Safety Design and Certification For Test and Measurement Products

Part 2

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Part 1 of this article appeared in the November 2003 issue of EE.

Learn more about the three important steps to developing safe designs for products used in today's higher voltage applications.

It is essential that engineers understand the underlying principles of safety so that they can design safe products. Safety does not cover the performance or functional characteristics of the product. Instead, the evaluation only has to prove that the product meets the standards and doesn't pose a hazard to the user.

Designers should take into account the normal operating conditions of the equipment and likely fault conditions, consequential faults, foreseeable misuse, and external influence such as temperature, altitude, pollution, moisture, and overvoltages. Products must meet the standards and be inherently safe when possible, even after a single fault. Caution statements should not take the place of safe design.

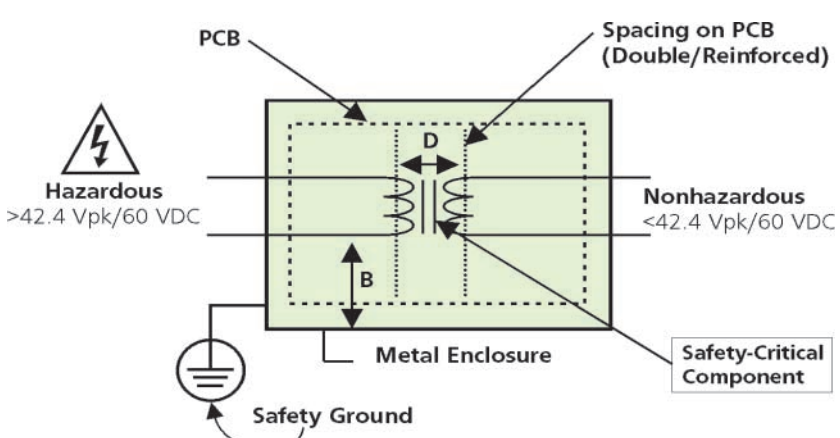

Figure 1. Insulation System
B = basic insulation
D = double insulation

Steps to a Safe Design

These steps to producing a safe design are presented in order of priority:

1) Components—Identify safety-critical components with safety marks to confirm they meet U.S. and EU standards: UL/CSA for North America and VDE/TUV for Europe.
2) Construction and Design—Meet all construction and design requirements such as insulation, PCB spacings, enclosures, labels and markings, wiring, materials, and user documentation.
3) Testing—Products shall pass all relevant safety tests after components and construction are in order. Tests include dielectric withstand, ground continuity, temperature, and abnormals. Complete product safety evaluation and testing should be performed by qualified people to ensure conformity.

Safety Principles

Users must be protected from electrical hazards during normal product operation and after a single fault. User-accessible parts are protected through the use of various

Basic Insulation[2] Pollution Degree 2 Measurement Category II					Double or Reinforced Insulation[2] Pollution Degree 2 Measurement Category II				
Working Voltage (rms or DC) up to	Clearance	Creepage on PCB (CTI >175)	Creepage In Equipment (CTI >100)	rms Test Voltage	Working Voltage (rms or DC) up to	Clearance	Creepage on PCB (CTI >175)	Creepage In Equipment (CTI >100)	rms Test Voltage
50	0.2	0.2	1.2	350	50	0.2	0.4	2.4	510
100	0.2	0.2	1.4	490	100	0.4	0.4	2.8	740
150	0.5	0.5	1.6	820	150	1.6	1.6	3.2	1,400
300	1.5	1.5	3.0	1,350	300	3.3	3.3	6.0	2,300
600	3.4	3.0	6.0	2,200	600	6.5	6.5	12.0	3,700
1,000	5.5	5.5	10.0	3,250	1,000	11.5	11.5	20.0	5,550

Table 1. Creepage and Clearance Per IEC 61010-1:1990[1]

1. Table 1 is for illustration only. Refer to IEC 61010-1 for tables and actual values.
2. Distances in millimeters; PCB is not coated. Conformal coating does not reduce distances.

forms of insulation, enclosures, and other means. A part is accessible if it can be touched with a finger or pin.

Hazardous live voltage is >42.4 Vpk/60 VDC, which may cause shock. Working voltage is the highest rms value of AC or DC voltage that can occur across any particular insulation.

Safe voltage limits in normal conditions are 30 Vrms/ 42.4 Vpk/60 VDC in IEC 61010-1:1990 and 33 Vrms/ 46.7 Vpk/70 VDC per IEC 61010-1:2001. If hazardous live voltage is bridged to safety extra-low voltage (SELV), damage to the product could result, and the user may risk electric shock or burn.

Nonhazardous voltage circuits are everywhere and may be accessible to the user. These SELV circuits are <42.4 Vpk/60 VDC. Examples include accessible connector pins for printers, keyboards, and PCs that typically are SELV and considered safe to touch. For that reason, SELV circuits must be adequately insulated from hazardous live voltages to protect the user.

Insulation is achieved through various forms such as barriers, grounding, or distance. Basic insulation is a single layer or distance and the first protection level. Supplemental insulation is several layers of insulation or a distance equal to two times basic insulation.

Caution statements should not take the place of safe design.

With double insulation, if there is a fault on one layer, the basic insulation still remains to protect the user. Reinforced insulation is a single body of insulation. It equals several layers of insulation or a distance equal to two times the basic insulation.

Figure 1 illustrates an insulation system where hazardous live voltage is separated from nonhazardous voltages by double insulation, and the enclosure is separated from hazardous live by basic insulation. If the enclosure were not safety grounded, double insulation would be required.

Safety-Critical Components

Safety-critical components may affect the safety of the product or user. Safety-critical components should comply with the relevant component standards and be rated for use per the end-product standard.

Safety-critical components typically are located in hazardous live circuits (>42.4 Vpk/60 VDC) with special focus on components that bridge double/reinforced insulation (SELV to 250/300 V). Examples are optical isolators, transformers, relays, fuses, and AC input components such as inlets, switches, terminal blocks, and power supplies.

UL and IEC component standards are not yet harmonized for most components. As a result, two safety marks may be required to verify compliance for the United States and Europe. Certification body marks are evidence that the component meets the standards.

With respect to safety, the CE Marking is for products, not components. Ignore the CE Marking when found on components.

Insulation

Products designed with insulation between conductive parts adequately protect the user from hazardous live voltages. The minimum insulation (spacing) values depend on five factors:
1) Measurement category.
2) Pollution degree.
3) Working voltage.
4) Insulation: basic, supplementary, double/reinforced.
5) Comparative tracking index (CTI).

Clearance is the shortest distance between two conductive parts measured through air. Creepage is the shortest distance between two conductive parts measured along a surface. Creepage always should be at least as large as clearance. Interpolation of creepage in **Table 1** is permissible. Here are some examples of required insulation between circuits:

• Double/reinforced insulation between hazardous live voltages (>42.4 Vpk/60V DC) and SELV (<42.4 Vpk/60 VDC).
• Basic insulation between hazardous voltages and safety ground circuits/enclosures.
• Double/reinforced insulation between hazardous voltages and an ungrounded metal enclosure.

Safety Design Checklist

ENCLOSURES

Enclosures provide protection against electric shock, fire, and mechanical hazards. Mechanical and electric hazards shall not lead to a hazard in a normal or single-fault condition. Moving parts shall not crush, cut, pierce, or severely pinch an operator's skin. Parts are considered accessible if they can be touched with a test pin or finger. If the operator must perform actions in normal use, with or without a tool that increases the accessibility of parts, these actions shall be taken before testing. Examples include any doors, covers, or parts opened or removed.

Product Enclosures

- ❑ Jointed test finger (12 mm) applied to all sides and openings with 10-N force for accessibility
- ❑ Top openings test pin (4-mm dia × 100-mm long)
- ❑ Bottom openings; 2-mm dia max × 3-mm spacing or wire mesh or baffle
- ❑ Pre-set controls openings (for tool adjust) test pin (3-mm dia × 100-mm long)
- ❑ Fasteners for covers/filters over hazardous live parts and mechanical hazards shall require tool to remove

Additional Considerations for chassis and rack equipment, as applicable (IEC 61010-1)

- ❑ Stability: 10° tilt and must not overbalance
- ❑ Equipment of >1-m height and >25-kg; mass: 250 N/20% weight test
- ❑ Handles capable of withstanding force of four times the weight of the equipment
- ❑ Static test (impact hammer): 12-mm dia × 30 N
- ❑ Dynamic Test (ball impact): 50-mm dia sphere
- ❑ Corner Drop Test: 25 mm ±2.5 mm or 30°, one drop each of four corners

GROUNDING, WIRING, AND CONNECTIONS

User-accessible conductive parts shall be bonded to the Protective Earth (PE) (safety-ground) conductor terminal if they could become hazardous live in the case of a single fault, or parts shall be separated from other parts which are hazardous live. The integrity of the PE bonding shall be assured. Circuit/wiring connections shall not cause accessible parts to become live in normal or single fault condition.

Protective Earth (PE)

- ❑ PE required for accessible conductive part, such as a metal enclosure, if the part can become hazardous live as the result of a single fault (not if part/enclosure separated by double/reinforced)
- ❑ Products using PE shall provide a suitable terminal for connection of PE conductor
- ❑ PE soldered connection/s require mechanical securement in addition to solder
- ❑ PE shall not be used for other purposes such as fixing constructional parts
- ❑ Hinges and slides shall not be used for PE path
- ❑ Exterior metal braids/foils of cables shall not be considered as PE bonding
- ❑ PE conductors may be bare or insulated; clear or green/yellow for PE insulation color

General Construction

- ❑ If power disconnect switch used, locate close to supply, disconnect L&N
- ❑ Circuit breakers for AC supply should break L&N since not polarized in Europe
- ❑ Plugs and connectors for AC supply connection to comply with the relevant standards
- ❑ Keep hazardous voltage wires separated from uninsulated SELV circuits
- ❑ Security of wiring connections shall not depend on soldering
- ❑ Accidental loosen of wiring and screws shall not cause accessible part to become live
- ❑ Self-tapping screws and screws of insulating material should not be used for electrical connections
- ❑ Double fix wire connections
- ❑ Edges, corners accessible to users and wireways shall be rounded or smoothed
- ❑ Circuits and connectors for external use (PCBs and cables) shall have limited energy
- ❑ Unmated measuring terminals at hazardous live shall not be accessible

LABELS AND MARKINGS

Products shall bear voltage, power, and frequency ratings and company identification markings. Symbols shall be in accordance with IEC standards; for example, V (voltage), A (amperage), Hz (hertz), AC/DC (alternating/direct current) or

Safety Design Checklist

AC/DC symbols. Check standard for markings, caution wording, and exceptions. The user documentation needs to reflect the product’s rating.

Markings and Labels Visible to the User

- ❑ Manufacturers name and/or logo, model number, and factory ID on label
- ❑ Input RATING in V, A, and Hz for AC power such as 100 to 240 VAC, 4 to 2 A, 60/50 Hz
- ❑ 115/230 VAC convenience outlets marked such as 100 to 240 VAC, 3 A max
- ❑ On and off symbols (I/O), standby or push-push symbols for disconnect switch

Markings Typically Internal to the Product

- ❑ AC terminals shall be identified (L, N, PE)
- ❑ PE symbol (IEC 60417-5019) adjacent to ground terminal
- ❑ Earth (ground) symbol (IEC 60417-5017 or other) for nonsafety grounds

Markings for Measurement Products Visible to the User

- ❑ CATI marking is not typically required for nonhazardous voltage products
- ❑ Measurement terminals marked with rated V or A and symbol 14
- ❑ Measurement terminals for CATII to IV marked with rated V or A and category

FLAMMABILITY OF MATERIALS

Materials are classified for burning resistance, such as V-0 Class for vertical burn test where the flame will extinguish within 5 s and flaming drops will not ignite cotton. V-1 extinguishes within 25 s. HB is a horizontal burn class, and HF class is for foamed materials. Components, wiring, and parts inside an enclosure and materials that support live parts shall be constructed of materials intended to reduce the propagation of fire. A fire enclosure is intended to minimize the spread of fire from within, such as fire resulting from a single fault.

Minimum Flammability Ratings

- ❑ Plastics for fire enclosures rated V-1 after molding
- ❑ PCB rated V-1
- ❑ V-2 for plastics enclosures that have other means to prevent the spread of fire; for example, a metal subenclosure
- ❑ Plastics in I/O connectors with nonhazardous voltages, rated V-2
- ❑ Connectors and plastic on which components are mounted, rated V-2
- ❑ Plastic air filters, rated V-2 or HF-2
- ❑ Plastic enclosures and decorative parts outside fire enclosures, rated HB
- ❑ Plastic wire insulation, rated FV-1
- ❑ Exempt: PVC/TFE/PTFE/FEP/neoprene wire insulation, small parts on PCBs, layers of insulation, adhesive tape, nameplates, mounting feet, cable ties, knobs, and others

NOTE: This checklist gives a safety overview based on IEC 61010-1. Flammability of material requirements are from IEC 61010-1 and IEC 60950-1. The checklist covers some design tips; refer to the standards for other safety requirements, tests, and pass/fail criteria.

Table 2. Safety Design Checklist

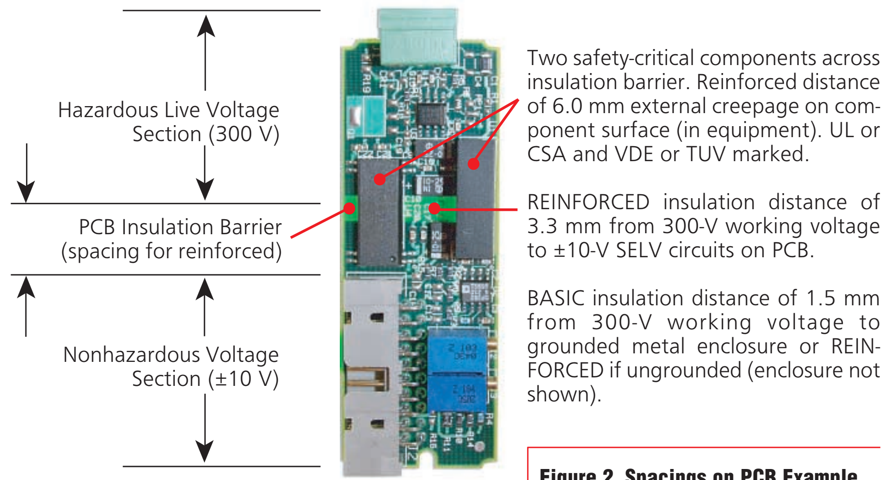

Figure 2. Spacings on PCB Example for 300 V – CAT II

• Basic insulation within hazardous voltage circuits preferred.

Measurements on PCBs and parts are noted between the two closest conductive parts such as edges of pads around soldered connections on PCBs. In-equipment distances are spacings between parts not on PCBs, such as connector pins or pins on optical isolators.

The CTI is used to determine spacing distances (creepage) on PCBs, connectors, and other parts. CTI expresses the voltage that causes tracking across insulating materials. CTI values typically are specified in vendor specifications with the lowest CTI used when unspecified such as CTI >175 on PCBs and CTI >100 in equipment (not on PCB).

Using **Figure 2** and **Table 1**, one evaluation method first determines the pollution degree (typically 2) and measurement category (CAT II) for the operating environment. A block diagram sections circuits as hazardous, SELV, and safety grounds:

• Block 1 = Hazardous live voltage circuit section >42.4 Vpk/60 VDC.

• Block 2 = SELV secondary circuit section <42.4 Vpk/60 VDC.

• Block 3 = Grounds such as safety-ground traces and/or metal enclosure.

Measure the distances on PCBs and parts to see if the spacings meet the requirements. The closest distance between two parts should be at least as large as the value in the appropriate table in IEC 61010-1. Measurement examples are PCB trace-to-trace, connector pin-to-pin, optical isolator input-to-output pins, and ground trace/metal enclosure to live circuits.

Conclusion

With international standards becoming the *de facto* rules worldwide and consumer awareness of safety increasing, it is incumbent on manufacturers to understand and apply a sound safety design policy. By reading the standards and understanding safety concepts, product manufacturers will be better equipped to design products that comply with established safety norms.

To get started, use the information contained in this article along with the standards and the Safety Design Checklist (**Table 2**). It is important to remember the steps to a safe design are components, construction and design, and testing.

About the Author

David Lohbeck is a senior safety engineer at National Instruments. Previously, he worked for Motorola, Memorex, Dell, and TUV in the field of international product safety and EMC. Mr. Lohbeck is the author of the CE Marking Handbook: A Practical Approach to Global Safety Certification. He received a B.S. from Arizona State University and an M.A. from the University of Phoenix. National Instruments, 11500 N. Mopac Expressway, Bldg. C, Austin, TX 78759, 512-683-8474, e-mail: dave.lohbeck@ni.com

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Reprinted from *EE-Evaluation Engineering*, December 2003