

IEEE Standard for Environmental Specifications for Spaceborne Computer Modules

Sponsor
**Bus Architecture Standards Committee
of the
IEEE Computer Society**

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Abstract: Fundamental information on minimum environmental withstand conditions for space electronics is provided. The intent is to achieve uniformity and reproducibility in the test conditions for all spaceborne computer modules that may make up larger systems and are purported to have a rated environmental performance level. The specifications pertain to both the natural and artificial environments to which spaceborne computer modules may be exposed. These conditions include, but are not limited to, thermal, mechanical, electrical, and radiation stresses.

Keywords: spaceborne computers, spaceborne modules, spaceborne systems

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

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Introduction

(This introduction is not part of IEEE Std 1156.4-1997, IEEE Standard for Environmental Specifications for Spaceborne Computer Modules.)

Environmental conditions for computer modules intended for use in space vehicles are not currently encompassed by existing standards. The Bus Architecture Standards Committee of the IEEE Computer Society found it appropriate to write a separate standard for core environmental withstand conditions for spaceborne computer modules.

This standard provides design engineers and system engineers with core environmental conditions that all components and modules used in spaceborne computers should be able to withstand. These conditions include (but are not limited to) thermal, mechanical shock and vibration, electrical, and radiation environments. Since launch and space environments can vary widely from mission to mission and the severity of the environmental test specifications can significantly affect cost, weight, and performance, this standard identifies levels of environmental withstand requirements referred to as performance levels.

At the time that this standard was approved, the following members of the working group had contributed to the document.

William Schneider, Chair
Gary Gardner, Vice Chair
Ed Marian (Technical Editor)

Peter Alcivar
Mitch Beaumont
Steve Belvin
Tuhina Bera
Rob Bertin
Chip Bettencourt
Erasmus Brenes
Don Caldwell
Doug Caldwell
Art Campbell
Andy Capobianco
Marlin Clark
Tom Clark

Lewis Cohn
Jerry Edwards
Mike Foster
Tom Hillyer
Joe Hoffman
Ed Jacques
Jerry Keller
Dennis Kern
Dave Kirk
Cal Laurvick
Joe Marshall
Fred Martin
Fenton McDonald

John W. McKinstry
Thanos Mentzelopoulos
Ron Moody
Lisa Moy-Yee
Ken Muzzy
Tom Reglein
Dan Sherick
Dennis Smith
William Stapor
Richard Straedey
Nebuabi Sugiura
Lance Sundstrom
David Wasler

The following persons were on the balloting committee:

Ghassan A. Abbas
Malcolm J. Airst
Keith D. Anthony
Stephen E. Belvin
Charles Brill
Charles P. Brothers
Robert C. Cutler

Gary A. Gardner
Herbert Hecht
David H. Hilland
Thomas M. Kurihara
Conrad A. Laurvick
Joseph R. Marshall

John W. McKinstry
Deb M. Newberry
Fred J. Orlando
Elwood T. Parsons
George D. Salapski
Ravi Shankar
Janusz Zalewski

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John S. Ryan
Chee Kiow Tan
Howard L. Wolfman

*Member Emeritus

Also included are the following nonvoting IEEE Standards Board liaisons:

Satish K. Aggarwal

Alan H. Cookson

Kristin Dittmann
IEEE Standards Project Editor

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IEEE Standard for Environmental Specifications for Spaceborne Computer Modules

1. Overview

1.1 Background

The environment that electronic systems designed for space applications must withstand and operate within is one of the factors that differentiates such systems from terrestrial systems. All spaceborne systems must withstand the launch environment in either an operational or nonoperational state. Many spaceborne systems must operate for years after launch in the space environment, which differs greatly from terrestrial environments.

The difficulty in specifying the “space environment” for standard products arises from the fact that launch, orbital and deep space environments vary greatly from mission to mission. Numerous factors affect the severity of the space environment, including launch vehicle type, mounting of the electronics system within the host vehicle, mission profile (low earth orbit, geosynchronous earth orbit, elliptical orbit, or deep space trajectory), orbit inclination, and mission duration.

An extensive survey was conducted to gather environmental data on as many different launch vehicles, spacecraft, satellites, and other programs as possible as a starting point in establishing an environmental specification that would be applicable to spaceborne computer modules for a variety of missions. A database was prepared and attempts were made at enveloping the various environments in establishing a set of environmental parameters. These were circulated within industry and government for comment and recommendations. The outcome of the survey and subsequent Working Group meetings culminated in the numbers for the different performance levels as given in this document. The radiation environment was the most difficult one on which to reach agreement. Various radiation experts were called upon to help in defining this environment where it could be easily understood and implemented by the design engineer.

Rather than develop unique specifications for each mission profile, launch vehicle, or other driving factor, this standard identifies several levels of environmental withstand requirements. This approach allows the end user to select the appropriate environment levels (e.g., thermal, pressure and humidity, dynamics, and radiation) for hardware based on the failure physics relevant to a particular mission application, thereby optimizing cost and mission reliability.

1.2 Scope

This standard specifies minimum environmental withstand conditions applicable to spaceborne computer modules and all of the components attached to such modules. It was originally designed to provide general environmental withstand conditions for IEEE Std 896.10-1997 [B8]¹, but is expected to apply to spaceborne electronic equipment in general.

1.3 Purpose

The purpose of this standard is to provide a common set of specifications for the physical integrity and environmental performance levels of computer modules and their components. It is the responsibility of the system designer to evaluate the relationship between this module-level specification and the system-level environmental specifications for the enclosure that contains the modules.

2. References

This standard shall be used in conjunction with the following documents, which form a part of the standard to the extent specified herein. In case of conflict between this document and a referenced document, this document shall take precedence. Other relevant documents are listed in Annex E.

JESD57, Test Procedure for the Management of Single Event Effects in Semiconductor Devices from Heavy Ion Irradiation (Dec. 1996).²

MIL-STD-461C, Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference.³

MIL-STD-883B, Test Methods and Procedures for Microelectronics.

MIL-STD-1540C, Military Standard Test Requirements for Launch, Upper-Stage and Space Vehicles.

3. Definitions

3.1 Special word usage

3.1.1 may: Indicates flexibility of choice with no implied preference.

3.1.2 shall: Indicates a mandatory requirement. For example, “Designers shall implement all such mandatory requirements to ensure interoperability with other IEEE Std 1156.4 conformant products.”

3.1.3 should: Indicates flexibility of choice with a strongly preferred implementation. The phrase *it is recommended* is used interchangeably with the key word *should*.

¹The numbers in brackets preceded by the letter B correspond to those of the bibliography in Annex E.

²This publication, from the JEDEC committee, is available from Electronic Industries Association, 2500 Wilson Blvd., Arlington, VA 22201-3834, USA.

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

3.2 Other definitions

3.2.1 burn-in: A test performed for the purpose of screening out devices with inherent defects or defects resulting from manufacturing aberrations that cause time and stress dependent failures. Burn-in is intended to eliminate infant mortality and early lifetime failures by stressing devices at or above maximum operating conditions.

3.2.2 G: Acceleration normalized with respect to acceleration of gravity at the surface of the Earth (9.81 ms^{-2}) (sea level).

3.2.3 geosynchronous earth orbit (GEO): Circular orbit in the equatorial plane of the Earth—6.62 Earth radii from the center of the Earth.

3.2.4 linear energy transfer (LET): the ratio $\Delta E/\Delta X$ of the average energy loss ΔE over the path length ΔX of a charged particle of specified energy in a medium.

3.2.5 low earth orbit (LEO): Typically orbits below 1500 km to 1800 km altitude.

3.2.6 module: A board or board set consisting of one or more nodes that share a physical interface, although only one board in a module connects to bus signals. Each board connection could provide power from the bus.

3.2.7 single event effect (SEE): Any measurable or observable change in state or performance of a microelectronic device, component, subsystem, or system (digital or analog) resulting from the passing or traversal of a single particle.

3.2.8 total ionizing dose (TID): The radiation dose accumulated in a component, device, or module.

4. Parameters and performance

Levels of environmental withstand requirements, referred to as performance levels, are defined by this standard. The set of qualification tests prescribed herein are intended to establish the minimum robustness of the design electrically and mechanically as well as the robustness of the fabrication processes. Additionally, the set of acceptance tests prescribed herein are intended to identify workmanship flaws and to a lesser extent, residual design flaws. The performance levels include a number of parameters that generally increase in severity from Level I to Level III. It is the responsibility of the system designers to specify quantitatively the performance levels that are applicable to their mission.

4.1 Parameter categories

The behavior of an electronic module is affected by many environmental parameters. In order to facilitate the specification of module performance, these parameters are grouped into four parameter categories: thermal, pressure and humidity, mechanical, and radiation.

4.1.1 Thermal

Thermal performance includes nonoperating and operating temperature ranges, particularly in vacuum, and thermal cycling.

4.1.2 Pressure and humidity

Pressure and humidity include pressure, pressure rate of change, and humidity conditions, nonoperating and operating.

4.1.3 Mechanical

Mechanical performance includes dynamic behavior—pyrotechnic shock and random vibration. Sine vibration is not included in this standard.

4.1.4 Radiation

Radiation performance includes primarily total ionizing dose and single-event effect specifications. Additionally, transient upset rate, transient survivability, and displacement damage are specified at the highest Performance Level.

4.2 Performance levels

For each of the parameter categories, a performance level should be specified that is the highest performance level satisfied by all parameters within the category. Conforming modules shall explicitly indicate the individual performance levels for each parameter category. Categories may not be subdivided nor may different levels of conformance be claimed for various parameters within a category. The preferred labeling of such modules is [Ta:PHa:Ma:Ra2) where a indicates the performance levels (I, II, III, IV, or IVa) for each of the four parameter categories (Thermal, Pressure and Humidity, Mechanical, and Radiation). The performance levels are listed below as a guide to application.

While it might be desirable to label a given module with a single overall level, this is not reasonable in all cases; many applications demand nominal levels for most parameter categories and a higher level for only one. Forcing all parameters of a given module to meet a single level is likely to adversely affect costs. However, allowing “exceptions” (e.g., “a Level II module with Level III total dose and vibration”) would lead to a proliferation of module classifications and create an intractable interoperability problem. As a compromise, the stated approach is taken.

4.2.1 Performance Level I

Performance Level I is a nominal environment, primarily intended for missions with relatively benign thermal cycle, mechanical, and radiation environments. This is the least demanding of the three levels. A short-lived, low earth orbit spacecraft placed into orbit by a launcher with a “soft ride” might be a typical application.

4.2.2 Performance Level II

Performance Level II is an extended exposure environment, primarily intended for missions of longer duration with more severe thermal cycle, mechanical vibration, and radiation environments. This performance level has more demanding requirements than Level I, but less demanding requirements than Level III.

4.2.3 Performance Level III

Performance Level III is an extended exposure environment with a severe thermal cycling and radiation environment. Although some requirements may overlap Level II, other requirements are more severe than the other two levels.

4.2.4 Performance Level IV (natural space radiation only)

Performance Level IV is an extreme exposure environment primarily intended for missions in elliptical orbits that traverse the radiation belts on a daily basis.

4.2.5 Performance Level IVa (radiation only)

Performance Level IVa addresses nuclear survivability for missions with strategic requirements in addition to the natural environment for the mission.

4.3 Performance level examples

Table 1 provides examples of how the various performance levels might be combined for some hypothetical applications. Not all mission types or orbits are covered; many other combinations of performance levels are reasonable, even within the given example classes. Thermal levels are frequently specified higher than that which

would be experienced in practice to facilitate reliability testing. Dynamics levels [e.g., for a geosynchronous earth orbit (GEO) mission] may be higher to accommodate the loads imposed by larger launch vehicles.

Table 1— Hypothetical performance level examples

Mission class	Thermal* operational/ nonoperational level	Operational/ Nonoperational* pressure/relative humidity	Mechanical level	Radiation level	Module labeling[†]
Low earth orbit (LEO)	I	I	I	I	T1:PH1:M1:R1
Geosynchronous earth orbit (GEO)	II	II	II	III	T2: PH2:M2:R3
Military	II	III	I	IV*	T2: PH3:M1:R4*
Deep space	III	I	I	II	T3: PH1:M1:R2
Launch vehicle	II	II	III	I	T2: PH2:M3:R1

*For thermal level and pressure/relative humidity level, the single module labeling paragraph specifies the performance level for both operating and nonoperating.

†T—Thermal; PH—Pressure and humidity; M—Mechanical; R—Radiation.

5. Test approach

5.1 Performance level qualification

In order to claim conformance to this standard, the module shall be tested in accordance with the test methods specified for the corresponding performance level parameter. Due to the difficulty of radiation testing at the module level, module radiation performance may be extrapolated from piece part radiation test data. It is the intent of this standard that for each defined performance level, all the parameters specified within that level shall be met in their entirety.

Qualification to one performance level for a particular environment also qualifies the module to all less demanding levels, i.e., qualification for dynamics to Level III (the severe performance level) also carries automatic qualification to Levels II and I. The intent of this document is to allow mixing and matching of the performance levels defined in this standard.

Another facet of this document's intent is to standardize the values of environmental parameters and their test methods to assist systems engineers who must integrate modules from various manufacturers. Deviating from the minimum values specified by this standard shall be construed as using this document for guidance only and conformance to this standard may not be claimed.

5.2 Test duration

When test duration is specified, timing begins after the item under test has achieved stability with regard to the test parameter.

5.3 Initial and final measurements

The measurements shall include all measurements needed to verify that the module under test meets all aspects of the module's detail specification before and after the test procedure for nonoperating tests. The time at which these detail

specification tests are to be performed is given in the MIL-STD-1540C⁴, Section 6.4.1, test description. For operating tests, the measurements should also be performed during the test at the minimum and maximum specified input voltage and clock frequencies at test durations during power-on suggested by MIL-STD-1540C procedures. The particular parameters to be monitored shall also be specified in the relevant module document. Records of the testing and results of the qualification testing shall be available by the module manufacturer to the customer upon request.

5.4 Qualification testing

Qualification tests demonstrate that a hardware design is robust enough to ensure that the product will be in specification from the beginning of mission to the end of mission. The qualification article should be similar in design, materials, and processes used in the flight article. In order to achieve this verification in a realistic amount of time, qualification test levels and/or durations are established that are more severe than the actual mission. For example, dynamic qualification test environments involve both higher levels and longer durations than the environment during the mission. Similarly, the thermal cycling qualification test utilizes a wider temperature range for a number of test cycles greater than the equivalent total number of flight thermal cycles. On the other hand, the thermal/vacuum qualification test involves more severe levels, but for durations shorter than the mission.

Test hardware should be configured such that all the power dissipated within the unit is conducted across the unit/module thermal interface. Other surfaces should be blanketed off to minimize convective thermal transport effects. The functional testing performed during the qualification testing shall include robustness tests as prescribed in 7.1.1. Functional testing prior to, during, and after each qualification test shall be performed as stated in 7.1.

5.5 Acceptance testing

Acceptance tests are intended to demonstrate the flight-worthiness of each deliverable item. Acceptance tests should demonstrate that the performance of the hardware will be in specification at the beginning of the mission and should provide confidence of acceptable performance throughout mission life. The acceptance tests should measure performance parameters. The results should reveal inadequacies in the manufacturing process such as workmanship, material defects, or variations in the module radiation response due to normal manufacturing tolerances and process control limitations.

Test hardware should be configured such that all the power dissipated within the unit is conducted out of the unit across the module/thermal interface. Other surfaces should be blanketed off to minimize convective thermal transport effects. The functional testing performed during the acceptance testing shall include robustness tests as prescribed in 7.2.1. Functional testing prior to, during, and after each acceptance test shall be performed as stated in 7.2.

6. Test requirements

6.1 Nonoperating conditions

Computer modules and components shall withstand, without damage, the nonoperating environmental specifications for temperature, pressure and relative humidity as shown on Table 2 for the appropriate performance level. All testing shall be performed without a shipping container unless otherwise specified. Nonoperating conditions encompass pre-launch, on orbit (power-down) and other storage for the module. These conditions may be incurred for relatively long durations compared to the operational life.

⁴Information on references can be found in Clause 2.