

Developing Reliable Isolation Circuits: When to use a digital isolator vs. an optocoupler



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Introduction

Isolation circuits designed to withstand the rigors of industrial environments are the focus of this white paper. Industrial electronic equipment commonly uses galvanic isolators to protect systems and users from potentially hazardous voltages. It is well known that industrial equipment must operate reliably in the harshest environments, where strong electromagnetic fields, surges, fast transients, and high noise floors are the norm. This environment presents challenges for designing reliable isolation circuits that deliver error-free operation over long equipment lifetimes.

Over the last four decades, optocouplers have been the “default” signal isolation device, but recent breakthroughs in silicon isolation technology have spawned smaller, faster, and more reliable and cost-effective solutions that have already begun supplanting optocouplers in many end applications. This white paper discusses industrial isolation issues and ways RF isolation technology can be applied to increase system robustness and performance.

RF Isolator and Optocoupler Basics

Figure 1 shows top-level block diagrams of an optocoupler and Silicon Labs’ ISOpro isolator. As shown in Figure 1a, the optocoupler is a hybrid assembly having a light-emitting diode (LED) that emits light when forward biased, with brightness being proportional to LED forward current. Emitted light passes through an optically transparent insulating film (or dielectric), striking a photo detector and causing a current flow that biases the output transistor on. When LED forward current no longer flows, light emission ceases, and the output transistor turns off.

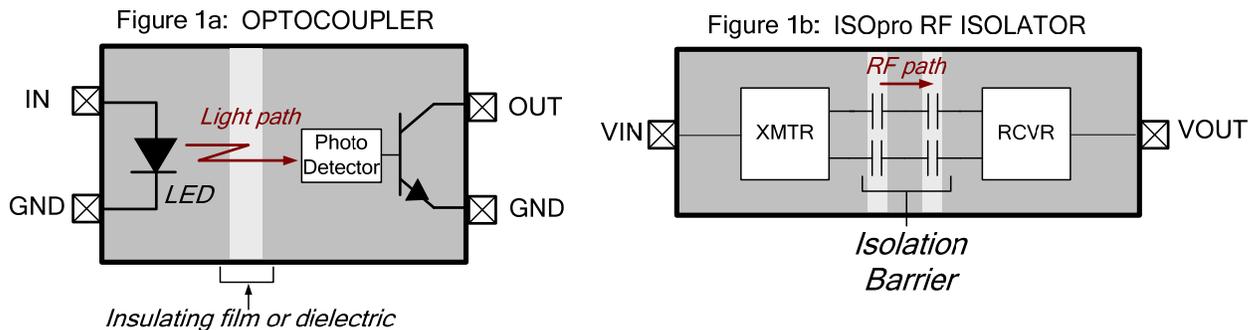


Figure 1. Basic Operation of Optocoupler vs. ISOpro Isolator

The basic operation of the ISOpro isolator is analogous to that of the optocoupler, except that an RF carrier is used instead of light (Figure 1b). The ISOpro isolator consists of two identical semiconductor dies connected together within a standard IC package forming an RF transmitter and receiver separated by a differential capacitive isolation barrier. Data is transferred from input to output using simple on/off keying (OOK). When VIN is high, the transmitter generates an RF carrier that propagates across the isolation barrier to the receiver. The receiver asserts logic 1 on VOUT when sufficient in-band carrier energy is detected. When VIN is low, the transmitter is disabled, and no carrier is present. The receiver, therefore, detects no in-band carrier energy and drives VOUT low.

Unlike the optocoupler, each ISOpro channel occupies little die area, making possible cost-effective, high-channel-count isolators. Additionally, monolithic semiconductor process technology enables ISOpro technology to be combined with other semiconductor functions and processes to create highly integrated products with built-in isolation, such as isolated analog data converters and communication transceivers. These integration advantages enable a broader, more comprehensive ISOpro product roadmap than the optocoupler.

System Considerations

Regardless of implementation, isolators must meet safety standards for robust galvanic isolation. They must also be reliable enough to outlast the equipment in which they are installed, which, in the industrial world, can mean decades of use. Designers must ensure that isolation circuits can withstand electrical stresses that can cause physical damage and reject data-corrupting noise from any number of sources. Therefore, the designer must carefully consider key isolator operating parameters, such as common-mode transient immunity, key timing parameters, such as propagation delay and pulse width distortion, and field-related specifications, such as EMI and RF susceptibility. Likewise, continuous working voltage and mean time-to-failure (MTTF) are important indicators of device service life.

High Voltage Insulation Reliability

Insulation reliability directly affects the isolator’s ability to safeguard against user exposure to high voltage and is of paramount importance. The insulator is the “heart” of the isolation barrier and key to maintaining system safety. It is very important that the insulation be uniform, with no voids that can cause a localized breakdown. Insulator uniformity is a function of insulator material and the fabrication process.

The dielectric strength of the optocoupler’s injection-molded plastic compound can vary by as much as 300% due to voids created during fabrication. In contrast, ISOpro isolators use semiconductor oxide layers for its primary insulator. The CMOS oxide deposition process is very tightly controlled and highly uniform, and the resulting variation in dielectric strength is only 20%. Each oxide layer has a breakdown voltage of 500 V_{ACRMS} per micron (millionth of a meter). Higher voltages (e.g. 5 kV_{ACRMS}) are implemented by simply stacking oxide layers during wafer fabrication. The result is a higher absolute maximum breakdown voltage in a substantially smaller size compared to optocouplers and insulator reliability that is independent of the packaging process.

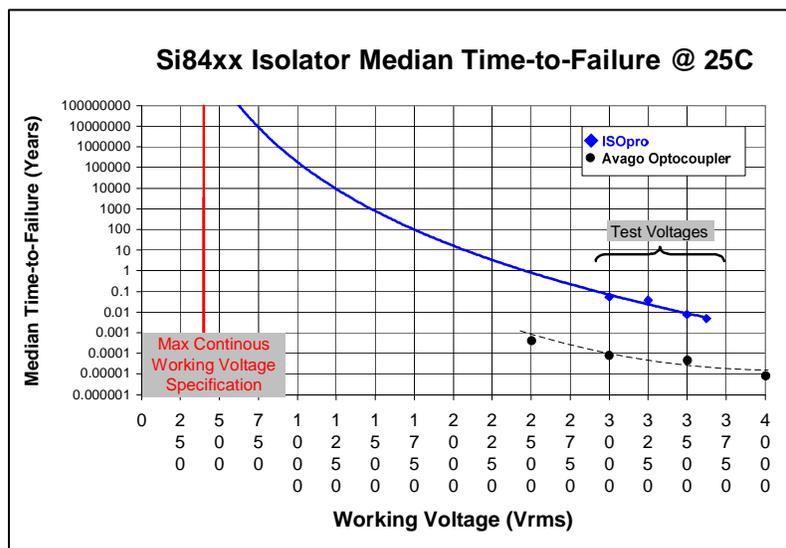


Figure 2. ISOpro Isolator vs. Optocoupler Mean Time to Failure

Figure 2 compares the median time-to-failure of the ISOpro isolator versus an optocoupler. Both devices were measured on the same equipment and under the same conditions. As shown, the extrapolated median time-to-failure for a 2.5 kV_{ACRMS}, 6-channel ISOpro trends toward 1x10⁸ years at 25 °C with 500 V_{DC} applied.

Safety Certifications

International safety standards provide test methodologies and guidelines to ensure end-equipment safety from electrical shock, mechanical hazard, and fire and electromagnetic interference. The component-level international safety standards for optocouplers and other isolators (including ISOpro isolators) are summarized geographically in Table 1.

Table 1. International Certification Agencies and Standards (Optocoupler Components)

International	Europe	U.S.	Canada	Germany
IEC	CENELEC	UL	CSA	DIN/VDE
IEC 60747-5-2	EN 60747-5-2	1577	Component Acceptance Notice #5A	DIN EN 60747-5-2

Isolator classifications include “Basic” and “Reinforced”. Basic isolation is intended to provide a single-level of protection against electrical shock only and cannot be considered failsafe. While these devices are accessible to a user, they must be contained within the system. Basic isolation devices are 100% safety tested at 2.5 kV_{ACRMS} for a period of 1 minute and, typically, have a minimum creepage of 3.2 mm. Reinforced isolation provides two levels of protection, making these devices failsafe and allowing user access. These devices are 100% safety tested at 5 kV_{ACRMS} for a period of 1 minute and typically provide a minimum creepage of 6.4 mm. Note that the exact creepage distance and rated isolation voltage requirements vary from one system to another according to the system's specifications and targeted environmental operating conditions (pollution degree).

Certification testing involves subjecting the isolator component to various stresses as prescribed by test standards while monitoring the device under test for failures that could compromise safety.

Table 2. Test Voltages per IEC60950

Grade of Insulation	Points of Application (where appropriate)		
	PRIMARY CIRCUIT to BODY PRIMARY CIRCUIT to SECONDARY CIRCUIT between parts in PRIMARY CIRCUITS		
	WORKING VOLTAGE		
	$U \leq 184 \text{ V}$ peak or d.c.	$184 \text{ V} < U \leq 354 \text{ V}$ peak or d.c.	$354 \text{ V} < U \leq 1.41 \text{ kV}$ peak or d.c.
	Test Voltage, Volts RMS		
Functional	1,000	1,500	See IEC60950 Va in Table 5B, part2
Basic, Supplementary	1,000	1,500	See IEC60950 Va in Table 5B, part 2
Reinforced	2,000	3,000	See IEC60950 Va in Table 5B, part 2

Table 2 is an excerpt from the electrical strength test prescribed by IEC60950. The test voltages shown assume homogeneous joined package surfaces, such as molding compound only. However, different materials are used in the isolation barrier of both optocouplers and the ISOpro isolators. For example, the ISOpro isolator barrier uses silicon dioxide as the primary insulator and plastic molding compound as the secondary insulator. This type of non-homogenous, joined construction is referred to as “cement joint” and requires the certification agency to *proof test* the isolator by increasing the test voltages of Table 2 by a factor of 1.6. For example, reinforced components that support a peak or dc working voltage of 354 V must tolerate a 4,800 V_{ACRMS} dielectric withstand potential for 1 minute to pass agency certification for a rated voltage of 4,800 V_{ACRMS} . In addition, the manufacturer’s production test for this isolator must include testing each component at 120% of its rated value for 1 second. Therefore, the 354 V isolator referenced above would be production tested for 1 second at 5,760 V_{ACRMS} (4,800 V_{rms} x 1.2) to ensure its integrity.

Operating Power

At a minimum, optocouplers require current to bias the LED and some form of bias on the output side. The total input plus output current varies widely, depending on the type of optocoupler. When forward biased, the optocoupler LED is low-impedance, and device power consumption increases with LED forward current, which can range from 1 mA to over 15 mA. In some cases, the LED may require an external driver, further decreasing system efficiency while increasing BOM complexity and cost. The optocoupler output impedance can be low or high depending on its architecture. Most low-cost optocouplers have a simple transistor output that is high-impedance when LED forward current is at zero and relatively lower impedance when LED forward current is in its specified operating range. Other (usually higher speed) optocouplers have an active photo coupler and output driver that requires an external bias voltage. Such devices have low output impedance but at the expense of increased total operating current, which can range from 15 mA to over 40 mA.

Compared to optocouplers, ISOPro isolators offer significantly higher operating efficiency, consuming approximately 1.7 mA per channel at 10 Mbps at VDD = 5.0 V with a 15 pF load. Its high-impedance input buffer consumes only microamps of leakage current while its 50 Ω CMOS output driver can source or sink 4 mA. The bulk of the ISOPro isolator’s power savings results from the use of an RF carrier instead of light, eliminating the power-hungry LED. Losses in the isolation path are minimized by the isolation capacitor structures, which are optimized for robust data transfer and minimum power loss. ISOPro isolators’ power dissipation remains relatively flat and substantially less than that of the optocoupler. The only noteworthy contributor to increased supply current is increased data rate, yet even this increase is relatively shallow as shown in Figure 3.

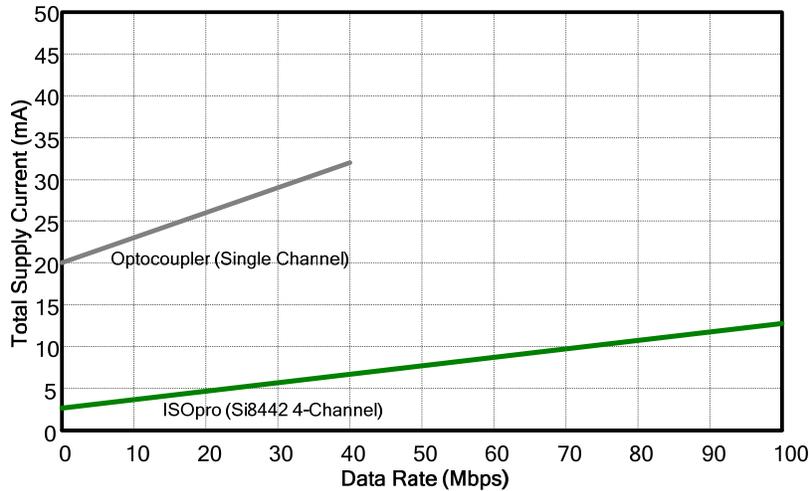


Figure 3. Current Consumption of ISOPro Isolators vs. Optocoupler Operating Stability

Timing Characteristics

Timing specifications are important in digital isolator applications to ensure proper and consistent system operation. Figure 4 compares the propagation delay characteristics of the 10 Mbps ISOPro isolators with those of a competing digital optocoupler. Propagation delays were measured with different LED currents, both with and without a “peaking” capacitor.

Note: The peaking capacitor in this case is 20 pF in parallel with the LED current limit resistor. This capacitor momentarily increases LED current during turn-on and turn-off for faster optocoupler response.

In Figure 4, curves B and C show propagation times for LED currents of 0.5 mA and 1.0 mA and no peaking capacitor. As shown, a 0.5 mA decrease in LED current results in a 50% increase in propagation time (80 ns to 120 ns) at 20 °C, demonstrating the large timing variations that result from changes in LED current and/or wear-out. Propagation delay is not symmetrical; curve A shows a high-to-low transition fastest propagation time of roughly 35 ns at 20 °C, but the low-to-high transition is twice the propagation delay time. Therefore, a system using this component must take into account these asymmetric delays and provide additional timing margin. While this example demonstrates the changes in propagation time, it is important to note that other optocoupler timing parameters, such as pulse width distortion, channel-to-channel matching, rise and fall time, etc., will follow the same trend because all timing behavior, including LOP effects, is related to LED emission.

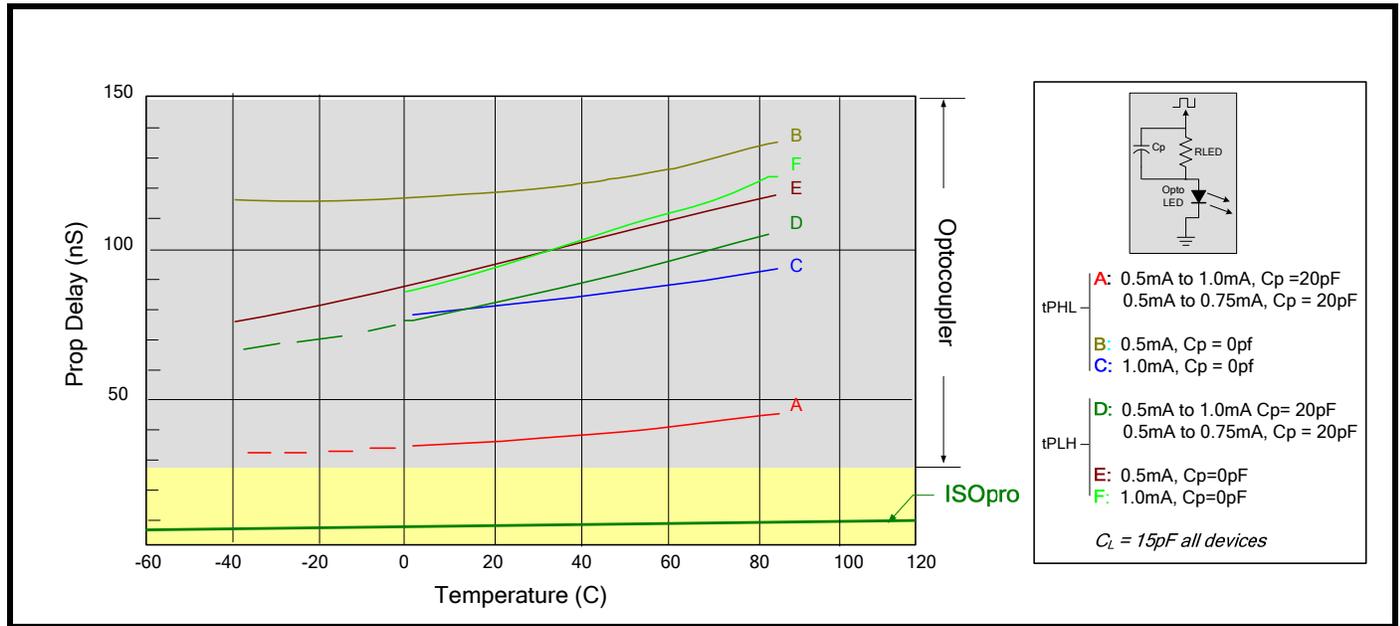


Figure 4. Optocoupler vs. ISOpro Propagation Delay

Unlike the optocoupler, the ISOpro isolator's timing parameters are a function of internal precision timing circuits and fixed propagation delays within its signal path. All timing parameters vary only slightly with changes in VDD, and all remain flat over temperature. For example, rise and fall times vary by only 1 ns across temperature and supply voltage, and worst-case propagation time is approximately 9 ns at 120 °C. Table 3 shows the operating characteristics of a 50 Mbps optocoupler compared to the ISOpro isolator.

Table 3. Characteristics of ISOpro vs. Optocoupler Devices

Product	Channels	Operating Temp Range (Deg. C)	Supply Voltage (V)	Max Supply Current (input + output) (mA)	Max Prop Delay Time (ns)	Minimum Pulse Width (ns)	Maximum Data Rate (Mbps)	Pulse Width Distortion (ns)	Prop Delay Skew (ns)	Output Rise Time (ns)	Output Fall Time (ns)	Channel-to-Channel Skew (ns)
ISOpro	4	-40 to +125	2.7 to 5.5	7	10	6	150	1.5	2	4	4	0.5
Optocoupler	1	-40 to +85	4.5 to 5.5	17.5	22	20	50	2	16	8	6	20

Common-Mode Transient Immunity (CMTI)

Common-mode transients are one of the leading causes of data corruption in isolation applications. CMTI is commonly measured in kV per microsecond and refers to the ability of an isolator to reject noise that is present between the isolator input and output. Figure 5a shows an optocoupler subjected to common-mode noise, V_{CM} . As V_{CM} changes due to fast transients, i_{LP} and i_{LN} either aid or oppose the LED current, causing a momentary change in LED light emission, often in spite of the detector shield added by manufacturers to reduce parasitic capacitive input/output coupling.

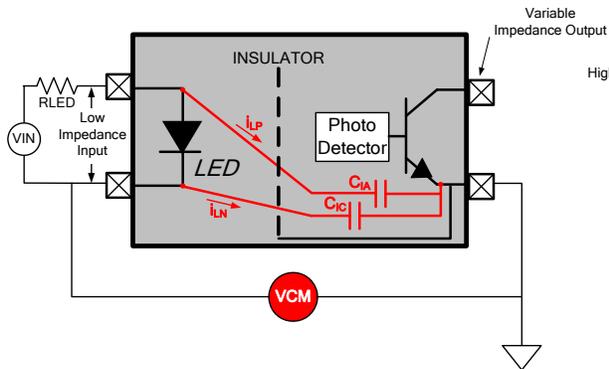


FIGURE 5a. Optocoupler Equivalent Circuit

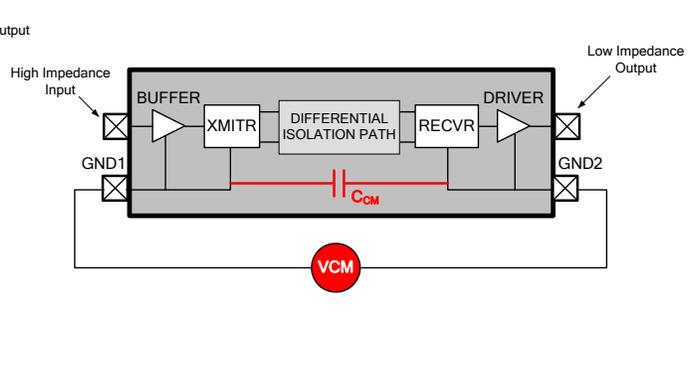


FIGURE 5b. ISOpro Equivalent Circuit

The optocoupler parasitic coupling between grounds is typically in the range of tenths of picofarads (e.g. 0.6 pF for the Avago HCPL-0703), which greatly decreases CMTI. Some degree of CMTI improvement can be obtained using the “quasi-differential” drive shown in Figure 6, where LED current-limiting resistors are placed on both sides of the LED, each having half the value of R_{LED} in Figure 5.

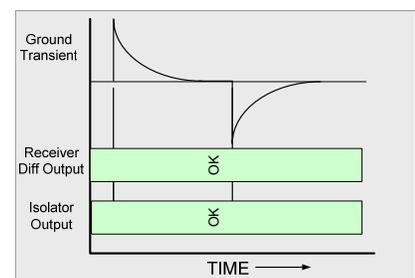
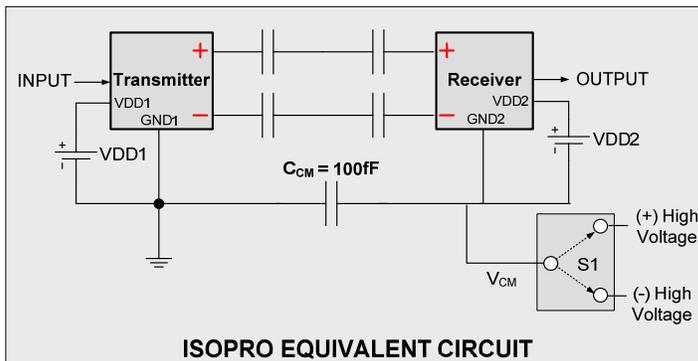
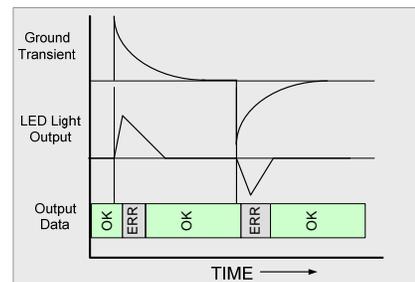
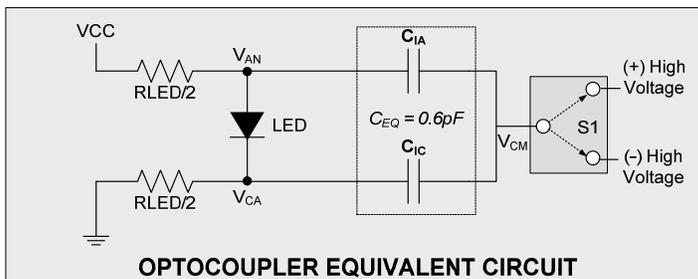


Figure 6. Common Mode Transient Models for Optocoupler and ISOpro

As shown in the optocoupler timing diagram of Figure 6, a positive-going ground transient on the optocoupler’s right-side ground (with respect to the left-side ground) causes a momentary increase in LED current. This LED “glitch” can cause data errors, depending on the magnitude of the transient and the amount of parasitic coupling present in the optocoupler. For example, a 0.6 pF coupling may be sufficient to erroneously turn on the LED momentarily when it should remain off. Likewise, a negative-going transient can erroneously turn off the LED when it should remain on. The inherently low CMTI of optocouplers is discussed at length in application manuals issued by optocoupler manufacturers, some of which recommend over-driving the LED while in the on state and reverse-biasing the LED while in the off state when operating in high common-

mode environments. While this technique is effective, it increases LED power dissipation and hastens the wear-out due to LOP. In any case, the parasitic coupling is unavoidable and degrades optocoupler CMTI performance.

The bottom graphic of Figure 6 shows the ISOpro isolator with its common-mode voltage, V_{CM} , and its 100 femtofarad input-to-output capacitance (C_{CM}), which is six times smaller than that of the optocoupler. Its fully-differential isolation path rejects common-mode voltages, and the high selectivity of the receiver rejects all but the carrier frequency for even greater noise immunity. For these reasons, the ISOpro isolator has a *typical* CMTI of 25 kV/ μ s, substantially higher than most optocouplers using external components to improve CMTI.

RF Immunity

RF immunity is the ability of the isolator to reject strong local electromagnetic fields, thereby maintaining error-free data transfer. Intuitively, one might assume that ambient RF fields would interfere with the ISOpro isolator's internal RF data transmission. However, ISOpro isolators demonstrate an extremely high degree of external RF noise rejection by virtue of its design.

Local fields induce common-mode voltages within the ISOpro isolator's internal signal path that are rejected by a combination of the ISOpro isolator's differential isolation signal path and high receiver selectivity. Signal levels on each side of the ISOpro isolator's internal differential signal path are tightly matched, causing common-mode voltages at the receiver's inputs to be rejected. The receiver then amplifies only the differential input voltage within a very narrow frequency band and rejects all other input. Together, these mechanisms reject interference from external fields and enable very high CMTI and robust operation in the harsh electrical environments common in industrial applications.

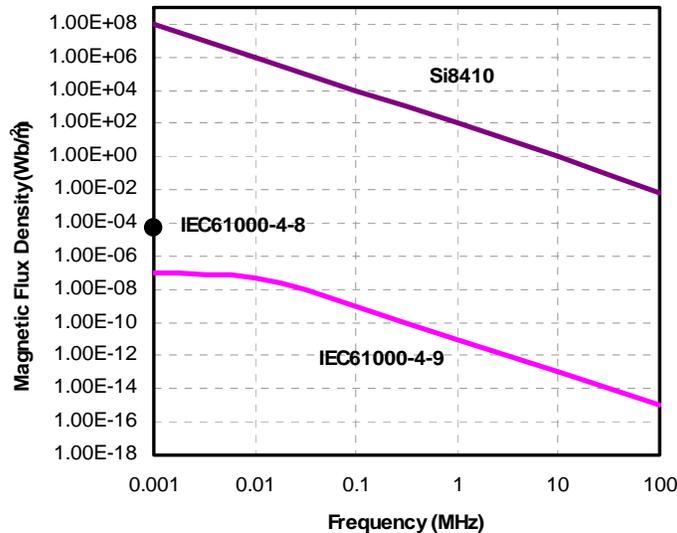


Figure 7. ISOpro Magnetic Field Immunity

As shown in Figure 7, ISOpro isolators' magnetic field immunity enables it to be used in close proximity to large motors and other magnetic field-producing equipment. It is theoretically possible that data transmission errors may occur if the magnetic field is too large and/or too close to the isolator. However, in actual use, ISOpro isolators provide extremely high immunity to external magnetic fields and has been independently evaluated to withstand magnetic fields of at least 1000 A/meter (per IEC 61000-4-8 and IEC 61000-4-9 specifications). A field of this kind can be generated by 10^7 amperes through a 0.1 m conductor located 0.1 m away from the ISOpro

isolator. It is highly unlikely that such a condition would be found in any operating environment. Such a field would most likely destroy surrounding circuitry before damaging the ISOpro isolation barrier circuit. In addition, ISOpro isolators have high electric field immunity (20 V/meter minimum) as measured by independent laboratories.

Application Examples

Unlike optocouplers, which need external components to improve performance, provide bias, or limit current, the ISOpro isolators need only two external VDD bypass capacitors (0.22 to 1 μF) to operate. Their TTL level-compatible input terminals draw only micro amps of leakage current, allowing them to be driven without external buffering circuits. The output terminals have a characteristic impedance of 50 Ω (rail-to-rail swing) and are available in both forward and reverse channel configurations. Note that the circuit of Figure 8 is typical for most applications and is as easy to use as a standard CMOS logic gate.

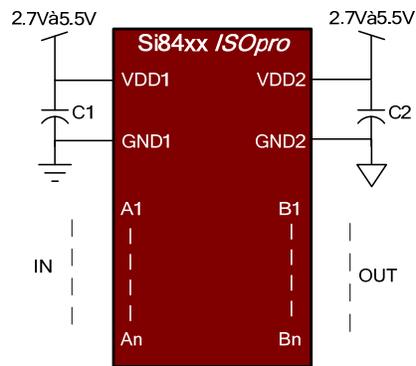


Figure 8. ISOpro Application Schematic

Figures 9, 10, and 11 show three different circuits recommended by optocoupler suppliers, each requiring additional external components when compared to the ISOpro isolators. Figure 9 shows an isolated CMOS logic application. Here, a CMOS input buffer provides the correct input logic levels while supplying drive current for the optocoupler LED. Resistor R_L limits LED current, and peaking capacitor C_p accelerates LED turn-on and turn-off time to reduce propagation delay to roughly 300 ns. The output circuit consists of a CMOS Schmitt trigger, which improves rise and fall time and provides additional noise immunity and low output impedance.

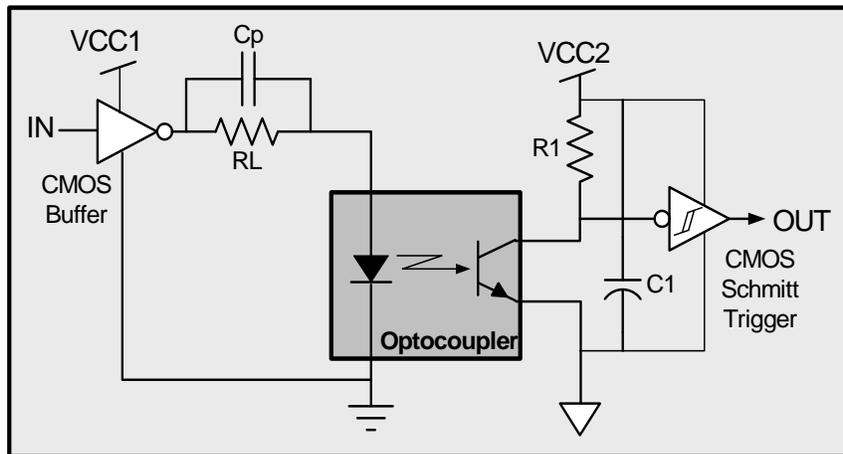


Figure 9. CMOS Driver

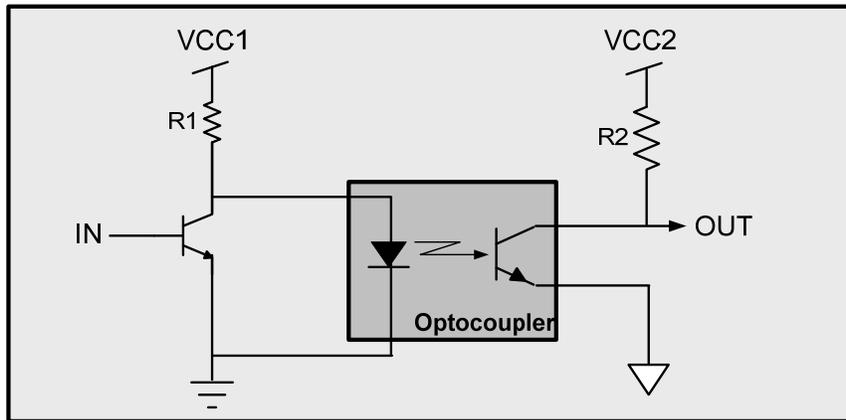


Figure 10. High CMTI Isolator

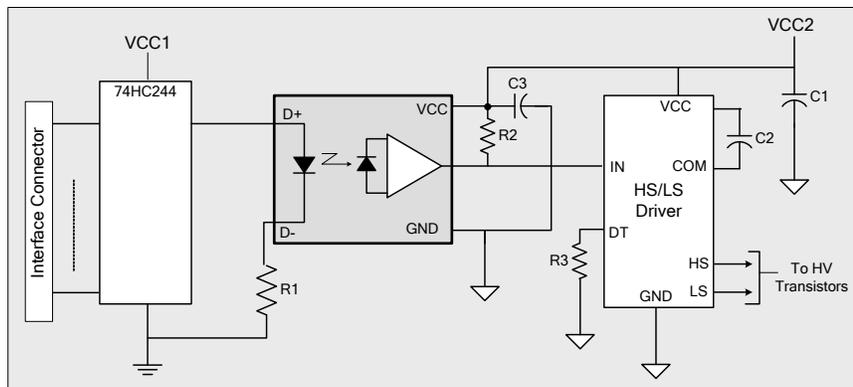


Figure 11. Plasma Display Driver

The circuit of Figure 10 trades higher power consumption and reduced LED life for improved CMTI. Note that this circuit can be combined with that of Figure 9 to improve its CMTI as well, but it requires additional external components. Resistor R1 has a relatively low value and overdrives the LED for improved CMTI when Q1 is off. The LED is turned off when transistor Q1 is on, shunting current around the LED to ground. Note that the efficiency of this circuit is poor because roughly the same amount of current is drawn from VCC1 whether the LED is off or on.

Figure 11 shows a high-voltage drive circuit for a plasma display. The incoming digital signal is conditioned by a logic buffer, which also provides drive current for the optocoupler LED. The optocoupler output drives a 600 V high-side/low-side driver, which, in turn, drives the high-voltage transistors that control the display.

Figures 12, 13 and 14 show the impact of ISOpro isolators on the circuits of Figures 9-11. In all cases, the ISOpro isolator offers a substantial reduction in size and BOM while delivering better timing performance, lower power consumption, and higher reliability than the optocoupler. The circuits in Figures 12 and 13 show the ISOpro isolator as a single-chip solution for the circuits shown in Figures 9 and 10. Figure 14 implements the circuit of Figure 11 using an ISOdriver, a device that combines RF isolation technology with a fully-featured, high-side/low-side IGBT/MOSFET driver capable of delivering up to 4 A peak.

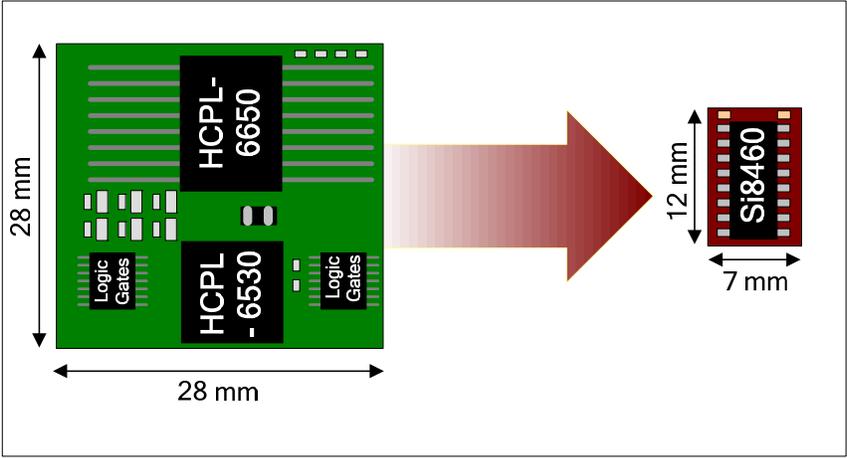


Figure 12. 6-Channel CMOS Level Shifter

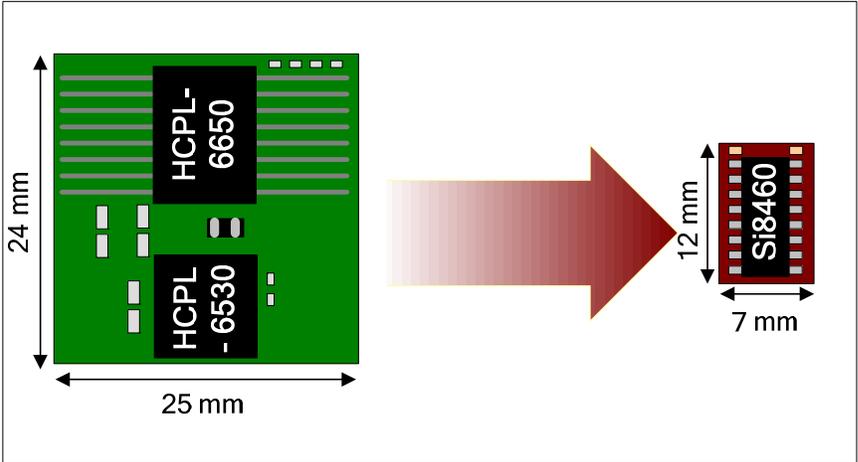


Figure 13. 6-Channel High CMTI Isolator

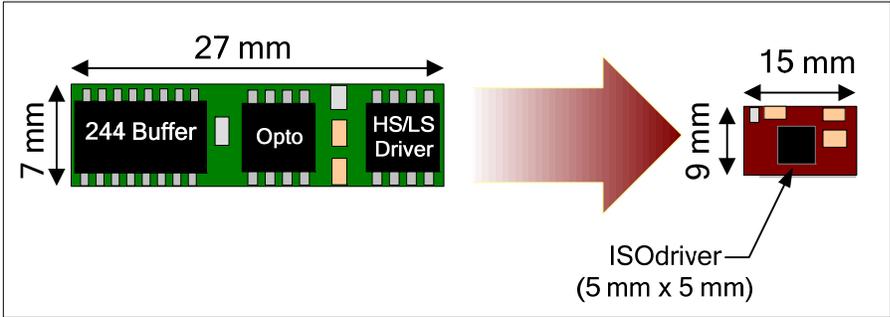


Figure 14. Single-Channel Plasma Display HV Driver

Summary

While optocouplers have been the dominant signal isolation device for many years, the advent of the RF isolator gives designers a smaller, more integrated, faster, and lower power alternative with none of the stability or wear-out mechanisms of optocouplers. ISOpro isolators are the best-in-class RF isolators and enable designers to access world-class isolator technology in a single package that is as easy to apply as a CMOS logic gate. Benefits of ISOpro isolators include:

- Higher integration: smaller size and lower cost-per-channel on multi-channel versions
- Higher performance: faster, tighter timing and substantially lower power
- Longer service life: no wear-out mechanisms as in optocouplers
- Higher reliability: operating parameters remain stable over VDD, temperature, and device age
- High CMTI: fully differential isolation signal path and high receiver selectivity for CMTI greater than 25 kV/ μ s
- Low EMI: meets FCC Class B Part 15
- High electric-field immunity: > 20 V/m, as measured by independent laboratories
- Industry-leading ESD tolerance: 4 kV HBM on all devices
- Lower external bill-of-materials: requires only two inexpensive VDD bypass capacitors
- Easy to use: single-chip, complete isolation solution

The history of the semiconductor industry is one of ever-increasing device performance and cost effectiveness with each process generation. Monolithic devices have always supplanted their hybrid counterparts, and RF isolation versus the hybridized optocoupler is no different.