MEMS at ESA

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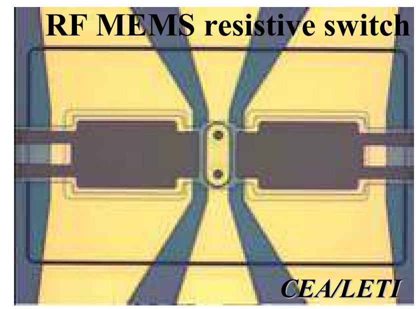
- ***Main types of MEMS addressed for Space applications:***
  - RF MEMS
  - Inertial MEMS for AOCS
  - MEMS for propulsion systems
  - MOEMS

- ***Generic supporting activities include:***
  - Reliability and failure modes studies
  - Radiation effects
  - Packaging and integration approach
  - Methodology for Space validation

- **What's next?**
  - MNT in ESA TRP Work Plan 2008-2010
  - NEOMEx Strawman Mission

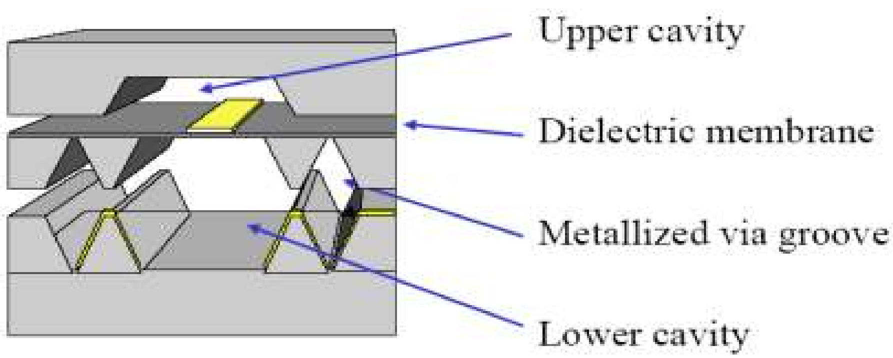
RF MEMS

- ***RF MEMS switches and switching matrices*** **(TRL 3/4)**
  - Advantages:
    - Low insertion loss, high isolation, high linearity, low consumption
    - Integration with planar interconnect on a microwave substrate (higher integration and reduced losses)
  - Space applications:
    - Reconfiguration, redundancy and routing in RF equipments
    - Phased array and reflect array antennas



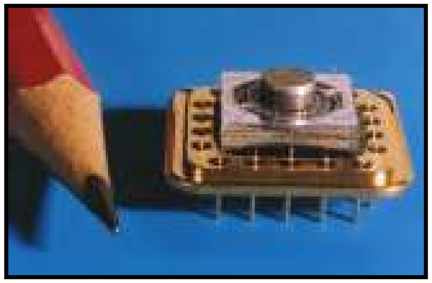
- **Main ESA partners:**
  - TAS-F, CEA/LETI (F), LAAS & NKUA (Athens Univ.)
  - TAS-F & XLim (F)
  - TAS-I & FBK (I)
- **Present ESA activities include:**
  - Several switch technology development
  - Proof-of-concept demonstrator of a switching matrix
- **Performance has been demonstrated. The major concern is still the reliability**
  - Longest lifetime obtained with the dielectric-less capacitive switch from Xlim.
  - New study on the characterisation and the avoidance of dielectric charge trapping
  - On-going study on sensitivity to radiation of electrostatic RF MEMS switch

- ***RF micro-machined planar filters*** **(TRL 4)**
  - Description: Resonators on a membrane into a shielded cavity
  - Application: telecom satellite repeaters in the Ka (27-40 GHz) and Q/V (40-50 GHz)
  - Merge advantages of both standard planar filter and waveguide filter technologies:
    - Miniaturization
    - Batch fabrication (Potential cost reduction)
    - High quality factor in the Ka and Q/V bands (up to 800 at 30 GHz).
  - Initially developed by an academic laboratory (**XLim**, F)
  - **Successfully transferred to an industrial small volume production** (**Reinhardt Microtech AG, CH).**
  - Status: On-going **Space evaluation and industrial qualification** (RMT and TAS-F)



Inertial MEMS

- ***MEMS gyrometer for satellites*** **(TRL 5)**
  - o Developed by **Atlantic Inertial Systems** (former BAe), **SEA** and **SELEX.**
  - o **Spin-in** from original automotive application
  - o Moderate performance (~5°/h), low-cost sensors, complementing star sensors for:
    - Rate determination, failure detection & rate damping
  - o **Flight Model was delivered for technology demonstration on Cryosat 2**
  - o **Sentinel-3** is foreseen as another flight opportunity
    - **EQM qualification** is now starting



- **MEMS sensors spin-in process is rather complex:**
  - o Need to re-design read-out and commands electronics
  - o Require Rad-Hard IEEE parts

- **The MEMS itself account for a few % of the total gyrometer mass (770g).**
  - o Mass and volume are mainly driven by the box and the electronic PCB

- ***MEMS accelerometer for satellites IMU (Inertial Measurement Unit)*** **(TRL2)**
  - o **System study for an IMU** (finishing soon)
    - Performed by **TAS-F** (with MEMSCAP and SEA)
    - Definition of the specification for an accelerometer
    - Survey of existing accelerometers and gyrometers for use in an IMU
  - o Follow-on in 2009: **Accelerometer for IMU demonstrator** (TRP, open-competition)

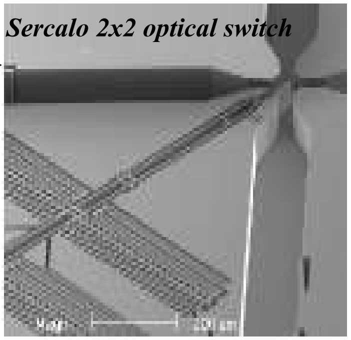
- ***MEMS accelerometer for launchers*** **(TRL 2)**
  - o **Theon Sensors** (with EADS Astrium ST and X-Fab)
  - o Finished in 2008: feasibility study for a MEMS accelerometer
    - Design and simulations of the MEMS with the read-out electronics
  - o Follow-on in 2009: Development and characterisation of the MEMS and the electronics.

- ***MEMS-based IMU for planetary rovers*** **(TRL 1/2)**
  - **Mass and volume constrained application**
  - Specific environmental conditions
  - Starting: Feasibility study on the integration of the MEMS gyro and the MEMS accelerometer with the electronics in a single package.

Optical MEMS

- ***Optical switch and switch matrices for telecom payload*** **(TRL 3)**
  - Advantages: Flexible, Low loss, High isolation between channels,
    Low power consumption
  - Applications: optical cross-connection of µ-wave signals
    optical generation & distribution of high-frequency LO's
    optical frequency mixing and down-conversion
- **Development of a large order *optical switch matrix* size for reconfigurable repeater and interconnects**
  - Developed by **Sercalo** (CH), with IMT, EPFL and TAS-F
  - Status: Manufacturing a proof-of-concept demonstrator
- **Evaluation of commercially available MOEMS**
  - Low port count optical switch from **Sercalo** (CH)
  - ***Variable optical attenuator*** from **MEMSCAP** (F)
  - They appear sufficiently robust for space application, but Rad-Hard electronic is required
  - Drafting of methodology for MOEMS space qualification

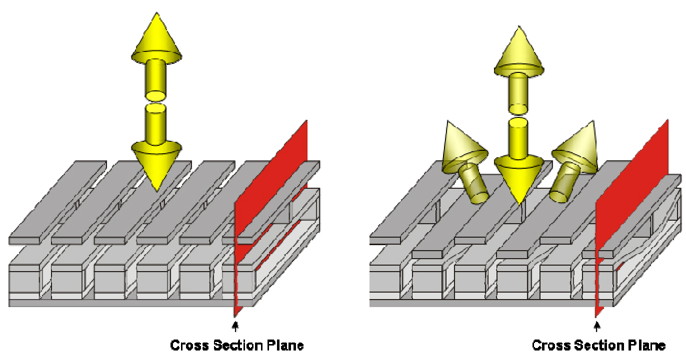
Sercalo 2x2 optical switch



➢ *Programmable Micro-Diffraction Gratings (PMDG) for Spectroscopy* **(TRL 3)**

- Description: Array of micromechanical phase gratings (one per pixel) providing controlled diffraction of incident light.
- **Investigations on devices commercially available**
  - The optical and electrical properties of Polychromix, Silicon Light Machines devices were characterised.
- **Identification spectrometer concepts using PMDG**
  - Pros: Flexibility, which could speed-up search for specific spectral responses
  - Cons: Limited to non-imaging applications
  - Potential application: Spectral analysis for Exoplanet search or for planetary exploration
- Status: **Design and prototyping of a European PMDG device**

  Performed by **CSEM** (CH)

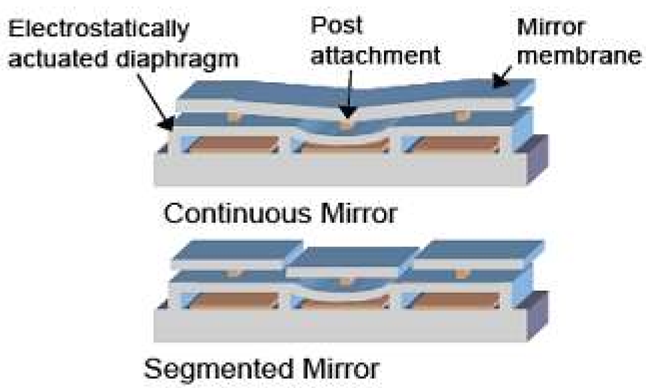


➢ *Evaluation of a Digital Micro Mirror Arrays (DMMA) for Multi-Object Spectrometers*

- Description:
  - **Arrays of miniature tiltable mirrors**, where each individual mirror correspond to one pixel in a pattern.
  - High resolution, high contrast ratio
- Application: flexible **selection of objects in the field of view** of a spectrometer
- **Investigations of commercial DMMA in preparation to Euclid mission**
  - Performed by **Visitech** (Norway) and **LAM** (France)
  - **Texas Instrument's DMD** is the only available device with 2MPixels
  - Evaluation of the DMD device against mission requirements
  - Will serve as a Go/No Go for further development of the Euclid mission.

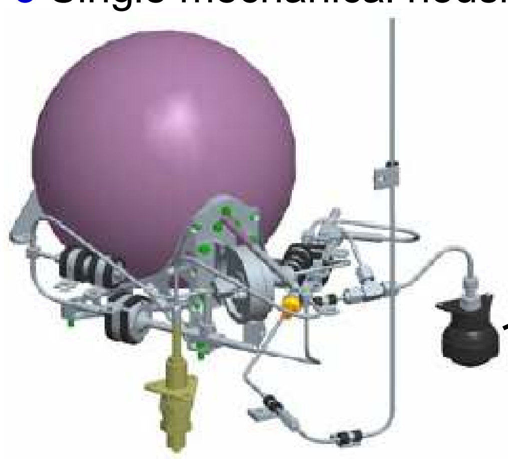
➢ *MOEMS Deformable Membrane Mirrors (DMMs) for Adaptive Optics* **(TRL 2/3)**

- Description: **Light wavefront correction** by dynamic deformation of the mirror surface, either with a continuous or segmented membrane.
- Applications: Wavefront correction in **large science telescopes**, **optical telecommunications** (space-ground links, intersatellite links), and for high power laser beam shaping (e.g. for **LIDARs**).
- Under a past ESA study, Astrium has investigated:
  - TU Delft **continous mirror**: suitable for low-spatial frequency correction
  - Fraunhofer IPMS **segmented mirror array**: suitable for high spatial frequency correction
- No follow-on ESA activity for a few years. A **new development activity** is now in the GSTP work plan on "**Adaptive Deformable Mirrors**", but is will only be implemented after confirmation of financial support from a national delegation. (Not restricted to MEMS)



MEMS for propulsion

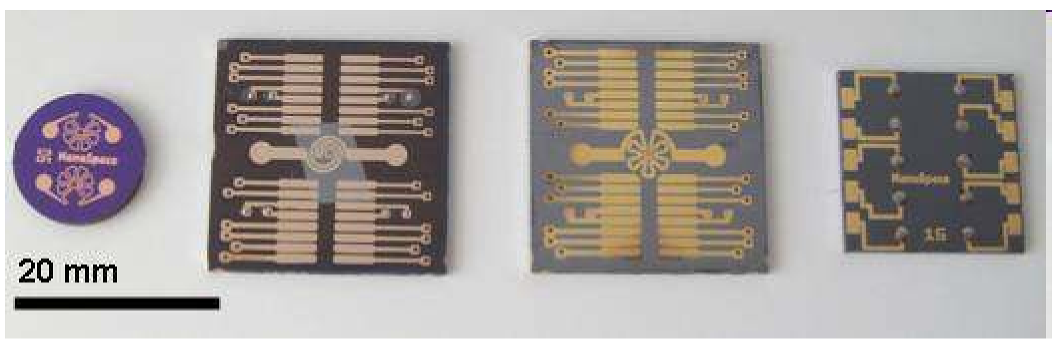
- ***MEMS-based cold-gas thrusters for micropropulsion* *(TRL 4)***
  - o Development performed by **Nanospace AB** (Sweden)
  - o Description:
    - Pod with MEMS thrusters, proportional flow control valve, filter and gas heater
    - MEMS isolation valve, MEMS pressure relief valve
  - o Performance:
    - Thrust: 10 µN to 1 mN
    - Specific impulse: 50-100 s for nitrogen propellant
  - o In-flight demonstration: PRISMA formation flying satellite (SNSB)
  - o Status: **Starting on-ground experimental evaluation of the performance**
- **Miniaturisation of the thruster pod** (mass < 115 g, diameter < 5 cm) thanks to:
  - o Stacking of silicon wafers
  - o Single mechanical housing for several functions



Thruster pod

- ***MEMS-based Xenon fluid handling systems for electric propulsion* (TRL 3)**
  - Developed by **Nanospace AB** (Sweden)
  - MEMS-based Xenon feed system including filters, isolation valves, flow control valves, thermal flow restrictors.
  - The system is placed between the tank and the engine to control the propellant flow.
- **Miniaturisation** to a mass < 200 g thanks to:
  - Stacking of silicon wafers
  - Single mechanical housing for several functions
- **Status**: Proof-of-concept demonstrated.

  Now prototyping and functional testing for application in a mini-ion engines
- **Stand-alone components** were also developed (e.g. MEMS isolation valve)



- **Pressure sensor for tanks/lines of propulsion systems (TRL 4)**
  - Developed by **Presens** (Norway)
  - **Spin-in** from the oil and gas industry.
  - Up to 250 bars; Accuracy better than 0.1%.
  - Housing compatible with high-pressure and aggressive fluids.
  - A flight model was procured for PRISMA satellite
  - Follow-on activity in 2009/2010:
    - Consolidation of the design for Space (e.g. rad-hard electronics)
    - Evaluation testing
  - A low-pressure MEMS-based sensor is also in development.
- **Miniaturisation is limited by the housing, the electronics and the connection.**

PRESENS sensor assembled to PRISMA spacecraft

MEMS piezoresistive sensing element

Generic supporting activities

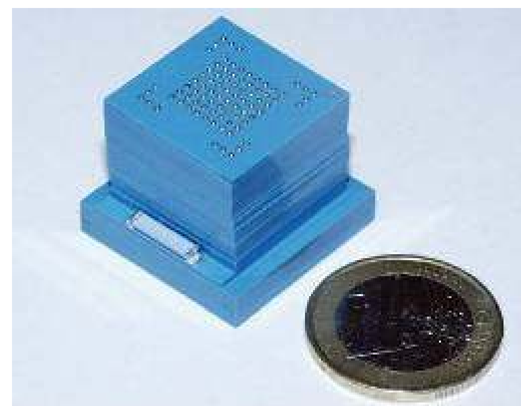
- **Reliability and failure modes of MEMS**
  - **MEMSRAD study on the effect of Space radiation on MEMS**
    - On-going with **EADS-ST**, TAS-F & Infoduc
    - Drafting MEMS radiation testing guidelines
    - Test on hardware samples (RF MEMS switch and MEMS accelerometer), including TID, SEE and Displacement damage.
  - **Avoidance of MEMS dielectric charge trapping**
    - Starting in January 2009
    - Defining methods for the characterisation of dielectric charge trapping
    - Investigating new technological solutions
- **MOEMS Space validation methodology**
  - Finished in 2007. Performed by **Thales Alenia Space**.
  - A qualification methodology for optical-MEMS was developed and applied to two candidate devices (an optical switch and a variable optical attenuator).

➢ Packaging and integration

- **WALES (WAFER level encapsulation for micro-systems): intended TRP study**
  - Development of wafer level packaging techniques for RF MEMS and non-RF MEMS
  - Development of innovative hermeticity testing methods

- **Microsystem integration with a wafer-scale SiP (System-in-Package) approach**
  - Development performed by **ÅAC** (Sweden).
  - Technology and performance was demonstrated.
  - Reliability needs to be investigated.

- **3D-Stacking for microsystem integration**
  - ESA may soon initiate activities to assess 3D-stacking techniques



Prototype of EADS micropack
Size: 16cm³ (20x20x25 + 25x25x9)
Power Consumption: < 10mW

What's next?

- **Present open Invitation to tender related to MEMS :**

  - **Microwave micromachined filters** (ARTES 5)
    - Objective: Design and manufacture Micro-machined membrane filters with multilayer topology, suitable for L/S-band and Ka-band.
  - **Xenon flow-meter for propellant gauging** (ARTES 5)
    - Objective: Design, manufacture and test an EM of a xenon flow meter to be used primarily for accurate gauging of xenon consumption on telecom satellites. – Not restricted to MEMS-based devices.
  - **MEMS-based Electric Propulsion** (General Study)
    - Objectives: Assess the feasibility of a novel MEMS-based Electric Propulsion

→ Check: http://emits.esa.int/

- **Intended Invitation to tender related to MEMS technology in the Technology Research Program (TRP), in 2008-2009:**

  - **Widely-tunable MEMS LC tank for Wideband Oscillators**
    - Objective: develop, manufacture, and test a MEMS LC tank featuring a wide tunability while maintaining a stable Q-factor
  - **High-Q MEMS resonator for high-performance oscillators**
    - Objective: Develop a MEMS based mechanical resonators, as an alternative to crystal resonators both in oscillators and filters.
  - **RF MEMS based reconfigurable telecommunication dual reflector antenna**
    - Objective: Investigate the feasibility of using MEMS switches for programmable contoured beams in Ku- and Ka-band dual-reflector telecom antennas
  - **Accelerometer for IMU feasibility demonstrator**
    - Objectives: Develop an accelerometer demonstrator to be implemented as the accelerometer component of a low-cost IMU for Spacecrafts

→ Check: http://emits.esa.int/

- In addition, ESA decided to support a **strawman mission initiative** in order to co-ordinate cross disciplinary technology developments and to introduce microsystems perspective.
- This Technology Research Programme (TRP) initiative, for a total bugdet of 7M€ over 3 years will support the following developments (presently under implementation).
- These are precursor development for an in-orbit demonstration of Near Earth Object Micro Explorer (NEOMEx) mission to be developed under GSTP/New Pro programmes

❖ ***Strawman Payload***

Microtelescope array space instrument

❖ ***System design and Architecture***

Architect of the System-of- μsystems nanospacecraft

Standard modular microsystems interface

Data handling system design and proof-of-concept

❖ ***Attitude and Orbit Control System and Navigation***

Definition and sizing of AOCS (incl. propulsion)

Digital sun sensor on the chip prototyping

❖ ***Propulsion***

Medium Δv low-power and voltage μ-thruster

Propellant management and storage module

❖ ***Structure***

Integrated harness technology

Multifunctional structures

❖ ***Thermal***

Temperature-dependent thermal coatings

Micro phase-change materials

Micro heat management systems

❖ ***Communication***

Transmitter Vacuum Electric Power Amplifier

Receiver low power analog decoder

❖ ***Power***

Thin-film Lithium Battery development

Ultra-thin Multijunction GaAs Solar power generator

❖ ***Reliability, manufacture, standardization***

Connectivity and Packaging

Advanced manufacturing method

Reliability and Standardisation

Conclusion

- **Many promising developments on MEMS for Space in Europe**
- Technology is available but mostly still at low maturity for Space
- The "**spin-in**" approach from terrestrial applications can shorten development cycles, however:
  - Space is a small market → Lack of interest from large manufacturers
  - Reliability requirements are different→ Non-negligeable testing and redesign effort needed
- Efforts are still required to understand and mitigate **MEMS failure mechanisms**
- Efforts are still required on **packaging and integration** of MEMS
- No test standard is available for the Space qualification of MEMS:
  - Define & validate screening, evaluation and qualification procedures
  - In the longer term, write related ESCC specifications

- ***More information available on*:**

- **6th Round Table on Micro/Nano Technologies for Space (October 2007)**

  Presentations available on:

  https://escies.org/ReadArticle?docId=766

Expected use of MEMS in ESA missions

MEMS-based propulsion

Proba 3 ?

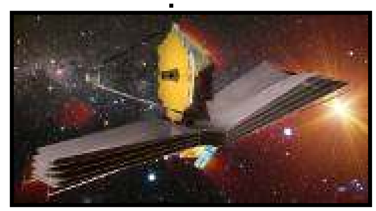
MEMS flow sensor in Cold gas µ-propulsion

Gaia

RF MEMS Switching matrix

Alphasat

MEMS µ-shutter array on NIRSpec

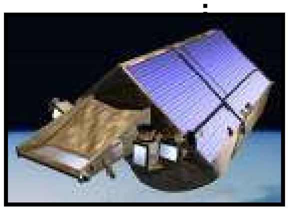


JWST

Digital Micromirror array (TI DMD ?)

Euclid (2015-2025)

2009 2010 2011 2012 2013 2014 2015 2016

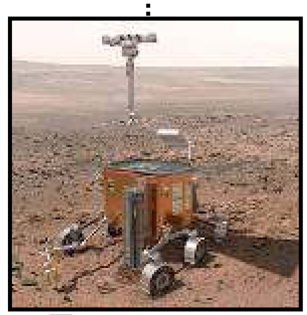


Cryosat 2

MEMS gyrometer

Sentinel 3

MEMS gyrometer



Exomars

MEMS IMU

Bepi-Colombo

MEMS bolometer