UL 101

STANDARD FOR SAFETY

Leakage Current for Utilization Equipment

UL Standard for Safety for Leakage Current for Utilization Equipment, UL 101

Sixth Edition, Dated July 31, 2017

SUMMARY OF TOPICS

This revision of ANSI/UL 101 dated October 5, 2023 addresses GFCI Interoperability Issues; 1.1, 2.1, 3.1A – 3.1C, 3.5A, 3.5B, 3.7A, 3.7B, 3.7.1 – 3.7.3, 3.9A, Table 4.1, 5.1.2, subsection 5.2, 5.3.1, Figure 5.3, Figure 5.4 , Section 6, Section A6 (title only), A7.1, A7.3, Section A8, and Appendix B

Text that has been changed in any manner or impacted by ULSE's electronic publishing system is marked with a vertical line in the margin.

The new and revised requirements are substantially in accordance with Proposal(s) on this subject dated December 23, 2022 and May 26, 2023.

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Leakage Current for Utilization Equipment

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This ANSI/UL Standard for Safety consists of the Sixth Edition including revisions through October 5, 2023.

The most recent designation of ANSI/UL 101 as an American National Standard (ANSI) occurred on October 5, 2023. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, and Title Page.

Comments or proposals for revisions on any part of the Standard may be submitted to ULSE at any time. Proposals should be submitted via a Proposal Request in the Collaborative Standards Development System (CSDS) at https://csds.ul.com.

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INTRODUCTION

1 Purpose

1.1 To minimize the user's risks of physical reaction to electrical shock or inability to let go a live part, or burns, from exposure to leakage currents from utilization equipment under foreseeable use conditions, this standard provides:

a) Leakage current limits;

b) Methods, specifications for measuring equipment, and test conditions for measurement of leakage currents;

c) GFCI Interoperability test limits, methods, specifications for measuring equipment, and test conditions for measurement of differential currents.

2 Scope

2.1 This Standard applies to utilization equipment (see Definitions, Section 3) typically rated 50 A or less, nominal 50 or 60 Hz, and intended for use on supply circuits not exceeding 300 V to ground.

2.2 This standard does not apply to utilization equipment having a grounded connection made at the factory to the neutral terminal. The values in this standard do not provide protection against the minute currents which could cause ventricular fibrillation if applied directly to the heart, as via a heart catheter.

3 Definitions

3.1 APPLIANCE – (As referred to in this standard) – Utilization equipment that uses electric energy for some function, usually complete in itself, generally other than industrial, normally built in standardized sizes or types which is installed or connected as a unit to perform one or more functions. For example, a toaster, flatiron, washing machine, hand drill, food mixer, air conditioner, gas appliance with electrical controls, kerosene heater with electric blower.

NOTE: Appliances not intended for normal household use but which nevertheless may be a source of danger to the public, such as appliances intended to be used by laymen in shops, appliances used in commercial kitchens, in light industry, and the like, are within the scope of this standard.

3.1A CORD-AND PLUG-CONNECTED PRODUCT – Utilization equipment that is connected to the electrical supply by a cord set or by a power-supply cord terminating in an attachment plug.

3.1B DIFFERENTIAL CURRENT – The current (I_{Δ}) that is determined to be flowing to earth based upon the difference between all current carrying conductors (e.g. L1, L2, N), excluding any protective earthing conductor.

3.1C FIXED PRODUCT– Utilization equipment that is fastened or otherwise secured at a specific location.

3.2 *Revised and relocated to 3.7.1*

3.3 *Revised and relocated to 3.7.2*

3.4 *Revised and relocated to 3.7.3*

3.5 FORESEEABLE USE – Specified use conditions and other use conditions which a prudent person might assume would cause no immediate hazard. An open ground is considered to be a condition of foreseeable use.

3.5A GROUND CURRENT – Current flowing to earth either through via the grounding conductor of the utilization equipment or through an alternate path to earth.

3.5B IIU – INTEROPERABILITY INDICATION UNIT – Is weighted differential current from the measurement instrument in Figure 6.1: IIU is the output voltage (V2) in millivolts rms and complying with all requirements for the measurement instrument specified in GFCI Interoperability Test, Section 6.

3.6 LEAKAGE CURRENT – Electric current which flows through a person upon contact, between accessible parts of an appliance and:

a) Ground, and

b) Other accessible parts of the appliance.

3.6.1 LET-GO CURRENT – A threshold current value, above which a substantial portion of the population may cause involuntary muscle reaction and not able to let-go of an electrically-energized part(s).

3.7 MIU-MEASUREMENT INDICATION UNIT – Is the output voltage (V3) in millivolts rms from the measurement instrument in Figure 5.3 divided by 500 (the value in ohms of the resistance in parallel with V2 in the measurement instrument circuit). (The indication is essentially the rms value of a 60 Hz sinusoidal leakage current in mA. It may not be a direct indication of the rms or other common amplitude quantifier of leakage current when the leakage current is of complex waveform or frequency other than 50 or 60 Hz.)

3.7A PERMANENTLY-CONNECTED PRODUCT – Utilization equipment that is connected to the electrical supply by means other than a supply cord and an attachment plug (e.g. the product is permanently wired to the branch circuit).

3.7B PORTABLE PRODUCT– Utilization equipment that is actually moved or can easily be moved from one place to another in normal use.

3.7.1 *Revised and relocated as 3.1C*

3.7.2 *Revised and relocated as 3.7B*

3.7.3 *Revised and relocated as 3.9A*

3.8 REACTION CURRENT – A threshold current value, above which a substantial portion of the population may be caused to react involuntarily to the sensation of current.

3.9 SHEATHED HEATING EQUIPMENT LEAKAGE CURRENT – Current through insulating material (normally MgO) between the current-carrying conductor and the metallic sheath.

3.9A STATIONARY PRODUCT– Utilization equipment that is not easily moved from one place to another in normal use.

3.10 UTILIZATION EQUIPMENT – A product that utilizes electric energy for electronic, electromechanical, chemical, heating, lighting, or similar purposes.

NOTE 1: Throughout this standard the terms ″product,″ and ″unit″ refer to utilization equipment.

NOTE 2: Utilization equipment covered in this in this standard include appliances, luminaires, information technology and similar equipment.

PERFORMANCE

4 Leakage Current Limits

4.1 General

4.1.1 When measured in accordance with the test method covered in this standard, the measurement indication shall not exceed the values shown in Table 4.1.

Table 4.1
Maximum Allowable Measurement Instrument Indication Based on Reaction

Type of products	Indication in MIU (for a 60 Hz sine wave leakage current, the values are approximately milliamperes, rms)	Measurement frequency sensitive network
Two-wire cord- and plug-connected products	0.50 MIU	Reaction (Figure 5.3)
Three-wire (including grounding conductor) cord- and plug-connected portable products	0.50 MIU	Reaction (Figure 5.3)
Three-wire (including grounding conductor) cord- and plug-connected stationary or fixed products	0.75 MIU	Reaction (Figure 5.3)
Four-wire (including grounding conductor) stationary or fixed product. Less than or equal to 150 V to ground	0.75 MIU	Reaction (Figure 5.3)
Three-wire (including grounding conductor) portable and permanently connected lighting products. Less or equal to 150 V to ground	0.5 MIU	Reaction (Figure 5.3)
Three-wire (including grounding conductor) portable and permanently connected lighting products. Higher than 150 V to ground	0.75 MIU	Reaction (Figure 5.3)
4.1.2 Exception No. 1	2.5 MIU	Let-Go (Figure 5.4)
4.1.2 Exception No. 2	3.5 MIU	Let-Go (Figure 5.4)
4.1.2 Exception No. 3	5 MIU	Let-Go (Figure 5.4)

4.1.2 In addition to the limits in Table 4.1, to avoid undue risks of severe body tissue burns, the leakage current shall be not greater than 70 mA rms, measured as V2 (volts rms) divided by 0.5 (kilohms), using the measuring instrument of Figure 5.3 with the frequency-sensitive network disconnected. (See Appendix B for the performance specifications of the modified measuring instrument). Because in the low frequency range, the maximum allowable current based on reaction is less than the maximum allowable current based on body tissue burn, the burn current limit generally applies only when high frequencies are involved.

Exception No. 1: For products having metal-sheathed heating elements for which the operating conditions and present technology does not permit compliance with the limits in Table 4.1 during heat-up and cool-down, the maximum allowable indication of the measurement instrument for periods not exceeding 5 minutes during heat-up and not exceeding 5 minutes during cool-down is 2.5 MIU. For other periods of operation, the leakage current shall be within the limits specified in Table 4.1. (See 5.4.12 and 5.4.13.)

Exception No. 2: Those conductive parts of an product that comply with all of the specifications in Items (a) through (e) below may be permitted by the product standard to have a leakage current from simultaneously accessible parts to the grounded supply conductor higher than specified in Table 4.1, but in no case shall the leakage current be greater than 3.5 MIU. The leakage current between simultaneously accessible parts shall not exceed the values shown in Table 4.1. (See 5.4.2.)

a) The product requires EMI suppression filtering for compliance with FCC regulations. (See A3.1.)

b) The product is equipped with a grounding-type supply cord and plug.

c) There is a low probability that a path for available current through the body will exist in the expected environment. If the available current flows to ground, this will involve consideration of the probability that the user will be grounded during the use of the product.

d) There is a low probability that high leakage conductive parts will be contacted during normal use, as defined in the product standard.

e) The probability of injury resulting from an involuntary reaction is small. (See Rationale.)

Exception No. 3: For an product that upon loss-of-grounding, dependably disconnects all sources that can produce leakage current, the leakage current, when measured in accordance with the test method covered in this standard, shall not exceed 5 MIU with the grounding conductor open and with the loss-of-grounding circuit disabled. (See A5.)

The leakage current, when measured in accordance with the test method covered in this standard, except that the equipment grounding conductor is connected to the grounded supply conductor at the receptacle feeding the product, shall not be more than the values shown in Table 4.1. This measurement will typically not involve current between accessible parts and the grounded supply conductor, but will involve currents that may flow from one part of the product to another.

4.2 Departure from leakage current limits

4.2.1 Leakage currents for certain additional tests (see A1.4) that do not represent normal use (but may reflect some degree of abuse or certain failure modes) and exceeding the limits stated above, but not exceeding 5 MIU at 50 – 60 Hz (see A5.2) may appear in individual product standards. If so they should appear with a statement justifying them.

5 Test Method and Instrumentation for Measurement of Leakage Current

5.1 General

5.1.1 This test provides a measurement of leakage current from utilization equipment.

5.1.2 The leakage current test is applicable to cord and plug-connected products; see Table 4.1 for the types of products subjected to the leakage current test.

5.2 Characteristics of measurement circuit and instrument

5.2.1 Measurement circuit – The measurement circuits for leakage current shall be as shown in Figure 5.1 and Figure 5.2. The measurement instrument shall be as described in Appendix B1.

5.2.2 The measurement instrument as shown in Figure 5.3, is only to be used where the current limit is not greater than 2 MIU. Above these values, measurement instrument Figure 5.4 shall be used.

5.2.3 *Deleted*

5.2.4 *Deleted*

5.2.5 *Deleted*

5.2.6 *Deleted*

5.3 Test conditions

5.3.1 The product is to be tested for leakage current without any previous energization after the manufacturing, packaging and shipping process. The grounding conductor, if any, is to be open at the receptacle feeding the product.

5.3.2 Additional testing should be carried out at conditions such as preconditioning, temperature, humidity, as prescribed in relevant product standards, or lacking a product standard, at conditions which are intended to stimulate anticipated use.

5.3.3 The supply voltage is to be sinusoidal of 50Hz or 60Hz, without a DC component, adjusted to the first available of the following:

a) The voltage specified for the leakage current test in the product standard;

b) The voltage specified for the normal temperature test in the product standard; or

c) Maximum rated voltage.

5.3.4 Motor-operated products shall be operated under the condition and duration of load simulating normal operation, which is generally specified for the normal temperature test in the product standard. In addition, products with speed controls are to be tested at the speed setting producing the maximum leakage currents.

5.3.5 Heating and cooking products are to be operated under that set of conditions considered to represent normal operation (ordinarily the normal temperature test as specified in the product standard, with the maximum heat setting of the controls), except that cycling of the thermostat is to be induced by a reduced setting, if necessary, before completing the test program. Some heating products such as broilers, are constructed with thermostats that do no open when at their highest settings. To detect the maximum leakage current, the cycling condition may be required to be induced.

5.4 Test procedure

5.4.1 Connect the product for test as shown in Figure 5.1 or Figure 5.2, whichever is appropriate as determined by the rating of the product.

5.4.2 The measurement instrument shall be connected:

a) Between the accessible parts and the grounded supply conductor; and

b) Between simultaneously accessible parts of the product.

Simultaneously accessible parts shall be tested individually and collectively for current in a path to the grounded supply conductor and from one part to another. The grounding terminal at the attachment plug is considered to be an accessible part.

5.4.3 Parts shall be considered to be accessible unless guarded by an enclosure considered suitable for protection against shock hazard.

5.4.4 Parts shall be considered to be simultaneously accessible when they can be readily contacted by one or both hands of a person at the same time.

5.4.5 These measurements do not apply to intentionally energized conductive parts operating at voltages that are considered to be nonhazardous and are so stated in the product standard.

5.4.6 If a conductive surface other than metal is used for the enclosure or part of the enclosure, the leakage current is to be measured using a metal foil with an area of 10 x 20 centimeters in contact with the surface. Where the surface is less than 10 x 20 centimeters, the metal foil is to be the same size as the surface. The metal foil is not to remain in place long enough to affect the temperature of the product. This test method in the product standard may need to be modified for application to a specific type of product design.

5.4.7 With test switch S1 open and the product in the "as received" condition, the product shall be connected to the measurement circuit. All its switches and thermostats are to be closed, but its grounding conductor shall be open at the receptacle feeding the product.

5.4.8 With test switch S2 in the A position note the measurement instrument indication.

5.4.9 Repeat 5.4.8 with test switch S2 in the B position.

5.4.10 Test switch S1 shall then be closed energizing the product.

5.4.11 Within a period of 5 seconds, after the closing of S1, the leakage current shall be measured using both positions of test switch S2. In the case of a product with more than one speed, the various speed conditions are to be checked as quickly as possible to determine the maximum leakage current condition.

5.4.12 Measure the leakage current, using both positions of S2 until final operating test conditions are reached.

5.4.13 Open S1 – measure the leakage current as the product cools, using both positions of S2. Continue to measure until the leakage current has stabilized or is decreasing.

Figure 5.1

Leakage current measurement circuit used for products intended for connection to 120 V circuits

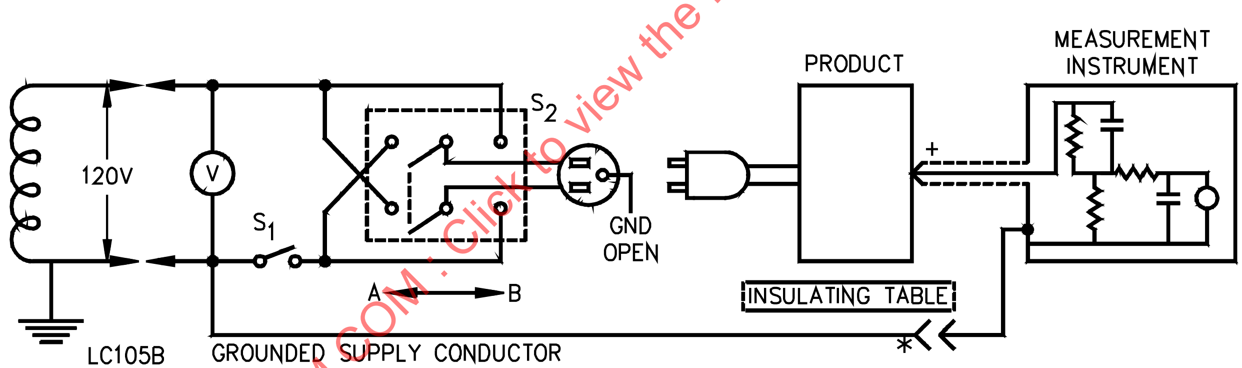
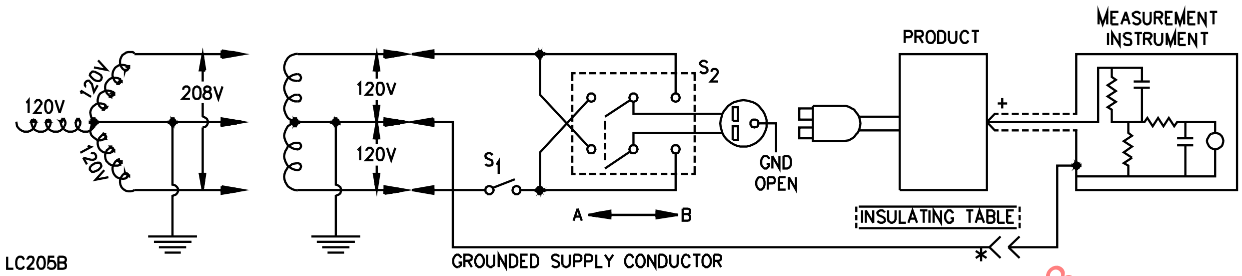


Figure 5.2

Leakage-current measurement circuit used for grounded or ungrounded 208 V or 240 V products intended for connection to three-wire neutral grounded circuits



* Separated and used as clip when measuring currents from one part of product to another.

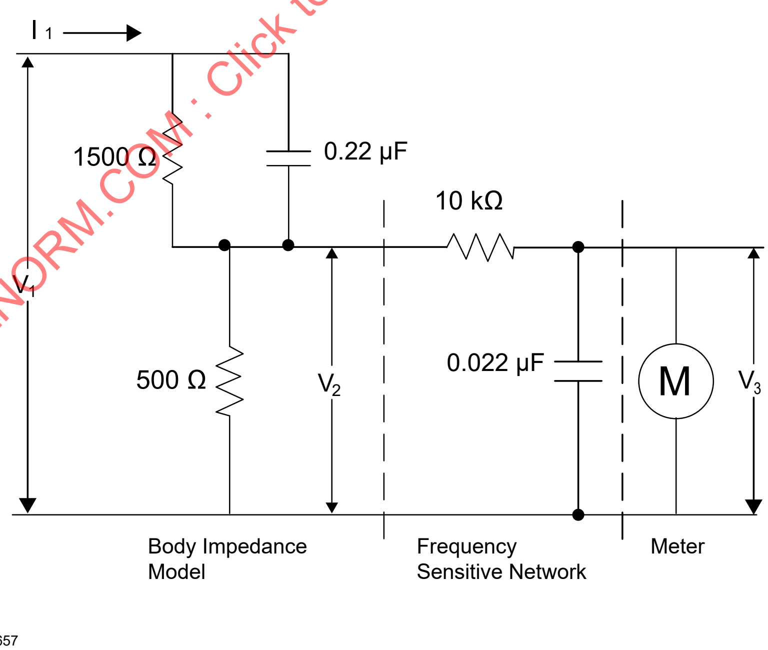
+ Probe with shielded lead.

Note 1. All voltages shown in Figure 5.1 and Figure 5.2 are nominal. (See 5.3.3.)

Note 2. If it is not feasible to isolate the product from ground, the supply circuit shall be isolated from ground. It may then also be necessary to reverse the leads of the measurement instrument.

Figure 5.3

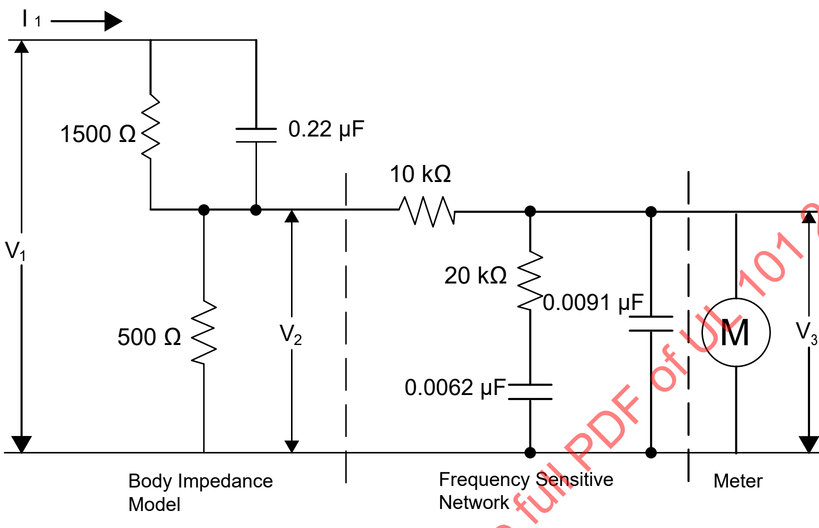
Measurement Instrument for Reaction



Guidance for the calibration of this instrument is given in Appendix B.

Figure 5.4

Measurement Instrument for Let-Go



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6 GFCI Interoperability Test

6.1 General

6.1.1 The GFCI Interoperability Test provides a measurement of weighted differential line currents (IIU) to determine compatibility with Class A GFCI devices evaluated to the Standard for Ground-Fault Circuit-Interrupters, UL 943.

6.1.2 The GFCI Interoperability Test is applicable to cord and plug-connected products, and permanently-connected products.

6.1.3 The Interoperability Indication Unit (IIU) shall be not greater than 3.5, using the measuring instrument of 6.1 or Figure 6.2 complying with requirements provided in the remaining subsections of Section 6.

6.1.4 The measurement instrument shall be as described in Section B3, Meter for GFCI-Interoperability Test.

6.1.5 Filtering components provided with the product shall remain in the measurement circuit. A grounding conductor provided with the product shall remain in the measurement circuit. If no grounding conductor provided product shall be tested according to 6.3.4.

6.2 Test conditions

6.2.1 The product is to be tested for GFCI Interoperability after the manufacturing, packaging and shipping process. Testing of a previously energized product is acceptable. The product shall be evaluated for a minimum of one minute under each operating mode, including time before and after transition events. Transitional events are those changes which energize or de-energize loads, change speeds or otherwise introduce a different electrical response.

6.2.2 Motor-operated products are to be operated under the conditions simulating normal operation, which is generally specified for the normal temperature test in the product standard. In addition, consideration is to be given to products with speed controls being tested over the full motor speed range.

6.2.3 Heating and cooking products are to be operated under that set of conditions considered to represent normal operation, which is generally specified for the normal temperature test in the product standard. Temperature regulating controls may be adjusted to a lower setting to induce cycling.

6.2.4 The supply voltage is to be sinusoidal of 50 or 60 Hz, without a DC component, adjusted to the first available of the following:

a) The voltage specified for the leakage current test in the product standard;

b) The voltage specified for the normal temperature test in the product standard; or

c) Maximum rated voltage.

6.3 Test procedure

6.3.1 The product is to be connected as shown in Figure 6.1 or Figure 6.2, whichever is appropriate as determined by the rating of the product.

Figure 6.1

Measurement Instrument for GFCI Interoperability Test Intended for Connection to 120 V Circuits

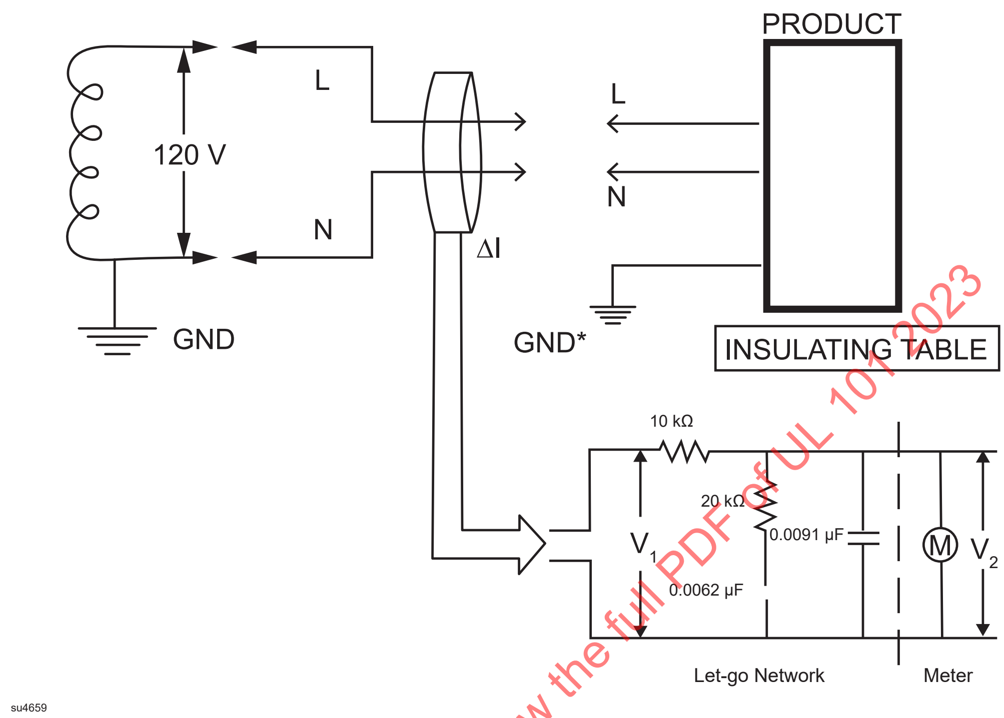
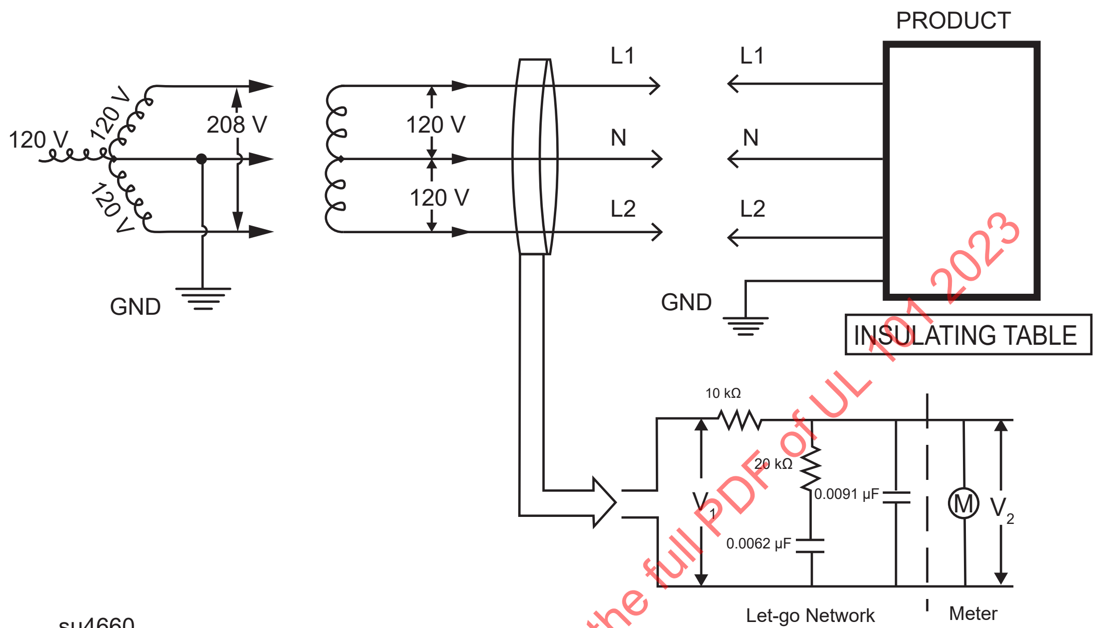


Figure 6.2

Measurement Instrument for GFCI Interoperability Test for Grounded or Ungrounded 208 V or 240 V Products Intended for Connection to Three-wire Neutral Grounded Circuits



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6.3.2 The measurement instrument is to be connected such that it measures the differential current of the product under test.

6.3.3 The product is to be operated from its starting condition, then cycle through the operation of steady state conditions and transitional events that introduce different signals to the meter. Specific operational conditions may be specified by an individual product standard.

6.3.4 For a product provided with a cord-set which does not have a grounding conductor, the differential current is to be measured using a metal foil with an area of 10 x 20 cm in contact with the surface and connected to ground. Where the surface is less than 10 x 20 cm, the metal foil is to be the same size as the surface. The metal foil is not to remain in place long enough to affect the temperature of the product. This test method in the product standard may need to be modified for application to a specific type of product design.

APPENDIX A

This appendix is not a part of the American National Standard for Leakage Current for Utilization Equipment. They are intended to provide background and assistance in utilizing the standard.

RATIONALE

A1 Rationale for Limits

A1.1 The experiments on which this standard are based were done at 60 Hz. The results have been extrapolated to 100 kHz, based on the work by Dalziel. The limits set are not low enough to prevent being felt, but are below the reaction current for most people. In addition, the limits set are sufficiently low that they should protect against direct injury (asphyxiation or ventricular fibrillation), or indirect injury (inability to let go) provided that the current path is through the person's skin.

A1.2 This standard is not intended to provide protection against the minute currents which could cause ventricular fibrillation if applied directly to the heart, as via a cardiac catheter.

A1.3 The 70 mA limit (generally applicable only at high frequencies) incorporated in this standard may not prevent a burn if the area of contact is small, and exposure is of extended duration. This 70 mA limit will be encountered under the following conditions:

Limit in MIU	Frequency in kHz
0.5	100
0.75	67.6
2.5	20.0
3.5	14.5
5.0	10.2

A1.4 Other leakage current limits between 0.5 MIU and not exceeding 5.0 MIU may be specified in some product standards, such as:

a) 5.0 MIU after the product has been subject to abnormal conditions, such as a shorted thermostat or a burnout test, (see 4.2).

b) 3.5 MIU in situations where it has been determined that reaction is not likely to result in an injury (see Table 4.1, exception 2).

c) 5.0 MIU for products having a loss-of-grounding detector which dependably opens all live conductors upon loss of ground (see Table 4.1, exception 3). The 5 MIU limit is based on work by Dalziel on the physiological hazard of let-go.

A1.5 The term MIU (Measurement Indication Units) has been used in this standard to identify the numerical indication of the output meter. This indication is often erroneously labeled “milliamperes”, although in the case of 60 Hz sine wave leakage current it is approximately correct. (0.5 MIU @ 60 Hz is approximately 0.5 mA). The difficulty is that at 100 kHz, 70 mA of sine wave current will flow, and still produce an indication of only 0.5 MIU. This is just the situation desired, since it requires 140 (70 mA / 0.5 mA) times as much current for a person to perceive a 100 kHz sine wave as it does to perceive a 60 Hz sine wave.

A1.6 The intent is to have the meter produce the same numerical indication (MIU) for a shock perception of the same intensity, regardless of the frequency and current actually flowing. In some IEC standards, the term “weighted current” is used in place of MIU.

A1.7 Some difficulty is encountered experimentally in comparing the perception levels over frequencies from 60 Hz to 100 kHz as the sensation changes at about 50 kHz from one of internal muscle stimulation to a feeling of warmth (where a steady contact is maintained). Intermittent contact will generally produce a pinprick sensation and introduce other break points.

A2 Rationale for Flexible Metal Foil

(See 5.4.6.)

A2.1 A 10 x 20 cm foil is used to simulate a hand touching a highly resistive, but conductive surface. Where this contact is intended to sum the leakage currents available over the surface, it will be necessary to take special care (in some cases conductive gel may be necessary) to see that the foil is in intimate contact over its entire surface.

A2.2 Foil may also be used at high frequencies to sum the capacitively coupled leakage currents from an insulating surface. In this case, intimate contact is not as important.

A3 Rationale for Products Requiring EMI Filtering to Meet FCC Requirements

(See 4.1.2, Exception 2)

A3.1 EMI filtering generally involves the use of capacitors between the supply conductors and the grounding conductor. This increases the leakage current, which may be as high as 3.5 MIU. The higher leakage current value may be accepted if the product complies with all of the specifications in Exception 2 of 4.1.2. An example of a product that has a low probability of producing an injury resulting from an involuntary reaction is one whose use does not involve:

a) Dangerous heights, such as, use on a ladder or a roof top;

b) Dangerous moving parts, such as, tools or electric knives; and

c) Injurious spills, such as, a cooking product with hot liquid;

d) Frequent exposure to grounded objects;

e) Frequent contact with conductive parts on the product that involve leakage currents greater than 0.5 MIU (with an open ground).

A4 Rationale for Humidity Conditioning

(See 5.3.2.)

A4.1 Humidity conditioning generally has an effect on the leakage current from products, particularly those utilizing fiberous insulation or insulation having hygroscopic properties. It is suggested that unless otherwise specified for the product, that the following humidity conditioning and leakage current testing be conducted.

A4.2 After being operated for a sufficient period of time to eliminate most previously absorbed moisture, the product is to be heated to a temperature above 34°C to reduce the likelihood of initial moisture condensation during conditioning. The heated sample is to be placed in a humidity chamber and is to remain for 48 hours with the chamber controlled to a relative humidity of 88 ±2% within a temperature range of 32 ±2°C.

A4.3 Following the conditioning, the sample is to be tested unenergized as described in 5.4.1 – 5.4.9. The sample is then to be energized, and tested as described in 5.4.10 – 5.4.13. The test of 5.4.12 is to be discontinued when the leakage current stabilizes or decreases.

A4.4 If possible, these leakage current tests should be conducted in the humidity chamber. If this is not feasible, the tests should be conducted as quickly as possible after the sample has been removed from the chamber so as to reduce the drying effect of the cooler room air.

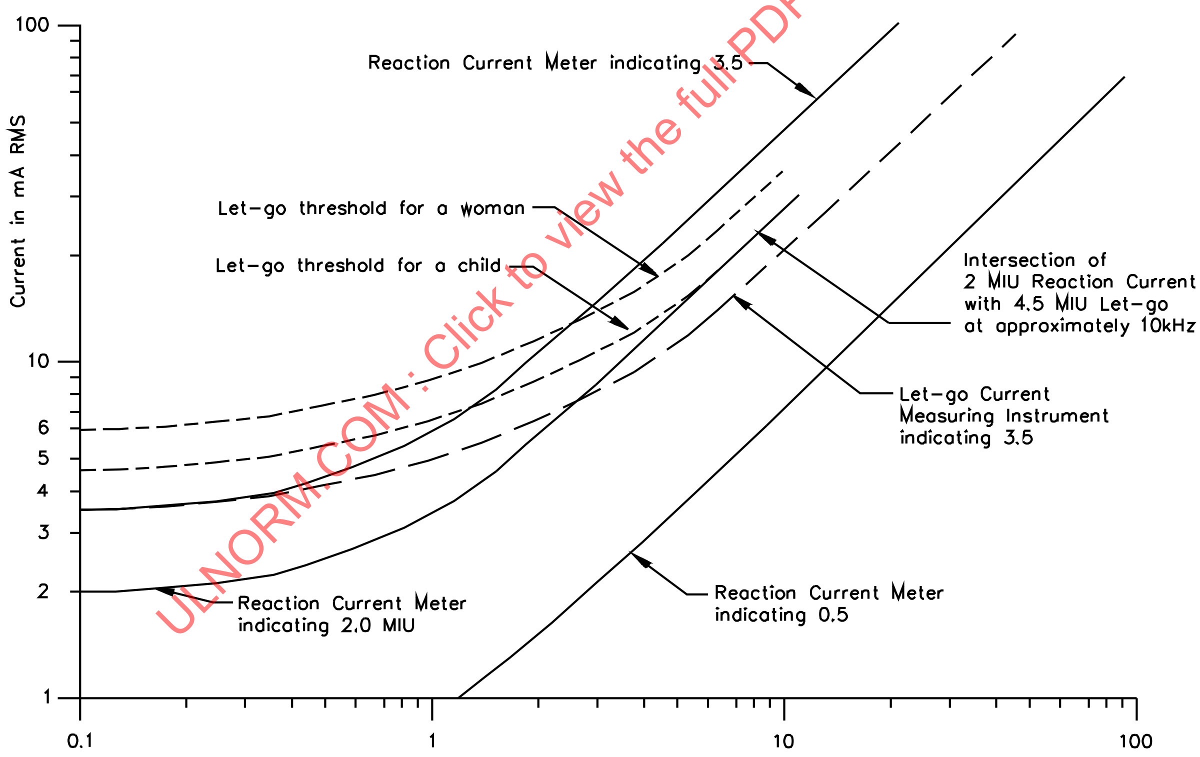
A5 Rationale for Higher Leakage Current Levels

(See 4.1.2 Exception 3, 4.2 and Figure A5.1.)

A5.1 Under special situations, the product standard may elect to be concerned about other physiological effects such as let-go. Such consideration is generally outside the scope of this standard. Suggested methods of measurement for these higher values may be found in Technical Report IEC 60990, Methods of Measurement of Touch-Current and Protective Conductor Current.

A5.2 Let-go thresholds exceed 4.5 mA at 50 – 60 Hz and follow a different frequency response curve than is provided by the networks described in this standard. Where higher frequency (generally above 10 kHz) limit values exceed 2.0 MIU, the frequency response network based on the physiological effect of let-go should be used. (IEC 60990, Methods of Measurement of Touch-Current and Protective Conductor Current)

Figure A5.1



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A6 Rationale for Choice of Meter, and Alternative Meters for Leakage Current Test

(See 5.2.2.)

A6.1 The instrument specified in the 1986 and prior editions of this standard to measure the leakage current of products used an averaging type display meter with a shunt combination of a 1500 ohm resistance and a 0.15 mfd capacitor (Average Responding System). The combination provided a reading that was 1.11* times the average of a full wave rectified composite waveform. An example of this type of meter is the commonly used 20 Hz – 100 kHz Simpson 229–2.

A6.2 Earlier work by Dalziel, supported and extended by recent investigations by member of ANSI C101, suggest that peak current is a significant parameter in describing the body's response to complex waveforms. The Average Responding System does not accurately predict this response to current of complex waveforms. Since complex waveforms are becoming increasingly more common in modern electrical equipment, the need to address this problem is more important.

A6.3 The network introduced in the 1992 issue provides a more appropriate means for measuring leakage currents of complex waveforms than the Average Responding System and has several aspects to it that deserve mention.

a) The input impedance more accurately reflects the combination of skin and internal body impedance and therefore reflects more accurately the current that would be drawn from the source by an individual.

b) The new network, like its predecessor the Average Responding System, weights currents to be measured in correspondence with human perception of electric shock as a function of frequency.

c) The frequency range of the network and meter have been extended to 1 MHz in order to include more commonly encountered high frequency currents.

d) The network harmonizes with IEC Technical Report 990 and some IEC standards.

A6.4 The committee has actively explored the use of a peak reading meter in the instrument with an eye toward harmonization with IEC 990. In order to provide a sound basis for making a change from the Average Responding System, the committee has conducted basic research into the body's perception of shock from a variety of complex waveforms and frequencies. This work has not refuted the peak value of the waveform as being the significant characteristic accounting for physiological response.

A6.5 This research was carried out on a number of repetitive sinusoidal and non-sinusoidal waveforms such as square and triangular waves, phase controlled sinusoids, rectangular pulses, etc. that could result from products using present technologies. The research did not convincingly identify any one measurement instrument (ave., rms, or peak) as being superior, not did it indicate that any particular instrument would mask the detection of unsafe waveforms.

*1.11 is the ratio between the rms value of a sine wave and the average value of a full wave rectified sinusoid.

A6.6 Considering these three candidates further in practical use, the committee has found that reading with a peak meter is subject to unsteadiness from line noise as well as noise from devices such as commutator motors to the extent that it can be difficult to assign a value to the leakage current. The choice then fell to the average or rms instrument. The availability of laboratory quality rms instruments at reasonable cost, and the relative unavailability of averaging ac laboratory quality instruments has led the committee to compromise on an rms instrument at this time.

A6.7 If further research establishes a clear advantage for the peak reading instrument, the standard can be considered for modification at that time.

A6.8 The Average Responding System is still adequate for measurement of essentially sinusoidal leakage currents in the approximate frequency range of 20 Hz to 100 kHz. It is expected that the Average Responding System will give a slightly higher indication of leakage current (because of the lower input impedance of the Average Responding System) than the instrument described in the 1992 edition. Therefore, it is quite reasonable to expect that the Average Responding System can continue to be used for essentially sinusoidal measurements.

A6.9 For products with non-sinusoidal leakage current waveforms, it is expected that individual product safety committees will allow adequate time for the incorporation of the new measurement system into their standards, particularly where they have previously determined that the Average Responding System is adequate for characterizing the leakage current performance of their products. The Average Responding System has not been found to result in unacceptable reaction to leakage current from present technology equipment, where the MIU value is within specified limits. This standard has not defined the rms instrument as ac only or ac-dc. Under the proper circumstances, either may be used, however the product standards committee should be cognizant of the ramifications.

A6.10 The network defined in this standard will pass a dc component of the leakage current waveform along to the meter. The limits expressed (0.5 MIU, 0.75 MIU etc.) were chosen on the basis of ac waveforms. There is no known investigative data on the body's perception of reaction effect to combined waveforms of ac and dc current, however studies of pure ac and pure dc indicate that 2 mA dc is perceived to be roughly equivalent to 0.5 mA ac at 50 – 60 Hz. The following statements can then be made:

a) If there is not dc present, the rms meter can be ac or ac-dc.

b) If there is dc present and an ac-dc rms meter is used, and the resulting MIU is within the limits of this standard, the result may be accepted since the rms value of the current threshold of reaction for most combinations of ac and dc leakage current will be higher that the MIU limit.

c) If there is dc present and an ac-dc rms MIU reading exceeds the limits in this standard, it is left to the product standards committee to define limits for the composite waveform.

The rms meter should also be able to handle a crest factor commensurate with the leakage current waveform. Crest factor is the ratio of the peak of the waveform to the rms value of the waveform.

A7 Rationale for Measurement Circuits

(See Figure 5.1 and Figure 5.2.)

A7.1 Figure 5.1 and Figure 5.2, Leakage Current Measurement Circuits are based on power supplies known to be commonly connected to home in the United States and Canada. European receptacles provided for cord connected products more commonly employ 220 to 240 V in the configuration of Figure 5.1, with one conductor grounded. Standards dealing with international products including a 220 – 240 V rating may wish to specify that the leakage current test be conducted using the measurement circuit of Figure 5.1, but at a voltage in keeping with the rating of the product.

A7.2 Figure 5.1 and Figure 5.2 are shown with the leakage current meter returned to the grounded supply conductor rather than to earth ground or the grounding conductor. Ordinarily the specified connection will result in reduced interference from other loads on the same circuit which might otherwise couple into the measurement through the common impedance of the grounded supply conductor or stray currents in the grounding path. An alternative, (generally specified in IEC standards) is to supply the product under test through an isolating transformer having negligible capacitive coupling from primary to secondary. The product under test becomes the transformer's only load and leakage current measurements are made from accessible parts of the product to each of the transformer secondary leads.

A7.3 Figure 6.1 and Figure 6.2, Differential Current Measurement Circuits are based on power supplies known to be commonly connected to home in the United States and Canada.

A8 Rationale for GFCI Interoperability Test

A8.1 The 3.5 IIU limit was developed based on single load with the proposed Class A GFCI 4.0 IIU lower limit. Multiple loads were not included in the development of this requirement however the impact on a circuit of multiple loads is assumed to be accumulative. For equipment that is not typically used on a dedicated branch circuit, the impact of measuring cumulative IIU with multiple devices on the same branch circuit should be considered by each end-product standards' technical committee.

A8.2 In the Standard for Ground-Fault Circuit-Interrupters, UL 943 specifies that the current-time relationship,

$$T = \left(\frac{20}{I}\right)^{1.43}$$

is to be met even when the fault current to ground is split between R_N and R_G, as described in Figure 6.7.4.1 and the supplementary high resistance test circuit in UL 943, where the worst-case values produce a current divider which results in only the fraction,

$$\frac{R_N}{R_N + R_G} = \frac{0.25}{0.25 + 1.4} = 0.151515$$

of the fault current passes through the CT of the GFCI. In order to satisfy this requirement, the GFCI must actually perform according to a modified time relationship defined as:

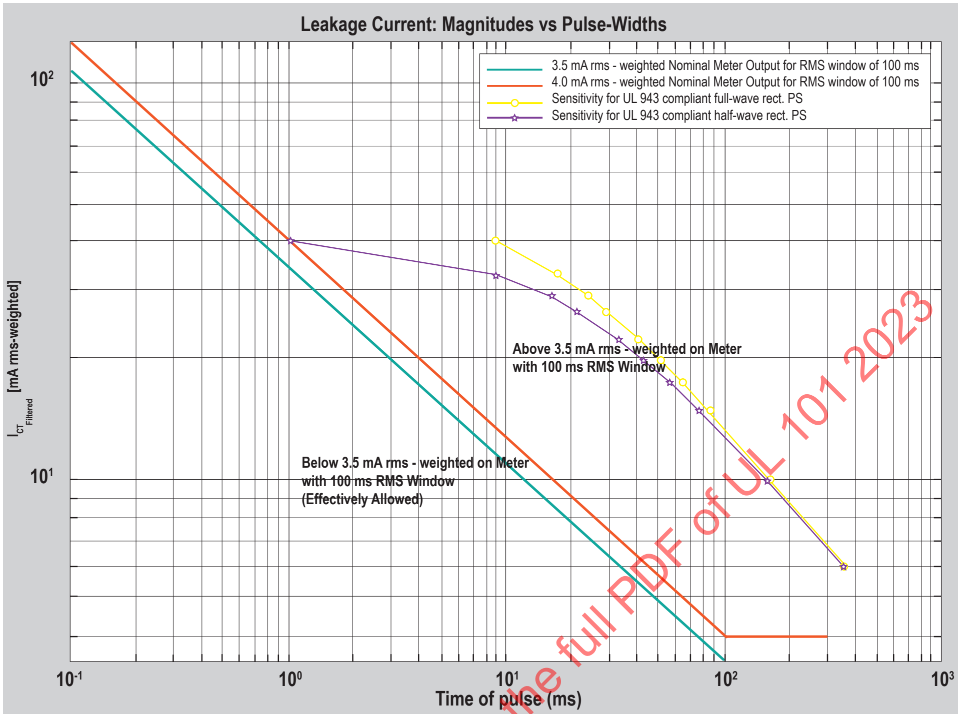
$$T_{GN} = \left(\frac{20\left(\frac{R_N}{R_N + R_G}\right)}{I_{CT}} \right)^{1.43}$$

where I_{CT} is the portion of the fault current to ground which flows through the CT of the GFCI and T_{GN} is the time required for the GFCI to trip, assuming the worst-case values for R_N=0.25 Ω and R_G=1.4 Ω. This time relationship must be met in the case where the GFCI contacts are closed on a circuit in which the fault is already present and dictates the time between the instant when the contacts are first closed onto the fault and the instant when the fault is cleared. Therefore, depending on the phase of the voltage when the GFCI contacts are closed onto an existing fault, if we assume that a full-wave rectified power-supply may take up to 8 ms to initialize (16 ms for half-wave) and the solenoid actuated by the SCR could take another 8 ms to open the circuit contacts, then the time left for the GFCI electronics to sample data and make a decision is shown in the two right-most columns.

A8.3 The resulting practical effect on the sensitivity of the GFCI ICs for currents of various magnitudes and pulse-envelope-widths is plotted in Figure A8.1. The combinations of magnitudes and pulse-envelope-widths at which the “Meter M for GFCI Interoperability” of Section 6 would indicate 3.5 MIU (3.5 mA rms-weighted) when using and rms window size of 100 ms is also superimposed onto the graph. Therefore, GFCI ICs with sensitivities which lie above and to the right of the 3.5 mA rms-weighted reference line would be guaranteed to be interoperable because they are only sensitive to currents which would indicate a value larger than 3.5 mA rms-weighted on the output of the meter. In contrast, GFCI ICs with sensitivity below that are not guaranteed to be interoperable because they can trip on currents for which the meter would indicate a value less than 3.5 mA rms-weighted.

Figure A8.1

Differential Current: Magnitudes vs Pulse-widths



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A8.4 In the worst-case practical scenario with a half-wave rectified power supply shown in Table A8.1, to comply with UL 943, a GFCI may recognize and issue an electronics trip signal after only 1 ms of a 40 mA rms fault current. Therefore, to ensure interoperability with practical implementations of GFCIs which pass UL 943, we want to ensure that the UL 101 test will not permit an appliance to pass if it leaks 40 mA for 1 ms. Considering 100 ms rms window, a 1 ms pulse-envelope of 40 mA will result in the meter output value of 4 mA rms, based on the equation:

$$m_{RMS}(I_{CT}, T_p, T_W) = I_{CT}\sqrt{\frac{T_p}{T_W}}$$

where I_{CT} is the differential current (mA) through the current transformer, T_p is the pulse width (ms) of the transient event of differential current I_{CT}, and T_w is the measurement widow of the interoperability test.

NOTE: This equation holds true for when m_{RMS} and I_{CT} are given in milliamperes rms and when they are both given in milliamperes rms-weighted, which is equivalent to IIU for the measurement instrument defined in GFCI Interoperability Test, Section 6. Therefore, this analysis is accurate for both 60 Hz sinusoidal currents measured in milliamperes rms and for complex-multifrequency currents measured in milliamperes rms-weighted (i.e IIU for Figure 6.1).

$$m_{RMS}(40mA,\ 1ms,\ 100\,ms) = 40\,mA \cdot \sqrt{\frac{1\,ms}{100\,ms}} = 4\,mA\ (RMS)$$

Therefore, a 100 ms window allows to demonstrate interoperability with ground fault protection in the case of 1 ms short pulse-envelope of 40 mA rms differential current. This and all other scenarios for GFCI trip sensitivities to short pulse-envelopes of differential current from the table above are plotted in Figure A8.1 and compared to the output value of the measurement instrument in with a 100 ms rms window defined in GFCI Interoperability Test, Section 6. This shows that the 40 mA 1 ms pulse-envelope case is the most concerning case for possible problems with interoperability.

Table A8.1
GFCI Time to Sample Data to Meet Time-dependent Trip Requirements During Grounded Neutral

I_{CT} [mA]	T_{GN} [ms]	Time to sample data (full-wave rectified power-supply) [ms]	Time to sample data (half-wave rectified power-supply) [ms]
6	377	361	353
10	181	165	157
15	102	86	78
17.5	81	65	57
20	67	51	43
22.5	57	41	33
26.5	45	29	21
29	40	24	16
33	33	17	9
40	25	9	1