Micro-Sensors and Micro-actuators for Space system

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MEMS interest for space applications

- When mass or power of the payload is very costly for the mission :
  - ✍deep space satellites instrumentation, planetary landers and rovers
- When the space vehicle itself has a very reduced size :
  - ✍satellites lighter than 100 kilograms
- When the required function is used on a wide number of satellites : cost reduction of equipment and/or performance improvement :
  - ✍AOCS, propulsion, RF links
- When technical requirements are closed to industrial or military ones : optical instruments, energy conversion
- Finally, MEMS are also interesting when people want to increase the bandwidth or decrease the thermal response time of a sensor or an actuator.

Difficulties to overcome

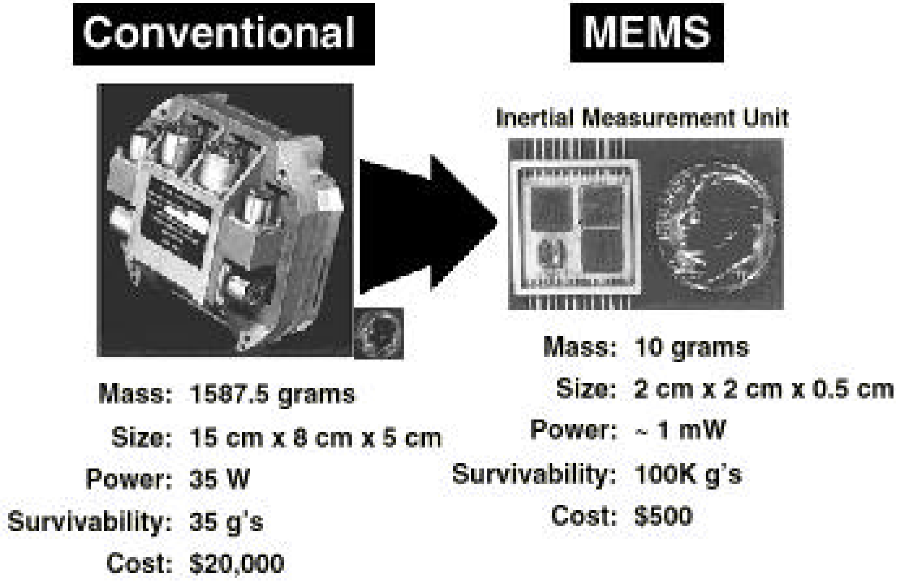
Sensors

- Measurement range generally different
- Affordable performances often lower than those needed
- Control of cross-sensitivities
- Difficulty in obtaining mechanical alignment over the full range of temperature
- Radiation hardness

Actuators

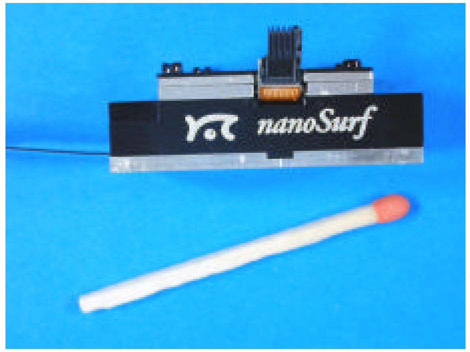
- Failure during life time
- Pollution sensitivity
- Interface problem with satellite structure
- Resistance to launch environment
- Need for reliability demonstration
- High development cost versus low production volume

MEMS Interest for space



From « Microelectromechanical Systems Opportunities », US DoD

Some space applications



Scientific sensors :

Sensors for Mars Penetrator	JPL
Seismometer (Netlander…)	JPL
Meteorology sensors	JPL
AFM (Mars MEC)	Swiss

AOCS sensors

Microgyros, magnetometers, accelerometers...

Actuators

Microthrusters

Nanosatellites

Some projects :	Europe	Uppsala, Surrey
	USA	Nasa, Air force, Aerospace Corp.

3 axes Microaccelerometer (1)

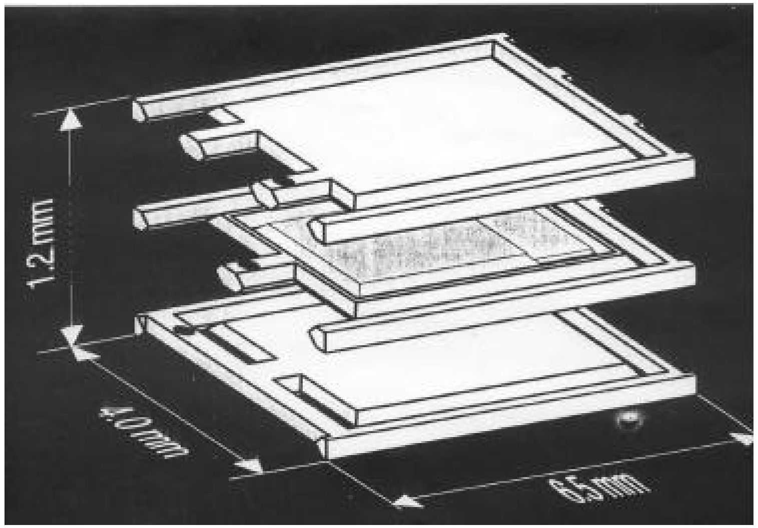
CSEM - SAGEM

- **Objective** :
  - To answer to space needs for planetary rovers navigation, orbital rendez vous and microdynamic instrumentation of satellites (microgravity, optical line stabilisation).
  - To reach a high bias stability over 24 hours (< 10 µg)
- **Requirements** :
  - Measurement range : ? 1g
  - Bandwidth : static to 300 Hz
  - Noise (< 10 Hz) : ? 1 µg / ? Hz
  - Scale factor Non Linearity : < 10^{-2} full scale
  - Residual bias after compensation : < 1 mg
  - Bias stability over 24 hours : < 10 µg
  - Scale factor thermal sensitivity : 10^{-4} /°C
  - Thermal bias variation on -10°C, 50°C after compensation : < 10 µg
  - Axes misalignment : <0,2°

3 axes microaccelerometer (2)

Définition of the sensitive cell : (6,5 mm x 4 mm x 1,2 mm)

- Closed loop concept with capacitive detection and electrostatic actuation to reach the bias stability.
- ASIC circuit for data treatment, control correctors and numerical output elaboration.
- Hybrid circuit for the axes common functions management (clock, temperature, reference voltage, power supply).



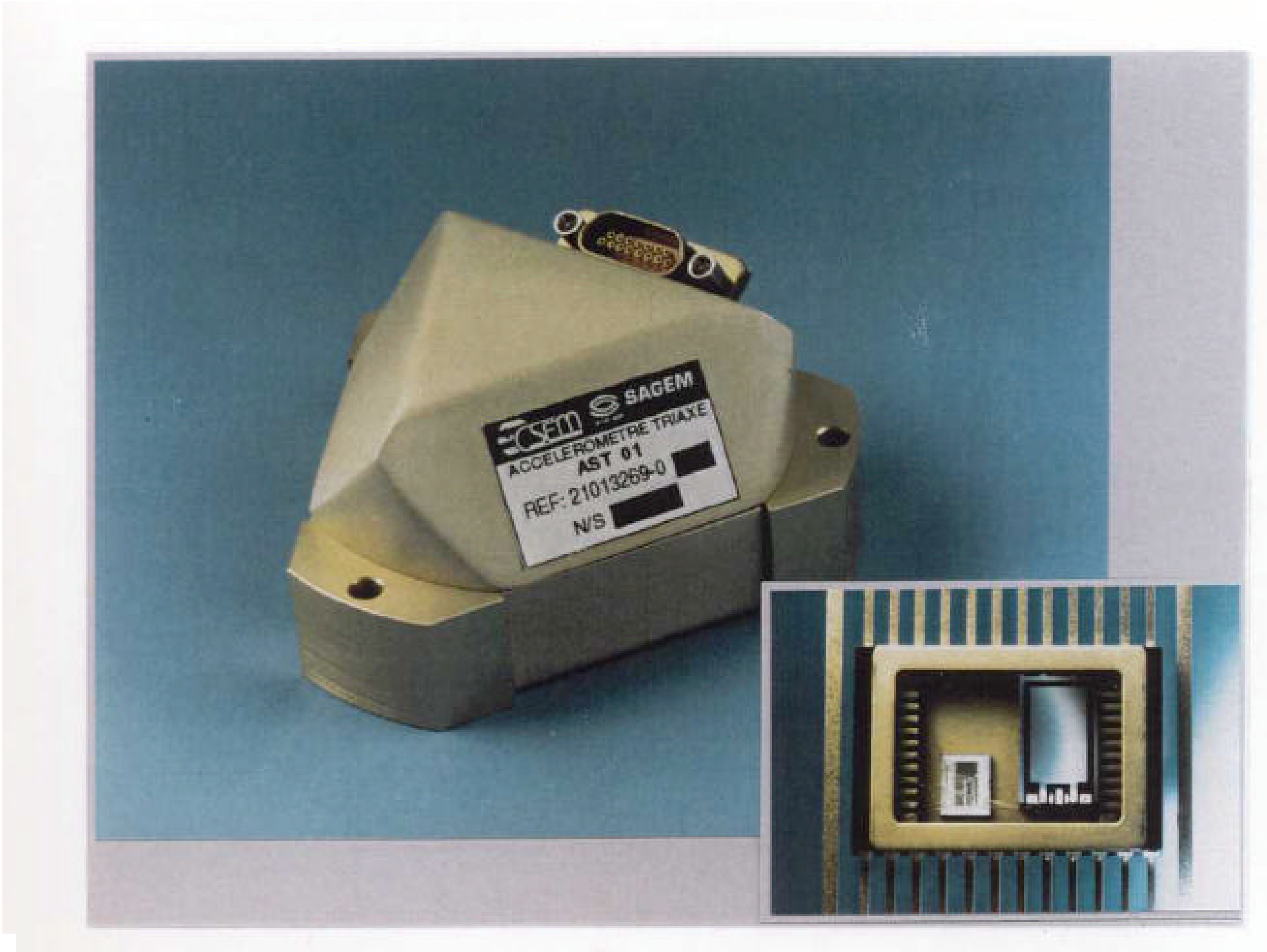
3 axes microaccelerometer (3)

- **Status** :

		Spec.
The noise specification cannot be reached	: 10 µg/?Hz	1 µg/ ?Hz
– Absolute compensation of the bias was	: 2 mg	1 mg
– Bias stability over 24 hours was	: 15 µg	10 µg
– The thermal residual bias was	: 20 µg	10 µg
– The axes misalignment was	: 0,3°	0,2°

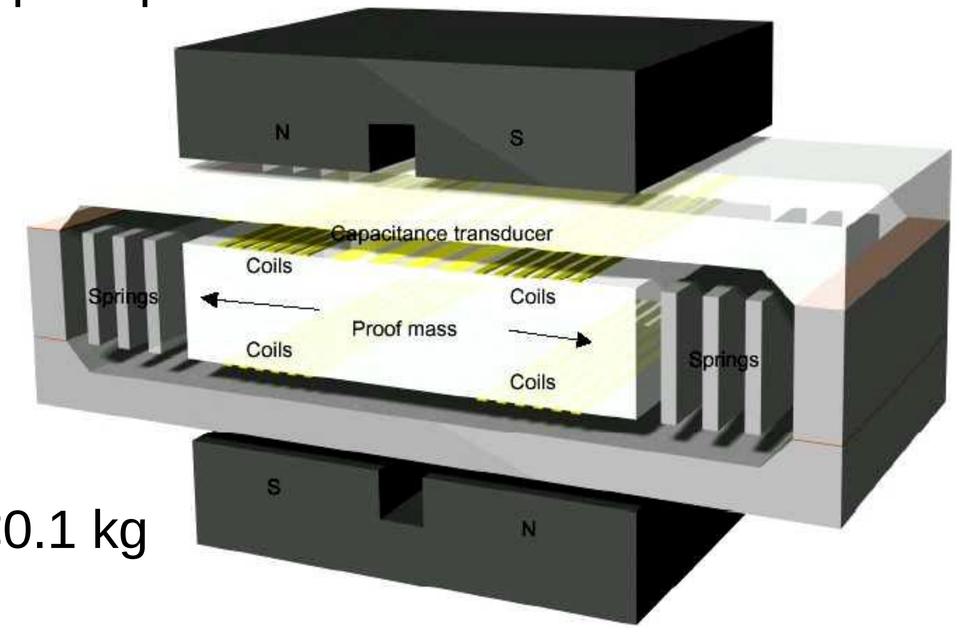
The final product with the 15V power supply weights 120 grams and has a 70 mm diameter for a 33 mm height. The power consumption is 450 mW

3 axes microaccelerometer AST 0I



Microseismometer JPL (1)

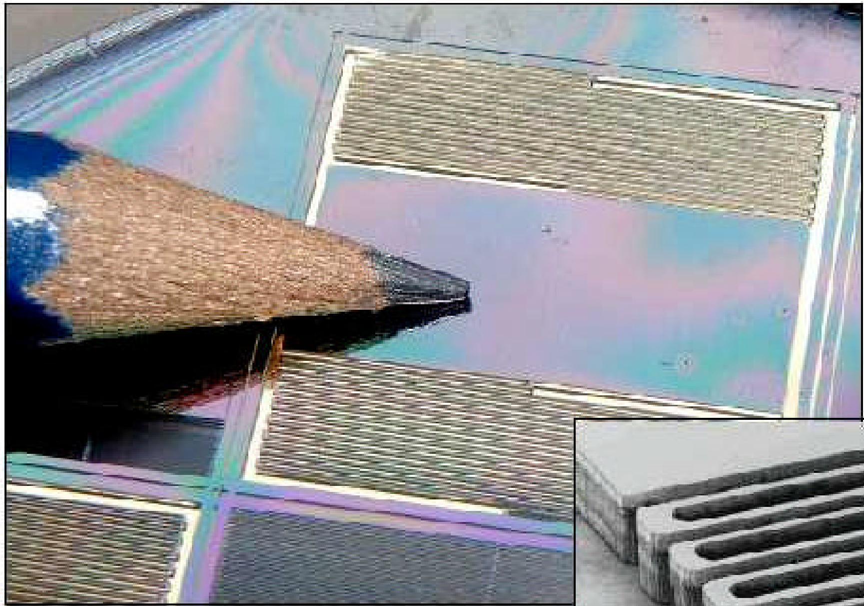
- **Principle**
  - System based on mass-spring principle
  - Capacitive detector
  - Electromagnetic feed back



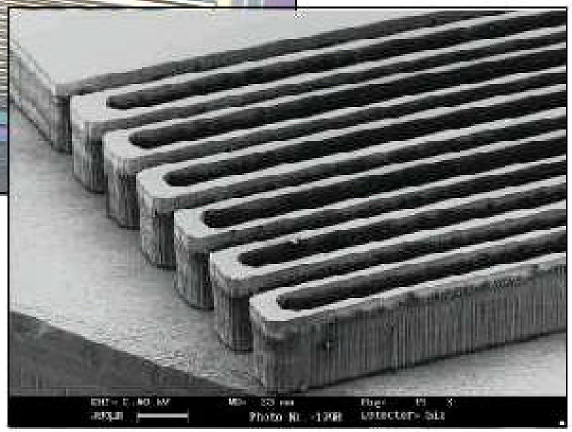
- **Performances**
  - Sensitivity $10^{-9}\ g/\sqrt{Hz}$
  - Bandwidth 0.1-100 Hz
  - total mass for 3 axes system <0.1 kg

- **Use**
  - Planetary missions

Microsismometre JPL (2)



Proof mass

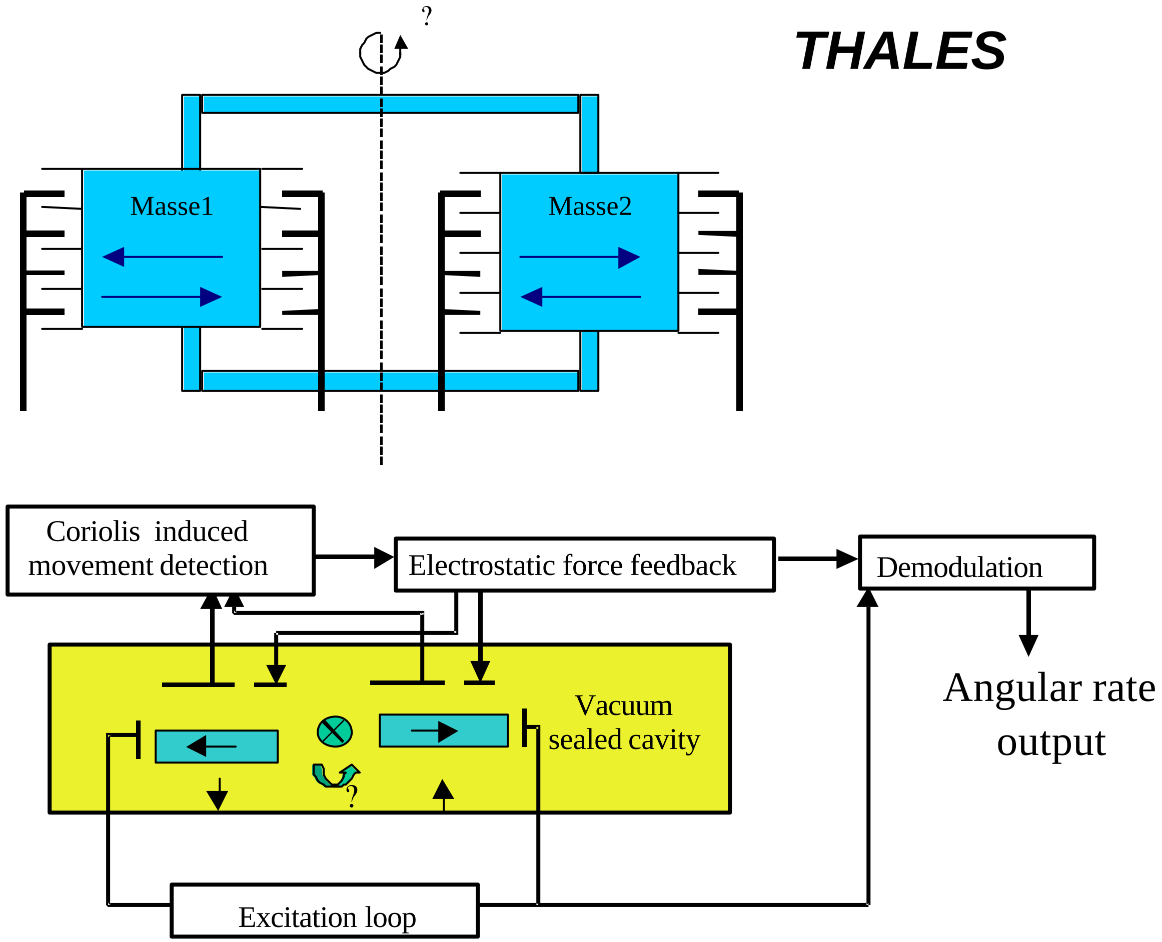


Suspension spring

Silicon rate gyro : Principle

THALES

- Coriolis force measurement
- In plane electrostatic excitation
- Out of plane electrostatic detection
- Electrostatic force feedback



Silicon microgyrometer :Performances

Range	± 100 °/s	± 30 °/s
Bandwidth	100 Hz	> 10 Hz
Short term bias stability	40 °/h (qq heures)	5°/h (1heure)
Bias repeatability	720 °/s (1 an)	50°/h
Scale factor error	1% / 1an	1000 ppm /1 mois
random walk	$0,6°/h^{1/2}$	$1°/h^{1/2}$
volume (uncompensated output)	4 cm3	n.s.
Mass	< 10 g	200 g
Power consumption	0,5 W	3 W
Temperature	-40°C à +95°C	-40°C à +95°C
Vibrations	20 g RMS	20 g RMS (OFF)
Shocks	200 g	

Attitude Micromagnetometer

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<u>Goal</u> :

Attitude magnetometer for AOCS miniaturisation

<u>Development</u> :

3 axes fluxgate Micromagnetometer
Sensor built in microtechnology
Non integrated Electronic (for budget reason)

Attitude Micromagnetometer

	Requirements	Performances
Range	? 60 µT	? 66 µT
Bandwidth	100 Hz	10 kHz
Absolute accuracy	? 400 nT	? 700 nT
Zero offset	? 500 nT	? 200 nT à 25°C
Scale factor thermal stability	? 0.5 %	? 3.6 %
Noise	50 nT rms à 16 Hz	3 nT/vHz

Status :

Thermal drift to be improved
Electronic miniaturisation to perform
Residual Alignment error unacceptable (? 0.7 °)
Noise problem

Silicon Microthrusters

Goal : Development and fabrication of microthruster matrix for micro/nano satellite AOCS

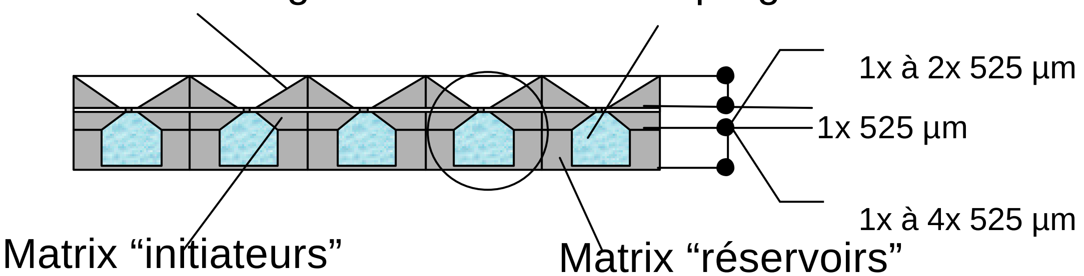
Means :

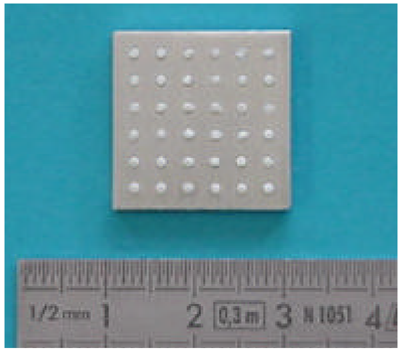
– Use of MEMS technology : low cost, miniaturisation, integration …

– Use of solid propellant packed in micro-reservoirs.

Targeted performances :

Several µN to about 100 mN thrust





Matrix of 36 loaded microthrusters

cnes

lms Laboratoire de Microanalyse des Surfaces

Microtribology

Prospective activity :

– Evaluation of tribological behaviour (under low loads, small displacements) of MEMS materials (silicon, polysilicon…) and some lubricants (DLC, CNx)

Test performed :

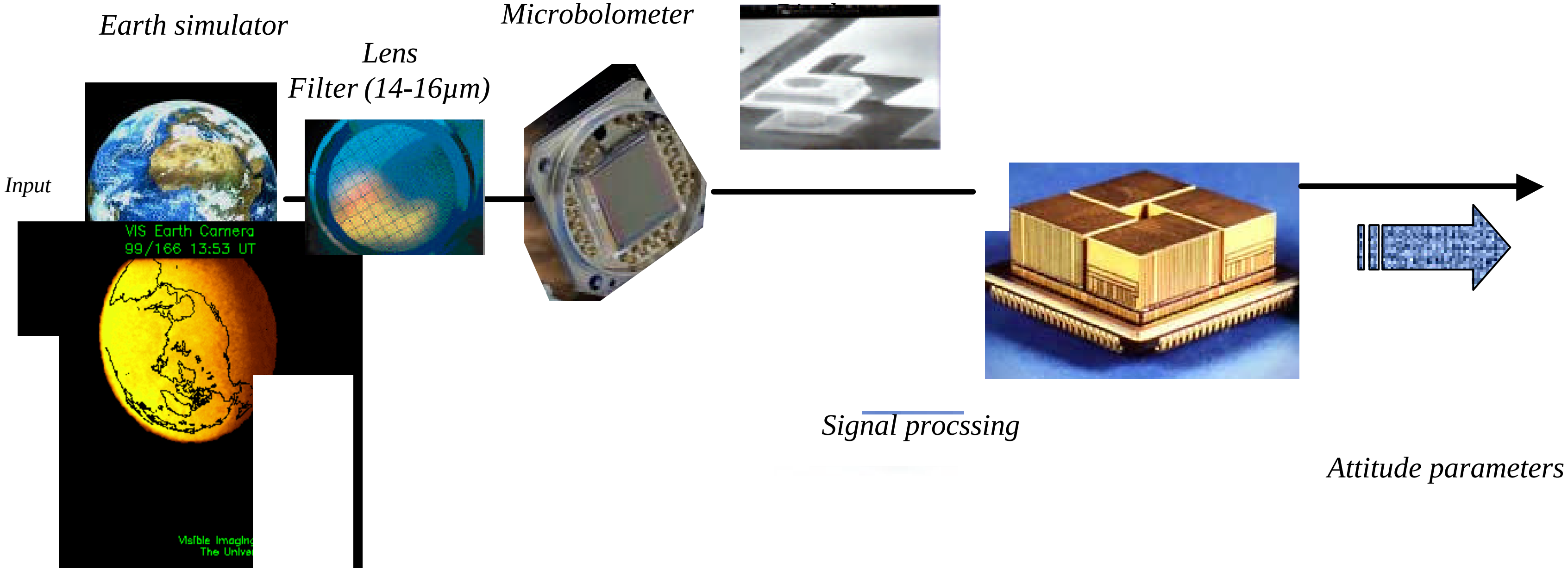
– Test performed on several tribometers (0.05 up to 50 N)
– Test performed in air environment and under nitrogen
– Surface characterisation (SEM, nano-indentation…)

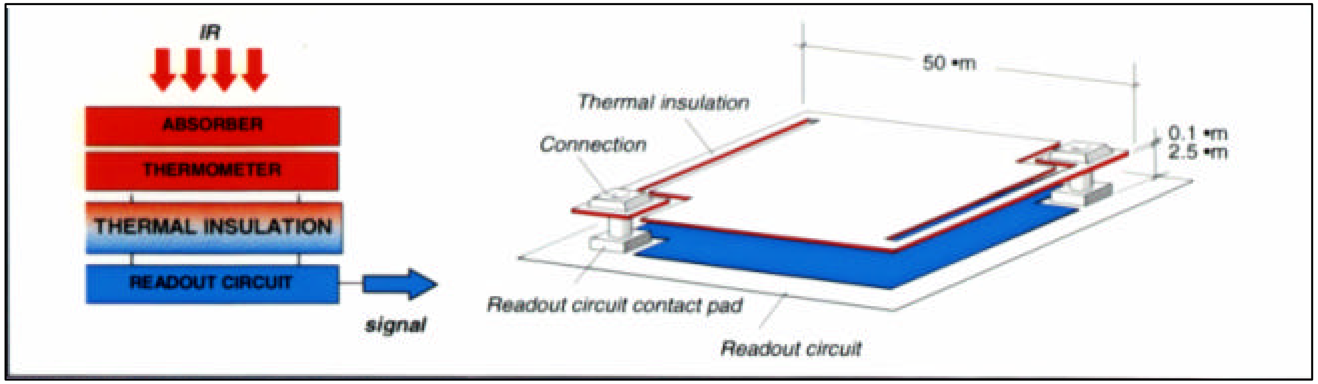
Results :

– Tribological classification of materials (friction, wear, adhesion…)

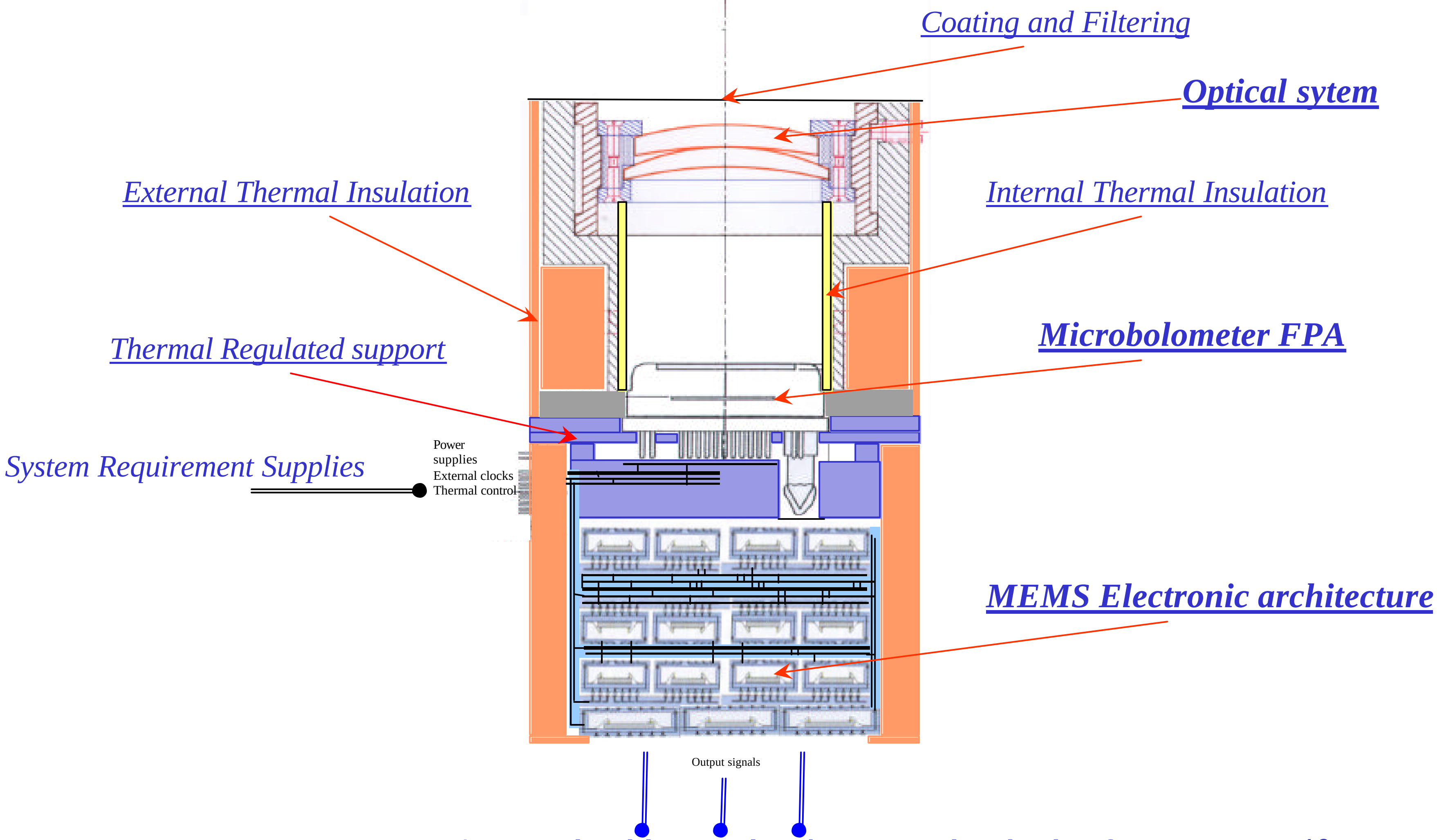
– Quantification of the interest of such lubricants (DLC ou CNx) for friction, non-adhesion and wear improvements.

Miniaturised earth sensor built with microbolometers - MIRES (1)





Miniaturised earth sensor built with microbolometres - MIRES (2)



Miniaturised Earth sensor built with microbolometers - MIRES (3)

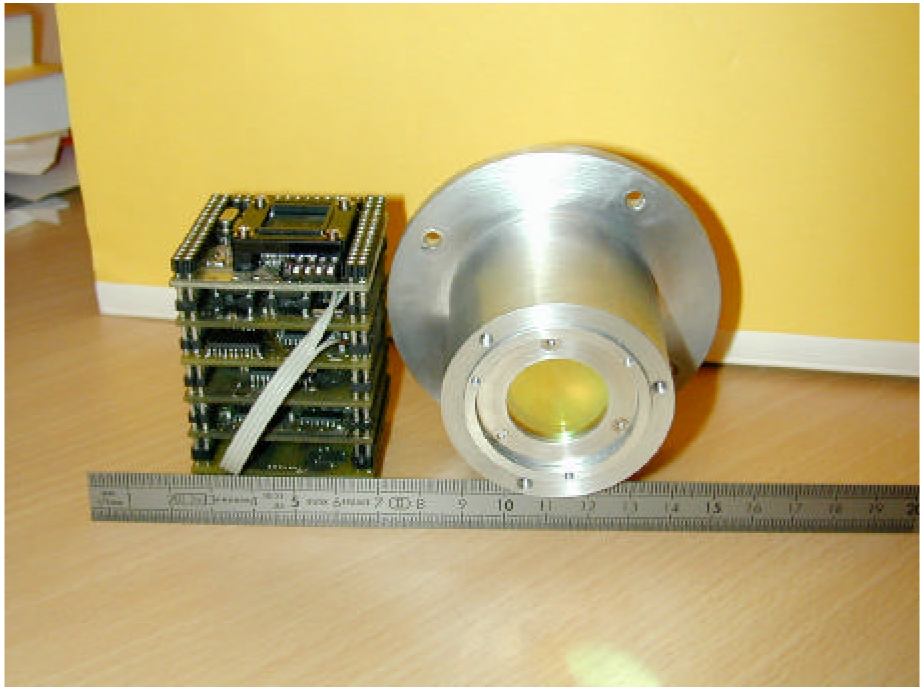
Characteristics	STD16	STS03	µST - MIRES
Mass (kg)	3.4	1.3	0.4
Consumption (W)	7	3.5	1
Volume (cm^3)	13900 (38.6*20.6*17.5)	6800 (21.7*21.7*14.5)	200 (cube 6cm)
Precision (degrees)	0.07	0.07 - 0.16	0.05 - 0.1
Operationnal frequency (Hz)	1	4	10
Detector	4 bolometers	4 bars of thermocells (4*32 pixels 500µm)	3 bars of (*) microbolometers (3*240 pixels 50µm)
Number of optical heads	1	4	3

Specifications

All specification are reached except the power due to thermal regulation needed.

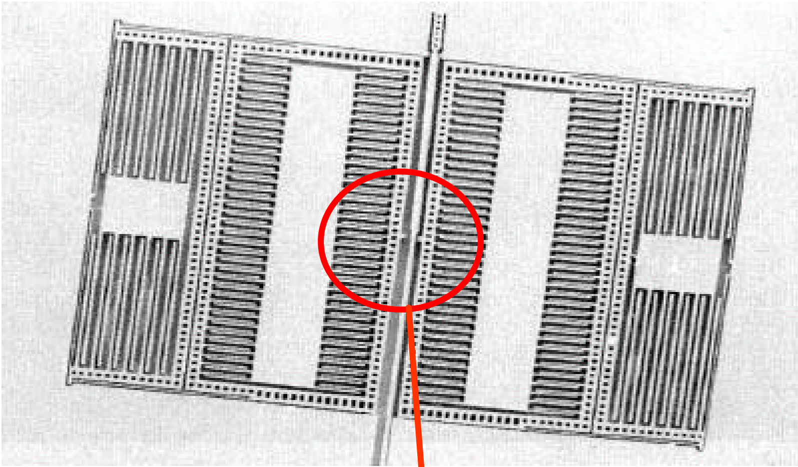
New development could avoid this thermal regulation.

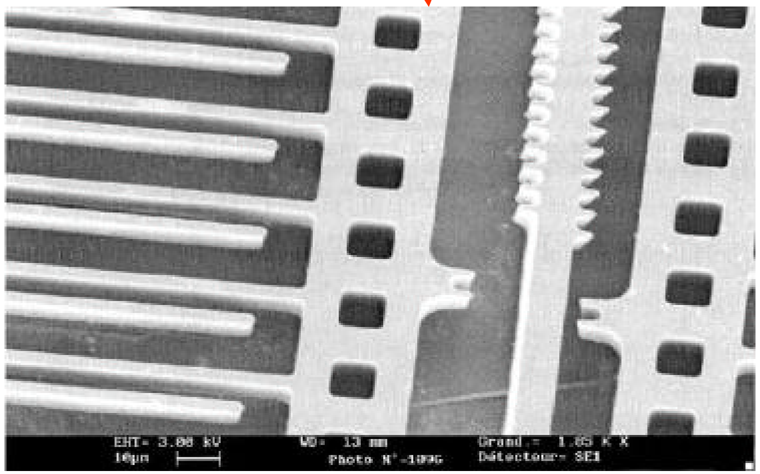
Miniaturised earth sensor built with microbolometres - MIRES (4)



MIRES : MicroEarth Sensor developed by the LAAS-CNRS
(CNES project)
(Volume:electronics 80 cm^3, optics 24 cm^3)

R&T study on « Micro actuators »





- **<u>Goal</u>** : Comparative study between MEMS mechanisms and conventional mechanisms.
- **<u>Application</u>** :Balance mechanism for a martian seismometer.
- **<u>Specification</u>** : 44 mm displacement of a mass of 5g with a resolution of 3µm
- **<u>Principle</u>** : rack transmission (photos).

- **<u>Main difficulties</u>** :
  - Interfaces of the micro-actuator with metallic pieces (moving mass).
  - Wide numbers of parallel actuators needed to reach the required force
  - Development cost very high compared to classical miniature technologies
- Behaviour under space environment not tested (vibrations, shocks, thermal…)

✍ *Interest of MEM actuator inside a miniature non MEMS equipment?*

Conclusion

- MEMS components begin to appear in the space landscape, mainly for environment parameters sensing on payloads with severe mass and consumption constraints -(planetary or cometary missions, small rovers).
- American heavy military foundings in the field of **inertial sensors** and the wide civilian market (transportation) will bring benefit to space, especially on missions using star sensors based ACS which relaxes the drift stability requirements on the gyroscopes. However, the global economic gain with respect to classical miniature sensors is not clear today , taking into account the R and D efforts to put in place if American components will not be available for Europe.
- In the actuators field, the medical and micro-robotic industry will pull the MEMS technologies. In space, except for applications based on mechanical deflexion of pieces (limited amplitude and fatigue strength) with no rolling or sliding friction, MEMS will probably not replace the miniature classical actuators which still exhibit a better compromise between mass, robustness, lifetime and reliability.