CDSM – A New Scalar Magnetometer

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Outline

- CDSM = Coupled Dark State Magnetometer
- scalar magnetic field measurement device
- completely new measurement principle
- simple sensor unit design
  - no excitation coils
  - no dead zones
  - no double cell unit
  - no moveable parts
- less resource-demanding instrument design (500g, 1W)

Contents

- Introduction of involved institutions
- Why Scalar Magnetometer?
- Introduction of the CDSM principle
- Development of CDSM at IWF and IEP
  - current setup and performance
  - future setup, expected resources and performance
- Advantages of CDSM in space
- Challenges of CDSM in space
- Outlook

IWF and IEP

- Space Research Institute (IWF) of AAS in Graz, Austria
  - development of fluxgate magnetometers, satellite potential control units, atomic force microscope, electron drift instrument ...
  - involved in Cluster, Rosetta, BepiColombo, MMS, etc.
- Institute for Experimental Physics (IEP) of TUG in Graz, Austria
  - focus in optical spectroscopy
  - CDSM invented by IEP senior scientist Roland Lammegger

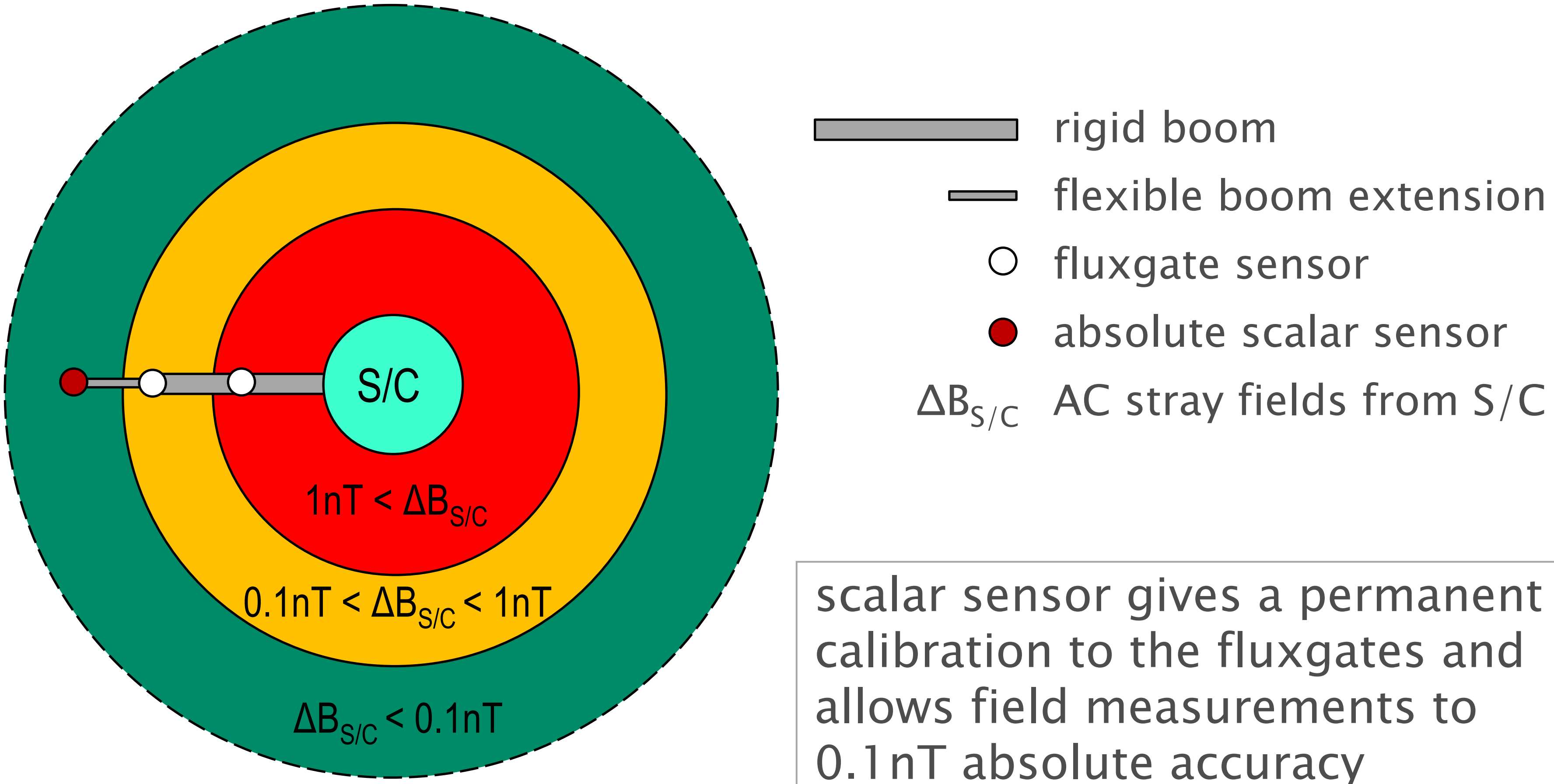
Why Scalar Magnetometer?

- fluxgate magnetometers require in–flight calibration in solar wind condition or frequent S/C roll–manoeuvres for offset determination and a final absolute accuracy of better than 1nT
- especially on a 3–axes stabilized S/C the boom should be in addition more than 3m long or a very stringent magnetic cleanliness program is required, respectively
- the fluxgate sensor would have to be extremely temperature stable and might require heater power for a tight regulation of the sensor temperature
- during the science phase, both EJSM S/C won’t be in the solar wind

ideal configuration for an absolute accuracy of better than 1 nT:

Ideal Sensor Suite

- fluxgate gradiometer on 3m long rigid boom and flexible 1-2m long boom extension for light weight, scalar sensor



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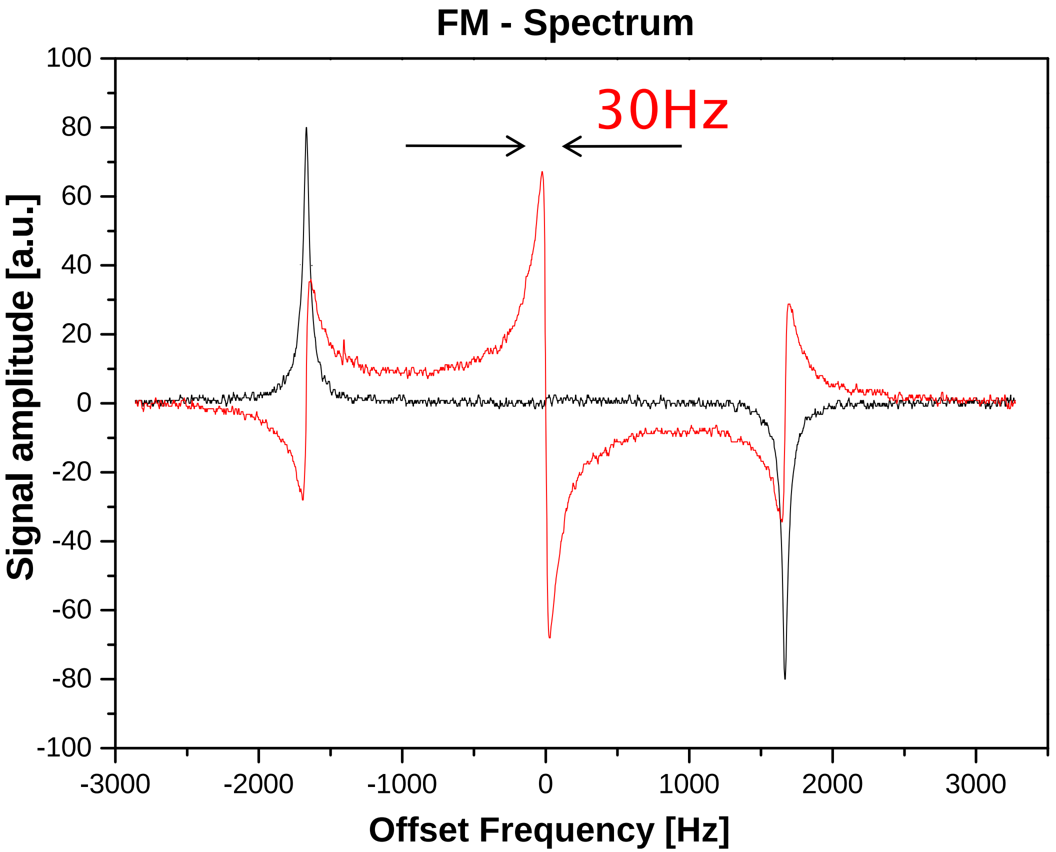
scalar sensor gives a permanent calibration to the fluxgates and allows field measurements to 0.1nT absolute accuracy

Measurement Principle

- CDSM = Coupled Dark State Magnetometer
- excitation of free alkali atoms using a multi chromatic laser field
- Zeeman effect: measure splitting of a spectral line into several components in the presence of a magnetic field
- Coherent Population Trapping (CPT) effect = quantum interference effect
- magnetic field measurement = frequency measurement + well-known natural constants (using Breit-Rabi formula)
- CPT: narrow (strict) constaints

Measurement Principle

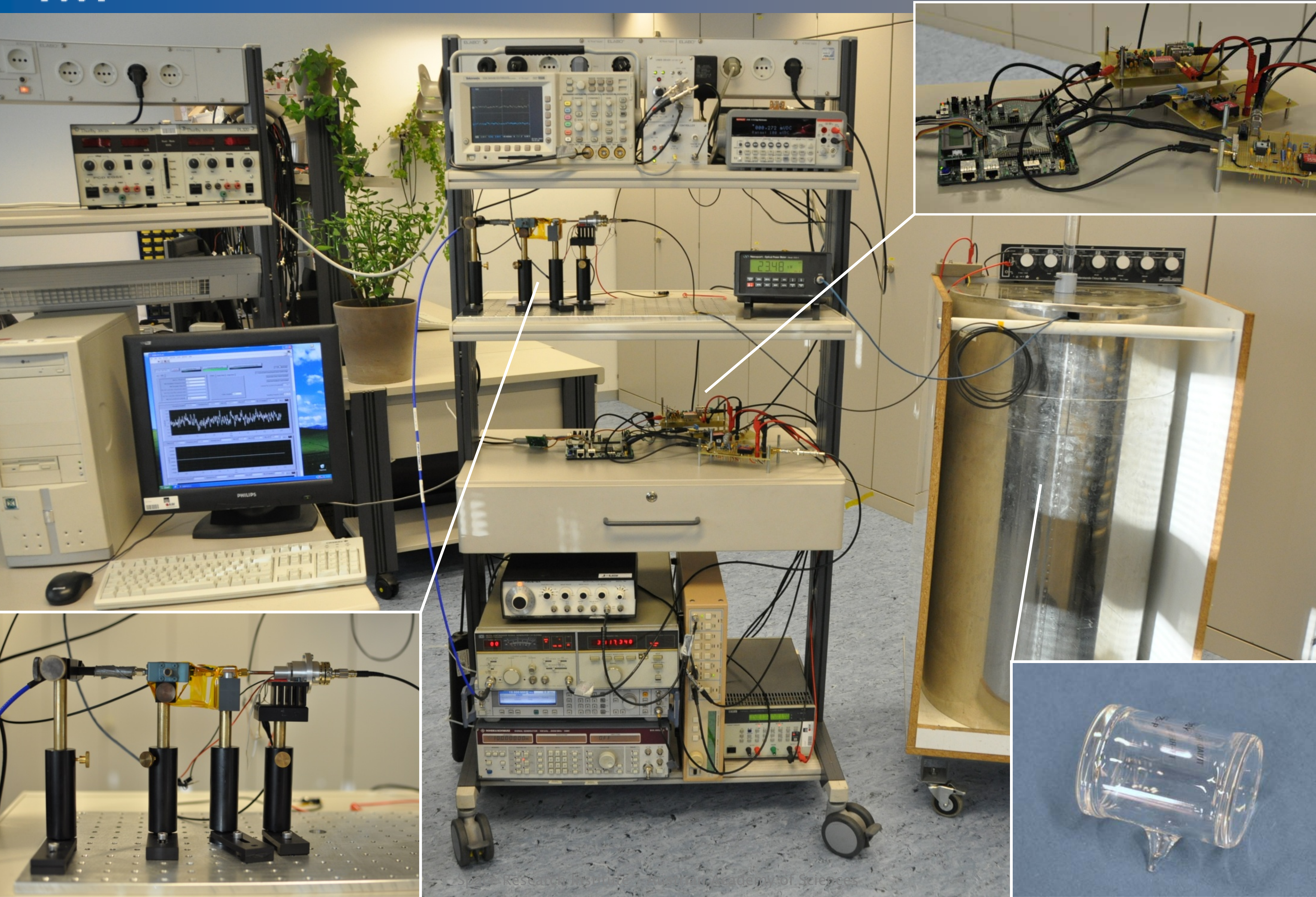
- very narrow line width of CPT or so called Dark State effect: 30Hz
- extremely high slope at zero crossing -> very accurate frequency value -> very accurate magnetic field value



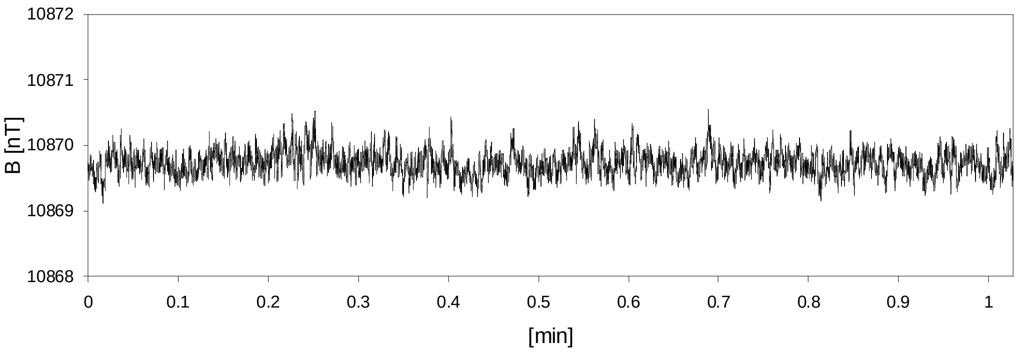
Measurement Principle

- single CPT resonance
  - frequency depends on the external magnetic field AND the temperature (because of buffer gas in sensor cell)
  - NO distinction between temperature and magnetic field changes possible
  - not usable for scientific space applications
- BUT temperature dependency can be cancelled out by coupling two CPTs in parallel: CDSM
- CDSM: magnetic field measurement is NOT temperature dependant

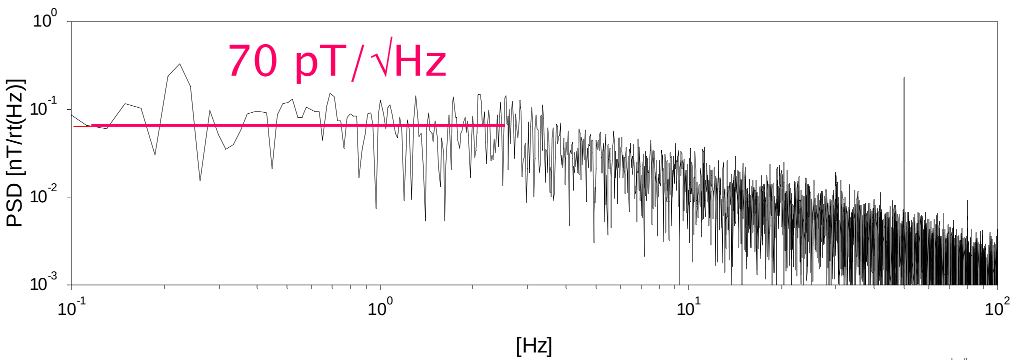
Current CDSM Test Setup

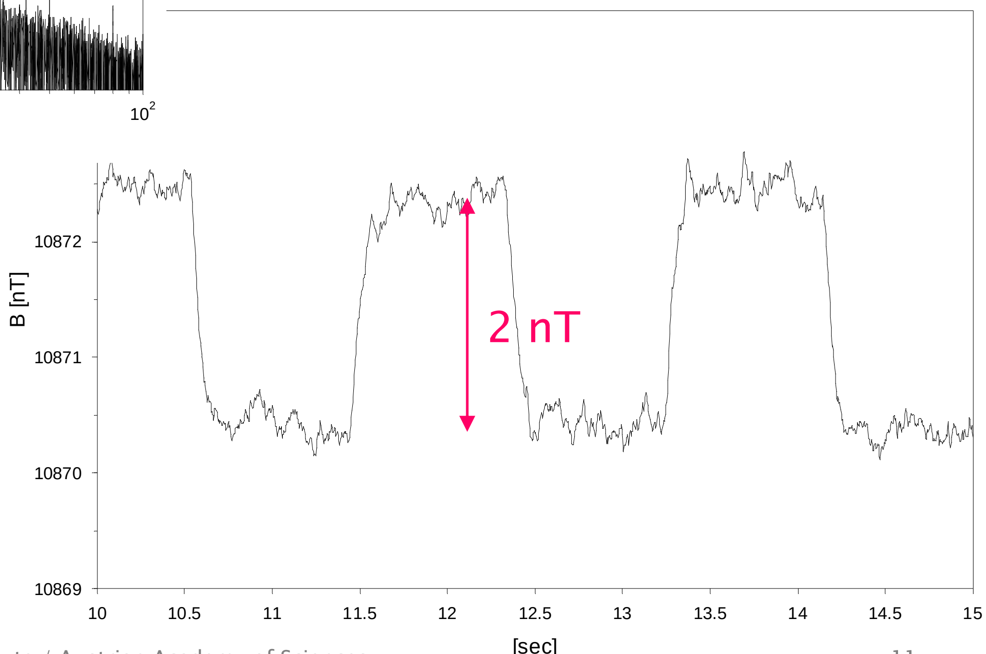


Current Performance



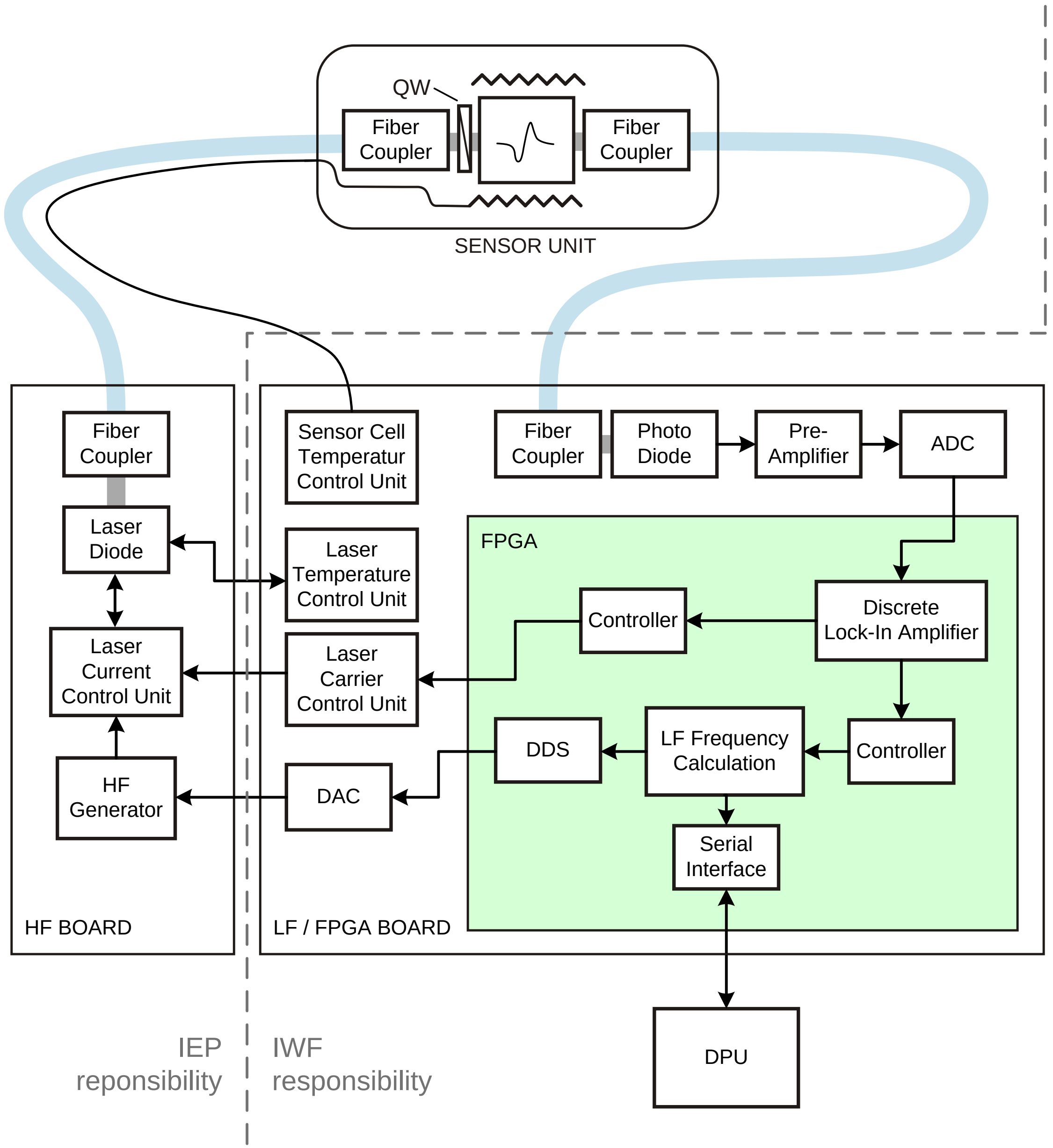
Current Performance	
PSD	70 pT/Hz½
Corner Frequency	3 Hz
Characteristics	no 1/f below 3 Hz



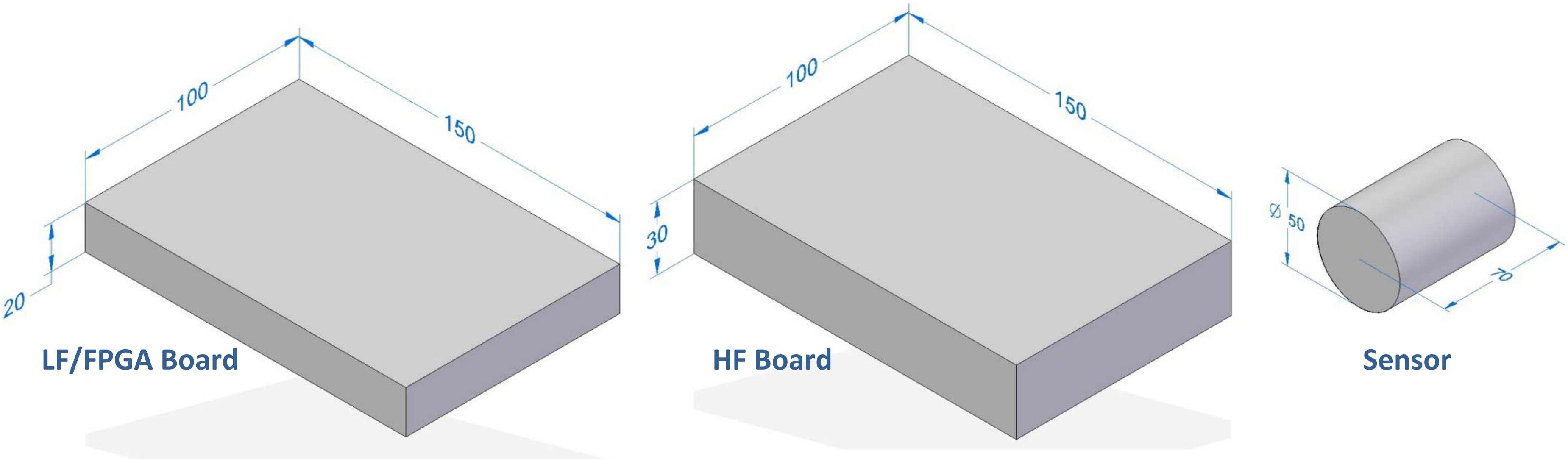


- CDSM can detect small AC fields on large DC fields

Until End of 2010



Expected Resource Requirements



Sub-unit	Mass [g]	Power [mW]	Envelope [mm³]
Sensor	150	250[2)]	70x50x50
HF Board	200	300	100x150x30
LF/FPGA Board	150	450	100x150x20
Sensor Harness	20 g/m	-	-
Total	500[1)]	1000	-

[1)] without sensor harness and thermal hardware
[2)] heater power

Expected Performance until End of 2010

- road map to increase performance
  - change laser field from Rubidium D2 to D1 excitation line
  - rough sensor cell heating (target window ± 5°C)
  - already known hardware improvements

Expected Performance until End of 2010	
PSD	2 pT/Hz½
Corner Frequency	100 Hz
Characteristics	no 1/f below 100 Hz

Advantages of CDSM

- absolute measurement (only well-known natural constants)
- simple sensor unit design
  - no excitation coils
  - no double cell unit
  - no moveable parts
  - radiation / temperature critical electronics inside spacecraft
- no temperature dependance because of the „C“
- possible mounting on a flexible boom
- resource advantages over existing absolute magnetometer
  - mass: 3–5 times ($<$ 500g)
  - power: 2–3 times ($<$ 1000mW)

Challenges for CDSM

- radiation hardness of critical parts
  - VCSEL laser diode:
    - publications of similar VCSELs promise good radiation hardness and life-time performance
  - photo diode:
    - shielding against total dose effects
    - single events may increase shot noise: trade-off between bandwidth and sensitivity possible
    - BUT: no influence on accuracy
- no heritage for a prestigious mission like EJSM so far

Outlook

- increase sensitivity to 2 $pT/Hz^{1/2}$ until end of 2010
- decrease resources to 500g / 1000mW until end of 2010
- investigation of radiation hardness of critical parts

- application for development activities in 2010 and 2011 will be send to Austrian Space Application Program as soon as ASAP7 is going to be announced (Feb. 2010)
- space qualification on a Chinese science satellite (CSES)
  - engineering model required in spring 2011 (TRL 5)
  - launch in 2013 (TRL 7)
  - perfect conditions for getting heritage for „bigger“ missions

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