White Paper

Building a Safe and Robust Industrial System with Broadcom® Optocouplers

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Introduction

Should production line stoppage occur at an industrial automation company, millions of dollars and opportunity costs can be lost while trying to fix the problem and get the lines running again.

Some of the areas where breakdown can occur are in the electromagnetic interference, high voltage surges, or safety standards. These areas of concern need to be checked at the initial design level rather than later, after manufacturing has been developed and built.

The harsher environment on the factory floor poses issues not relevant in an office environment. With the advent of the Ethernet[1] integration into the industrial automation arena, it became all that more relevant to have stringent requirements in the Fieldbus and device levels for data collection at the receiver end.

Optocouplers are used extensively in industrial networking systems for numerous purposes. They allow electrical circuits and highly diverse voltage levels to work together as a system and can be coupled while remaining electrically isolated or galvanically[2] separated from one another. They are also used to ensure error-free data transmission, retain data integrity, and protect interconnected equipment for high-speed Fieldbus communications. Usage of optocouplers in industrial communication applications include industrial input-output systems, sensors and temperature controlling systems, power supplies and regulation systems, electric motor control and drive systems, instrumentation and medical systems.

In this white paper, we are going to discuss the important factors that need to be taken into considerations when building a safe and robust industrial system.

1. **Ethernet**: A technology that interconnects computers into a high-speed network originally developed by Xerox Corporation. Ethernet is widely used for LANs because it can network a wide variety of computers. It is not proprietary, and components are widely available from many commercial sources.
2. **Galvanic Isolation**: Refers to a design or material techniques that guarantees voltage and noise isolation across an insulating barrier.

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Optocoupler Basics

A basic optocoupler consists of a light-emitting diode (LED), a photodetector, and an optically transparent, electrically insulating film or dielectric. When a current drives the LED, it emits light, which is coupled to the photodetector through the dielectric. The photodetector generates a current that is proportional to the coupled light. This current can be manipulated by various circuitry to perform specific functions. The major function of an optocoupler is to prevent high voltages or rapidly changing voltages on one side of the circuit from damaging components or distorting transmissions on the other side. This is done by optically passing desired signals while maintaining electrical isolation between two systems.

Figure 1: Cross-Sectional Area of Broadcom® Optocoupler

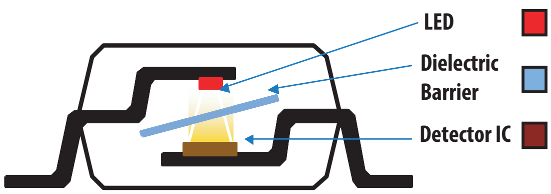
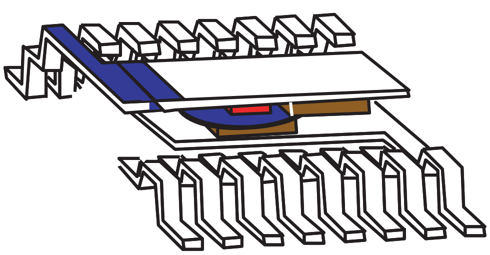


Figure 2: Side View of an Optocoupler



Circuit designers, when designing their applications, can encounter three types of isolation related issues:

- **Voltage Transients:** These are potentially *high current or voltage surges* that might damage components causing electric shock and can endanger human life. They are usually brief and intense surges between two circuits or systems.
- **Ground Loops Currents:** These are unwanted signals between interconnections of different ground potentials, which cause disruptive ground loops. They are usually found in communication networks having *different grounds* at various connecting nodes. The potential difference between these grounds can be alternate current (AC) or direct current (DC) with a combination of various noise components found in that communication system. If the voltage potential is large enough, it can cause damage to equipment (e.g., communication ports), transmission error, or degradation of data signals. Long-term exposure results in the heating and burning of circuit boards, which damages components and causes electric shock, some potentially deadly to human beings.
- **High-Voltage Level Shifting:** With the migration of digital ICs to lower operating voltages, the need for devices to separate sensitive electronics from high power electronics is growing. In order to ensure reliable information exchanges and prevent current flow between different ground reference voltages, there is a need to use isolation. For example, in a motor control application, the electronic system of a motor consists of 2 stages: the low voltage controller and the power module. Within such a system, it is important to protect and insulate the two stages from switching transients and common mode voltage fluctuations. At the same time, it is necessary to provide *level shifting* and *signal isolation* of interface control and feedback circuits.

Safety Standard for Isolation Devices

International Safety Standards are published to ensure equipment and products are used at a basic standard level of safety—not only for the equipment, but also for the people using them. These standards are focused on public safety in the areas of electrical shocks, mechanical hazards and fire, and electromagnetic interferences. At the system and component levels, there are many isolation safety standards both geographically and varying within equipment applications. In the industrial market, the system-level safety standards are IEC 604[3] (International Electrotechnical Commission) for Worldwide or International standards, and UL508[4] (Underwriters Laboratories) for the United States and EN 62477[5] (European Union) for Europe. At the component level for optocouplers, the safety standards are IEC 60747-5-5 for International, UL 1577 for United States and EN 60747-5-5 for Europe.

For future optocoupler standards and maintenance, the IEC will become the de-facto standard worldwide. To receive an IEC 60747-5-5 approval, optocoupler components undergo a stringent set of qualification tests that include environmental, mechanical, isolation, and electrical testing. The criteria for passing the component is the Partial Discharge (PD) test with a rigorous upper limit of 5 pC.

Insulation, as a resistor to current flow, is an important factor in product safety design. The fundamental principles of designing for product safety is the separation of circuits that present a danger of electrocution from other circuits, or certain parts of the equipment that a user might come into contact with, or that connect to other equipment. The circuit must be safe, not only during normal usage, but also under fault conditions. Two main levels of insulation with clear distinction of safety are *Basic Insulation*[6] and *Reinforced Insulation*[7].

Basic Insulation

Since January 2004, the German safety standard certification for optocouplers VDE 0884 has been replaced by IEC/EN/DIN EN 60747-5-5[8], This new safety standard is directly applicable to optically isolated devices. Although this standard specifically pertains to optical isolators only, devices using other isolation technologies such as magnetic or capacitive isolation barriers, have also surprisingly and perhaps erroneously, obtained certifications to this optocoupler safety standard. This recognition is limited to Basic Insulation only. This level of insulation might not provide *failsafe* operation.

Devices that are certified and approved under IEC/EN/DIN EN 60747-5-5 with recognition for Basic Insulation only provide basic protection against electrical shock. They cannot be considered as *failsafe*[9]. Such devices should not be accessible to a user.

3. **IEC 604**: Industrial international standard for equipment and machinery (http://www.iec.ch).
4. **UL 508**: US Industrial standard for machines (http://www.ul.com/).
5. **EN 62477**: Safety requirements for power electronic converter systems and equipment (https://www.cenelec.eu).
6. **Basic Insulation**: Insulation applied to live parts to provide basic protection against electric shock (http://www.601help.com/Disclaimer/glossary.html)
7. **Reinforced Insulation**: Single insulation system applied to live parts which provide a degree of protection against electric shock equivalent to double insulation under the conditions specified in IEC 60601-1 (http://www.601help.com/Disclaimer/glossary.html).
8. **IEC/EN/DIN EN 60747-5-5**: International safety standards (http://www.cenelec.org/).
9. **Failsafe**: A mode of system termination that automatically leaves system processes and components in a secure state when a failure occurs or is detected in the system.

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Reinforced Insulation

The level of insulation required is very much dependent on the failure mode of a component under fault conditions. Reinforced Insulation is only approved for a failsafe component. This means that Reinforced Insulation not only provides protection from electric shock, it has a failsafe design with user's accessibility is permissible.

Broadcom has manufactured optocouplers for more than 50 years, with a wide range of product offerings from phototransistors to the Sigma Delta modulator for current/ voltage sensing. Broadcom offers one of the highest insulation working voltages at 2262 Vpeak.

All Broadcom optocouplers are approved and recognized by component-level safety standards; these include UL1577 (Underwriters Laboratories), CSA (Canadian Standard Association) and IEC/EN/DIN EN 60747-5-5. The UL and CSA ratings are based on momentary dielectric withstand voltage capability for one minute while the IEC/EN/DIN EN ratings are based on the continuous working voltages and transient over-voltages.

As shown in Table 1, Broadcom optocouplers provides a failsafe level of high voltage isolation as indicated in data sheets for all the optocoupler product offerings.

Table 1: IEC/EN/DIN EN 60747-5-5 Insulation Characteristics[a]

Description	Symbol	Characteristic	Unit
Installation Classification per DIN VDE 0110/39, Table 1 For Rated Mains Voltage ≤ 600 Vrms For Rated Mains Voltage ≤ 1000 Vrms		 I – IV I – IV	
Climatic Classification		40/105/21	
Pollution Degree (DIN VDE 0110/39)		2	
Maximum Working Insulation Voltage	V_{IORM}	2262	V_{PEAK}
Input to Output Test Voltage, Method b[a] V_{IORM} x 1.875 = V_{PR}, 100% Production Test with t_m = 1 sec, Partial Discharge < 5 pC	V_{PR}	4242	V_{PEAK}
Input to Output Test Voltage, Method a[a] V_{IORM} x 1.6 = V_{PR}, Type and Sample Test, t_m = 10 sec, Partial Discharge < 5 pC	V_{PR}	3619	V_{PEAK}
Highest Allowable Overvoltage[a] (Transient Overvoltage t_{ini} = 60 sec)	V_{IOTM}	12000	V_{PEAK}
Safety-limiting Values – Maximum Values Allowed in the Event of a Failure Case Temperature Input Current Output Power	 TS $I_{S, INPUT}$ $P_{S, OUTPUT}$	 175 230 1000	 °C mA mW
Insulation Resistance at T_S, V_{IO} = 500V	R_S	$>10^9$	W

a. Refer to IEC/EN/DIN EN 60747-5-5 Optoisolator Safety Standard section of the Broadcom Regulatory Guide to Isolation Circuits, AV02-2041EN for a detailed description of Method a and Method b partial discharge test profiles.

NOTE: These optocouplers are suitable for *safe electrical isolation* only within the safety limit data. Maintenance of the safety data shall be ensured by means of protective circuits. Surface mount classification is Class A in accordance with CECC 00802.

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Reliability of High Voltage Insulation

Optocouplers are often used in environments where high voltages are present. Though many safety standard regulations have been established to provide guidelines to the industry on the application of high voltages, the concern with this insulation is the uncertainty in its reliability due to poorly understood aging and failure mechanisms under electrical and thermal stress.

Evaluation testing was carried out recently to determine the time duration of an isolation device that will successfully insulated one side of the isolation barrier from high voltages on the other side. The test was performed to assess the reliability of a device in the areas of high voltage performance and insulation integrity.

The high voltage life test performed was defined as a destructive test since high voltages of 2.5 KV were applied constantly to Competitor A devices, and for the Broadcom optocouplers, 3.75 KV was applied based on the Broadcom specification from the data sheets. The lifespan of the units were then monitored hourly until the isolation barriers were broken down or until the test units were destroyed.

Several of Competitor A magnetic isolator parts were randomly selected for the test. As shown in Table 2, the results of the test highlight that the units were destroyed between 8.5 hrs to 10.5 hrs. Broadcom optocouplers survived a minimum duration of 168 hrs of high voltage at 3.75 KV. This is proven through our reliability testing process.

Table 2: High Voltage Life Test Results

	High Voltage	
	2.5 KV	3.75 KV
	Magnetic Isolators	Optocouplers
Competitor A 3-Channels Device	Failed at 8.5 hrs	
Competitor A 4-Channels Device	Failed at 10.5 hrs	
Broadcom Digital High-Speed CMOS Part (25 MBd)		Still working at 168 hrs
Broadcom High-Speed CMOS Part (50 MBd)		Still working at 168 hrs

Electrostatic Discharge

One of the primary causes of component failure in high-speed logic circuits is Electrostatic Discharge (ESD). ESD occurs in various situations, from improper device or board handling, improperly designed interfaces, or some other phenomenon that causes a large voltage spike on a device interface. When devices are damaged by ESD, the affected devices might cease to function, exhibit parameter degradation, or demonstrate high failure rates. The only solution is the replacement of the damaged component.

Optocouplers are excellent devices for protecting against ESD problems, especially in situations where two systems are being linked together in electrically demanding environments. Optocouplers allow for ground isolation, making it possible for systems to remain electrically neutral within themselves even though they may be floating in an electrically noisy environment. These environments can include motor control, switching power supplies, industrial networks, and medical applications.

An ESD test was carried out recently to assess and evaluate the performance of optical and magnetic technologies. The test evaluated the impact of ESD pulses applied onto the dielectric materials of two different technologies. Abiding by the testing requirements of the IEC-6100-4-2 standard, five randomly selected magnetic isolators from Competitor A underwent ESD pulses injected into their input side, while all the pins were shorted together on both the input and output sides, as shown in Figure 3, Step 1. The resistance between the input and the output was then measured (Figure 3, step 2) and the results were tabulated in Table 3 and Table 4.

Test Result

As mentioned in the previous section, the test was carried out by injecting ESD pulses into the input side of five units from Competitor A. The ESD voltage level was increased from 5.5 KV in steps of 0.5 KV, until the units failed or broke down. Upon measuring the resistance across the input and output, the readings were close to zero ohms. This implied that the devices under test short-circuited. Three Broadcom optocouplers were then tested using the same method. The result indicated that Broadcom optocouplers showed no dielectric failure, even up to an ESD voltage level of 11 KV. At ESD voltage levels of about 11.5 KV, external arcing did occur on the optocouplers which prevented further testing.

Table 3 shows that the dielectric failure occurred for three of the five units of Competitor A parts at approximately 10 KV, while the other two units failed at an even lower ESD voltage levels of 6.5 KV and 8.0 KV, respectively. This indicated that Competitor A might be more prone to ESD stress than Broadcom optocouplers. The test also showed that the insulating capability of the optocouplers was undisturbed by the ESD stress throughout the testing.

To investigate the cause of failure for the parts under test, the units were decapsulated. Burn marks were found on the transformer IC and the driver IC (see Figure 4). ESD caused a *punch through* effect, resulting in damage to these magnetic devices.

Figure 3: ESD Testing

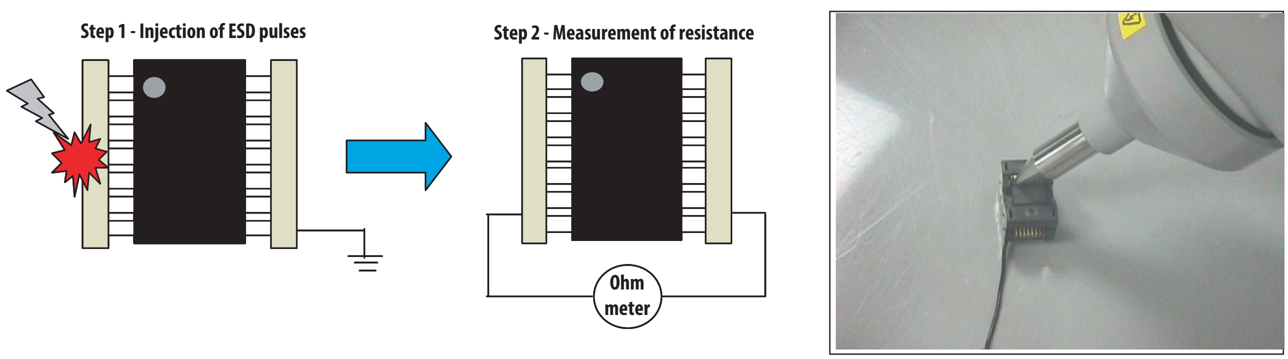


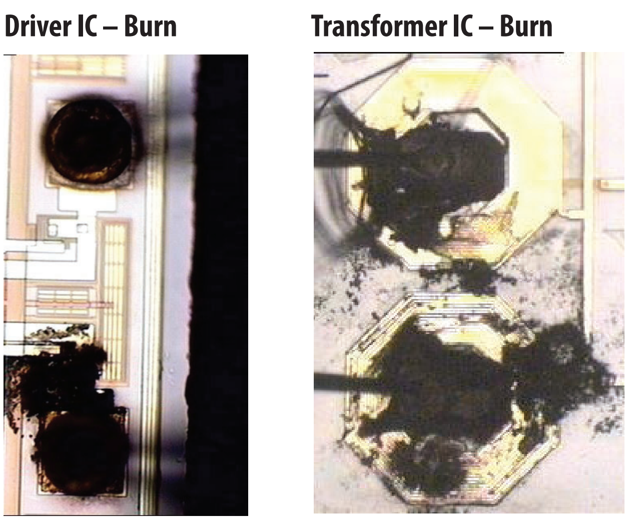
Table 3: Competitor A - Magnetic Isolators

Unit	Competitor A KV	Resistance (Gnd-to-Gnd) KΩ	Comment
1	6.5	4.7	Shorted
2	10.0	9.3	
3	10.0	191.2	
4	8.0	11.1	
5	10.5	13.9	

Table 4: Broadcom HCPL-314J Optocouplers

S/N	HCPL-314J KV	Resistance (Gnd-to-Gnd) KΩ	Comment
1	11.5	—	External arcing occurs
2	11.5	—	
3	11.5	—	

Figure 4: Burn Mark on Competitor A Parts



Electromagnetic Interference (EMI)

Electromagnetic interference (EMI) can be defined as any electromagnetic disturbance that disrupts, degrades, or otherwise interferes with authorized electronic emissions limiting the effective performance of electronics and electrical equipment. It can be induced intentionally, as in some form of electronics warfare, or unintentionally, as a result of spurious emissions and responses, intermodulation products, atmospheric disturbances (including lightning), and extra-terrestrial sources (such as sunspots). Radio Frequency Interference (RFI) is a special class of EMI in which radio frequency transmissions (usually narrow-band) cause unintentional problems in equipment operation. Radio frequency interference can originate from a wide range of sources such as mobile phones or power lines, transformers, medical equipment, electromechanical switches, and many others that can be found in industrial environments.

There are two forms of EMI: **Radiated EMI** and **Conducted EMI**. While Radiated EMI is interference that travels from a source, through the air, to the receiving source, Conducted EMI travels along a conducting path. Both can lead to transmission of unwanted electronic signals. This interference can propagate the authorized signals, which can interfere in the proper operation of the equipment or device by alternating normal operating parameters. These failures are generally categorized as Electromagnetic Interference or EMI failures.

Addressing EMI issues is a challenge. When electromagnetic interference is suspected, the first step in resolving the problem is to determine the mechanism for energy transfer to the affected device(s): radiation, conduction, or induction. Improvements can be achieved by limiting the amount of induced energy either by removing the root cause (physical separation) or by protecting the failing device, e.g., by shielding in the telecommunication area. The best way to avoid potential EMI problems is by choosing less sensitive or immune devices, by optimizing the layout to minimize coupling effects and proper shielding.

All of the various isolators and couplers in the market consist of integrated CMOS or bipolar ICs. The coupling unit, which is the main differentiator between the different technologies available today, can be optically coupled isolators (optocouplers), magnetic coupled isolators (magnetic couplers), and capacitive coupling isolators (capacitive couplers). Each of these behave differently in the presence of strong electromagnetic fields. While the optocoupler LED/photodiode combination is known to be immune against electromagnetic interferences due to the optical coupling path, the magnetic isolators have limitations with respect to EMI due to their microstructure and the magnetic coupling. Failures of the magnetic couplers can occur at the DC level of the field (0 Hz) as well as at various frequencies at different levels of field strength.

The key factor of consideration for designers is to avoid potential future EMI problems in their applications or equipments used in an industrial environment or close proximity of the motor control. Optocouplers are the best choice to use, as they provide superior EMI performance and can withstand much higher electromagnetic fields compared to all other isolators currently available in the market.

Summary and Conclusion

In designing a good industrial system, equipment and component safety plays an important part and is one of the main considerations, especially when high voltages (above DC 48V, AC 110) are involved. These types of systems are usually surrounded by motor starters, servo drives, programmable logic controllers, and/or power converters. Providing a safe environment for personnel to work in, plays a vital role in system design. System critical applications are expected to be failsafe.

Broadcom optocouplers have proven to provide reliable and failsafe parts to meet necessary application requirements. We have discussed four factors when designing a safe and robust industrial system:

- The various safety standards for isolation devices. (Broadcom optocouplers have *Reinforced Insulation*, which provides failsafe operations.)
- Reliability of high voltage insulation, which will minimize the frequency of components breakdown due to high voltage surge into the system. (Broadcom optocouplers can endure a high-voltage of 3.75 KV for a minimum of 168 hrs without failure.)
- ESD causes system degradation or malfunction. (Even at an ESD voltage level of 11 KV, Broadcom optocouplers did not shows any dielectric breakdown failure.)
- EMI is another factor that causes failure of industrial systems. (Broadcom optocouplers have proven to provide superior performance and are nearly immune to EMI.)

While designers usually consider size, low power, and cost in their initial selection for isolation products, it must not be forgotten that the basic requirement for isolation is actually to isolate unwanted signals while insulating against high voltages.

References

Broadcom Regulatory Guide for Isolation Circuits, https://docs.broadcom.com/docs/AV02-2041EN, Publication number AV02-2041EN, pp. 75 to 83.

ACNT-H313 2.5 A Output Current IGBT Gate Drive Optocoupler in 15 mm Stretched SO8 Package, https://docs.broadcom.com/docs/AV02-4249EN, Publication number AV02-4249EN, p. 3, Table 1, IEC/EN/DIN EN 60747-5-5 Insulation Characteristics.

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