ThalesAlenia Space
A Thales / Finmeccanica Company

Getting ready for RF MEMS GEO flight demonstration

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(1) CEA LETI MINATECH

(2) CNES

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ESA MNT Round table 8-12/10/2007

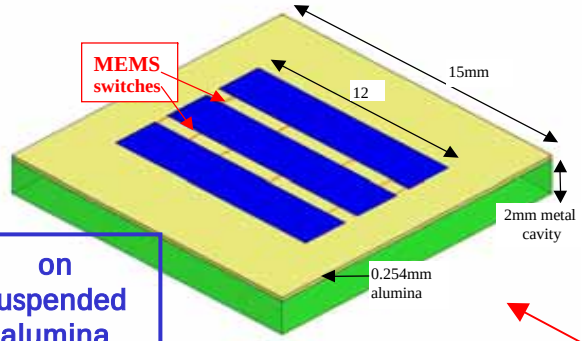
Template reference : 100181700C-EN

Outline

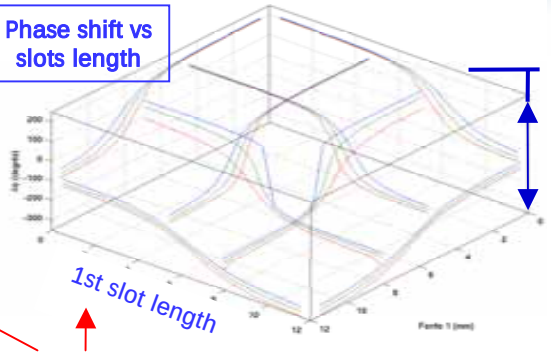
- Introduction
- Mission/experience presentation
- Description of the equipment constituents
  - Mechanical overview
  - TMTC
  - FPGA and dedicated ASIC
  - MEMS based hybrids
- EM manufacturing and test
- Conclusion and perspectives

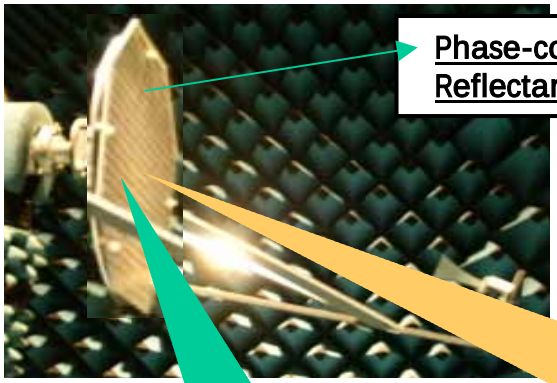
Demonstration of MEMS based space representative prototype (2/2)

MEMS-controlled ReflectArray



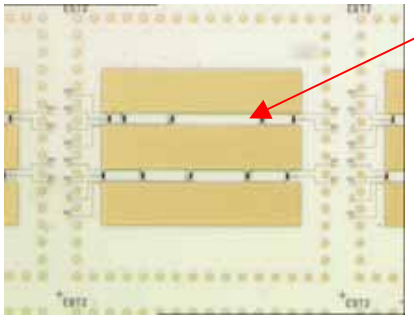
on suspended alumina



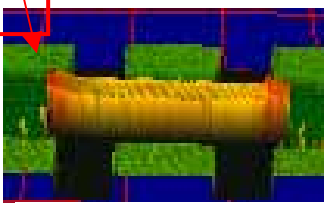


Phase-controlled Reflectarray cells

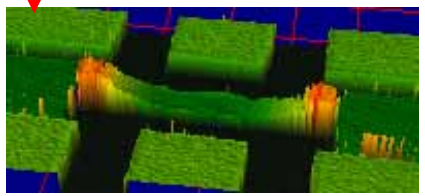
on thinned silicon



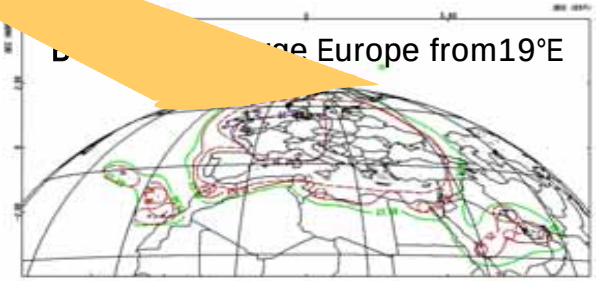
MEMS-switches control the effective slots length



Bridge in Up position



Bridge in Down position



TAS-F +LETI, LAAS

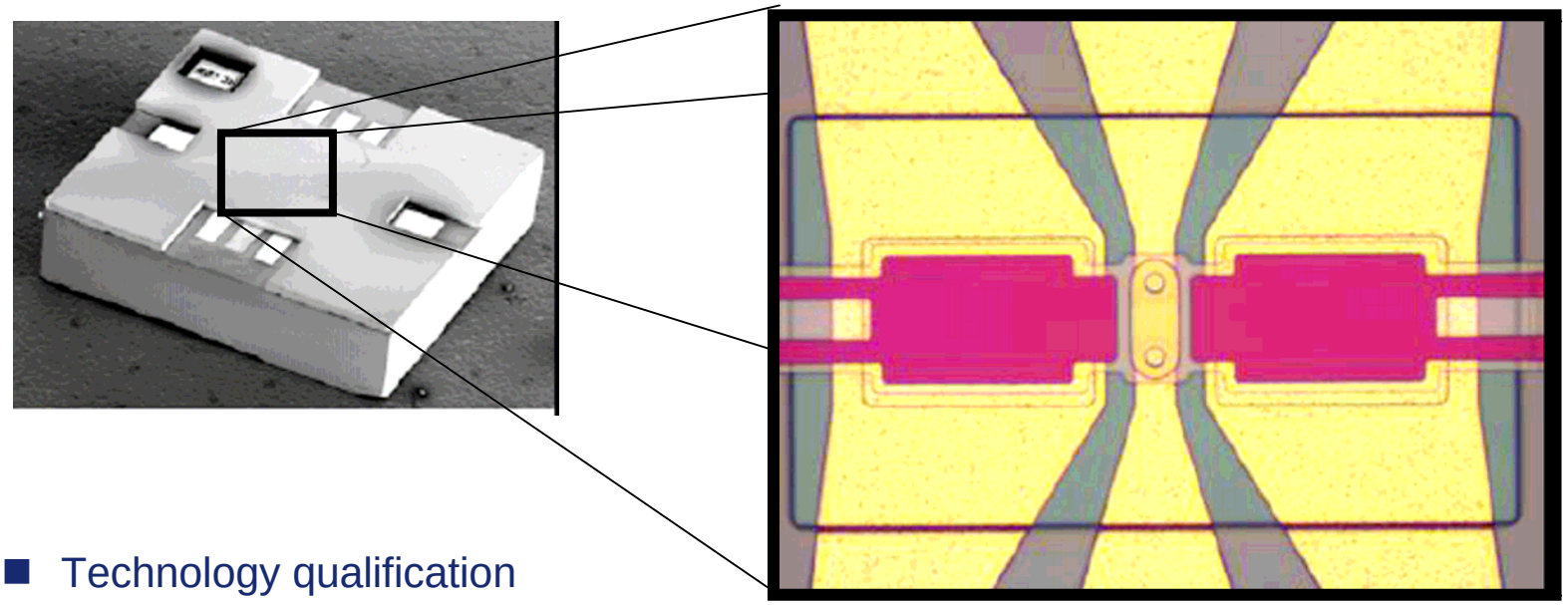
Typical power-handling: 2 to 4 W per refelcting cell **1 to 2 W max through 1 switch** in worst case states of the 10 controllable ones

Flight demonstration, what for ?

- Visibility of the new technology vs future customers
  - Internal
  - External
- Go from mid to high TRL
  - Refine design/test methodology applicable to flight models
  - Documentation
  - Industrialisation approach
- Enhance know-how of the new technology
  - Use into industrial environment
  - Technology integrated into flight proven technologies
  - Risk assessment
- Qualification of the available technology prior to flight demonstration

RF MEMS flight demonstrator : the team

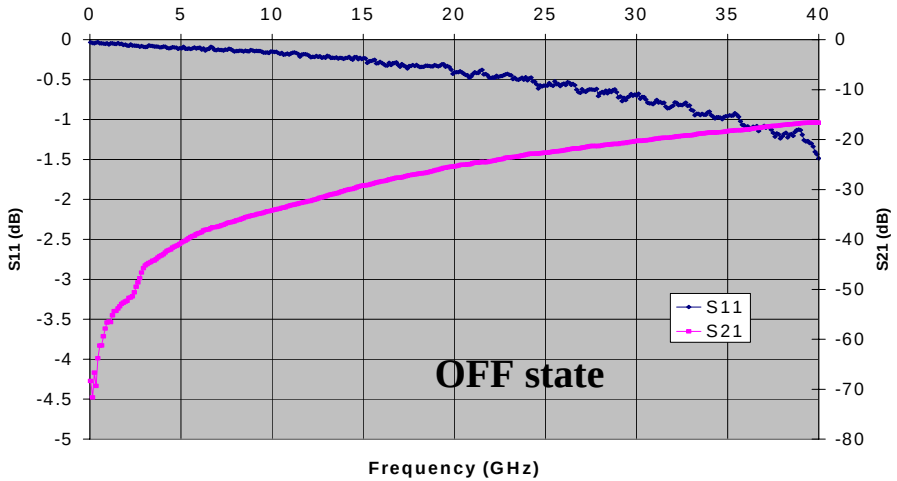
- CNES contract
- Thales Alenia Space : Prime contractor, design, manufacturing and test of the demonstrator
- RF MEMS technology
  - Ohmic switch technology from CEA LETI

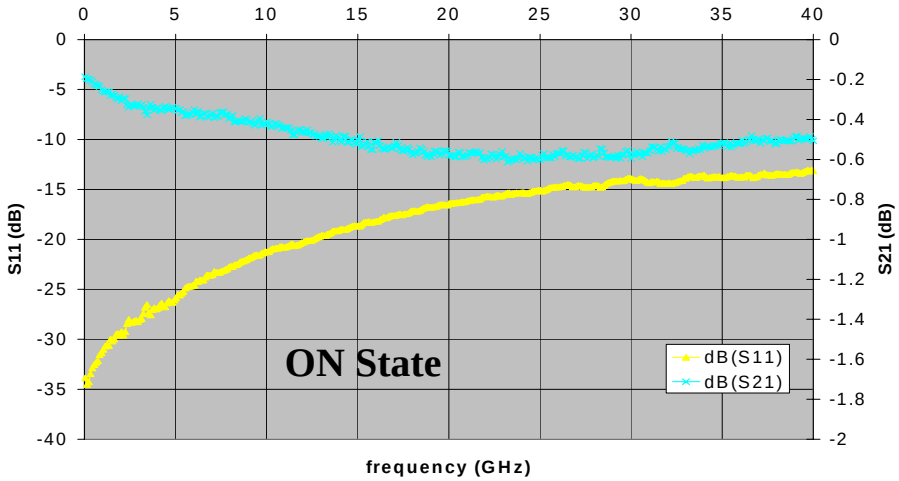


- Technology qualification
  - Technical support from CNES at component level
  - TAS in-house capability

Electrical characteristics

Ohmic contact, serie switch from CEA-LETI (after flip-chip mounting)





- Comparaison with a standard diode (Diode beam lead HPND 4005)

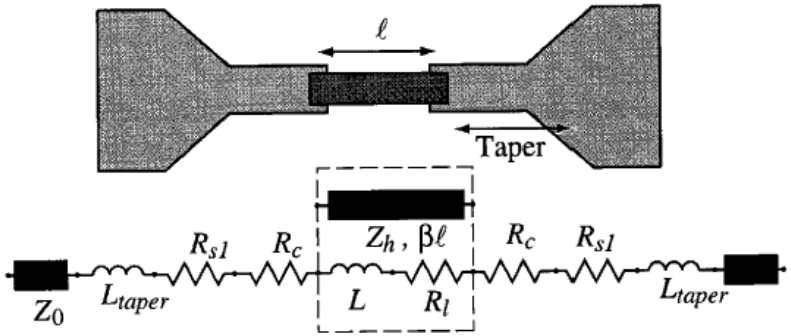
	Pertes de transmission : Etat ON à 30 GHz	Isolation : Etat OFF à 30 GHz	RON	COFF	1/(RON,COFF)
MEMS	0,29 dB	19,9 dB	1,7 ohms	9,8 fF	60 THz
Diode	0,76 dB	8,9 db	5 ohms	22 fF	9 THz

Base for demonstrator definition

- Observed failure mode for ohmic contact switches
  - Contact :
    - Contact degration
    - *Stiction metal-metal*
  - Membrane :
    - Residual stress, stress gradient, thermal stress
    - *Creep*
  - Electrostatic activation
    - Dielectric charging

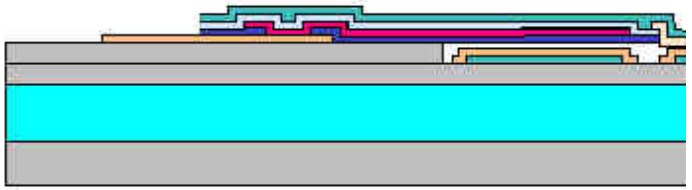
Basement for experiment definition

- Based on DC parameters
  - Fundamental sollicitation modes
    - Application (redundancy, fast switching)
  - Advanced RF switch intrinsic characteristics : Rc (On) et Vp



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

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



↕ g = gap

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

Membrane spring constant

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

Technical background

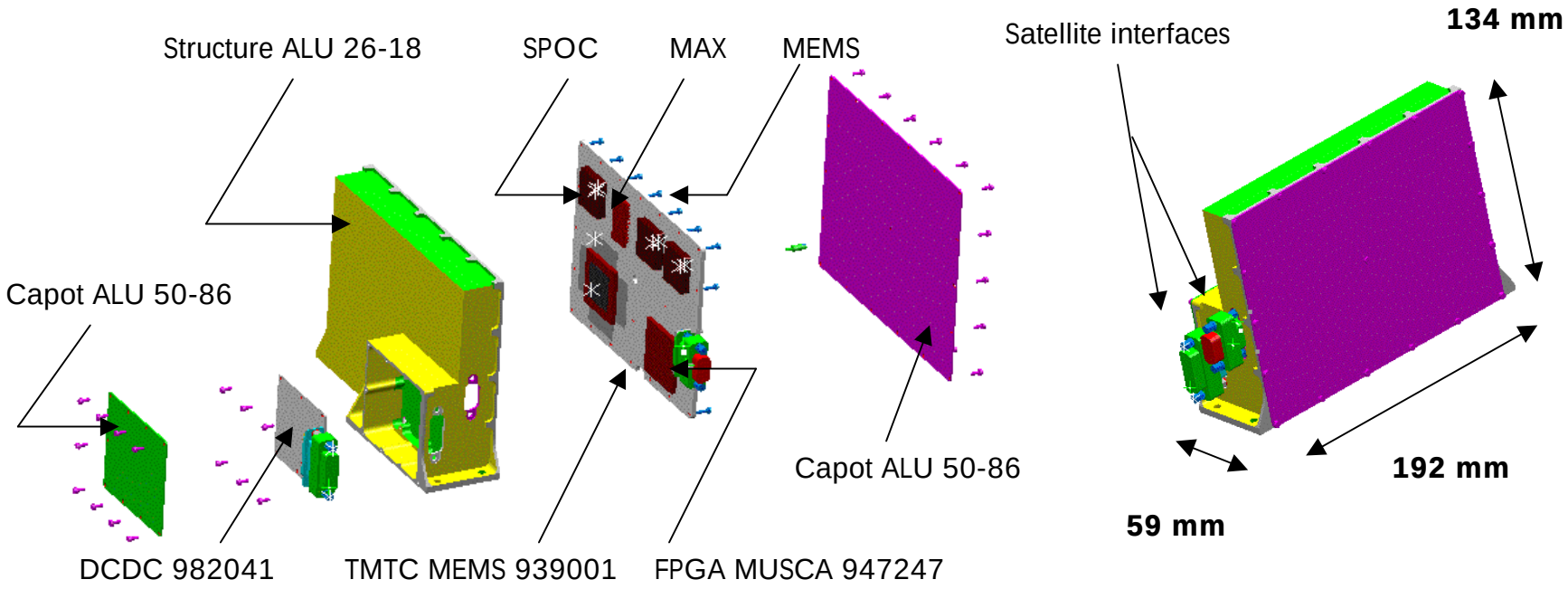
Measured characteristics	*Static performances*	***RF preformances***	*Impact on reliability assessment*
Number of cycles with various profile	N/A	N/A - -	Reliability rough figure Effect according to cycling profile
Serie resistance of the switch (Rs)	Contact resistance (Rc) derived from analytic equation (2)	S_{12} is derived from equation : insertion loss (1) - -	Contact aging (pollution, tribology, radiations,…) stiction, microsolduring,…
Pull-in voltage (Vp)	At known material characteristics, can be calculated (k) (4) and derived gap (g_0) (3)	S_{12} is derived from EM 3D model : isolation	- Membrane deformation

Basic functions of the 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(4): Pull-in/Pull-out measurements
  - TC launched sequence : 4 MEMS
- Temperature monitoring

Demonstrator is composed of 2 PCBs : 1 DCDC et 1 TMTC/MEMS

- Mono-structure in Al with 2 caps.
- Interfaces to satellite platform by Sub-D connectors (15pts DCDC et 9pts TMTC)



Récurrence avec la carte DCDC 715970

Masse estimé = 688 g

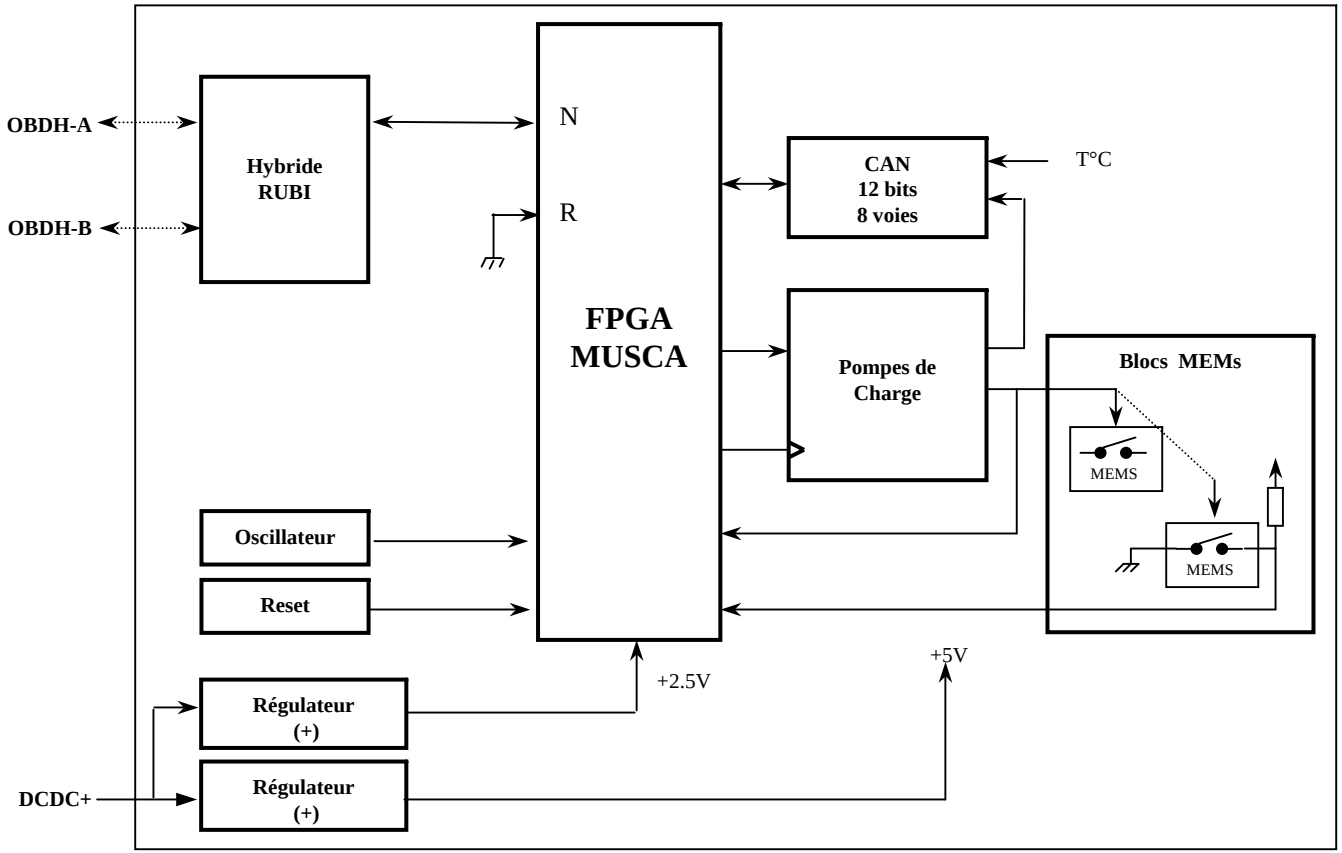
TMTC building block

Main functions realized by TMTC building block:

- Interface with SB4000 bus OBDH 485
- Regulated biasing generation based on DCDC provided voltage
- Generation of clocks and test signals
- Acquisition, management and processing of MEMS commands
- Acquisition, management and processing of MEMS measurements
- Generation of TM.

- This card is able to drive and monitor up to 5 charge pumps and up to 20 MEMS.

TMTC building block



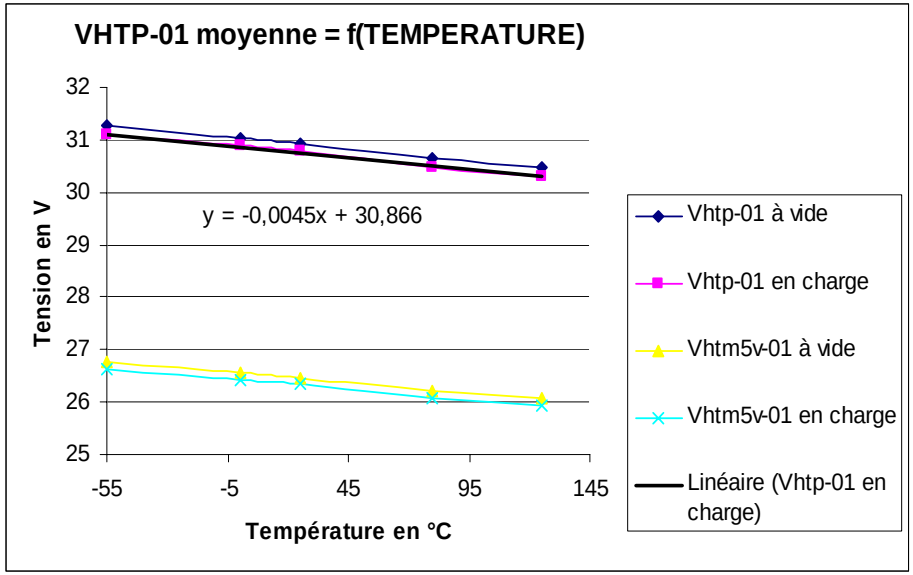
FPGA

- Receive, decode, validation of serial bus ML16 coming from hybrid RUBI
- Management and treatment of data coming from RUBI through serial bus CS16
- Management of init procedure
- Management of MEMS though the charge pumps
- Management of the charge pumps (clocks, output voltage monitoring)
- Management of serial bus com/acq of 12 bits ADC
- Acquisition and treatment of data for TM
- Send TM on serial bus AS16 via RUBI.
- FPGA address set at 00000.

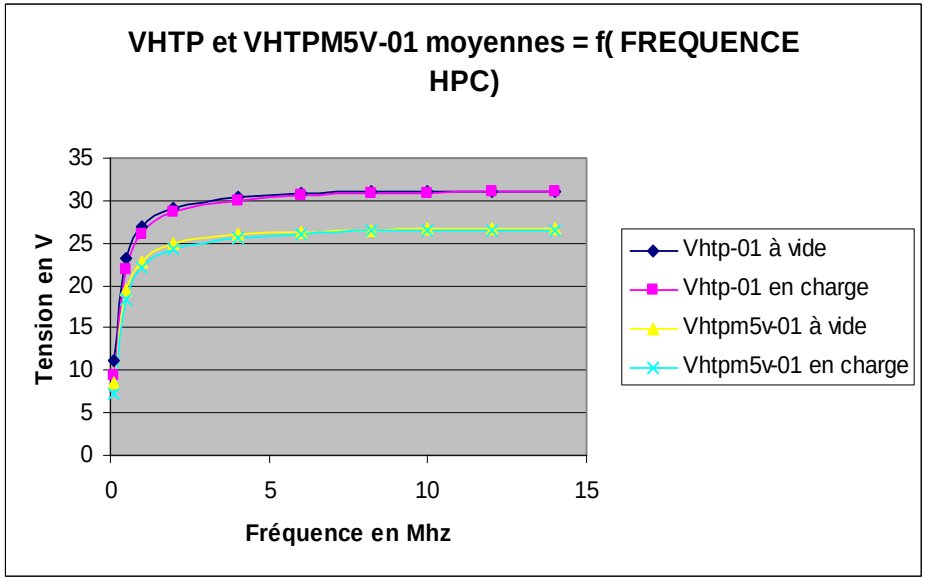
Charge pump ASIC

- **Robustness of the design, compliant with space constraintes**

Temperature stability



Stabilité en fréquence HPC



- **Packaged in hermetic ceramic package, qualified by lot**

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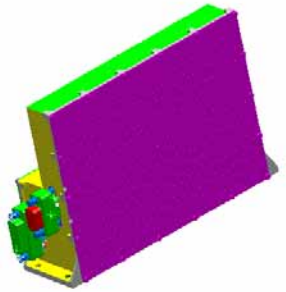
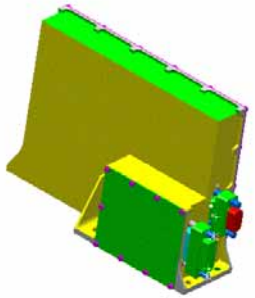
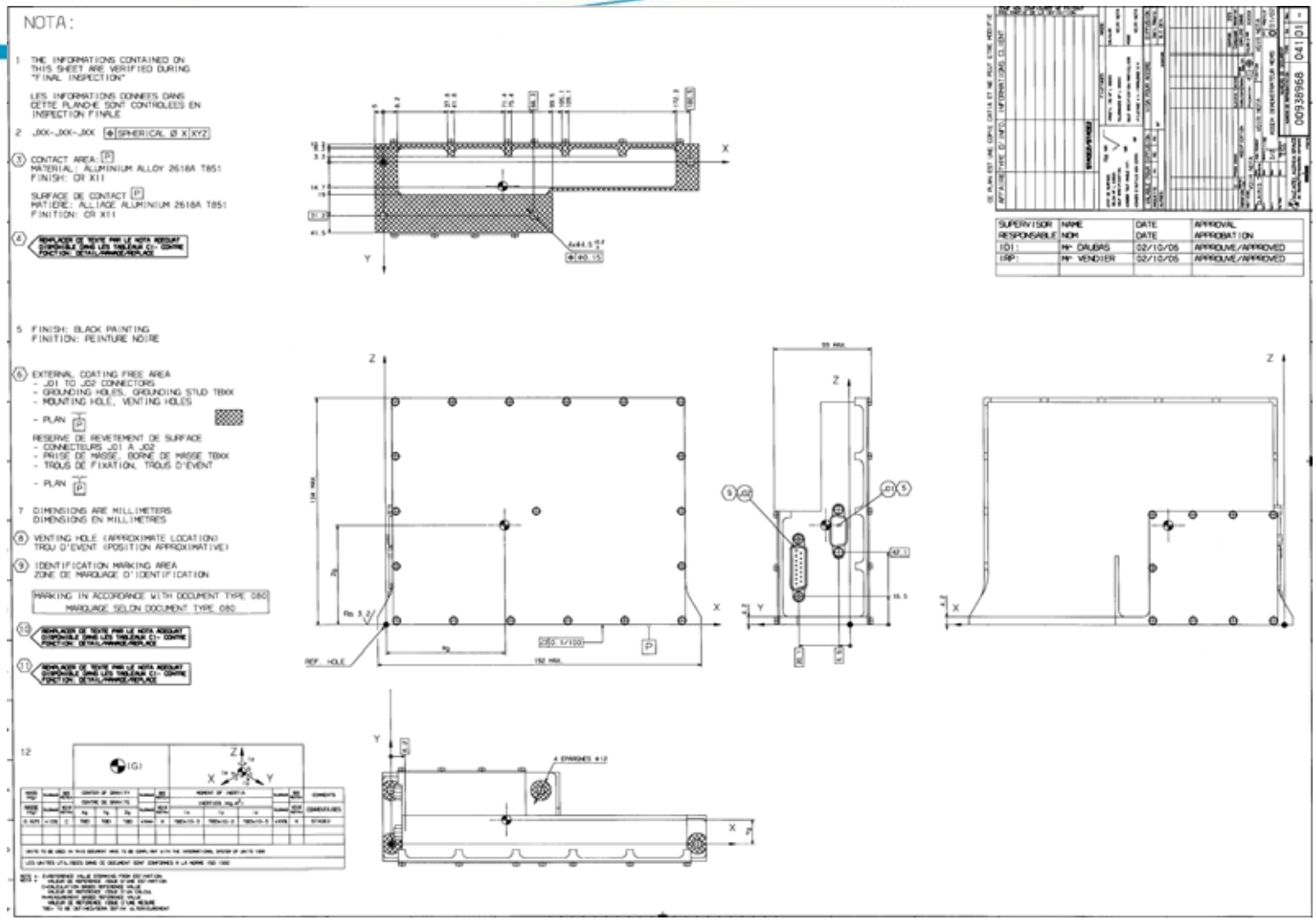
Overall Mass analysis

SUBASSEMBLY :					Total			Total
					Basic mass			Max mass
MEMS CNES					625	*10%*	*63*	688
938968								
Eléments	Date	Reference	Qty	Unit	Total	Tolér,	Uncert.	Max mass
				basic mass	basic mass			
				(g)	(g)	(%)	(g)	(g)
Structure mécanique		938970	1	300	**300**	10%	30	**330**
Capot TMTC MEMS		938981	1	40	**40**	10%	4	**44**
Capot DCDC		938985	1	10	**10**	10%	1	**11**
Carte DCDC		982041	1	45	**45**	10%	5	**50**
Carte TMTC MEMS		939001	1	200	**200**	10%	20	**220**
Visserie		**	1	20	**20**	10%	2	**22**
Peinture		**	1	10	**10**	10%	1	**11**







Mechanical environment : SB4000 specification S000329 ed04

Zone A (1A+2A) : larger covering for P/L equipment

Sinus :

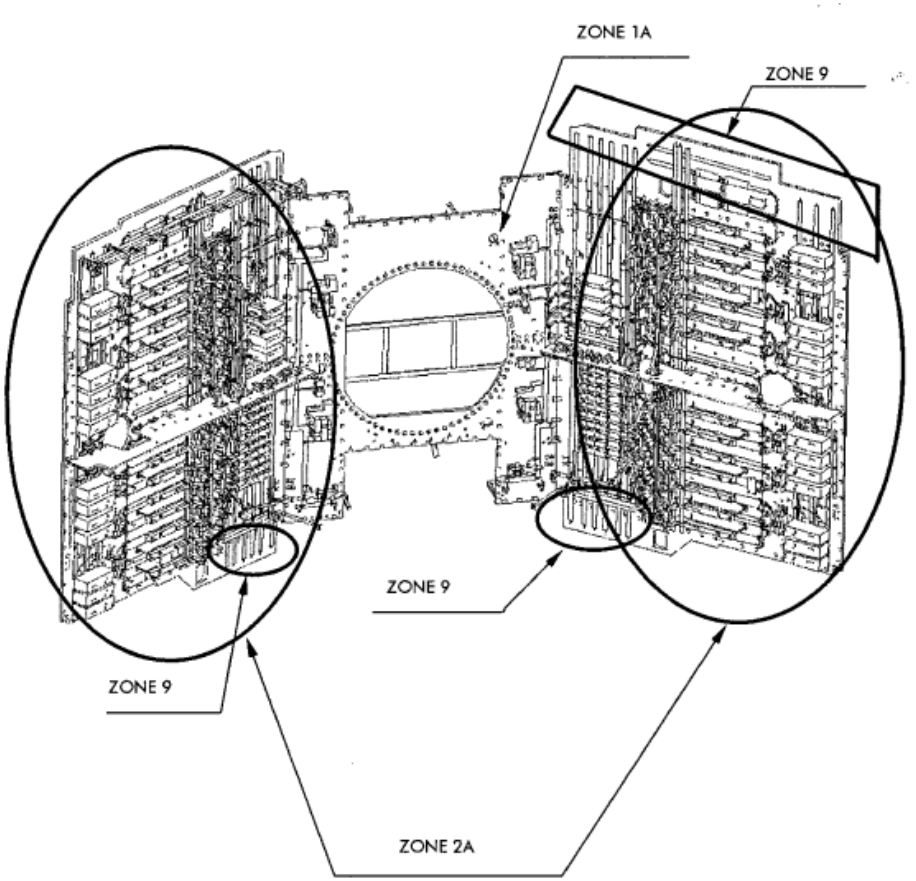
Perpendicular to mounting plane (Z)		parallel to mounting plane (X, Y)	
Range (Hz)	Level	Range (Hz)	Level
5 – 21 21 – 100	±10 mm ± 18 g	5 – 17 17 - 100	±10 mm ± 12 g

Vibrations

Perpendicular to the mounting plane (Z)		Parallel to the mounting plane (X, Y)	
Range (Hz)	PSD Level	Range (Hz)	PSD Level
20 - 50 50 - 350 350 - 447 447- 1000 1000 - 1565 1565 - 2000	+ 6 dB/oct 0.8 g²/Hz - 12 dB/oct 0.3 g²/Hz - 12 dB/oct 0.05 g²/Hz	20 -100 100 - 500 500 - 2000	+ 6 dB/oct 0.1 g²/Hz 0.05 g²/Hz
Global : **23.76 g RMS**		Global : **10.9 g RMS**	

Shocks : Zone S4

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



•**Thermal environment:** SB4000 specification S000329 ed04

Environment RX TTC

	Operating mode	
	T min. (°C)	T max. (°C)
Qualification	-30	+70
Acceptance	-25	+65

Equipment with black paint : emissivity of 0.85

Start up cold : -35°C Qualif et –30°C Acceptance

Dissipated power for TMTC = 1.24W typical

Dissipated power for DCDC = 0.56 W typical

•**EMC environment** : SB4000 spécification S000330 Ed 03

Equipment OFF during launching

•**Radiating environment** : SB4000 specification CN11 et CN12

Al cube 0.8 mm in thickness.

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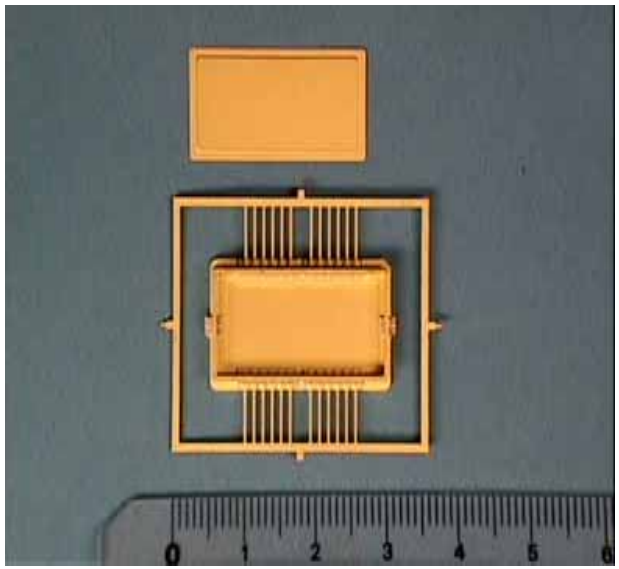
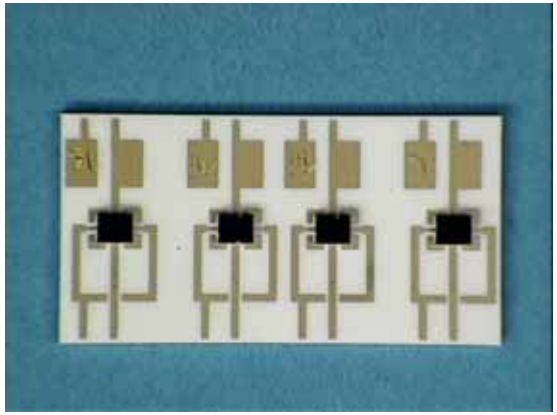
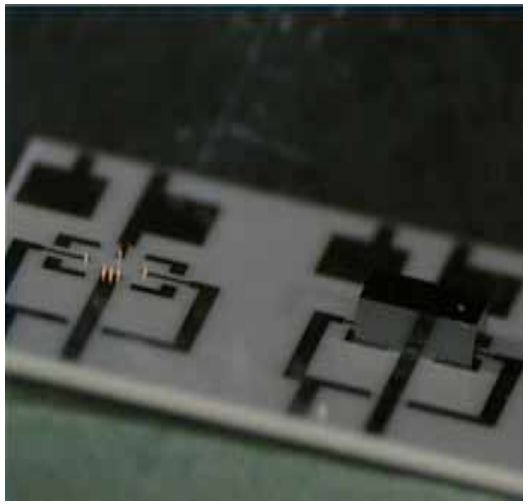
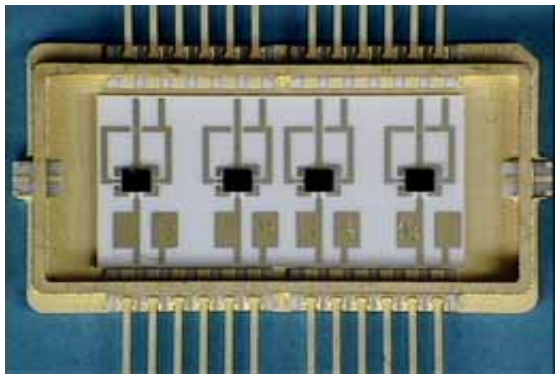
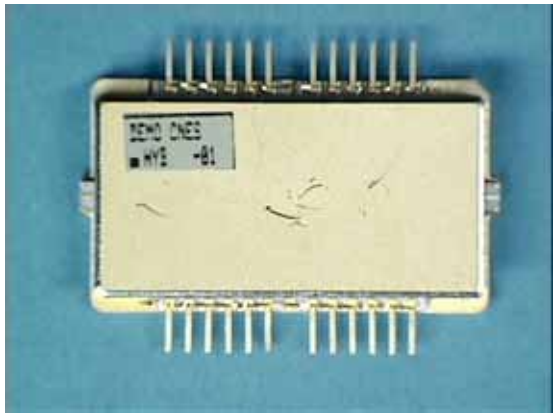
MEMS hybrid manufacturing



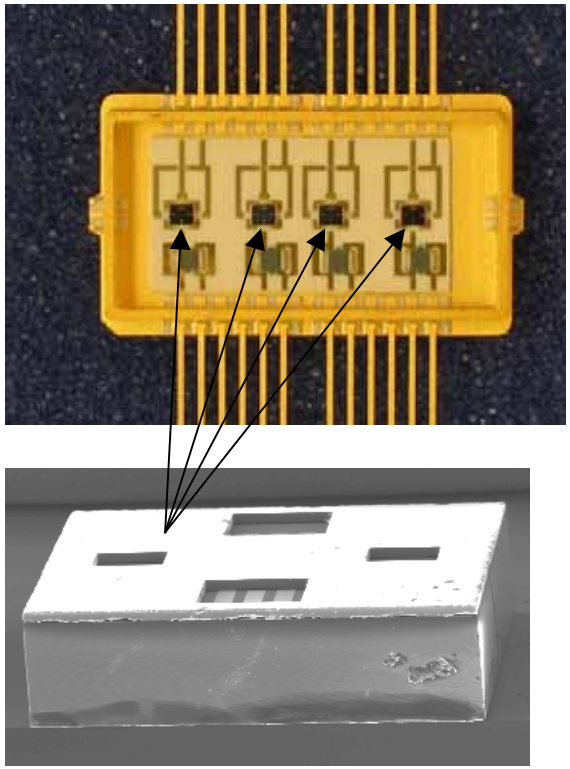








RF-MEMS Flight Model Reliability Demonstrator



Micro-package
w/ 4 MEMS

Manufactured MEMS Demonstrator
(EM)

Ex of TC for TM request:

16 bits Serial command (CS16)																Actions	
@FPGA					CMI				COM ID						P		
b0	b1	b2	b3	b4	b5	b6	b7	b8	b9	b10	b11	b12	b13	b14	b15		
									n° Mode(1)		S/j/a		n° MEMS			**TC-TM-Acq Mode(1)**	
									0	0	0	0	0	0		TC-TM-Acq MEMS n°1	seconde
														1		TC-TM-Acq MEMS n°2	
													1	0		TC-TM-Acq MEMS n°3	
														1		TC-TM-Acq MEMS n°4	
											0	1	0	0		TC-TM-Acq MEMS n°1	jour
														1		TC-TM-Acq MEMS n°2	
													1	0		TC-TM-Acq MEMS n°3	
														1		TC-TM-Acq MEMS n°4	
											1	0	0	0		TC-TM-Acq MEMS n°1	an
														1		TC-TM-Acq MEMS n°2	
													1	0		TC-TM-Acq MEMS n°3	
														1		TC-TM-Acq MEMS n°4	
@ FPGA					0	0	0	1	n° Mode(2)				n° MEMS			**TC-TM-Acq Mode(2)**	
									0	1	0	0	0	0		TC-TM-Acq MEMS n°1	
														1		TC-TM-Acq MEMS n°2	
													1	0	P	TC-TM-Acq MEMS n°3	
														1		TC-TM-Acq MEMS n°4	
									n° Mode(4)				n° MEMS			**TC-TM-Acq Mode(4)**	
									1	1	0	0	0	0		TC-TM-Acq VPi1, Vpo1	
														1		TC-TM-Acq VPi2, Vpo2	
													1	0		TC-TM-Acq VPi3, Vpo3	
														1		TC-TM-Acq VPi4, Vpo4	
																TC-TM-Acq Etat(x)	
									1	1	0	1	0	0		TC-TM-Acq-Etat(1)	
														1		TC-TM-Acq-Etat(2)	
													1	0		TC-TM-Acq-Etat(3)	
														1		TC-TM-Acq-Etat(4)	
											1	0	0	0		TC-TM-Acq-T°C-EQ	

Example of TC used for demonstrator operation:

16 bits Serial command (CS16)																	Actions
@FPGA					CMI				COM ID						P		
b0	b1	b2	b3	b4	b5	b6	b7	b8	b9	b10	b11	b12	b13	b14	b15		
									n° Mode					on/off			**TC-START/STOP Modes(x)**
					1	0	0	0	0	0	0	0	0	0			TC-STOP Mode(1) (x2)
														1			TC-START Mode(1)
										1				1			TC-START-A Mode(2)
													1	1			TC-START-B Mode(2)
											0	0		1			TC-START Mode(4)
																	TC-START Gen
									0	0	1	1	0	1			TC-START-GEN
											n°bus		Val. bus				**TC-CPC(x)**
													0	0			TC-CPC1(1)
												0		1			TC-CPC1(2)
													1	0			TC-CPC1(3)
											0			1			TC-CPC1(4)
													0	0			TC-CPC2(1)
												1		1			TC-CPC2(2)
													1	0			TC-CPC2(3)
					1	0	1	0	0	0				1			TC-CPC2(4)
													0	0			TC-CPC3(1)
												0		1			TC-CPC3(2)
													1	0			TC-CPC3(3)
											1			1			TC-CPC3(4)
													0	0			TC-CPC4(1)
												1		1			TC-CPC4(2)
													1	0		p	TC-CPC4(3)
														1			TC-CPC4(4)
					1	1	1	0	1	0	1	0	1	0			**TC-INIT**
					1	1	1	1	0	1	0	1	0	1			**TC-RESET** (x2)

Example of TM received on the on-board processor emulator, when equipment plugged into

	TC EMISE		TM WORD1 ATTENDUE	TM WORD1 RECUE		TM WORD2 ATTENDUE	TM WORD2 RECUE	ANALYSE
********** TC-TM-ACQ mode(1) Seconde - (pas de TC-TM) -								
MEMS n°1	NOP	NA	1111111111111111	1111111111111111	OK	1111111111111111	1111111111111111	OK (pas de demande de TM préalable)
********** TC-TM-ACQ mode(1) Seconde								
MEMS n°1	0000000010000000	OK	0000000000000001	0000000000000001	OK	0000000000000001	0000000000000001	OK
MEMS n°2	0000000010000011	OK	0000000000000010	0000000000000010	OK	0000000000000001	0000000000000001	OK
MEMS n°3	0000000010000101	OK	0000000000000100	0000000000000100	OK	0000000000000001	0000000000000001	OK
MEMS n°4	0000000010000110	OK	0000000000000111	0000000000000111	OK	0000000000000001	0010000000000000	NOK (MEMs NOK)
********** TC-TM-ACQ mode(1) Jour								
MEMS n°1	0000000010001001	OK	0000000000001000	0000000000001000	OK	0000000000000001	0010000000000000	NOK (MEMs NOK)
MEMS n°2	0000000010001010	OK	0000000000001011	0000000000001011	OK	0000000000000001	0000000000000001	OK
MEMS n°3	0000000010001100	OK	0000000000001101	0000000000001101	OK	0000000000000001	0010000000000000	NOK (MEMs NOK)
MEMS n°4	0000000010001111	OK	0000000000001110	0000000000001110	OK	0000000000000001	0000000000000001	OK
********** TC-TM-ACQ mode(1) An								
MEMS n°1	0000000010010001	OK	0000000000010000	0000000000010000	OK	0000000000000001	0000000000000001	OK
MEMS n°2	0000000010010010	OK	0000000000010011	0000000000010011	OK	0000000000000001	0010000000000000	NOK (MEMs NOK)
MEMS n°3	0000000010010100	OK	0000000000010101	0000000000010101	OK	0000000000000001	0010000000000000	NOK (MEMs NOK)
MEMS n°4	0000000010010111	OK	0000000000010110	0000000000010110	OK	0000000000000001	0000000000000001	OK
********** TC-TM-ACQ mode(2)								
MEMS n°1	0000000010100001	OK	0000000000100000	0000000000100000	OK	0000000000000001	0000000000000001	OK
MEMS n°2	0000000010100010	OK	0000000000100011	0000000000100011	OK	0000000000000001	0000000000000001	OK
MEMS n°3	0000000010100100	OK	0000000000100101	0000000000100101	OK	0000000000000001	0000000000000001	OK
MEMS n°4	0000000010100111	OK	0000000000100110	0000000000100110	OK	0000000000000001	0000000000000001	OK
********** TC-TM-ACQ mode(4)								
VPi(1), VPo(1)	0000000011100000	OK	0000000001100001	0000000001100001	OK	0000000000000001	0000000000000001	OK
VPi(2), VPo(2)	0000000011100011	OK	0000000001100010	0000000001100010	OK	0000000000000001	0000000000000001	OK
VPi(3), VPo(3)	0000000011100101	OK	0000000001100100	0000000001100100	OK	0000000000000001	0000000000000001	OK
VPi(4), VPo(4)	0000000011100110	OK	0000000001100111	0000000001100111	OK	0000000000000001	0000000000000001	OK

Conclusions

- New equipment developed aiming at prove in-orbit operation
  - Autonomous, interface to the platform is flight proven
  - Compatible with GEO telecom platform
    - SB4000 from Thales or E*3000 from Astrium
- Functionality of EM validated, passed the standard procedure applied to commercial satellite equipment (EMC, thermal vacuum, vibration/chocs)
- FM produced, waiting the end of the RF MEMS qualification

- Know-how increased on how to implement RF MEMS into FM space equipments