The CzechTechSat – A Space-friendly CubeSat-class Picosatellite

10th Annual CubeSat Developers' Workshop, Cal Poly, Apr 24th 2013, San Luis Obispo, CA, USA

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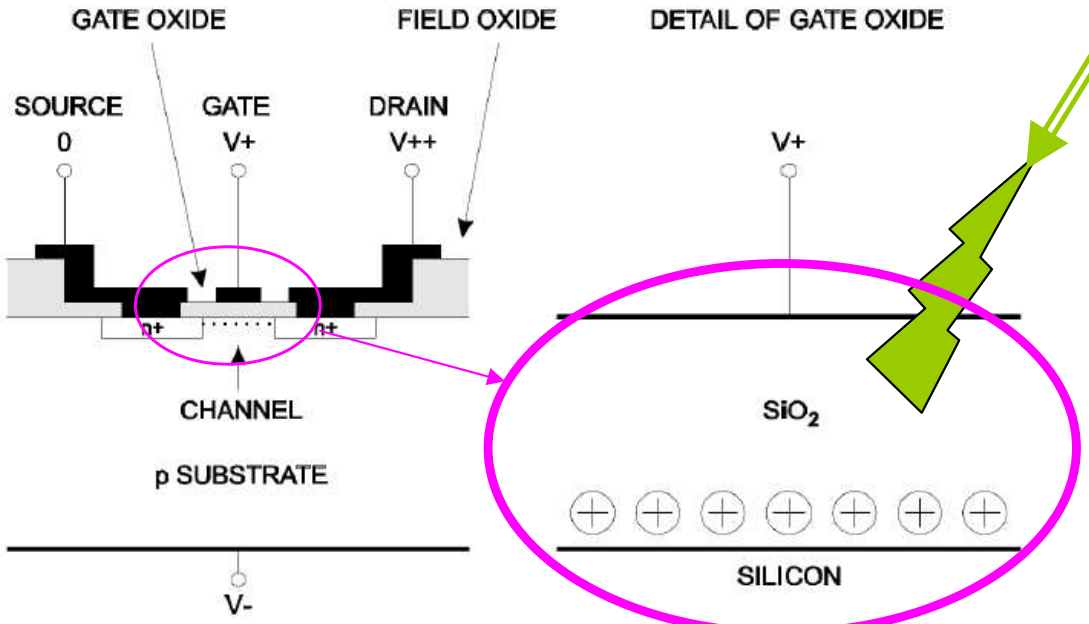
CzechTechSat Objectives & Design Drivers

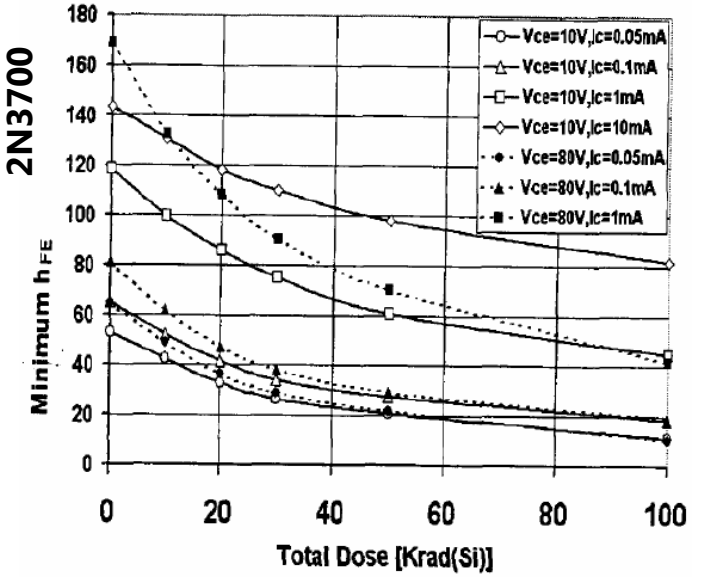
- build a „space-friendly“ platform in terms of rad.
- prove radiation tolerance concepts in real environment
- learn the space engineering
- to give students the ‘Space’ hands-on opportunity
- to proof Low-noise Fluxgate Magnetometer
- to proof Langmuir Probe instrument concept
- to build and fly ‘the first Czech’ CubeSat

Image credits: *Steve Vance, http://www.aeroflex.com/ams/news/articles/cos-EconomyClass.pdf*

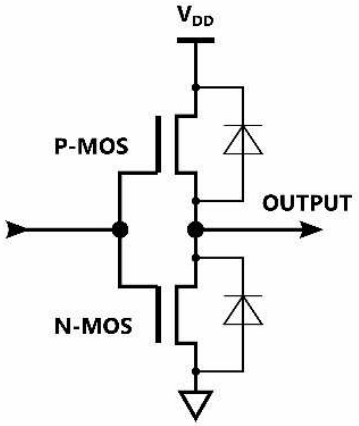
Semiconductors vs. Reliability

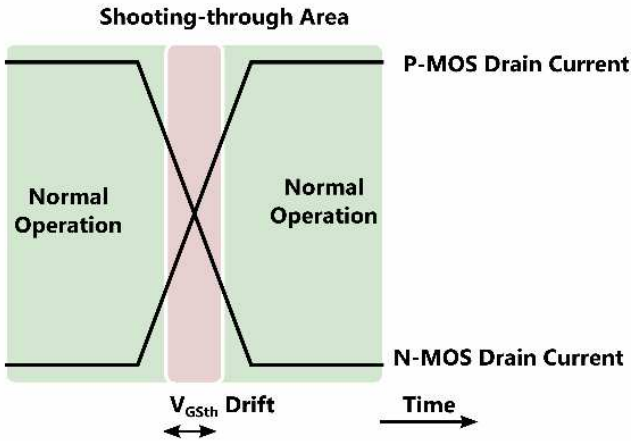


BJT - gain decreases (only) 10-100×



- Charge deposition ⇒ charge growth
- Charge in insulator ⇒ **channel becomes opened, V_{TH} decreases**
- Charge cannot be removed (only a little bit by the tunnelling, leakage, long term annealing…)





In **CMOS:**

⇒ **(1)** Dynamic losses increases

⇒ **(2)** Static losses increases

⇒**(3)** Short-circuit occurs (burnout, etc..)

In **BJT, JFET**:

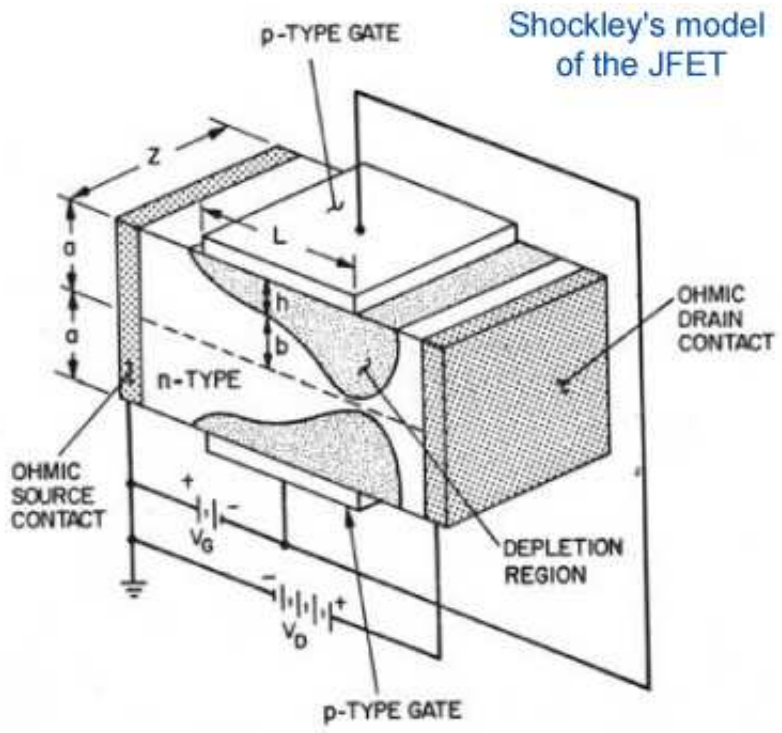
⇒ **(1)** Gain decreases, but **still** switching

Image Credits: http://www-physics.lbl.gov/~spieler/radiation_effects/rad_tutor.pdf

Image Credits: http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/38472/1/03-1928.pdf

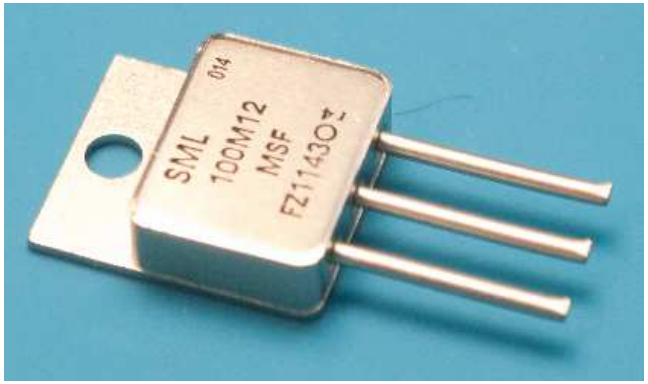
Radiation Effects in JFETs – EPS Switch Candidate

- **JFET** without insulated gate to deposit parasitic charge



- Highly doped channel (10^{15} - 10^{18} n/cm^3) ⇒ Sensitive to overdopping at very high doses

- Black, M. N. 2011: *High Energy Gamma Radiation Effects on Commercially Available SiliconCarbide Power JFET Transistors – Semisouth SiC JFET – survived **7 MRad**!*



- New TT-Electronics Semelab **SiC JFET** for **Aerospace**

- **Non-ITAR** product

- Type SML100M12MSF, cheap (200 Eur/pc.)

- **N**ormally-**Off JFET**

- Very High Power switching capability 1200V/17A = Margin

- R_{DSon} = **100 mΩ** @ 17 A, C_g = **650 pF** ⇒ **Low Switching Losses**

- Driving voltage 0 Volt (1 mA leakage) to 3 Volt (fully opened channel)

- Wide bandgap (2,9 eV) - can operate at high temperatures (SiC chip up to 500°C), bulky package (TO-257AA)

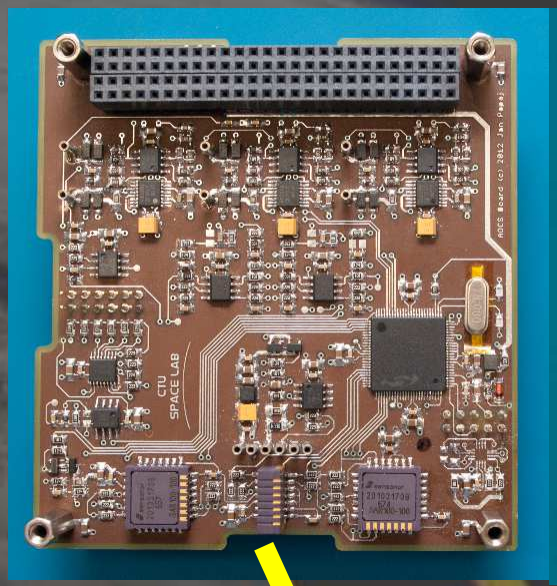
- New product = not Space Qualified, **no Rad Data available**

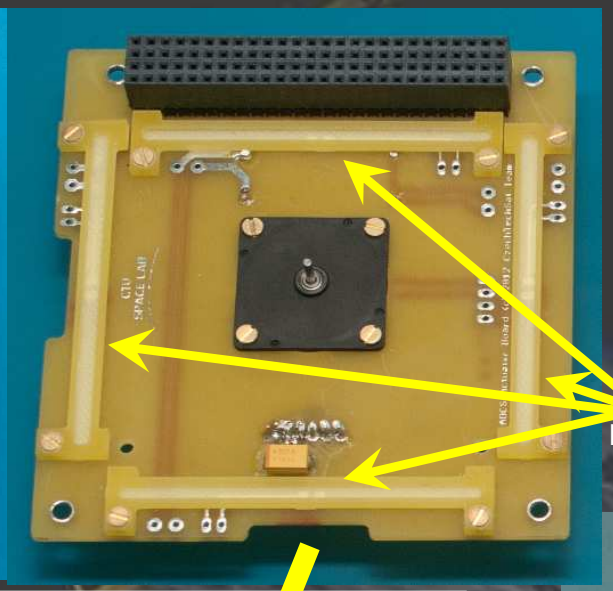
http://subodhtripathi.files.wordpress.com/2011/11/1950s-shockley-model-of-jfet.jpg

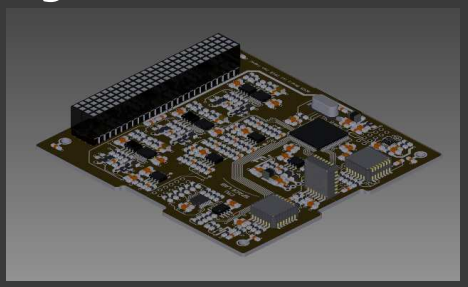
Attitude Determination and Control Subsystem

FEATURES:

- 1× AMR Magnetometer
- 3× MEMS Gyros 100°/s (5000g shock survival)
- 3× MTQ (2× Vitrovac Cores, 1× Air Coil)
- MTQ Driver with Electromagnetic 'Brake' Mode
- MTQ Temp and Current Measurement
- 1× Reaction Wheel, Vacuum-Proof **BLDC** Motor
- 6× Photodiode Sun Sensors inputs
- HK Measurements
- Doubled Data Bus
- Smart Power Management
- IGRF-2010 model
- Kalman Filtering
- Compact Set

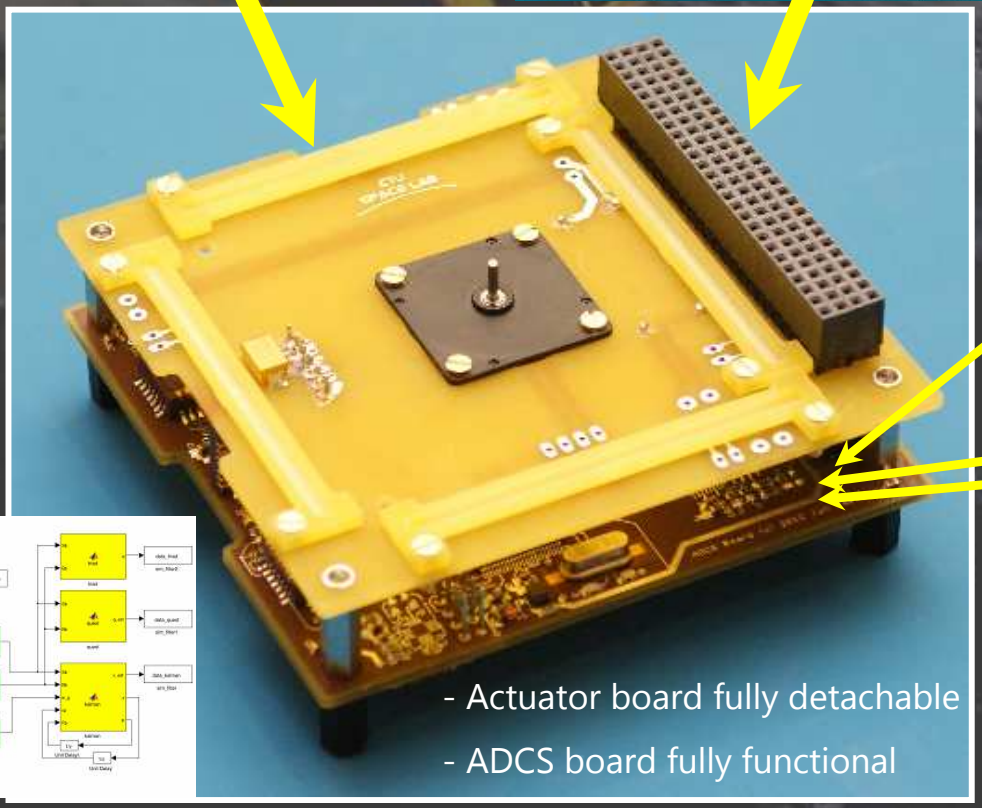




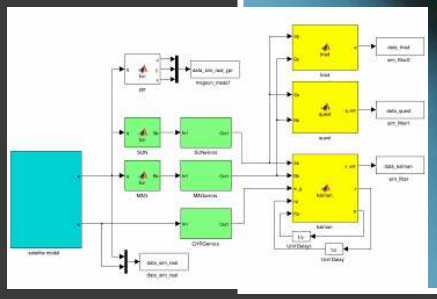


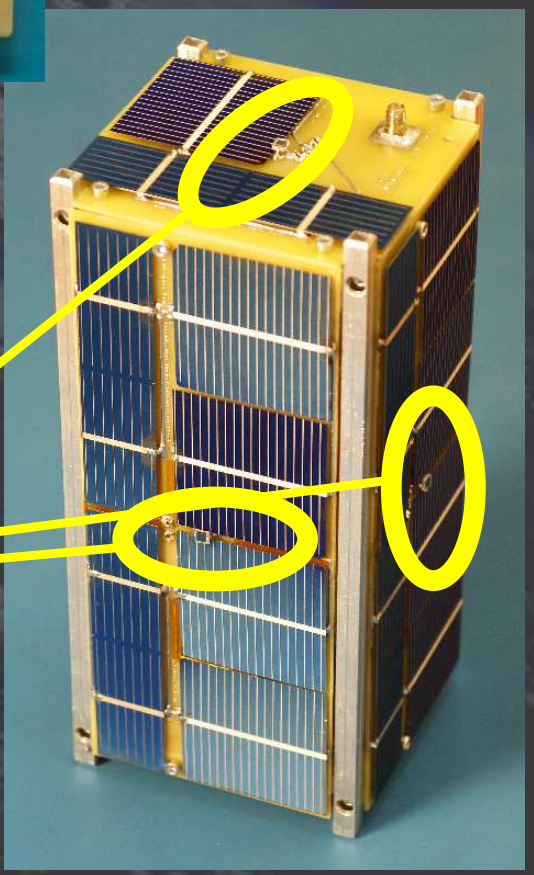
ADCS - Center-of-Gravity (CoG) Digitally Determined

MTQ Holders with groove for high permeability magnetic core

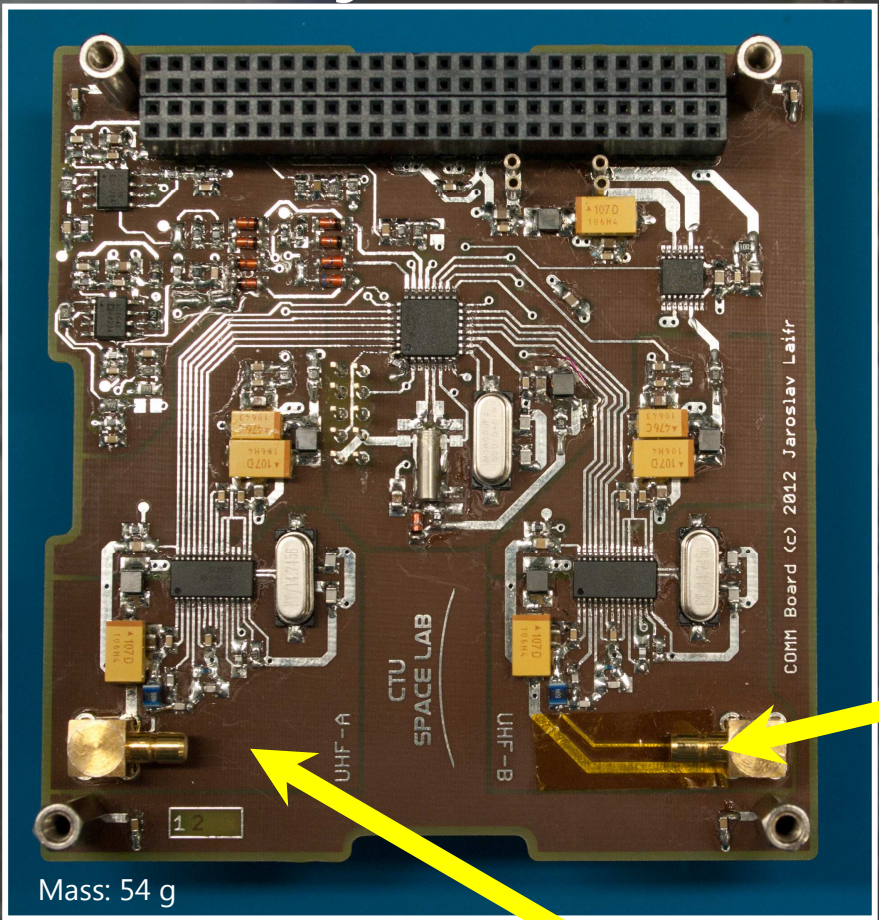


- Actuator board fully detachable
- ADCS board fully functional





Communication subsystem – UHF transceiver



Mass: 54 g

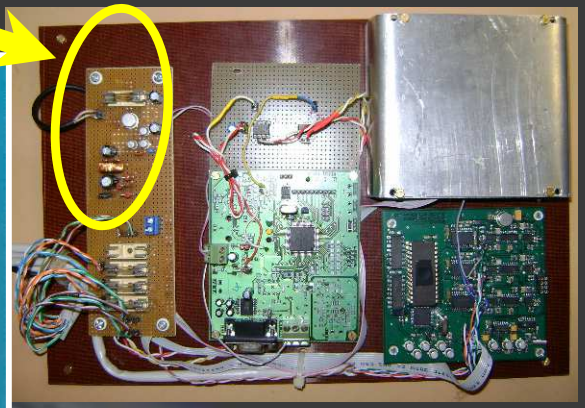
FEATURES:
- 2× 435 MHz Band TRX
- TI's CC1000-based
- Up to 76800 Bps
- HK measurements
- Sensitivity -110 dBm @ 2400 bps w/o LNA

RELIABILITY IMPROVEMENTS:
- Backup DTMF for Uplink Planned, AX.25 TNC + FEC
- Beacon Mode (TX+PA)
- VHF Uplink planned (RX+LNA)
- Wide Voltage Input of Control MCU (2.0 – 5,5V)
- Power Switch + Fuses
- Doubled Comm Bus TRXes based on Derivators

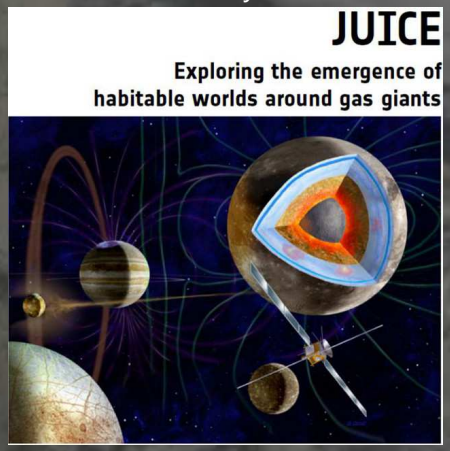
Deployable UHF/VHF RHCP/LHCP antennas, JFET-based LNA under development

Electrical Power Supply

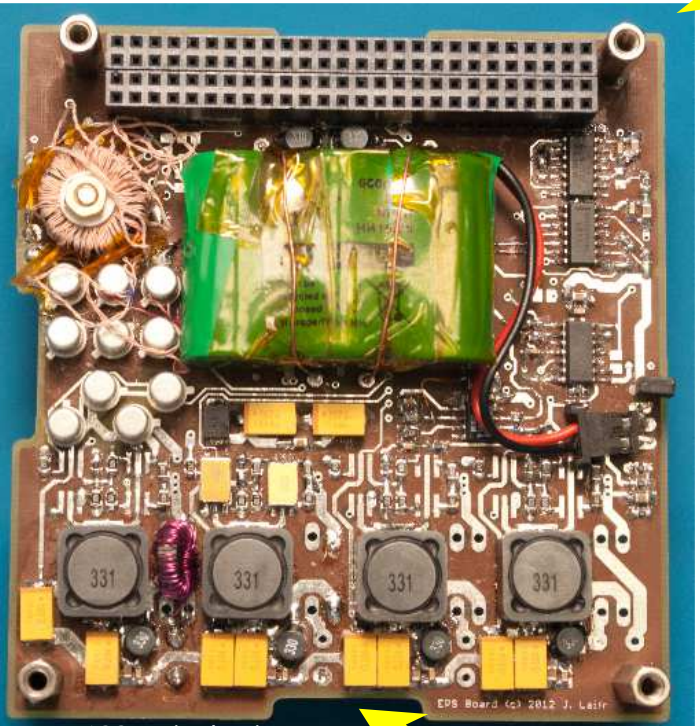
BJT-Based Step-down DC/DC $30V_{DC}/5V_{DC}$ 300 mW survived **363 kRad(Si)!**, Laifr J., Diploma Thesis, 2011



Precursor for **ESA/JUICE/RPWI Low Voltage Power Supply** to be flown to **Jovian** system in 2022



Note: NiMH Pack implemented to minimize safety risk during development



Mass: 39 g

Mass: 133 g (incl. NiMH)

2U/1side/Si-cells - 2,6V & 700mA = 1,8 W

FEATURES:

- BJT Power Switches (radiation)
- Discrete MPPT Regulator Step-up (charger), Main Converter Push-Pull, Nanocrystalline **VITROPERM Core** (high permeability, ultra-low losses)
- Assumed 2× **A123** 18650 **$LiFePo_4$** 3,2V Cells, 2×1,1 Ah
- Four Separated Step-ups, (due to BJTs η ~ 70%)
- BBM Output power (from Battery) ~ 0.8W @ 5V + 1.4W @ 3V3
- 3-4 sides covered by **Si-cells**, 2-3 sides covered by **GaAs/GaInP/Ge TJ** Cells

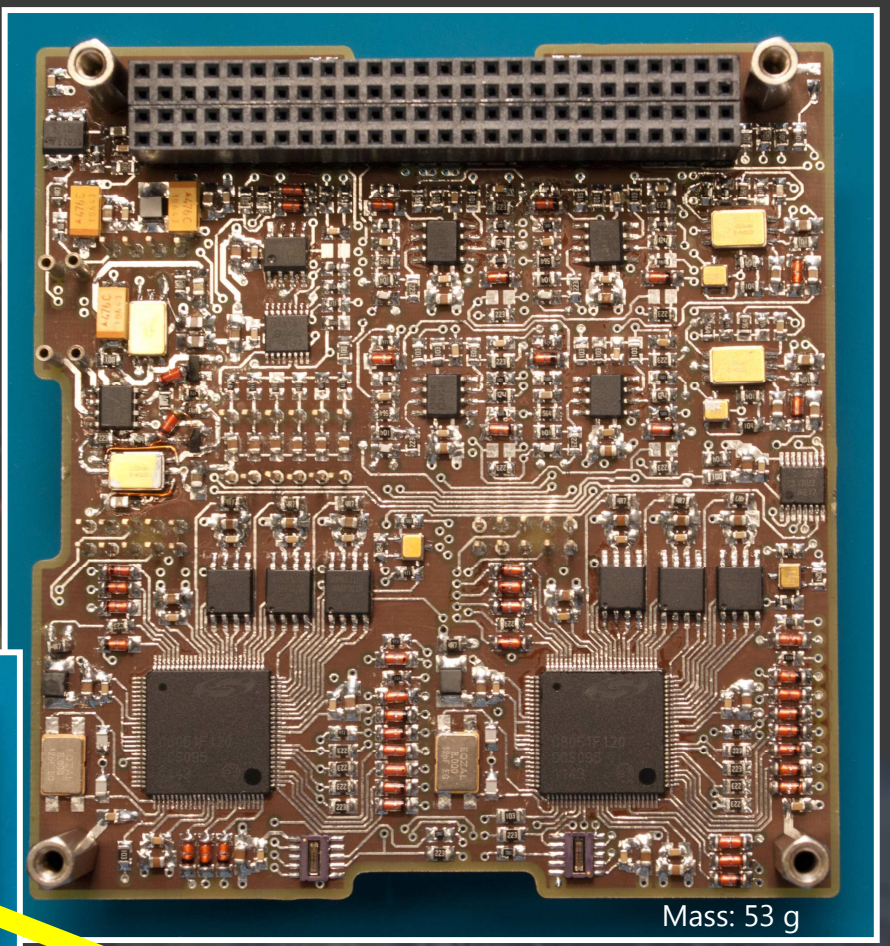
RELIABILITY IMPROVEMENTS:

- **Discrete Design,** finally only **3 SiC JFETs** needed
- SiC JFET Design Ongoing, Multi-input Choke TB implemented into One

Cold Redundant OBC

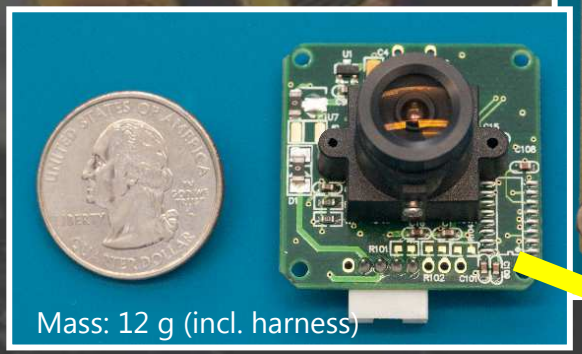
FEATURES:

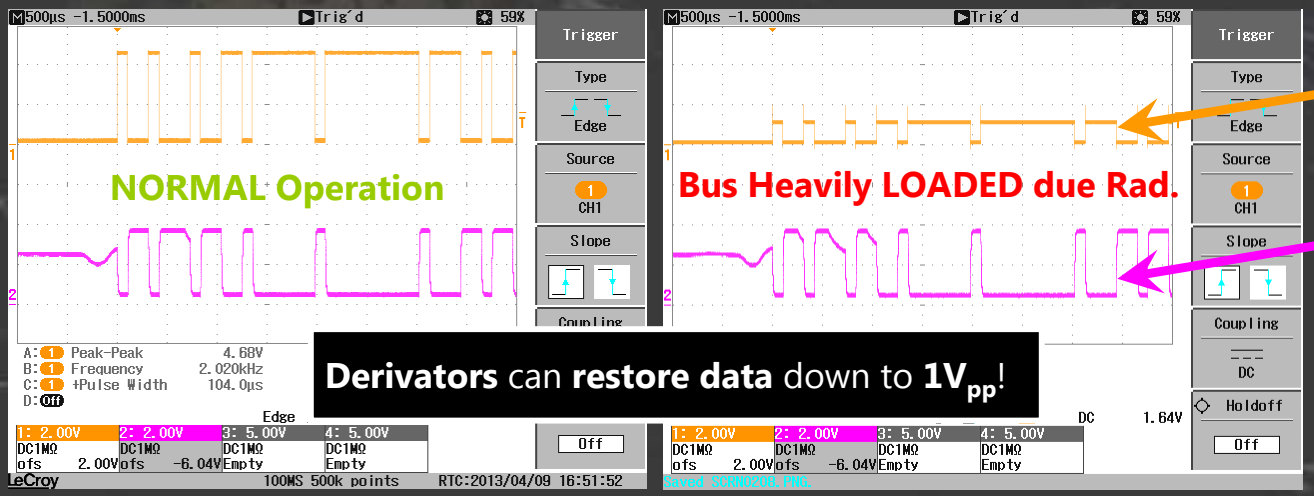
- 2× Silicon Laboratories Flash-based **8051** 'flight proven' MCUs
- 2× Triplets of serial FLASHes 32Mb used as data buffer
- 2× RTC for Data stamps, uptime
- Digital VGA Cam input (TTL UART Cam)
- Complete HK measurements
- JFET&BJT-based linear voltage regulators (3V3)
- Distrubutes RESET signal to All Subs
- **8 MIPS @ 80 mW/5 V** (with Cam ON 190 mW)



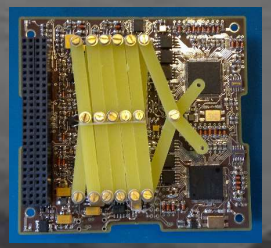
RELIABILITY IMPROVEMENTS:

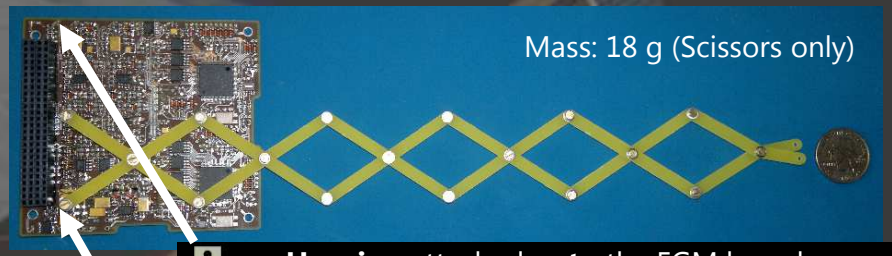
- **Discrete Power Arbiter** with fuses
- 2× **Discrete** BJT-based **WDTs**
- Doubled Comm bus (Master)
- **TMR** Implemented for **Data** R/W
- Bus Drivers based on Derivators





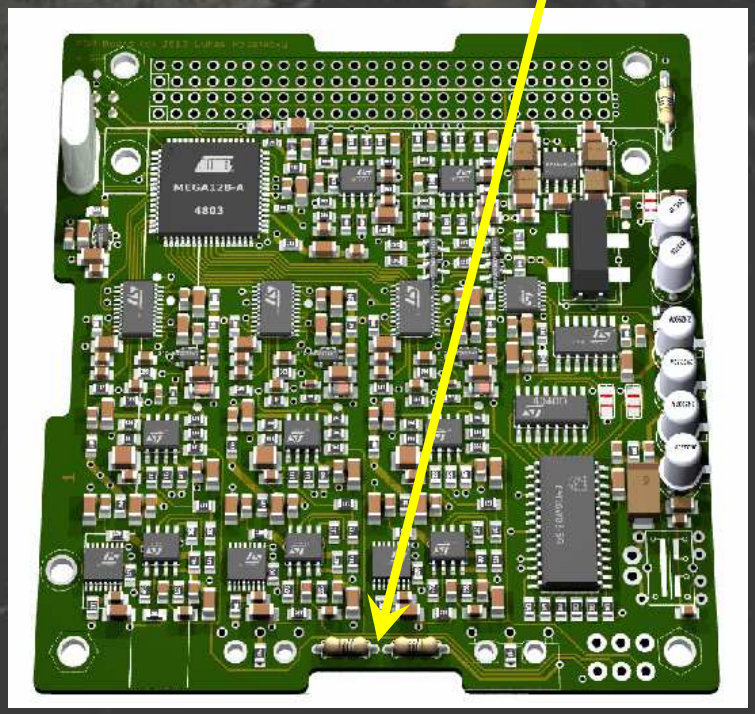
Low-Noise Fluxgate Magnetometer with PWM-based Coherent Demodulation and Non-magnetic Detachable Scissor Boom

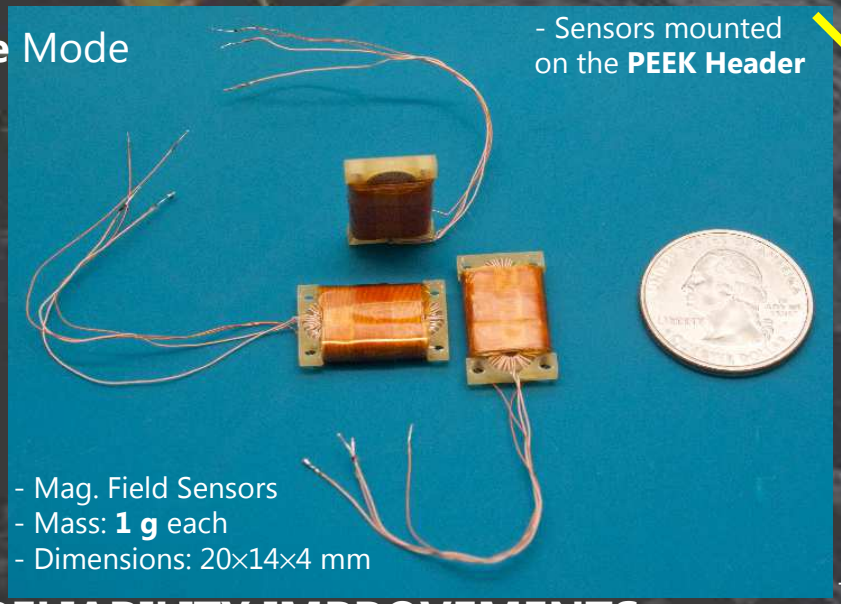




FEATURES:

- Low-noise Fluxgate Triplet (**15pT**/√Hz @ 1Hz)
- **Boom** with electronics **fits** single board volume, incl. Doubled Firing (resistors+separation switches)
- **1W / 10 s Firing**
- **250 mW@5 V Operational, 1 mW** in **Idle** Mode





- All - Non-magnetic **Brass Joints**

RELIABILITY IMPROVEMENTS:

- FRAM for the PWM-Sinus Data Samples (digi excitation & demod.)
- MOSFET-based power switch + additional fuse (OC won't kill S/C)
- 3× AD7714-5 type, 3ch each, **24-bit Σ-Δ** ADC, **TMR** cross-strapping
- Each channel digitized also by the internal ADC in MCU (10 bit)

Langmuir Probe Experiment

FEATURES:

- Two separated inputs for Langmuir Probes
- Plasma I/V Curves determination (± 50μA, sweep ± 12V)
- Plasma Potential measurement (± 1500 V)
- Controlled **Floating Ground** potential (-15 up to +50V)

Intended to ESA/Lunar Lander/Lunar Dusty Environment and Plasma Package (**L-DEPP**) together with L-DEPP consortia leaded by Astronomical Institute, AS CR

- Current version 160×200 mm (6.3×7.8")
- Planned as a miniaturised PC/104 version for CTS

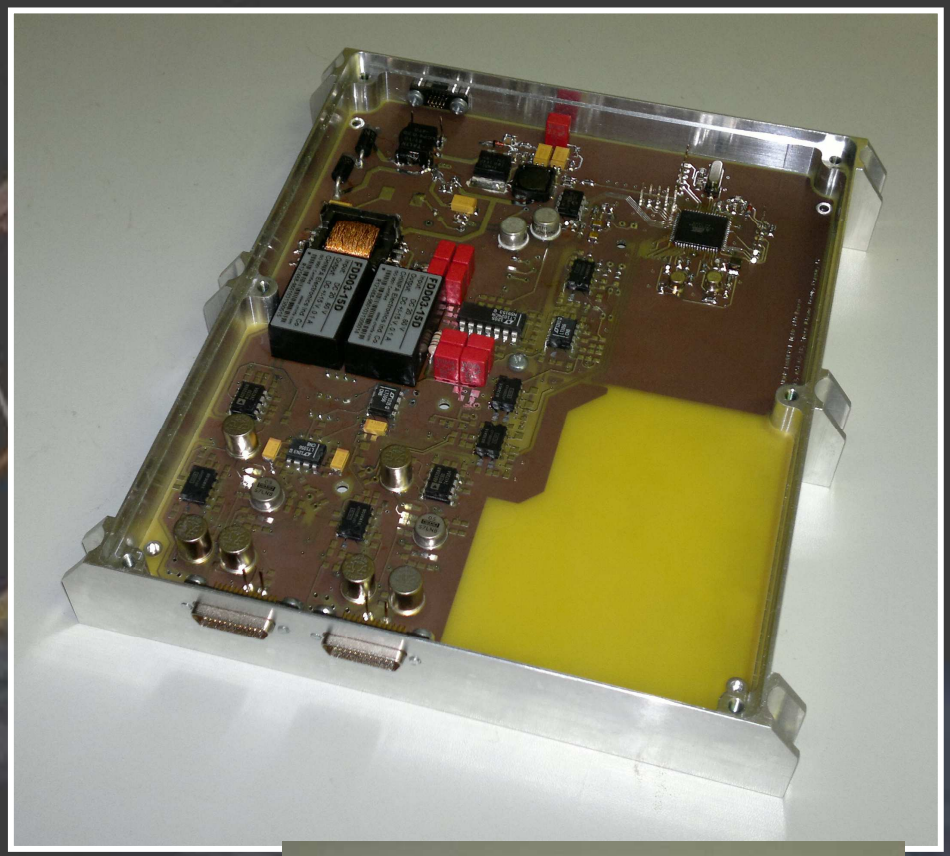
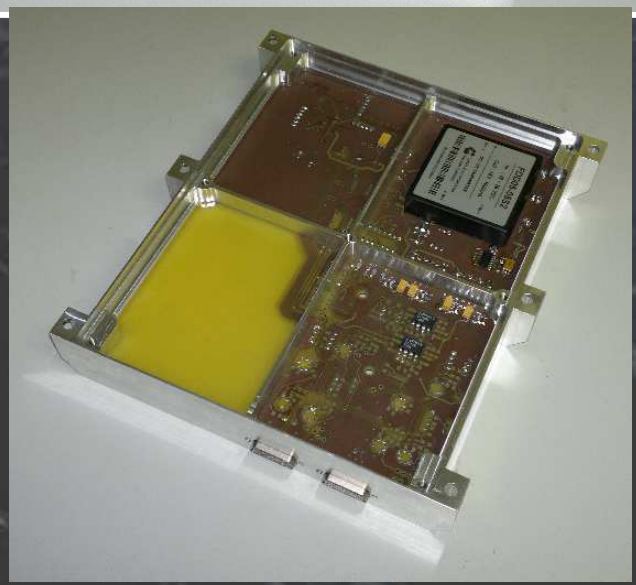
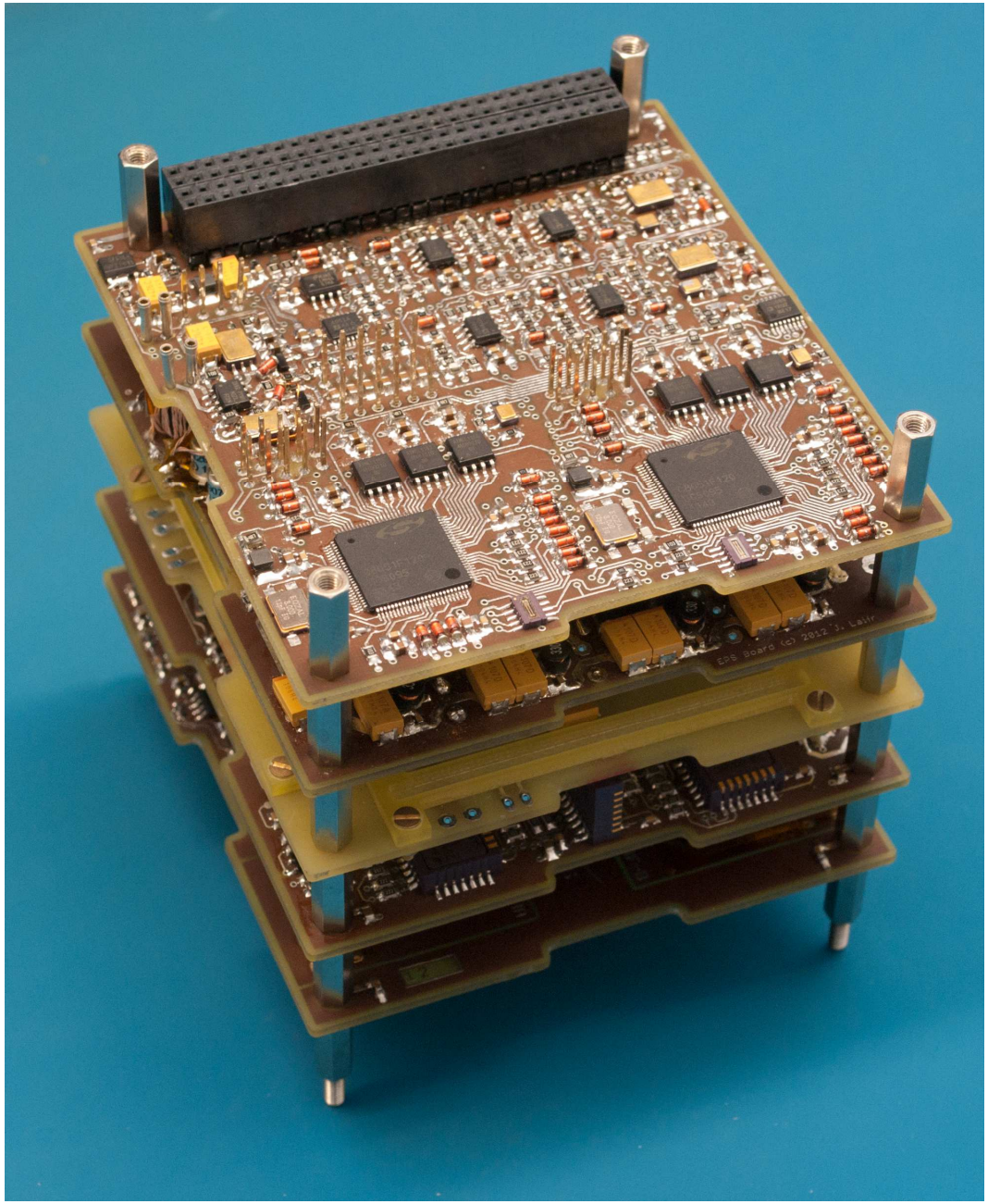
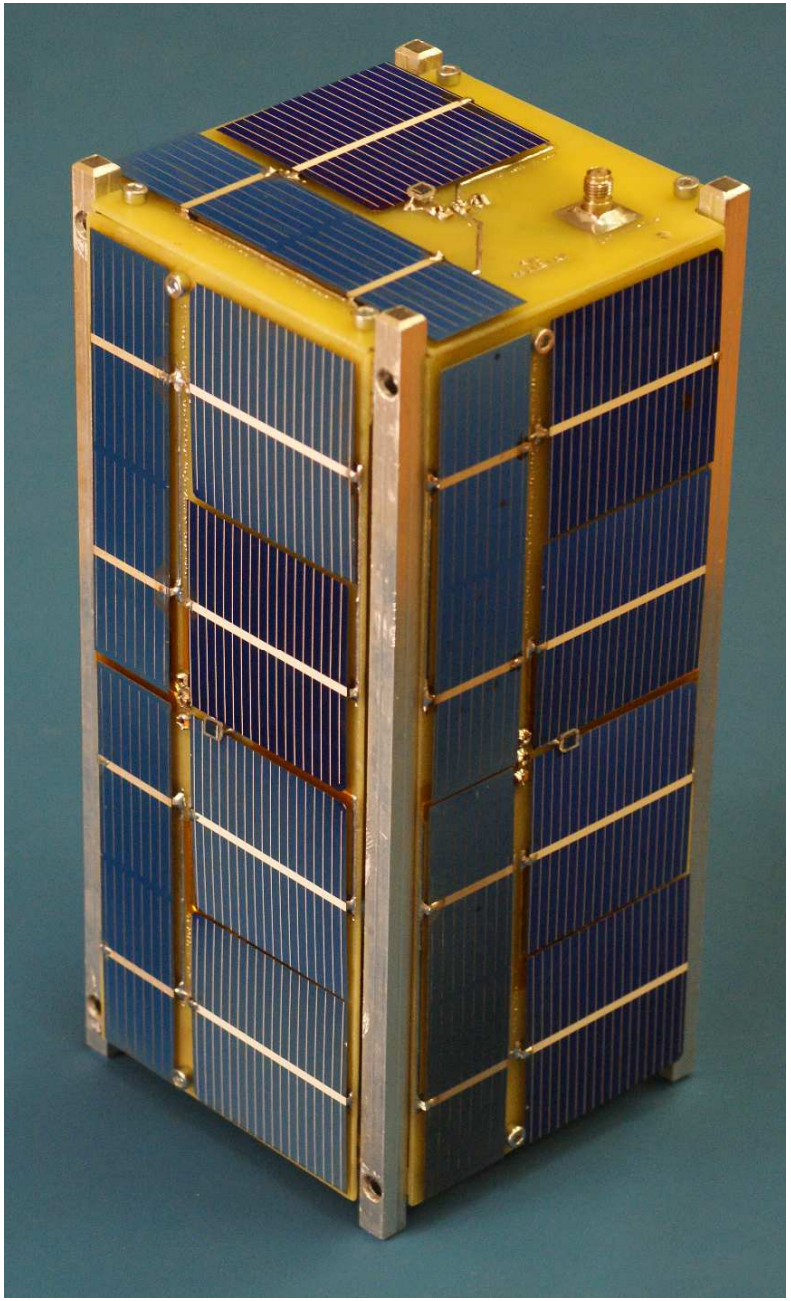


Image Credits: ESA



CzechTechSat Breadboard Model





The ‘Tiny Solar Simulator’ – a ‘Space’ on the Earth

160 × 30 × 35 cm (63 × 11.8 × 13.8”)

- Planned: Optical-based magnetic levitator (easy implementation)

- Satellite hanging on thin 1 m/3ft long thread

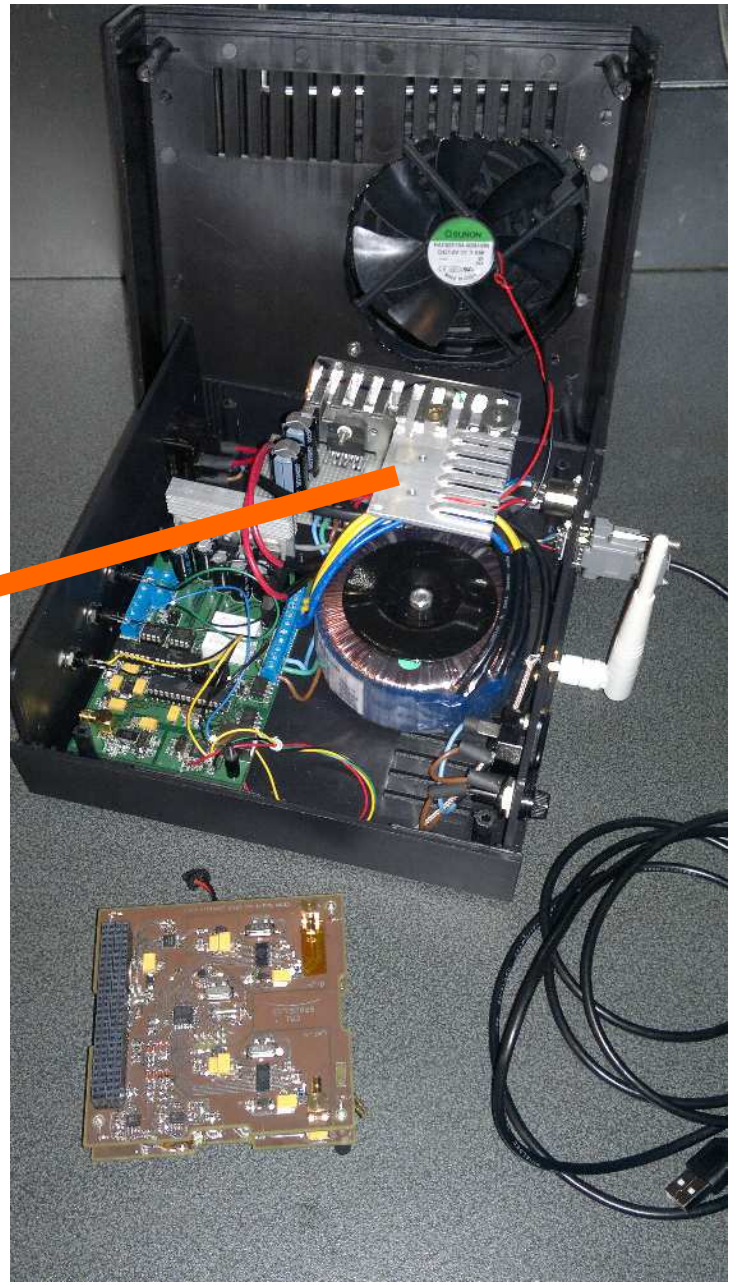
- Simulates: Single degree of freedom, Solar power input, Structure Heating

- Helmholtz Coils (~1000 m / ~3300 ft) of coil wire

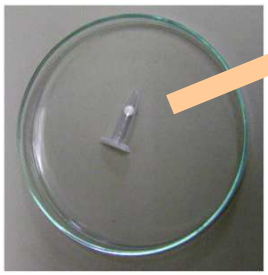
- Linear Halogen light 200 W - equal to **Sun** at **LEO** (~1200W/m^2)

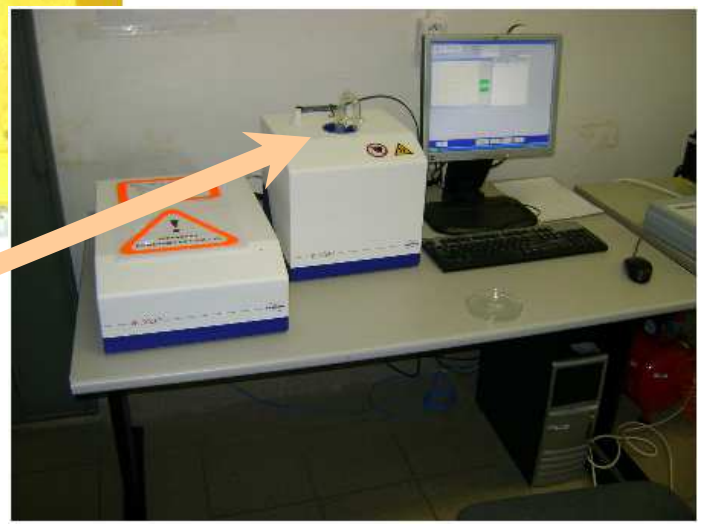
- Interface with UHF TRX

- Helmholtz Coil drivers manufactured (± 300 µT)
- USB
- PC SW developed



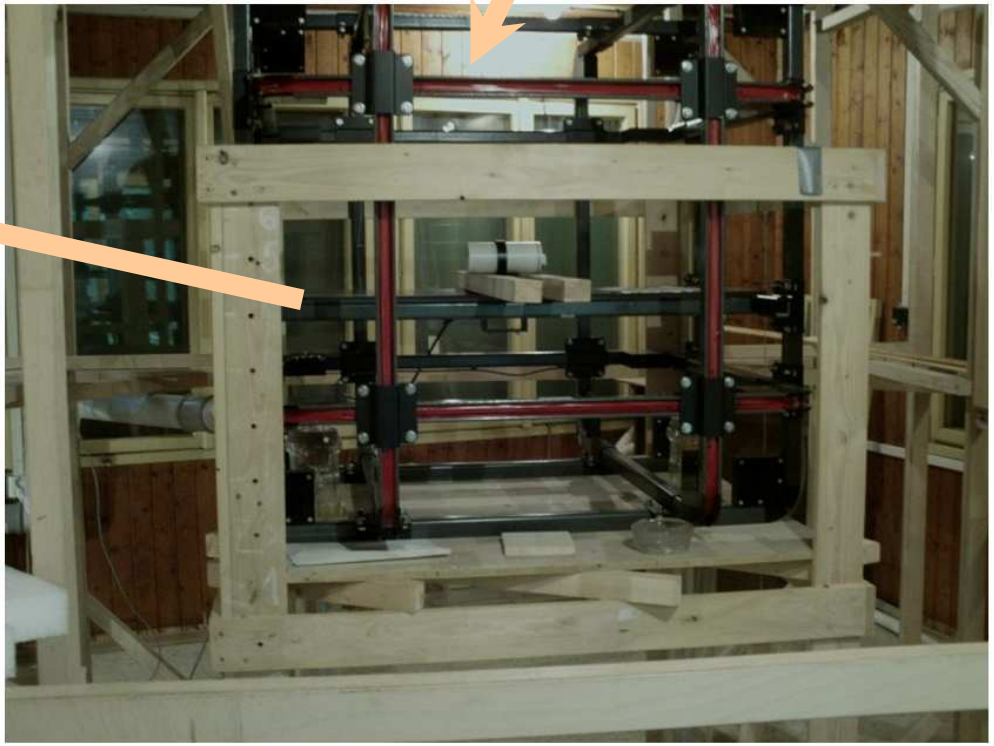
Supporting Facilities – UJV Rez, plc. – TID Tests





- ^{60}**Co γ-irradiation well** for **TID** tests
- **Dose Rate** down to **600 mRad/s**
- **Alanin/EPR Dosimetry**

Supporting Facilities – Pruhonice



- **Non-magnetic Calibration Facility**

-**Billingsley Aerospace & Defense Helmholtz Coils** inside of **2 m Braunbek coils**

- **Geomag. Field** can be **cancelled, artificial** preciselly **created**

Supporting Facilities – MAGLAB

www.MAGLAB.cz
Sensors and Magnetics Laboratory

+

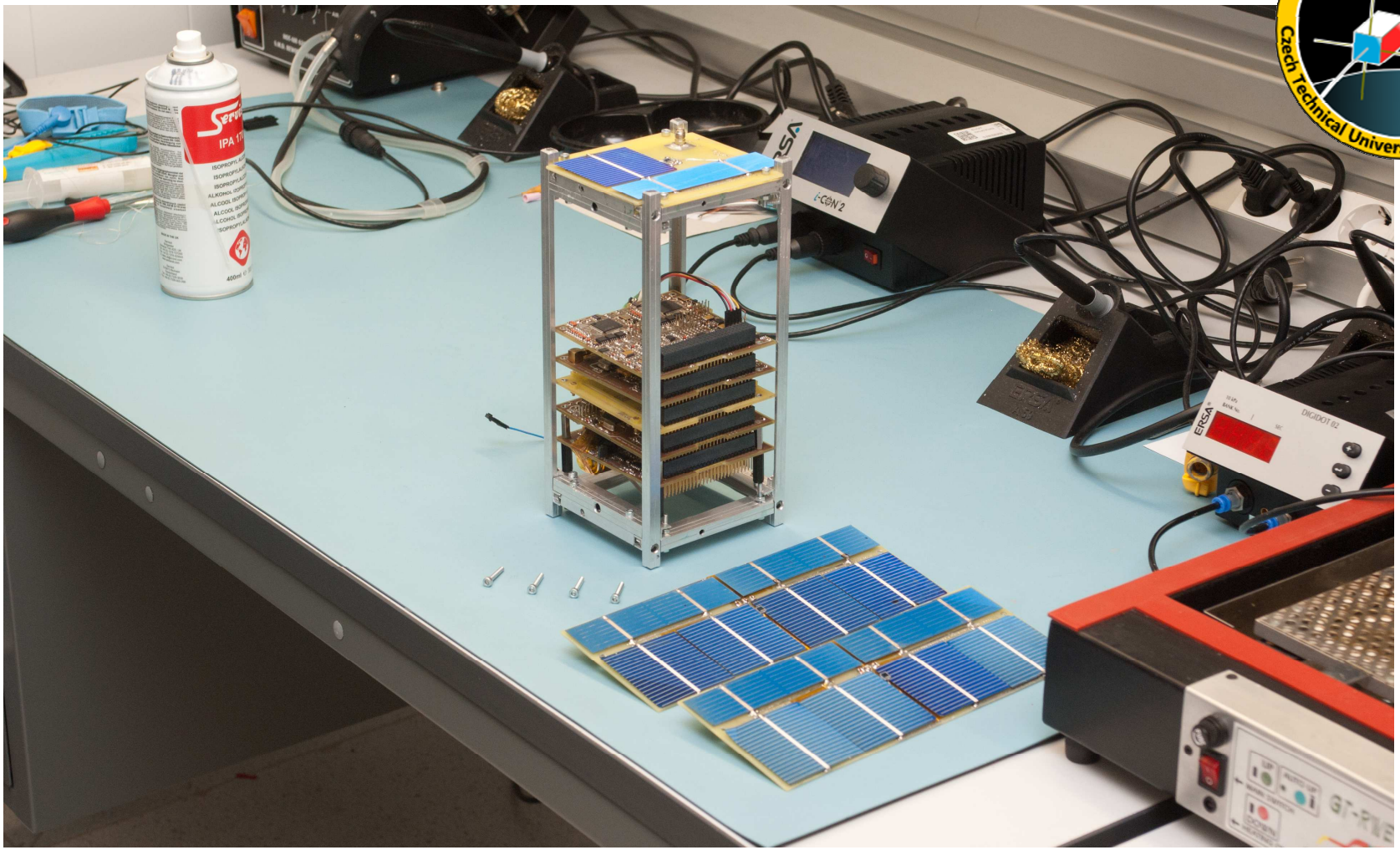
Technologická agentura České republiky

- Magnetic calibrating facility for offsets and noise of magnetic sensors

- **Thermostated chamber -30 up to +90°C**

- **Guaranteed shielding factor** of **100.000× @ DC**

Conclusion & Outlook



- 9/2013 submit a proposal for ESA/BEXUS 18/19 (Strato Balloons), take a photo from the edge of Space
- continue in CTS development for next EU/Non-EU Launch opportunities
- go to 1U structure
- test the CzechTechSat avionics under irradiation

Stay tuned at 435 MHz!

73 de RS0CTS