Building a Safe and Robust industrial system with Agilent's Optocouplers

White Paper

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Introduction

In an industrial automated company whereby any problems regardless big or small will usually cause stoppage to their automated production systems. These in turn potentially result in millions of dollars and opportunity cost wasted, additional resource and money are spent just to get the system up and running again. Sometimes reasons for these breakdowns are actually caused by problems involving initial design considerations overlooking areas like electromagnetic interference, high voltage surges, or even safety standards.

With the growth of Ethernet[1] and its migration to the industrial environment, a change from once an office configured hardware to a harsh and rugged hardware to be used on the factory floor will definitely pose stringent challenges. Adding this to the integration of Ethernet into Fieldbus and Device levels, the accuracy of data collected at the receiver end is now much more important than ever before.

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 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 what are those important factors that need to be taken into considerations when building a safe and robust industrial system.

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.

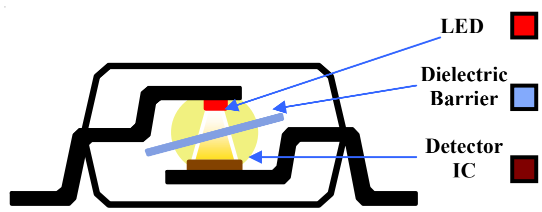

Figure 1. Cross-sectional Area of Agilent's optocoupler

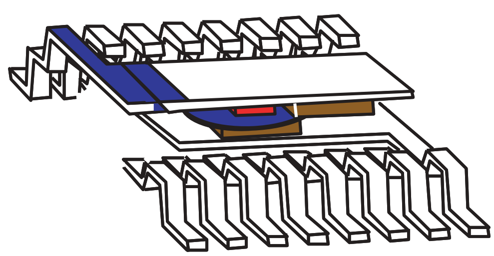

Figure 2. Side view of an optocoupler

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:** Refer to a design or material techniques that guarantees voltage and noise isolation across an insulating barrier

Circuit designers, when designing their applications are usually encounter three types of isolation related issues, namely:

- **Voltage Transients**: These are potentially **high current or voltage surges** that may damage components causing electric shock and may 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 may cause damage to equipments (e.g. commumnication ports), transmission error or degradation of data signals. Long term condition can results in heating and burning of circuit boards thus damaging components and causing 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 preventing 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.

(A) Safety Standard for Isolation Devices

International Safety Standards are published to ensure safe equipments and products are consistent. These standards are concerned about public safety in the areas of electrical shocks, mechanical hazards, fire and electromagnetic interferences. At system and component levels, there are many isolation safety standards both geographically and varying with various 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 United States and EN 50178[5] (European Union) for Europe. While at component level for optocouplers, the safety standards are **IEC 60747-5-2** for International, **UL 1577** for United States and **EN 60747-5-2** for Europe.

It is known that for future optocoupler standards and their maintenance, International Electrotechnical Commission (IEC) will take the lead and become more universal. For IEC 60747-5-2 approval, optocoupler's components undergo a unique amount of stringent qualification tests that include environmental, mechanical, isolation and electrical testing. The criterion for passing the component is the **Partial Discharge** (PD) test with a rigorous upper limit of 5pC.

Insulation is defined as the property of a material that resists the flow of current until component breakdown. Therefore, insulation is an important factor for product safety designing. The basic 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 which a user may come into contact or which connects to other equipments. 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]'.

3 **IEC 604:** Industrial International standard for equipments and machine (Web link http://www.iec.ch)
4 **UL 508:** US Industrial standard for machines (Web link http://www.ul.com/)
5 **EN 50178:** European standard for industrial equipments (Web link http://www.newapproach.org/)
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)

- **Basic Insulation**

  With effect from January 2004, the German safety standard certification for optocouplers VDE 0884 was replaced by **IEC/EN/DIN EN 60747-5-2**[6], this is the safety standard 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 the optocoupler safety standard. However, their recognition is limited to '**Basic Insulation**' only, this given level of insulation may not provide '**Failsafe operation**'.

  This means that devices that are certified and approved under IEC/EN/DIN EN 60747-5-2 with recognition for '**Basic Insulation**' only provide basic protection against electrical shock. They **cannot** be considered as '**Failsafe**[9]' and therefore such devices should not be accessible to a user. One of our competitors offers an isolation that uses monolithic air core transformer, as quoted from their datasheet under footnote for Insulation Characteristics: "This isolator is suitable for basic electrical isolation only...". Since this technology is not optical isolation technology that the IEC/EN/DIN EN 60747-5-2 standard is supposed to be for, hence they are certified and approved by the certifying bodies for '**Basic Electrical Isolation**' only. As noted, basic insulation by definition is considered to fail or become shorted under a single fault condition.

- **Reinforced Insulation**

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

Agilent Technologies has manufactured optocouplers for more than 30 years and we have one of the widest range of product offerings from phototransistors to industry's fastest optocoupler at 50MBd. We are one of the leading suppliers with the highest insulation working voltage at $1414V_{peak}$. All of Agilent's optocouplers are approved and recognized by component-level safety standards, these include UL1577 (Underwriters Laboratories), CSA (Canadian Standard Association) and IEC/EN/DIN EN 60747-5-2 (International Electrotechnical Commission, European Union, German National Standard). 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 Figure 3, Agilent's optocouplers provides a '**Failsafe**' level of high voltage isolation as indicated in datasheets for all the optocoupler product offerings.

IEC/EN/DIN EN 60747-5-2 Insulation Related Characteristics (Option 060)

Description	Symbol	HCPL-772X Option 060	HCPL-072X Option 060	Units
Installation classification per DIN VDE 0110/1.89, Table 1 for rated mains voltage ≤ 150 V rms for rated mains voltage ≤ 300 V rms for rated mains voltage ≤ 450 V rms		 I-IV I-IV I-III	 I-IV I-III	
Climatic Classification		55/85/21	55/85/21	
Pollution Degree (DIN VDE 0110/1.89)		2	2	
Maximum Working Insulation Voltage	V_{IORM}	630	560	V peak
Input to Output Test Voltage, Method b† V_{IORM} x 1.875 = V_{PR}, 100% Production Test with t_m = 1 sec, Partial Discharge < 5 pC	V_{PR}	1181	1050	V peak
Input to Output Test Voltage, Method a† V_{IORM} x 1.5 = V_{PR}, Type and Sample Test, t_m = 60 sec, Partial Discharge < 5 pC	V_{PR}	945	840	V peak
Highest Allowable Overvoltage† (Transient Overvoltage, t_{ini} = 10 sec)	V_{IOTM}	6000	4000	V peak
Safety Limiting Values (Maximum values allowed in the event of a failure, also see Thermal Derating curve, Figure 11.) Case Temperature Input Current Output Power	 T_S $I_{S,INPUT}$ $P_{S,OUTPUT}$	 175 230 600	 150 150 600	 °C mA mW
Insulation Resistance at T_S, V_{10} = 500 V	R_{IO}	$\geq 10^9$	$\geq 10^9$	Ω

†Refer to the front of the optocoupler section of the *Isolation and Control Component Designer's Catalog*, under Product Safety Regulations section IEC/EN/DIN EN 60747-5-2, for a detailed description.

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.

Note: The surface mount classification is Class A in accordance with CECC 00802.

suitable for "safe electrical isolation"

Figure 3. Extracted from Agilent's optocoupler HCPL-0720 datasheet (Page 6)

8 **IEC/EN/DIN EN 60747-5-2:** (Web link 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. (http://homepage.mac.com/antallan/gistf.html)

(B) Reliability of High Voltage Insulation

Optocouplers are often used in the 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 problem of this insulator is the uncertainty in its reliability due to poorly understood ageing 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 insulate one side of its 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 2.5KV was applied constantly to competitor (A) devices and for the Agilent's optocouplers, 3.75KV was applied based on Agilent's specification in the datasheets. The lifespan of the units were then monitored hourly till the isolation barriers were broken down or till the test units were destroyed.

Several of Competitor (A) magnetic isolator parts were randomly selected for the test. As shown in the table below, the results of the test highlight the units under test were destroyed between the time duration of 8.5hrs to 10.5hrs. On the other hand, Agilent's optocouplers, survived a minimum duration of 168hrs of high voltage at 3.75KV. This is proven through our reliability testing process for Agilent's optocouplers families, Table 1 shows the testing summary of Competitor (A) and Agilent's devices.

(C) Electrostatic Discharge

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

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

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 the two different technologies. Abiding by the testing requirements of IEC-6100-4-2 standard, five units of randomly selected samples of Competitor (A) parts undergoes ESD pulses injected into their input side while all the pins were shorted together on both the input and output sides respectively as shown in Figure 4, step 1. The resistance between the input and the output was then measured (Figure 4, step 2) and the results were tabulated on table 2.

Table 1. High Voltage Life Test Results

	High Voltage	
	2.5KV	3.75KV
	Magnetic Isolators	Optocouplers
Competitor (A) 3-channels device	Failed at 8.5hrs	
Competitor (A) 4-channels device	Failed at 10.5hrs	
Agilent Digital High-Speed CMOS part(25MBd)		Still working at 168hrs
Agilent Digital High-Speed CMOS part(50MBd)		Still working at 168hrs

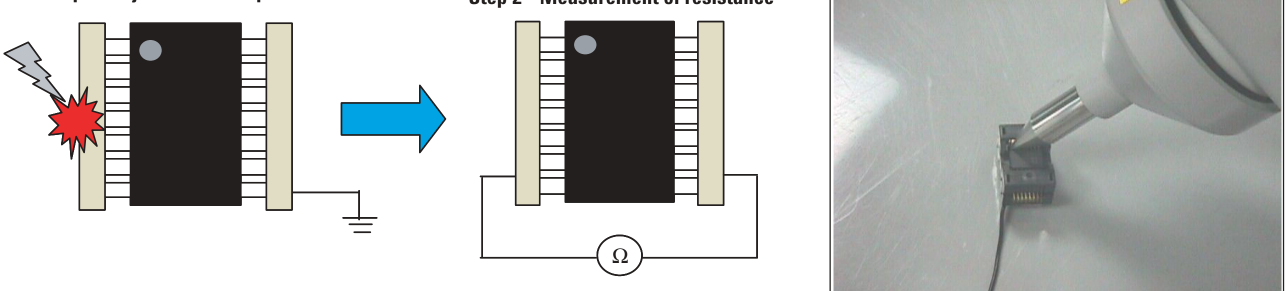

Figure 4. ESD Testing

- **Test Result**

As mentioned earlier, the test was carried out by injecting ESD pulses into the input side of five units of Competitor (A), the ESD voltage level was then increased from 5.5KV upwards in steps of 0.5KV until the units failed or broken down. This mean that upon measuring the resistance across the input and output, the readings were observed to indicate close to zero ohms. Which implies that the devices under test were short-circuited. Next, three units of Agilent's optocouplers were also tested using the same method, the result indicated that Agilent's optocouplers show no dielectric failure even up to an ESD voltage level of 11KV. However, at ESD voltage level of about 11.5KV external arcing occurs on the optocouplers hence prevents further testing.

If we look at table 2, it can be seen that the dielectric failure occurred for three of the five units of Competitor (A) parts at approximately 10KV while the other two units failed at an even lower ESD voltage levels of 6.5KV and 8.0KV respectively. This indicated that Competitor (A) might be more prone to ESD stress than Agilent's optocouplers. The test also showed that the optocouplers insulating capability was undisturbed by the ESD stress throughout the testing.

To investigate the cause of failure for the parts under test, the units were decapsulated. It was observed that burned marks on the transformer IC and the driver IC could be found, see figure 5. This illustrated the impact of ESD on the magnetic devices which causes a 'punch through' effect resulted in damaging of the devices under test.

Table 2.

Competitor (A) - Magnetic Isolators

Unit	Competitor (A) KV	Resistance (Gnd-to-Gnd) Kohm	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	

Agilent HCPL-314J optocouplers

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

Driver IC – Burn **Transformer IC – Burn**

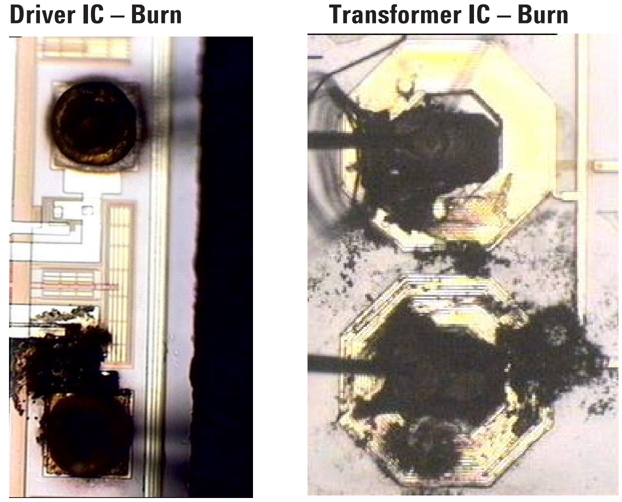

Figure 5. Burn mark on Competitor 'A' parts

(D) 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 unintentional emitters that can be found especially in the industrial environment.

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 transmitting unwanted electronic signals, which propagates the authorized signals interfering 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 major 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. There are **costs involved** in this process too. 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.

Looking at the various isolators and couplers in the market they all consist of integrated CMOS or bipolar IC. The coupling unit, which is the main differentiator between the different technologies available today, is optically coupled isolators (optocouplers), magnetic coupled isolators (magnetic couplers) and capacitive coupling isolators (capacitive couplers). Each of them behaves 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 do have its limitations with respect to EMI due to their microstructure and the magnetic coupling. Failures of the magnetic couplers can occur at 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 especially those used in the industrial environment and close proximity of the motor control. **Optocouplers** are the best choice to use as they do 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, equipments and components safety play an important part and is one of the main considerations especially when high voltages (above DC 48V, AC 110) are involved. These type of systems are usually surrounded by motor starters, servo drives, Programmable Logic Controllers, Power converter, hence, providing a safe environment for personnels to work plays a vital role in system design. In addition to this, system critical applications are expected to be **failsafe** whereby a breakdown in components, which result in machine failure, will be costly for the business as mentioned in the introduction.

Agilent's optocouplers have been in the industry for more than 30 years, and have been used in many applications in the industrial market and have proven to provide reliable and failsafe parts to meet those application requirements. We have discussed four factors when designing a safe and robust industrial system. They are,

- The various safety standards for isolation devices, taking note that Agilent's 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. Note that Agilent's optocouplers can endure a high-voltage of 3.75KV for a minimum of 168Hrs without failure.
- Electrostatic Discharge (ESD), which causes system degradation or malfunction. Taking note that even at an ESD voltage level of 11KV, Agilent's optocouplers did not shows any dielectric breakdown failure.
- Electromagnetic Interference (EMI) is also another factor that causes failure of industrial systems. Again, Agilent's optocouplers have proven to provide superior performance and are almost immuned 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. Therefore, the four important points highlighted above serve as a good selection criteria when you intend to design a safe and reliable industrial system.

References

[1] Agilent Regulatory Guide for Isolation Circuits

Publication number: 5989-0342EN
Web link: http://www.agilent.com/view/optocouplers
Page 61 to 69

[2] Agilent High Speed CMOS digital optocoupler datasheet

Publication number: 5989-0790EN
Web link: http://www.agilent.com/view/optocouplers
Page 6, IEC/EN/DIN EN 60747-5-2 Insulation Related Characteristic (Option 060)

[3] ESD Considerations in High Speed Circuits

Integrated Device Technology, Inc.
Application Notes AN-123
Web link: http://www1.idt.com/pcms/tempDocs/AN_123.pdf

[4] Isolation and Safety Standards for Electronic Instruments

National Instrument Developer Zone
Web link: http://zone.ni.com/devzone/conceptd.nsf/webmain/6D1C1BE6590C0D4A86256C1A0078763C?opendocument

[5] IEC/UL 60950-1 Application Guideline 3.1.9-1

CENELEC released a standard, EN50116 that defines the routine electrical safety tests and their procedures to be applied during or after the manufacturing process of IT equipment certified or declared as complying with EN60950.
Web link: http://zone.ni.com/devzone/conceptd.nsf/webmain/6D1C1BE6590C0D4A86256C1A0078763C?opendocument

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November 18, 2004
5989-1774EN

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