Miniaturized Dutch Spacecraft based on MicroSystem Technology:
Status and Perspectives

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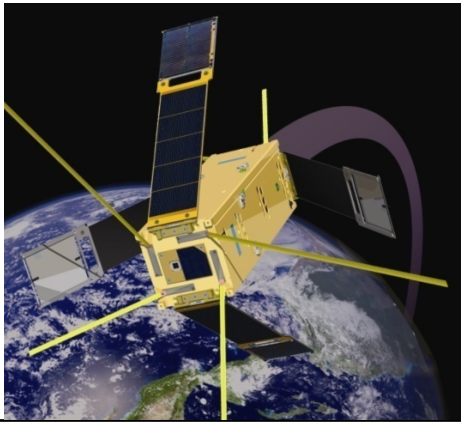
J. Leijtens, R. Tijsterman, B. Sanders

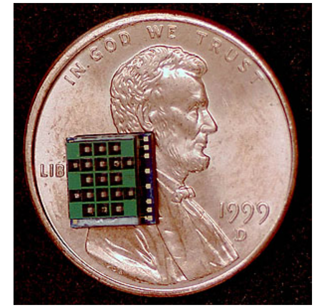
Outline

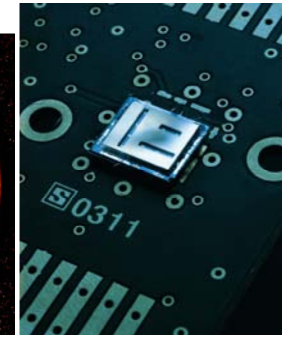
- Introduction
- Previous Dutch activities on space MST
- Current Dutch developments on space MST
- Perspectives of Dutch space MST
- Conclusions

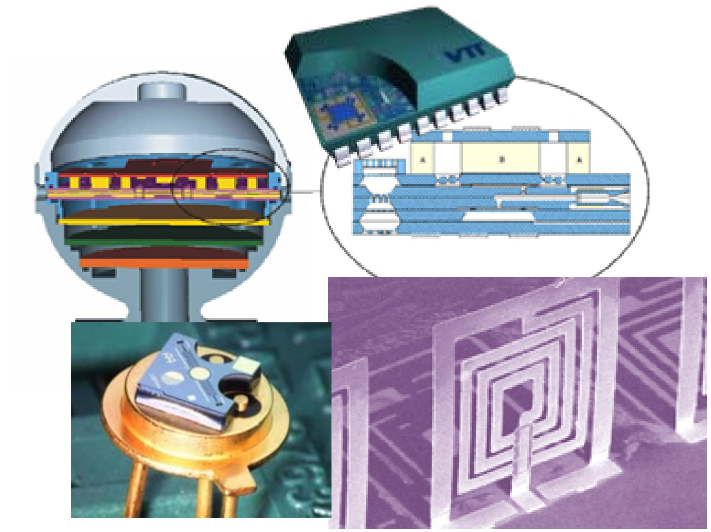


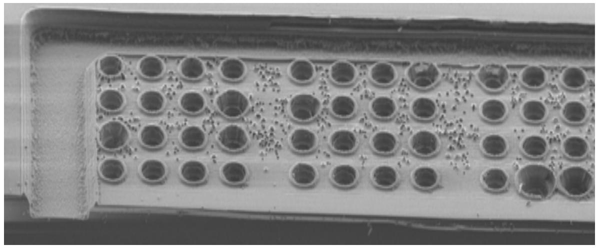
Introduction

MST for Space Applications





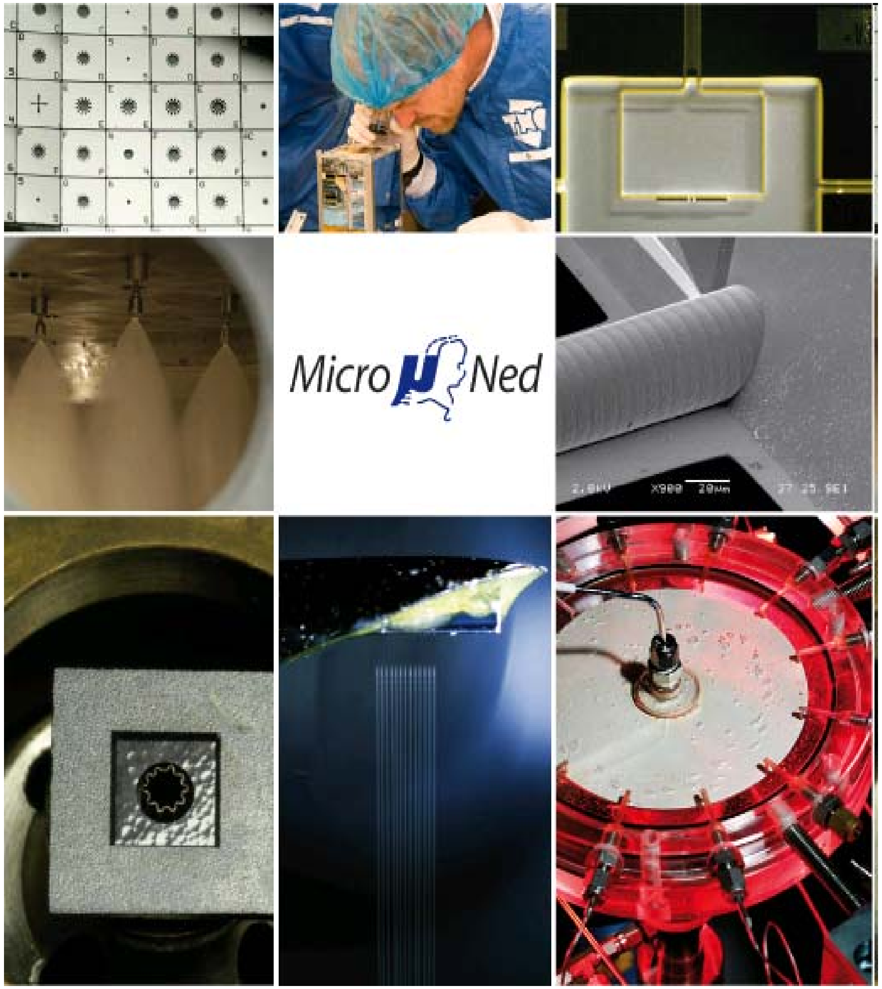




- Sensors
  - Star tracker
  - Sun sensor
  - Magnetometer
  - Micro Inertial Measurement Unit (MIMU)
- Actuators
  - Micro propulsion
  - Reaction wheel
  - Magnetorquer
- Communication devices
  - Optical
  - RF
- Others
  - Thermal control
  - Lab-on-Chip

Introduction
MST R&D in NL

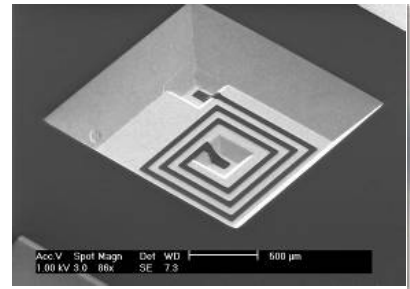
- The MicroNed Programme
- Objective
  - Establish a market-oriented, dynamic and sustainable public-private knowledge infrastructure on MEMS
- Organization
  - Cluster 1: Micro satellite (MISAT)
  - Cluster 2: Smart microchannel technology (SMACT)
  - Cluster 3: Microfactory (MUFAC)
  - Cluster 4: Fundamentals, modelling and design of microsystems (FUNMOD)
  - Auxiliary projects

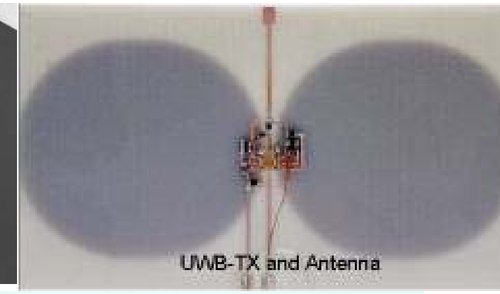


Introduction

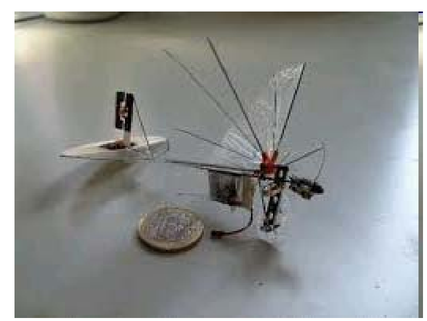
MST R&D in Delft

- Delft Institute of Microsystems and Nanoelectronics (DIMES)
  - 87 scientific staff and 200 PhD students
  - Research fields cover: high frequency electronics, Silicon on Anything (SOA), HF-MEMS, miniaturized space systems, et.al.





- Faculty of Aerospace Engineering
  - The largest aerospace faculty in western Europe
  - Expertise on miniaturized aerospace systems, e.g. DelFly Micro, the smallest (3 grams) flying ornithopter carrying a camera in the world!



Previous Activities on Space MST

MISAT Research Cluster

MiSat

- Dutch national research cluster on space-based MST
- Objective
  - Advancement and dissemination of MST and fundamental knowledge for space-oriented science and technology
- Organization
  - Cluster leader: TUD-SSE
  - 4 work packages (bus, payload, architecture, distributed systems)
  - 24 projects
  - 25 partners
- Key achievements
  - Autonomous wireless sun sensor
  - Micro-propulsion
  - Delfi-C[3]

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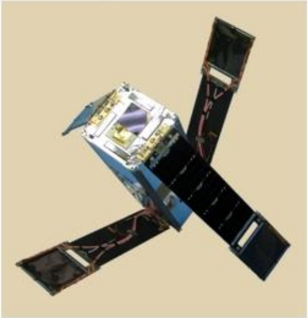
Delfi-C3

28 April 2010

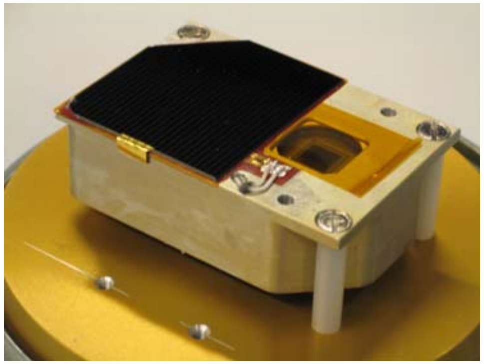


TWO YEARS IN ORBIT

Previous Activities on Space MST

Autonomous Wireless Sun Sensor (AWSS)

General Specifications	
Sensor Type	Quadrant Sun Sensor
Mass	80 g
Dimensions	60x40x20 mm (lxwxh)
Field of view	90°x90°
Inaccuracy	~ 1°
Data rate	1 Hz

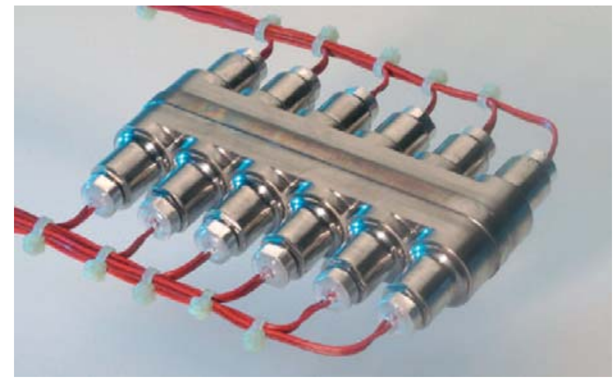


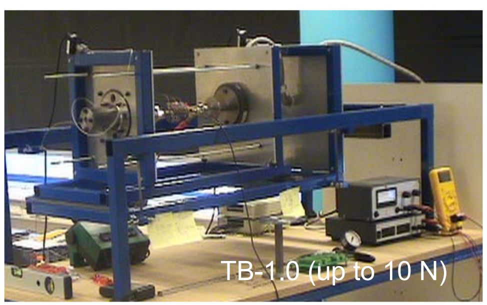
RF Specifications	
Frequency	915.0 MHz
Modulation	Gaussian Frequency Shift Keying (GFSK)
Bitrate	150 kbps (50 kbps effective due to encoding)
Encoding	Manchester
Protocol	Nordic Semiconductor ShockBurst (proprietary)

Previous Activities on Space MST

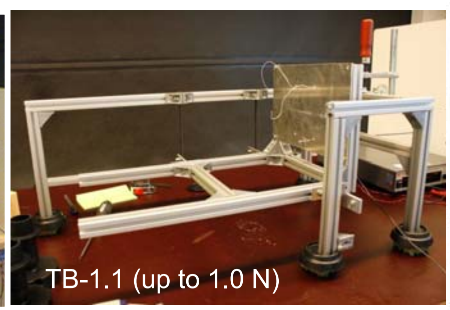
Micro-propulsion System

- Solid cold-gas generator onboard Proba-2
  - Unpressurized and leak-free
  - Long storage lifetime
  - Mass and volume efficient

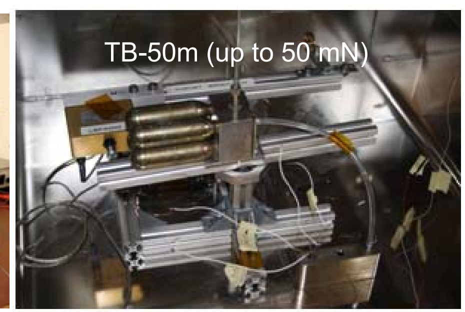




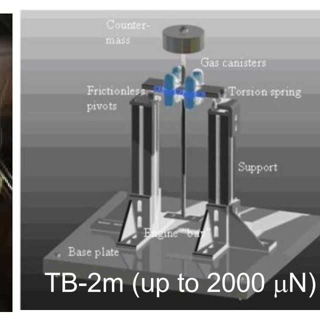
TB-1.0 (up to 10 N)



TB-1.1 (up to 1.0 N)



TB-50m (up to 50 mN)



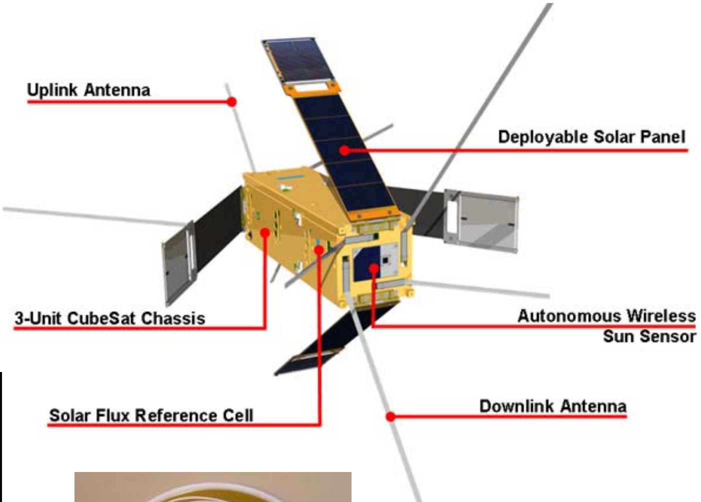
TB-2m (up to 2000 μN)

- Thrust test benches for micro propulsion systems

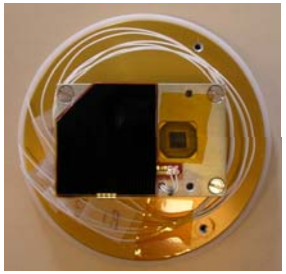
Previous Activities on Space MST

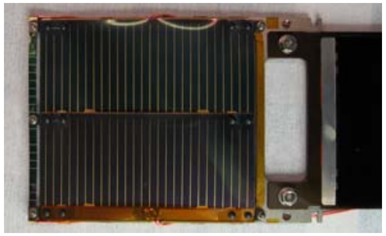
Delfi-C3

- First Dutch university satellite
- Developed by students in SSE
- Piggyback launch 28th April 2008



Key Specifications	
Dimensions	100x100x300 mm^3
Mass	2.2 kg
ADCS	Passive magnet control
CDHS	Decentralized, each PCB controlled by microcontroller
EPS	Decentralized, each PCB protected by microcontroller
TTC	Uplink UHF @ 435 MHz, 600 bps FSK; Downlink VHF @ 145 MHz, 1200 bps BPSK
Thermal	Passive
Payload	Autonomous wireless sun sensors, thin-film solar cells, transponder

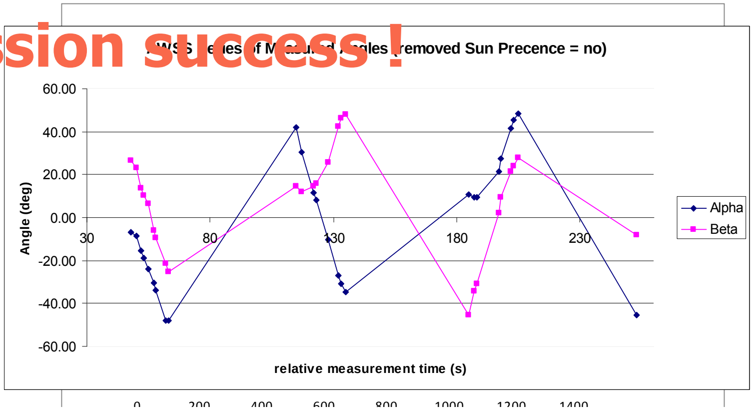


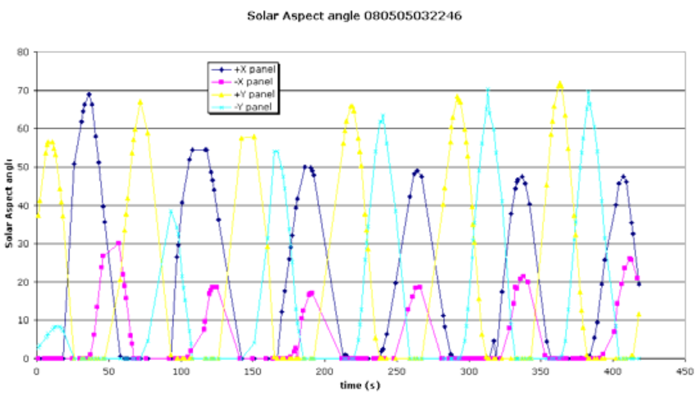


Previous Activities on Space MST

Status of Delfi-C³

A full mission success !



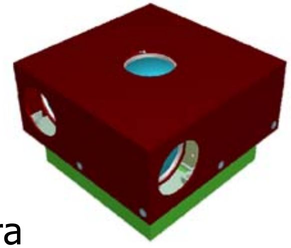


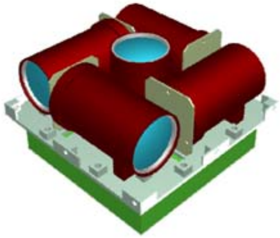
- Mission
  - So far more than 800 days of operations
  - ~ 300 participating radio amateurs
- Payload
  - Telemetry from all payload received
  - AWSS Z+ working, Z- little data, but still useful enou
  - More than 53000 accurate I-V curves of thin-film sol have been harvested
  - Radio amateur transponder decreased after some m
- Platform
  - All 4 solar panels and 8 Rx/Tx antennas deployed
  - All subsystems fully operational
  - Rotation rate decrease from 5.06 °/s after ejection to 0 – 0.7 °/s
  - Some reliability issues on CDHS
  - Some data integrity issues on ground segment

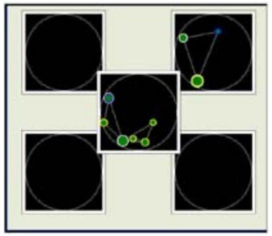
Current Developments on Space MST

Miniaturized Multi-aperture Star Tracker

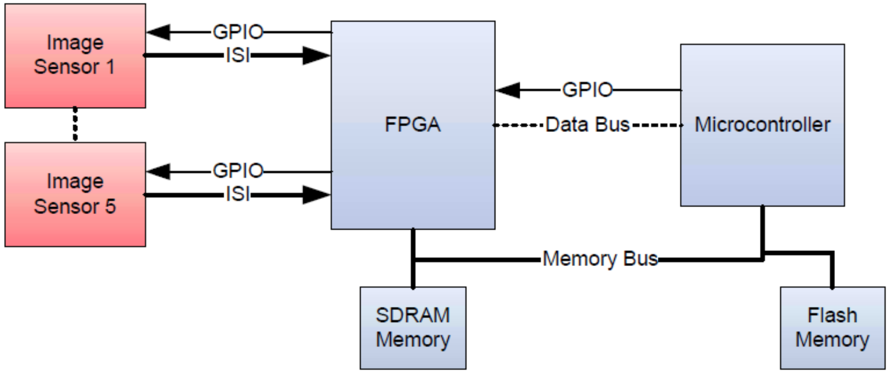
- Characteristics
    - Large FOV and small baffles
    - 5 apertures for high availability
    - Robust against Sun/Earth blinding
    - Star triangles across multiple camera heads improve accuracy
    - Low system costs







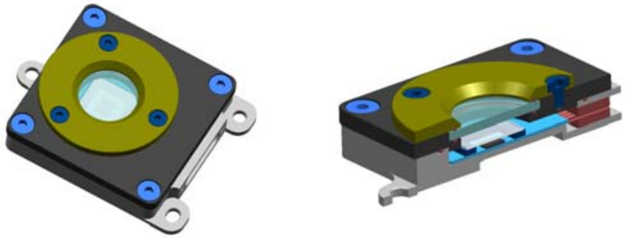
General Specifications	
Success rate	> 95%
Accuracy	0.01°-0.02° (three axis)
Power consumption	< 300 mW (average)
Mass	< 500 grams
Dimensions	100X100X50 mm^3
Life time	3 years (LEO)

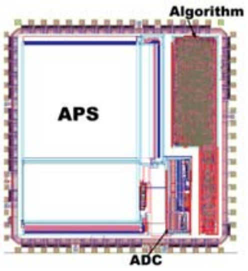


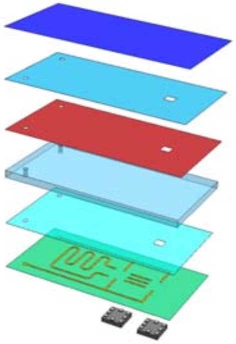
Current Developments on Space MST

Micro Digital Sun Sensor

- Key specifications of current development
  - Accuracy 0.1° (3σ)
  - FOV ±47°X±47°
  - Albedo insensitive
  - Average power consumption < 100mW @ 5V input
  - Digital output (UART)
  - Volume 52mmX52mmX14mm excluding mounting
  - Based on APS+ chip (0,18 μm CMOS)
  - Integrated micro connector
- The future: very light (<5 grams), low cost, autonomous configurations (self powered, wireless)



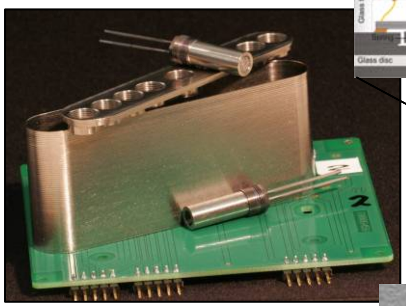


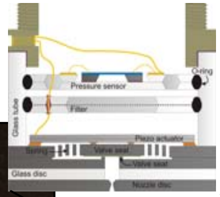


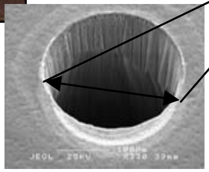
Current Developments on Space MST

Cold-gas Micro Propulsion System

- T^3-µPS
  - Thrust: 1-100mN (scalable)
  - Cool gas generators to limit propellant volume
  - Pressure measurement using strain gages
  - Filter pore size: 5µm





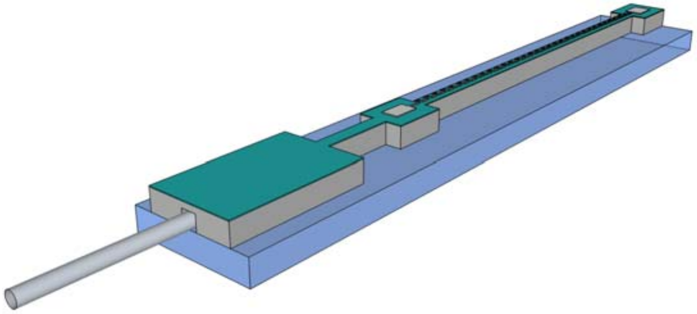


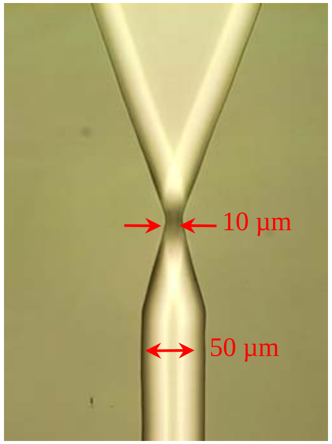
- Extended systems
  - More cold gas generators can be added
  - Very modular and flexible
  - Allow distributed installation within spacecraft

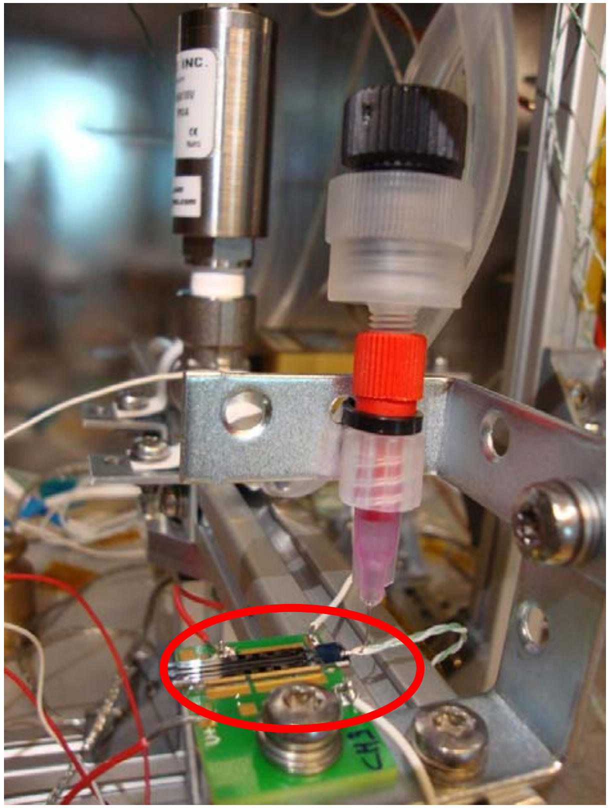
	Nitrogen	Oxygen	Hydrogen
Gas output (normal l/kg)	260	200	1000
Gas release (normal liters/liters gas generator)	290	220	1000
Design output pressure range (MPa)	0.1 - 15	0.1 - 10	0.1 - 20
Gas Purity	>99%	>99%	>95%
Sensitivity to friction and impact	no	no	no

Current Developments on Space MST

Micro Electric Propulsion System (1)



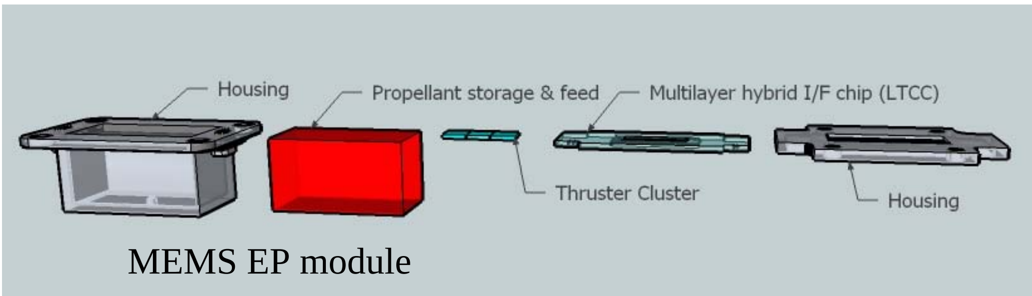




Silicon-based Micro-resistojet System		
Flow channel dimensions	**Value**	**Limitations**
Length	1 cm	No
Height	30-50 µm	No
Width of channel walls	50 µm	Should not be less, in order to have good wafer bonding

Current Developments on Space MST

Micro Electric Propulsion System (2)



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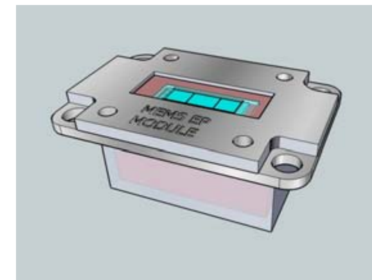
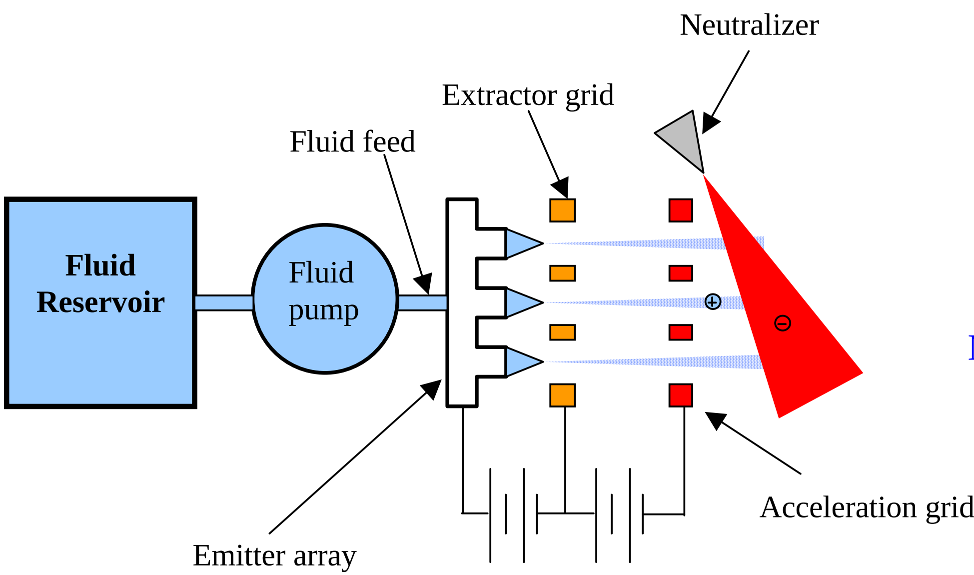
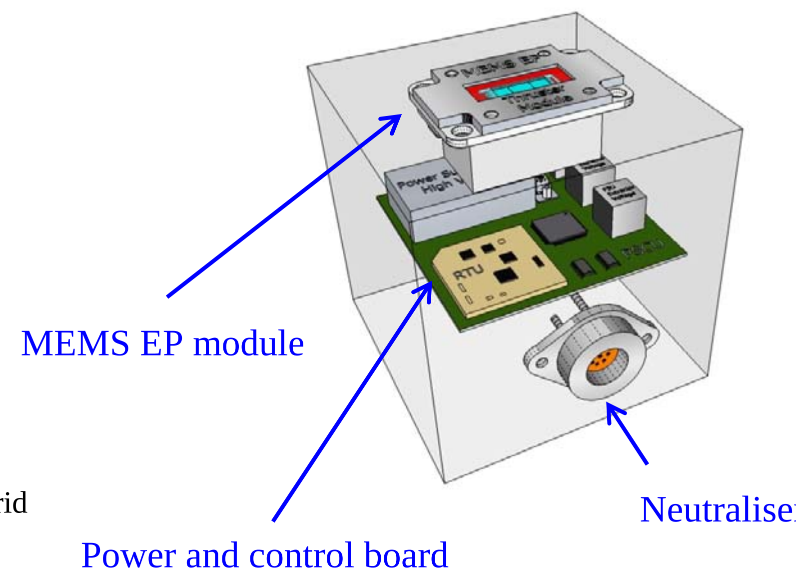


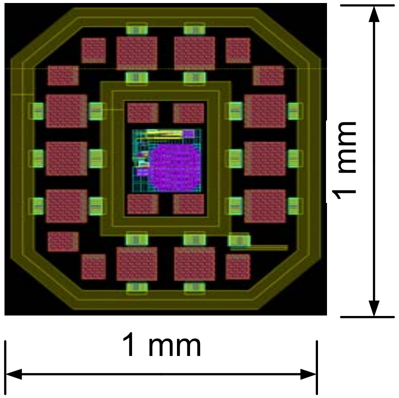




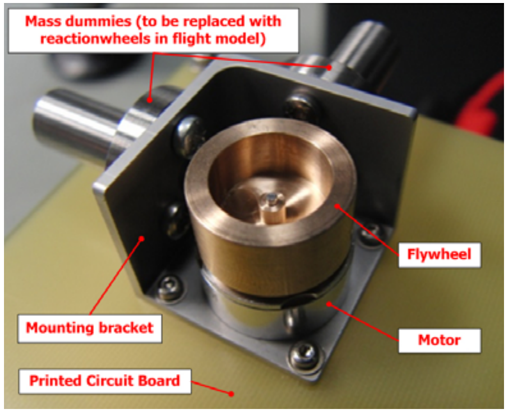
Current Developments on Space MST

Other Miniaturized Systems

- Single-chip GPS/Galileo receiver front-end
    - Detailed design was finished
    - Prototype will be available in 2011
    - One of the smallest in the world
    - Next step will be a complete single-chip GPS/Galileo receiver



- Micro reaction wheel
    - Maximum torque 0.09 mNm
    - Angular momentum storage 1.5·10-3 Nms
    - Total mass (bracket + 3 wheels) 104 gram
    - Peak power consumption ~400 mW



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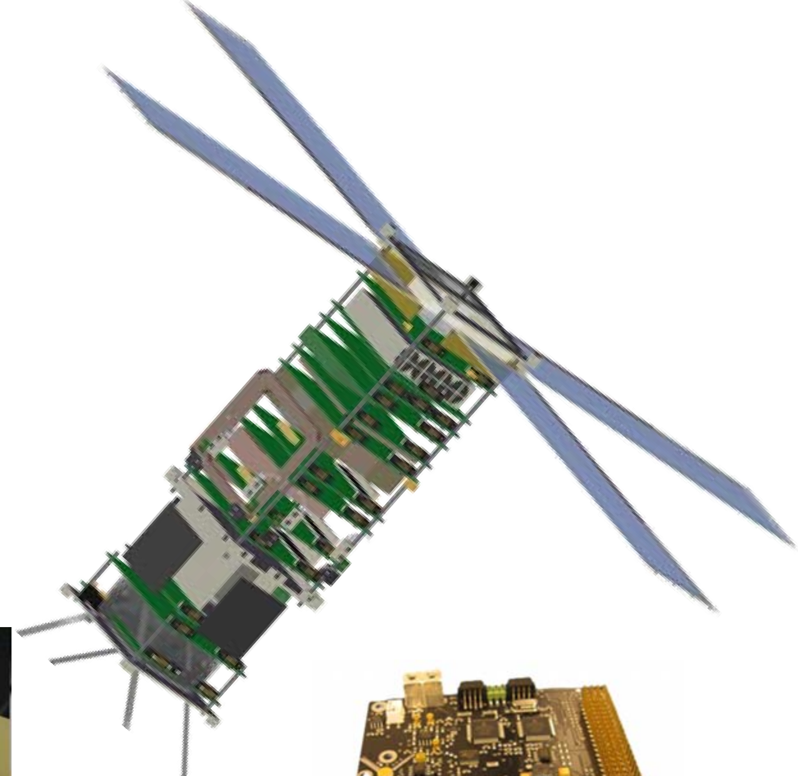
Current Developments on Space MST

Nano-satellite for MST Demonstration

- Delfi-NEXT
- Successor of Delfi-C3
- MST components will be demonstrated as payloads

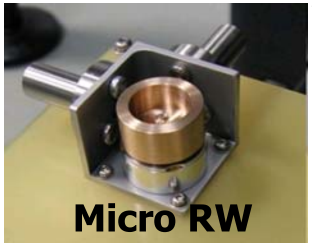


SDM

TUD

$T^3\mu$PS

TNO, TUD, UT



Micro RW

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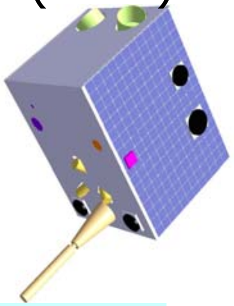
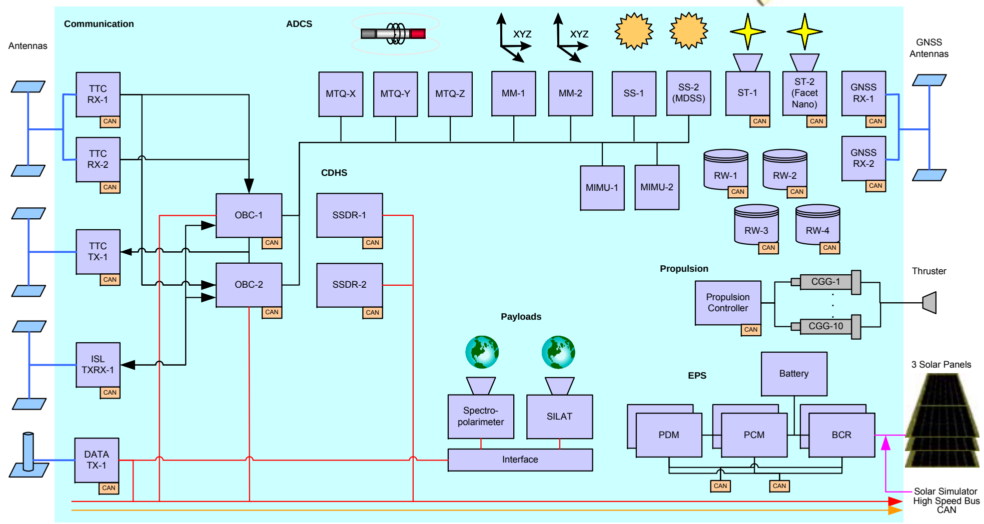
Current Developments on Space MNT

MST-based Micro-satellite

- Formation for Atmospheric Science and Technology Demonstration (FAST)
- The System Engineering (SE) philosophy
  - Extensively utilizes MST components as constituents of the platform
  - "Functional redundancy" + "hardware redundancy" for higher reliability
  - Allows some technical risks for low cost and short development time
  - A mixture of MST and conventional technologies

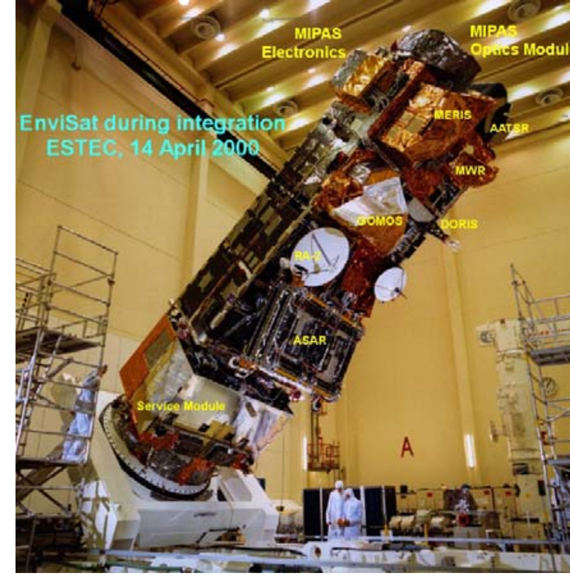


- Key specifications
  - Mass < 50 kg including payloads
  - Dimensions 700X500X500 mm^3
  - Sensors: micro sun sensors, multiple-heads CMOS star tracker
  - Actuators: cold gas propulsion, micro reaction wheels
  - Others: electronical kernel, miniaturized S-band transceiver

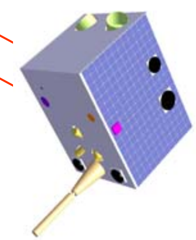


Perspectives of Space MST

The Goal



Powerful individual satellite



A cluster of SoMS satellites

- Drivers of utilizing space MST
  - Mission
  - Cost
  - Mass (?)

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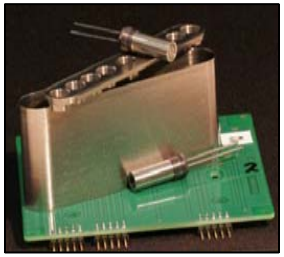
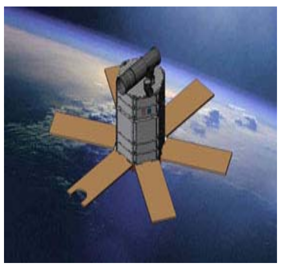
Perspectives of Space MST

Suggested Roadmap

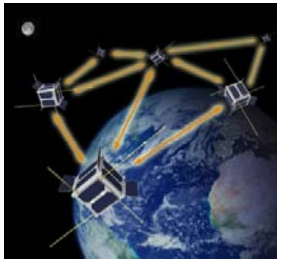


- MST-based components
  - Miniaturized payload
  - System-on-Chip (SoC) sensors
  - Multi-functional components and structure
  - Low power electric micro propulsion



- Spacecraft architect
  - System-of-MicroSys
  - Modularity
  - Low-cost and mass

- Infrastructure
  - Testbeds for individual spacecraft
  - Testbeds for distributed system



- Distributed systems
  - Distributed onboard autonomy
  - Miniaturized inter-satellite link

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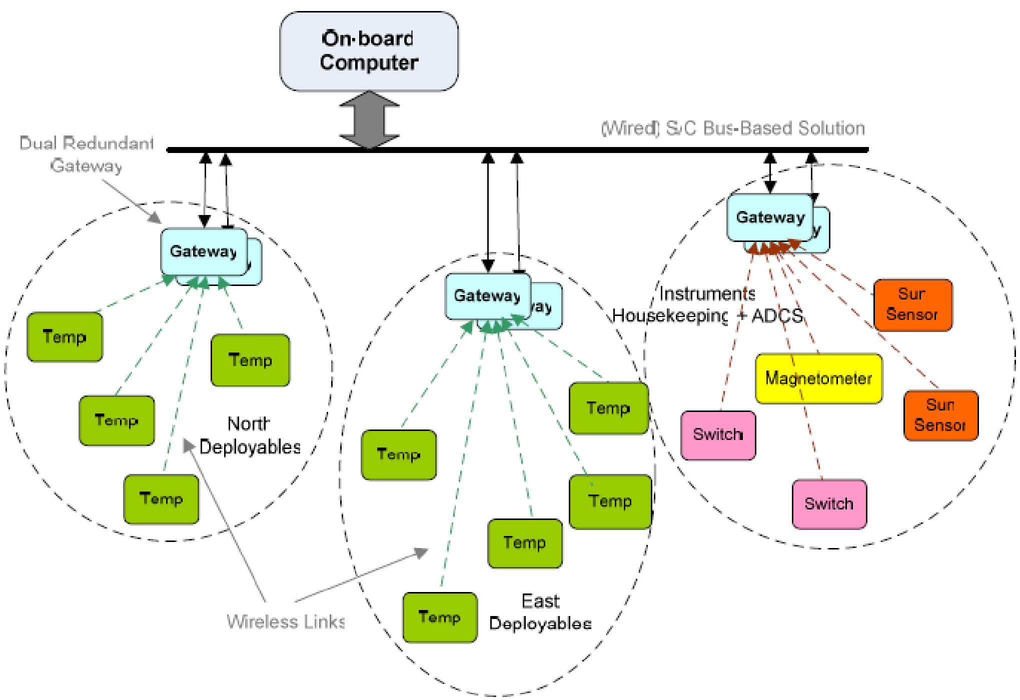
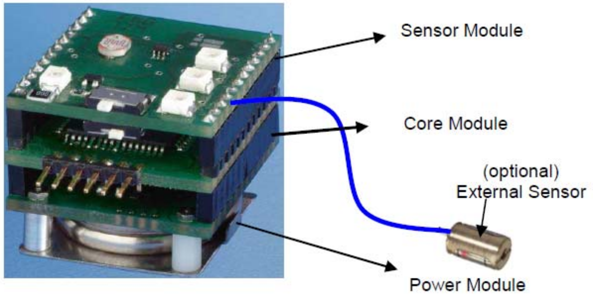
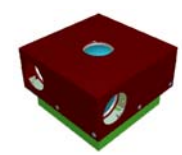
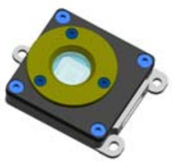
Perspectives of Space MST

Wireless Interface for Modularity and Integration






Core Module


Core Module

Conclusions

- MST offers potentials and opportunities for micro- and nano-satellites
- System-of-MicroSystem spacecraft is a supplement of “big” satellite, especially for missions requiring distributed manner
- Significant progress have been achieved through Dutch space MST activities
- Future developments will focus on architecture level
- A step-by-step strategy should be utilized to develop System-of-MicroSystem spacecraft

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