Accelerating automated manufacturing with advanced circuit isolation technology

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Anyone who has felt a tingle of electric current when touching a wall socket or a badly grounded appliance isn't eager to repeat the experience. After all, the next time it could be fatal.

Stray currents and excessive voltages—the same phenomena that are potentially dangerous to human beings—can also damage equipment, especially electronic controls, which are extremely sensitive to overcurrents and overvoltages. Even when these conditions don't cause permanent damage, they can interfere with electronic signals and cause equipment to malfunction. Protecting people, equipment and operating signals from this type of interference is the job not only of various types of insulation, but also of isolation between different circuits. Isolation, while less well-known than insulation, is nonetheless very important—so important, in fact, that devices that provide isolation represent as much as a one billion dollar market annually.

Circuit isolation matters in all areas of electronics, ranging from hand-held consumer gadgets up to large equipment used in communications infrastructure, transportation and heavy industry. Today isolation is especially significant in industrial environments, as more and more automated factory equipment communicates with each other and outside networks. This increase in machine intelligence and automation is occurring so rapidly that it has been dubbed the Fourth Industrial Revolution. Intelligent sensors, actuators, motors, robots and other factory equipment must be protected from power surges and transients and shielded from stray signal interferences in order to operate reliably. Circuit isolation is key to achieving these goals on factory floors. It is also key to safe and reliable electronic operation in automobiles, medical equipment, telecommunications, office machines, consumer products and a number of other application areas.

To deal with increasing demands for safety and robust reliability, equipment makers are demanding more sophisticated isolation solutions from integrated circuit (IC) suppliers. Among the leading semiconductor manufacturers, Texas Instruments (TI) devotes considerable resources to research and development of advanced technologies for isolation, then uses these technologies to create products that fulfill the requirements of industrial and other systems. As more advanced isolation devices become available, system manufacturers can create circuits for power, communications and control that are better protected. These circuits then help distribute intelligent automation on the factory floor, bringing higher quality, cost control and energy efficiency to manufacturing processes, along with increased worker productivity and safety.

The need for circuit isolation

Isolation, also referred to as galvanic isolation, is a means of preventing direct current and unwanted alternating currents from passing between two different parts of a system while allowing signal and power transfer to occur. As the word suggests, isolation means the physical separation of one part of a circuit from another via a transformer, capacitor, optocoupler or other device. In application, an isolator is typically used for either the low voltages and currents associated with signal transfers, or the much higher voltages and currents associated with line power. In some cases, however, a single component may serve for both power and signal isolation.

Equipment operating on line power may be subject to surges, when a voltage higher than the rated voltage is sustained for a period of time, as well as brief spikes or transients at extremely high voltages. Line voltage disruptions can occur when heavy equipment such as motors power on and off or change loads, affecting other equipment supplied from the same source. Electronic noise that enters along with line power or by other means can interfere with signals in the control circuitry, potentially causing operational problems. Many types of equipment develop frequencies that have to be prevented from feeding back onto the line power and thus being transmitted to other equipment where they might interfere with signals. Switching power supplies, for instance, which are commonly used in industrial equipment to convert line voltage into pulsed voltage, develop high frequencies in the conversion process. Power isolation serves to protect the equipment, including its control electronics, while also helping to prevent the unit from feeding back unwanted signals onto the line.

Even when the current and voltage levels are not sufficient to damage the control devices, they can still corrupt communications among systems and among different areas of the same system. Equipment such as programmable logic controllers (PLCs) can operate with multiple voltage levels and ground references, so that different parts of the system have to be isolated from each other to maintain signal integrity. Communications cables between equipment can result in a ground loop that subjects the systems to environmental electrical noise. Some parts of an electronic system, such as transmitters or processors, may develop high frequencies that have to be prevented from corrupting signals in low-frequency circuits.

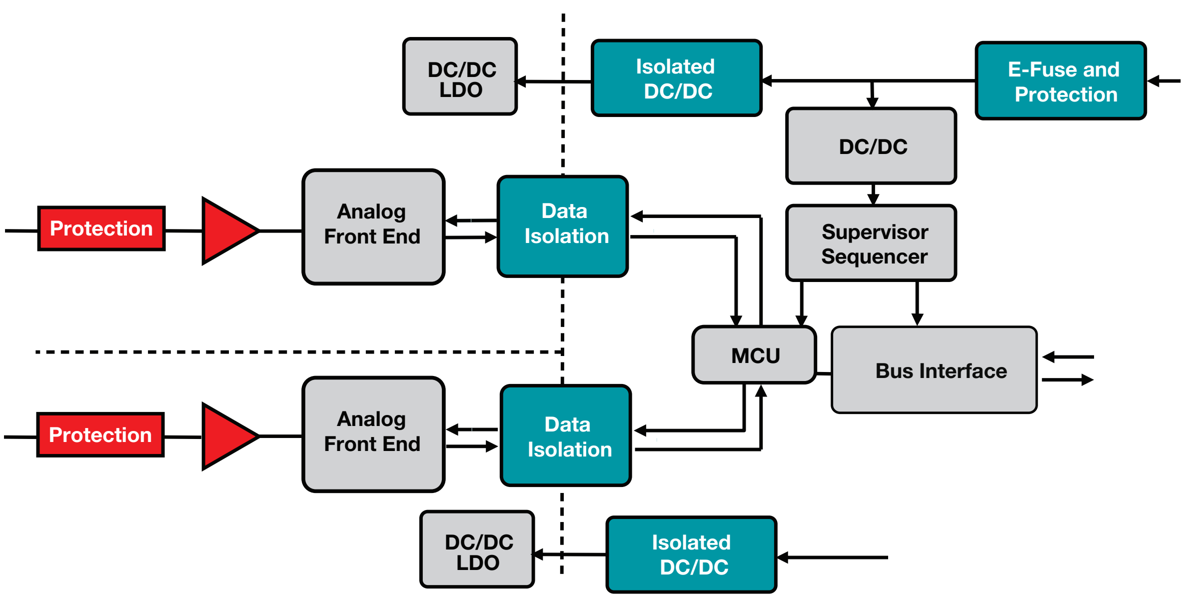

Figure 1. PLC with isolation

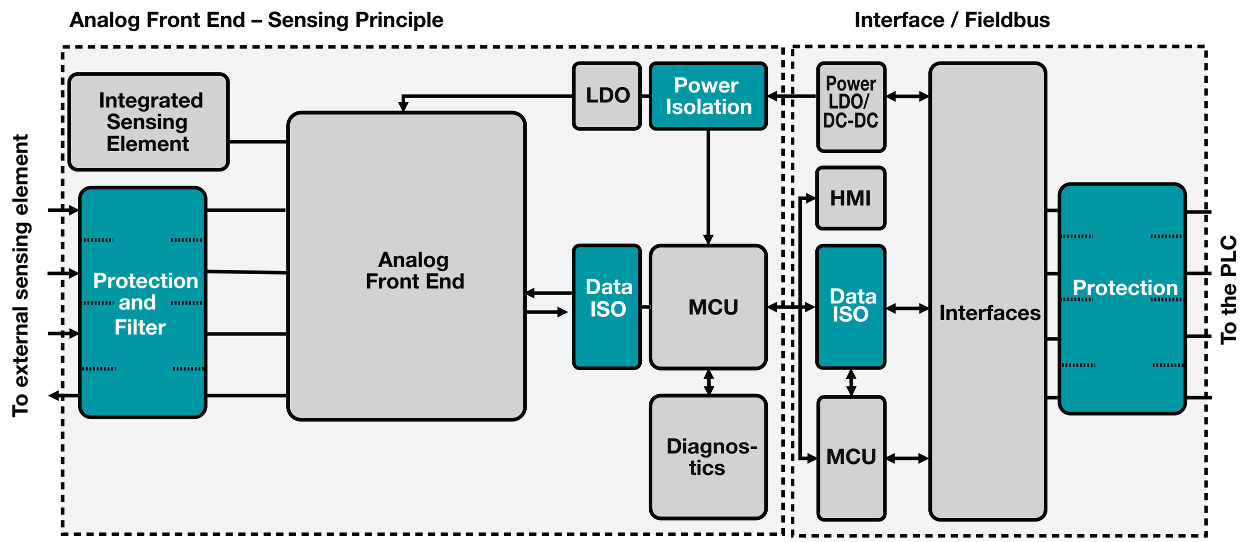

Figure 2. Sensor with isolation

These issues apply even in systems without line power, such as battery-operated sensors, which incorporate high-frequency microcontrollers and communicate with control systems via high-frequency wireless transmission. Sensors also operate from an extremely low current and often need protection from sensing elements that are subjected to external materials that may be electrically active. In all these cases and others, isolation serves to prevent signal noise from being passed along and potentially corrupting needed communications.

A manufacturing environment typically focuses equipment control on PLCs, the central units that communicate with and regulate multiple units on the factory floor (field units). PLCs, in turn, are usually programmed and monitored by users at computer terminals that are networked with the plant offices and the Internet. All of these factory and office units require isolation at various points for power protection and signal integrity. Figure 1 shows the need for isolation in the functional blocks of a PLC, and Figure 2 shows isolation in a battery-operated wireless sensor. This sensor could be battery operated or use power provided by the isolated power block.

Requirements for improved isolation technologies

Like all electronic components, ongoing requirements for smaller scale with the same or higher performance drive the isolating elements. These requirements are particularly strong in factory automation, where processes for temperature, moisture, vibration, chemical and other types of control are rapidly incorporating small footprint sensors. PLCs also require rescaling to introduce more communications channels, enabling manufacturers to pack more operational control in the same space. In addition, new high-speed communications in PLC backplanes demand reduced signal latency for greater bandwidth in the control of more systems. On the power side, new transistor technologies such as gallium-nitride (GaN) and silicon-carbide (SiC) demand higher isolation voltage and frequency characterization to achieve greater energy efficiency.

Traditionally, isolators have been relatively bulky components that are somewhat sluggish in signal response. Based on technology that makes integration difficult, isolators have usually been discrete components that consume considerable board space outside of the chips that contain most of the system circuitry. One primary goal of isolation technology development today is finding more effective ways to rescale isolating components and integrate them in chip packages, while at the same time improving signal bandwidth and lowering latency. Achieving this goal is especially challenging because miniaturizing the isolating components while improving their characterization is very difficult. In addition, integrating them introduces into the IC package the same power and signal interferences that are meant to be kept away by the isolators.

Another industrial requirement is high reliability. Isolation components must be rigorously tested to meet a variety of specifications that are spelled out in industrial standards. Key parameters include maximum repetitive peak voltage levels, maximum transient and surge levels, and working voltage levels over time. Common mode transient immunity (CMTI), a measure of how well the isolator prevents rapid changes in current (di/dt, or the slew rate) from rippling across the barrier, is also very important. To help designers prevent conditions that can short around the isolator, measurements are also specified for distances separating the outside pins of the package along the surface and through air, and for the ability of the package to withstand breakdown. While many of these parameters are determined by direct test measurement, others result from accelerated-stress measurement tests that extrapolate the behavior of the isolator in application over the course of many years. Protecting the system is important both immediately and throughout its lifetime.

Isolation that provides sufficient protection for operation is referred to as basic or functional isolation. Industrial standards demand double this level of isolation for safety, a specification that equipment designers have often met by using two isolation components in series. IC manufacturers are now working to introduce more effective reinforced isolation, which meets the specification and saves space by providing the equivalent of two or more times the value of basic isolation in a single component. Reinforced isolation requires improvements in design and packaging, as well as the introduction of a more highly rated dielectric, the insulating material between the two sides of the transformer, capacitor or other isolating component. Fortunately for the goal of integrating isolation functions, the silicon dioxide (SiO2) that provides insulating layers between components within ICs is an excellent dielectric and can serve well for on-chip isolation.

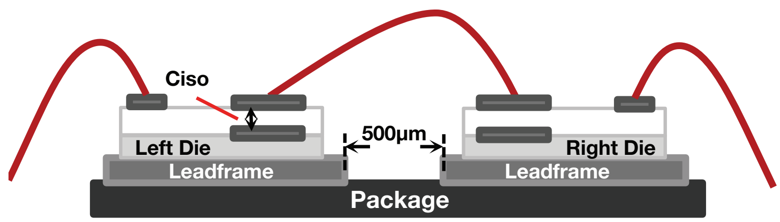

Figure 3. Block diagram of MCM with isolation capacitors

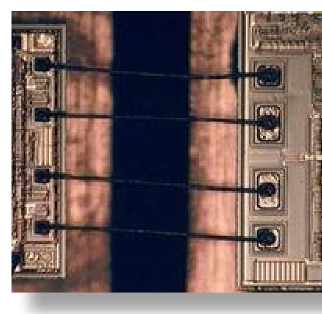

Figure 4. Photo of MCM with isolation capacitors

Innovative integration of capacitor-based isolation

All isolation devices must deal with capacitance, the potential difference established between two separated conducting surfaces when one side is energized. Capacitance is parasitic in most types of isolators; however, capacitors serving as isolating devices make a virtue of what is a design problem for other isolation techniques. The technology for integrating capacitors (using SiO2 as a dielectric) is also well established, though new applications such as isolation always bring new issues in design and manufacture.

While isolating capacitors can be integrated on a die along with circuitry, the speeds that are operative still require a degree of physical isolation between high- and low-frequency circuits that can be achieved only by using separate chips. Figure 3 illustrates how capacitors are used for signal isolation in a multichip module (MCM), and Figure 4 shows a photo of the same. The high-frequency circuitry is on one chip, and lower-frequency circuitry is on the other. Bond wires between the two devices connect to capacitive pads that isolate incoming signals before relaying them to internal circuitry. As the inset figure shows, the capacitor is formed between the plate of the bond pad and a plate at a lower level in the IC.

Recently introduced IC solutions leverage this technology to provide capacitor-based reinforced isolation in an MCM. TI's ISO78xx multichannel digital isolators, for instance, provide protection for up to 8000 volts at peak and transmission speeds up to 100 megabits per second (Mbps). These modules not only provide reinforced isolation that meets industrial specifications, but they also do so in a space-saving MCM that can be used in PLCs and a variety of other factory equipment.

Circuit isolation pulls factories together

Protecting people and equipment, and maintaining signal integrity are responsibilities of circuit isolation. Today, this long-standing technology is receiving renewed attention as factory automation demands more connection, communication and control to achieve new levels of precision and efficiency. Intelligent PLCs and sensors are today driving the need for new forms of isolation, but the benefits will extend to all industrial equipment, as well as to automotive, telecommunications, office machines and other markets. New integrated solutions with reinforced capacitor-based isolation technology are already proving their value in these systems, and continued innovation is expected in the future.

TI plays a leading role in researching new isolation technologies and using them to develop innovative solutions to continue to evolve the industrial market. TI technology advancements are an important enabler of intelligent factory equipment -- accelerating industrial automation today and in the years to come.

For more information:

- White paper: High-voltage reinforced isolation: Definitions and test methodologies
- TI's reinforced isolation web page

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