

IEEE Standard Test Methods for Surge Protectors and Protective Circuits Used in Information and Communications Technology (ICT) Circuits, and Smart Grid Data Circuits

IEEE Power and Energy Society

Sponsored by the
Surge Protective Devices Committee

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IEEE Standard Test Methods for Surge Protectors and Protective Circuits Used in Information and Communications Technology (ICT) Circuits, and Smart Grid Data Circuits

Sponsor

Surge Protective Devices Committee
of the
IEEE Power and Energy Society

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IEEE-SA Standards Board

Abstract: Surge protectors for application on multiconductor balanced or unbalanced information and communications technology (ICT) circuits and smart grid data circuits are addressed in this standard. These surge protectors are designed to limit voltage surges, current surges, or both. The surge protectors covered are generally multiple-component series or parallel combinations of linear or nonlinear elements, packaged or organized for the purpose of limiting voltage, current, or both. The methods of testing and criteria (where appropriate) for the characteristics and ratings of surge protectors used in ICT circuits and smart grid data circuits are also described in this standard. Packaged single gas tube, air gap, varistor, or avalanche junction surge-protective components are not covered by this standard, but rather are covered by IEEE Std C62.31™, IEEE Std C62.32™, IEEE Std C62.33™, and IEEE Std C62.35™, respectively. Specifically excluded from this standard are test methods for low-voltage power circuit applications. For protection of wire-line communication facilities under the specialized conditions found at power stations, consult IEEE Std 487™.

Keywords: ICT surge protection, IEEE C62.36™, signal line surge protection, smart grid surge protection, SPD, surge-protective circuits, surge protector, telecommunication line protector unit, transient overvoltage protector

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Introduction

This introduction is not part of IEEE Std C62.36-2016, IEEE Standard Test Methods for Surge Protectors and Protective Circuits Used in Information and Communications Technology (ICT) Circuits, and Smart Grid Data Circuits.

This standard applies to surge protectors for application on multiconductor balanced or unbalanced information and communications technology (ICT) circuits and smart grid data circuits. These surge protectors are designed to limit voltage surges, current surges, or both. The surge protectors covered are generally multiple-component series or parallel combinations of linear or nonlinear elements, packaged or organized for the purpose of limiting voltage, current, or both.

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Contents

1. Scope	10
2. Normative references.....	11
3. Definitions, acronyms, and abbreviations	11
3.1 Definitions	11
3.2 Acronyms and abbreviations	12
4. Service conditions	13
4.1 Normal service conditions	13
4.2 Unusual service conditions	14
4.3 Radiation.....	15
5. Basic configurations	15
6. Standard design test procedure	17
6.1 Standard design test criteria.....	17
6.2 Statistical procedures	17
6.3 Test conditions.....	17
6.4 Test measurements	17
7. Surge protector characteristics.....	17
7.1 General	17
7.2 DC series resistance.....	18
7.3 Capacitance.....	19
7.4 Inductance.....	24
7.5 Insulation resistance (IR) test	26
7.6 Standby current test	28
7.7 DC ringing current.....	32
7.8 Distortion.....	34
7.9 Transmission properties: insertion loss, return loss, phase shift.....	39
7.10 Longitudinal conversion transfer loss (LCTL)	46
7.11 Voltage reset [electronic current limiters (ECLs)].....	49
7.12 Impulse reset.....	52
7.13 Transition current test for thermally activated components.....	57
7.14 Time-to-trip test for thermally activated components.....	60
7.15 Transverse surge generation	65
7.16 DC-limiting voltage	69
7.17 Impulse-limiting voltage.....	74
7.18 In-line surge protector: protected port surge current let-through.....	78
7.19 In-line surge protector: surge series resistance	80
7.20 In-line surge protector: protected port ground potential rise (GPR).....	83
7.21 In-line surge protector: protected port ground lead inductive voltage spike.....	86
8. Preferred surge protector ratings under specified conditioning	89
8.1 Surge protector ratings under environmental cycling with impulse surges	89
8.2 Surge protector ratings under environmental cycling with ac exposure	93
8.3 Surge protector ratings under ac life (durability).....	97
8.4 Surge protector ratings under impulse life (durability).....	99
8.5 Surge protector ratings under maximum single-impulse discharge	103
9. Failure modes	105

Annex A (informative) Examples of internal arrangements of surge-limiting components	106
Annex B (informative) Test measurement techniques	109
B.1 Warning	109
B.2 Oscilloscopes	109
B.3 Voltage measurements	110
B.4 Current measurements	111
Annex C (informative) Impulse generators	112
C.1 Introduction	112
C.2 Types of impulse generator	112
C.3 Impulse generator parameters	112
C.4 Impulse generators typically used for surge protector testing	115
C.5 Impulse generator circuits	117
C.6 Combination wave generators	121
C.7 Expanding single-output generators to multiple output	123
C.8 Generator variants	126
Annex D (informative) Cable discharge events	131
D.1 Background	131
D.2 Event characteristics	131
D.3 Test methods	132
Annex E (informative)	134
GDT-based surge protector oscillation test	134
E.1 Background	134
E.2 Purpose	135
E.3 Equipment	135
E.4 Equipment states subject to test	135
E.5 Procedures	136
E.6 Alternative methods	136
E.7 Suggested data	137
E.8 Comments	138
Annex F (informative) Multiport surge protector	139
F.1 Introduction	139
F.2 Individual service protection	139
F.3 Standards that address multiport coupling	140
Annex G (informative) Comments on characteristics and ratings	142
Annex H (informative) Signal transformers voltage-time product	143
H.1 Background	143
H.2 Purpose	143
H.3 Equipment	143
H.4 Protector states subject to test	143
H.5 Procedures	143
H.6 Alternative method	144
H.7 Suggested test data	144
H.8 Requirement	144
H.9 Comments	145
Annex I (informative) Bibliography	146

IEEE Standard Test Methods for Surge Protectors and Protective Circuits Used in Information and Communications Technology (ICT) Circuits, and Smart Grid Data Circuits

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1. Scope

This standard applies to surge protectors for application on multiconductor balanced or unbalanced information and communications technology (ICT) circuits and smart grid data circuits. These surge protectors are designed to limit voltage surges, current surges, or both. The surge protectors covered are generally multiple-component series or parallel combinations of linear or nonlinear elements, packaged or organized for the purpose of limiting voltage, current, or both.

This standard describes the methods of testing and criteria (where appropriate) for the characteristics and ratings of surge protectors used in ICT circuits and smart grid data circuits. This standard is not intended to cover packaged single gas tube, air gap, varistor, avalanche junction, or self-restoring current limiter surge-protective components (SPCs), which are covered by IEEE Std C62.31 [B20], IEEE Std C62.32 [B21], IEEE Std C62.33 [B22], IEEE Std C62.35 [B23], and IEEE Std C62.39 [B24], respectively. Specifically excluded from this standard are test methods for low-voltage power circuit applications. For protection of wire-line communication facilities under the specialized conditions found at power stations, consult IEEE Std 487 [B16] series of documents.^{1, 2}

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WARNING

Because of the high-voltage energy levels employed in some of the tests described herein, these tests should be considered hazardous. Take appropriate safety precautions in their performance.

2. Normative references

At the time of publication, this document has only bibliographic references and does not have any normative references; see Annex I.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.¹ See also C3.6.1 for waveshape descriptions.

assembly: A subordinate element of a system that comprises two or more components. [Adapted from ISO/IEC 14776-121, ed. 1.0 (2010-10)]

balun: A device for transforming an unbalanced voltage to a balanced voltage or vice versa. (Adapted from IEV 161-04-34²)

bias voltage: The value of an applied voltage, under stated conditions, which determines the operating point of a circuit.

component: Constituent part of a device that cannot be physically divided into smaller parts without losing its particular function. (Adapted from IEV 151-11-21)

device: Material element or assembly of such elements intended to perform a required function. (Adapted from IEV 151-11-20)

NOTE—A device may form part of a larger device.³

ground potential rise (GPR) (lightning): Voltage between a grounding system and a remote reference ground.

maximum ground surge current (surge protector), I_{GM} : Highest peak current in the ground terminal when all the cable-side terminals are simultaneously surged under the V_{LM} test conditions.

maximum ground surge current (surge protector), I_{GM} : Highest peak current in the ground terminal when all the cable-side terminals are simultaneously surged under the maximum limiting voltage test condition.

¹ IEEE Standards Dictionary Online subscription is available at http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

² IEV = International Electrotechnical Vocabulary (<http://www.electropedia.org>).

³ Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

maximum limiting voltage (surge protector), V_{LM} : Highest peak voltage at the protected port under specified surge conditions.

maximum short-circuit output current (surge protector), $I_{O(SC)M}$: Highest peak protected output surge current into a short circuit under specified surge conditions.

multiport surge protector: A surge protector that connects equipment to external systems whereby all conductors connected to the protected equipment are routed, physically and electrically, through a single enclosure containing two or more surge protectors.

NOTE—The surge-protective devices (SPDs) may be part of a device that includes other features like splitting, combining, and multiple outputs.

protector: *See:* **surge protector.**

surge-protective device (SPD): An assembly of protective elements that is used to mitigate surge voltages and that, in addition, may mitigate surge currents. It may contain linear or nonlinear components, or a combination of the two.

surge protector: An assembly of protective components consisting of one or more series, parallel, or any combination of elements used to mitigate surge voltages, currents, or both. *Syn:* **protector.**

transition current: The current required at a given temperature and duration to cause a current-protective device to change state.

3.2 Acronyms and abbreviations

DMM	digital multimeter
DSL	digital subscriber line
DSO	digital storage oscilloscope
DUT	device under test
ECL	electronic current limiter
ESD	electrostatic discharge
GDT	gas discharge tube
GPR	ground potential rise
IR	insulation resistance
LCR	inductance, capacitance, and resistance
LCTL	longitudinal conversion transfer loss
LGPR	lightning ground potential rise
MOV	metal oxide varistor

MSPD	multiservice (multiport) surge-protective device
PN	P and N type semiconductor materials (forming a junction)
POTS	plain old telephone system
PTC	positive temperature coefficient
RF	radio frequency
RLC	resistance, inductance, capacitance
SCR	silicon controlled rectifier
SPC	surge-protective component
SPD	surge-protective device
TCTL	transverse conversion transfer loss
THD	total harmonic distortion
TLP	transmission line pulse
USB	universal serial bus
VI	voltage-current
xDSL	any of the various digital subscriber line technologies, e.g., ADSL or VDSL

4. Service conditions

4.1 Normal service conditions

In the absence of special requirements, the items listed in 4.1.1 to 4.1.4 shall be specified, as appropriate.

4.1.1 Environmental conditions

Environmental conditions include the following:

- a) Operating and storage temperature ranges
- b) Humidity
- c) Mechanical shock and vibration
- d) Atmospheric pressure range

4.1.2 Physical properties

Physical properties include following:

- a) Solvent resistance
- b) Solderability
- c) Flammability
- d) Package rupture during overload
- e) Electrical connection to metallic case

4.1.3 System conditions

System conditions include the following:

- a) Nominal system frequencies
- b) Maximum continuous system voltage
- c) Peak impulse currents
- d) Transient repetition rate

4.1.4 Surge rating of the surge protector under system conditions

Ratings of the surge protector under system conditions include the following:

- a) Rated average power dissipation
- b) Peak pulse power
- c) Current temperature derating
- d) Lifetime rated pulse currents

4.2 Unusual service conditions

The service conditions in 4.2.1 to 4.2.3 might require special consideration in the design or application of surge protectors and should be called to the attention of the manufacturer.

4.2.1 Environmental conditions

Environmental conditions include the following:

- a) Ambient temperature exceeding the normal service conditions
- b) Exposure to
 - 1) Damaging fumes or vapors
 - 2) Excessive dirt or current-conducting deposits, excessive humidity, moisture, dripping water, steam or salt spray, explosive atmospheres, abnormal vibrations, and mechanical shocks
- c) Usual transportation or storage conditions
- d) Flammability rating

4.2.2 Physical conditions

Physical conditions include limitations on weight or space, for example, clearance to nearby conducting objects.

4.2.3 System conditions

System conditions include the following:

- a) System voltages, currents, repetition rates, or frequency operating conditions whereby the ratings of the devices are exceeded (see Clause 9)
- b) System impulse currents exceeding the rating of the device (see Clause 9)
- c) Exposure to direct lightning strike (see Clause 9)
- d) Electromagnetic field effects (see Clause 9)
- e) Unusual ground potential situations (see Clause 9)
- f) Any other unusual conditions known to the user

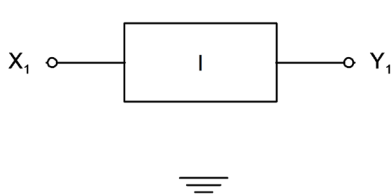
4.3 Radiation

Some protectors might contain radioactive material. Manufacturers of such protectors shall mark them in accordance with applicable regulations.

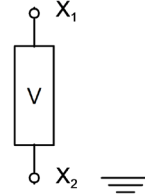
5. Basic configurations

This clause illustrates, by functional block diagrams, the surge protectors described by this standard. A protector assembly might be composed of any number of the protectors in Figure 1. Where several surge protectors are in a housing, e.g., surge protection strip containing one or more radio frequency (RF), data, power, and voice surge protectors, multiport testing shall be performed as explained in Annex F.

2 Terminal Devices

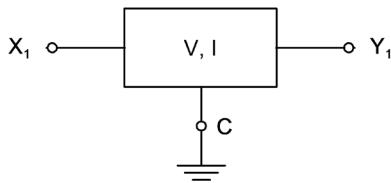


Configuration 2A

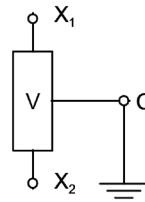


Configuration 2B

3 Terminal Devices

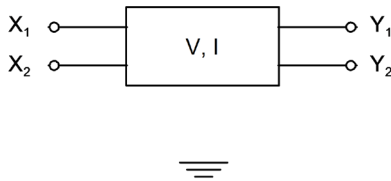


Configuration 3A



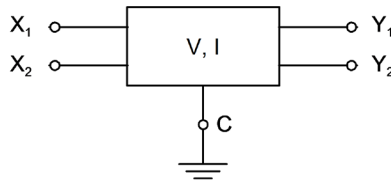
Configuration 3B

4 Terminal Device



Configuration 4

5 Terminal Device



Configuration 5

C is common terminal
I is current-limiting function
V is voltage-limiting function
X₁, X₂, Y₁, Y₂ are signal terminals

NOTE 1—The V,I designation in Figure 1 indicates that a surge protector might have a voltage-limiting function, a current-limiting function, or both.

NOTE 2—Surge protectors intended for coaxial cable circuits are tested, as described in Clause 7 and Clause 8, using Configuration 3A. Outer conductors of the transmission lines are connected to the common terminal of the surge protector during the tests. (See examples of surge protectors on coaxial lines in Figure A.2.)

NOTE 3—Surge protectors intended for twinaxial cable circuits are tested, as described in Clause 7 and Clause 8, using Configuration 5. Outer conductors of the transmission lines are connected to the common terminal of the surge protector during the tests. (See examples of surge protectors on twinaxial lines in Figure A.3.)

Figure 1—Basic configurations

6. Standard design test procedure

6.1 Standard design test criteria

The design tests described in Clause 7 and Clause 8 provide standardized methods for making single observations of a specified characteristic of a surge protector. These properties might vary from device to device, making it necessary to provide statistical descriptions of the property in order to compare products.

6.2 Statistical procedures

The following procedure shall be used to describe any characteristic that has been determined to have important statistical aspects. A product sample shall be chosen in a manner consistent with the definition of design tests as provided by the *IEEE Standards Dictionary Online*. A sufficient number of devices shall be tested and the characteristic or rating in question measured as described in the applicable design test until the parameters of the underlying statistical distribution are determined within specified confidence limits. Typical values relating to the product sample are mean, median, maximum, minimum, and standard deviation.

6.3 Test conditions

The tests in Clause 7 and Clause 8 shall be performed on the surge protector as required by the application. Unless otherwise specified, ambient test conditions shall be as follows:

Temperature	25 °C ± 5 °C
Relative humidity	less than 85%
Atmospheric pressure	60 cmHg –78 cmHg

For temperatures other than 25 °C, the surge protector, mounted as intended to be used, shall be maintained at the specified test temperature but with the air flow controlled to provide a free convection heat transfer, unless otherwise specified. The protector temperature shall be allowed to stabilize before tests are performed.

6.4 Test measurements

General guidance on test measurement techniques that have been useful in measuring the characteristics of surge protectors is contained in Annex C.

7. Surge protector characteristics

7.1 General

A characteristic is an inherent and measurable property of a device expressed as a value for stated or recognized conditions. Characteristics might also be a set of related values, usually shown in graphical form.

7.2 DC series resistance

7.2.1 Background

Protectors might contain a series resistance for purposes such as loop stability or coordination. In such cases, the value of the protector series resistance might be of interest. This test is applicable if the type of protector used introduces a resistance in series with the line. The dc series resistance is measured using a continuous current having a value that is appropriate for the application. The current source is applied to the relevant terminals of the surge protector, and the voltage across the terminals is measured. The dc resistance is then calculated as the quotient of the voltage drop and specified current (e.g., 100% rated current, 80% rated current).

7.2.2 Purpose

The purpose of this test is to evaluate the dc series resistance of a protector.

7.2.3 Equipment

The equipment for this test is a digital multimeter (DMM) or Kelvin bridge having the following accuracy:

- For readings $>10\ \Omega$, 1% or better
- For readings >2 to $10\ \Omega$, 2% or better
- For readings $\leq 2\ \Omega$, 5% or better

7.2.4 Protector states subject to test

The protector is to be tested in an unbiased state at room temperature.

7.2.5 Procedures

The procedures for testing dc series resistance are as follows:

- a) Connect the multimeter resistance-measuring terminals to the surge protector input terminal X_1 and output terminal Y_1 (Figure 1). For resistances less than $1\ \Omega$, use a Kelvin bridge or DMM with a four-wire resistance measurement function.
- b) Measure the resistance.
- c) If the protector also has X_2 and Y_2 (Figure 1) terminals, then connect the multimeter resistance-measuring terminals to X_2 and Y_2 , and measure the resistance. For resistances less than $1\ \Omega$, use a Kelvin bridge or DMM with a four-wire resistance measurement function.

7.2.6 Alternative methods

None.

7.2.7 Suggested test data

The suggested test data is the resistance for each set of terminals.

7.2.8 Requirement

None—this is a characteristic.

7.2.9 Comment

The accuracy of the DMM reading for low resistance measurements is often improved by integrating the reading over a number of ac power cycles. This procedure generates a comb filter with nulls at ac power harmonics, which improves the accuracy of the meter reading by reducing the noise in the measurement.

7.3 Capacitance

7.3.1 Background

Protectors have varying amounts of capacitance between their terminals. The amount depends on characteristics of the components used for voltage limiting or current limiting and on the physical dimensions of the package. For example, a voltage-limiting protector of Configuration 3B (Figure 1) has capacitance between terminals X_1 and X_2 , X_1 and C, and X_2 and C. The capacitance between terminals X_1 and C might differ from that between X_2 and C, and this difference results in a shunt capacitive imbalance. The capacitance between X_1 and X_2 might differ from either of the other two. Because capacitive reactance is an inverse function of frequency, higher transmission frequencies on a protected line cause a protector of given capacitance to constitute a lower bridging impedance. Therefore, the capacitance of the protector shall be selected to be low enough to not affect transmission at the highest frequency to be used.

Excessive capacitance might introduce degradations such as signal attenuation (insertion loss), pulse-shape distortion (e.g., in digital transmission systems), echo (return loss), or propagation delay. Capacitive imbalance might add to the susceptibility of a system to interference from radiated noise, or it might increase radiated emissions from the system.

Because capacitance might vary with applied signal and dc bias voltage, the capacitance test shall be conducted using voltages determined by the application.

7.3.1.1 General

Capacitance values are indicators of high-frequency performance in terms of attenuation and, for devices with a ground terminal, the capacitive line balance. Shunt surge-protective devices (SPDs) apply their capacitance values between the connection nodes (see Figure 2). In-line surge protectors without intentional series impedance between the input and output ports do likewise (see Figure 3). In-line surge protectors having intentional series impedance between the input and output ports partially decouple the input and output capacitance components (see Figure 4).

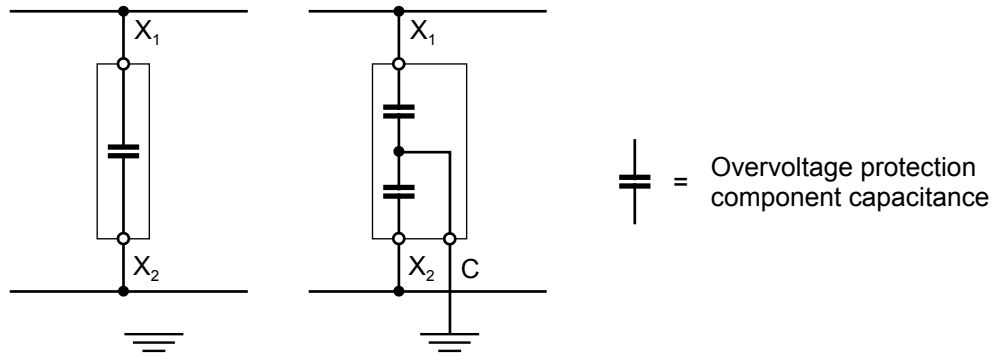


Figure 2—Examples of shunt surge protector capacitance

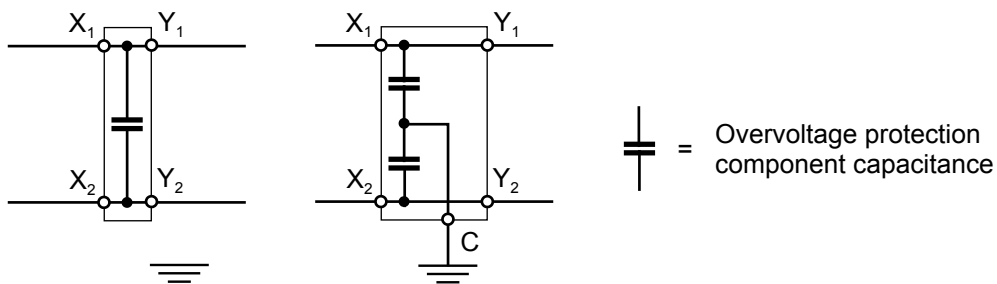


Figure 3—Examples of in-line surge protector capacitance

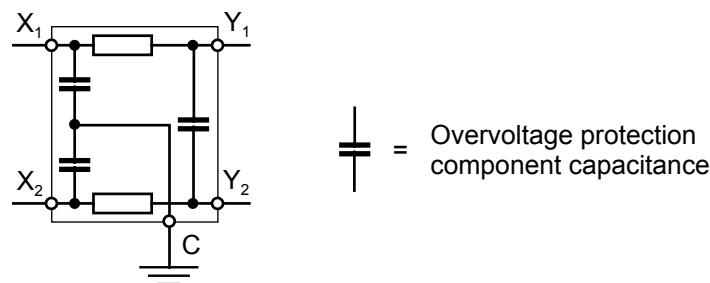


Figure 4—Examples of in-line surge protector capacitance decoupling by series impedance

7.3.1.2 Voltage-dependent capacitance

Devices built with components containing semiconductor PN junctions, like avalanche diodes and thyristors, have a capacitance that varies with voltage (Figure 5). Capacitance variation has two main effects:

- Line unbalance because the powering dc causes different capacitance values of the components connected to the common
- Signal distortion of high amplitude signals, e.g., any digital subscriber line technology (xDSL), caused because the signal modulates the capacitance value

Distortion in xDSL systems due to the frequency spectrums and amplitudes of the transmitted and received signal results in a reduction of the system reach. Testing this type of device requires capacitance measurement at dc voltage bias levels, V_D , of zero and the maximum signal voltage level, typically 15 V for xDSL, for unpowered lines. Powered lines require a further test at the dc powering voltage, typically 50 V. The actual value of measured capacitance also depends on the ac test voltage, V_d . It is important to standardize the ac test voltage and use equipment that maintains a fixed test voltage independent of the capacitance value.

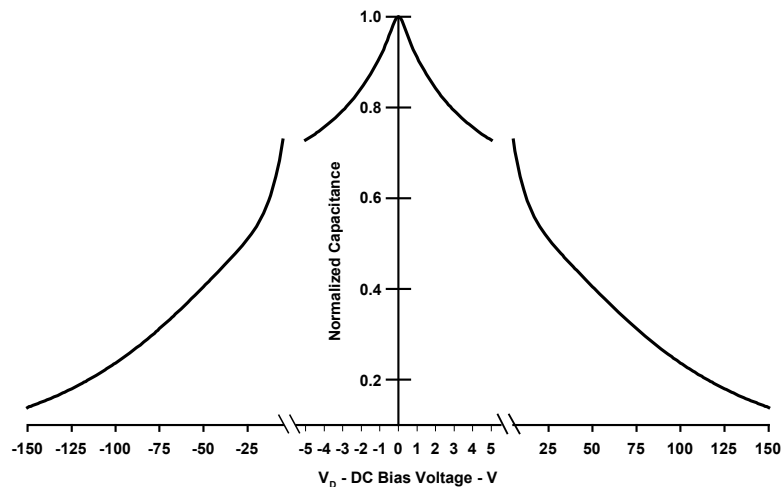


Figure 5—Example capacitance variation of a symmetrical PN junction component

7.3.1.3 Separating out the individual capacitive components

The left circuit of Figure 6 is a simple example of a surge protector with overvoltage protection components connected between X_1 and X_2 , Y_1 and C , and Y_2 and C . If a capacitance measurement is made between two terminals, the series combination of the other two capacitances is in parallel with the direct terminal capacitance (see the center circuit of Figure 6). Operating switch S_1 to short- or open-circuit the third, unmeasured, terminal does not give the correct capacitance value for the Y_1 and Y_2 component. To remove the unwanted capacitance components from the measurement, a network analyzer with a guarded measurement capability is required (see the right circuit of Figure 6). The unmeasured terminal is connected to the analyzer guard, and this connection nulls the capacitive components connected to this terminal. The network analyzer voltage (H_V and L_V) and current (H_I and L_I) leads are connected as close as possible to the device terminals Y_1 and Y_2 .

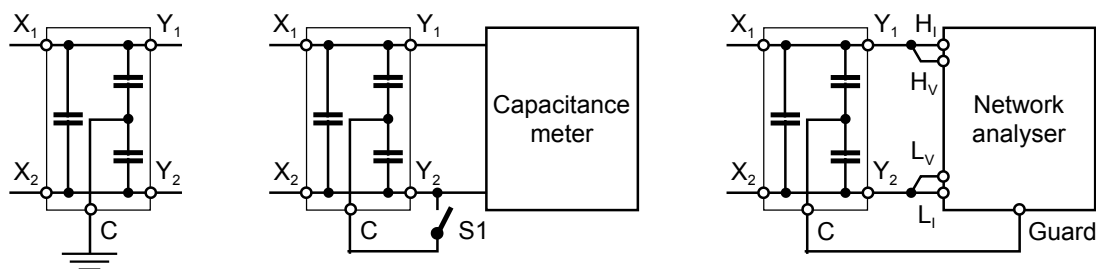
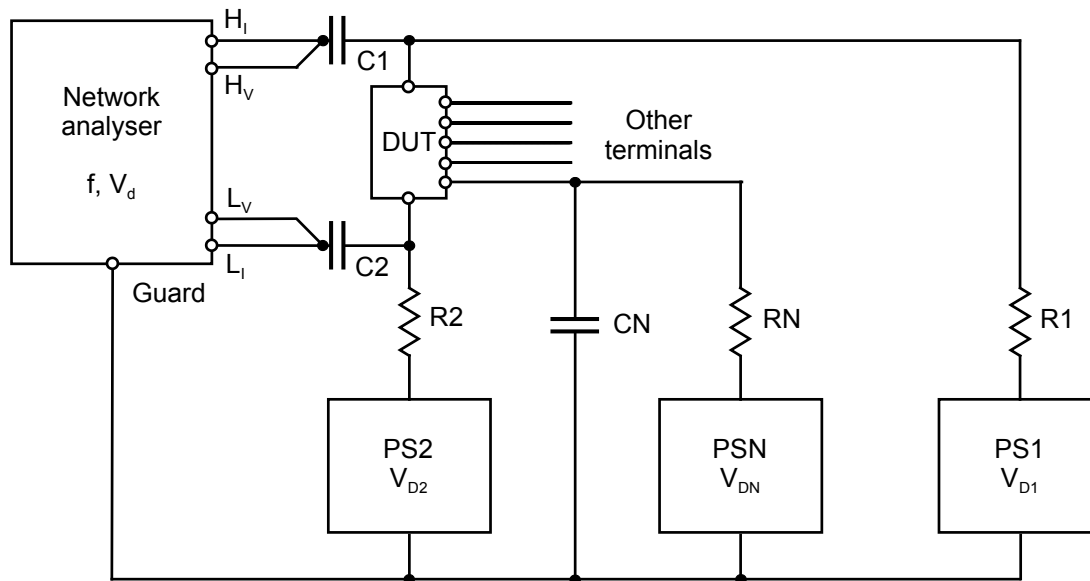


Figure 6—Removing unwanted capacitive components by using a network analyzer

7.3.2 Equipment

The test equipment includes following:

- Network analyzer capable of a frequency of 1 MHz and an ac test voltage of 1 V rms
- If required, dc power supplies to bias the device under test (DUT) terminals (see Figure 7)
- If required, dc blocking capacitors (see Figure 7)
- If required, dc feed resistors (see Figure 7)



DUT	is device under test
C1, C2.....CN	are dc blocking capacitors, $C1 = C2.....CN \gg$ measured capacitance
R1, R2.....RN	are dc feed resistors, $R1 = R2.....RN \ll$ terminal insulation resistance (IR)
PS1, PS2.....PSN	are variable voltage dc power supply for $V_{D1}, V_{D2}.....V_{DN}$
H_v	is H_i voltage sense
H_i	is H_i current feed
L_v	is L_o voltage sense
L_i	is L_o current return
Guard	is guard-ground terminal (nulls the capacitance of that terminal from the measurement)

Figure 7—Test circuit for capacitance of a biased multi-terminal surge protector

7.3.3 Equipment states subject to test

The equipment is to be tested as follows:

- Terminal pairs connected as specified in Figure 7.
- Surge protectors without voltage-dependent capacitance are measured at zero dc bias voltage.
- Surge protectors with voltage-dependent capacitance are measured at 0, 15 V, and 50 V dc bias voltages or at voltages appropriate for the SPD being tested.

7.3.4 Procedures

The procedures for testing capacitance are as follows:

- a) Connect the circuit up as shown in Figure 7.
- b) Set the analyzer to a frequency of 1 MHz and an ac test voltage of 1 V rms.
- c) If required, set the power supply voltages to the DUT terminals to the required levels.
- d) Record the value of terminal pair capacitance and the dc bias levels applied.
- e) Repeat step c) and step d) with other specified dc bias voltages.
- f) Reconfigure Figure 7 circuit to measure the next terminal pair set.
- g) Repeat step c) to step e) for that terminal pair set.
- h) Repeat step f) and step g) until all the required DUT terminal pairs are measured.

7.3.5 Alternative methods

Two terminal surge protectors without voltage-dependent capacitance can be measured with a capacitance meter operating at a frequency equal or greater than 100 kHz.

7.3.6 Suggested test data

This standard recommends collecting the following test data:

- a) Network analyzer frequency and test voltage level
- b) Terminal pair tested
- c) Terminal dc bias level
- d) Measured capacitance value at each voltage

7.3.7 Requirements

None—this is a characteristic.

7.3.8 Comments

Acceptable values of capacitance are system dependent. For a plain old telephone system (POTS), a maximum value of 200 pF is considered acceptable, and for digital subscriber line (DSL), a value of 30 pF is considered acceptable.

For voltage-dependent capacitance values, the change in capacitance with dc bias variation is the most important factor, rather than the absolute capacitance value. For xDSL, a maximum change shall be below 10 pF for a dc bias change equal to the maximum signal amplitude.

Some components containing semiconductor PN junctions might not have the symmetrical capacitance characteristic as shown in Figure 5. Asymmetry can cause severe signal distortion. Asymmetry is checked for by reversing the polarity of the dc supply and comparing the capacitance values in both supply polarities. The measured values shall be within a few percent of each other.

7.4 Inductance

7.4.1 Background

Communications protectors are generally for use on either single-wire unbalanced or two-wire balanced systems. The latter are widely used in the telephone system. It is unusual for the single-wire unbalanced protectors to contain inductors. In contrast, protectors used in telephone line applications might contain heat coils and might also contain common-mode chokes.

Protectors for use in digital circuits generally do not contain heat coils, as they distort the digital signals. The inductance of protectors without heat coils is low and usually not specified or measured. For protectors without heat coils, the effect of whatever inductance is present is evaluated by the insertion loss and return loss measurements.

Very high signal levels applied to inductors with cores of magnetic material might cause the inductor to operate beyond the knee of the B-H curve, in which case harmonics and possibly intermodulations may be generated (see the harmonic distortion test in 7.8).

Protectors have varying amounts of inductance between their terminals. The amount depends on characteristics of the components used for voltage limiting or current limiting and on the physical dimensions of the package. For example, a current-limiting protector of Configuration 4 in Figure 1 has inductance between terminals X_1 and Y_1 and between X_2 and Y_2 . The inductance between terminals X_1 and Y_1 might differ from that between X_2 and Y_2 , and this difference results in a series inductive imbalance.

Because inductive reactance is proportional to frequency, higher transmission frequencies on a protected line cause a protector of given inductance to constitute a higher series impedance. Therefore, the inductance of the protector shall be selected to be low enough to not affect transmission at the highest frequency to be used.

Excessive inductance might introduce degradations such as signal attenuation (insertion loss), pulse-shape distortion (e.g., in digital transmission systems), echo (return loss), or propagation delay. Inductive imbalance might add to the susceptibility of a system to interference from radiated noise, or it might increase radiated emissions from the system.

Because inductance might vary with applied signal frequency and dc bias current, the inductance test shall be conducted using frequency and bias determined by the application.

7.4.2 Purpose

This test is conducted to determine the inductance between specified terminals of a surge protector. In the case of a telephone line protector, the terminals are tip-in to tip-out and ring-in to ring-out.

7.4.3 Equipment

The equipment for this test is a resistance, inductance, and capacitance (RLC) meter.

7.4.4 Protector states subject to test

The protector is to be tested in an unbiased state.

7.4.5 Procedures

Test circuits are shown in Figure 8 and Figure 9. The inductance of protectors for two-wire balanced systems is measured by connecting the two sides of the protector in series, as shown in Figure 9, and dividing the resulting measured inductance by 2 to get the inductance for a single side of the protector. The reason for doing this step is that the inductance of protectors containing a common mode choke would be inaccurate if only one side of the protector were measured.

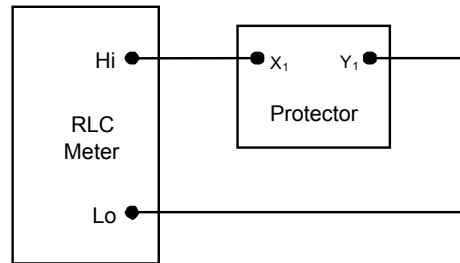


Figure 8—Inductance measurement of a single-wire unbalanced protector

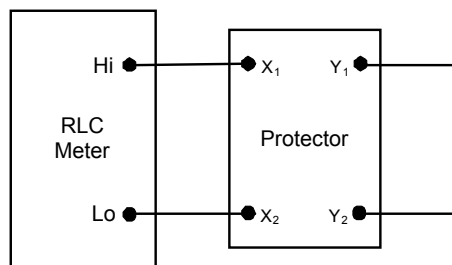


Figure 9—Inductance measurement of a two-wire balanced protector

The procedures for testing inductance are as follows:

- Depending on whether the protector is for single-wire or two-wire use, set up the test as shown in Figure 8 or Figure 9, respectively.
- Set the RLC meter the specified frequency. Default frequency is 1 MHz.
- Read and record the value of the inductance measured.

7.4.6 Alternative methods

None.

7.4.7 Suggested test data

This standard recommends collecting the following test data:

- Measurement frequency
- Value of inductance

7.4.8 Requirements

None—this a characteristic.

7.4.9 Comment

None.

7.5 Insulation resistance (IR) test

7.5.1 Background

IR within the normal range of operation is important because if it is too low, it affects system performance, especially the automatic line test function in a telecom network. IR might depend on temperature, in which case, IR needs to be measured at the extremes of the specified operating temperature range as well as at room temperature. The IR is usually measured with an instrument called a *megohmmeter/hi-pot tester*, which applies a voltage and measures the resultant current.

The IR is the calculated result of dividing the applied voltage by the measured standby current (see 7.21). This test usually applies across terminals that are intended to be a high resistance such as on a voltage limiter or insulation. All protector terminals not being measured shall be left completely disconnected during the measurement so that other current leakage paths, if present, are not inserted into the measurement circuit. Additionally, IR can be measured between the external surface of the protector housing (sometimes wrapped in metallic foil) and the terminals. The results of this test indicate whether the protector contains an undesirable leakage current path, which would interfere with normal circuit operation. The IR of a surge protector might depend on the magnitude of the applied voltage, polarity of the applied voltage, ambient temperature, altitude, and humidity.

This test is meant to be a steady-state measurement so that the capacitance of the surge protector shall be allowed to charge to the applied voltage before the current is measured. Any additional capacitance from the test circuit wiring and components might require even longer settling times.

As the applied voltage increases, the standby current of the surge protector might increase, depending on the components used. When measuring the IR, the magnitude of the applied voltage shall not cause any parallel component to go into conduction. The magnitude of any system dc bias voltage used during normal circuit operation shall be considered as at least one voltage used to measure the IR of a protector.

With some solid-state SPCs, the standby current is relatively constant over a large part of the applied voltage from zero to the dc-limiting voltage. In this case, the measured IR increases as the applied dc voltage increases, or conversely, the measured IR decreases as the voltage decreases, even though the standby current is not changing. The needs of the protected circuit shall be considered when determining whether to specify either standby current or IR of the protector.

The IR might also be affected by ambient temperature, altitude, and humidity; and different types of protection components react differently to these conditions. The IR of surge protectors incorporating air gaps (carbon blocks or gas discharge tubes (GDTs) having backup air gaps) can increase as the relative humidity of the nearby atmosphere rises. Moisture condensation inside these types of protectors might bridge the gap and thereby provide a leakage path for current.

The IR of a protector might also depend on the polarity of the applied test voltage, particularly for solid-state bidirectional thyristor SPCs.

The IR of the device is sometimes used as an indication of the condition of the device, especially as the device ages. The IR might change with time, temperature, environment, bias, and exposure to repeated electrical surges. For instance, the electrodes of spark gap components (carbon blocks or GDTs) can melt from the high temperatures produced by the arc formed during the overvoltage condition. When this reaction happens, molten electrode material might be sprayed onto the surfaces surrounding the gap and eventually deposit enough material to form a current leakage path across the gap. Some solid-state components also deteriorate with repeated surges; some might be sensitive to surges having a very steep current slope (di/dt).

Finally, any protector might contain internal or surface contamination, possibly leading to the formation of a current leakage path. For this reason, protector housings are often designed to have convoluted surface paths between their terminals to minimize the risk of leakage path formation over time. Because of concern about contamination, consideration shall be given to using a voltage source of specified limited short-circuit current capacity. Current is limited to levels available in the application to avoid possible disturbance of any contaminants on or in the DUT. The intention of this testing is to detect the contamination and not to remove it unless the available current in the application would have done so.

7.5.2 Purpose

The purpose of this test is to verify that the IR of a protector is greater than a specified value.

7.5.3 Equipment

The equipment for this test is a megohmmeter/hi-pot tester/hi-pot.

NOTE—Most test labs have a megohmmeter/hi-pot tester, which is permitted for this test. However, megohmmeter/hi-pot testers apply a voltage that might activate any overvoltage protection components present in the protector. The voltage of the megohmmeter/hi-pot tester shall be adjusted to avoid activating any overvoltage components present.

7.5.4 Protector states subject to test

The protector is to be tested at room temperature (20 °C to 25 °C) and, if required, at maximum or minimum surge protector operating temperature.

7.5.5 Procedures

The procedures for testing IR are as follows:

- a) The IR shall be measured with an applied voltage less than the breakdown voltage of any overvoltage protective components present.
- b) If required, put the DUT into the environmental chamber, with suitable test ports on the outside of the chamber. Set the temperature of the chamber to the lowest value of the operating temperature range. Stabilization is reached when three successive temperature readings taken 2 min apart do not differ by more than 1 °C. If not required, skip to step g).
- c) Use the megohmmeter/hi-pot tester, per the instructions that come with the instrument, set to the appropriate voltage to measure the IR while the DUT is in the chamber.
- d) All combinations of ground and input or output terminals shall be measured one at a time; all terminals not involved in the measurement shall be left open-circuited. Select one combination to begin the test.

- e) Increase the temperature of the environmental chamber to the highest value of the operating temperature range. Stabilization is reached when three successive temperature readings taken 2 min apart do not differ by more than 1 °C.
- f) Repeat step c) and step d).
- g) Remove the DUT from the environmental chamber, and leave it for an hour at room temperature.
- h) Repeat step c) and step d).

7.5.6 Alternative methods

An alternative method for testing IR is to replace step c) in 7.7.5 with the following:

- c) Measure the standby current as described in 7.6, and then calculate the IR as the ratio of applied voltage to standby current.

7.5.7 Suggested test data

Enter data in a table such as Table 1.

Table 1—Test data example table

Data category	Temperature of the DUT		
	Lowest surge protector operating temperature	Room temperature	Highest surge protector operating temperature
Temperature °C			
Volts applied			
Resistance, megohms			

7.5.8 Requirements

None—this a characteristic.

7.5.9 Comment

The test circuit shall be tested without the DUT to verify that it has a higher IR than the specified IR of the DUT.

7.6 Standby current test

7.6.1 Background

Standby current is the continuous current that is conducted between specified terminals of a surge protector when applying a specified dc voltage across these terminals. This test usually applies across terminals that are intended to be a high resistance such as on a voltage limiter or insulation. All protector terminals not being measured shall be left completely disconnected during the

measurement so that other current leakage paths, if present, are not inserted into the measurement circuit. If required, the standby current can also be measured between the external surface of the protector housing (sometimes wrapped in metallic foil) and the terminals. The results of this test indicate whether the protector contains an undesirable leakage current path, which would interfere with normal circuit operation. The standby current of a surge protector might depend on the magnitude of the applied voltage, polarity of the applied voltage, ambient temperature, altitude, and humidity.

This test is meant to be a steady-state measurement; therefore, the capacitance of the surge protector shall be allowed to charge to the applied voltage before the current is measured. Any additional capacitance from the test circuit wiring and components might require even longer settling times.

As the applied voltage increases, the standby current of the surge protector might increase, depending on the components used. When measuring the standby current, the magnitude of the applied voltage shall not cause any parallel component to go into conduction or exceed the rated voltage of the protector because the protector might be significantly conductive at or above its rated voltage. The magnitude of any system dc bias voltage used during normal circuit operation shall be considered as at least one voltage used to measure the standby current of a protector.

With some solid-state SPCs, the standby current is relatively constant over a large part of the applied voltage from zero to the rated voltage. Therefore, the calculated IR increases as the applied dc voltage increases, or conversely, the calculated IR decreases as the voltage decreases, even though the leakage current is not changing. The needs of the protected circuit shall be considered when determining whether to specify either standby current or IR of the protector.

The standby current might also be affected by ambient temperature, altitude, and humidity; and different types of protection components react differently to these conditions. In particular, the standby current of solid-state SPCs increases as the component temperature increases. On the other hand, the standby current of surge protectors incorporating air gaps (carbon blocks or GDTs having backup air gaps) can increase as the relative humidity of the nearby atmosphere rises. Moisture condensation inside these types of protectors might bridge the gap and thereby provide a leakage path for current.

The standby current of a protector might also depend on the polarity of the applied test voltage, particularly for solid-state bidirectional thyristor SPCs.

The standby current of the device is sometimes used as an indication of the condition of the device, especially as the device ages. The standby current can change with time, temperature, environment, bias, and exposure to repeated electrical surges. For instance, the electrodes of spark gap components (carbon blocks or GDTs) can melt from the high temperatures produced by the arc formed during the overvoltage condition. When this happens, molten electrode material might be sprayed onto the surfaces surrounding the gap and eventually deposit enough material to form a current leakage path across the gap. Some solid-state components also deteriorate with repeated surges; some might be sensitive to surges having a very steep current slope (di/dt).

Finally, any protector might contain internal or surface contamination, which possibly leads to the formation of a current leakage path. For this reason, protector housings are often designed to have convoluted surface paths between their terminals to minimize the risk of leakage path formation over time. Because of concern about contamination, consideration shall be given to using a voltage source of specified limited short-circuit current capacity. Current is limited to levels available in the application to avoid possible disturbance of any contaminants on or in the DUT. The intention of this testing is to detect the contamination and not to remove it unless the available current in the application would have done so.

7.6.2 Purpose

The purpose of this test is to verify that the standby current of a protector is less than a specified value.

7.6.3 Equipment

The test equipment includes following:

- a) Ammeter capable of measuring microamps (microammeter)
- b) DC voltage source adjustable from 0 to 200 V, limited to a maximum of 10 mA output current
- c) Environmental chamber capable of covering the required temperature range

7.6.4 Protector states subject to test

The protector is to be tested at room temperature (20 °C to 25 °C) and, if required, maximum or minimum surge protector operating temperature.

7.6.5 Procedures

The procedures for testing standby current are as follows:

- a) Set up the circuit shown in Figure 10.
- b) The standby current shall be measured with an applied voltage less than the breakdown voltage of any overvoltage protective devices present.
- c) Put the DUT into the environmental chamber, with suitable test ports on the outside of the chamber. Set the temperature of the chamber to the lowest value of the operating temperature range. Stabilization is reached when three successive temperature readings taken 2 min apart do not differ by more than 1 °C.
- d) Set the appropriate voltage to measure the standby current while the DUT is in the chamber.
- e) All combinations of ground and input or output terminals shall be measured one at a time; all terminals not involved in the measurement shall be left open-circuited. Select one combination to begin the test.
- f) Increase the temperature of the environmental chamber to the highest value of the operating temperature range. Stabilization is reached when three successive temperature readings taken 2 min apart do not differ by more than 1 °C.
- g) Repeat step c) and step d).
- h) Remove the DUT from the environmental chamber, and leave it for an hour at room temperature.
- i) Repeat step c) and step d).

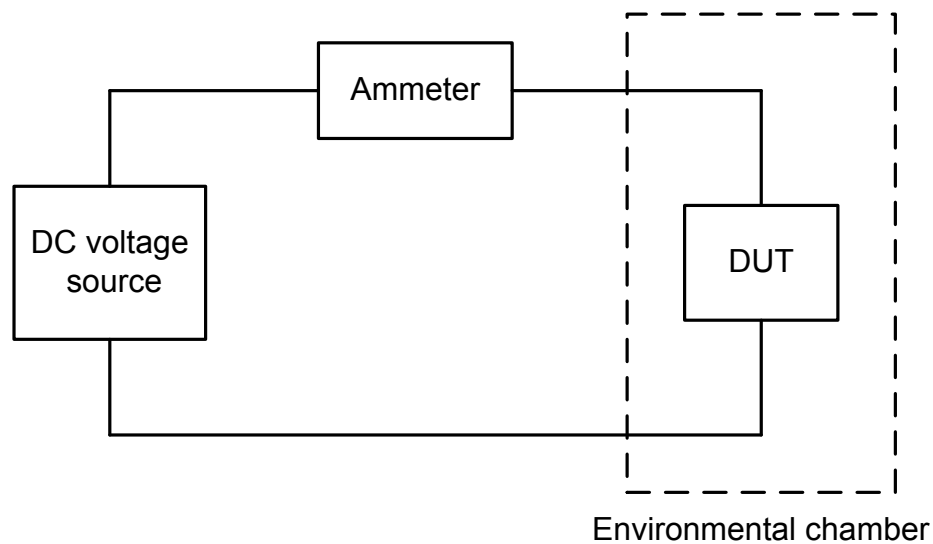


Figure 10—Test configurations for standby current

7.6.6 Alternative methods

None.

7.6.7 Suggested test data

Enter data in a table such as Table 2.

Table 2—Test data example table

Data categories	Temperature of the DUT		
	Lowest surge protector operating temperature	Room temperature	Highest surge protector operating temperature
Temperature °C			
Volts applied			
Current, microamps			

7.6.8 Requirements

None—this a characteristic.

7.6.9 Comment

None.

7.7 DC ringing current

7.7.1 Background

This test applies to surge protectors used on POTS lines. In a POTS, the exchange normally detects that a telephone has been picked up (gone off hook) by detecting the dc load of the phone drawing current in the (metallic) battery powering loop. If the current drawn by the phone exceeds a certain value, typically 4 mA to 10 mA, the exchange switches to a dialing or communications mode.

When the exchange rings a telephone, the exchange provides a ringing signal consisting of a dc voltage source to detect an off-hook condition and a cadenced ac voltage source for the telephone ringer or bell (UL 60950-1 [B40]). The ac voltage cadencing (ac voltage on to off) ratio varies around the world; typically the United States uses a 2 s ringing signal followed by 4 s of silence. The ac frequency is usually in the 25 Hz region with a ringing voltage amplitude of no more than 300 V peak to peak and 200 V peak to ground (UL 60950-1).

If the nonlinear limiting characteristic of a surge protector asymmetrically clips the ringing signal, a dc component is produced that might be sufficient to cause false off-hook detection.

7.7.2 Purpose

This test determines the value of dc produced by a surge protector when a specified POTS ringing signal is applied.

7.7.3 Equipment

The test equipment includes following:

- a) Ring generator: The ring generator consists of a dc voltage source and an ac source. For test purposes, an ac power frequency source is allowed and fed via an isolating transformer. The generator source resistance is usually equal to the line transmission impedance and equally split between the wires. In Figure 7, the two 300 Ω resistors form the ring generator source resistance of 600 Ω .

Figure 7 shows the test circuit for a ground-backed ring generator. The dc and ac voltage sources are connected in series and to one wire via a 300 Ω source resistance. The second wire of the pair is connected to ground via a 300 Ω source resistance.

Figure 8 shows the dc and ac voltage source arrangements for the ground-backed and balanced generator configurations. For ground-backed ringing, the dc voltage source is connected to one wire via a 300 Ω source resistance, and the ac source voltage is connected to the other wire via a 300 Ω source resistance. For balanced ringing, the dc voltage source and 50% of the ac source voltage are connected in series and to one wire via a 300 Ω source resistance, and the other 50% of the ac source voltage is connected to the other wire via a 300 Ω source resistance.

- b) DC and ac meters

7.7.4 Protector states subject to test

Protected port open circuit.

7.7.5 Procedures

Figure 11 shows the test circuit. See 7.7.6 for alternative ring generator descriptions.

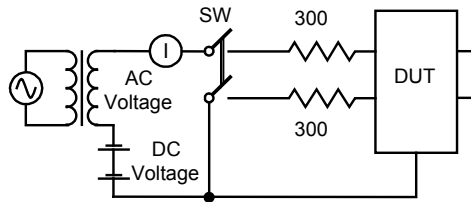


Figure 11—DC ringing current test circuit with a battery-backed ring generator

The procedures for testing dc ringing current are as follows:

- Set dc and ac voltage sources to the required levels. Normally, the dc voltage source is an adjustable power supply, and the ac source is adjusted in value by using transformer taps or an isolated variable transformer.
- Close ganged switch, SW.
- Record the value of current registered by meter I.
- Open ganged switch, SW.
- Reverse the wire connections to the surge protector.
- Repeat step b) to step d).
- Adjust the power supply voltage, and record the current values for the actual generator cadence value (see 7.7.3a).
- Compare the calculated current values with minimum value of ring trip current for the system under consideration.
- Record a pass if the minimum value of ring trip current is higher than any of the calculated current values.

7.7.6 Alternative generators

Not all ring generators use a battery-backed configuration (for example, see Figure 11). Figure 12 shows two alternative configurations: ground-backed and balanced (see 7.7.3a)).

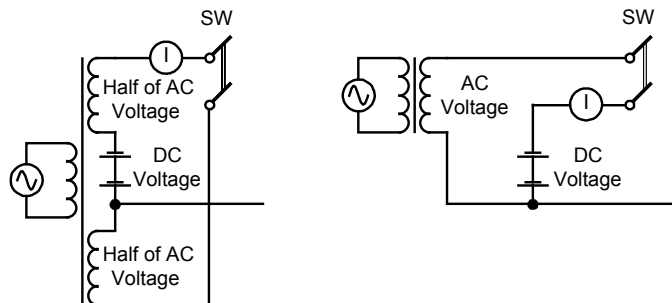


Figure 12—Balanced and ground-backed ring generators

7.7.7 Suggested test data

This standard recommends collecting the following test data:

- a) Ring generator configuration
- b) DC voltage level
- c) AC voltage level
- d) Generator source resistance
- e) Surge protector identification details
- f) Recorded values of dc ringing current
- g) Values of dc ringing current adjusted for cadence value (see 7.7.3a))
- h) Minimum value of ring trip current for the system under consideration
- i) Pass/Fail result

7.7.8 Requirements

None—this is a characteristic.

7.7.9 Comments

The following comments apply:

- a) Conformance by design. This test is fulfilled if the minimum values of surge protector working voltage over the ambient temperature range and for the different protection modes are higher than those of the ring generator.
- b) Ambient temperature. If the surge protector uses temperature-sensitive limiting components, such as thyristors or breakdown diodes, the surge protector limiting voltage is lowest at the lowest ambient temperature. For such surge protectors, the test shall be done at the lowest value of ambient temperature.

7.8 Distortion

7.8.1 Background

Distortion is known to be caused by nonlinear elements in a circuit. These elements have voltage or current responses that are typically represented by a power series. If the signal is sinusoidal (e.g., $\sin(\omega t)$), this power series results in terms like $\sin^2(\omega t)$, $\sin^3(\omega t)$, ..., etc. Using trigonometric identities, $\sin^2(\omega t)$ has a $\sin(2\omega t)$ term, $\sin^3(\omega t)$ has a $\sin(3\omega t)$ term, etc. These harmonics are known to degrade transmission in DSL systems using the common discrete multitone modulation scheme.

Distortion, often measured as total harmonic distortion (THD), is measured as a ratio of the power in the harmonics to the power in the fundamental. The formula used for this evaluation is shown in Equation (1).

$$\%THD = \frac{100}{E_f} \sqrt{\sum_1^N E_h^2} \quad (1)$$

where

$\%THD$ is total harmonic distortion as a percentage
 E_h is voltage of harmonic h
 E_f is voltage of the fundamental frequency
 N is number of harmonics considered

The signal source generally has harmonics in it; therefore, the THD of the signal generator needs to be measured and subtracted from the measurements on the protector. Calling E_s the voltage of signal generator harmonics and using the first 10 harmonics of the signal, the %THD of the protector ($\%THD_p$) is shown in Equation (2).

$$\%THD_p = \frac{100}{E_f} \left[\sqrt{\sum_1^{10} E_h^2 - \sum_1^{10} E_s^2} \right] \quad (2)$$

7.8.2 Purpose

The purpose of this test is to verify that the surge protector does not cause undesirable signal distortion.

7.8.3 Equipment

The test equipment includes following:

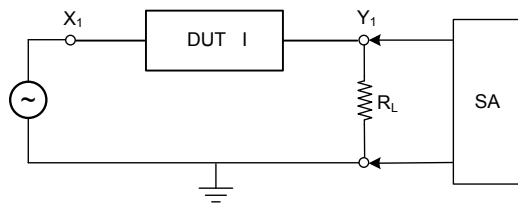
- a) Spectrum analyzer with a frequency range of 100 Hz to 300 MHz
- b) High-impedance differential probe
- c) Signal generator with a range of 100 Hz to 30 MHz and a voltage capability of 30 V peak to peak
- d) Optional: Amplifier to boost the output of the signal generator to the specified voltage and current
- e) Attenuators as appropriate
- f) A load resistance R_L equal to 100 Ω for a universal protector or to 600 Ω if the application is POTS only

7.8.4 Protector states subject to test

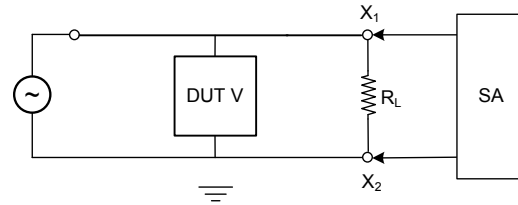
The protector is to be tested as follows:

- a) Terminal pairs as specified in Figure 13
- b) Biased
- c) Unbiased

Two-Terminal Devices

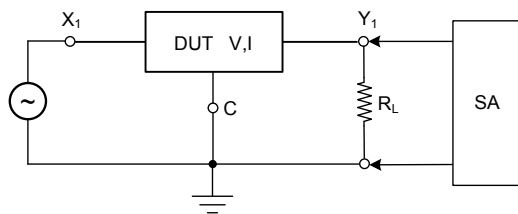


Setup 2A (unbalanced)

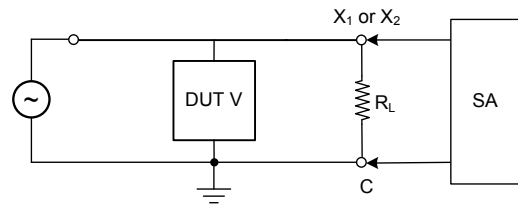


Setup 2B (balanced)

Three-Terminal Devices

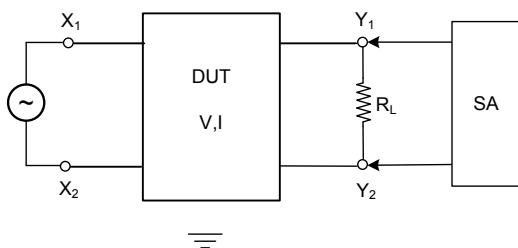


Setup 3A (unbalanced)



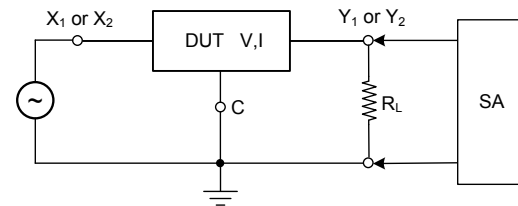
Setup 3B (unbalanced)

Four-Terminal Device



Setup 4 (balanced)

Five-Terminal Device



Setup 5 (unbalanced)

X_1, X_2, Y_1, Y_2 is signal terminals
C is common terminal
 R_L is noninductive resistors
V, I or (V,I) is DUT
SA is spectrum analyzer

Figure 13—Test circuits for distortion measurement

7.8.5 Procedures

The procedures for testing distortion are as follows:

- Select a test setup from Figure 13 appropriate to the protector being tested (see test circuits in Figure 1).
- Connect the R_L to the output of the DUT, as shown in the selected setup of Figure 13.
- Connect the differential probes to the spectrum analyzer.
- Connect the differential probes to measure the voltage across R_L .

- e) Connect the signal generator to the input of the DUT, as shown in the selected setup of Figure 13.
NOTE—If the signal generator is not capable of supplying the 30 V peak-to-peak signal specified in step i), then an amplifier is required to boost the input signal to the required levels.
- f) Place the DUT in an environmental chamber, and allow the temperature of the chamber to stabilize at the lowest rated temperature of the DUT.
- g) Set the bias to zero.
- h) Set the frequency of the signal generator to 100 Hz.
- i) Set the signal generator output to 30 V peak to peak.
- j) Use the spectrum analyzer to measure the amplitude of the fundamental and the first 10 harmonics, E_h .
- k) Set the frequency of the signal generator to the next frequency in the progression 1, 3.16, 10, e.g., 10 kHz, 31.6 kHz, 100 kHz.
- l) Use the spectrum analyzer to measure the amplitude of the fundamental and the first 10 harmonics, E_h .
- m) Repeat step k) and step l) until the progression reaches 30 MHz.
- n) Repeat step g) to step m), but with the environmental chamber set at the highest rated temperature of the DUT.
- o) If the SPD shown in test circuit 3B or test circuit 5 in Figure 13 is being tested, select a combination of input and output that has not been tested, and repeat step b) to step n), until all possible combinations have been tested. The SPD shown in test circuit 3B needs to be tested in both Setup 2B and Setup 3B (Figure 13). The SPD shown in test circuit 5 needs to be tested in both Setup 4 and Setup 5 (Figure 13).
- p) If the biased state is to be tested, apply the specified bias and repeat step a) to step o). Suggested methods of applying bias are shown in Figure 14 and Figure 15.
- q) To measure the harmonic distortion of the generator, remove the DUT, and connect the spectrum analyzer and the load R_L directly to the signal generator (or signal generator plus amplifier) output. If a bias injection circuit is used, connect the spectrum analyzer and R_L to the output of the bias injection circuit (terminals X_1 or X_2 in Figure 14 and Figure 15).
- r) Set the bias to zero.
- s) Set the frequency of the signal generator to 100 Hz.
- t) Set the signal generator output to 30 V peak to peak.
- u) Use the spectrum analyzer to measure the amplitude of the fundamental and the first 10 harmonics, E_s .
- v) Set the frequency of the signal generator to the next frequency in the progression 1, 3.16, 10, e.g., 10 kHz, 31.6 kHz, 100 kHz.
- w) Use the spectrum analyzer to measure the amplitude of the fundamental and the first 10 harmonics, E_s .
- x) Repeat step v) and step w) until the progression reaches 30 MHz.
- y) If the biased state is to be tested, apply the specified bias (see step o)) and repeat step s) to step x).

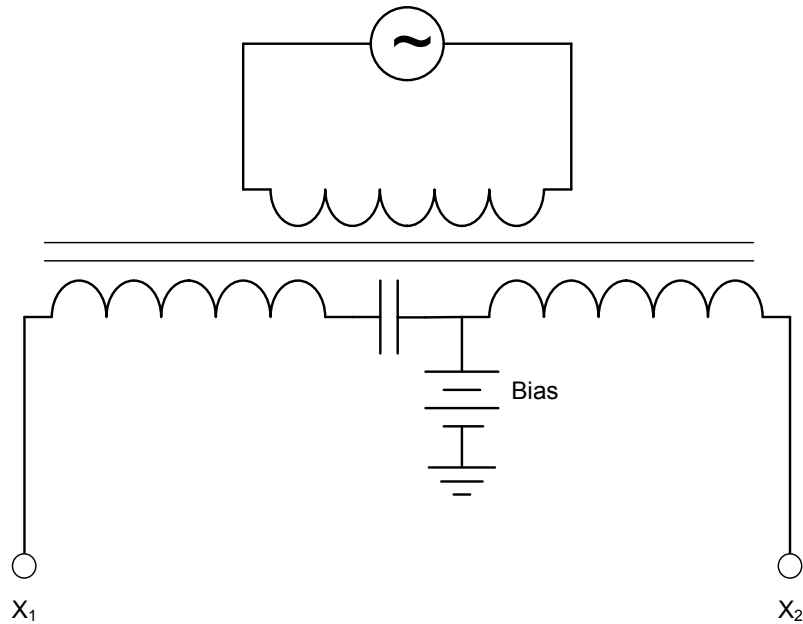


Figure 14—Bias injection circuit for balanced lines (2B or 4 in Figure 13)

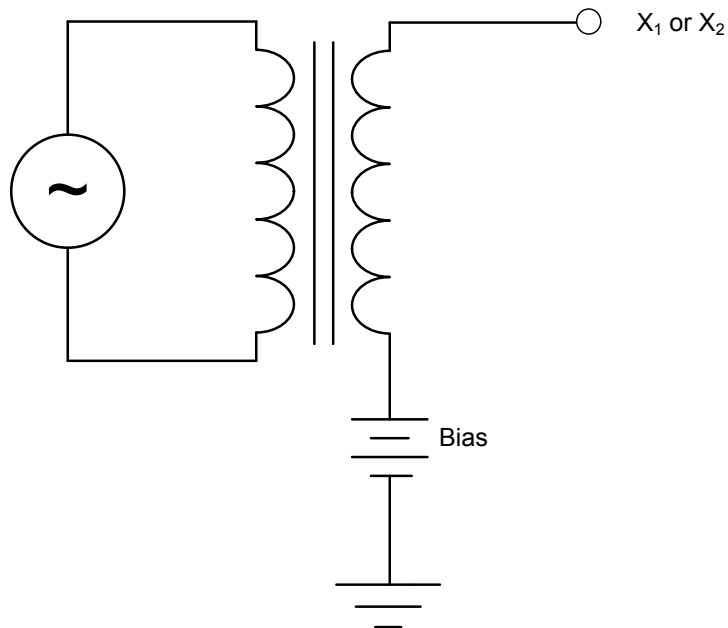


Figure 15—Bias injection circuit for unbalanced lines (2A, 3A, 3B, or F in Figure 13)

7.8.6 Alternative methods

None.

7.8.7 Suggested test data

This standard recommends collecting the following test data:

- a) Equipment state(s).
- b) Leads tested.
- c) Calculate the THDp for each case tested, using Equation (2) (7.8.1). The bias or no bias data of step q) to step y) in 7.8.5 shall be paired with the corresponding bias or no bias data from step f) to step p) (7.8.5).
- d) Present the THDp as calculated in step c) in this subclause as a plot of THDp versus frequency

7.8.8 Requirements

None—this is a characteristic.

7.8.9 Comments

The generation of signal harmonics is mostly a concern of digital systems. Digital systems have various means of dealing with corrupted signals. But in general what they do is scan the spectrum they use, and assign frequencies for use based on the amount of interference they encounter. The spectral response of the system is determined by the installation, and varies from time to time, and place to place. So the harmonics generated by a protector in a specific frequency band might be significant. Thus a test for the impact of specific harmonics on the performance of a system is really a system test and not a protector test. But a THD test could have value.

The THD method defined here is meant to provide a basis for comparing protectors. In that regard the THD versus frequency plot could be used as a rough guide to estimate the impact of available protectors on the performance of a specific system. But the actual impact needs to be determined in a system test.

7.9 Transmission properties: insertion loss, return loss, phase shift

7.9.1 Background

Insertion loss, return loss, and phase shift are important characteristics of a protector, as they might significantly affect the performance of a system.

Insertion loss measures the amount of signal power lost in traversing a DUT. It is measured in the forward direction (input to output), and in the reverse direction (output to input). The forward and reverse insertion losses might be the same, but are not necessarily so. Every component of the system potentially reduces this signal power. In measuring insertion loss, consider that the protector might be used on a line that operates at high frequency. For example, frequency components might exist for asymmetric digital subscriber line (ADSL) at up to 10 MHz, very high data rate digital subscriber line (VDSL) at up to 30 MHz, and versions of Ethernet at over 100 MHz.

Insertion loss is influenced by many factors. For example, if the characteristic impedance of the measuring system and the test object are not the same, then energy reflected by the impedance mismatch (measured as return loss) might cause the measured value of insertion loss to appear to be higher than it actually is. If the element causing insertion loss is other than a pure resistance (over the range of test frequencies), insertion loss depends on frequency. If the test object is nonlinear, a potential applied to it (bias) might introduce a

notable change the insertion loss. Placing the test object in a magnetic field might have a similar effect. The insertion loss might be sensitive to environmental conditions such as temperature and humidity.

Insertion loss is an important determinant of system performance. In some cases, insertion loss is beneficial: a minimum insertion loss is required to prevent “singing” on POTS and might be required for the stability of line-drive amplifiers. But generally, insertion loss is detrimental, and often system specifications, such as IEEE Std 802.3™-2005 [B18] for Ethernet, set a maximum value.

Insertion loss is a complex number, the real part of which increases with frequency for passive components. An important passive component is wire, in which insertion loss is proportional to the product of frequency and distance. Therefore, for a given insertion loss, higher operating frequencies are coupled with shorter distance. For example, DSL systems are often characterized by families of curves that show the range versus frequency (in form of data rate) for a given insertion loss.

The system budget for insertion loss is allocated among the components that make up the system, including the wire (in most systems) and the protectors. Therefore, if a protector has a high insertion loss, less loss budget is left for the wire and other components. Considering the characteristics of wire, the impact of protector insertion loss on system performance is a reduced data rate, reduced range, or both. For more information, see Chrysanthou et al. [B5].

Return loss measures the amount of power reflected from the DUT toward the source (forward return loss), or from the DUT toward the load (reverse return loss). The reflections are due to a difference between the impedance looking into the input of the DUT and the characteristic impedance of the source or between the impedance looking into the output of the DUT and the characteristic impedance of the load (impedance mismatch).

Phase shift is the difference in phase of the signal at the input and the output of the DUT.

During testing, it is important to adjust the voltage level and frequency of the signal as required for the application. Some applications provide a bias voltage, bias current, or both to the load and, therefore, to the surge protector. The magnitude of any applied bias voltage or current might contribute to additional return loss.

7.9.2 Purpose

The purpose of this test is to measure the insertion loss, return loss, and phase shift of a protector.

7.9.3 Equipment

The test equipment includes following:

- a) Network analyzer capable of making S-parameter measurements over the frequency range for which the protector is rated
- b) Baluns (50 Ω unbalanced to 100 Ω balanced, or as appropriate)⁴
- c) Precision load (100 Ω for a twisted-pair cable surge protector; 50 or 75 Ω for a coax protector)

⁴ An example balun is the North Hills Model 0300BB, which is 50 Ω unbalanced to 100 Ω balanced, for frequencies from 100 kHz to 100 MHz. This information is given for the convenience of the users of this standard and does not constitute an endorsement by the IEEE of this product. Equivalent products are permitted if they have been shown to give the same results.

7.9.4 Protector states subject to test

The protector is to be tested as follows:

- a) No bias applied
- b) Bias applied

7.9.5 Procedures

7.9.5.1 Twisted-pair cable surge protector, no bias

These units have a balanced input and output (tip and ring) and are generally evaluated for use in a system with 100 Ω characteristic impedance.

The procedures for testing a twisted-pair cable surge protector, no bias, are as follows:

- a) The basic measurement setup is shown in Figure 16. The coaxial cables are precision assemblies that generally come with the network analyzer. The baluns are needed to convert the 50 Ω coaxial interface of the network analyzer to the tip-ring-ground configuration of the protector.
- b) Connect the network analyzer to the baluns, using the precision coaxial cable assemblies.
- c) Set the network analyzer to scan the desired frequency range. The default range is 100 kHz to 100 MHz. A log frequency scan shall be used.
- d) Begin the full two-port error calibration, as described in the instruction manual for the network analyzer. Typically the calibration starts by measuring a short, open, and precision 100 Ω load on TP1. The measurements are stored. Calibration then continues with the same short, open and precision 100 Ω load on TP2. These measurements are also stored. An alternative to the precision 100 Ω load is a noninductive resistor whose value has been measured to within a range of 99.9 Ω to 100.1 Ω .
- e) To finish calibration, short lengths of wire are connected from the tip of TP1 to the tip of TP2, the ring of TP1 to the ring of TP2, and the ground of TP1 to the ground of TP2. The forward and reverse transmission characteristics are then measured and stored.
- f) Connect the input tip, ring, and ground of the twisted-pair cable surge protector to the corresponding terminals of TP1.
- g) Connect the output tip, ring, and ground of the twisted-pair cable surge protector to the corresponding terminals of TP2.
- h) Measure and store the forward and reverse S-parameters S_{11} , S_{21} , S_{12} , and S_{22} .

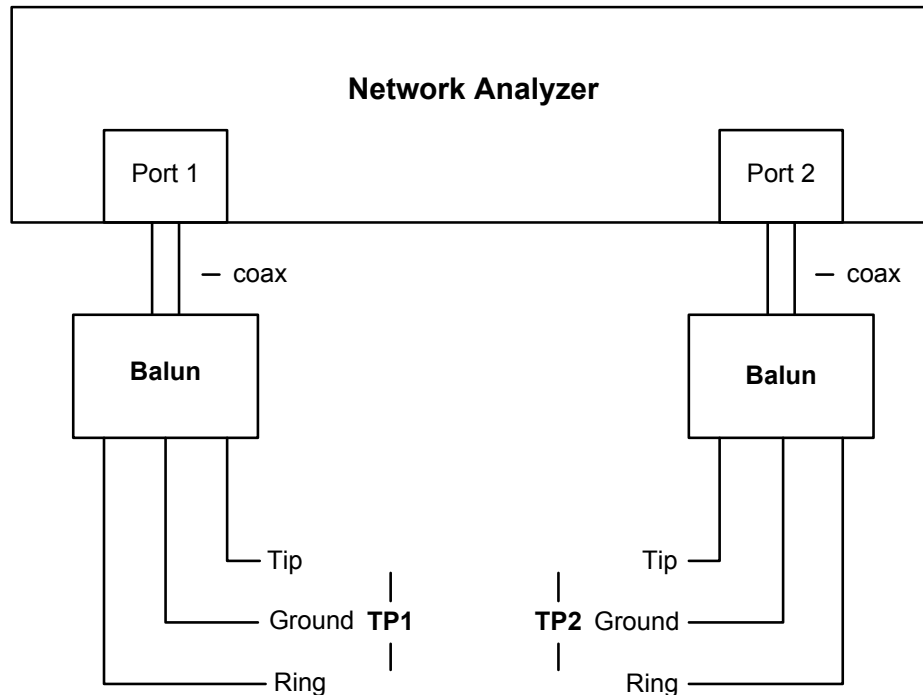


Figure 16—Test setup for measuring a twisted-pair cable surge protector
(The input and output of the surge protector are connected to TP1 and TP2, respectively.)

7.9.5.2 Twisted-pair cable surge protector, biased

These units have a balanced input and output (tip and ring), and are generally evaluated for use in a system with 100 Ω characteristic impedance.

The procedures for testing a twisted-pair cable surge protector, biased, are as follows:

- The basic measurement setup is shown in Figure 16, except that the balun on port 1 is replaced with a bias injection circuit, an example of which is shown in Figure 17. The coaxial cables are precision assemblies that generally come with the network analyzer. The baluns are needed to convert the 50 Ω coaxial interface of the network analyzer to the tip-ring-ground configuration of the protector.
- Connect port 1 of network analyzer to the bias injection circuit, an example of which is shown in Figure 17, using the precision coaxial cable assemblies. Connect port 2 to the balun.
- Apply bias.
- Set the network analyzer to scan the desired frequency range. The default range is 100 kHz to 100 MHz. A log frequency scan shall be used.
- Begin the full two-port error calibration, as described in the instruction manual for the network analyzer. Typically, the calibration starts by measuring a short, open, and precision 100 Ω load on TP1. The measurements are stored. Calibration then continues with the same short, open, and precision 100 Ω load on TP2. These measurements are also stored. An alternative to the precision 100 Ω load is a noninductive resistor whose value has been measured to within a range of 99.9 Ω to 100.1 Ω .
- To finish calibration, short lengths of wire are connected from the tip of TP1 to the tip of TP2, the ring of TP1 to the ring of TP2, and the ground of TP1 to the ground of TP2. The forward and reverse transmission characteristics are then measured and stored.

- g) Connect the input tip, ring, and ground of the twisted-pair cable surge protector to the corresponding terminals of TP1.
- h) Connect the output tip, ring, and ground of the twisted-pair cable surge protector to the corresponding terminals of TP2.
- i) Measure and store the forward and reverse S-parameters S_{11} , S_{21} , S_{12} , and S_{22} .

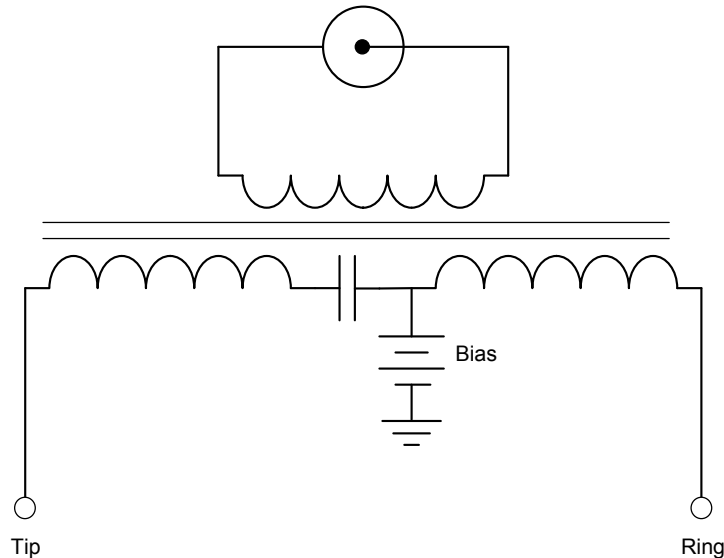


Figure 17—Replacement circuit for the input or output balun in Figure 16 when measuring the twisted-pair cable surge protector under bias

7.9.5.3 Coaxial or unbalanced protectors, no bias

Coaxial protectors are generally designed for either 50 Ω or 75 Ω systems. Unbalanced protectors are not designed for a specific impedance, but 100 Ω is representative.

Network analyzers typically have a 50 Ω characteristic impedance, although network analyzers with a 75 Ω characteristic impedance are available. If a network analyzer with a 50 (or 75) Ω characteristic impedance is used to measure a protector designed for some other impedance, a lossless impedance-translating adaptor (basically a transformer) is necessary.

The procedures for testing a coaxial or unbalanced protector, no bias, are as follows:

- a) The basic measurement setup is shown in Figure 18. The coaxial cables are precision assemblies that generally come with the network analyzer.
- b) Set the network analyzer to scan the desired frequency range. The default range is 100 kHz to 100 MHz. A log frequency scan shall be used.
- c) Begin the full two-port error calibration, as described in the instruction manual for the network analyzer. Typically the calibration starts by measuring a precision short, open, and load on TP1. The measurements are stored. Calibration then continues with the same precision short, open, and load on TP2. These measurements are also stored. The precision load shall match the characteristic impedance of the system for which the protector is intended. A precision open, short, and load are generally part of the calibration kit for the network analyzer and are generally used if the characteristic impedance of the protector is the same as that of the network analyzer.

- d) To finish calibration, a “through” (a near zero length of rigid coax, with connectors on both ends) is connected from TP1 to TP2. The forward and reverse transmission characteristics are then measured and stored.
- e) Connect the input of the coaxial protector to TP1.
- f) Connect the output of the coaxial protector to TP2.
- g) Set the network analyzer to measure S-parameters in polar form (magnitude and phase).
- h) Start the frequency scan to measure and store the forward and reverse S-parameters S_{11} , S_{21} , S_{12} , and S_{22} .

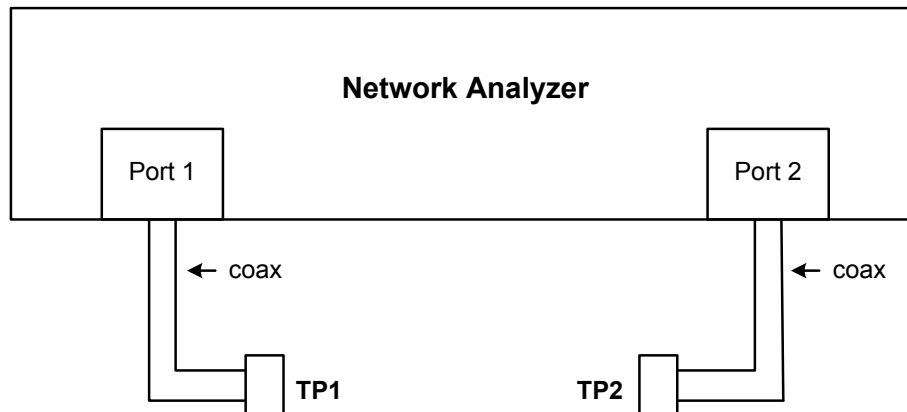


Figure 18—Test setup for measuring a coaxial or unbalanced protector
(The input and output of the coaxial protector are connected to TP1 and TP2, respectively.)

7.9.5.4 Coaxial or unbalanced protectors, biased

Coaxial protectors are generally designed for either 50 Ω or 75 Ω systems. Unbalanced protectors are not designed for a specific impedance, but 100 Ω is representative.

Network analyzers typically have a 50 Ω characteristic impedance, although network analyzers with a 75 Ω characteristic impedance are available. If a network analyzer with a 50 (or 75) Ω characteristic impedance is used to measure a protector designed for some other impedance, the turns ratio of the transformer in the example bias injection circuit of Figure 18 is selected to provide the required impedance match.

The procedures for testing a coaxial or unbalanced protector, biased, are as follows:

- a) The basic measurement setup is shown in Figure 18, except that TP1 is connected to a bias injection circuit, an example of which is shown in Figure 19. The coaxial cables are precision assemblies that generally come with the network analyzer.
- b) Apply bias.
- c) Set the network analyzer to scan the desired frequency range. The default range is 100 kHz to 100 MHz. A log frequency scan shall be used.
- d) Begin the full two-port error calibration, as described in the instruction manual for the network analyzer. Typically the calibration starts by measuring a precision short, open, and load on TP1-biased. The measurements are stored. Calibration then continues with the same precision short, open, and load on TP2. These measurements are also stored. The precision load shall match the characteristic impedance of the system for which the protector is intended. A precision open, short, and load are generally part of the calibration kit for the network analyzer and are generally used if the characteristic impedance of the protector is the same as that of the network analyzer.