IEC/TS 62396-2

Edition 1.0 2008-08

TECHNICAL SPECIFICATION

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

IEC/TS 62396-2:2008(E)

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

INTERNATIONAL ELECTROTECHNICAL COMMISSION

PRICE CODE U

ICS 03.100.50; 31.020; 49.060

ISBN 2-8318-9958-3

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 62396-2, which is a technical specification, has been prepared by IEC technical committee 107: Process management for avionics.

This standard cancels and replaces IEC/PAS 62396-2 published in 2007. This first edition constitutes a technical revision.

The text of this standard is based on the following documents:

Enquiry draft	Report on voting
107/80/DTS	107/86/RVC

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

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

A list of all parts of the IEC 62396 series, 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 publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended

A bilingual edition of this document may be issued at a later date.

INTRODUCTION

This industry-wide technical specification provides additional guidance to avionics systems designers, electronic equipment component manufacturers and their customers to determine the susceptibility of microelectronic devices to single event effects. It expands on the information and guidance provided in IEC/TS 62396-1.

Guidance is provided on the use of existing single event effects (SEE), SEE data, sources of data and the types of accelerated radiation sources used. Where SEE data is not available considerations for testing is introduced including the 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

The purpose of this technical specification is to provide guidance related to the testing of microelectronic devices for purposes of measuring their susceptibility to single event effects (SEE) induced by the 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 devices and boards due to the atmospheric neutrons in the atmosphere at aircraft altitudes.

2 Normative references

The following referenced documents are indispensable for the application of this document, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC/TS 62396-1, *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 purpose of this document, the terms and definitions of IEC/TS 62396-1 apply.

4 Abbreviations used in the document

BPSG	Borophosphosilicate glass
CMOS	Complimentary metal oxide semiconductor
COTS	Commercial off-the-shelf
D-D	Deuterium-deuterium
DRAM	Dynamic random access memory
D-T	Deuterium-tritium
DTS	Draft technical specification
E	Energy
ESA	European Space Agency
eV	electron volt
FPGA	Field programmable gate array
GeV	Giga electron volt
GV	Giga volt (rigidity unit)
IBM	International Business Machines
ICE	Irradiation of Chips and Electronics
IEEE Trans. Nucl. Sci.	IEEE Transactions on Nuclear Science
JEDEC	JEDEC Solid State Technology Association
JESD	JEDEC standard

JPL	Jet Propulsion Laboratory
LET	Linear energy transfer
LETth	Linear energy transfer threshold
MBU	Multiple bit upset
MeV	Mega electron volt
NASA	National Aeronautical and Space Agency
RADECS	Radiations, effets sur les composants et systèmes.
RAM	Random access memory
RVC	Result of voting (IEC)
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 latch
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
TRIUMF	Tri-University Meson Facility (Canada)
TSL	Theodore Svedberg Laboratoriet (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 ICs. In addition, many tests are performed on individual devices, but some tests expose an entire single board computer to radiation fields that can induce SEE effects. 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 device or board of interest has to be carried out.

5.2 Use of existing SEE data

The simplest solution is to find previous SEE data on a specific IC device. This is not nearly as simple as it appears. First, the largest interest lies in SEE data that is directly usable for purposes of estimating the SEE rate in avionics. Thus, SEE tests that have been carried out on devices using heavy ions, data which is directly applicable for space missions, is data that is not directly applicable for avionics purposes. 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. Therefore, heavy ion SEE data should not be used for application to the atmospheric neutron environment, except by scientists and engineers who have extensive experience in using this kind of data. For that reason, unless otherwise stated explicitly, when SEE data is discussed in the remainder of this technical specification, it refers only to single event testing using a neutron or proton source, not to the results from testing with heavy ions.

If SEE data on a device of interest is found from SEE tests using high energy neutrons or protons, it will still require expertise regarding how the data is to be utilized in order to calculate a SEE rate at aircraft altitudes. Data obtained by IC vendors for their standard application to ground level systems are often expressed in totally different units, FIT units, where one FIT is one error in 10^9 device hours, which is taken to apply at ground level.

IC devices are constantly changing. In some cases, devices which had been tested, become obsolete and are replaced by new devices which have not been tested. The fact that a device is made by the same IC vendor and is of the same type as the one it replaced does not mean that the SEE data measured in the first device applies directly to the newer device. In some cases, small changes in the IC design or manufacturing process can have a large effect in altering the SEE response, but in other cases, the effect on the SEE response may be minimal.

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 devices, 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 there is no real alternative but to carry out one's own SEE testing. The advantage of such a test is that it pertains to the specific device 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), 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 the following clauses.

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 technical specification, 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 devices 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 device that results in the device 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 device itself, but can also be propagated to another device 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 state. The high energy neutrons in the atmosphere can induce all of these effects: SEU, SEFI and SEL. Where semiconductor devices are operated at high voltage stress (200 V and above) they may be subject to single event burn-out, SEB or single event gate rupture, SEGR; these effects are covered in detail in IEC/TS 62396-4

One of the important simplifying assumptions to be used in this technical specification is that, for single event effects, including SEU, SEFI and SEL, the response from high energy protons, i.e., those with E > 100 MeV, is the same as that from high energy neutrons of the same energy. The SEE response is generally measured in terms of a cross section (cm²/dev), which is the number of errors of a given type divided by the fluence of particles to which the device was exposed. Therefore, for the SEU, SEFI and SEL cross sections, measurements made with high energy protons can be used as the same cross section from the atmospheric neutrons. This is far more than an assumption, since it has been demonstrated by direct measurement in many different devices see [1] to [5][1)] and IEC/TS 62396-1. In these references, SEU was measured in the same devices using monoenergetic proton beams and using the neutron beam from the Weapons Neutron Research (WNR) facility at the Los Alamos National Laboratory. The energy spectrum of the neutrons in the WNR is almost identical to the spectrum of neutrons in the atmosphere. An estimate of the SEE rate at aircraft altitudes in a device can be obtained by the simplified equation:

$$\text{SEE rate per device} = 6\,000\ [\text{n/cm}^2\text{h}] \times \text{avionics SEE cross section}\ [\text{cm}^2 \text{ per device}] \quad (1)$$

Here, the integral neutron flux in the atmosphere, E >10 MeV, is taken to be 6 000 n/cm^{2}h, the approximate flux at 40 000 ft (12,2 km) and 45° latitude as in IEC/TS 62396-1. This shows the importance of the SEE cross section. As indicated above, the avionics SEE cross section is taken to be the SEE cross section obtained from SEE tests with a spallation neutron source such as the WNR, and also with a proton or neutron beam at energies > 100 MeV. The simplified approach of Equation (1) is used in IEC/TS 62396-1and is the nominal flux under the above conditions.

A more elaborate approach for calculating the SEE rate is to utilize a number of measurements of the SEE cross section as a function of neutron or proton energy, and integrate the curve of the SEE cross section over energy with the differential neutron flux. The details for this approach are given in the standard JESD-89A [6], although the neutron flux given in this standard is at ground level and would have to be multiplied by approximately a factor of 300 to make it relevant to avionics applications (see 6.2.3).

Thus the data that is most valuable for estimating the SEE rate in avionics is from SEE cross section measurements made with: a) a spallation neutron source such as the WNR, b) a monoenergetic proton beam and c) a quasi-monoenergetic neutron beam. Other SEE data that are also valuable are SEU cross sections made with a monoenergetic 14 MeV neutron beam. Based on comparisons of SEU cross section measurements with a 14 MeV neutron beam and the WNR, the WNR SEU cross section is approximately a factor of 1,5 to 2 higher than the 14 MeV SEU cross section for relatively recent devices ([3], feature size < 0,5 µm), and a factor of 4 times higher for older devices [4]. For some of the very latest devices, the factor is close to 1.

6.2.2 Sources of data, proprietary versus published data

As indicated above, SEE cross section measurements that are relevant to avionics SEE rates are being made by a variety of different groups. These include:

a) Space organizations that use only monoenergetic proton beams for their SEE testing,
b) IC vendors who use neutron sources to measure the upset rate at ground level [which they refer to as the soft error rate (SER), rather than the SEU rate, although the terms have the same meaning],

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1) Numbers in square brackets refer to the bibliography.