INTERNATIONAL STANDARD

ISO 21980

First edition
2020-01

Space systems — Evaluation of radiation effects on Commercial-Off-The-Shelf (COTS) parts for use on low-orbit satellite

Systèmes spatiaux — Évaluation des effets des radiations sur les parties commerciales sur étagère (COTS) destinées aux satellites à orbite basse

Reference number
ISO 21980:2020(E)

COPYRIGHT PROTECTED DOCUMENT

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document describes methods of evaluating the radiation effects on COTS (Commercial-Off-The-Shelf) parts used in low Earth orbit (LEO) satellites. Many small (<180 kg) and nano/microsatellites (1 kg to 50 kg) are launched to LEO altitudes where space radiation exists but is less than at higher altitudes. As a result, the designers and manufacturers of such satellites are using COTS semiconductor devices for their satellite components and boards. New industries taking advantage of nano/microsatellite and CubeSat [1,33 kg × (1U-3U)] satellite capabilities now include IT ventures, mobile phones, and internet industries along with universities and research institutions.

Satellite manufacturers who prioritize investment efficiency also aim to extend mission lifetimes (up to three, five and ten years) longer than one-year missions that were common for educational and technical demonstrations using nano/microsatellites.

Even with relatively lower space radiation conditions in LEO compared to higher orbits, a longer mission life in LEO poses critical radiation environment constraints for COTS devices onboard small and nano/microsatellites as well as CubeSats.

While there are methods of evaluating the radiation resistance of space parts, there are limited methods for evaluating COTS parts used for LEO satellites and these are often based on legacy parts usage.

This document provides guidance for evaluating radiation tolerance of COTS parts that can help increase confidence levels of longer-term mission lifetimes.

INTERNATIONAL STANDARD **ISO 21980:2020(E)**

Space systems — Evaluation of radiation effects on Commercial-Off-The-Shelf (COTS) parts for use on low-orbit satellite

1 Scope

This document outlines the evaluation methods for environmental tests that can be conducted on COTS (Commercial-Off-The-Shelf) spacecraft parts intended for use on LEO satellites. The radiation effects considered consist of total dosage, single event, and displacement damage. In addition, this document describes tests that are useful for satellites operating in LEO.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
galactic cosmic rays
GCR
high-energy-charged particle *fluxes* (3.2) penetrating the heliosphere from local interstellar space

Note 1 to entry: Galactic cosmic rays are composed primarily of high-energy protons and atomic nuclei. Upon impact with the Earth's atmosphere, cosmic rays can produce showers of secondary particles that sometimes reach the Earth’s surface. There is evidence that a significant fraction of primary cosmic rays originate from stellar supernova explosions and perhaps from active galactic nuclei.

[SOURCE: ISO 15390:2004, 2.1, modified — Note 1 to entry has been added.]

3.2
flux
number of particles passing through a specific unit area per unit time

[SOURCE: ISO 12208:2015, 2.3]

3.3
fluence
time-integrated *flux* (3.2)

Note 1 to entry: Fluence is measured as the flux per unit area per unit time. This is used to express the environment during the operational lifetime of a spacecraft or space instrument. The integrated particles fluence unit is expressed as particles m^{-2}. The energy integral fluence unit is expressed as particles m^{-2} MeV^{-1}. When the directional fluence is included, add per steradian (sr^{-1}).

[SOURCE: ISO 12208:2015, 2.4, modified — Note 1 to entry has been added.]

3.4
absorbed dose

D

amount of energy imparted by ionizing radiation per unit mass of irradiated matter

Note 1 to entry: The quotient of $\mathrm{d}\bar{\varepsilon}$ by dm where $\mathrm{d}\bar{\varepsilon}$ the mean energy imparted by ionizing radiation to matter of mass $\mathrm{d}m$ is

$$D = \frac{\mathrm{d}\bar{\varepsilon}}{\mathrm{d}m}.$$

Note 2 to entry: The special name of the unit for absorbed dose is the gray (Gy). 1 Gy = 1 J·kg^{-1}.

[SOURCE: ISO 15856:2010, 3.1.1]

3.5
dose

idiomatic term which expresses the radiation dose and the absorbed energy

Note 1 to entry: Dose is used to express various meanings, such as the *absorbed dose* (3.4), exposure dose, etc.

3.6
total dose

total *absorbed dose* (3.4) received by components or materials to a specific point

3.7
single event effect

SEE

effect, such as malfunctions of circuit elements (software errors), or latch up, which are caused by the effect of a single high energy particle

3.8
bremsstrahlung

photon radiation, continuously distributed in energy up to the energy of the incident particle radiation, emitted from a material due to deceleration of incident particle radiation within the material, mainly due to electrons

Note 1 to entry: Bremsstrahlung is any radiation produced due to the deceleration (negative acceleration) of a charged particle, which includes synchrotron radiation (i.e. photon emission by a relativistic particle), cyclotron radiation (i.e. photon emission by a non-relativistic particle), and the emission of electrons and positrons during beta decay. The term is frequently used in the narrower sense of radiation from relativistic electrons (from whatever source) slowing as they penetrate matter.

[SOURCE: ISO 15856: 2010, 3.1.3 — The alternative term "brake radiation" has been removed; Note 1 to entry has been added.]

3.9
solar flare

explosion phenomenon which occurs on the surface of the sun, accompanied by the release of high energy particles

3.10
spectrum

array of entities, such as light waves or particles, ordered in accordance with the magnitudes of a common physical property, such as wavelength or mass

Note 1 to entry: In this document, the spectrum refers to the items that express the particle *flux* (3.2) density of the radiation for each energy.

3.11
anneal

phenomenon in which the characteristics degraded by radiation recover due to heat

3.12
linear energy transfer
LET
energy delivered by a charged particle passing through a substance and locally absorbed per unit length of path

Note 1 to entry: It is measured in joules per metre. Other dimensions are $\text{keV} \cdot \mu\text{m}^{-1}$, $\text{J} \cdot \text{m}^{2} \cdot \text{kg}^{-1}$, $\text{MeV} \cdot \text{cm}^{2} \cdot \text{mg}^{-1}$.

[SOURCE: ISO 15856:2010, 3.1.10]

3.13
dose rate
dose (3.5) per unit of time

3.14
heavy ion
ion particles with a large atomic number

Note 1 to entry: Heavy ion generally refers to particles of He or more.

3.15
non-ionizing energy loss
NIEL
damage not caused by ionization of the incidence particles

4 Abbreviated terms

CREME-MC	cosmic ray effects on microelectronics MC
SEU	single-event upset
SET	single-event transient
SEL	single-event latch up
SEB	single-event burnout
SEGR	single-event gate rupture
MCU	multiple bit upset
TID	total ionizing dose
HUP	direct ionization-induced SEE rate calculation
PUP	proton-induced SEE rate calculation
CCD	charge coupled device
CMOS	complementary metal oxide semiconductor
EOL	end of life
SPENVIS	space environment information system
HAST	high acceleration stress test
RTS	random telegraph signals
ADC	analog-to-digital converter

DAC	digital analog converter
NPN	negative-positive-negative
FPGA	field-programmable gate array
MOSFET	metal-oxide-semiconductor field-effect transistor
MSM	metal semiconductor metal
LED	light emitting device
DC	direct current
PN	positive-negative
PIN	P-intrinsic-N
FPL	focused pulsed laser
SOA	system operating area
ELDRS	enhanced low dose rate sensitivity
EDAC	error detection and correction
CTE	charge transfer efficiency
CTR	current transfer ration
TTL	transistor transistor logic
IC	integrated circuit
DD	displacement damage

5 Radiation resistance design

5.1 Overview

Satellite designers and manufacturers can implement measures against TID, SEU, SEL, and displacement damage as part of the radiation resistance design when using consumer parts on LEO satellites. See Annex A for radiation tolerance design procedures.

Generally, TID for a satellite is calculated using the knowledge of total dose in a satellite's orbit for a year timed by the design lifetime in years. To mitigate TID effects, the radiation shielding thickness is increased to a level such that the function and performance of the parts used are still acceptable. Programs such as SHIELDOSE-2 are often used to estimate total dose in parts. For satellite designers who cannot use the SHILDOSE-2 program, a contour map that easily estimates the total dose is shown in Annex C.

To estimate SEU as well as SEL, programs such as HUP and PUP are often used. Generally, if one concludes that there is no effect on reducing the occurrence frequency of SEU and SEL even after thickening the shielding material, the measures prescribed in Annex G and Annex H can be taken.

Displacement damage refers to lattice defects that are generated in a semiconductor due to the collision from energetic particles (heavy ions, alphas, protons, neutrons, or electrons) or high-energy photons. Such damage is inevitable regardless of COTS parts/space parts, and even increasing the shield thickness only has a limited effect. In lattice defects, a charge is captured and released, so the influence becomes conspicuous in CCD, CMOS sensors, photocouplers, solar cells, and other optical components. Often the magnitude of such lattice defect damage depends on the temperature and options may include lowering the operating temperature during use or applying sensor signal processing. Conversely, the radiation resistance design should also consider the state of deterioration (i.e., amount of deterioration) at the satellite's EOL. See Annex J.

5.2 Basic idea of using COTS parts

5.2.1 Concept of parts selection

In cases of failure regarding COTS parts, and unlike the parts for space, the user is responsible for failure analysis. Generally, support from the parts manufacturers cannot be expected. It is therefore important to select parts covered by failure analysis service or parts having a known internal structure.

With regard to radiation sensitivity that can depend on each manufactured lot of parts and, where possible, identification management of lots should be carried out.

5.2.2 COTS parts evaluation

As part of the evaluation methods, when the payload is an important or critical one, certain standard screening tests (e.g., temperature cycling, high-temperature burn-in test) can be conducted to assure the ruggedness of the COTS devices.

In the case where a long-life mission is planned, such tests as the HAST and sample life test can be conducted.

5.2.3 Concept of evaluation method

In addition to the task of evaluating each part separately, the merits of higher-level evaluation, such as at the board or unit level, should also be considered.

5.2.4 Concept of application of COTS parts/consumer technology

Risk assessment is based on the identity of the part being evaluated, the environment in which it will be used, and the criticality of the part used. Such an assessment usually helps to determine whether the parts should be used. A reference for parts risk evaluation methodology is RNC - CNES - Q - 60 – 516[6].

5.3 Space radiation environment prediction

5.3.1 Space environment

The natural space radiation environment can be classified into two populations:

1) transient particles that include protons along with heavier ions of all elements of the periodic table as well as atmospheric albedo (back scattered) neutrons; and

2) trapped particles that include protons, electrons, and heavier ions.

The transient radiation consists of GCR particles and particles from solar events (e.g., coronal mass ejections, solar flares, and interplanetary medium acceleration shocks). The solar-related events periodically produce energetic protons, alpha particles, heavy ions, and electrons. Table 1 lists the orders of magnitude of the maximum energy of the radiation particles.

Table 1 — Maximum energies of particles

Particle type	Maximum energy
Trapped electrons	10s of MeV
Trapped protons &heavier ions	100s of MeV

Table 1 *(continued)*

Particle type	Maximum energy
Solar protons	100s of MeV
Solar heavy ions	GeV
Galactic cosmic rays	TeV

5.3.2 Space radiation environment model

Space environment models that can be used for environmental specification include:

- trapped electrons: AE-8[7], AE-9[8];
- trapped protons: AP-8[9], AP-9[8];
- solar protons: JPL-91[10];
- galactic cosmic rays: CREME -MC[11], ISO 15390:2004;
- geomagnetic vertical cut-off model: ISO 17520:2016;
- ionizing dose model: SHIELDOSE-2[12];
- single event effects (SEE): HUP and PUP[11].

All models contain uncertainty and a good practice for evaluating a design is to add a margin in one of the following ways:

(a) add a margin to the model input parameters (shielding thickness, lifetime in environment, etc.) and conduct design evaluation;

(b) first, design and evaluate a part's use with a model using no margin then add the margin (including uncertainty other than in the model) to the obtained result.

5.3.3 Various parameters

Various model input parameters such as orbital conditions, mission period, solar activity cycle, and Earth's magnetic shield should be properly selected.

5.3.4 Environmental conditions necessary for evaluation

The following environmental conditions are necessary for evaluation:

- dose-depth curve;
- integrated energy spectrum of trapped electrons, trapped protons, and solar-related protons;
- LET spectrum of galactic cosmic rays.

Using these calculation results, conduct the radiation evaluation tests specified in Clause 6.

6 Radiation tolerance test

6.1 Types of irradiation test

6.1.1 Cobalt 60 (gamma ray) irradiation test

Cobalt 60 generates high energy gamma rays at 1,17 and 1,33 MeV and such a source decays at a rate of 1 % per month (half-life is 5,3 years). This test is suitable for total dose testing and cannot test single events.

6.1.2 Proton beam irradiation test

The proton irradiation test for silicon requires a cyclotron accelerator which can accelerate protons to at least 50 MeV. In this test, it is possible to simultaneously test the total dose and single event incidents, including the evaluation of displacement damage. Tests with LET of 25 MeV-cm^2/mg or more are also possible using secondary (metal) heavy ions generated by collisions between protons and metal atoms within the semiconductor.

6.1.3 Heavy ion test

For the heavy ion test, an accelerator should be used, or alternatively a radioisotope (such as Californium 256) should be used. The heavy ion test using an accelerator is very expensive. It is a difficult test to conduct, so it is excluded except when it is judged essential in 5.2.4. The method that uses spontaneous fission of radioisotopes (such as Californium 256) can irradiate a target with heavy ions.

6.2 Alternative irradiation test — Laser pulse test

Pulsed picosecond lasers can be evaluated for SEU in a number of different circuits, as can such devices as SRAM, DRAM, logic circuit, and an analog/digital converter.

6.3 Test procedure

6.3.1 Total dose test

The total dose test is conducted to evaluate the amount of deterioration accumulated during the mission due to radiation effects. Refer to MIL-STD-883 TM1019[13] and ESCC 22900[14] for details on how to conduct the total dose test.

6.3.2 Single event test

The single event test is conducted to evaluate the effects of energetic particles such as galactic cosmic rays and trapped protons. Refer to MIL-STD-883 TM1020[15]/1021[16] and ESCC 25100[17] for the test method.

6.3.3 Displacement damage test

This test is conducted to evaluate the displacement damage caused by particles of protons and ions entering the semiconductor. See Annex K for the displacement damage test method.

6.3.4 Laser pulse test for SEE test

An evaluation equivalent to that of radiation irradiation can be conducted by using a laser pulse. See Annex L for the laser pulse test method.

Annex A
(informative)

Radiation resistance design procedure

A.1 Total dose

A.1.1 Energy spectrum of electrons & protons

The radiation environment (total dose amount) received by the satellite is calculated by the radiation environment model, taking into account the operational conditions during orbit (e.g., launch date, six trajectory elements, mission period).

A.1.2 Calculation of the total dose received by parts

Calculate the shield thickness of the satellite as well as the shield thickness of each device. Calculate the total dose received by the parts used in the equipment. (The shield is generally made of different materials, but in order to simplify the evaluation, the value converted to the equivalent shield thickness of aluminum is used.)

A.1.3 Consideration of shield thickness

When it is difficult to secure the total dose resistance of the parts used, mounting of parts, mass of equipment etc., consider partial shielding or increase the shield thickness of the equipment housing. In this way, change to a shield that ensures the total dose tolerance of the parts.

Annex B describes the total dose prediction method in detail. And Annex B also gives the radiation guidelines for total dose using contour maps. Note that the total predicted values based on Annex B tend to be overestimated. Annex D describes a comparative example between model prediction including measured values. Annex E describes the radiation deterioration of electronic components. The design flow for total dose is shown in Figure A.1.

A.2 Single event upset, single event latch-up

A.2.1 Proton energy spectrum

The radiation environment (heavy ions and proton fluence) received by the satellite is calculated by using the radiation environment model, taking into consideration the operational conditions in orbit (e.g., launch date, six trajectory elements, mission period).

However, heavy ions need not be considered for the evaluation of parts other than those used in important equipment.

A.2.2 Calculation of SEE

Confirm the radiation tolerance data for the selected parts (or conduct an irradiation test if there is no data). Calculate SEE incidence in orbit from the data, heavy ions, and proton spectrum. Perform critical analysis of the equipment.

A.2.3 Measures for SEU and SEL

If SEU and SEL resistance is not acceptable in the system, reselect the parts or take countermeasures.

Consider countermeasures to avoid failure by SEU at the component level, circuit level, or equipment level. The design flow for a single event is shown in Figure A.2.

Annex F gives an overview of the single event effect.

Annex G describes the measures for single events of electronic components.

Annex H describes the measures for single events of devices.

A.3 Displacement damage

A.3.1 Fluence of protons

In consideration of the operational conditions in orbit (e.g., launch date, six trajectory elements, mission period), use the radiation environment model to calculate the radiation environment (proton fluence) received by the satellite.

A.3.2 Calculation of displacement damage

Confirm the radiation tolerance data for the selected parts (or conduct a proton irradiation test when there is no data), calculate displacement damage in orbit from the data together with the proton spectrum, and then predict possible degradation.

A.3.3 Measures for displacement damage

If the value of degradation in the system is not acceptable, reselect the parts or take countermeasures for the equipment. The deterioration prediction method by displacement damage to devices in orbit is shown in Figure A.3.

Annex I describes the prediction method of displacement damage.

Annex J describes the resistance to displacement damage of each device.