Technical White Paper
Improve Your System Performance by Replacing Optocouplers with Digital Isolators

TEXAS INSTRUMENTS

ABSTRACT

Galvanic isolation, generally referred to as isolation, is a means of preventing DC and unwanted AC currents and avoiding a direct conduction path between two sections of a system. Isolation performs these actions while still allowing signal transfer, power transfer, or both, between those two sections. Semiconductor devices that offer galvanic isolation are referred to as isolators. Optocouplers are one of the first isolators to be introduced in the semiconductor industry and have dominated the industry for several decades as an exclusive isolation technology.

With semiconductor technological advances in the last couple decades, there are many other isolation technologies, like capacitive and magnetic isolation, that offer similar functionality as optocouplers with better overall performance. Among the competing technologies, TI's silicon dioxide (SiO_2)-based digital isolation technology offers best-in-class performance, especially on high voltage rating, electrical characteristics, switching characteristics, and reliability. This white paper compares TI digital isolators to some of the commonly-available optocouplers with respect to various performance parameters. To compare TI digital isolators to optocouplers in standard interface circuits, see *How to Replace Optocouplers with Digital Isolators in Standard Interface Circuits*. When looking for a reliable and robust upgrade to optocoupler designs, consider TI's pin-to-pin opto-emulator products.

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1 Isolator Construction

Even though both digital isolators and optocouplers offer similar functionality, these devices are quite different in construction and working principle. Optocouplers use an LED to transmit digital or analog information across an isolation (or insulation) barrier (often just an air gap). Some optocouplers use epoxy as the insulating material which offers slightly better dielectric strength than air, as shown in Figure 1-1. Conversely, digital isolators can utilize either capacitive or magnetic isolation. Capacitive digital isolators are constructed with two series isolation capacitors using SiO_2 as the dielectric, as shown in Figure 1-2. Magnetic isolation utilizes coils separated by a dielectric. TI utilizes SiO2 for both capacitive and magnetic isolation, offering one of the highest dielectric strengths among insulating materials and significantly stronger performance compared to dielectrics used by competing isolation technologies, as shown in Table 1-1.
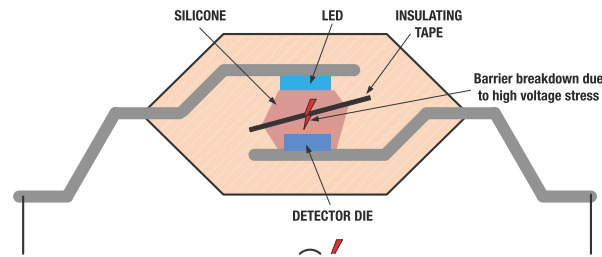
Figure 1-1. Construction of a Typical Optocoupler
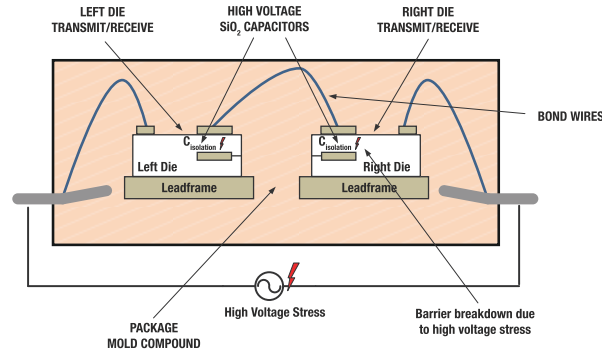

Figure 1-2. Construction of a TI Digital Isolator

Table 1-1. Dielectric Strength of Various Insulating Materials

Insulator Materials	Dielectric Strength
Air	About 1 V_{RMS}/μm
Epoxies	About 20 V_{RMS}/μm
Silica Filled Mold Compounds	About 100 V_{RMS}/μm
Polyimide	About 300 V_{RMS}/μm
SiO_2	About 500 V_{RMS}/μm

2 Switching Performance

Isolators are extensively used in many industrial and automotive applications where isolation of data, control or status signals is needed. To enable processing of the isolated data, control, or status signals in a timely manner, it is critical for the isolator to have optimum switching characteristics, minimizing the impact on the overall system timing performance. Optocouplers fare very poorly when it comes to switching characteristics whereas digital isolators offer one of the best switching characteristics in the industry, enabling more systems to meet their performance requirements.

General purpose optocouplers usually do not have any supported data rates mentioned in their data sheets, making it difficult to know their suitability for a given application. Most of these optocouplers also have an open-collector output, due to which they are only characterized to a few select pullup or load resistor values. One of TI's latest digital isolators, ISO6441, has its maximum supported data rate clearly specified in the data sheet as 150Mbps, which makes it easy to know its suitability for a given application. Unlike optocouplers, digital isolators do not require any external pullup resistors for operation and the maximum data rate is not heavily dependent on external components.

Table 2-1 compares timing specifications of a general purpose optocoupler with TI digital isolators. The information in the table also estimates the asynchronous and synchronous data rates that are achieved using the data sheet timing specifications. Table 2-1 shows that the data rate achieved using a general purpose optocoupler is much lower than what can be achieved using digital isolators. The two pullup resistor options listed with R_L = 100 Ω and R_L = 1.9 kΩ for optocoupler consume significantly higher current compared to digital isolators, making them unsuitable for many applications.

Table 2-1. Timing Specifications of General Purpose Optocoupler vs TI Digital Isolators

Part Number	General Purpose Optocoupler		ISO6441	ISO6741
Parameter	R_L = 100 Ω	R_L = 1.9 kΩ	VCC = 5 V	VCC = 5 V
Input forward current / ICC1 per channel (typ, mA)	2.0	16.0	2.2	1.8
On state collector current / ICC2 per channel (typ, mA)	50.0	2.6	4.5	3.2
Rise time, t_r (typ, µs)	2.0	0.8[1]	0.002	0.005
Fall time, t_f (typ, µs)	3.0	35.0[1]	0.002	0.005
Turn on time / propagation delay, t_{pHL} (typ, µs)	3.0	0.5	0.006	0.011
Turn off time / propagation delay, t_{pLH} (typ, µs)	3.0	40.0	0.006	0.011
Propagation delay skew, t_{sk} (max, ns)	-	-	0.003	0.006
Max asynchronous data rate (($T = max(t_r, t_f) \times 2/0.6 + t_{sk}$), typ, Mbps)	0.1	0.008	80.6	47.6
Max synchronous data rate (($T = max(t_{pHL}, t_{pLH}) \times 4$), typ, Mbps)	0.028	0.006	41.7	22.7

(1)   Estimated Values

High-speed optocouplers offer better switching characteristics compared to general-purpose optocouplers. Table 2-2 compares a typical high-speed optocoupler with TI digital isolators in which the asynchronous and synchronous data rates for the devices are estimated using the timing specifications given in their respective data sheets. As shown in the comparison table, digital isolators still support much higher data rate compared to the high-speed optocoupler.

Table 2-2. Timing Specifications of High-Speed Optocoupler vs TI Digital Isolators

Part Number	High-Speed Optocoupler		ISO6441	ISO6741
Parameter	I_F = 14 mA	I_F = 6 mA	VCC = 5 V	VCC = 5 V
Input forward current / ICC1 per channel (typ, mA)	14.0	6.0	2.2	1.8
Rise time, t_r (typ, ns)	15.0	15.0	2	4.5
Fall time, t_f (typ, ns)	15.0	15.0	2	4.5
Turn on time / propagation delay, t_{PHL} (typ, ns)	33.0	40.0	6.2	11
Turn off time / propagation delay, t_{PLH} (typ, ns)	27.0	30.0	6.2	11
Propagation delay skew, t_{sk} (max, ns)	30.0	30.0	3	6
Max asynchronous data rate ((T = max(t_r, t_f) × 2/0.6 + t_{sk}), typ, Mbps)	12.5	12.5	80.6	47.6
Max synchronous data rate ((T = max(t_{pHL}, t_{pLH}) × 4), typ, Mbps)	7.6	6.3	41.7	22.7

3 Isolator Lifetime Through TDDB Test

Time dependent dielectric breakdown (TDDB) test is an industry standard accelerated stress test for determining lifetime of a dielectric as a function of voltage. The test consists of applying various stress voltages across the isolation barrier of a device that are much higher than the typical working voltages and monitoring the amount of time it takes for the dielectric to break down. These voltage vs time coordinates are plotted on an appropriate graph, and the coordinates are extrapolated to lower stress voltages to determine expected dielectric lifetimes for the suitable working voltages.

Figure 3-1 compares TDDB plot of a TI digital isolator against a popular optocoupler, it can be noticed that the average TDDB line of optocoupler is approximately 2 divisions (100 times) lower than digital isolator average TDDB line. The primary reason for such a large difference in TDDB lifetimes of the two technologies is the large difference in dielectric strengths of the insulating material they use (see Table 1-1). Note that the lifetime of an optocoupler for a given stress voltage varies considerably from one sample to another while the same is consistent across samples for the digital isolator.
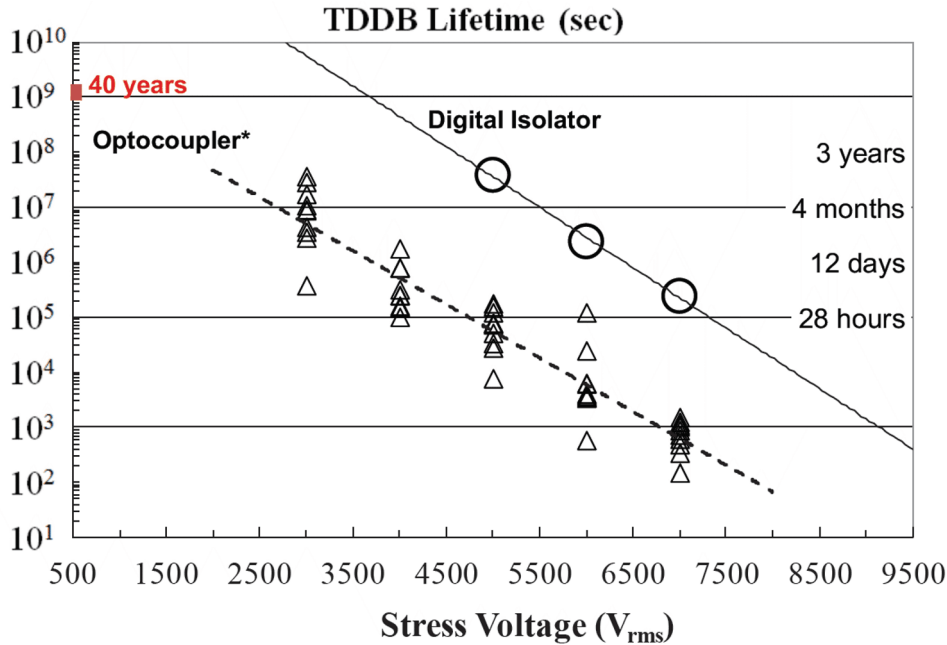

Figure 3-1. TDDB Lifetime of Optocoupler vs TI Digital Isolator

4 Solution Size

An optocoupler works on the principle of converting electrical signal into light and then back into electrical signal to achieve isolation. This limits the choice of dielectric that can be used for insulation to the ones that are optically transparent like air and epoxy. Since the dielectric strengths of air and epoxy are significantly low, they occupy considerable amount of space in a single-channel package, thereby limiting the maximum number of channels that can be fit into a given optocoupler device.

Also, digital isolators use SiO_2 as a dielectric, which has significantly higher dielectric strength and occupies a much lower space to realize a single isolation channel, hence multiple channels can be easily integrated into a small package. A typical single channel optocoupler is usually available in a package size of 3.7 mm × 4.55 mm whereas ISO7762 with SSOP package can fit 6 high-performance channels in a small package area of 4 mm × 5 mm.

Figure 4-1 compares amount of space occupied by eight single-channel optocouplers and four dual-channel optocouplers each with two ISO6441 devices to realize an eight-channel isolation solution. The figure also places ISO7762, six-channel digital isolator, by the side showing the highest channel density achieved in a wide-body SOIC-16 package.
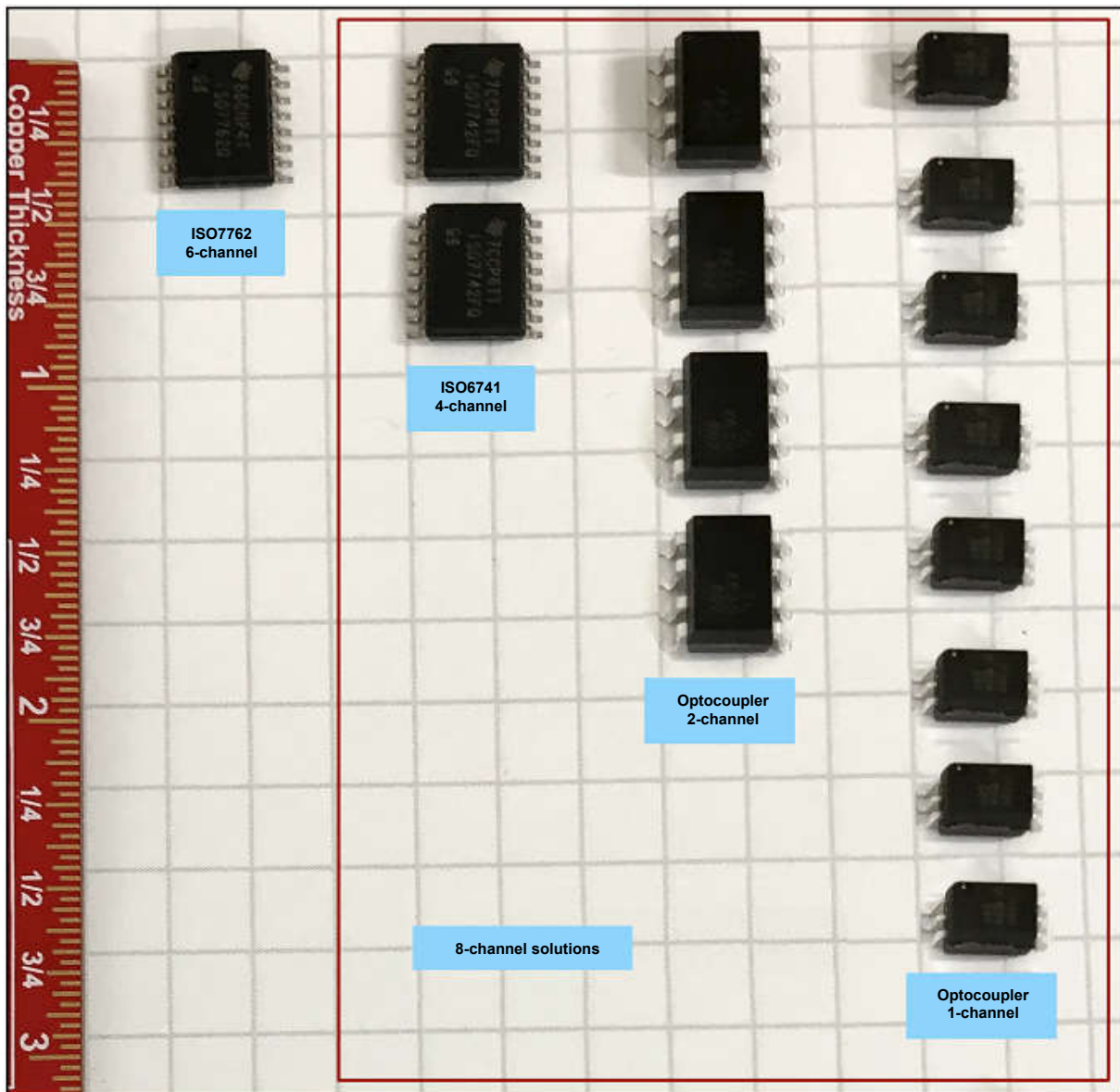

Figure 4-1. Comparing Amount of Space Occupied by Optocouplers With ISO6741 and ISO7762

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5 Aging and Reliability

It is a well-known phenomenon that the actual light output of LEDs degrades over time. Degradation of light output affects many optocoupler device parameters and most of them are usually not mentioned in data sheet. Current transfer ratio (CTR) is one such parameter where aging can be clearly seen. An example of CTR degradation as a function of test time is shown in the application note by Toshiba titled *Basic Characteristics and Application Circuit Design of Transistor Couplers*.

At some point in optocouplers life, CTR falls to a level at which the device fails to operate normally, leading to poor reliability (high FIT rate and low MTBF). Also, digital isolators isolation and control circuits are very well trimmed, minimizing their performance variation due to aging. Aging is also already considered as part of device minimum and maximum specifications in the data sheet. The very well-controlled manufacturing process of digital isolators also achieves very high reliability (low FIT rate and high MTBF).

6 Common-Mode Transient Immunity (CMTI)

There are many applications (like solar inverter) that have very high voltages being switched for either conversion or regulation, leading to high common-mode switching noise, and there are other applications (like motor drives) that have inductive loads causing high ringing noise. These common-mode noises appearing across the isolator can couple into an internal circuit of the device and disrupt normal operation.

One of the ways to prevent such noise from affecting internal circuit is to implement a differential design with good common-mode noise rejection. The single-ended channel design of an optocoupler and absence of a common-mode noise rejection circuit makes the receiver in optocoupler vulnerable to external common-mode noise.

Even with internal Faraday shielding, a typical high-speed optocoupler only supports a minimum CMTI of ±20 kV/μs. In comparison, ISO6441 employs a differential isolation channel design and a receiver with very high common-mode noise rejection, thereby offering a minimum CMTI of ±150 kV/μs.

7 Optocoupler Current Input vs Digital Isolator CMOS Voltage Input

All optocoupler inputs are current-driven and require > 2 mA of steady bias current for the device to operate. Many optocouplers may need > 10 mA of input current for them to meet minimum application performance requirements. This makes them less suitable to be directly driven by any TTL or CMOS outputs and hence they may need a buffer to be able to drive the optocoupler.

Optocouplers are also not suitable to be used with low-voltage digital circuits (< 3.3 V) as the optocoupler performance can drastically change with a small change in input voltage. Digital isolators like ISO6441 offer high impedance CMOS inputs that are voltage driven. The CMOS inputs consume a maximum of ±10 μA of steady current and hence can be directly driven by any TLL or COMS outputs without requiring any external buffer. This makes them compatible to be directly interfaced with most other digital devices like MCU, ADC, and so on.

Digital isolators can also work with a wide range of power supply and logic voltage levels and also support 1.8-V low-voltage operation. Some variation in input supply voltage or logic voltage levels also does not affect the output logic voltage levels. The input capacitance of digital isolators (about 1.5 pF for ISO6441) is also significantly low compared to an optocoupler (about 60 pF for a typical high-speed optocoupler), thereby making digital isolators switch much faster and easier compared to optocouplers.

8 Conclusion

Optocouplers were one of the first isolators to be used in various applications for data isolation. They had been dominant in the industry for a long time, but are now seeing a steep decline in their popularity and acceptance due to their inability to meet present time performance needs. Digital isolators are fast replacing optocouplers across applications, and TI digital isolators are one of the high-performance isolators filling the void left out by the optocouplers in meeting current industry performance needs.

Various performance parameters of TI digital isolators have been looked at and are compared to general-purpose and high-speed optocouplers. Some of the topics discussed include isolator construction, TDDB lifetime, switching performance, solution size, aging and reliability, CMTI and CMOS voltage inputs. It is observed that TI digital isolators offer superior performance over optocouplers in all of these aspects and are fast replacing the legacy optocouplers.

9 References

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