Process management for avionics – Atmospheric radiation effects – Part 1: Accommodation of atmospheric radiation effects via single event effects within avionics electronic equipment
Process management for avionics – Atmospheric radiation effects –
Part 1: Accommodation of atmospheric radiation effects via single event effects within avionics electronic equipment

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PROCESS MANAGEMENT FOR AVIONICS –
ATMOSPHERIC RADIATION EFFECTS –

Part 1: Accommodation of atmospheric radiation effects via
single event effects within avionics electronic equipment

FOREWORD

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International Standard IEC 62396-1 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) removed, in Clause 7 related to system design, reference to level A Type I and Type II (system and references). As Clause 7 is now for guidance, "shall" statements have been changed to "should" and in 9.5.2 the requirement for electronic component management is clarified;
b) all current definitions included in Clause 3 are those used within the IEC 62396 family of documents;

c) incorporated in Annex G related to new technology or latest news reference to some new papers and issues which have appeared since 2011;

d) solar flares and extreme space weather reference added in 5.6 to a proposed future Part 6;

e) reference added in 7.1 to a proposed new Part 7 on incorporating atmospheric radiation effects analysis into the system design process;

f) reference added in 6.2.10 d) to a proposed future Part 8 on other particles including protons, pions and muons;

g) clarification on calculating event rates where cross-sections have been obtained with non-atmospheric radiation like neutron sources, addition of a new Annex H, and changes to 5.3 and 8.2.

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

<table>
<thead>
<tr>
<th>FDIS</th>
<th>Report on voting</th>
</tr>
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<tbody>
<tr>
<td>107/271/FDIS</td>
<td>107/275/RVD</td>
</tr>
</tbody>
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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 the 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 publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication 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 informs avionics systems designers, electronic equipment manufacturers, component manufacturers and their customers of the kind of ionising radiation environment that their devices will be subjected to in aircraft, the potential effects this radiation environment can have on those devices, and some general approaches for dealing with these effects.

The same atmospheric radiation (neutrons and protons) that is responsible for the radiation exposure that crew and passengers acquire while flying is also responsible for causing the single event effects (SEE) in the avionics electronic equipment. There has been much work carried out over the last few years related to the radiation exposure of aircraft passengers and crew. A standardised industry approach on the effect of the atmospheric neutrons on electronics should be viewed as consistent with, and an extension of, the on-going activities related to the radiation exposure of aircraft passengers and crew.

Atmospheric radiation effects are one factor that could contribute to equipment hard and soft fault rates. From a system safety perspective, using derived fault rate values, the existing methodology described in ARP4754A (accommodation of hard and soft fault rates in general) will also accommodate atmospheric radiation effect rates.

In addition, this International Standard refers to the JEDEC Standard JESD 89A, which relates to soft errors in electronics by atmospheric radiation at ground level (at altitudes less than 10 000 ft (3 040 m)).
1 Scope

This part of IEC 62396 is intended to provide guidance on atmospheric radiation effects on avionics electronics used in aircraft operating at altitudes up to 60 000 ft (18.3 km). It defines the radiation environment, the effects of that environment on electronics and provides design considerations for the accommodation of those effects within avionics systems.

This International Standard is intended to help avionics equipment manufacturers and designers to standardise their approach to single event effects in avionics by providing guidance, leading to a standard methodology.

Details of the radiation environment are provided together with identification of potential problems caused as a result of the atmospheric radiation received. Appropriate methods are given for quantifying single event effect (SEE) rates in electronic components. The overall system safety methodology should be expanded to accommodate the single event effects rates and to demonstrate the suitability of the electronics for the application at the component and system level.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.


IEC 62396-3, Process management for avionics – Atmospheric radiation effects – Part 3: System design optimization to accommodate the single event effects (SEE) of atmospheric radiation

IEC 62396-4:2013, Process management for avionics – Atmospheric radiation effects – Part 4: Design of high voltage aircraft electronics managing potential single event effects

IEC 62396-5, Process management for avionics – Atmospheric radiation effects – Part 5: Assessment of thermal neutron fluxes and single event effects in avionics systems

EIA-4899, Standard for Preparing an Electronic Components Management Plan

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.
NOTE Users of this international standard can use alternative definitions consistent with convention within their companies.

3.1 aerospace recommended practice
documents relating to avionics which are published by the Society of Automotive Engineers (SAE)

3.2 analogue single event transient
ASET
spurious signal or voltage produced at the output of an analogue component by the deposition of charge by a single particle

3.3 availability
probability that a system is working at instant $t$, regardless of the number of times it may have previously failed and been repaired

Note 1 to entry: For equipment, availability is the fraction of time the equipment is functional divided by the total time the equipment is expected to be operational, i.e. the time the equipment is functional plus any repair time.

3.4 avionics equipment environment
<aeronautical equipment> applicable environmental conditions (as described per the equipment specification) that the equipment is able to withstand without loss or degradation in equipment performance during all of its manufacturing cycle and maintenance life

Note 1 to entry: The length of the maintenance life is defined by the equipment manufacturer in conjunction with customers.

3.5 capable
ability of a component to be used successfully in the intended application

3.6 certified
assessed and compliant to an applicable standard, with maintenance of a certificate and registration

3.7 characterisation
process of testing a sample of components to determine the key electrical parameter values that can be expected of all produced components of the type tested

3.8 component application
process that assures that the component meets the design requirements of the equipment in which it is used

3.9 component manufacturer
organisation responsible for the component specification and its production

3.10 could not duplicate
CND
reported outcome of diagnostic testing on a piece of equipment

Note 1 to entry: Following receipt of an error or fault message during operation, the error or fault condition could not be replicated during subsequent equipment testing (see IEC 62396-3).
3.11 critical charge
smallest charge that will cause an SEE if injected or deposited in the sensitive volume

Note 1 to entry: For many electronic components, the unit applied is the pico coulomb (pC); however, for small geometry components, this parameter is measured in femto coulomb (fC).

3.12 cross-section
$\sigma$
combination of sensitive area and probability of an interaction depositing the critical charge for a SEE

Note 1 to entry: The cross-section may be calculated using the following formula:

$\sigma = \text{number of errors/particle fluence}$

Note 2 to entry: The units for cross-section are cm$^2$ per electronic component or per bit.

3.13 double error correction triple error detection
DECTED
system or equipment methodology to test a digital word of information to determine if it has been corrupted, and if corrupted, to conditionally apply a correction

Note 1 to entry: This methodology can correct two-bit corruptions and can detect and report three-bit corruptions. (Used within IEC 62396-3.)

3.14 digital single event transient
DSET
spurious digital signal or voltage, induced by the deposition of charge by a single particle that can propagate through the circuit path during one clock cycle

Note 1 to entry: See 6.2.4.

3.15 electron
elementary particle having a mass of approximately 1/1840 atomic mass units, and a negative charge of $1,602 \times 10^{-19}$ C

3.16 electronic components management plan
ECMP
equipment manufacturer's document that defines the processes and practices for applying electronic components to an equipment or range of equipment

Note 1 to entry: Generally, it addresses all relevant aspects of the controlling components during system design, development, production, and post-production support.

3.17 electronic component
electrical or electronic device that is not subject to disassembly without destruction or impairment of design use

EXAMPLE Resistors, capacitors, diodes, integrated circuits, hybrids, application specific integrated circuits, wound components and relays.

Note 1 to entry: An electronic component is sometimes called electronic device, electronic part, or piece part.

3.18 electronic equipment
item produced by the equipment manufacturer, which incorporates electronic components
EXAMPLE  End items, sub-assemblies, line-replaceable units and shop-replaceable units.

3.19  
**electronic flight instrumentation system**
EFIS
avionics electronic system requiring system development assurance level A and for which the pilot will be within the loop (within the control loop) through the pilot/system information exchange

3.20  
**expert**
person who has demonstrated competence to apply knowledge and skill to the specific subject

3.21  
**firm error**
<semiconductor community> circuit cell failure within an electronic component that cannot be reset other than by rebooting the system or by cycling the power

Note 1 to entry: Such a failure can manifest itself as a soft fault in that it could provide no fault found during subsequent test and impact the value for the MTBUR of the LRU.

Note 2 to entry: See also soft error.

3.22  
**firm fault**
<aircraft function level> failure that cannot be reset other than by rebooting the system or by cycling the power to the relevant functional element

Note 1 to entry: Such a fault can impact the value for the MTBF of the LRU and provide no fault found during the subsequent test.

3.23  
**fly-by-wire**
FBW
avionics electronic system requiring system development assurance level A and for which the pilot will not be within the aircraft stability control loop

3.24  
**functional hazard assessment**
FHA
assessment of all hazards against a set of defined hazard classes

3.25  
**giga electron volt**
GeV
energy gained when an electron is accelerated by an electric potential of $10^9$ volts, that is, radiation particle energy of giga electron volts (thousand million electron volts)

Note 1 to entry: The SI equivalent energy is 160,2 pico joules.

3.26  
**gray**
Gy
SI unit of ionising radiation dose, defined as the absorption of one joule (J) of radiation energy per one kilogram (kg) of matter

Note 1 to entry: Related units are centigray (cGy) and rad. 1 cGy is equal to 1 rad.
3.27 hard error
permanent or semi-permanent damage of a cell by atmospheric radiation that is not recoverable even by cycling the power off and on

Note 1 to entry: Hard errors can include SEB, SEGR and SEL. Such a fault would be manifest as a hard fault and can impact the value for the MTBF of the LRU.

3.28 hard fault
<aircraft function level> permanent failure of a component within an LRU

Note 1 to entry: A hard fault results in the removal of the LRU affected and the replacement of the permanently damaged component before a system/system architecture can be restored to full functionality. Such a fault can impact the value for the MTBF of the LRU repaired.

3.29 heavy ion
positively charged nucleus of the elements heavier than hydrogen and helium

3.30 in-the-loop
test methodology where an LRU is placed within a radiation beam that provides a simulation of the atmospheric neutron environment and where the inputs to the LRU can be from an electronic fixture external to the beam to enable a closed loop system

Note 1 to entry: The electronic fixture can contain a host computer for the aircraft simulation model. The electronic fixture can also contain appropriate signal conditioning for compatibility with the LRU. In the case of an automatic control function, the outputs from the LRU can be, in turn, sent to an actuation means or directly to the host computer. The host computer would automatically close a stability loop (as in the case of a fly-by-wire control system). In the case of a navigation function, the outputs from the LRU could be sent to a display system where the pilot could then close the navigation loop.

3.31 integrated modular avionics
IMA
implementation of aircraft functions in a multitask computing environment where the computations for each specific system implementing a particular function are confined to a partition that is executed by a common computing resource (a single digital electronic circuit)

3.32 latch-up
triggering of a parasitic p-n-p-n circuit in bulk CMOS, resulting in a state where the parasitic latched current exceeds the holding current

Note 1 to entry: This state is maintained while power is applied.

Note 2 to entry: Latch-up can be a particular case of a soft fault (firm/soft error) or in the case where it causes electronic component damage, a hard fault.

3.33 linear energy transfer
LET
energy deposited per unit path length in a semiconductor along the path of the radiation

Note 1 to entry: The units applicable are MeV·cm²/mg.

3.34 linear energy transfer threshold
\( LET_{th} \)
for a given component, the minimum LET to cause an effect at a particle fluence of \( 1 \times 10^7 \) ions·cm\(^{-2}\)
3.35 line replaceable unit
LRU
piece of equipment that may be replaced during the maintenance cycle of the system

3.36 mega electron volt
MeV
energy gained when an electron is accelerated by an electric potential of $10^6$ volts, that is, radiation particle energy of mega electron volts (million electron volts)

Note 1 to entry: The SI equivalent energy is 160,2 femto joule.

3.37 mean time between failure
MTBF
measure of reliability, which is the mean time between failure of equipment or a system in service

Note 1 to entry: MTBF is a term from the world airlines’ technical glossary referring to the mean time between failure of equipment or a system in service such that it generally requires the replacement of a damaged component before a system/system architecture can be restored to full functionality and thus it is a measure of reliability requirements for equipment or systems.

3.38 mean time between unscheduled removals
MTBUR
measure of reliability, which is the mean time between unscheduled removal of equipment or a system in service

Note 1 to entry: MTBUR is a term from the world airlines’ technical glossary referring to the mean time between unscheduled removal of equipment or a system in service that can be the result of soft faults and thus is a measure of reliability for equipment or systems. MTBUR values can have a major impact on airline operational costs.

3.39 multiple bit upset
MBU
energy deposited in the silicon of an electronic component by a single ionising particle and which causes upset to more than one bit in the same word

Note 1 to entry: The definition of MBU has been updated due to the introduction of the definition of MCU, multiple cell upset.

3.40 multiple cell upset
MCU
energy deposited in the silicon of an electronic component by a single ionising particle and which induces several bits in an integrated circuit (IC) to upset at one time

3.41 neutron
elementary particle with atomic mass number of one and which carries no charge

Note 1 to entry: It is a constituent of every atomic nucleus except hydrogen.

3.42 no fault found
NFF
reported outcome of diagnostic testing on a piece of equipment

Note 1 to entry: Following receipt of an error or fault message during operation, the equipment is found to be fully functional and within specification during subsequent equipment testing. See IEC 62396-3.
3.43 particle fluence
<unidirectional beam of particles> number of particles crossing the unit surface area at right angles to the beam

Note 1 to entry: For isotropic flux, this is the number entering a sphere of unit cross-sectional area.
Note 2 to entry: The units applicable are particle-cm$^{-2}$.

3.44 particle flux
fluence rate per unit time

Note 1 to entry: The units applicable are particle-cm$^{-2}$-s$^{-1}$.

3.45 pion
sub-atomic particle

Note 1 to entry: The charge possibilities are (+1, −1, 0) and they are produced by energetic nuclear interactions.
Note 2 to entry: The term "pi-meson" can be used in lieu of "pion" in some documents or standards.

3.46 preliminary system safety assessment
PSSA
systematic evaluation of a proposed system architecture and implementation based on the functional hazard assessment and failure condition classification to determine safety


3.47 proton
elementary particle with an atomic mass number of one and a positive electric charge and which is a constituent of all atomic nuclei

3.48 reliability
$R(t)$
for a system with constant failure rate, the conditional probability that a system will remain operational over the time interval 0 to $t$ given by:

$$R(t) = e^{-\lambda t} \text{ and } \lambda = 1/\text{MTBF}$$

3.49 risk
measure of the potential inability to achieve overall program objectives within defined cost, schedule, and technical constraints

3.50 single bit upset
SBU
<semiconductor device> radiation absorbed by the electronic component which is sufficient to change a single cell’s logic state

Note 1 to entry: After a new write cycle, the original state can be recovered.

$^1$ Numbers in square brackets refer to the Bibliography.
3.51 single event burnout
SEB
burnout of a powered electronic component or part thereof as a result of the energy absorption triggered by an individual radiation event

3.52 single error correction, double error detection
SECDED
system or equipment methodology to test a digital word of information to determine if it has been corrupted, and if corrupted, to conditionally apply a correction

Note 1 to entry: This methodology can correct one-bit corruption and can detect and report two-bit corruptions.

3.53 single event effect
SEE
response of a component caused by the impact of a single particle (for example galactic cosmic rays, solar energetic particles, energetic neutrons and protons)

Note 1 to entry: The range of responses can include both non-destructive (for example upset) and destructive (for example latch-up or gate rupture) phenomena.

3.54 single event functional interrupt
SEFI
occurrence of an upset, usually in a complex electronic component (e.g. a microprocessor), such that a control path is corrupted, leading the electronic component to cease to function properly

Note 1 to entry: This effect has sometimes been referred to as lockup, indicating that sometimes the electronic component can be put into a “frozen” state (see 6.2.6).

Note 2 to entry: SEFI can be recoverable by resetting the configuration register (F/F) to default values.

3.55 single event gate rupture
SEGR
<gate of a powered insulated gate component> radiation charge absorbed by the electronic component, which is sufficient to cause gate rupture and is destructive

3.56 single event latch-up
SEL
in an electronic component containing a minimum of 4 semiconductor layers (p-n-p-n), fixed state of a component that occurs when the radiation absorbed by the component is sufficient to cause a node within the powered semiconductor component to be held whatever input is applied until the component is de-powered

Note 1 to entry: Single event latch-up can be destructive or non-destructive.

Note 2 to entry: The ionization deposited by the interaction of a single particle of radiation in an electronic component causes triggering of a parasitic p-n-p-n circuit in semiconductor materials (including bulk CMOS) to occur, resulting in a state where the parasitic latched current exceeds the holding current; this state is maintained while power is applied. Single event latch-up can be a particular case of a soft fault (firm/soft error) or in the case where it causes electronic component damage, a hard fault.

3.57 single event transient
SET
momentary voltage excursion (voltage spike) at a node in an integrated circuit caused by a single energetic particle strike
Note 1 to entry: The specific terms ASET (analogue single event transient) and DSET (digital single event transient) may be used.

Note 2 to entry: See 6.2.4.

3.58 single event upset
SEU
<semiconductor component> radiation absorbed by the electronic component which is sufficient to change a cell’s logic state

Note 1 to entry: After a new write cycle, the original state can be recovered.

Note 2 to entry: A logic cell may be a memory bit cell, register bit cell, latch cell, etc.

3.59 single hard error
SHE
single event induced hard error
radiation (in a single event) absorbed by the electronic component, which is sufficient to cause a permanent stuck-bit in the component, and a hard error within the equipment

3.60 soft error
erroneous output signal from a latch or memory cell that can be corrected by performing one or more normal functions of the electronic component containing the latch or memory cell

Note 1 to entry: 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.

Note 2 to entry: Soft errors can be generated from SEU, SEFI, MBU, MCU, and or SET. The term SER has been adopted by the commercial industry while the more specific terms SEU, SEFI, etc., are typically used by the avionics, space and military electronics communities.

Note 3 to entry: The term “soft error” was first introduced (for DRAMs and ICs) by May and Woods of Intel in their April 1978 paper at the IEEE International Reliability Physics Symposium (IRPS) [135] and the term “single event upset” was introduced by Guenzner, Wolicki and Alias of Naval Research Laboratory, Washington DC, in their 1979 IEEE Nuclear & Space Radiation Effects Conference (NSREC) paper [136].

3.61 soft fault
<aircraft function level> characteristic of invalid digital logic cell(s) state changes within digital hardware electronic circuitry

Note 1 to entry: It is a fault that does not involve replacement of a permanently damaged component within an LRU but it does involve restoring the logic cells to valid states before a system/system architecture can be restored to full functionality. Such a fault condition has been suspected in the "no fault found" syndrome for functions implemented with digital technology and it can probably impact the value for the MTBUR of the involved LRU. If a soft fault results in the mistaken replacement of a component within the LRU, the replacement can impact the value for the MTBF of the LRU repaired.

Note 2 to entry: Logic cell(s) include(s) logic gates and memory elements.

3.62 solar energetic particle event
SEP event
enhancement of solar particles (protons, ions and some neutrons) caused by solar flare activity or coronal mass ejections

Note 1 to entry: The enhancement can last from a few hours to several days. A small fraction has sufficiently energetic spectra to produce significantly enhanced secondary neutron fluxes in the atmosphere.

3.63 substitute component
component used as a replacement in equipment after the equipment design has been approved