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SAE INTERNATIONAL

AEROSPACE INFORMATION REPORT

AIR6219™

Issued 2018-08
Reaffirmed 2023-07

Development of Atmospheric Neutron Single Event Effects Analysis for Use in Safety Assessments

RATIONALE

This document provides an example process for analyzing neutron Single Event Effects (SEE) for an electronic based airborne system for use in system safety assessments.

AIR6219 has been reaffirmed to comply with the SAE Five-Year Review policy.

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1. SCOPE

This document provides an example process for analyzing neutron Single Event Effects (SEE) for an electronic based airborne system for use in system safety assessments. This example has been used when the safety assessment process was in need of a SEE analysis.

1.1 Purpose

Galactic cosmic rays and solar rays penetrate the earth's atmosphere and produce particle cascades. The atmospheric radiation is comprised mainly of high energy neutrons that can interact with a semiconductor device's silicon structure causing adverse behavior.

This document describes an example process to evaluate the effects of atmospheric radiation at the equipment level, based on effects on electronic circuits. Additional atmospheric radiation information can be found in other industry documents including the IEC 62396 series. This AIR is intended to support a safety analysis; there may be other uses for this SEE analysis, but these are not specifically addressed in the document. The document is not intended to define specific data formats or organizational responsibilities. There may be other acceptable approaches to supporting SEE analyses within safety assessments.

NOTE: This document only addresses the activities that are used for equipment level SEE considerations. Benefit from system level mitigation may be used during the system safety assessment process (ARP4761/ED135). For the purposes of this document, equipment is defined as any self-contained assembly composed of one or several hardware and software items that perform a distinctive function necessary to the operation of the system.

This document primarily covers neutron effects, as they have the greatest impact on semiconductor device behavior in the atmospheric radiation environment. This document does not address the following:

- Alpha particles
- Other cosmic particles
- Electronic noise or other electronic sources of adverse behavior

1.2 Document Format

This AIR contains the following sections:

Section 1 is an introduction to the document, giving its scope and format. Also included is background information on the atmospheric environment and definitions of the resulting Single Event Effects.

Section 2 contains a list of references to other documents, definitions and acronym lists.

Section 3 describes the purpose for which the example SEE analysis process was used.

Section 4 describes the example SEE analysis process.

Section 5 provides the application of the example SEE analysis process.

1.3 Description of Atmospheric Radiation

High energy primary cosmic rays continuously arrive at the Earth and interact with atoms in the Earth's atmosphere creating secondary high energy particles. Of the various secondary particles created, high energy neutrons have been shown to be the main cause of SEE in electronic aircraft devices, as reported since the early 1990s. Single Event Upsets (SEU) are one type of SEE. SEE cover a range of effect types which are all caused by a single energetic particle. The different types of SEE are described in Table 1. A full discussion of the atmospheric radiation environment is covered in detail in IEC 62396-1.

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For neutrons, as well as all other secondary particles within the atmosphere, altitude, latitude, and energy are the primary parameters aiding our understanding of the SEE rate of occurrence. The result of the neutron interaction with the atmosphere is (1) a maximum flux rate at about 60000 feet; this is referred to as the Pfotzer maximum, and (2) an overall variation of the neutron flux (energy range of 1 to 10 MeV) with altitude (based on aircraft measurements). Figure 1 presents the neutron flux density as it varies with altitude[1]. The latitude variation of the atmospheric neutrons is governed primarily by the earth's magnetic field[1]. The overall variation of the atmospheric neutron flux (energy range of 1 to 10 MeV) with latitude (based on aircraft measurements) is shown graphically in Figure 2[1].

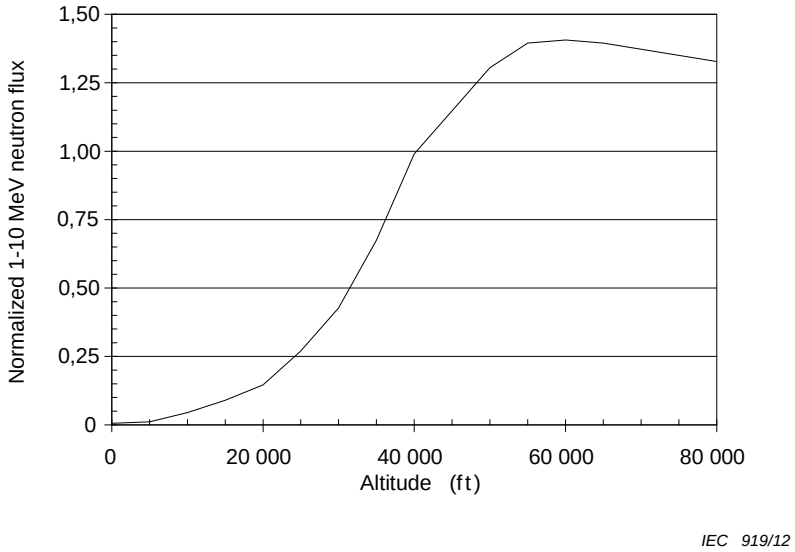


Figure 1 - Simplified model of atmospheric neutron flux variation with altitude

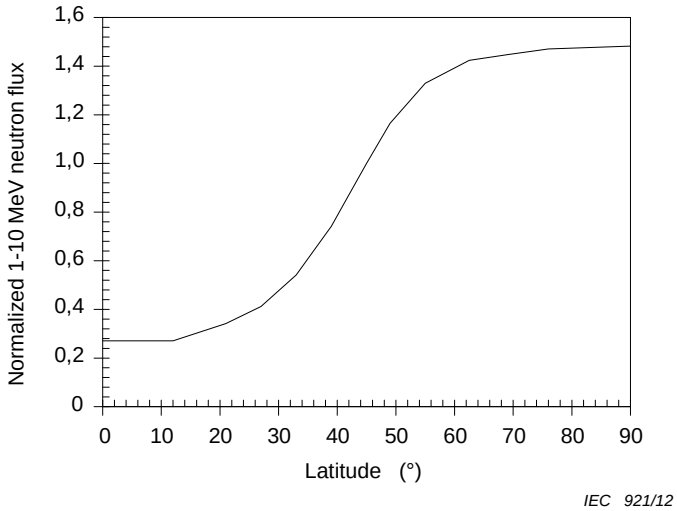


Figure 2 - Simplified model of atmospheric neutron flux variation with latitude

[1] IEC 62396-1.

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1.4 SEE Types

SEE are induced by the interaction of an ionizing particle with electronic components. A SEE occurs when the charge resulting from the ionization is greater than the critical charge in the component. The term SEE encompasses all of the potential effects on a semiconductor device caused by its interaction of a single particle of radiation, in this case a neutron. Table 1 provides a list of the most common SEE behaviors. IEC 62396 contains a comprehensive list of SEE types and effects.

The various types of SEE can cause a momentary or permanent change in the state of a device. Electronic hardware can be damaged, as is the case of a burn out or gate rupture, but most often the failures are non-destructive. Consideration of each applicable SEE type within a component is useful as input to the design phase, when determining mitigation techniques, and the part selection process. Note: even if non-destructive, some SEE may have an impact on system safety.

Table 1 - SEE type description and component examples

Single Event Effects	Definition	Additional Information for Device/Function Level Response
Single Event Upset (SEU)	A change of state in a bit, register or latch in a device when the radiation absorbed by the device is sufficient to change the logic state of a bit. NOTE: After a new write cycle, the original state can be recovered.	SEUs typically appear as transient pulses in logic or support circuitry, or as bit flips in memory cells or registers.
Multiple Bit Upset (MBU)	The energy deposited in the silicon of an electronic component by a single ionizing particle causes upset to more than one bit in the same word.	A MBU can cause multiple bit errors in a single word. Conventional error correcting code (ECC) schemes used in memories and caches may not correct double bit errors. MBUs have been shown to increase for smaller technologies, and recent advances in feature size have led to some components with MBU rates that are comparable to SEU rates. Interleaving may provide protection.
Multiple Cell Upset (MCU)	A single event that induces two or more bits in an Integrated Circuit (IC) to upset at the same time. NOTE: The error bits are usually, but not always, physically adjacent.	MCUs can affect a large number of cells. The errors in an MCU tend to be physically close and therefore it is likely that they affect more than one bit of the same memory word, which could be classified as an MBU. Interleaving may provide protection.
Single Event Latchup (SEL)	The triggering of a parasitic PNPN circuit in bulk CMOS, resulting in a state where the parasitic latched current exceeds the holding current. This state is maintained while power is applied. The condition is caused by an increase in current due to a regenerative current flow condition which activates the device. Both high current and low current SELs can occur. Low current latchups will still require power cycling but will not damage the component.	Latchup can cause circuit lockup and/or device failure. May or may not cause permanent failure but requires power cycling to return IC to normal operations if undamaged.

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Single Event Effects	Definition	Additional Information for Device/Function Level Response
Single Event Transient (SET)	Spurious signal or voltage induced by the deposition of charge by a single particle that can propagate through the circuit path during one clock cycle.	Produces transients which may affect subsequent circuits if not well filtered in the design. Examples include transients on external signals for comparators, and internal transients for CMOS devices leading to erroneous data. NOTE: For frequencies above 100 MHz the potential for SET in digital devices increases.
Single Event Functional Interrupt (SEFI)	The occurrence of an event, usually in a complex device (e.g., microprocessors, modern memory components, complex power management components, FPGAs, etc.) such that a control path is corrupted, leading the part to cease to function properly.	A single event effect in a complex device such that a control path is corrupted, leading to a temporal loss of device functionality. Often induced from an SEU in the control registers of a complex device and recovered by reset or power cycle. NOTE: This effect has sometimes been referred to as lockup, indicating in which case the device is put into a “frozen” state.
Single Event Gate Rupture (SEGR)	Occurs in the gate of a powered insulated gate component when the radiation charge absorbed by the device is sufficient to cause gate rupture, which is destructive. An SEGR is manifested by an increase in gate leakage current and can result in either the degradation or the complete failure of the device.	Devices which may be susceptible include: power MOSFETs, non-volatile NMOS structures, large integrate devices, and linear devices.
Single Event Burnout (SEB)	The burn out of a powered electronic component or part thereof as a result of the energy absorption triggered by an individual radiation event.	A condition which causes device destruction due to a high current state in a power semiconductor device. Power MOSFETs are most susceptible.
Single Event Hard Error (SHE)	Hard errors in devices such as memory, take the form of “stuck” bits. The error is “hard” because the device no longer functions properly, even after power reset and re-initialization.	A SHE causes a change to the operation of a device which may persist over multiple flight cycles. The device may no longer meet its performance expectations as the same bit remains incorrect after re-write cycles. Error detection and correction (EDAC) may provide a solution.

1.5 Independence and Probabilistic Nature of SEE

Due to the random nature of atmospheric neutron energy at a particular device location and the highly localized nature of SEE, the resulting events are considered independent from each other, and SEE rates are estimated probabilistically.

1.6 Consideration of Extreme Space Weather

The sun can influence the neutron flux within the atmosphere in two main ways: (1) the impact of solar activity on the intensity of galactic cosmic rays reaching earth and, (2) occasional extreme space weather events which can result in large bursts of solar particles arriving in the atmosphere, creating a short increase in the atmospheric neutron flux.

During periods of high solar activity (e.g., solar flares) the flux density may rise to a level significantly higher than that normally experienced. The flux density utilized for design analysis purposes is based on average levels determined by the airframer and as this includes occasional periods of extreme space weather events, further consideration in this respect is not necessary.

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No consideration is provided for rare solar events that might significantly increase neutron flux for short periods (hours to days). During these events, the faults would continue to be random (i.e., not a Common Mode). These events are outside the scope of this example.

The protection and mitigation incorporated into airborne electronic systems based on the normal levels of atmospheric radiation will also provide some protection and mitigation for the extreme solar and cosmic radiation event environments. Further information regarding extreme space weather can be found in the following report: *Extreme Space Weather – Impacts on Engineered Systems and Infrastructure. Royal Academy of Engineering – February 201*3 and *EASA Safety Information Bulletin SIB No. 2012-09 Effects of Space Weather.*

1.7 Thermal Neutrons

There is an additional SEE rate in some devices contributed by very low energy neutrons (called thermal neutrons). While the high energy neutrons cause SEE through interaction with the Si atoms, thermal neutrons cause SEE through their interaction with Boron-10 that is found in some microelectronics. Parts containing Boron-10 or natural boron are typically avoided when possible. When assessing SEE rates, thermal neutron effects may be considered when appropriate; information can be found in 5.6 of IEC 62396-1 and in IEC 62396-5.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606- 7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

ARP4761 Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment

2.1.2 EUROCAE Publications

Available from EUROCAE Secretariat, 102 rue Etiene Dolet, 92240 Malakoff, France, Tel: +33 1 40 92 79 30, www.eurocae.net.

ED135 Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment

2.1.3 IEC Publications

Available from IEC Central Office, 3 rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 62396-1 Process Management for Avionics – Atmospheric Radiation Effects – Part 1: Accommodation of atmospheric radiation effects via single event effects within avionics electronic equipment (2016) Note: Section 7 should not be applied in support of the ARP4761.

IEC 62396-2 Process Management for Avionics – Atmospheric Radiation Effects – Guidelines for single event effects testing for avionics systems (2012)

IEC 62396-3 Process Management for Avionics – Atmospheric Radiation Effects – Guidelines to optimize avionics system design to reduce single event effects rates (2013)

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IEC 62396-4 Process Management for Avionics – Atmospheric Radiation Effects – Guidelines for designing with high voltage aircraft electronics and potential single event effects (2013)

IEC 62396-5 Process Management for Avionics – Atmospheric Radiation Effects – Guidelines for assessing thermal neutron fluxes and effects in avionics systems (2013)

2.1.4 EASA Publications

Available from European Aviation Safety Agency, Ottoplatz, 1, D-50679 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu.

EASA Certification Memorandum – EASA CM No.: EASA CM – AS – 004 Issue: 01 issued 08 January 2018. Single Event Effects (SEE) Caused by Atmospheric Radiation.

EASA Safety Information Bulletin SIB No. 2012-09 and Cert Memo

2.2 Other References

EIA JEDEC JESD 89A (2006) Measurement and Reporting of Alpha Particles and Terrestrial Cosmic Ray-Induced Soft Errors in Semiconductor Devices

EIA JEDEC JESD 89-3 (2005) Test Method for Beam Accelerated Soft Error Rate

2.3 Definitions

This section provides definitions for unique terms used in this document. Citations are provided to other industry sources when usage in this document is consistent with the definition in the referenced source material.

CROSS-SECTION (σ): A combination of sensitive area in the component and probability of an interaction depositing the critical charge for a SEE. The cross-section may be calculated using the following formula: σ = number of errors/particle fluence. The units for cross-section are cm^2 per semiconductor device or cm^2 per bit.

EQUIPMENT: For this document, any self-contained assembly composed of one or several items that perform a distinctive function necessary to the operation of the system.

FIT: Failures in time. For SEE 1 FIT equals one event per 1E9 device hours.

INTERLEAVING: By interleaving memory, logically adjacent bits are physically separated.

SINGLE EVENT EFFECT: Response of a semiconductor device caused by the impact of a single particle (e.g., galactic cosmic rays, solar energetic particles, energetic neutrons and protons).

SEE TYPE: A unique semiconductor device behavior, identified as being related to an atmospheric radiation event.

2.4 Acronym List

ADC Analog to Digital Converter

CMOS Complementary Metal Oxide Semiconductor

CRC Cyclic Redundancy Check

ECC Error Correcting Code

EIA Electronic Industries Alliance

EDAC Error Detection and Correction

EEPROM Electrically Erasable Programmable Read Only Memory

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FET	Field-Effect Transistor
FIT	Failure In Time
FPGA	Field Programmable Gate Array
IC	Integrated Circuit
IEC	International Electrotechnical Commission
JEDEC	Joint Electron Device Engineering Council
LET	Linear Energy Transfer
MBU	Multiple Bit Upset
MCU	Multiple Cell Upset
MeV	Million electron Volts
MOSFET	Metal-Oxide Semiconductor Field-Effect Transistor
PLD	Programmable Logic Device
N	Neutron
NMOS	N-type Metal-Oxide-Semiconductor
PSSA	Preliminary System Safety Assessment
RAM	Random Access Memory
SEB	Single Event Burnout
SEE	Single Event Effects
SEFI	Single Event Functional Interrupt
SEGR	Single Event Gate Rupture
SHE	Single Event Hard Error
SEL	Single Event Latchup
SEU	Single Event Upset
SER	Soft Error Rate
SET	Single Event Transient
SOI	Silicon On Insulator
SRAM	Static Random-Access Memory
SSA	System Safety Assessment
TLB	Translation Lookaside Buffer

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