MEMS-Based Closed-Loop Flow Control in Cold Gas and Electric Propulsion Systems

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9th ESA Round Table on Micro and Nano Technologies.
Lausanne, Switzerland, 10-13 June 2014

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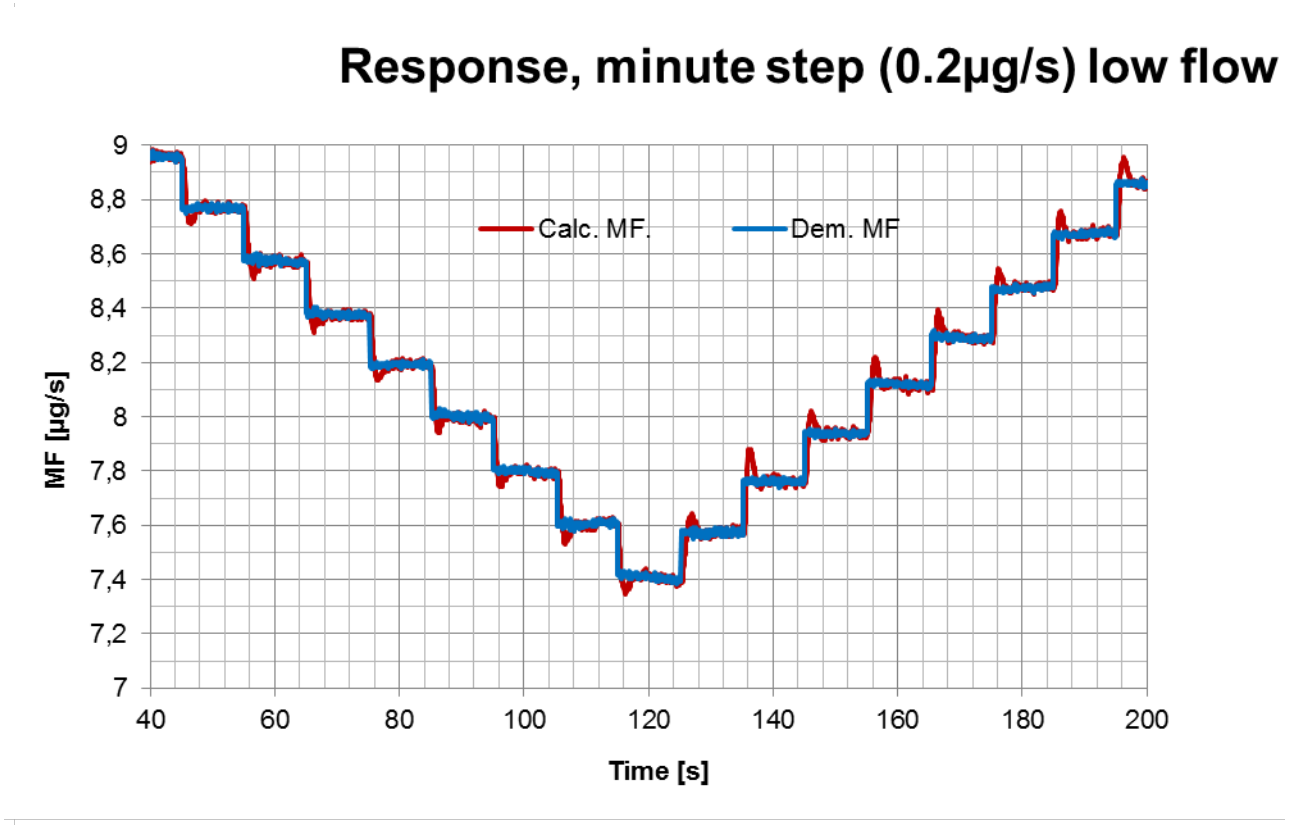
Test Results



Benefits of MEMS

- Possibility to manufacture valves and sensors in the same silicon stack.
- Small size
- Ideal for lower flow rates
- Possibility to integrate components on chip level, resulting in extremely small dead volumes

MEMS Micropropulsion Components

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

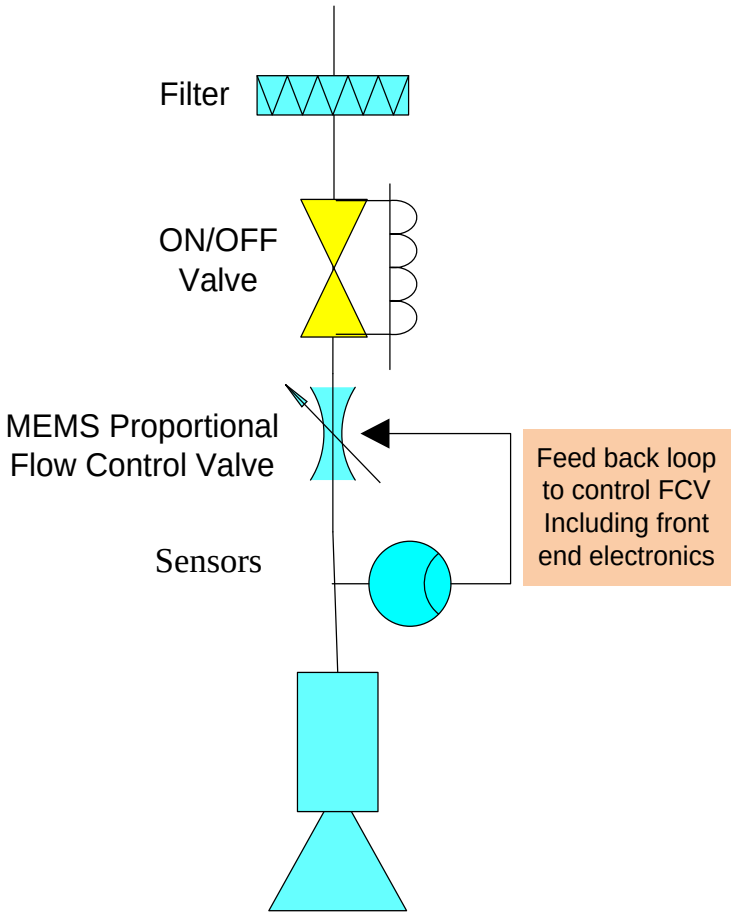
- Next generation MEMS micropropulsion:
  - ***Closed-loop control***

Xenon flow control module

CubeSat propulsion module

Closed-loop flow control

- Thermally actuated flow control valve
- Pressure, temperature and mass flow sensors
- Mass flow is feed back signal



Applications

- Same technology, different applications
- Cold Gas thruster applications
  - CubeSat propulsion unit
- Electric propulsion
  - Mass flow controller to µg/s flow rate ion engines

CubeSat propulsion

Extremely tough requirements

- Size
- Mass
- Power

Functionality?

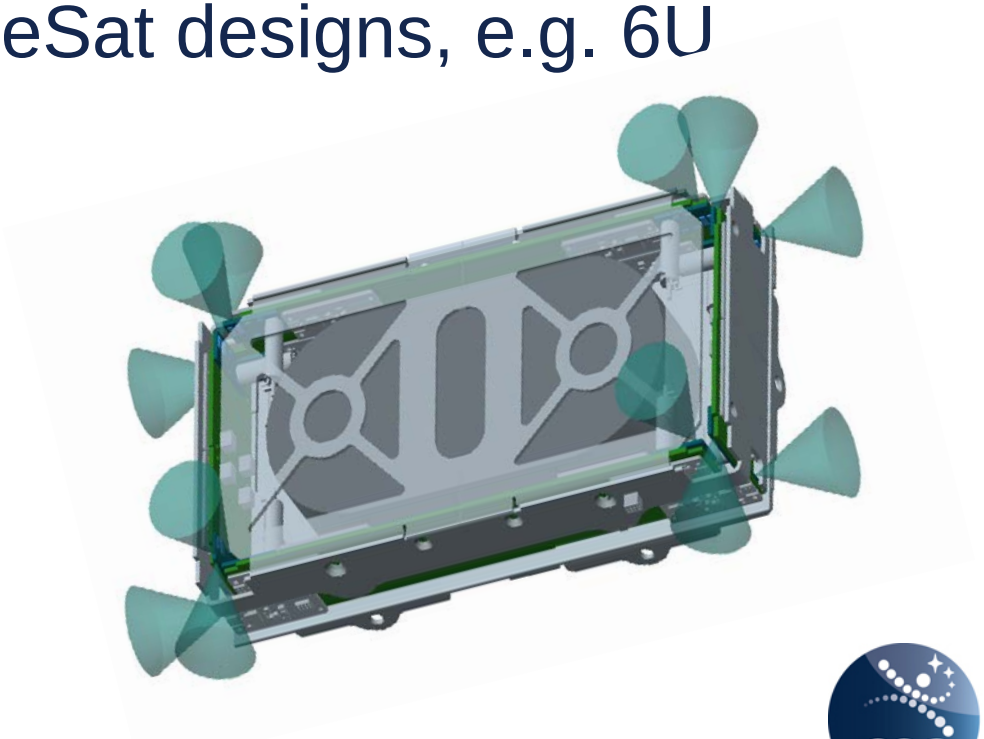
Target specification and performance

CubeSat

- Four <1 mN thrusters with closed-loop thrust control
- Thrust resolution: 10µN
- Propellant: Butane
- Total impulse: 40 Ns
- Size: 10x10x3cm
- Weight: 250g (dry)
- Propellant capacity: 50g (butane)
- Operating pressure: 2-5 bar
- Power consumption: 2 W (average, operating)
- Mechanical interface: CubeSat payload I/F
- Electrical interface: 21 pins analog (0-12V) and digital (SPI)

Design, specification and performance changes possible

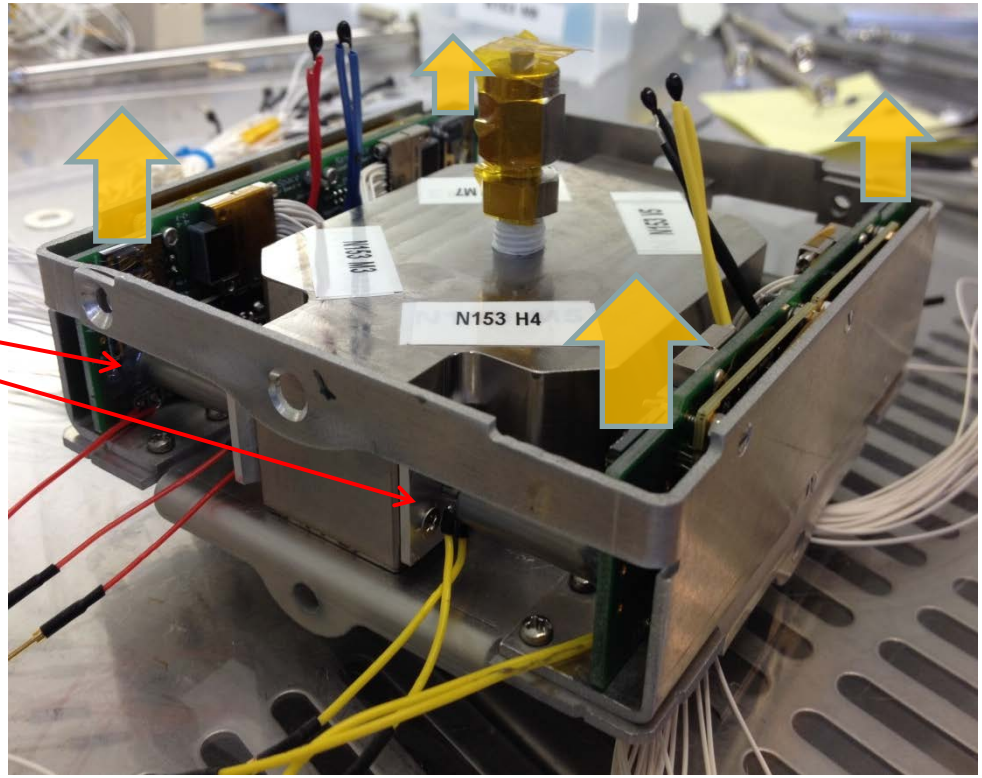
- Thrust levels
- Number of thrusters
- Other CubeSat designs, e.g. 6U
- Tank size



Propulsion module design

CubeSat

- Titanium tank
- Thermistors
- Four solenoid valves
- Four thrusters modules
  - Sensors
  - Proportional valve
  - Chamber
  - Nozzle
  - Front end electronics



Results

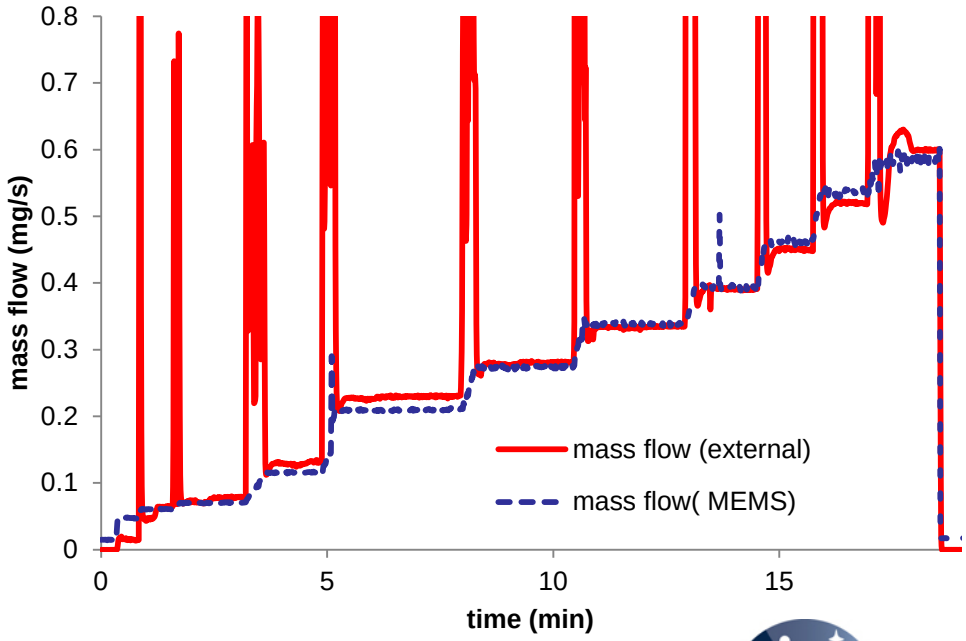
CubeSat

First module under calibration and testing

- Varying feed pressure, 0-4 bar

Sensor signals:

Mass flow

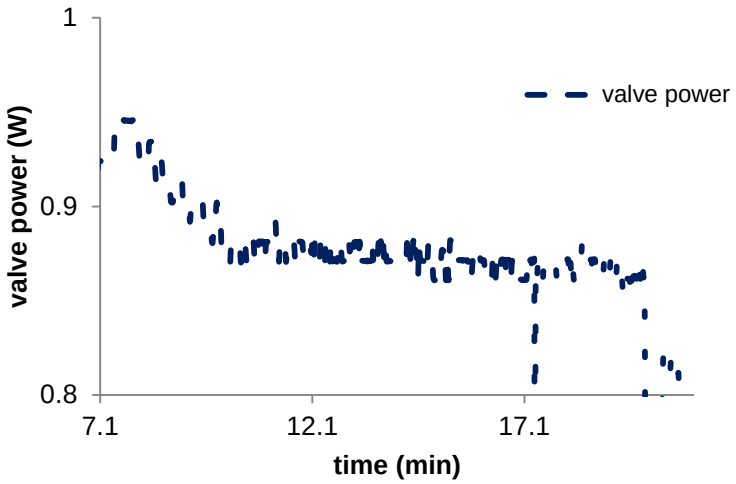


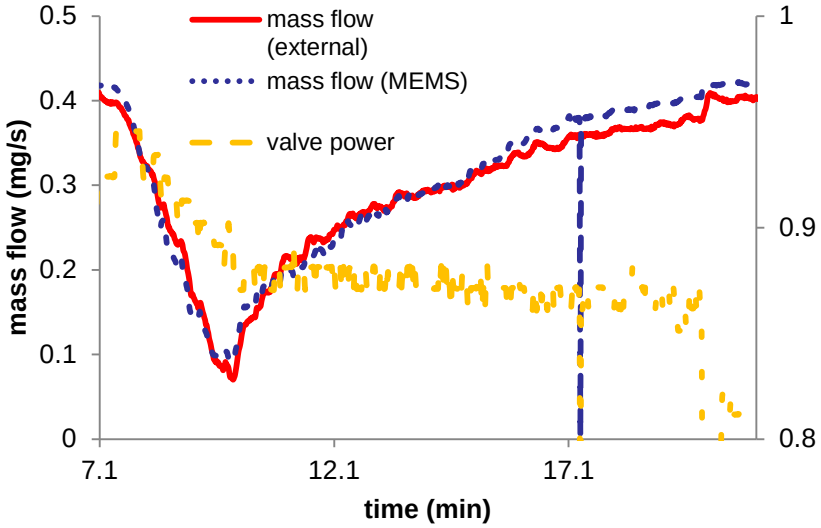
Results cont.

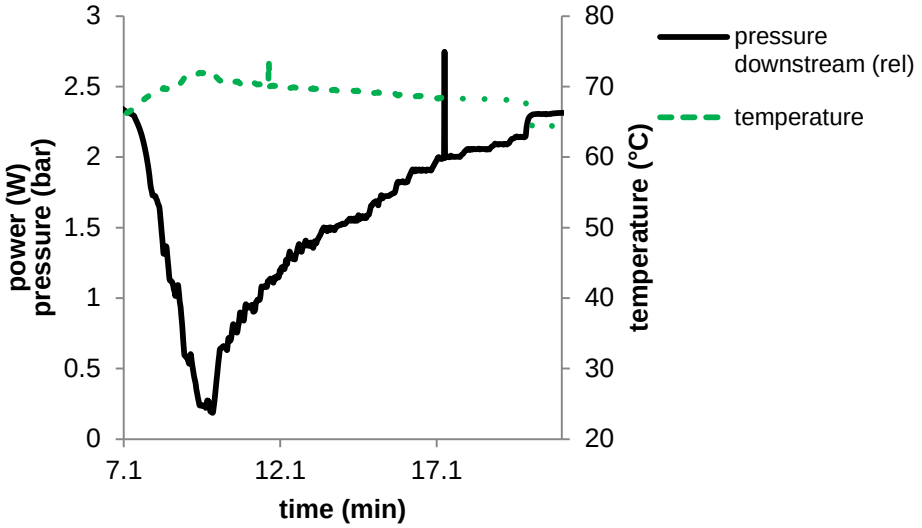
CubeSat

Constant feed pressure, 3 bar

- Proportional valve actuated







Summary CubeSat

- A CubeSat propulsion module with closed-loop thrust control
- High integration level
- Scalable design
- Promising test results

Key requirements

Flow Control

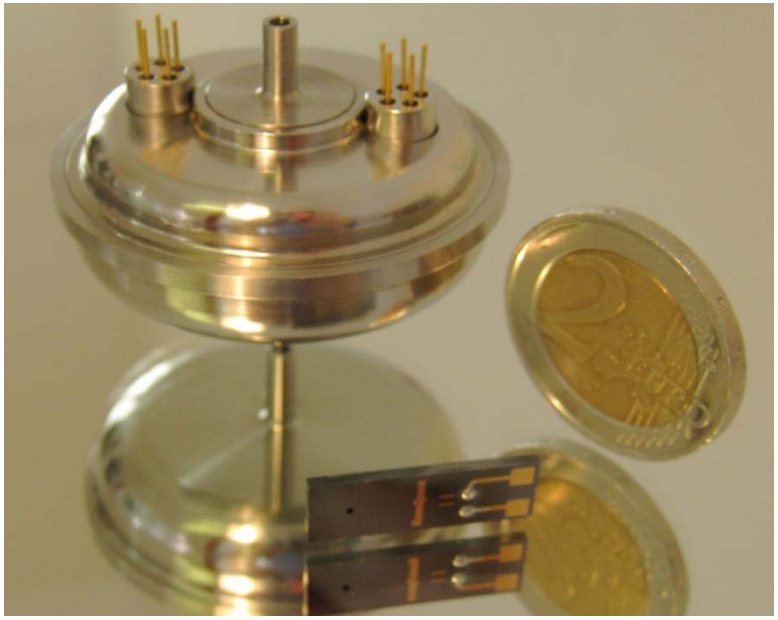
Flow rate range	5 – 50 µg/s (target) 5 – 25 µg/s (minimum)
Flowrate control accuracy	+/- 5% across the flow range (target) +/- 5% above 25 µg/s and +/- 10% below 25 µg/s (minimum)
Flow rate control resolution	+/- 0.5 µg/s
MEOP	2 BarA
Power	<3W

Manufacturing

Flow Control

One housing including:

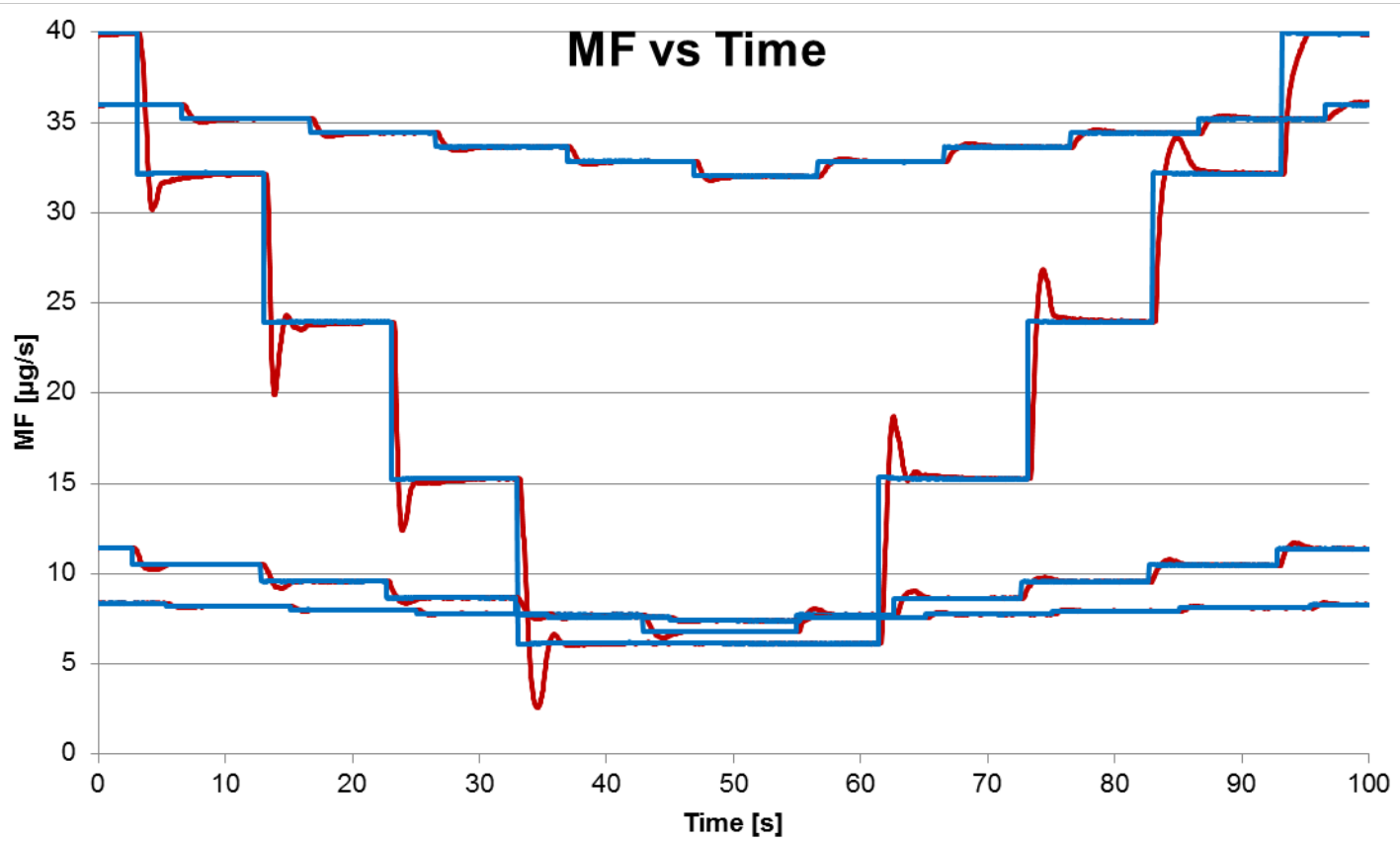
- Proportional valve
- Flow sensing device
- Pressure sensors
- Temperature sensors
- Filter
- Front end electronics



Mass: <100 Gram

Results

Flow Control



Required voltage ~6 V
Required power: ~0.6 W

Conclusion

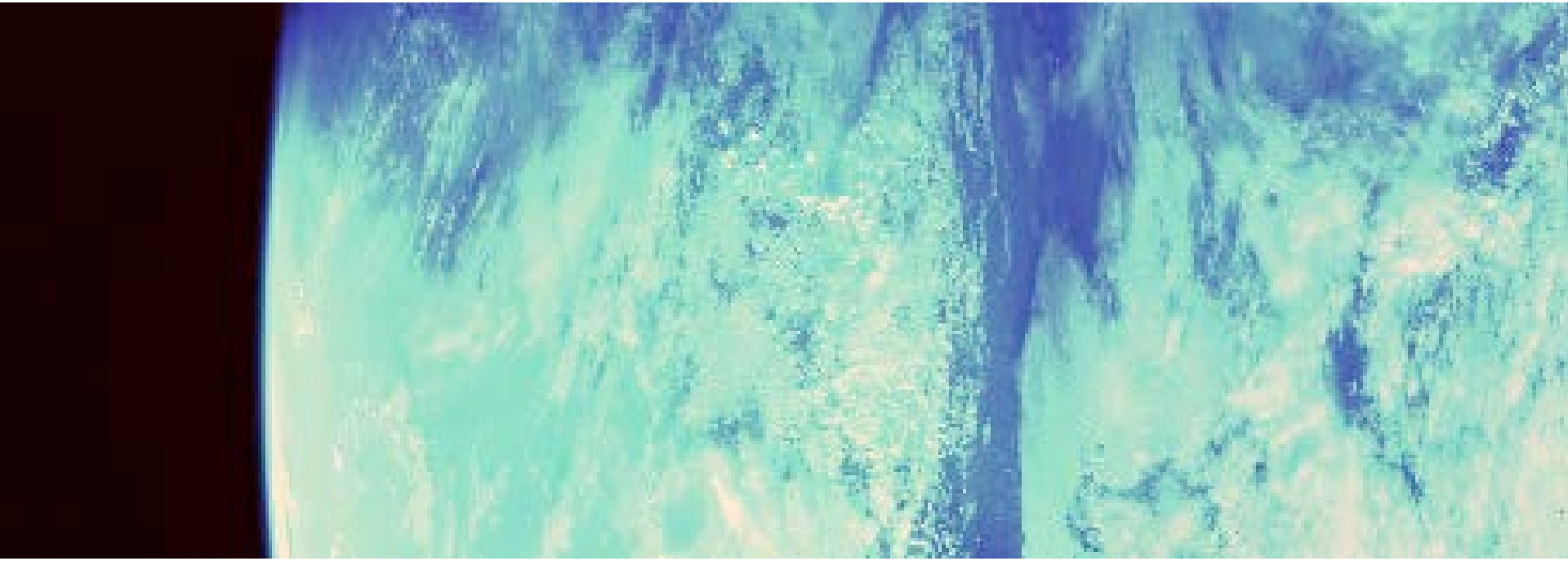
Flow Control

- Resolution < 100ng/s
- Sufficient dynamic range
- Fully operational in full flow range
- Mass: less than 100 grams
- Low Power requirements

Conclusion technology

- Miniaturized flow control modules designed, manufactured and tested
- Different flow ranges (µg/s-mg/s)
- Different media (Xe, N2, Butane)
- Proportional valve and flow sensor integrated in same chip
- Improved response time
- Closed loop flow control demonstrated

Thank you!



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