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ALCATEL SPACE

RADIATION REQUIREMENTS

Product Code 00000

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CHANGE RECORDS

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1. FOREWORD

The unit shall be designed to survive the space radiation environment during the Radiation Design Lifetime (2 times the nominal lifetime). The purpose of this document is to provide Space Radiation Requirements to follow during program in order to prove that the equipment will continue to perform its function throughout its Radiation Design Life.

2. SCOPE

General damage mechanisms to which the satellite will be subjected include :

- Total dose damage of electronics and solar arrays due to electrons and protons.
- Single event phenomena (Upsets, Latchups, Burnouts, Transients, Hard Error, Functional Interrupt, ...) of electronics due to the cosmic ray, solar flare environments and trapped protons.
- Physical damage to external components and solar arrays due to debris and micrometeoroid environment
- Displacement damage induced by protons

The major factors that will effect the design of the electronic systems are total dose ionization damage, single event phenomena and displacement damages. The present document presents the analyses and procedures that will be used to ensure that the equipment will be designed to survive these environments.

3. APPLICABLE DOCUMENTS

[1] Herschel/Planck Environment and Test Requirements, Ref : H-P-1-ASPI-SP-0030

[2] Herschel/Planck General Design and Interface Requirements, Ref : H-P-1-ASPI-SP-0027

4. REFERENCE DOCUMENTS

The following documents, of exact issues shown, are listed for reference only.

[RD-1] : MIL-STD-883C, METHOD 1019.5

[RD-2] : « Total Dose Steady State Irradiation Test Method», ESA/SCC Basic Specification N° 22900, issue 3, November 1993.

[RD-3] : MIL-HDBK- 279, « Total Dose Hardness Assurance Guidelines for Semiconductor Devices and Microcircuits », 25 January 1985.

[RD-4] : «Single Event Effects Test Method and Guidelines », ESA/SCC Basic Specification N°25100, Draft A, February 1995.

[RD-5] : JEDEC Test Standard # 57, « Procedures for the Measurement of Single Event Effects in Semiconductor Devices from Heavy Ion Irradiation », May 1996.

[RD-6] Product Assurance Requirements for FIRST/Planck Satellite, Ref : SCI-PT/RS/MPA04683 Iss 2 Rev 1.

In case of conflict between these Reference Documents, this « Radiation Requirements » document is the priority.

5. DEFINITIONS

1. **EQUIVALENT PART** : An equivalent part is a part from the same manufacturer, same technology, same mask manufactured on the same wafer fab.

2. **RADLAT** : RADiation Lot Acceptance TEST. Radiation testing to perform (Total Dose, Displacement Damage) to ensure that the flight lot will perform in a manner that is consistent with characterization (Evaluation) data.

3. **RDL** : Radiation Design Lifetime. This is the mission duration taken into account for the Radiation design of the satellite.

4. **TDT** : Total Dose Threshold. This is the minimum total dose level that all parts shall withstand in order to be used for the program.

5. **LDR** : Low Dose Rate . This is a dose rate lower or equal to 360 rad(Si)/hour.

6. **RR** : Radiation Review. Review dedicated to Radiation issues : parts, calculation tools and methods, analysis, data review, etc .....

7. **WCA** : Worst Case Analysis : End of Life analysis to demonstrate that the equipment will withstand aging, temperature, Total Dose and Displacement Damage effects.

8. **DDEF** : Displacement Damage Equivalent Fluence. This is the minimum fluence level that all parts shall withstand in order to be used for the program.

9. **LET** : Linear Energy Transfer.

6. SPACE RADIATION ENVIRONMENT

The radiation Space Radiation Environment applicable for this mission is given in Applicable Document [1].

7. TOTAL DOSE EVALUATION AND HARDNESS ASSURANCE

RAD-01	**The Equipment unit shall be designed to account for the Total Dose Effect, during the Radiation Design Lifetime (RDL) equal to 2 times the nominal lifetime, as specified in Applicable Document [2].**

The Space Radiation Hardness activities will proceed through these non-chronological tasks :

- Parts selection, characterization and Radiation Lot Acceptance Testing
- Radiation Review at sub-contractor facility **(RR**)
- Deposited doses calculations
- Equipment worst case analysis **(WCA**)
- Corrective actions.

7.1 PARTS SELECTION

Parts shall be selected in order to survive the on-orbit space radiation environment for the specified mission time as well as still permitting the units in which they are installed to meet all their performance specifications. The minimum allowable radiation level is the Total Dose Threshold **(TDT**) level defined behind 4 mm of Aluminum of a Solid Sphere shielding, according to reference document [RD-6].

RAD-02	**All parts need to meet the Total Dose Threshold (TDT) of 10 krad(Si), as specified in Reference Document [RD-6].**

The subcontractor shall justify the use of EEE parts, according to Total Dose Evaluation data provided by the procurement authority :

RAD-03	**Total Dose Degradation Database shall be submitted, during the Radiation Review (see para. 10), to ALCATEL SPACE for validation**

7.2 RADIATION LOT ACCEPTANCE TESTS

Due to the lot-to-lot variability in Total Dose effect, all active parts, who are not in Radiation Hardened (RADHARD) technology, shall be submitted to Radiation Lot Acceptance Tests (RADLAT) according to the following table :

	MOS / BiCMOS			BIPOLAR			
FAMILY	Test Criteria	Test Method	Dose Rate	Test Criteria	Test Method	Dose Rate	Sample Size
Transistors	**All**	RD-1 or RD-2	Low or High	**10**	RD-1 or RD-2	Low or High	5
Analog Ics	**1**	RD-1 or RD-2	Low or High	**2**	RD-2	Low	5
Logic Ics	**1**	RD-1 or RD-2	Low or High	**6**	RD-2	Low	5
ASICs, FPGA	**2**	RD-1 or RD-2	Low or High	**2**	RD-2	Low	2-3
RAM, PROM, Processors	**2**	RD-1 or RD-2	Low or High	**6**	RD-2	Low	2
RADHARD	**All**	RD-1 or RD-2	Low or High	**All**	RD-1 or RD-2	Low or High	2-5
Optoel., CCD	**All**	RD-1 or RD-2	Low or High	**All**	RD-2	Low	5

Table 1 : Total Dose Screening Matrix

CATEGORY	TEST CRITERIA
All	All diffusion lots tested
1	Lot tested if flight diffusion lot number different of data diffusion lot number and data date code older than **1** year.
2	Lot tested if flight diffusion lot number different of data diffusion lot number and data date code older than **2** years.
4	Lot tested if flight diffusion lot number different of data diffusion lot number and data date code older than **4** years.
6	Lot tested if flight diffusion lot number different of data diffusion lot number and data date code older than **6** years.
10	Lot tested if flight diffusion lot number different of data diffusion lot number and data date code older than **10** years.

Table 2 : RADLAT Test Criteria

Low Dose Rate is lower or equal to 360 rad/hour (0.1 rad/sec).

Some device technologies are inherently hard to total dose ionizing dose effects. The following classes of parts are considered as total dose insensitive :

Non Zener Diodes	Not sensisitive up to 300 krad(Si).
GaAs	Gallium Arsenide devices such as FETs and HEMTs show little parametric variation.
Std TTL Logic	Extensive testing on 54XX, 54L, 54S devices show these parts to be only marginally degraded.
ECL	Emitter Coupled Logic devices exhibit little parametric shift out to several Mrad(Si).
Microwave Devices	Step Recovery, Varactor, Schottky, Microwave Mixer and Multiplier Diodes exhibit negligible shifts.

Calculated deposited dose levels shall be lower than 300 krad(Si). If not, experimental data shall be provided during the Radiation Review for review and approval.

RAD-04 **A Radiation Review shall be held in order to validate Device Under Test bias conditions (worst case), irradiation facility and sources, test conditions, parameters to measure, dose steps, dose rate, ...**

RAD-05 **Radiation Lot Acceptance Tests (RADLAT) and/or Characterization/Evaluation tests shall be defined during the Radiation Review, according to Evaluation Database available and Radiation Screening Matrix given in Table 1.**

RAD-06 **Total Dose Irradiation Test plans will be submitted to ALCATEL for approval, prior testing.**

7.3 DEPOSITED DOSE CALCULATIONS

The subcontractor shall perform an accurate deposited dose calculation on the equipment. The subcontractor is required to perform a 3D modeling of the equipment, including part case models as detector points. The subcontractor shall described the calculation method used for these deposited doses calculations. The subcontractor will use the following preliminary simple 3D spacecraft model. The satellite structure will be modeled by an aluminum cubical box of 2 meters size. Thicknesses to take into account are as follows :

Equipment Location	Mounting Surface mm Al	Other Surfaces mm Al
Inside	0.8	0.8
Outside	1.6	0.1

Table 3 : Preliminary Satellite Radiation model

In case of mass out of specification, a more detailed ray tracing analysis at spacecraft level will be provided to the subcontractor in order to optimize the mechanical design, and deposited dose calculation shall be re-issued.

Two Deposited Dose calculation methods are allowed :

- **Ray Tracing** : In order to carry out Solid Angle Sectoring Analysis, particle fluxes are converted into Dose Depth Curves for Solid Sphere Shielding. If necessary, Dose Depth Curves for other target material could be provided. This calculation method is based on the straight ahead approximation. **Solid Angle Sectoring Analysis** are performed taking into account the angle of incidence between the ray and the shielding **(Slant Path**). The Dose Depth Curve for a **Solid Sphere** shielding shall be applied. A minimum sectoring resolution of 800 elementary solid angles is required.
- **3D Monte Carlo** : This accurate calculation method may be used, but taking into account the problem to have an accurate resolution versus the complexity of the model, the ALCATEL approval required before calculation.

RAD-07	**To perform Deposited Dose calculations on active parts, using either Ray Tracing or 3D Monte Carlo technics.**

7.4 WORST CASE ANALYSIS

Circuit WCA is needed to evaluate susceptibility to the radiation environment. The specific details describing the objectives, methods, and requirements need to be described. WCA includes the effects of temperature, aging, and radiation degradation. This equipment WCA is a valuable tool to identify clearly critical parts. Because there is a ‘ within one lot variability’ , it is necessary to use statistical tools in order to estimate the Post-Rad parameters values. This Post-Rad value, for each electrical parameter shift, will either be calculated using one of the following tools :

- **3 sigma approach** :

$$\text{Delta } X_L = <\text{delta } x> + 3 \cdot \sigma \text{ For increasing total dose shift}$$

$$\text{Delta } X_L = <\text{delta } x> - 3 \cdot \sigma \text{ For decreasing total dose shift}$$

- **One sided tolerance limit** statistical tool could be used, based upon RD-4. Confidence Level as well as Lot Quality factors shall be submitted to ALCATEL for approval.

RAD-08	**To perform Equipment Worst Case Analysis according to the Evaluation Total Dose Database* validated during the Radiation Review.**

** radiation tests reports used as input for the WCA*

RAD-09	**Equipment Worst Case Analysis shall be updated according to RADLAT results, if necessary**

8. SINGLE EVENT PHENOMENA HARDNESS ASSURANCE

Cosmic rays, solar flares and high energy trapped protons can induce various effects, caused by the energy deposited by a high energy particle as it interacts with the sensitive portions of an electrical device. These effects are :

- Single Event Upset **(SEU**) : SEUs are any disturbance of a circuit. The response could be a soft error (a bit flip that can be reset). This is a non destructive effect.
- Single Event Latch-Up **(SEL**) : This phenomena can occur in CMOS BULK or EPI parts. It turns out that the CMOS fabrication process results in parasitic PNPN paths that are well known and have been studied for conventional radiation induced latchup. This is a destructive effect.
- Single Event Burnout **(SEB**) : This phenomena can occur in power MOSFET N-channel transistors. The parasitic bipolar NPN transistor is switched on, and induces a short circuit between drain and source. This is a destructive effect.
- Single Event Gate Rupture **(SEGR**) : This phenomena can occur in power MOSFET. This is a destructive event.
- Single Event Transient **(SET**) : This phenomena can occur on Linear Bipolar devices and Digital Optocouplers. This is a non destructive effect.
- Single Event Hard Error **(SHE**) : This is a permanent bit flip, due to a local micro-dose deposited by the ion within the memory cell. Not destructive effect for the device, but permanent damage for the memory cell.

8.1 PARTS SELECTION AND CHARACTERIZATION

8.1.1 Single Event Upset

Taking into account that the SEU is a nondestructive effect, there is no requirement in terms of minimum LET threshold or maximum cross section. The subcontractor is requested to analyze the effect and the criticality of SEU for the equipment.
For digital technologies, the subcontractor shall use parts with a well known SEU sensitivity in terms of LET threshold and cross section (refer to paragraph « Single Event Phenomena (SEP) Rate Calculation »). If no data is available, the subcontractor is responsible to perform a Single Event Upset test :

- An **Heavy Ions testing** shall be performed in order to determine the Device Cross Section versus LET response of the device,
- If the orbit is exposed to proton environment and if the Heavy Ions LET threshold is lower than 15 MeV.cm^2 /mg, then a **Proton induced SEU testing** shall be performed Test plans and the use of these parts requires express approval from ALCATEL.

There is no lot-to-lot variability, there is no lot testing requirements. Data collected for ' equivalent parts' (see para. 5) will be acceptable.

8.1.2 Single Event Latchup

RAD-10	**As a preferred baseline approach, only Single Event Latchup Free parts shall be used.**

RAD-11	**Single Event Latchup sensitive parts could be used upon a case by case basis and requires ALCATEL approval.**

Single Event Latchup sensitive part use shall be justified with a technical report providing : full device cross section versus LET curve (up to LET of 60 MeV.cm^2 /mg), risk assessment, detection/correction circuitry, impact on reliability analysis, etc ..... The sub-Contractor shall demonstrate the compliance to mission requirements in terms of reliability.

8.1.3 Single Event Burnout

RAD-12	**As a preferred baseline approach, only Single Event Burnout free parts shall be used.**

In order to prevent permanent damage, bias requirement is as follows :

RAD-13	**For N-Channel Power MOSFETs from Harris & International Rectifier, design requirements are as follows :** V_{DS} **< 50 % BVDSS @ BVDSS $\leq$ 200 Volts**

RAD-14	**For VDS above 50% or BVDSS > 200 Volts or other manufacturers, Heavy Ions data shall be provided in order to demonstrate SEB free behavior**

POWER MOSFET P-CHANNEL and BIPOLAR POWER transistors are SEB free.

RAD-15	**Single Event Burnout sensitive parts <u>could be</u> used upon a case by case basis and requires ALCATEL approval.**

Single Event Burnout sensitive part use shall be justified with a technical report providing : full device cross section versus LET curve (up to LET of 60 MeV.cm^2 /mg), SEB risk assessment, detection/correction circuitry, impact on reliability analysis, etc ..... The sub-Contractor shall demonstrate the compliance to mission requirements in terms of reliability.

8.1.4 Single Event Gate Rupture

RAD-16	**As a preferred baseline approach, only Single Event Gate Rupture free parts shall be used.**

RAD-17	**For Power MOSFETs from Harris & International Rectifier, design requirements are as follows : N Channel : VG $\geq$ 0 Volt P Channel : VG $\leq$ 0 Volt**

RAD-18	**Single Event Gate Rupture sensitive parts <u>could be</u> used upon a case by case basis and requires ALCATEL approval.**

Single Event Gate Rupture sensitive part use shall be justified with a technical report providing : full device cross section versus LET curve (up to LET of 60 MeV.cm^2 /mg), SEGR risk assessment, impact on reliability analysis, etc ..... The sub-Contractor shall demonstrate the compliance to mission requirements in terms of reliability.

8.1.5 Single Event Transient

This includes such devices as Linear integrated circuits that do not suffer logic upset as such, but may produce a large output spike that can appear as a false command. Design analysis shall be performed in order to assess the sensitivity of applications using sensitive devices. In case of sensitive application, experimental data shall be provided in order to justify the use of selected parts, and SET frequencies shall be determined.

8.1.6 Single Event Hard Error (stuck bit)

These hard errors are due to total dose effects from a few ions impinging on the gate oxide of sensitive transistors. Up to date, hard errors have been seen only in commercial SRAM cells as well as in DRAMs.

8.2 SINGLE EVENT UPSET RATE CALCULATION

For a given phenomenon, the part cosmic rays response is a curve of Device Cross Section versus LET of incident ions.

8.2.1 Heavy Ions Induced SEU

The Heavy Ions SEU rate τ_{hi} shall be calculated for each active part. The sub-contractor shall submit its SEU rate calculation method to ALCATEL ESPACE for approval. If no tools are available to the sub-contractor, the SOCRATE (Single Event Upset Optimized Calculation RATE) EXCEL macro-sheet will be provided to the sub-contractor.

8.2.2 Protons Induced SEU

The Proton SEU rate τ_{pr} shall be calculated for each active part having an Heavy Ion SEU LET threshold lower than 15 MeV.cm^2 /mg, and if the orbit is exposed to proton environment. The sub-contractor shall submit its SEU rate calculation method to ALCATEL ESPACE for approval. If no tools are available to the sub-contractor, the SOCRATE (Single Event Upset Optimized Calculation RATE) excel macro-sheet will be provided to the sub-contractor.

8.2.3 Total SEU Rate

The Total SEU rate will be $\tau_{seu} = \tau_{hi} + \tau_{pr}$

RAD-19	**The subcontractor is required to calculate SEP rates for all parts sensitive to cosmic rays and protons effects.**

8.3 SINGLE EVENT UPSET EFFECTS ANALYSIS

RAD-20	**The subcontractor is required to perform a SEU effects analysis in order to identify the SEU effects and criticality.**

8.4 SINGLE EVENT TRANSIENT EFFECTS ANALYSIS

RAD-21	**The subcontractor is required to perform a SET effects analysis in order to determine the effects of SET on equipment performance.**

It is required to determine the following effects on performance :

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.	$\Delta V_{max} = \pm V_{cc}$ & $\Delta t_{max} = 10\ \mu s$
PWMs	Double Pulses, two missing pulses, multiple missing pulses in a row, device shut off. Assess impact in specific application.
PLL	Transients and permanent changes in output voltage. In synthesiser circuits can cause phase, amplitude and frequency transients with duration determined by loop response.
Digital Optocouplers	$\Delta V_{max} = \pm V_{cc}$ & $\Delta t_{max} = 100\ ns$

For those applications, demonstrate that a SET will not produce an out of specification.

8.5 DESTRUCTIVE SINGLE EVENT EFFECTS

All Destructive Single Event Effects (Latchup, Gate Rupture, Burnout, Hard Errors, ...) could be acceptable only if the equivalent Destructive Single Event Failure Rate is 10 times lower than the intrinsic reliability failure rate of the part (@ 25°C).

RAD-22	**The calculation rate method shall be submitted to ALCATEL for approval.**

9. DISPLACEMENT DAMAGES

If the orbit is exposed to proton environment, then Displacement Damage effects is a serious problem to electronic devices.

9.1 ENVIRONMENT

Both protons and electrons can induce displacement damage in semiconductor devices. The part of deposited energy involved in displacement defects creation is called NonIonizing Energy Loss (NIEL). The electrons and protons fluxes spectra are converted into a fluence of monoenergetic particles producing the same amount of defects (typically 1 MeV neutrons or 10 MeV protons). This correlation between different particles with different energies is based on the energetic dependency of the NIEL for the considered particles and materials. For convenience an equivalent fluence of 10 MeV protons in the target material is selected .

The hardness of the environment will be expressed as a fluence of 10 MeV(Target Material) equivalent protons behind aluminum spherical shields of various thicknesses. The Displacement Damage Equivalent Fluence depth curve is computed with NOVICE code for solid sphere shielding. This curve provides a lower Displacement Damage Equivalent Fluence for the mission:

$$\Phi_{eq.}(10\text{ MeV, Target Material}) = \mathbf{DDEF}\ \text{p/cm}^2\ @\ 10\text{ MeV protons}$$

9.2 PARTS SELECTION

Parts shall survive the lower Displacement Damage Equivalent Fluence calculated for the mission. At the DDEF level to be considered for the Herschel/Planck mission, only Optoelectronic devices (CCD, LED, Optocoupler,…) are displacement damage sensitive. For Bipolar and MOS devices, this effect can be ignored because the sensitivity threshold is high enough. The acceptance of the parts will be based on displacement damage test data. The data will be taken from neutrons testing databases and protons test results.
Equivalence between protons and neutrons will be deduced from NIEL values in the target material. If no data are available, protons irradiation evaluation tests shall be performed. The test plan will be submitted to ALCATEL for approval.

Displacement Damage tests shall be performed using the following sources :

- Protons @ energy > 50 MeV
- Neutrons @ 1 MeV

The electrical parameters drifts induced by displacement damage must be added to Total Dose drifts in the Worst Case Analysis.

RAD-23	**All designs must account for the Displacement Damage produced by the Equivalent Fluence (DDEF), as specified in Applicable Document [1].**

The subcontractor shall justify the use of EEE parts, according to Displacement Damage evaluation data.

RAD-24	**Displacement Damage Degradation Database shall be submitted, during the Radiation Review, to ALCATEL SPACE for validation.**

RAD-25	**Equipment Worst Case Analysis shall be performed using this Displacement Damage Database.**

10. RADIATION REVIEW

A Radiation Review shall be held, at Preliminary Design Review time frame (PDR, EQSR, ...) in order to address the following points :

- To review total dose test reports, in order to validate the subcontractor radiation database These data will be used for equipment circuit WCA
- To determine part types that shall be submitted to a characterization and/or a RADLAT, selected parameters to be measured and to review radiation test plan for such parts
- To review proposed packaging design approach to achieve maximum inherent shielding · To review preliminary shielding analysis
- To review preliminary circuit design analysis.
- To review SEU parts data, in order to validate the subcontractor radiation database. These data will be used for equipment SEU effects analysis
- To determine part types that shall be submitted to a Single Event Upset testing, and to review radiation test plan for such parts
- To review circuit SEU effects analysis.
- To review the assessment on displacement damage on electronics if significant.
- ......

RAD-26	**As a minimum, one Radiation Review meeting will be held at sub-contractor facility.**

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