RF-MEMS Onboard a Satellite:

WE LOOK AFTER THE EARTH BEAT

Validation of the MEMO experiment at satellite level: RF MEMS GEO flight demonstration

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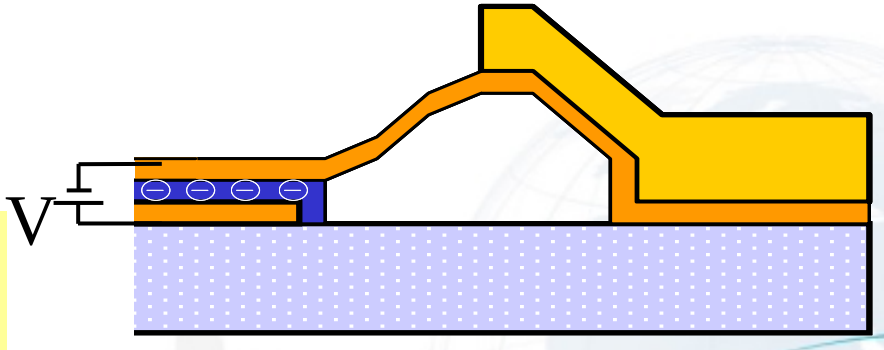
Outline

- Introduction of MEMO: Experience description
- RF-MEMS inside MEMO
- MEMO Design
- Manufacturing and Ground Testing of MEMO
- First in-orbit test results
- Conclusion

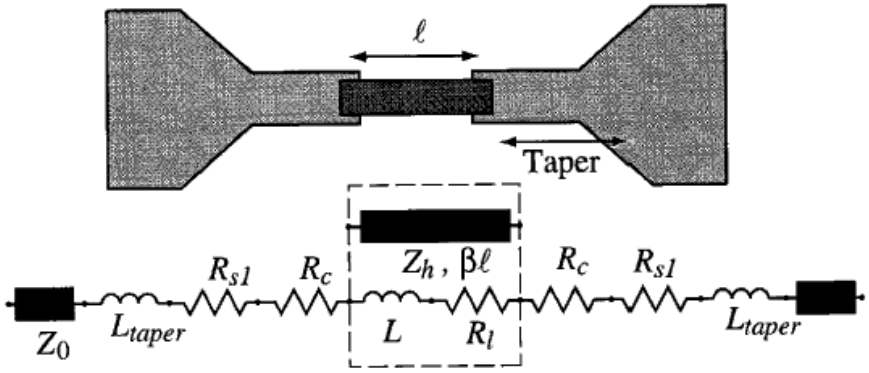
MEMO: Experience description

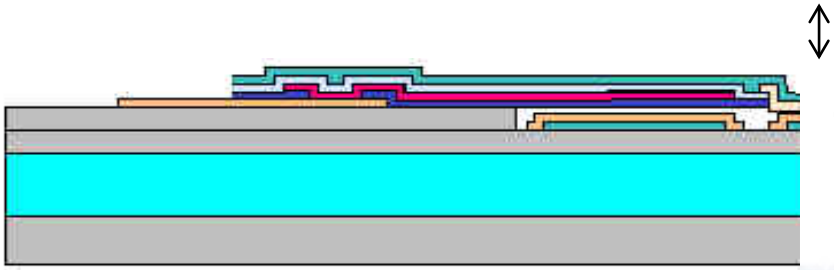
- Base for a Demonstrator definition
  - Observed failure modes for RF-MEMS Switches
    - **Contact :**
      - **Contact degration**
      - **Stiction metal-metal**
      - *Electromigration (seen at high signal level)*
    - **Membrane :**
      - **Residual stress, stress gradient, thermal stress**
      - *Creep (in case of metallic membrane)*
    - **Electrostatic activation**
      - **Dielectric charging**



>20 Volts over 0.2 µm
Charge injection + trapping is the main failure mode for RF-MEMS capacitive and ohmic switches

- Based on DC parameters
  - Fundamental sollicitation modes
    - Address all kind of applications (redundancy, fast switching)
  - Direct link with RF intrinsic characteristics :
    - Rc (On) => Insertion Loss
    - Vp => Isolation
  - **No need for RF parameters direct monitoring**





$$V_p = \sqrt{\frac{8k}{27\varepsilon_0 W w}} g_0^{3/2}$$

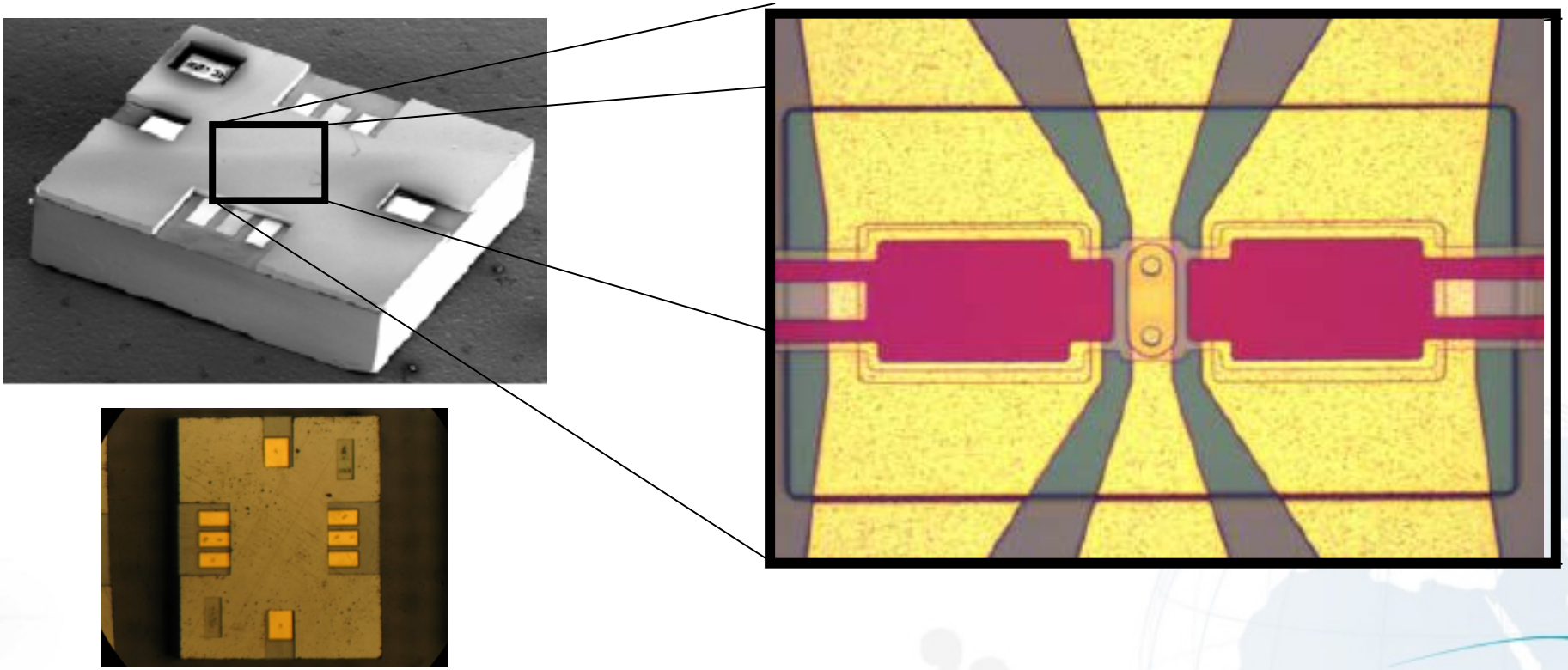
$$R_s = 2R_c + 2R_{sl} + R_l$$

$$losses = \frac{4R_s Z_0}{\left| Z_s + 2Z_0 \right|^2}$$

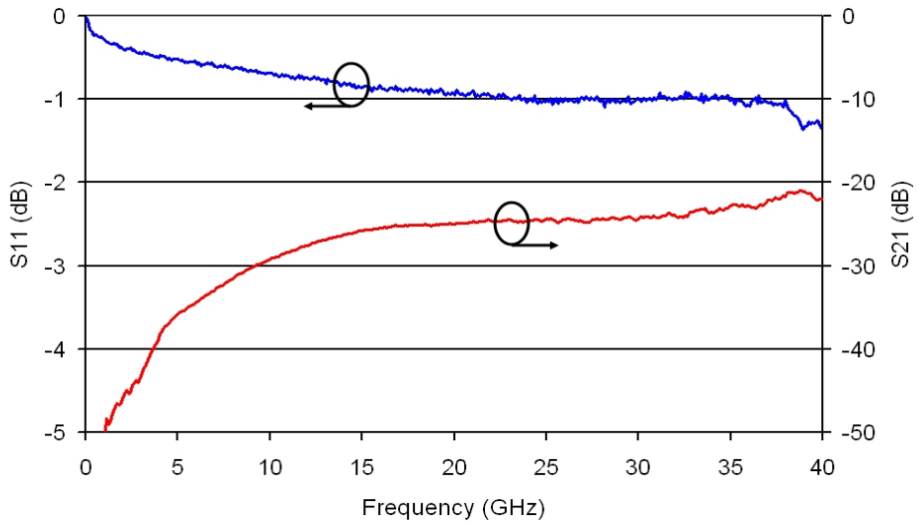
Membrane spring constant

$$k = 4Ew\left(\frac{t}{l}\right)^3$$

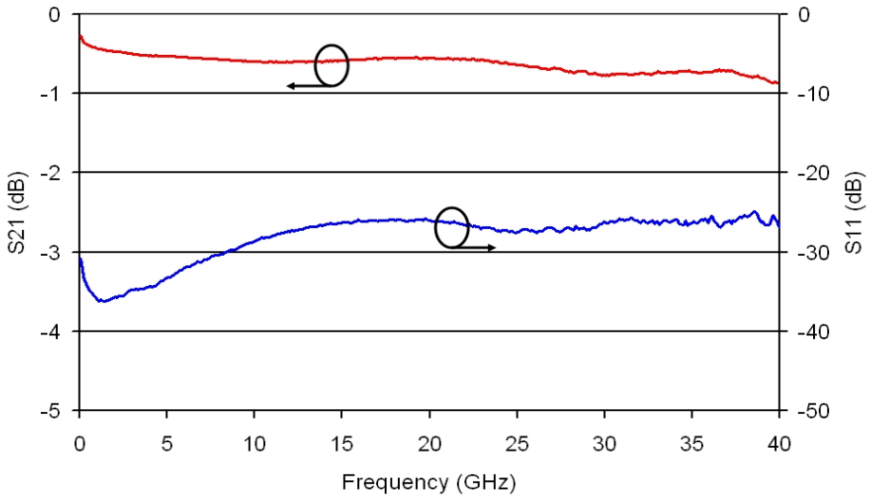
- First RF-MEMS technology:
  - Ohmic switch technology from **CEA LETI, dielectric membrane, electrostatic actuator, non hermetic packaging at wafer level, Ruthenium contacts**



Switch Performance : Ohmic switch (CEA-LETI technology)

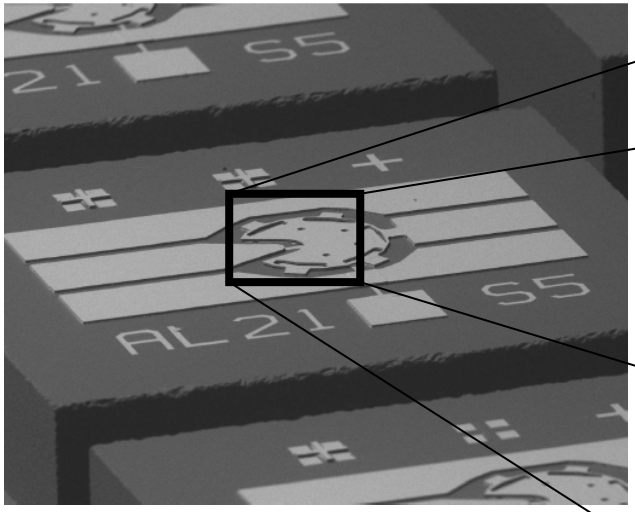


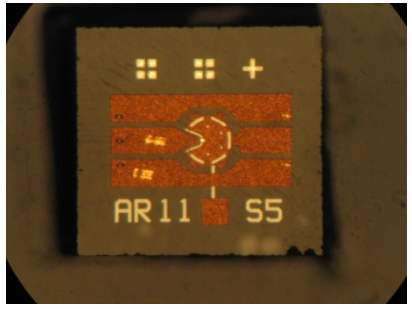
a) Membrane UP

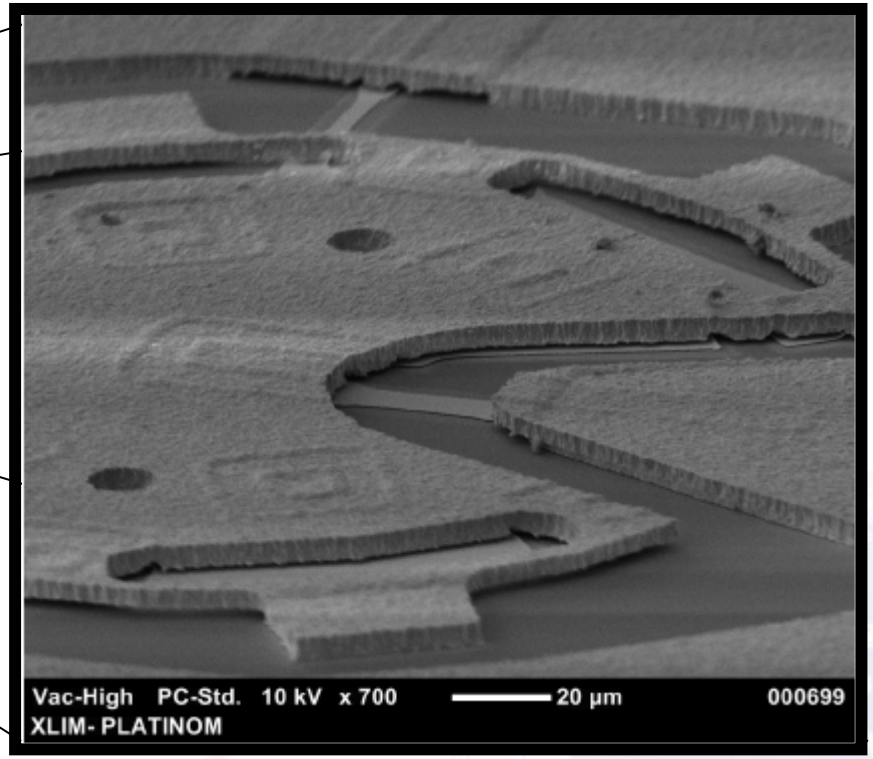


b) Membrane DOWN

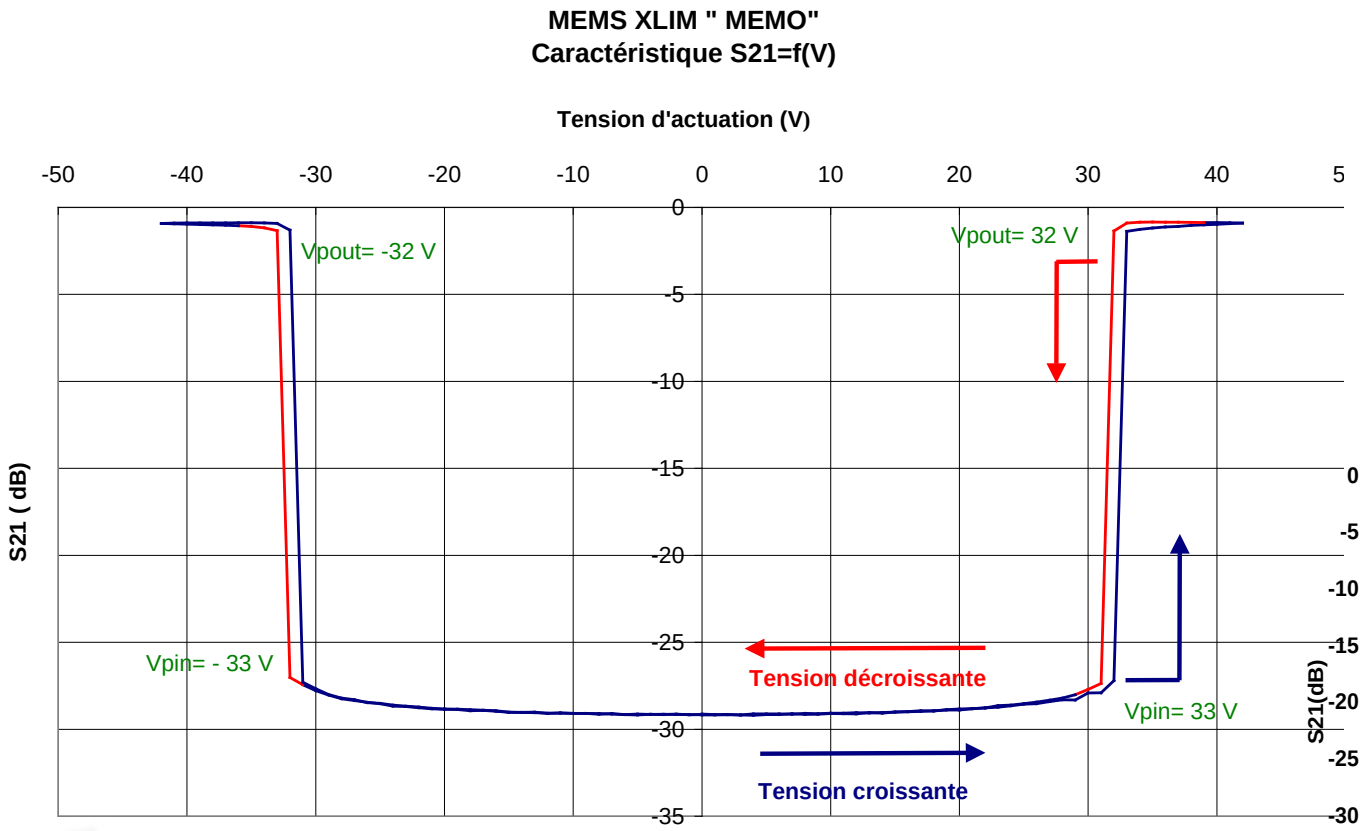
- Second RF-MEMS technology
  - Ohmic switch technology from **XLIM, metallic membrane, electrostatic actuator, no packaging, Au Alloy contact**

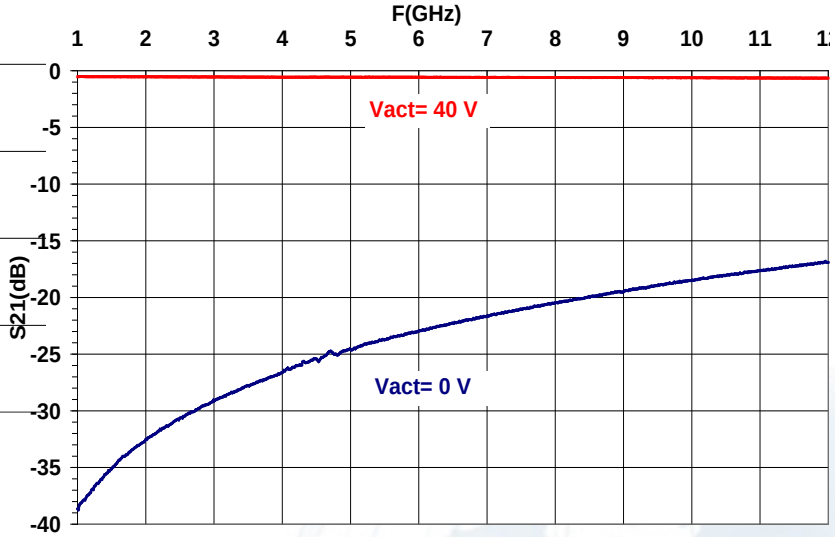






F= 3 GHz



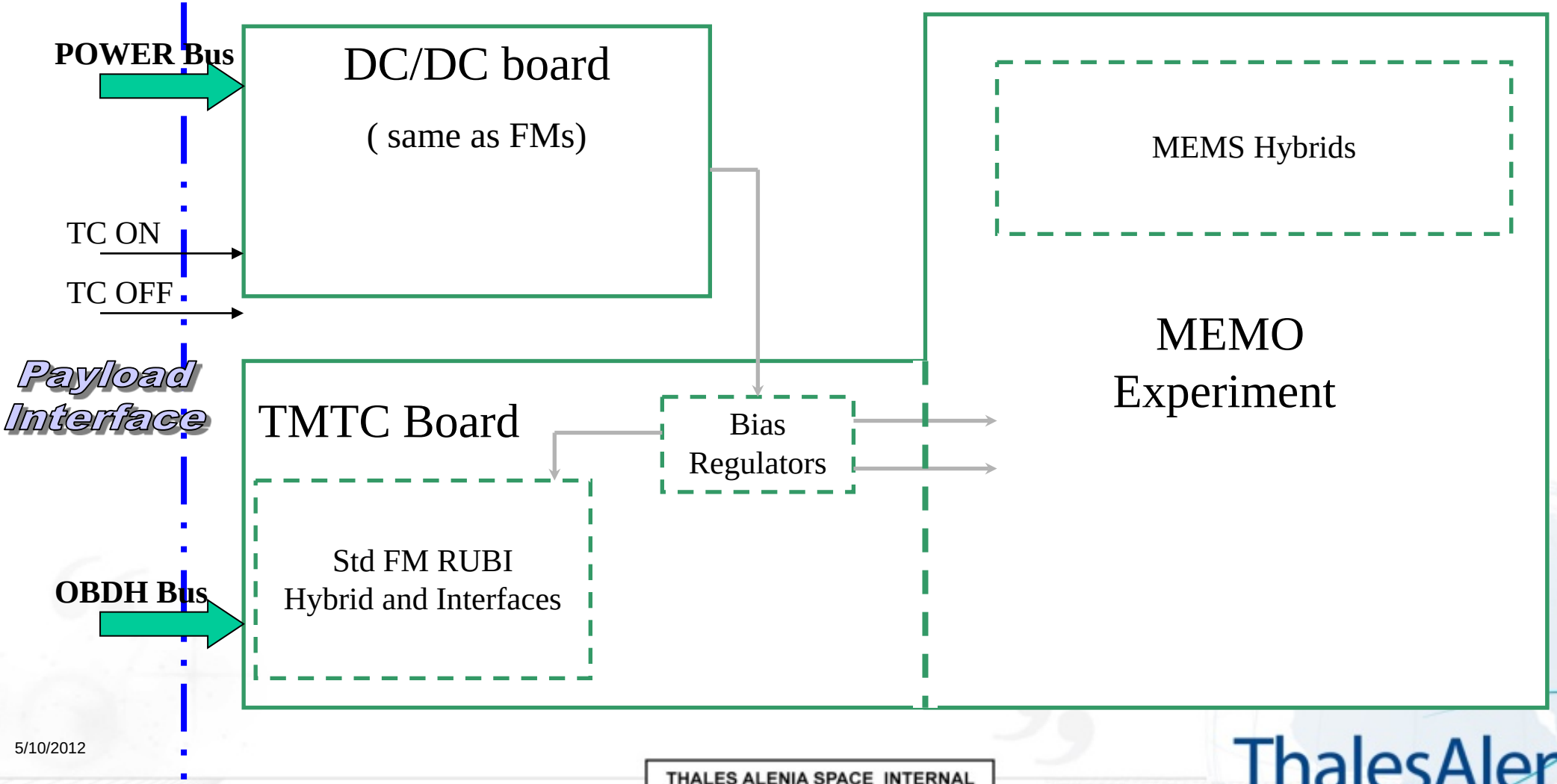


Basic Functions of MEMO Demonstrator

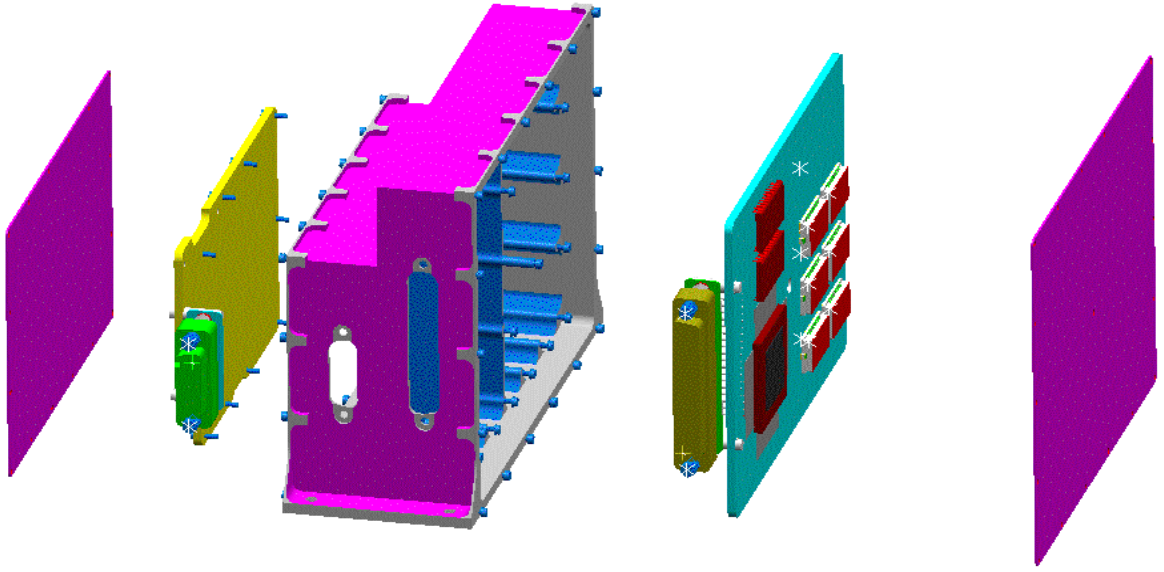
- Mode INIT: all the MEMS are switched On/Off 5 times, launched by TC
- Mode(1) : MEMS aging due to On/Off cycling, launched by TC
  - 1 Cycle On/Off per second : 4 MEMS
  - 1 Cycle On/Off per day : 4 MEMS
  - 1 Cycle On/Off per year : 4 MEMS
- Mode(2) : MEMS aging with sollicitation close to redundancy application
  - TC launched switch : 4 MEMS .
- Mode(Vpin/Vpout): Monitoring of Pull-in/Pull-out voltages
  - TC launched sequence : 4 MEMS
- Temperature monitoring

MEMO includes 20 RF-MEMS Switches

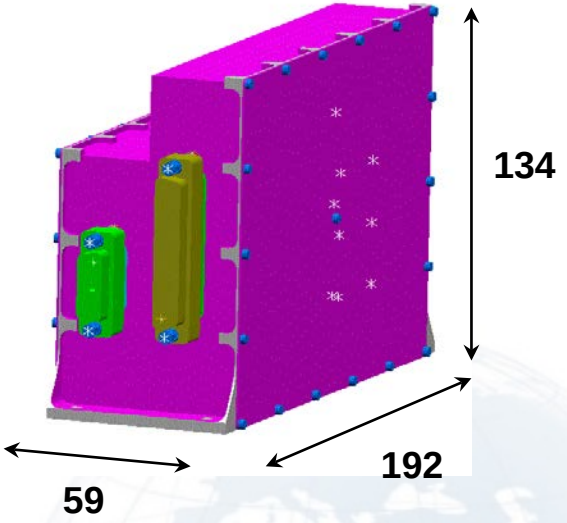
MEMO Demonstrator Block Diagram

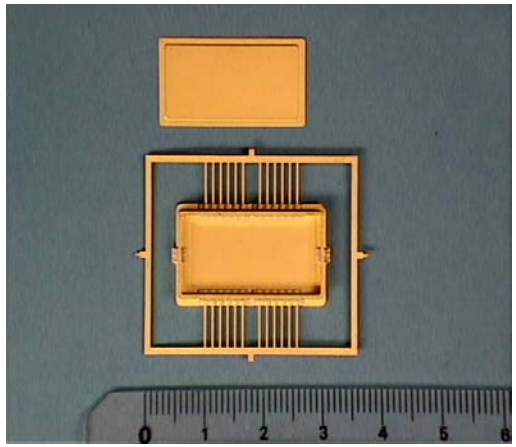


- **Demonstrator is composed of 2 Boards (PCB):**
  1 DC/DC et 1 TM/TC + MEMS Hybrid
- Aluminium Mono-structure with 2 covers.
- Interfaces to satellite platform by Sub-D Connectors

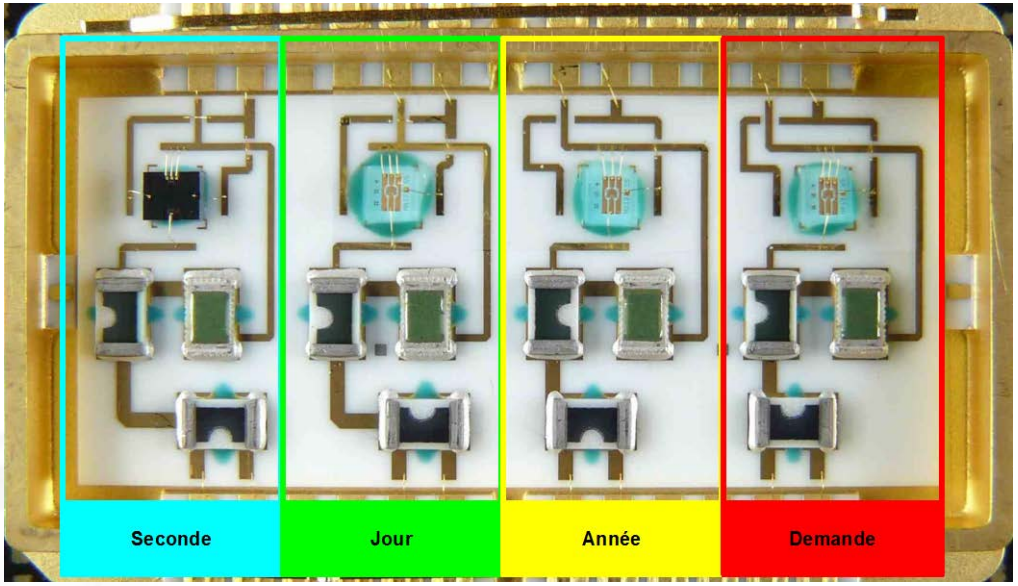


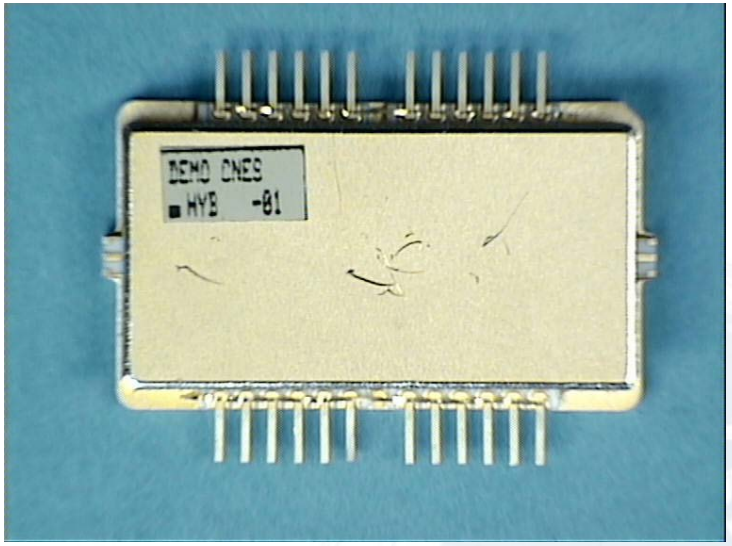
DC/DC Cover | **DC/DC Board** | **Housing (Aluminium)** | **TMTC + MEMS Board** | **TMTC + MEMS Cover**





- ✓Packaged into an Hermetic micro-package
- ✓MEMS bonding: glued, wired
- ✓According to TAS hybrid PID



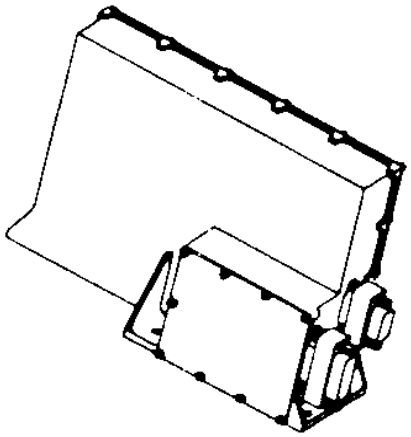


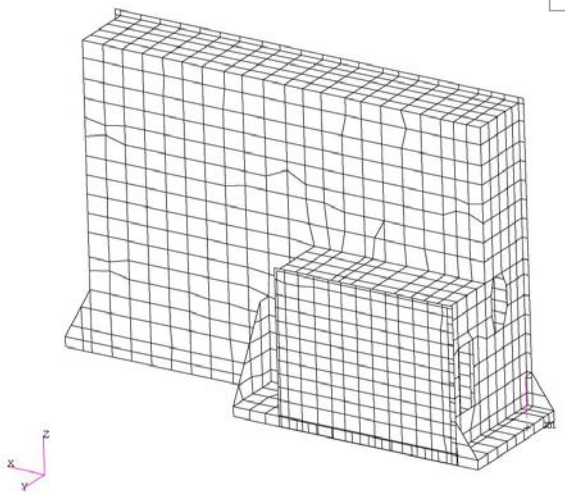
Mechanical Analysis

- STANDARD MECHANICAL ENVIRONMENT : Specs for Vibrations
- **Quasi static load :** Qualification level for quasi-static loads acting separately on each axis: ±10 g for out-of-plane axis, ±12 g for in-plane axes
- **Shocks**
- The equipment has to withstand a S4 severity shock test.
- The applicable shock spectrum corresponds to:

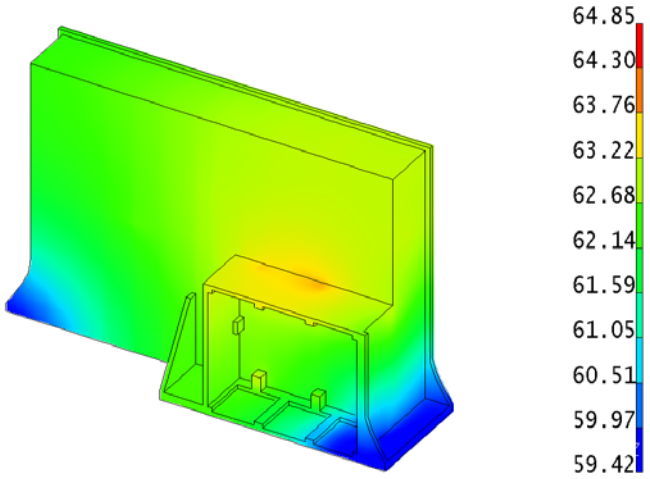
Frequency (Hz)	Qualification Shock Response (g) / Q = 10
500	200
3000	2000
10000	2000

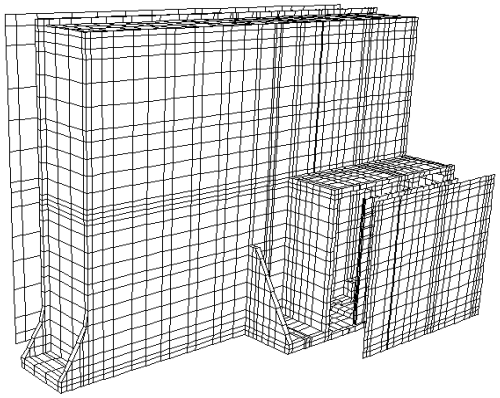
Maximum mass = 0.754 kg





➢Thermal analysis:





MODULES	PUISSANCE (W)
Carte TM/TC	2,544
Carte DC/DC	0,795
TOTAL	**3,339 W**

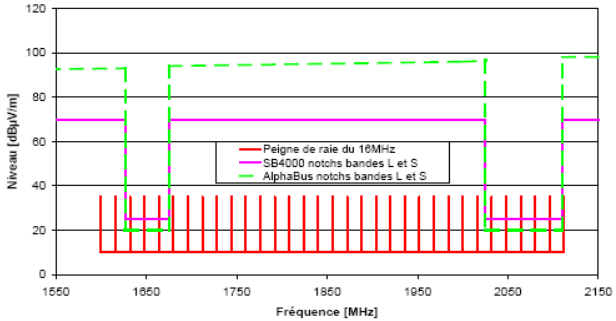
Power dissipation

T° Range	Operating mode	
	Tmin (°C)	T max (°C)
Qualification	-35	65
Acceptance	-30	60

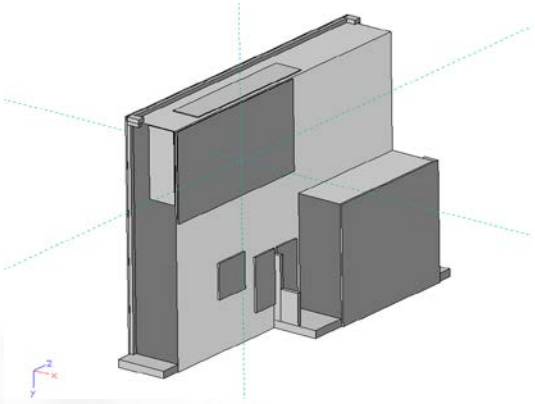
- **Conclusion :**
  - Thermal analysis shows that all component junction temperature remains below the value specified in internal reliability data base.
  - Thermal flux are also shown compliant with SB4000 requirements

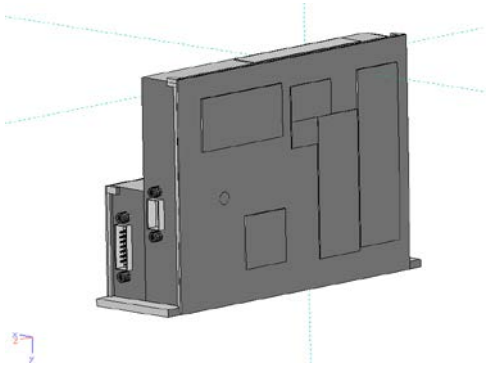
➢EMC analysis:

Ref. para.	Titre	Conformité	Commentaires
4.1	Emission conduite sur les lignes de puissance (CE) – Domaine fréquentiel	C.	
5	Emission conduite sur le bus OBDH	C.	
6.1	CS sinus sur les lignes d'alimentation	C.	
6.2	Transitoire sur les lignes d'alimentation	C.	
6.3	Transitoire sur les lignes de tellecomande	C.	
7.2	Emission rayonnée (RE)	C.	A confirmer pour les notchs bande L et S
7.3	Champ magnétique continu	C.	Par analyse. Pas de mesure prévue.
7.4	Susceptibilité en champ électrique	C.	
7.5	Susceptibilité en champ magnétique	C.	
8.	Décharge électrostatique (ESD)	C.	A confirmer par un test ESD sur une maquette représentative

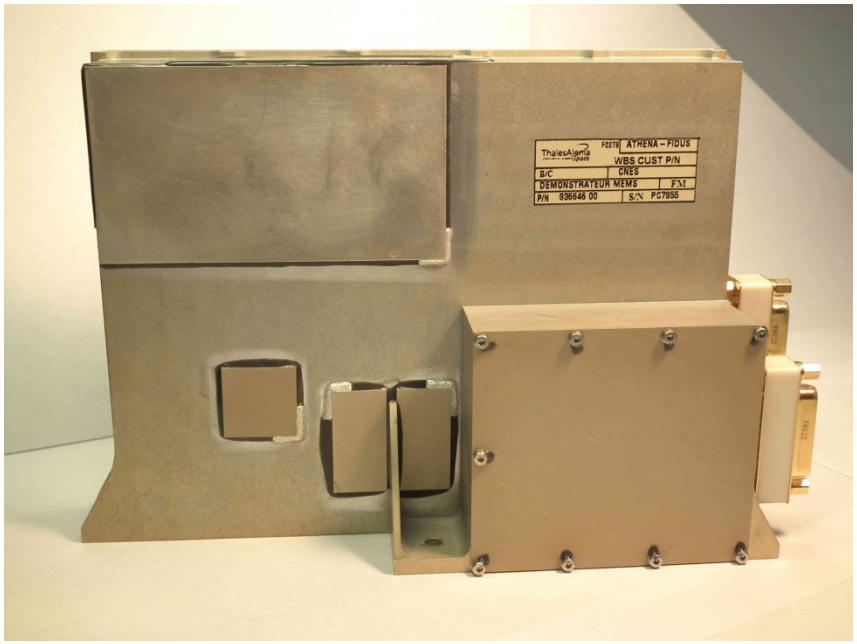


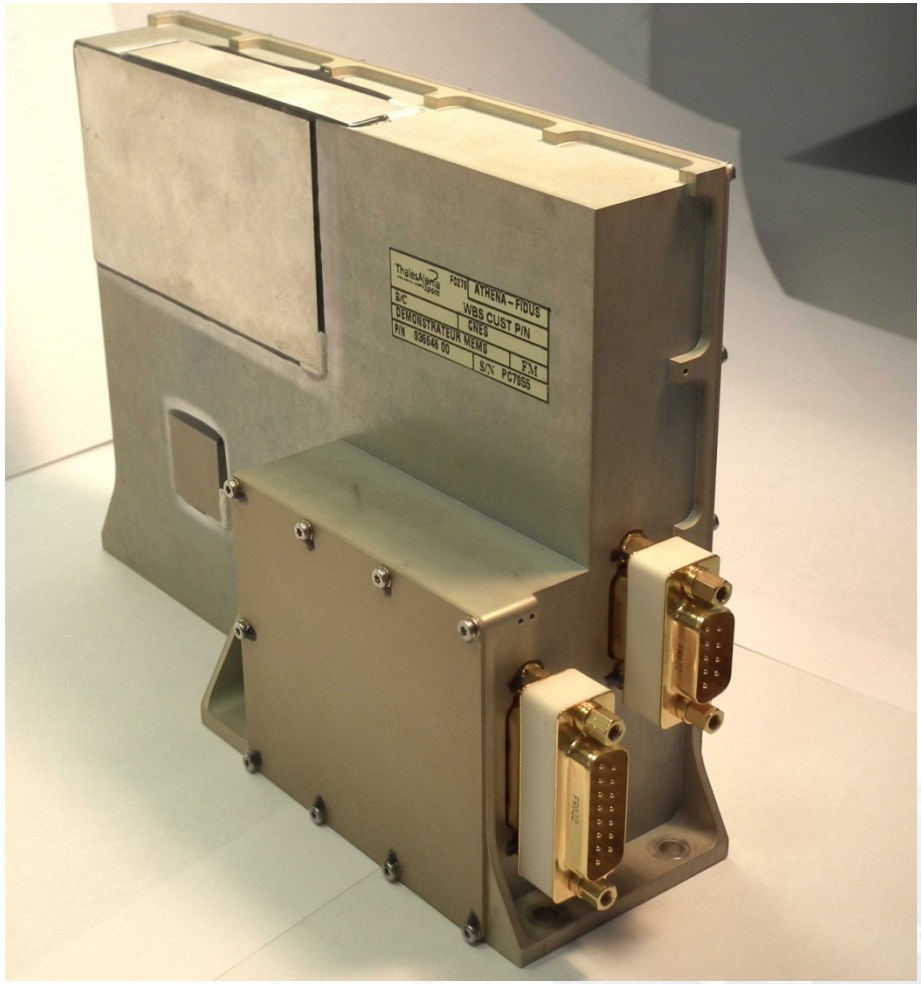
➢Radiation analysis:





Compliance to all environmental constraints has been demonstrated





Test Plan at equipment level

Electrical Tests

Mechanical Tests

Electrical Tests

3 Temperature Tests

Electrical Tests

EMC Tests

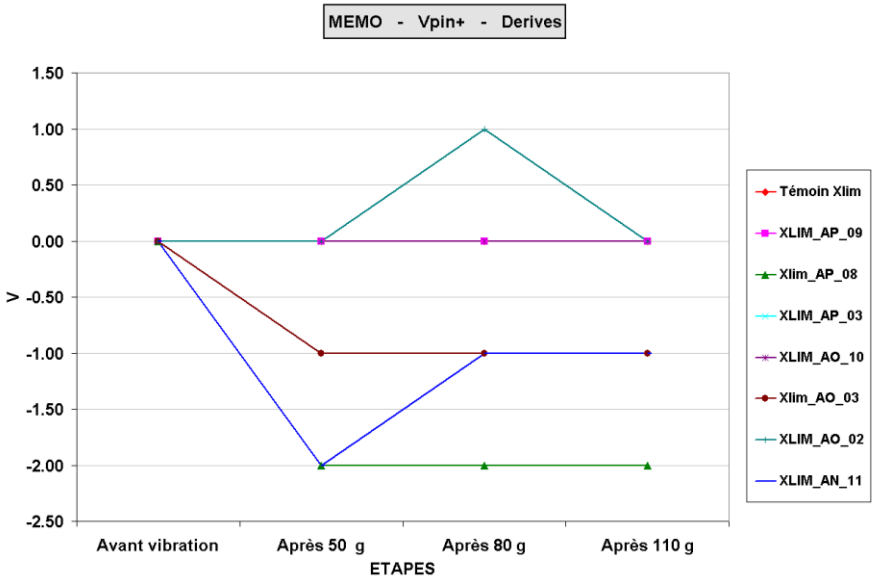
Electrical Tests

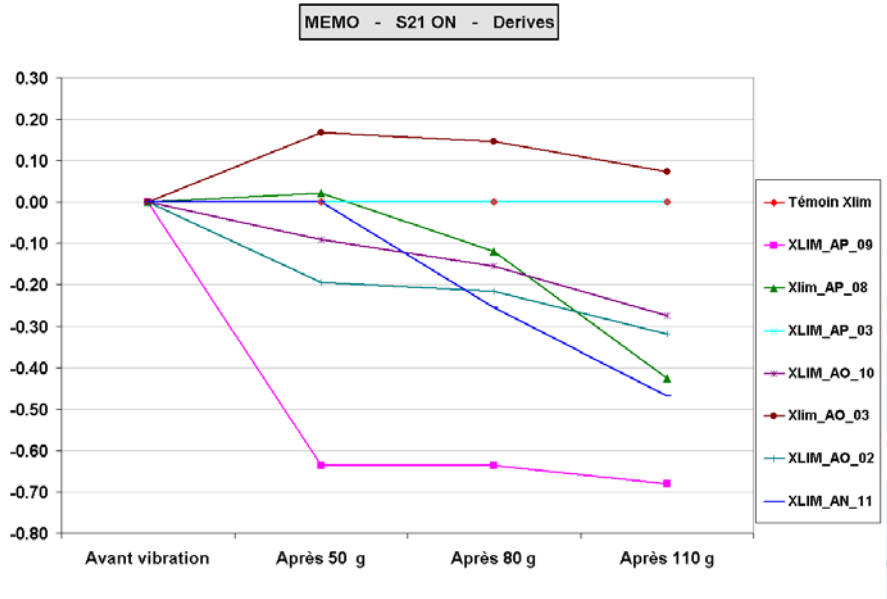
	Tests	Conditions	Comments
T1	Initial inspection	X	
T2-T3	Initial performance tests [IPT]	AP - TE + TC + TR	
T4	Low level Sine survey	X	
T5	Random vibration	A -TE	
T6	Low level Sine survey Post vibration tests	X	1er mode Variation: Frequency 10%, Level 40%
T7	Functional tests @ 25°C [AFT 1]	AP - TE + TR	
T8	OFF cycling	AP / A / 4(1)	Unit is OFF and not powered.
T9	ON cycling	AP / A / 3(1)	Unit is ON and powered Consumption monitored
T10	Functional tests @ 25°C [AFT 2]	AP	
T11	Hot functional tests [HFT]	AP/ TE+TC	
T12	Cold start [CST]		Sans activation des MEMS
T13	Cold functional tests [CFT]	AP/ TE+TC	
T14	Ambient functional test [ARFT]	AP/ TE+TC	
T15	Functional tests @ 25°C [AFT 3]	AP - TE + TR	
T16	Bounding / Grounding & Isolation	X	
T17	CE On Power Line	X	
T18	CE on OBDH	TR	
T19	CS (CW)	TR	RE : pas de RF dans l'équipement
T20	CS (Discrete)	TR	
T21	Radiated Susceptibility	TR	Spray test – success criteria: [TR]
T22- T23	Final Functional tests @ 25°C [FFT]	AP - TE + TC + TR	
T24	Final inspection, mass properties	X	
	Package for delivery	X	

X : to be performed A : Acceptance level AP : Ambient Pressure AT : Ambient Temperature

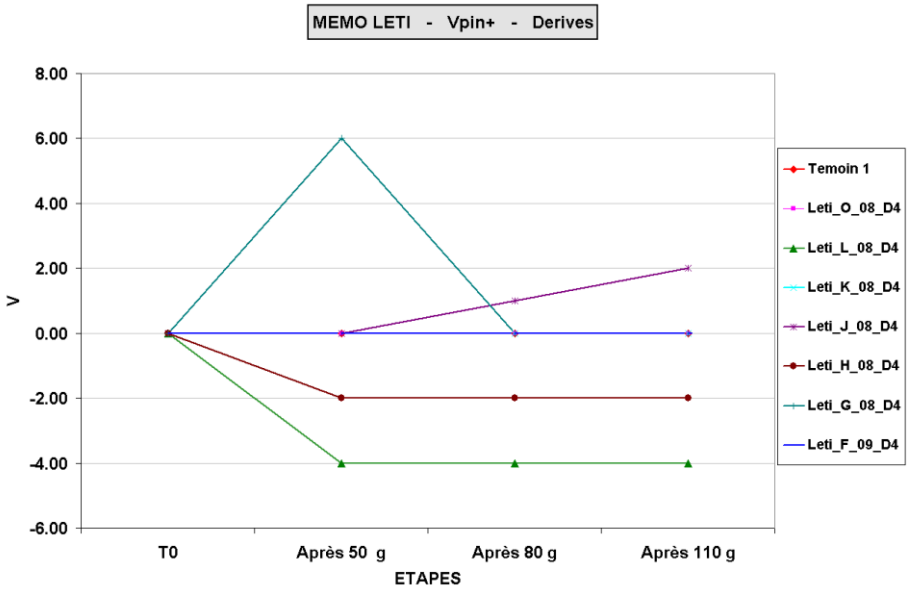
TE : Electrical Test TC : Complete Functional MEMS Test TR : Reduce Functional MEMS Test

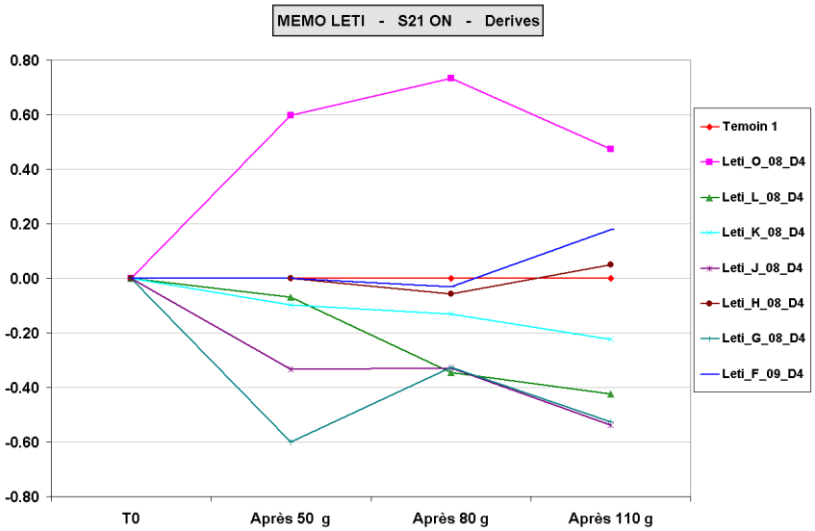
- Evaluation of RF-MEMS sensistivity in Vibration
  - Application of ECSS standard
    - ECSS-Q-ST-70-08C « Space product assurance : Manual soldering of high reliability electrical connections ». §13.2 Vibration
  - Progressive Test Plan
    - 50g RMS, 80 g RMS, 110 g RMS in Random
  - MEMS Measurement (Vact, RF Loss) after every accelerating step





Focus on vibration Tests

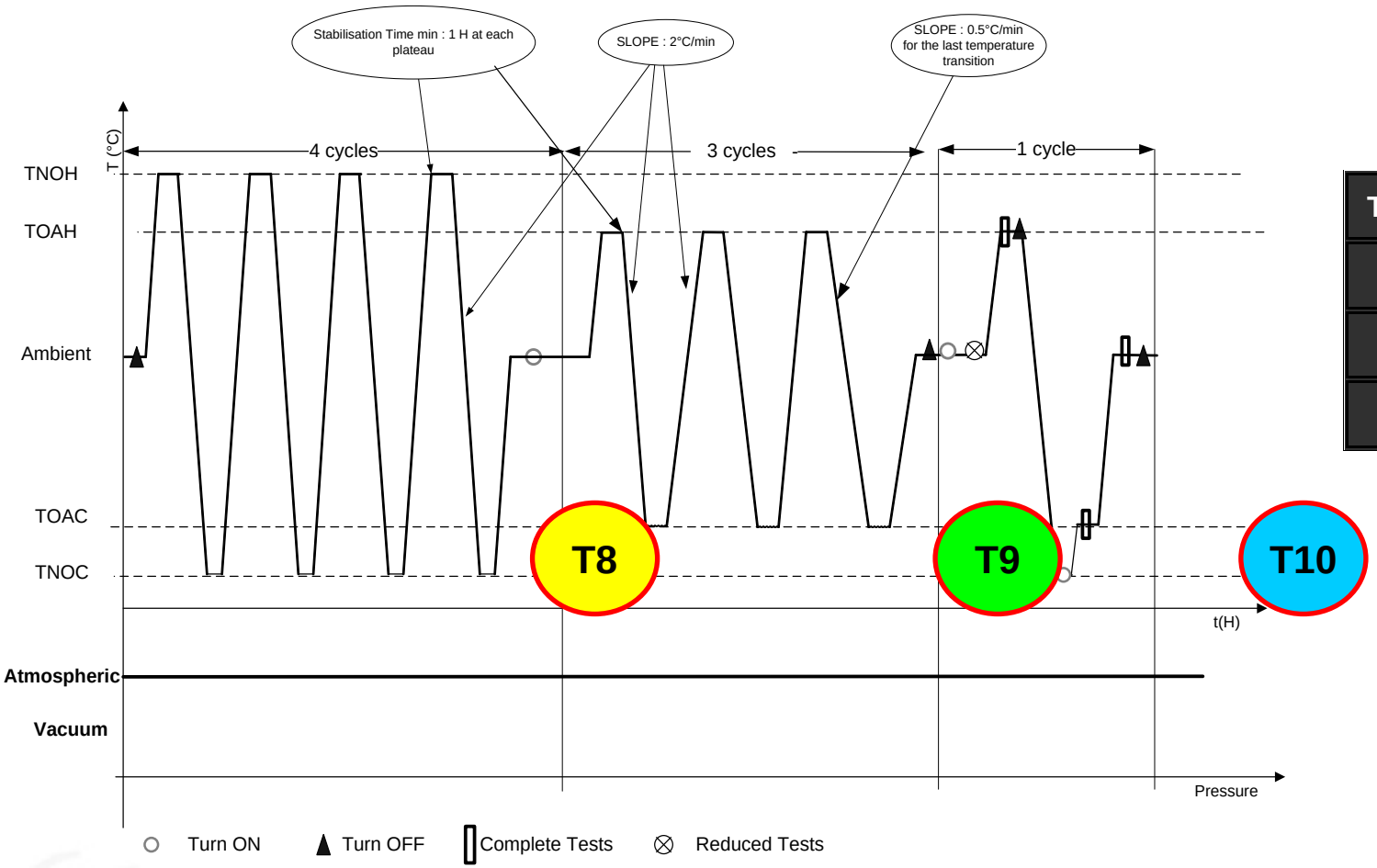




- Results:
  - Limited on Vact drift
  - Negligible impact on contact quality

- Conclusion: No major risk for the mission

3 Temperature Tests



Températures	I max (mA)	C/NC
-10 °C	29.6	C
+ 25°C	29.6	C
+60 °C	29.3	C

TNOH = T° Non Operating Hot (+65°C)

TNOC = T° Non Operating Cold (-30 °C)

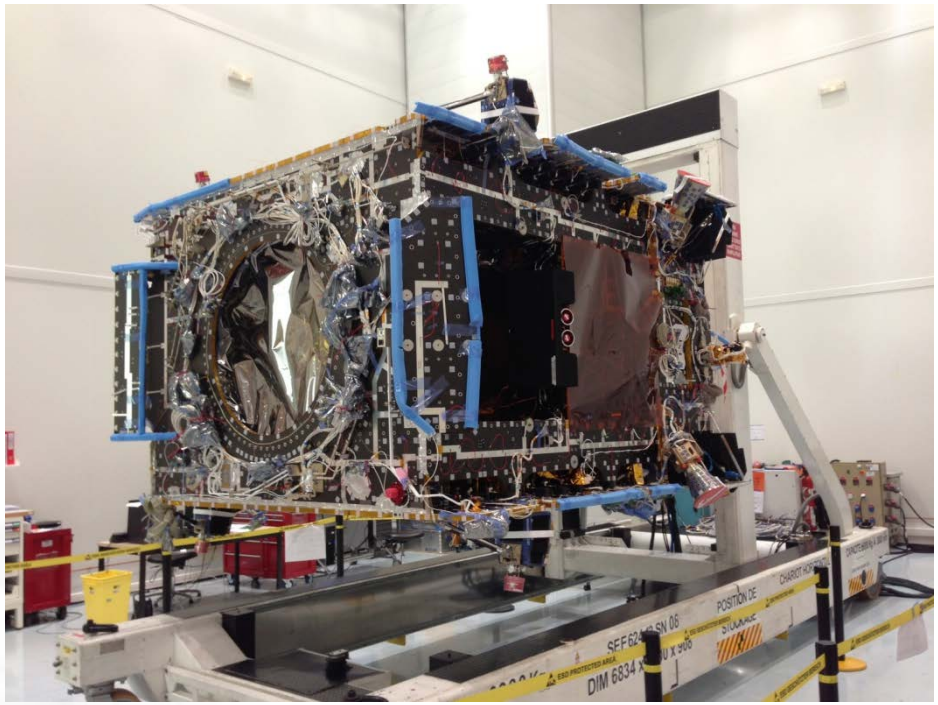
TOAH = T° Operating Acceptance Hot (+60°C)

TOAC = T° Operating Acceptance Cold (-10°C)

	NON OPERATING MODE			OPERATING MODE	
	T min	T max	Cold start	T min	T max
ACCEPTANCE	-30°C	+65°C	-30°C	-10°C	+60°C

In orbit exploitation of MEMO

- Flight opportunity
  - On-board a GEO satellite, platform SB4000
  - MEMO in Orbit since end of February 2014
- Joint exploitation of data between TAS and CNES



In-orbit test results : comparison with results obtained at AIT test

	FFT at equipment level	FFT at satellite level	First in-orbit test	Status (cumulated testing >100hrs)
Mode 1s S1	C	C	C	No error
Mode 1s S2	C	C	PC	5 errors
Mode 1s S3	C	C	C	No error
Mode 1s S4	NA	N/A	N/A	Signal routing error from start
Mode 1d S1	C	C	C	No error
Mode 1d S2	C	C	PC	5 errors
Mode 1d S3	C	C	C	No error
Mode 1d S4	C	C	C	No error
Mode 1y S1	C	C	C	No error
Mode 1y S2	C	C	C	No error
Mode 1y S3	C	C	C	No error
Mode 1y S4	C	C	C	No error
Mode2 S1	C	C	C	No error
Mode2 S2	C	C	C	No error
Mode2 S3	C	C	C	No error
Mode2 S4	C	C	C	No error
Charge pump 1 (V)	39.9	39.9	40.1	charge pump set at max value
Charge pump 2 (V)	39.9	39.9	39.9	charge pump set at max value
Charge pump 3 (V)	39.9	39.9	40.1	charge pump set at max value
Charge pump 4 (V)	39.9	39.9	39.9	charge pump set at max value
Temperature (°C)	42.8	41.7	30	Equipment temperature
mode 4 S1 Vpi/Vpo (V)	29.9 / 29.3	29.9 / 29.3	29.9 / 29.3	Vpi/Vpo increased by less than 10%
mode 4 S2 Vpi/Vpo (V)	31.9 / 24.7	31.9 / 28	31.9 / 28.7	Vpi/Vpo increased by less than 10%
mode 4 S3 Vpi/Vpo (V)	33.2 / 33.2	33.9 / 33.2	34.6 / 33.2	Vpi/Vpo increased by less than 10%
mode 4 S4 Vpi/Vpo (V)	35.2 / 33.2	35.8/ 34.5	35.9 / 35.2	Vpi/Vpo increased by less than 10%

Lessons learned

- A new unit has been developed aiming in-orbit MEMS reliability demonstration
  - Autonomous and immune
  - Flight proven interface, compatible with GEO telecom platforms SB4000 from Thales Alenia Space
- It passed the standard procedure applicable to commercial satellite equipment Analysis and test (EMC, thermal vacuum, vibration/shocks)
- Mid TRL MEMS from CEA-LETI 200mm and XLIM wafer fabs
- Recently in-orbit has shown full operation of the demonstrator as performed during FFT at satellite level
  - No evolution of pull-in/pull-out voltage
  - Actuation error less than 1 %
- Next steps :
  - Exploitation of Data on long term period (months, years,…)
  - Selection of European source, proceed with industrialization and subsequent space qualification according to ESA roadmap

MEMO project team

- TAS : Equipe MEMO
  - QA : M. Perrel
  - IEP : B. Jacquet/V. Lavalette
  - IES : L. Mesthé
  - IDI : J. Bornet
  - Qualité Etude : F. Grosjean
  - CPE : O. Vendier
- Support TAS Toulouse Payload :
  - S. Forestier
- Support TAS Cannes Satellite :
  - O. Brize
- CNES
  - F. Courtade, J. Dhennin (Fialab)
  - C. Zanchi, F. Pressecq
- CEA LETI
  - B. Reig
- XLIM
  - P. Blondy