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INTERNATIONAL STANDARD

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Process management for avionics – Atmospheric radiation effects –
Part 2: Guidelines for single event effects testing for avionics systems

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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PROCESS MANAGEMENT FOR AVIONICS – ATMOSPHERIC RADIATION EFFECTS –

Part 2: Guidelines for single event effects testing for avionics systems

FOREWORD

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International Standard IEC 62396-2 has been prepared by IEC technical committee 107: Process management for avionics.

This second edition cancels and replaces the first edition published in 2012. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition.

a) improvements and changes to test facilities have been added in Clause 7, which includes new facilities at TSL, TRIUMF and ChipIr,

b) links with IEC 60749-38 and IEC 60749-44 are made in 7.1.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
107/316/FDIS	107/318/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62396 series, published under the general title *Process management for avionics – Atmospheric radiation effects*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This industry-wide international standard provides additional guidance to avionics systems designers, electronic equipment manufacturers and their customers for determining the susceptibility of electronic components to single event effects. It expands on the information and guidance provided in IEC 62396-1:2016.

Guidance is provided on the use of existing single event effects (SEE) data, sources of data and the types of accelerated radiation sources used. Where SEE data is not available considerations for testing are introduced, including suitable radiation sources for providing avionics SEE data. The conversion of data obtained from differing radiation sources into avionics SEE rates is detailed.

PROCESS MANAGEMENT FOR AVIONICS – ATMOSPHERIC RADIATION EFFECTS –

Part 2: Guidelines for single event effects testing for avionics systems

1 Scope

This part of IEC 62396 aims to provide guidance related to the testing of electronic components for purposes of measuring their susceptibility to single event effects (SEE) induced by neutrons generated by cosmic ray interactions in the Earth's atmosphere (atmospheric neutrons). Since the testing can be performed in a number of different ways, using different kinds of radiation sources, it also shows how the test data can be used to estimate the SEE rate of electronic components and boards due to atmospheric neutrons at aircraft altitudes.

Although developed for the avionics industry, this process can be applied by other industrial sectors.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62396-1:2016, *Process management for avionics – Atmospheric radiation effects – Part 1: Accommodation of atmospheric radiation effects via single event effects within avionics electronic equipment*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62396-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 Abbreviated terms

ANITA	Atmospheric-like Neutrons from thIck TArget (TSL, Sweden)
BL1A, BL1B, BL2C	beam line designations at the TRIUMF facility (Canada)
BPSG	borophosphosilicate glass
ChipIr	beam line at the ISIS neutron source facility (Rutherford Appleton Laboratory, UK)
CIAE	China Institute of Atomic Energy
CMOS	complementary metal oxide semiconductor
COTS	commercial off-the-shelf

CUP	close user position, neutron beam facility (TSL, Sweden)
CYRIC	CYclotron and Radio Isotope Center (Tohoku University, Japan)
D-D	deuterium-deuterium
DRAM	dynamic random access memory
D-T	deuterium-tritium
DUT	device under test
E	energy
EEPROM	electrically erasable programmable read only memory
EMC	electromagnetic compatibility
EPROM	electrically programmable read only memory
ESA	European Space Agency
eV	electron volt
FinFET	fin field effect transistor
FIT	failures in time (failures in 10^9 h)
FPGA	field programmable gate array
GeV	giga electron volt
GNEIS	Gatchina Neutron Spectrometer (Russia)
GSFC	Goddard Space Flight Center
GV	giga volt (rigidity unit)
IBM	International Business Machines
IC	integrated circuit
ICE	Irradiation of Chips and Electronics
IEEE Trans. Nucl. Sci.	IEEE Transactions on Nuclear Science
ISIS	neutron beam source (Rutherford Appleton Laboratory, UK)
IUCF	Indiana University Cyclotron Facility (USA)
JEDEC	JEDEC Solid State Technology Association
JESD	JEDEC standard
JPL	Jet Propulsion Laboratory
LANSCE	Los Alamos Neutron Science Center (USA)
LET	linear energy transfer
LETth	linear energy transfer threshold
MBU	multiple bit upset (in the same word)
MCU	multiple cell upset
MeV	mega electron volt
NASA	National Aeronautical and Space Agency
PCN	product change notification
PIF	Proton Irradiation Facility (TRIUMF, Canada)
PNPI	Petersburg Nuclear Physics Institute (Russia)
PSG	phosphosilicate glass
QMN	quasi-monoenergetic neutron
RADECS	RADiations, Effects on Components and Systems
RAL	Rutherford Appleton Laboratory (UK)
RAM	random access memory

RCNP	Research Center of Nuclear Physics (Osaka, Japan)
SBU	single bit upset
SDRAM	synchronous dynamic random access memory
SEB	single event burn-out
SEE	single event effect
SEFI	single event functional interrupt
SEGR	single event gate rupture
SEL	single event latchup
SEP	solar energetic particles
SER	soft error rate
SET	single event transient
SEU	single event upset
SHE	single event induced hard error
SRAM	static random access memory
SW	software
TID	total ionizing dose
TNF	TRIUMF neutron facility (TRIUMF, Canada)
TRIUMF	neutron beam source (Vancouver, Canada)
TSL	Theodor Svedberg Laboratory (Uppsala, Sweden)
WNR	Weapons Nuclear Research (Los Alamos, USA)

5 Obtaining SEE data

5.1 Types of SEE data

The type of SEE data available can be viewed from many different perspectives. As indicated, the SEE testing can be performed using a variety of radiation sources, all of which can induce single event effects in electronic components. In addition, many tests are performed on individual electronic components, but some tests expose an entire single board computer to radiation fields that can induce SEE. However, a key discriminator is deciding on whether existing SEE data that may be used is available, or whether there really is no existing data and therefore a SEE test on the electronic component or board of interest has to be carried out.

5.2 Use of existing SEE data

5.2.1 General

The simplest solution is to find previous SEE data on a specific electronic component. Data may be available on SEE caused by heavy ions, protons, high energy neutrons, or thermal neutrons. Heavy ion data is normally only applicable to space applications, where direct ionization by the primary cosmic ray flux is of concern. However, heavy ion data can be useful for screening purposes, as described in 5.2.2. Proton data is usually also gathered for space applications, where primary cosmic rays and trapped particles are of concern. However, high energy protons provide a good proxy for neutrons in SEE measurements, as they undergo very similar nuclear interactions with electronic component materials. Therefore, both existing neutron data and existing proton data may be applicable to the evaluation of SEE rates in a device of interest, as described in 5.2.3. Low-energy ("thermal") neutrons can also cause SEE in some electronic components but such data is only available on a very small number of electronic components (see 5.2.4) and it involves neutron interactions with boron-10 rather than silicon.

Electronic components are constantly changing. In some cases, electronic components which had been tested become obsolete and are replaced by new electronic components which have not been tested. The fact that an electronic component is made by the same vendor and is of the same type as the one it replaced does not mean that the SEE data measured in the first electronic component applies directly to the newer electronic component. In some cases, small changes in the electronic component design or manufacturing process can have a large effect in altering its SEE response. In addition, electronic component manufacturers typically follow JESD46 [1][1] for product change notices (PCNs) to inform customers of component design changes. JESD46 [1] recommends a part number change when a die shrink or die foundry or die process change occurs but not when the die metallisation layout is altered, which can also lead to different SEE results. All SEE test data published therefore should refer to the specific manufacturer, the specific die geometry and full component part number.

5.2.2 Heavy ion data

An important resource that can be utilized to eliminate electronic components are the results from heavy ion SEE testing carried out to support space programs (~80 % of the electronic components tested for space applications are tested only with heavy ions). This heavy ion SEE data can be used to calculate SEE data from high energy neutrons and protons by utilizing a number of different calculation methods, but this requires the active involvement of a radiation effects expert in the process. Heavy ion testing is characterized by the LET (linear energy transfer) of the ions to which the ICs are exposed. The LET is the energy that can be deposited per unit path length, divided by the density (units of MeV·cm^2/mg). With neutron SEE, secondary particles or recoils created by the neutron interactions act as heavy ions, and the highest possible LET of neutron-induced recoils in silicon is ~15 MeV·cm^2/mg [1, 2]. Thus, any electronic component tested with heavy ions that has a LET threshold > 15 MeV·cm^2/mg will be immune from neutron-induced SEE. In a recent paper summarizing SEE testing at NASA-GSFC [3], twenty-one ICs of various types were tested with only heavy ions and eight of them (~40 %) had LET thresholds > 15 MeV·cm^2/mg for diverse SEE effects.

However, for the rare commercial SRAMs that are susceptible to SEL from heavy ions [4], this susceptibility can be increased due to the presence of small amounts of high Z materials within the IC, for example tungsten plugs, because higher Z recoils are created which can cause SEE reactions due to their higher values of LET. The high Z materials also lead to higher proton and neutron SEL cross-sections due to the neutron/proton reactions producing these recoils with higher LET and energy. Therefore heavy ion SEL cross-sections need to be examined carefully for applicability to proton-neutron SEL susceptibility caused by embedded high Z materials in the SRAMs. A suggested conservative value of LET threshold above which an electronic component can be considered immune from SEL induced by neutrons is 40 MeV·cm^2/mg [4]. However, this caution does not apply to the primary rationale given above for eliminating some electronic components from consideration for neutron SEE sensitivity based on heavy ion SEE testing, since only some electronic components incorporate these higher Z materials and the limitation applies to SEL.

Heavy ion SEE data should not be used for application to the atmospheric neutron environment for calculation of neutron cross-section, except by scientists and engineers who have extensive experience in using this kind of data. Unless otherwise stated explicitly, when SEE data is discussed in the remainder of this document, it refers only to single event testing using a neutron or proton source, not to the results from testing with heavy ions.

NOTE IEC 62396-1:2016, B.3.2, provides an approach to transforming heavy ions data into proton/neutron SEE cross-sections.

5.2.3 High energy neutron and proton data

If SEE data on an electronic component of interest is found from SEE tests using high energy neutrons (for example ground level testing as per JESD89A [10]) or protons, it will still require expertise regarding how the data is to be utilized in order to calculate a SEE rate at aircraft

[1] Numbers in square brackets refer to the Bibliography.

altitudes. Data obtained by electronic component vendors for their standard application to ground level systems is often expressed in totally different units, FIT units, where one FIT is one error in 10^9 electronic components hours, which is taken to apply at ground level.

5.2.4 Thermal neutron data

There is little data on thermal neutron cross-section. However a number of the spallation neutron sources including TRIUMF, TSL and ISIS (Vesuvio) contain a substantial percentage of thermal neutrons within the high energy beam. Using thermal neutron filters or time of flight it is possible at such sources to determine thermal neutron cross-section. In addition there are a number of dedicated thermal neutron sources and these are listed in IEC 62396-1.

A continuing problem with the existing SEE data is that there is no single database that contains all of the neutron or proton SEE data. Instead, portions of this kind of SEE data can be found published in many diverse sources. The SEE data in the larger databases is mainly on much older electronic components, dating from the 1990s and even 1980s, and is primarily from heavy ion tests that were performed for space applications and not from testing with protons and neutrons.

5.3 Deciding to perform dedicated SEE tests

If existing SEE data is not available, for any one of the many reasons discussed above and which will be further expanded upon below, then one should refer to IEC 62396-1 for the other alternatives; in case there is no real alternative, SEE testing can be considered. The advantage of such a test is that it pertains to the specific electronic component or board that is of interest, but the disadvantage is that it entails making a number of important decisions on how the testing is to be carried out. These pertain to selecting the most useful test article (single chip or entire board), the nature of the test (static or dynamic (mainly applicable to board testing)), assembling a test team, choosing the facility that provides the best source of neutrons or protons for testing, scheduling and performing the test, coping with uncertainties that appear during the test and, finally, using the test results to calculate the desired SEE rate for avionics. Many of these issues will be discussed in Clauses 6 and 7.

6 Availability of existing SEE data for avionics applications

6.1 Variability of SEE data

Because of the diverse ways that SEE testing is carried out, and the multitude of venues for how and where such data is published, the availability of SEE data for avionics applications is not a simple matter.

6.2 Types of existing SEE data that may be used

6.2.1 General

SEE data can be derived from a number of different kinds of tests, and all of the differences between these tests need to be understood in order to make comparisons meaningful. Although there are many different types of single event effects, for the purposes of this document, the focus is on three of them: single event upset (SEU), single event functional interrupt (SEFI) and single event latchup (SEL). SEU pertains to the energy deposited by an energetic particle leading to a single bit being flipped in its logic state. The main types of electronic components that are susceptible to SEU are random access memories (RAMs, both SRAMs and DRAMs), field programmable gate arrays (FPGAs, especially those using SRAM-based configuration) and microprocessors (the cache memory and register portions). A SEFI refers to a bit flip in a complex electronic component that results in the electronic component itself or the board on which it is operating not functioning properly. A typical example is an SEU in a control register, which can affect the electronic component itself, but can also be propagated to another electronic component on the board, leading to board malfunction. SEL refers to the energy deposited in a CMOS device that leads to the turning on of a parasitic p-n-p-n structure, which usually results in a high current in the device and a non-functioning