

1573™

IEEE Recommended Practice for Electronic Power Subsystems: Parameters, Interfaces, Elements, and Performance

IEEE Power Electronics Society

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Standards Committee



Published by
The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

31 March 2004

Print: SH95146
PDF: SS95146

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**Standards Committee
of the
IEEE Power Electronics Society**

Approved 11 September 2003

IEEE-SA Standards Board

Approved 11 February 2004

American National Standards Institute

Abstract: A technical basis for implementation of electronic power subsystems is provided in this recommended practice. It is intended for electronic systems engineers and integrators, electronic power subsystem designers and integrators, as well as power element manufacturers and suppliers. It addresses system-level issues in element or subsystem integration, adaptation, and accommodation. It also defines system-level interface parameters, test methods, and test conditions. It provides for a systems engineering approach to acquisition, adaptation, and integration of electronic power subsystems, facilitates and promotes a modular approach to element or subsystem integration, and enables effective communication between the end users of power electronics and their manufacturers or suppliers.

Keywords: adaptation, commercial or military electronic power distribution, electronic power subsystem, integrators, interaction, logistics, power electronics, power supply, specification, specification language, system interface

The Institute of Electrical and Electronics Engineers, Inc.
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Print: ISBN 0-7381-3830-4 SH95178
PDF: ISBN 0-7381-3831-2 SS95178

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Introduction

(This introduction is not part of IEEE Std 1573-2003, IEEE Recommended Practice for Electronic Power Subsystems: Parameters, Interfaces, Elements, and Performance.)

Electronic power subsystems are integral to electronic systems. They perform the tasks of power processing, management, and distribution to all user-level electronics. Clear definition and precise understanding of system-level performance parameters are crucial in building commonalities among different users of electronic power elements. Additionally, system-level understanding of the available electronic power elements or subsystems is the cornerstone to their successful adaptation and integration.

IEEE Std 1573-2003 facilitates implementation of electronic power subsystems. This recommended practice provides specification language at a system-level. It also provides for system-level adaptation and accommodation of commercially available elements or subsystems for specific applications. System-level adaptation and accommodation approaches are provided for use of such elements or subsystems in applications other than those for which they were marketed.

IEEE Std 1573-2003 is a companion to IEEE Std 1515TM-2000, IEEE Recommended Practice for Electronic Power Subsystems: Parameter Definitions, Test Conditions, and Test Methods.^a While IEEE Std 1515-2000 defines the parameters commonly used in specifying power electronic elements, IEEE Std 1573-2003 focuses on system-level parameters used to enhance effective element adaptation and integration in developing a subsystem.

IEEE Std 1573-2003 provides for a systems engineering approach to acquisition, adaptation, and integration of electronic power subsystems. This recommended practice facilitates and promotes a modular approach to element or subsystem integration, and enables effective communication between the end users of power electronics and their manufacturers or suppliers. It is intended for general users as well as for users for whom performance and logistics are paramount to achieve subsystem availability and affordability.

This recommended practice is intended for use by system engineers, designers, integrators, and manufacturers of power electronic elements. It allows for and promotes effective user-manufacturer cooperation to facilitate element or subsystem specification, acquisition, adaptation, and integration with the performance and logistics predictability and integrity required by today's demanding applications. It will also be useful for engineers and graduate students who are just entering the field of electronic power systems, since many of the parameters are seldom discussed comprehensively in university courses or in professional educational seminars.

^aInformation on references can be found in Clause 2.

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IEEE Recommended Practice for Electronic Power Subsystems: Parameters, Interfaces, Elements, and Performance

1. Overview

1.1 Scope

This recommended practice provides a technical basis for implementation of electronic power subsystems. It is intended for electronic systems engineers and integrators, electronic power subsystem designers and integrators, as well as power element manufacturers and suppliers. It addresses system-level issues in element or subsystem integration, adaptation, and accommodation. It also defines system interface parameters, test methods, and test conditions.

This recommended practice applies to ac–dc and dc–dc electronic power subsystems. The range of electronic power subsystems includes those with dc, single-phase, and three-phase inputs, having power levels from a fraction of a watt up to 20 kW. The voltage range is 600 V and below at a frequency or frequencies of dc 1 kHz. Internal operating frequencies within elements or subsystems may be much higher than 1 kHz.

This recommended practice may be used outside the range where applicable.

This recommended practice builds on and supplements IEEE Std 1515-2000.¹

1.2 Purpose

The purpose of this recommended practice is threefold:

- a) To provide a systems engineering approach to acquisition, adaptation, and integration of electronic power subsystems.
- b) To facilitate and promote a modular approach to element or subsystem integration.
- c) To enable effective communication between the end users of power electronics and their manufacturers or suppliers.

¹Information on references can be found in Clause 2.

1.3 Organization of this recommended practice

This recommended practice is organized into eleven clauses and four annexes.

Clause 1 is an overview of the scope, purpose, and organization of this recommended practice.

Clause 2 lists the references that should be consulted when using this recommended practice.

Clause 3 identifies definitions and acronyms used throughout the text of this recommended practice.

Clause 4 contains parameters that are at element level. These parameters can be added to IEEE Std 1515-2000 upon its revision.

Clause 5 identifies essential considerations for designing and implementing electronic power subsystems in the areas of requirements definition, architectural considerations, and system interaction. Four interfaces are defined: electrical interface, mechanical interface, environmental interface, and system effectiveness interface.

Clause 6 identifies electrical interface parameters related to electrical interactions between elements, or between an element and its higher level subsystem, including parameter definitions, test methods, and test conditions.

Clause 7 presents mechanical interface parameters related to mechanical interactions between elements, or between an element and its higher level subsystem.

Clause 8 presents environmental interface parameters that concern the subsystems' local conditions such as temperature, humidity, vibration, and dust.

Clause 9 contains system effectiveness interface parameters including reliability, logistics, and methods to predict or extend the life cycle of a subsystem.

Clause 10 discusses system integration issues of electronic power systems design and specification. It is intended to cover the major issues of concern and provide guidance to the designer as to the applicability of commercial items.

Clause 11 discusses adaptations that can be made to any or all of the system interfaces described in 5.1. The benefits of adapting a commercial item must be favorable with regard to a custom development considering schedule, risk, performance, and total cost.

Annex A is a list of additional readings (bibliography) that one may find helpful in understanding this recommended practice.

Annex B provides a list of performance parameters. It provides performance levels that are "commonly available" (from manufacturer's catalog items). This allows designers to use this recommended practice to determine the extent that an existing product (element) may be used to configure a particular electronic power subsystem. The data are dynamic and they change with technology.

Annex C is an index for all the parameters that are defined in both IEEE Std 1515-2000 and in IEEE Std 1573-2003.

Annex D is a brief summary of definitions, test methods, and commonly used corrective actions related to (nuclear) radiation effects for natural as well as man-made radiation effects on electronics.

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.

Although current practice favors the use of commercial and/or international standards, several military standards are ubiquitous to the commercial market.

IEEE Std 1515-2000, IEEE Recommended Practice for Electronic Power Subsystems: Parameter Definitions, Test Conditions, and Test Methods.^{2,3}

Federal Acquisition Regulations (FAR), Part 2, Definitions of Words and Terms (FAC 97-17), 25 April 2000.⁴

United States Air Force Scientific Advisory Board, Report on Ensuring Successful Implementation of Commercial Items in Air Force Systems, SAB-TR-99-03, April 2000.⁵

3. Definitions, abbreviations, acronyms, and symbols

For purposes of this recommended practice, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition [B16]⁶ should be referenced for terms not defined in this clause.

The 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 the Power Sources Industry* [B41].

Abbreviations and acronyms frequently encountered are also included for easy reference.

3.1 Definitions

3.1.1 combined effects: The condition where two or more parameters act on an element to influence performance.

3.1.2 commercial component: Any component that is a commercial item as defined in Federal Acquisition Regulations (FAR), 25 April 2000.

3.1.3 commercial item: Any component that is a commercial item as defined in Federal Acquisition Regulations (FAR), 25 April 2000.

Commercial item means:

- a) Any item, other than real property, which is of a type customarily used for non-governmental purposes and that
 - has been offered for sale, lease, or license to the general public; or,
 - has been offered for sale, lease, or license to the general public.
- b) Any item that evolved from an item described in a) of this definition through advances in technology or performance and that is not yet available in the commercial marketplace, but will be available in the commercial marketplace in time to satisfy the delivery requirements.

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⁴The Federal Acquisition Regulation (FAR) is available online (<http://www.arnet.gov/far/>).

⁵The USAF Scientific Advisory Board Report on Ensuring Successful Implementation of Commercial Items in Air Force Systems is available online (http://stinet.dtic.mil/str/tr_fields.html) using accession number ADA411926.

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

- c) Any item that would satisfy a criterion expressed in a) or b) of this definition, but for
 - modifications of a type customarily available in the commercial marketplace; or
 - minor modifications of a type not customarily available in the commercial marketplace.

3.1.4 commercial off-the-shelf: Items which can be purchased through commercial retail or wholesale distributors, as is, and are generally available as a catalog item as defined in U.S.A.F. Scientific Advisory Board, April 2000.

3.1.5 cooling medium: Cooling medium is the material used to transfer heat in a heat flow path.

3.1.6 electrical terminations: Physical attachments to achieve electrical interface connections.

3.1.7 element: An element is an accessible building block of an electronic power subsystem. Depending on the context, usage, or the intended use, it can be referred to as component, circuit card, assembly, subsystem, or product. The functions and features of an element can be unambiguously defined at its interfaces by the corresponding interface parameters. An element could be acquired as either a commercial or a custom item and where its features and function could be subjected to adaptation to accommodate specific demands of the intended applications.

3.1.8 input voltage spikes: Input voltage spikes are bi-directional voltage levels of a shorter duration than transients. Spikes can be caused by lightning strikes, inductive kicks, load changes, or any other input line voltage abnormality. Spikes typically can be suppressed by unidirectional or bi-directional transient suppressors such as metal oxide varistors (MOV), bipolar transient absorbers, and gas discharging tubes.

3.1.9 input voltage transients: Input voltage transients are voltage levels that are outside steady-state levels. Since it is a transient, it will not be sustained for a steady-state condition. These transients are generally random in nature and have a duration of up to seconds; however they typically result in very low duty cycles, less than 1%.

3.1.10 logistics: Logistics is the discipline of planning and accomplishing acquisition, storage, movement of materials, and the maintenance of systems.

3.1.11 platform: A platform is an end using system such as an airplane, an automobile, a battle tank, a satellite, medical equipment, personal computer, etc.

3.1.12 power density: Power density is the ratio of total rated output power to the physical volume of the electronic power subsystem, including all interface requirements imposed by the identified electronic power subsystem. This normally includes EMI filters and heat exchanger volume. A given electronic power subsystem can have different power density ratings in different applications.

3.1.13 supportability: The degree to which system design characteristics and planned logistics resources support system operations and readiness needs throughout the system's service life at an affordable cost.

3.1.14 synchronization of elements: Operation of power electronic elements at a common frequency, multiple of a common frequency, or a fraction of common frequency, achieved via a synchronization signal between elements and/or the external interface.

3.2 Abbreviations, acronyms, and symbols

A	ampere
ac	alternating current
ASIC	application-specific integrated circuit
ASSL	abnormal steady-state limit
ATP	acceptance test procedure/plan
BABT	British Approvals Board for Telecommunications (Certification Company)
BIT	built-in-test
BW	bandwidth
°C	degrees Celsius

CAN	controller area network
CB	circuit breaker
CCA	circuit card assembly
CE	European Union Conformity Mark (European Commission)
CFM	cubic feet per minute
CG	center of gravity
CI	commercial item
CM	common mode
COTS	commercial-off-the-shelf (equivalent to CI)
CSA	Canadian Standards Association
dc	direct current
di/dt	rate of current change
DIN	Deutsche Institut für Normung (German Standards Institute)
DIP	dual in-line pins
DM	differential mode
DMM	digital multimeter
EEE	electronic, electrical, and electro mechanic
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EPSS	electronic power specification standardization
ESD	electrostatic discharge
ESS	environmental stress screening
ESSL	emergency steady-state limit
ET	elapsed time
FAR	Federal Acquisition Regulations
FCC	Federal Communications Commission
FIT	failure in time
GIDEP	Government-Industry Data Exchange Program
HALT	highly accelerated life test
HASS	highly accelerated stress screening
HCP	horizontal coupling plane
HIRF	highly intensified radio frequency
Hz	hertz
I	current
I/F	interface
I/V	current/voltage
IC	integrated circuit
ID	identify or identification
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
I_{in}	input current
ISA	Industry Standard Architecture
ISO	International Standardization Organization
JEDEC	Joint Electron Device Engineering Council
kHz	kilohertz
LFM	linear feet per minute
LRU	line replaceable unit
MHz	megahertz
ms	milliseconds
MOSFET	metal oxide semiconductor field effect transistor
MOV	metal oxide varistor
MSDS	material safety data sheet
MTBF	mean time between failure
NA	not applicable

nom	nominal
NSSL	normal steady-state limit
OVP	overvoltage protection
OSJTF	open systems/joint task force
PCMCIA	Personal Computer Memory Card International Association
p-p	peak-to-peak
PFC	power factor correction
ppm	parts per million
PSI	pounds per square inch
pwb	printed wiring board
pwm	pulse width modulation
QPL	qualified parts list
RF	radio frequency
RTS	resonant transition switching
SAM	standard aerospace module
SEM	standard electronic module
SIP	single in-line pins
SPC	statistical process control
STP	standard temperature and pressure
TCE	thermal coefficient of expansion
TEC	thermo-electric cooler
TUV	TÜV Rheinland (Certification Company)
TVS	transient voltage suppressors
U	eurostandard height unit approximately 1.75 in.
UL	Underwriters Laboratories
UUT	unit under test
UVP	undervoltage protection
μs	microsecond
V	volt
Vac	ac voltage
Vdc	dc voltage
VCP	vertical coupling plane
VDE	Verband Der Elektrotechnik (The Association for Electrical, Electronic and Information Technologies for the German Republic)
V_{in}	input voltage
VHDL	VHSIC hardware description language
VHSIC	very high speed integrated circuits
VME	Versa Module Europa (A European Standard for Packaging Electronics). VME is also an IEEE and an ANSI Standard
V_{out}	output voltage
W	watt
Z_{in}	input impedance
Z_{load}	load impedance
Z_{out}	output impedance
ZCS	zero current switching
ZVS	zero voltage switching

4. Element-level parameters

Parameters defined in this clause are applicable at the element or system level and are commonly tested at the system level. These parameters logically belong to the companion document of IEEE Std 1515-2000. This can be done upon its revision.

4.1 Set point voltage accuracy

4.1.1 Definition

Set point voltage accuracy is the ratio of the measured to the nominal output voltage, $(V_m - V_n) \times 100/V_n$. (See also IEEE Std 1515-2000, 4.4.2.)

4.2 Maximum power dissipation

4.2.1 Definition

The amount of power that will be dissipated by the electronic power subsystem under the combined specified conditions. (See IEEE Std 1515-2000, 4.3.2.).

4.3 Contact resistance

4.3.1 Definition

The electrical resistance found between two mating surfaces.

4.3.2 Test method

Apply a current equal to the mated rating of the connecting feature (pin, screw terminal, bus bar) and measure the voltage drop across the junction of the connection using a four-wire method. The value obtained by dividing the measured voltage drop by the current applied represents the contact resistance.

4.3.3 Test condition

Per IEEE Std 1515-2000, 4.7.1.

4.4 Input undervoltage protection

4.4.1 Definition

Input undervoltage protection is the function of a component or circuit in an electronic power subsystem designed to sense and provide protection against an input voltage that is below the level of normal or safe operation. Protection is achieved by shutting down or reducing operating stress.

4.4.2 Test method

Connect the test setup as shown in Figure 1. Use a digital multimeter (DMM) that measures the dc voltage or root mean square (rms) value of an ac voltage input to the unit under test (UUT). With the input to the UUT initially adjusted to nominal voltage, slowly decrease the input. Record the voltage level at which the UUT generates an input undervoltage signal and verify that the UUT has shut down. Some UUTs will actually continue to operate at low input voltages until the output voltage decreases to a level that generates an output undervoltage signal. Readjust the input voltage to nominal and verify the response of the UUT. Some UUTs will reset themselves and return to normal operation, while in other UUTs the fault may latch up and wait for a restart command to recover to normal operating conditions.

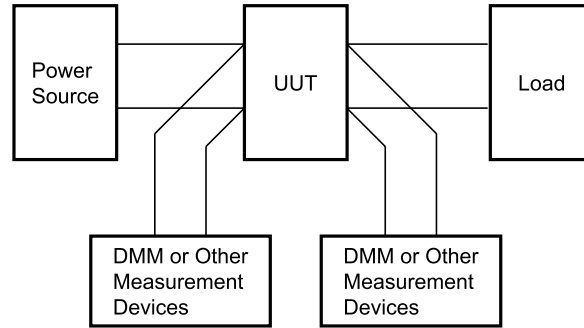


Figure 1—Test setup for input undervoltage protection

4.4.3 Test condition

Operate and test the UUT over the full temperature range. The load shall be adjusted from $I_{\min}$ to $I_{\max}$.

4.5 Input overvoltage protection

4.5.1 Definition

Input overvoltage protection is a circuit function in an electronic power subsystem designed to sense an input voltage that is above the level of normal or safe operation and provide protection, e.g., by shutting down or reducing operating stress.

4.5.2 Test method

For a steady-state input overvoltage test use the test setup shown in Figure 2. Use a DMM that measures dc voltages, or the rms value of an ac voltage across the UUT input. In either case of operation, slowly increase the UUT input voltage and record the voltage level at which the UUT generates an input overvoltage signal. In some UUTs the fault may latch-up and turn off the UUT. Readjust the input to nominal and verify the response of the UUT. Some UUTs will reset themselves; others wait for a restart command to recover to normal operating conditions.

Refer to IEEE Std 1515-2000, 4.15.2.2 and 4.15.3.2, for an output overvoltage test method.

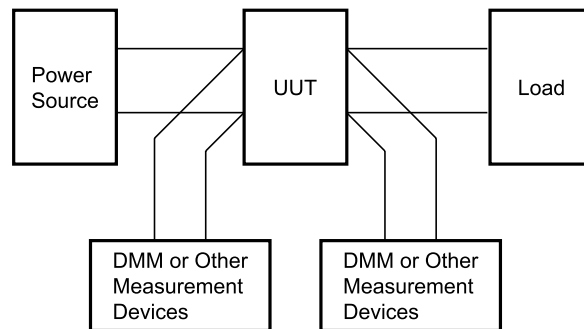


Figure 2—Test setup for input overvoltage protection

4.5.3 Test conditions

Adjust the input voltage to nominal conditions. Operate and test the UUT over the full temperature range. The load shall be adjusted from $I_{\min}$ to $I_{\max}$. For output overvoltage test conditions, refer to IEEE Std 1515-2000, 4.15.2.3 and 4.15.3.3.

4.6 Overtemperature shutdown

4.6.1 Definition

An overtemperature shutdown is a feature of protection that causes the subsystem to automatically shut itself down if the temperature at a defined monitoring point exceeds a predetermined temperature threshold. At recovery, there is usually hysteresis. This fault condition is usually reported to a monitoring system by the subsystem as a failure.

4.6.2 Test method

Use a temperature chamber to perform the tests. Connect the test setup as shown in Figure 3. With the DMM or oscilloscope measure the output voltage. Attach the thermocouples directly to the defined location of interest on the UUT to measure and use the thermometer to record the temperature at which the UUT shuts down. To conduct the test, slowly increase the ambient temperature in the chamber while operating the UUT under the desired test conditions. Some UUTs may generate an overtemperature signal and shut off when the fault occurs. Others may only shut off at the temperature limit of operation. Cooling the UUT, verify and record the temperature at which the UUT restarts itself. In some UUTs, the fault may latch-up and only turn back on with a restart command.

Monitor the temperature rise of the base-plate to protect the UUT by turning off the power source in case the UUT thermal protection mechanism malfunctions.

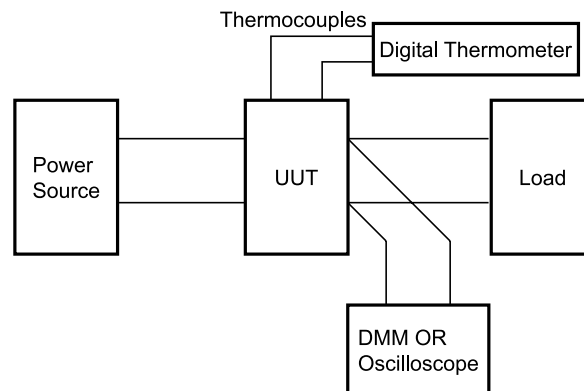


Figure 3—Test setup for overtemperature shutdown

4.6.3 Test condition

Test conditions are shown in MIL-STD-810F(2) (Test Method 520) [B31].

4.7 Reverse voltage protection

4.7.1 Definition

Reverse voltage protection is a function performed by a circuit or circuit component to protect the electronic power subsystem from any damage that can be caused by the application of a voltage of reverse polarity at the subsystem's input or output terminals.

Two examples of input reverse polarity protection are a shunt diode or a diode in series with the input of the UUT. An example of output reverse polarity protection is the addition of a rectifier outside the output filter of the UUT.

4.7.2 Test method (input reverse voltage)

For input reverse voltage protection, connect the test setup as shown in Figure 4. Use a current-limited source or add a fuse or circuit breaker with the appropriate voltage and current rating in series with the input of the UUT. Begin by adjusting the power source output voltage to zero. Turn on the UUT. Swap the output leads from the power source as shown in Figure 5. Verify that as the power source output voltage is slowly increased the UUT withstands the reverse polarity condition without failure. Repeat the test, adjusting the power source voltage to the steady-state range prior to application to the UUT. A programmable voltage source or suitable switching device should be used.

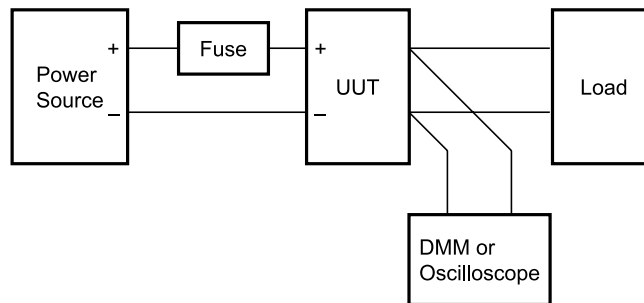


Figure 4—Test setup for normal input polarity connection

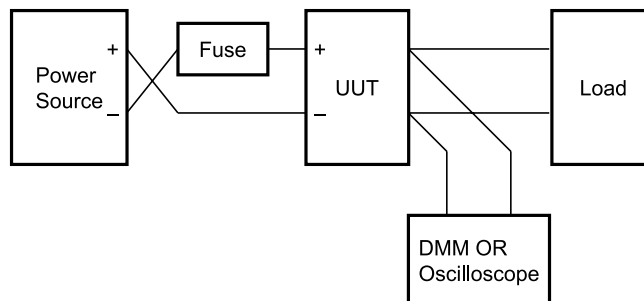


Figure 5—Test setup for reverse input polarity connection

4.7.3 Test method (output reverse voltage)

For output reverse voltage protection, connect the setup as shown in Figure 6, with a test power supply connected in reverse polarity to the output of the UUT. If necessary, apply a minimum load to

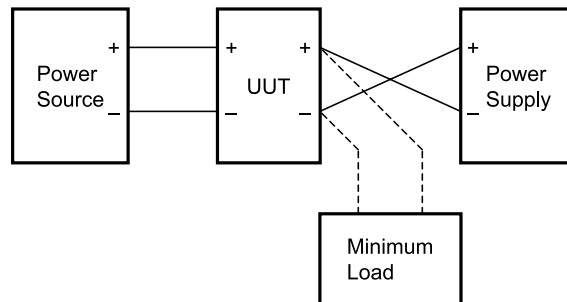


Figure 6—Test setup for reverse output polarity connection

the UUT. Turn on the power source and UUT, and verify the UUT operates normally with a nominal input voltage. Turn on the test supply and slowly increase the output of the test supply up to the maximum reverse voltage rating of the UUT while monitoring the current drawn from the test supply. Confirm the current drawn from the test supply is as expected—a high current if the UUT is protected by a shunt element across its output, but a low or zero current if the protection is by a series blocking element (diode, MOSFET, or similar). If the UUT has a reverse voltage indicator verify it turns on at the expected voltage level. Reduce the voltage of the test supply to zero and confirm that the UUT returns to normal operation.

4.7.4 Test condition (input reverse voltage)

For input reverse voltage protection, adjust the load current to $I_{\min}$.

4.7.5 Test condition (output reverse voltage)

For output reverse voltage protection, adjust the input voltage to the UUT to nominal. Adjust the output load to minimum.

4.8 Turn-on time

4.8.1 Definition

Turn-on time is the time it takes to begin operating within the specifications after the proper power has been applied.

4.9 Regulation, combined

4.9.1 Definition

The sum of the effects of line, load, and temperature variation as defined in IEEE Std 1515-2000, 4.4.1 through 4.4.3, respectively.

4.9.2 Test method

Per IEEE Std 1515-2000, 4.4.1 through 4.4.3.

4.9.3 Test condition

Per IEEE Std 1515-2000, 4.4.1 through 4.4.3.

4.10 Regulation effects due to aging

4.10.1 Definition

Regulation effects due to aging are degradation in combined regulation due to life or long-term effects.

4.11 Lightning

4.11.1 Definition

Lightning is a natural phenomenon that occurs when electrical potential energy is discharged directly to the ground or through another object. A lightning strike is a large current that increases voltage potential between two points in a subsystem due to high-level current flow. The series impedance is the dominant factor for voltage spikes since lightning strikes may range as high as 100 kA. (The largest spike recorded was 3 MA, but this is a rare occurrence.)

4.12 Surge

4.12.1 Definition

A surge is a sudden voltage increase on the power mains. A surge is limited by the source impedance and has the greatest affect on the loads with the lowest input impedance. They are often caused by load changes that are a small percentage of the total load capacity.

4.13 Sag

4.13.1 Definition

Sag is a sudden decrease in input voltage due to increased load on the main power subsystem. Long lasting sags may be referred to as *brown-out*.

5. Electronic power subsystems

Electronic power subsystems are an integral part of electronic systems. All electronic systems, whether medical, telecom, automotive, avionics, or consumer electronics, or whether military, industrial, or commercial, require electrical power to operate.

An electronic power subsystem is a collection of power elements that convert, manage, and distribute electrical power from the input source to load.

This clause identifies essential considerations in designing and implementing electronic power subsystems. It focuses on the interface issues among elements of an electronic power subsystem and between a subsystem and its user-level electronic system.

It is beyond the scope of this recommended practice to discuss the internal aspects of elements that compose an electronic power subsystem or to specify their design. However, there are methods to facilitate matching existing elements to application requirements. These methods fall into the categories of requirements definition, architecture selection, and consideration of system interaction and logistics. These methods are discussed as they pertain to the interfaces between a user-level electronic system and an electronic power subsystem, and to the interfaces between elements within a subsystem.

Since one of the purposes of this recommended practice is to facilitate implementation of electronic power subsystems using commercial items in demanding applications, this clause and several of the follow-up clauses, specifically Clause 11, contain adaptation approaches to allow use of such elements in applications beyond that for which they were intended. The use of commercial items can reduce technical and schedule risk, as well as total cost.

Subclause 5.1 defines the four interfaces, in simple terms, which apply to subsystems and elements. Subclause 5.2 discusses an important issue in electronic power subsystem development, requirements definition. Subclause 5.3 discusses architectural considerations for a successful development of an electronic power subsystem. Subclause 5.4 provides top-level details on the important issues of system interaction.

5.1 Interface definition

Interface refers to connections and interactions between elements, or connections and interactions between elements and the higher-level subsystem.

In this recommended practice, interfaces are organized into four categories. They are the electrical, mechanical, environmental, and system effectiveness interfaces. In order for an element to function as expected, the four interfaces need to be adequately defined, the requirements imposed on the interfaces need to be satisfied, and both normal and fault conditions need to be addressed.

It is noted that the electrical interface and mechanical interface are physical interfaces in the sense that they are integral to the element. The environmental interface is physical but not all aspects of the environmental interface may be present in a given utilization scenario. The system effectiveness interface is a virtual interface that is descriptive of performance metrics such as efficiency, failure rates, mean-time between failures, mean-time to repair, etc.

Figure 7 is a simplified diagram that illustrates the relationship between these interfaces and an element.

It should be noted that interfaces are bi-directional. In other words, a higher-level subsystem can affect the operation of an element and vice versa.

In practice, by specifying interface parameter performance and variations, it can be determined whether a particular element can meet the requirement with or without adaptation. Table 1 lists examples of issues and parameters that should be considered in the development and integration of electronic power subsystems.

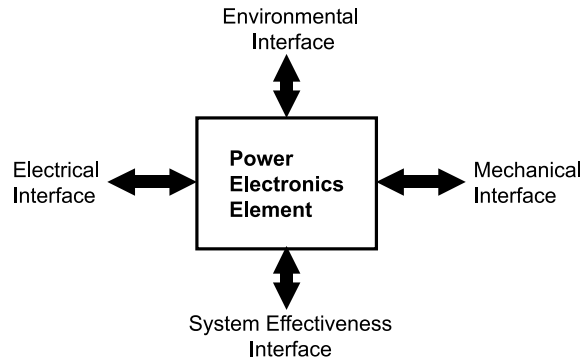


Figure 7—Relationship between an element and its interfaces

Table 1—Example interface considerations

Electrical	Mechanical	Environmental	System effectiveness
Input voltage range	Dimensions	Operating temperature range	Reliability
Input frequency range	Thermal interface	Storage temperature	Life expectancy
EMI/EMC	Structural requirements	Humidity	Regulatory requirements
Input voltage/frequency transients	Mounting	Shock	Component quality
Output voltage and current	Power dissipation	Vibration	Configuration management
Efficiency	Center of gravity	Salt spray	Derating
Control and status signals	Cooling medium	Explosive atmosphere	Component/product obsolescence
Dynamic load and signal requirements	Weight	Radiation	Quality assurance
Overcurrent/overvoltage protection		Sand and dust	Safety

5.1.1 Electrical interface

The electrical interface includes connections and interactions between elements, or between an element and its higher level subsystem, that can be described by electrical parameters, such as voltage, current, and power. The electrical interface may also include control signals that will change the electrical operating conditions of the element and higher level subsystem. It may also include the means to measure and change the operation of an element to ensure its proper operation, such as test points in the manufacturing process.

The electrical interface between elements, or between an element and its higher level subsystem, can be illustrated as shown in Figure 8.

For any given electronic power element, the input and output are typically voltage and current. There may also be control signals from the system to change the operating conditions of an element and/or signal(s) from an element to the system to indicate its status.

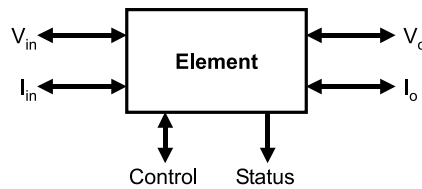


Figure 8—Electrical interface

Note that bi-directional arrows are used for V_{in} , I_{in} and V_o , I_o to indicate that there will be electrical interaction between an element and the system. An example is a power supply that converts one voltage level to another level to power digital circuits. In this case, the power supply takes the voltage and current from the system (the influence from the system) and provides another voltage level to power the digital circuits (the function of the element). The power supply will generate EMI noise affecting the system and it will also change the impedance of the system bus affecting both voltages and currents at every node in the system; these are influences from a particular element.

5.1.2 Mechanical interface

The mechanical interface is defined as connections and interactions between elements, or between an element and its higher level subsystem, that can be described by mechanical parameters, such as size, mounting methods, thermal aspects, and internal and external connections.

Note that there may be significant interaction between any given element and the system. This is a particularly important consideration at the system definition and initial system design stage.

In addition, human-machine interface should also be considered. One obvious example for human-machine interface requirements is that the equipment should be easy and safe to install and to remove.

5.1.3 Environmental interface

The environmental interface encompasses the interactions between an element and its higher level system that can be described by environmental parameters, such as temperature, altitude, and humidity. Operating and non-operating environments are among the environmental parameters to be defined. There may be several different environments within one platform such as manned vs. unmanned areas of vehicles. Environmental conditions influence life expectancy, robustness, and reliability.

5.1.4 System effectiveness interface

The system effectiveness interface includes logistics, support, and life cycle parameters driven by design trade-offs and interactions among the three other interfaces that contribute to the functionality of an electronic power subsystem for a given application.

System effectiveness is a broad concept. It includes issues that are not covered in the three other interfaces. The system effectiveness interface can be divided into two areas. One includes system-level issues that are not directly related to the above three interfaces, such as product life, warranty, system configuration management, cost, schedule, etc. The other includes connections and interactions among the above three interfaces in order to achieve best system-level performance.

Some of the examples of system effectiveness interface are the following:

- The logistics of a program, technical support, and lifecycle maintenance of the product.
- The schedule of a program and the element and system configuration management.
- System design aspects such as the inclusion of built-in test, and the system software capability.
- System quality and derating.
- Impact of failure–failure modes, effects and criticality, system redundancy, etc.

Some other more detailed examples of the system effectiveness interface include the following:

- Advanced pins are often used in the system to allow certain circuits of the element to contact the system first during plug-in. One such example is the advanced pins for power connection. Similarly, in some cases, retarded pins are used to achieve the opposite objective.
- Mechanical interlock is sometimes used to ensure that the electrical operations of the element can be achieved only after the element is seated properly into the system. In some other cases, interlock is used in the system so that the element cannot be removed from the system before it terminates electrical functionality.
- Overtemperature shutdown of the power element is an example of the inter-reaction between the electrical interface and the environmental interface. In this case, the environmental parameter (temperature) influences the operation of the electrical function of the element.

It should be emphasized that system effectiveness interface parameters can be complicated and are sometimes mutually conflicting. A systematic approach is usually required and strongly recommended to define and achieve an optimal system effectiveness interface.

5.2 Requirements definition

Requirements definition is the process of identifying application, interface, and regulatory requirements and constraints. Defining requirements clearly is a primary task for successful completion of subsystem development. The requirements definition generally results in a specification for the electronic power subsystem.

The requirements definition process begins at the interface between the electronic power subsystem and the related system. All parameters of this interface should be considered including electrical input and output, mechanical aspects, environmental exposure, and system effectiveness. Where applicable, normal operating extremes and worst-case transient limits should be identified. Requirements should subsequently be defined for each of the elements of an electronic power subsystem, as appropriate. These requirements are derived from requirements at the subsystem interface and from constraints imposed by the architectural design. Analysis and/or prototype system-level tests may be required to derive the requirements of the individual element(s) from the total subsystem requirements.

Guidelines for successful requirements definition include specifying interface parameters as openly as practical while adequately specifying, and involving manufacturers of building block elements under consideration in trade-off decisions during the requirements definition process. Requirement definition and the power subsystem product concept should be worked in parallel so that limitations, imposed on the concept by requirement, can be fully understood and challenged before either the requirements or the concept is frozen. An iterative process of requirements definition and subsystem architecture is critical to increasing the probability of successful use of commercial item elements. This process generally involves the participation of the subsystem designer, the customer, application end-user, and element providers jointly participating in requirements definition and trade-off studies.

Overspecification is potentially a limiting factor at each level in the development process, particularly when considering the use of commercial items (CI). The requirements definition process should

anticipate system evolution and accommodate potential changes with minimal design impact. Proper requirements definition covers all parameters of all the interfaces of a subsystem. A parameter that is not defined may take values that allow unpredictable system performance. It may cause unpredictable behavior of the subsystem and may ultimately result in catastrophe.

Overspecification is mitigated by providing common terminology and definitions for subsystem parameters and by identifying parameters requiring quantification. Typical parameter values commonly available in commercial items are included in Annex B. Caution, however, is urged in the use of these typical parameter values. They represent the commercial market at a particular element level at the time of issuing this recommended practice. Further, subsystems defined by combinations of these parameter values may be neither commercially available nor economically achievable. For example, typical values for power density or reliability available in low-level building block elements will generally have to be re-evaluated for subsystems built with combinations of these and other elements. The observed common trend is for subsystem reliability and efficiency, relative to a single constituent element, to decrease as elements are combined to form subsystems. Unless proper attention is paid to the thorough definition of requirements, it is likely that the performance, reliability, and efficiency of the power subsystem will be compromised, and the final cost will be unnecessarily high.

5.3 Architectural considerations

An electronic power subsystem architecture is driven by the defined requirements and architectural strategies, including planned technology insertion. Often the architectural choices open to the designer are constrained by nontechnical system requirements or constraints such as prior decisions, system architecture and packaging, or schedule. Even when the constraints are limited to the technical aspects of an electronic system interface, more than one architectural approach will usually meet the interface requirements. Choosing among these architectures is primarily an optimization process, usually involving parameters that are difficult to quantify accurately during conceptual design in areas such as life cycle cost, reliability, and obsolescence. The life cycle goals of the application and associated system, and customer decision criteria should be understood when performing the trade-off analysis.

An electronic power subsystem architecture is the methodology by which the input power source is converted to load power requirements, within the constraints imposed by the four subsystem interfaces. Architectural choices range from highly integrated to modular solutions. Highly integrated architectures may achieve the best performance and lowest recurring unit cost but may not be adaptable to evolving electronic system requirements. When such evolution or technology insertion is anticipated at the electronic system-level, a modular solution involving multiple physical elements may be preferable, even if achieved at higher initial acquisition cost.

The approach diagrammed in Figure 9 is a block schematic example of a highly integrated solution for a four-output ac to dc converter requirement. The simplified schematic example illustrates a power conversion scheme involving a single conversion stage with isolation, regulation, and filtering accomplished using a single integrated magnetic device. The success of such an approach relies on optimization of the magnetic and circuit design to the application specific load voltages and currents, including knowledge of minimum loads and cross loading extremes. The specificity of such an approach to the application requirements usually requires a custom development with its associated cost, risk, and schedule. Subsequent changes due, for example, to system evolution will generally require significant product redesign.

The approach diagrammed in Figure 10 accomplishes the same power conversion requirement with a modular architecture. In this example, a non-isolated boost converter performs conversion of the input ac voltage to an intermediate dc link voltage. The dc link is followed by independent isolated dc-dc converters for three of the four outputs with the fourth output provided by a non-isolated dc-dc

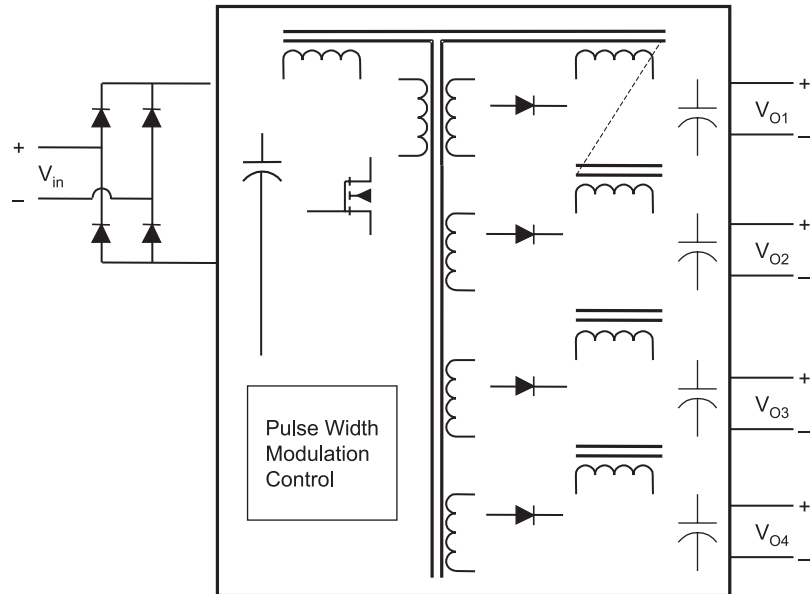


Figure 9—Highly integrated power subsystem

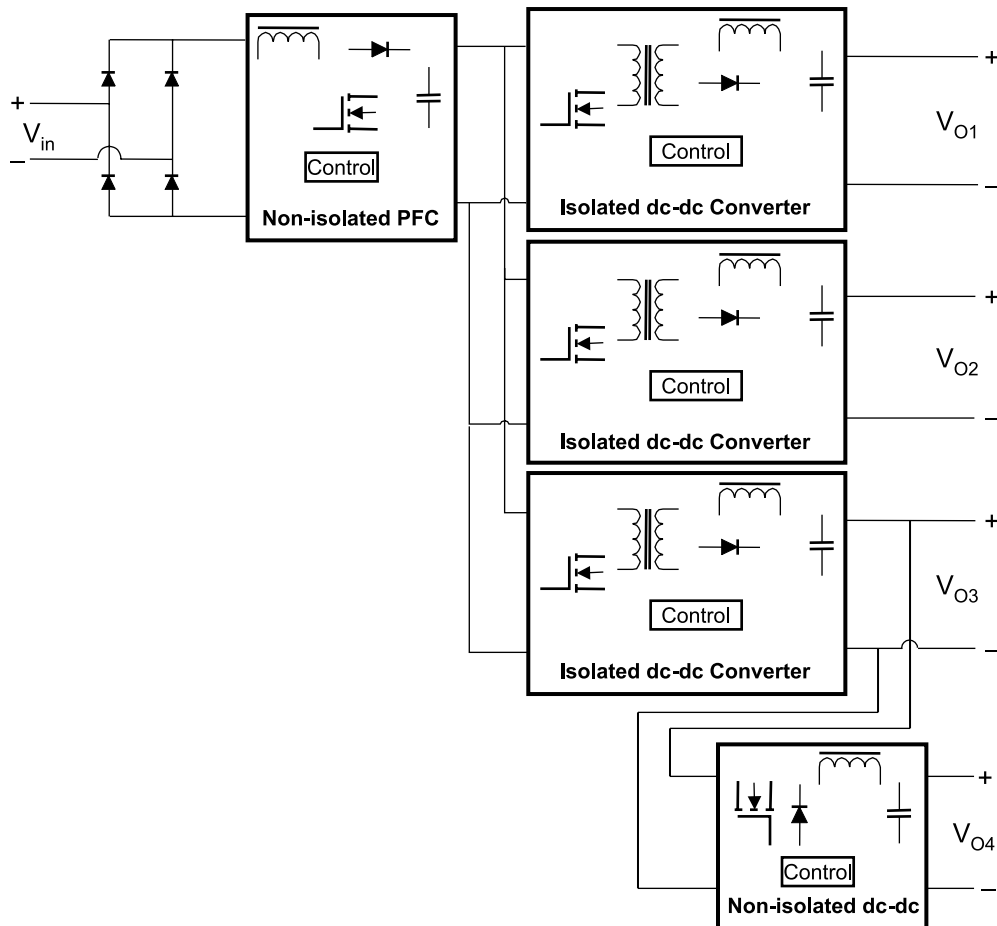


Figure 10—Modular power subsystem

converter sourced by output number two. This approach involves multiple stages of conversion and duplication of circuit functions when compared to that of Figure 9. Such duplication will generally result in higher recurring product cost. However, total cost may be lower when the initial development cost and evolutionary requirement changes are considered. The lower development and redesign costs assume that the modular building blocks are either commercially available or exist in a standard circuit design library. Even the recurring product cost may be lower when the individual building block modules are available commercially from high volume manufacturing lines.

These two examples represent divergent approaches with regard to the architectural choice of integrated versus modular architecture, yet each approach is valid. The integrated approach, for example, is appropriate for high volume cost sensitive applications, especially *disposable* products or those with limited product life. They may also be appropriate when the application requirements cannot be met by available modules or when available modules cannot be adapted to particularly demanding aspects of an application's requirements, such as environmental extremes. Architectural choices can facilitate the use of commercially available items.

A major architectural option is the choice between centralized versus distributed electronic power subsystems. Centralized solutions combine all stages of conversion in a common element, usually a circuit card or enclosure including one or more circuit card assemblies (CCA). Distributed solutions are characterized by use of a final conversion stage onboard the electronic system circuit cards. Distributed architectures may convert the input source to an intermediate voltage or the input source may be distributed directly to the electronic system circuit cards for onboard voltage conversion. Highly integrated architectures are necessarily centralized. Modular architectures may be either centralized or distributed. The majority of electronic power subsystems are a hybrid of centralized and distributed approaches. In a hybrid architecture, an electronic power subsystem element converts the input source to one or more outputs for use throughout the electronic system, while other system load voltages are locally derived either from the input source, another system load voltage, or an intermediate voltage. Figure 11, Figure 12, and Figure 13 show examples of centralized, distributed, and hybrid architectures.

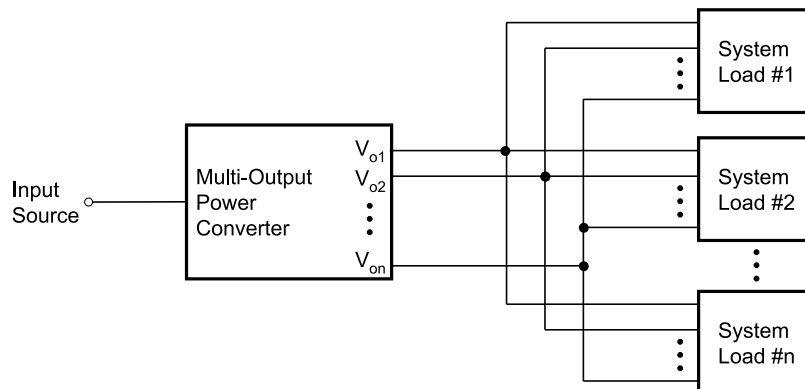


Figure 11—A typical centralized architecture for electronic power subsystems

Centralized architectures most often require custom solutions, though it is often possible to construct the custom solution using commercial item power electronic elements as building blocks. Centralized solutions may facilitate standardized approaches at the electronic system-level. Open system architecture approaches, such as VME, specify a standard complement of dc voltages (+5, ± 12 , +3.3) and standard system interface and BIT signals that favor a centralized electronic power subsystem approach. Centralized architectures often result in the lowest recurring hardware cost for the electronic power subsystem, though it may not result in the lowest life cycle cost. Centralized

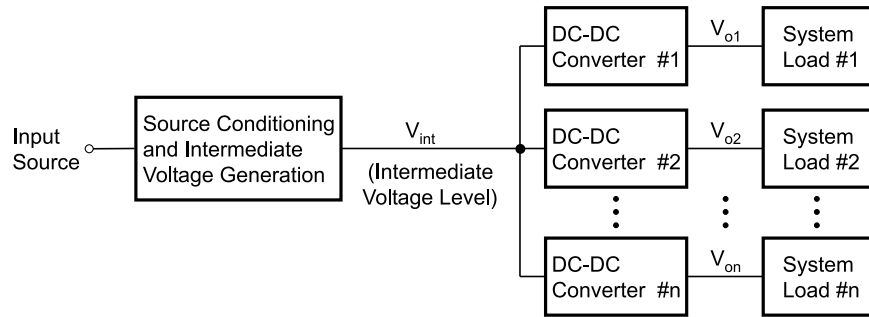


Figure 12—A typical distributed architecture for electronic power subsystems

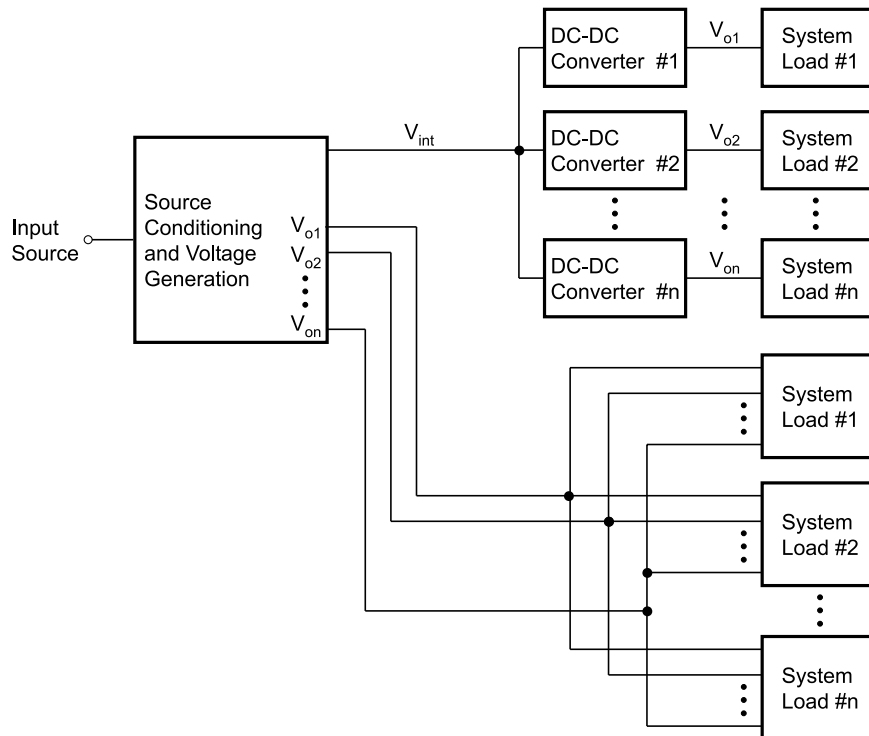


Figure 13—A typical hybrid architecture for electronic power subsystem

solutions typically have higher development costs and longer development time, and are less adaptable to change. Such architectures may accommodate changes by use of replaceable modules or programmable outputs.

Distributed solutions facilitate the use of commercial items, particularly at latter stages of conversion. The distributed voltage is generally limited by safety or other requirements thus requiring an initial conversion stage(s) when the input source voltage is other than the distributed voltage. Distributed architectures are ideal for systems requiring battery back up. The distribution voltage in such a system is typically the battery charge voltage. Additional benefits of distributed approaches include distribution of the heat load, easier implementation of redundancy, easier regulatory compliance (through use of pre-approved elements), and lower development cost but with potentially higher recurring costs. Distributed electronic power subsystem architectures may dictate a custom solution at the electronic system-level due to the requirement for a common

distributed bus voltage, and embedding final stages of the electronic power subsystem within the electronic system.

Many electronic power subsystems are a hybrid of distributed and centralized approaches. A first stage of conversion may be used both to generate a distributed voltage bus and to supply a number of lower power and/or higher voltage buses. The distributed voltage bus can then be used to supply dc–dc converters located near the point of use within the electronic system for low-voltage, high-current loads. This type of system is used in some personal computer supplies, where a centralized power element converts the ac source to dc voltages, for the display, and provides an isolated intermediate dc voltage bus for distribution to dc–dc converters, located near the low-voltage, high-current processing loads.

The pace of technological change and component obsolescence dictate that modern systems with long intended lifespans must be designed with planned technology insertion in mind. This often means accommodating lower dc voltages in future iterations. As system voltages continue to decrease and current demand increases, centralized solutions will become increasingly difficult to implement. In such cases, distributed dc–dc converters at the point of use may be required for the final generation of the low voltage.

Attention to architectural decisions are essential to successful electronic power subsystem implementation, particularly when considering the use of commercial item elements. Element interfaces, as defined in this recommended practice, are electrical, mechanical, environmental, and system effective. Interface performance may not ideally map from an application's requirement to an element's capability. Mapping between these interface requirements and available performance may be possible with specific architectural arrangements of available elements and by providing additional circuitry for interface adaptation, or other adaptations, between system and element interfaces.

Figure 14 depicts these interfaces and represents adaptations. Examples of methods for mapping required interfaces to available elements are provided in Table 2 and discussed in further detail in Clause 11.

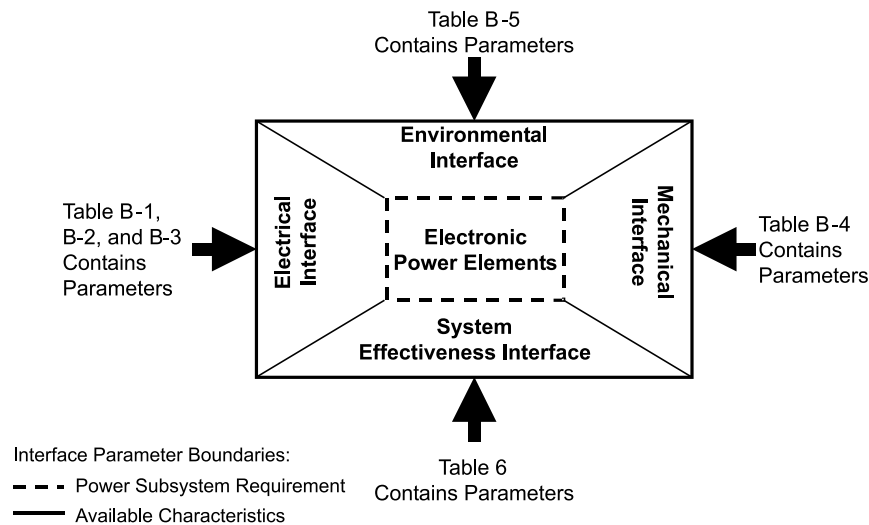
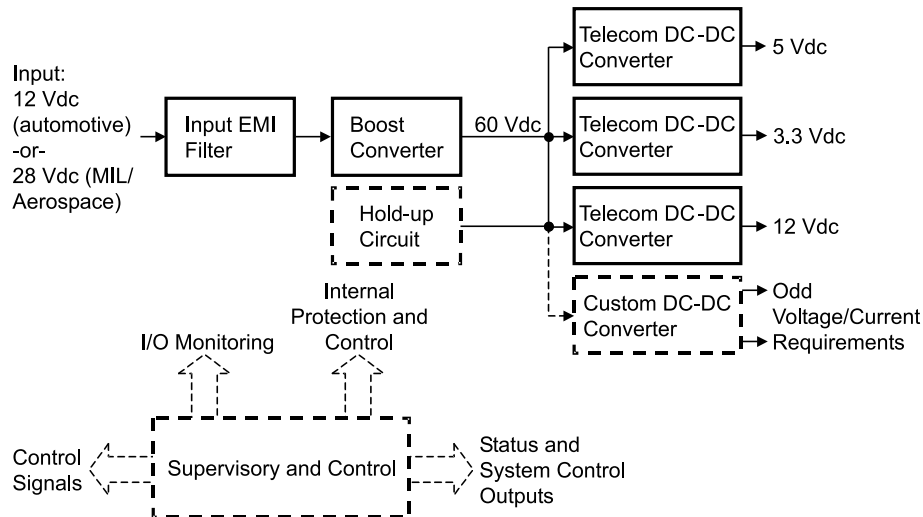


Figure 14—Electronic power element interfaces and system adaptation

An example that includes electrical adaptations to allow use of widely available telecommunication dc–dc converter elements in applications that traditionally do not use them is provided in Figure 15. Such an approach could be implemented in either centralized or distributed system architecture.

Table 2—Architectural interface adaptations

Interface	Example adaptations
Electrical	Transient protection, filtering, voltage translation (up/down conversion), galvanic isolation
Mechanical	Vibration damping, heatsinking, encapsulation
System effectiveness	Redundancy, derating, built-in-test (BIT), programmability
Environmental	Special cooling, moisture control, shock reduction; conformal coating, encapsulation, vibration damping, bonding

**Figure 15—An adaptation example using a telecom power subsystem for automotive, or military applications**

5.4 System interaction

Combining electronic power subsystem elements that operate as specified in isolation may create significant problems due to adverse interactions between the elements. Potentially adverse system interactions can occur in each of the four defined interfaces.

Electrical interactions may result in subsystem instability, load imbalance for parallel converters, noise coupling, and electromagnetic interference. Subsystem instability can occur particularly in distributed architectures when the negative impedance of a converter load is incompatible with the converter's source impedance and/or distributed impedance. (This concern is further addressed in 10.1.)

Where elements (usually dc–dc converters) are used in parallel to either increase output current or to provide redundancy, load imbalances are possible in either normal-operating modes or fault modes. Such imbalance can result in unacceptable thermal conditions, high ripple, and/or voltage oscillations. Load sharing methods are often used to mitigate this concern and are addressed in 10.1.2.

The high frequency switching converter elements, frequently used in electronic power subsystems, are sources of electrical noise from which the system usually requires protection. The same concern exists within the subsystem where elements, particularly control and monitoring circuitry, require protection from other elements. Filtering, shielding, and synchronization (for fixed-frequency converters) are among the methods used to mitigate these issues.

Mechanical interactions may include effects such as thermal and structural coupling, material incompatibility (e.g., dissimilar metals), and mismatch of thermal coefficients of expansion. Whenever multiple elements are integrated into a common physical assembly the thermal and structural environment is elevated above that of the interface to the assembly of the subsystem or system. The thermal and structural interface for an individual element is dependent on the physical structure of the assembly and on influences of the other elements. Therefore, analysis and/or test of the integrated system should be performed. When indicated, packaging methods to mitigate these effects can be incorporated including cooling, vibration isolation, or stiffening of the assembly and are addressed in 11.2.

Environmental effects are usually viewed as phenomena imposed on a subsystem. There are, however, undesirable responses to the imposed environments due to certain combinations of elements. Such responses include outgassing and nutrient growth due to organic materials. An example is the potential for explosive conditions when a non-hermetic relay is used in conjunction with an element that can create hydrogen outgassing, such as an aluminum electrolytic capacitor in fault mode.

System effectiveness concerns may include life cycle issues such as cost, reliability, maintainability, and testability. These issues are driven by the system effectiveness capability of individual elements, by the combination of the elements, and by the method of interconnection. Parallel connections of elements can adversely affect testability due to the inability to determine which element has failed. System effectiveness issues and methods that mitigate one issue may compromise another. Reliability, for example, can be enhanced beyond that of individual elements through redundant configurations, although cost and testability may be impacted.

Complete system-level analysis and appropriate tests are required to prove system functionality and integrity according to applicable specification at all levels of system integration.

6. Electrical interface parameters

Electrical interface parameters related to electrical interactions between elements, or between an element and its higher level subsystem, are described herein. Where illustrative, test methods and test conditions are described. Electrical interface parameters usually considered at the element level are defined in IEEE Std 1515-2000. Annex C, Table C.1, Table C.2, and Table C.3 are directories to the locations of electrical interface parameters described in either this recommended practice or IEEE Std 1515-2000.

6.1 Status monitoring

Status monitoring is the capability to detect that essential parameters of the electronic power subsystem are within predetermined limits, and provide an indication if one or more of the monitored parameters is outside the predetermined limits. This capability may also provide an indication if a failure is detected in a subsystem or an element, even if performance parameters remain within the predetermined limits.

6.2 Supervisory control

Supervisory control is the capability to allow alteration of one or more parameters of the electronic power subsystem to meet system-level performance objectives. This may be achieved through a local or a remote control interface. Examples include remote resetting of protection circuits, remote on-off capability, alteration of output voltage and/or current settings, etc.

6.3 Built-in-test

6.3.1 Definition

Built-in-test (BIT) is the capability to exercise all or part of a system (in this case, an electronic power subsystem) in order to determine whether it is functioning correctly. It is implemented by providing additional dedicated circuitry or software, separate from that required, to achieve the normal functionality. BIT capability may be intended for use only during production testing, or it may be intended to run periodically or on command, as part of routine maintenance. Examples include exercising of redundant or standby elements, checking of battery capacity, testing of alarm circuits, etc.

The scope and complexity of BIT varies widely depending on system needs and element capabilities. Consequently it is not possible to recommend a generic test method suitable for all BIT implementation. Test methods, test condition, and expected response must be defined by the designer or manufacturer. Running BIT outside the parameters specified may cause system malfunction or damage.

6.4 Electromagnetic compatibility/electromagnetic interference

Electromagnetic compatibility (EMC) is the satisfactory operation of an element in its intended electromagnetic environment.

Electromagnetic interference (EMI) is described as the conducted or radiated electromagnetic emissions from an element that interferes with the normal operation of another element.

Conducted emissions and susceptibility are often tested at the element level and are covered in IEEE Std 1515-2000. Radiated emissions and susceptibility are usually tested at the system-level and are covered herein. Many sources of information are available about EMI testing and requirements. This subclause should be used as an introduction to the general topic of EMI, with the testing information serving as benchmark testing guidance prior to formal EMI testing.

The notion that EMC is mechanical is sometimes considered since shields are used for reduction or containment of radiated fields. This is somewhat misleading because, although it is often convenient to make the shield part of the supporting structure, the requirement for the shield is strictly electrical. The interest is in the shielding effect on the incident electric and magnetic waves.

Power subsystem elements such as rectifiers or switching power supplies have non-linear characteristics, and they present a complex impedance that usually changes with load. In addition, they may draw complex harmonic currents when fed from an ac source. Their EMI performance will therefore vary as input voltage or load changes, and such variations must be considered during design and testing.

6.4.1 Conducted interference

Conducted interference consists of differential mode, common mode, and conducted susceptibility described herein.

6.4.1.1 Differential mode interference

Differential mode interference is an undesired signal, voltage, or current passed in opposite directions, that is, out of phase, through two wires. The differential voltage is measured across the two wires; the differential current is measured in only one wire.

6.4.1.2 Common mode interference

Common mode interference is an undesired signal, voltage, or current passed in the same direction, that is, in phase, through all wires. Common mode currents are measured in all wires simultaneously.

6.4.1.3 Conducted susceptibility

The conducted susceptibility level of an element, at a given frequency and for a given conductor, is the level of conducted signal required to cause a system malfunction or an out of tolerance condition.

6.4.2 Radiated interference

Radiated interference has two aspects, emissions and susceptibility. Emissions are fields radiating from the UUT to the environment and susceptibility is the level of external fields the UUT can tolerate and still perform the desired function.

6.4.2.1 Radiated emissions

6.4.2.1.1 Definition

Emission of electromagnetic energy by radiation directly from the UUT, or from wiring connected to it.

6.4.2.1.2 Test method

Radiated emissions tests are performed in a shielded enclosure to keep external noise sources from interfering with measuring the UUT. MIL-STD-462D [B27] is a military specification that specifies four well-established methods for EMI/EMC testing. FCC Regulation 15 [B14] is a widely used method and for the European market; CISPR 22-2003 [B10] is the governing standard for EMI/EMC testing. Antennas used for EMI/EMC testing are designed for specific test purposes such as:

- Loop magnetic fields 10 kHz to 30 MHz
- Rod or monopole 10 kHz to 30 MHz
- Bi-conical and di-pole 20 MHz to 200 MHz
- Log-conical or spiral 200 MHz to 1000 MHz

6.4.2.1.3 Test conditions

In a shielded room with properly grounded equipment, and with connecting cables routed away from the UUT to avoid unintentional coupling, position the antenna as shown in Figure 16, MIL-STD-461E [B26], *The Authoritative Dictionary* [B16], and CISPR 22-2003 [B10]. Type of antenna, RF power, and distance between the antenna and UUT are as specified for the particular EMI/EMC test specifications. Tests have to be conducted with UUT power *off* to test pre-conditions (referred to as *ambient radiation*) before the test is conducted with UUT power *on*. Some tests will also differentiate between a device *idle* and a device *active* state.

6.4.2.2 Radiated susceptibility

6.4.2.2.1 Definition

The radiated susceptibility level of an element, for a given source type and frequency, is the level of radiated signal required to cause a system malfunction or an out of tolerance condition.

6.4.2.2.2 Test method

Verify that the UUT can withstand the radiated magnetic and electric fields. See 6.4.2.1. Susceptibility is not considered in the FCC regulations, but is fully addressed in MIL-STD-462D [B27].

6.4.2.2.3 Test condition

Test conditions are defined in MIL-STD-462D [B27].

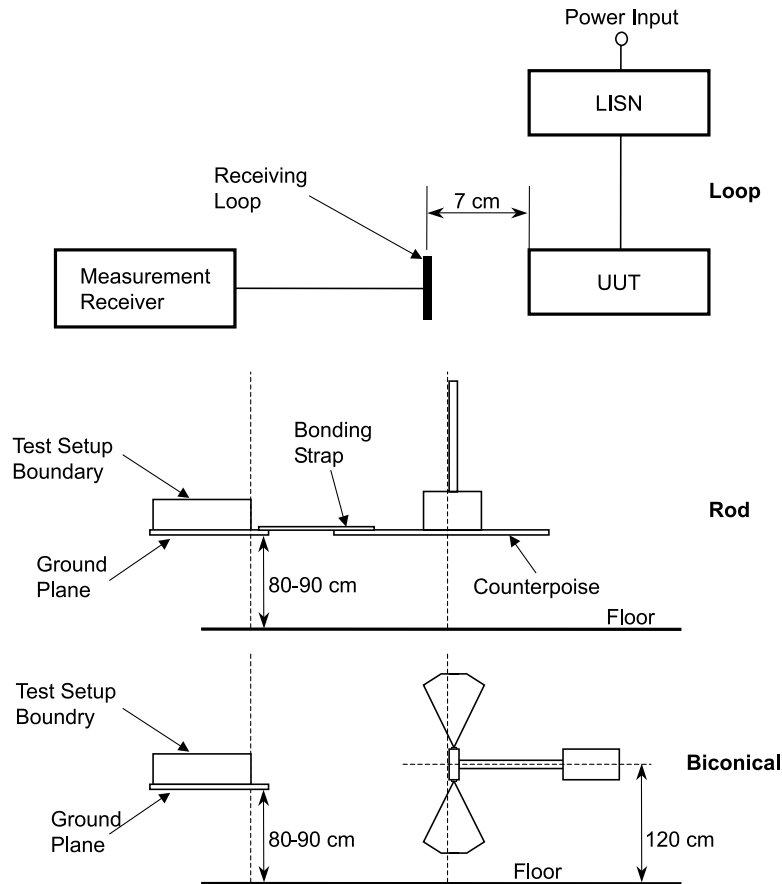


Figure 16—An illustration of various configurations for radiated EMI/EMC tests

6.4.3 Electrical noise

Noise is any undesired electrical signal present in a circuit. These signals are not the product of non-linearity that causes distortion. Noise is produced by

- Random fluctuations within the system (intrinsic)
- Machinery such as motors, arc welders, fluorescent lights, radio transmitters and their local oscillators
- Natural disturbances including lightning, galactic noise, and ESD (electrostatic discharge)

6.4.4 Electrical noise spectrum

6.4.4.1 Definition

Noise spectrum is the noise amplitude vs. frequency. The spectrum to be considered in a particular application will depend upon the sensitivity of the subsystem.

6.4.4.2 Test method

A baseline measurement is taken to determine the ambient noise of a test set-up to determine if the environment is satisfactory for the measurement intended. Following ambient measurement, other measurements are taken to measure noise emissions and its effects on the affected frequency range(s). Spectrum analyzers are a class of instruments useful in measuring noise levels and frequencies.

6.4.5 Electrostatic discharge

6.4.5.1 Definition

Electrostatic discharge is the spontaneous occurrence of current flow where a difference in dc voltage is equalized by a flow of charge between two electrically isolated bodies. This equalization is characterized by rapid current flow and may involve a spark discharge. After ESD, the voltage on the bodies is essentially equal; the primarily capacitive charge between the involved bodies having been equalized. Electrostatic discharge control is the process of minimizing the possibility of the occurrence of a rapid charge transfer.

6.4.5.2 Test method

Varying voltage levels are generally stored in a fixed capacitance and then applied through fixed impedance to the UUT. All externally accessible electrical interfaces to the module should be tested in accordance with the intended environment. MIL-STD-1686C [B36] as well as other industry standards were developed to specify levels of ESD and the precautions required to protect electric circuits from ESD damage. Table 3 lists ESD test standards/methods.

Table 3—ESD test standards/methods for classification of ESDS parts

ESD model	ESD test standard/method
Human body model (HBM), ESD class 1, 2, and 3	ESD STM5.1-2001 [B11] MIL-STD-883E Method 3015 [B32] MIL-STD-750C Method 1020 [B30]
Machine model (MM)	ESD STM5.2-1999 [B12]
Charged device model (CDM)	ESD STM5.3.1-1999 [B13]

6.4.5.3 Test conditions

Full characterization of the ESD susceptibility of a part is accomplished by classification to three defined models: the human body model (HBM), machine model (MM), and charged device model (CDM); see MIL-STD-1686C [B36]. The HBM, MM, and CDM sensitivity classification of parts shall be in accordance with Table 4 and Table 5. The HBM, MM, and CDM voltage levels do not correlate with each other.

7. Mechanical interface parameters

Mechanical interface parameters related to mechanical interactions between elements, or between an element and its higher level subsystem are described herein. Where illustrative, test methods and test conditions are described. Non-system-level, mechanical interface parameters are defined in IEEE Std 1515-2000. Annex C, Table C.4 is the directory to the location of mechanical interface parameters described in either this recommended practice or IEEE Std 1515-2000.

7.1 Packaging

Packaging is defined as the physical characteristics of an element. This includes: physical dimensions, weight, density, materials, potting, sealing, etc., described by dimensional drawings, identification of connectors, thermal performance data, and generic package identification.

Note that the distinction between component, card (or circuit card assembly), and assembly is made in this recommended practice to facilitate definition of electrical and mechanical interface parameters for different assembly levels of electronic power subsystems. Packaging examples are shown in Figure 17.

Table 4—ESD classification

ESD model	ESD class ^a	Voltage range
HBM	1	>0–1999 V
	2	2000–3999 V
	3	4000–15 999 V
MM	M1	0–100 V
	M2	101–200 V
	M3	201–400 V
	M4	401–800 V
	M5	>800 V
CDM	C1	0–124 V
	C2	125–249 V
	C3	250–499 V
	C4	500–999 V
	C5	1000–1499 V
	C6	1500–2999 V
	C7	>8300 V

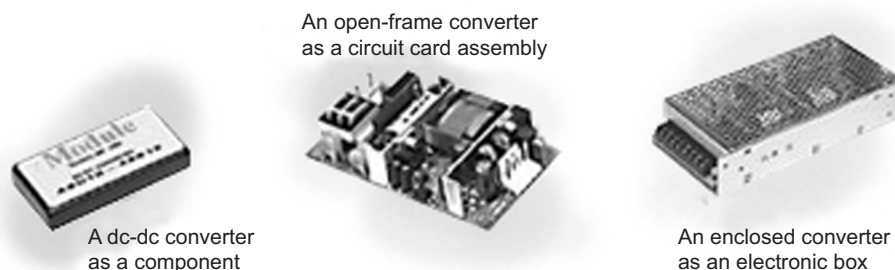
^aThe above classes may be divided into subclasses.

Table 5—ESD testing

Test type	ESD model	Test locations	Functional level	ESD hardening requirement
Direct contact, non-operating	Body/finger or hand/metal HBM	Inputs, outputs and interface connections ^a	All assemblies	2000 V
Direct contact, operating	Hand/metal HBM	Operator accessible controls and the center of each plane surface	Field maintained equipment	4000 V
Indirect contact, operating	Furniture model	Horizontal coupling plane (HCP) or vertical coupling plane (VCP) ^b	Digital office equipment	15 000 V

^aInputs, outputs, and interface connection points are those points where the assembly is electrically connected to items external to it.

^bThe HCP (or VCP) is a horizontal (or vertical) metal plate that is capacitively coupled to the equipment, to which pulses are applied to simulate discharges to objects adjacent to the equipment.



Source: Photograph reprinted with permission from a product brochure of Astrodyne Corporation

Figure 17—Component, CCA, and assembly packaging of electronic power subsystems

7.1.1 Component

A component is a single low-level replaceable circuit element. Components may be discrete items such as resistors or capacitors (passive components), MOSFETs or integrated circuits (active components), or they may be constructed from multiple sub-components such as hybrid circuits, or multi-chip modules (MCMs).

7.1.2 Circuit card assembly

A card or circuit card assembly (CCA) is a power electronic element in a subsystem that consists of individual passive and active electronic components and power electronic elements such as dc-dc converters. The card or assembly may include one or more daughter boards that also can consist of passive and active electronic components.

7.1.3 Assembly, chassis, enclosure, box, or rack

An assembly, chassis, enclosure, box, or rack is a power electronic element consisting of multiple cards or CCAs and/or other assemblies within an enclosed housing. Such elements may be a replaceable part of a larger assembly or a standalone module.

7.2 Center of gravity

7.2.1 Definition

The center of gravity is the physical location within an element for which the mass in all three planes (X , Y , Z) is centered.

7.2.2 Test method

Use a clamping device of suitable size for the element being measured and a mechanism to allow the element to rotate freely. Position the clamp near the apparent center of the element and tighten. Rotate the element about the clamping device and allow the element to come to rest naturally. Once at rest, loosen the clamping device and reposition the clamp on the element at a point lower than the initial position. Repeat this process until the element is positioned in the clamp such that when rotated and allowed to come to rest naturally, the resulting at-rest position is random. Analytical methods for locating the CG of a physical object are well established.

Repeat the procedure for the remaining planes to be measured.

7.3 Cooling or thermal energy dissipation process

The cooling process is divided into general methods involving either various means of conduction or electromagnetic wave radiation emission to dissipate the heat generated by a power system. Radiation is in the infrared spectrum. In either method, heat flows from regions of higher energy density to regions of lower energy density.

7.3.1 Thermal interface

A thermal interface is normally a junction where there is a physical break along with a change in the conductive material type in a heat flow path. This interface is sometimes considered the thermal