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GUIDE FOR THE PRODUCTION AND ACQUISITION OF RADIATION-HARDNESS ASSURED MULTICHIP MODULES AND HYBRID MICROCIRCUITS

Contents

Foreword

This document is intended for use by suppliers and users of radiation-hardness-assured (RHA) multichip modules (MCMs) and hybrid microcircuits. It provides guidance as to how to achieve, maintain and ensure the required levels of radiation-hardness given the fact that the constituent dice can have different levels of hardness and hardness assurance. It has been prepared under the direction of JEDEC JC-13.5 (Hybrid, RF/Microwave, and MCM Technology) Committee, and contributions of the JEDEC JC-13.4 (Radiation-Hardness Assurance) Committee and the members of the AF/NASA/DTRA Space Parts Working Group Hardness Assurance Committee and Users Group.

Introduction

The development of radiation-hardened multichip modules and hybrid microcircuits can take place in one of three ways:

- Build-To-Print, where the buyer (also referred to as the original equipment manufacturer, OEM) assumes responsibility for all aspects of the performance of the finished module.
- Build-To-Spec, where the buyer provides the performance specifications, including radiation, to the manufacturer, who then interprets them, and designs, acquires the component parts, assembles, and tests the module.
- A joint effort between the buyer and the manufacturer, with each one taking responsibility for different parts of the development. For example, the buyer could take responsibility for the calculation of the radiation specifications and for the radiation testing. The manufacturer would then be responsible for the design, piece-part procurement, and assembly.

Because this document is primarily for use by the manufacturers, it will present the tasks as though the procurement is a build-to-spec type, where the manufacturer has the responsibility for all of the tasks. We recognize that is not always the case, with the joint effort scheme probably used more often. The development process is a complex undertaking because:

- The dice used for the circuits can come from a wide variety of suppliers ranging from qualified sources of radiation hardened microcircuits or discretes, where the radiation response of their devices is specified, to high volume commercial suppliers that provide no guarantees concerning device hardness.
- The radiation response of an MCM/hybrid must be addressed as a subsystem rather than simply as a collection of dice. That is, it is possible that the within-specification radiation response of a die can result in the malfunctioning of an MCM/hybrid device due to the interaction of the interconnected die.
- In very high dose rate environments, the actual MCM/hybrid structure (lands, grooves, etc.) can become a source of radiation-induced current, further impacting individual die response.
- The actual hybrid/MCM construction methods (e.g., ground connections, die attach, etc.) can influence the overall package and individual die response.

Introduction (cont'd)

This Guide describes how to deal with the various situations that an MCM/hybrid developer, procuring activity or user will encounter. The guidance is intended to supplement that already provided in the two relevant performance specifications: MIL-PRF-38534, General Requirements for Custom Hybrid Microcircuits and MIL-PRF-38535, General Specification for Integrated Circuits (Microcircuits) Manufacturing, as well as MIL-PRF-19500, General Specification for Semiconductor Devices.

This Guide is designed to provide support to several potential user groups, including:

1) Government Program Office (PO) personnel, will be able to use the Guide as a metric to:

   a) quantify the rigor of the hardening effort for the MCM/hybrid devices used in their system or equipment;
   b) adopt the radiation test data obtained during the characterization of the MCM/hybrid to support nuclear hardening and survivability analysis.

2) Original Equipment and System Manufacturers (OEMs), who can use the Guide to:

   a) formulate the details of the acquisition/procurement document used to obtain MCM/hybrid devices concerning radiation response issues, e.g., testing and analysis;
   b) determine the level of effort required to obtain RHA MCM/hybrids as a function of radiation environment;
   c) establish a radiation response database to support any subsequent system radiation hardening and survivability analysis or determination.

3) MCM/Hybrid Suppliers (Manufacturers):

This Guide should be especially useful to manufacturers that lack experience or expertise in nuclear hardening and survivability (NH&S) and RHA since it outlines various issues that must be considered. In addition, for those manufacturers who will use third parties for radiation issues, the document can be used as a guide to identify the relevant concerns and facilitate communications. It will serve to:

   a) formulate the details of any die acquisition/procurement documents with respect to radiation effects and RHA;
   b) assist in the identification of critical requirements and RHA issues;
   c) assist in the implementation of an MCM/hybrid RHA system and identify the level of effort required to provide RHA devices;

Many MCM/hybrid manufacturers do not possess an RHA capability. For them, the document will facilitate their interaction with either third party sources or others, e.g., the system or equipment manufacturer, and will establish a baseline for the activities needed to provide radiation-hardness-assured MCMs and hybrids. This use of the Guide should be especially valuable.

GUIDE FOR THE PRODUCTION AND ACQUISITION OF RADIATION-HARDNESS ASSURED MULTICHIP MODULES AND HYBRID MICROCIRCUITS

(From JEDEC Council Ballot JCB-05-44, formulated under the cognizance of the JC-13.5 Subcommittee on Hybrid, RF/Microwave, and MCM Technology.)

1 Scope

The information contained herein is intended for use with MIL-PRF-38534 for those multichip modules and hybrids that are marked as radiation-hardness-assured parts and produced under the provisions of that document or that are built to a radiation specification. Guidance is provided concerning the design, development, fabrication, acquisition and test of multichip modules and hybrid circuits that have radiation requirements. This document is not intended to provide detailed guidance about how to assure the hardness of the dice, since it is recognized that dice with a wide range of hardness will have to be used. If non-RHA dice are used, the user-developed RHA procedures found in MIL-PRF-38535 should be used. Rather, this document provides guidance as to how to assure the hardness of the entire module, given the wide range of the radiation hardness and level of hardness assurance of the individual dice to be used in the module. Specifically, four types of dice are available (in order of decreasing level of specification controls):

- Radiation hardness-assured QML controlled (or equivalent). Dice of this type can be used with no additional testing.
- Non-hardened QML (or equivalent) change-controlled dice. Such devices require radiation characterization. However once this is done, minimal lot testing would be necessary.
- Inherently radiation hard or non-hard dice that are not under a formally recognized change control system, but supplier support (e.g., change control notice, etc.) is available.
- Commercial grade or other grade die that appear to have adequate radiation tolerance, but where no supplier support is provided for the qualification or radiation-hardness assurance. This presents a worst-case situation and requires the most stringent RHA program to ensure that the radiation performance requirements of all of the modules produced are satisfied.

The use of dice from any of the above noted categories, combined with the various types of MCM/hybrid suppliers, can then lead to the following categories of MCM/hybrid devices.

- Commercial module designs screened for RHA
- Commercial module designs upgraded with radiation-hardened dice
- Standard product RHA modules
- Custom product RHA modules.

The relationships between the various types of dice and finished modules are shown in figure 1. The objective of this Guide is to provide guidance to allow a supplier or user to establish and complement the RHA requirements for any of these MCM/hybrid combinations.

1 Scope (cont'd)

Two acquisition strategies can be inferred from figure 1. The first is where significant knowledge concerning the constituent chips is available. This approach, as exemplified by the right branch of the figure, places emphasis on component acquisition (i.e., screening and characterization) and subsequent analysis (as required) to obtain MCM/hybrid certification and qualification. It would apply to module manufacturers and to users who have access to accurate component lists, design rules, fabrication methods, etc. It is discussed in detail in subsequent sections of this Guide and should result in the most accurate and cost-effective course of action to obtain RHA qualification. The second approach is where little or nothing is known about the constituent chips. This approach, as exemplified by the left branch of the figure, represents a worst-case situation from both a technical and cost a point-of-view. If only input/output information is available, one has no choice but to try to determine the failure or response distribution of the module for each of the applicable radiation environments. This method may be acceptable if a statistically significant sample size can be tested and considerable margin exists with respect to the specified radiation levels. The key issues involved here are: an adequate sample size, the homogeneity of the sample, and the sample correlation to flight components. Thus significant effort must go into the development of the RHA test program for this technique.

If some minimal knowledge of the component types is available (e.g., high speed bipolar, power MOSFET, etc.), it can be used to guide the development of the RHA test program. For example, if it is known that a power MOS circuit is used, emphasis on Single Event Effects (SEE) testing would be appropriate. Conversely, if a module is known to contain only high speed CMOS digital circuits, then neutron testing and enhanced low rate dose sensitivity (ELDRS) testing can be eliminated. Thus, despite a lack of detailed knowledge about the module, some choices can be made about the radiation testing to improve the test coverage and optimize the test effort.

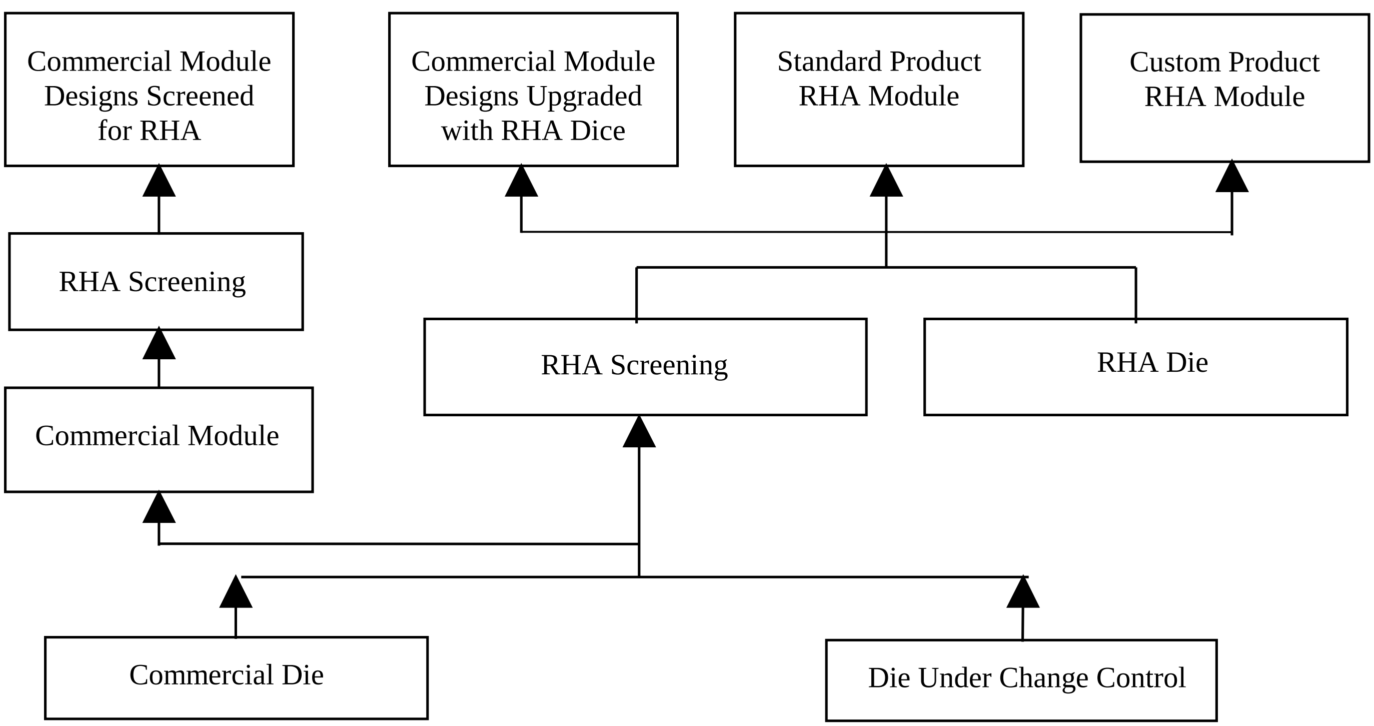

Figure 1 — Makeup and categories of MCM and hybrid devices

2 Normative references

The following standards contain provisions that, through reference in this text, constitute provisions of this Guide. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

MIL-STD-750, *Test Methods for Semiconductor Devices*.

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

MIL-PRF-38534, *Performance Specification, Hybrid Microcircuits, General Requirements for*.

MIL-PRF-38535, *Performance Specification, Integrated Circuits (Microcircuits) Manufacturing, General Specification for*.

MIL-PRF-19500, *Performance Specification, Semiconductor Devices, General Specification for*.

QML-38534, *Qualified Manufacturers List of Custom Hybrid Microcircuits Qualified under Military Specification MIL-PRF-38534, Custom Hybrid Microcircuits, General Requirements for*.

QML-38535, *Qualified Manufacturers List of Advanced Microcircuits Qualified under Military Specification MIL-PRF-38535, Microcircuits Manufacturing, General Requirements for*.

QPL-19500, *Qualified Products List of Semiconductor Devices Qualified Under Military Specification MIL-PRF-19500, Semiconductor Device, General Specification for*.

EIA/JESD57, *Test Procedures for the Measurement of Single-Event Effects in Semiconductor Devices from Heavy Ion Irradiation.*

JESD89, *Measurement and Reporting of Alpha Particle and Terrestrial Cosmic Ray-Induced Soft Errors in Semiconductor Devices.*

3 Definitions, abbreviations, and acronyms

displacement damage: Displacement of atoms in the silicon lattice caused by their interaction with incident neutrons, protons, or other energetic particles or ions.

dose rate burnout: The catastrophic failure of a circuit caused by the very large currents produced by a high-intensity pulse of ionizing radiation.

dose rate upset: The disruption of a device caused by a high-intensity pulse of ionizing radiation that produces a change in stored data, a change of operating state, or a transient output signal that is large enough to affect other circuit elements.

3 Definitions, abbreviations, and acronyms (cont'd)

enhanced low dose rate sensitivity (ELDRS): The characteristic of a device that exhibits an enhanced total dose response at dose rates below 50 rad(Si)/s.

internal electromagnetic pulse (IEMP): An electromagnetic pulse generated by electrons that are ejected from the surfaces interior to an enclosure with conducting walls due to the interaction of a pulse of energetic photons with the surface material(s).

linear energy transfer (LET): The amount of energy lost per unit path length by a charged particle as it traverses a material.

NOTE 1 The energy loss is the sum of the ionizing and non-ionizing loss mechanisms.

NOTE 2 LET is strictly defined in terms of energy divided by distance, e.g., MeV/cm, eV/nm, or keV/nm. However, since the energy lost is directly proportional to the density of the material traversed, a useful quantity that is independent of density can be derived simply by dividing the LET by the density of the material. For the purposes of this publication, this derived quantity, whose units are typically expressed as $MeV \bullet cm^2/mg$ (i.e., MeV/cm divided by mg/cm^2), is also referred to as linear energy transfer (LET).

qualified manufacturers list (QML): A list of manufacturers whose production lines have been certified and qualified by the Defense Supply Center Columbus (DSCC) for the production of devices used in military or space applications.

qualifying activity: (1) The organizational element that grants certification status; this element may be a part of a) the acquiring activity; b) a quality organization within the manufacturer's company that is independent of the group(s) responsible for the device production, screening, and marketing; or c) an independent third-party organization.
(2) The organizational element of the government that grants certification and QML status.

quality management plan (QMP): A plan presented in military specifications (e.g., MIL-PRF-19500, MIL-PRF-38534, and MIL-PRF-38535) that describes the methods used by a supplier to assure conformance to the applicable requirements, including design, manufacturing, and verification.

radiation hardness assurance (RHA): The aspect of product assurance that ensures that parts continue to perform within specifications or degrade in a specified manner when subjected to given radiation environments..

radiation hardness assured (RHA): Possessing the aspect of product assurance that ensures that parts continue to perform within specifications or degrade in a specified manner when subjected to given radiation environments.

radiation-hardness-assured capability level (RHACL): The radiation level to which the die manufacturer guarantees satisfactory performance.

single event burnout (SEB): An event in which a single energetic-particle strike induces a localized high-current state in a device that results in its destruction.

3 Definitions, abbreviations, and acronyms (cont'd)

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 a single energetic-particle strike.

single event gate rupture (SEGR): An event in which a single energetic-particle strike results in a breakdown and subsequent conducting path through the gate oxide of a MOSFET.
NOTE: SEGR is manifested by an increase in gate leakage current and can result in either degradation or complete failure of the device.

single event latchup (SEL): An abnormal high-current state in a device caused by the passage of a single energetic particle through sensitive regions of the device structure and resulting in the loss of device functionality.
NOTE: SEL may cause permanent damage to the device. If the device is not permanently damaged, power cycling of the device (off and back on) is necessary to restore normal operation.

single event transient (SET): A momentary voltage excursion (voltage spike) at a node in an integrated circuit caused by a single energetic-particle strike.

single event upset (SEU): A soft error caused by the transient signal induced by a single energetic-particle strike.

snapback: A high-current regenerative state in an NMOS device that can be induced by a single heavy-ion strike or by a high dose-rate pulse.

soft error, device: An erroneous output signal from a latch or memory cell that can be corrected by performing one or more normal functions of the device containing the latch or memory cell. NOTE: As commonly used, the term refers to an error caused by radiation or electromagnetic pulses and not to an error associated with a physical defect introduced during the manufacturing process.

technical review board (TRB): A supplier's dedicated system of review that is responsible for the implementation of the quality management program, maintenance of all certified and qualified processes, process change control, reliability data analysis, failure analysis, device recall procedures, and qualification status of the technology.

total ionizing dose (TID) effects: Circuit degradation or failure resulting from ionizing radiation-induced charge trapped in insulating layers (usually oxides).

4 Requirements

4.1 General requirements

This Guide is applicable to multichip modules and hybrid circuits that are built to a radiation specification or marked as radiation-hardness assured parts. The guidance defined herein for the manufacture of radiation-hardness assured (RHA) multichip modules or hybrid circuits should be performed in the context of a supplier's certified and qualified quality assurance program as documented in the quality management plan (QMP). ISO 9000 certification is desirable. The QMP should identify the steps in the MCM or hybrid process or manufacturing fabrication flow that affect the radiation sensitivity. Figure 2 shows the elements of a typical technology flow for radiation-hardness assured modules. The supplier will do some and some may be done by the buyer, depending on the nature of their arrangement (see Introduction). The oval elements represent the product of some activity that feeds into or results from the actions noted in the rectangles; the rectangles are each discussed in this Guide. Each can be broken down into its constituent parts by a functional flow analysis showing the performer, oversight organization, tools used, and resources available. This is shown in Table 1 for a build-to-spec product.

As described in the Scope, there are many variations of MCM and hybrid technologies, and consequently not all provisions of this Guide will be applicable to a specific vendor's product. Those provisions that do not apply or are otherwise unique should be identified for review and verification by the qualifying activity. The supplier of radiation-hardness-assured multichip modules or hybrids in compliance with this Guide is responsible for assuring that the customer requirements were properly interpreted, and that appropriate test facilities and parts acquisition, design, production, and assembly personnel are used. In addition, QMP documentation should be maintained to document and demonstrate compliance with the provisions of this Guide as they apply to the supplier's technology and radiation environment specified for the part. The supplier may use third parties, such as radiation test contractors or assemblers, for any of the functions depicted in the technology flow in Figure 2.

However, the participation of those third parties should be covered in the QMP, and their activities should be controlled through a documented vendor verification program or incoming inspection procedure. The use of third party vendors in no way relieves the supplier of responsibility for product quality and radiation–hardness assurance.

4 Requirements (cont'd)

4.1 General requirements (cont'd)

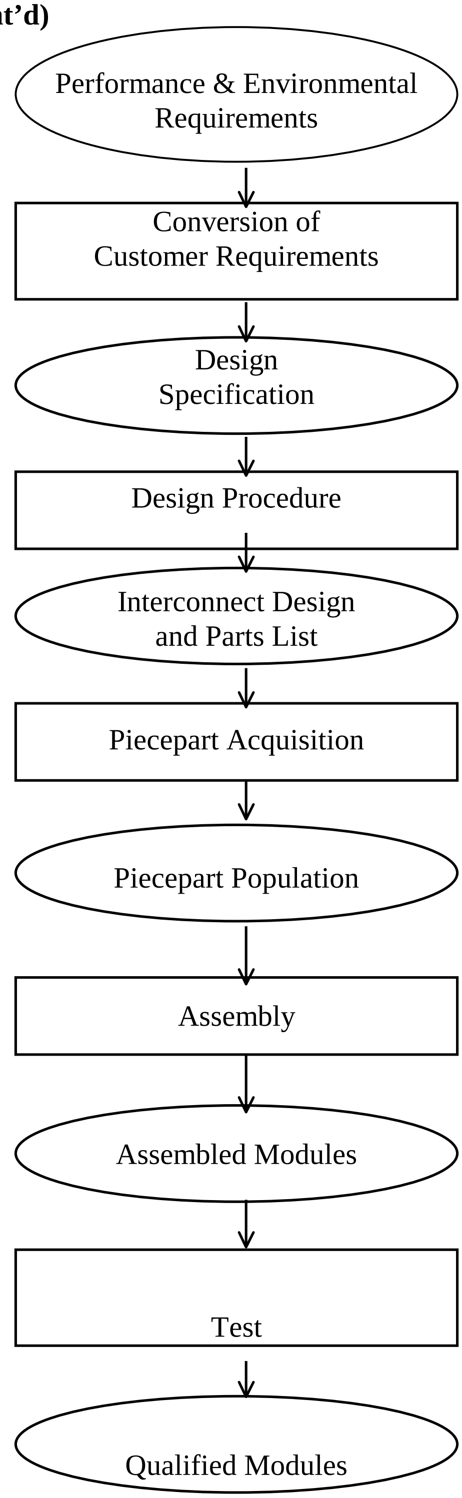

Figure 2 — Typical technology flow for RHA modules

4 Requirements (cont'd)

4.1 General requirements (cont'd)

Table 1 — MCM/RHA functional flow analysis for a build-to-spec product

Activity	Oversight	Performer	Tools	Resources
Conversion of Customer Requirements	Technical Review Board (TRB) or Equivalent	Radiation engineering	Codes for converting from free-field environments to package environments. Engineering computational tools, parameter values, and checking procedures.	Radiation Hardening (RH) consultant.
Design Procedure	TRB or equiv.	Design engineering	Engineering computational tools, parameter values, and checking procedures.	Design rules. Hardened devices. Shielding materials. Specification document. RH consultant.
Piecepart Acquisition	TRB or equiv.	Procurement engineering	Procedures for tracking and control of RHA and non-RHA dice. Change control and acquisition lot control plans. Lot sampling plans.	RH die suppliers. Specification document. RH consultant.
Assembly	TRB or equiv.	Assembly department	Statistical process control (SPC) or incoming inspection of the assembly materials, shielding materials, and protective coatings. Assembly process parameters.	Guidelines for RHA substrate design and construction. Documentation procedures for controlling critical assembly process parameters.
Test	TRB or equiv.	Test department	Radiation simulators.	Test plan.

4 Requirements (cont’d)

4.2 Detailed requirements

The manufacture of an RHA multichip module or hybrid circuit should be performed in the context of a supplier's standard technology flow and should make use of and be consistent with the requirements for quality and reliability set forth in MIL-PRF-38534. The procedures for achieving an RHA line are consistent with those for achieving QML or equivalent status: certification, qualification, and maintenance. Requirements to notify the qualifying activity, e.g., the Defense Supply Center Columbus (DSCC), of major, minor, and editorial changes should be consistent with the Quality Assurance Requirements as established in MIL-PRF-38535 or MIL-PRF-19500. All process or assembly modifications that affect the radiation-hardness of the MCM or hybrid should be considered major changes. Examples of these are changes to oxide growth conditions and packaging materials.

4.2.1 Certification requirements

Certification should consist of the certification procedures of MIL-PRF-38534 and the additional RHA enhancements outlined herein. The RHA enhancements should be documented in the supplier's QMP and should consist of the (1) RHA management program (see ref. 1 for a discussion of the nature of a hardness assurance program in a system development), (2) demonstration of RHA capability, (3) validation of RHA management and technology by the qualifying activity, and (4) demonstration of the supplier’s control of third party vendors. Specific requirements for RHA for the certification procedures associated with each of the technology flow activities are described in the following paragraphs.

4.2.1.1 Conversion of customer requirements

If the customer does not supply a procedure for converting their requirements, the supplier should have a documented procedure for converting all customer RHA requirements into multichip module or hybrid microcircuit RHA design and fabrication requirements for the applicable radiation environments as listed below. The supplier may use a third party for conversion of customer requirements, but the supplier should be able to demonstrate how the third party is controlled under the QMP and how the results of the third party are integrated into the design, piecepart selection, fabrication, assembly, and test activities.

The customer generally converts the application environment parameters such as altitude, orbit, space mission, and weapon threat into requirements applied to each of the technology flow activities. If that is not supplied by the customer, e.g., the OEM, the supplier or his contractor should have in place a documented procedure for performing that task. When the supplier cannot obtain all of the required environmental information, the supplier will need to obtain secondary parameters from the customer (e.g., from photocurrent source models) so that the remaining technology flow activities can be done.

Since suppliers’ multichip modules and hybrids are required to perform many of the functions traditionally done by system manufacturers, for each of the applicable radiation environments the supplier should be able to analyze and deal with any radiation-induced interactions between dice in a module.

4.2 Detailed requirements (cont'd)

4.2.1.1 Conversion of customer requirements (cont'd)

A brief discussion of the various radiation environments and their effects on microelectronics is provided to facilitate this and subsequent discussions. Procedures for determining the MCM or hybrid response to each of these effects should be demonstrated during certification.

a) Single Event Effects

Environmental sources considered for single-event effects (SEE) include galactic cosmic rays, alpha particles, protons, and neutrons (see refs. 2-5 for discussions of space environments). The effects to be considered include single-event upset (SEU), single-event latchup (SEL), single-event burnout (SEB), single-event gate rupture (SEGR), and single-event transients (SET).

b) Dose Rate and IEMP

The sources of ionizing dose rate and IEMP effects are nuclear weapons. The dose rate environment includes the amplitude, spectrum, and shape of the ionizing radiation pulse. A high dose rate creates ionization, generating excess charge carriers in the IC. IEMP creates high fields around the IC. The effects to be considered include current and voltage transients, upset, latchup, snapback, and high dose rate burnout. Particular attention should be given to combined IEMP effects and input/output (I/O) photocurrent effects among interconnected pieceparts. Where the supplier uses shielding to reduce the x-ray component of a high dose-rate environment, procedures to model the shield's effectiveness should be demonstrated and the effects of the environment as modified by the shield must be considered.

c) Total Dose

Environmental sources considered for ionizing total dose include the space radiation belts (protons and electrons), nuclear reactors, nuclear weapons (X rays and gamma rays), and medical or industrial X-ray equipment. The characteristics of these sources in terms of energy spectrum, dose rate and total dose expected over the life of the part is particularly important. For example, the dose rate at which the total dose is delivered varies by many orders of magnitude for the various sources. This has a significant influence on the total dose effects that are seen. Specific total ionizing dose effects include functional failure, increased leakage and standby currents, timing degradation, and decreased I/O drive capability. The specification for the MCM or hybrid should encompass the effects from the total ionizing dose accumulated over the mission life at the worst-case dose rate and the total dose characteristics of the pieceparts. When looking for ELDRS effects, it may be impracticable to irradiate at the very low space dose rates. Alternative procedures are discussed in MIL-STD-883/method 1019 and in more detail in ASTM standard F1892.

4.2 Detailed requirements (cont'd)

4.2.1.1 Conversion of customer requirements (cont'd)

d) Neutrons and Protons (displacement damage)

Environmental sources considered for neutron irradiation include those created by collisions of cosmic rays with atmosphere molecules, nuclear reactors and nuclear weapons. For protons, the environmental source is the space radiation belts. For both, the particle environment is specified in terms of fluence and energy. Specific displacement damage effects are technology and application dependent, where: (1) bipolar devices can suffer gain degradation and increased noise, (2) both bipolar and metal oxide semiconductor (MOS) power devices suffer increased bulk resistance (resulting in increased power dissipation and reduced efficiency), (3) MOS devices used as charge-coupled devices show increased levels of background (dark) current and charge transfer efficiency (CTE) degradation, and (4) some types of optoisolators and optocouplers exhibit charge transfer ratio (CTR) degradation. Degradation from the neutron pulse of a nuclear weapon is significantly worse at short times; some of the degradation will anneal rapidly over time as a function of temperature and operating current density. Consideration of this additional short-term degradation should be included in the conversion and specification process when appropriate.

4.2.1.2 RHA design requirements

Certification of a supplier's RHA design system is based on the documentation of his design flow and methodology. Documentation should be in place to address the RHA design methodology and issues for each applicable radiation environment. The methodology should include engineering computational tools, parameter values, device radiation effects models and procedures for applying them to design issues arising from the applicable RHA environment. Such issues include but are not limited to: piecepart (active and passive) selection, functional design, piecepart placement and attachment, interconnection, material selection (substrate, package, and lid), selection of protective coatings, and application of shielding. Whenever possible, radiation-hardened design rules should be established and documented. Design rule, electrical check, and layout verification techniques should be in place and used to ensure that designs are in compliance with manufacturing and design requirements.

4.2 Detailed requirements (cont'd)

4.2.1.2.1 RHA design issues

For each of the radiation environments, there are issues that the supplier should address during the design process and evaluate during the certification process. Typically design issues are:

a) Single Event Effects

Documentation Recommendations

- The supplier should document and demonstrate how selection criteria are set for each die type in an MCM or hybrid to ensure that it is not subject to catastrophically destructive single-event effects (e.g., SEL, SEGR, SET, and SEB). The documentation should also indicate how the designer records the specific actions required to maintain the SEL suppression in an MCM or hybrid circuit (e.g., backside preparation, ohmic die attach, and backside contacts for epitaxial-CMOS) and how these requirements are passed on to the supplier's organizations responsible for die procurement, substrate fabrication, assembly, and testing. The design records should include those cases where no design action is required, such as the use of only silicon-on-insulator (SOI) technology die. They should indicate the reason for the inaction, and any constraints on die procurement should be noted (e.g., procure only SOI die).

- The supplier should document and demonstrate how single-event upset (SEU) specifications are developed for an MCM or hybrid circuit. Procedures should be in place for recording the specific single-event upset characteristics for each die type used in a particular MCM or hybrid (see ref. 6 for a discussion of test and data analysis approaches). The SEU performance for each die should be specified in terms of a threshold linear energy transfer (LET), a cross section, and an error rate (and the associated upset mode if more than one is possible). The methodology for calculating the error rate should be included in the documentation. The documentation should indicate the methodology used for SEU hardening. It should also indicate the specific actions required to maintain the SEU hardness in the MCM or hybrid circuit, or mitigating design functions such as error detection and correction (EDAC). If no design action is required, the reason for the inaction should be documented and any constraints on dice procurement should be noted.

- The supplier should document and demonstrate how the single event transient (SET) specification is developed for the MCM or hybrid. The design methodology used to suppress single-event I/O transients from propagating between dice or the consequences of such an occurrence on module performance should be documented.

4.2 Detailed requirements (cont'd)

4.2.1.2.1 RHA design issues (cont'd)

Implementation Recommendations

As previously discussed, SEE are caused by energetic ionic species, protons, and neutrons that exist in the space environment or are generated by solar activity. The methods used to mitigate SEE are:

- Selection of devices with low upset rates and low susceptibility to latchup or other catastrophic failure modes, e.g., gate rupture or burnout. Devices fabricated using dielectric isolation methods (e.g., SOI, SOS, etc.) or bulk silicon technology devices using epitaxial layers have generally been shown to provide good to excellent immunity to SEE.

- Selection of analog devices with low susceptibility to SEE-induced transients or with rapid recovery.

- Derating of parts. This technique is especially effective for the mitigation of catastrophic failure modes, such as SEGR and SEB.

- Use of shielding to reduce or mitigate the effects of protons. Note that shielding is not very useful for naturally occurring heavy ions because of their very high energies. .

- Introduction of error detection and correction (EDAC) circuits into dice, subsystems and systems to reduce the impact of chip upset on overall system performance. (Note that EDAC and similar approaches can be confounded if devices that display a multiple bit upset response are used in the MCM/hybrid.)

- Introduction of methods to identify device latchup and affect a rapid recovery prior to burnout. This method is not generally recommended since latchup in some circuits is very localized and results in only small, barely perceptible increases in current. This condition is known as a microlatch.

- Introduction of methods to reduce SEU/SET for MCM/hybrid devices with photonic components (e.g., fiber optic data bus receiver/ transmitter, etc.). These are generally invoked on a subsystem level, and include such solutions as operating the data bus at higher levels of transmit power, increasing overall circuit bandwidth, etc.

- Fabrication methods to ensure a low ohmic resistance chip-to-substrate contact to reduce SEL sensitivity.

In general, in a complex MCM/hybrid, many of the above noted methods will be involved to provide cost-effective solutions to obtaining the required level of SEE performance.

4.2 Detailed requirements (cont'd)

4.2.1.2.1 RHA design issues (cont'd)

b) Dose Rate and IEMP

<u>Documentation Recommendations</u>

- The supplier should document and demonstrate the selection criteria for each die type in an MCM or hybrid to ensure that it meets the specified dose rate upset level and it is not subject to destructive dose rate effects (e.g., latchup, snapback and high dose rate burnout). The documentation should also indicate how the specific actions required to control upset and to eliminate catastrophic dose rate effects in the MCM or hybrid circuit (e.g., backside preparation, ohmic die attach, and backside contacts for epitaxial-CMOS) are recorded and how these requirements are passed on to the supplier's organizations responsible for die procurement, substrate fabrication, assembly, and testing. The design records should indicate those cases where no design action is required (e.g., SOI technology). They should note the reason for the inaction and any constraints on die procurement (e.g., procure only SOI die).

- The supplier should document and demonstrate the MCM or hybrid circuit design methodology for preventing catastrophic dose rate effects (e.g., burnout) for the die to be used. Documentation should include design layout rules, computational techniques, and parametric values to support design and layout hardening techniques (e.g., resistive current limiting, power supply "crowbarring", etc.).

- The supplier should document and demonstrate the MCM or hybrid circuit design methodology used to establish the dose rate and IEMP upset hardness for dice used in these circuits. Documentation should include design and layout rules, analytic techniques, and parametric values to support design and layout hardening techniques. The guidelines should deal with inductive and resistive rail span collapse as they relate to the MCM or hybrid power bus design, bypass capacitor selection, and the number of interconnects allowed between the die power bus and the MCM or hybrid power bus. They should also treat dose rate and IEMP cumulative effects associated with die-to-die interconnection and interaction. The design methodology should consider the combination of IEMP currents on the interconnect traces and I/O photocurrents of the connected dice as they contribute to inter-die electrical transients that may exceed the noise margin. Additionally, the impact of high dose rate irradiation on cross-talk isolation and basic signal integrity must be considered. The analytic techniques should be appropriate for a variety of ionizing radiation energy spectra including the effects of any shielding. Material parameters should be appropriate for the MCM or hybrid technology being certified and should encompass the variations consistent with the relevant statistical process control (SPC) charts.

4.2 Detailed requirements (cont'd)

4.2.1.2.1 RHA design issues (cont'd)

Implementation Recommendations

As discussed earlier, the sources of a high ionizing dose rate and an IEMP are an ionizing radiation pulse from a nuclear weapon (see ref. 7 for a discussion of dose rate hardness assurance techniques). A high ionizing dose rate acts directly on the dice while IEMP acts indirectly by creating high-intensity fields around the IC. The various methods of achieving satisfactory dose-rate performance in these environments include:

- Selection of devices with minimal sensitivity to prompt ionizing radiation effects, e.g., CMOS/SOS, CMOS/SOI, or enhanced resistance through the use of robust power bus design, epitaxial die construction, etc.
- Design of MCMs/hybrids and selection of materials to minimize IEMP currents. Specific design methods include the layout and dimensions of the actual lands and grooves, the selection of materials with low current-drive characteristics and the use of interior wall and device conformal coatings to reduce secondary electron effects.
- Use of MCM/hybrid package fill methods to mitigate ionization effects at very high dose-rates (e.g., $>10^{10}$ rad/s).
- Circuit design methods to ensure that intra-chip photocurrent interaction or IEMP direct drive currents do not result in MCM/hybrid performance degradation or failure through upset or burnout.
- MCM/hybrid fabrication methods that would ensure a low resistance chip-to-substrate connection. This is required to ensure that voltage drop across this connection resulting from the ionizing radiation-engendered chip photocurrents will not cause upsets in individual die.

As a general statement for dose rates below 10^9 rad(Si)/s, the use of hardened or suitable tolerant parts in conjunction with some attention to circuit design (intra-chip loading, etc.) provides an adequate response. However for dose-rates above 10^9 rad(Si)/s, where IEMP begins to be a factor, a combination of all five methods, with emphasis on package design and material selection is the key to success.

4.2 Detailed requirements (cont'd)

4.2.1.2.1 RHA design issues (cont'd)

c) Total Dose

Documentation Recommendations

- The supplier should document and demonstrate the selection criteria and their rationale for each die type in an MCM or hybrid to ensure that it is suitable for meeting the specified total ionizing dose hardness requirement. The criteria should consider the die hardness as a function of dose rate as well as total accumulated dose. The effects of any radiation shielding incorporated into the MCM or hybrid should also be considered. The documentation should also indicate how the specific post-irradiation design limits that serve as the basis for the total dose hardened design are recorded. It should show how these limits are passed on to the supplier's organizations responsible for die procurement so that appropriate constraints can be placed on die acquisition.

- The supplier should document and demonstrate the analytical tools, parameter values, and design methodology used to evaluate dose enhancement as a function of energy spectrum for the MCM or hybrid technology used. If shielding is employed as a hardening technique at the MCM or hybrid level, the procedures for applying the tools and parameters to the selection of shielding material, shielding thickness, and shield placement should be documented.

Implementation Recommendations

Total ionizing dose can come from trapped electrons and protons in the Van Allen belts, gamma radiation from a nuclear reactor, x-rays from medical or industrial irradiators, and x and gamma radiation from a nuclear weapon. The methods that can be used to mitigate or reduce the effects of total ionizing dose include:

- The selection of appropriately robust devices, including for enhanced low dose-rate sensitivity (ELDRS) effects (see ref. 8 for a discussion of total dose hardness assurance techniques and ref. 9 for a discussion of ELDRS).

- MCM/hybrid chip design rules to prevent known chip performance degradation from compromising module performance. Specifically, radiation-caused changes in chip drive current or input and output voltage, can result in degraded operation of the module due to chip interactions. The design methodology and design limits for electrical parameters should encompass the post-irradiation performance of the selected devices. Radiation induced parametric changes in digital devices include, but are not limited to, variations in standby current, operating current, timing, input leakage, and output drive. In analog and mixed signal circuits, the methodology should also address variations in offset, gain, noise, linearity, and other critical design parameters.

- The use of shielding against the x-rays and electron radiation. However, shielding against gamma rays and high-energy protons is not practicable.

In general, an appropriate technical approach is to invoke a balanced hardening methodology to develop a cost-effective solution using all of the above noted methods.

4.2 Detailed requirements (cont'd)

4.2.1.2.1 RHA design issues (cont'd)

d) Displacement Damage

Documentation Recommendations

- The supplier should document and demonstrate how the selection criteria are chosen for each die type in an MCM or hybrid to ensure that it is capable of achieving the operating requirements under the specified radiation conditions (e.g., neutron or proton fluence, etc.) The design methodology and design limits for electrical parameters should encompass the post-irradiation performance of the selected devices. Procedures should be in place for determining whether rapid annealing after neutron irradiation is important in a specific application. For those cases where rapid annealing is important, design and analysis approaches should be in place for estimating the limit of rapid annealing effects and incorporating them into the design methodology. The documentation should also indicate how the designer records the specific post-irradiation design limits that serve as the basis for the neutron hardened design and how these limits are passed on to the supplier's organizations responsible for die procurement so that appropriate constraints can be placed on die acquisition.

Implementation Recommendations

Displacement damage in semiconductor devices is caused by energetic particles damaging the semiconductor lattice structure. The particles can be protons in the natural space environment, or neutrons from nuclear weapons, from reactors, or from cosmic ray interactions in the atmosphere.

- Device degradation caused by displacement damage is generally addressed at the piecepart level through the selection of suitably robust devices (see ref. 8 for a discussion of neutron hardness assurance techniques). In general, majority carrier devices (e.g., MOS) are relatively immune to displacement damage effects. This is not true, however, for MOS devices used in charge coupled device applications. Also, higher frequency bipolar technology transistors, e.g., >50 MHz, have a higher level of immunity to displacement damage than low frequency transistors. However, in devices where low bulk resistivity is important (e.g., power MOS and bipolar technologies), displacement damage can be a concern. Additionally, some types of optoisolators and optocouplers have displayed a significant sensitivity to displacement damage from protons.

- Shielding can be somewhat useful for reducing the damage caused by naturally occurring protons.

4.2 Detailed requirements (cont'd)

4.2.1.2.1 RHA design issues (cont'd)

e) Combined Effects

- In addition to addressing the itemized effects a) through d) above, the supplier should document and demonstrate how combinations of these effects are taken into consideration in the design of the MCM or hybrid to the specified performance. For example, some devices are degraded by both total dose and displacement damage. These considerations should include non-radiation degrading environments such as time and temperature that may contribute to degraded end of life electrical design parameters used in the worst-case circuit analysis. A further issue that should be considered is the impact of operating stress (time and temperature) on total ionizing dose degradation. Hence, if a hybrid/MCM is subjected to a burn-in or long temperature soak, it may be important to ensure that the die used in the module are tested after being subjected to the same time/temperature stressing (see ref. 10 for a discussion of time/temperature stressing and radiation degradation).

4.2.1.2.2 Third party RHA design requirements

The supplier may be certified to accept radiation hardened designs from a third party under either of two cases. In the first case, the third party should be certified as part of the technology flow. The third party should participate in the management of design modifications, and his design flow should be under change control as specified in the QMP. In the second case, the supplier should furnish to the third party documented radiation hardened design guidelines appropriate to his technology that address each of the applicable criteria. Furthermore, the supplier should have in place and documented an auditable methodology to assure compliance with the guidelines.

4.2.1.3 Die acquisition

Considerable effort and planning should go into the die acquisition strategy. The important parameters to be considered are the radiation requirements, the number of devices of each type needed, and the sources of the various devices. The sources include (1) vendors of QML/RHA die, (2) vendors who cooperate with the MCM/hybrid supplier to place their dice under change control, and (3) vendors who are not under change control, offering only industrial or commercial grade die. If there is only a small margin between the mean radiation failure level(s) and the radiation specification(s), or if several radiation requirements must be met simultaneously (e.g., total dose, dose rate, and SEE), the MCM/hybrid supplier may be better off using controlled devices with well-established RHACLs as opposed to noncontrolled devices. This could be the case either because the noncontrolled parts cannot meet the radiation performance requirements or they cannot meet them without unacceptable screening fallout.

If the parts acquisition strategy is not carefully planned and implemented, an MCM/hybrid supplier could be in the position where:

- a complex and costly RHA program must be implemented, or
- because of an unsuccessful hardness assurance program for high performance but noncontrolled parts, last minute substitution of RHA devices would result in reduced module performance.

4.2 Detailed requirements (cont'd)

4.2.1.3 Die acquisition (cont'd)

The supplier of radiation hardened hybrids or multichip modules should have documented procedures in place that support the procurement of die and pieceparts to the appropriate RHA level. During the certification, the supplier should be able to demonstrate how radiation-hardness specifications on active and passive pieceparts are translated into die acquisition constraints to ensure the required radiation-hardness of all pieceparts.

The MCM or hybrid supplier should also demonstrate procedures for positive tracking and control of RHA die and non-RHA die of the same type. For the situation where a supplier uses an RHA and a non-RHA version of the same die in RHA and non-RHA modules, respectively, procedures should be in place to ensure the segregation and identification of RHA and non-RHA versions of the same type of die in all stages of the acquisition and technology flow. Dice that were acquired as an RHA version and are subsequently found to fail RHA screens may be down graded to non-RHA versions and used in non-RHA hybrids or MCMs provided that they pass all quality and reliability controls and screens required by the non-RHA technology flow. Any die that has been irradiated should be removed from the down graded population.

a) QML/RHA Die Vendors: Die from QML/RHA vendors can be accepted as qualified for the specified RHA level with no additional radiation testing required when the post-irradiation parameter limits for the application lie within the radiation-hardness assurance capability limits (RHACL) specified by the vendor. (See ref. 9 for a discussion of the specifications for RHA/QML devices.) The die used in the hybrid microcircuit or multichip module should pass all technology conformance inspection or quality conformance inspection (TCI/QCI) tests for the specified RHACL of the QML die fabrication technology including any single chip package RHA testing required by the vendor's approved RHA plan.

b) Die Vendors Under Change Control: The MCM or hybrid supplier may establish a relationship with a die vendor to place the vendor under change control for RHA. Under this relationship, specific die types are qualified to an RHACL for appropriate radiation environments. A lot sampling plan for RHA is then put in place for subsequent lots of that die type. Die from a lot that has passed the lot sampling criteria can be accepted as RHA. The MCM or hybrid supplier should document and demonstrate his approach for placing a cooperating die vendor under change control and establishing an RHACL for a die type. Vendors who are qualified under MIL-PRF-38535 or MIL-PRF-19500 and listed on the Qualified Manufacturers List but are not QML/RHA qualified can be considered to fall within this category. The approach given in MIL-PRF-38535 for establishing an RHACL includes identifying the dominant failure mechanism(s) for each applicable radiation environment, selecting a test sample representative of the product population, choosing a test quantity suitable for establishing the RHACL to at least a 90% probability and 95% confidence limit, executing a test plan appropriate for determining the RHACL for the dominant failure mechanism, and determining a lot sample test plan (test quantities and radiation levels) suitable for monitoring compliance to the RHACL. The probability and confidence limit values are provided as recommendations, but the 90/95% specification is often used. The actual requirements should be established by mutual agreement between the qualifying activity and the MCM/hybrid supplier. The documentation should also address provisions for change notification by the die vendor and procedures for determining the effect of changes on the RHACL (e.g., the need for requalification).

4.2 Detailed requirements (cont'd)

4.2.1.3 Die acquisition (cont'd)

c) Vendors Not Under Change Control: Unless there is a large margin between the radiation specification and the mean failure level of a noncontrolled part, the use of such a noncontrolled part is risky (ref. 13). This is because of the large variation that often occurs in the radiation response of noncontrolled chips. Given the typical large variation in device response, a user would have two options. The first is to purchase all of the required chips from one furnace lot so as to minimize the device response variation. However, if that is not feasible or if the number of parts needed exceeds the number of die available from a single furnace lot, several lots must be sampled. This is not a desirable alternative, because large sample sizes are required to obtain a meaningful measure of the radiation response distribution of noncontrolled parts. Thus, rather than dealing with the problem of obtaining statistically significant data from often non-gaussian distributions, it may be better to select RHA or controlled parts.

   If the MCM or hybrid supplier must use die from an industrial/commercial grade vendor who does not provide change control, the supplier should document and demonstrate the approach for establishing a reliable RHACL for each acquisition lot. The approach should address procedures for selecting and verifying that the acquisition lot represents a homogeneous population (i.e., same wafer, same wafer lot, same process lot, etc.) Furthermore, the approach should include provisions for identifying the dominant failure mechanism(s) for each applicable radiation environment, selecting a test sample representative of the product population, choosing a test quantity suitable for establishing the RHACL to the agreed upon probability and confidence limits, and executing a test plan appropriate for determining the RHACL for the dominant failure mechanism. If the MCM or hybrid build cannot be accomplished with the die from a single acquisition lot and other lots are required, these other lots should undergo the same procedure to determine their RHACL. If one of these approaches is not used, a larger number of the finished MCM/hybrid must be used to assure that lot-to-lot variations are not significant.

4.2.1.4 MCM/Hybrid substrate fabrication

The supplier should document procedures that define the RHA considerations and requirements for procurement, design and fabrication of substrates used in RHA MCMs or hybrid modules. RHA rules and/or guidelines for substrate design and construction should be documented to ensure performance at the specified RHA level. The supplier should demonstrate analytically or experimentally that the substrate design, construction, and fabrication technology is capable of supporting the RHA requirements specified for the completed MCM or hybrid microcircuit. As a recommended minimum, the following radiation environments should be addressed for each MCM substrate or hybrid microcircuit technology.

a) Dose Rate and IEMP: The supplier should provide data to demonstrate that the material properties of the substrate, interlevel dielectric, metallization system, package, and lid are under SPC or incoming inspection control to ensure that their parametric values as they relate to dose rate and IEMP effects lie within the design limits established for the technology.

4.2 Detailed requirements (cont'd)

4.2.1.4 MCM/Hybrid substrate fabrication

b) Total Dose: For MCM or hybrid microcircuit designs that use shielding to reduce total ionizing dose, the supplier should provide data to establish that the shield thickness and composition are under SPC or incoming inspection control. Furthermore, the supplier should demonstrate that all parts of the assembly that could degrade the total dose hardness through dose enhancement are under SPC or incoming inspection control.

4.2.1.5 Assembly process

The supplier should identify assembly process parameters critical to assuring performance of the completed MCM or hybrid at the specified RHA level and should document procedures for controlling those process parameters. The supplier should utilize techniques such as incoming inspection of materials and statistical process control of assembly process parameters that have a significant impact on the RHA performance of the completed MCM or hybrid circuit. As a minimum, the supplier should address the impact of the following RHA environments as they relate to control of the assembly process.

a) Latchup: The supplier should document his procedures for ensuring low resistance backside contacts to dice that need such contacts to prevent dose rate and single-event induced latchup. The supplier should also provide data to demonstrate the effectiveness of these procedures and a monitoring plan to ensure that such contacts are successfully implemented on production units.

b) Dose Rate Upset and IEMP: The supplier should document his procedures for ensuring low resistance contacts between capacitive energy storage elements and the power bus distribution metallization. Data should be provided to demonstrate the effectiveness of these procedures and a monitoring plan should also be provided to ensure that such contacts are successfully implemented on production units.

4.2.1.5 Assembly process (cont'd)

The supplier should provide data to demonstrate the efficacy of any package fill or coating method (e.g., inert atmosphere, encapsulant) used for IEMP mitigation. The supplier should also be able to demonstrate that the fill or coating method has no effect on reliability (e.g., hermeticity) and that the method is under statistical process control.

4.2.2 Qualification

In general, qualification requires the successful development and documentation of an internal system that addresses: (1) Conversion of Customer Requirements Qualification, (2) Design System Qualification, (3) RHA Die (piecepart) Acquisition Qualification (4) RHA Substrate Fabrication Qualification and (5) RHA Assembly Process Qualification. An MCM or hybrid supplier seeking qualification should be able to demonstrate his ability to design, acquire the required dice, fabricate, and assemble an RHA MCM or hybrid of typical complexity for the technology being qualified using established QML procedures. Qualification can be granted by the qualifying agency upon the receipt and approval of documented design, acquisition, fabrication, and assembly information and radiation test results. Specific requirements for RHA qualification in each of the technology flow activities are described in the following paragraphs.

4.2 Detailed requirements (cont’d)

4.2.2 Qualification (cont’d)

Under certain circumstances, requalification may be required. An example would be the case where a chip is replaced with one whose radiation response is unknown. In such a case, the radiation performance of the MCM/hybrid could be compromised since electrical equivalence is no guarantee of equivalent radiation performance. For such a situation, the MCM/hybrid must be requalified.

4.2.2.1 Conversion of customer requirements

Qualification of the supplier's system for conversion of customer requirements will be based on a demonstration of his ability to provide modules that meet the specified requirements through test, analysis and similarity, or any combination thereof.

4.2.2.2 Design

At the time of certification, the supplier should identify an MCM or hybrid microcircuit that will serve as the qualification vehicle for the supplier’s design system. This qualification vehicle should be consistent with the typical complexity of the supplier's certified MCM or hybrid microcircuit fabrication technology. The supplier should design a qualification vehicle that has been subjected to the certified design flow, including parts selection, electrical design, layout design, and package design. The complete design documentation package should be submitted to the qualifying activity as part of the requirements for qualification. Successful completion of the qualification vehicle TCI/QCI testing will form the basis for qualification of the supplier’s RHA design system.

4.2.2.3 RHA die (piecepart) acquisition

All microcircuits and other semiconductor die used in the qualification vehicle should be capable of meeting or exceeding the RHA levels to which the qualification vehicle is specified, allowing for any shielding or other design methods implemented to achieve the radiation requirements. The piecepart procurement package should be submitted to the qualifying activity as part of the requirements for qualification. Die in the qualification vehicle may be acquired from one or more of the following sources.

4.2.2.3.1 QML qualified die acquisition

When die are procured from a qualified QML vendor and application parameter limits lie within the die specification, the die can be accepted as qualified for the specified RHA level with no additional testing required. The die used in the hybrid microcircuit or multichip module should pass all TCI/QCI tests for the specified RHACL of the QML die fabrication technology including any single chip package RHA testing required by the vendor’s approved RHA plan. When the specified RHA levels and parameter limits for the qualified die and planned circuit application do not match, additional specification controls are needed.

4.2 Detailed requirements (cont'd)

4.2.2.3.2 Approved vendor die acquisition

When die are procured from a vendor that has acceptable change control procedures, the RHACL of each die type should be established for each RHA environment of the demonstration vehicle. The RHA qualification test requirements should be based on the provisions of a documented and approved change control qualification plan.

4.2.2.3.3 Industrial/Commercial grade vendor die acquisition

When die are procured from an industrial/commercial grade die supplier who does not guarantee change control, the RHACL of each die type should be established for each RHA environment of the demonstration vehicle. The RHA qualification test requirements should be based on the provisions of a documented and approved acquisition lot qualification plan.

4.2.2.4 RHA Hybrid/MCM assembly

The supplier should assemble the demonstration vehicle according to his certified QML procedures. The assembly traveler and copies of any SPC control charts (with the qualification vehicle designated on the chart) should be submitted to the qualifying activity as part of the requirement for qualification.

4.2.2.5 Qualification testing

The supplier should submit a test plan to the qualifying activity for approval with sufficient lead time to permit a thorough review, including comment resolution, generally no later than one month before the test. The test plan should be designed to focus on possible weaknesses in the subject module, e.g., burnout of a power MOSFET. It should document test circuits, radiation sources, bias conditions, test vectors, test sequences, and quantities of MCMs or hybrids to be tested in each radiation environment for which qualification is sought. The test plan should include justification for selection of bias conditions and test vectors in terms of establishing the worst-case conditions for radiation response. Radiation tests should be performed to failure or a mutually agreed upon overtest level, e.g., several times the radiation specification level. A minimum of two demonstration MCMs or hybrids should be tested for each radiation environment for which qualification is sought. No failures below the specification level are allowed (i.e., 2(0) criterion). Radiation testing should be performed only on devices passing all test provisions of MIL-PRF-38534. Radiation testing should be performed in accordance with the approved test plan, and the test results should be provided to the qualifying agency as a test report. The test report should clearly elucidate which specifications were met and any that were not. RHA qualification will be granted based on review and approval of all phases of the documentation of the demonstration vehicle specification, design, piecepart acquisition procedures, fabrication, assembly, and test.

4.2.3 RHA maintenance requirements

The supplier should maintain the qualified technology flow for RHA in accordance with the approved QMP. Any major changes, including those from die vendors, should be reported to the qualifying activity within one month of the date they were instituted.

Annex A (informative)

Bibliography

Useful space radiation data and extensive information and additional references on RHA can be found in the following documents:

1. MIL-HDBK-817, *System Development Radiation Hardness Assurance*.
2. J. Adams, et.al., *The Ionizing Radiation Environment and its Effects on Satellites* (CREME-96), can be found at the World-Wide Web site http://crsp3.nrl.navy.mil/creme96/.
3. Vette, J. L., *The AE8 Trapped Electron Model Environment*, NSSDC 91-24, National Space Science Data Center, Greenbelt MD, Nov. 1991.
4. Sawyer, D. M., and Vette, J. L., *AP8 Trapped Proton Environment for Solar Maximum and Solar Minimum*, NSSDC 76-06, National Space Science Data Center, Greenbelt MD, Dec. 1976.
5. IEEE Standard P1156.4, *Standard for Environmental Specifications for Spaceborne Computer Modules*, 1996.
6. JEDEC JESD 57, *Test Procedures for the Measurement of Single Event Effects in Semiconductor Devices from Heavy Ion Irradiation*.
7. MIL-HDBK-815, *Dose Rate Hardness Assurance Guidelines*.
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9. Pease, R.L., et. al., *A Proposed Hardness Assurance Test Methodology for Bipolar Linear Circuits and Devices in a Space Ionizing Radiation Environment*, IEEE Trans. Nucl. Sci. NS-44, 1984 (1997).
10. M.L. Shaneyfelt, et. al., *Impact of Aging on Radiation Hardness*, IEEE Trans. Nucl. Sci. NS-44, 2040 (1997).
11. MIL-HDBK-816, *Guidelines for Developing Radiation Hardness Assured Device Specifications*.
12. ASTM F1892, *Standard Guide for Ionizing Radiation (Total Dose) Effects Testing of Semiconductor Devices.*
13. MIL-STD-1766B, *Nuclear Hardness and Survivability Program Requirements for ICBM Weapon Systems (1994*).

Annex B (Informative) Differences between JEP133B and JEP133A

This table briefly describes most of the changes made to entries that appear in this standard, JEP133B, compared to its predecessor, JEP133A (July 2001). If the change to a concept involves any words added or deleted (excluding deletion of accidentally repeated words), it is included. Some punctuation changes are not included.

Page (Title)	Description of Change
(Forward)	Added DTRA member
(Intro)	Added three development areas; build to print, build to spec, joint effort
(Scope)	Added “or that are built to a radiation specification”. Added tie in to MIL-PRF-38535 if non-RHA dice are used
	Added “of all of the modules produced” with commercial grade, stringent RHA program is required.
	Added lot homogeneity of sample for RHA testing.
	Clarified SEE term, Single Event Effects
(Normative Refer)	Added EIA/JESD57
	Added JESD89
(Definitions)	Updated definitions for:
	Displacement Damage, Dose Rate Burnout, Dose Rate Upset, ELDRS, IEMP, LET, QML, Qualifying Activity, QMP, RHA, SEB, SEE, SEGR, SEL, SET, SEU, Snapback, Soft Error device, TRB, TID
(Requirements)	Added “built to a radiation specification”
	Added tie into Introduction of the three RHA development areas
(Table I)	Clarify title…analysis for a build-to-spec product.
	Oversight from Technology to Technical
	Performer from Sales Eng to Radiation Eng
	Resources from RH Consultant to Radiation Hardening (RH) consultant
(4.2.1.1)	Clarification of Conversion of Customer requirements
(4.2.1.1.a)	Added SET and removed reference to analog circuits after SET
(4.2.1.1.b)	Added “should be demonstrated” for shield effectiveness and consideration of a modified shield.
(4.2.1.1.c)	Added on example of total dose from various sources
	Added ELDRS effects and tied in alternative procedures for testing ELDRS.
(4.2.1.1.d)	Added general clarifications
(4.2.1.2.1.a)	Added “demonstrate how the SET spec is developed” and should be documented.
(4.2.1.2.1.a)	Clarified Implementation Recommendations
(4.2.1.2.1.b)	Clarified documented recommendations for Dose rate and IEMP analytic Techniques
(4.2.1.2.1.b)	Clarified Implementation Recommendations
(4.2.1.2.1.c)	Clarified Implementation Recommendations
(4.2.1.3.c)	Clarified Die acquisition for Vendors not under Change Control
_(4.2.2.)	Added requalification under certain circumstances
(4.2.2.5)	Changed radiation test to failure level from 10X to several times
(Annex)	Changed title of ASTM F1892
	Added MIL-STD-1766B

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   - ☐ Test method number __________ Clause number __________

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   ☐ Other ____________________

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2. Recommendations for correction:

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3. Other suggestions for document improvement:

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