14 May 2012

Space product assurance

Radiation Hardness Assurance - EEE components for JUICE

14 May 2012

Change log

ESA TEC-QE-2012-155 issue 1	First issue

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1.
Scope

This document specifies the tailoring of ECSS-Q-ST-60-15C radiation hardness assurance (RHA) requirements for JUICE project. These requirements form the basis for a RHA program that is required for all space projects in conformance to ECSS-Q-ST-60,. This document addresses the three main radiation effects on electronic components: Total Ionizing Dose (TID), Displacement Damage or Total Non-Ionizing Dose (TNID), and Single event Effects (SEE).

Spacecraft charging effects are out of the scope of this document.

In this document the word "component" refers to Electrical, Electronic, and Electromechanical (EEE) components only. Other fundamental constituents of space hardware units and sub-systems such as solar cells, optical materials, adhesives, polymers, and any other material are not covered by this document.

2.
Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this document. For dated references, subsequent amendments to, or revision of any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

ECSS-Q-ST-10-09	Space product assurance – Non conformance control system
ECSS-Q-ST-30	Space product assurance – Dependability
ECSS-Q-ST-30-11	Space product assurance – Derating – EEE components
ECSS-Q-ST-60	Space product assurance - Electrical, electronic, and electromechanical (EEE) components
ECSS-E-ST-10-04	Space engineering – Space environment
ECSS-E-ST-10-12	Space engineering - Methods for the calculation of radiation received and its erects, and a policy for design margins
ESCC 22900	ESCC Basic Specification: Total Dose Steady State Irradiation Test Method
ESCC 25100	ESCC Basic Specification: Single Event Effect Test Method and Guidelines
MIL-STD-750 method 1080	MIL-STD: Single Event Burnout and Single Event Gate Rupture Testing
MIL-STD-750 method 1019	MIL-STD: Steady Total Dose Irradiation Procedure
MIL-STD-883 method 1019	MIL-STD: Ionizing (Total Dose) Test Procedure
MIL-HDBK-814 (February 1994)	Ionizing Dose and Neutron Hardness Assurance Guidelines for Microcircuits and Semiconductor Devices

3. Terms, definitions and abbreviated terms

3.1 Terms from ECSS standards

For the purpose of this document, the terms and definitions from ECSS-S-ST-00-01 apply, in particular for the following terms:

Applicable document

Approval

Assurance

Derating

EEE component

Environment

Equipment

Failure

Information

Outage

Recommendation

Required function

Requirement

Review

Risk

Specification

Standard

Subsystem

System

Test

Traceability

Validation

Verification

For the purpose of this document, the terms and definitions from ECSS-Q-ST-60 apply, in particular for the following terms:

Characterization

Commercial Component

Screening

Space qualified parts

For the purpose of this document, the terms and definitions from ECSS-E-ST-10-04 apply, in particular for the following terms:

Dose

Equivalent fluence

Fluence

Flux

Linear Energy Transfer (LET)

For the purpose of this document, the terms and definitions from ECSS-E-ST-10-12 apply, in particular for the following terms:

Cross section

Displacement damage

LET threshold

Multiple cell upset (MCU)

(total) non-ionizing dose, (T)NID, or non-ionizing energy loss (NIEL) dose

NIEL

Projected range

Radiation design margin (RDM)

Sensitive volume (SV)

Single event burnout (SEB)

Single event dielectric rupture (SEDR)

Single event effect (SEE)

Single event functional interrupt (SEFI)

Single event gate rupture (SEGR)

Single event latchup (SEL)

Single event transient (SET)

Single event upset (SEU)

Solar energetic particle event (SEPE)

Total ionizing dose (TID)

3.2 Terms specific to the present document

3.2.1 component type TIDS

TID level at which the part exceeds its parametric/functional requirements

3.2.2 component type TNIDS

TNID level at which the part exceeds its parametric/functional requirements

3.2.3 enhanced low dose rate sensitivity (ELDRS)

increased electrical parameter degradation of a part when it is irradiated with a lower dose rate

3.2.4 equivalent LET

averaged value of the LET curve inside a sensitive volume

3.2.5 one sided tolerance limit

limit that will not be exceeded with a probability P and a confidence level C, assuming that TID degradation of electrical parameters follow a normal distribution law

NOTE If <delta x> is the mean shift among tested population of n samples, σ is the standard deviation of the shift, and K is the one sided tolerance limit factor, then:

- Delta XL = <delta x > + K σ, for increasing total dose shift
- Delta XL = <delta x > - K σ, for decreasing total dose shift
- K depends on the number of tested samples n, the probability of success P and the confidence limit C. K values are available in MIL-HDBK-814. A 3 sigma (K=3) approach is often used. With 10 samples tested it gives a probability of success P of 90% with a confidence level C of 99%.

3.2.6 radiation design margin (RDM)

ratio of TIDS over TIDL for TID and ratio of TNIDS over TNIDL for TNID

3.2.7 radiation lot acceptance test (RADLAT)

radiation test performed on sample coming from the same diffusion lot as the flight parts

NOTE This test is also known as “radiation verification test (RVT).

3.2.8 radiation verification test (RVT)

radiation test performed on sample coming from the same diffusion lot as the flight parts

NOTE This test is also known as “radiation lot acceptance test (RADLAT).

3.2.9 total ionizing dose level (TIDL)

calculated TID level received by the part at the end of the mission

3.2.10 total non-ionizing dose level (TNIDL)

calculated TNID level received by the part at the end of the mission

3.3 Abbreviated terms

For the purpose of this Standard, the abbreviated terms from ECSS-S-ST-00-01 and the following apply:

Abbreviation	**Meaning**
APS	active pixel sensor
ASIC	application specific integrated circuit
CCD	charge coupled device
CDR	critical design review
DCL	declared part list
ELDRS	enhanced low dose rate sensitivity
EOL	end of lifetime
FMECA	failure mode effects and criticality analysis
LET	linear energy transfer
MCU	multiple cell upset
MOS	metal oxide semiconductor
NCR	nonconformance report
NIEL	non-ionizing energy loss
PDR	preliminary design review
QR	Qualification Review
RADLAT	radiation lot acceptance testing
RDM	radiation design margin
RHA	radiation hardness assurance
RVT	radiation verification testing
SEB	single event burnout
SEDR	single event dielectric rupture
SEE	single event effect
SEFI	single event functional interrupt
SEGR	single event gate rupture
SEL	single event latchup
SET	single event transient

Abbreviation	**Meaning**
SEU	single event upset
SRR	system requirement review
TID	total ionizing dose
TIDL	total ionizing dose level
TIDS	total ionizing dose sensitivity
TNIDL	total non-ionizing dose level
TNIDS	total non-ionizing dose sensitivity
TNID	total non-ionizing dose
TNIDL	total non-ionizing dose level
TNIDS	total non-ionizing dose sensitivity
WCA	worst case analysis

5.
Requirements

5.1 TID hardness assurance

a. Applicable Mission TID radiation environment shall be JUICE Environment Specification JS-14-09 issue 4.

b. An environmental margin of 2 shall be applied to ensure allowance for uncertainties of Jupiter radiation environment models.

c. No effect due to TID shall cause permanent damage to a system or subsystem, or degrade its performances outside its specification limits.

d. Each EEE part belonging to families and sub-families listed in Table 5-1 shall be assessed for sensitivity to TID effects to the level specified in this table.

NOTE Hybrids can also be treated as an electronic box. In this case, RHA requirements, as listed in this document, are applicable to every die used in the hybrid.

Table 5-1: EEE part families potentially sensitive to TID

EEE part family	**Sub family**	**TIDL**
Diodes	Voltage reference, Zener	all
	Switching, rectifier, Schottky	> 300 krad-Si eq.
Diodes microwave		> 300 krad-Si eq.
Integrated Circuits		all
GaAs Integrated Circuits		> 300 krad-Si eq.
Oscillators (hybrids)		all
Charge Coupled devices (CCD)		all
Opto discrete devices, Photodiodes, LED, Phototransistors, Opto couplers		all
Transistors (MOS and bipolar)		all
GaAs Transistors		> 300 krad-Si eq.
Hybrids containing active parts		all

e. TID test data used to assess TIDS shall comply with the following rules to be acceptable:

  1. tests are performed in conformance to ESCC 22900, MIL-STD 883 method 1019, or MIL-STD-750 method 1019, and
  2. devices that contain bipolar transistors are tested at a dose rate of 36 to 360 rad/h, and
  3. tested parts are manufactured with technology identical to the technology of flight parts: same process, same diffusion mask, and same wafer fabrication facility, and
  4. test bias conditions are worse or equivalent to the application.

f. If acceptable component TID test data does not exist, ground testing shall be performed in conformance to ESCC 22900 and requirements 5.1e.2 to 5.1e.4

g. Acceptable component TID test data shall be available latest at CDR.

h. Component type TIDS shall be based on the parametric and functional limits given in component detail specification or manufacturer data sheet, or on the maximum parameter degradation acceptable to ensure equipment operation in compliance with equipment performance specification at the end of overall lifetime (EOL).

NOTE TIDS is defined by comparing part parametric/functional requirements with TID test data

i. Component type TIDS shall be the total dose level at which the one sided tolerance limit to guarantee a probability of survival Ps of at least 95 % with a confidence level of at least 90% exceeds its limits as defined in requirement 5.1h . One sided tolerance limit factor values for probability of survival of 95% with a 90% confidence level are given in Table 5-2.

Table 5-2: K values for P=0,95 and C=0,9 as function of the number of tested samples n

N	K
3	5.311
4	3.957
5	3.4
6	3.091
7	2.894
8	2.755
9	2.649
10	2.568

j. Component received TID level (TIDL) shall be calculated using tools valid for the expected spacecraft environment in conformance with ECSS-E-ST-10-12.

k. Any necessary additional radiation shielding material shall be defined on the basis of detailed shielding analyses.

l. Shielding analyses shall be performed at platform and equipments levels during all project phases

m. Shielding analyses shall be performed at system level for SRR taking into account preliminary system design and models of equipments.

n. Integrated analyses of equipment and platform shielding that take into account details of the platform and equipments shall be performed at PDR.

o. Integrated analysis shall be iterated at equipments and platform CDRs to reflect increased available detail.

p. Minimum required RDM shall be 1.

q. For any component that is estimated to have on-orbit performance degradation due to TID, it shall be demonstrated, performing a WCA in accordance with ECSS-Q-ST-30, that the function performs within EOL technical specification limits.

r. If requirements 5.1p and 5.1q are not met, mitigation shall be implemented to eliminate the possibility of damage to equipment or degradation of its performance outside its specification limits.

s. Mitigation shall be verified by analysis or test.

t. The supplier shall document the TID analysis in the equipment radiation analysis report in conformance to Annex B– DRD of ECSS Q-ST-60-15C.

u. TID radiation verification test (RVT) or RADLAT on flight lots shall be performed in accordance with Table 5-3.

Table 5-3: TID RVT criteria

Family	Sub-family	RDM	RVT Requirement
diode	Zener, voltage reference	-	RVT if flight diffusion lot number different of data diffusion lot number and date code older than 10 years
integrated circuits	Silicon Monolithic CMOS	-	RVT if flight diffusion lot number different of data diffusion lot number and date code older than 4 years
	Silicon Monolithic bipolar, BiCMOS	> 4	RVT if flight diffusion lot number different of data diffusion lot number and date code older than 4 years
		<4	RVT required
transistors	High power NPN High power PNP	> 4	RVT if flight diffusion lot number different of data diffusion lot number and date code older than 4 years
		<4	RVT required
	FET P channel, FET N channel	-	RVT if flight diffusion lot number different of data diffusion lot number and date code older than 4 years
CCD, CMOS APS		> 4	RVT if flight diffusion lot number different of data diffusion lot number and date code older than 4 years
opto discrete devices		< 4	RVT

v. Conformity of RVT or RADLAT results with as designed radiation analysis shall be checked.

NOTE As designed radiation analysis includes TIDL based on shielding, TIDS based on existing data and radiation drifts considered in WCA

w. Nonconformities of RVT or RADLAT results with as designed radiation analysis shall be reported in a NCR in conformance with ECSS-Q-ST-10-09.

5.2 TNID hardness assurance

a. Applicable Mission TNID radiation environment shall be JUICE environment specification JS-14-09 issue 4.

b. An Environmental margin of 2 shall be applied to ensure allowance for uncertainties of Jupiter radiation environment models.

c. No effect due to TNID shall cause permanent damage to a system or subsystem, or degrade its performances outside its specification limits.

d. Each EEE part belonging to families and sub-families listed in Table 5-4 shall be assessed for sensitivity to TNID, to the levels specified in this table.

NOTE Guidelines and NIEL rates for calculating monoenergetic equivalent proton fluences are provided in ECSS-E-HB-10-12 clause 7.5.

Table 5-4: List of EEE part families potentially sensitive to TNID

Family	Sub-Family	TNIDL
CCD, CMOS APS, opto discrete devices	all	all
Integrated circuits	Silicon monolithic bipolar or BiCMOS	> $2x10^{11}$ p/cm^2 50 MeV equivalent proton fluence
Diodes	Zener Low leakage Voltage reference	> $2x10^{11}$ p/cm^2 50 MeV equivalent proton fluence
Transistor	Low power NPN Low power PNP High power NPN High power PNP	> $2x10^{11}$ p/cm^2 50 MeV equivalent proton fluence

e. TNID data used to assess TNIDS shall satisfy the following criteria to be acceptable:

1. Tests are performed with protons or electrons and tested levels encompass the specified mission environment;
2. Tested parts are manufactured with technology identical to the technology of flight parts: same process, same diffusion mask, and same wafer fabrication facility.

f. If acceptable component TNID test data does not exist, ground testing shall be performed in conformance to requirement 5.2e.2.

g. TNID irradiation test plans shall be submitted to customer approval.

NOTE This is because no standard method exists for TNID testing.

h. TNID irradiations should be performed with protons and electrons at several energies encompassing the specified mission radiation environment.

NOTE This is because of the limitations of NIEL calculations for some technologies and component families.

i. Acceptable TNID test data shall be available latest at CDR.

j. Component type TNIDS shall be based on the parametric and functional limits given in detail specification or manufacturer data sheet, or on the maximum parameter degradation acceptable to ensure equipment operation in compliance with equipment performance specification at the end of overall lifetime (EOL).

NOTE TNIDS is defined by comparing part parametric/functional requirements with TNID test data

k. Component type TNIDS shall be the TNID level at which the one sided tolerance limit to guarantee a probability of survival Ps of at least 95% with a confidence of at least 90% exceeds its limits as defined in requirement 5.2j.

l. Component TNID level (TNIDL) shall be calculated using tools valid for the expected spacecraft environment in conformance to ECSS-E-ST-10-12.

m. Minimum required RDM shall be 1.

n. For any component that is estimated to have on-orbit performance degradation due to TNID, a WCA of the function shall be performed in accordance with requirements of ECSS-Q-ST-30 to demonstrate that the function performs within specification despite radiation induced drifts in its constituent part parameters at EOL.

o. Both TNID and TID degradations shall be combined to define the component parameter drifts for WCA.

p. If Combined TNID and TID tests are used to get the combined TID/TNID sensitivity, such test plans shall be submitted to customer approval.

NOTE Generally, TNID sensitive parts are also sensitive to TID.

q. If requirements 5.2m, 5.2n, and 5.2o cannot be met, mitigation shall be implemented to eliminate the possibility of damage to equipment or degradation of its performance outside its specification limits.

r. Mitigation shall be verified by analysis or test.

s. The supplier shall be document the TNID analysis in the equipment radiation analysis report in conformance with Annex B– DRD of ECSS-Q-ST-60-15C.

t. TNID radiation verification test (RVT) or RADLAT on flight lot shall be performed in accordance with Table 5-5.

Table 5-5: TNID RVT requirements

Family	Sub-family	RDM	RVT Requirement
Diodes	voltage regulator, Zener	-	RVT if flight diffusion lot number different of data diffusion lot number and date code older than 4 years
integrated circuits	Silicon Monolithic bipolar	-	RVT if flight diffusion lot number different of data diffusion lot number and date code older than 4 years
transistors	Low power NPN, Low power PNP, High power NPN, High power PNP	-	RVT if flight diffusion lot number different of data diffusion lot number and date code older than 4 years
CCD, CMOS APS		-	RVT required
opto discrete devices		-	RVT if flight diffusion lot number different of data diffusion lot number and date code older than 4 years

NOTE It is part of hardness assurance to perform RVT or RADLAT on flight lot based on the following criteria: age of available test data, part type and technology, and RDM.

u. Conformity of RVT or RADLAT results with as designed radiation analysis shall be checked.

NOTE As designed radiation analysis includes TIDL based on shielding, TIDS based on existing data and radiation drift considered in WCA

v. Nonconformities of RVT or RADLAT results with as designed radiation analysis shall be reported in a NCR in conformance with ECSS-Q-ST-10-09.

5.3 SEE hardness assurance

a. Applicable mission SEE radiation environment shall be JUICE environment Specification JS-14-09 issue 4.

b. No SEE shall cause damage to a system or a subsystem or induce performance anomalies or outages not compliant with mission specifications.

c. Each EEE part belonging to families and sub-families listed in Table 5-6 shall be assessed for sensitivity to SEE.

NOTE A description of different types of SEE can be found in ECSS-E-ST-10-12.

Table 5-6: List of EEE part families potentially sensitive to SEE

Family	Sub-family
Integrated Circuits	all
Integrated Circuits Microwave	all
Transistors	FET N channel FET P channel
Transistors Microwave	all
CCD, CMOS APS, opto discrete devices	all

d. SEE test data shall meet the following criteria to be acceptable:

1. Test are performed in conformance to
    (a) MIL-STD-750E method 1080 for power MOSFET,
    (b) ESCC25100 for all other parts.

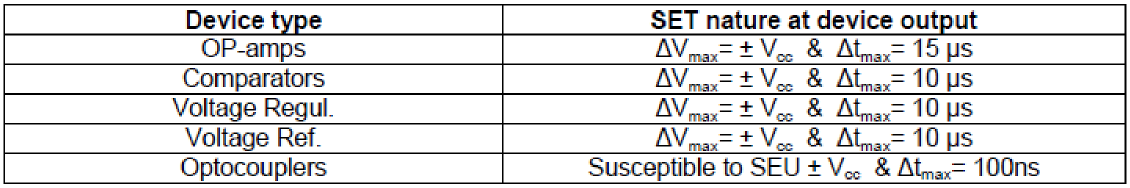
    NOTE Useful information about SEE testing is also provided in EIA/JESD 57.
2. Tested parts are manufactured with technology identical to the technology of flight parts: same process and same diffusion mask
3. Test conditions are worse or equivalent to the application

    NOTE Test conditions include, but are not limited to, bias conditions, clock frequency, test pattern, and temperature.

e. If acceptable component test data does not exist, heavy ion ground testing shall be performed.

f. For the SET criticality analysis of SET in analog ICs, worst case SET templates in Table 5-7 may be used in the absence of acceptable test data.

Table 5-7: worst case SET templates



Device type	SET nature at device output
OP-amps	$\Delta V_{max} = \pm V_{cc}$ & $\Delta t_{max} = 15\ \mu s$
Comparators	$\Delta V_{max} = \pm V_{cc}$ & $\Delta t_{max} = 10\ \mu s$
Voltage Regul.	$\Delta V_{max} = \pm V_{cc}$ & $\Delta t_{max} = 10\ \mu s$
Voltage Ref.	$\Delta V_{max} = \pm V_{cc}$ & $\Delta t_{max} = 10\ \mu s$
Optocouplers	Susceptible to SEU $\pm V_{cc}$ & $\Delta t_{max} = 100ns$

g. All SEE testing shall be performed in conformance to requirements of clause5.3d.

h. SEE analysis and proton testing shall take place based on LET threshold (LETth) of the candidate devices as specified in Table 5-8.

NOTE In accordance with this table, no further analysis is necessary above a LETth of 60 MeVcm²/mg, because parts are commonly considered immune to SEE in the space environment.

Table 5-8: Environment to be assessed based on LETth

Device LETth (MeVcm^2/mg)	Environment to be assessed
LETth < 15	Heavy ions (GCR, solar event ions) Protons (trapped, solar event protons)
LETth= 15-60	Heavy ions (GCR, solar event ions)
LETth>60	No analysis required

i. Below a LETth level of 60 MeVcm^2/mg, heavy ion induced SEE analysis shall be performed.

j. Below a LETth of 15 MeVcm^2/mg proton and heavy ion induced SEE sensitivity analysis shall be analyzed.

k. Proton SEE sensitivity of SEE hardened parts shall be assessed.

NOTE The LETth of 15 MeVcm^2/mg for performing proton SEE tests is not an absolute value. For VLSI hardened IC employing high-Z material in the vicinity of sensitive volumes, the LET of secondaries can be higher than 15 MeVcm^2/mg.

l. The LETth levels as described in, 5.3h, to 5.3k shall be recalculated for parts made of other material than Silicon (i.e. GaAs).

m. Proton SEE test data shall satisfy the requirement 5.3d to be acceptable.

n. If acceptable proton SEE data is not available, proton ground testing shall be performed.

o. Proton SEE testing shall be performed according to requirement 5.3d.

p. Acceptance of simulation tools to obtain proton SEU cross-section curves on digital devices shall be subject to project approval.

NOTE For SEUs, proton cross-section curve can be obtained from heavy ion cross-section curve with simulation tools such as SIMPA or PROFIT.

q. For any component that is not immune to destructive SEE analysis, it shall be demonstrated that the probability of occurrence in the mission environment is more than 10 times lower than component intrinsic failure rate.

NOTE Examples of destructive SEE are: SEL, SEB, SEGR and SEDR.

r. One of the following two power MOSFET SEB/SEGR assessment methods shall be applied:

1. SEB/SEGR failure rates based on SEB/SEGR cross-section versus equivalent LET curves;

NOTE Power MOSFET have a deep sensitive volume. Therefore, LET can vary significantly along ion path in sensitive volume.

2. V_{DS}max, V_{GS}off max derating based on V_{DS} versus V_{GS} SOA.

s. Practical implementation of the method used to assess power MOSFET SEB/SEGR sensitivity, as specified in 5.3r, shall be submitted to customer approval.

t. For non-destructive SEEs the criticality of a component in its specific application shall be defined including impacts at higher level, ie. subsystem and system.

NOTE Examples of non-destructive SEE are: SEU, SET, MCU, and SEFI.

u. For the criticality analysis of SET in analog ICs, the analysis method, electrical simulations or hardware electrical injection, shall be submitted to customer approval.

v. The mission event rate shall be calculated when a SEE on a given component for a given application is considered critical or potentially critical..

w. The mission event rate shall be calculated for the mission background environment and a solar event environment as defined in mission radiation environment specification in conformance to ECSS-E-ST-10-12.

x. When proton SEU rate is based on simulation from heavy ion data, A SEE RDM of 10 shall be applied on calculated error rate.

NOTE When proton SEU rate is based on actual proton test data, no SEE RDM applies on proton SEU rate

y. The calculated event rates, shall be such that the application meets the project availability, performance, and reliability requirements.

z. If requirements 5.3q and 5.3y are not met, mitigation shall be implemented to eliminate the possibility of damage to equipment or degradation of its performance outside its specification limits.

aa. Mitigation shall be verified by analysis or test.

bb. All data and analysis shall be documented in Radiation Analysis report in conformance with Annex B – DRD of ECSS-Q-ST-60-15C

5.4 Radiation analysis report

a. A draft equipment radiation analysis report shall be available for equipment PDR

b. A final radiation analysis report shall be available for for equipment CDR

c. A draft system radiation analysis report shall be available at system CDR

d. A final system radiation analysis report shall be available at system QR

5.5 Equipments radiation reviews

a. In addition to draft equipment radiation analysis to be provided in equipment PDR data package, equipment radiation review shall be held around PDR timeframe to review available test data, and define radiation tests to perform.