It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is most adaptable to change.

Attributed to C. Darwin

Utilization of COTS in ESA Missions

Presentation to NEPP Electronics Technology Workshop

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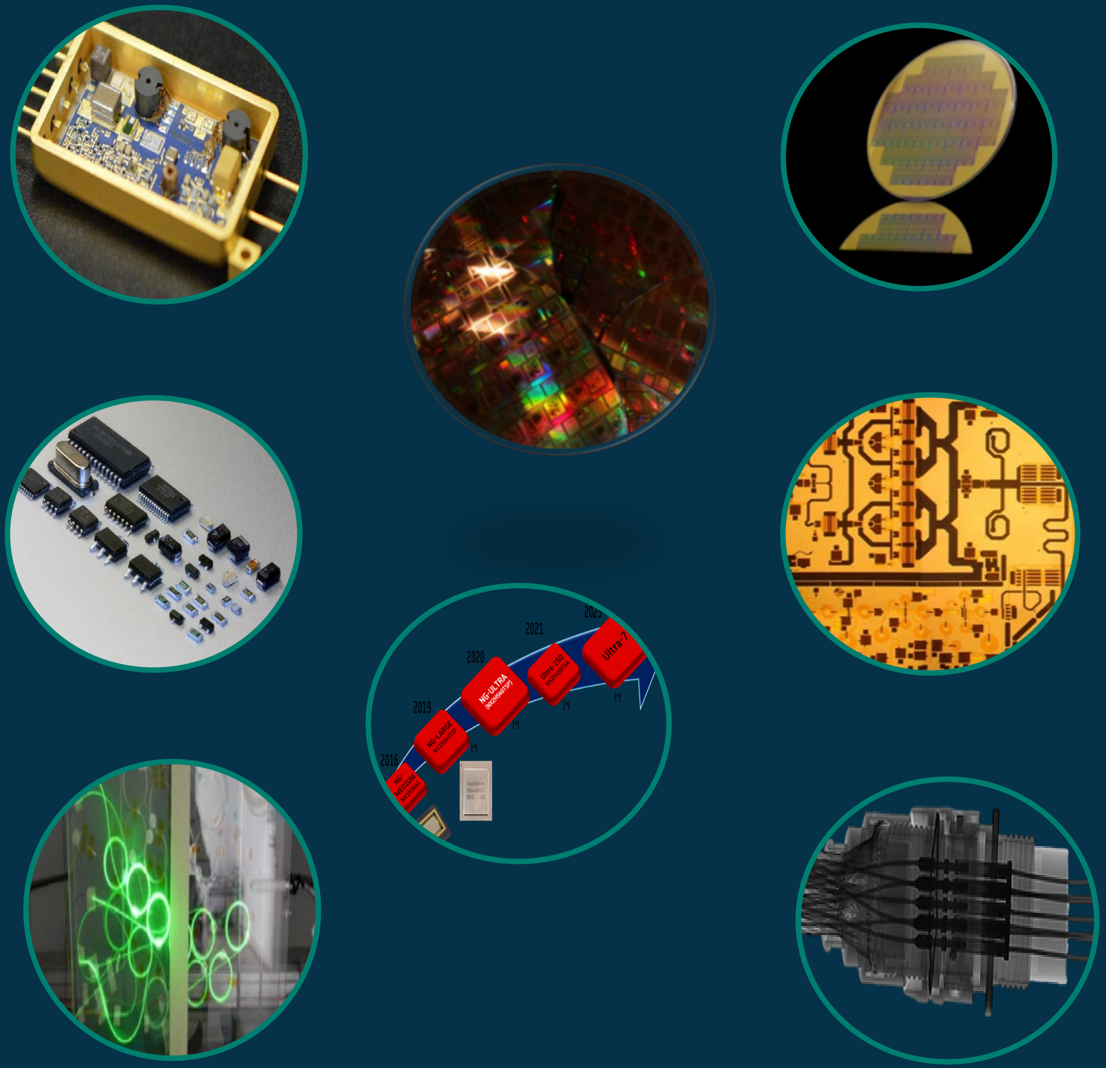
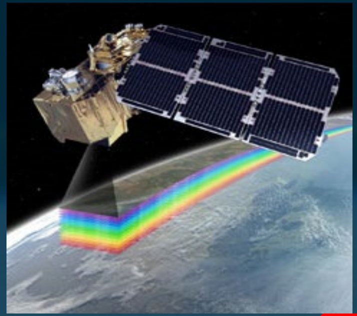
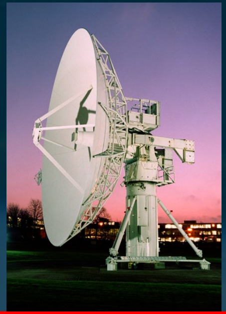
Content

- COTS – key concerns
- ESA COTS Work-plan
- ESA Open space Innovation platform (OSIP)
- ESA Mission Classification
- ESA COTS Guideline Document
- Component Criticality



COTS



Noticeable increase in the use of commercial components (COTS) for space applications.

Cost, performance and availability are the driving factors.

But ..
The supply of EEE-components for space cannot be covered by only COTS.

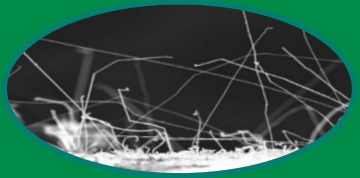
Missions are becoming heavily reliant on heritage units for which EEE availability cannot be maintained based on commercial components.

Some key COTS concerns:

- EEE product cycles are short
- Low traceability
- Minimum order quantities
- Qualification and Reliability
- Maintaining supply chain for ESCC components
- Access to reliable performance/radiation data
- Lack of space heritage
- Design mitigation

ESA COTS Work-plan

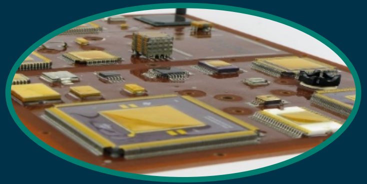
Technical



- Safe Operating Template for Component Criticality Classes
- COTS and Modules Data Information gathering
- Definition of activities for Reference Application Circuits
- New Test Methods for Modules and Boards
- Lead Free WG Recommendations
- Best practices for Radiation Environment and Test

Policy

- ESA COTS synthesis document:
  "Guidelines for the utilization of COTS components and modules in ESA".

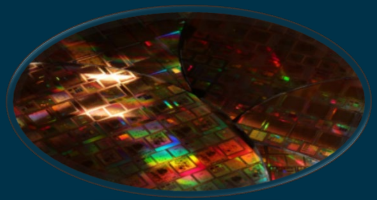


Normative

- COTS Standard ECSS-Q-ST-60-13 update:
  implementing final changes prior to public review.
- Rad Hard devices in "plastic" packages:
  Specification ESCC9000 "P" update in preparation.

Communication

- Coordination, Bilateral Discussions and Workshops:
- ACCEDE workshops (2022),
- Regular bi-laterals with Industry, Agencies,
- ESA-NASA-JAXA trilateral, TRISMAC……



OSIP (COTS) Initial list of targeted topics

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Radiation

- Single Event Effect homogeneity
- Heavy ion failure rate computation in GaN/AlGaN FETs
- Modelling Heavy Ion effects for High Voltage HEMT
- Radiation sensitivity of Photonics Integrated Circuits (PICs) technology
- Board level testing
- DDR-MRAM Spin-transfer
- Radiation effects on wideband transceivers
- Integrated approach for SEE robust designs

Design Mitigation

- SoC lockstep-based SEE mitigation
- Reconfigurable high-performance avionics modelling
- AI Space Computing
- InGaAs Technology for Uncooled Space Cameras
- Radiation-induced errors in COTS microprocessors
- Intelligent solutions for Robotic Applications
- Minimalistic Supervisor Components

Testing & IOD

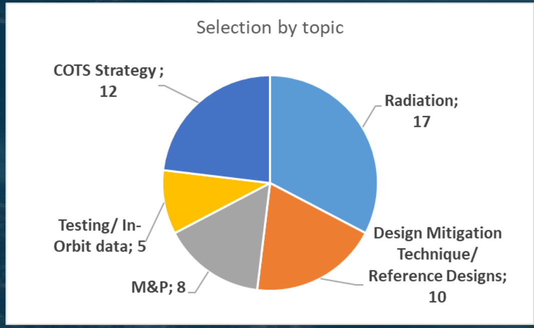
- Reliability analysis of plastic packages
- SEE characterization - Commercial MOSFET
- Extreme temperature effects on Plastic Parts
- Long term wear out testing

M&P

- Delaminations in plastic package
- Pseudo-hermeticity on PEM

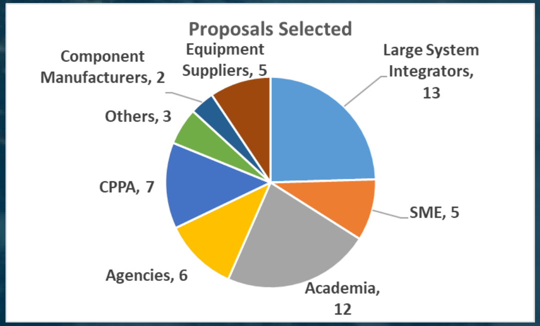
Strategy

- Automotive Certification and Qualification Standards (Processors/SoC)



OSIP call: June 2020
Submitted ideas: 130
Selected ideas: 52

- 20: Early Tech Development (ETD),
- 26: Studies,
- 6: Co-sponsored research



ESA Mission Classification

ESA Mission Classification provides:

- ESA programme and project managers with a framework to define the appropriate management, engineering and product assurance controls, tailored to the profile of the mission.
- A systematic approach for optimising resources in accordance with mission objectives.
- Programme and project managers a framework to develop novel implementation strategies in areas such as project management, system engineering and product assurance.
- A basis for the introduction of novel elements (e.g. COTS) and working methods aiming at reducing development time and cost.
- ESA & its Member States a new structured framework to manage the programmatic risks.

ESA Mission Classification

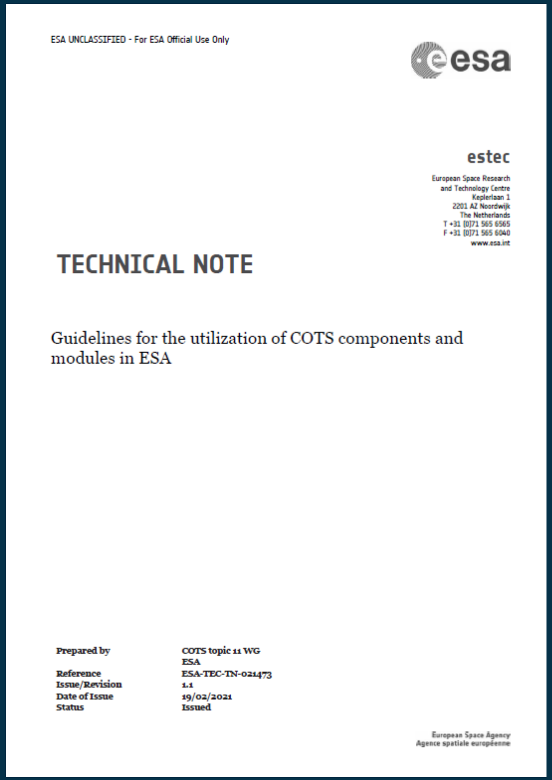
Requirement is to ensure the Mission success within the constraints of available budget and timescale

- Supporting element for mission success is also the equipment criticality
- Can split the mission into elements of different risks
- Tailoring down the requirements to match the mission and equipment classification

Class Type	I	II	III	IV	V
Mission Criteria					
Criticality to the Agency Strategy (flagship mission, international cooperation, impact on ESA Strategic goals and image)	Extremely High Criticality	High Criticality	Medium Criticality	Low Criticality	Educational purposes
Mission objectives (Directorate priority and purpose, e.g. in-orbit demonstration, educational)	Extremely High Priority	High Priority	Medium Priority	Low Priority	Educational purposes
Cost (Cost at completion including phase E1)	>700M€	200-700M€	50-200M€	50-1M€	<1M€
Mission Lifetime (nominal mission life duration)	>10 years	5-10 years	2-5 years	2 years - 3 months	<3 Months
Mission complexity (design interfaces, unique payloads, new technology development)	High	High to Medium	Medium to Low	High (IOD/IOV) Low (Commecially driven)	Low

ESA COTS guideline as an official handbook, why?

- **It is a set of guidelines and not requirements.**
- It contains a very reasoned and balanced approach among all impacted engineering aspects, according to a progressive scheme from higher to lower risk taking.
- It addresses the issue of **small procurement lots** and relevant **lot homogeneity issues**
- Addressing the application of COTS parts in modules, equipment or subsystems of **different criticality categories for ESA institutional missions.**
- It goes beyond a simple and not realistic tailoring of ECSS requirements to address COTS applications for institutional space applications.
- Introduces how commercial standards might be used to allow an effective use of COTS components and modules with a controlled risk posture.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TECHNICAL NOTE

Guidelines for the utilization of COTS components and modules in ESA

Prepared by	COTS topic 11 WG ESA
Reference	ESA-TEC-TN-021473
Issue/Revision	1.1
Date of Issue	19/02/2021
Status	Issued

European Space Agency
Agence spatiale européenne

The ESA COTS guideline has been endorsed by the ESA Quality Standardisation Board to become an official ESA handbook (April 2021)

COTS – Overall Approach w.r.t equipment criticality

COTS EEE Components and modules

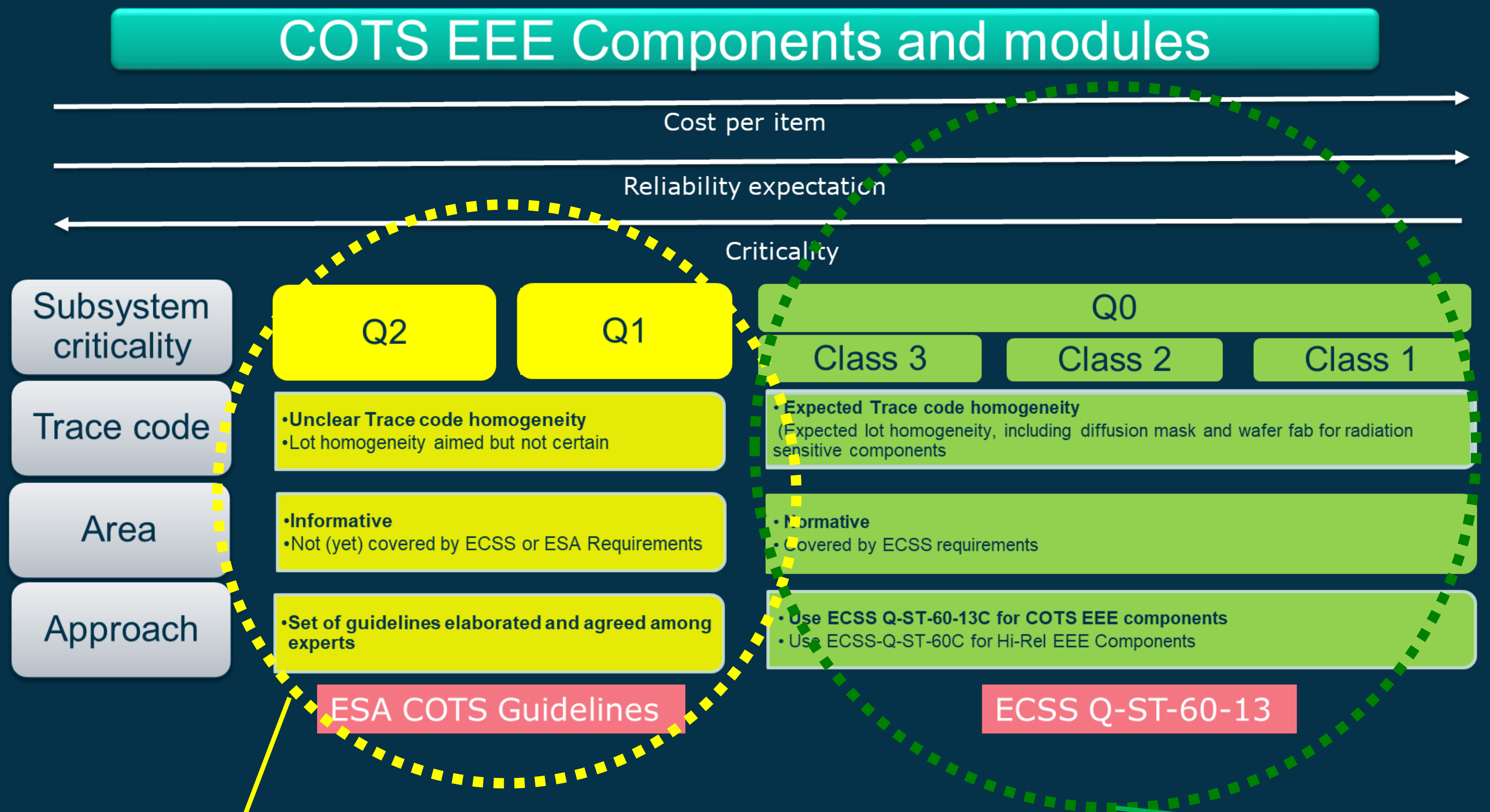
→ Cost per item

→ Reliability expectation

← Criticality

Subsystem criticality	Q2	Q1	Q0: Class 3	Q0: Class 2	Q0: Class 1
Trace code	•**Unclear Trace code homogeneity** •Lot homogeneity aimed but not certain		• **Expected Trace code homogeneity** (Expected lot homogeneity, including diffusion mask and wafer fab for radiation sensitive components		
Area	•**Informative** •Not (yet) covered by ECSS or ESA Requirements		• **Normative** • Covered by ECSS requirements		
Approach	•**Set of guidelines elaborated and agreed among experts**		• **Use ECSS Q-ST-60-13C for COTS EEE components** • Use ECSS-Q-ST-60C for Hi-Rel EEE Components		
	ESA COTS Guidelines		ECSS Q-ST-60-13		

Overall concepts



***"Engineering"* space:**
innovation, experiments, look into the future, recommendations, economy, risk

***"Product assurance"* space:**
solidity, reliability, consolidation, availability, requirements, cost

Relevance of criticality categories for COTS

- ***To expand the possibility to use and fly promising COTS component and modules with limited budget and time impacts***

- ***Allowing a minimum risk taking thanks to the "do not harm" (recommendations) contained – see next slide -***

- ***Giving the possibility to use the dependable telemetry chains of higher mission classes to have reliable information on COTS-based designs functionality and performance***

- ***Finally putting more clarity in R&D so to indicate the risk posture of the developed equipment***

COTS EEE Components and modules

Cost per item →

Reliability expectation →

← Criticality

Subsystem criticality	Q2	Q1	Q0 – Class 3	Q0 – Class 2	Q0 – Class 1
Trace code	• **Unclear Trace code homogeneity** • Lot homogeneity aimed but not certain		• **Expected Trace code homogeneity** (Expected lot homogeneity, including diffusion mask and wafer fab for radiation sensitive components		
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	ESA COTS Guidelines		ECSS Q-ST-60-13		

The "do not harm" principle

- Introduction of a reliable, well designed and validated SAFETY BARRIER to be the interface between equipment of criticality classes (CC) Q_2 / Q_1 and of Q_0
- The scope of the SAFETY BARRIER interface is to avoid that any type of failure can propagate from the item of CC Q_2 / Q_1 to any equipment of CC Q_0 (through power, signal lines, thermal or mechanical interfaces)

Subsystem criticality	Q2	Q1		Q0: Class 3	Q0: Class 2	Q0: Class 1
Trace code	•**Unclear Trace code homogeneity** •Lot homogeneity aimed but not certain		↔ SAFETY BARRIER INTERFACE ↔	• **Expected Trace code homogeneity** (Expected lot homogeneity, including diffusion mask and wafer fab for radiation sensitive components		
Area	•**Informative** •Not (yet) covered by ECSS or ESA Requirements			• **Normative** • Covered by ECSS requirements		
Approach	•**Set of guidelines elaborated and agreed among experts**			• **Use ECSS Q-ST-60-13C for COTS EEE components** • Use ECSS-Q-ST-60C for Hi-Rel EEE Components		
	ESA COTS Guidelines			ECSS Q-ST-60-13		

ESA COTS Guidelines

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Area	Criticality Category	TID limit	*Recommended Mission Application*	*Time limit*
Normative	**Q0**	N/A	*All*	*N/A*
Informative	**Q1**	10-15 Krad (just indicative, see note)	All, **but** depending on the SEE test and validation performed (heavy ions and/or protons)	up to 5 years
	Q2	5 Krad	Low LEO orbits (<400Km), if availability is not required through South Atlantic Anomaly and poles (e.g. the equipment can be switched OFF there) Outer space regions far from stars and radiative planets (e.g. Jupiter) if the equipment is switched ON for reduced time (esp. to reduce the risk of destructive events due to heavy ions or protons)	up to 1 year

- The **TID limit** for class Q2 is **not arbitrary**, but it derives from the simple consideration that many of the common EEE technologies (apart few cases and in general the electro-optical ones) are **able to withstand a radiation level of 5Krad** without major degradation impairing their use.
- The **TID** limit for **Q1** is **only indicative**, taking into account that homogeneity of the procured lot in Q1 is not certain. The TID limit is formulated to keep risk under reasonable control under this circumstances. Higher TID limits can be pursued in Q1, but considering that in spite of the recommended radiation testing there is still the risk to fly something different than what was tested on ground.
- Most of the limitations for Q2 and Q1 derive from environmental considerations relative to SEE (heavy ions and protons), especially of destructive nature (SEL with destructive effects, SEGR, SEB).
- Take care that total dose received is independent on ON/OFF condition.
- Recommended time limit are based on the uncertainty in correlating the results of Tin whiskers susceptibility test (JSD201) and the lifetime of the application.

Critical aspects coverage

For each criticality category Q_2, Q_1, Q_0 the following aspects are addressed:

- Perimeter of application

- Methods to resolve the critical points relevant to
  - ✓ **RAMS** (Safety, dependability, FMECA…)
  - ✓ **Material and processes**
  - ✓ **EEE components** general issues
  - ✓ **Radiation** (TID, TNID, SEE)
  - ✓ **Economy of scale/supply chain**
  - ✓ **Application**, including

    approaches for data sheets review, electrical analyses needs, mitigation techniques, reference application circuits, modules

ESA COTS guidelines – some details…

In red the changes with respect to the previous CC (starting from top)

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Criticality class	What	RAMS	M&P	EEE components	Radiation: TID/TNID	Radiation: SEE	Procurement aspects	Application
Q2	Recommendations!	- "Do not harm" approach - For safety related application, provide the same design features and qualification evidence than for Q_0 items (or not be used) - No quantitative dependability requirements to respect. - There should be ways to observe failures of critical nature - Outage budget should be set	- "Do not harm" approach - for pure Sn finished parts follow GEIA-STD-0005-02 level 1 - for PCBs follow IPC-6012E class 3 or higher - for soldering, the requirements of IPC-J-STD-001 class 2 maybe used, class 3 is recommended - do not use materials which may cause safety hazards -outgassing properties to be controlled if it is a concern	- AEC-Q components are preferred - recommended manufacturer's temperature range -40°C to 85°C or wider - as per M&P for safety hazards and outgassing - avoidance of critical EEE parts - minimum DCL provision	- Radiation analysis to be provided - If TIDL < 5KRad (Si) then untested COTS may be used - Warning for components sensitive below 5KRad limit - Reliance on design robust to TID parametric drifts - TNIDL to be calculated for opto-devices - strong advice to test optoelectronic components for TNID in proton rich environments	- Radiation analysis to be provided - SEE experimental verification recommended, not required, with high energy protons - strong reliance on SEE mitigation techniques at design level	- Procure from official distributors only and directly from manufacturers if possible - Procure complete reels of components - Keep traceability to date codes, aim for lot homogeneity.	- Check of datasheet information by test for critical parameters - Apply deratings equal or in excess of Q_0 standards, even though formal delivery of PSA is not required - Consider degradation effects on WCA parameters (apart ageing, but taking into accout typical or specific effects of radiation), even though formal delivery of WCA is not required - Apply design mitigation techniques at component, module/board and system/subsystem level to avoid radiation effects and random failures (lots of information provided in the document) - Resort to reference application circuits - Special provisions for COTS modules
Q1	Recommendations!	- "Do not harm" approach - For safety related application, provide the same design features and qualification evidence than for Q_0 items (or not be used) - Quantitative dependability recommendations (FIDES approach) - There should be ways to observe failures of critical nature - Autonomous recovery - Robust FDIR at system level	- "Do not harm" approach - for pure Sn finished parts follow GEIA-STD-0005-02 (at least control level 2B) - for PCBs see document annex 5 - for soldering, document annex 6 - do not use materials which may cause safety hazards - outgassing properties to be controlled if it is a concern - DML, DPL and DMPL provision	- AEC-Q components are preferred - recommended manufacturer's temperature range -40°C to 85°C or wider - justification document as per ECSS-Q-ST-60-13 annex F - follow ECSS-Q-ST-60-13 class 3 with some relaxation - as per M&P for safety hazards and outgassing - avoidance of critical EEE parts - minimum DCL provision	- Radiation analysis to be provided - TID/TNID tests on components unless 3x margin can be demonstrated at board/module level - If TIDL exceeds 5 KRad (Si), test according to ESCC 22900 - If TNIDL exceeds 2E11 p/cm2 50 MeV equivalent proton fluence, test bipolar technologies according to ESCC 22500 - Test Optoelectronic in any case according to ESCC 22500 - Specific ERCB (Equipment Radiation Control Board) to be done	- Radiation analysis to be provided - If the EEE components can be delidded and the chip exposed, test for SEE heavy ion, otherwise test with high or very high energy HI facilities - if the above cannot be done, test at least with high energy protons - SEE tests at component or board/module level - The following SEE LET threshold (LETth) acceptance levels should be applied: * For any SEE effects (destructive and non-destructive): LETth > 38 MeV.cm²/mg: EEE components or board is accepted * For destructive effects with no mitigation possible (inclusive destructive SEL): LETth =< 38 MeV.cm²/mg: part or board should not be used * For non-destructive effects (inclusive non-destructive SEL): ** LETth =< 38 MeV.cm²/mg: component or board accepted with mitigation implemented and tested, and SEE analysis should be performed for GCR & solar heavy-ions ** LETth < 15 MeV.cm²/mg: Proton test should be performed and additional SEE analysis should be performed for trapped & solar protons. - The LETth levels as described above should be revised for EEE components made of a material other than Silicon (i.e. GaAs, GaN, SiC, ...) - The effectiveness of any SEL mitigation to be demonstrated during irradiation tests. - Specific ERCB (Equipment Radiation Control Board) to be done	- Procure from official distributors only and directly from manufacturers if possible - Procure complete reels of components - Keep traceability to date codes - Aim for lot homegeneity and as needed check for procured lot (marking, visual, X-ray, sample measurements) - Re-lifing possible following ECSS-Q-ST-60-14	- Check of datasheet information by test for critical parameters - Apply deratings equal or in excess of Q_0 standards - Delivery of PSA - Consider degradation effects on WCA parameters (including ageing, and taking into accout typical or specific effects of radiation) - Delivery of WCA - Apply design mitigation techniques at component, module/board and system/subsystem level to avoid radiation effects and random failures (lots of information provided in the document) - Resort to reference application circuits - Special provisions for COTS modules
Q0	Requirements!	As per applicable ECSS RAMS standards	As per applicable ECSS M&P standards - For pure Sn finished parts follow GEIA-STD-0005-02 (control level 2C) - Assembly processes verification for Q0 class 3 should comply with the approaches defined in document Annex 6	As per applicable ECSS EEE components standards	As per applicable ECSS and ESCC TID/TNID standards	As per applicable ECSS and ESCC SEE standards	- As per applicable ECSS and ESCC standards - Traceability of EEE components should be ensured between the parts subjected to evaluation, screening and lot tests on ground and the ones that are used for flight purposes	- Check of datasheet information by test for critical parameters - Apply deratings as per relevant ECSS standard - Delivery of PSA - Consider degradation effects on WCA parameters (including ageing, and taking into accout typical or specific effects of radiation) - WCA to be done following relevant ECSS handbook - Delivery of WCA - Apply design mitigation techniques at component, module/board and system/subsystem level to avoid radiation effects and random failures (lots of information provided in the document) - Resort to reference application circuits - No COTS modules in Q0, the adoption of COTS parts is controlled at EEE components only

Example of internal activities

COTS Topic 2, Safe Operating Template For Criticality classes Q2 and Q1

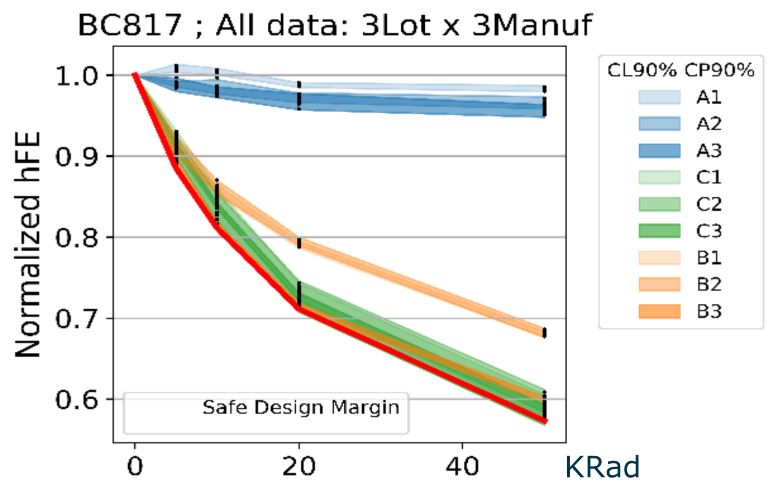
Topic 2, Safe Operating Template For Criticality classes Q2 and Q1

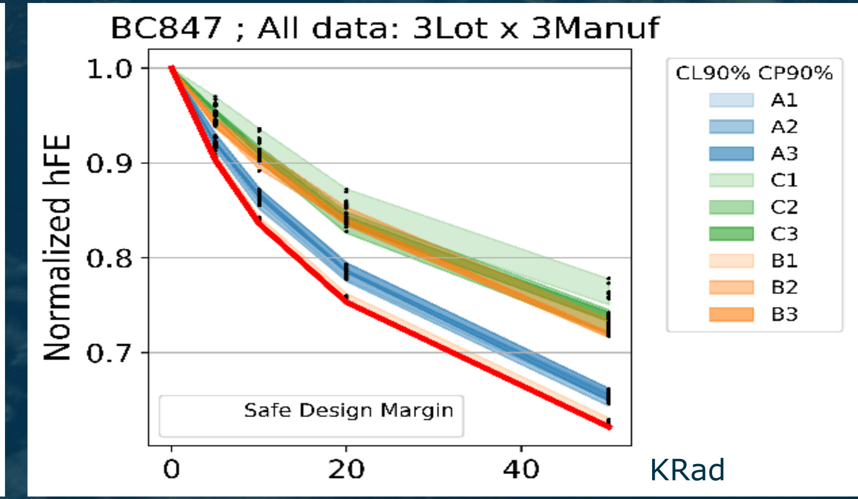
Scope

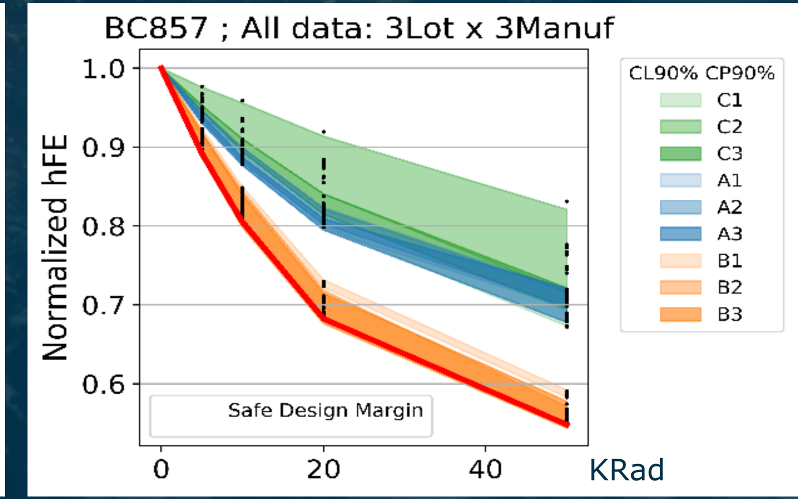
- Identification of safe operation factors for criticality categories Q2 and Q1

Status

- Organised "intelligent DB" structure to collect and identify variability in TID of key components parameters (for example, hfe on BJTs, Vref on band gap references)
- Tested 270 COTS BJTs in radiation from different manufacturers and production lots
- Collected and elaborated data for 322 BJTs low power PNP, NPN to identify max "envelope" percent hfe loss in function of TID level







Topic 2, Safe Operating Template For Criticality classes Q2 and Q1 (cont'd)

Status (cont'd)

- Procurement of promising COTS band gap reference components is being organised, to get variability of relevant reference voltage and extrapolate its max percent deviation with TID
- Tests foreseen in Q2/2021 in TEC-QEC lab

Next Steps

- Conclusion of ongoing band gap reference exercise
- Drafting of "intelligent DB" structure guideline to extend the method to other components
- Publication of data and guideline in a Sharepoint repository
- Continuation of the effort as a low profile continuous activity

Completion (apart last bullet)

- Q2/2021

Thanks for your attention

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Acronyms list

AEC	Automotive Electronics Council	**LET**	Linear Energy Transfer
AEC-Q	The set of AEC automotive qualification standards	**LETth**	LET threshold
AI	Artificial Intelligence	**M&P**	Materials and Processes
BJT	Bipolar Junction Transistor	**DMPL**	Declared Materials and Processes List
COTS	Commercial Off The Shelf (components and modules)	**MRAM**	Magnetoresistive Random Access Memory
DB	Database	**MTTF**	Mean Time To Failure
DCL	Declared Components List	**OSIP**	Open Space Innovation Platform
DDR	Double Data Rate (memory)	**PSA**	Parts Stress Analysis
DML	Declared Materials List	**RAMS**	Reliability, Availability, Maintainability, Safety
DPL	Declared Process List	**RF**	Radiofrequency
ECSS	European Cooperation for Space Standardisation	**SEB**	Single Event Burnout
EEE	Electrical, Electronic and Electromechanical	**SEE**	Single Event Effect
ERCB	Equipment Radiation Control Board	**SEGR**	Single Event Gate Rupture
ESCC	European Space Components Coordination	**SEL**	Single Event Latch-up
FDIR	Failure Detection Isolation and Recovery	**SW**	Software
FPGA	Field Programmable Gate Array	**TID**	Total Ionizing Dose
GEIA	Government Electronics & Information Technology Association	**TIDL**	Total Ionizing Dose Level
GNSS	Global Navigation Satellite System	**TNID**	Total Non Ionizing Dose
GPU	Graphics Processing Unit	**TNIDL**	Total Non Ionizing Dose Level
HEMT	High Electron Mobility Transistor	**WCA**	Worst Case Analysis
HW	Hardware	**WG**	Working Group
IPC	Institute of Interconnecting and Packaging Electronic Circuits		