BROADCOM®

White Paper

Building Safe and Reliable Electrical Systems with Optocouplers

Overview

Electrical systems, no matter what their purpose, share three primary requirements: reliable, safe, and long life operation. To ensure safe operation, users must be double insulated from any dangerous high voltages the equipment employs. To ensure reliable and long life operation, control electronics must also be protected from hazards such as electromagnetic interference and voltage spikes. Broadcom® optocouplers provide safety and protection unmatched by any other isolation technology.

Designers must consider many factors when selecting an isolation technology. The primary factor, of course, is the safety of equipment and personnel. Industrial equipment typically operates using signals of several hundred to several thousand volts. Yet the threshold of human safety can be as low as 42 V DC or 60 V AC. Electronic equipment can be even more sensitive when composed of integrated circuits that can typically be damaged by even a few tens of volts applied across the wrong pins.

To prevent humans and electronics from harm, they must work in the safety extra low voltage (SELV) realm even though other parts of the electrical system use high voltages. Keeping these two voltage realms separated while also passing information between them is the job of the isolation device. These isolation devices must be able to operate with a continuous stress across their isolation barrier of hundreds of volts.

A second factor to consider is the isolation device's insulation rating. There are three levels of insulation rating: functional, basic, and reinforced or double. Functional insulation is that needed for the device to operate and implies nothing about safety. Basic insulation provides protection for users from electrical shock, as long as the insulating barrier remains intact. Reinforced, or double, insulation provides failsafe operation so that if one level of insulation fails, a second level will continue to protect the user. All signal lines going from the high voltage realm to electronic circuits driving interfaces that a user might touch, such as switches and displays, require isolation with a reinforced insulation rating. One of the prime considerations in achieving a reinforced insulation rating is the distance through insulation (DTI) that a high-voltage signal must traverse in order to reach a human.

Consider More Than Safety

While not directly related to human safety, an important factor for the safety of electronic equipment as well as for reliable operation of the equipment is electromagnetic compatibility (EMC). Parameters such as common mode noise immunity and radiated susceptibility are important in assuring that an isolation device will transmit control signals without error. Radiated emissions are an important measure of whether or not an isolation device will generate errors in other signal lines.

Designers should also be aware of the wear out mechanisms that can lead to failure in isolation devices over time. High-voltage transients such as electrostatic discharge (ESD) and voltage surges represent one type of failure mechanism. ESD most often arises from static buildup on human operators while voltage surges arise as the result of changing loads on system power as well as kickback from switching inductive loads. These voltage transients might not themselves result in immediate device failure, but can cause damage that can lead to failure later.

Continuous high-voltage stress across the isolation barrier can also lead to failures, particularly when there are voids in the insulation material. Partial discharges within those voids can wear away the insulating material, eventually leading to failure. To ensure that this failure does not occur during the working lifetime of equipment, designers must consider the high-voltage life rating of their isolation device.

Isolation Technologies

There are several different types of isolation technologies for developers to consider. One of the simplest types utilizes a capacitor to prevent DC voltages on either side of the isolation barrier from equalizing. Also known as AC coupling, capacitive isolation only passes changes in logic signal levels, not the logic levels themselves. Capacitive coupling depends upon changes in the electrostatic field between plates to carry information.

Magnetic isolation uses the equivalent of a transformer in the signal path, magnetically coupling across an insulation barrier from an input coil to output coil. Such magnetic coupling can only pass high-frequency AC signals, not DC levels. A method for encoding logic levels as AC signals must be included in a magnetic isolation device.

RF isolation uses *on-off* encoding to convert logic signals into radio pulses that magnetically or capacitively couple from a transmitter to a receiver. This approach solves the problem of preserving DC logic levels. It suffers, however, from the additional complexity of needing active RF components.

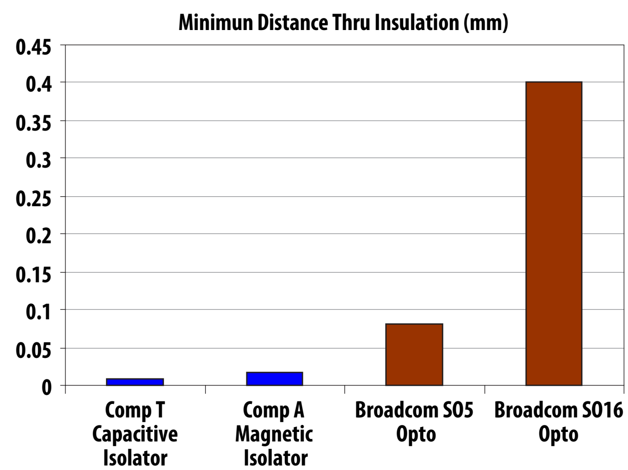
Optocouplers, as their name suggests, use light to carry information through an isolation barrier. Input signals modulate the output intensity of a light emitting diode. A photodiode responds to the optical signal by switching an output transistor on and off. Unlike the magnetic or electrostatic fields used in other isolation techniques, optical coupling does not require extremely close proximity to be effective.

Technology Comparisons: Distance Through Insulation

This freedom from the need for proximity gives optocouplers a tremendous advantage over other isolation techniques in the critical parameter distance through insulation. As shown in Figure 1, the DTI of optocouplers can be one or more orders of magnitude greater than that of other isolation techniques. The typical magnetic isolation device, for example, is built on monolithic CMOS IC material with a thin layer of spin-on polyimide as insulation. Its DTI can be as low as 17 µm. Similarly, capacitors for both capacitive and RF isolation uses layers of SiO_2 as thin as 8 µm. Optocouplers have insulation thicknesses of 80 µm to 1000 µm.

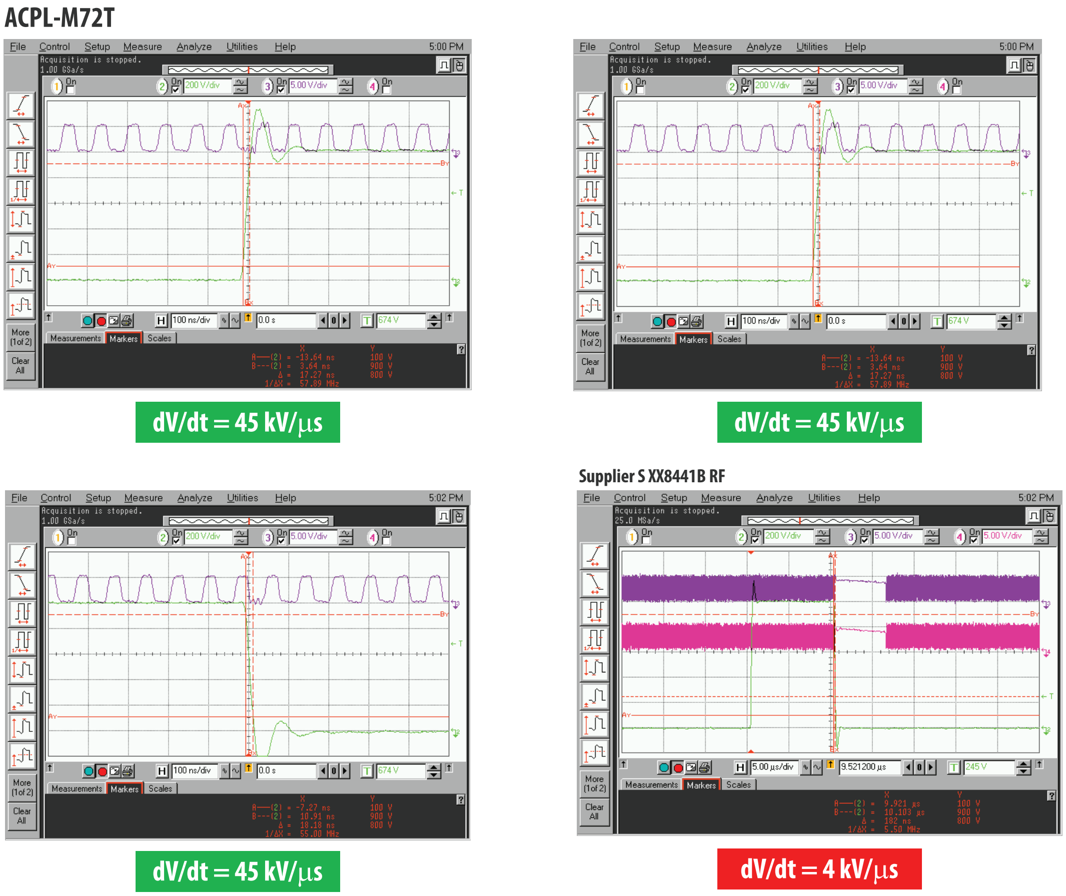
DTI is an important element in isolator design for many reasons. The thinner the insulation layer, for instance, the greater the electrostatic stress on the insulator both during ESD and surge events as well as normal operation at its working voltage. The thick insulation layer of optocouplers thus helps reduce stress on the insulator, providing optocouplers with higher reliability and greater lifetime. DTI is also important in the insulation safety rating. Solid insulation needs to be 400 µm or greater in thickness, and thin sheet insulation must be at least two layers deep to achieve reinforced status. Broadcom optocouplers have three layers of insulation with a total DTI of 400 µm while other isolation techniques typically offer only one thin layer.

Figure 1: Broadcom optocouplers have orders of magnitude greater DTI than other isolation technologies, making them inherently safer for users and equipment.



Technology Comparisons: Immunity to Common Mode Noise

Figure 2: A high-voltage common-mode noise spike creates barely a ripple in optocoupler output but completely shuts down RF isolators.



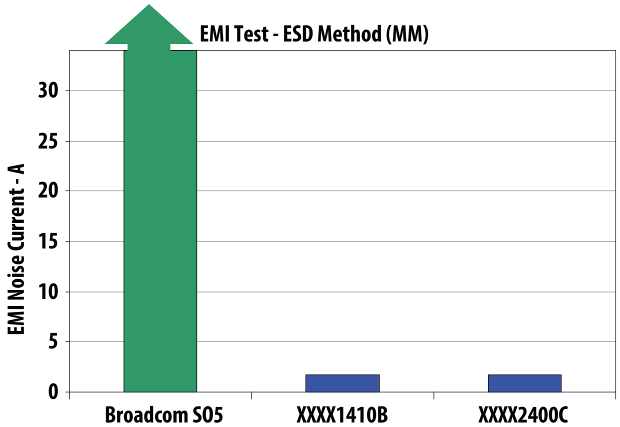
Because optocouplers utilize optical instead of electronic pathways across the isolation barrier to carry their information signals, they also exhibit a greater immunity to common mode noise than other technologies. This is easily demonstrated by applying a high-voltage pulse between the output ground reference and the input supply ground reference of an isolator device. The Broadcom optocouplers output shows barely a ripple upon application of a 1 kV spike in the common mode voltage, as shown in Figure 2. An RF-based isolation device, however, became temporarily inoperative when the voltage spike terminated. Measurements show the optocouplers has more than 10 times the immunity to common mode transients than RF isolation technology.

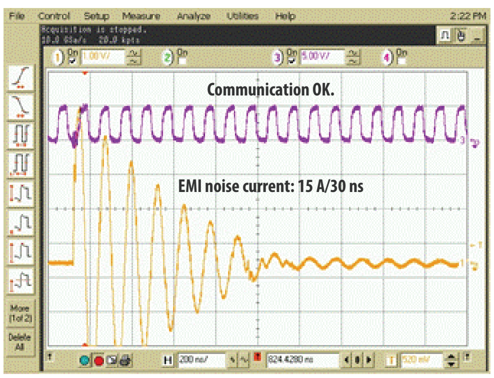
Technology Comparisons: EMI

In evaluating the EMI performance of isolation devices, developers need to explore two aspects: immunity from radiated EMI in the environment and the amount of EMI the device itself generates. As with common mode immunity, the utilization of optical rather than electronic pathways gives optocouplers the advantage over other technologies.

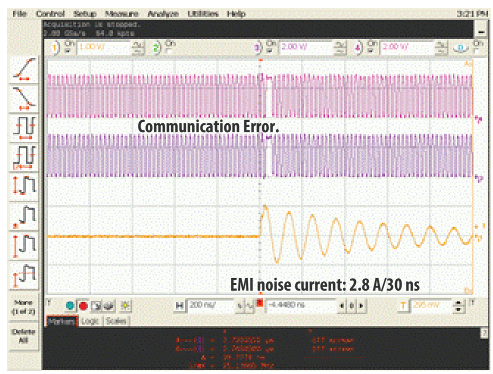
To test for susceptibility to the kinds of EMI commonly found in industrial environments, discharge a high-current spike through a coil centered around the isolation device. This will generate a wideband noise burst with both electric and magnetic components. As can be seen in Figure 3 optocouplers continued performing properly with EMI spikes as great as 15A/30 ns. Magnetic isolation devices, however, failed at levels as low as 2.8A/30 ns.

Figure 3: Optocouplers are virtually immune to EMI at levels far in excess of those that corrupt data in magnetic isolators.





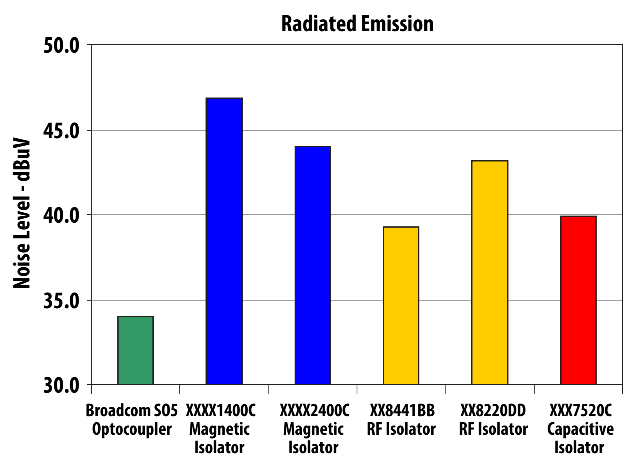
Broadcom Optocoupler – No missing bits seen at 15 A of loop current nearby.



Magnetic Isolator – Missing bits seen at 2.8 A of loop current nearby.

The measurement of radiated EMI uses the same kind of loop antenna, but connected to a spectrum analyzer rather than a voltage source. The spectrum analyzer provides a direct measure of both the magnitude and frequency of the radiated EMI. As can be seen in Figure 4, optocouplers generate significantly less EMI than other isolation devices.

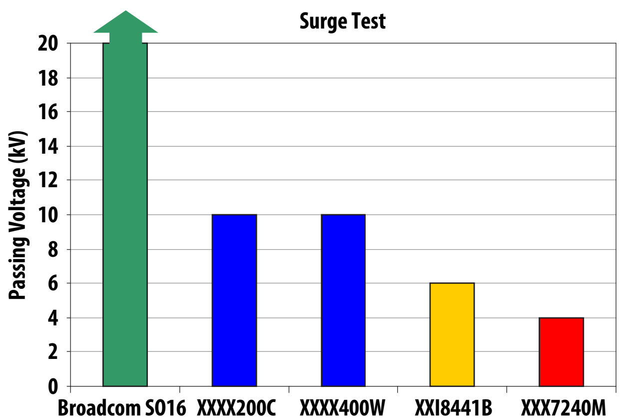
Figure 4: Optocouplers radiate much less EMI than other isolation techniques.



Technology Comparisons: High Voltage Surge Immunity

Common mode noise and EMI have an instantaneous effect on the accuracy of information across an isolation barrier. The integrity of the barrier itself, which is essential to the safety of equipment and users, must prove resistant to voltage surges and electrostatic discharges (ESD). To test this resistance, in accordance to IEC standard 60747-5-5, apply a 10 kV spike across the isolation barrier. The voltage at which breakdown occurs provides a reliable measure of the isolation barrier's resilience. As can be seen in Figure 5, optocouplers are able to tolerate voltage surges in excess of 20 kV while other isolation technologies fail between 4 kV and 10 kV.

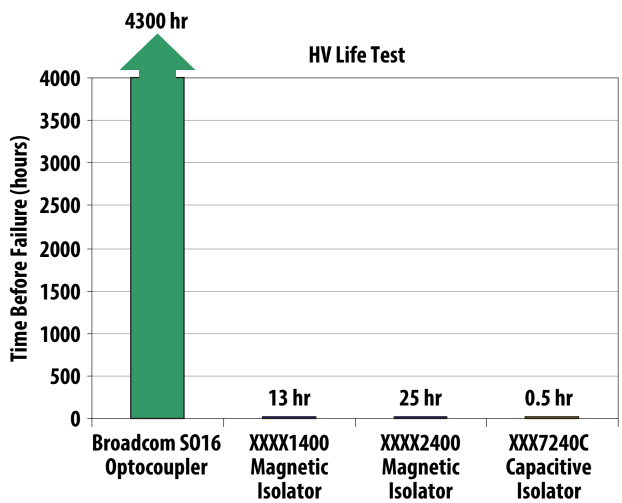
Figure 5: High voltage surges can cause failure in isolation devices, but optocouplers are far more resistant than other technologies.



Technology Comparisons: High Voltage Life Time

Another measure of isolation barrier integrity is the high-voltage life test. This is accomplished by simply applying a high-voltage across the isolation barrier and measuring how long it takes for failure to occur in a high temperature environment. As can be seen in Figure 6 magnetic and capacitive isolation devices quickly failed. RF isolation devices fared somewhat better but still only lasted a few hundred hours. Broadcom optocouplers survived several thousand hours of stress without a single failure.

Figure 6: Under continual over-voltage stress, most isolation technologies quickly fail, but optocouplers last for thousands of hours.



Conclusion

It is therefore clear that optocouplers provide the highest levels of protection and reliability in electrical system. They generate the least EMI and are most resistant to EMI of all the isolation technologies. Similarly, they are the most resistant to damage or disruption by high-voltage transients. Optocouplers also have the only well-defined safety specification that allows them to receive a reinforced rating for safety critical applications. Broadcom optocouplers meet this specification, making them the premier choice for safety and reliable isolation in electrical systems.