Getting ready for RF MEMS GEO flight demonstration

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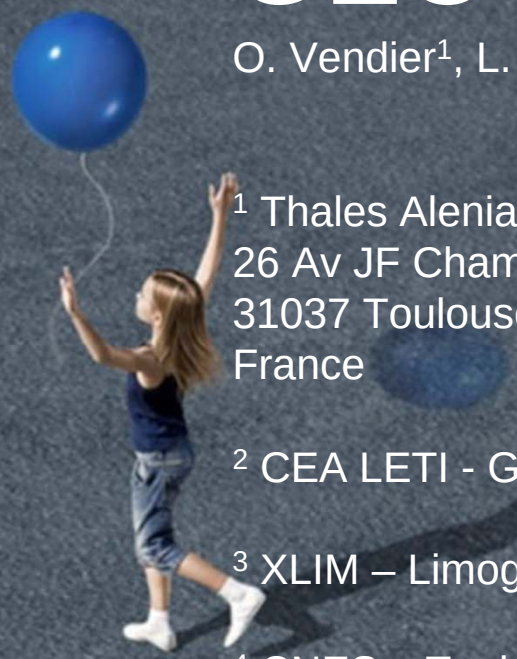

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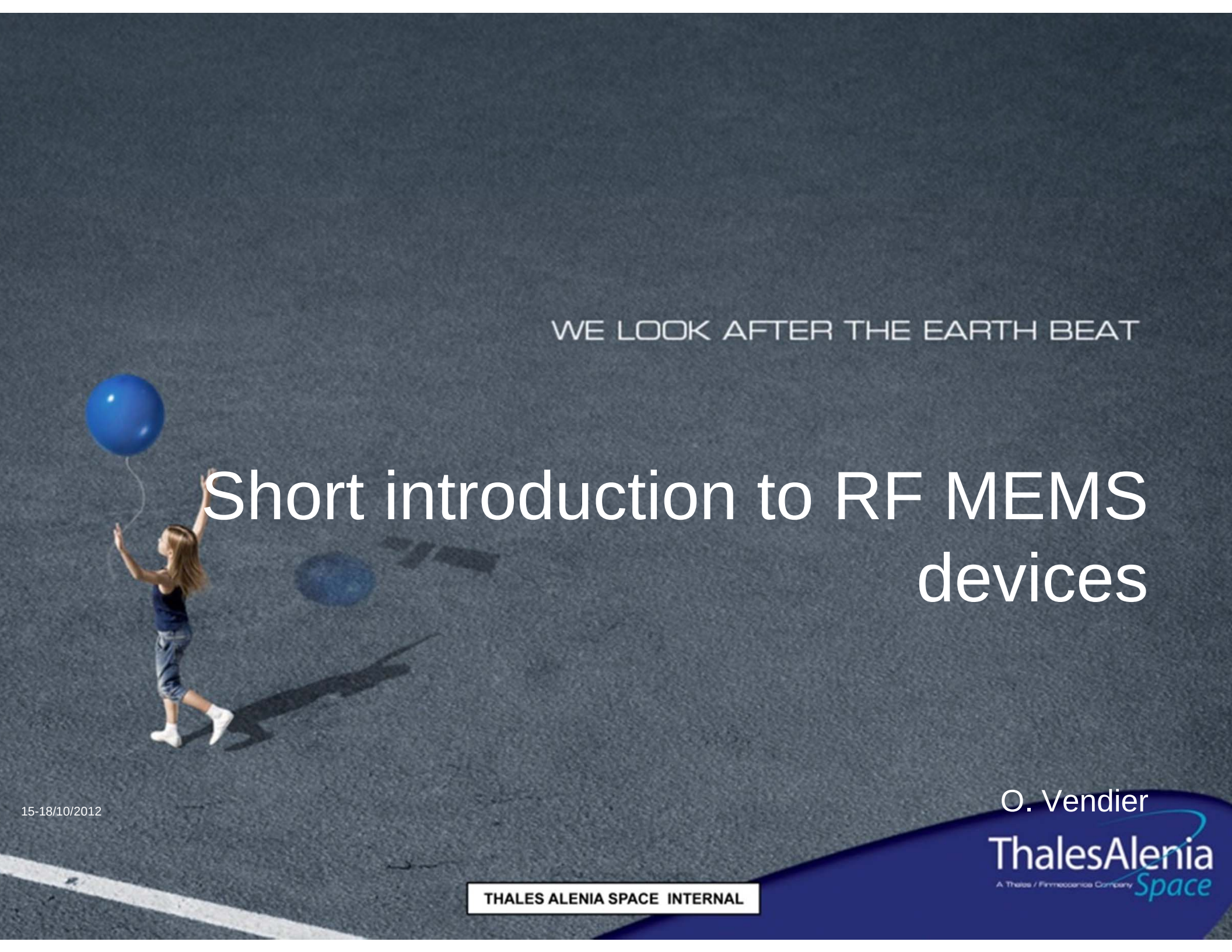
Outline

- Introduction
- Mission objective
- Demonstrator description & QA aspects
- Focus on MEMS based hybrids
- Conclusion



Short introduction to RF MEMS devices

O. Vendier

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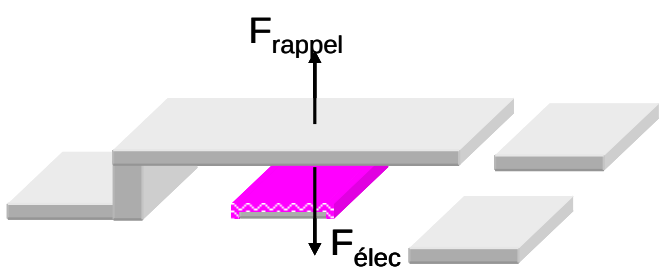
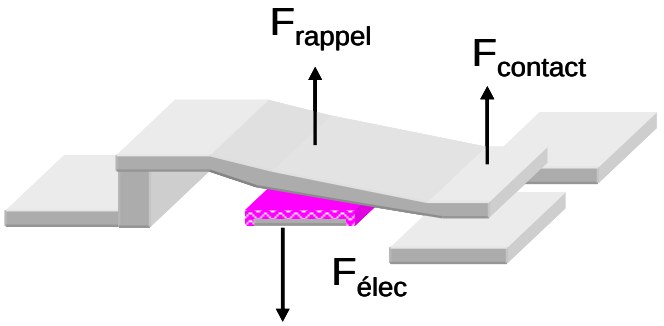
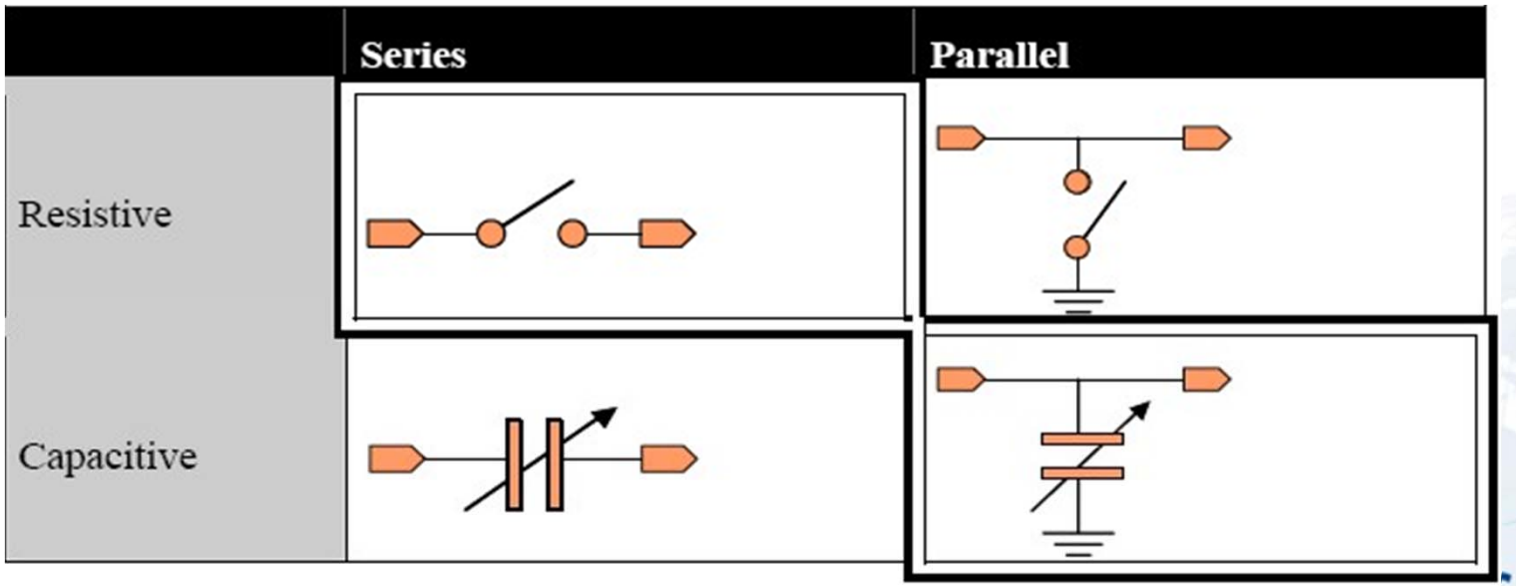
Focus on RF MEMS Switches

- Switch principle :

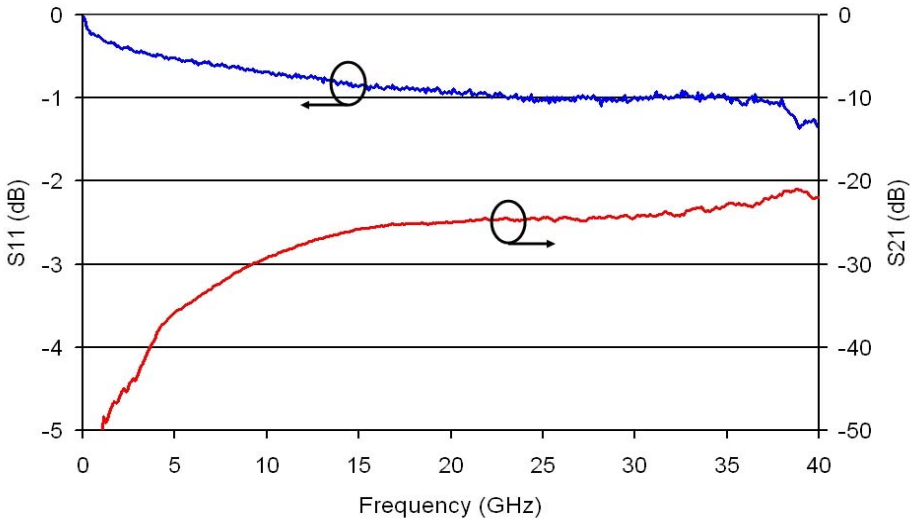




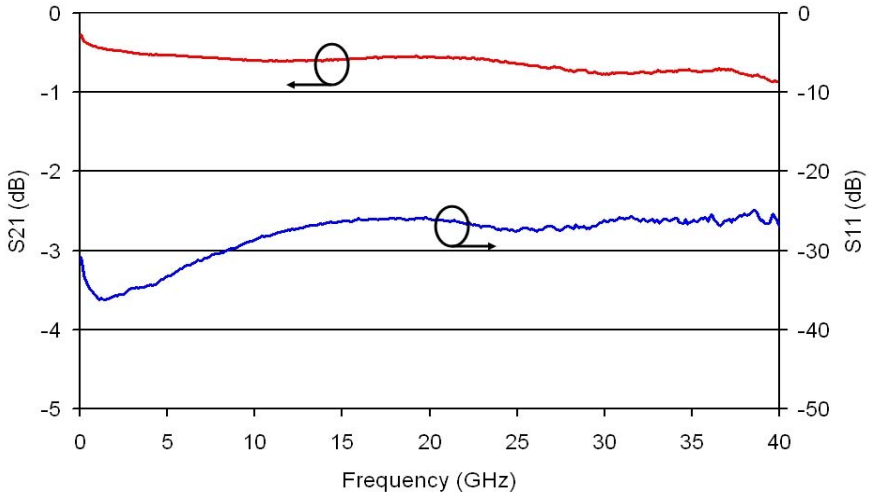
- Switch classification :



Switch Performance : Ohmic switch

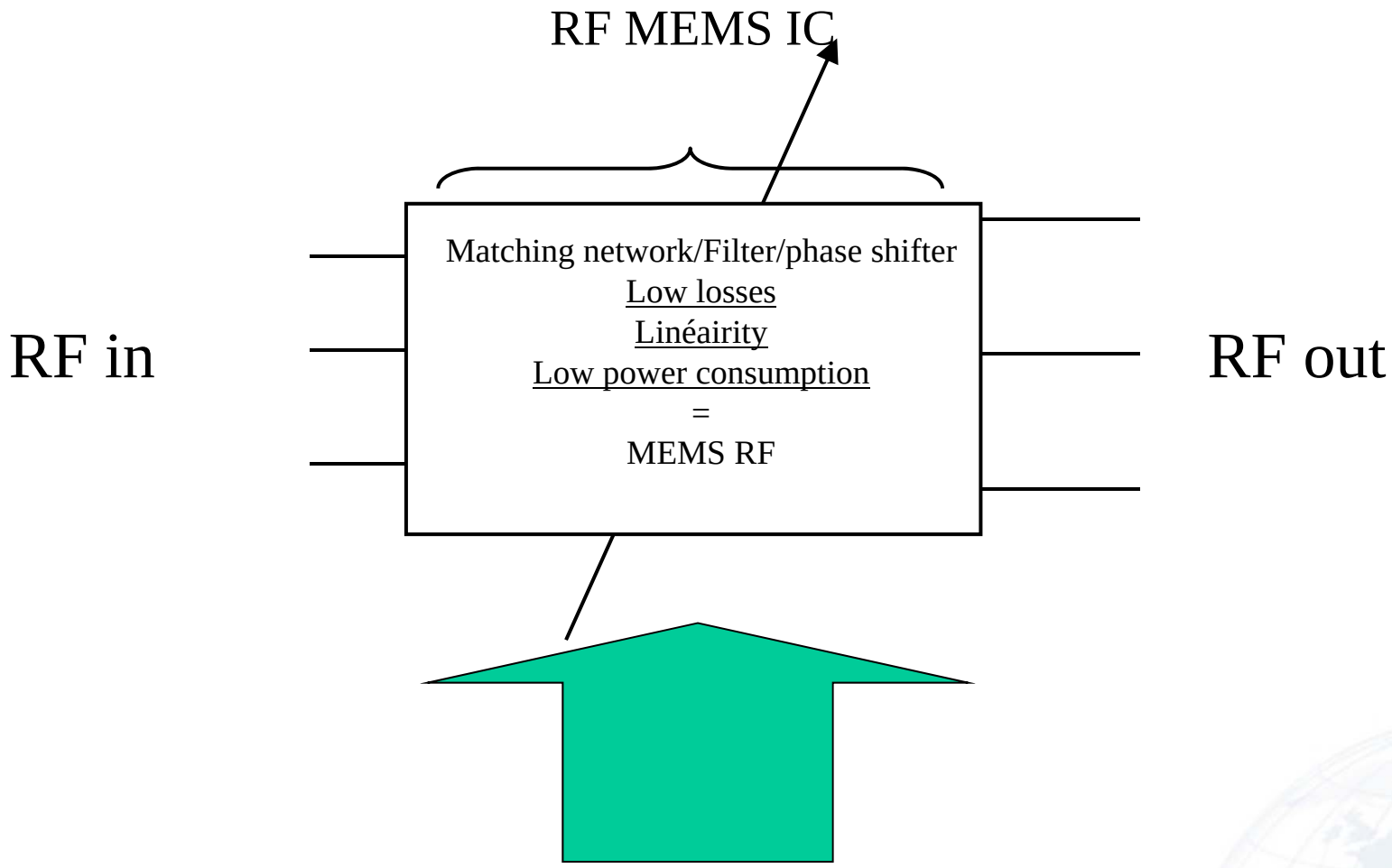


a) Membrane UP



b) Membrane DOWN

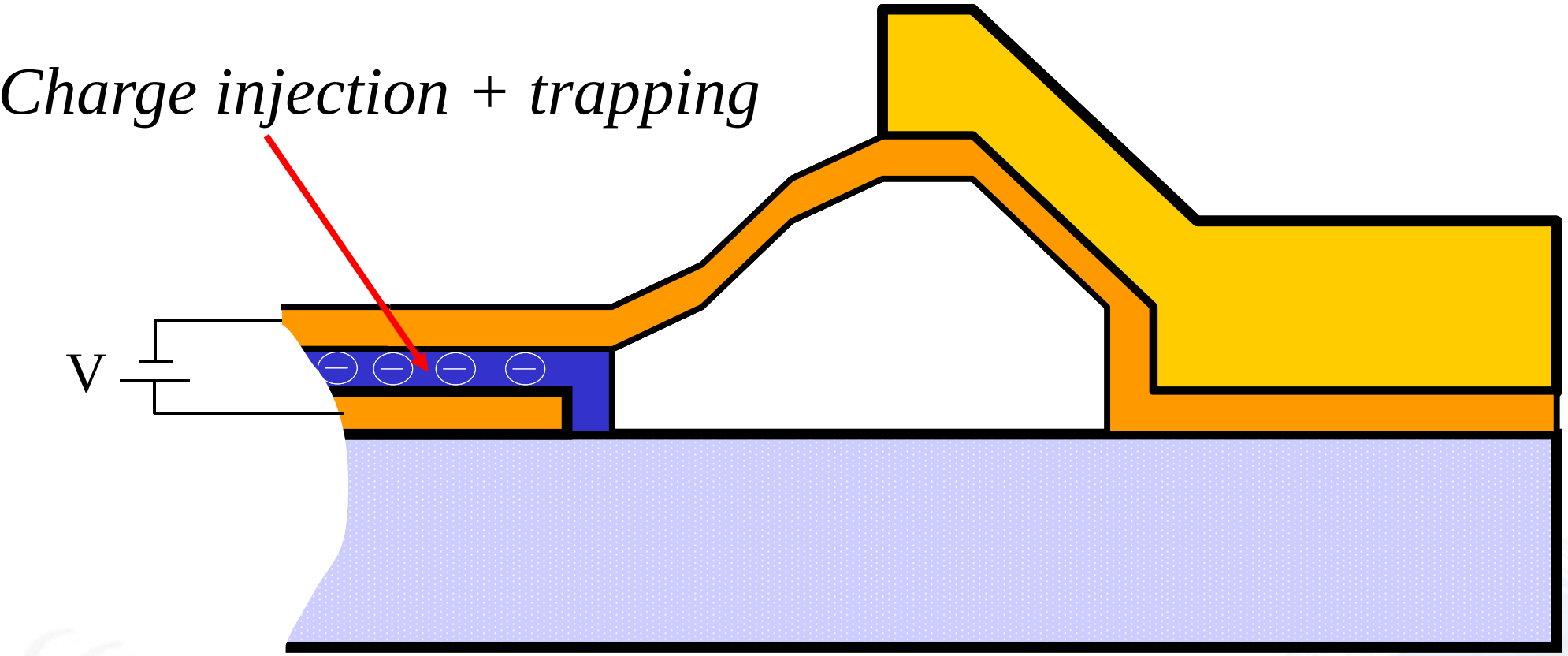
Application of RF MEMS : View for the future



Challenges : Reliability

- Main degradation mechanisms :
  - Dielectric charging
  - Contact degradation
  - Creep
  - Electromigration : Seen at high power level

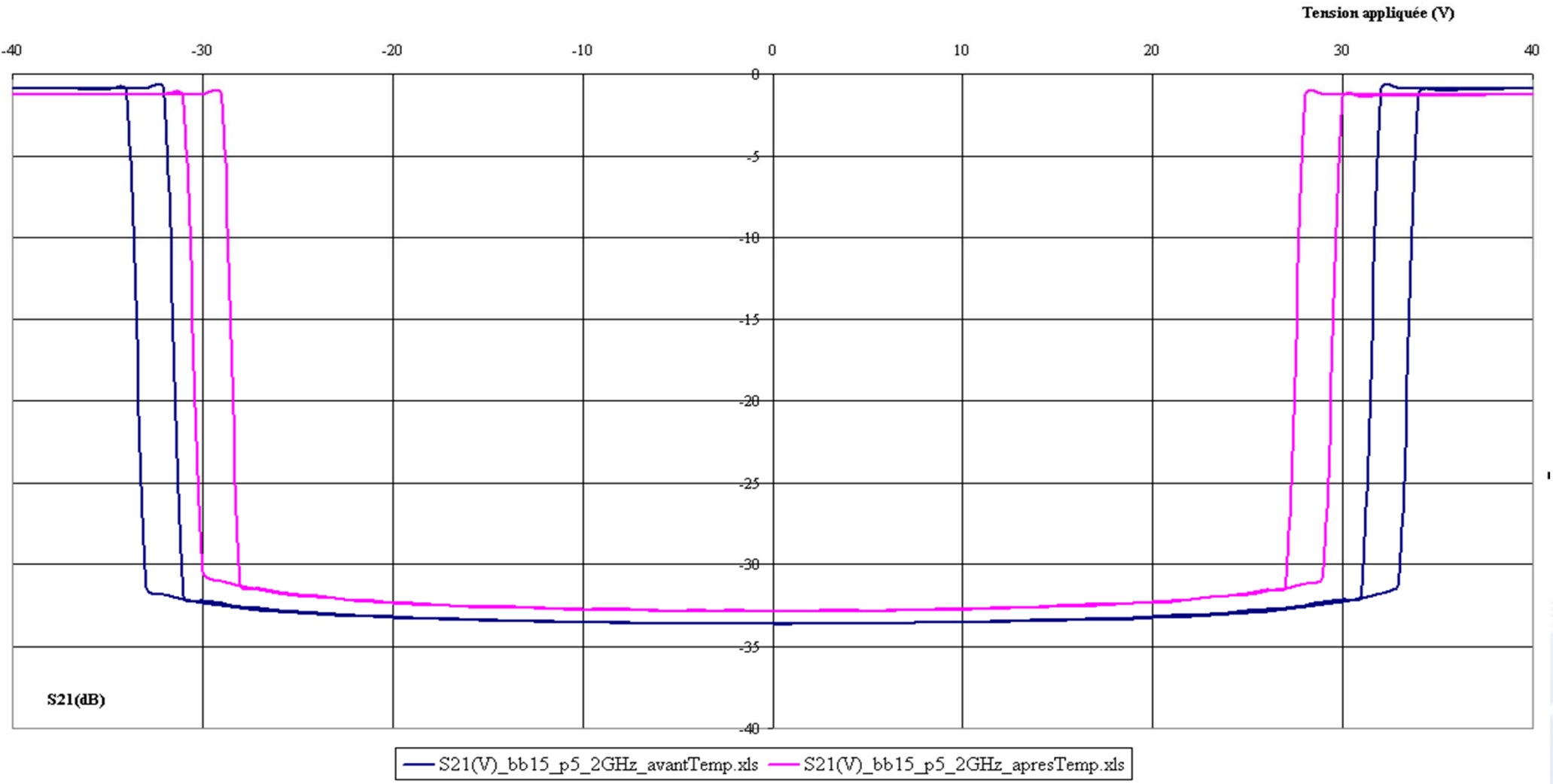
MEMS reliability : focus on dielectric charging



>20 Volts over 0,2 µm

Charge trapping is the main failure mode for RF-MEMS capacitive and ohmic switches

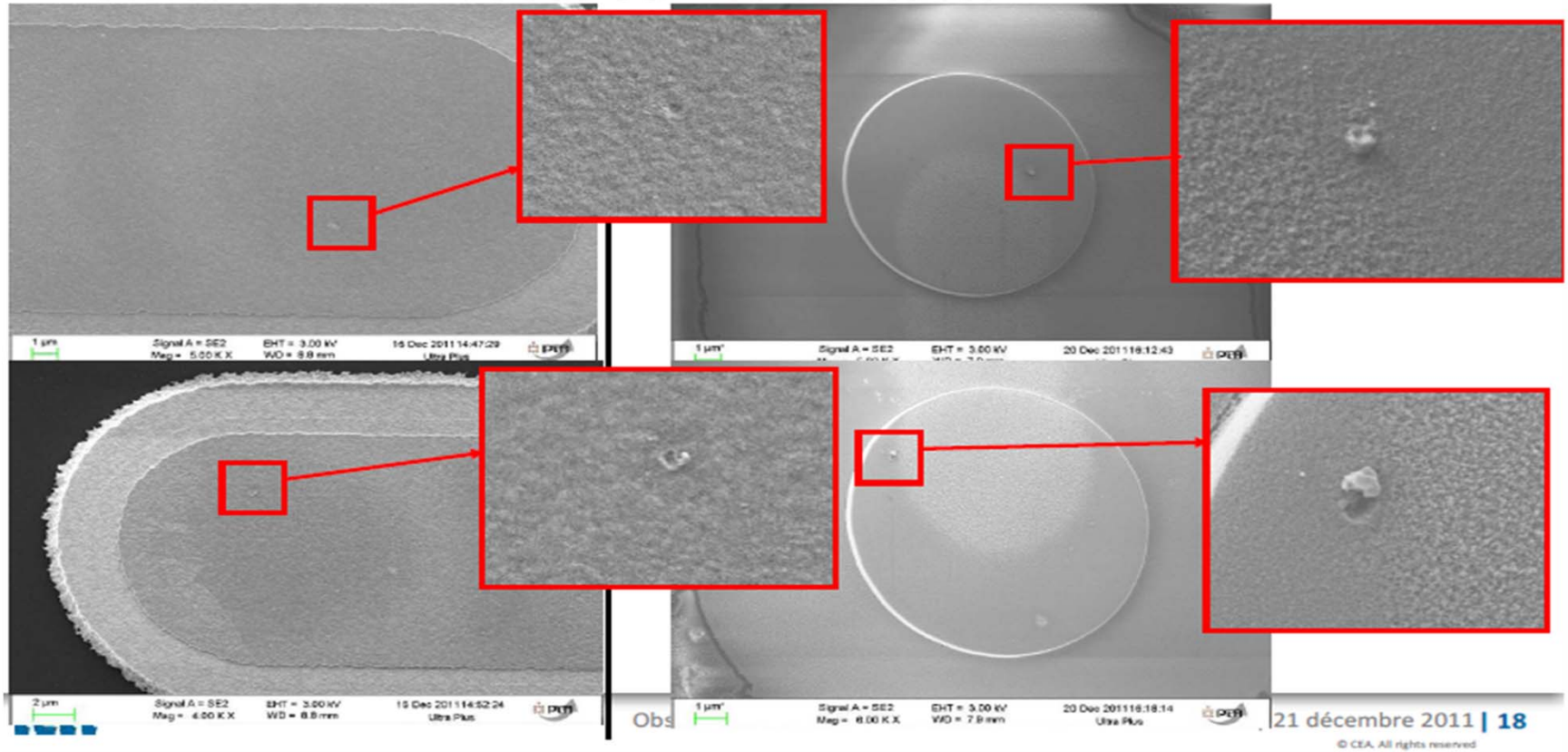
Dielectric charging signature on RF MEMS parameters



Actuation voltages for pull-in et pull-out can evolve with thermal or electrical stress

Metal Contact degradation

- Contact degradation (500h holding test 3V/100µA)



SEM View after holding test

WE LOOK AFTER THE EARTH BEAT

Mission objective

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MEMO : Core objective of the mission as required from CNES

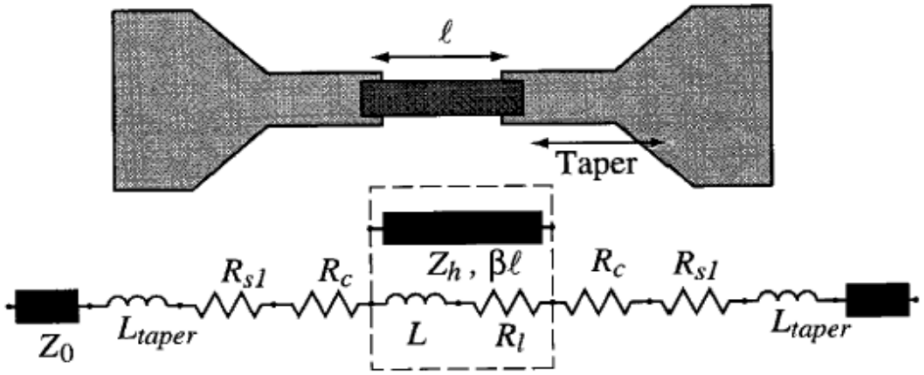
- To demonstrate In-Orbit Reliability
  - Cumulating flying heritage
  - To be integrated on a telecom satellite as a piggy bag
    - **Compliant with FM requirements** for all interface to the satellite
    - **Absolutely immune, 0-risk**, for the host satellite mission (no critical items in FMEA)
    - Easily integrable, limited interfaces, very low consumption, small mass (no impact on payload level)

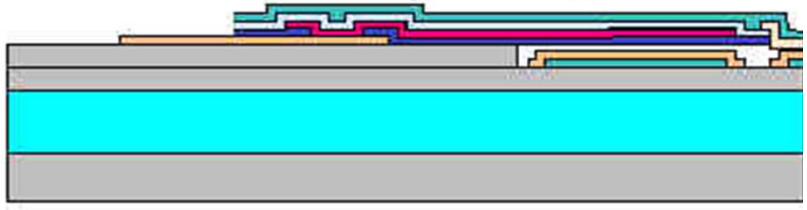
Technical Background : Base for MEMO definition

- failure modes focus for ohmic contact switches to be analyzed in MEMO
  - Contact :
    - Contact degration
    - Stiction metal-metal
  - Membrane :
    - Easily integrable, limited interfaces, very low consumption, small mass (no impact on LETI)
    - Residual stress, stress gradient, thermal stress
  - Electrostatic activation
    - Dielectric charging

Technical Background : Base for MEMO definition

- Based on DC parameters
  - Fundamental sollicitation modes
    - Address all kind of Applications (redundancy, fast switching, even power hot switching)
  - Direct link with RF intrinsic characteristics : Rc (On) => Inser.Loss and Vp => Isolation
  - => no need for RF parameters direct monitoring





↕ g =gap

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

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

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

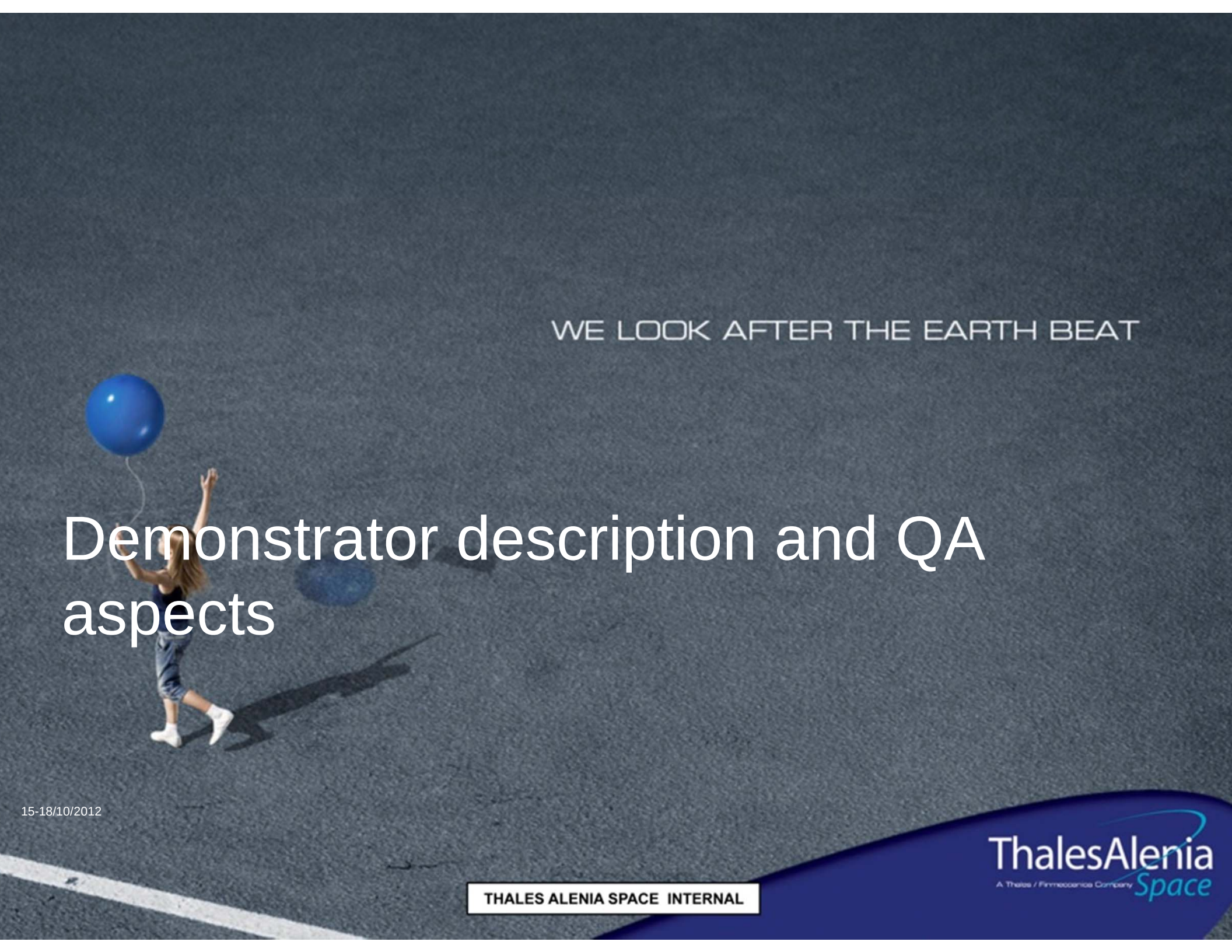
Membrane spring constant

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

Basic Functions of MEMO Demonstrator

Includes 20 RF-MEMS Switches

- 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 (3) (not implemented): Monitoring of Rcontact
- Mode(4): Monitoring of Pull-in/Pull-out voltages
  - TC launched sequence : 4 MEMS
- Temperature monitoring



Demonstrator description and QA aspects

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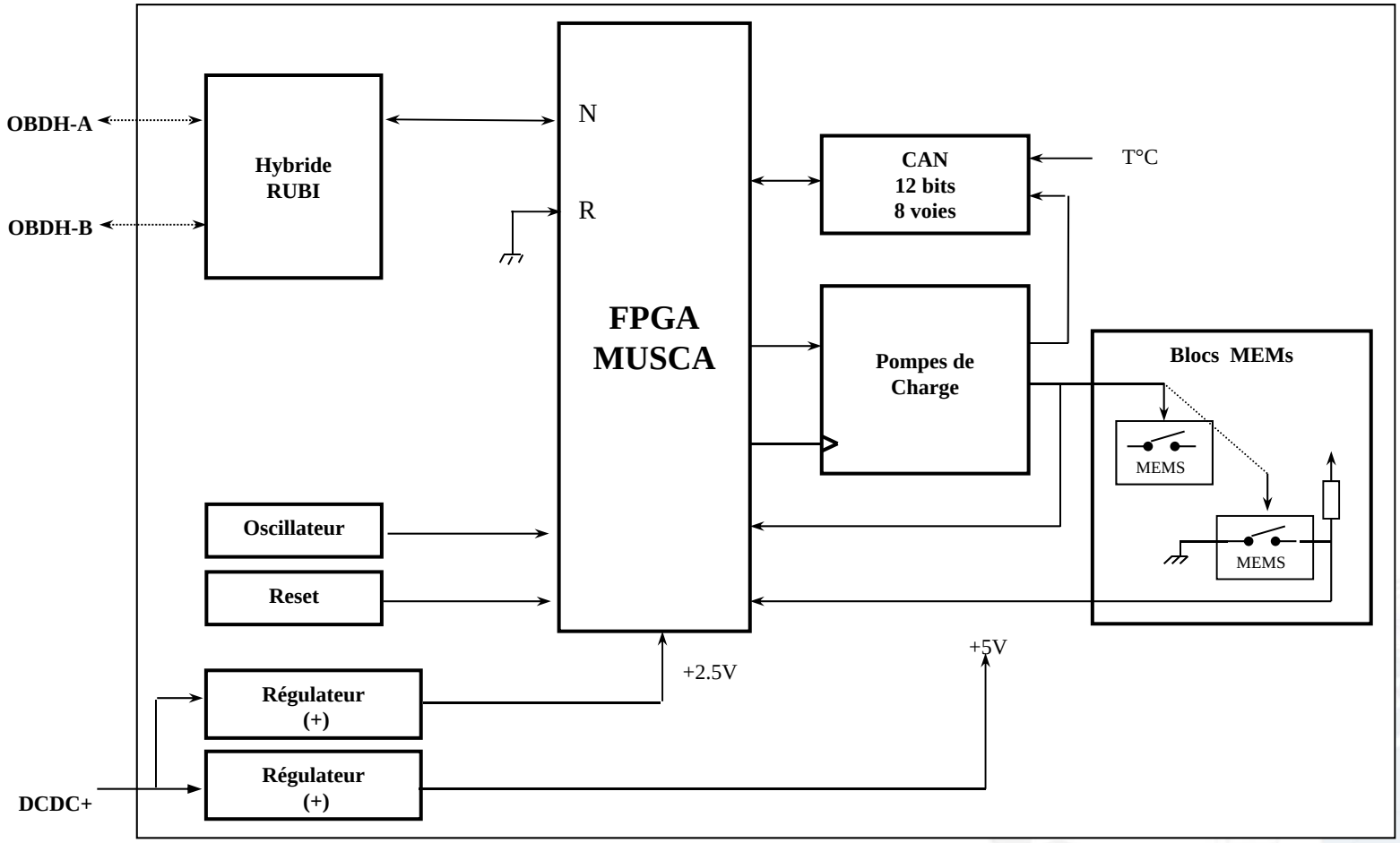
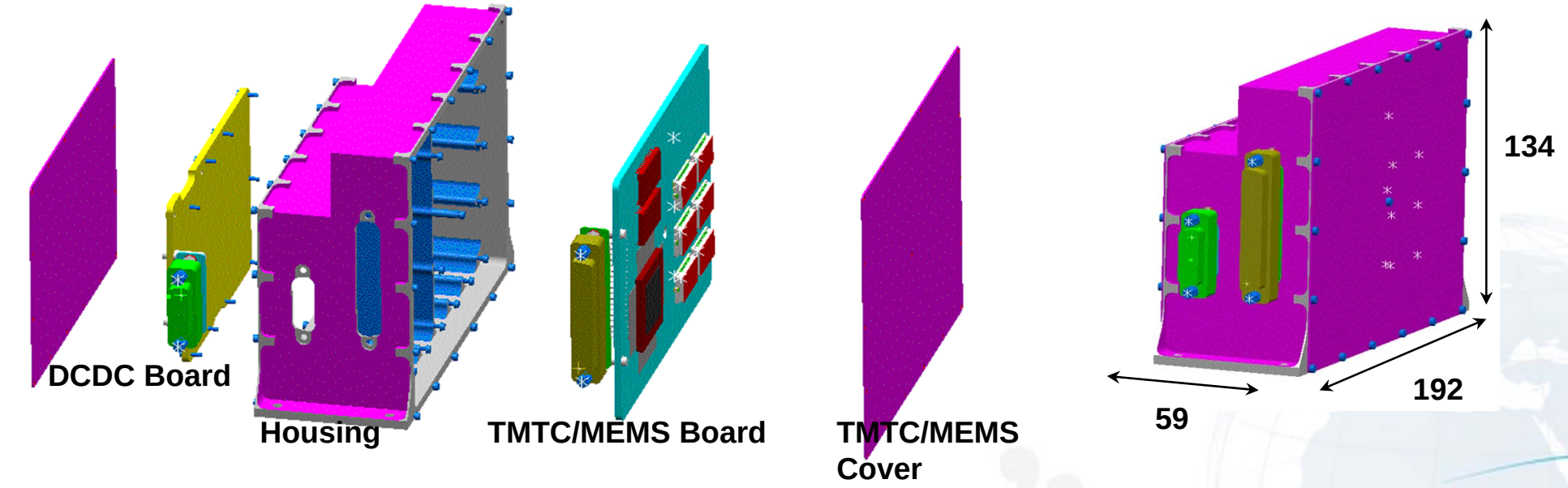
Demonstrator description

Experiment board



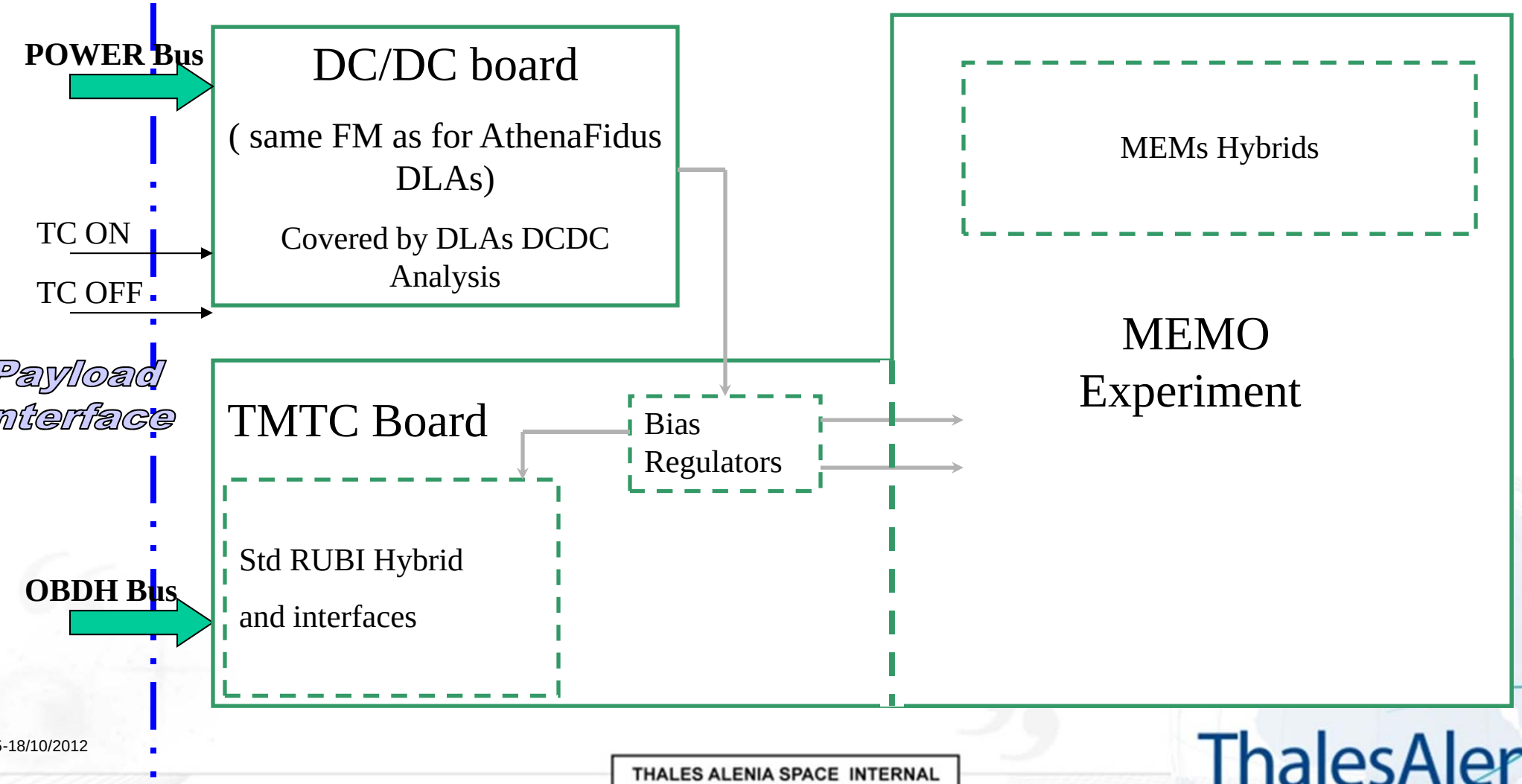
Equipment description

- This MEMS demonstrator is composed of 2 electronic boards : 1 DCDC and 1 TM/TC – MEMS which are integrated in an aluminium housing.
- Compared to CDR : initial DC/DC has been replaced by DLA DC/DC to be compliant with FMEA
- Satellites interfaces are ensured by two D-Sub connectors



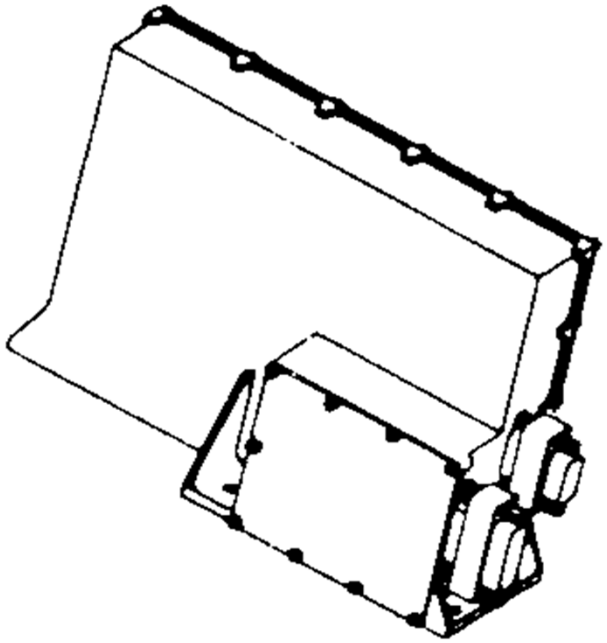
MEMs Demonstrator - Quality concern

MEMs demonstrator – FMEA & Analysis Approach Diagram

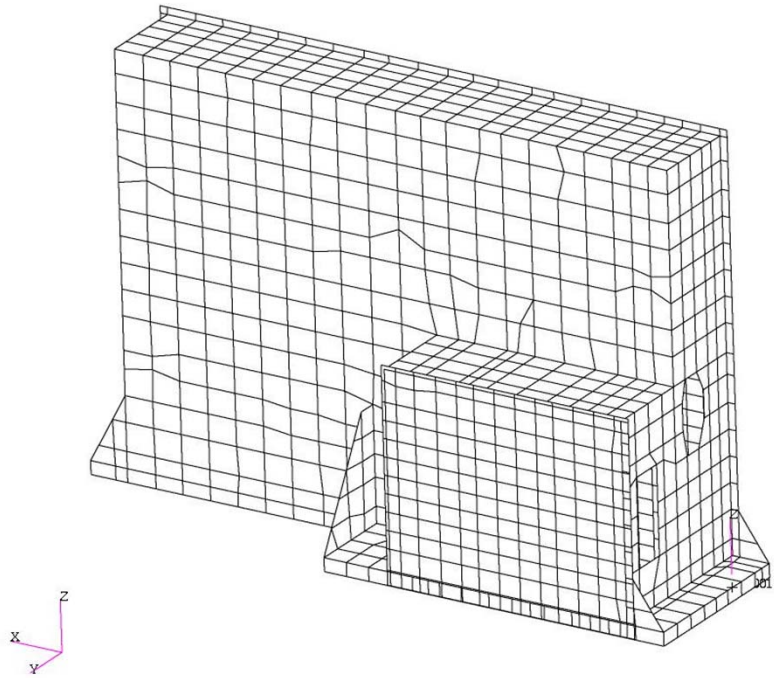


Mechanical analysis

Mechanical Design :



Mechanical Model :



Maximum mass = 0.754 kg

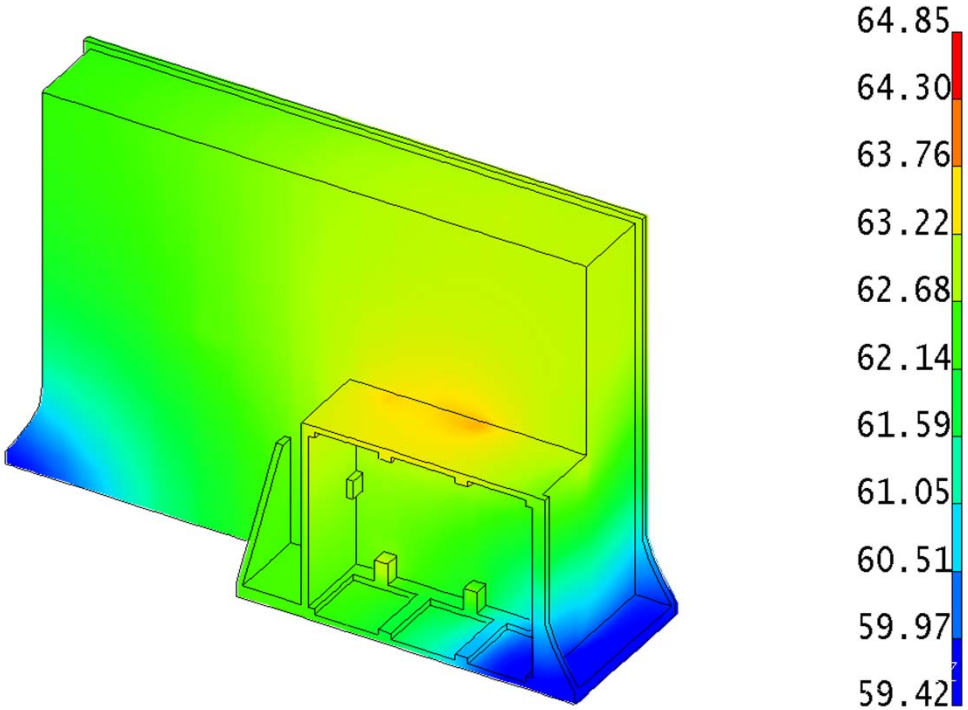
Mechanical analysis : conclusion

Compliance Matrix / Conclusion :

§	Title	Status	Notes
[AD01]			
4.4	**Equipment structural design**		
4.4.1.2	Safety Margin definition	C	
4.5.2.2	Number of attachment points	C	11.2 N < 20 N
4.8	Equipment venting	C	
6.1	**Mechanical Environment**		
6.1.1	Ground operations	C	Covered by random vibrations
6.1.2.1	Frequency requirements	C	F1 = 508 Hz > 140 Hz
6.1.2.2	Design quasi-static load factors	C	Covered by random vibrations
6.1.2.3	Sine vibrations (zone A)	C	Covered by random vibrations
6.1.2.4	Random vibrations (zone A)	C	Levels under components compliant with Thales design rules Positive margins of safety in the structural assembly
6.1.2.5	Shock (S4)	C	Compliance will be demonstrated by test on EQM.

Thermal analysis : Conclusion

Thermal :



Gradient de 5.4°C

Module	Température minimale (°C)	Température moyenne (°C)	Température maximale (°C)
Carte DC/DC	60,8 (60,25)	63,5 (61,78)	65,1 (63)
Carte TM/TC	60,5 (60,6)	62,9 (62,2)	64,9 (63,7)

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Focus on MEMS hybrids

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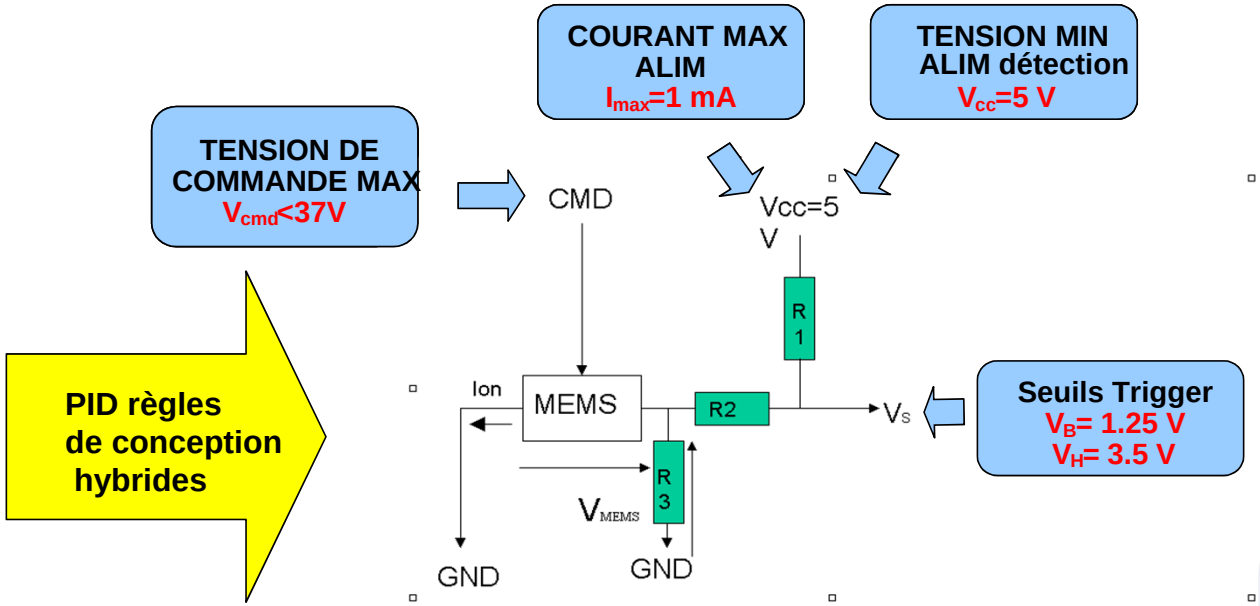
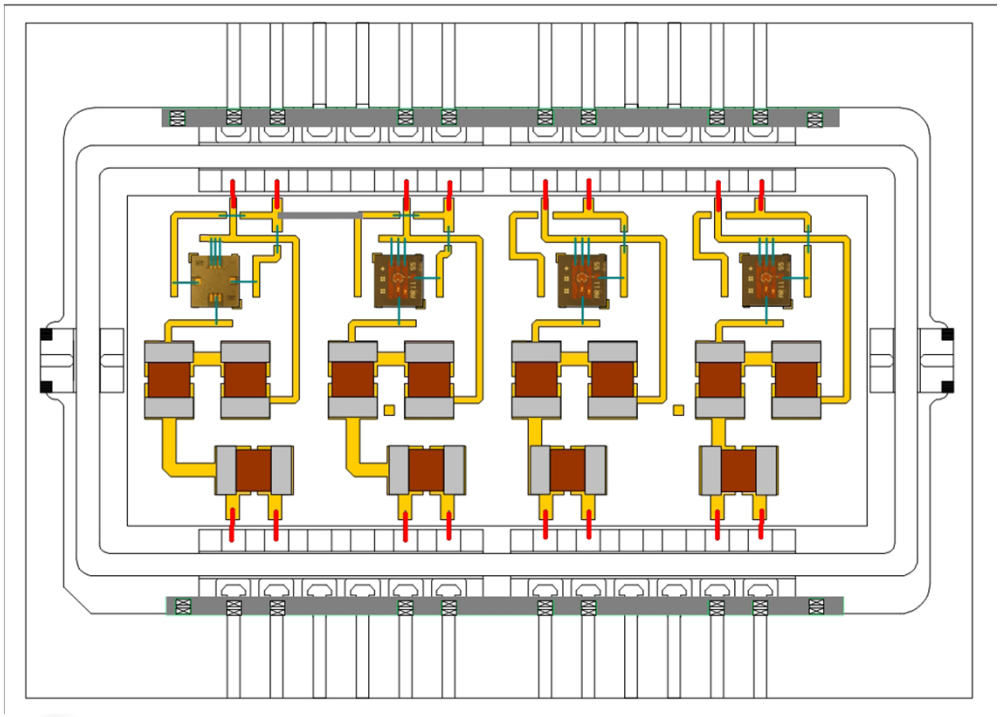
Reminder on RF MEMS constraints

- Mission (15 years)
  - Mission « second » : ~ 500 Millions switching
  - Mission « day » : ~ 5500 switching
  - Mission « year » : 15 switching
  - Mission « demand » : long period > one year

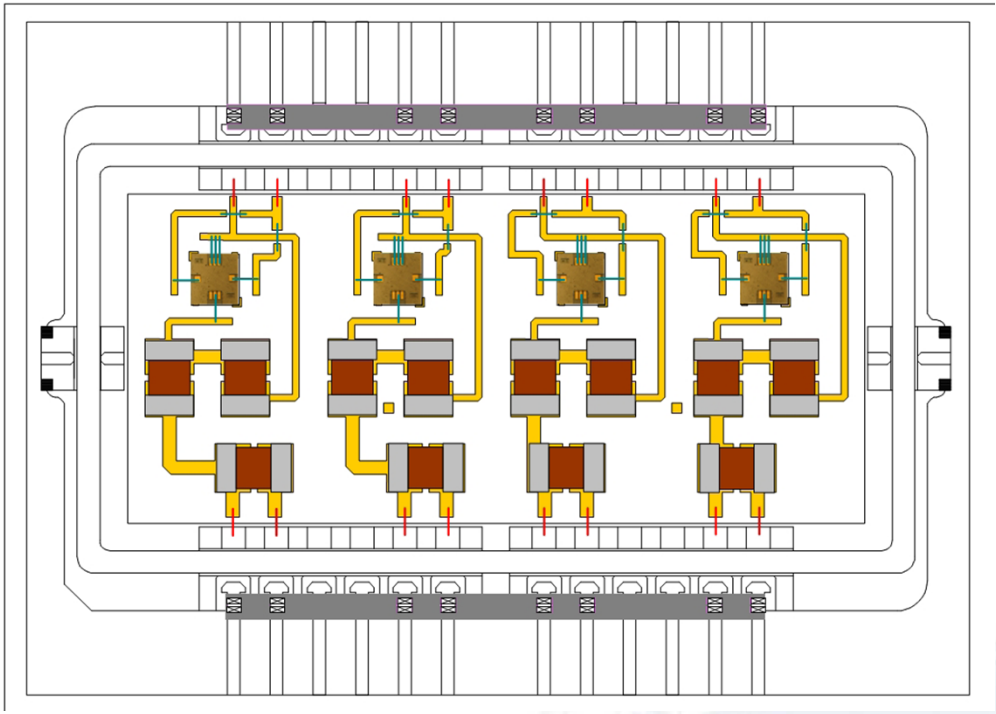


Hybrid design

Layout XLIM



Layout LETI



Manufacturing flow

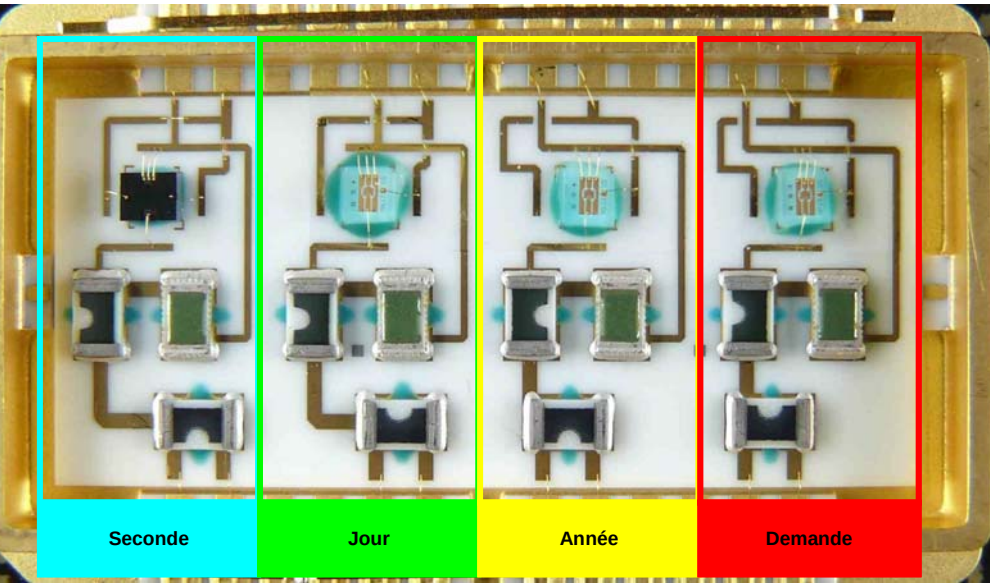
Flow applied to ref 127 5005 et 127 5008

N° OPERATION	DESCRIPTION
004	SERVI
080	BRASAGE
085	CONTROLE BRASAGE
090	COLLAGE AUTO DES CMS
093	COLLAGE MANUEL DES MEMS
100	// GAP DE MASSE
110	CABLAGE MANUEL THERMOSONIC 25 µm
120	CABLAGE AUTOMATIQUE BALL BONDING 17.5 µm
155	CONTROLE VISUEL
190	MONTAGE EN STRUCTURE DE TESTS
200	**MESURES AVANT FERMETURE**
210	DEMONTAGE
695	CONTRÔLE VISUEL
700	FERMETURE MOLETTE
709	TEST D'HERMETICITE
710	TESTS CLIMATIQUES
930	MONTAGE EN STRUCTURE DE TESTS
940	**MESURES APRES FERMETURE**
950	DEMONTAGE
980	TEST D'HERMETICITE
995	RECETTE

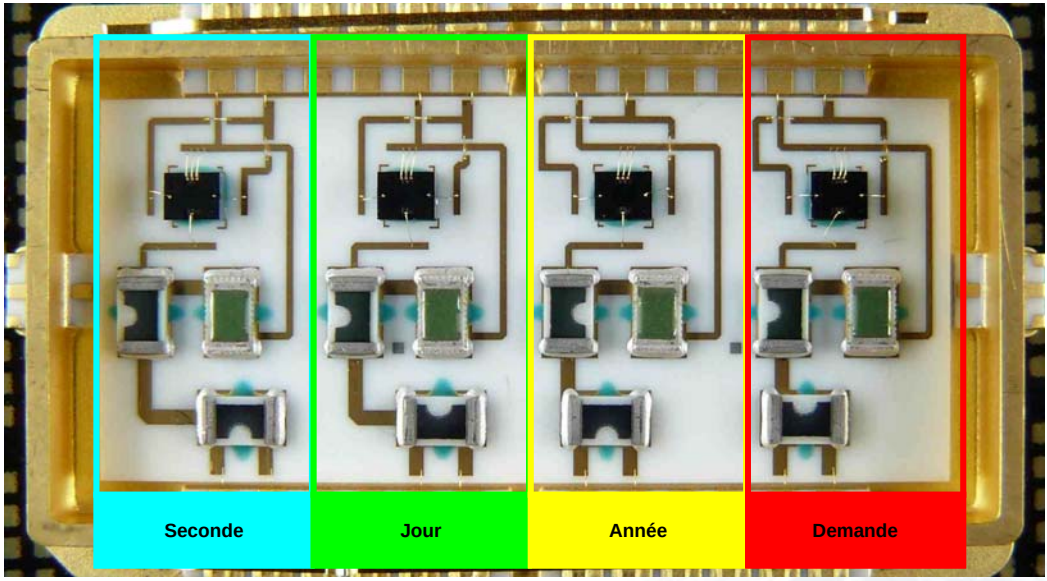
Partie Screening Hybride

Aspect Fabrication

- Hybrid type “XLIM MV”
  - 127 5005



- Hybrid type “LETI MV”
  - 127 5008



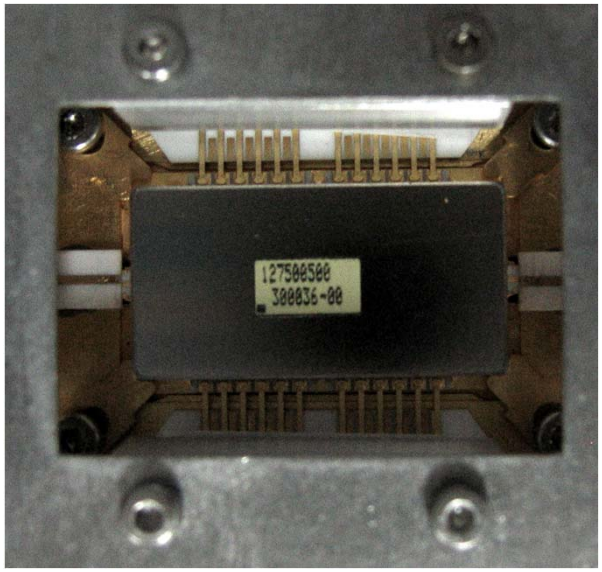
Manufacturing traceability

				FONCTIONS DES MEMS			
	N° Article	Type	OF	DEMANDE	ANNEE	JOUR	SECONDE
1	1275008	LETI 1	300022	J09 D4	I09 D4	H09 D4	G09 D4
2	1275008	LETI 2	300023	I 10 D4	L09 B4	L09 D4	K09 D4
3	1275008	LETI 3	300024	N10 D4	M10 D4	L10 D4	J10 D4
4	1275008	LETI 4	300025	J11 B4	J 11 D4	H11 D4	O10 D4
5	1275008	LETI 5	300026	N11 B4	M11 D4	K11 D4	I11 D4
6	1275008	LETI 6	300029	H12 D4	G12 D4	F12 B/D4	O11 D4
7	1275008	LETI 7	300030	L12 D4	K12 D4	J12 D4	I12 D4
8	1275008	LETI 8	300032	N13 D4	N13 B4	G13D4	F13
9	1275005	XLIM 1	300034	AN12	AP12	AN02	*M12 D4*
10	1275005	XLIM 2	300035	AQ10	AQ09	AQ08	*O12 D4*
11	1275005	XLIM 3	300036	AR11	AR09	AR08	O13 D4
12	1275005	XLIM 4	300037	AS10	AS09	AS07	G14 D4
13	1275005	XLIM 5	300038	AT10	AT09	AT08	H ? D4
14	1275005	XLIM 6	346497	AU10	AU09	AT11	K14 D4
15	1275005	XLIM 7	346498	AX03	AW11	AV10	M? D4

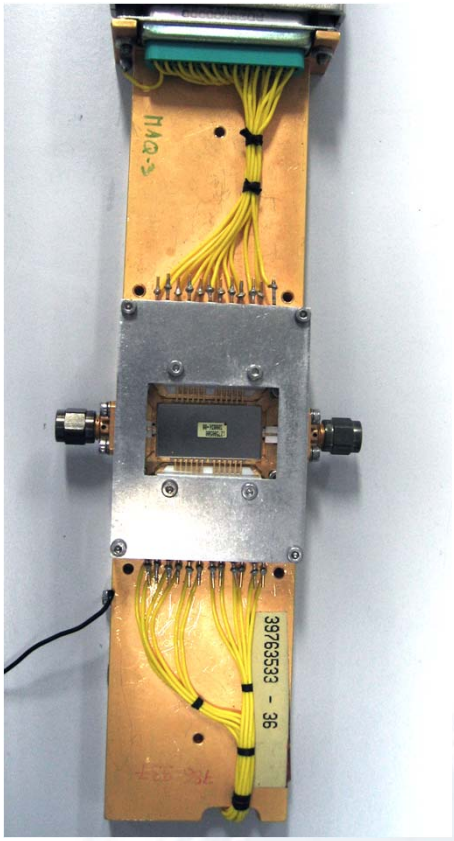
Test approach

- **Functional tests**
  - **Actuation voltage (V_{pin} et V_{pout})**
  - **Contact resistance (Rc)**

Test bench



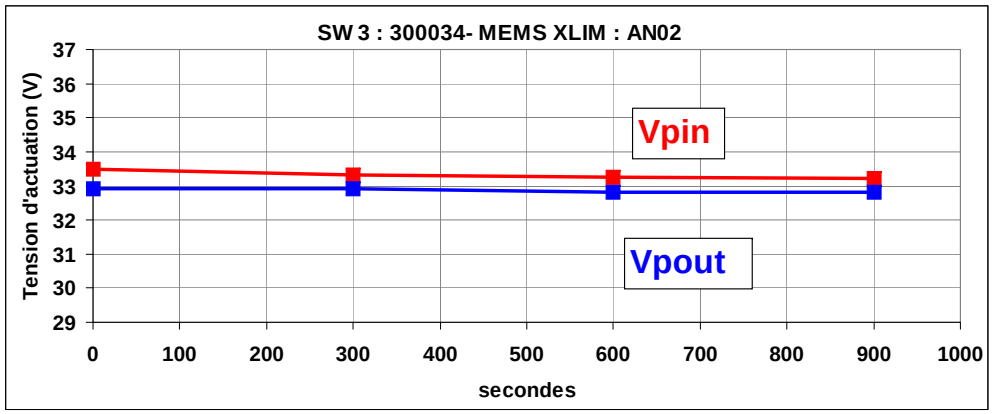
RF MEMS hybrid after sealing



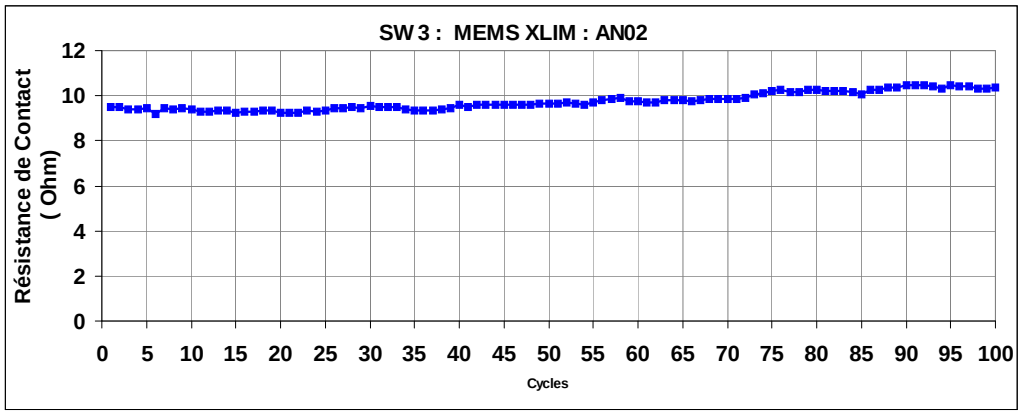
Test structure

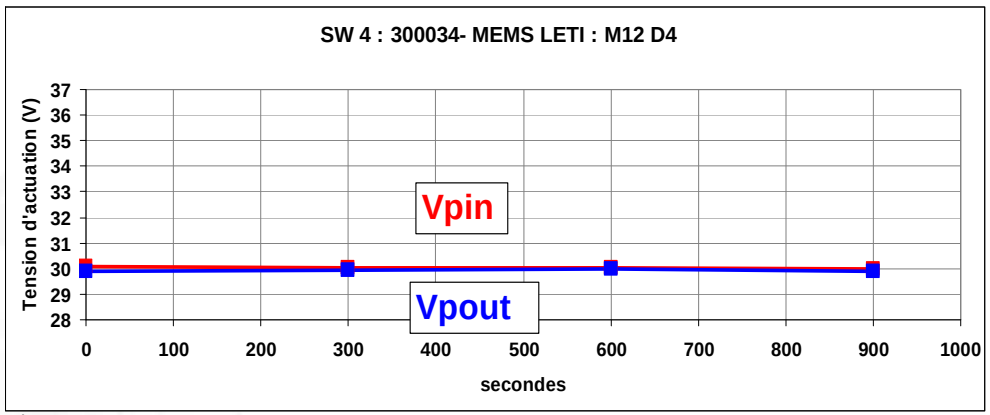
Test results

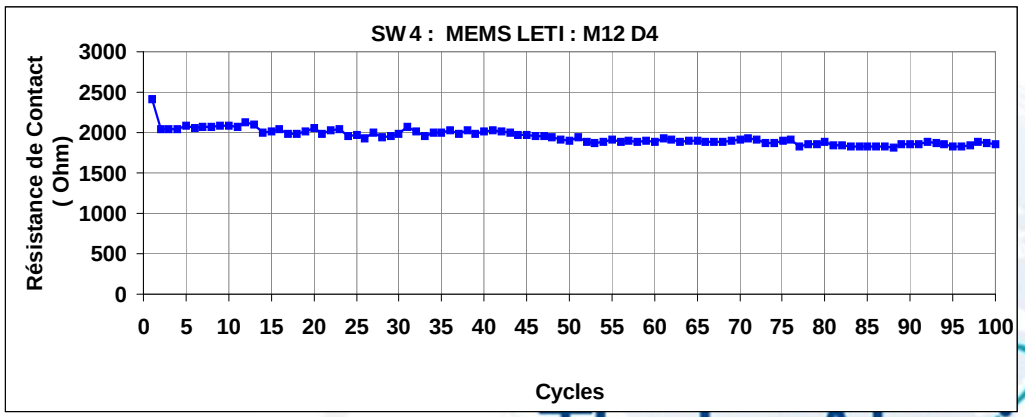
Example of actuation voltage monitoring during holding stress test V > V_{act}



Example of contact resistance monitoring with hot switching test condition







Manufacturing status

Prior screening

N° Articles	OF	C /NC	Remarques
1275005	300 034	C	
	300 035	C	
	300 036	C	
	300 037	C	
	300 038	C	
	346 597	-	Fabrication en cours
	346 598	-	Fabrication en cours
1275008	300 022	C	
	300 023	NC	Fissures sur des aires de câblage de MEMS
	300 024	NC	Fissures sur des aires de câblage de MEMS
	300 025	NC	Fissures sur des aires de câblage de MEMS
	300 026	NC	Fissures sur des aires de câblage de MEMS
	300 029	C	
	300 030	C	
	300 032	C	
Maquettes	MQXLIM1	-	Maquette non fermée
	MQXLIM1 bis	-	Maquette non fermée
	MQXLIM4	-	Maquette non fermée
	MQXLIM4 bis	-	Maquette non fermée
	MQLETI2	-	Maquette non fermée
	MQLETI3	-	Maquette non fermée
	MQLETI3 bis	-	Maquette non fermée

Screening approach

- Compliance to TAS quality standards
  - PID HYBRID : réf. 39 731 284/ 924
- General objective
  - Eliminate hybrids with weaknesses by using
    - Thermal stress tests
    - Mechanical stress tests
    - Electricam stress tests
- Specific objective due to MEMO mission
  - Select the most robust hybrids

Screening approach

- **Flow validated according to CNES, LETI and XLIM**
  - Thermal shocks
    - PID Hybrid QF 130.03.00
    - 10 shocks : -55°C /+ 125°C, 15 min step, transitions < 1min
  - Pind Test
    - Cycle = (4*(3 pré-chocs à 1000 G + Vibrations 20 g à 70 Hz)): 3 cycles
  - Electrical test (equivalent to burn-in)
    - Hot switching (100 cycles with Rc monitoring)
    - Holdind stress test Vp> Vact (4 time V_{act} measurement each 300 s)
  - Hermiticity test according to PID hybrid
    - Fine leaks QF 117.04.00
    - Gross leaks QF 117.05.00

Aspect Screening

Résultats après screening

N° Articles	OF	Contrôle Visuel	Test Fonctionnel	Pind Test	Contrôle Herméticité	Tension d'Actuation	Résistance de contact	Dérive Tension d'Actuation	Erreurs de commutation	Contrôle Herméticité Final
		C /NC	C /NC	C /NC	C /NC	C /PC/NC	C /NC	C /NC	C /NC	C/NC
1275005	300 034	C	C	C	C	C	C	C	C	
	300 035	C	C	C	C	PC	C	C	C	
	300 036	C	C	C	C	NC	C	C	C	
	300 037	C	C	C	C	PC	C	C	C	
	300 038	C	C	C	C	C	C	C	C	
	346 597	-	-	-	-	-	-	-	-	-
	346 598	-	-	-	-	-	-	-	-	-
1275008	300 022	C	C	C	C	NC	NC	NC	NC	
	300 023	NC	C	C	C	C	C	C	C	
	300 024	NC	C	-	-	-	-	-	-	-
	300 025	NC	C	-	-	-	-	-	-	-
	300 026	NC	C	C	C	C	C	C	C	
	300 029	C	C	C	C	C	C	C	C	
	300 030	C	C	C	C	C	C	C	C	
	300 032	C	C	C	C	NC	NC	NC	NC	

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Conclusion

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Conclusion

- This study has allowed us to increase the TRL of RF MEMS technolog until TRL6
  - On RF MEMS process (XLIM & LETI)
  - On methodology to qualify the technology for flight demonstration
  - Constraints applied on RF MEMS goes beyond ‘low level’ needs as hot switching constraints were applied
- Demonstrator has been found compliant with space standards as required in telecommunication geostationnary satellite
- Delivery of demonstrator is planned end of 2012 :
  - Screening of RF MEMS hybrid is being completed
  - Equipment assembly and TRR planned end of October
  - TRB s48