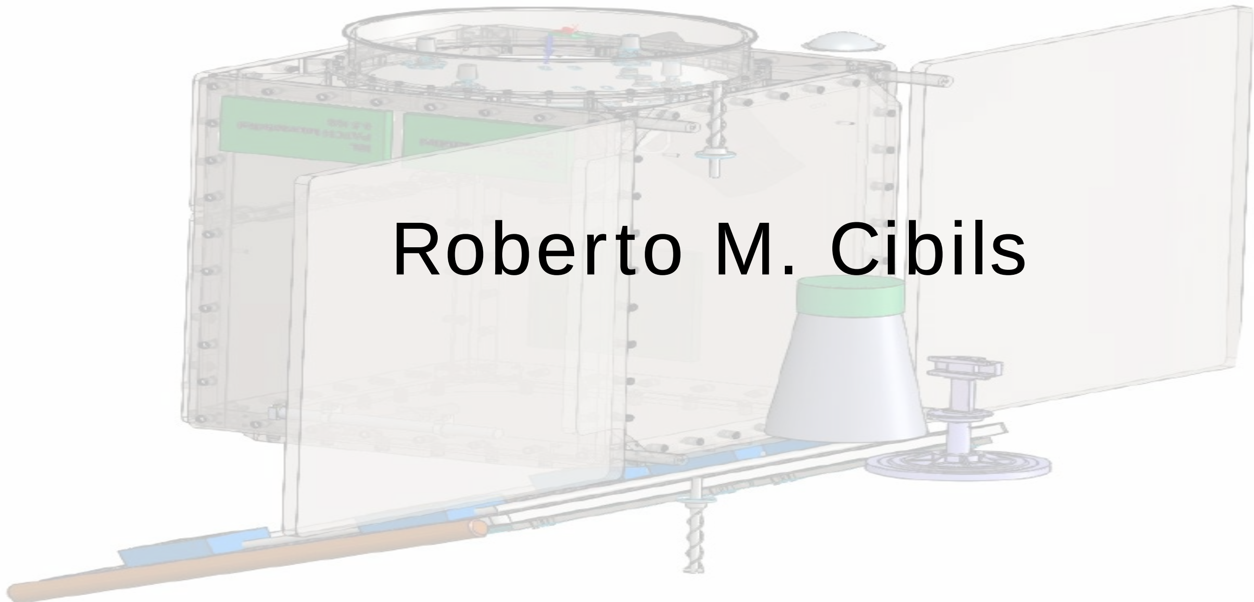
Small Satellites Hardened by Design for the use of Non-Space Qualified EEE Parts



Roberto M. Cibils

INVAP

Contents

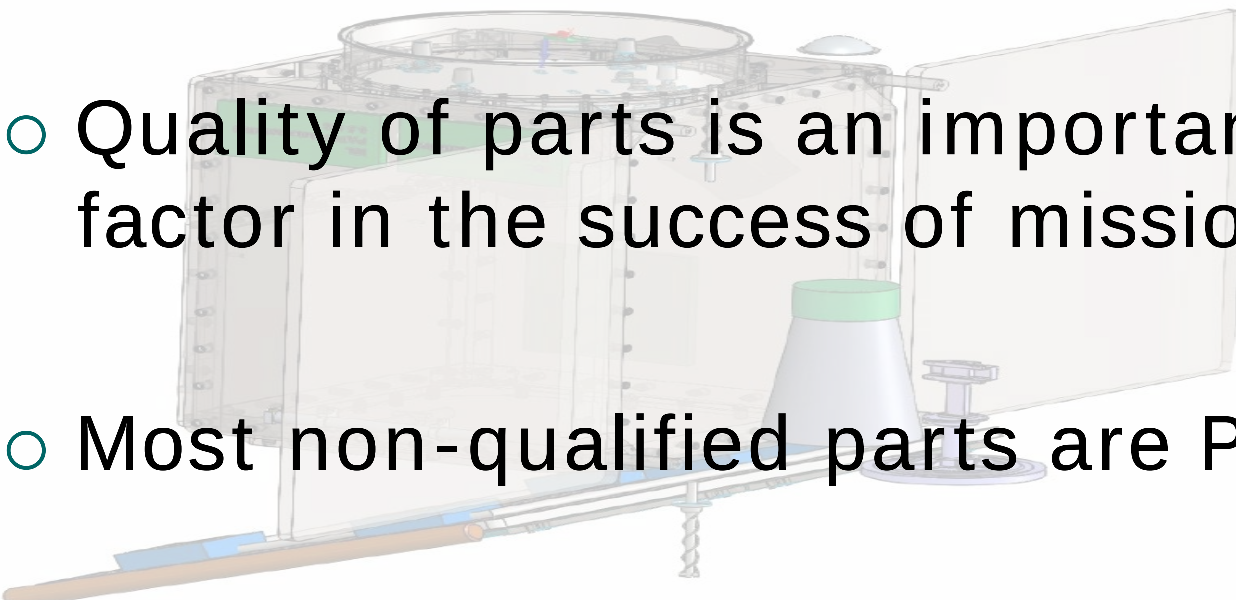
- Motivation
- Risk reduction strategy
- Up-screening
- Radiation hardening strategy
- Early wear out hardening strategy
- Levels of Redundancy
- Conclusions

Motivation

- Class C or D missions: medium or high risk

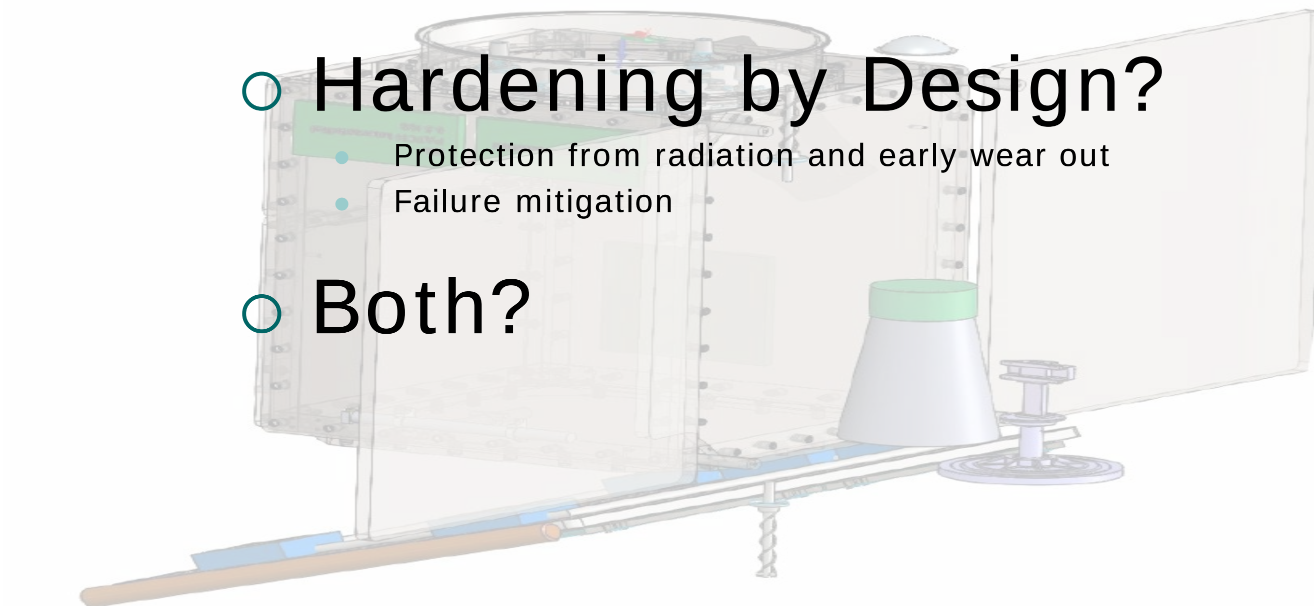
- Quality of parts is an important factor in the success of missions

- Most non-qualified parts are PEMs



Risk reduction strategy

- Upscreening?
  - Screening
  - Qualification tests
- Hardening by Design?
  - Protection from radiation and early wear out
  - Failure mitigation
- Both?



Up-screening - Is it enough?

Table 1 MONOLITHIC INTEGRATED CIRCUIT REQUIREMENTS (Page 1 of 2) 1/

Part Designation	Use As Is	Screen To Requirements in Table 2 2/	Qualify To Requirements in Table 3 2/
Level 1:			
1) Class V or Class S	X		
2) Class Q or Class B		X 3/, 4/, 5/	
3) SCD		X 4/, 5/	X
4) 883-Compliant or Class M 5/		X 4/, 5/, 6/	X
Level 2:			
1) Class V or Class S	X		
2) Class Q or Class B		X 4/	
3) 883-Compliant or Class M 6/		X 4/, 8/	X 9/
4) SCD		X 4/, 8/	X 9/
5) Mfr. Hi-Rel 7/		X 4/, 8/	X 9/
6) Commercial		X 4/, 8/	X 9/

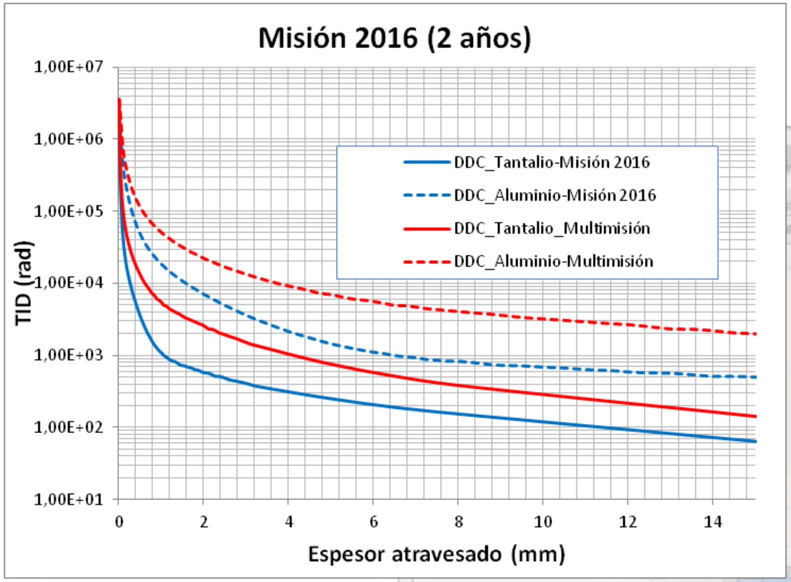
- The more demanding environmental requirements
- The lower the size of the accepted batch; **if any**

Parts needs to be protected by design

Risk Reduction Strategy

- **Reduction of the Problem Dimensions**
  - Information Search
    - Heritage /Open Databases
  - Testing
    - Radiation tolerance/Reliability
  - Criticality Analysis (FMEA)
- **Protection**
  - Radiation hardening strategy
  - Optimized Thermal design
  - Derating
- **Mitigation**
  - Redundancy/FDIR

TID and DD mitigation



- Radiation shielding
  - Electrons and low energy protons
  - Satellite/Boxes level
    - Ray trace analysis
  - Spot shielding
    - Secondary radiation
- Derating
  - Design for degraded parameters ie: supply current
- Operating Temperature
  - Dark current increase in CCDs

SEE Mitigation: Destructive

- **SEL**
  - Current limiting with reset
- **SEB**
  - **Power MOSFETs**
    - Drain current limiting (protection)
    - Derating of Drain-Source Voltage (prevention)
- **SEGR**
  - **Power MOSFETs**
    - Using in a safe operating range
  - **Memory cells**
    - High purity oxides diminishes risk

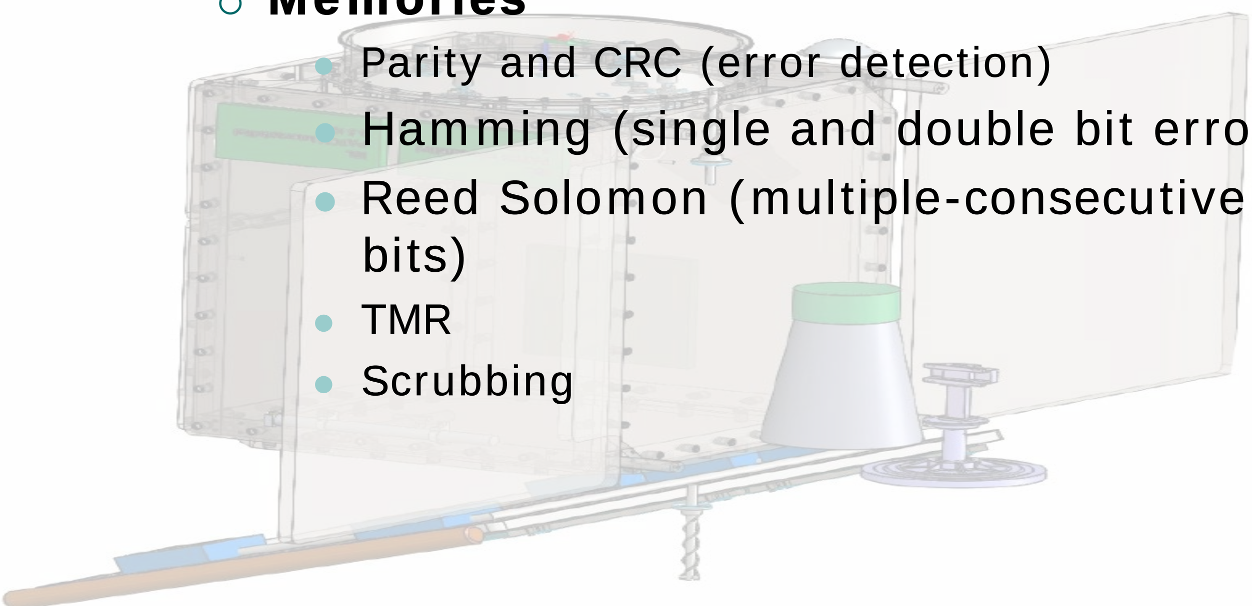
SEE Mitigation: Non-Destructive

- **Service Loss**
  - **SEU**
    - **Processors**
      - Redundancy in time
      - Steplock
      - Watch dog
  - **SET**
    - Moderate clock speed

INVAP

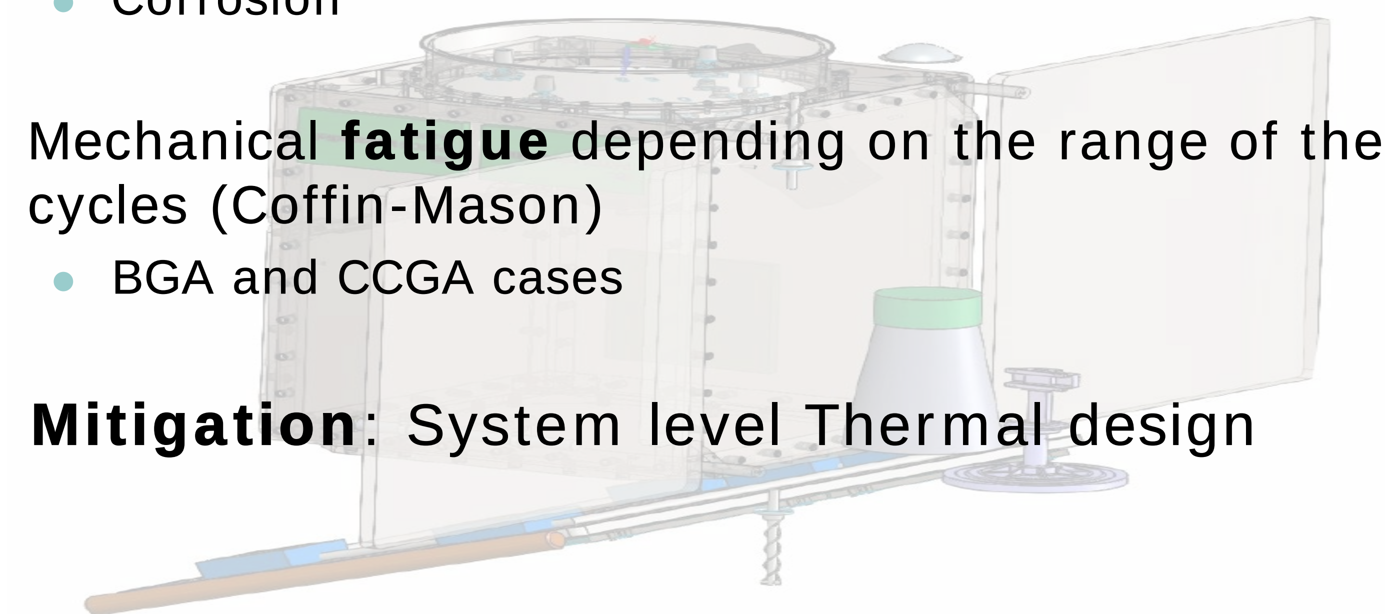
SEE Mitigation

- **Data Quality Loss**
  - **SEU**
    - **Memories**
      - Parity and CRC (error detection)
      - Hamming (single and double bit errors)
      - Reed Solomon (multiple-consecutive bits)
      - TMR
      - Scrubbing

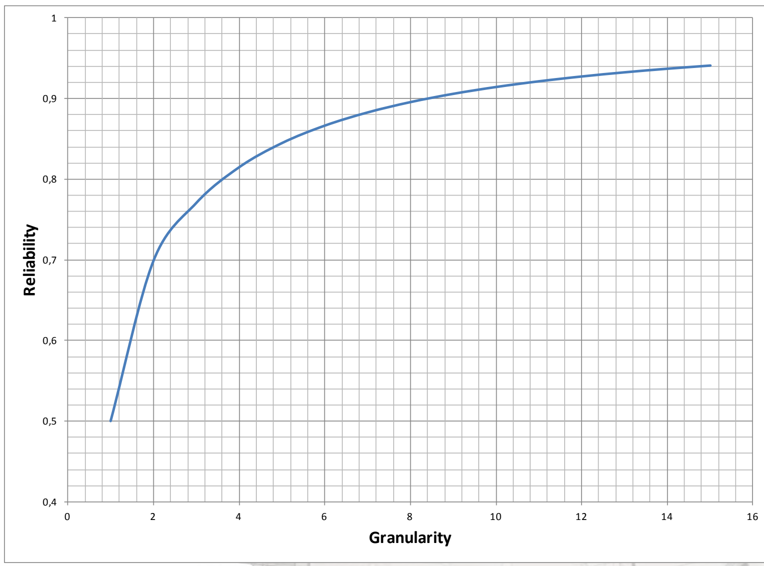


Optimized Thermal Design

- **Wear out** activated by high semiconductor junction temperature:
  - Electromigration (Blacks equation)
  - Corrosion
- Mechanical **fatigue** depending on the range of thermal cycles (Coffin-Mason)
  - BGA and CCGA cases
- **Mitigation**: System level Thermal design



Redundancy Mitigation



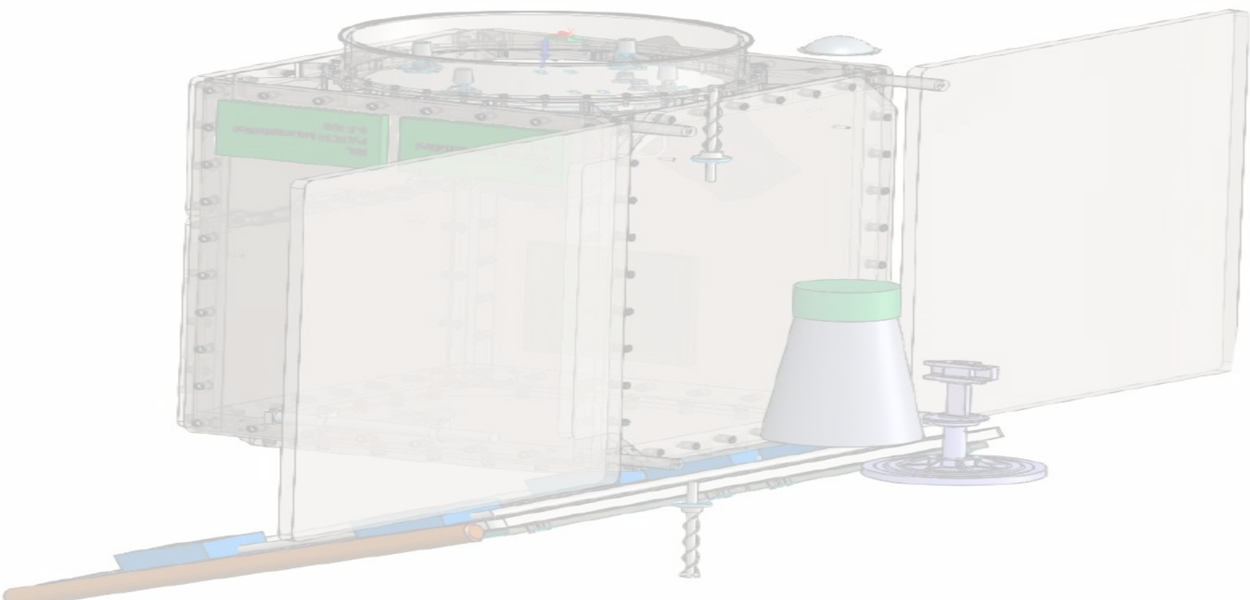
- Although the reliability figure decreases because of **interconnections** when the granularity level at which the redundancy is applied is too fine.
- There is always an **optimun** value of reliability for granularity levels greater than one.
- Redundancy at **constellation and satellite level** is not always the best strategy.

Conclusions

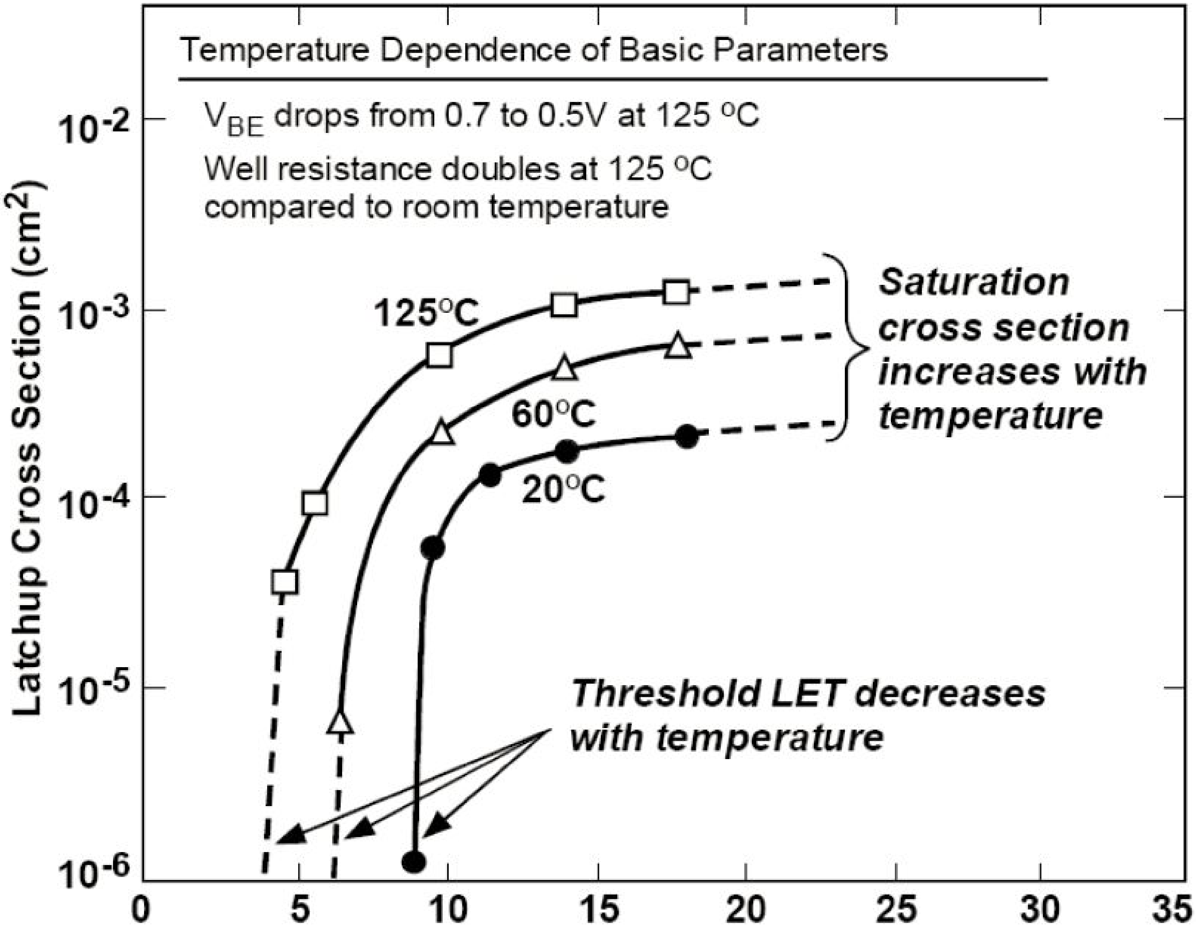
- The use of non space-qualified electronic parts in space missions is becoming **more and more frequent**
- They can be “use as is” only when **high risk is tolerated**
- **Up-screening** of these parts is necessary for extending mission lifetime expectations
- **Special design practices** are needed to guarantee the success of the up-screening processes

INVAP

Complementary slides

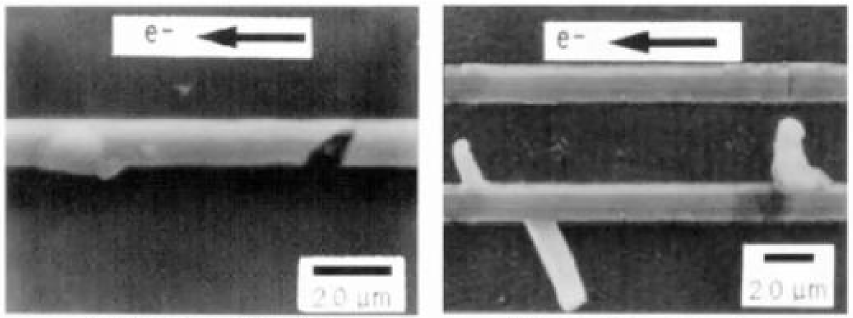


Latchup



Temperature Dependence of Basic Parameters
V_{BE} drops from 0.7 to 0.5V at 125 °C
Well resistance doubles at 125 °C compared to room temperature
125°C
60°C
20°C
Saturation cross section increases with temperature
Threshold LET decreases with temperature
Latchup Cross Section (cm²)
10-2
10-3
10-4
10-5
10-6
0
5
10
15
20
25
30
35

Electromigration



Voids (Open Circuits) Hillocks (Short Circuits)

Blacks Equation

Mathematical Model for Mean Time to Failure (MTTF)

$$MTTF = \frac{A}{J^N}.\exp\left(\frac{E_a}{k.T}\right)$$

A	Cross-section-area-dependant constant
J	Current Density
N	Scaling factor, usually set to 2
E_a	Activation energy for electromigration
k	Boltzmann constant
T	Temperature

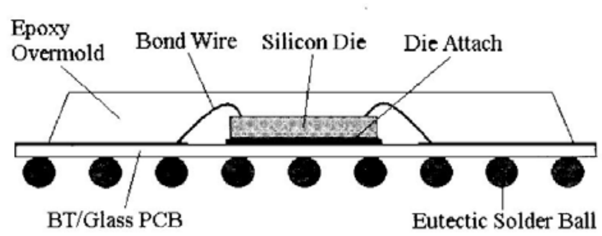
Corrosion

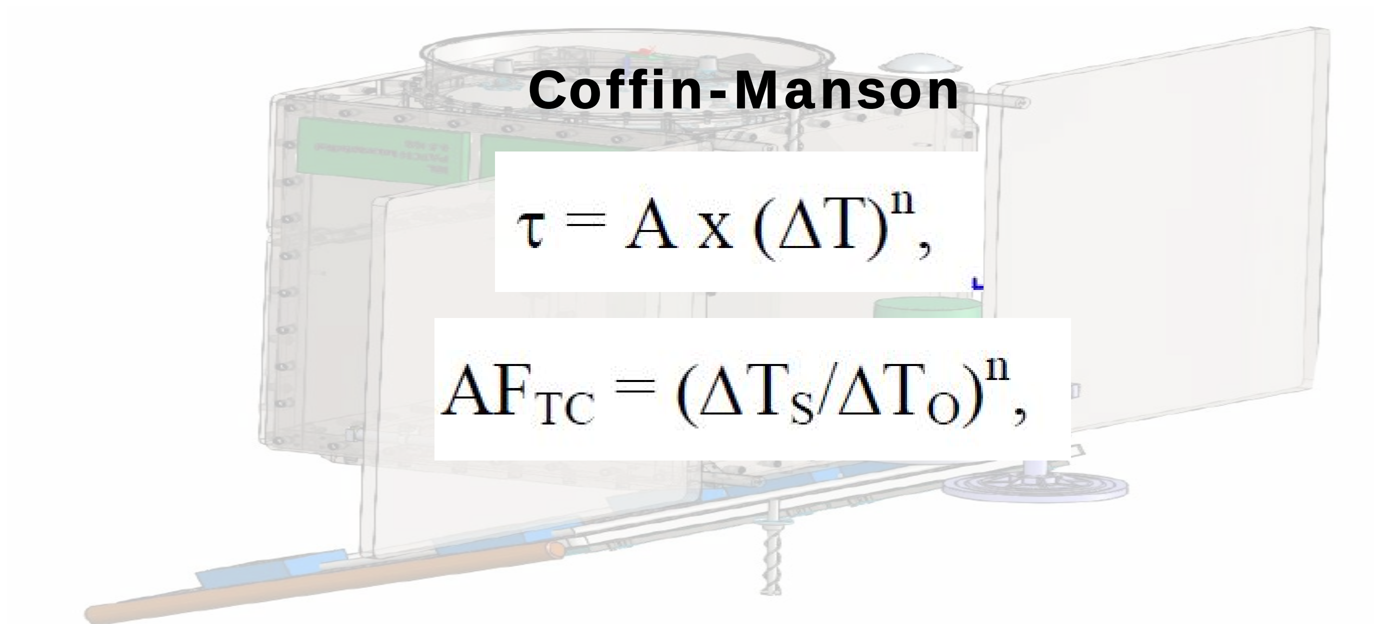
- Electronic devices with aluminum or aluminum alloy with small percentages of copper and silicon metallization are subject to corrosion failures and therefore can be described with the following model :

$$L(RH,V,T) = B_0 \exp[(-a)RH] f(V) \exp(E_a / kT)$$

- where:
- B0 is an arbitrary scale factor.
- ɑ is equal to 0.1 to 0.15 per % RH.
- f(V) is an unknown function of applied voltage, with empirical value of 0.12 to 0.15.

Mechanical Fatigue





Coffin-Manson

$$\tau = A \times (\Delta T)^n,$$

$$AF_{TC} = (\Delta T_S / \Delta T_O)^n,$$