



BSI Standards Publication

Process management for avionics — Atmospheric radiation effects

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

National foreword

This British Standard is the UK implementation of IEC 62396-1:2016. It supersedes BS IEC 62396-1:2012 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GEL/107, Process management for avionics.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2016.

Published by BSI Standards Limited 2016

ISBN 978 0 580 90359 5

ICS 03.100.50; 31.020; 49.060

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 January 2016.

Amendments/corrigenda issued since publication

Date	Text affected
-------------	----------------------



INTERNATIONAL STANDARD



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

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 03.100.50; 31.020; 49.060

ISBN 978-2-8322-3078-7

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD.....	6
INTRODUCTION.....	8
1 Scope.....	9
2 Normative references	9
3 Terms and definitions	9
4 Abbreviations and acronyms.....	18
5 Radiation environment of the atmosphere.....	21
5.1 Radiation generation.....	21
5.2 Effect of secondary particles on avionics	21
5.3 Atmospheric neutrons	21
5.3.1 General	21
5.3.2 Atmospheric neutrons energy spectrum and SEE cross-sections	22
5.3.3 Altitude variation of atmospheric neutrons	24
5.3.4 Latitude variation of atmospheric neutrons.....	25
5.3.5 Thermal neutrons within aircraft.....	27
5.4 Secondary protons.....	27
5.5 Other particles	28
5.6 Solar enhancements	29
5.7 High altitudes greater than 60 000 ft (18 290 m)	29
6 Effects of atmospheric radiation on avionics	30
6.1 Types of radiation effects.....	30
6.2 Single event effects (SEEs)	30
6.2.1 General	30
6.2.2 Single event upset (SEU).....	31
6.2.3 Multiple bit upset (MBU) and multiple cell upset (MCU).....	31
6.2.4 Single effect transients (SETs)	33
6.2.5 Single event latch-up (SEL)	34
6.2.6 Single event functional interrupt (SEFI)	34
6.2.7 Single event burnout (SEB)	34
6.2.8 Single event gate rupture (SEGR).....	35
6.2.9 Single event induced hard error (SHE).....	35
6.2.10 SEE potential risks based on future technology	35
6.3 Total ionising dose (TID).....	36
6.4 Displacement damage.....	37
7 Guidance for system designs.....	37
7.1 Overview.....	37
7.2 System design	40
7.3 Hardware considerations.....	41
7.4 Electronic devices characterisation and control.....	42
7.4.1 Rigour and discipline	42
7.4.2 Level A systems	42
7.4.3 Level B	42
7.4.4 Level C	43
7.4.5 Levels D and E	43
8 Determination of avionics single event effects rates.....	43

8.1	Main single event effects	43
8.2	Single event effects with lower event rates.....	44
8.2.1	Single event burnout (SEB) and single event gate rupture (SEGR)	44
8.2.2	Single event transient (SET).....	44
8.2.3	Single event hard error (SHE).....	45
8.2.4	Single event latch-up (SEL)	45
8.3	Single event effects with higher event rates – Single event upset data.....	45
8.3.1	General	45
8.3.2	SEU cross-section	46
8.3.3	Proton and neutron beams for measuring SEU cross-sections	46
8.3.4	SEU per bit cross-section trends in SRAMs	50
8.3.5	SEU per bit cross-section trends and other SEE in DRAMs.....	51
8.4	Calculating SEE rates in avionics.....	53
8.5	Calculation of availability of full redundancy.....	54
8.5.1	General	54
8.5.2	SEU with mitigation and SET	54
8.5.3	Firm errors and faults	55
9	Considerations for SEE compliance	55
9.1	Compliance.....	55
9.2	Confirm the radiation environment for the avionics application	55
9.3	Identify the system development assurance level.....	55
9.4	Assess preliminary electronic equipment design for SEE	55
9.4.1	Identify SEE-sensitive electronic components	55
9.4.2	Quantify SEE rates	55
9.5	Verify that the system development assurance level requirements are met for SEE.....	55
9.5.1	Combine SEE rates for the entire system.....	55
9.5.2	Management of electronic components control and dependability	56
9.6	Corrective actions.....	56
Annex A (informative)	Thermal neutron assessment	57
Annex B (informative)	Methods for calculating SEE rates in avionics electronics.....	58
B.1	Proposed in-the-loop system test – Irradiating avionics LRU in neutron/proton beam, with output fed into aircraft simulation computer	58
B.2	Irradiating avionics LRU in a neutron/proton beam	58
B.3	Utilising existing SEE data for specific electronic components on LRU.....	59
B.3.1	Neutron proton data.....	59
B.3.2	Heavy ion data	60
B.4	Applying generic SEE data to all electronic components on LRU.....	61
B.5	Component level laser simulation of single event effects.....	62
B.6	Determination of SEU rate from service monitoring	63
Annex C (informative)	Review of test facility availability	65
C.1	Facilities in the USA and Canada.....	65
C.1.1	Neutron facilities.....	65
C.1.2	Proton facilities.....	66
C.1.3	Laser facilities	68
C.2	Facilities in Europe	69
C.2.1	Neutron facilities.....	69
C.2.2	Proton facilities.....	71
C.2.3	Laser facilities	72

Annex D (informative) Tabular description of variation of atmospheric neutron flux with altitude and latitude	73
Annex E (informative) Consideration of effects at higher altitudes	75
Annex F (informative) Prediction of SEE rates for ions	80
Annex G (informative) Late news as of 2014 on SEE cross-sections applicable to the atmospheric neutron environment	83
G.1 SEE cross-sections key to SEE rate calculations	83
G.2 Limitations in compiling SEE cross-section data.....	83
G.3 Cross-section measurements (figures with data from public literature)	84
G.4 Conservative estimates of SEE cross-section data.....	84
G.4.1 General	84
G.4.2 Single event upset (SEU).....	85
G.4.3 Multiple cell upset (MCU).....	87
G.4.4 Single event functional interrupt (SEFI)	88
G.4.5 Single event latch-up (SEL)	89
G.4.6 Single event transient (SET)	91
G.4.7 Single event burnout (SEB)	92
Annex H (informative) Calculating SEE rates from non-white (non-atmospheric like) neutron cross-sections for small geometry electronic components	94
H.1 Energy thresholds	94
H.2 Nominal neutron fluxes	94
H.3 Calculating event rates using non-atmospheric like cross-sections for small geometry electronic devices	95
Bibliography.....	96
Figure 1 – Energy spectrum of atmospheric neutrons at 40 000 ft (12 160 m), latitude 45°	22
Figure 2 – Model of the atmospheric neutron flux variation with altitude (see Annex D).....	25
Figure 3 – Distribution of vertical rigidity cut-offs around the world.....	26
Figure 4 – Model of atmospheric neutron flux variation with latitude.....	26
Figure 5 – Energy spectrum of protons within the atmosphere	28
Figure 6 – System safety assessment process.....	38
Figure 7 – SEE in relation to system and LRU effect.....	40
Figure 8 – Variation of RAM SEU cross-section as function of neutron/proton energy	48
Figure 9 – Neutron and proton SEU bit cross-section data	49
Figure 10 – SEU cross-section in SRAMs as function of the manufacture date.....	51
Figure 11 – SEU cross-section in DRAMs as function of manufacture date	52
Figure E.1 – Integral linear energy transfer spectra in silicon at 100 000 ft (30 480 m) for cut-off rigidities (R) from 0 GV to 17 GV	76
Figure E.2 – Integral linear energy transfer spectra in silicon at 75 000 ft (22 860 m) for cut-off rigidities (R) from 0 to 17 GV	76
Figure E.3 – Integral linear energy transfer spectra in silicon at 55 000 ft (16 760 m) for cut-off rigidities (R) from 0 GV to 17 GV	77
Figure E.4 – Influence of solar modulation on integral linear energy transfer spectra in silicon at 150 000 ft (45 720 m) for cut-off rigidities (R) of 0 GV and 8 GV.....	77
Figure E.5 – Influence of solar modulation on integral linear energy transfer spectra in silicon at 55 000 ft (16 760 m) for cut-off rigidities (R) of 0 GV and 8 GV.....	78

Figure E.6 – Calculated contributions from neutrons, protons and heavy ions to the SEU rates of the Hitachi-A 4 Mbit SRAM as a function of altitude at a cut-off rigidity (R) of 0 GV	79
Figure E.7 – Calculated contributions from neutrons, protons and heavy ions to the SEU rates of the Hitachi-A 4 Mbit SRAM as a function of altitude at a cut-off rigidity (R) of 8 GV.....	79
Figure F.1 – Example differential LET spectrum.....	81
Figure F.2 – Example integral chord length distribution for isotropic particle environment.....	81
Figure G.1 – Variation of the high energy neutron SEU cross-section per bit as a function of electronic device feature size for SRAMs and SRAM arrays in microprocessors and FPGAs.....	85
Figure G.2 – Variation of the high energy neutron SEU cross-section per bit as a function of electronic device feature size for DRAMs.....	86
Figure G.3 – Variation of the high energy neutron SEU cross-section per electronic device as a function of electronic device feature size for NOR and NAND type flash memories.....	87
Figure G.4 – Variation of the MCU/SBU percentage as a function of feature size based on data from many researchers in SRAMs [43, 45].....	88
Figure G.5 – Variation of the high energy neutron SEFI cross-section in DRAMs as a function of electronic device feature size	89
Figure G.6 – Variation of the high energy neutron SEFI cross-section in microprocessors and FPGAs as a function of electronic device feature size.....	90
Figure G.7 – Variation of the high energy neutron single event latch-up (SEL) cross-section in CMOS devices (SRAMs, processors) as a function of electronic device feature size.....	91
Figure G.8 – Single event burnout (SEB) cross-section in power electronic devices (400 V to 1 200 V) as a function of drain-source voltage (V_{DS}).....	92
Table 1 – Nomenclature cross reference.....	39
Table B.1 – Sources of high energy proton or neutron SEU cross-section data	60
Table B.2 – Some models for the use of heavy ion SEE data to calculate proton SEE data	61
Table D.1 – Variation of 1 MeV to 10 MeV neutron flux in the atmosphere with altitude.....	73
Table D.2 – Variation of 1 MeV to 10 MeV neutron flux in the atmosphere with latitude.....	74
Table G.1 – Information relevant to neutron-induced SET	92
Table H.1 – Approximate SEU energy thresholds for SRAM-based devices.....	94
Table H.2 – Neutron fluxes above different energy thresholds (40 000 ft, latitude 45°).....	94

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

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

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:

FDIS	Report on voting
107/271/FDIS	107/275/RVD

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)).

PROCESS MANAGEMENT FOR AVIONICS – ATMOSPHERIC RADIATION EFFECTS –

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

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 TS 62239-1:2015, *Process management for avionics – Management plan – Part 1: Preparation and maintenance of an electronic components management plan*

IEC 62396-2:2012, *Process management for avionics – Atmospheric radiation effects – Part 2: Guidelines for single event effects testing for avionics systems*

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.