ECSS-Q-ST-60
EEE Components in ESA missions (and beyond)

Lionel Bonora

Senior EEE engineer, ESA/ESTEC

2023

Summary

- Product Assurance … let’s set the scene
- 1/ What is EEE?
- 2/ Space Environment: what a wonderful world for EEE !!
- 3/ The tablets of Law: EEE standards and specifications
- 4/ EEE Components major failure mechanisms
- 5/ Reliability and Reliability testing
- 6/ EEE DERATING
- 7/ EEE requirements in space projects
- 8/ The future -- “New Space” ?
- 9/ A few words on COTS (Components off the Shelf)
- 10/ Conclusions
- Annexes: Useful links and acronyms

Preamble: PA, what for ?

Product Assurance

A discipline devoted to the study, planning and implementation of activities intended to assure that the design, controls, methods and techniques in a project result in a satisfactory level of quality in a product (ECSS-S-ST 00-01C)

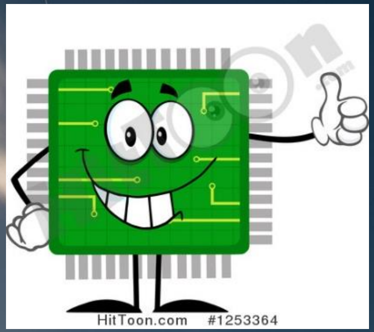
Now let's try to formulate a more practical version:

- To make as sure as possible that all the EEE parts used in ESA missions will
  - Perform their required functions (*they do the job* …)
  - In the defined mission conditions
  - When you need and for as long as you need
    - i.e. they are **RELIABLE** in their application

To help achieve that purpose, there is rules/requirements, based on years of experience, and failure, from many experts in Europe, and translated into **ECSS Standards**

Chapter 1

But first …
what do we mean by EEE?

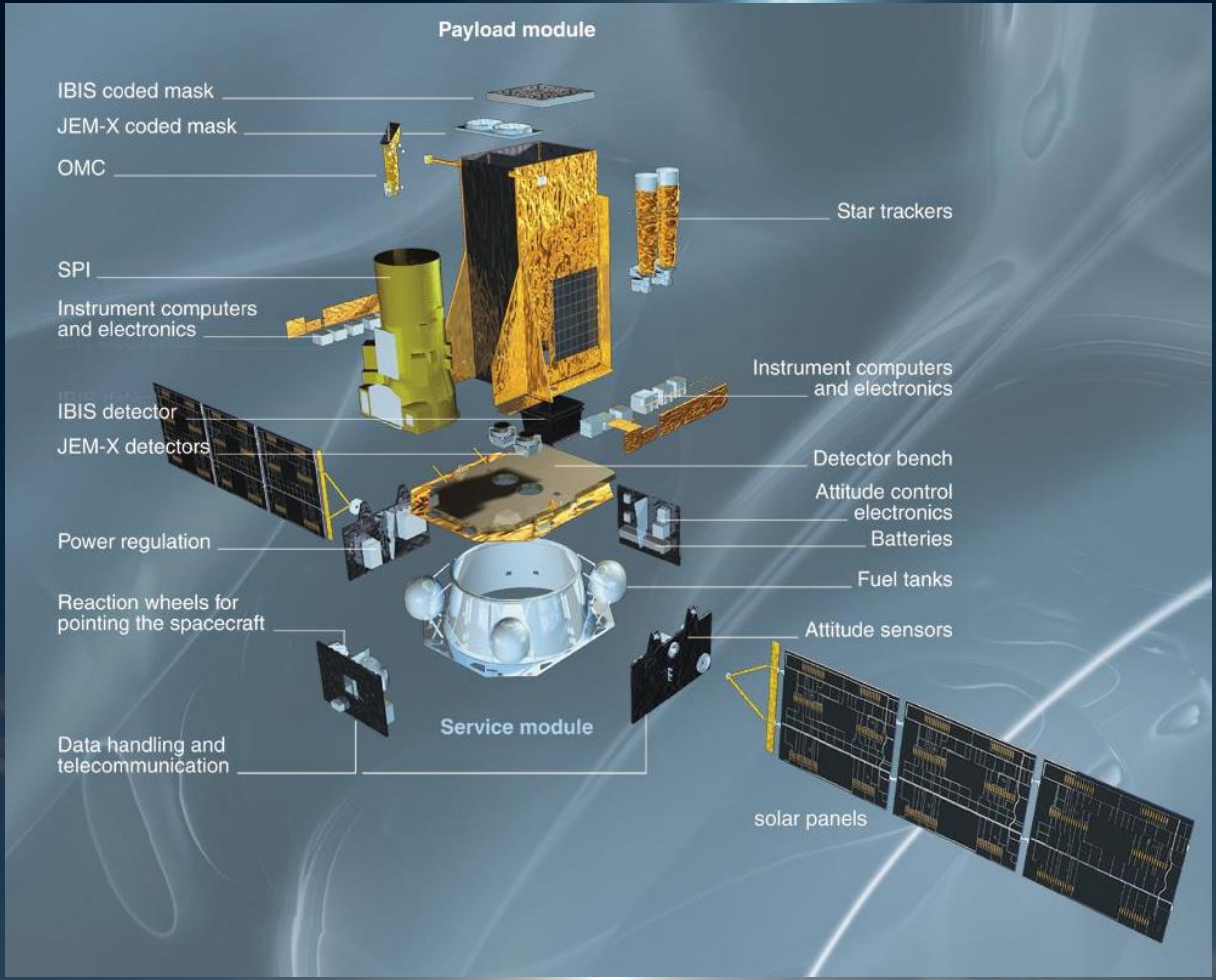


Where are the EEE parts ?

WARNING
ACRONYMS
AHEAD

- Many types of satellites wrt orbits, functions, lifetime etc… but
- Many commonalities in the overall structure as well, you always need:

- 1/ Power
- 2/ Altitude/orbit control
- 3/ Propulsion
- 4/ Thermal control
- 5/ Telecommunication
- 6/ Command and data handling
- 7/ Payload



1/ Solar array deployment (SADE/SADM), battery control, power conditioning (EPC, PCDU) …

2/ Reaction wheels (RW), inertial control (IMU), Sun sensors, star trackers, navcam …

3/ Thruster control …

4/ Heaters …

5/ Antennas and pointing mechanisms (ADPM), transponders, power amplifiers (SSPA), wave tubes (TWTA) …

6/ computer (OBC), mass memory (MMU) …

7/ sensors, antennas, radars, read out electronics (ROE), processing etc …

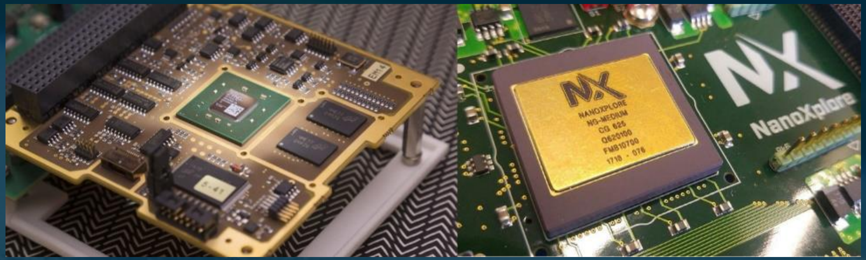
8/ and harnesses

And EEE are in most

What do we mean by EEE ?

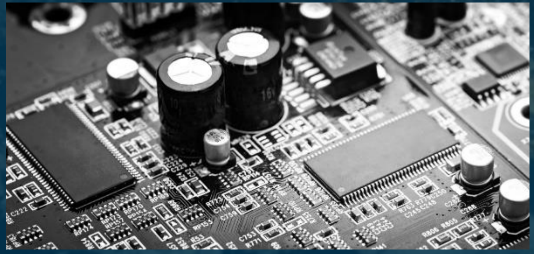
Many different families !

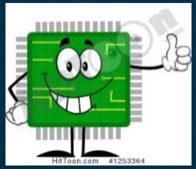
- Silicon based (analog, digital, mixed
- Power (Si, GaN)
- Radio Frequency (GaAs, GaN)
- Hybrid
- Photonics
- Micro / Nano tech.
- Passive
- Electro-mechanical
- Connectivity



X 10000€ each

~10€ each (space grade)
<1 € for good commercial





Significant part of an equipment cost , up to ~ 25-75% (down to ~10% or less if the launch and ground segment cost are included)

ECSS families – to be found in DCLs

Passive parts

1. Capacitors / 3. Crystals / 5. Filters / 6. Fuses / 7. Magnetics (e.g. inductors, transformers, including in-house products) / 11. Resistors, heaters / 14. Thermistors

Connectivity

2. Connectors / 15. Wires and Cables

Electromechanical

10. Relays / 13. Switches (including mechanical, thermal)

Hybrid

9. Hybrid circuits

Active parts

4. Discrete semiconductors (diodes and transistors) / 8. Monolithic Microcircuits (including MMICs (RF)) / 16. Optoelectronic Devices

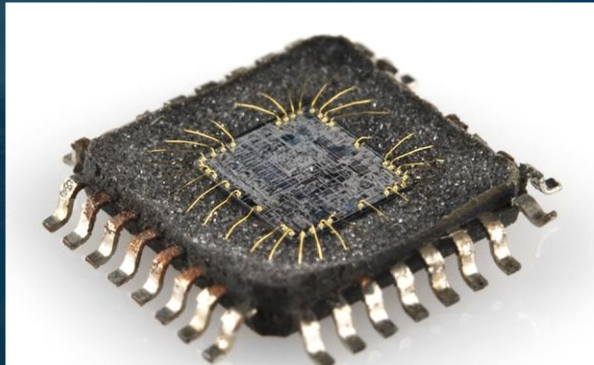
RF passive parts

12. Surface acoustic wave devices / 17. Passive Microwave Devices

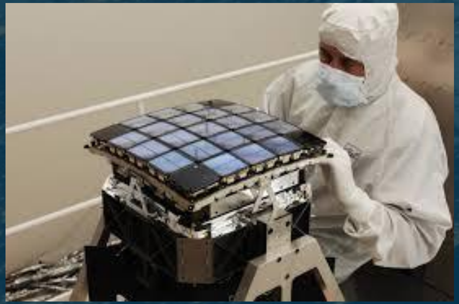
EEE types

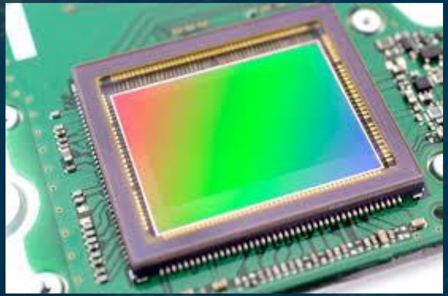
Semiconductor based, not RF:

- *Discrete*: diodes , transistors, power Mosfets, power diodes
- *Integrated*: digital (FPGAs, microprocessors, memories, ASICs, etc.), analog (Amplifiers, comparators, references etc.), conversion (DAC & ADCs), power management (e.g. PWMs) and sensing.



Not really flightworthy anymore...





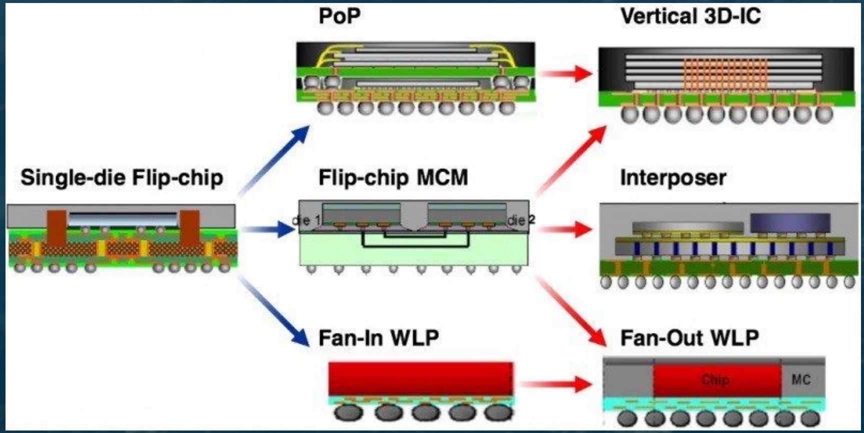
Photonics:

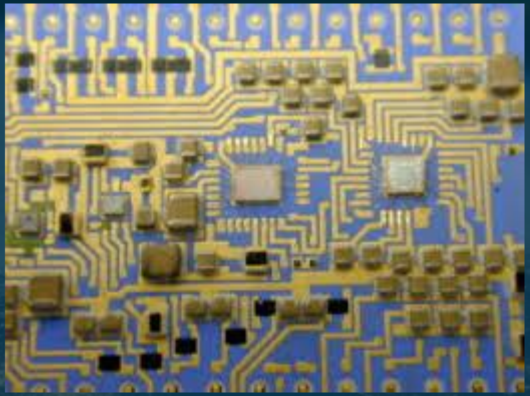
- Light Sources: lasers, LEDs …
- Light Detection: diodes PIN and APD (Active Pixel Diode)
- Fiber optics links and Fiber Based Communication systems
- Laser pumped optical Atomic Clocks
- Quantum Technologies
- Detectors: CCD, CMOS...from UV to far IR

EEE types

Hybrid Components and Packaging:

Hybrid circuits include; thin and thick film technologies with integrated and discrete passives and active components as well as the associated packaging, sealing, die attach and wiring techniques.

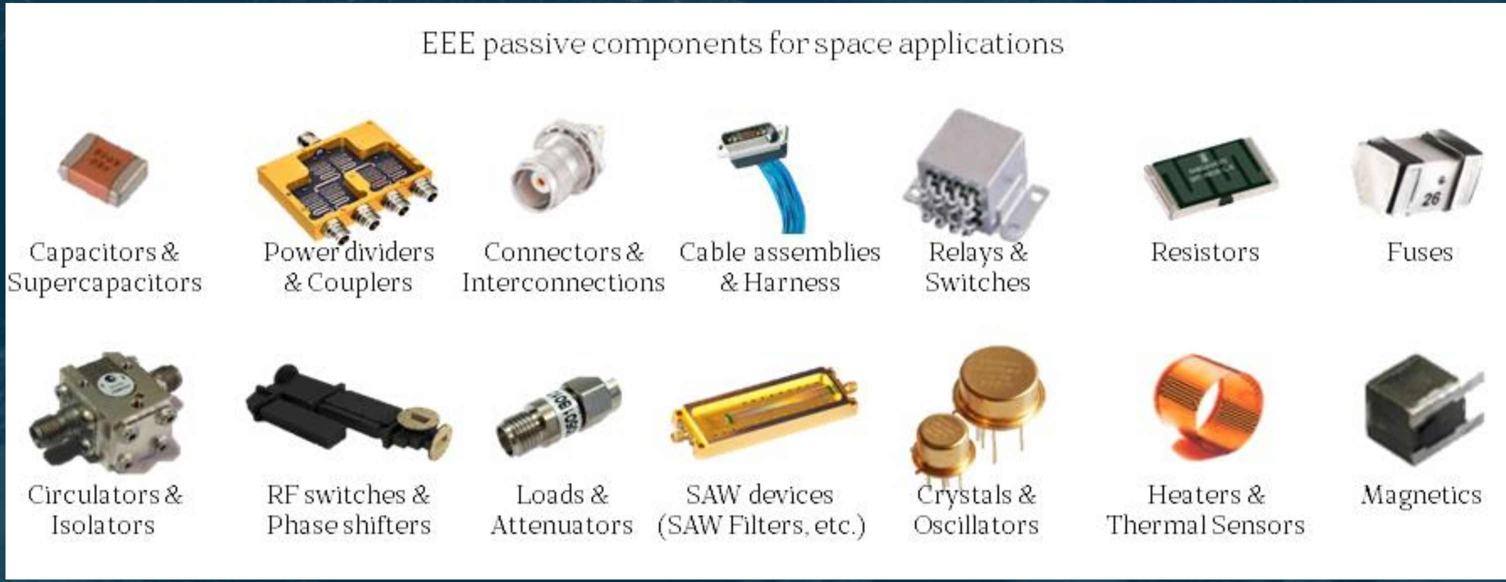




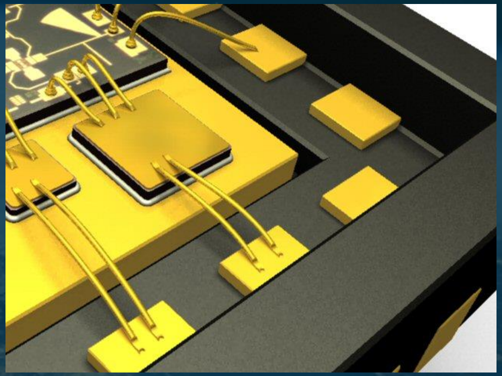
Hybrid does not mean necessarily Japanese car …

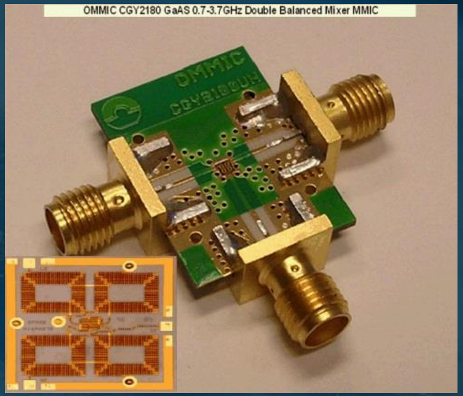
Passive and RF passive components:

resistors, capacitors, connectors & cables, relays, switches, circulator & isolators (RF), crystals, oscillators, SAW filters etc.



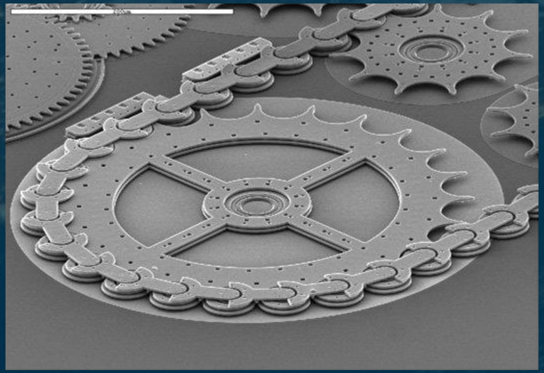
EEE types





RF, Microwave, mmwave and sub-mmwave devices and MMICs:

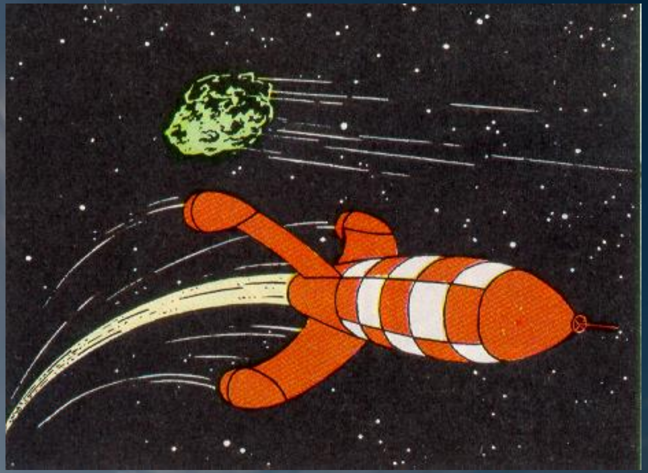
GaAs components, Si, SiGe devices, and Wide Bandgap (GaN and SiC) semiconductor technologies. Including discrete components and MMICs (Microwave Monolithic Integrated Circuits).



MNT Components:

MEMS devices (*AOCS*: MEMS accelerometers, gyroscopes, IMUs, magnetometers. *Propulsion*: pressure sensors, Nozzles, Gas Filters, Thrusters *RF MEMS:* RF Switches and matrices, MEMS RF filters, varactors, phase shifters,

SPACE ENVIRONMENT
What a wonderful world !



Space Environment

- Each space mission remains a challenge
  - Large financial investments
  - Long duration, some years to 15/18 years (Geo Telecom)
  - Harsh environment
  - Complex technologies, large number of components
  - Limited production (except for constellations)
- Reliability assessment & ground testing are essential
  - Remoteness = no repair
  - Qualification = Verification that every component will survive the mission(s)
  - Reliability testing addressing all the constraints (pre-launch, launch. Flight incl. cruise if significant)

Keep in mind the complete mission profile … the journey starts on the ground

Space Environment

- Pre-launch: assembly, testing, humidity, ESDs etc.

  (Humidity includes cleaning fluids)

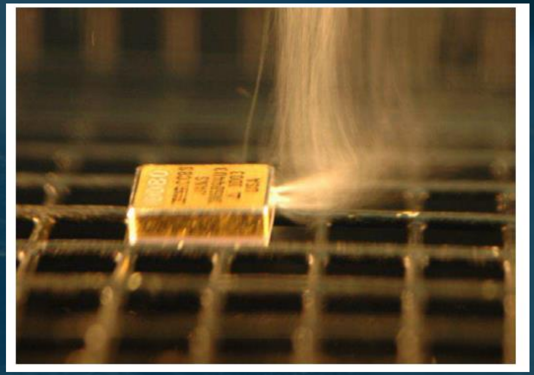
- At launch, some typical values:
  - Launch shock ~ 15g, 8-10 ms, sawtooth
  - Launch "steady state" acceleration
  - ~ up to 10g (A5 ~5g, Saturn ~8g)
  - Vibrations ~ 15g rms
  - Acoustic Env. ; up to 140 dB (A5) -> pressure waves, random vib.
  - Pyro shocks (stages separation) ~ 3000g, 0.25 ms

source IEEE

- In flight
  - Thermal cycling ~ -20°C to 60/70°C (controlled interior)
    - ~ -160°C to 220°C (uncontrolled ext.)
  - Vacuum → outgassing , thermal dissipation problems
  - On / Off cycles
  - Radiation (Sun, Earth Belts, Deep Space)
  - Atomic oxygen (low orbits)
  - Specific conditions for deep space missions
  - Corona and multipactor effects
  - High Voltages (specific applications but increasing trend)
  - Space debris

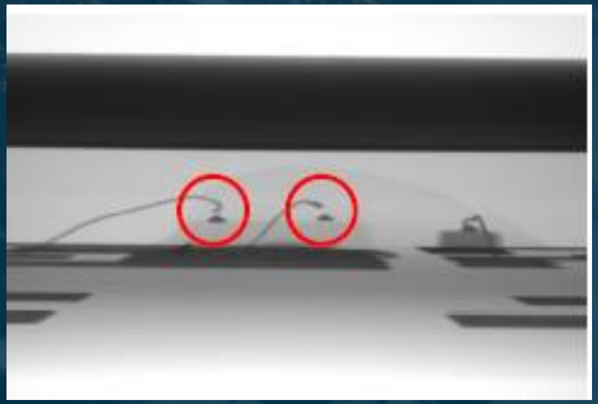
Thermal Constraint

The Sun can generate flux which varies with seasons (approximately 1500W/m^2) and which can raise the temperature of exposed systems up to + 220°C
- When in shadow: temperature can then go down to - 150°C



⇒In extreme conditions, temperature gradient can reach 300°K, certain missions can have up to 15/17 thermal cycles per 24 hours depending on their orbit.

⇒This has thermoplastic effects which can influence CTEs (Coefficients of Thermal Expansion) and other material properties, the thermal dimensioning for space is very specific, coolers and heaters are often required to maintain temperature gradients between ~ -20°C to 60°C of internal subsystems

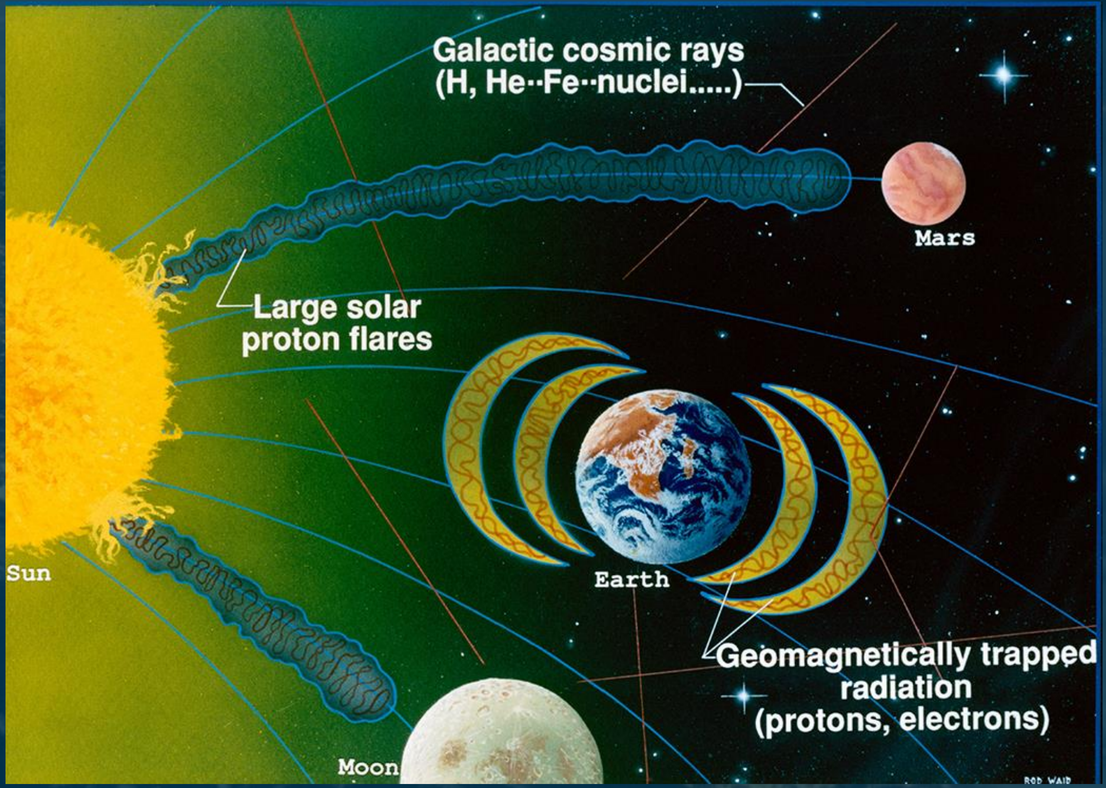


Radiation

The causes

- Solar Events - protons & heavy ions
  - solar cycle ~ 11 years with max activity ~ 7 years
  - solar wind - continuous flux of very low energy p^+
  - solar flares – a few days each, high energy p^+ & HI

- Earth's Radiation Belts – protons & electrons
  - e^- : inner belt ~ 10^4km ; outer ~ 4.10^4km
  - p^+: between 600 and 10^4 km
  - high energies: e^- up to 7 MeV; p^+ up to 400 MeV



Cosmic Rays – 85% p^+ ;14% α ; 1% HI

Very high energy levels (up to 10 GeV per nucleon)

A long time ago in a galaxy far, far away…

Radiation

Science RSS

Space Radiation Blamed for Phobos-Grunt Crash

Topic: **Phobos-Grunt spacecraft**

The recent crash of Russia's Mars probe was caused by a glitch in the onboard computer system under the impact of space radiation, Federal Space Agency head Vladimir Popovkin said on Tuesday.

14:52 31/01/2012 © RIA Novosti.

VORONEZH, January 31 (RIA Novosti)

Tags: Phobos-Grunt, Roscosmos, NASA, Vladimir Popovkin, Voronezh, Russia

Space radiation triggered a glitch in the on-board computer system causing the recent crash of Russia's Mars probe, Federal Space Agency head Vladimir Popovkin said on Tuesday.

"Two components of the onboard computer system were spontaneously rebooted and it switched into a standby mode," he said.

Related News

- Russia to Test if U.S. Radar Downed Phobos Probe
- Russian Deputy PM Rogozin to oversee investigation of Phobos-Grunt failure

- **Nature – Feb. 2012**

Failed Mars probe Russia's Phobos-Grunt spacecraft, which failed to escape Earth orbit in its attempt to reach Mars's moon Phobos last year, was doomed by electronics components not certified for use in space, which in turn led to a computer glitch, according to an official analysis commissioned by the country's space agency, Roscosmos. Its main conclusions were released on 3 February. Once the craft reached orbit, **two electronics chips suffered radiation damage (which they had not been designed to withstand), causing two processors to reboot and crashing the on-board computer program**

Electrostatic charges

Reproduction in 2004 by JAXA labs of the of the failure recorded in October 2003

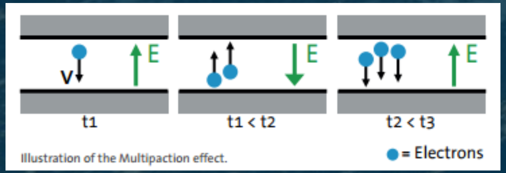
Loss of ADEOS 2 on 25 October 2003

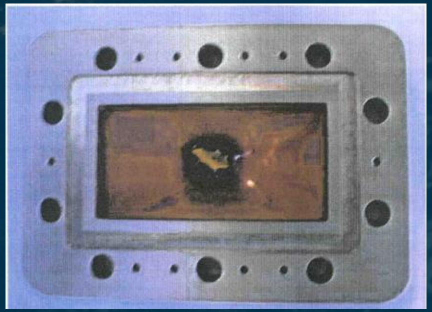
- Solar eruption on 24 Oct. 2003
- Charges accumulation (e-) on the sur les MLI (Multi Layers Insulation): thermal protection: resulted in electrostatic voltage > 600 V
- Breakdown between the MLI et surroundings cables
- Lost of the power supply

Corona & Multipactor effects

Spontaneous **corona discharges** occur naturally in high-voltage systems unless care is taken to limit the electrical field strength. The corona will occur when the strength (potential gradient of the electric field around a conductor) is high enough to form a conductive region, but not high enough to cause electrical breakdown or arcing to nearby objects

Known as fires of Saint Elmo…



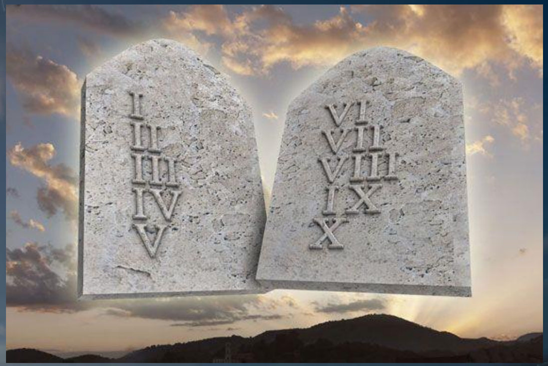


Multipaction breakdown on a waweguide window

Multipaction effect :

The multipaction effect is a phenomenon in RF amplifier, vacuum tubes and waveguides, where, under certain conditions in terms of RF power and vacuum level, secondary electron emission in resonance with an alternating electric field leads to exponential electron multiplication, possibly damaging and even destroying the RF device.

The tablets of Law:
The different standards and specifications



Why do we need standards and specifications ?

esa

- Standards provide people and organizations with a basis for mutual understanding, and are used as tools to facilitate **communication**, **measurement** and **manufacturing**.

- Standards are everywhere and play an important role, by:
  - facilitating interaction
  - enabling companies to comply with relevant requirements
  - providing interoperability between new and existing products and processes

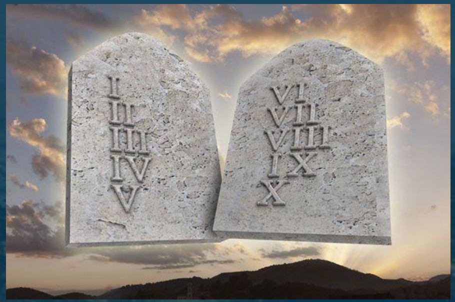
- Standards also disseminate knowledge in industries where products and processes supplied by various providers must interact with one another.

- For space activities major standards and specifications are ECSS (Europe, all space domains) , ESCC (Europe, EEE components). US-MIL (US, EEE components)

The Tablets of Law

- To help achieve the reliability / robustness objective, there is rules/requirements originated in years of experience (and mistakes) of many experts

  - ➢ That's what is captured in **ECSS standards**



EEE: Q60 series and Q30 for derating

- The standard defines 3 EEE component classes (class 1= highest level of assurance, lowest risk … and highest cost)
- For each class and type of component, to get a consistent approach across projects, the standard specifies
  - The baseline quality level as defined in recognized international systems
    - ➢ US-MIL (QML, QPL, JAN, FR etc.) & ESCC ** for Europe
  - How to achieve an equivalent level for parts without existing qualification, or how to up-screen commercial parts

*** (warning: ESCC and ECSS are different things)*

  - Specific tailoring / recommendations will be released shortly, targeting low cost missions where high risk is accepted

(outcome of the COTS and Mission Classification WGs)

Of course the standard does not prevent application of common sense wherever pertinent (mission profile is the key)

Other systems

- **Launchers** have their own set of requirements addressing their specificities (short duration, several stages, high mechanical constraints, passenger equipment etc.) but they are derived from ECSS (at least for the recent ones)

- With the emergence of "New Space", an other system is more and more considered (esp. by industry):
  - **AEC** (for Automotive Electronics Council), Q series

    → *Does it mean that we fly cars now ? … not really, at least for most of us*
  - Differences with classical military / space dedicated systems are significant and make their use not straightforward

ECSS

- **ECSS**:
  - The European Cooperation for Space Standardization was established to develop
  - a coherent, single set of standards for use in all European space activities

- **ECSS-Q-ST-60:** Requirements for **Space PA for EEE components** at equipment level
  - It defines for the 3 classes *what to do*, not *how to do*
  - It addresses:
    - Component management (PCB, DCL, PADs etc.)
    - Selection, evaluation, approval
    - Procurement, control, handling, storage
    - QA aspects
  - Some “grey” areas exist between the 2 systems (e.g. Q-ST-60-05 for Hybrids, Q-ST-60-12 for MMICs)


Space product assurance
Electrical, electronic and electromechanical (EEE) components

ECSS-Q-ST 60

- For each class and for each type of component, the ECSS standard specifies the baseline in terms of acceptable quality level as defined in recognized international systems:
  - US-MIL (QML, QPL, JAN, FR etc.) or ESCC
  - and how to achieve an equivalent level for parts without formal qualification or commercial

	Class 1	Class 2	Class 3
Screening level examples	QML V, K JANS FR R, C ESCC B	QML Q, K JANTXV FR R, C ESCC B	QML Q, H JANTXV FR R, C ESCC B
LAT/QCI on qualified product		None	
LAT/QCI on non-qualified product	Required, 2 year old data can be accepted	To be agreed	To be agreed
Precap on qualified product	Relays, crystals, oscillators, hybrids	None	
Precap on non-qualified product	Extensive list	Relays, crystals, oscillators, hybrids	None

ECSS-Q-ST 60

	Class 1	Class 2	Class 3
DPA on qualified product	Relays and oscillators	None	
DPA on non-qualified product	Extensive list	Relays, oscillators, commercial parts	Relays, commercial parts
Evaluation	"…in absence of an approved demonstration that a component has the ability to conform to the requirements …"		

	Class 1	Class 2	Class 3
Commercial components*	Extensive evaluation, screening and LAT.	Extensive evaluation. LAT and screening based on results.	Minimum evaluation; constructional analysis and radiation test.
Radiation	Reference to ECSS-Q-ST-60-15		
Organization	DCL, PAD, JD PCB		DCL, PAD, JD No PCB

* For standard monolithic active parts only (passive parts are in process to be included)

Mission classification in a (tiny) nutshell

-New concept (at ESA) , addressing all domains, including EEE (as well as materials, SW, rad etc.)

-At that stage only at mission level, not at equipment level yet

-Rather straightforward for EEE, thanks to existing Q60 classes

-Basically

- -Mission cat. 1 /2 /3 imply Q60 classes 1 /2 /3 respectively
- -Cat. 4 is class 3 with some further relaxations (e.g. AEC-Q parts can be used “as is”)
- -Cat. 5: No harm philosophy (like the existing ISS payload policy)

-More complex for radiation as they are not class based but environment based

- -Cat 1 /2 : full RHA (as per Q60-15) applicable
- -Cat 3 / 4/ 5: lower requirements wrt RDM & SEE threshold, board level testing possible etc …)

-Launchers are not included

ECSS-Q-ST-60 series

- ECSS-Q-ST-60-02C – ASIC and FPGA development
- ECSS-Q-ST-60-05C Rev.1 – Generic procurement requirements for hybrids
-
- ECSS-Q-ST-60-12C – Design, selection, procurement and use of die form monolithic microwave integrated circuits (MMICs)
- ECSS-Q-ST-60-13C – Commercial electrical, electronic and electromechanical (EEE) components → see chapter 9
- ECSS-Q-ST-60-14C – Relifing* procedure
  - * Relifing is a term for assuring old (>7 years) parts still fit for flight
- ECSS-Q-ST-60-15C – Radiation hardness assurance
- ECSS-Q-ST-30-11 – Derating
- ECSS standards can be found on http://ecss.nl/

ESCC

- ESCC stands for **European Space Components Coordination**
- Applicable to European EEE components
- ESCC
  - An international system for the specification and qualification (by ESA), and procurement (by users) of EEE components for use in Space programmes
    - Requirements for the manufacture and qualification of Hi-Rel EEE components so as to achieve the performance and reliability levels demanded by space applications
    - Programmes for EEE component research and development
  - ESA and National Space Agencies resources manage the system
  - Qualification Authority is ESA
  - Products are listed for reference on the ESCC QPL/QML,
  - An EPPL (European Preferred Part List) assists projects with type standardization and type diversity reduction taking advantage of successful results

ESCC

- The ESCC System is a self standing system which provides for
  - The technical specification of EEE parts
  - Methodologies for component evaluation and qualification
  - Outline of necessary test methods
  - Quality Assurance requirements
  - Operational provision

- All ESCC Specifications are freely available from the ESCIES web site. The web address is https://escies.org

ESCC

- Documentation structure

- A total of 5 levels of documents and specifications

- For users, only 3 levels need to be known
  - BASIC Specs: objectives, test methods, qualification methodologies and general requirements applicable to all ESCC components
  - GENERIC Specs: requirements for screening, periodic or lot acceptance testing and qualification testing for individual families of components
  - DETAIL Specs: performance requirements and procurement specification for individual or ranges of particular components (basically, they are comprehensive data sheets)

- Detail Spec. shall be read in conjunction with the corresponding Generic Spec. and referenced Basic Spec.

The American System (MIL-PRF / STD)

- Issued by DLA = Defence Logistics Agency

- Covers military and space
  –> Not all Mil parts are suitable for space!

- Generic and detailed specifications, standards and qualified parts/manufacturer lists

- Known concepts/levels:
  - JAN for diodes/transistors; JAN-S highest level on top of JAN-TXV
  - QML V and Q for microcircuits, V highest level
  - Class K and H for hybrids, K highest level
  - Established failure rates (S, R, P) or QPL for passive parts (T, M …)

- NASA has also Q60 equivalent documents, but often site specific (Glenn, Goddard, JPL, JSC etc.)

The American System

- The MIL system is widely used for selection and procurement of parts for space applications
- Standards such as STD-883 and STD-750 are reference documents used in ESCC Specifications

Reliability Level	SPACE	MILITARY	883B
Integrated Circuits MIL- PRF-38535	QML V	QML Q	Class M
	.Formerly Class S in M-38510 .Still associated with class S in MIL-STD-883	.Formerly Class B in M-38510 .Still associated with class B in MIL-STD-883	Not Qualified and not QML listed
Discrete MIL-PRF-19500	JAN S	JAN TXV	JANTX
Hybrids MIL-PRF-38534	Class K	Class H	

Note: there are now also classes for non-hermetic and plastic parts!

US Generic Spec. (PRF)
- Applicable to component families
- Several Reliability Levels
- Passive Parts: notion of Established Reliability (ER)
- To be read in conjunction with Standards (STD)
  - 38535 <-> STD 883
  - 19500 <-> STD 750

What about “New Space” ?

Welcome to the Jungle !

So far an unchartered territory but

- Main primes have started to establish their specific rules for the selection and control of EEE parts (essentially COTS / Automotive)

- ESA is also working on the subject on its own (COTS use (as COTS and not fully up-screened), Mission Categories etc.) and with the main primes

- Far less clear with the multiple new players with limited or different experience
- -------------------------→ more details in chapter 8

Automotive standards (AEC-Q)

-Baseline:

-Mass production allowing pertinent SPC (Statistical Process Control)

-Strong initial qualification (similar to ESCC or US-MIL but in some cases less (e.g. ceram. caps life)

-No periodic testing required (only if major processes or fab plant change)

-No screening

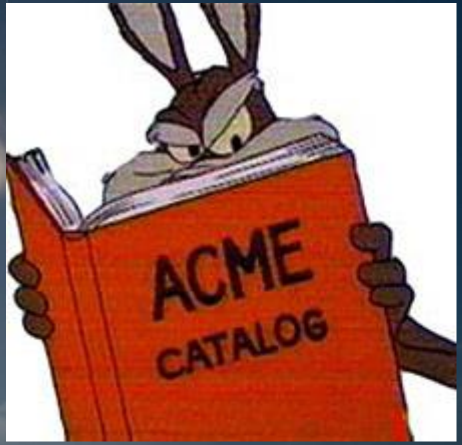
-Several temperature ranges

-PPAP (similar to PID), but not always available for customers

-Process Change Notifications (PCN) released, but only for “major” changes

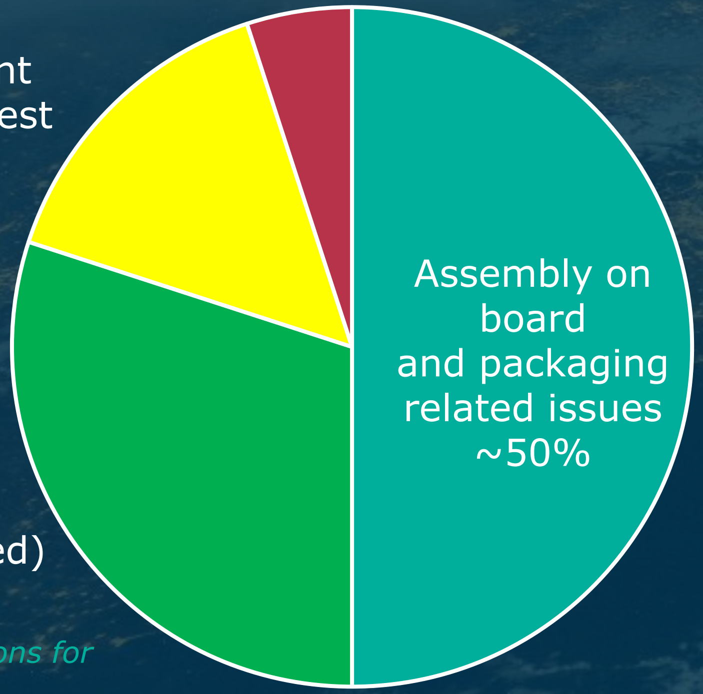
Note: AEC-Q assumes strong customer/manufacturer relationship!
There is no qualifying agent.

Major Failure Mechanisms

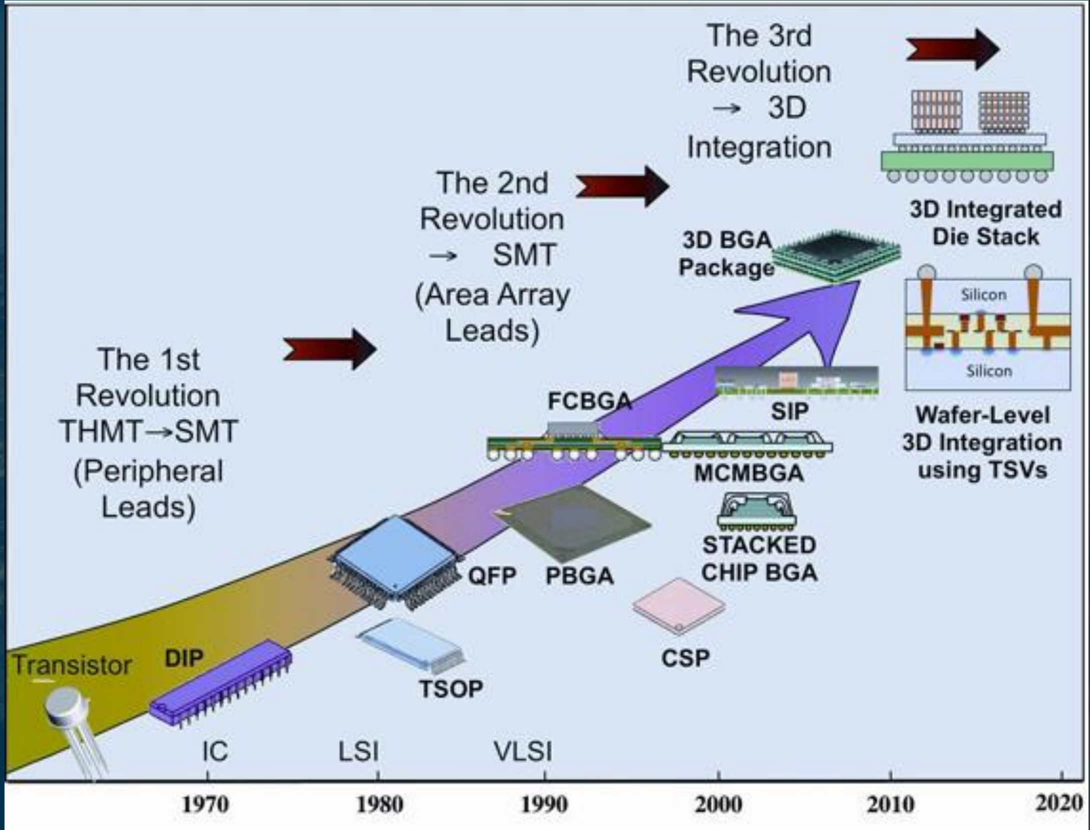


Main failure mechanisms

Murphy's law fully applicable …



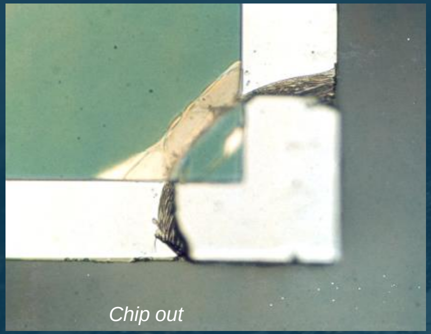
→ One of the reasons for Derating

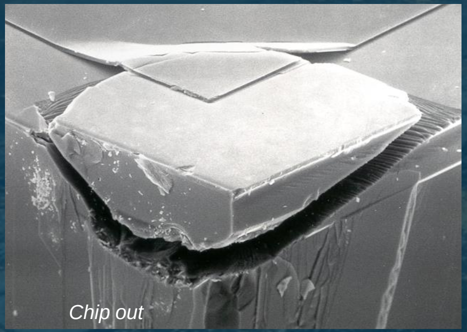


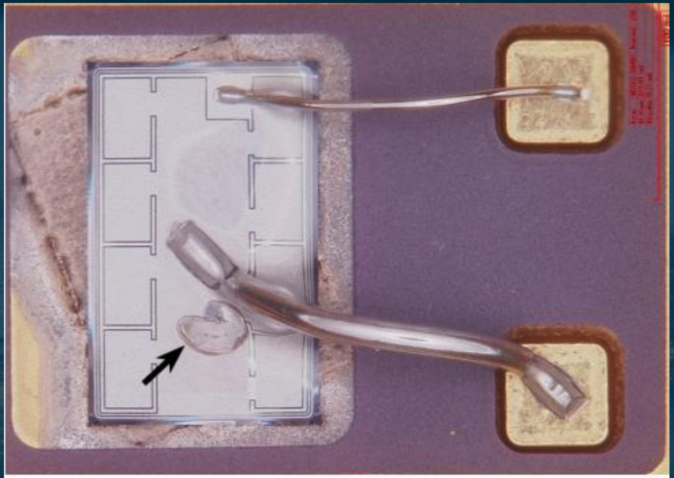
So many things can go wrong… but with major usual suspects

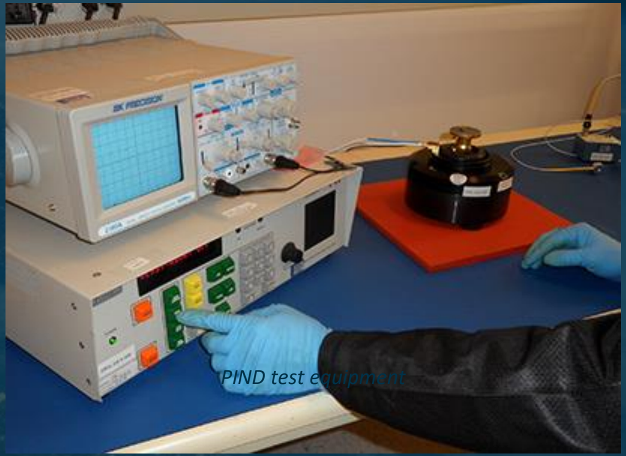
Not to forget, *in a large majority of cases, EEE components failures are related to assembly on board/packaging defects followed by incorrect usage of the component*

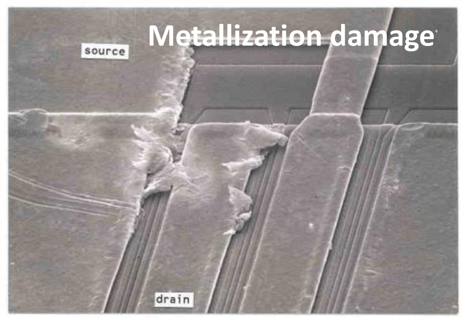
Exples: Die defects (active parts) & particles



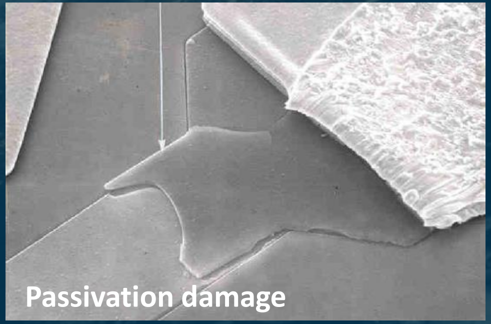



MOSFET die overstressed by external electrical stimulus

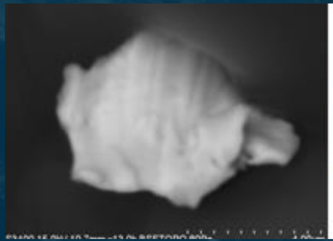


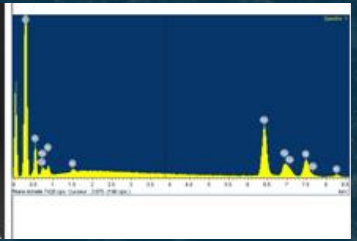


Metallization damage


Passivation damage

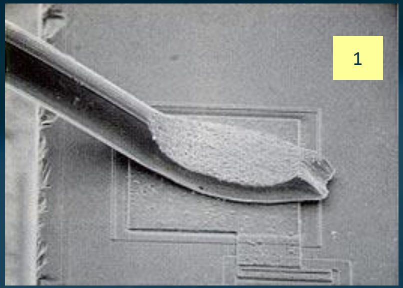
PIND test
(Particle Impact Noise Detection)

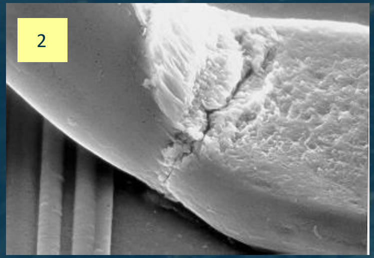


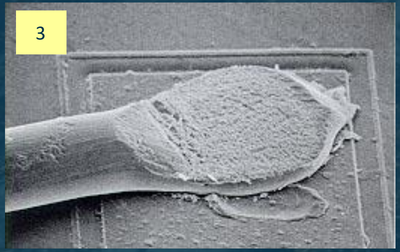


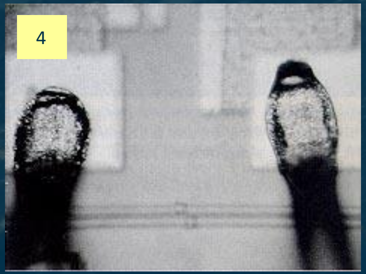
Particle Material Analysis (EDX spectrum): Kovar (Fe-Ni-Co) are detected the particle originates from the package

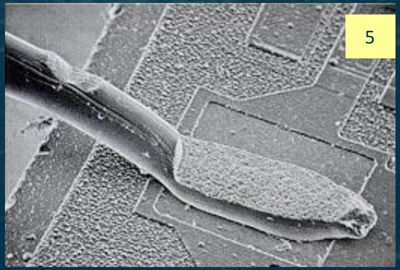
Exples: Wire bonds defects

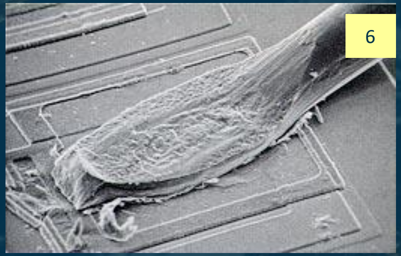




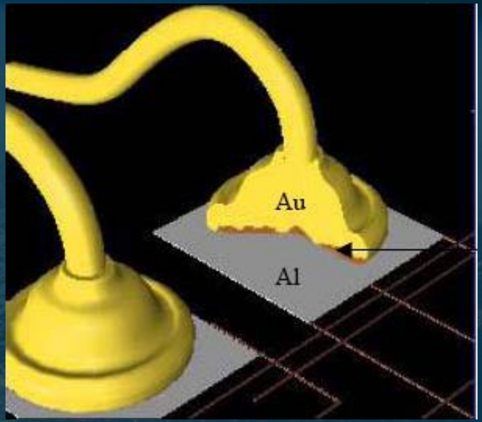


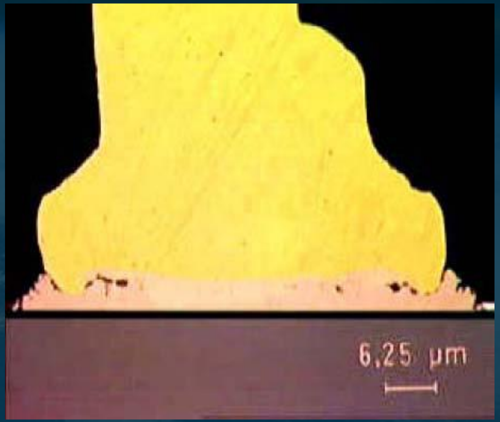






2 - **heel cracking**: fragile wire or backbend motion too important .
3 – **crushed wire**: strength or temperature too high during bonding
4 – **Burnt aspect**: excessive duration of ultrasound (wire crystallisation)
5 – **Nick or indent**: wrong usage of the bonding tool
6 – **Damaged surface:** Usage of an aged bonding tool or improper cleaning of the

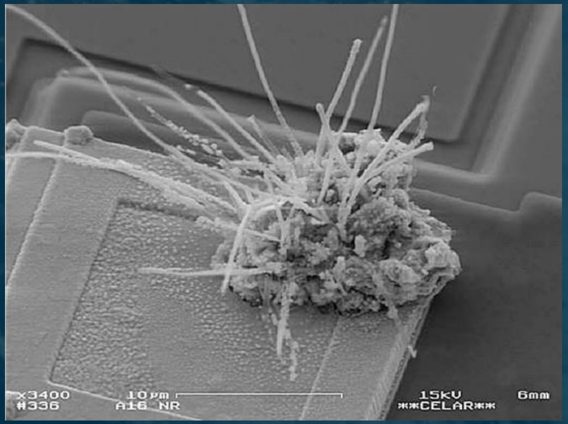




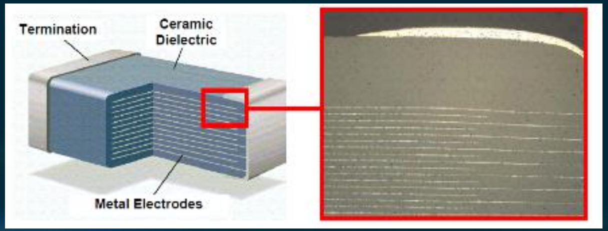
Purple plague formation (AuAl2 intermetallic compound) due to the combination of an Au cable on an Aluminium metallisation (or vice versa)

What s that little beast???

Purple plague formation (intermetallic AuAl) observed on a IC following Thallium contamination. Thallium is found at the needles extremity



Exples: Passive parts



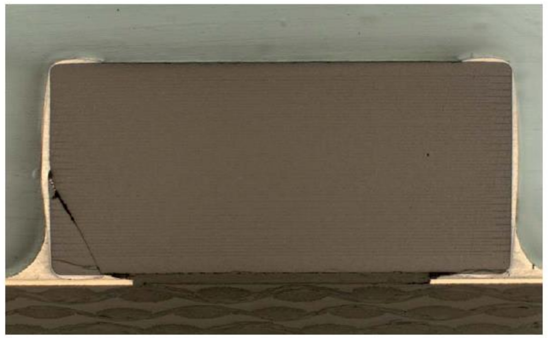
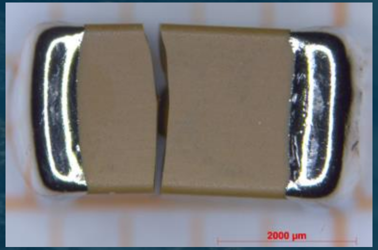


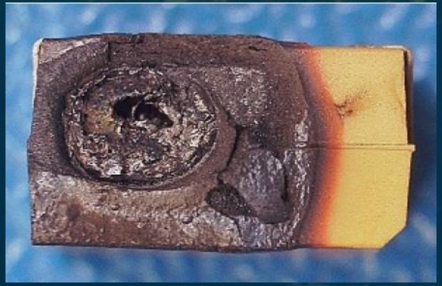
Figure 10: Optical micrograph of flex crack in MLCC

Passive Components

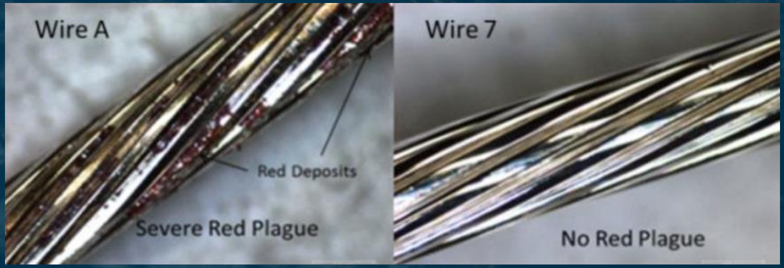
- Ea values are difficult to determine in a generic way
- Wide variety of mechanisms / causes:
  - Film Resist.: termination leaching (Pb free or bad Ni barrier); open circuit; pollution; EOS (thick film); ESD (thin film)…
  - Ceramic Caps: substrate cracks; ceramic porosity; delamination;
  - termination leaching …
  - Ta Caps: short circuits; corrosion; correct biasing essential …
  - Relays: lack/loss of hermeticity (coil burn-out, insulation degradation…); pollution; fatigue
  - Wires / Cables: Red plague if insufficient Ag plating thickness, insulation/ shielding material degradation (moisture, radiation …); mechanical damages …
  - Connectors: mating/demating; crimping; plating; debris; contact corrosion …

“little” issue during solderability test





Ta capacitor



Wrong connector selection and “repair”

And radiation …

Total Ionizing Dose (TID)

- Cumulative long term effect
- Ionization of materials followed by charge trapping
- Dose is deposited by incident p^+ & e^- but also due to secondary effects (Bremmschtralung)
- Gradual Degradation of µelectronics and optoelectronics

Single Event Effects (SEE)

- Single charged particles (protons, heavy ions) passing through a semiconductor material and generating a high density of mobile charges along the track
- Can be at the origin of many different types of soft & hard errors with temporary or permanent (incl. destructive) effects
- Experimental sensitivity must be correlated with the environmental characteristics (orbit, duration, shielding effects …) to obtain the event rate probability.

Total Non Ionizing Dose (TNID)

- Gradual Degradation of optoelectronics (GaAs, other III-V or II-VI …), CCDs, optical fibres, even bipolar technologies in very harsh environments

Chapter 5

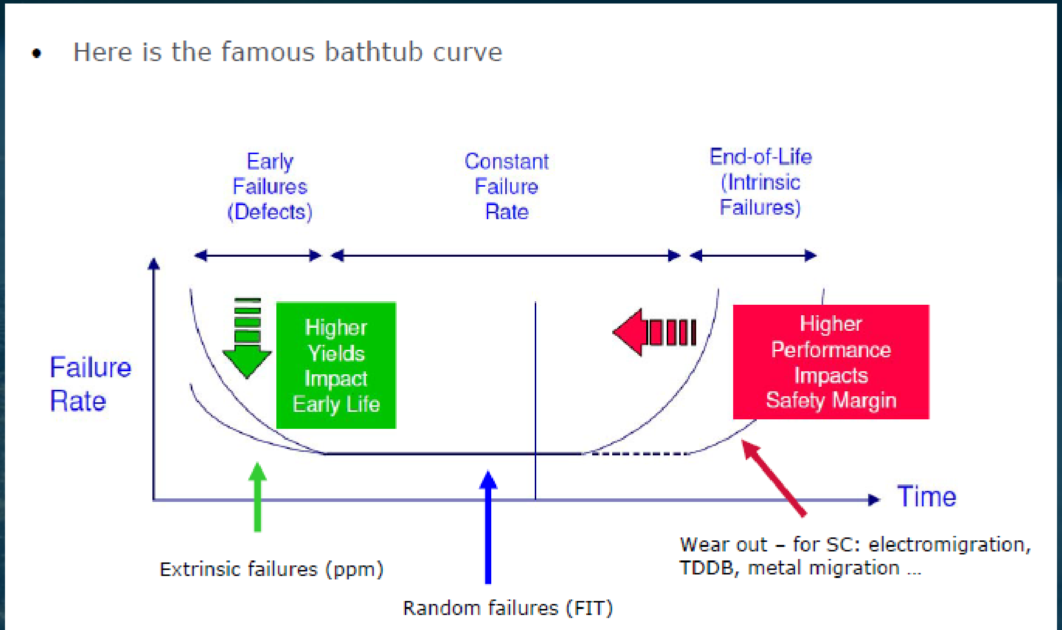
Reliability
and Reliability Testing

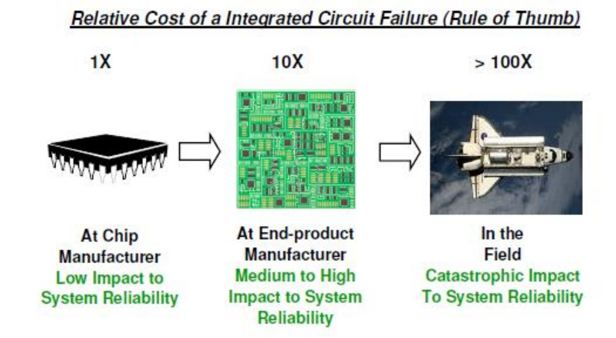
Reliability

The **Failure Rate** of components is normally inherently low but they have to survive during long periods without possibility of maintenance

Elevated stresses are used to produce the same Failure Mechanisms, but in much **shorter periods**, on components or test structures when necessary -> **acceleration**

Some other tests do not identify direct Failure Mechanisms but conditions that would facilitate the occurrence of a failure (e.g. seal test, RGA, ESD …)





To keep in mind:
A good experiment never exceeds the lifetime of the experimenter …
Chinese Wisdom

Testing : the different contexts

Obviously we do not test for the sole sake of testing , but there are different situations

-A) Your part / techno needs to be suitable for most space missions, various environmental conditions and profiles, and the part / techno will be available on the mid/long term:

-You need to find the survival limits and then deduce the margins available

-Typical context for an *Evaluation* where parts are “worn to the bone” through testing

-B) You need to perform a lot/batch validation (aka LAT / LVT / QCI)

-Performed regularly to maintain a formal Qualification status in Space Systems (e.g. ESCC, US-MIL) → ensure that quality is consistent over time

-Performed to validate specific lots for non formally qualified parts, and whether a specific need exists (e.g. lot-to-lot variation for TID)

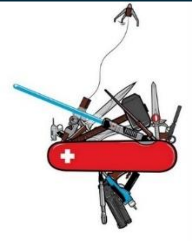
-C) You need to use specific parts (maybe commercial) in a single (few) mission(s) or specific application conditions

-A subset of A) & B) where the mission profile (+ margin) is the target → upscreening

-D) Screening wherever required

…. And combinations of the above

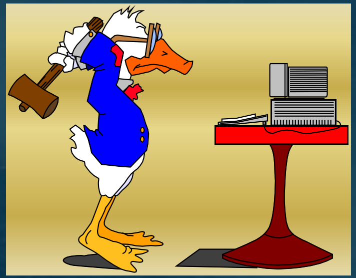
Reliability: the toolbox



Our toolbox

Endurance (Life Test)	Environment - Thermal	Environment - Mechanical	Radiation
Inspections (Visual, Xrays…)	Construction Analysis	Package Tests	Assembly
Outgassing	Humidity	Intrinsic Reliability (semicond.)	Specific (Corrosion, cold, etc …)

Highly accelerated endurance test



Note sometimes very difficult to accelerate, for example low temperature and vacuum.

Test methods are essentially drawn from:

- MIL-STD-883 (Microcircuits)
- MIL-STD-750 (Discrete components)
- MIL-STD-202 (Passive components)
- IEC (Passive components)

Reliability: some classical methods

esa

Endurance Tests

TEST	Purpose / principle	STD-883	Comments
Steady State Life **-HTOL** **-HTRB**	-Accelerated ageing -Acceleration of TDDB, EM, HCI, charge effects, mobile ions … -HTRB: junction degradation, mobile ions, …	1005	.2000h min HTOL in ESCC .Tj always < 175C for space level Si devices .HTRB mainly used for discrete devices
Intermittent life test	- ON-OFF cycles	1006	
Stab. bake or High Temp. Storage	-Preconditioning, mat. instab. -HTS: Oxidation, intermetallic growth …	1008	Unbiased parts
Burn-In	- Early failures removal	1015	.T < max operating rating .Tj always < 175C for space level Si devices

Environmental / Thermal Tests

TEST	Purpose / principle	STD-883	Comments
Moisture Resistance	- Cycles of combined high temp. (70C) and moisture - Corrosion, moisture ingress	1004	.Minimum 10 cycles
Temperature Cycling	-Fatigue failure (die/package cracking, wire breaks, bond lifting) -Param: transfer time (<1mn), dwell time (>10mn), reaching time (<15 mn).	1010	.ESCC: cond C in general i.e. -65/+150 .Air chambers
Thermal Shocks	-Param: transfer time (<10s), dwell time (>2 mn), reaching time (<5 mn). -Mechanical weakness (mismatching of θ expansion coeff.)	1011	.ESCC: cond C in general i.e. -65/+150 .Liquid chambers normally
HAST/THB /Autoclave (PCT)	-Corrosion (metal lines, thin film) -Low power dissip. but maximized voltage stress, humidity, temp.	JESD	.96h, 130C, 85 RH - HAST .1000h, 85C, 85RH - THB .Precond necessary

Environmental / Mechanical Tests

TEST	Purpose / principle	STD-883	Comments
Constant Acceleration	-Mechanical strength limits of the various elements of a package (metallization, lead frame, die attach, wire bonds …)	2001	.20000g (cond D) or 30000g (E) in ESCC
Mechanical Shock	-Suitability for use in equipment subjected to moderately severe shocks	2002	.Cond B i.e. 1500g, 0.5 ms in ESCC
Vibrations	-2005: vibration fatigue, cste ampli -2007: variable frequency -2026: random vibrations	2005/2007/2026	.ESCC: 2007 (sine vib), 20g .2026 may be used in evaluation

Other Tests

TEST	Purpose / principle	STD-883	Comments
Radiation	- ESCC 22900 TID - ESCC 25100 SEE - DD: to come	1019 (TID)	
Inspections	- ESCC 20400: IVI - ESCC 20500: EVI - ESCC 20900: radiography (defects of sealed cases) - ESCC 21400: SEM (metallization)	2010 2009 2012 2018	
ESD	-ESCC 23800		
Step Stress Testing	-Determination of the relevant Ea by successive increases of an acceleration factor		.Temperature step stress .Power (Voltage) step stress
Misc. specific tests	. Data retention (NV memories); Mating test (connectors); A&B, cut through, abrasion (cables); Surge current test (Ta caps); EM/HCI/TDDB/SM (semicon) . Die shear / bond pull; PPBI (FPGAs) etc etc etc.		

Reliability Models

Note: remember that models are only … models

Acceleration Models & Factors

- Everything will decay or degrade with time (2nd Law of Thermodynamics)
- Degradation of matter is generally due to atomic or molecular changes accelerated by external factors such as temperature
- But it takes time → need to accelerate these deteriorations for ground testing

- The Arrhenius Law describes these **temperature driven** mechanisms
- Process Rate:

$$R = C.\exp - Ea/_{kT}$$

- Acceleration factor:

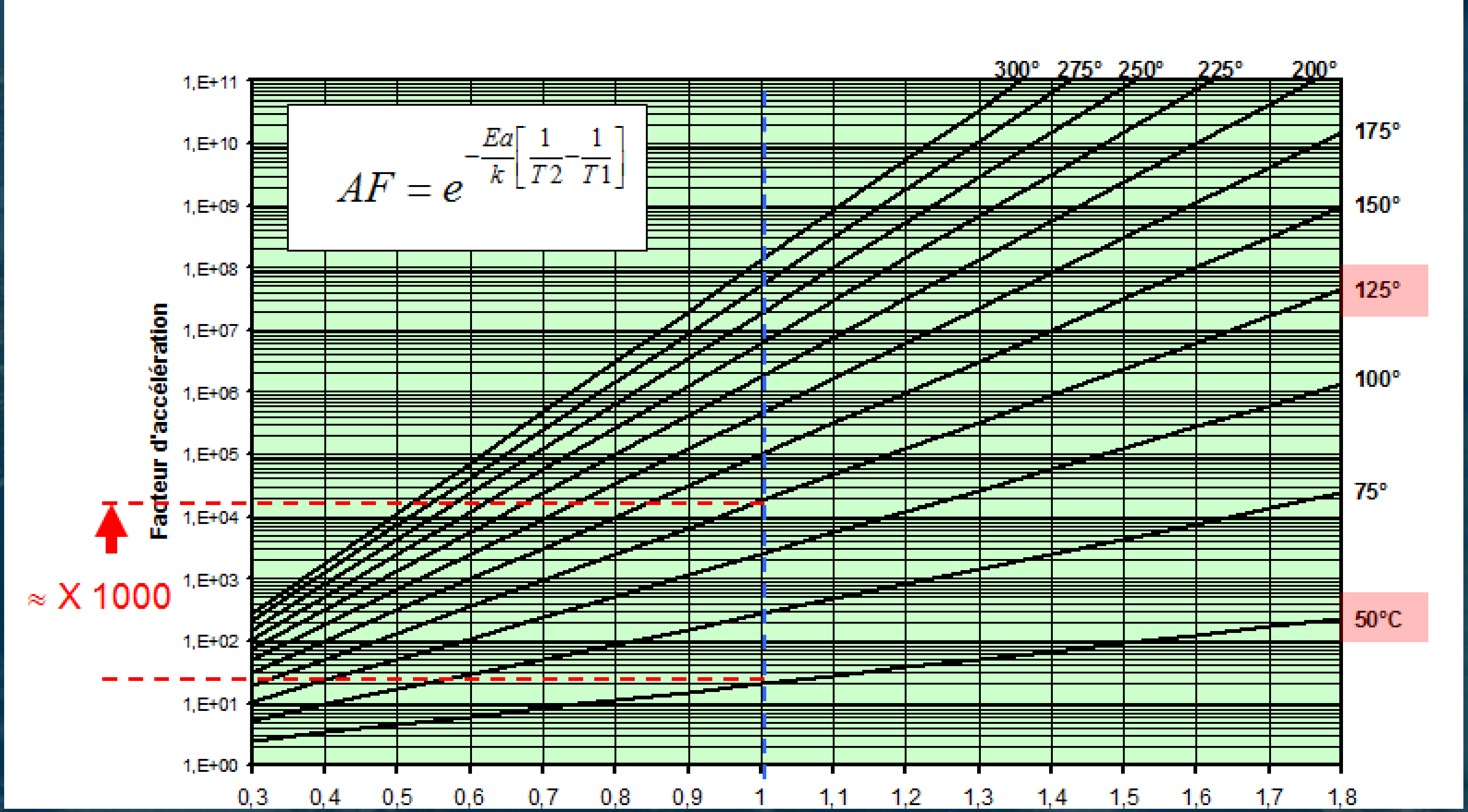
$$AF_T = R_{test}/_{R_{use}} = \exp\left(\left(-Ea/_k\right)\left(1/_{T_t} - 1/_{T_u}\right)\right)$$

Reliability Models

Note: remember that models are only … models

Arrhenius law allows to describe the speed variation of a chemical reaction as a function of temperature
Here for example, with an Ea of 1 eV, testing at 125ºC accelerates by a factor 1000 compared to same test performed at 50ºC,
written slightly differently: 6 weeks @ 125°C ≈ 100 years (5200 weeks) @ 50°C (real operating condition)

But if Ea is 0.7eV, the acceleration is "only" 100.



Activation energy Ea in eV

Reliability Models

Note: remember that models are only … models

Intrinsic & Extrinsic reliability for semiconductor components (examples)

General Failure Mechanism Class	Typical (eV)	Min (eV)	Max (eV)
Surface / Oxide	1.0	0.75	1.40
Charge Loss (dynamic memory)	0.6	0.5	1.30
Dielectric Breakdown			
Field > 0.04 micron thick	0.3	0.30	1.0
Field < 0.04 micron thick	0.7	0.28	1.0
Metallization			
Electromigration (Aluminum, alloys, and multi-layer aluminum)	0.6	0.5	0.7
Corrosion – Chlorine	0.70	0.53	0.95
Corrosion – Phosphorus	0.53	0.30	0.80
Wafer Fabrication			
Chemical contamination	1.00	1.00	1.00
Silicon / crystal defects	0.50	0.30	0.50

- Electromigration (J & T) – Black eq.
  - $AF = (J_t / J_u)^n . AF_T$
  - Ea = 0.5 – 0.7 eV for pure Al
- TDDB (T & V)
  - $AF = AF_T . AF_V$
  - Ea = 0.8 – 0.9 eV
- HCI (T& V)
  - $AF = AF_T . AF_V$
  - Ea = -0.2 – - 0.06 eV

  (accelerated by low temperatures)
- Bond /Solderability failures (T)
  - Arrhenius with Ea = 1eV for Au-Al bonds, 0.5 to 0.75 eV for Sn based leadfinish

Reliability Models

Note: remember that models are only … models

- Moisture/temperature – Peck model

$$TTF \equiv Ao \times RH^{-N} \times e^{\left(\frac{Ea}{kT}\right)}$$

- Thermal cycling - Coffin-Manson

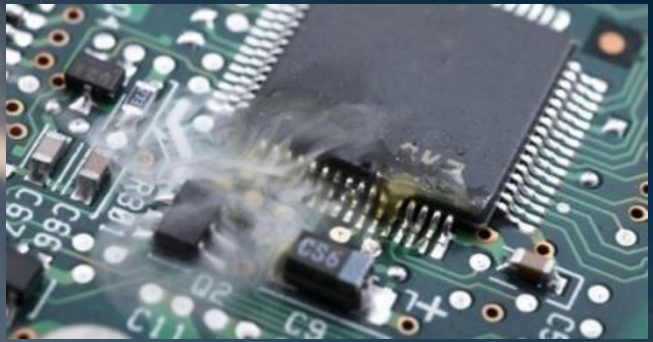
$$Nf \equiv Co \times (\Delta T)^{-n}$$

- Voltage/Current/Power

Several others….

DERATING

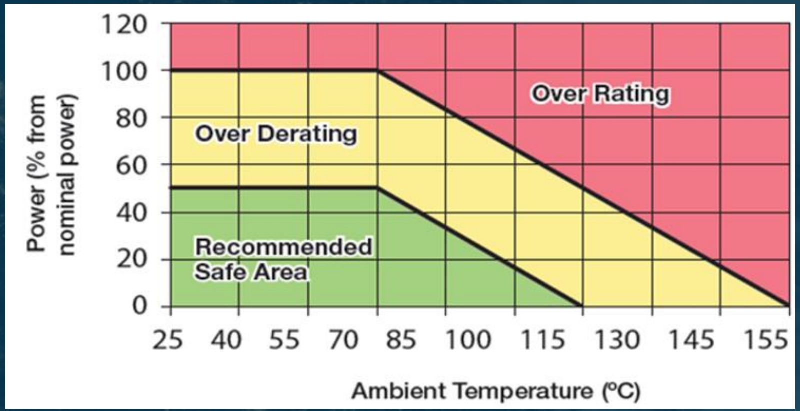
He who wishes to ride far spares his horse



Derating

For practical reasons robustness may be more important to address than reliability, this leads into… Derating

- ECSS-Q-ST-30-11 is a dependability standard for derating, also called part stress analysis
- Definition: “process of designing a product such that its
- components operate at a significantly reduced level of
- stress to increase reliability and to insure useful life and
- design margins.”



- The aim is to assure that all components are operating
  - well within their rated range in nominal conditions (normally at acceptance high temperature)
  - within maximum ratings in short durations, transients, failure cases etc

Derating exemples

- Junction temperatures of Si semiconductor devices 40C below maximum rated temperature and in any case at maximum 110C.
- Capacitor voltage typically limited to 60% of maximum rated and temperature to 110C.
- Reverse voltages in semiconductors typically limited to 75% of maximum rated.
- Resistor voltage at 80% and power at 50% of maximum rated.
- N.B. "…only applies to approved components for which quality was proved after rigorous testing in accordance with ECSS-Q-ST-60"

Note: derating is aimed at saving lifetime but not only, that's also a margin against unexpected events (e.g. transient signals, voltage/current spikes, short overload etc. , as maximum ratings should never be exceeded)

Requirements for EEE parts in a space project

EEE requirements in space projects

- Find out what are the requirements !

Probably based on ECSS-Q-ST-60 but there can be considerable tailoring in all directions:

  - asking less, or more
  - But also what is the need i.e. project specific issues
    - Orbit / Environment (e.g. cryogenic temp., long term storage, high radiation constraint etc.)
    - Mission Class (from Microsats to Telecom Geo Sats)
    - Lifetime (from hours to decades)
    - Performances (qualified parts may not be available)

- In any ESA project, ESA would issue PA requirements, these are then reflected, and tailored by prime contractor into requirements for subcontractors

- *Cost and schedule* are also nowadays key parameters that impact the course of a project → serious risk related to shortcuts

- A qualification within a specific project does not mean necessarily pertinent heritage for another project

EEE requirements in space projects

- Few problems with standard **space/hirel parts** (qualified or equivalent)
  - Where used as expected and in their derated range
  - 100% screened and regularly re-qualified by the manufacturers
  - Complete traceability >>> but high component cost

- There are many/more problems with **non-standard parts** (esp. commercial)
  - Lack of heritage, possible lack of traceability
  - Possible issues with the thermal range
  - Compatibility with assembly on the board / RoHS terminations
  - Radiation concern
  - Upscreening often necessary (screening + LAT/Eval)
    - A single part is far cheaper, but testing costs a lot
- The basic requirement to evaluate non-standard part is often overlooked!

Focus on the right parts!

EEE requirements in space projects – PCB / RCB

Let's discuss !

- The key element is the **PCB**
  - Mandatory for class 1 and 2
  - Not for 3 or informal support but strongly recommended
  - **-> call it whatever you want but do it !**
  - Should not be the old fashion "control only" board especially with companies presenting a limited experience
  - A privileged moment of direct contact with the suppliers where we can discuss, explain the requirements/needs, advise, give orientation, stop non-sense …
  - DO NOT rely only on RIDs "ping-pong" and formal Reviews -> ineffective
- **ESA EEE expert must be part of the PCB →** tendency to forget the "final customer" sometimes (or special agreement on a case by case)
- Review of the DCL(s) , PADs and associated documents necessary for the approval of the parts
- Recently appeared also the **RCBs** (Rad Control Boards)
  - → good but it does not mean that some rad data are not checked in PCB
  - → different role: PCB -> are they tested properly ? / RCB -> are the test results acceptable in the specific applications/designs considered ?

EEE requirements in space projects - DCL

DCL=Declared Component List Example

Detailed Specification	Issue	Quality Level	Space qualified	EPPL status	Procurement	RVT
ESCC 3009/003	-	ESCC C	EQPL	Part 1	CPPA	-

Example, number of line items in Consolidated satellite DCLs

- GAIA 1984 including instrument (launched 2013)
- Lisa Pathfinder 3590 including instrument (launched 2015)
- Exomars 2016 (orbiter + lander) 4471 excluding instruments (launched 2016)
- Bepi Colombo (MTM+ MPO) 6124 excluding instruments (to be launched 2018)

EEE requirements in space projects - PADs

esa

PAD=

Part Approval Document

Defines how part is procured and tested

DCL and PADs are reviewed during PCBs: Part Control Boards

PROJECT:................ Doc n°:.................... Prepared by: ....
Issue:...................... Date:...................

Approval requested by:..............................
Family:.................... Fcode [ ] Group:.................. Gcode [ ]
Component Number:..
Commercial Equivalent Designation:......................
Manufacturer/ Country:................................
Technology/Characteristics (value or range of values with tolerance, voltage, package etc): ....
Pure tin free (Y/N) [ ]
Generic specification:......................
Detail specification:...................... Issue:..... Rev.:..... variant:.......
Specification amendment: .... Issue:..... Rev.:..... variant:.......
Quality level:......................... Procurement by:.............................

APPROVAL STATUS

EPPL Part 1/2 listed (1/2/N) [ ]
ESCC QPL or EQML listed. (Y/N) [ ]
MIL QPL or QML listed (Y/N) [ ] If yes: QPL/QML Reference:...............................
Other approvals/former usage ....
Evaluation programme required (Y/N) [ ]
If yes reference of the Evaluation Programme:.............................

PROCUREMENT INSPECTIONS and TESTS

Precap (Y/N) [ ]
Lot acceptance:
ESCC LAT/LVT level or subgroup [ ]
MIL QCI/TCI group [ ]
Buy-off (Y/N) [ ]
DPA (Y/N) [ ] if yes: sample size ....

Complementary tests ....

RADIATION HARDNESS DATA

Radiation Hardness Assurance Plan applicable (Y/N)[ ]
Doc. Ref.: ....

Total Dose Effects:
Evaluation Test Data (report) reference: ....

Single Event Effects: SEL/SEU/SET/SEFI/SEB/SEGR/others: *(cross out when non applicable)*
Evaluation Test Data (report) reference: ....

RVT required (Y/N)[ ]

REMARKS

Approval customer .... Date ....
Approval first-level supplier .... Date ....

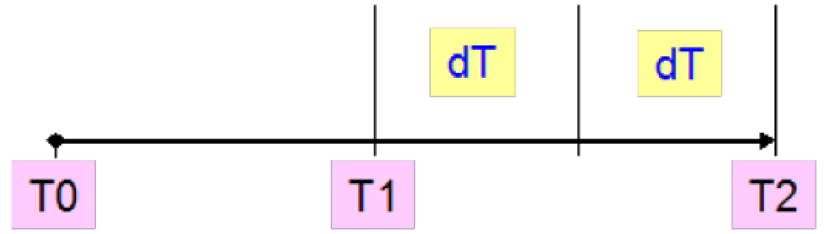
More from Q-60

- Parts for Ground Segment (GSE) – section 4/5/6.1.5
  - If interfacing with flight HW, parts (esp. connectors and savers) must be FFF compatible and manufactured from identical material, but don't need to be space qualified (e.g. C&K FR022)
- Parts and material restrictions – section 4/5/6.2.2.2
  - E.g. potentiometers, non passivated die, pure tin (<3%) but here things change, etc.
- Initial customer source inspection (precap) – section 4/5/6.3.4
  - Class 1/2 mainly for non qualified parts and/or critical components (e.g. relays, hybrids); not required for class 3
- Destructive physical analysis (DPA) , usually 3 parts / lot required (can be reduced for expensive ones)
  - Class 1: most non-qualified + Relays and oscillators
  - Class 2/3: on non qualified relays and oscillators (Class 2 only)
- Relifing: ECSS-Q-ST-60-14 updated recently; max. 15 years now but relifing requirement remains
- One Time Prog. Devices: PPBI typically no longer required (neither for PROMs nor FPGA) but PP sequence remains necessary (typically @ board / equipment level, functional, 3 temperatures, full speed)

Q-ST-60-14 Relifing

- Relifing is a term for assuring old (>7 years) parts still fit for flight.
- Standard also addresses storage conditions.
- Rev 1 was issued 2019, there are rather major changes for example
  - Maximum age extended from 10 to 15 years
  - Different requirements for Class 1&2 and 3 respectively.

T1	T2	dT
7 years	15 years	4 years



T0	Original date code
T1	Maximum allowed storage period from T0 with no relifing control
T2	Maximum duration between the original date code of part and its mounting
dT	Maximum allowed storage period after a relifing control which can be repeated once

What needs to be done at T1&T2 varies with component family from nothing to 100% screening.

Chapter 8

NEW SPACE

Sailing towards Terra Incognita …

New Space

What do we mean by NEW SPACE ?

Really a new world ? The term is a kind of “rag-bag” but distinct trends may be observed in Europe

1/ Classical major companies seeking mainly for

- significant cost reduction
- higher performances,

>>> through the massive use of “good” commercial and an evolution of existing rules

2/ New commercial players:

- targeting small satellites for low Earth orbits (but not only !)
- accepting a higher risk, even by using “black boxes”
- “architectural reliability” approach (… not always very clear actually…)

New Space

Classical vs "New"

But behind the scene, at least for the major space companies, lies a very significant financial and technical effort !

- Internal policy in place, no improvisation
- Thorough selection, systematic review of manufacturers reliability data
- Additional tests wherever deemed necessary (from a CA to a complete upscreening as per Q60-13)
- Systematic radiation verification for active parts
- Significant proportion of the types / lots rejected during the selection process (not just a few %)
- Assembly qualification

-> Affordable mainly in a "volume" approach context (constellations & recurrent products)

-> The picture may be quite different for new players …

but targets may also be quite different and not comparable.

Classical	New Space
Hirel parts or fully upscreened parts	Mainly AEC or equivalent
100% screening at component level	Almost NO screening at component level, replaced (to some extent) by board/ equipment level screening *(see note 1)*
LAT: periodic (Hirel) or systematic (non qualified)	No LAT for AEC parts or equivalent, only for parts with very limited existing data *(see note 2)*
Active parts in hermetic package	Plastic packages
Assembly with SnPb processes	RoHS processes (lead free) *(note 3)*
Full traceability	Not systematic, it depends really of the commercial agreement with the supplier, some provide a complete traceability, some don't
Radiation guarantee or tests	Radiation tests systematic (ideally…) associated with a control of the process changes (efficient to some extent, cannot be anyway compared with full visibility as PCNs** only address measurable and visible changes, not necessarily all the manufacturing processes) *(notes 4)* ** PCN stands for Process Change Notification

COTS i.e. “Commercial Parts”

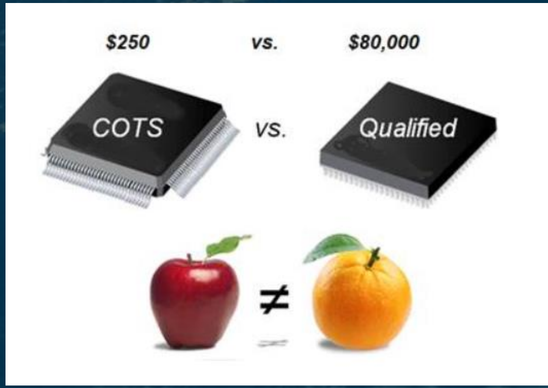
Commercial Components aka COTS

•EEE definition of Commercial :

"neither designed, nor manufactured with reference to military or space"

- But the notion of COTS covers <u>many different realities</u> from rather poor quality to high grades like automotive or enhanced commercial ***

- Plastic packaged parts are not, and have never been, forbidden in ESA missions for any class (but they are upscreened. There has sometimes been reluctance in the past though.



*** One should not compare what is not directly comparable:

- Both Hi-Rel and automotive /enhanced commercial are quality parts, but different philosophies behind
  --- roughly: statistical control vs systematic control
  --- reliability is not an absolute notion
- Mass production parts are not "better":
  --- Tightened electrical parameter distribution does not mean higher reliability or longer lifetime

COTS

Q60-13
The 3 classes (of COTS upscreening)

- This standard is now updated:
  - to include passive part families:
    - Ceramic chip capacitors
    - Tantalum chip capacitors
    - Film resistor chips
    - Magnetics
    - Fuses
    - Thermistors
  - to recognize (more explicitly) automotive qualified parts (require less activities for these)
  - to remove mandatory re-tinning and RFW when using pure tin-plated parts (N.B. from EEE perspective only)

	CLASS 1	CLASS 2	CLASS 3
EVALUATION	COMPLETE - Construction analysis - Electrical charact. (3T+10°C margin) - Meca shocks + Vib. + Const. Acc. *(for cavity package)* - Precond + HAST 96h or THB 1000h - Lifetest 2000h-125°C + DPA - Precond + 500T/C -55°C/+125°C - Radiation evaluation (TID, SEE)	COMPLETE - Construction analysis - Electrical charact. (3T+10°C margin) - Meca shocks + Vib. + Const. Acc. *(for cavity package)* - Precond + HAST 96h or THB 1000h - Lifetest 2000h-125°C + DPA - Precond + 500T/C -55°C/+125°C - Radiation evaluation (TID, SEE)	LIMITED - Construction analysis - Radiation evaluation (TID, SEE)
JD (Justification Doc)	DATA COLLECTION - Component manufacturer data - Approval status - Evaluation tests - Procurement inspection and test - Lot acceptance tests - Radiation hardness data and RVT	DATA COLLECTION - Component manufacturer data - Approval status - Evaluation tests - Procurement inspection and test - Lot acceptance tests - Radiation hardness data and RVT DATA COLLECTED *(EFR, lifetest, thermal cycling)* used for screening reduction	DATA COLLECTION - Component manufacturer data - Approval status - Evaluation tests - Procurement inspection and tests - Lot acceptance tests - Radiation hardness data and RVT DATA COLLECTED *(lifetest, HAST, thermal cycling)* used for lot test reduction
CUSTOMER PRECAP	no	no	no
SCREENING	COMPLETE - X-rays - Serialisation - 10T/C -55°C/+125°C - PIND test (if applicable) - Initial electrical test @ 25°C - Dynamic burn-in 240h-125°C - Final electrical test @ 3T° - PDA (5%) - Hermeticity (if applicable) - External visual inspection	LIMITED (if data collected) - PIND test (if applicable) - Hermeticity (if applicable) + if no data collected (see JD) - Serialisation - 10T/C -55°C/+125°C - Initial electrical test @ 25°C - Dynamic burn-in 160h-125°C - Final electrical test @ 3T° - PDA (5%) - External visual inspection	LIMITED - PIND test (if applicable) - Hermeticity (if applicable)
LOT TEST (on screened parts) (when applicable)	COMPLETE - Construction analysis - Meca shocks + Vib. + Const. Acc. *(for cavity package)* - Precond + HAST 96h or THB 1000h - Lifetest 2000h-125°C - Precond + 100T/C -55°C/+125°C - RVT (Radiation Verification test)	COMPLETE (but LT 1000h) - Construction analysis - Meca shocks + Vib. + Const. Acc. *(for cavity package)* - Precond + HAST 96h or THB 1000h - Lifetest 1000h-125°C - Precond + 100T/C -55°C/+125°C *(may be waived i.a.w. application)* - RVT (Radiation Verification test)	LIMITED (if data collected) - Construction analysis - RVT (Radiation Verification test) + if no data collected (see JD) - Precond + HAST 96h or THB 1000h - Lifetest 1000h-125°C - Precond + 100T/C -55°C/+125°C
CUSTOMER BUY-OFF	no (replaced by incoming)	no (replaced by incoming)	no (replaced by incoming)
INCOMING	yes	yes	yes

Q-ST-60-13 What is a JD ?

- JD stands for Justification Dossier
- Similar in essence to a PAD for COTS, with more details, as these parts are not manufactured and controlled based upon well defined military or space systems
- A JD provides details about:
  - The part type (manufacturer, package, temperature range, MSL, ESD level, lead finish, molding characteristics, data sheet / procurement spec. and associated documents (ANs, PCNs etc.))
  - Existing reliability data
  - Evaluation and procurement tests
  - Traceability information (wafer fab, die revision, assembly plant etc.)
- *In principle it describes also why such commercial part is needed (instead of a HiRel)*

COTS

Plastic ≠ commercial, commercial ≠ plastic

- Plastic package does not necessarily mean commercial.
- Many manufacturers are releasing now various types of COTS+ parts (some radiation guarantee, often based on automotive products).
- State of the art complex microcircuit may not be possible to package in ceramic/hermetic package, FPGAs an example (same for very high frequency components)
- In the past plastic packaged parts have not been possible to formally qualify to space level, this is changing in ESCC and Mil
- ECSS-Q-ST-60-13 :
  - Addresses the procurement and test of commercial components for classes 1 to 3.
  - Does not fully address plastic packaged parts produced directly for space applications!

Many shades of ….

Quality / Reliability

R. Baumann, "From COTS to Space Electronics: Improving Reliability for Harsh Environments," 2016 Single Event Effects (SEE) Symp. and the Military and Aerospace Programmable Logic Devices (MAPLD) Workshop, May 23-26, 2016.

	COTS / COTS+		Enhanced Intermediate Grades			Space Grade	
	Commercial	AEC-Q100	EP	QMLQ	Space EP	QML-V	QMLV-RHA
Packaging	PLASTIC	PLASTIC	PLASTIC	CERAMIC	PLASTIC	CERAMIC	CERAMIC
Single Controlled Baseline	NO	NO	YES	YES	YES	YES	YES
Bond wires	Au or Cu	Au or Cu	Au	Al	Au	Al	Al
Pure Sn Used	YES	YES	NO	NO	NO	NO	NO
Burn-in Performed	NO	NO	NO	NO	NO	YES	YES
Radiation Tested	NO	NO	NO	NO	YES	YES	YES
Radiation Assured	NO	NO	NO	NO	YES	NO	YES
Temperature Range	-40 to 85°C	-40 to 125°C (only grade 1)	-55 to 125°C (majority)	-55 to 125°C	-55 to 125°C (majority)	-55 to 125°C	-55 to 125°C
100% 3 Temp Test	NO	NO	NO	YES	25, 125°C	YES	YES
Extra Qual/Process Monitors	NO	YES	YES	YES	YES	YES	YES
Life Test per lot	NO	NO	NO	NO	NO	YES	YES

The move to the middle!

After Baumann, Radiation Effects on Components and Systems (RADECS) conference, Gothenburg, Sweden, September 16-21, 2018.

Typical problems with COTS

- Requirements not understood, e g commonly it is believed that up-screening is always needed.
- Low budget projects expect (from contractor to ESA level) even lower requirements.
- Selection of part types for which there are no requirements in place; crystals, oscillators, hybrids… For these groups questions are
  - if parts are at all suitable?
  - what type of evaluation/LAT/upscreening to apply?
- Packaging and assembly including retinning to remove pure Sn
- Plastic package delaminations
- Data sheets trusted as if they were specifications – they are certainly not!
- Lot homogeneity and traceability
- Re-use of existing test data
- Derating
- No plan B for evaluation failures
- Common belief that different levels of the same component have the same robustness/quality
- Misunderstanding of reliability vs assurance

History of COTS in ESA projects

PLASTIC PACKAGED IC IN SPACE APPLICATION
TWO CASE STUDIES OF PEM EVALUATION

Karin Lundmark
Saab Ericsson Space
405 25 Gothenburg, SWEDEN
phone: +46 31 735 40 45
telefax: +46 31 735 40 00
karin.lundmark@space.se

Abstract

This paper will describe two cases of PEM evaluation for space application. They differ in many ways, e. g.:
- digital versus analogue part
- program requirements
- test on sample basis only versus screening and sample testing

Focus will be mainly on the second evaluation, which is in process. The PEM in this study is an 8-bit A/D converter, AD9054 from Analog Devices. First case was a DRAM, KM44V16004BK-6 from Samsung.

EVALUATION RESULTS
DIE & PACKAGE

TYPE	PROCURED LOT	CONSTRUC-TION ANALYSIS	OUT GASSING	ASSY QUALIF	EVAL. RESULTS
AD 8028	One DC	OK	OK	OK	OK
MAX 313	One DC	FAILED	Not done	Not done	REJECTED
ADG 451	One DC	ACCEPTABLE	OK	OK	OK
EL 7457	One DC	OK	OK	OK	OK
AD 7621	One DC	OK	OK	OK	OK
MAX 521	One DC	OK	OK	OK	OK

ASTRIUM

STATISTIC

- **14 Evaluation performed by CPPA**
- **15 Line items were submitted to screening by CPPA**

08	Microcircuit	AD8005
12	Transistor	BF862
18	Optoelectronic	OZ150
18	Optoelectronic	SFH4253-Z PLCC-2
12	Transistor	2SK3320
08	Microcircuit	LT1352IS8
01	Capacitor	MKS4D024703C00KSSD
01	Capacitor	MKS4D021003C00KSSD
18	Optoelectronic	UVTOP255TO18FW
99	Miscellaneous	DW-AD-603-03-686
04	Diodes	MMBD1503
12	Transistor	U404
04	Diodes	BAV99S SOT-23
18	Optoelectronic	RZ677

Solar Orbiter

- The figures herein reported are limited to those items that were fully commercial (manufacturers not equipped/interested to offer any upscreening/qualification activities)
- Additional delta qualifications were performed with the support of manufacturers and are not herein considered, however they constitutes the bulk of the 518 Not Qualified items procured by CPPA

COTS Fibre Optic Components in SMOS/MOHA

COTS Fibre Optic Components in SMOS

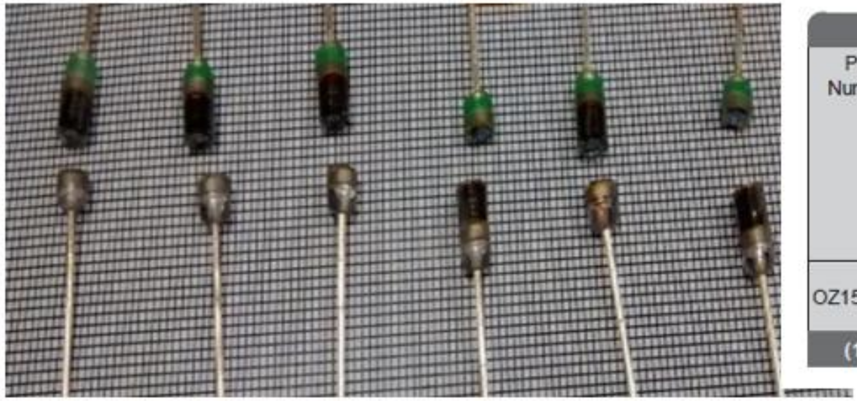
Fibre Optic Laser Transmitter	
Fibre Optic Receiver	
Fibre Optic Coupler Assembly	
Fibre Optic Cable / Pigtails	

Contraves Space

100+ commercial types are used on JUICE instruments

COTS evaluation demonstrated datasheet ratings wrong

High voltage optical diode: after 1 thermal cycle -40°C to 85°C 49 out 72 samples failed!



ELECTRICAL CHARACTERISTICS AND MAXIMUM RATINGS

Part Number	Working Reverse Voltage (Vrwm)	Average Rectified Current (Io)		Reverse Current @ Vrwm (Ir)		Forward Voltage (Vf)		1 Cycle Surge Current tp=8.3ms (Ifsm)	Repetitive Surge Current (Ifrm)	Reverse Recovery Time (3) (Trr)	Thermal Impedance θ_{J-L}			Junction Cap. @50VDC @ 1kHZ (Cj)
		55°C(1)	100°C(2)	25°C	100°C	25°C		25°C	25°C	25°C	L=000	L=.125	L=.250	25°C
	Volts	Amps	Amps	µA	µA	Volts	Amps	Amps	Amps	ns	°C/W	°C/W	°C/W	pF
OZ150SG	15000	0.30	0.15	1.0	25	18	0.30	10	2.00	3000	6	9	18	5.0

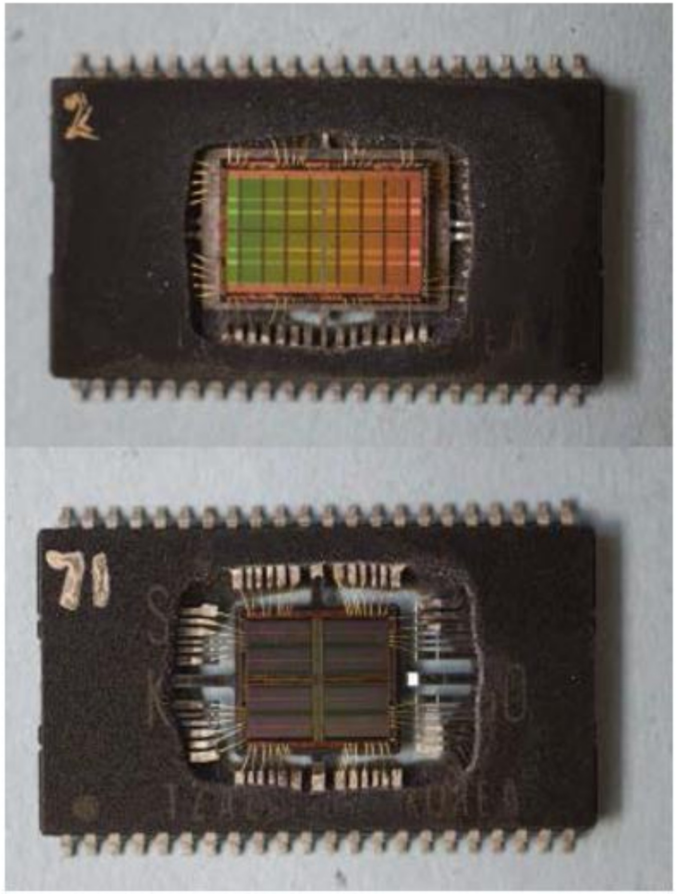
(1)TL=55°C L=0.375" (2)TL=100°C L=0.375" (3)If=0.5A, Ir=1.0A, Irr=0.25A *Op.Temp.= -65°C to +175°C Stg.Temp.= -65°C to +200°C

*Op.Temp.= -65°C to +175°C Stg.Temp.= -65°C to +200°C

Manufacturer responded that they had recently updated the data sheet with a tighter temperature range (-40 °C to + 70°C) and with the warning that this part should not see thermal cycling!

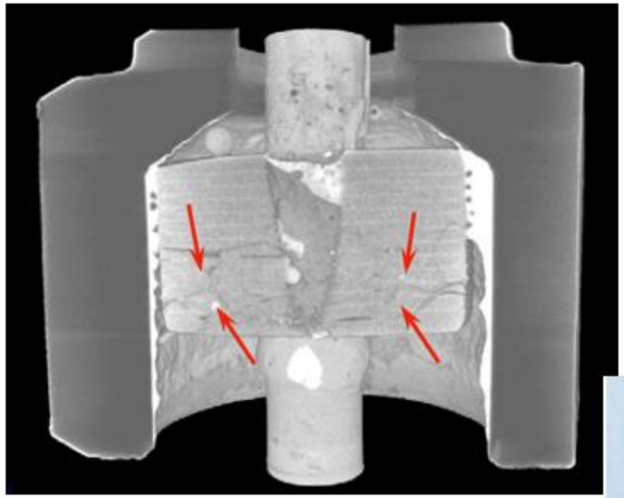
COTS

Memory where well known SRAM lot contained two different die revisions – one latch-up sensitive. Caused latch-up in orbit.

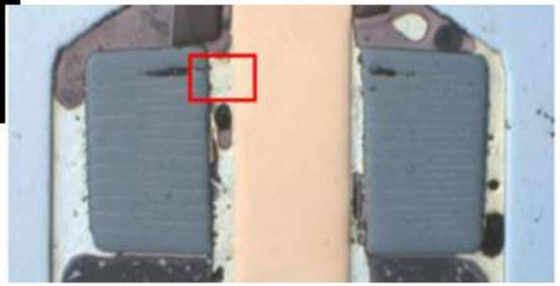


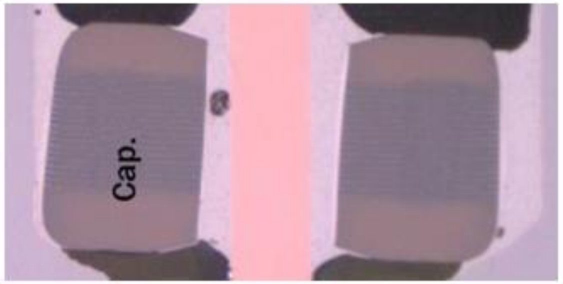
Commercial Feed-through filter capacitor

Failure occurred In-orbit :
Short-circuit due to cracks in the ceramic capacitor

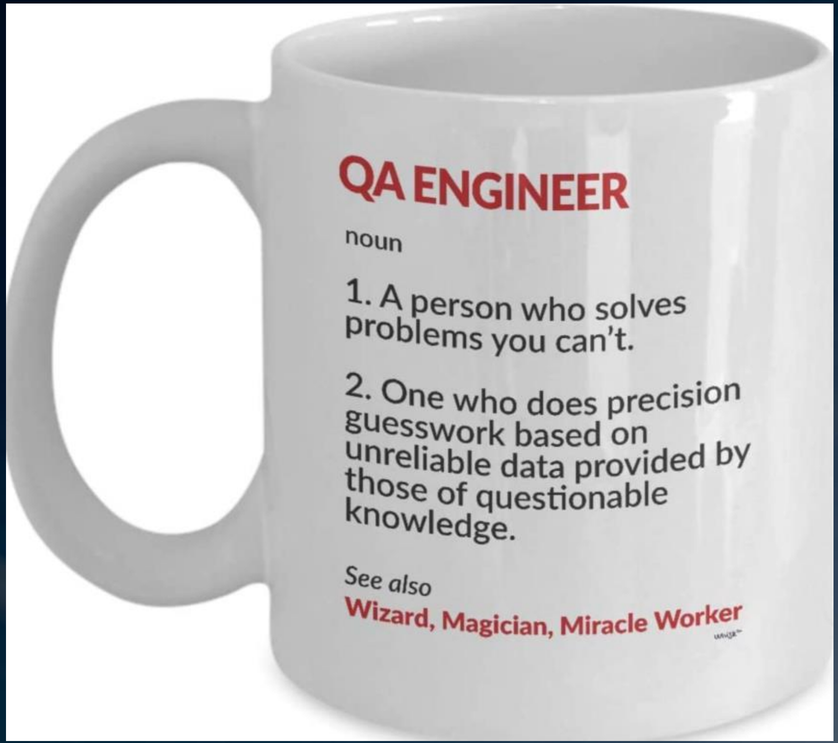


Root cause:
Different internal designs :
different ceramic parts
although same capacitor values





CONCLUSIONS



CONCLUSIONS

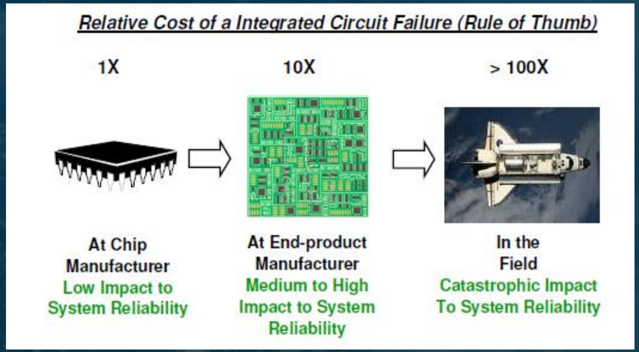
- Know your mission requirements before starting selecting your EEE components! All components do not work well in space environment - selection and verification is crucial!

- *Cost and schedule* impact the course of a project:
  serious risk related to hasty shortcuts if you do not know where and how you can apply them safely

- Plan B when using commercial solutions

- Test for radiation first but not only!

- Think about reliability aspects and future application constraints as early as possible



- Many EEE components non-conformance and failures are still related to their assembly on board processes and/or their application conditions

- Pay attention to the notion of heritage, it does not mean necessarily relevant / appropriate heritage in your mission context !