FEEDBACK ON IN-FLIGHT PROJECTS USING COTS: INTRODUCTION TO THE RHA APPROACH USED FOR “NEW SPACE”

ESCCON2021

March 11th, 2021

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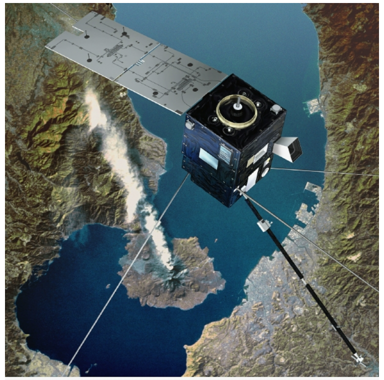
cnes

Feedback on in-flight projects using COTs:
Introduction to the RHA approach used for “new space”



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Introduction

Evolutions of satellites at CNES

First COTS in CNES projects

Feedback / Lesson learned

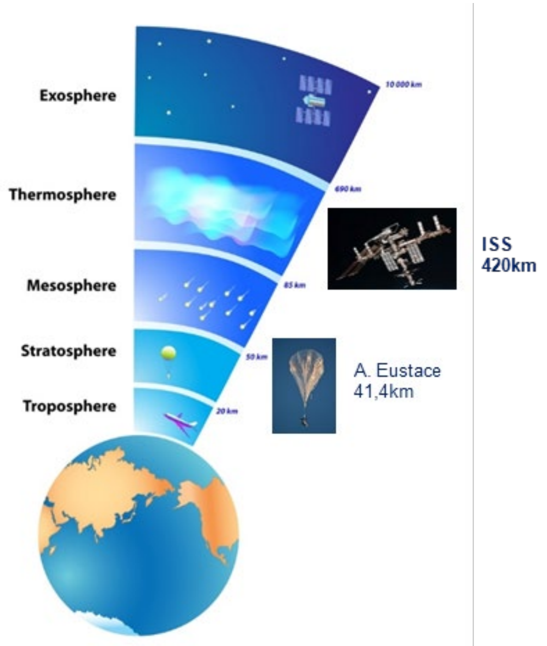
Proposed RHA for New Space

Conclusion

Introduction / Definitions

- **Commercial Off-The-Shelf, COTS:**
  - Electronic component or equipment
  - From commercial, industrial or automotive offer
  - Not HiRel (High Reliability, Military & Space)

- **Radiation**
  - Space,
  - Atmospheric,
  - Terrestrial applications.



Do not confuse High Reliability components & Radiation Hardened or Radiation Tolerant ones.

HiRel = RH, RT or not hardened but COTS = not hardened

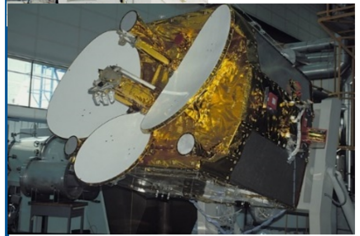
Evolution of satellites at CNES

1985 – 1993 – 1998 – 2012 – 2016 – 2020

On Board Computing, integration level, proportion of COTS, number of models

SPOT1

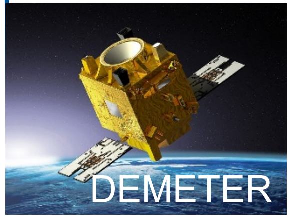
Telecom1



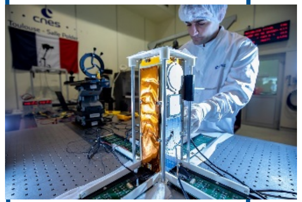
Big satellites > 1T
Dedicated to a given mission

Minisatellites
500kg
PROTEUS
Platform
6 satellites

Microsatellites
100-150kg
MYRIADE
Platform
18 satellites



Nanosatellites
1-30kg



JANUS
Eyesat

ANGELS

Constellations of nanosatellites

kinéis

Size, Mass, Conception cost & delay

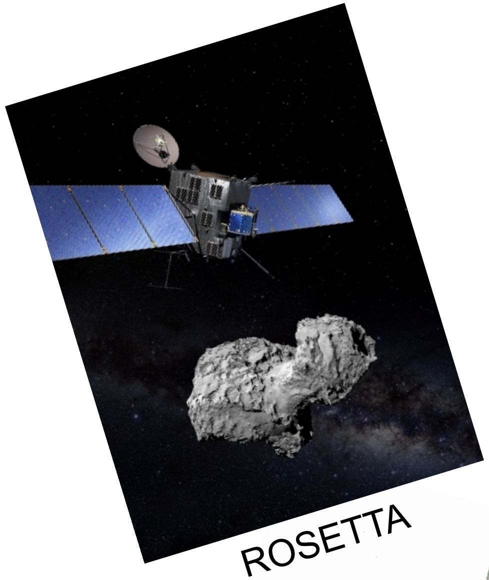
First COTS in CNES projects

In the middle of the 90's

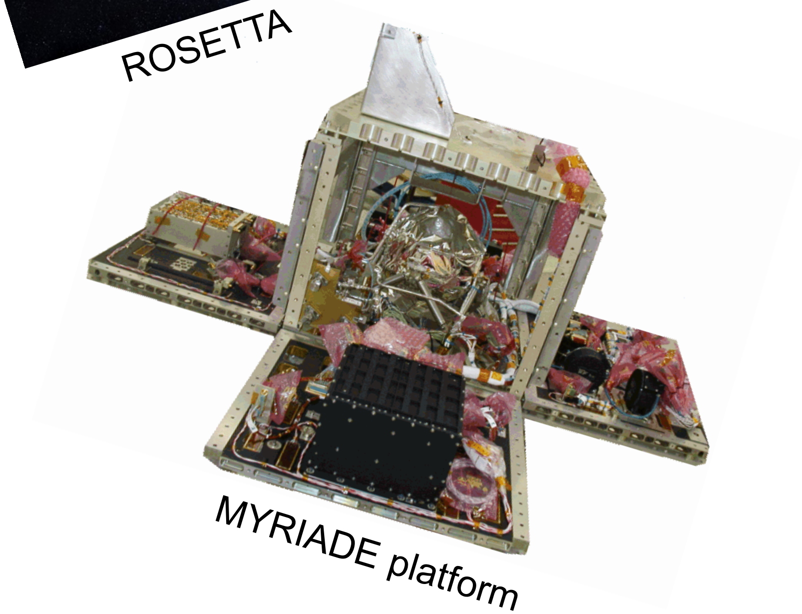
Need for satellites with lower costs

- Smaller satellites (launch less expensive)
- Generic platform
- Limitation of conception delays

=> Trade-off performance/risk/cost → **COTS**



ROSETTA



MYRIADE platform

First candidates: Scientific projects or demonstrators (risk accepted)

But the beginnings were timid:

- Lots of qualification tests including radiation tests
- Real possession cost not really low
- The use of COTS was mainly driven by performance.

→ **Interest for production of series**
Importance of strategic procurement

Feedback: A lot of good results

In most of cases, no radiation issue has been reported on COTS even if they were not specifically hardened.

<ins>**Example**</ins>: PIC 16C76 microcontroller (Microchip).

- Selected thanks to its very low current consumption
- TID tested => OK up to 15krad
- Tested sensitive to SEU and SEL under heavy ions and protons
    - Anti SEL system implemented (based on the SEL currents detected during the tests)
    - Watchdog and external boot used to limit the impact of SEUs

} 1995/1996

No radiation related issue reported in flight.

How to perform TID/SEE tests under radiation on more complex devices or architectures?
=> Static vs dynamic and transposition to real application?

For the first time, in 2002, CNES performed radiation tests at board level.

Feedback: Test TID at board level

Pros:
- Limits the number of tests (vs test at component level)
- Avoid to accumulate margins
- Closer to the final application

Cons:
- One model is sacrificed (only one: need to apply margin?)
- In case of bad result, huge impact
- Tested model shall be 100% representative of the FM

2002: EQM of the MYRIADE Platform OBC tested under Cobalt 60 at low dose rate.
- 10kRad targeted
- After 1kRad: No more functional (2 voltage references out of specification)
- Replaced by compatible COTS from another manufacturer
- Additional irradiation up to 10krad

OBC TID qualified up to 10krad

Feedback: Test SEE at board level under protons and/or neutrons

Pros:

- Fault injection (SET, SEU, MBU, SEFI, SEL, SEB, SEGR…) in the final application
- Identification of errors signatures (allowing dedicated corrections)
- Verification of the efficiency of the circumvention techniques implemented.

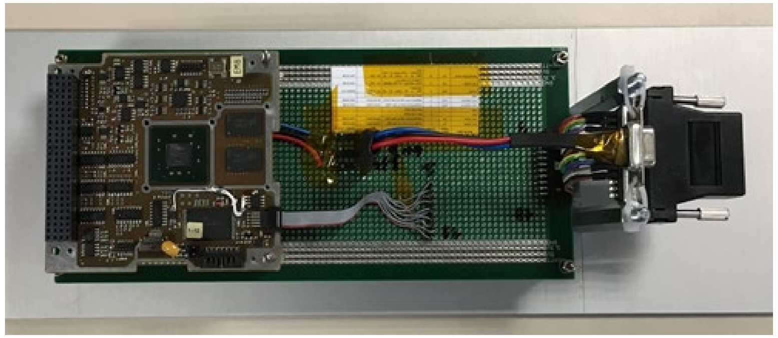
Cons:

- One model is sacrificed
- In case of bad result, huge impact on schedule.
- Tested model shall be 100% representative of the FM,
- The design shall be mature, including Fault Detection Isolation & Reconfiguration (HW +SW)
- Test under protons/neutrons does not cover SEE induced by high LET ions (>15MeV/(mg/cm^2))

2016: Validation of the FDIR implemented on the Ninano OBC tested under mixed field at CHARM (CERN).

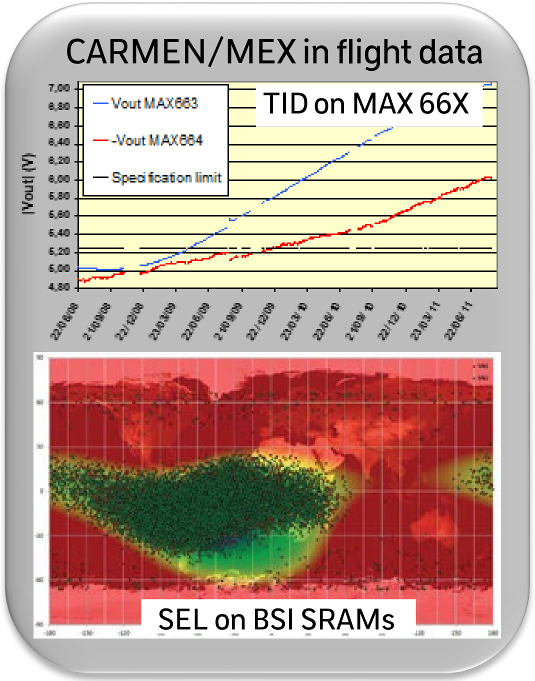
- No SEL
- Several SEU, SEFI but autonomous recovery demonstrated.

⇒ **OBC SEE qualified for the EYESAT mission**



Warning: Sometimes, COTS have very bad radiation behavior

Examples from CNES experience:



Total Ionizing Dose: MAXIM MAX66x voltage references **out of spec after 1kRad**.
- Revealed by MYRIADE OBC test at board level
- Confirmed by a test at component level under Co60
- Confirmed on the CARMEN/MEX instrument on various orbits.

Single Event Latchup: SRAMs Brilliance Semiconductor inc. very sensitive
- First detected at component level (Rejected by scientific project)
- Occurred on board of CNES stratospheric balloons (Polar, 40km)
- Confirmed by a test at component level (protons + ions)
- Confirmed on the CARMEN/MEX instrument on board of JASON3 **(14 SEL/day).**

SEU, MBU, SEFI: Memories are sensitive to SEU and usually protected by EDAC but other events may occur such as Intermittent Stuck Bits. This was observed on a CNES microsatellite on a COTS SDRAMs not sufficiently characterized. A flight SW upgrade was necessary to recover a correct data flux.

These examples show that a minimum characterization phase is mandatory to avoid critical failures.

Proposed RHA for New Space 1/3: Cumulative effects

What is the minimum characterization required:

Total Ionizing Dose:

- Depends on the orbit and mission duration.
- Trade-off shielding or test
- Devices may be not functional after 1kRad
- Impacts the end of the mission

Total Non Ionizing Dose:

- Depends on the orbit and mission duration.
- Devices may be not functional after 1E9 p_{50MeV}/cm^2
- Impacts the end of the mission
- Less critical than TID except on photonics

If TID after shielding >1krad:
- Use available data or test at component level
Or
- Test at board level

Select dose rate and samples with care

If TNID after shielding > 1E9 p_{50MeV}/cm^2 :
- Data available or test at component level (photonics only)
Or
- Test at board level (coupled with SEE)

How can we guarantee that the test is covering the FM behavior?

Alternative option: Do nothing and cross fingers
Accept the risk to limit the mission duration

Proposed RHA for New Space 2/3: Destructive SEE

What is the minimum characterization required:

Single event destructive phenomena:

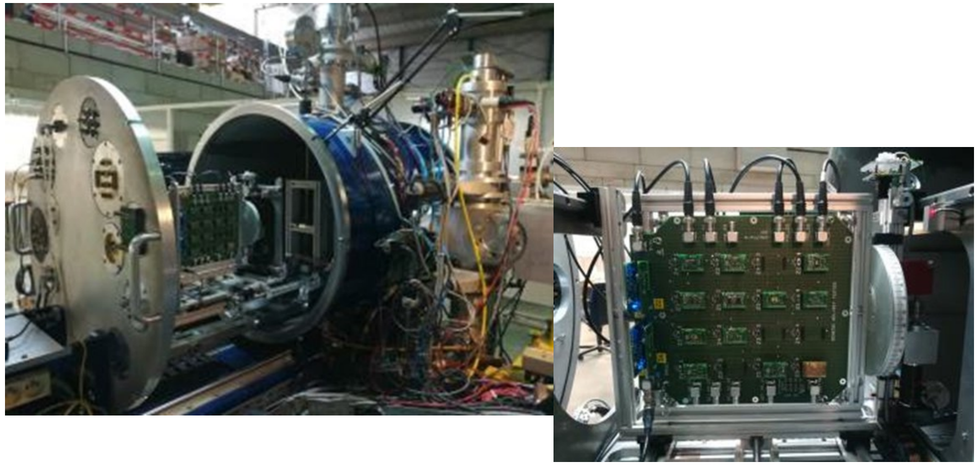
- SEL on CMOS/BiCMOS
- SEB, SEGR on Power MOSFETS
- An event may occur very soon in the mission
- No standard protection available

Destructive SEE test are <u>mandatory</u>:

- Use available data or test component under heavy ions
  - Rate prediction & SEL Protection system definition
  - SOA in the case of MOSFETs

Optimization of tests to save time & money

Group together several tests



Limit the number of tests – Go/NoGo selection

Example:

LETth>40 or 60* MeV/(mg/cm²) => Accepted

LETth<15MeV/(mg/cm²) => Rejected

(the DUT will be sensitive to protons)

15<LETth<40MeV/(mg/cm²) => X section

*: depending on the mission and the level of risk accepted

Proposed RHA for New Space 3/3: Not destructive SEE

What is the minimum characterization required:

Single event Not destructive phenomena:
- SEU, MBU, SEFI, SET, ISB…
- Test at component level is expensive
- Standard circumvention techniques exist

Risk analysis at system level is mandatory:
- If risk is acceptable: no test
- If not: use available data or perform test

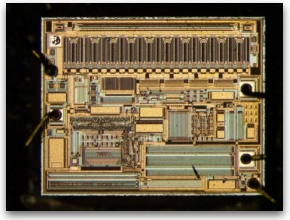
Test may be done under protons (complete board) or heavy ions (target on a few critical components)

Most of the time the simpler solution will be to perform a functional test at board level under proton or neutron beam
It will cover the most frequent risks for LEO (trapped protons)

WARNINGS:

Validity of exiting data: very difficult to establish

- Same version? Lot? die revision?
- Same bias condition or test configuration?



One shall consider strategic procurement and lot qualification tests

Test at board level:

- Only solution for real COTS equipment (black box).
- The most interesting for complex designs based on lots of COTS not previously characterized.

Selection with care of the model to be tested (may be an EM)
No SEE test at board level without preliminary FDIR implementation against critical events

Conclusion

COTS are not bad components but we generally have less information than usual.

=> it is **necessary to adapt RHA** as well as quality control in general.

Supply is one of the keys (traceability): Prefer official distributors & «automotive» range.

The number of tests can be limited but not completely eliminated.

Sometimes considered a black box, **COTS returns the RHA from the component to the system.**

In New Space, the risk accepted at component/equipment/satellite level can be high if the consequence on the whole system is considered acceptable.

Thank you for your attention