TOSHIBA

Digital isolation supports the growing needs of industrial designs

Executive summary

Galvanic isolation between circuit blocks is a key requirement in systems where high- and low-voltage circuitry need to interact. Low-voltage circuitry that is sensitive to electrical surges and spikes must be protected to avoid damage that may cause safety hazards or decrease system reliability. As system designs become more sophisticated and turn to higher frequency operation to improve efficiency, issues arise with traditional approaches to isolation such as the use of optocouplers, in terms of both component size and speed of response. Digital isolation based on Toshiba's magnetic coupling technology provides the speed and flexibility to meet these challenges.

The need for isolation

Isolation is a vital element of many electronic system designs, particularly those that maintain industrial processes, automotive systems and consumer appliances. The circuit boards of these systems often need to support subsystems that operate at high voltage and current levels that interact with control elements that deal with much lower voltage supplies and signals.

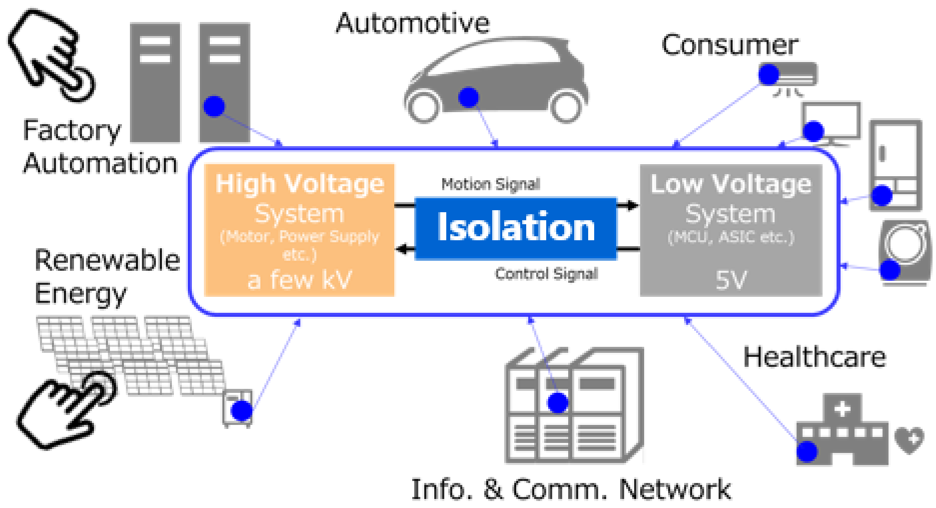

Figure 1: Numerous types of applications call for galvanic isolation between high- and -low voltage subsystems

The presence of high-voltage and high-current circuitry on the same PCB can give rise to many problems, from data corruption to safety hazards. If the different sections of the system are not isolated from each other, electrical noise and spikes can propagate from high-voltage subsystems and external I/O to the low-voltage circuitry.

The electrical noise can affect the inputs to sensitive mixed-signal components such as analog-to-digital converters, resulting in false readings. Stronger pulses may lead to bits being flipped in transfers from memory and other digital peripherals to the host processor. Stronger spikes may cause damage to semiconductor components, potentially resulting in latch-up conditions that lead to total system failure. The heat generated in components not designed to handle the stresses can lead to fires. And the breakdown of insulation caused by these spikes may lead to I/O cables that are normally considered safe to handle delivering dangerous electrical shocks to operators and users.

Even at relatively low levels, exposure to repeated electrical surges can lead to reduced system reliability. Inadequate protection can not only affect the performance of the circuit itself but can also lead to the equipment generating electromagnetic interference that is coupled onto I/O lines and power cables, potentially disrupting the operation of

nearby electronic equipment. Such a condition will probably result in equipment being unable to pass the electromagnetic compatibility (EMC) testing needed in most territories where it will go on sale.
Systems will need isolation at most points where low- and high-voltage subsystems need to interact, such as the control signals that are delivered to power converters or to electrical motors. Effective isolation prevents direct current transfer from one side to the other.

Increasing demands

As system designs become more sophisticated, isolation has to meet tougher demands. In automotive applications, manufacturers increasingly take advantage of devices that are made on more advanced semiconductor processes. These components operate at lower voltages and are more sensitive to over-voltage and over-current conditions.

Design changes are also being exploited on the high-voltage side of the system. Wide-bandgap power semiconductors can handle far higher switching frequencies than conventional silicon devices. Motor designers are embracing these devices because their ability to handle high switching rates not only reduces overall size but also delivers significant improvements in power efficiency. Compared to traditional architectures, these switching strategies call for higher frequencies on the control lines used for tasks such as pulse width modulation (PWM) that pass between the low- and high-voltage domains.

The increased use of networked control in which data signals are passed to each other by cooperating systems such as programmable logic controllers (PLCs) or the management systems in green-energy installations puts additional demands on isolation used to protect against EMC and voltage surges from external equipment. These distributed control systems demand the ability to support high-speed digital protocols at speeds that can reach 100Mb/s and beyond. Not all isolation products can support this requirement.

Conventional technologies

Traditionally, the optocoupler has proven to be a reliable form of isolation for many applications. The technology offers excellent isolation between domains because there is no electrical connection between the two sides of the device. The optocoupler uses a light-emitting diode (LED) on the transmitter side to convert incoming electrical signals into photons. A non-conductive transparent barrier conveys the light to a photodetector on the receiver side.

Because the LED can generate a light signal that is proportional to the electrical input, the optocoupler can either support analog or digital signals. Further, it offers a high degree of EMC, because photons are unaffected by electrical interference. Optocouplers can be obtained in compact packages, making them suitable for designs where space is at a premium and where isolation is needed only for a few channels. Because they are often supplied as discrete parts, size can become more problematic if the design calls for a larger number of parallel communications channels to be isolated. Isolation of high- and low-side PWM outputs and fault-signal inputs, for example, can call for as many as eight devices.

Though optocouplers can work well for lower-datarate protocols such as I2C and analog signals, the transmission bandwidth is limited by the response times of both the LED and the photodetector. In practice, the maximum achievable digital datarate is around 50Mb/s. A further issue is that the light output of the LED degrades over time, which may affect system performance and accuracy.

Capacitive coupling provides another form of isolation that can be suitable in scenarios where a lower level of isolation is required. Manufacturers have employed this form of isolation in integrated devices that need to support both high-

voltage and low-voltage electrical paths. The coupler works by using the charge and discharge of a capacitor, blocking a direct flow of current up to the breakdown voltage. An advantage of capacitive coupling is that it is simple to integrate, supporting multichannel communications. However, isolation is limited to the breakdown voltage of the insulating layers of the capacitor, which may not block potentially damaging high-voltage spikes. Another drawback is that they can only support digital signals, which may limit applications in I/O circuitry.
One of the earliest forms of galvanic isolation to be used, inductive coupling can offer a better combination of features. This form of isolation takes advantage of induction to transmit signals across an insulating barrier. The electromagnetic field produced by changes in current in the primary winding induces a current in the secondary winding, allowing a signal to pass.

Used in electrical transmission, magnetic inductance can operate in very high voltage systems and deliver highly effective isolation into the range of hundreds of volts. The transformers can have a very long operational life and can work across a broad frequency range that is larger than that supported by optocouplers.

A new generation of magnetic coupling

Though magnetic coupling may be more familiar in the form that calls for bulky discrete transformers, advances in semiconductor technology have made it possible to integrate inductors into much smaller chip-level products. An example is the DCL54x01 series developed by Toshiba Electronic Devices & Storage. This digital isolator comprises two co-packaged chips, one acts as a modular and the other demodulates the received signal. Separated by a dual insulation barrier, magnetic coupling from the windings etched into the modulator passes the signal to the windings on the demodulation chip.

Sometimes known as inductive coupling, the high-integration isolation provided by Toshiba's magnetic coupling technology delivers safe operation in systems that involve high-current and high-voltage circuit paths. To ensure protection against voltage surges as high as 12.8kV, as measured using the tests specified in the IEC 61000-4-5 standard, the DCL54x01 employs a double-isolation structure to ensure safe operation, even under extreme conditions. In addition to the air gap between independent chips, insulation film resistant to high voltages protects the electrical structures on each chip. The structure prevents shorts between the two sides of the isolation if the primary insulation barrier fails and enables the device to satisfy the demands of the VDE V 0884-11 standard. The design provides a long insulation life of an estimated 70 years, based on measurements using standard time-dependent dielectric breakdown (TDDB) tests with 1.2kVrms pulses. This long life supports green energy and industrial applications where the service life may extend for decades.

The modulation scheme used by the DCL54x01 takes the form of off-keying, in which high- and low-level states are represented as the presence and absence of a carrier signal, respectively. This digital-signaling method provides a highly reliable method for passing data at rates of 100Mb/s and higher. It also delivers high noise immunity, including the common-mode transients that are often encountered in high-power circuitry.

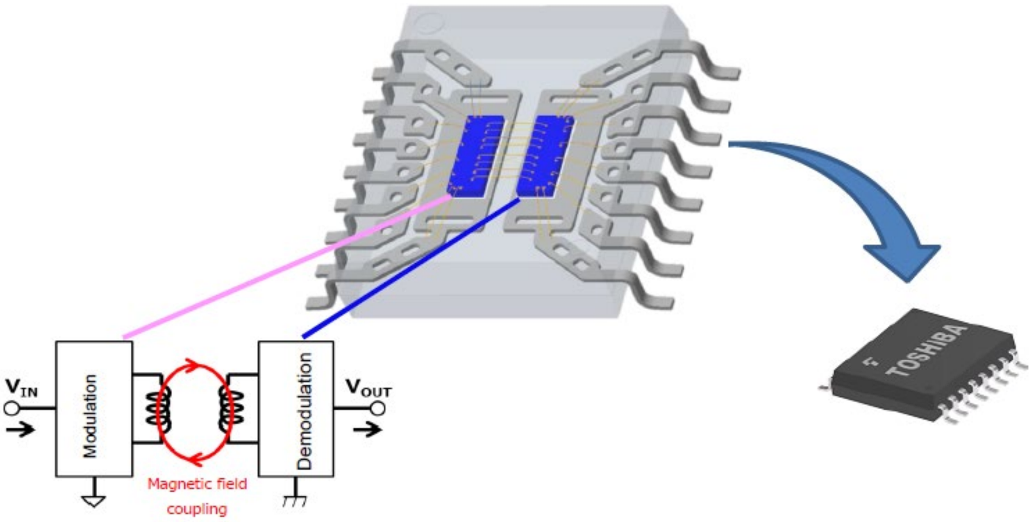

Figure 2: Digital Isolator Structure

Common-mode noise is a type of noise where current flows in the same direction on both the signal and ground lines. Isolation against this form of noise is more difficult to achieve because the displacement current acts on both signal and ground lines. This noise might couple through an isolation barrier, particularly in the case of capacitive isolation products. If the current coupled onto the receiver side reaches a certain level, it may cause a malfunction not just in the isolation interface itself, but across the entire system. High common-mode transient immunity (CMTI) is essential for reliable operation. Magnetic coupling products deliver this immunity. The DCL54x01 has been tested to deliver protection at more than 200kV/µs under standard CMTI protocols.

Off-keying modulation provides a highly effective and reliable method of communicating PWM signals from a microprocessor to the gate drivers controlling a motor or inverter on the high-voltage side of the PCB. In the DCL54x01, the method delivers a pulsewidth distortion of less than 3ns, ensuring accurate transmission of PWM and other high-speed logic-level signals.

The high integration available with semiconductor-based inductive coupling provides the ability to implement multiple parallel channels into the same package. Products in the DCL54x01 family provide up to four channels in a variety of forward-reverse configurations, including four forward channels and two pairs of forward and reverse channels with the option to enable controls on one or more of the input channels. With a propagation delay of 21ns, channel-to-channel propagation delay difference lower than 3.9ns.

Integration: an example

Flexible configurations available with the DCL54x01 provide many locations for high-grade isolation in PLCs and similar systems. A PLC is typically separated into several cooperating modules connected by a common backplane supporting low-voltage power rails up to 24V alongside 5V control paths. The power module will require isolation for the PWM signals responsible for switching power transistors on and off, as well as to protect control signals that monitor the power circuitry. To avoid shoot-through and similar switching issues, multiple PWM signals may be needed, which increases the number of parallel control signals. Support for reverse-direction signals in the same isolation device enables error signals to pass from the power stage to the controller. Any motor-controller modules will require a similar combination of isolated paths.

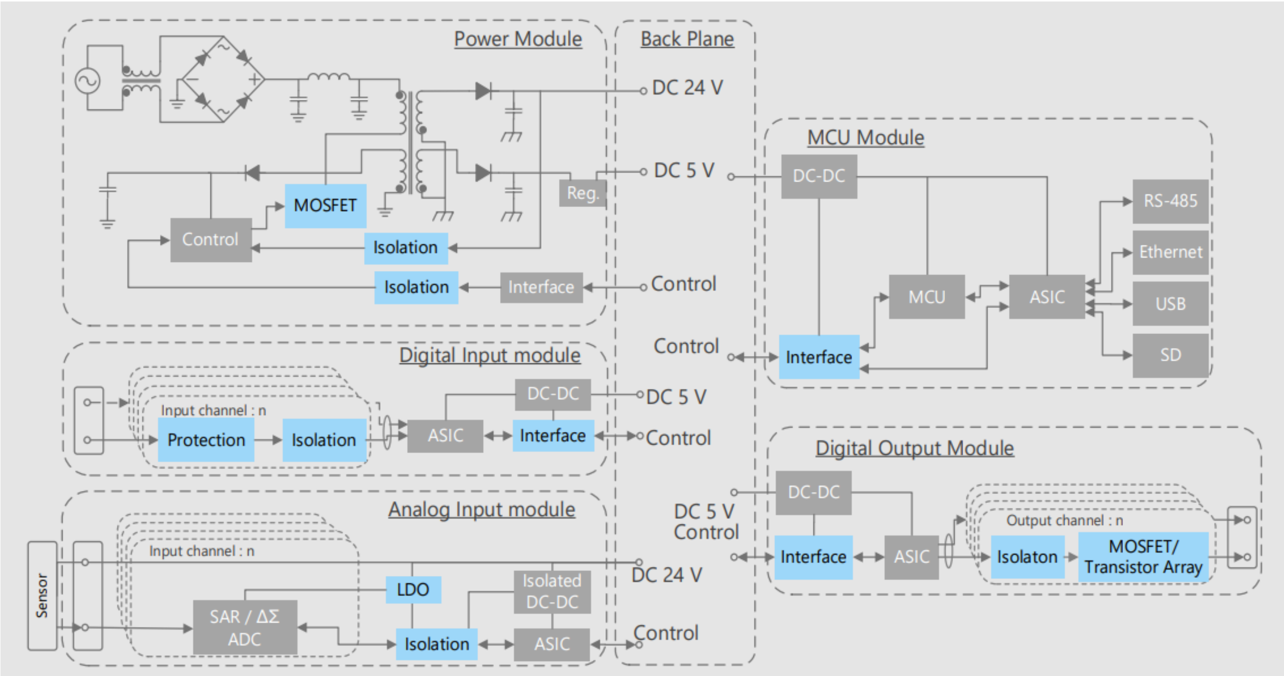

Figure 3: Programmable logic controller: Overall block diagram

In an analog-input module, isolation will often be used to ensure reliable clock signals are passed to a successive-approximation (SAR) data converter. In digital I/O modules, there will be a need to support multiple channels for communicating with other PLCs and for general-purpose I/Os that control external equipment. The flexible configurations of the DCL54x01 ensure it is possible to provide isolation that supports high transmission rates with the minimum of board space required.

Conclusion

In an environment where there is a growing demand for reliable high-voltage isolation that can deal with increasing system frequencies and communications datarates, Toshiba's DCL54x01 provides an effective and space-efficient solution.

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