driven by a FET circuit.

There are other implementations of flyback diodes, for different turn OFF performances. The examples in Figure 6 show different diode circuits for an electromechanical relay.

For motor applications, two diodes are required. The bottom diode will conduct when the power is shut off abruptly to conduct current away from the switch. The top diode will conduct when the motor is braking or going in reverse and current is directed to the power supply. Both diodes are also required for IEC 61000-4-5 surge testing.
Protection of the drivers is important for the longevity and long-term operation of the circuit. Incorporating the diodes or some protection circuitry from kickback can save PCB space, but the potential downside is that the current conducted inside the package will increase junction temperature, potentially wearing out the IC compared to external protection. Most designers prefer to have external protection (secret sauce), using a protection circuit that has been proven in the field with their customers. Other beneficial features are monitoring of temperature, supply levels, and global or individual driver channel diagnostics.

There are, however, integrated, multi-channel, digital output drivers, better known as industrial high-side switches. They combine many different diagnostics and configurability, for a wide variety of performance options. A standout in the market is the MAX14900E from Maxim Integrated. It’s an eight channel, 850mA high-side switch that is highly configurable with extensive diagnostics. What differentiates this device from others are the low latency and low power performances. Its short 0.8μs propagation delay, in push-pull mode, is right in line with the trend toward increasing throughput to boost efficiency. Its comparatively low power is attributable to the low 165mΩ RDS(on) of the FETs at 125°C. This allows for improved power densities and a smaller form factor in the DO module designs. Another notable feature is the CRC error detection, which is proven to be more robust and accurate than parity error detection.

When it comes to the design of digital input and digital output modules, designers need to take note of the integrated options in the market. Discrete designs are time-consuming and sometimes make it difficult to squeeze in more features while either maintaining the same or smaller size. Maxim Integrated is a leader in this space, with superior performance in power savings, throughput, and robustness.

To learn more, go to http://www.maximintegrated.com/PLC_Solutions.

About the Author
Robert Gee's 25-year career encompasses in-depth experience in the fields of application engineering and product marketing. He currently serves as Executive Business Manager for Maxim's Mass Market Solutions Business Unit. Robert earned his BSEE from the University of Massachusetts at Amherst.