Development of a Mobility Drive Unit for Low Gravity Planetary Body Exploration

Dr.-Ing. Josef Reill German Aerospace Center - DLR
Institute of Robotics and Mechatronics

Co-Authors:
Hans-Jürgen Sedlmayr
Sebastian Kuß
Philipp Neugebauer
Maximilian Maier
Andreas Gibbesch
Bernd Schäfer
Alin Albu-Schäffer

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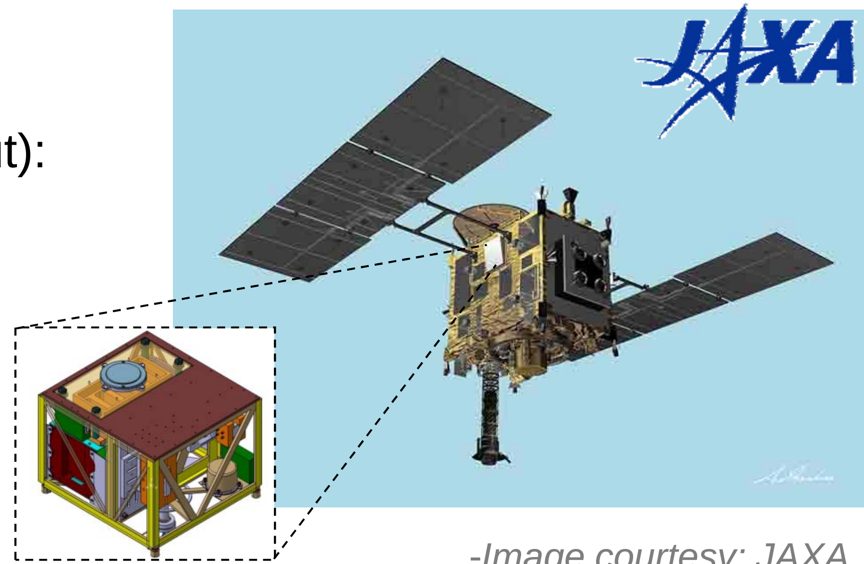
MASCOT Mission Overview



-Image courtesy: JAXA

MASCOT (Mobile Asteroid Surface Scout):

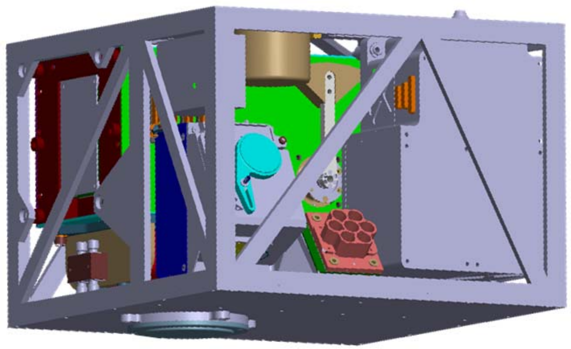
- DLR Contribution to Hayabusa II of JAXA
- Target: Asteroid 1999JU3
- Launch: Dec. 2014
- Arrival: 2018
- 10 kg with the size of 30 x 30 x 20 cm

Target Body 1999JU3 Properties:

- C-Type Asteroid (NEA)
- Diameter approx. 920 m
- Gravity approx.: 1.7e-5 g
- Rotation period: 7.5 h
- Escape speed: 23 cm/sec

Requirements:

- Carry several instruments for science
- MASCOT is the scout for JAXA's sample return experiment (bring asteroid dust down to earth)!
- System needs to be able to relocate on asteroid and upright into nominal position (needed by some instruments)!



-Image DLR RY

MASCOT Mission Overview

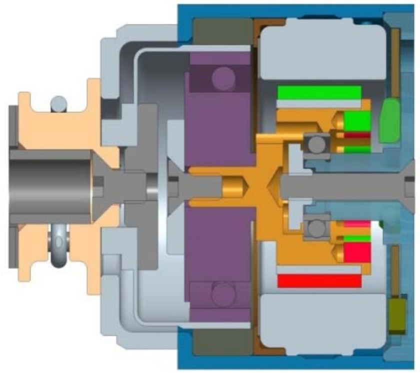
Mobility Subsystem:

- Innovative hopping mechanism to relocate MASCOT on asteroid surface
- Independent of asteroid surface
- As much redundant system as possible (up righting is essential!)
- Supply voltage is limited to 12 volts
- Compact subsystem with high power density
- As small and light as possible!

⇒No Wheels or paddles used but an innovative hopping mechanism!

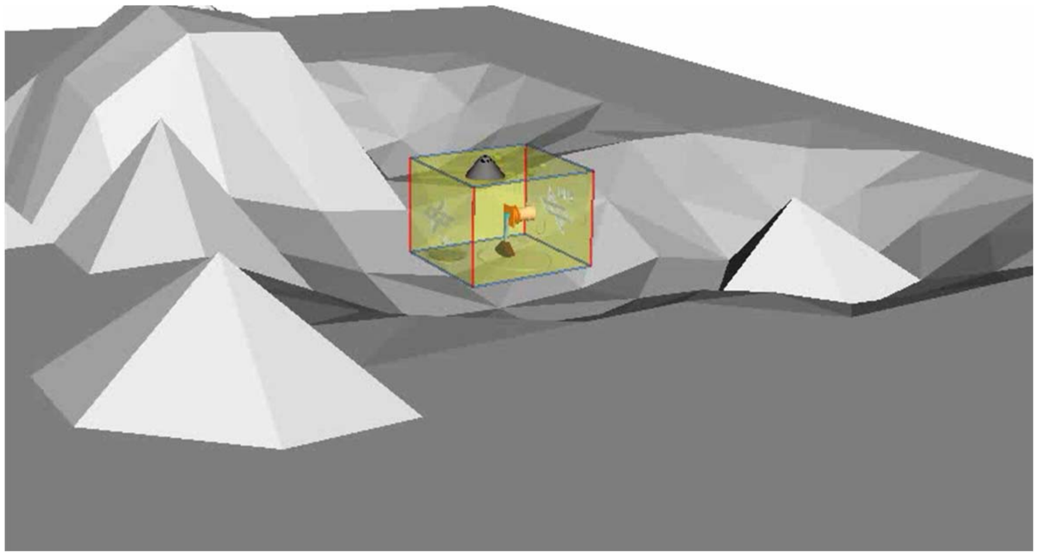
Powerful drivetrain is available at the Institute of Robotics and Mechatronics since there was the ROKVISS and DEXHAND project!

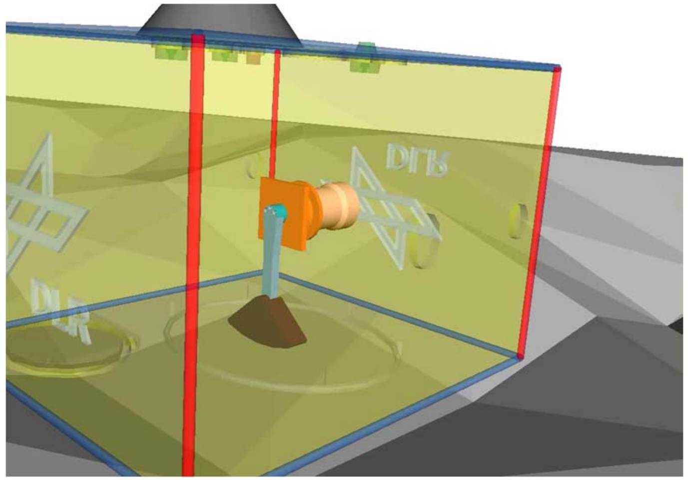
- ILM25 RoboDrive Motor
- Harmonic Drive HFUC8
- 2.4 Nm nominal, 4.8 Nm peak
- 9 Nm collision torque
- 46 g mass of the whole unit
- 8000 rpm (HD limited)
- dia. 27 mm x 17.5 mm length



Simulation of the Hopping Principle

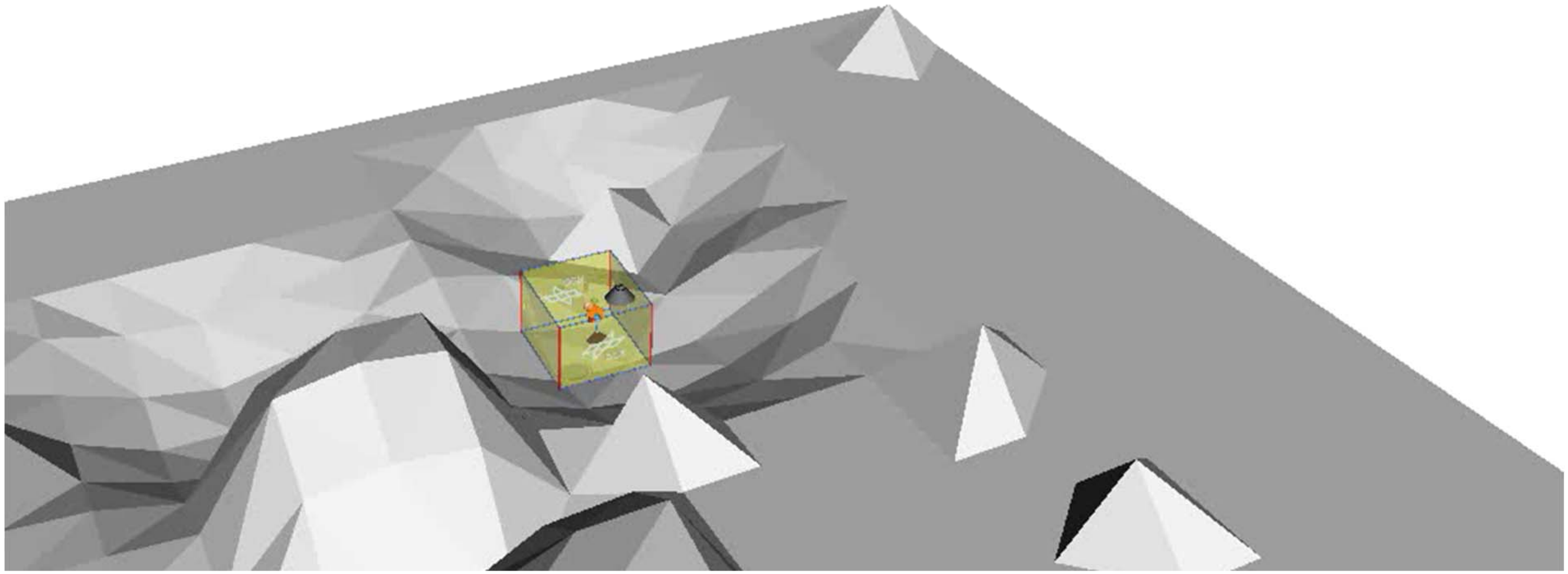
- Based on the reactive force generated by an eccentric arm
- No drive wheels because of asteroid surface uncertainties
- Polygonal contact model approach (PCM) to model surfaces
- Hopping and up righting maneuvers are possible
- Eccentric arm trajectory is defined by only five parameters (start and stop position, acceleration, deceleration, maximum link speed)
- Mass distribution is of significant importance
- Verification by parabolic flight campaign (Novespace)





Simulation of the Hopping Principle

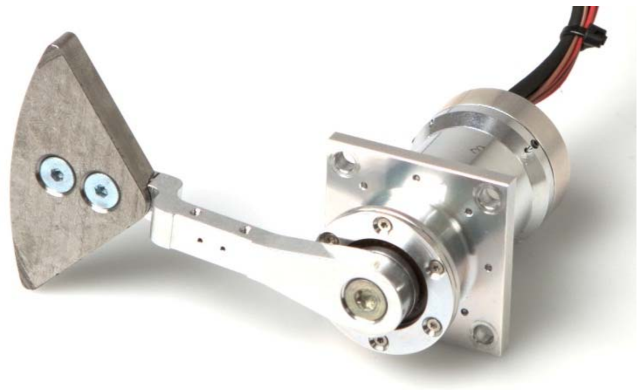
- Hopping mechanism is also useful in tricky scenarios
- Terrain conditions are not so important
- Movement is quite slow due to low gravitation
- Never exceed the escape speed of 23 cm/seconds!

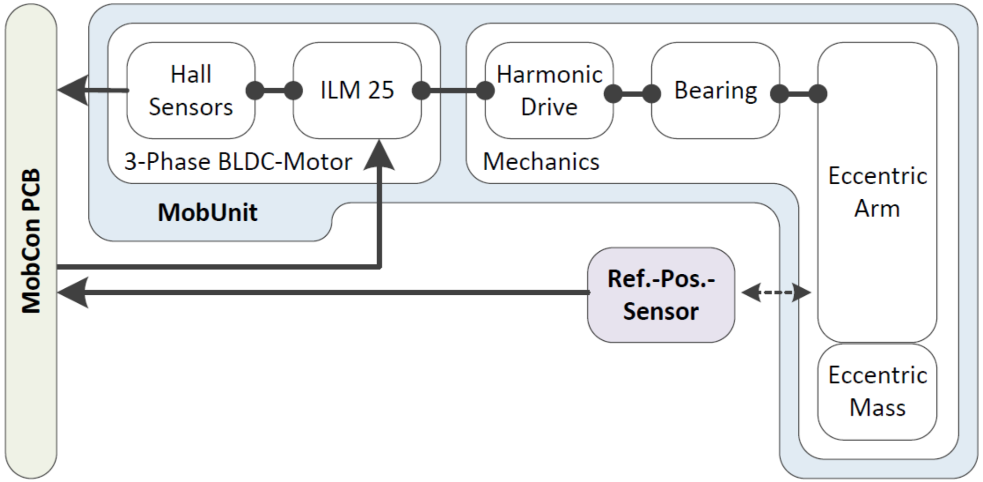


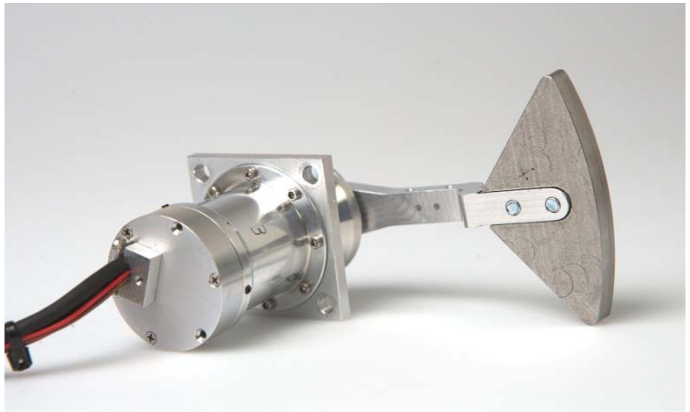
Mobility Subsystem – Mechanics – Overview

MobUnit - Motor and eccentric arm mechanics:

- BLDC Motor with six-step-commutation
- Harmonic drive gearing
- Eccentric arm with mass
- Reference magnets to get the absolute position of the eccentric arm via hall sensors
- Strain relief for the cables







Mobility Subsystem – Mechanics – Motor

Why use a BLDC motor?

+ Low number of mechanical components reduces the probability of failure
    - stator
    - rotor with magnets
    - rotor bearing
    - HD wave generator (WG)
    - HD flex spline (FS)
    - HD circular spline (CS)
    - output bearing
+ Simplification of construction and maintenance
+ No brushes or sliding contacts (this also minimizes the risk of cold welding)
+ High peak torque for a short time possible
+ Higher torque and output power per volume compared to DC motors
+ The BLDC principle is very reliable and well known since 1962

Drawbacks:
- You need know how
- You need two additional MOSFETs

Mobility Subsystem – Mechanics – Lubrication

Solutions to prevent cold-welding:

- Cold-welding resistant materials combination
  - Best combination is non-metallic and metallic
  - Can be used in hybrid ball-bearings:
  - combination stainless-steel rings, Peek bearing cages and ceramic balls
  - => Used in MobUnit bearings

- Cold-welding resistant coating
  - Coating with Dicronite DL-5 or MoS2
  - Dicronite is well known from different Mars-Exploration-Rovers
  - => MoS2 is used in ball-bearings and HD gear-teeth of MobUnit
  - => Dicronite is used in HD Wave-generator-bearing of MobUnit

Confirmed with cold welding materials test campaign!

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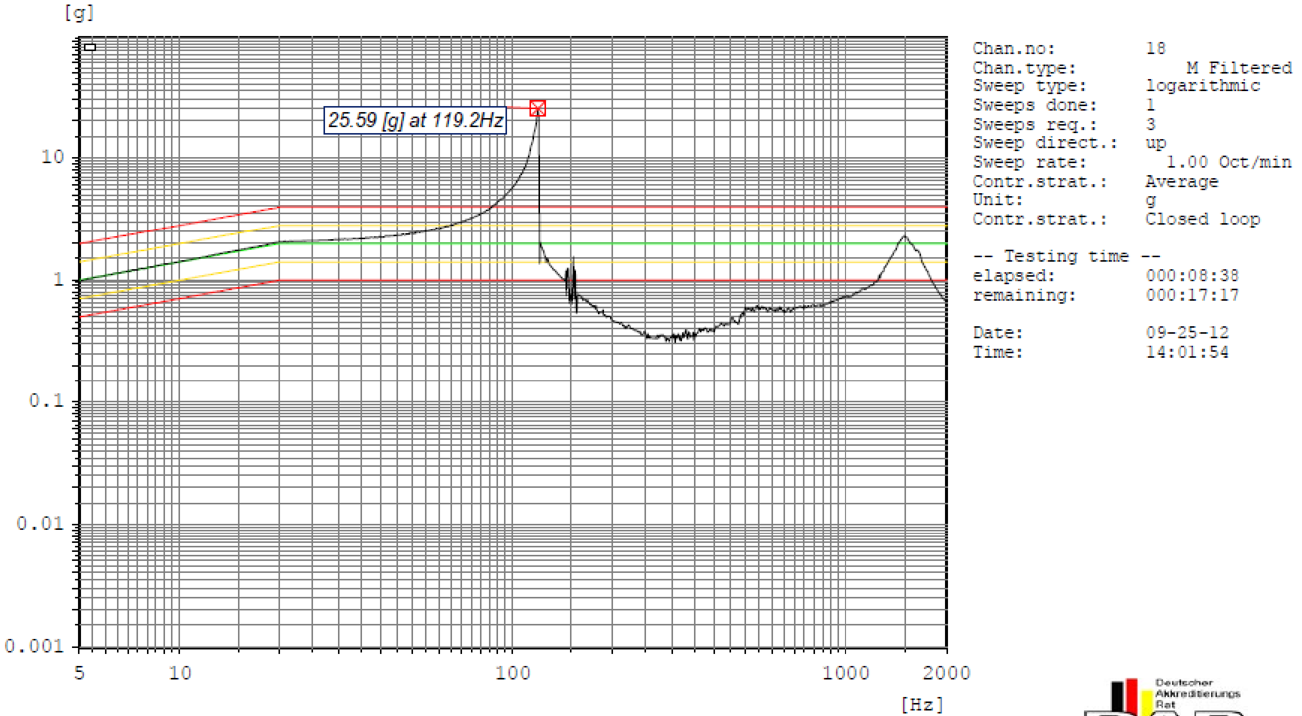
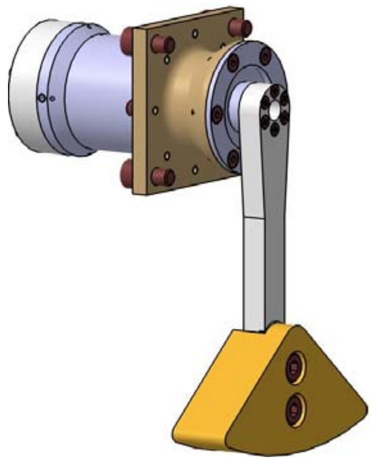
Mobility Subsystem – Mechanics – Shaker Test

Mechanical design optimization:

- Measure the eigenfrequency of the unit
- Optimize the stiffness of the single mass oscillator
    - Angular contact bearings
    - Improve connection motor shaft to eccentric arm





FEM calculations validated!

DAP-PL-3185.00

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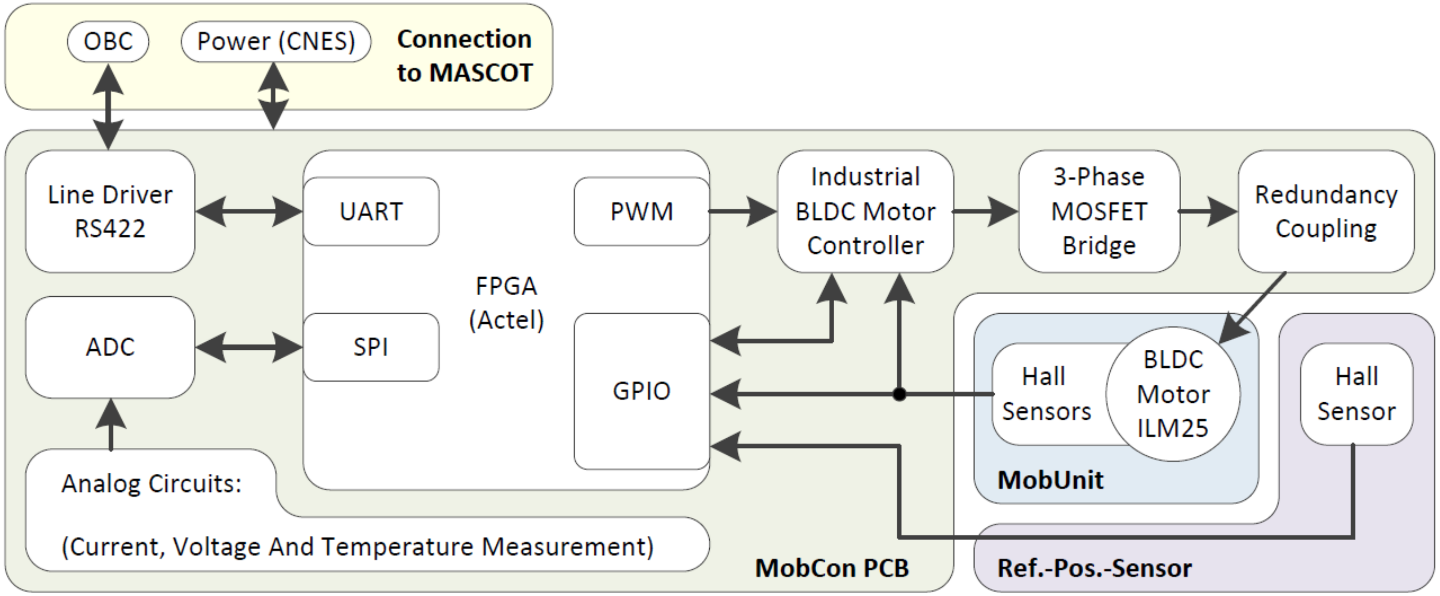
Mobility Subsystem – Electronics – Overview

- PCB electronics MobCon with two fully cold redundant signal paths
- OBC decides which path is to be activated
- Redundancy decoupling network
- FPGA (programmed in native VHDL)
  - Calculate the absolute position of the eccentric arm
  - Compute the control algorithm and safety features
  - Data collection and communication
- Error detection and correction algorithms in RAM implemented



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Mobility Subsystem – Electronics – Overview

Electronics PCB Qualification Model:

- Size: 95 mm x 105 mm x 18 mm
- Weight: ~200 g
- Mounted with wedge locks

Top-Side – Digital Electronics:

- FPGAs in CCGA Package (Microsemi)
- Line-Drivers RS422
- 12 Bit / 8 channel ADC
- Motor connectors

Bottom-Side – Power-Electronics:

- Motor controller (automotive)
- MOSFETs radiation tolerant and ITAR free (Infineon BUY25CSJ; European Component Initiative ECI)
- Shunt-Resistors

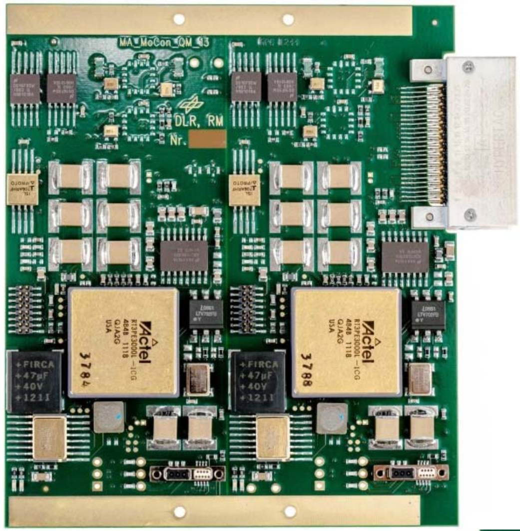

Fig.: Top side of the PCB

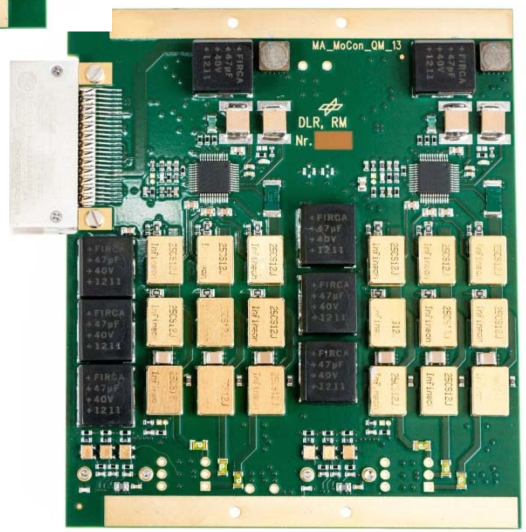

Fig.: Bottom side of the PCB

Mobility Subsystem – Electronics – Radiation Tests

- Radhard components for BLDC motor control could not be used due to their huge form factor and the need for voltage levels higher 12 Volts
- Spin-In of a BLDC motor controller and MOSFET driver is used (automotive part)

Most of the components are rad-hard with the exception of the Motor Controller (3-Phase BLDC Controller and MOSFET Driver)

- TID Test (Helmholtz Zentrum Berlin - Germany)
- Proton Test (Cobalt 60 source at Helmholtz Zentrum Berlin - Germany)
  Test of Single Event Latch-up sensitivity
  Tested energies: 68, 60, 50, 40, 30 MeV
- Ion Test (RADEF - Finland)
  Test of Single Event Latch-up (SEL) and Single Event Functional Interrupt (SEFI) sensitivity

Result:

- Limit is at 12 kRad (expected in mission 4.2 kRad)
- No significant disturbance or SEFI were monitored up till 27.4 MeVcm2/mg

Mobility Subsystem – Electronics – Thermal Tests

- PCB temperature in action
- Motor was driven with 50% PWM
- Laminar thermal dispersion in the PCB
- Hot spots are the line drivers for RS422 communication
- Note that the time for one hopping maneuvers is just a few seconds!
- PCB gets warm only a little even after 10 minutes!

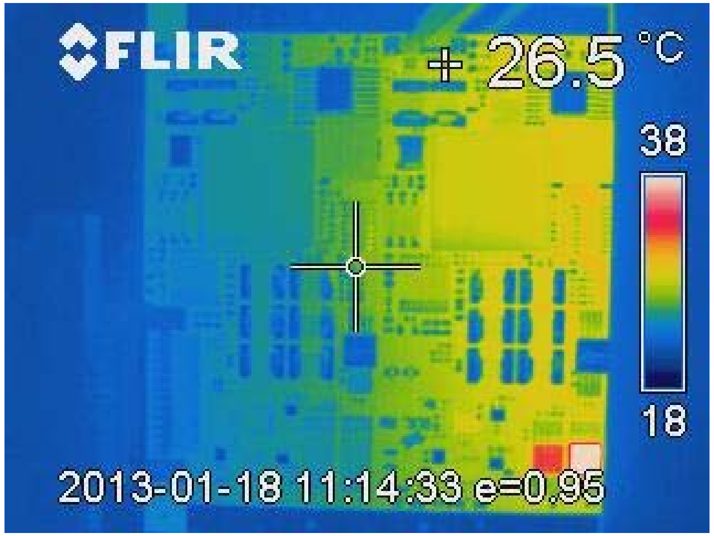

Fig.: Top side of the PCB after 7.5 minutes

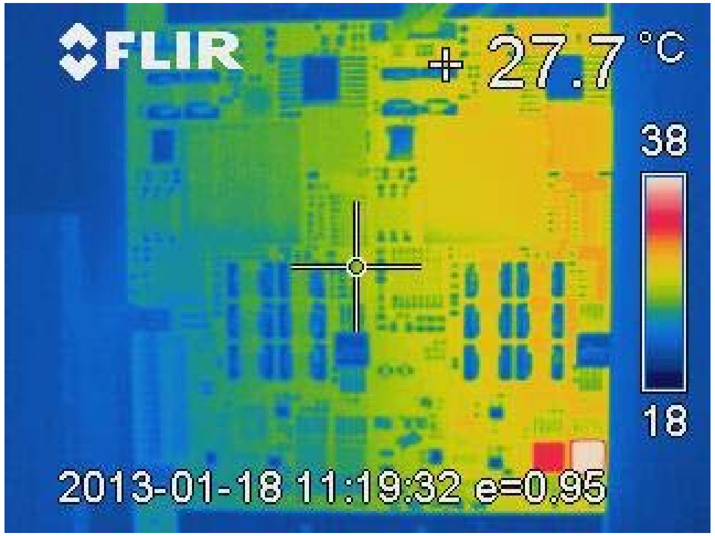

Fig.: Top side of the PCB after 10 minutes

Summary

- Development of a tightly packed motion controller PCB
- Mobility system working in rough space environment
- High power density drive unit
  - Size: 31 mm diameter with 64 mm length
  - Weight: 166 g
  - Output torque: 3 Nm
- High power density drive unit
  - Size: 95 mm x 105 mm x 18 mm
  - Weight: ~200 g
  - Power output: 12 V and 4 A nominal
- High reliability due to less mechanical parts and a fully redundant power electronics
- Module may also be used in other applications (Pan-Tilt-Mechanism)

Actually the flight model of this unit is being manufactured !

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