Application Note

Introduction to Opto-Emulators

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ABSTRACT

Texas Instruments (TI) opto-emulators combine the behavior of traditional optocouplers with TI's silicon dioxide (SiO_2)-based isolation technology. Despite their preferred isolation performance, digital signal isolators cannot directly replace optocouplers in all circuits due to the analog characteristics of optocoupler inputs and outputs. Opto-emulators bridge this gap by providing equivalent input and output signal behavior while offering pin-to-pin package compatibility with the industry's most popular optocouplers, facilitating seamless integration into existing designs. These products appear just like optocouplers from a system design engineer's perspective but leverage TI's expertise for the emulated input and output circuitry and TI's SiO_2 isolation barrier technology. Why create such a semiconductor product? The answer is simple: provide designers the best of both worlds.

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1 Introduction

Electrical isolation is a means of preventing unwanted direct current (DC) and alternating current (AC) between two parts of a system while still enabling signal and power transfer between those two parts. Signal and power isolation is needed in a wide variety of applications for electrical safety, as well as for the protection of sensitive circuitry under fault conditions, to protect human operators and low-voltage circuitry from high voltages, to improve noise immunity, and to safely withstand ground potential differences between communicating circuits.

Optocouplers, also known as photocouplers, opto-isolators, and optical isolators, are recognized by most design engineers as a common design for achieving galvanic isolation for their system signals. Since optocouplers were one of the first isolators introduced in the semiconductor industry and have been around since the 1970's, optocouplers have and continue to play a critical role in providing both basic and reinforced safety isolation for most industrial end equipment. While significant improvements have been made to optocoupler technology over the past 50 years, there seems to be a ceiling to their advancement in electrical characteristics, high-voltage reliability, and capability to integrate additional system functionality. This problem has left designers looking for alternative designs to keep up with the pace of their quickly evolving system needs. With semiconductor technological advances in the last couple decades, there are many other isolation technologies, such as capacitive and magnetic isolation, that offer similar functionality as optocouplers with better overall performance. Among the competing technologies is TI's silicon dioxide (SiO_2)-based digital isolation technology. TI has been improving and investing in this technology since the early 2000's. Before now, this technology has been used to design and grow a vast portfolio of digital isolator products. While digital isolators and optocouplers both provide isolation, (for example, to allow signal communication while blocking high-voltage and breaking ground loops) the two isolator types have plenty of differences that system design engineers must consider.

2 What are Optocouplers?

Optocouplers are isolation devices containing a light-emitting and light-sensitive component to transmit signals while blocking ground potential differences (GPDs) between the them. The light-emitting component is typically a light-emitting diode (LED) while the light-sensitive component is usually a phototransistor or photodiode.

For an optocoupler to achieve signal isolation, the LED and phototransistor (or photodiode) inside are physically separated by distance and an insulated material. This insulated material can be an epoxy, mold compound, or just an air gap: all three of which have relatively low dielectric strength properties for voltage insulation. Figure 2-1 shows an illustrated cross section of an optocoupler:

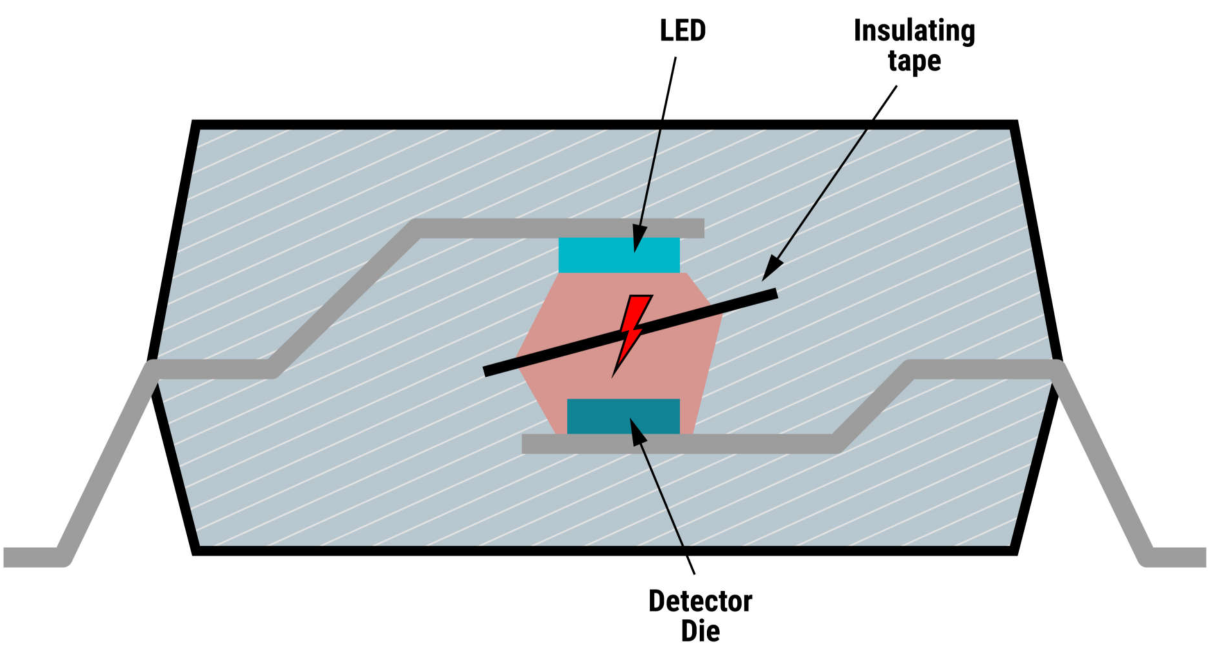

Figure 2-1. Optocoupler Cross-Section

With time, signal transmission through optocouplers is degraded by aging of the LED and clouding or yellowing of the semi-transparent isolation material used. As the LED dims or the epoxy yellows with age, strength of the transmitted light erodes; thus, more current is required to drive the LED input to the brightness achieved when the optocoupler was new. If the system designer does not compensate for this signal transmission degradation, the optocoupler's ability to transmit input signals to the isolated output can eventually reach a marginal point and even completely fail. To counter this, most optocouplers require a guardband of input current additional to the data sheet specifications be included in designs so that the LED can better transfer the signal across the lifetime. This additional input current results in higher and potentially unnecessary power consumption by the optocoupler and entire system starting from the very beginning of the design.

During normal operation, high slew rate or high frequency transients on either side of an isolated device can corrupt data transmission across the isolation barrier. Common mode transient immunity (CMTI) is the maximum tolerable rate of rise or fall of the common mode voltage applied between two isolated circuits. This is usually measured in dv/dt, and the unit is normally kV/µs or V/ns. CMTI is a critical signal integrity parameter that correlates to isolated signal robustness for all isolated signal devices which are subject to differential voltages between two separate ground references. With the increasing progress and adoption of new generation power semiconductor devices, customer end equipments and applications are requiring faster switching frequencies with higher magnitudes. Most high-speed digital optocouplers have CMTI specifications of 25 kV/µs maximum. This low of a CMTI maximum value allows for glitches in the output signals of digital optocouplers during fast common-mode transients between ground planes, such as during switching of transistors in power supply or inverter applications. For this reason, optocouplers are not typically used in applications requiring fast switching of high-density power applications.

Many popular optocouplers are known for their diode input and transistor output characteristics and are used such that the output transistor sinks a current proportional to that flowing through the input LED. The parameter quantifying this attribute is known as the current transfer ratio (CTR) and is defined as the ratio of output current (I_C) through the transistor to input current (I_F) of through the input LED expressed as percentage. With time and temperature, most optocoupler CTR values can vary dramatically. Similar to the case with LED aging, this means that to make sure the output drive strength is high enough for proper signal transmission, system designers must consider the worst-case variation and increase the input forward current accordingly. This also results in undesired, and possibly unnecessary, power dissipation through the optocoupler.

3 What is an *Opto-Emulator?*

Texas Instruments opto-emulators combine the behavior of traditional optocouplers with TI's SiO_2-based isolation technology. Figure 3-1 shows that opto-emulators are pin-to-pin compatible with the industry's most popular optocouplers, facilitating seamless integration into existing designs and providing equivalent input and output signal behavior.

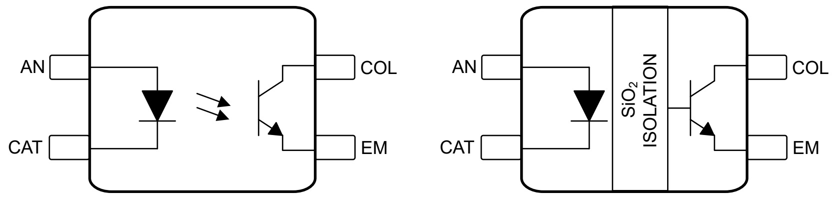

Figure 3-1. Functional Comparison of Optocoupler (Left) and Opto-emulator (Right)

Figure 3-1 is an illustrative cross section of a TI opto-emulator, showing the three die inside which contain input, isolation, and output circuitry.

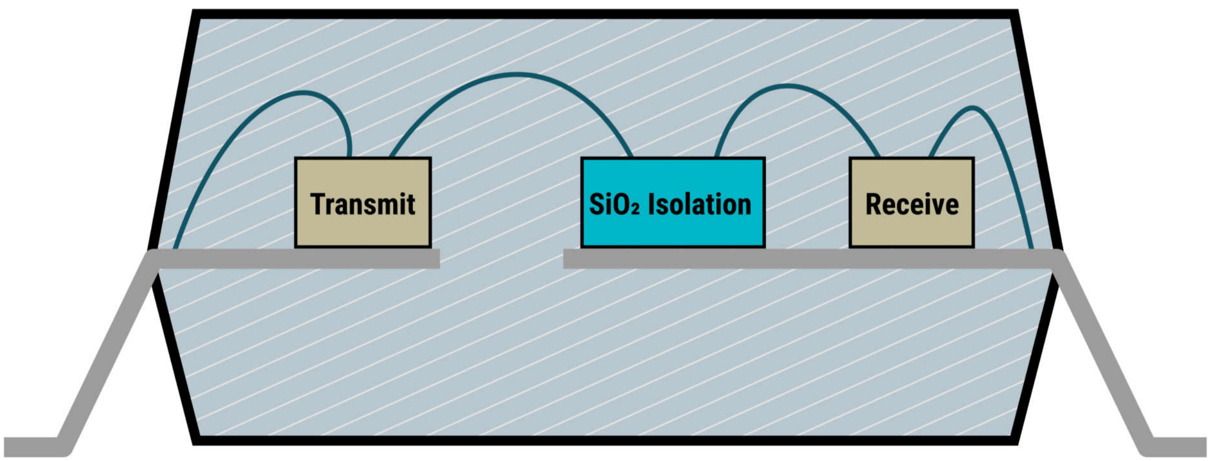

Figure 3-2. Cross Section of Opto-Emulator

Table 3-1 shows a comparison table of the dielectric strengths of different insulative materials traditionally found in optocouplers along with SiO_2, found in TI's opto-emulators. Opto-emulators boast improved high-voltage capabilities, making them designed for applications demanding robust isolation. TI Opto-emulators leverage SiO_2 for the insulating barrier, which is significantly stronger than air and materials used in many optocouplers on the market. To learn more about TI's SiO_2 technology and reliability, read *Addressing High-Voltage Design Challenges With Reliable and Affordable Isolation Technologies*.

Table 3-1. Dielectric Strength of Various Insulating Materials

Insulator Materials	Technology	Dielectric Strength
Air	Optocouplers	approximately 1 V_{RMS}/µm
Epoxies	Optocouplers	approximately 20 V_{RMS}/µm
Silica Filled Mold Compounds	Optocouplers	approximately 100 V_{RMS}/µm
SiO_2	Opto-emulators	approximately 500 V_{RMS}/µm

TI's opto-emulators replicate the behavior of an LED on the input pins, so the signal transmission and electrical parameters of the input circuit are similar to that of optocouplers. However, there is no actual LED inside of opto-emulators, which results in several benefits:

1. Since there is no internal LED for signal transmission or transparent insulation material that can cloud or yellow with time, the additional power that optocouplers require to compensate for this degradation over their entire lifetime is not required when using TI's opto-emulators. Since opto-emulators do not transmit signals using an LED, this over design practice does not apply. The signal transmission, power consumption, and other operating parameters for TI's opto-emulators are specified for their entire operating lifetime and already account for process, voltage, and temperature variations.
2. Building on TI's existing digital isolator technology, TI's first high-speed opto-emulator devices, the ISOM871x family, feature a minimum CMTI specification of 125 kV/μs, surpassing some traditional optocouplers by >100 kV/μs! This allows opto-emulators to be used in applications with very high common-mode switching noise or high ringing amplitudes where traditional optocouplers cannot be used.
3. In typical applications, like in feedback control loops of isolated power supplies, CTR variation of optocouplers impacts the power supply feedback loop response, complicating feedback loop design and creating challenges for system designers when factoring in the appropriate compensation. TI opto-emulators, like the ISOM8110, come standard with a variety of narrow CTR ranges that have higher stability over lifetime and temperature.
4. Typical high-speed optocouplers support data rates from 100kbps up to 1Mbps, while ISOM8710 and ISOM8711 can transmit data rates up to 25Mbps across the isolation barrier. This enables higher throughput and use in more high-speed applications.
5. Many optocouplers are limited to operation in temperatures up to +85°C. TI's ISOM871x devices are specified for operation from −40°C to +125°C, meaning their data sheet parameters are specified for conditions many high-speed optocouplers are not designed for. TI's ISOM811x family of opto-emulators support a further extended temperature range of –55°C to +125°C.

TI's opto-emulators achieve signal isolation much like our digital isolator devices. The *emulation* in opto-emulators refers to the recreation of input and output structures that operate like optocouplers while isolating signals using TI's isolation technology.

Standard optocouplers use an LED as the input stage. When the input is turns the diode ON, these LEDs brighten as input forward current increases. The light from the LED shines through an air or epoxy gap onto a photo transistor inside of the package, which in turn sinks current on the output side. This is the core operation of optocouplers, where the isolation barrier is the air or epoxy gap between the LED and photo transistor, and additional circuitry can be designed around the input or output create AC inputs or logic, triac, or gate-driver outputs.

In opto-emulators, the input signal is transmitted across the isolation barrier using an on-off keying (OOK) modulation scheme. The transmitter sends a high frequency carrier across the barrier to represent one digital state and sends no signal to represent the other digital state. Signal transmission in analog opto-emulators functions similarly, and a receiver demodulates the signal after advanced signal conditioning and produces the signal through the output stage. The concept of the OOK modulation scheme is shown by the waveforms in Figure 3-3.

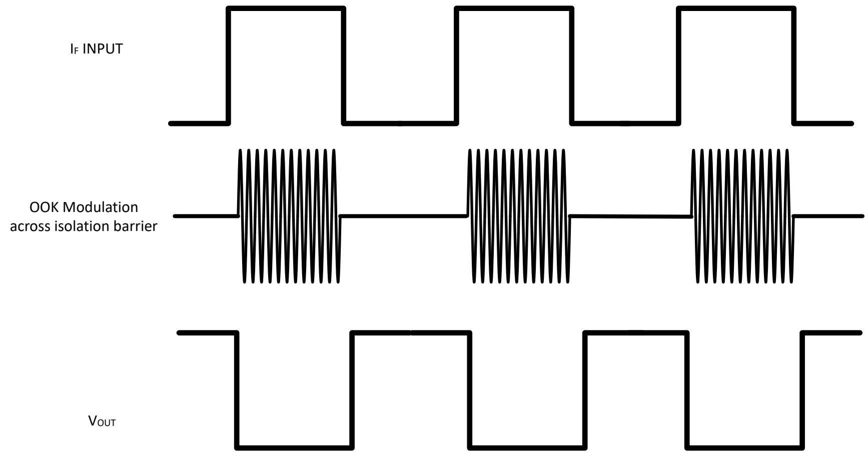

Figure 3-3. On-Off Keying Based Modulation Scheme

4 Classic Circuits Using Opto-Emulators

TI's opto-emulators are designed to be pin-to-pin upgrades for optocoupler components in existing schematics. Circuits which classically use optocouplers can now be upgraded to use opto-emulators and preserve the familiar functionality while enhancing performance, reliability, and safety. Examples of classic circuits using opto-emulators are shown in this section.

4.1 Typical Isolated Power Supply Application Using ISOM811x

ISOM811x opto-emulators have analog output behavior, and are design to replace optocouplers commonly used to transmit isolated signals in the feedback control loops of isolated power supplies.

In these power supplies, the output voltage is isolated from main input voltage using a transformer (for example: flyback converter). For analog power supply units, the controller IC is usually on the primary side of the transformer, and for closed loop control, the output voltage on the secondary side is measured and fed back to the controller on the primary for regulation. The most common way of isolating this analog feedback control signal is using an analog-output optocoupler, replaced by ISOM8110 in this example, an error amplifier (commonly TL431), and a voltage comparator to form a feedback loop across the isolation barrier

Figure 4-1 illustrates a typical isolated power supply. In this implementation, the output voltage is sensed by an error amplifier through the resistor divider. Depending on the voltage level that it senses, the TL431 can drive the current of the ISOM811x higher or lower which is then compared to a voltage reference. The information is passed across the isolation barrier through ISOM811x to the primary side, where the PWM control circuit modulates the power stage to regulate the output voltage. The TL431 and ISOM811x play an important role for stable feedback and control loop.

The ISOM811x devices enable improvements in transient response, reliability, and stability as compared to commonly used optocoupler as the CTR is stable over wide temperature range of -55°C to 125°C providing a small, low-cost, highly reliable, and easy-to-design design as highlighted in the *Isolating Feedback Signals in Power Supplies* product overview.

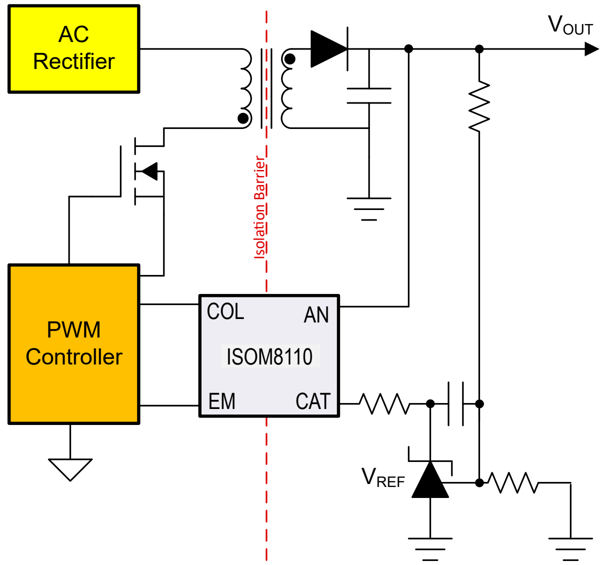

Figure 4-1. Typical Isolated Power Supply Application Using ISOM811x

4.2 High-Speed Signal Isolation Using ISOM871x

Serial communication interfaces are commonly used to transmit and receive data between two or more devices in industrial and automotive systems. For digital applications, common interface types used in short distance, intra-board communication are UART, SPI, and I2C. When used in these applications, traditional optocouplers tend to limit data throughput due to low data rate capabilities and high propagation delays.

TI's digital opto-emulator devices like ISOM8710 and ISOM8711 feature high data-transmission rates and can be used to create isolated, high-speed communication systems to reliably transmit SPI, UART, I2C, and I/O signals between controller devices, like MCUs and FPGAs, and peripheral devices like sensors, data converters, and other controllers in separate voltage domains. When paired with transceiver devices, ISOM871x devices can also be used to complete isolated interface designs, such as for CAN and RS-485, as shown in Figure 4-2 and Figure 4-3.

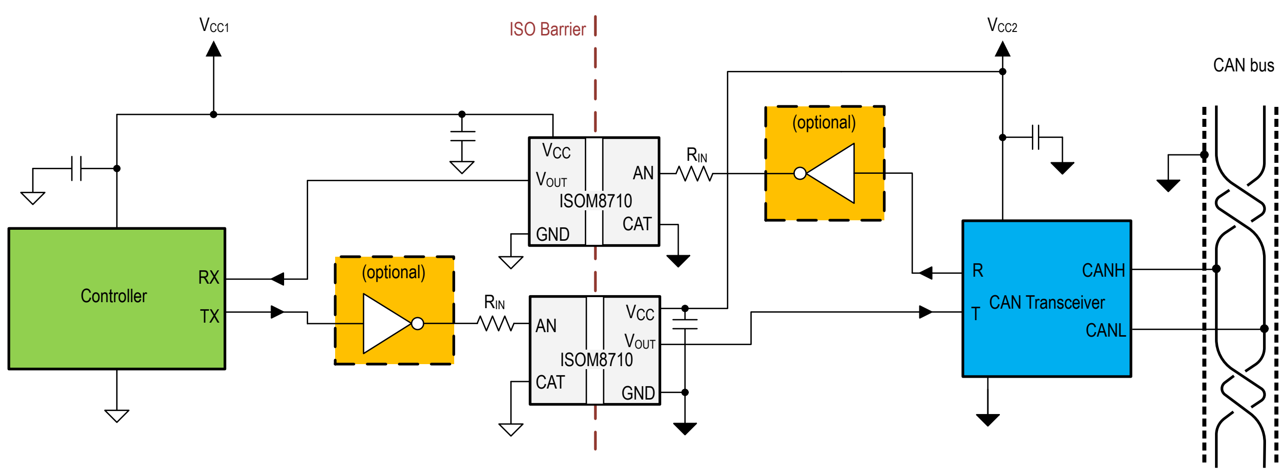

Figure 4-2. Isolated CAN Application Using ISOM8710

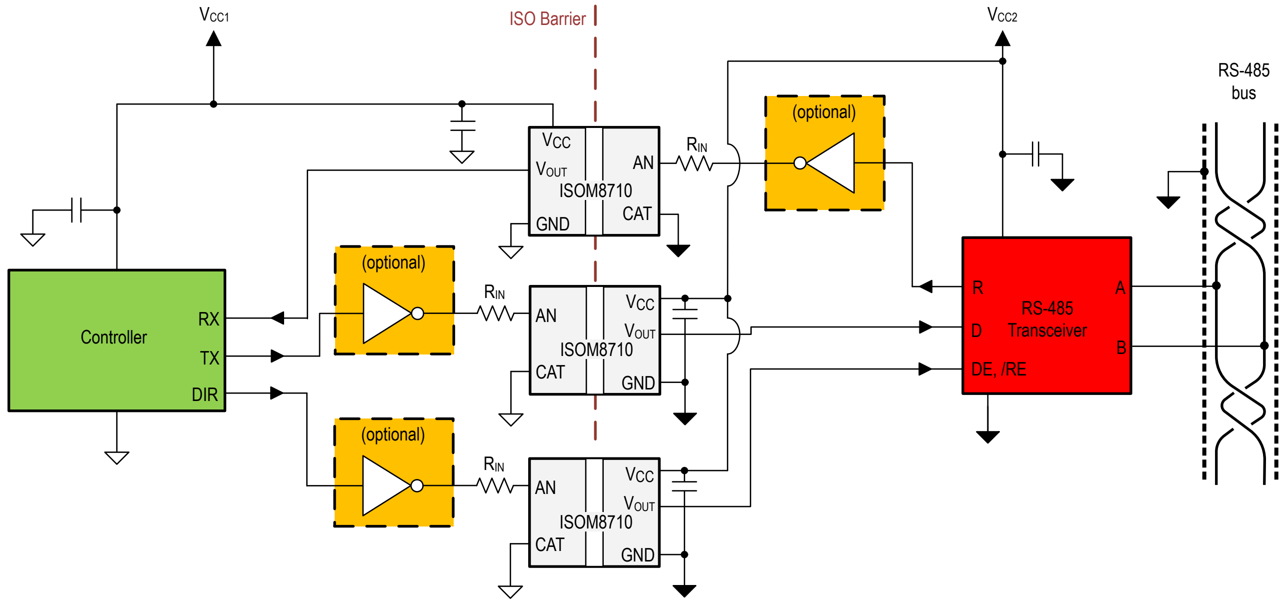

Figure 4-3. Isolated RS-485 Application Using ISOM8710

5 Summary

Optocouplers are a common design for achieving galvanic isolation for system signals. Light-emitting and light-sensitive components used to transmit signals inside of optocouplers are sensitive to temperature and time, so their performance can vary widely over operating temperature and time. Because of these components, optocouplers also tend to have slower response times, higher power consumption, and lower data rates. With semiconductor technological advances in recent decades, TI has developed opto-emulators with similar functionality as optocouplers and lower power consumption, improved CMTI and CTR, higher data rates and bandwidth, wider operating temperature ranges, and longer isolation lifetimes.

See TI's cross reference search tool to find the best opto-emulator upgrade to the existing optocouplers used in your designs today!

6 References

- Texas Instruments, *Addressing High-Voltage Design Challenges With Reliable and Affordable Isolation Technologies*, white paper.
- Texas Instruments, *ISOM8710* product folder and data sheet.
- Texas Instruments, *ISOM8110* product folder and data sheet.
- Texas Instruments, *Standard Optocoupler Circuits* product overviews.
- Texas Instruments, *Isolating Feedback Signals in Power Supplies* product overview.
- Texas Instruments, *TI Cross Reference Tool*.