

**UNDERSTANDING SAFETY-ISOLATION RULES AND TESTING REQUIREMENTS ENABLES YOU TO ADDRESS POTENTIAL SAFETY-ISOLATION VULNERABILITIES.**

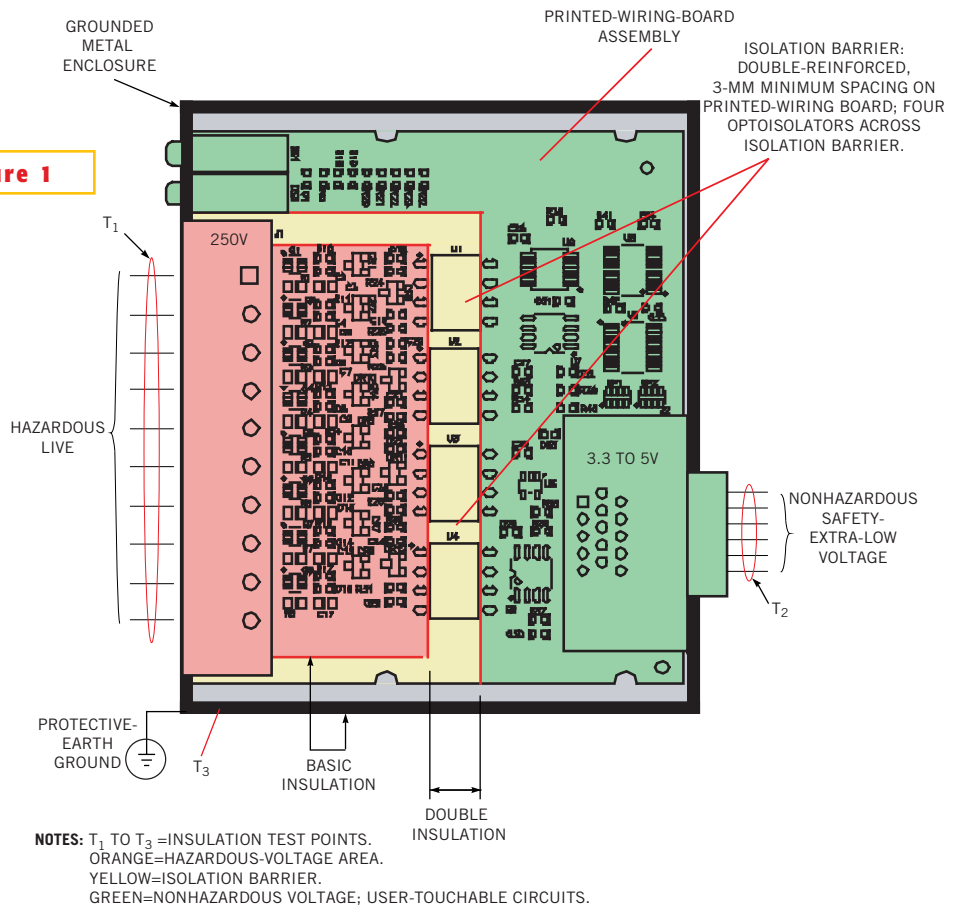
# Safety isolation protects users and electronic instruments

**S**AFETY ISOLATION is important for both manufacturers and consumers. Its purpose is to physically separate hazardous circuits and transient sources from users and to protect products and their surroundings. Manufacturers need to adequately protect consumers. Design engineers must understand safety-isolation rules and testing requirements to address potential safety-isolation vulnerabilities and to better guarantee successful test-lab certification. Consumers must be able to interpret manufacturers' specifications, and they often rely on safety certifications to guide them when making purchasing decisions with performance and safety in mind. The isolation principles in this article are based on the product-safety standards for IEC 61010-1 for test-and-measurement instruments and IEC 60950-1 for information-technology equipment.

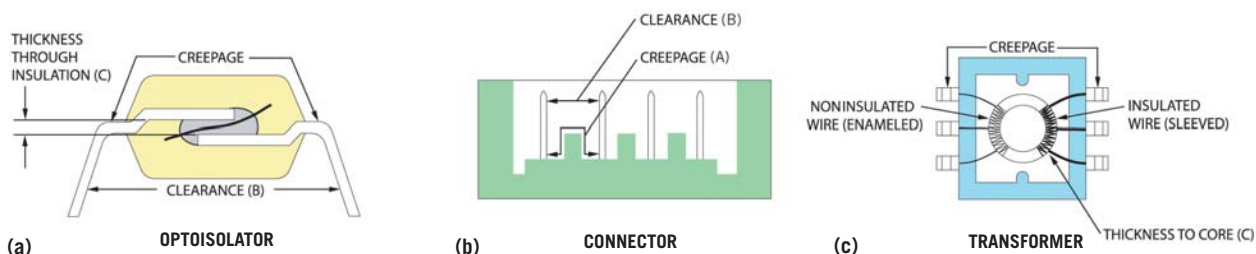
Increasing voltage capabilities of measurement instruments—often 1000V and higher—is a concern because users can receive severe electric shocks or burns, and a potential exists for fire damage to instruments and their surroundings. Other hazards include sudden transient overvoltages occurring within the electrical distribution system of buildings caused

by lightning strikes during storms or power surges from heavy-duty equipment, motors, and device switching. Even short-lived transients of 1500V or more lasting for as short as a few microseconds can damage semiconductor devices in products, alter data communication, and degrade performance.

**Figure 1**



**This isolation circuit includes basic insulation, double insulation, protective Earth (safety ground), insulation test points, hazardous-voltage area (red), isolation barrier (yellow), and nonhazardous voltage.**



**Figure 2**

Examples of component-isolation spacing include 6-mm minimum creepage (a), 3-mm minimum clearance (b), and 0.4-mm distance through insulation (c).

Product users must not underestimate hazards potentials associated with high voltage. Each year, electricity causes more than 30,000 workplace injuries and more than 1000 workplace deaths. Although many of us are familiar with the unpleasant sensation of a mild shock, a severe electrical shock can cause ventricular fibrillation and cardiac arrest. Shocks and burns of varying degrees of severity are the most common injuries. Other injuries can result from an electric current that acts as a trigger that initiates a chain reaction of mishaps, including involuntary muscle reaction that cause bruises, bone fractures, and injury from colliding with objects or falling. Proper understanding of the possible effects of electrical hazards may help prevent some of these injuries.

Basic electronics teaches us that an electric circuit has three properties: voltage (electric force), current (electron flow), and resistance (an inhibitor of current flow). Current is the most dangerous component, and as voltage increases, so does the hazard. Insulators resist flow, and conductors allow flow. All objects are either resistors or conductors, and electricity flows along the path of least resistance toward earth ground.

The effects of current flow through a human body are a function of the magnitude of the current, the human body's

resistance, and the duration of time. The human body can conduct current that results in burns or shock when the current is above safe levels (Table 1, Reference 1). Even low currents can cause injury, and 100 mA flowing through the body for only two seconds can cause death. Coupling high currents with extra-low voltages can also cause severe injuries. Safety standards limit voltage, current, and transient levels through various isolation techniques.

Isolation means that no direct electrical connection, or conductor, exists between two or more circuits or between circuits and accessible parts. Its purpose is to limit transient overvoltages and to electrically segregate circuits that if connected directly could allow the flow of harmful voltage, current, energy, or charge. Isolation prevents unacceptable current from flowing as a result of a potential ac or dc difference between the circuits. It also allows the isolated circuits to communicate magnetically via a transformer or by using light via an optoisolator. You use safety isolation to isolate hazardous, or "live," voltages greater than 30V rms and 42.4V peak or 60V dc from user-accessible SELV (safety extra-low-voltage) circuits. Safety isolation also minimizes the possibility of transient voltage arc-over or -through insulation to user-touchable

circuits and enclosures.

Galvanic isolation is the most popular method. Transformers and optoisolators are examples of galvanic isolation. Transformers use separate windings to magnetically convert power from inputs to outputs. Optoisolators convert input signals into light and then convert it back for the output signals.

It is important to clearly differentiate between a product's rated voltage and its isolation voltage. The rated voltage of the product is the allowable continuous operating voltage that the manufacturer specifies; isolation voltage is based on a qualification test voltage that stresses the insulation of the product. Isolation-voltage testing is a short test to ensure adequate safety insulation if an unforeseen event occurs, such as a lightning strike to a power line or a dielectric breakdown within the product. For example, a product with 2300V rms isolation and 30V rating can operate to only 30V. In this case, 2300V rms goes well beyond the rated 30V operating limit of the product. Isolation voltage is for safety testing and specification. Users should not operate a product at isolation voltages.

Working voltage is the highest possible root-mean-square value of the ac and dc voltage across insulation when the product is operating at its rated volt-

**TABLE 1—THRESHOLD AND UL LIMITS FOR CONTINUOUS 60-Hz CURRENT AND THEIR EFFECTS**

Physiological effect	Reaction	Threshold for continuous 15- to 100-Hz current (mA)	Limit used by UL for continuous 60-Hz sinusoidal current (mA)
Involuntary muscular reaction	Perception level, tingling sensation	0.5	0.51
Inability to let go (tetanized muscle)	Painful shock, freezing current, "can't let go"	10	5.0
Ventricular fibrillation	Heart rhythm affected, death may occur	35	20

**Notes:**

1. Ordinarily, a limit of 0.75 mA applies to stationary or fixed, cord-connected products with equipment-grounding conductors.
2. Data in column 3 is described in IEC Publication 479.
3. Table adapted from Reference 1.

age. Product designers and test labs use the measured working voltage to determine the required insulation spacings from tables and figures in the safety standards.



**Figure 3** Safety marks include UL, TUV, VDE, and others.

**ISOLATION AND INSULATION**

Users have access to voltage and current through touchable connectors, cables, and user-interface devices you find on most products. Voltages must be less than or equal to 42.4V ÷ 60 peak dc to meet safe limits and to be SELV. SELV circuits are considered safe to touch and are double-insulated from hazardous voltages in case of a single fault. SELV circuits are commonplace and find use in product inputs/outputs and inter-connection, such as logic circuits for printers, PC keyboards, and telecommunications devices.

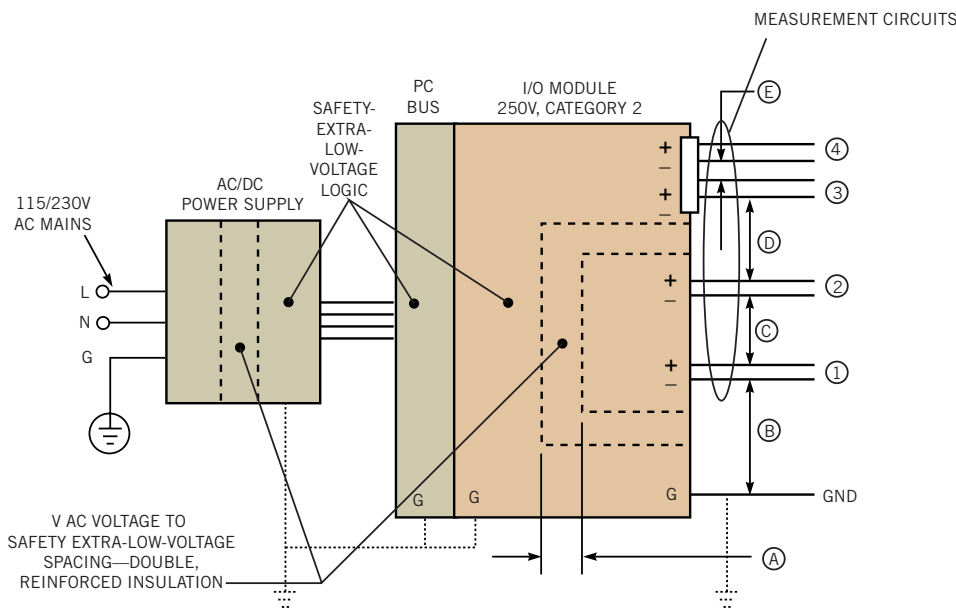
The requirements in safety standards establish permissible voltage and current limits for accessible parts. Potentially harmful voltages, hazardous live, are those greater than 42.4V peak/60V dc that are in many areas of a device, such as 115/230V ac primary circuits and in measuring circuits connected to voltages in excess of these levels. Manufacturers must protect, or isolate, users from hazardous voltages during a product’s normal operation and during a single fault, such as a component short circuit.

Manufacturers use various levels of types of insulation to obtain isolation.

They base insulation on spacing, or separation, distances and dielectric-withstand, or isolation, tests. The standards list the required spacings, creepage, and clearance. Creepage is a spacing distance measured over a surface, such as between two traces on a printed-wiring board or across the surface of an optoisolator. Clearance is the shortest distance through air, such as from the pin-to-pin of a connector. For example, a 250V-rated product with a peak working voltage of 300V requires 3 to 4 mm of creepage on the printed-wiring board and 6 mm of creepage on other parts between hazardous and nonhazardous voltages

(Figure 1). Dielectric-withstand testing measures the amount of voltage the insulation can withstand for a specified period of time, such as 2300V rms for one minute across the isolation barrier. This article uses the terms “isolation” and “insulation” interchangeably.

There are five types of insulation: functional, basic, supplementary, double, and reinforced. Functional insulation is necessary only for the correct functioning of a product. Functional or operational insulation does not protect or isolate against electrical shock. Basic insulation is a single level of insulation that provides basic protection against shock. Supplementary insulation is an independent insulation that manufacturers apply in addition to basic insulation to reduce the risk of electrical shock in the event of a failure of basic insulation. Double insulation comprises both basic and



- NOTES:**
1. ISOLATION IS FOR EXAMPLE ONLY. OTHER DESIGNS MAY REQUIRE ADDITIONAL OR DIFFERENT ISOLATION. REFER TO THE STANDARDS FOR REQUIREMENTS.
  2. CREEPAGE DISTANCE FOR SPACINGS ON PRINTED-WIRING BOARDS IS 3 MM FOR DOUBLE AND 1.5 MM FOR BASIC. DISTANCES CAN INCREASE FOR OTHER CIRCUITS OR COMPONENTS, SUCH AS OPTOISOLATORS, TRANSFORMERS, CONVERTERS, RELAYS, AND CONNECTORS. REFER TO THE STANDARDS FOR VALUES IN ALL CASES.
  3. CHANNEL-TO-CHANNEL SPACINGS CAN REQUIRE ISOLATION, DEPENDING ON THE INSTALLATION AND RESULTS OF TESTING, INCLUDING HIGH POTENTIALS, FAULTS, AND GROUNDS.
  4. DESIGNS USING METAL ENCLOSURES, METAL GROUND CONNECTIONS, OR BOTH THAT DO NOT RELIABLY BOND, OR GROUND, TO EARTH REQUIRE DOUBLE, 2300V-RMS, ONE-MINUTE ISOLATION.
  5. MEASUREMENT CIRCUITS CAN REQUIRE ADDED SAFETY GUARDING, CIRCUIT PROTECTION, OR BOTH. REFER TO THE STANDARDS FOR REQUIREMENTS.

**Figure 4** A system isolation for a typical 250V I/O-measurement system shows isolation: “A” channel-to-bus isolation is double: 2300V rms/one minute. “B” channel-to-ground isolation is basic: 1350V rms/one minute. “C” channel-to-channel isolation is none (functional) or basic: 1350V rms/one minute. “D” channel-to-channel/bus isolation is double: 2300V rms/one minute. “E” channel-to-channel isolation is none (functional) or basic: 500V rms/one minute. Channels 1 and 2 are 250V continuous, and channels 3 and 4 are less than 42.4V peak/60V dc continuous. “GND” is a safety ground reliably connected to earth.

supplementary insulation. Reinforced insulation is a single insulation system that provides electrical-shock protection equivalent to double insulation.

Double, reinforced, and basic insulations are the most important insulation types for safety isolation. The minimum spacing requirements for safety insulation are double from hazardous live to SELV—for example, 3 mm on printed-wiring board—and basic from hazardous live to safety ground—for example, 1.5 mm to a grounded enclosure. When a manufacturer fails to reliably ground a metal enclosure or ground circuit, you need double insulation from hazardous live to the ungrounded enclosure or circuit. You use functional insulation between circuits to maintain the operation of the product, but you do not rely on it for safety isolation. You should use basic insulation between hazardous voltage circuits, but the requirement depends on the applicable safety standard, function of the product, environment, and testing.

Electrical breakdown can occur between two conductive parts either through air (clearance) or along a surface (creepage). Insulating materials, such as printed-wiring-board and component surfaces, can become partially conductive when you expose them to deposits or deterioration from humidity, contamination, chemicals, and altitude. Conductive insulating materials can allow electrical tracking, or creepage, over the material's surface. Clearance helps prevent electrical arc-over between conductive parts that air ionization causes. Factors affecting air ionization include humidity, pollution, and temperature. Electrical breakdown can also occur through void-free solid insulation of components and between traces on inner layers of printed-wiring boards. To address solid-insulation requirements, safety standards may specify a distance through insulation at reduced levels that include spacings, dielectric tests, surge tests, or a combination of all three. Spacing examples include optoisolator input-to-output-pin spacing, connector pin-to-shell spacing, printed-wiring-board trace-to-trace spacing, and wiring-to-enclosure spacing. Always refer to the standards for all creepage, clearance, and solid (void-free) insulation requirements (figures 1 and 2).

Safety-critical components carry hazardous voltages and can affect the safety compliance of a product. Components that bridge, or isolate, hazardous voltage and SELV circuits are especially safety-critical, because dangerous voltages could become user-accessible if a manufacturer fails to meet safety requirements. Safety-critical components in **Figure 1** include optoisolators, a 250V connector, a printed-wiring board, and a fuse on each 250V I/O line. Safety-critical components must meet the relevant component standards and the end product's safety requirements. Always demand evidence of compliance in the way of safety marks on safety-critical components. The CE (European Conformity) marking is the self-declaration symbol of a manufacturer, not an independent certification or safety-approval mark, and, as such, you should not rely on it for safety. The best practice is to use only safety-critical components that an independent safety agency tested and approved to ensure they meet isolation requirements (**Figure 3**). You may need two marks on safety-critical components because the United States uses UL (Underwriters Laboratories) standards, and the European Union uses EN (European Norms) and the IEC (International Electrotechnical Commission) standards, which in many cases differ. Certifying agencies include UL, CSA (Canadian Standards Association), VDE (Verband Deutscher Elektringenieure), TÜV (Technischer Überwachungsverein, or Technical Inspection Association), and Demko (Danmarks Elektriske Materielkontrol). Safety-critical components include transformers, optoisolators, power supplies, relays, and fuses.

#### **VERIFICATION**

Once the spacings and components of a product are in order, you can perform isolation tests to verify the design and production of the product and to ensure conformity with the standards. You use dielectric-withstand testing, also known as electric strength and high potential, to verify isolation. The product must pass a one-minute  $V_{rms}$  or  $V_{dc}$  test. The tester performs a one-minute test on a representative test sample for design verification, and a one- to two-second routine test on 100% of production before shipping. Dielectric-withstand

test values can vary somewhat between the standards, such as basic insulation of 1350V rms for test-and-measurement instruments or 1500V rms for information-technology products rated at 250V. Product specifications occasionally show component-isolation specifications when the isolation of the end product is most important and not the isolation of a single component within the product. Additional safety tests, such as ground-bond and leakage, may be necessary for safety conformity. Refer to the relevant safety standards for pertinent tests and requirements.

The following process illustrates one method of dielectric-withstand testing using **Figure 1**.

1. Set up test sample and instrument:
  - a. Test sample for temperature and humidity preconditioning for 48 hours. Refer to the standard for requirements.
  - b. Connect the 250V circuits together ( $T_1$ ).
  - c. Connect the 3.3 to 5V circuits together ( $T_2$ ).
  - d. Establish a connection point on the metal enclosure ( $T_3$ ).
  - e. Set the V rms or V dc value current (V rms/120 k $\Omega$ ), 10-sec or less ramp, and one-minute dwell time.
2. Test 1: 250V to SELV, double insulation:
  - a. Connect one lead of the test instrument to  $T_1$  and the other to  $T_2$ .
  - b. Perform one-minute 2300V rms or 3250V dc dielectric-withstand test from  $T_1$  to  $T_2$ .
  - c. Record the pass/fail result.
3. Test 2: 250V to enclosure, basic insulation:
  - a. Connect one lead of the test instrument to  $T_1$  and the other to  $T_3$ .
  - b. Perform a one-minute, 1350V rms or 1900V dc dielectric test from  $T_1$  to  $T_3$ .
  - c. Record the pass/fail result.

In this test, substitute double insulation of 2300V rms or 3250V dc if the metal enclosure is not reliably grounded.

If you lack the expertise to assess isolation or perform the tests, you can send the product to a qualified safety lab for evaluation and certification. Manufacturers can use certification and marks to limit their risks, demonstrate safety compliance, increase market potential, and, most importantly, protect the consumer. The best route to ensuring that

a product meets isolation and other safety requirements is to purchase certified products that bear a safety mark. Safety marks are evidence of isolation and safety conformity. Look for them on products with ratings greater than 42.4V peak or when isolation claims are greater than 400V rms.

Safety isolation protects information-technology and measurement products and users from electrical hazards. Information-technology and measurement instruments operate as intended and are considered safe when you design them following all isolation and applicable safety rules. **Figure 4** shows the basics of isolation and specification, as they relate to a typical 250V I/O-measurement system. The circuit shows safety-isolation types in order of priority: channel-to-bus, channel-to-ground, and channel-to-channel. Double, reinforced insulation barriers separate hazardous live from nonhazardous voltages. For products using hazardous voltages—greater than 42.4V peak or 60V dc—the channel-to-bus and channel-to-ground isolation are critical to protect the product and user. Channel-to-channel isolation may be necessary, depending on the product design, the safety standard, or the safety test. Even though it is not mandatory in some cases, channel-to-channel isolation is often a quality-, functional-, or market-driven requirement (**Reference 2**). □

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#### REFERENCE

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2. *Product Certification*, [www.ni.com/certification](http://www.ni.com/certification).

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#### AUTHOR'S BIOGRAPHY

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