Miniaturized Components for Space Systems:

Needs, Status and Perspectives

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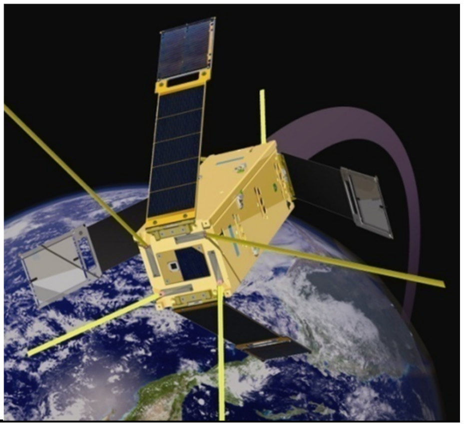
Outline

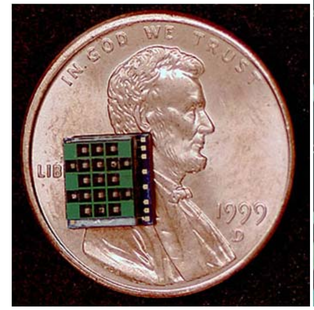
- Introduction
- Needs of miniaturized space systems
- Miniaturized space systems @ TU Delft
- Perspectives of miniaturization in space
- Conclusions

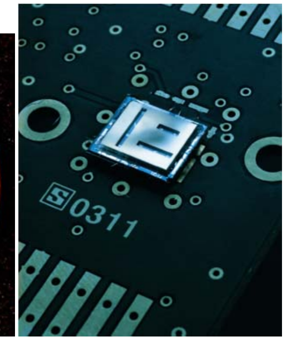


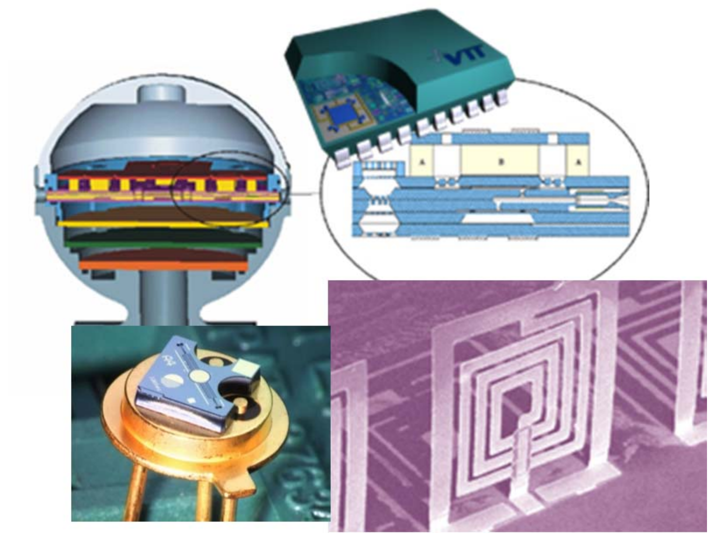
Introduction

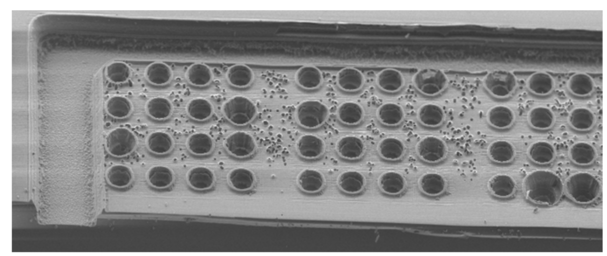
Miniaturization for Space

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









Needs of
Miniaturized Space Systems

Needs of Miniaturized Space Systems

Overview of Missions

Mission name	Mission type	Developer	# of s/c	Mass [kg]	Miniaturized components	Launch year
MEMS Picosat	Demonstration	DARPA	2	0.4	MEMS RF switch	2000
THNS-1	Demonstration	Tsinghua University	1	25	MIMU, Miniature magnetometer, μ-propulsion	2004
ST-5	Demonstration	NASA	3	25	Thermal louvers, μ-thruster, Miniature magnetometer, Miniature spinning sun sensor	2006
MEPSI	Demonstration	DARPA	2	1.4 and 1.1	Miniaturized imager, MEMS gyros, μ-propulsion	2006
PRISMA	Demonstration	Swedish Space Corporation	2	150 (Mango), 40 (Tango)	μ-Pressure sensors and MEMS μ-propulsion	2010
NEOMEx	Demonstration	ESA	1	20	μ-propulsion, μ-sun sensor, modular μ-systems interface, etc.	2018
PAM	Science	NASA	1000	1	Carbon nanotubules structure, etc.	2020-2025
OLFAR	Science	Dutch institutes	50	10	Extensively using MEMS technology (μ-propulsion, MEMS star tracker, etc.)	TBD
APIES	Science	ESA	19	45	Arcjet thruster	TBD

Needs of Miniaturized Space Systems

Needs for Miniaturization

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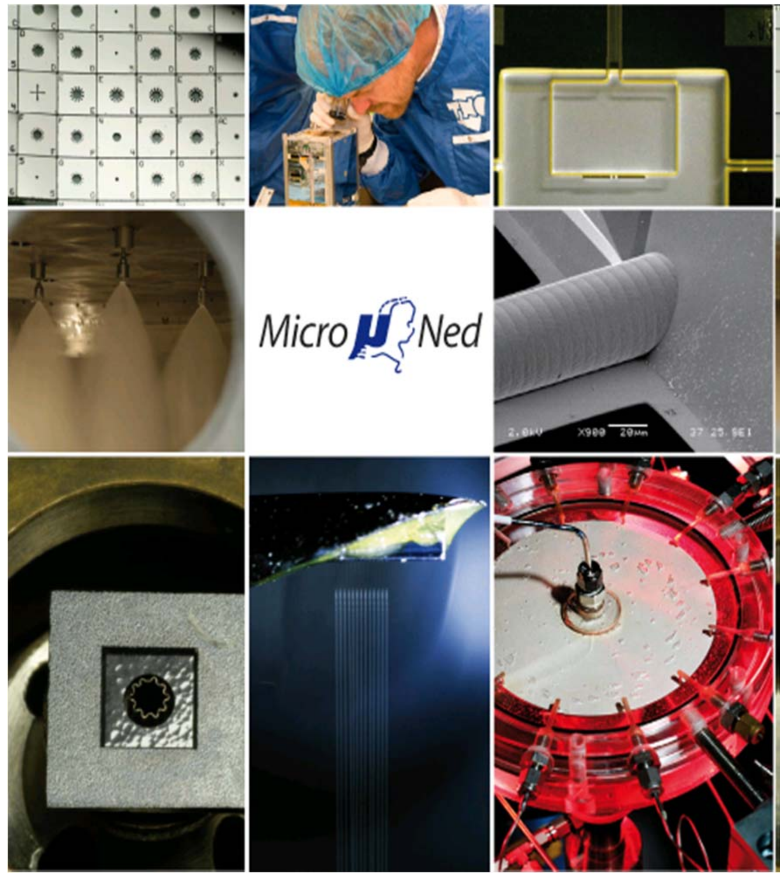
- Extensive validation, especially for radiation and thermal, before utilization
- Lost-cost and modular components for a large range of missions, especially by modifying terrestrial components for improved reliability and performance
- Primary need is high-precision, low-cost and modular AOCS components

Miniaturized Space Systems in TU Delft

Miniaturized Space Systems @ TU Delft

Dutch Activities

- 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



Miniaturized Space Systems @ TU Delft

MISAT Research Cluster

- 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 Space Systems Engineering (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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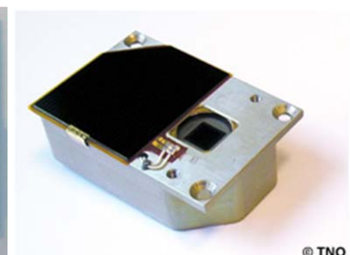

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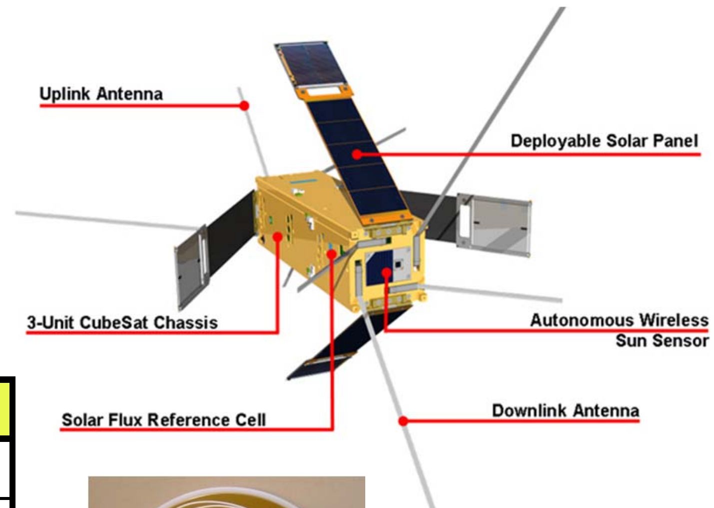
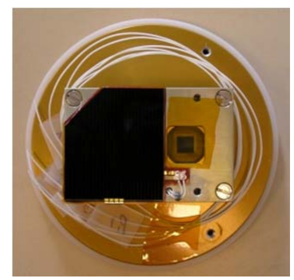
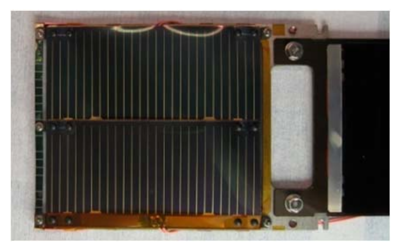
Delfi-C^3

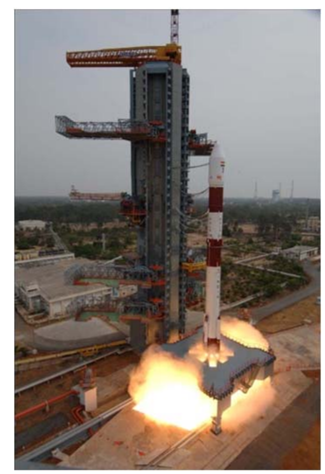
- First Dutch university satellite
- Developed by students in SSE
- Piggyback launch 28th April 2008



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



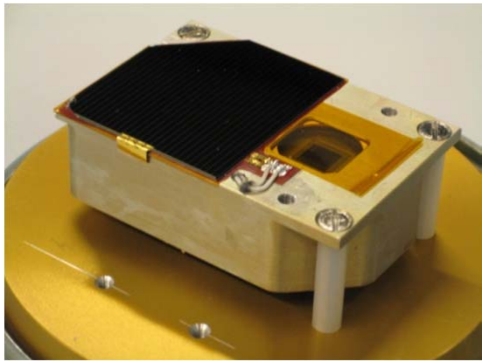




Miniaturized Space Systems @ TU Delft

Autonomous Wireless Sun Sensor on Delfi-C^3

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

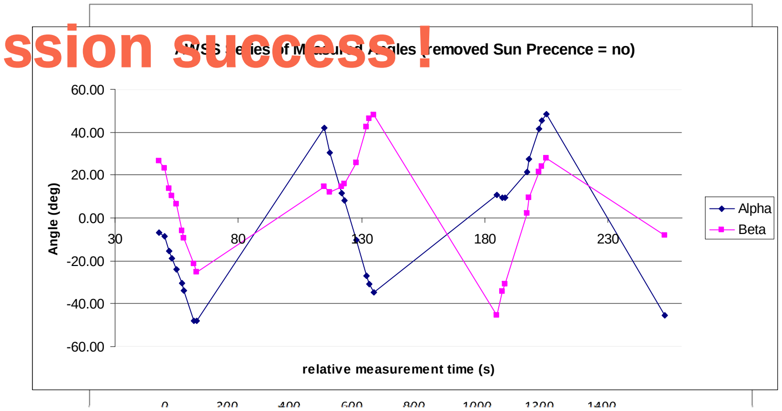


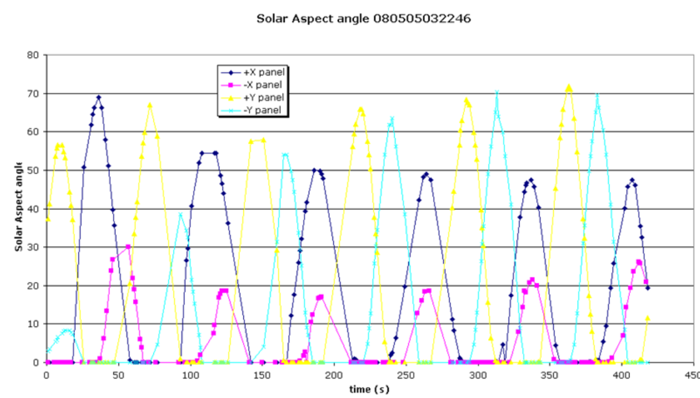
RF Specifications	
Frequency	915.0 MHz
Modulation	Gaussian Frequency Shift Keying (GFSK)
Bitrate	150 kbps (50 kbps effective due to encoding)
Encoding	Manchester
Protocol	Nordic Semiconductor ShockBurst (proprietary)

Miniaturized Space Systems @ TU Delft

Status of Delfi-C^3

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 53,000 I-V curves of thin-film solar cells 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 injection to 0 – 0.7 °/s
  - Some reliability issues on CDHS
  - Some data integrity issues on ground segment

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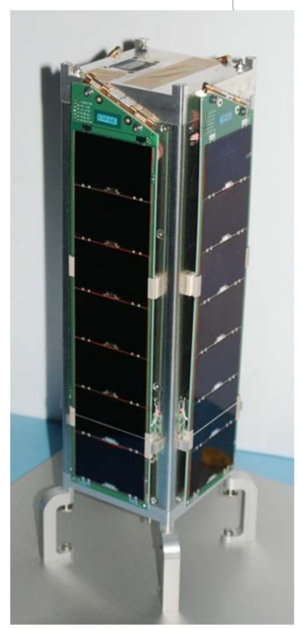
Miniaturized Space Systems @ TU Delft

Delfi-n3Xt

- Successor of Delfi-C3
- MST components demonstrated as payloads
- To be delivered for launch within one month!

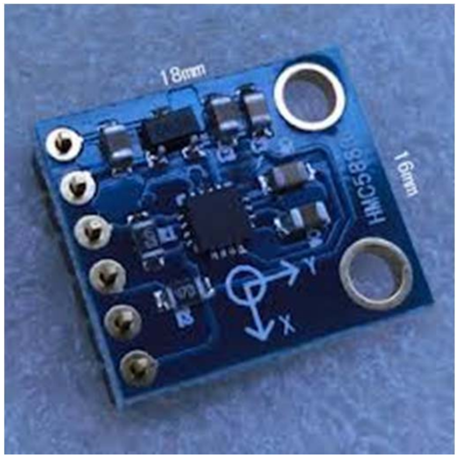
Key Specifications	
Dimensions	100x100x300 mm^3
Mass	3 kg
ADCS	3-axis stabilized using reaction wheels
CDHS	Decentralized, each PCB controlled by microcontroller
EPS	Decentralized, each PCB protected by microcontroller
TTC	Uplink UHF @ 435 MHz, 600 bps FSK; Downlink VHF @ 145 MHz, 1200 bps BPSK
Thermal	Passive
Payload	T^{3}μPS, SDM, ISIS Transceiver

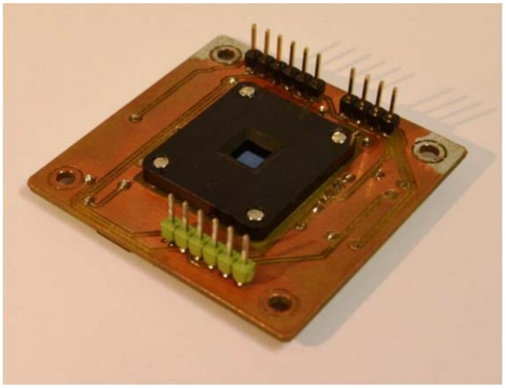


Miniaturized Space Systems @ TU Delft

ADCS Sensors on Delfi-n3Xt

Magnetometer		
Section	Parameter	Input
General	Brand / Model	Honeywell HMC5883L
	Communication Type	I²C
	Configuration	Triple-axis, orthogonal
Specification	Measurement Range	±100 μT
	Nominal Range In-orbit (scalar)	20 μT up to 47 μT
	Measurement Resolution	65 nT
Accuracy	Noise Type	white, Gaussian
	Noise Level (open field)	170 nT (1σ)



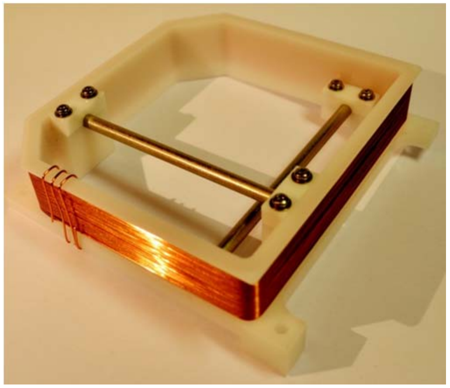


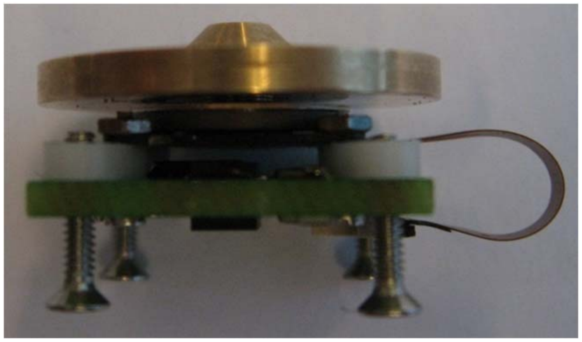
Sun Sensor		
Section	Parameter	Input
General	Brand / Model	TU Delft μSS-1
	Architecture	Quadrant Photodiode
	Communication Type	I²C
	Configuration	1 on each satellite face (6 total)
Specification	Field of View (FOV)	±60º
	Power Consumption	26 mW idle, 66 mW measuring
	Mass	10 g
	Max. Read-out Frequency	120 Hz
Accuracy	Noise Type	white, Gaussian
	Noise Level	0.4º (1σ)
	Bias	< 3º, steady

Miniaturized Space Systems @ TU Delft

ADCS Actuators on Delfi-n3Xt

Magnetorquer		
Section	Parameter	Input
General	Brand / Model	TU Delft µMTQ System
	Communication Type	analogue
	Configuration	2 rods and 1 open coil
	Current Driving	pulse-width modulation
Specification	Range	±0.06 A·m^2
	Resolution	-/off/+
	Power Consumption	90 mW





Reaction Wheel		
Section	Parameter	Input
General	Brand / Model	TU Delft RW System
	Communication Type	I^{2}C
	Configuration	triple-axis, orthogonal
Specification	Range	±1.5·10^{-3} N·m·s
	Resolution	3.5·10^{-6} N·m·s
	Power Consumption (1 RW, full speed)	400 mW

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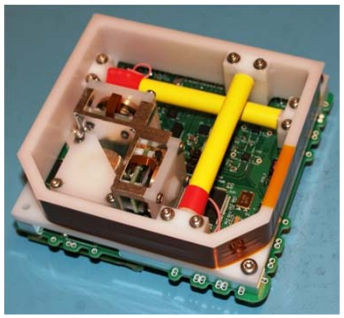
Miniaturized Space Systems @ TU Delft

Other Miniaturizations on Delfi-n3Xt



ADCS Subsystem	
Parameter	Input
Mass	330 g
Power	1600 mW (max)
Volume	90X90X34.6 mm^3
Data	1 Kbits, 2 Hz

Section	Parameter	Input
Microcontroller	Brand / Model	TI MSP-430F1611
	Clock Speed	8 MHz
Timekeeping	Brand / Model	Maxim Dallas DS1318
	Range	13.6 years
	Resolution	0.1 s
General	Power Consumption (at DSSB)	151 mW

Section	Parameter	Input
General	Dimensions	90 mm x 90 mm x 27 mm
	Mass	140 g
	Power Consumption	0.063W (idle), 10.6 W (ignition)
	Data Interface	I^2C, 100 kbit/s
Performance	Thrust Level	$6.4 \cdot 10^{-3}$ N (max)
	Specific Impulse (I_{sp})	69 s (average)
	Total Impulse	0.114 Ns


DelFFi
Formation Flying of Two CubeSats within QB50

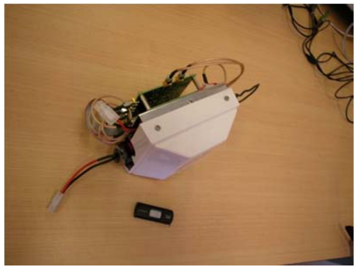
Miniaturized Space Systems @ TU Delft

Miniaturized Inter-satellite Sensor on DelFFi

- SPaceborne Active Ranging and Communicating System
  - Uses FMCW (Frequency Modulated Continuous-Wave) technology for versatile applications
  - Based on a TNO development for terrestrial safety applications
  - To be further developed jointly by TNO and TUD/SSE for space application
  - Highly miniaturized and low power for cubesats
  - Separations from 1 m - 1000 km with high accuracy (~cm) and high data rate (up to 1Mb/s)

First demonstrator
- Power 6W
- Mass 0,8kg

Completed



Second demonstrator
- Power 3W
- Mass 0,2kg

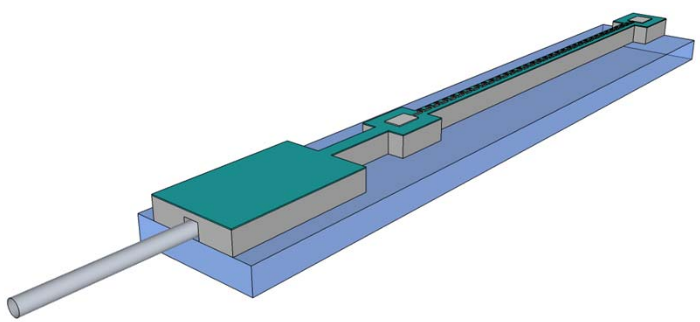
TX-RX lock demonstrated
Distance measurement in development

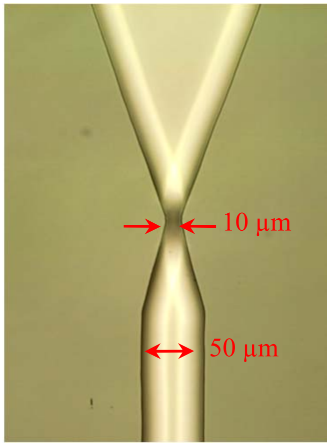
Wearable system
- Power ~ 0,5mW
- Very low mass

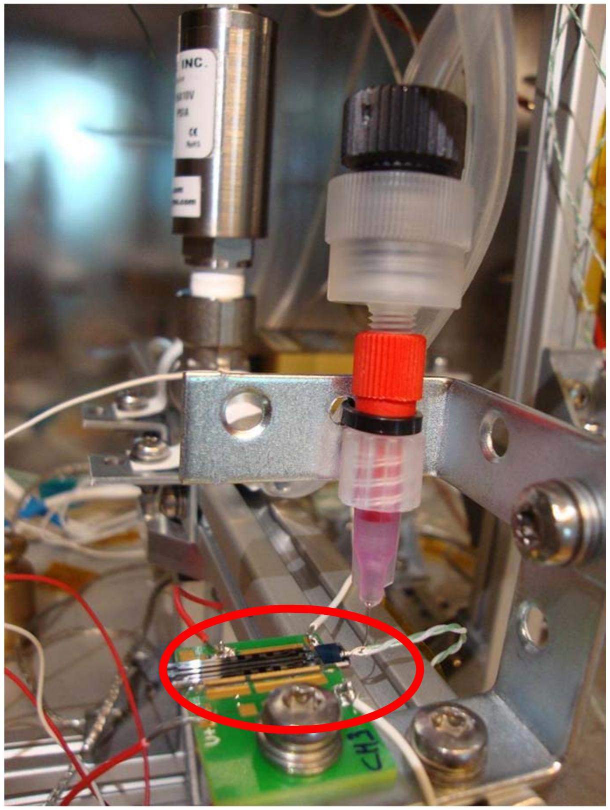
In development

Miniaturized Space Systems @ TU Delft

Micro Resistojet Thruster on DelFFi





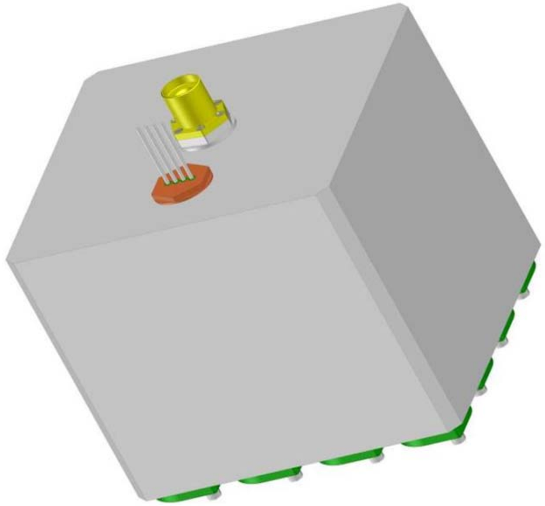


Silicon-based Micro-resistojet System		
Flow channel dimensions	**Value**	**Limitations**
Length	1 cm	No
Height	30-50 µm	No
Width of channel walls	50 µm	Should not be less, in order to have good wafer bonding

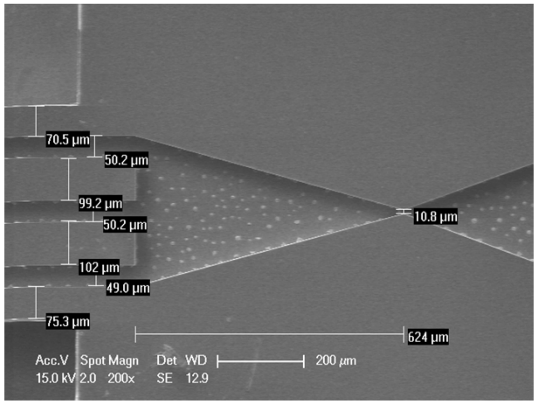
Miniaturized Space Systems @ TU Delft

Micro-Propulsion on DelFFi

- Larger & more CGGs
- MEMS resistojet



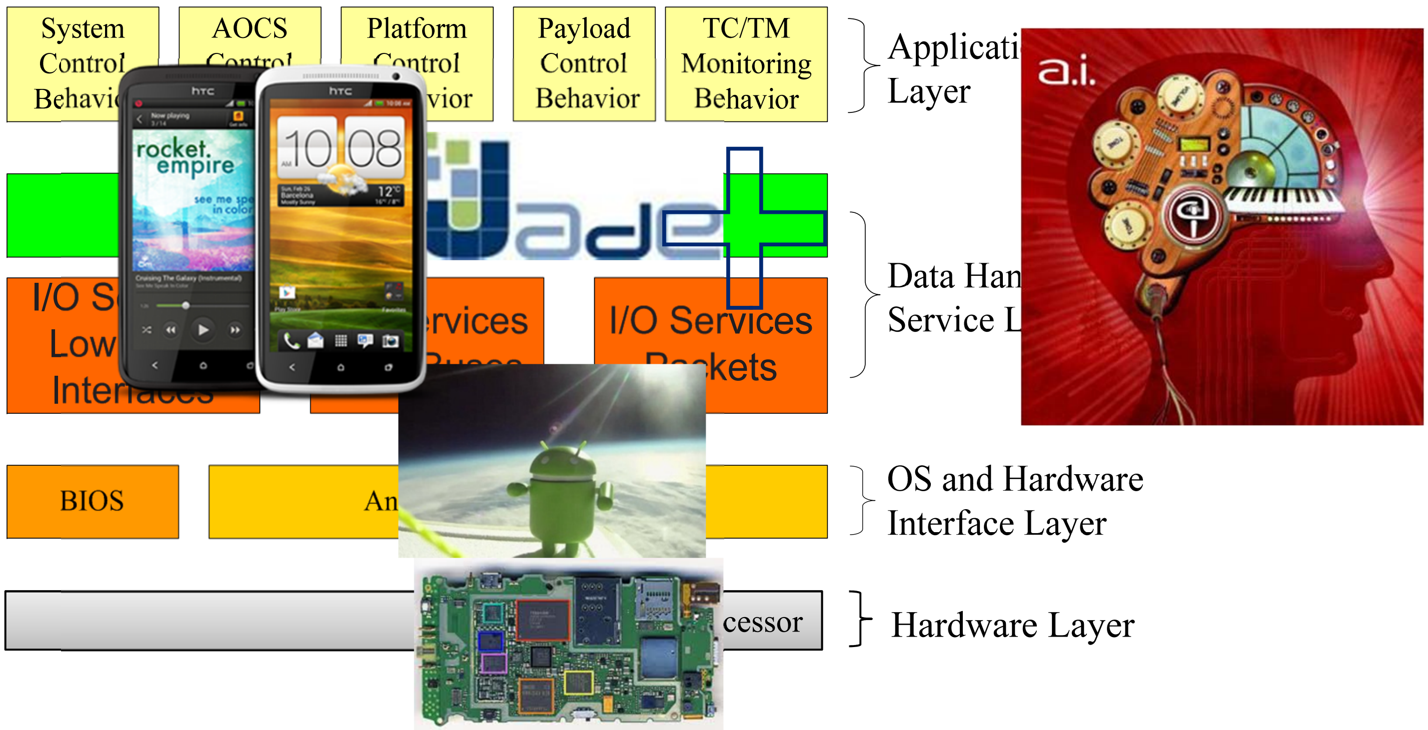
- m_{prop} = 40 g (from 1.2 g)
- I_{sp} = 150 s (from 70 s)
- ΔV_{tot} = 20 m/s (from 0.3 m/s)



- Formation Acquisition
- Formation Flying (30 days - 120 days)
- Controlled Re-entry (i.c.w. 30d FF)

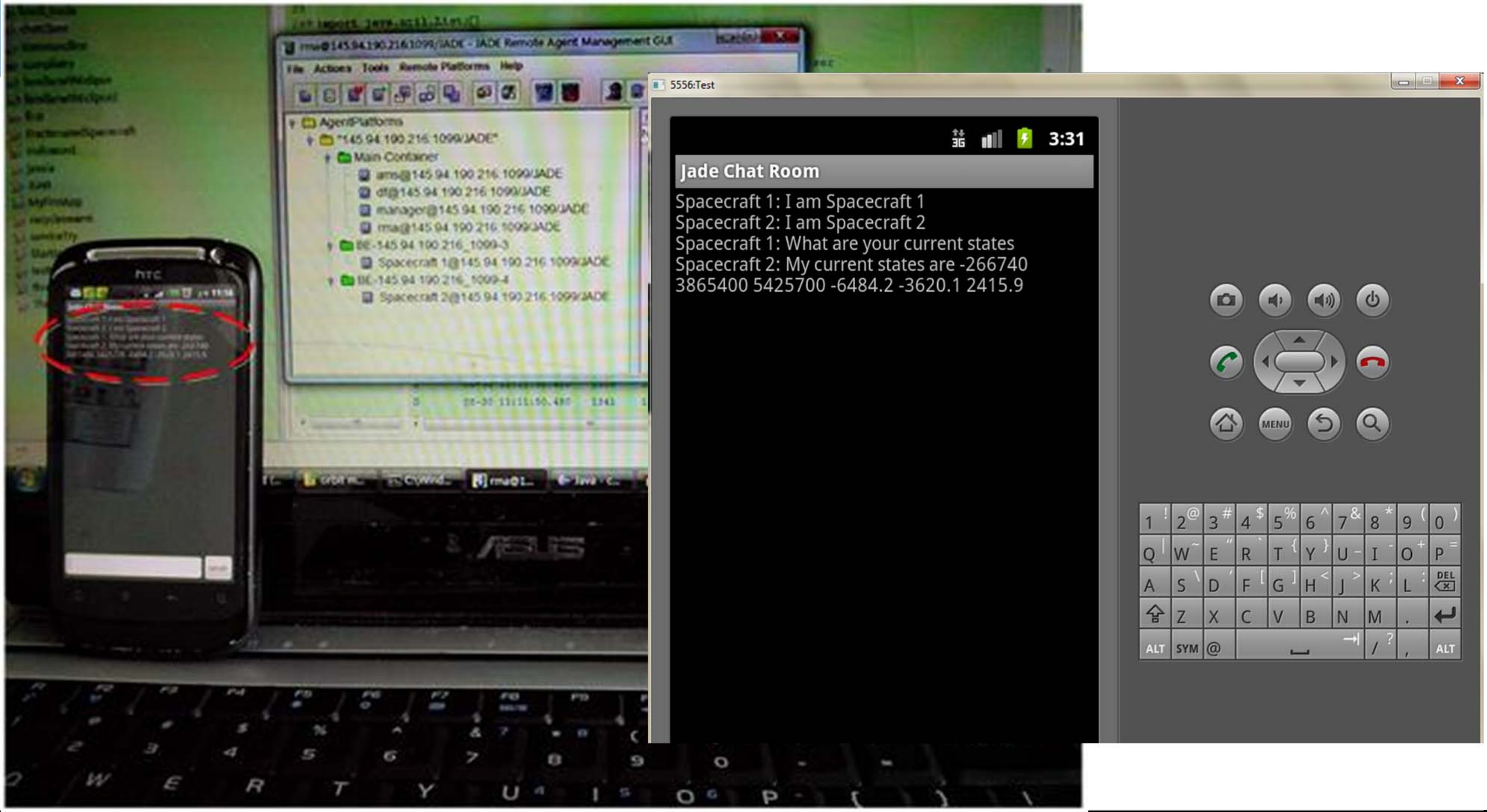
Miniaturized Space Systems @ TU Delft

Formation Flying Avionics on DelFFi



Miniaturized Space Systems @ TU Delft

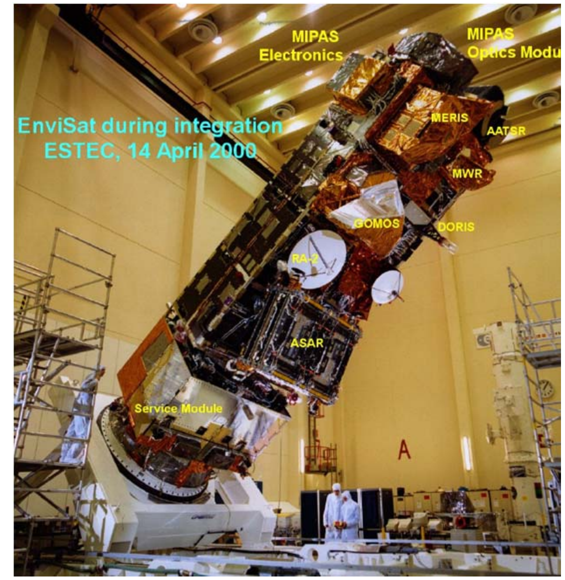
Formation Flying Avionics on DelFFi - Experiment



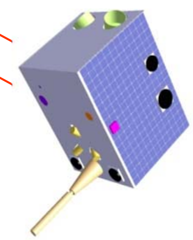
Perspectives of Miniaturization in Space

Perspectives of Miniaturization in Space

The Goal



Powerful individual satellite



A cluster of SoMS satellites

Drivers of utilizing space MST

- Mission
- Cost
- Mass (?)

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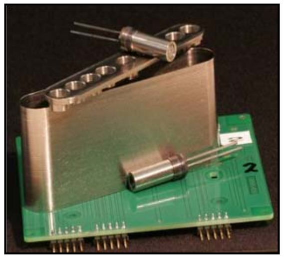
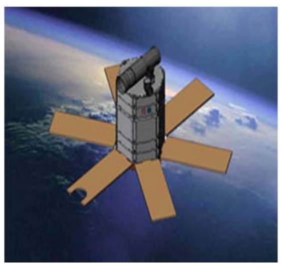
Perspectives of Miniaturization in Space

The Roadmap



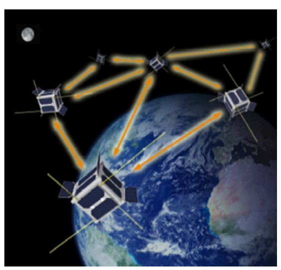
MST-based components

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



Spacecraft architectu

- System-of-MicroSystems
- Modularity
- Wireless
- Low-cost and mass prod

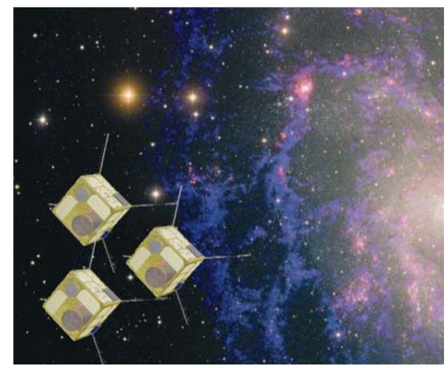


Distributed systems

- Distributed onboard autonomy
- Miniaturized inter-satellite link

Infrastructure

- Testbeds for individual spacecraft
- Testbeds for distributed system



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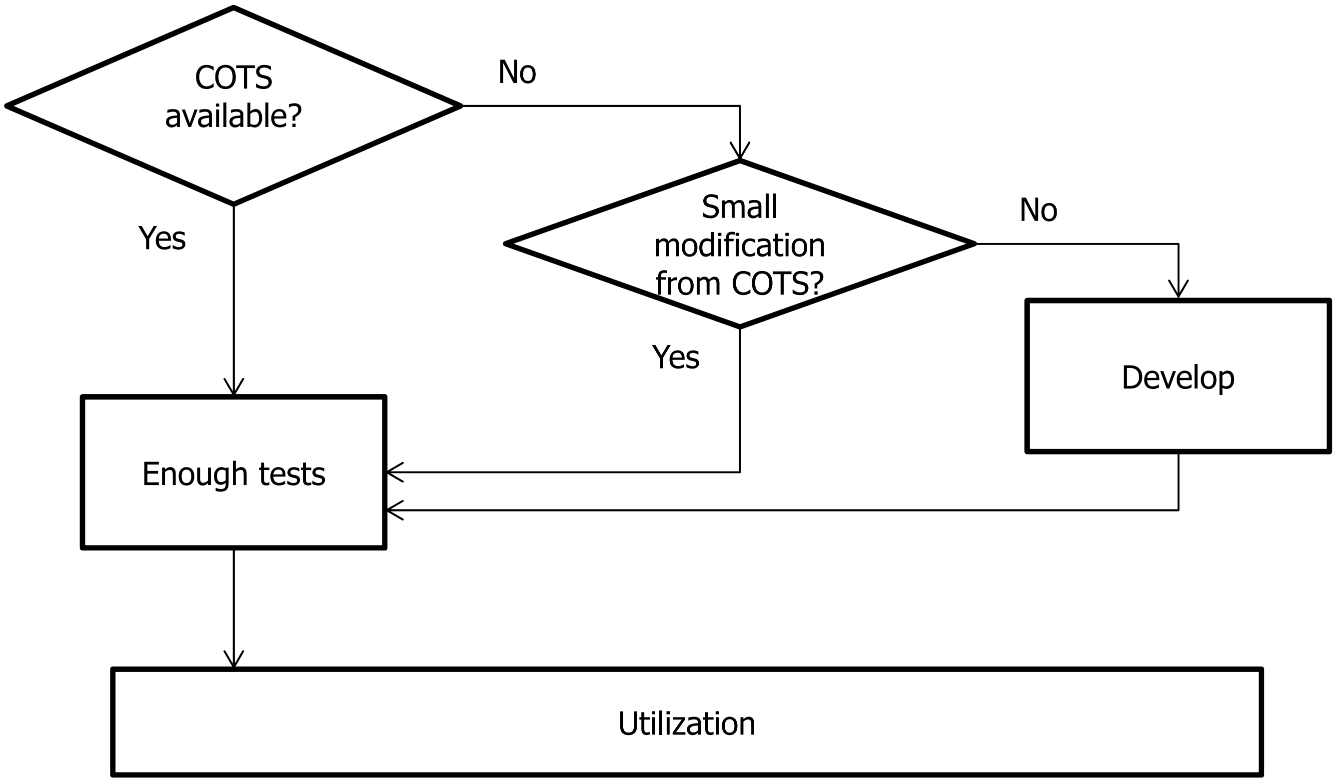
Perspectives of Miniaturization in Space

Approach of Miniaturization



Conclusions

- Exciting potential of miniaturization for micro- and nano-satellites
- System-of-MicroSystem spacecraft for distributed space architectures
- Significant progress achieved worldwide
- Step-wise strategy to develop System-of-MicroSystem spacecraft
- Cost is the driver, so utilize COTS components and develop miniaturization only when necessary

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