IEEE Recommended Practice for Electronic Power Subsystems: Parameter Definitions, Test Conditions, and Test Methods

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Abstract: This recommended practice defines many common parameters for ac-dc and dc-dc electronic power distribution components and subsystems. This enables electronic system engineers, manufacturers, and researchers to speak with a common language and hence facilitates effective and efficient communications. Furthermore, implementation of a common specification language will allow the power electronics industry as well as the user communities, including government system developers, to acquire cost- and time-effective electronic power subsystems with significantly enhanced interchangeability.
Keywords: electronic power distribution, power subsystem, power supply, specification, specification language

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Introduction

(This introduction is not part of IEEE Std 1515-2000, IEEE Recommended Practice for Electronic Power Subsystems: Parameter Definitions, Test Conditions, and Test Methods.)

Electronic power subsystems are integral parts of any electronic system. They perform the tasks of power processing, management, and distribution. Clear definition and precise understanding of the terms (or terminology) used in a specification are crucial to successful and cost-effective development programs.

This recommended practice attempts to define a parameter specification language for common parameters used to describe ac-dc and dc-dc electronic power distribution components and subsystems. This parameter specification language consists of test parameter definitions, test methods, and test conditions.

In the past two decades, the power electronics industry has experienced tremendous success and growth. For instance, switched-mode power supplies now occupy 95% of the market (compared to only 12% in the 1970s) and switched-mode motor devices are replacing traditional motor drives in virtually all applications. As with many other maturing technologies, unprecedented growth creates a problem that hinders further success and growth. That problem is the lack of a common parameter specification language.

Lack of a common parameter specification language creates confusion among industry manufacturers and systems developers. Different manufacturers and subsystem developers use similar terms to indicate different performance. This confusion not only hinders effective communication and the interchangeability among products, but also increases the cost and time for both development and procurement. This is particularly true for high-end customer designs, such as those intended for military and aerospace applications.

A common specification language will allow the power electronics industry and the government system developers to acquire cost- and time-effective electronic power subsystems with significantly enhanced interchangeability. This recommended practice was written with test methods that include test equipment characteristics rather than a requirement for specific test equipment. Implementation of this recommended practice will allow the subsystem designer to make performance comparisons among the contending electronic power distribution subsystem components that have been specified to the same criteria. Products will have been consistently specified and performance tested; thereby, minimizing buyer confidence testing.

The evaluation of competing products from different manufacturers for intra-operability will be a less expensive effort. The component developer who adheres to this recommended practice will ensure that customers can unambiguously understand their product specifications, increasing customer confidence and satisfaction.

This recommended practice collects, in a single document, most of the parameters used in specifying a power electronic product. As such, it will be useful both for systems engineers (who specify requirements for products) and for designers (who qualify their products to the specifications). This will also be useful for engineers and graduate students who are entering the field of power electronics, since many of the parameters are seldom discussed fully in university courses or in professional educational seminars.

Participants

The preparation of this recommended practice was accomplished by the IEEE Working Group on Electronic Power Specification (P1515). At the time of its completion, the Working Group consisted of the following members:

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1. Overview

1.1 Scope

This recommended practice is written to provide a standard specification language for common parameters used to characterize the performance of electronic power distribution subsystem elements. Specifically, these are parameters relating to the integration of power supplies into electronic power distribution subsystems. The specification language consists of parameter definitions, test methods, and test conditions for the parameters. The specification language is meant to be used by both electronic power subsystem developers and designers and component manufacturers to insure unambiguous communication.

The specification language is intended to be applied to ac-dc and dc-dc electronic power distribution subsystems. The range of power subsystems includes single-phase and three-phase systems, with power levels from a fraction of a watt to 20 kW. The voltage range is from a few volts to 600 V, at a frequency or frequencies of dc –1 kHz. However, this recommended practice can be used outside the range.

1.2 Purpose

The purpose of this recommended practice is to standardize a specification language, not to specify or enforce "a standard specification." A specification written in compliance with this language will ensure easy and precise understanding between manufacturers and users without, in any way, limiting manufacturers' ability to present features that are special to their products.

Efforts have been made to include as many common parameters as possible, but this recommended practice is by no means meant to be all-inclusive.

1.3 Organization of the recommended practice

This recommended practice is organized into five clauses and two annexes. Clause 1 is an overview of the scope, purpose, and organization of the document. Clause 2 lists all the references that should be consulted when using this recommended practice. Clause 3 identifies the terms and acronyms that are used throughout the text of this recommended practice. Clause 4 presents parameters related to electrical performance of a power distribution subsystems, including parameter definitions, test methods, and test conditions. Each test method is the recommended method of testing a given parameter, and the test condition defines the range of values for test variables that are essential to the test.

Clause 5 collects common parameters related to reliability, maintainability, environmental parameters, and mechanical aspects of a power subsystem. Reliability and environmental parameters are crucial for a power subsystem to operate reliably, but they are out of the realm of electrical engineering. Hence, only definitions are given, together with relevant references to military standards. It is felt that this will be sufficient for circuit designs and will provide the necessary leads for further investigation. Mechanical parameters are given as a simple list of definitions for completeness.

Annex A is a list of additional readings that one may find helpful in understanding this recommended practice. Finally, Annex B provides a rather detailed discussion on "do's and don'ts" when it comes to measuring data. Many people may find it helpful.

2. References

This recommended practice shall be used in conjunction with the following publications. If the following publications are superseded by an approved revision, the revision shall apply.

ASTM E595-93 (1999), Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment.[1]

IEC 60950:1999, Safety of Information and Technical Equipment Including Electrical Business Equipment.[2]

IEC 61000-3-2:1998, Electromagnetic compatibility (EMC)—Part 3-2—Limits for harmonic current emissions.

MIL-HBK-217, Reliability Prediction of Electrical Equipment, 1991.[3]

MIL-STD-139, Interface Standard for Shipboard Systems, Section 300A: Electric Power, Alternating Current (Metric), 1992.

MIL-STD 462D, Test Method Standard for Measurement of Electromagnetic Interference Characteristics, 1999.

MIL-STD-704E, Aircraft Electric Power Characteristics, 1991.

MIL-STD-810E, Environmental Engineering Considerations and Laboratory Tests, 1995.

[1]ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (http://www.astm.org/).

[2]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[3]MIL publications are available from Customer Service, Defense Printing Service, 700 Robbins Ave., Bldg. 4D, Philadelphia, PA 19111-5094.

MIL-STD-883E, Test Method Standard for Microcircuits, 1999.

MIL-STD-1540D, Test Requirements for Launch, Upper-Stage, and Space Vehicles, 1999.

RTCA DO-160D-1997, Environmental Conditions and Test Procedures for Airborne Equipment.[4]

UL 1950-1997, Information Technology Equipment Including Electrical Business Equipment.[5]

3. Definition of terms and acronyms

The terms defined here can be grouped into three categories—terms for test equipment characteristics, terms to be used in this document, and acronyms and abbreviations.

Definitions of the characteristics of the test equipment, which influence desired measurements, are solely included to convey the expectations of the test equipment for consistent measurements, without detailing the specific test equipment.

Terms collected here are not all inclusive of the terms used to describe an electronic power distribution subsystem. Additional terms can be found in Handbook of Standardized Terminology for Power Sources Industry published by the Power Sources Manufactures Association (PSMA).

Acronyms and abbreviations frequently encountered are also included for easy reference.

3.1 ac signal: A time-varying signal whose polarity varies with a period of time *T*, and whose average value is zero.

3.2 active or real power: The average power consumed by a unit. For a two terminal device with current and voltage waveforms *i(t)* and *v(t)* which are periodic *T*, the real or active power *P* is

$$P = \frac{1}{T}\int_0^T v(t)i(t)dt$$

3.3 ambient temperature, T_a: Temperature of the ambient air immediately surrounding the unit under test (UUT).

3.4 BIT: The abbreviation for built-in-test.

3.5 composite signal: A signal that is composed of both ac and dc components.

3.6 current probe(s): A current probe is used to measure dc, ac, or composite currents. DC current probes should measure dc and composite currents to within ± 1% with a probe calibrator and ± 3% without the calibrator. AC current probes should measure ac currents to within ± 5%. This accuracy should be maintained up to the worst case expected peak current. Proper bandwidth should also be ensured.

3.7 dB: The abbreviation for decibels.

[4]RTCA standards are available from the Sales Department at 1140 Connecticut Ave., NW, Suite 1020, Washington, DC 20038, USA (http://www.rtca.net/).

[5]UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).

3.8 crest factor (cf): The ratio of the peak value to the rms value of an ac waveform measured under steady-state conditions. It is unit-less, and the ratio for a pure sine wave is equal to $\sqrt{2}$.

$$cf = \frac{V_{in,pk}}{V_{in,rms}}$$

where

V_{in} is the voltage at the user input terminals.

3.9 dc signal: A signal whose polarity and amplitude do not vary with time.

3.10 digital multimeter (DMM): A DMM is used to measure electrical quantities such as dc or ac voltage, ac or dc current, resistance, etc. The input resistance/impedance should be at least 1000 times the resistance/impedance of the circuit being measured.

3.11 distortion (current or voltage): The rms value of the ac signal exclusive of the fundamental component. It may include various harmonic and inter-harmonic components. In a dc system, distortion is the rms value of the ac (ripple) component on the (fundamental) dc level.
Harmonics are sinusoidal distortion components that occur at integer multiples of the fundamental frequency. Inter-harmonics are distortion components that occur at non-integer multiples of the fundamental frequency.

3.12 distortion factor (current or voltage): The ratio of the rms value of an ac signal, exclusive of the fundamental, to the rms value of the fundamental component of the ac signal, expressed as a percent. For example, voltage distortion factor may be expressed as:

$$D_V = \sqrt{\left(\frac{V_2}{V_1}\right)^2 + \left(\frac{V_3}{V_1}\right)^2 + \ldots \left(\frac{V_n}{V_1}\right)^2}$$

with

$$f_1 < f_n \le f_{max}$$

where

D_V is voltage distortion factor in percent,
V_1 is rms value of the fundamental frequency component,
V_n is rms value of an individual non-fundamental frequency component,
f_1 is the fundamental frequency,
f_n is frequency of other individual waveform components, including harmonics and inter-harmonics (non-integral multiples of the fundamental),
f_{max} is the maximum frequency of measurement.

3.13 EMI: The abbreviation for electromagnetic interference. EMI is any disturbance that interrupts, obstructs, or otherwise impairs the performance of electronic equipment.

3.14 EMC: The abbreviation for Electromagnetic Compatibility

3.15 external: Not associated with the equipment design.

3.16 fundamental frequency: The frequency of the primary power-producing component of a periodic waveform supplied by the generation system (component of order 1 of the waveform's Fourier series representation).

3.17 gain margin: The reciprocal of the gain of a control loop (expressed in dB) at the frequency for which there is 180° of phase shift around the control loop.

3.18 I_{max} output: The maximum allowable output load current over which the unit under test (UUT) output voltage is required to be maintained within the specified operational limits. I_{max} is also known as the rated current.

3.19 I_{avg} output: The average output load current at which to test the unit under test (UUT), $(I_{min} + I_{max})/2$.

3.20 I_{min} output: The minimum allowable output load current over which the unit under test (UUT) output voltage is required to be maintained within the specified operational limits.

3.21 I_{nom} output: The nominal load current for which the unit under test (UUT) output voltage is required to be maintained within the specified operational limits; the value should be between the minimum and maximum values.

3.22 line impedance stabilization network (LISN): A LISN is used to provide a standard connection from the power source to the unit under test (UUT) for EMI measurements. A LISN has input (power source), output (to UUT), signal output port, and a chassis ground connection. The signal output port must be terminated with a 50 ohm load when no measurement instrumentation is attached. The LISN schematic in Figure 1 is used in MIL-STD 462D. The LISN schematic in Figure 2 is used in RTCA DO-160D.

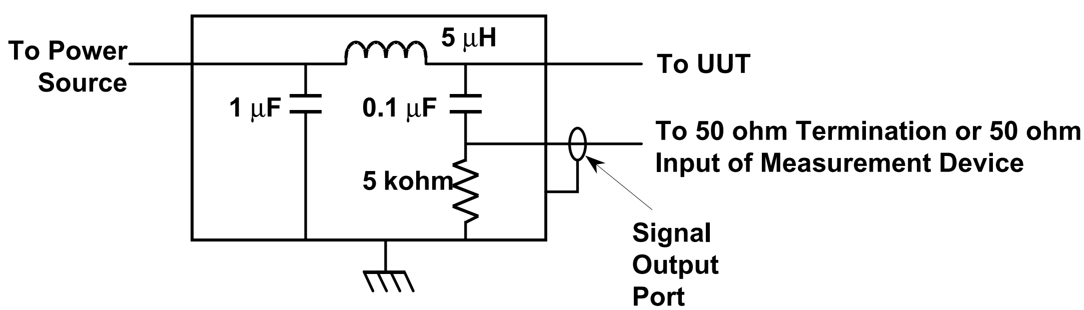


Figure 1—5 μH LISN schematic

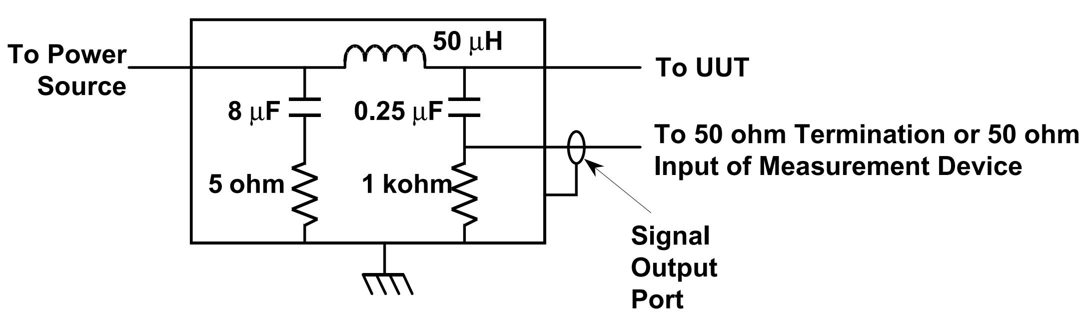


Figure 2—50 μH LISN schematic

3.23 load impedance: The load impedance begins at the equipment output termination (as shown in Figure 3) and ends at the equipment power return termination. Hence, all cabling is included in the load.

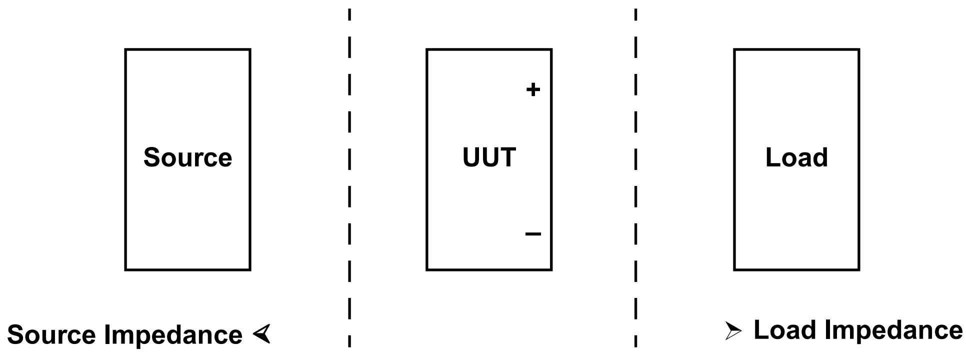


Figure 3—Electronic power distribution block diagram

3.24 loop stability: A term describing the stability of a control loop as measured against some criteria, e.g., phase margin and gain margin.

3.25 maximum frequency of interest: (1) For switching power supplies: 10 times the maximum power switch switching frequency. **(2)** For filter products: 10 times the 3 dB point.

3.26 operating temperature, T_{op}: The temperature a unit under test (UUT) operates at. It is often specified over a range and can have various definitions. Definitions include ambient temperature, baseplate temperature, inlet air temperature, etc.

3.27 oscilloscope: An instrument for measuring and displaying an electrical quantity (typically voltage) as a function of time. The bandwidth should be at least 10 times the maximum frequency of interest and include triggering capacity. *See also:* **maximum frequency of interest.**

3.28 overload: A condition in which the maximum current of the power supply is exceeded.

3.29 overtemperature protection: A feature in a power supply that senses and responds to an over-temperature condition.

3.30 PARD: The abbreviation for periodic and random deviation. PARD is the sum of all ripple and noise components measured over a specified bandwidth and stated, unless otherwise specified, in peak-to-peak values.

3.31 phase margin: The absolute value of loop phase angle subtracted from 180° found in a feedback system at the frequency for which its gain reaches unity. The margin from 180° represents a measure of dynamic stability.

3.32 point of regulation (POR): The location in the subsystem [unit under test (UUT)] where voltage is sensed for voltage regulation. The point of regulation can be remote or local to the voltage regulation equipment.

3.33 power factor (displacement): For user equipment, the displacement power factor is equal to the cosine of the angle, φ, between the input current and the input voltage at the fundamental frequency.

$$PF_{dp} = \cos\varphi$$

This definition of power factor does not include the effect of distortion in the input current (and/or voltage) waveform.

3.34 power factor (distortion): The distortion power factor is defined as

$$PF_{dt} = \frac{1}{\sqrt{1 + THD^2}}$$

where

THD (Total Harmonic Distortion) is defined as in 3.42

This definition of power factor does not include effect of displacement.

3.35 power factor (true): For user equipment, the true power factor is the ratio of the active, or real, power (P) consumed in watts to the apparent power (S) drawn in volt-amperes, with

$$PF = P/S$$

and

$$S = \sqrt{P^2 + Q^2}$$

where

PF is power factor,
P is active power in watts,
Q is reactive power in vars,
S is total power in volt-amperes.

This definition of power factor includes the effect of both displacement and distortion in the input current (and/or voltage) waveform.

Alternatively, if there are no inter-harmonics, the previous equation can be simplified to

$$PF = PF_{dp} \times PF_{dt}$$

3.36 reactive power: Reactive power (Q) is the vector difference between apparent and real power:

$$Q = \sqrt{S^2 - p^2}$$

3.37 remote on/off control: The control over the on/off operation of the unit under test (UUT) output power by means initiated externally or away from the UUT.

3.38 short circuit: The condition in which the output terminals of the power supply are directly connected together, resulting in near-zero output voltage.

3.39 source impedance: The source impedance is defined to begin at the power source termination (as shown in Figure 3) and end at the power source return termination. Hence, all cabling is included in the source impedance. The cables and interconnects used in the system should be used during test. Line impedance stabilization networks (LISNs) may be used in series with each input line to provide a uniform standard for source impedance. Different LISNs may be used for different test applications to test the UUT.

3.40 spectrum analyzer: A test instrument which measures and displays the measurements of amplitude versus frequency for a given signal. Its frequency range should be at least 100 Hz to 1500 MHz; resolution bandwidth should be at least 10 Hz to 3 MHz; the video bandwidth should be at least 1 Hz to 3 MHz, and amplitude range should be at least –135 to +35 dBm.

3.41 steady state: Steady state refers to the operating condition of a system wherein the observed variable has reached an equilibrium condition in response to an input or other stimulus in accordance with the definition of the system transfer function. This may involve a system output being at some constant voltage or current values in the case of power supplies. Referring to a subsystem operating parameter such as a thermal base-plate, it may refer to a temperature that has reached stability as a function of the system operating inputs, load, and ambient environment.

3.42 total harmonic distortion (THD): The ratio, expressed as a percent, of the rms value of the ac signal after the fundamental component is removed and inter-harmonic components are ignored, to the rms value of the fundamental. The formula defining total harmonic distortion is $PF = P/S$ and $S = \sqrt{P^2 + Q^2}$. The variables X_1 and x_n may represent either voltage or current, and may be expressed either as rms or peak values, so long as all are expressed in the same fashion.

$$THD_x = \frac{\sqrt{\sum_{n=2}^{\infty} x_n^2}}{X_1} \times 100\%$$

where

X_1	is fundamental value of current or voltage,
x_n	is n^{th} harmonic value of current or voltage.

3.43 total or apparent power: The total or apparent power (S) is the product of rms voltage and current (VA)

3.44 transient: Transient is a momentary departure of a characteristic from steady-state conditions and back to steady state conditions as a result of a system disturbance. Normal transients occur as a result of normal disturbances such as load or line changes. Abnormal transients result from abnormal disturbances such as a power interruption or wire fault.

3.45 UUT: The abbreviation for unit under test.

3.46 UVLO: The abbreviation for undervoltage lock-out.

3.47 V_{max} input: The maximum allowable input voltage rating at which the unit under test (UUT) can operate to specifications.

3.48 V_{min} input: The minimum allowable input voltage rating at which the unit under test (UUT) can operate to specifications.

3.49 V_{nom} input: The stated or objective value of the input voltage, which may not be the actual value measured. The value should be between the minimum and maximum input value.

3.50 voltage probe: A connecting device, usually consisting of a two-conductor shielded cable and frequency-compensating network, with a hand-held tip, for use with an oscilloscope to measure the amplitude and waveshape of a dc, ac, or composite signal. It should include a ground reference. The measurement bandwidth should be at least 10 times greater than the frequency of interest. The impedance should be at least 50 times greater than the node impedance under measurement.

4. Electrical performance parameters

In general, if a single test result is to be provided for a given unit under test (UUT), it shall be the value measured over the most demanding combination of environmental stresses, input, and load characteristics. If a single number is to be provided as part of a *data-sheet* characterization of the product, a suitable margin shall be added to allow for production variations, test equipment accuracy, and aging. Any limiting conditions on the above shall be clearly identified. (See Annex B for general test practices.)

4.1 DC voltage

4.1.1 DC input voltage

4.1.1.1 Definition

DC voltage is the dc input voltage to a UUT excluding any ac or transient voltage within a specified range. For example, 22V < V_{in} < 34 V is a typical voltage range of a 28 V bus.

4.1.1.2 Test method

Connect the test setup as shown in Figure 4. The measurement of the dc input voltage is performed with a digital multimeter directly across the UUT input terminals.

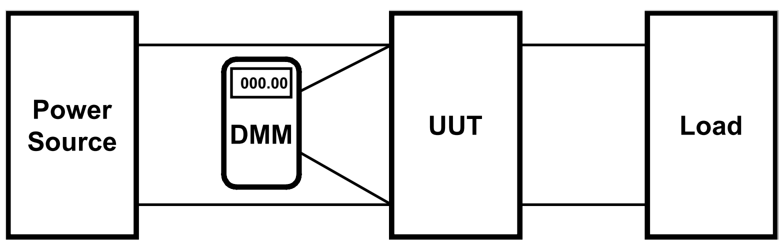


Figure 4—DC input voltage measurement test set up

4.2 AC voltage

4.2.1 RMS value (voltage)

4.2.1.1 Definition

The square root of the average of the square of the value of the function taken throughout the period. For instance, the rms voltage value for a sinewave may be computed as:

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T v^2(t)dt} \tag{1}$$

where

T is waveform time period,

v(t) is instantaneous voltage at time *t*,
V_{rms} is rms voltage value.

4.2.1.2 Test method

Details of this method are defined in the Handbook of Standardized Terminology for Power Sources Industry published by PSMA [B8].[6]

4.2.2 AC voltage (peak)

4.2.2.1 Definition

AC voltage (peak) is the maximum instantaneous value of a waveform reached during a particular cycle or waveform interval period. For a sine wave voltage the peak value is

$$V_{peak} = \sqrt{2} \times V_{rms} \tag{2}$$

For a voltage wave containing harmonics the peak value is

$$V_{peak} = V_{rms} \times cf \tag{3}$$

where

cf is the Crest Factor.

4.2.2.2 Test method

Connect the test setup as shown in Figure 5. Connect an oscilloscope to directly measure the peak value. Measurements can be taken phase-to-phase or phase-to-neutral for single- to multiple-phase systems.

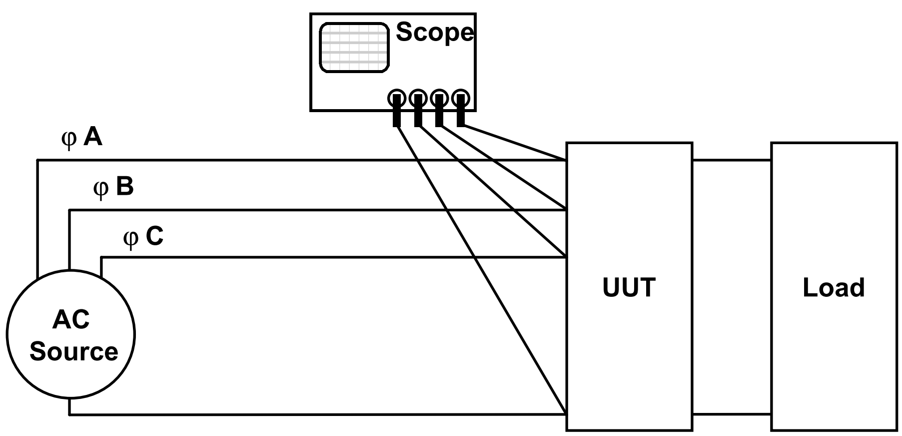


Figure 5—AC Voltage test setup for a wye-connected, 3-phase system

[6]The numbers in brackets correspond to those of the bibliography in Annex A.

4.2.3 AC voltage (steady state)

4.2.3.1 Definition

The value of any of the phase-to-neutral or phase-to-phase (in the absence of neutral) voltages supplied to single- or three-phase utilization equipment. All ac voltage values, unless otherwise specified, are root-mean-square (rms) values.

4.2.3.2 Test method

Connect the test setup as shown in Figure 6. Steady state AC voltage measurement test setup. Connect a rms meter as close to the UUT as possible to directly measure the value. Measurements can be taken phase-to-phase or phase-to-neutral for single- to multiple-phase systems.

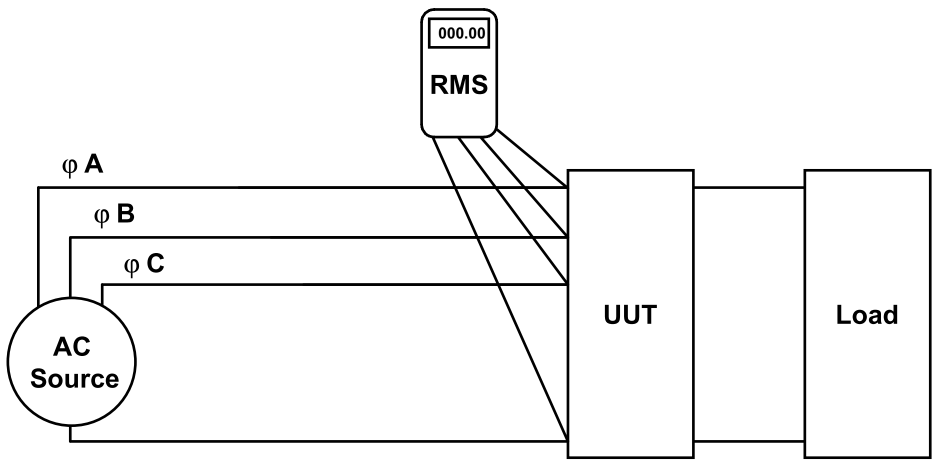


Figure 6—Steady state AC voltage measurement test setup

4.2.4 Voltage phase difference

4.2.4.1 Definition

Voltage phase difference is the difference in electrical degrees between the fundamental components of any two voltages taken at consecutive zero crossings traced in the negative to positive directions.

4.2.4.2 Test method

Connect the test setup as shown in Figure 5 using a three or more channel oscilloscope. The phase difference(s) may be read directly. Figure 7 illustrates a measure of voltage phase difference.

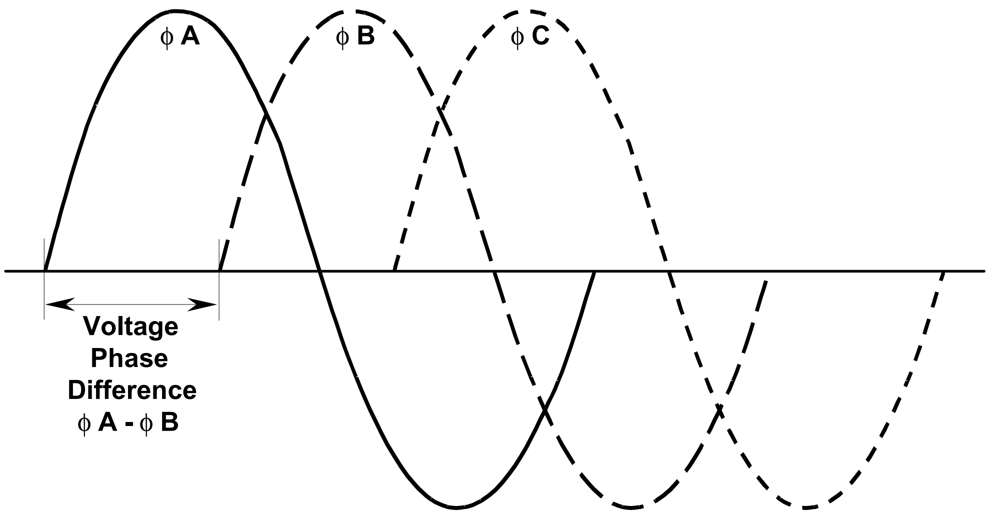


Figure 7—Three-phase voltage waveform

4.2.5 Voltage unbalance

4.2.5.1 Definition

Voltage unbalance is the maximum difference between rms phase-to-neutral or phase-to-phase voltage amplitudes at the UUT input terminals. For example, for a wye-connected, three-phase system

$$V_{UNB\%} = (max[V_{AN}, V_{BN}, V_{CN}] - min[V_{AN}, V_{BN}, V_{CN}]) \times 100 \quad (4)$$

where

V_{AN}, V_{BN}, V_{CN} are the phase voltage magnitudes,
$V_{UNB\%}$ is maximum phase voltage unbalance.

Percent voltage unbalance is calculated by multiplying the maximum voltage unbalance (V_{UNB}) by 100, and then dividing the result by the average of the three phase voltages.

$$V_{UNB\%} = \frac{V_{UNB}}{\left(\frac{V_{AN} + V_{BN} + V_{CN}}{3}\right)} \times 100 \quad (5)$$

4.2.5.2 Test method

Connect the setup as shown in Figure 5. AC voltage test setup for a wye-connected, three-phase system. Measure each phase and take the difference between the largest and smallest reading.

4.2.6 Phase sequence

4.2.6.1 Definition

Phase sequence is the order in which the voltages in a polyphase system successively reach their positive maximum values.

4.2.6.2 Test method

Connect the setup as shown in Figure 5 and verify the time sequence of phases A, B, and C.

4.2.7 Input current unbalance

4.2.7.1 Definition

Input current unbalance is the ratio of loads on each phase of a three-phase, sinewave ac system.

4.2.7.2 Test method

Connect the setup as shown in Figure 8. One current probe is attached to each of the three input phases. (If a neutral wire is present, it should also be monitored with a current probe). A rms current meter is used for each measurement. This test is only applicable to three-phase, ac power sources. It is only performed on the input of the UUT. Source voltage (amplitude, phase, and source impedance) should be balanced. The rms current on each of the three input phases is measured and compared.

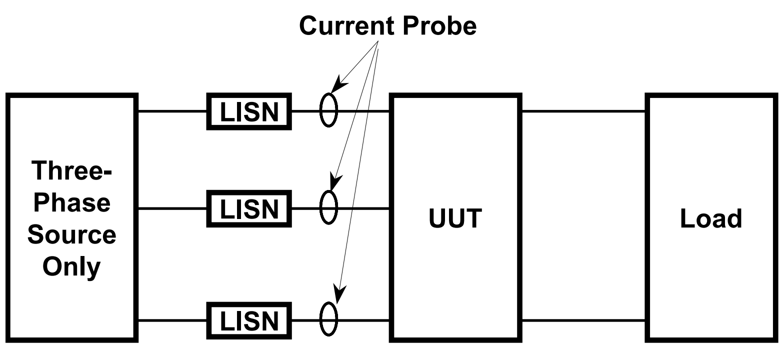


Figure 8—Input current unbalance test setup

4.2.7.3 Test condition

Test the UUT under conditions that produce the least favorable input current balance. This can be accomplished by changing the load and/or the mode of operation. Test the unit at 25 °C.

4.3 Efficiency

4.3.1 Efficiency

4.3.1.1 Definition

Efficiency is the ratio, expressed as a percentage, of the total real output power produced by a conversion process to the real power required to produce it using the following equation:

$$\eta = \frac{\sum_i P_{o,\,i}}{P_{in}} \times 100 \tag{6}$$

where $P_{o,i}$ is the output power of the i^{th} output. The input power includes all housekeeping and auxiliary circuits required for the converter to operate unless otherwise specified.

4.3.1.2 Test method

For a dc-to-dc converter, connect the test setup as shown in Figure 9. It is noted that the ratio defined in Equation (6) is zero at no-load and at short circuit. Therefore, it is desirable to define the UUT's efficiency curves as shown in Figure 10. The recommended curves would be plotted for the specified min., nom., and max. input voltages, with each curve consisting of 10 data points between no-load and max rated load.

To ensure valid measurements, input, and output power (and power factor where applicable) must be measured concurrently.

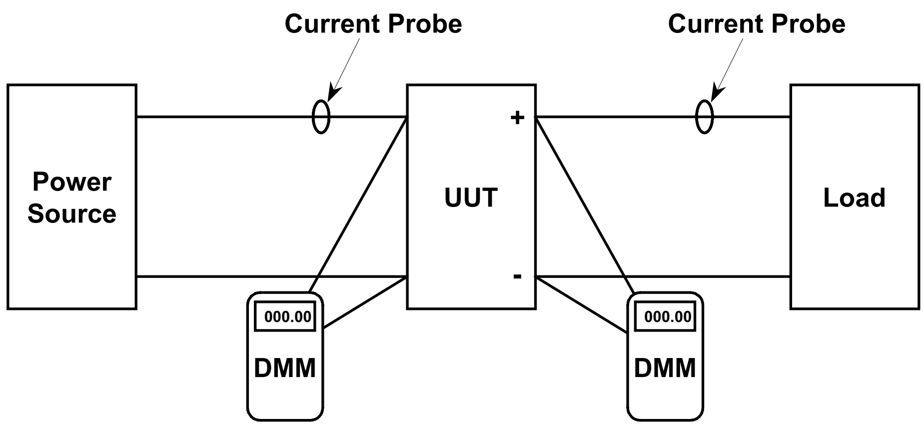


Figure 9—DC to DC converter efficiency and power dissipation measurement

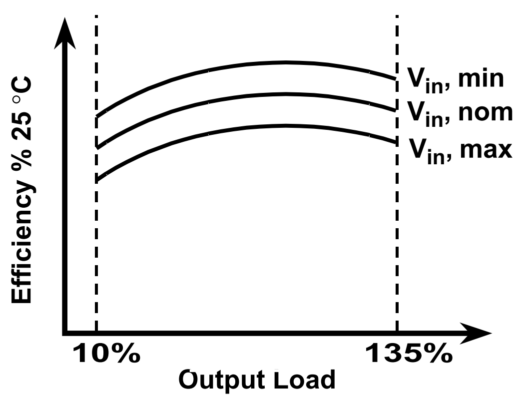


Figure 10—Efficiency vs. power curves

For an individual piece-part, a single useful value of UUT efficiency is obtained at the UUT's nominal input voltage and its maximum load. This is what is commonly referred to as a UUT maximum load efficiency.

4.3.1.3 Test condition

Adjust the input voltage and the output current from the minimum to the maximum specified limits. The operating temperature shall be minimum to maximum (stabilized after warm up).

Test conditions are as follows:

V_{in} = Min, nom, and max rated steady state input voltage
Loads = All loads adjusted from minimum load to max rated load.
Operating Temperature = Min, nom, and max (stabilized after warm up)

4.3.2 Electrical power dissipation

4.3.2.1 Definition

Electrical power dissipation is the difference between the electrical input power to the UUT and its electrical output power, expressed in watts.

$$P_{diss} = P_{in} - \sum_{i} P_{o,i} \tag{7}$$

Alternatively, power dissipation is expressed as:

$$P_{diss} = P_{in} - \sum_{i} P_{o,i} = (I - \eta) P_{in} \tag{8}$$

4.3.2.2 Test method

Use the same test setup as shown in Figure 9 to measure power dissipation. Power dissipation is obtained from the efficiency measurements of the input and output power as functions of line, load, and temperature. This should be the worst case value.

4.3.2.3 Test condition

Adjust the input voltage and the output load current from the minimum to the maximum specified limits and record the results.

4.4 Regulation

4.4.1 Line regulation

4.4.1.1 Definition

Line regulation is the percentage variation of the specified steady state output voltage, V_o, while the input voltage varies over the range of specified input voltage, V_{in}, at specified output load values, with all other factors constant. Line regulation is expressed in percentage as:

$$\pm \frac{V_{o,max} - V_{o,min}}{V_{o,max} - V_{o,min}} \times 100 \tag{9}$$

where

$V_{o,max}$ is the maximum measured output voltage,
$V_{o,min}$ is the minimum measured output voltage.

4.4.1.2 Test method

For line regulation tests, use the test setup shown in Figure 11. Output load and operating temperature are held constant. Measure V_o as close as possible between the plus and minus output connections of the UUT.

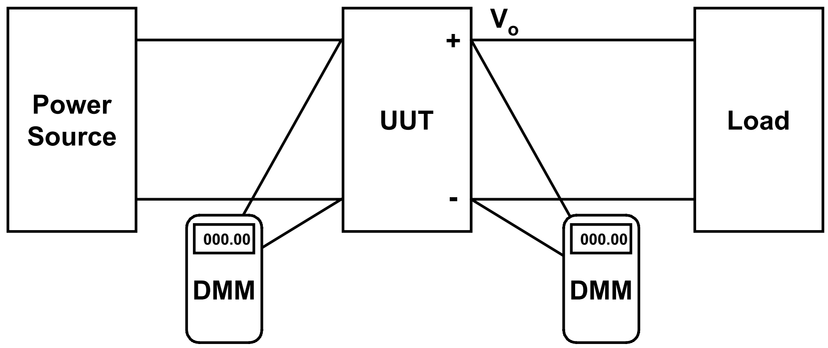


Figure 11—Line regulation test setup

4.4.1.3 Test conditions

Test for line regulation from minimum to maximum specified input voltage, holding the load and operating temperature constant, typically, at nominal values.

4.4.2 Load voltage regulation

4.4.2.1 Definition

The percentage variation of an output voltage, V_o, while that output's load is changed over the specified range, with all other factors held constant as specified. Figure 12 depicts the relationship between output voltage and load current. Load voltage regulation is expressed in percentage as:

$$\pm\frac{V_{o,\,max} - V_{o,\,min}}{V_{o,\,max} + V_{o,\,min}} \times 100 \tag{10}$$

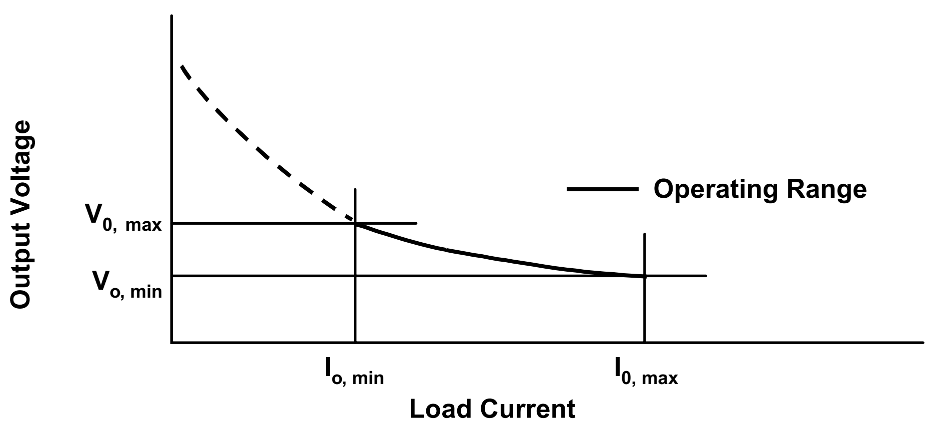


Figure 12—Load voltage regulation

4.4.2.2 Test method

Connect the test setup as shown in Figure 13. Measure the output voltage, V_o with a digital multimeter at the plus and minus outputs of UUT and as close as possible to the output connections.

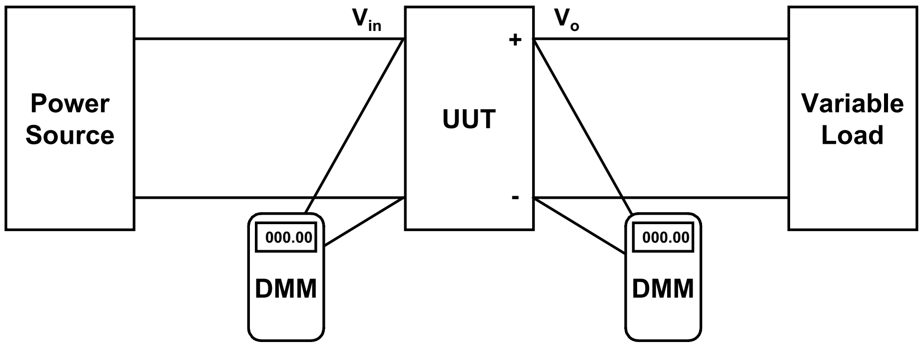


Figure 13—Load voltage regulation test setup

4.4.2.3 Test conditions

V_{in} shall be adjusted to the full operating range of input voltage, the output load shall be resistive and adjusted from I_{min} to I_{max}, and over the full operating temperature range, unless otherwise specified.

4.4.3 Temperature regulation

4.4.3.1 Definition

Temperature regulation is the change in the unit output due to a change in temperature with all other parameters held constant. As a power supply output specification, it is the percent positive and negative deviation around an average value, derived by the following formula:

$$\pm\frac{V_{o,\,max} - V_{o,\,min}}{V_{o,\,max} + V_{o,\,min}} \times 100 \qquad (11)$$

If the change is approximately linear with temperature, an acceptable alternative or supplement is to provide the highest value of the change of temperature within the specified range, expressed in units of %/°C.

$$\frac{\Delta V_o}{\Delta V_{o,\,min}} \times 100 \qquad (12)$$

4.4.3.2 Test method

Connect the UUT to a power source and the specified nominal load as shown in Figure 13. Measure the output voltage with a digital multimeter.

4.4.3.3 Test condition

Adjust the unit input voltage and the load current to nominal. Slowly increase the ambient temperature to maximum, allowing it to settle and maintain constant at specific points, and measure the output voltage.

4.4.4 Cross regulation

4.4.4.1 Definition

In a multiple output power supply, cross regulation is the percent voltage change at output *m* caused by the load change in output n. It is expressed in percentage as:

$$CR_{m/n} = \pm\frac{V_{o,\,m,\,max} - V_{o,\,m,\,min}}{V_{o,\,m,\,max} + V_{o,\,m,\,min}} \times 100\Big|_{I_{o,\,n,\,min}}^{I_{o,\,n,\,max}} \tag{13}$$

where

m is the m^{th} output voltage,
n is currents in n^{th} output and $m \neq n$.

4.4.4.2 Test method

Use the test setup shown in Figure 14. The loads are adjusted to rated current levels as indicated on the ammeters. The output voltages are measured as close as possible to the plus and minus connections of the UUT with a digital multimeter.

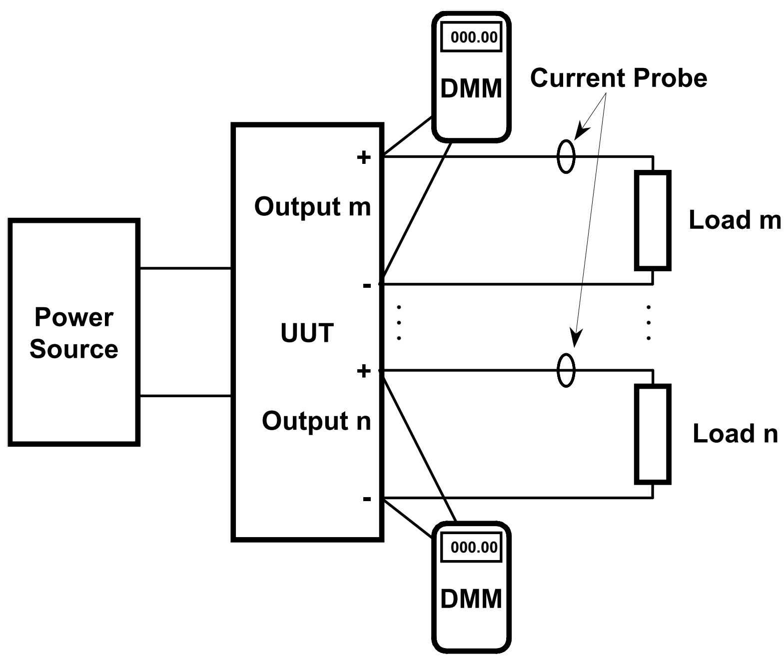


Figure 14—Cross regulation test setup

4.4.4.3 Test condition

Conduct over the full range of input voltage and output load (resistive). The temperature shall be held constant. Set the UUT output m to $I_{m,\,max}$, and sweep the n^{th} output from $I_{n,\,max}$ to $I_{n,\,min}$, and measure the output voltages. Set the output m to $I_{m,\,min}$ and sweep the n^{th} output from $I_{n,\,min}$ to $I_{n,\,max}$, and measure the output voltages.

4.4.5 System dynamics

4.4.5.1 Definition

System dynamics is defined as the desired performance characteristics of a system of any order may be specified in terms of the transient response to a step-function input. The dynamics of a system may be evaluated in terms of the following quantities, as shown in Figure 15:

a) Maximum overshoot, c_p, is the magnitude of the first overshoot of the target value. This may be also expressed in percent of the target or final value.

b) Time to maximum overshoot, t_p, is the time required to reach maximum overshoot.

c) Time to first zero error, t_0, is the time required to reach the final value the first time. It is sometimes referred to as the duplicating time.

d) Settling time, t_s, is the time required for the output response first to reach and thereafter remain within a prescribed percentage of the final value. This percentage must be specified in the individual case applied to the envelope that yields t_s. The settling time, t_p, may be smaller than t_s.

In cases where the oscillating frequencies are of interest, measurement should be taken.

The time response differs for each set of initial conditions. Therefore, to compare the time response of various systems it is necessary to start with standard initial conditions. The most practical standard is to start with the system at rest or at a nominal standard value. Then the response characteristics, such as maximum overshoot and settling time, can be compared significantly.

For some systems, these specifications are also applied for a ramp input. In such cases, the plot of error with time is used with the definitions. For systems subject to shock inputs, the response due to an impulse is used as a criterion of performance.

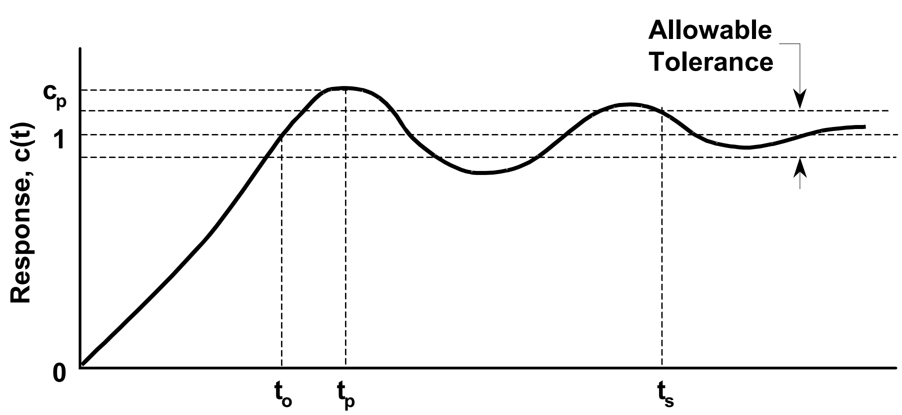


Figure 15—Typical underdamped response to a step function

4.4.6 Dynamic line regulation

4.4.6.1 Definition

Dynamic line regulation is the transient response of the output voltage of an electronic power distribution subsystem element to a step change in the input voltage.

4.4.6.2 Test methods

Test method a)—For a negative step change on the input voltage, V_{in}, use the circuit test setup shown in Figure 16. The dynamic source should produce a waveform at the input of the UUT as described in Figure 17. With the oscilloscope measure the excursion of the UUT output (V_o) for response time, dynamic regulation, the recovery time, and the final output voltage value (see Figure 17). The measurement of V_o should be between the plus and minus outputs of the UUT and as close as possible to the output connections.

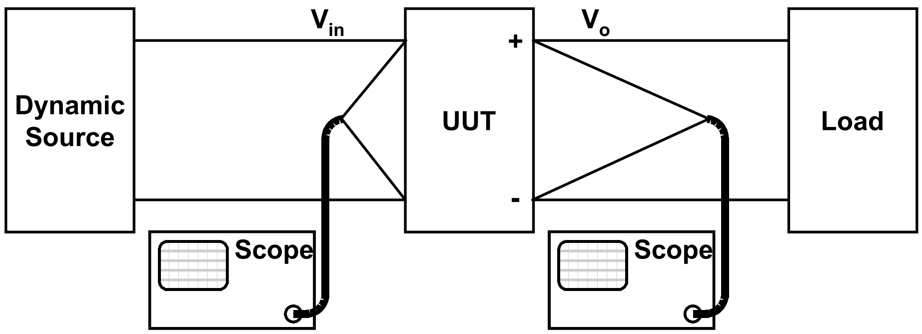
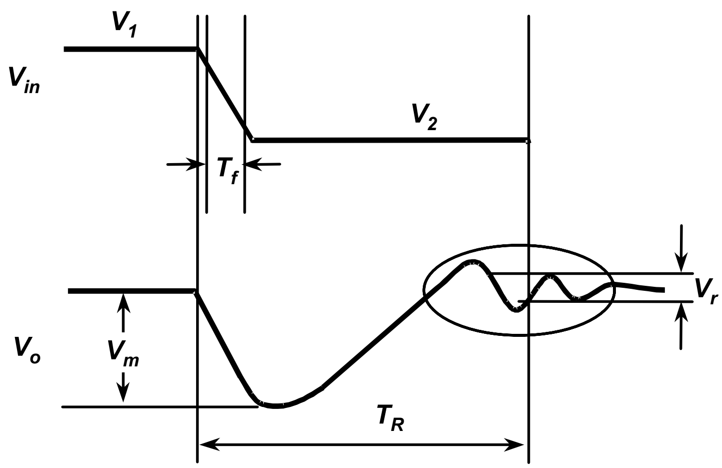


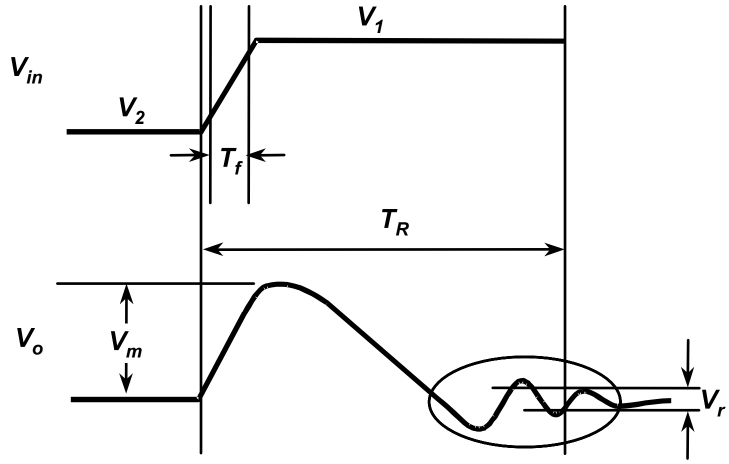
Figure 16—Dynamic line regulation test setup



V_1 = higher voltage value of V_{in}
V_2 = lower voltage value of V_{in}
T_r = 90%–10% fall time of V_{in}
T_R = total transient response time: the interval between the time when V_{in} starts to fall and the time when V_o enters the tolerance band
V_r = final output value tolerance band
V_m = maximum excursion (deviation)

Figure 17—Negative voltage step applied at the UUT input terminals with output response

Test method b)—For a positive step change to the input voltage, V_{in}, use the circuit test setup shown on Figure 16. The high-power dynamic source should produce a waveform at the input of the UUT as described on Figure 18. With the oscilloscope measure the excursion of the UUT output, V_o, for dynamic regulation, the recovery time, and the final output voltage value. The measurement of V_o should be between the plus and minus outputs of the UUT and as close as possible to the output connections.



V_1 = higher voltage value of V_{in}
V_2 = lower voltage value of V_{in}
T_r = 10%–90% rise time of V_{in}
T_R = total transient response time: the interval between the time when V_{in} starts to rise and the time when V_o enters the tolerance band
V_r = final output value tolerance band
V_m = maximum excursion (deviation)

Figure 18—Positive voltage step applied at the UUT input terminals with output response

4.4.6.3 Test conditions

Test condition a)—For a negative input step:

V_{in} = Set to V_{nom}
V_1 = see Figure 17.
Load = In a resistive configuration

Examples on how to actually record the test data results are shown in Table B.1. The table identifies the temperature and load conditions in the horizontal axis and the parameter to measure in the vertical axis. See Annex B for an example description of test conditions and a data collection tabulation.

Test condition b)—For a positive input step:

V_{in} = V_{nom}
V_2 = see Figure 18.
Load = In a resistive configuration

Examples on how to actually record the test data results are shown on Table B.1. The table identifies the temperature and load conditions in the horizontal axis and the parameter to measure in the vertical axis. See Annex B for example description of test conditions and a data collection tabulation.

4.4.7 Dynamic load regulation

4.4.7.1 Definition

Dynamic load regulation is the transient response of the output voltage of an electronic power distribution subsystem element to a step change in the load current.

4.4.7.2 Test methods

Test method a)—For a load increase to the output voltage, V_o, use the test setup described in Figure 19. The load switch unit should produce a current waveform as described in Figure 20. Measure the UUT output, V_o, for response time, dynamic regulation (excursion), recovery time, and final value of output, V_o. Measurement of V_o should be conducted between the plus and minus outputs of UUT and as close as possible to the output connections.

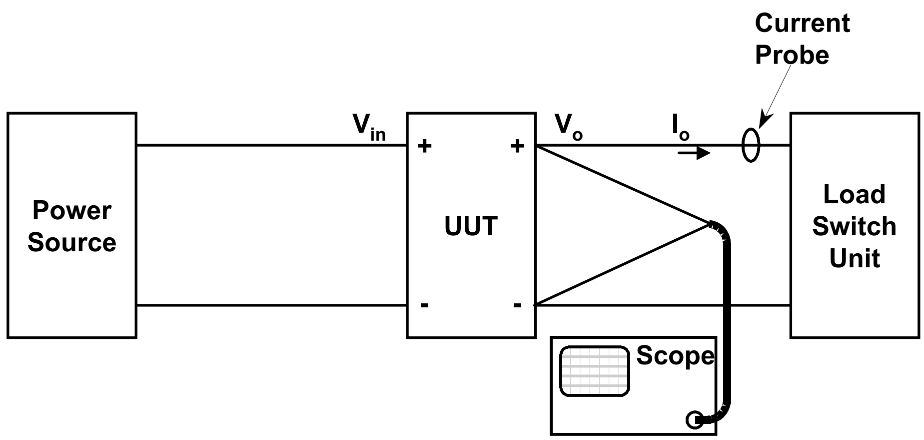


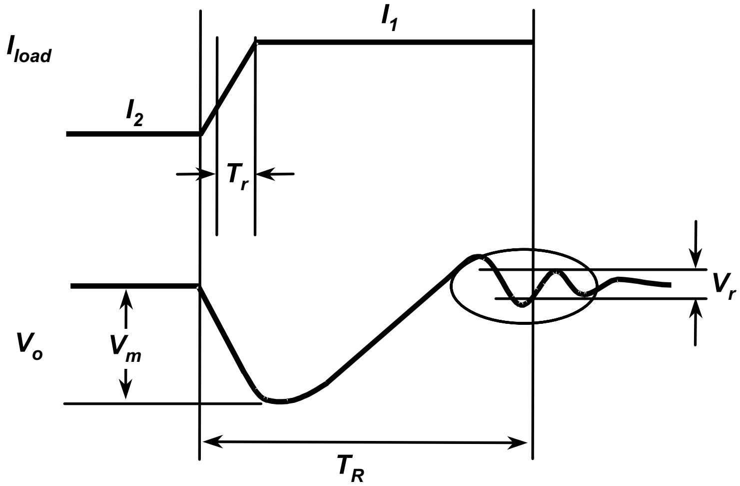
Figure 19—Dynamic load regulation test setup

Test method b)—For a load decrease to the output voltage, V_o, use the test setup described in Figure 19. The load switch unit should produce a waveform as described in Figure 21. Measure the UUT output for response time, dynamic load regulation, recovery time, and final value of output voltage (see Figure 21). Measurement of V_o should be conducted between the plus and minus outputs of UUT and as close as possible to the output connections.

4.4.7.3 Test conditions

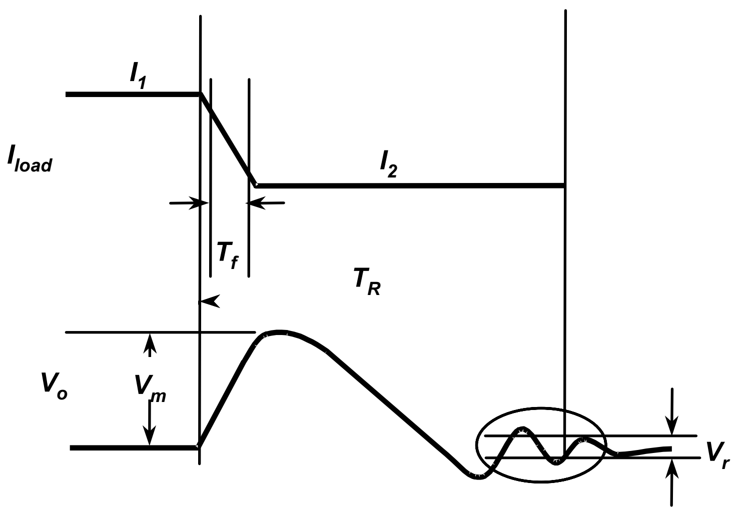
Test condition a)—For step load decrease, the load will be decreased from I_1 to I_2. The unit shall be tested at an operating temperature of minimum, nominal, and maximum specified.

Test condition b)—For step load increase, the load will be increased from I_2 to I_1. The unit shall be tested at an operating temperature of minimum, nominal, and maximum specified.



I_1 = higher value of load current regulation
I_2 = lower value of load current regulation
T_r = the time required for the current, I_o, to rise from 10% to 90%
T_R = minimum time to allow the output voltage, V_o, to settle to within the specified limits, measured from the time the load current starts to rise
V_r = final output value tolerance band
V_m = maximum excursion (deviation)

Figure 20—Power supply output response to positive load step



I_1 = higher value of load current regulation
I_2 = lower value of load current regulation
T_r = the time required for the current, I_o, to fall from 90% to 10%
T_R = minimum time to allow the output voltage, V_o, to settle to within the specified limits, measured from the time the load current starts to fall
V_r = final output value tolerance band
V_m = maximum excursion (deviation)

Figure 21—Power supply output response to a negative load step

4.5 Ripple and spikes

Ripple and spikes present at the output of the UUT, when connected in a static load, are important performance parameters for switched-mode power supplies. They represent two distinct physical phenomenons happening in a switched-mode power supply.

4.5.1 Output voltage ripple

4.5.1.1 Definition

The output voltage ripple is the maximum ac voltage present on a dc or low-frequency ac voltage stated in peak-to-peak voltage. The intent is to characterize the residual component associated with the switching action at the output switching frequency (or twice the output switching frequency). (See Figure 22.)

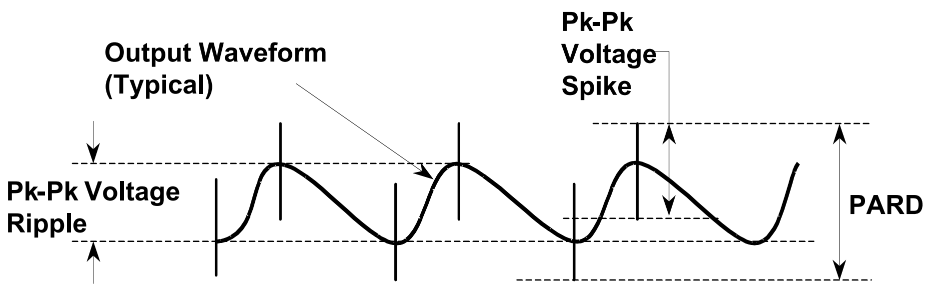


Figure 22—Typical output voltage ripple and spikes

4.5.1.2 Test method

Connect the test setup as shown in Figure 23. Use an oscilloscope with a differential input amplifier and measure differentially between the plus and minus output terminals of the UUT. Make sure the UUT is isolated from any other conducting surface. Other methods specified in 4.5.3 can also be used and should be stated explicitly.

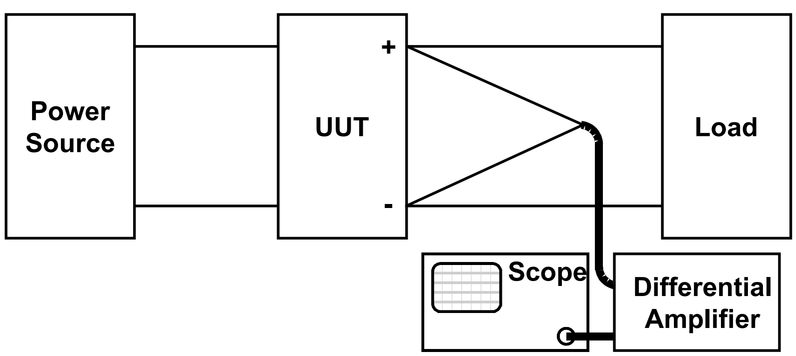


Figure 23—Output voltage ripple test setup

4.5.1.3 Test condition

The operating temperature should be from minimum to maximum; the input voltage should be V_{min}, V_{nom}, and V_{max}; the load should be resistive, and should be I_{min}, I_{nom}, and I_{max}. The bandwidth of the scope should be at least 10 times the switching frequency.

4.5.2 Output current ripple

4.5.2.1 Definition

The output current ripple is the maximum ac current component present on a dc or much lower frequency current stated in peak-to-peak current. The intent is to characterize the residual component associated with the switching action at the output switching frequency (or twice the output switching frequency). Output current ripple is usually not specified on a voltage-controlled output.

4.5.2.2 Test method

Connect the test setup as shown in Figure 24. Use a current probe to measure the current at the plus output of the UUT. Make sure the UUT is isolated from any other conducting surface.

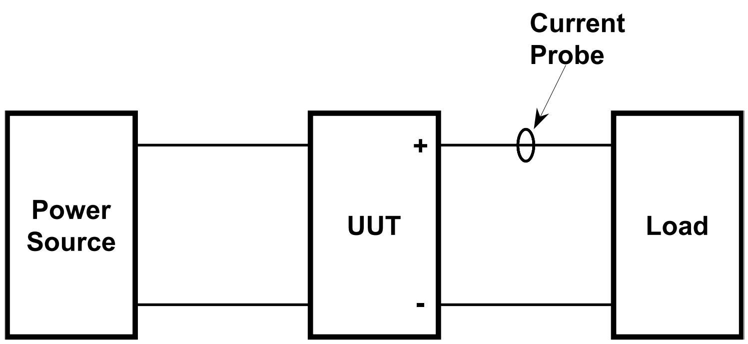


Figure 24—Output current ripple test setup

4.5.2.3 Test condition

The operating temperature should be from minimum to maximum; the input voltage should be V_{min}, V_{nom}, and V_{max}; the load should be resistive, and should be I_{min}, I_{nom}, and I_{max}. The bandwidth of the scope should be at least 10 times of switching frequency.

4.5.3 Switching spikes

4.5.3.1 Definition

Switching spikes are generated by commutations of load current among switching devices. Their duration is typically less than 1/10 of switching period, and their amplitude is expressed as a maximum peak-to-peak value.(See Figure 22.)

4.5.3.2 Test methods

Test method a)—Refer to Figure 25. The ground lead of a voltage probe is removed to avoid any high-frequency pick-ups. Press the tip against "Out +" and the ground ring (band) against "Out –" of the UUT. Wrap the probe lead several times around a high μ core to minimize common-mode noise.

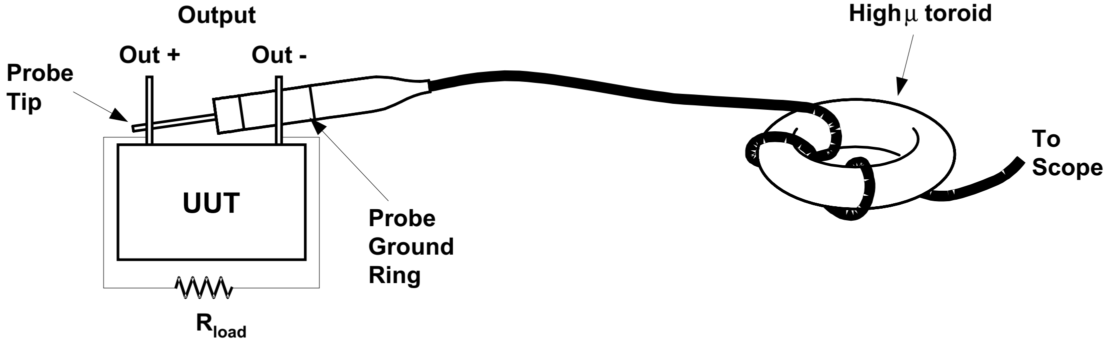


Figure 25—Measuring output voltage spikes —Test method a)

Test method b)—This method requires a simple set-up (a special probe). Refer to Figure 26. A coaxial cable is used to connect to a scope. A BNC "T" connector, terminated by a 50 Ω carbon resistor in series with a 0.68 μF ceramic capacitor, is used at one end connecting to a scope. At the other end, the BNC cable is split and connected to the output of the UUT.

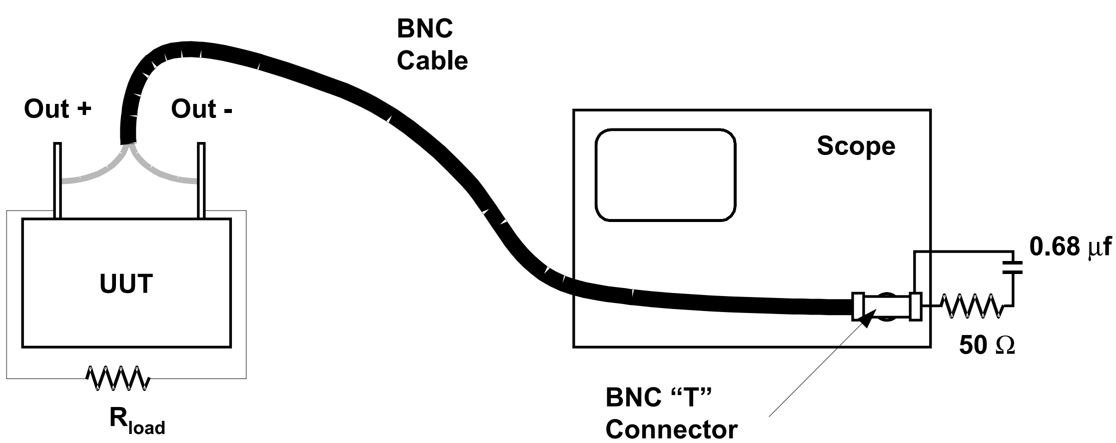


Figure 26—Measuring output voltage spikes—Test method b

Test method c)—This method requires a capacitor of up to 1μF in value added at the probe tip when measurements are made in an unshielded environment. The added capacitance is less than 0.1% of the system output capacitance. Refer to Figure 27.

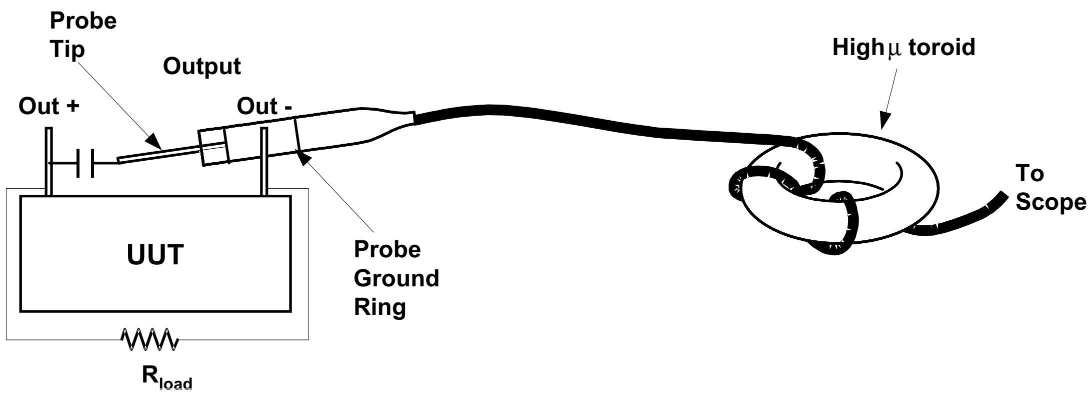


Figure 27—Measuring output voltage spikes —Test method c)

4.5.3.3 Test condition

The operating temperature should be from minimum to maximum; the input voltage to the UUT should be V_{nom}, V_{nom}, and V_{max}; the load is resistive, and should be I_{min}, I_{nom}, and I_{max}. All measurements should be over a specified bandwidth that is at least 100 times the switching frequency.

4.5.4 Input-induced ripple current

4.5.4.1 Definition

An input-induced ripple current is the high-frequency current imposed on the input power source by the operation of a switch-mode power converter. This happens at the switching frequency and its harmonics.

4.5.4.2 Test method

Connect the input of the UUT to a power source and connect the output to a load, as shown in Figure 28. The power source (dc only) must have an output impedance that is no more than 1/10 the input impedance of the UUT at the frequency of interest, and the connections from the source to the UUT must be as short as possible. Use a current probe and oscilloscope to monitor the input ripple current of the UUT. The bandwidth of the current probe must be at least 10 times (preferably 100 times) the UUT switching frequency.

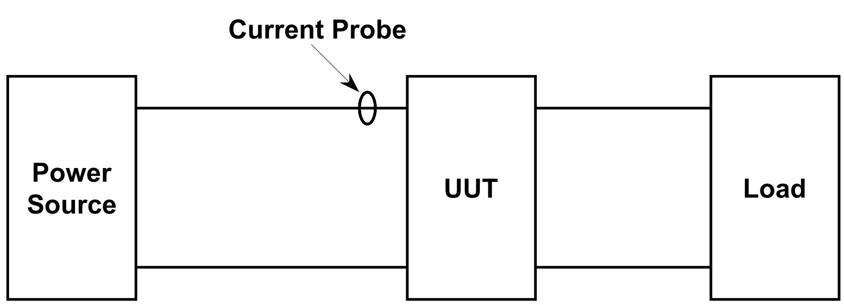


Figure 28—Input-induced ripple current measurement test setup

Switch on the power source. Measure the peak-to-peak and rms value of the input ripple current, and record the input current waveform. Measure the ripple current to find the highest value.

4.5.4.3 Test condition

Begin the tests with the input voltage to the UUT set at V_{min} and adjust the load to I_{max} specified for the UUT. Repeat the tests, varying input voltage and load current. The measurement shall be carried out at room temperature, and repeated at maximum and minimum specified ambient temperature.

4.6 Transients

4.6.1 Hold-up time

4.6.1.1 Definition

Hold-up time is the time, under the worst case conditions, during which a power supply's output remains within specified limits, when the input voltage drops below a specified voltage value or following the loss or removal of the input power (open circuit case).

4.6.1.2 Test method

Connect the test setup as shown in Figure 29 with S_1 in the closed position. There should not be any energy storage components externally connected to the UUT. Use S_1 to trigger the oscilloscope. Measure the voltage, V_o, as close as possible to the UUT output terminals after the switch S_1 is opened to interrupt the input and record the time V_o ramps down below a specific voltage limit.

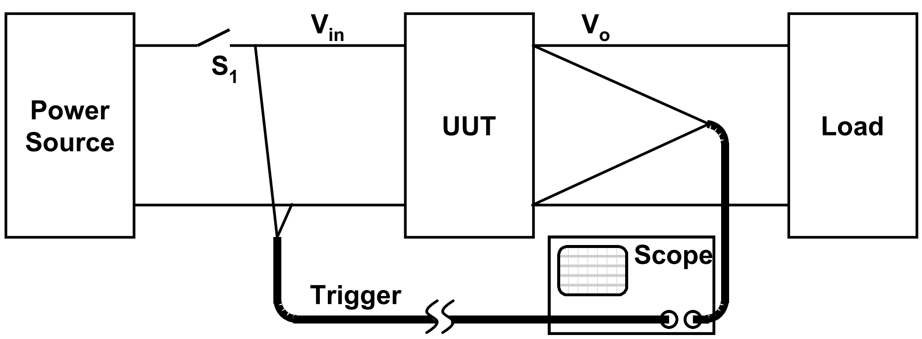


Figure 29—Holdup time measurement test setup

4.6.1.3 Test condition

Set the input voltage at V_{min} and the load current at I_{max}. Readjust the input voltage to V_{nom}, while the load current remains I_{max} per specification. Test at minimum, nominal, and maximum operating temperature values.

4.6.2 DC source inrush current

4.6.2.1 Definition

DC source inrush current is the waveform of the current drawn by the UUT when power is initially applied.

4.6.2.2 Test method

The UUT shall be fully discharged prior to performing the test. Connect the setup as shown in Figure 30. A current probe and a voltage probe are attached to the input power line. An oscilloscope is used for each measurement. The voltage probe is used to trigger the oscilloscope when power is applied. The low-impedance source is turned on with the switch S_1 (solid state or mechanical) initially open. The scope period should be of sufficient duration to capture all input current settling time. The intention of capturing this larger window is to determine where to focus the measurement. The test is then repeated to provide more resolution in the time interval when surges are present.

The output impedance of the power source should be no more than 1/10 the input impedance of the UUT.

If the dv/dt value of the input voltage is specified, precautions should be taken to assure supporting the inrush current conditions are met.

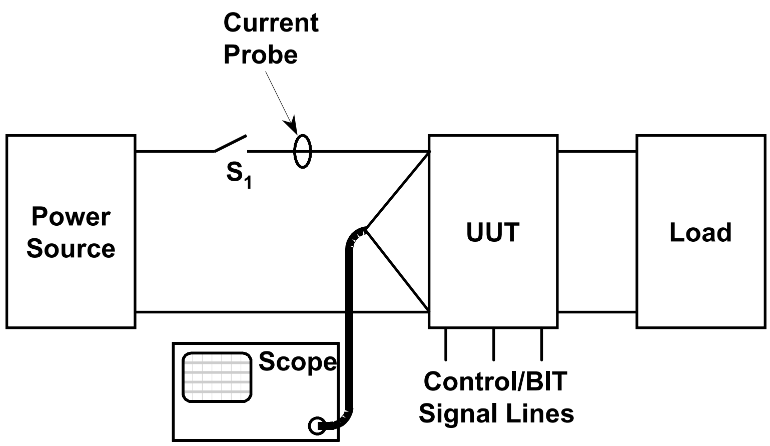


Figure 30—DC source inrush current test setup

4.6.2.3 Test conditions

Test condition a)—The inrush current is measured with S_1 initially open and the outputs enabled. Measure inrush current when S_1 is closed.

Test condition b)—Measure the inrush current with S_1 initially in the open position and the outputs disabled (UUT will not turn on when input power is applied). The inrush current is measured when S_1 is closed.

Test condition c)—Inrush current should also be measured with the power source active and the outputs disabled. Inrush current is measured after the outputs are enabled. The voltage probe is connected to the outputs enabled line to trigger this measurement (not shown in Figure 30).

Test at +25 °C and the minimum and maximum operating temperatures of the unit. Also, if not specified, the load should be resistive.

4.7 Impedance

4.7.1 Transfer impedance

4.7.1.1 Definition

Transfer impedance is the output voltage divided by the input current while the output is delivering rated current.

4.7.1.2 Test method

Use the test setup shown in Figure 31. Adjust the load until the UUT is delivering the rated load current. Measure output voltage, V_{out}, directly at the UUT's output connections and input current, I_{in}. Calculate transfer impedance from input port to output port, Z_{io}, from the following equation:

$$Z_{io} = \frac{V_o}{I_{in}} \quad (14)$$

For ac transfer impedance the ac input current and output voltage must be measured. Connect an ac source in series with the V_{in} of about one percent of V_{in}. Vary the ac source over the range of 10 Hz to 100 kHz. Measure the ac input current (I_{in}) at the frequency of the source. Measure the output voltage (V_{out}) directly at the UUT output connections at the frequency of the source. Plot the calculated Z_{io} with frequency. This test is normally only applied to dc input units.

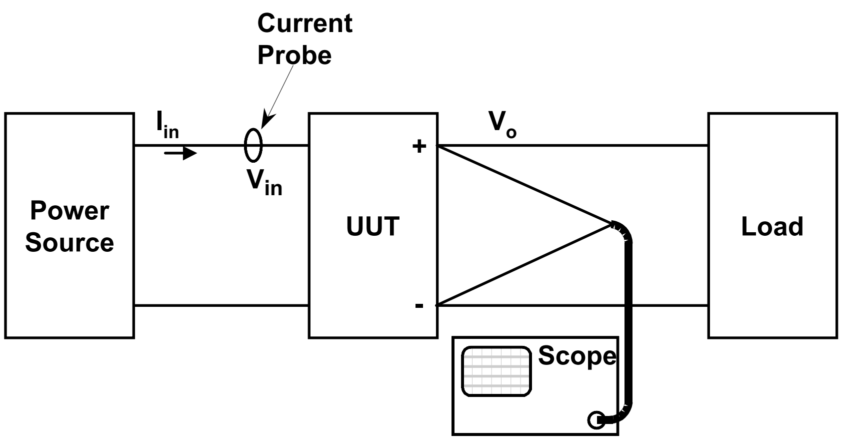


Figure 31—Transfer impedance test setup

4.7.1.3 Test condition

Perform the test with nominal input voltage and rated load. Test should be performed at minimum, nominal, and maximum temperature conditions. (This is a small signal test and all ac waveforms should be sine waves.)

4.7.2 Output impedance

4.7.2.1 Definition

Output impedance is the change in output voltage divided by the corresponding change in output current as a function of frequency.

4.7.2.2 Test method

Connect the test setup as shown in Figure 32. Adjust the dc load until 90% of rated output current is achieved. Connect remote sense leads to the UUT output. Connect an ac load across the dc load and set the ac modulating current at less than 10% of rated load current. Measure ac output voltage at the same frequency as the ac modulating current and directly at the UUT output. Measure output current at the same frequency as the ac modulating current.

Plot output impedance, $Z_o = V_o/I_o$, over the frequency range of interest. This test is valid for ac or dc inputs UUTs.

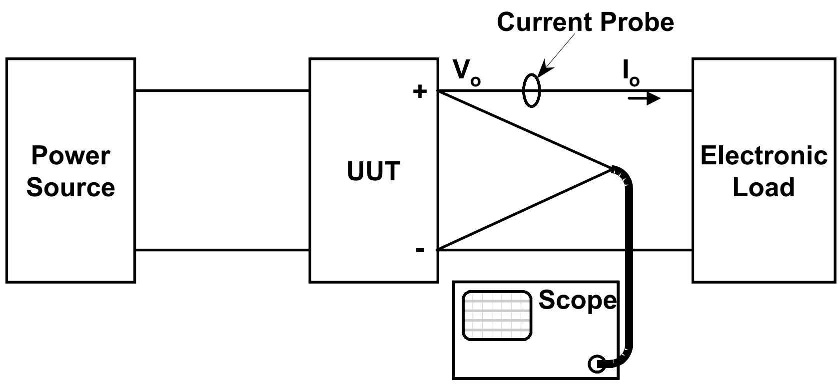


Figure 32—Output impedance test setup

4.7.2.3 Test condition

Adjust input voltage to V_{nom} at UUT. Sweep output load across frequency (range of interest). Total load current should not exceed rated maximum. This is a small signal test, and all waveforms should be sine waves. Test should be performed at minimum, nominal, and maximum temperature conditions.

4.7.3 Input impedance

4.7.3.1 Definition

Input impedance is the change in input voltage divided by a corresponding change in input current as a function of frequency. This test is normally only for dc input units.

4.7.3.2 Test method

Connect the test setup as shown in Figure 33. Adjust the input voltage to the nominal input voltage. Connect an ac source equal to 1% (peak) of the input voltage. Measure ac voltage at the same frequency as the ac source directly at the UUT input. Measure ac input current at the same frequency as the ac source. Plot input impedance, $Z_{in} = V_{in}/I_{in}$, as a function of frequency over the range of 10 Hz to 100 kHz.

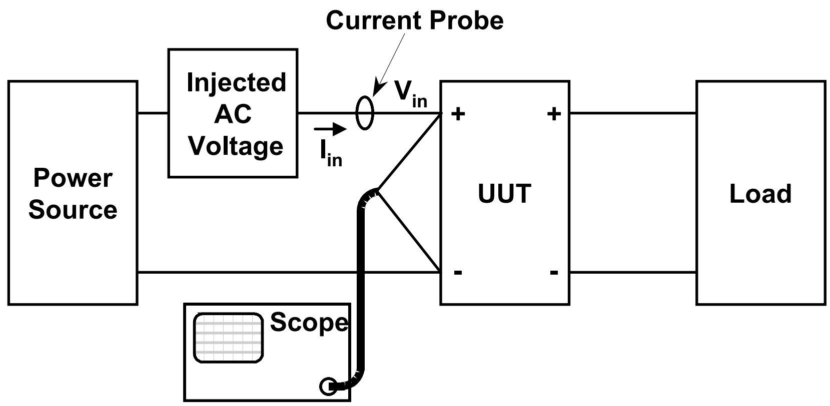


Figure 33—Input impedance test setup

4.7.3.3 Test condition

The UUT should be operating at rated load with nominal voltage on the input. This is a small signal test and all waveforms should be sine waves. The test should be performed at minimum, nominal, and maximum temperature conditions.

4.8 On/Off control

4.8.1 Start-up sequencing/remote on/off control

4.8.1.1 Definition

Start-up sequencing/remote on/off control is the sequence in which a power system's outputs reach their normal operating voltage following application of input power and/or remote on/off control.

4.8.1.2 Test method

Connect the input of the UUT to a power source and connect all outputs to electronic loads, as shown in Figure 34. Connect a storage oscilloscope to monitor all output voltages, and set to trigger from the S_1 at approximately 90% of the nominal output voltage, on a rising edge.

With the UUT operating normally at nominal load on all outputs, switch off the input power using S_1. Allow sufficient time for all outputs to decay to zero, then switch S_1 on again. Observe on the oscilloscope the sequence in which the voltage outputs reach their regulation bands. Check that all voltage outputs rise smoothly to nominal with no unexpected oscillations, excessive overshoots or other anomalies. Repeat this test at minimum input, maximum load and at maximum input, minimum load. Also repeat the test at any other input voltage/load combination that is critical for the application.[7]

If the UUT has a power on/off control input, repeat this test using the control input to confirm that output voltages still rise smoothly in the proper sequence. The exact details will vary depending on the specification of the on/off control input, but are shown conceptually as S_2 in Figure 34.

[7]Some electronic loads may have difficulty operating properly down to a low enough voltage. If necessary, passive loads may be used for this test.

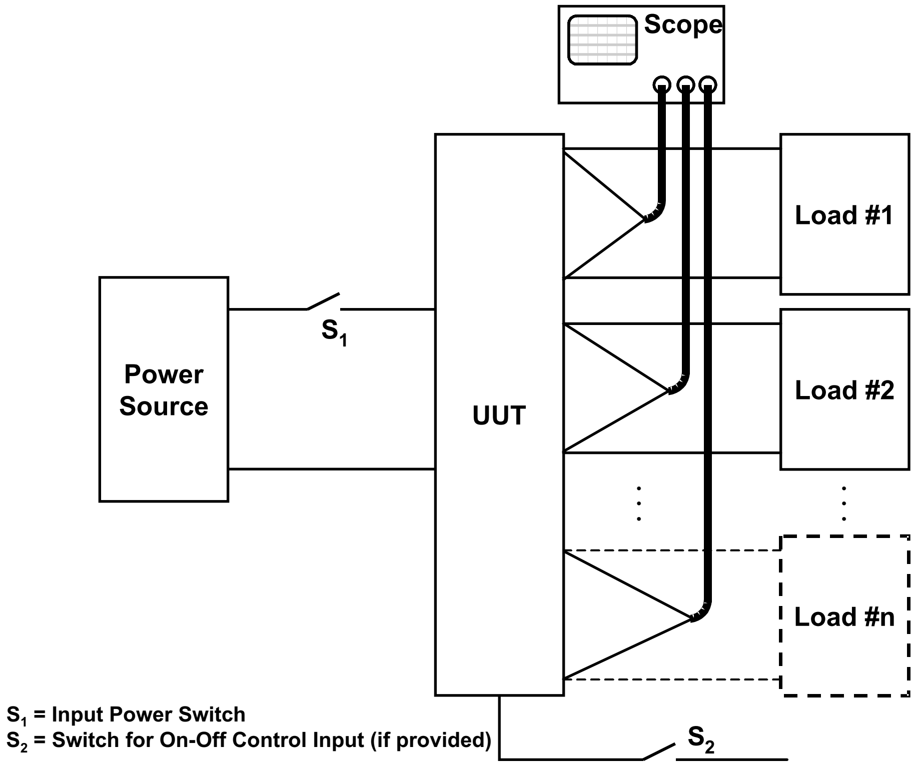


Figure 34—Startup sequencing measurement test setup

4.8.1.3 Test condition

The measurement shall be carried out at room temperature, and repeated at maximum and minimum specified ambient temperature.

4.8.2 Turn-off sequencing/remote on/off control

4.8.2.1 Definition

Turn-off sequencing/remote on/off control is the sequence in which a power system's outputs shut down following removal of input power and/or remote on/off control.

4.8.2.2 Test method

Connect the input of the UUT to a power source and connect all outputs to electronic loads as shown in Figure 34. Connect a storage oscilloscope to monitor all output voltages, and set to trigger from S_2 at approximately 90% of the nominal output voltage, on a falling edge.

With the UUT operating normally at nominal load (resistive) on all outputs, switch off the input power using S_1. Observe on the oscilloscope the sequence in which the outputs drop out of their regulation bands. Check that all output voltages decay in the required sequence to zero with no unexpected oscillations or anomalies.

Repeat this test at minimum input, maximum load and at maximum input, minimum load. Also repeat the test at any other input voltage/load combination that is critical for the application.[8]

If the UUT has a power on/off control input, repeat this test using the control input to confirm that output voltages still decay smoothly in sequence. The exact details will vary depending on the specification of the on/off control input, but are shown conceptually as S_2 in Figure 34.

4.8.2.3 Test condition

The measurement shall be carried out at room temperature, and repeated at maximum and minimum specified ambient temperature.

4.8.3 Input turn-on, input under voltage lock-out, and hysteresis

4.8.3.1 Definitions

Input turn-on is the input voltage at which the UUT starts when the input voltage is rising from zero (or from below the operating range).

Input under voltage lock-out (UVLO) is the voltage at which the UUT shuts down when the input voltage is falling from within the operating range.

Hysteresis is the difference between the threshold voltage for the UVLO and the threshold voltage for turn-on.

4.8.3.2 Test method

Connect the input of the UUT to a power source and connect the output to an electronic load, as shown in Figure 35. Monitor the output voltage across the load with an oscilloscope.

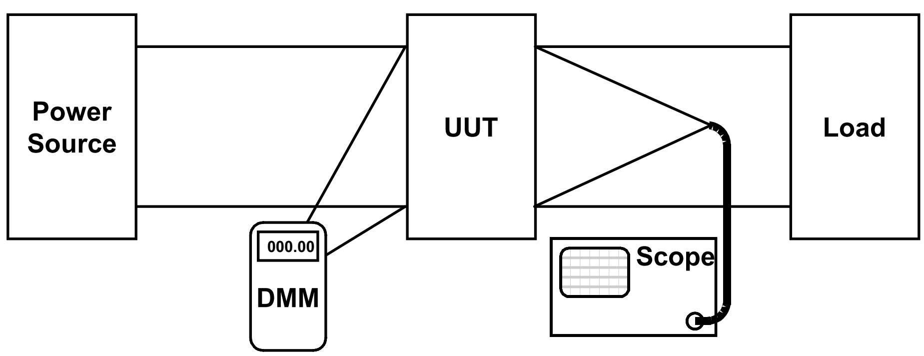


Figure 35—Low input shutdown and hysteresis measurement test setup

With the UUT operating at nominal input voltage and load current, slowly reduce the input voltage until the UUT shuts down (output voltage decays to zero). Repeat several times to find the exact trip point, and record the shutdown voltage. Slowly raise the input voltage until the UUT restarts, and record the restart voltage.

Calculate the hysteresis by finding the difference between the shutdown (UVLO) and restart (turn-on) voltages.

[8]Some electronic loads may have difficulty operating properly down to a low enough voltage. If necessary, passive loads may be used for this test.

4.8.3.3 Test condition

The measurement shall be carried out at room temperature, and repeated at maximum and minimum specified ambient temperature. For forced-air-cooled systems, the test set-up must include a means for providing the specified airflow.

4.9 Isolation and grounding

4.9.1 AC leakage current

4.9.1.1 Definition

AC leakage current is the current that is the difference between the positive and return current in a two-wire distribution system.

4.9.1.2 Test method

Connect the test setup as shown in Figure 36. One current probe is attached to monitor the positive input line and one current probe is attached to monitor the return line. The difference between the two measurements is the ac leakage current. Current probes for this test must be capable of measuring dc and ac current. The purpose of this test is to verify that return currents are not circulated through chassis ground.

Alternatively, a single current probe can be connected in common-mode configuration to enable more accurate differential measurements, especially for high dc load circuits.

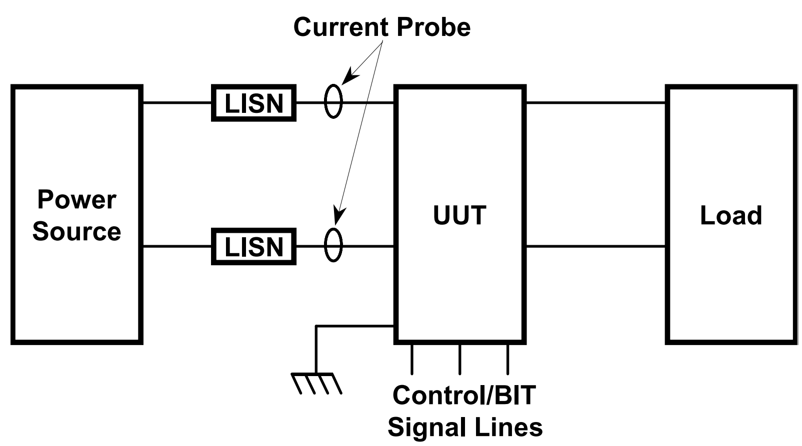


Figure 36—AC Leakage current test setup

4.9.1.3 Test condition

Allow the unit to reach steady-state operation after power-up. Operate at nominal input voltage and maximum output current.

4.9.2 Input-Output isolation resistance

4.9.2.1 Definition

Input-Output isolation resistance is the dc resistance, at the specified withstanding voltage, measured from the UUT's input to its output.

4.9.2.2 Test method

Connect the UUT input leads together, connect the output leads together. Isolate the chassis/case/baseplate from all conductive surfaces. Apply the specified voltage between the input and output leads. Measure the resistance or current as applicable.

4.9.2.3 Test condition

Test conditions should be in compliance with applicable standard(s) such as UL 1950-1997.

4.9.3 UUT grounding

4.9.3.1 Definition

UUT grounding is the dc resistance measured from the input UUT return to chassis ground or the UUT output(s) returns to chassis ground.

4.9.3.2 Test method

The isolated returns at the input and/or output shall be measured from the chassis to return(s). Measurements should be made with an ohmmeter capable of measuring in the milliohm range.

4.9.3.3 Test condition

V_{in} = Off
Loads = None
Temperature = +25°C

4.10 Distortion

4.10.1 Individual harmonic content (voltage or current)

4.10.1.1 Definition

The individual harmonic content is the voltage or current, as applicable, at a given harmonic frequency, expressed as a percentage of the fundamental. Equation (17) provides the formula for defining individual harmonic content (IHC). The variable X represents voltage or current, and may be expressed as a percent rms value or a peak value. The fraction expresses the amount of distortion at the n^{th} harmonic.

$$IHC_x = \frac{X_n}{X_1} \times 100 \qquad (15)$$

where

X_1 is the fundamental value of current or voltage,
X_n is n^{th} harmonic value of current or voltage.

4.10.1.2 Test method

When placed into the test setup of Figure 37 (single phase) or Figure 38 (three phase) with a solid state ac power source and distortion analyzer, the UUT's input current distortion spectrum (magnitude and frequency values) shall be measured and compared to allowed limits. A low impedance and low THD ac power source must be utilized.

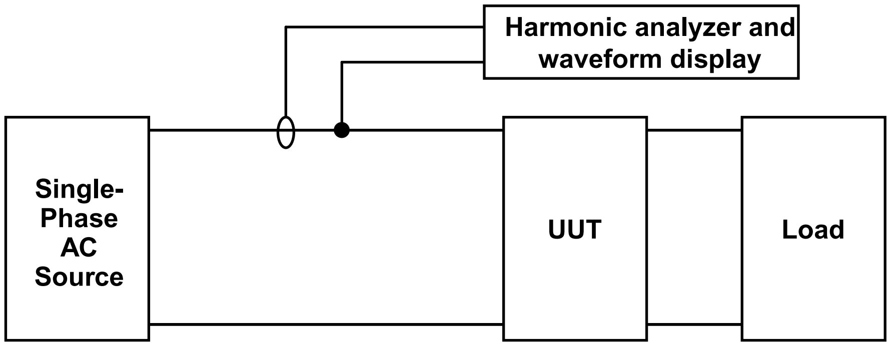


Figure 37—Single-phase UUT input current harmonics test setup

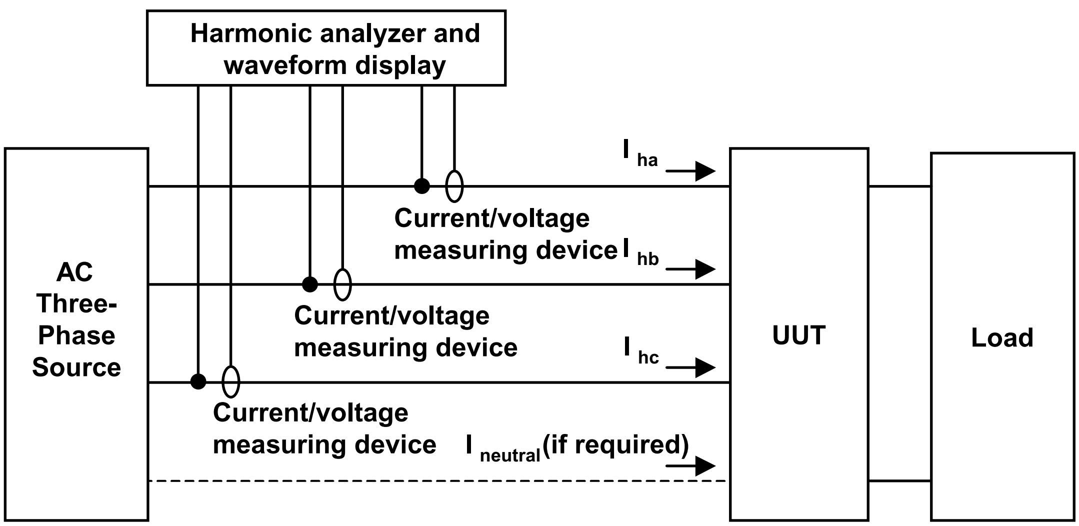


Figure 38—Three-phase UUT input current harmonics test setup

4.10.1.3 Test condition

All equipment shall be tested with their intended load and for all modes of operation. (For example, ballasts for fluorescent and other discharge lamps shall be tested with their intended lamp combination(s) for bright, dim, off, and other modes of operation.) Test conditions may be limited to those known to produce the worst case input current distortion.

Current harmonic measurements shall be performed in accordance with Figure 39 and Figure 40. Current measuring devices shall have an amplitude error of less than 3% and phase error of less than 5° for all frequencies up to 50 kHz.

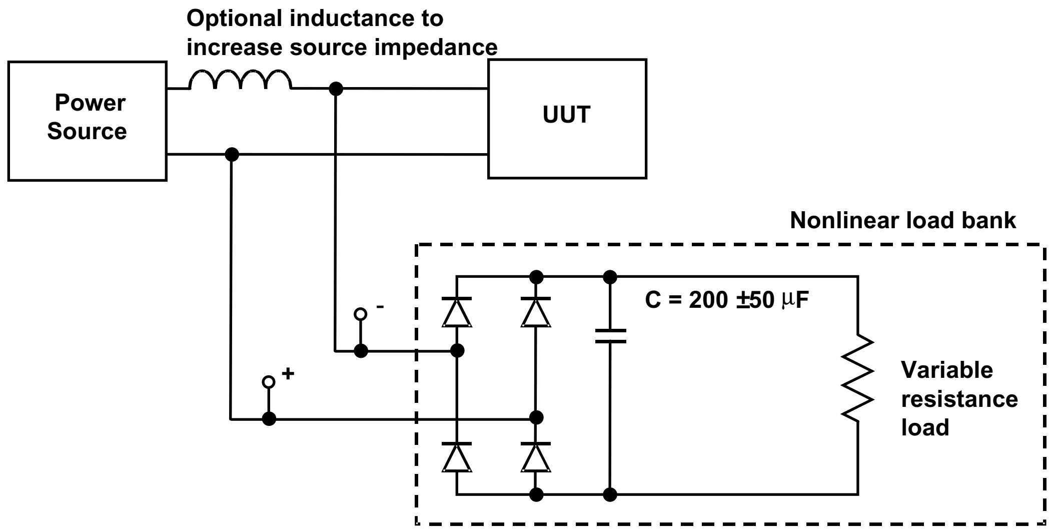


Figure 39—Single-phase UUT input current harmonics test setup

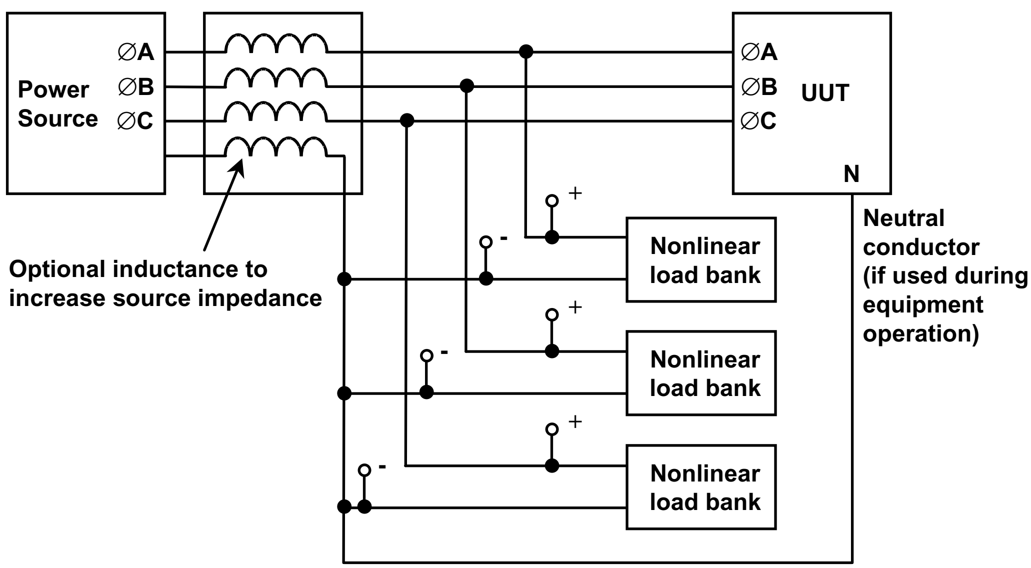


Figure 40—Three-phase UUT input current harmonics test setup

Disregard harmonic currents less than 5 mA, or less than 0.25% of the fundamental, whichever is greater.

For equipment that have multiple modes of operation and draw power at different levels depending on the mode of operation, I_n is the maximum harmonic current of order n which is obtained for all modes of operation, and I_1 is the rated fundamental, i.e., the maximum fundamental current obtained for all modes of operation.

Harmonic analysis equipment shall have the capability of sufficiently high sampling rate, sufficiently long time window, appropriate window functions and anti-aliasing filters so that the resulting error in harmonic current measurement is less than 5% of the permissible limit, and the resulting frequency spectrum shall have a resolution of less than 20 Hz. As a guideline, the following test features should be considered:

a) A sampling rate of 100 kHz or higher should be used.

b) A time window of 0.05 seconds or longer should be used.

c) An anti-aliasing filter with a corner frequency within 25 kHz to 100 kHz should be used.

d) Either Rectangular, Hanning, Hamming, or Blackman-Harris windowing should be used.

The equipment shall be tested under two conditions of input voltage distortion. In both cases, the equipment shall be supplied by a source having a voltage within 2% of nominal and a frequency that is within 1% of a nominal constant frequency or of the upper and lower frequency bounds of a variable frequency source. The supply voltage and frequency shall remain constant within these limits while measurements are made.

Test condition a)—In this test, the THD of the voltage at the input terminals of the equipment shall be less than 1.25% during all test conditions. (The output impedance of the source at each measured frequency shall be sufficiently low to keep V_{THD} at the input of the UUT below 1.25%.)

Test condition b)—In this test, the THD of the voltage at the input terminals of the equipment shall be greater than or equal to 5% (V_{THD} > 5%) during all test conditions. The voltage distortion may be produced via a full-wave rectifier bridge as shown in Figure 39. The level of voltage distortion can be controlled by varying the load on the rectifier(s), and insertion of source impedance in the line. Alternatively, input voltage to the UUT may be distorted by clipping the supply voltage as shown in Figure 40.

4.10.2 Harmonics

4.10.2.1 Definition

Harmonics are sinusoidal voltage or current components (distortion) of a periodic waveform that occur at a frequency that is an integer multiple of the fundamental frequency.

Most non-linear loads generate odd-numbered harmonics, for example, as a result of full wave rectification of the input power. The frequencies at which these *characteristic harmonics* are produced by a user with an input rectifier can be determined by the following equation:

$$f_H = (k \cdot q \pm 1) \times f_1 \tag{16}$$

where

f_H is the characteristic harmonic (e.g., the *third harmonic* when H = 3),
H is the number of the harmonic,
k is an integer, beginning with 1,
q is an integer, representing the number of rectifier commutations per cycle,
f_1 is the fundamental frequency.

Half-wave rectification produces even-numbered harmonics that cause very undesirable results (e.g., dc content) in the ac power system. Full wave rectification at the input of single-phase power loads results in *triplen* harmonics at odd multiples of three times the fundamental frequency. These are also very undesirable, considering the potential quantity of single-phase loads and the fact that these harmonics interact with the distribution system's normally high zero sequence impedance. Therefore, user distortion current requirements are intentionally restrictive for even and triplen harmonics.

4.10.2.2 Test method

See 4.10.1.2.

4.10.2.3 Test condition

See 4.10.1.3.

4.11 Conducted emissions

A complete discussion of EMI parameters and tests is beyond the scope of this recommended practice. Prevalent specification(s) or standard(s) should be used. However, the tests listed in 4.11.1 and 4.11.2 are recommended before formal EMI testing.

4.11.1 Common-mode current

4.11.1.1 Definition

Common-mode current is the algebraic sum of the supply and return currents of the UUT referenced to earth ground (ground table).

4.11.1.2 Test method

Connect the setup as shown in Figure 41. This test can be performed on the input or output of the power supply. One current probe is attached to encompass the positive and return lines of the output. A spectrum analyzer is used for each measurement. The UUT will be tested in the modes that produce the most emissions. If the UUT has multiple outputs, connect as shown in Figure 42 with the current probe encompassing all outputs and return lines.

Refer to Figure 43 when assembling the bench set-up.

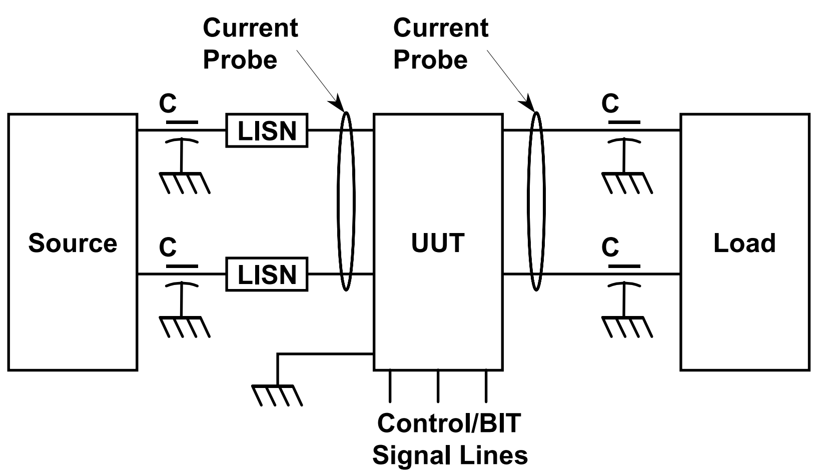


Figure 41—Common-mode current test setup for single output

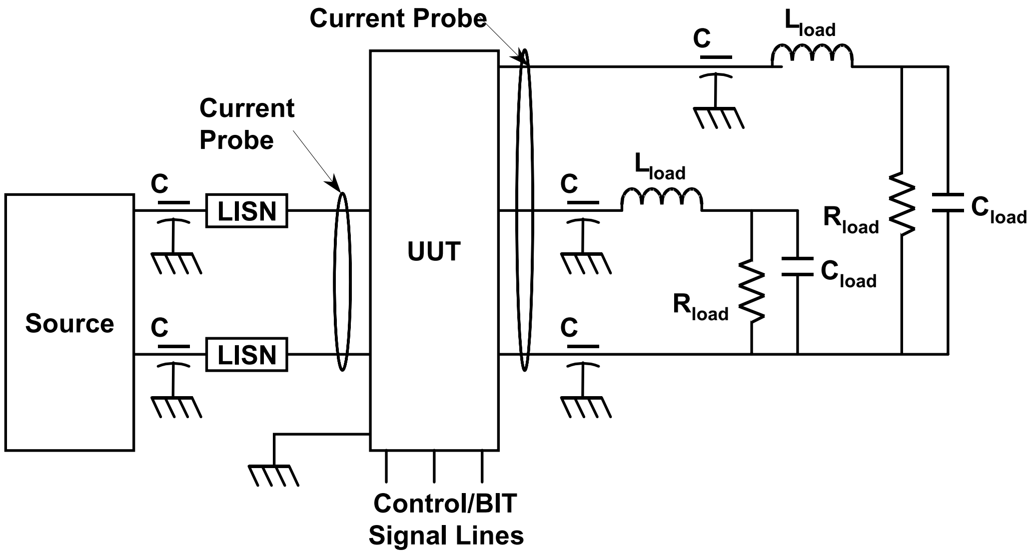


Figure 42—Common-mode current test setup for multiple outputs

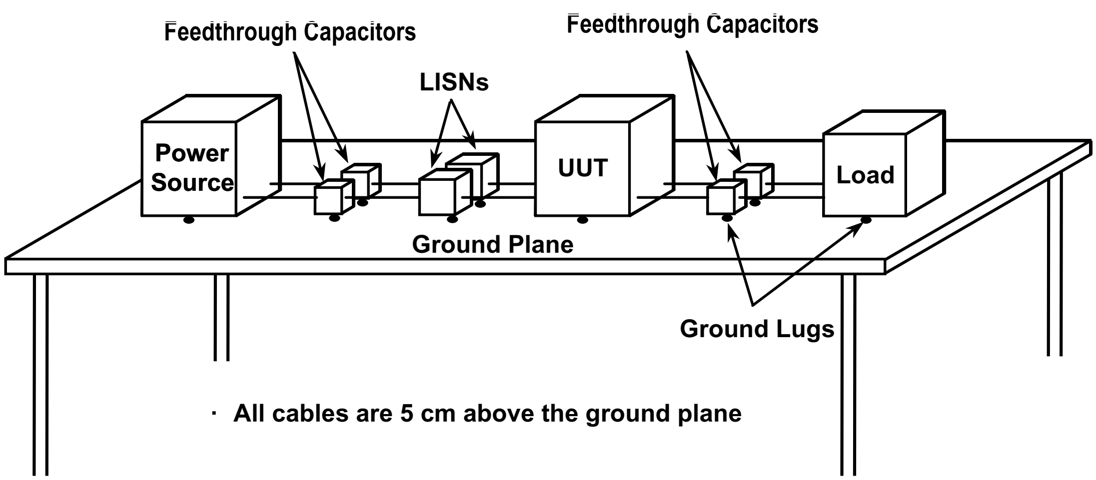


Figure 43—Conducted emissions bench test setup

4.11.1.3 Test condition

The UUT will be tested in the modes that produce the most emissions.

4.11.2 Differential-mode current

4.11.2.1 Definition

Differential-mode current is the current produced by equal and opposite currents in the supply and return line. Differential current is referenced from line-to-line, not from earth-to-ground.

4.11.2.2 Test method

This test measures the differential current emitted by the UUT. Connect the setup as shown in Figure 44. Power lines and their returns should be tested for differential current. A spectrum analyzer is used for each measurement. This test can be performed on either the input or output. Refer to Figure 43.

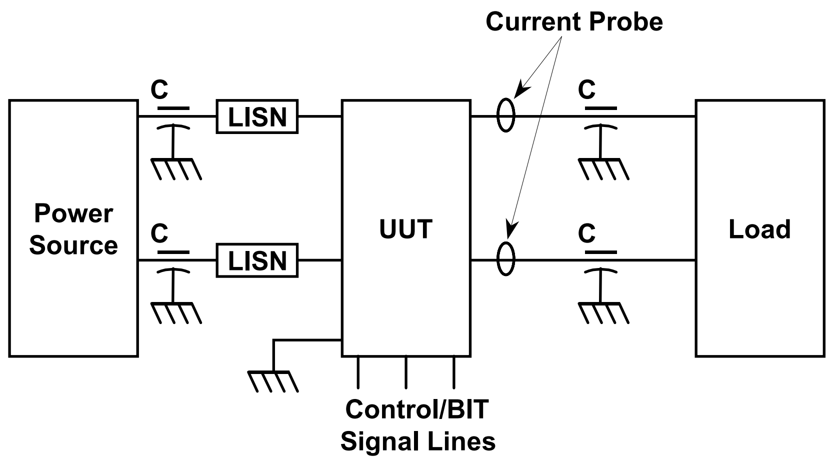


Figure 44—Differential-mode current test setup

4.11.2.3 Test conditions

Adjust the input voltage and output load to nominal specified levels. Ambient operating temperature should be nominal.

4.11.3 Signal line emissions

4.11.3.1 Definition

Signal line emissions is the conducted electrical interference and noise on the control and monitor lines.

4.11.3.2 Test method

Connect the setup as shown in Figure 45. One current probe is attached encompassing all signal lines attached to the UUT (if the signal lines have a different return than the power return, it should also be included). A spectrum analyzer is used for each measurement.

Terminations and driving sources should mirror the application as closely as possible. All operating and control conditions (power on, power off, power inhibit, etc.) should be tested. (See Figure 46.)

4.11.3.3 Test conditions

Operate the UUT at full load and nominal input voltage. Plot a graph of emission amplitude vs. frequency. Use an insulating material to raise all cables 5 cm above the ground plane. For repeatability and standardization, the current measurement probe should be placed 5 cm from the UUT. Place the measurement probe as close to the UUT as possible if it cannot be placed 5 cm from the UUT (due to physical interference of the UUT's shape or chassis).

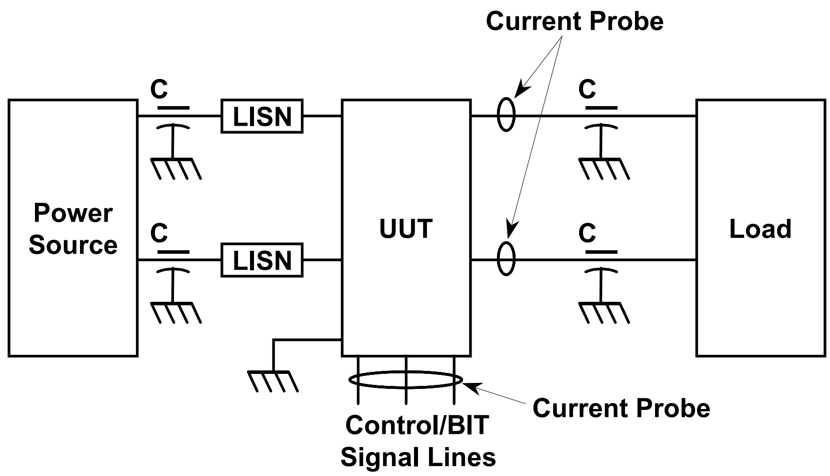


Figure 45—Conducted signal line emissions test setup

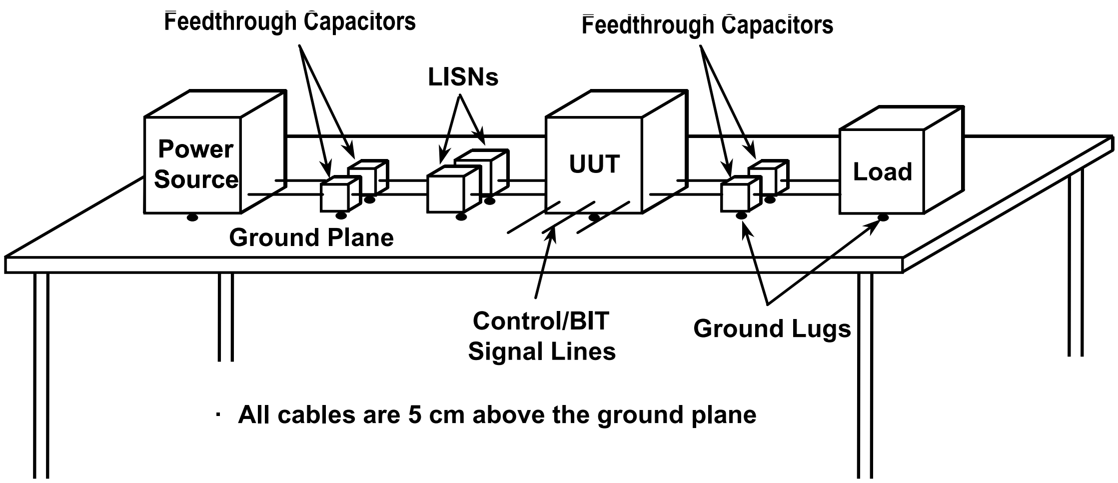


Figure 46—Conducted signal line emissions bench test setup

4.12 Susceptibility

4.12.1 Differential conducted susceptibility

4.12.1.1 Definition

Differential conducted susceptibility is the ability of a device to operate correctly while being subjected to differential conducted electrical interference.

4.12.1.2 Test method

This test is administered on the input power lines of the UUT while monitoring the output and BIT signal lines. A current injection probe is used to apply the 10 kHz to 100 MHz signal for the differential test. The calibration procedure for this test is similar to the calibration procedure for common-mode susceptibility. Set up the test system as shown in Figure 47. Set the signal generator to 10 kHz, unmodulated. Increase the applied signal until spectrum analyzer A indicates the current level specified. Record the *forward power* to the injection probe indicated on spectrum analyzer B. Scan the frequency band while recording forward power on spectrum analyzer B and maintaining the specified power amplitudes on spectrum analyzer A from 10 kHz to 100 MHz. The forward power plot will be used to establish the test level for the susceptibility evaluation test. The spectrum analyzers require a resolution bandwidth of at least 3 kHz (10 kHz recommended) and a video bandwidth of at least 30 kHz should be used. The spectrum analyzer is a peak responding rms calibration device. Substitute an oscilloscope when testing frequencies below the spectrum analyzer's bandwidth.

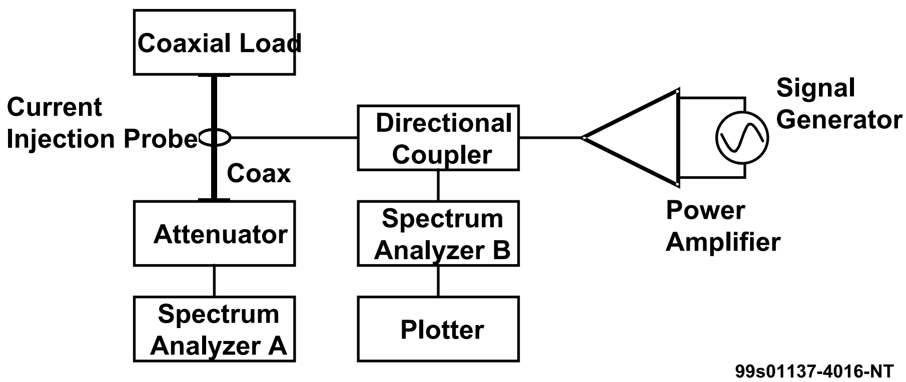


Figure 47—Current probe injection calibration

Connect the equipment as shown in the test setup in Figure 48 for the differential susceptibility testing. The output of the UUT is monitored for ripple and distortion. The BIT outputs from the UUT should also be monitored for alarms. Refer to Figure 46 for bench test setup.

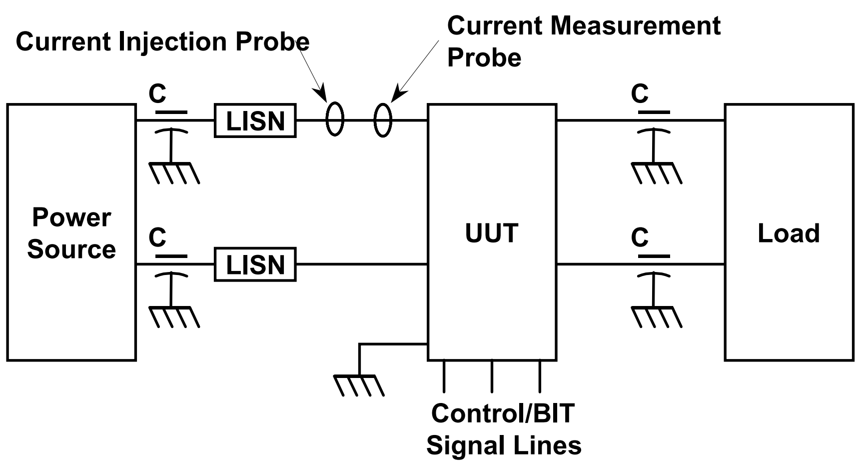


Figure 48—Differential conducted (current probe injection) susceptibility test setup

The following sweep rates shall be used as a baseline. If susceptibility is difficult to detect, a slower rate may be required. Once again substitute an oscilloscope for a spectrum analyzer when measuring frequencies below its detection range. Plot power required to cause improper performance of the UUT vs. frequency (listed in the table below) to illustrate the susceptibility of the UUT.

Frequency	Sweep rate
10 kHz to 1 MHz	1 kHz/sec
1 MHz to 30 MHz	10 kHz/sec
30 MHz to 100 MHz	150 kHz/sec

4.12.1.3 Test condition

The UUT shall be operated in the mode that it is most susceptible to conducted noise. This includes, but is not limited to, changing the input voltage, load value, etc. Plot a graph of amplitude vs. frequency that the UUT is able to operate without errors or degraded output. If a susceptibility error is observed, determine and record the threshold and frequency at which the undesirable response is no longer present.

4.12.2 Common-mode conducted susceptibility

4.12.2.1 Definition

Common-mode conducted susceptibility is the ability of a device to operate correctly while being subjected to common-mode conducted electrical interference.

4.12.2.2 Test method

Connect the test setup as shown in Figure 49. A current injection probe is used to couple the *noise* on the input power lines of the UUT. The current probe is calibrated with the same techniques used for the differential-mode susceptibility test. Plot the power required to cause improper performance of the UUT vs. frequency to illustrate the susceptibility of the UUT. (Refer to Figure 46 for bench test setup.)

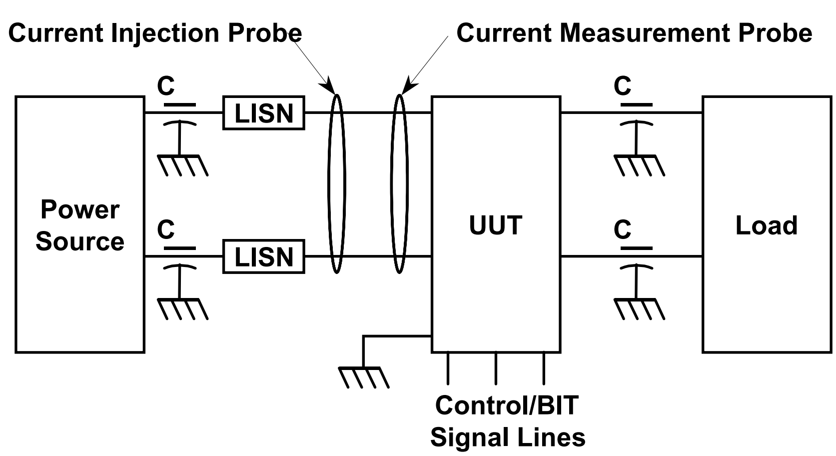


Figure 49—Common-mode conducted susceptibility test setup

4.12.2.3 Test condition

The UUT shall be operated in the mode that it is most susceptible to conducted noise. This includes, but is not limited to, changing the input voltage from V_{min} to V_{max}, load value of I_{min} to I_{max}, etc. Plot a graph of amplitude vs. frequency that the UUT is able to operate without errors or degraded output. If a susceptibility error is observed, determine and record the threshold and frequency at which the undesirable response is no longer present. Perform on the UUT input over the 10 kHz to 50 MHz range.

4.12.3 Load susceptibility

4.12.3.1 Definition

Load susceptibility is the distortion of the input current when active step loads are introduced.

4.12.3.2 Test method

Connect the setup as shown in Figure 50. A current probe is attached to the output to first calibrate the current source to the specified level and then measure the output current. An oscilloscope is used to measure the output current. Another current probe is attached to the input power line to measure the effect of the active load. A spectrum analyzer is used to monitor the input. Plot the attenuation in dB of the output load/input current ripple vs. frequency to illustrate the performance of the UUT. This test is only necessary for power supplies intended to drive dynamic loads.[9] Refer to Figure 46 when setting up for bench test.

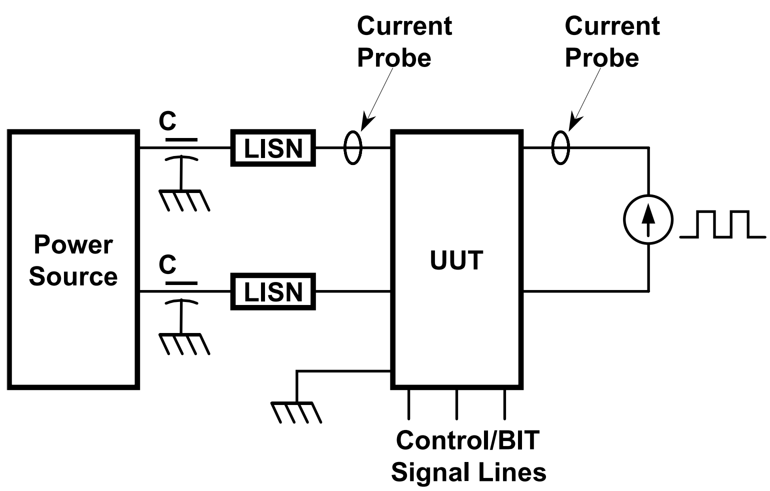


Figure 50—Load susceptibility test setup

4.12.3.3 Test condition

At nominal line input voltage, the output current load is varied as specified (typically 80–100%) at rates much lower than the switching frequency of the UUT. The frequency of the load is swept from dc to the maximum frequency that this load is designed to handle on its output. The rise and fall times of the dynamic load will be less than 5% of the period at a given frequency.

[9]The intent of this test is to measure the effect a varying load produces on the input. Since the measurement is a ratio of input and output current, an output current variation can be scaled to an input current variation.

4.12.4 Signal line susceptibility

4.12.4.1 Definition

Signal line susceptibility is the amount of electrical interference the control and monitor lines can withstand before the UUT fails to operate correctly.

4.12.4.2 Test method

Connect the setup as shown in Figure 50. A current measurement probe is attached to the signal line to calibrate the current source to the specified level. Record the results on the data sheets showing scanned frequency ranges and statements of compliance. Refer to Figure 46 for bench setup. Use an insulating material to raise all cables 5 cm above the ground plane. For repeatability and standardization, the current measurement probe should be placed 5 cm from the UUT. Place the measurement probe as close to the UUT as possible if it cannot be placed 5 cm from the UUT. The current injection probe should be placed 5 cm from the current measurement probe. The signal lines should be terminated as designed, and documented in a test report.

4.12.4.3 Test conditions

The UUT shall be operated in the mode that it is most susceptible to conducted noise. This includes but is not limited to changing the input voltage, load value, etc. Plot a graph of amplitude vs. frequency that the UUT is able to operate without interference on the signal lines to produce errors or degraded output. If a susceptibility error is observed, determine and record the threshold and frequency at which the undesirable response is no longer present.

4.12.5 Audio susceptibility

4.12.5.1 Definition

Audio susceptibility is the effect on a power converter output when audio frequency noise is superimposed on the input power source.[10]

4.12.5.2 Test method

Connect the input of the UUT to a low-impedance power source and connect the UUT output to the load, as shown in Figure 51. Connect a suitable transformer in series with the power source, with the transformer primary connected to an audio frequency generator. Use an oscilloscope to monitor the ac component of the input voltage, with a second probe to measure the resulting ac component of the UUT output voltage. Switch on the power source.

Set the signal frequency generator to 1 kHz and adjust its output. Measure the rms value of the output ripple voltage at the frequency of the audio generator, and record the input and output ripple voltage waveforms. (Both input and output voltage waveforms should be approximately sinusoidal. If not, the amplitude may be reduced, or else a different transformer and/or audio generator may be required.)

Audio susceptibility is determined by dividing the output ripple voltage by the input ripple voltage, and expressing the result in decibels.

Repeat the measurement over a range of audio frequencies of interest of the UUT.

[10]In this context, “audio frequency” means any frequency significantly lower than the switching frequency of the UUT. This test is used to measure the ability of the UUT to suppress input voltage noise.

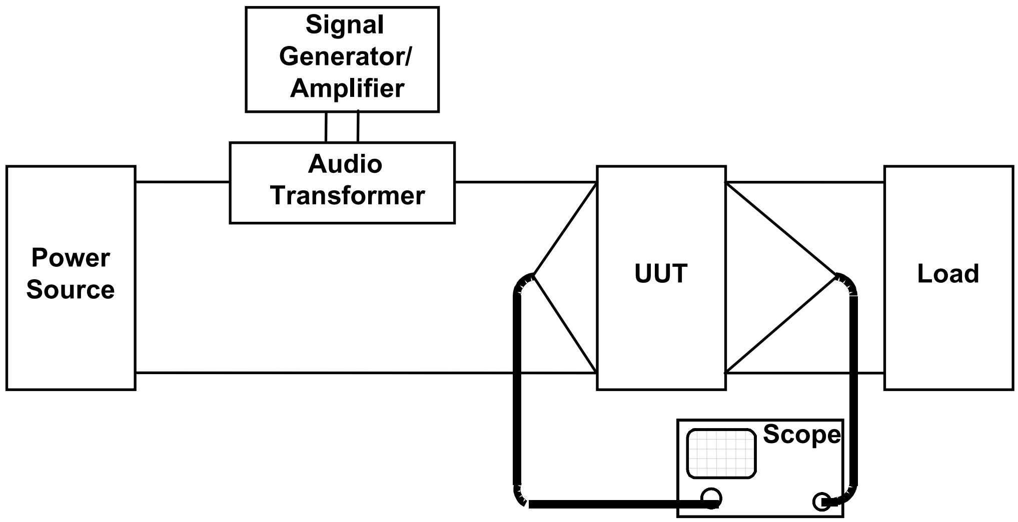


Figure 51—Audio susceptibility measurement test setup

4.12.5.3 Test condition

Set the dc input voltage and load current to nominal specified for the UUT.

The measurement shall be carried out at room temperature, and repeated at maximum and minimum specified ambient temperature. For forced-air-cooled systems, the test set-up must include a means for providing the specified airflow.

4.12.6 C-Message noise

4.12.6.1 Definition

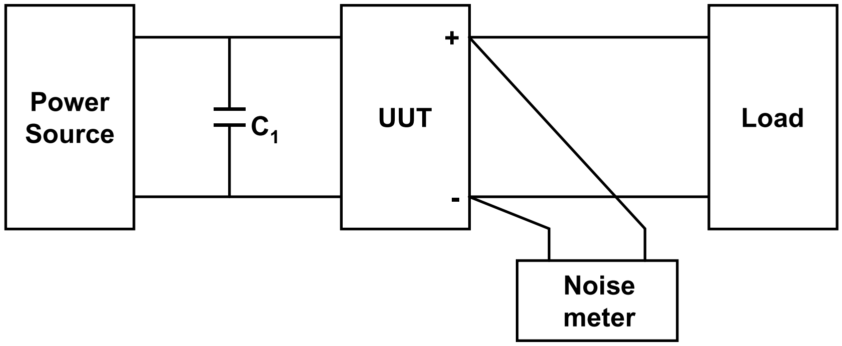
C-Message noise[11] is a noise level in decibels measured using a *C-weighted* filter, and indicated as dBrnC, where 0 dBrnC = –80 dBm.

4.12.6.2 Test method for output C-Message noise

Connect the input of the UUT to a power source and connect the output to an electronic load[12] as shown in Figure 52. Connect a noise meter with C-weighting filter across the output. Switch on and observe the noise level. Slowly vary the input voltage and load current within the normal operating range, and record the highest noise level indicated.

[11]The measurement of C-Message noise is used to characterize those telecommunications power systems in which the noise level may affect the analog voice circuits. The C-weighted filter has a pass band of 300 Hz to 3500 Hz, and is intended to reflect the sensitivity of the human ear. The filter characteristics are fully defined in a Bellcore standard. In European applications, C-Message noise is referred to as Psophometric Noise, and is measured using a Psophometer (a noise measuring instrument with a filter similar to the C-weighted filter.) The test method is the same.

[12]Some electronic loads may produce significant levels of noise, which can affect the result of this test. If necessary, passive loads may be used.

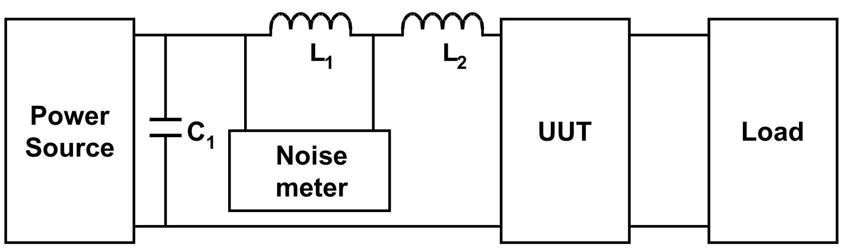


C_1 = 30,000 µF, low ESR
Noise Meter Input Impedance = 600 ohms

Figure 52—Input C-Message measurement test setup

4.12.6.3 Test method for Input C-Message noise

Connect the input of the UUT to a power source through the L-C network as shown in Figure 53. Connect a noise meter with C-weighting filter across the L-C network as shown. Switch on and observe the noise level. Slowly vary the input voltage and load current within the normal operating range, and record the highest noise level indicated.



L_1 = 3 µH
L_2 = 12 µH
C_1 = 30,000 µF, low ESR
Noise Meter Input Impedance = 600 ohms

Figure 53—Input C-Message measurement test setup

4.12.6.4 Test condition

Slowly vary the input voltage and the output load current over the specified limits. The measurement shall be carried out at room temperature, and repeated at maximum and minimum specified ambient temperature. For forced-air-cooled systems, the test set-up must include a means for providing the specified airflow.

4.12.7 Input wideband noise

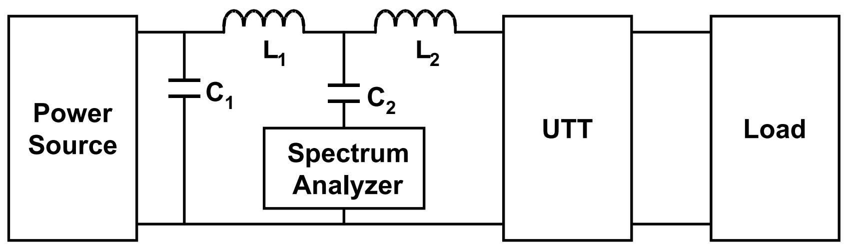
4.12.7.1 Definition

Input wideband noise[13] is the noise fed back to the power source due to the operation of an item of telecommunications equipment.

[13]Wideband noise is tested for telecommunications equipment that operates from the standard 48 V_{dc} power system, and is intended to limit the total noise level imposed onto the power system bus.

4.12.7.2 Test method

Connect the UUT as shown in Figure 54. Set the spectrum analyzer bandwidth to 3 kHz, frequency range 10 kHz to 20 MHz, and input amplitude measurement to linear. Switch on and measure the noise level, observing the highest peak on the spectrum analyzer. Slowly vary the input voltage and load current within the normal operating range, and record the highest noise level indicated.



L_1 = 3 μH
L_2 = 12 μH
C_1 = 30,000 μF, low ESR
C_2 = 10 μF
Spectrum Analyzer Input Impedance = 50 ohms

Figure 54—Input wideband noise test setup

4.12.7.3 Test condition

Slowly vary the input voltage and the load current over the specified limits. The measurement shall be carried out at room temperature, and repeated at maximum and minimum specified ambient temperature. For forced-air-cooled systems, the test set-up must include a means for providing the specified airflow.

4.13 Use of multiple power supplies in a system

4.13.1 Use of multiple units

4.13.1.1 Definition

The use of a number of devices or modules to provide continued operation, following most failures in a single device or module.

Multiple devices are also used to obtain higher output voltage/current to sustain higher input voltage/current, or simply, to boost power handling capability of the subsystem.

4.13.2 Redundancy

4.13.2.1 Definition

Redundancy is the duplication of elements in a system installation for the purpose of enhancing the reliability or continuity of operation of the system or installation.

4.13.3 Current sharing

4.13.3.1 Definition

Current sharing is the ability for multiple (two or more) paralleled modules or subsystems to share the load requirements of the system. Current sharing is often done equally (or $1/n$ of the total load) where n is the number of sharing modules or subsystems. The manufacturer shall specify the current sharing method and the level of accuracy by stating (in percent) the worst case deviation from equal current sharing. The worst case deviation from equal current sharing in percent, is defined as

$$max\left\{\frac{\left|I_j - \frac{I_L}{n}\right|}{\frac{I_L}{n}}\right\} \cdot 100 \tag{17}$$

where

I_L is the total output current,
n is the number of paralleled modules,
I_j is the current supplied by the j^{th} module, $j = 1, \ldots, n$.

4.13.3.2 Test method

Use the test setup shown in Figure 55 to measure for current sharing in each UUT.

4.13.3.3 Test condition

The input voltage to each UUT is adjusted to nominal. Adjust the load current, I_L, from a specified minimum to maximum value and measure each UUT output current.

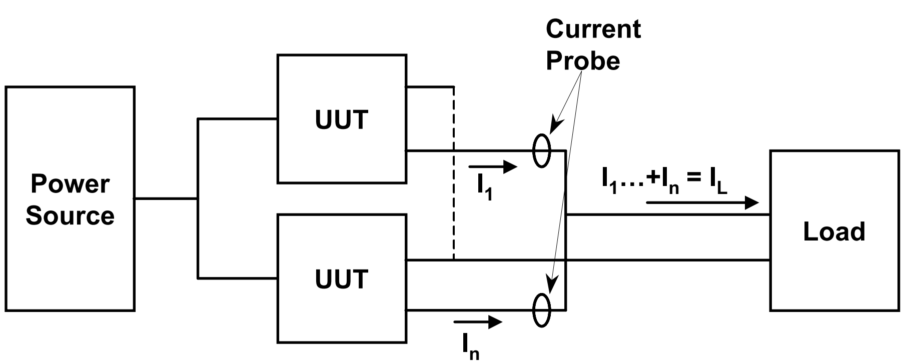


Figure 55—Current sharing test setup

4.14 Adjustments and control

4.14.1 Control inputs

4.14.1.1 Definition

Adjustments and control are signal lines (ports) added to a power supply to alter its operation. These are often application specific. Examples of control inputs are as follows:

a) Remote on/off control
b) Voltage trim
c) Override of an overtemperature shutdown sequence
d) Circumvention of effects in nuclear applications

4.14.2 Voltage trim

4.14.2.1 Definition

Voltage trim is a feature that allows for adjustment of the power supply output voltage.

4.14.2.2 Test method

For resistive trimming, connect the test setup as shown in Figure 56. The variable resistance should have a resistive range as recommended by the power supply manufacturer. Connect the resistor across the pins associated with the variable voltage function. Adjust the resistor value to maximum and record the output voltage as measured by the digital multimeter (DMM). Repeat with the resistor value set to the minimum value.

Verify that the maximum and minimum output voltage readings are within prescribed limits.

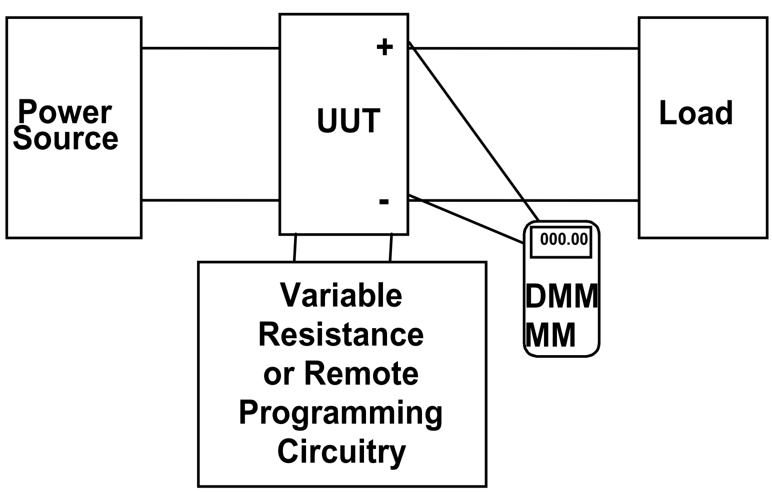


Figure 56—Voltage trim and remote programming test setup

4.14.2.3 Test condition

The input voltage and the output load current for the UUT should be set to nominal conditions. Operating temperature should also be at nominal conditions.

The thermal design needs to be checked to make sure it is sufficient over the specified range of output voltage.

4.14.3 Remote programming

4.14.3.1 Definition

Remote programming is the ability to program the output voltage by applying either an analog or digital signal to the programming port of the power supply. The output current could also be controlled in a similar manner.

4.14.3.2 Test method

For voltage programming, connect the test set up as shown in Figure 56. Send a command signal to the power supply with the remote programming circuitry that requests the maximum programmed voltage and record the output voltage as measured by the DMM. Again, send a command signal to the UUT that requests the minimum output voltage and record the output voltage as measured by the DMM.

Verify that the programmed quantities are within the expected values.

4.14.3.3 Test condition

See 4.14.2.3.

4.14.4 Remote sense

4.14.4.1 Definition

Remote sense is detection by the UUT of the load voltage at a remote point from the UUT, which enables the UUT to regulate output voltage and to compensate for the voltage drop across the power cables.

4.14.4.2 Test method

Connect wires from remote sense terminals +S, –S on UUT in parallel with output cables directly across the remote load. Use the test set up as shown in Figure 57.

4.14.4.3 Test condition

The initial test should be performed at input V_{nom} and output I_{max}. While comparing the voltage measured at the UUT with the voltage measured at the load, adjust the power output cables (gauge and length) so as to impose a measurable voltage drop ($V_{out} - V_{load}$). Ensure that the measured difference does not exceed the maximum allowable voltage specified. Adjust input voltage from V_{min} to V_{max} and while monitoring V_{load}. Confirm that the voltage measured at the load is within the regulation limits as detailed in the power supply data sheet. If voltage trim is an available feature, verify that V_{load} can be adjusted over the maximum specified range.

With the remote sense leads connected to the load, measure the voltage at the load, V_L, and at the UUT V_o. Confirm that the measured voltage is within the limits as detailed in the power supply data sheet. Measure the voltage at terminals +S and –S and compare the measured voltage with that recorded at the load. The voltage across +S, –S should be higher than that of the load voltage by approximately the limit detailed in

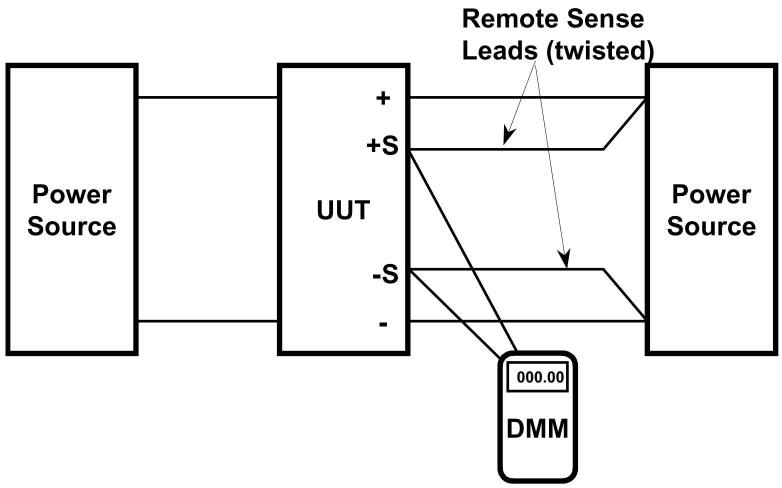


Figure 57—Remote sense measurement test setup

the power supply data, verifying that the remote sense circuit is operating. If voltage trim is an available feature, verify that the voltage (at the load) can be adjusted to the maximum specified value.

4.15 Fault protection

As a result of source or load fault conditions the power supply may shut down by means of its internal self-protection circuitry. The most common shutdown modes are either overcurrent, overvoltage, or overtemperature.

4.15.1 Recovery time

4.15.1.1 Definition

Recovery time is the time required to reestablish normal output operating conditions after removal of the associated load fault. Recovery time is commonly defined relative to a predetermined error band, allocated as a percentage of the normal steady state operating condition. Since the recovery characteristic can be oscillatory, the specified recovery time ends when the output returns to within the specified error band for the last time.

This applies only to non-latching power supplies.

4.15.1.2 Test method

With the test setup as shown in Figure 58, set the oscillator to the required frequency and duty cycle. This may be a single event or repetitive, and must allow sufficient time for recovery before repeating the cycle. The load fault simulator is to be set equivalent to the maximum expected fault condition, less the amount of the normal load that is present. This may be an overcurrent condition or a short, as desired. The load fault simulator must be non-inductive to avoid erroneous results. With the solid state switch activated by the oscillator output waveform, measure the recovery time with an oscilloscope connected at the output of the power supply. Measure the time duration when the output voltage recovers and settles into regulation.

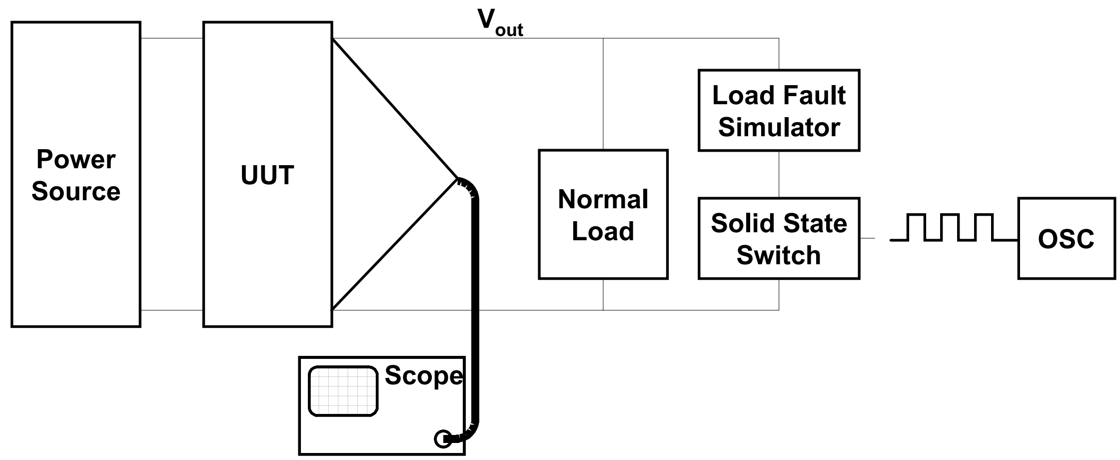


Figure 58—Recovery time test setup

4.15.1.3 Test condition

Conduct the tests at loads of maximum to minimum, as required. The input voltage should be nominal and the operating temperature should be from minimum to maximum.

4.15.2 Overvoltage response

4.15.2.1 Definition

Overvoltage response is the protective action taken by a power supply in response to an overvoltage condition on its output, induced either by an internal fault or by the external application of an overvoltage condition. Overvoltage protection circuits may result in a cyclic shutdown/restart or a latched off condition. Latch off circuitry is typically used if the circuit is intended to protect against internal unit failures.

Overvoltage response is a condition in which the power supply output voltage, having reached an overvoltage trip level, will be reduced to a quiescent safe voltage level. This voltage level may provide a false indication to the power supply output control circuitry that the overvoltage condition no longer exists, resulting in reinstatement of the prior overvoltage condition. Providing a latch to the power supply, after an overvoltage condition occurs, eliminates this from happening. A common practice to remove the latch, is to recycle input power. Non-latching overvoltage protection circuits should provide a fixed or minimum recycle time to prevent overstress due to rapid hysteretic cycling of the output and should control the reinstatement of the output voltage(s) to limit overshoot/undershoot.

4.15.2.2 Test method

The measurement of overvoltage can have varying degrees of complexity dependent on the method of overvoltage implementation. It is generally not possible to test a unit's overvoltage response to internal failure. Such a test requires access to internal circuit nodes or the routing of such nodes to a test or output connector. In the absence of such test access, the overvoltage response test is limited to the unit's response to an externally applied overvoltage fault. The following test methods are recommended:

a) *Test method a)*—For units with no overvoltage built-in-test (BIT) and independent output shutdown (multiple output units). See 4.15.2.2.1.

b) *Test method b)*—For units with overvoltage status BIT. See 4.15.2.2.2.

c) *Test method c)*—For units (or specific unit outputs) that result in shut down of all outputs in response to overvoltage. See 4.15.2.2.3.

4.15.2.2.1 Test method a)—For units with no overvoltage status BIT

The circuit shown in Figure 59 is one test setup approach. If there are multiple outputs, the output that provides closed loop regulation, when subjected to overvoltage, may cause other outputs to go low. Low voltage may in turn override the overvoltage signal providing a false representation. It is therefore necessary that the inter-relationships between the various outputs be determined prior to performing overvoltage testing. Additionally, overvoltage protection circuits may independently shut down individual outputs on a multiple output supply, or they may shut down the entire unit. For situations and/or units that result in complete shutdown in response to overvoltage, test method c) is a preferred alternative.

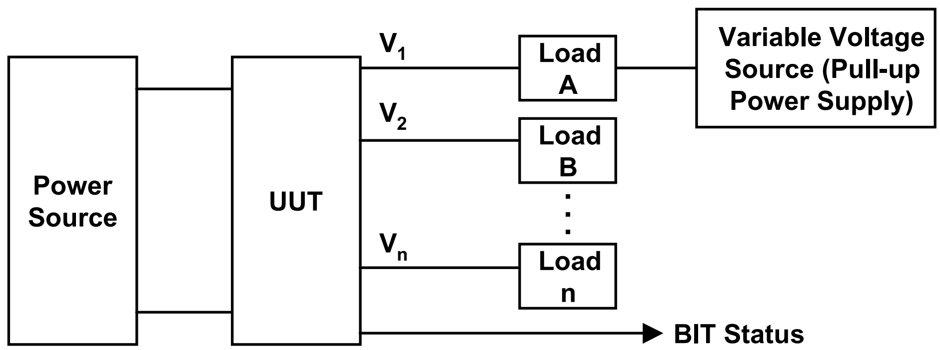


Figure 59—Overvoltage response test setup

For the particular output to be tested, reduce the load to the minimum, compatible with maintaining power supply specified tolerances. Increase the voltage on the variable voltage source to the specified overvoltage protection limit. Remove the variable voltage source and verify that the applicable unit output is reduced to a safe level (normally zero). Alternatively the external pull-up supply can be increased in fixed increments, removing before each adjustment, so that the trip point can more precisely be determined. For latching type protection circuits, the output shall remain at the trip level until input power is removed and reapplied or until some other means of overvoltage protection reset is activated. For units with a non-latching response to the overvoltage, the unit shall remain at the trip level for a predetermined length of time and then recover to normal operation. For non-latching circuits the recovery time and overshoot/undershoot should be verified. This method may not apply to overvoltage response of all power supplies.

4.15.2.2.2 Test method b)—For units with overvoltage status BIT

Connect the test setup as shown in Figure 59; however, with the availability of an overvoltage BIT status signal it is recommended that the external supply be slowly increased until the required overvoltage transition state occurs. At the transition point, check that the voltage level is within prescribed limits. Return the variable voltage source to the nominal value. Repeat the process for all outputs. Do not exceed the specified overvoltage trip point.

If the specified overvoltage trip limit is reached without status indication, remove the external supply and note whether

a) The applicable output is within normal operating limits

b) The applicable output has been reduced to a safe level (normally zero).

Condition a) indicates failure of the overvoltage protection circuit, condition b) indicates failure of the overvoltage BIT status circuit.

4.15.2.2.3 Test method c)—For units (or specific unit outputs) that result in shutdown of all outputs in response to overvoltage

The test set-up of Figure 59 can again be used; however, with situations that result in complete unit shutdown it is recommended that the external supply be slowly increased until the required overvoltage transition occurs. The transition point can be determined by monitoring the current demand from the power source, or alternately with the use of a current probe on one of the input source leads. The input current demand should reduce to zero or a near zero quiescent level. Check at the transition point that the output voltage level on the output under test is within prescribed overvoltage limits. Return the variable voltage source to the nominal value and recycle the input power for latching type. Repeat the process for all outputs. Do not exceed the specified overvoltage trip point on any output.

4.15.2.3 Test condition

Adjust the input voltage and load current to nominal specified value and over the specified operating temperature.

4.15.3 Output undervoltage/overvoltage indication

4.15.3.1 Definition

Output undervoltage/overvoltage is a status signal that indicates a condition where a power supply output is sufficiently removed from its normal operating voltage, so that undesirable load anomalies can occur.

These upper and lower voltage limits, V_{max} and V_{min}, take into account these anomalies that would otherwise occur if they were not specified. Undervoltage/overvoltage indication allows the power supply to operate without damage up to the chosen limits. This signal is often used by the parent system to protect itself, through shutdown or standby operation, from output voltages that are sufficiently far from normal conditions that abnormal system operation or damage might occur.

4.15.3.2 Test method

Use the test setup shown in Figure 60. The measurement of undervoltage/overvoltage indication can have varying degrees of complexity, depending on the method of overvoltage and overcurrent implementation. In addition, undervoltage/overvoltage indication, when available, may be an independent discrete signal, or part of an integrated overall BIT status.

The parameter, *overvoltage response*, can be used for overvoltage indication with the exception that the external supply is raised to the overvoltage indication level rather than the overvoltage protection level (overvoltage indication, when present, is typically set below the protection trip threshold). Knowledge of the unit operation and BIT indication circuits is required to determine the test method for undervoltage indication. Undervoltage indication can sometimes be tested by placing an overload on the applicable output. If the unit employs a linear or constant current overload protection scheme, then the output voltage will fold back in response to an overload. The overcurrent fault may, however, override the undervoltage indication or the BIT status may be a combined signal.

Another alternative is to measure the undervoltage status BIT during unit start-up or shutdown, monitoring the BIT signal as the output transitions through the BIT window. Limitations on this method include timing delays in the indication circuit, particularly if the output transition is fast, and override of the BIT signal occurs due to another output reaching the trip point first. And another method would be to lower the input voltage so as to cause the output voltage to be lowered through the undervoltage trip point.

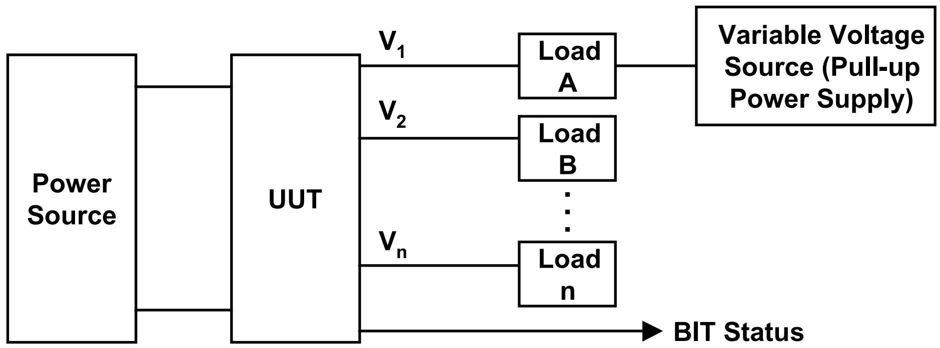


Figure 60—Output undervoltage/overvoltage indication test setup

4.15.3.3 Test condition

Set the input voltage and the load current to nominal specified values. Adjust the input voltage to minimum, V_{min}, and the load current to maximum, and verify *undervoltage* indication. Conduct the test at the specified operating temperature.

4.15.4 Overcurrent and short-circuit current protection

4.15.4.1 Definition

Overcurrent and short-circuit current protection is defined as features that prevent a power supply from producing a current greater than a specified percentage over the maximum rated current. Overcurrent protection allows the power supply to continue operating without damage or output voltage shutdown up to the rated overcurrent value. Recovery time and mechanism from an overcurrent (including short-circuit) condition should be specified. The maximum transient component of output voltage (overshoot or undershoot) resulting from an overcurrent condition should be specified. The power supply specification should list its I_{min}, I_{max}, I_{ocl} (overcurrent limit), and I_{sc}(short circuit) and recovery time after a fault.

4.15.4.2 Test method

Connect the test setup as shown in Figure 61. Verify that the UUT maintains the output voltage within a specified range for load currents up to and including the specified I_{max}. Monitor output voltage and recovery time with an oscilloscope and the output current with a current probe.

4.15.4.3 Test conditions

Test condition 1)—Adjust the UUT input voltage, load current to nominal, and nominal operating conditions for temperature. Increase the load current until the UUT output voltage either begins to foldback or collapses. Then record the I_{ocl}.

Test condition 2)—For short-circuit current, apply a short circuit and record output voltage and current. The short circuit should be of sufficiently low impedance to result in less than 0.1 V at the UUT output terminals. Maintain short circuit condition for at least one minute for units specified to operate continuously into a

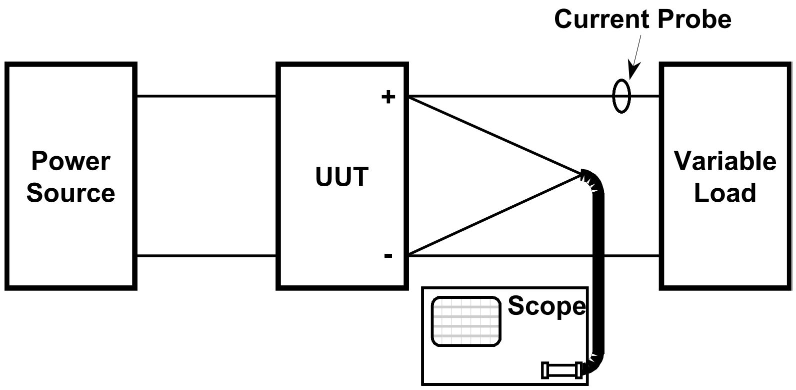


Figure 61—Overcurrent protection test setup

short circuit. Continuation of design verification/validation should include testing at a specified range of operating temperature extremes.

4.15.5 Delay time for overcurrent protection

4.15.5.1 Definition

Delay time for overcurrent protection is the delay between the time when the output current reaches the specified protection level and the output voltage falls below specification. Refer to Figure 62 for key features of the waveform.

4.15.5.2 Test method

Connect the test setup as shown in Figure 63. Connect a storage oscilloscope to monitor the output voltage. Use a current shunt or current probe to measure the output current. Use a storage oscilloscope to display and record the results.

Set the input voltage to nominal value. Switch the load into higher current (I_2) so that the UUT will shut down safely by overcurrent protection. Measure the time interval between the point when the output current reaches current limit level (T_1 as illustrated in Figure 62) and the point when the output voltage falls below the regulation range (T_2 as illustrated in Figure 62). This time interval ($T_{delay} = T_2 - T_1$) is the delay time for overcurrent protection. Check that the output voltage decreases without unexpected oscillations or anomalies. The waveform is an approximation of the actual response.

Repeat the above measurements at the minimum and maximum specified input voltage.

Use the above test method for all the outputs if the UUT has multiple outputs.

4.15.5.3 Test condition

The measurement shall be conducted at room temperature, and repeated at the maximum and minimum specified ambient temperature. For forced-air-cooled systems, the test setup must include a means for providing the specified airflow.

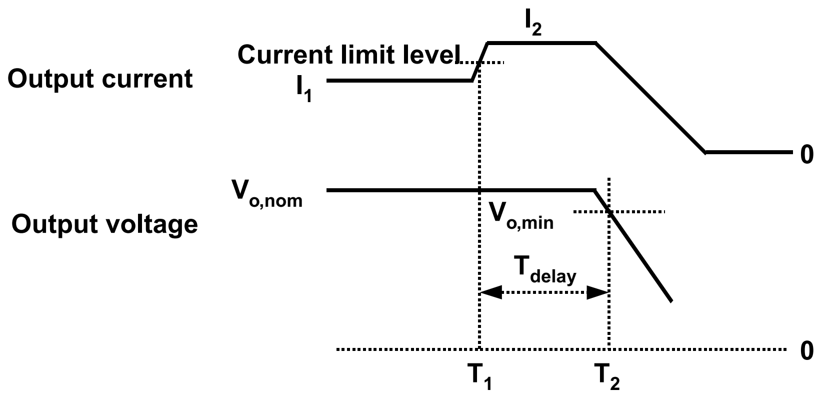


Figure 62—Typical waveform for overcurrent protection delay time measurement

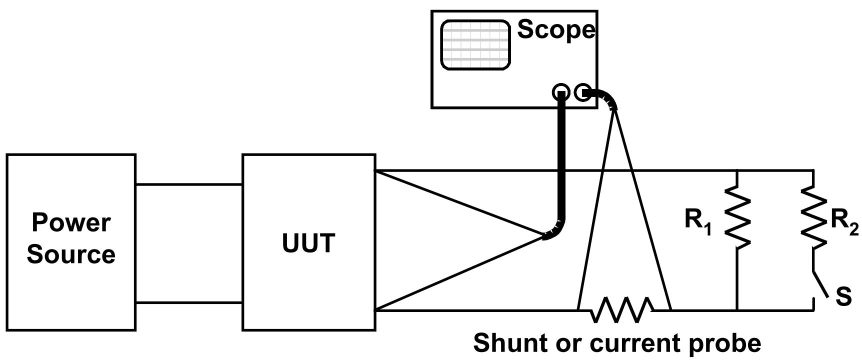


Figure 63—Overcurrent protection delay time measurement test setup

5. Reliability, maintainability, environmental, and mechanical parameters

5.1 Reliability

5.1.1 Reliability

5.1.1.1 Definition

Reliability is the ability of a unit to perform a required function for a stated period of time in the specified environment.

5.1.2 Fault tolerance

5.1.2.1 Definition

Fault tolerance is the ability of a system to continue to supply rated voltage and power to load after an unexpected failure. There are a number of systems and/or methods utilized to achieve fault tolerance. The most basic fault tolerance is defined as uninterrupted and continued operation after a single device/subsystem has failed.

5.1.3 MTBF (Mean Time Between Failure)

5.1.3.1 Definition

MTBF is the average length of time between system failures, exclusive of infant mortality and the rated end-of-life. A frequently used method of calculating MTBF is described in MIL-HDBK-217, 1991.

A closely related parameter is the failure rate λ (Lambda). For a system with a constant failure rate, $\lambda = 1/\text{MTBF}$. A plot of λ versus time shows a constant value after infant mortality and before wearout. Lambda has a normal distribution over time over this constant value range.

5.2 Maintainability

5.2.1 Maintainability

5.2.1.1 Definition

Maintainability is the ease by which a system is repaired or replaced in order to return to operating condition.

5.2.2 Hot swap

5.2.2.1 Definition

Hot swap is the ability to remove and replace a subassembly of a power system without interrupting the power entering or leaving the system in any way.

5.2.3 MTTR (Mean Time To Replace)

5.2.3.1 Definition

MTTR is the time required to perform each anticipated repair task weighted (multiplied) by the relative frequency with which that task must be performed (e.g., number of times per year). Data supplied by the manufacturers will be purely repair time, which will assume the fault is correctly identified and the required spares and personnel are available.

5.2.4 Backward compatibility

5.2.4.1 Definition

Backward compatibility is defined as being compatible with earlier models or versions of the same system. A new model or version of a system is said to be backward compatible if it can be used with or replace an older model or version of the same system

5.3 Environments

Most equipment applications do not experience environment considerations one element at a time. Rather, a set of varying conditions normally combines to make up the application environment. The expected environmental challenges the equipment will encounter will make up the equipment application profiles needed to support both design requirements and the end-item qualification testing.

There are some more focused environmental application descriptions for specific industries, such as the RTCA/DO-160D for civil airborne equipment, but probably the most comprehensive document describing environmental challenges to equipment can be found in MIL-STD-810E, 1995. Therefore, MIL-STD-810E, 1995 has been selected to represent the broad base of equipment environmental challenges.

A combined environment is needed for effective equipment application testing. Although there may be specific needs for cold plates and other specialized fixtures, the test chambers should be capable of producing the required combinations of temperature, altitude, humidity, random vibration, and cooling air mass flow.

Please refer to MIL-STD-810E, (paragraph 3, Definitions) for terminology used in 5.3.1 through 5.3.14.

5.3.1 Humidity

5.3.1.1 Definition

Humidity is the amount of water vapor present in the ambient air. It is commonly referred to as relative humidity. This is expressed as a percentage, and given free atmospheric air and a constant barometric pressure, the percentage of water in any given volume of air is directly proportional to the temperature. The effect of water vapor in air on convection cooling is complex, and beyond the scope of this definition.

5.3.1.2 Test method

Although there are many reasonably priced electronics-based, direct-reading, relative humidity meters on the market, the standard scientific method of measuring relative humidity involves the use of two bulb thermometers in what is known as a sling psychrometer configuration. This instrument involves the use of one *dry* bulb and one *wet* bulb. The wet bulb is covered with a cotton gauze material, wetted with plain drinking water, and the instrument is spun around in a circular motion (usually by hand at arms length) for several seconds so as to cause partial evaporation, and hence cooling of the wet bulb. A *psychrometric* table is used, which gives the relative humidity given the simultaneously read dry and wet bulb temperatures. In practice, most testing is performed with a particular application scenario in mind. Also see 5.3.9.

5.3.2 Operating altitude

5.3.2.1 Definition

For electrical equipment, particularly in aircraft installations, operating altitude normally relates to the density of the ambient air as a function of the equivalent barometric pressure attributed to a given altitude above mean sea level at a constant temperature, e.g., 15 °C in the U.S. Since density (mass per unit volume) decreases as altitude increases, convection cooling is less effective at higher altitudes. In general, in endoatmospheric environments, as the number of molecules decreases per unit volume, the arc distance increases since the ionizing molecular path length is increased. Stated differently, the voltage necessary to arc in air decreases for the same physical distance of separation as altitude increases.

5.3.2.2 Test method

Direct reading barometric pressure instruments that read directly in altitude above mean sea level are readily available. When testing, pressure chambers used for altitude purposes normally have intrinsic measuring capability and have temperature correction capability. In practice, most testing is performed with a particular application scenario in mind. Also see 5.3.9.

Application of voltage over 150 V (peak value) to equipment during the time the pressure chamber is being pumped down may result in failure. This is especially true for space systems meant to operate in a hard vacuum or in a test laboratory.

5.3.3 Salt fog

5.3.3.1 Definition

Salt fog is a general reference to the climatic chamber testing performed to characterize the life-cycle resistance of equipment to the effects of an aqueous sodium chloride (salt) presence in the atmosphere. Since salt is one of the most pervasive chemical compounds in the world, all equipment has a high likelihood of being exposed to some amount of salt during its lifecycle that may affect performance. However, the effects are normally not a performance issue except in marine or coastal regions. The effects of exposure of equipment to an environment containing an aqueous salt atmosphere are normally divided into three categories involving multiple corrosion types, electrical characteristics impairment, and physical clogging or binding.

5.3.3.2 Test method

MIL-STD-810E (Method 509.3) provides standard test methods for various item configurations. This testing is potentially damaging and should be conducted only after most other climatic tests. Testing is normally tailored to select the choice of test procedures. In general, aggressive salt fog testing should be used only for screening or discrimination. Its primary value lies in testing coatings and finishes on material for their resistance or susceptibility to a salt atmosphere.

5.3.4 Storage altitude

5.3.4.1 Definition

Storage altitude is the specific pressure condition of atmospheric ambient environment at lower pressure than *standard* or normally experienced at sea level. Storage pertains to the subject item being in a configuration required for storage or transit. The required test altitude determines actual conditions.

5.3.4.2 Test method

MIL-STD-810E (Method 500.3) provides a standard test method scenario. This testing involves the use of a pressure-reducing chamber or cabinet and auxiliary instrumentation capable of maintaining and continuously monitoring the specific conditions of low pressure. Testing should be tailored to select the procedures appropriate to the expected pressure environment

5.3.5 Mechanical shock

5.3.5.1 Definition

Mechanical shock is the relatively infrequent, non-repetitive transient vibration forces that an item may encounter over its life cycle in handling, transportation, and service environments. In general, shock will mechanically excite an equipment item to respond at both forced and natural frequencies. This response can cause, among other things, the following situations:

a) Failures due to increased or decreased friction, or interference between parts

b) Changes in dielectric strength, loss of insulation resistance, and variations in magnetic and electrostatic field strength

c) Permanent deformation due to physical material overstress

d) More rapid fatiguing of materials

Considerations for shock endurance are generally categorized into routine functional, noncontinuous or occasional functional, in-transit/transportation and bench handling. Noncontinuous functional shock includes sources such as vehicle crashes, pyrotechnic or explosive events, spacecraft reentry, and aircraft catapult launches/arrested landings. Only the last three types are atypical to routine commercial service. Transportation/handling shock includes sources such as transit dropping when packed for shipment or carrying, and railroad car impact in shipment. Bench handling involves the shock that may be encountered during a typical bench maintenance or repair environment. Also, there are the design concerns for fragility requiring protective shock isolation or absorption and protective packaging for shipping.

5.3.5.2 Test method

MIL-STD-810E (Method 516.4) provides a set of standard test method scenarios for the types of shock environments described in 5.3.5.1. Testing should be tailored to select the procedures appropriate to the expected shock environment. Shock testing for the expected life cycle environments for any given item requires significant knowledge of the shock environments along with careful planning.

5.3.6 Vibration

5.3.6.1 Definition

Typically, vibration is a representation of a repetitive mechanical displacement or oscillation about one or more axes, usually simultaneously at various physical displacements and frequencies of oscillation. The sources of vibration are primarily found in mobile or transport equipment application modes. The accumulated effects of vibration-induced stress may affect equipment item performance under other environmental conditions such as, temperature, altitude, humidity, leakage, or EMI/EMC. Vibration environments can be divided into twelve categories: three transportation-induced and nine application-induced. Whereas there are tailored variations and subcategories for specific applications, the following represent the broad equipment vibration categories:

a) Transportation/cargo-induced vibration
   1) Basic transportation, where equipment is carried as secured cargo
   2) Large assembly transport, involving large shelter, van, and trailer systems
   3) Loose cargo transport, where equipment is carried on ground vehicles as unrestrained cargo

b) Application-induced vibration
   1) Propeller aircraft and turbine engines, where equipment is installed in propeller aircraft and on turbine engines manned and unmanned
   2) Jet aircraft and tactical missiles, where equipment is installed in jet aircraft, manned and unmanned, and installed in free flight phase tactical missiles
   3) Helicopter, where equipment is installed in helicopters
   4) Equipment carried externally to jet aircraft as assembled equipment
   5) Equipment carried externally to jet aircraft, but installed internally to a pod
   6) Equipment carried externally to a helicopter as assembled equipment
   7) Ground mobile, where equipment is installed in wheeled vehicles, trailers, and tracked vehicles
   8) Marine, where equipment is installed in ships or other watercraft.

Although the uniquely military application environments are generally highly varied and severe, the civilian *commercial* subsets are essentially the same as for similar applications, particularly in transportation.

5.3.6.2 Test method

MIL-STD-810E (Method 514.4) provides a wide-ranging set of standard test method scenarios for the previously described types of vibration environments. When the cumulative environmental effects of vibration and other environmental factors must be evaluated, a single test item should be exposed to all pertinent environmental conditions, with vibration generally performed first.

5.3.7 Outgassing

5.3.7.1 Definition

Outgassing is aimed to determine volatile content of materials when exposed to a vacuum environment. Two parameters are typically measured—total mass loss (TML) and collected volatile condensable materials (CVCM). Typical materials that are likely to outgas include polymer potting components, shrink tubings, adhesives, coatings, fabrics, tie cords, and lubricants. The criteria for the acceptance and rejection is often determined by the user and based on a specific application. Historically, TML of 1.00% and CVCM of 0.10% have been used as a screening level for space materials.

5.3.7.2 Test method

ASTM E595-93 (1999) is frequently used as the test method. It specifies required set-up, test criteria, procedures, and interpretation of measured data.

Failure to allow sufficient time to outgas prior to turn-on of power may result in arcing due to the outgas products. The outgas time for printed circuit materials and coatings can typically require up to a week or more.

5.3.8 Thermal shock

5.3.8.1 Definition

Thermal shock is a rapid change in ambient temperature over a relatively short time period. This will subject equipment to mechanical stress owing to an associated rapid rate of thermal expansion or contraction due to the different thermal coefficients of expansion present in the various materials making up the equipment. Repetitive cycles of this shock may result in electrical terminations becoming disconnected and various mounting substrates separating from one another.

5.3.8.2 Test method

MIL-STD-810E (Method 503.3) provides a set of standard test method scenarios for the various application thermal shock environments. In general, temperature shock tests are conducted to determine if an item can withstand sudden changes in the temperature of the surrounding atmosphere without experiencing physical damage or deterioration in performance.

5.3.9 Operating temperature

5.3.9.1 Definition

Operating temperature is the temperature environment experienced by an item in its expected application. Often, this environment may be referenced to an internal portion of a system, and the actual ambient environment of the overall system is not *seen* by the item in question. Also, in practice, most operating temperature concerns are coupled with simultaneous extremes expected in the application for altitude, humidity, and vibration.

5.3.9.2 Test method

MIL-STD-810E (Method 520) provides a wide range of standard test method scenarios for the various combined application thermal, humidity, vibration, and altitude environments. The various application environment profiles are described to provide the test scenarios needed to drive both design and test processes.

5.3.10 Temperature (thermal) cycling

5.3.10.1 Definition

Temperature (thermal) cycling is defined as repetitive changes in temperature at specified time intervals and between specified temperatures. The purpose of a temperature (thermal) cycling test is to verify satisfactory functional performance of a UUT when it is exposed to design level extremes. Temperature (thermal) cycling is effective in exposing defects in components and surfaces. The stress that precipitates defects into failures during temperature cycling is mainly mechanical motion resulting from different expansion and contraction of materials. Typical failures include broken wires, cold or broken solder joints, changes of adjustment, and so forth.

5.3.10.2 Test method

MIL-STD-883E (Method 1010.7) provides six categories of temperature (thermal) cycling profiles with different temperature extremes and rates of change. MIL-STD-1540D provides corresponding requirements for launch vehicles and spacecraft.

5.3.11 Burn-in

5.3.11.1 Definition

Burn-in is a procedure that includes, as a minimum, the operation of a UUT for a specified time, at a specified load, and at a specified temperature. Burn-in test is frequently used as an acceptance test for components and assemblies. The purpose of burn-in is to detect material and workmanship defects that occur early in the component/assembly life. In other words, it is designed to eliminate infant mortality, *debug* hardware, and enhance long-term reliability. A burn-in test may include temperature (thermal) cycling, constant temperature soak, continuous power application, power cycling, vibration, and various combinations of these tests.

The most important burn-in test is temperature (thermal) cycling. The three key variables are the number of cycles, the rate of change in temperature, and the temperature range.

5.3.11.2 Test method

MIL-STD-1540D provides burn-in requirements for space applications. MIL-STD-883E lists a standard method for temperature thermal cycling. Temperature soak, continuous power application, and power cycling are frequently determined by prevalent practice and, sometimes, by experience.

5.3.12 Storage temperature

5.3.12.1 Definition

Storage temperature is the thermal environment expected for a unit in a non-operation condition, in any given climatic region over a daily and annual cycle. Thermal stabilization or other air conditioning is not normally anticipated. The extremes of storage temperature over time are the primary concern. Also, induced conditions arise from the storage enclosures that may encounter the added effect of solar heating. These enclosures may include unventilated enclosures, inside vehicle or aircraft bodies, and inside tents or under tarpaulins. Also, items may be stored near heat-producing devices that may influence or intensify the air temperature surrounding the item.

5.3.12.2 Test method

MIL-STD-810E (Method 501.3) provides a set of standard test method scenarios for high temperatures, while MIL-STD-810E (Method 502.3) provides a set of standard test method scenarios for low temperatures as may be encountered in various climatic locations.

5.3.13 Non-operating temperature

5.3.13.1 Definition

Non-operating temperature is defined as temperatures that may be present in an installed operating location, but not expected to be sustained after unit operation is started. These temperatures may be either higher or lower than the expected operating range limits. Usually some period of temperature adjustment is expected before operation is started to allow either cool down or warm up within acceptable operating range limits.

5.3.13.2 Test method

The use of storage temperature type testing may be used as precursor conditioning for test purposes. A particular operating start-up scenario should be developed on a case specific basis.

5.3.14 Fungus

5.3.14.1 Definition

Fungal growth impairs the functioning or use of equipment by changing its physical properties. Nonresistant materials are susceptible to direct attack as the fungi break the material down and use it for food. This process results in deterioration affecting the physical properties of the material. In general, any organic-based materials, or materials containing organic elements are susceptible to this attack. An indirect attack may occur when fungal growth on surface deposits of dust, grease, perspiration or other contaminants, deposited on a unit during manufacture or subsequent use, causes damage to the underlying material, even though that material may be resistant to a direct attack. Metabolic waste products excreted by fungi causes corrosion of metals, etching of glass, or staining or otherwise degrading of plastics and other materials. The by-products of these kinds of attack cause severe problems particularly in electrical, electronic, and optical systems. In addition, health and aesthetic factors in cases of attack may cause severe allergic reactions or present such cosmetically unpleasant conditions so as to render the unit unusable.

5.3.14.2 Test method

MIL-STD-810E (Method 508.4) provides a set of standard test methods and guidance for conducting fungus tests and evaluating results.

5.4 Mechanical

5.4.1 Pin-out

5.4.1.1 Definition

A pin-out is an ordered identification (such as numbering) of the pins of the unit so each pin can be identified with a particular function such as input, output, control, power, or ground

5.4.2 Footprint

5.4.2.1 Definition

Footprint is the total planar area of the mounting surface of the unit plus any necessary clearance that cannot be used for another purpose due to the presence of the unit. Shape and dimensions are to be indicated on a drawing. Items such as pins and mounting stakes located on the mounting surface are to be indicated and dimensioned.

5.4.3 Envelope dimension

5.4.3.1 Definition

Envelope dimension is the maximum dimensions including terminals, mounting hardware, etc., from the mounting surface to the surface opposite the mounting surface of the unit.

5.4.4 Mounting orientation

5.4.4.1 Definition

The orientation of a unit determined by, and corresponding to, the position of the base of the unit. The usual positions are as follows:

a) Vertical
b) Horizontal upright
c) Horizontal underhung
d) Angle from vertical

Also refer to IEEE 100-1996 [B4] for a definition of *Mounting Position.*

5.4.5 Connection types

5.4.5.1 Definition

Connection types provide a description of the type of electrical connection to the unit. Examples are pins, terminal lugs, connectors, stakes, etc. A complete description is required including connector part number, mating connector part number, screw size for terminal lugs, dimensions, etc.

5.4.6 Connection locations

5.4.6.1 Definition

Connection locations are the points at which the units physically interface with one another.

5.4.7 Cooling requirements

5.4.7.1 Definition

Cooling requirements are worst-case heat generation data and maximum operating case temperature data are required. Guidelines for forced air, heat sinks, conductive grease or pads, cold plates, etc. should be provided as equations, charts, or tables. Guidelines should include information such as ambient air temperature, whether the environment is sealed or open, and should be sufficient to allow the user to determine cooling provisions for the part.

5.4.8 Baseplate flatness

5.4.8.1 Definition

Baseplate flatness is the maximum deviation in plane of UUT baseplate.

5.4.9 Installation instructions

5.4.9.1 Definition

Installation instructions are information required by the user to install the unit such as, soldering temperature, plug-in cards, and torque.

5.4.10 Layout

5.4.10.1 Definition

Layout is defined as requirements provided for a unit that include keep-out areas necessary to install part, maintain part, and to make electrical connections.

5.4.11 Installation methods

5.4.11.1 Definition

Installation methods are information required by the user to install the unit, such as soldering temperature, plug in cards, bolt torque, and installation of thermally conductive greases or pads, and a description of the type of electrical connection to the unit. Examples are pins, terminal lugs, connectors, stakes, etc. A complete description is required including connector part number, mating connector part number, screw size for terminal lugs, dimensions, etc.

Annex A

(informative)

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Annex B

(informative)

General test practices

This annex defines general procedures and practices when performing testing on electronic power distribution equipment. The purpose is to ensure that testing activities, data collection, and result recording are done in an accurate, correct, safe and consistent manner. In principle, measurements taken on a given unit-under-test (UUT) by different test personnel, at different times, and in different locations should still give consistent repeatable results.

The following precautions should be taken:

a) Follow all recommended safety procedures particularly when working on high-power and/or high-voltage equipment.

b) Observe normal precautions to avoid damage due to electrostatic discharge (ESD).

c) Before conducting any tests, ensure that the proper and correct wiring interfaces between the test equipment and the UUT are made.

d) Wherever possible, all input and output voltage measurements of the UUT must be taken directly at the connector pins.

B.1 Data recording

B.1.1 Format

All test results must be recorded in a proper format (log book, data sheets, data manual, electronic media, etc.). Upon completion of the testing activities, the log book records shall be filed and documented for future reference.

The test observations must be made in a way that other personnel (apart from the originator) are able to refer to and, when required, interpret the importance of the information. For every page of the logbook, include the date when the data are recorded and the name of the operator. For every test set-up, draw a sketch in the logbook, the arrangement and interconnection of the test equipment. Briefly note down the application of test equipment in the sketch. Use a unique file name for each set of the captured waveforms or data.

Then proceed as follows:

a) Record the serial numbers and other pertinent identifying information relating to the UUT.

b) Record the start date for the testing and the date when all testing is complete.

c) Record the details of the test equipment used in each test, typically including the following: description, make, model number, application, calibration information.

d) Record the following environmental conditions: temperature, humidity, and altitude.

Examples on how to actually record the test data results are shown on Table B.1. The table identifies the temperature and load conditions in the horizontal axis and the parameter to measure in the vertical axis.

Table B.1—Example of a table to record the dynamic load regulation test data

Parameter/ Load	Operating temperature								
	min			nom			max		
	I_{min}	I_{nom}	I_{max}	I_{min}	I_{nom}	I_{max}	I_{min}	I_{nom}	I_{max}
T_r									
V_m									
V_r									
T_R									

B.1.2 Standard test conditions

Unless otherwise specified, tests should be performed under standard temperature, humidity, and altitude.

B.1.3 Waveforms and photographs

Waveforms should be captured electronically wherever possible, as a graphics file to be incorporated into the final test report. The format of the graphics file should be chosen to suit the requirements of the report. All files must be clearly named to ensure that the correct files are used for the final report.

B.1.4 Speed of measurement

In some cases, it is important that measurements are completed quickly to avoid errors caused by temperature drift. This is especially important where two measurements are to be compared to find the parameter being measured, and is also important when testing at low ambient temperatures.

B.1.5 Accuracy

Calibrate the equipment.

The accuracy of a measurement is a function of variables such as instrument/equipment used, equipment setups and their interconnections, and the readouts made by the user. For tests that require adjusting an equipment variable (such as voltage) to determine a measurement (such as input shutdown/recovery point), make sure the rate of change is slow enough to ensure good accuracy on the measurements. Allow a short delay following each change, to give sufficient time for proper response by measuring instruments before the measurement is taken. If the adjustment must be made in steps (for instruments having a digital control interface), make certain the step amplitude is small enough to ensure proper measurement accuracy. Refer to the manufacturer's specification on equipment accuracy to determine the measurement error contributed by each piece of equipment.

Where necessary, some test methods describe the measurement accuracy and the accuracy equations related to the test setup and readouts. Refer to them to determine the accuracy of your measurement.

The accuracy of component temperature rise measurements is affected by many other factors in addition to the accuracy of the test equipment itself. This is particularly true when the UUT is tested with a specified level of cooling airflow. The following is a list of the more important factors to be considered:

a) Set-up of the UUT inside the thermal chamber
b) Location of thermocouple attachment
c) Method of thermocouple attachment to the components
d) Location of airflow measurement
e) Airflow velocity measurement
f) Location of the ambient temperature measurement

It is important that all these factors are considered, and that care is taken, especially with the first four items.

B.2 Power source characteristics

B.2.1 Source impedance

The output impedance of the power source must be low enough to adequately represent the intended application of the UUT. If not, the test results may not be valid, particularly for measurements of inrush current, transient response, stability or any other test where source impedance can significantly affect the result. The rated capacity of the source should be much higher than the rating of the UUT, to ensure adequate surge capability. As a *rule of thumb*, the source power rating should be at least 10-times the UUT rating.

For dc power sources, it is sometimes convenient to obtain a very low impedance value by using a suitable battery, or else by connecting a large value capacitor in parallel with the source output. For ac power sources, it may be necessary to provide a special low impedance wiring connection directly from a high-power utility source transformer, or else use a special high-power artificial source of variable voltage and frequency.

B.3 EMI Testing

B.3.1 Feed-through capacitor

Feed-through capacitors are frequently in the order of 10 μF. Each module will also have an internal bleeder resistor (≅500 kΩ) attached in parallel with the capacitor to dissipate potentially dangerous charges. Feed-through capacitors are added to the input to reduce the resonant frequency of the LISNs to a more reasonable frequency. At the output, feed-through capacitors provide a path for common-mode signals. It would not be possible to make any common-mode output measurements without the capacitors.

B.4 Wiring and configuration

To avoid overheating of wires from excessive loading and to reduce excessive voltage drop across the wires leading to erroneous measurements for certain tests, use the appropriate AWG wires for different parts of the wiring connections according to the current carried and the wire length required.

Table B.2 lists commonly used values for different wire gages and their related voltage drops.

Table B.2—Commonly used values for wire gages and related voltage drops

Maximum current (amperes)	Maximum wire length (meters)	AWG	Voltage drop (mV) (each wire)
5	0.5	18	50
5	1.0	18	100
5	2.0	18	200
10	0.5	16	70
10	1.0	16	140
10	2.0	16	280
50	0.5	8 (or 3* 12)	50
50	1.0	8 (or 3* 12)	100
50	2.0	8 (or 3* 12)	200
100	0.5	5 (or 6* 12)	50
100	1.0	5 (or 6* 12)	100
100	2.0	5 (or 6* 12)	200

B.4.1 Wire configuration

To minimize risk of connection shorts and also to improve connection traceability in the test setup, where possible, wires used for interconnecting the UUT, equipment and measuring instruments must be kept short to reduce voltage drop and electromagnetic radiation. When making measurements with a voltmeter, twisted pair wire of approximately 0.5 turn per cm should be used with the measuring instrument. The twisted pair should also be less than one meter long and with typical wire gauge of 20 to 24 AWG.

When making ripple measurement, coax wire should be used in replacement of the above twisted pair wire. For accurate testing, ripple measurements should normally be done directly across the connector terminals of the UUT using very short leads (less than 15 mm). Longer connections using coax wire are acceptable for automated test fixtures.

B.4.2 Shunt calibration

The current through each of the shunts used in the test equipment setup must not exceed the rated values of the shunts. The high tolerance property of the shunts will be significantly affected when they are subjected to heating effects as a result of overcurrent. A shunt has to be calibrated periodically before use, or after it is used over a prolonged period of time at its maximum rating, or when it is accidentally subject to current exceeding its rated value. The shunt should be calibrated for consistent accuracy using a four-wire measurement method with a multimeter having four-wire measurement capability. Connect the multimeter terminals across the shunt terminals and connect the sense terminals of the multimeter across the voltage measurement terminals of the shunt. Measure the shunt resistance, and keep this resistance value for calculating the current through it when testing the UUT.

B.5 Measurement points

Voltage measurements should be made as close as possible to the UUT (preferably directly at the UUT terminals), using one pair of leads to carry the input current or load current and a separate pair for the measurement itself (see Figure B.1).

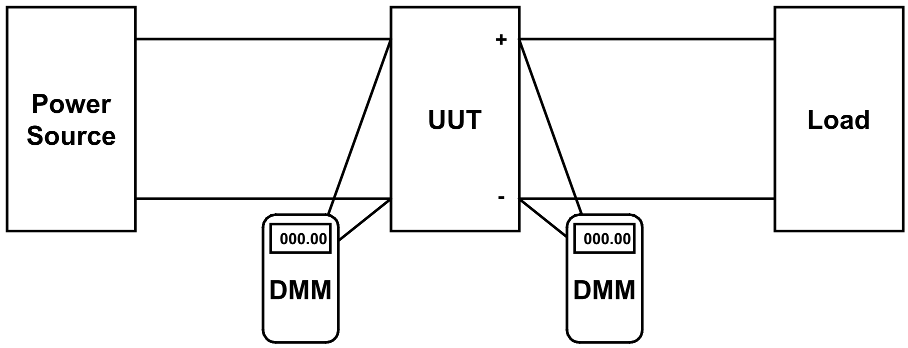

Figure B.1—Example of a measurement technique for input and output voltages

B.5.1 Remote sense terminals

If the UUT includes remote sense terminals, they must be connected directly to the load for point of load regulation or the output terminals for local sensing (as shown in Figure B.2).

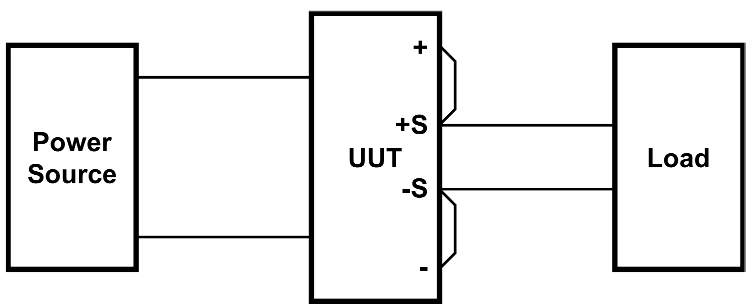

Figure B.2—Remote sense terminal connection

B.6 Measuring component temperatures

SAFETY WARNING—Thermocouples are conductive. Thermocouples also operate in the few millivolt region, hence even being routed near 60 Hz equipment cords can cause a few degrees of jitter in the measurements. When measuring temperatures of components that are operating at high voltage, the thermocouple may become *live.* Always switch off power before connecting or adjusting thermocouples.

Thermocouples consist of two wires made from different metals, welded (or soldered) together at one point (the thermocouple junction). The probe measures temperature at this junction, and is not affected by the temperature of the rest of the wire. However, the thermocouple wire itself can conduct heat away from small components, affecting the accuracy of the reading. For this reason, thermocouples with a small wire diameter should be used; 30 AWG is suitable for most measurements, but finer wire will be necessary if the components are very small.

To make accurate measurements of component temperatures, thermocouples should be glued directly onto the component surface at the point where the temperature is to be measured. Use a suitable thermally conductive epoxy and make sure the thermocouple wire junction itself is as close as possible to the component surface. For measuring ambient air temperature, use tape to support the thermocouple with its junction at the point where the air temperature is to be measured. Do not cover the wire junction itself with the tape.

DC voltages will not generally affect the temperature readings, but ac voltages can cause errors. If the thermocouple is attached to a point in the circuit that has a significant high-frequency ac voltage, it may be necessary to turn off power momentarily while the measurement is made.[15] As long as the measurement is taken immediately after the power is switched off, there will not be much effect on the accuracy.

B.6.1 Attaching thermocouples

The best point to attach the thermocouple will vary depending on the component type. Some common examples are given in B.6.1.1 through B.6.1.8.

B.6.1.1 Semiconductors, heatsink mounted

Glue the thermocouple to the center of the plastic case of the MOSFET or diode, taking care not to contact the tab or leads. Remember that there may be a high voltage on any metal part of the device. The measurement will show case temperature. Refer to the device databook for conversion to junction temperature (if necessary).

B.6.1.2 Extruded heatsinks with several devices

Measure the temperature at the top of the heatsink (when the UUT is mounted in its normal operating position). Glue the thermocouple to the part of the heatsink where the transistors mount (usually the thickest part of the metal), not to one of the fins. For the greatest accuracy, it may be possible to drill a small hole and glue the thermocouple inside it.

B.6.1.3 Single device heatsinks

Glue the thermocouple to the heatsink close to the device mounting point, but not touching the device body.

B.6.1.4 Integrated circuits (ICs)

Glue the thermocouple to the center of the case of the IC, taking care not to contact the leads. Remember that the reading will be case temperature. Refer to the device databook for conversion to junction temperature (if necessary).

B.6.1.5 Magnetics

Glue the thermocouple on the outside surface of the winding (for winding temperature), or onto the core (for core temperature). Do not try to push the probe inside the winding, or between the winding and core. If it is necessary to measure internal temperature, the magnetics designer should provide a special prototype magnetic component with an embedded thermocouple, placed in the winding during manufacture.

B.6.1.6 Axial components

Glue the thermocouple to the middle of the component body. Remember to use a fine wire thermocouple for small components.

[15]Even if the thermocouple itself is not directly in contact with the high-frequency voltage, a voltage may be induced in the thermocouple wire and may affect the measurement accuracy.

B.6.1.7 Electrolytic capacitors

Glue the thermocouple directly to the metal can—if necessary, remove part of the insulating sleeve. If the capacitor is mounted onto tracks carrying high current, also check the temperature close to the mounting leads since this may be the hottest point on the capacitor.

B.6.1.8 Printed circuit board (PCB) temperature

To measure the PCB hot-spot temperature, look for a point on the PCB close to the hottest components. If there are high-current tracks connecting to these component, glue the thermocouple directly onto the high-current track (if it is on an outer layer) or else immediately above it (if it is in an inner layer). The hottest point will usually be close to the pins of the hot component, directly on the high-current track.

B.6.2 Using the thermal chamber

Prototypes for verification testing will normally be set up inside the thermal chamber, so that the high- and low-temperature tests can be carried out easily. Set up the UUT in its normal mounting orientation, raised several centimeters above the floor of the chamber to allow air circulation. Since the chamber temperature setting may not be precisely controlled, use a thermocouple positioned to measure ambient air temperature just below the bottom of the UUT. Make sure that any test jigs or probes used inside the chamber are rated for the full planned ambient temperature range.

Thermal chambers have a circulating fan to maintain even temperature, and this fan will usually provide a higher rate of airflow than the amount specified for the UUT. It may be necessary to restrict the air circulation somewhat, to allow all components to reach a realistic equilibrium temperature, particularly in the case of products designed for natural convection cooling. One way of doing this is to enclose the prototype being tested inside a large cardboard box or other enclosure with a number of holes cut in it. Use one or more thermocouples to measure the air temperature inside the box—this will give the ambient temperature reading for the test—and adjust the chamber temperature setting as required.

Connecting wires from the test jig, thermocouples and oscilloscope probes should be run through the chamber access port. Make sure all wires are adequate to carry the currents required, and are rated for the maximum ambient temperature. Keep all wires as short as reasonably possible to minimize voltage drops and noise pickup, and make all voltage measurements directly at the test jig connector pins.

After any changes in settings, allow sufficient time to reach thermal equilibrium, typically a minimum of 30 minutes to one hour, depending on the UUT. If a box is used to restrict air circulation, the time to reach equilibrium will be longer. To test for start-up capability, first set up the input voltage and load currents required for the test, then disconnect the input power (using a separate switch in series with the power source) without changing any of the load settings.[16] Allow the chamber and prototype to fully reach equilibrium with no power applied, then switch on the input power (using the separate switch) to confirm that the UUT starts up properly.

Record all details of the test set-up used, including the exact location of all thermocouples, so that the tests could be repeated if necessary.

B.7 High frequency parasitic

High frequency parasitic can affect the accuracy of measurements. They include parasitic inductance, parasitic capacitance, skin effect, proximity effect, and magnetic and electrical effects.

[16] It is necessary to use a separate switch in series with the input power source to allow power to be suddenly applied while the power source is already operating.