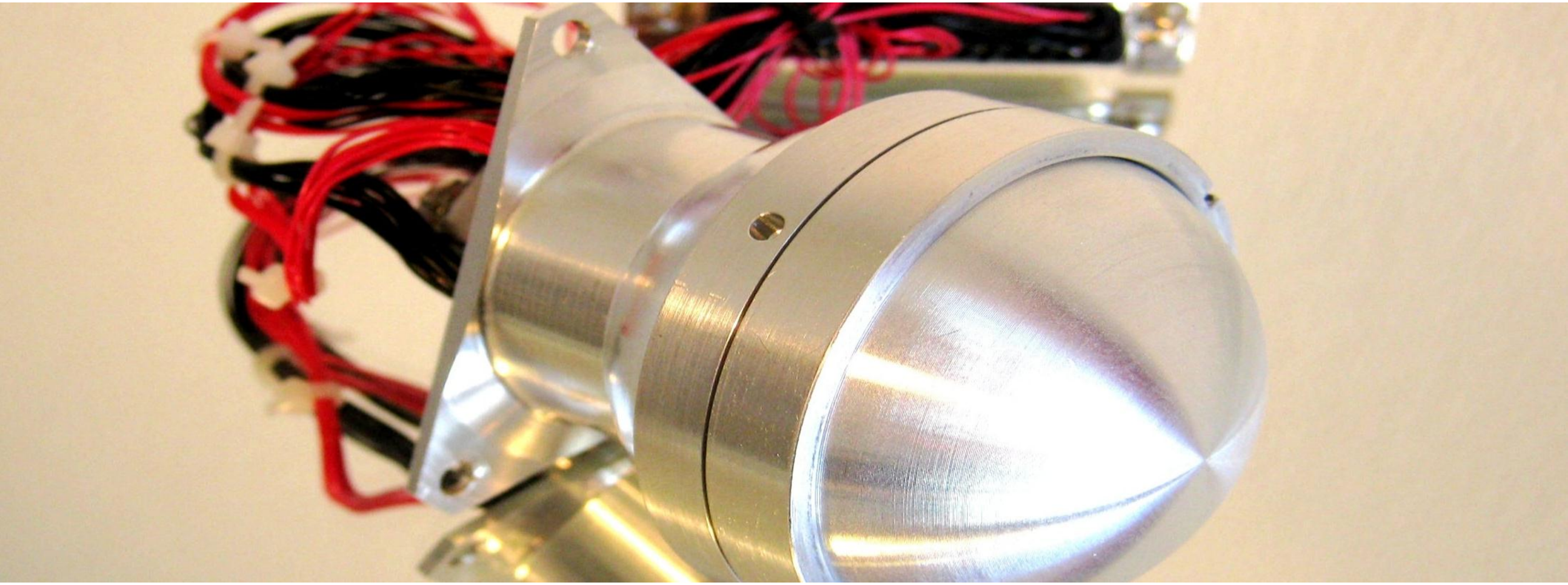
Advanced MEMS components in closed-loop micro propulsion applications



Pelle Rangsten, Johan Bejhed, Håkan Johansson, Maria Bendixen, Kerstin Jonsson, and Tor-Arne Grönland

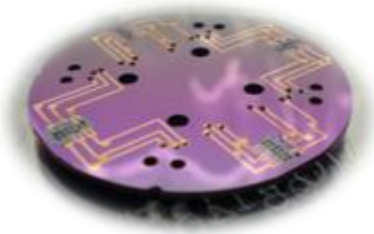
NanoSpace
Uppsala Science Park
SE-751 83 Uppsala
SWEDEN

e-mail: pelle.rangsten@sscspace.com
http: www.sscspace.com/nanospace

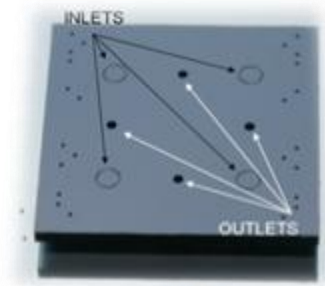
SMÖRGÅSBORD [ˈsmœrɡɔsˌbuːd]

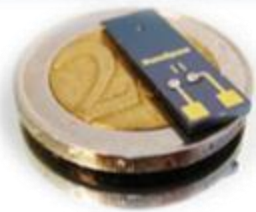
MEMS Micropropulsion Components for Small Spacecraft

Thrusters



Flow Control Valves





Filters

Pressure Sensors

Presens (N)

MEMS Isolation Valve

Pressure Relief Valve

www.sscspace.com/nanospace

SSC NANOSPACE

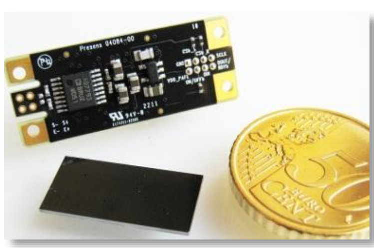
MEMS Micropropulsion Components

- First generation MEMS micropropulsion:
  - *Miniaturised, accurate and open-loop*

- Next generation MEMS micropropulsion:
  - *Closed-loop control*

Xenon flow control module

CubeSat propulsion module



NANOSPACE

www.sscspace.com/nanospace

Motivation - Advanced Nano- and Cube Sats

- *Propulsion to enable new missions*
  - Drag free flights, Orbit change, FF & RV , docking, de-orbit…

    -> New scientific results

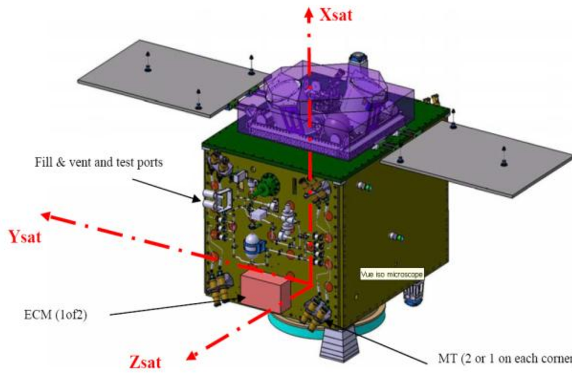
    -> Commercial applications

    -> Space debris mitigation

SSC NANOSPACE

Challenging requirements

Mission thrust requirements given by CNES for MICROSCOPE	
Thrust range	**1 – 300 µN**
Thrust resolution	**0.2 µN**
Response time	**250 ms**



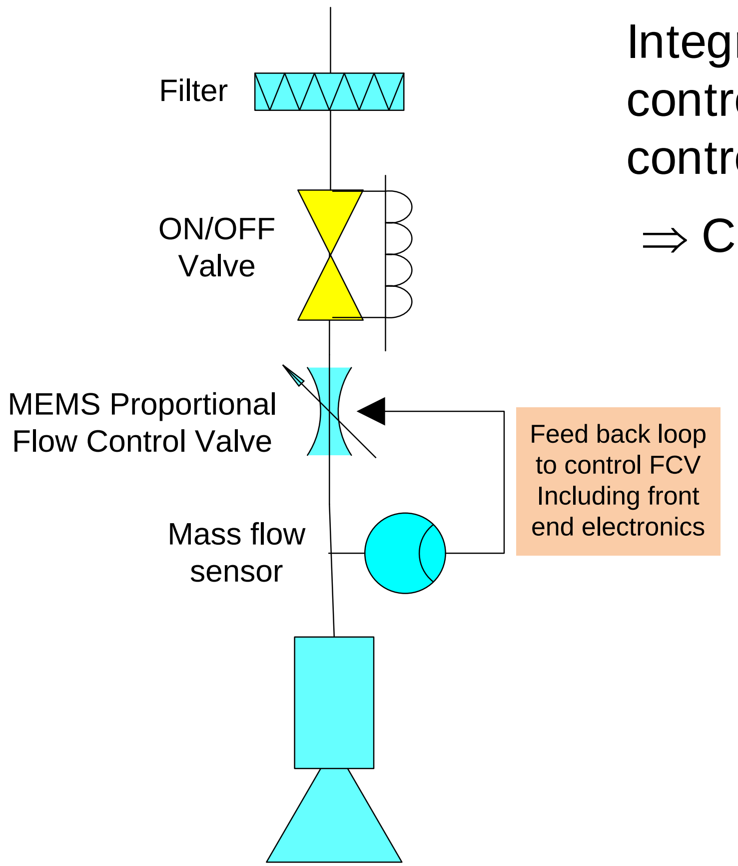
MICROSCOPE by CNES

Flow Control Requirements for next generation mini Ion engines	
Flow rate range	**5 – 50 µg/s**
Flow rate control accuracy	**+/- 5% across the flow range** **+/- 5% above 25 µg/s and** **+/- 10% below 25 µg/s**
Flow rate control resolution	**+/- 0.5 µg/s**

RIT-µX by Astrium

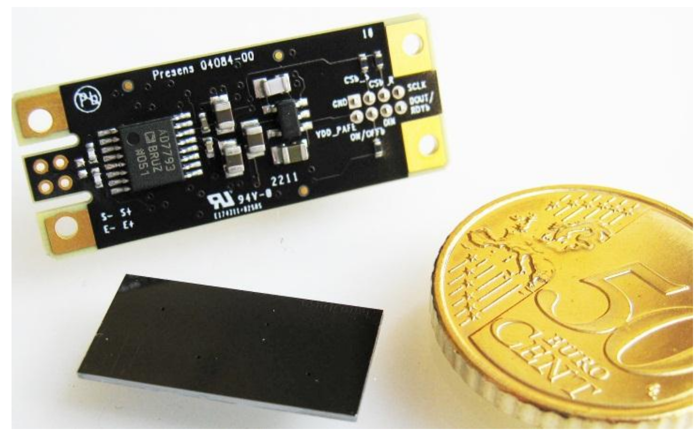
NANOSPACE

Closed–Loop Flow Control



Integrated mass flow sensor provides control signal to the proportional flow control valve

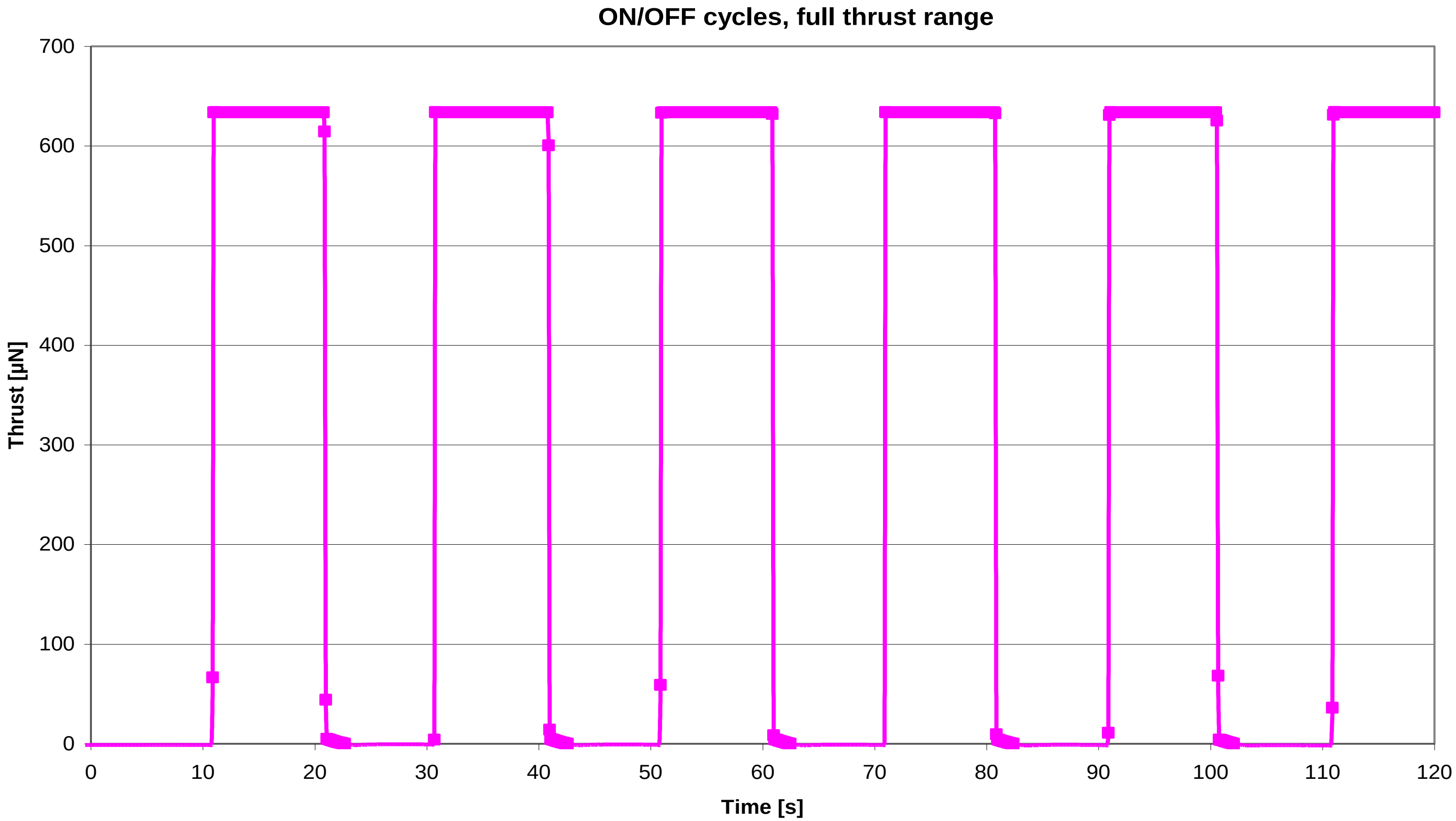
$\Rightarrow$ Closed-loop flow control



Thruster chip and front-end electronics

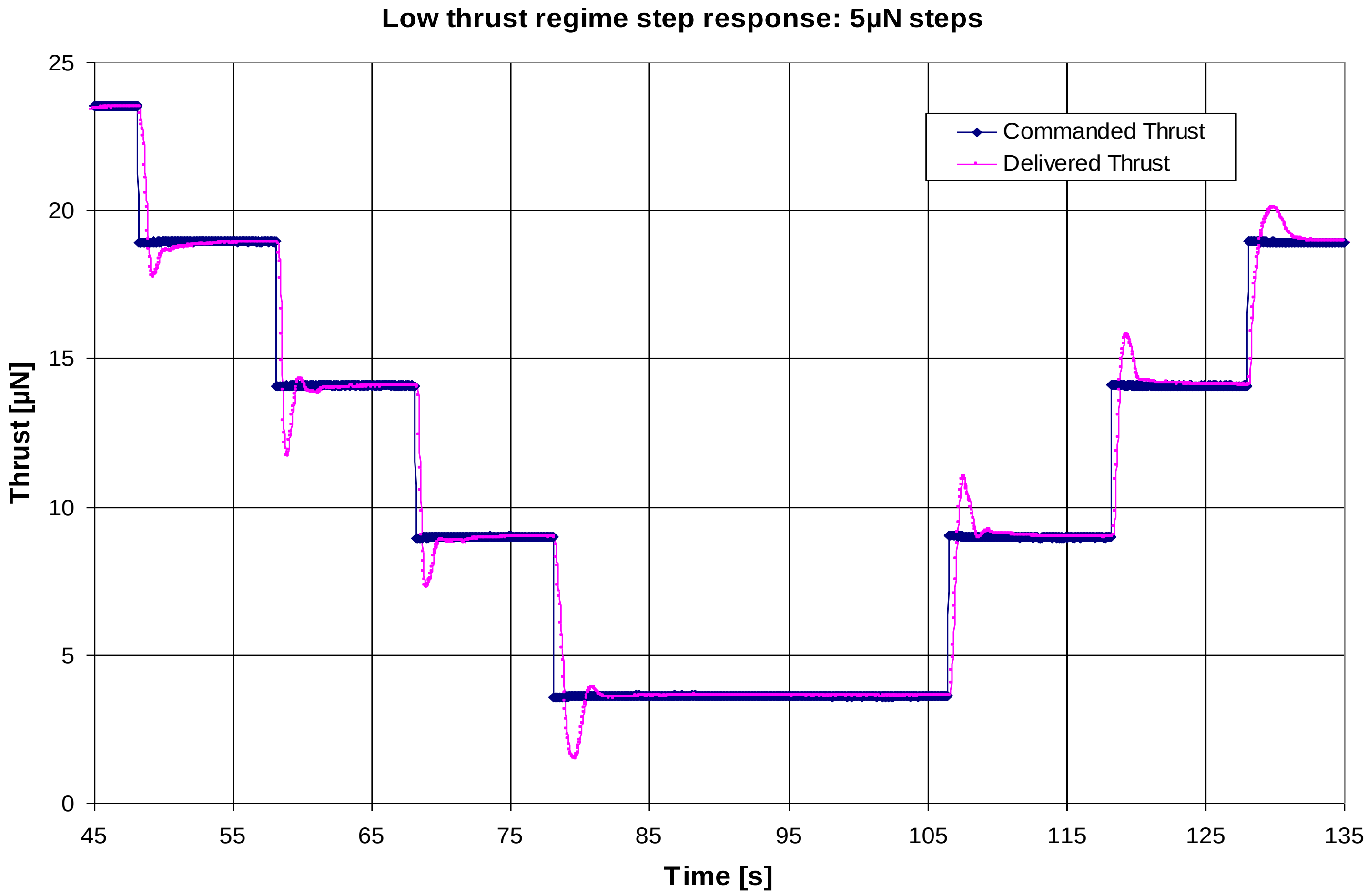
Schematic view of a complete closed -loop control thruster.

Key capabilities – Like any other



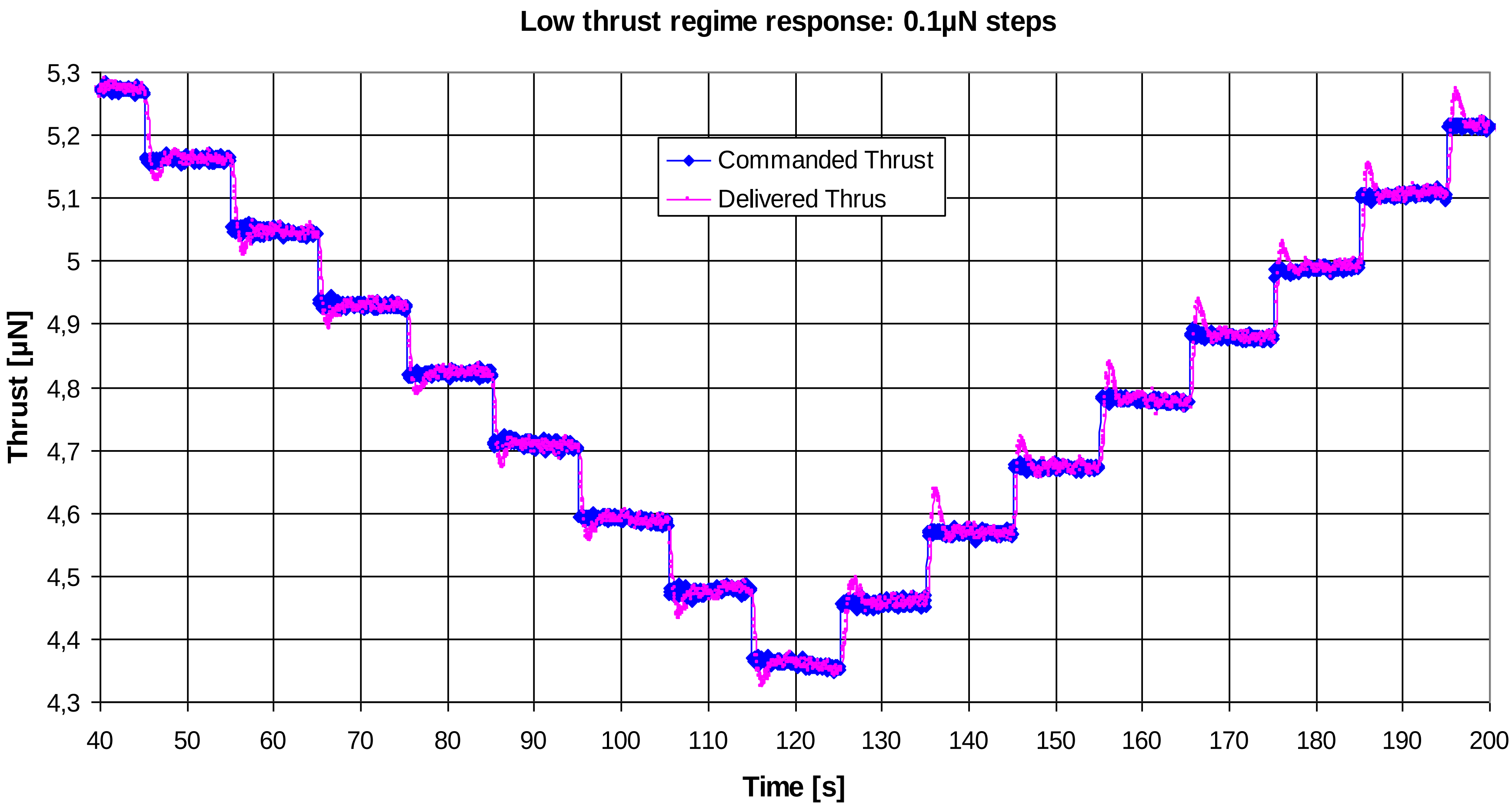
Test result of MEMS thruster operating in ON/OFF mode
(open loop, using solenoid valve only) to show thrust range.
Full thrust can be set in the range **50 micro-Newton** to **5 milli-Newton**

Key capabilities – Unlike any other



Test result of a MEMS valve operating in closed-loop control mode showing the thrust response to commanded steps of 5 µN.

Unique performance

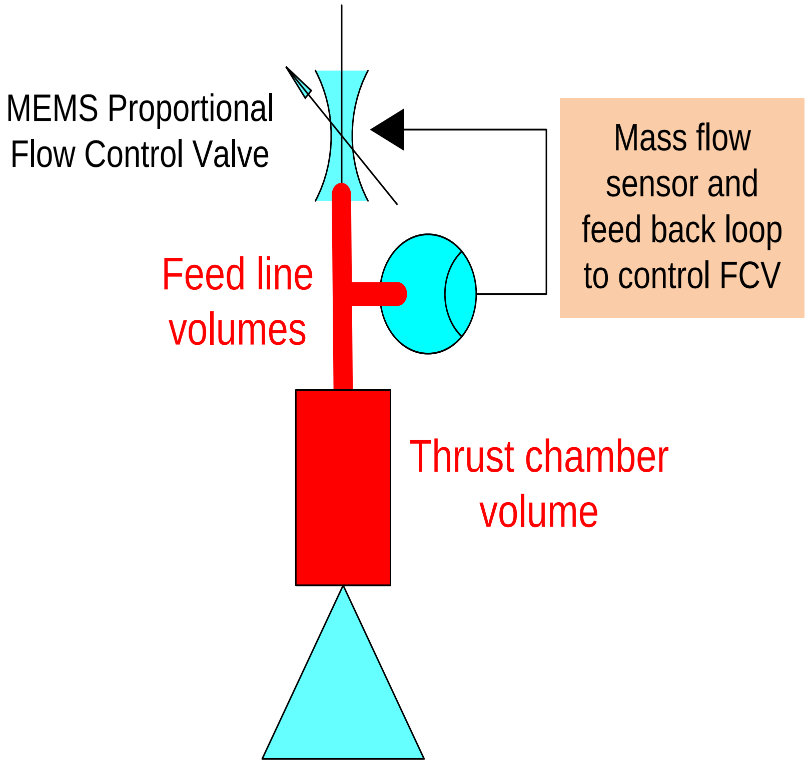


Test result of a MEMS valve operating in closed loop control mode responding to the commanded steps of 0.1 μN.

SSC NANOSPACE

Physics problem

Low flow rates in combination with the wish for fast response



Thruster case:
Requirement: 250 ms in response time
Flow rate: 5 µg/s

Response time increases linearly with the internal dead volume

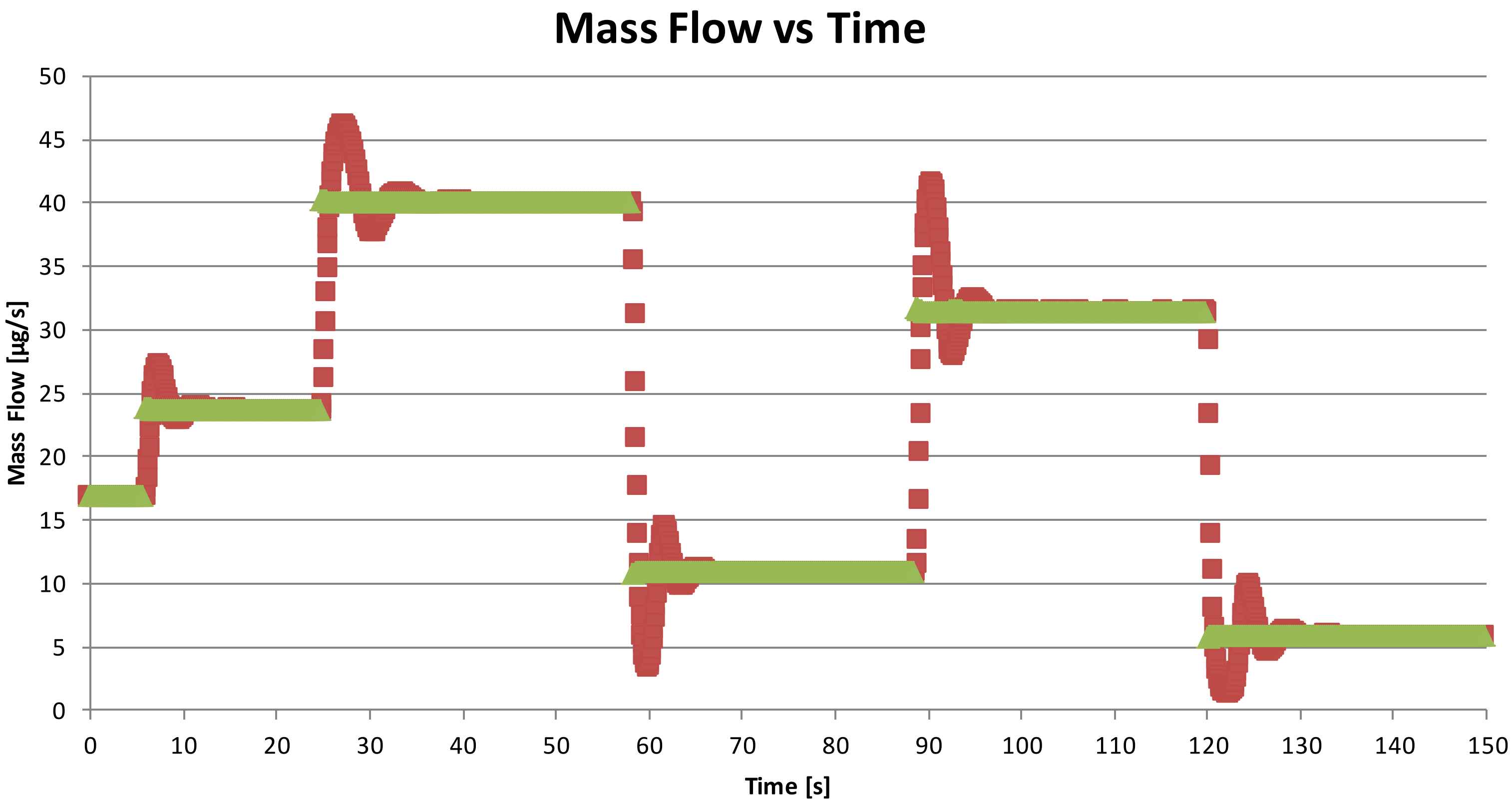
Simplified estimate: V ~ 10 mm3

Tubing	Length	Volume
1/8”	5 mm (0.2”)	9 mm3
1/4”	0.62 mm (0.025”)	10 mm3

The Solution - MEMS

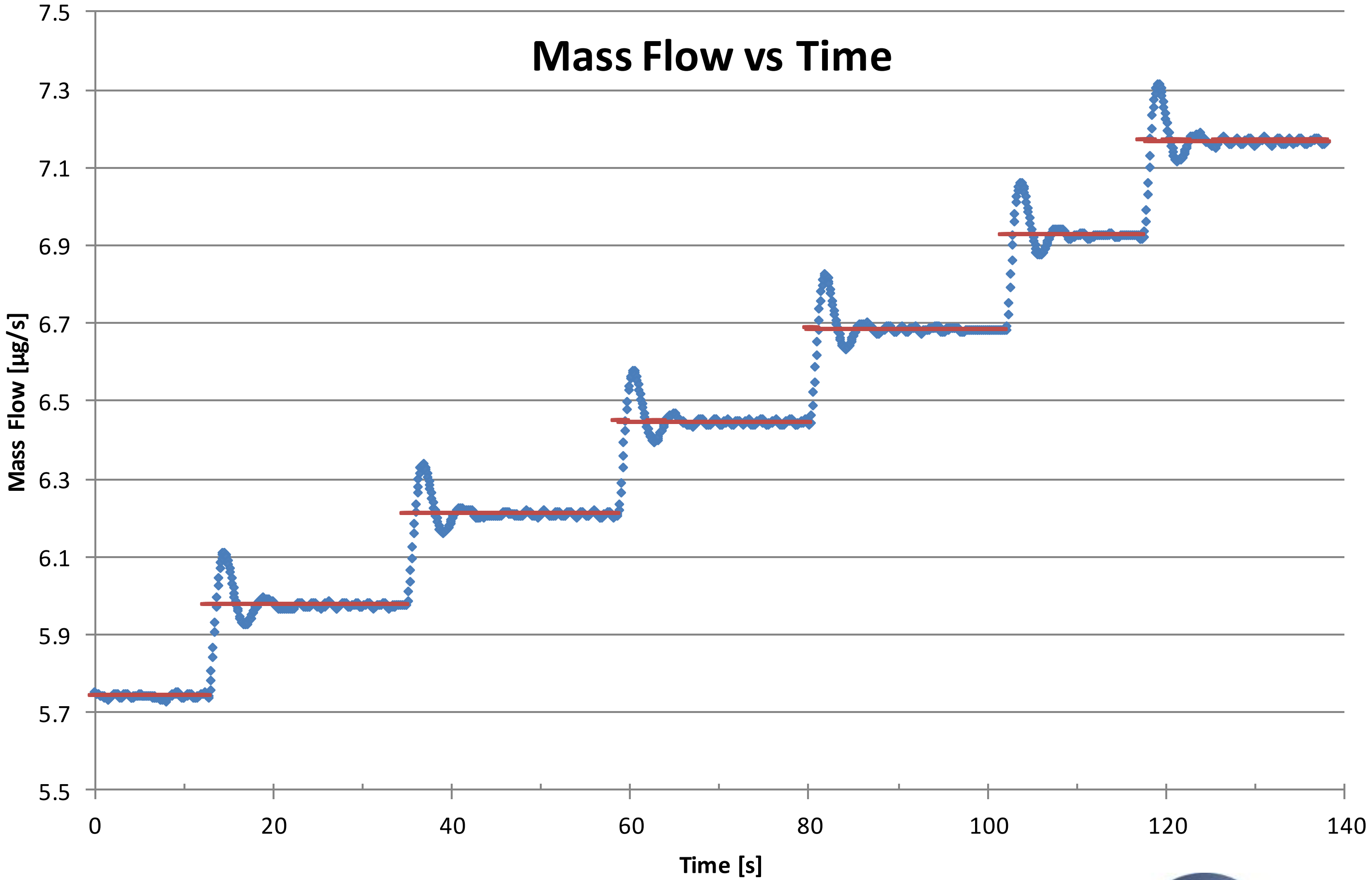
In our view, **using MEMS technology and integrating the flow control valve, mass flow sensor and chamber/nozzle on a single chip is the best –if not the only- way to realise a closed-loop control thruster that can meet the challenging requirements with low flow rates in combination with fast response**.

Results – Xenon Flow Control



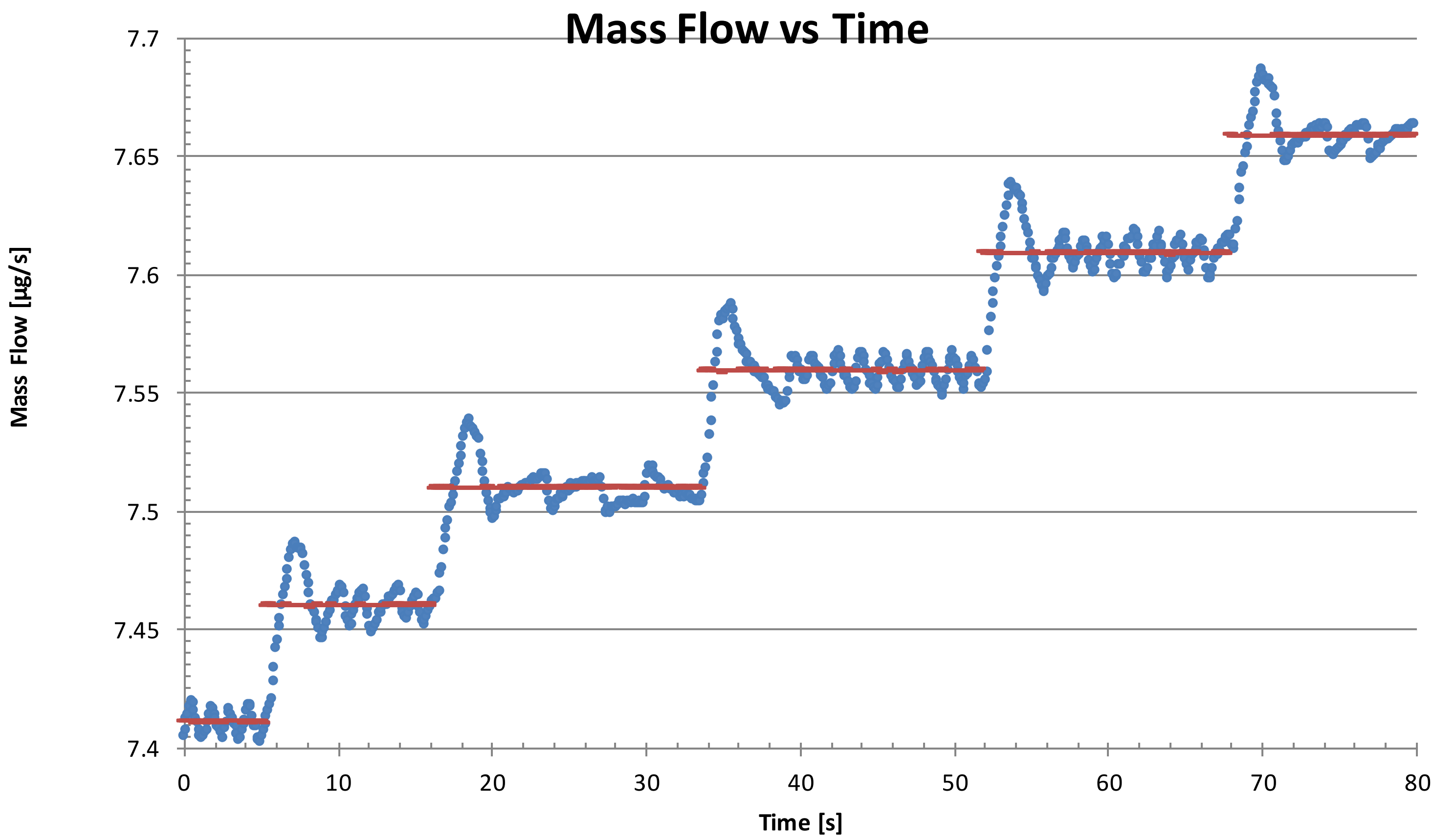
Capable to operate in full flow regime

Results – Xenon Flow Control



Capable to performe minute flow changes

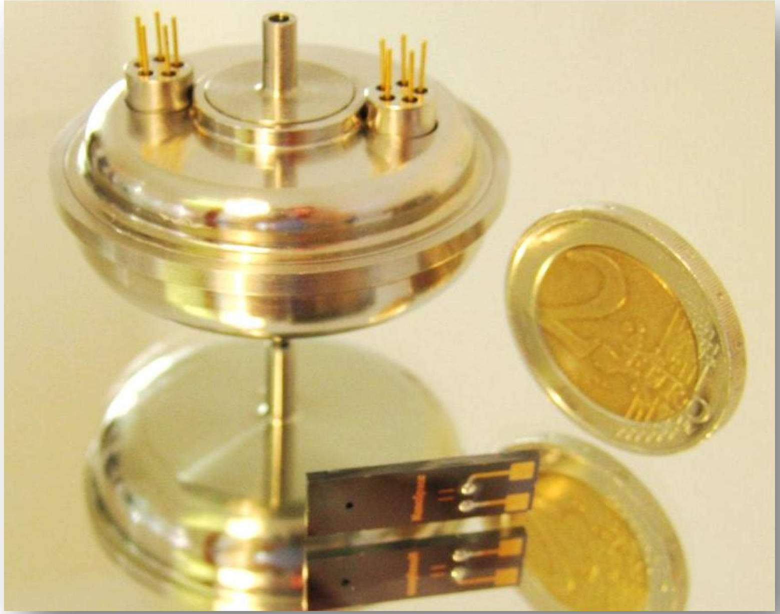
Record shattering resolution



Capable to resolve extremely small changes: 0.2 µg/s (200 ng/s)

Summary – XeFCM H/W

- Designed, manufactured, and tested a Xenon closed-loop flow control module!
- Mass: 63 grams
- Excellent dynamic range
- Step regulation < 200ng/s
- Fast response time



Next step:

- Testing together with mini Ion engine (Astrium´s µN-RIT engine)

NANOSPACE

Summary – Micro Thruster H/W

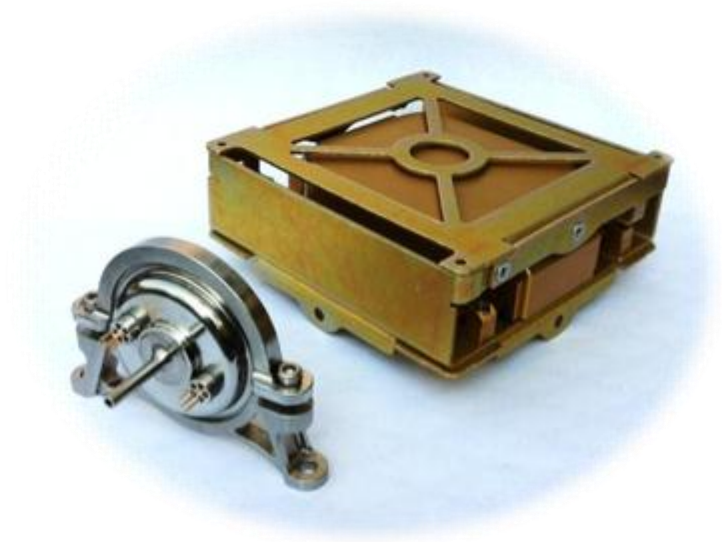
- Closed-loop thrust control demonstrated with unique performance (in terms of thrust and response time in the low thrust regime)
- Developing a CubeSat propulsion module
  - Four 1mN thrusters with closed-loop thrust control
  - Thrust resolution: <10µN
  - Propellant: Butane
  - Total impulse: 40Ns
  - Size: 10*10*3cm
  - Mass: 250g
  - Operating pressure: 2-5 bar
  - Power consumption: 2 W (average, operating)
  - Mechanical interface: CubeSat payload I/F (Pumpkin)
  - Electrical interface: 52 pins analog (0-12V) and digital (SPI)

Next step:

- Finalise the assembly, integration, and testing

Outlook

- Return to SmallSat in Logan next year for a live demonstration!!!
- Fly our closed-loop products in space



SSC booth 48-49

Swedish coins for size reference…

Thank you for your attention!

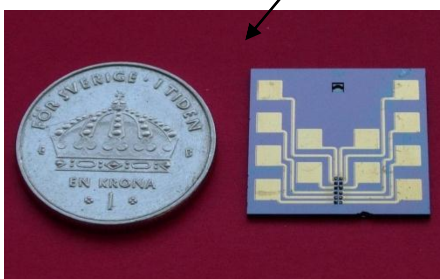
SSC NANOSPACE

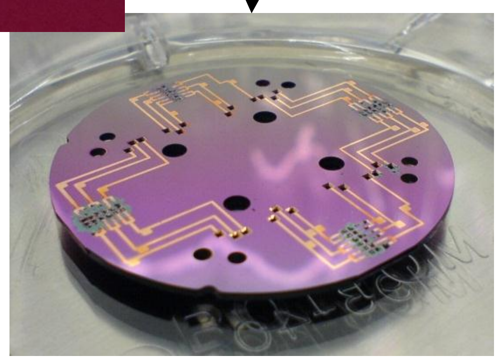
www.sscspace.com/nanospace

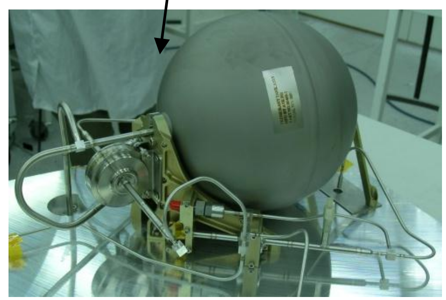
First generation developed for Prisma

2005 · 2006 · 2007 · 2008 · 2009 · 2010

- NanoSpace starts operation
- phase B contract
- First test of MEMS thruster
- 1st complete thruster module
- 1 st delivery of flight H/W
- Final delivery to Prisma
- End-to-end testing on S/C
- Launch!





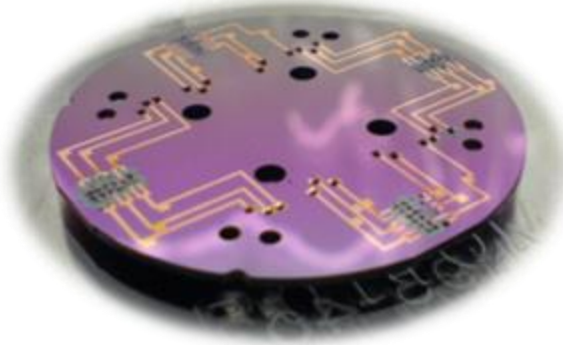


SSC NANOSPACE

www.sscspace.com/nanospace

Thruster Pod Assembly – Plenty of MEMS inside

∅= 44 mm (1.73”)
Four thrusters per pod
10 μN – 1 mN
Mass: 115 g



Six-wafer-stack MEMS Thruster Chip

NANOSPACE

Physics Lessons

Understanding the physics, an example:

Assume that the MEMS valve is closed. This implies (in vacuum) zero pressure and zero mass flow through the nozzle. Now assume that the valve immediately opens to allow a flow rate of 5µg/s (which corresponds to 2 µN). Also assume that the nozzle throat is sized such that this flow rate corresponds to 0.1 bar pressure in the chamber (which corresponds to thruster dimensioned for ~100 µN at full thrust).

Now, to reach this new steady state condition, the total volume between the valve and the nozzle throat must be "filled up" with gas from zero to 0.1 bar.

Assume that the total volume of feed lines and thrust chamber is 10 mm^3.

A first order estimate of the **response time of such a system is 230 ms**.

Response time increases linearly with volume.

This is an optimistic estimate neglecting a number of effects such as valve opening response, reduced flow rate as the pressure increases, delays in the control loop, etc which in reality will slow down the response time significantly.

However, this example illustrates how crucial it is to minimise the internal volumes in a regulated system with low flow rates.