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Toward an Optically Pumped Magnetometer Magnetoencephalography System with Full Head Coverage

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Introduction

Magnetoencephalography (MEG) is a non-invasive functional neuroimaging method with millisecond temporal and millimeter to centimeter spatial resolution. In MEG the magnetic fields of the brain are detected outside of the head using sensitive magnetometers. Traditional MEG scanners use superconducting quantum interference device (SQUID) sensors which are placed inside a cryogenic Dewar in a rigid, helmet-shaped configuration. The thermal insulation necessitated by the SQUIDs operating at around -269 °C sets the distance between the SQUID sensors and the subject's scalp to at least about 2 cm, limiting the spatial resolution of the SQUID-based MEG devices.

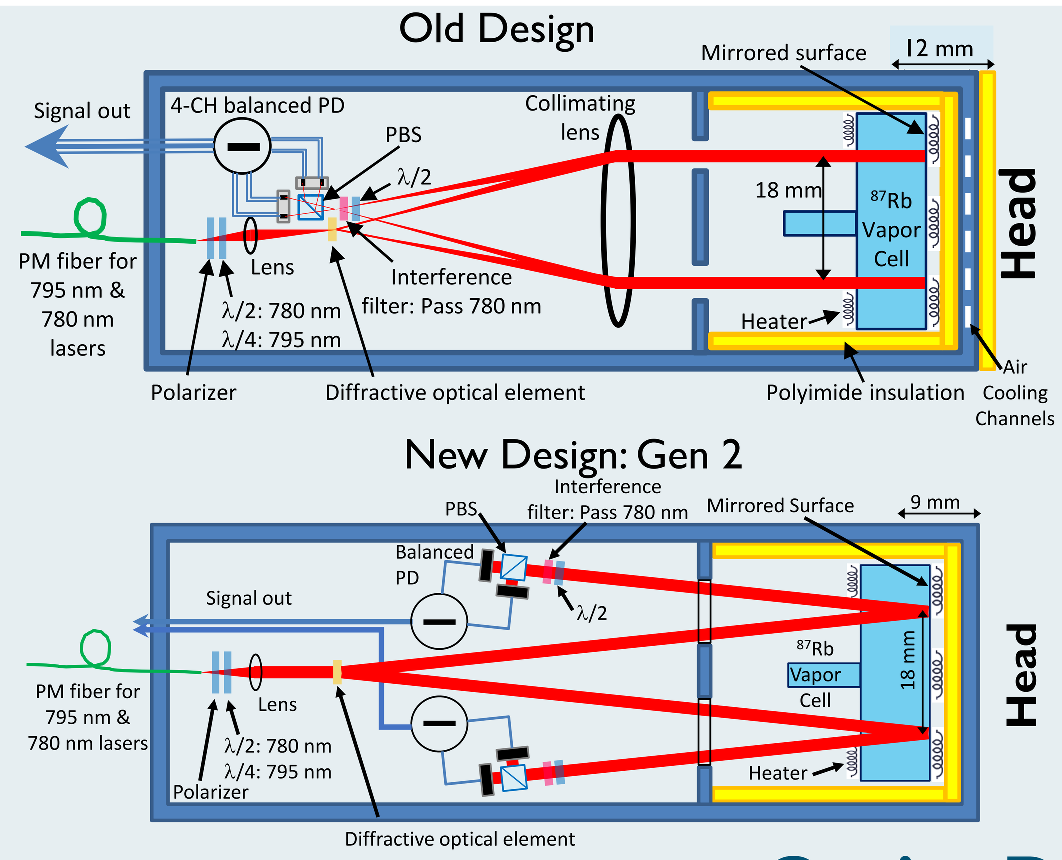
Recently, we have developed novel magnetometers for MEG that operate near room temperature [1]. These optically pumped magnetometers (OPMs) enable positioning of the sensors directly on the subject's scalp in a flexible manner, increasing the spatial resolution of MEG as compared to SQUID-based scanners [2].

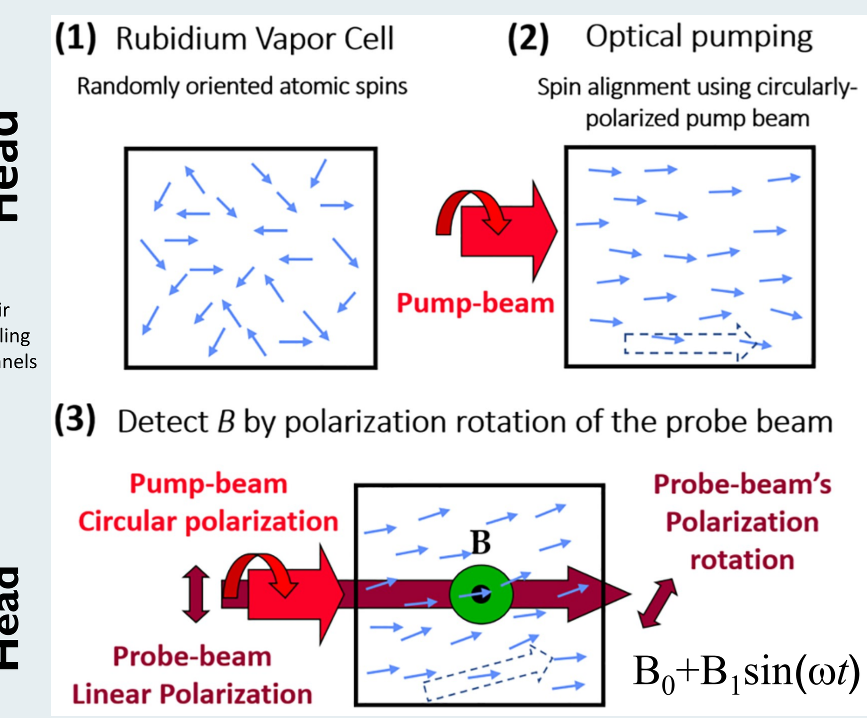
We are currently developing an OPM-based MEG scanner with a full-head coverage. **In this poster:**

- We describe our progress on the design and development of our next generation OPM sensor.
- We outline our plans for developing a complete MEG system with 108 channels

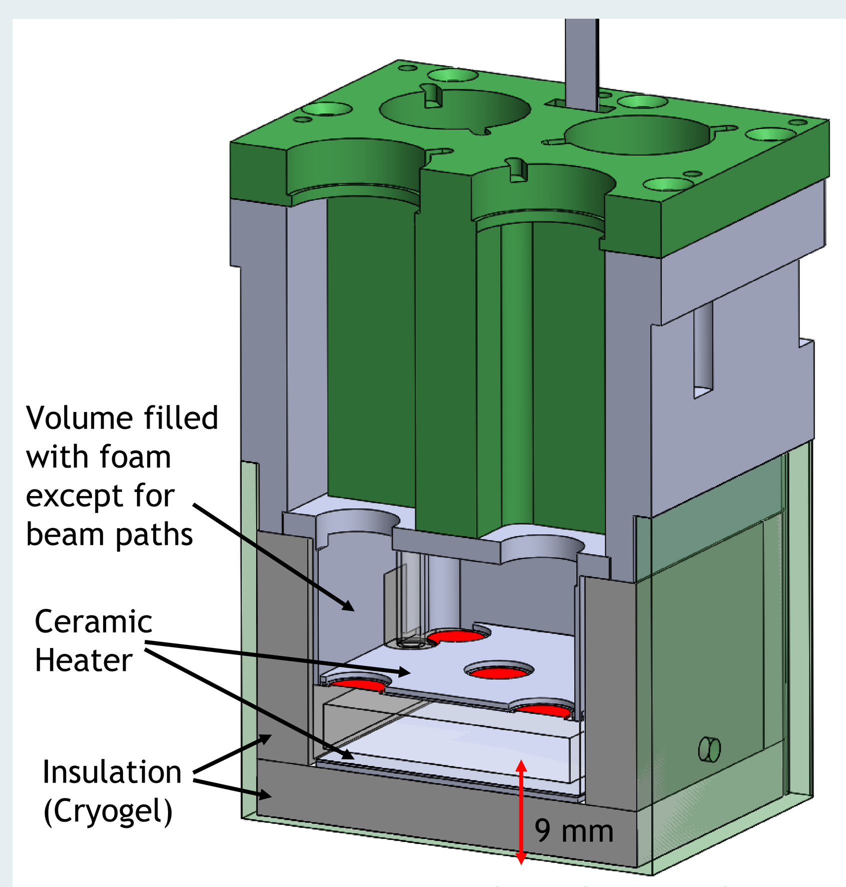
Redesign of the 4-channel sensor

- Reduce external temperature
- Reduce head to sensing volume distance
- Ease manufacturing
- Improve on-sensor magnetic field control
- Reduce optical power





Oven Design



Vapor cell center to sensor surface: 12 mm → 9 mm

Optics Design

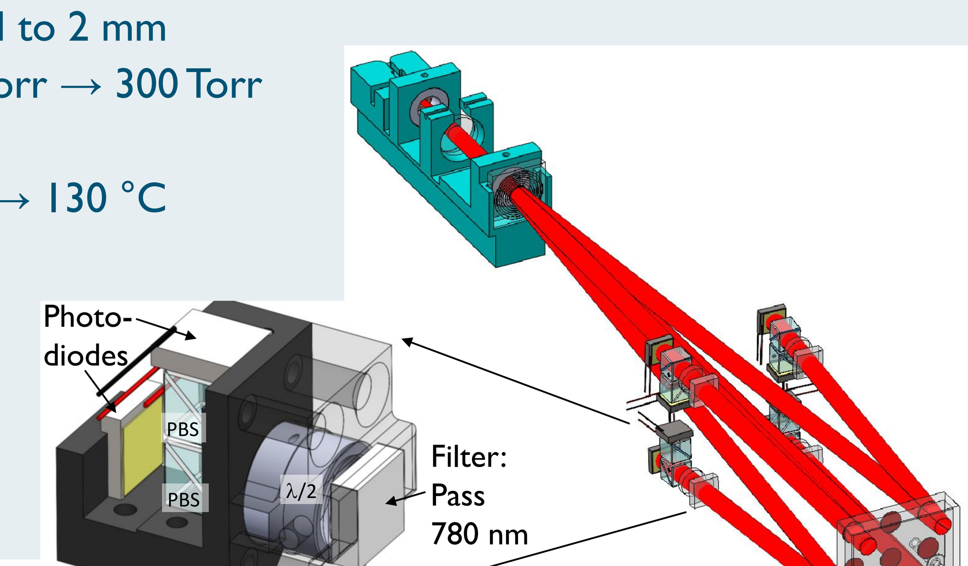
- Reduced beam size: 2.5 mm FWHM to 2 mm
- Reduced nitrogen buffer gas: 600 Torr → 300 Torr

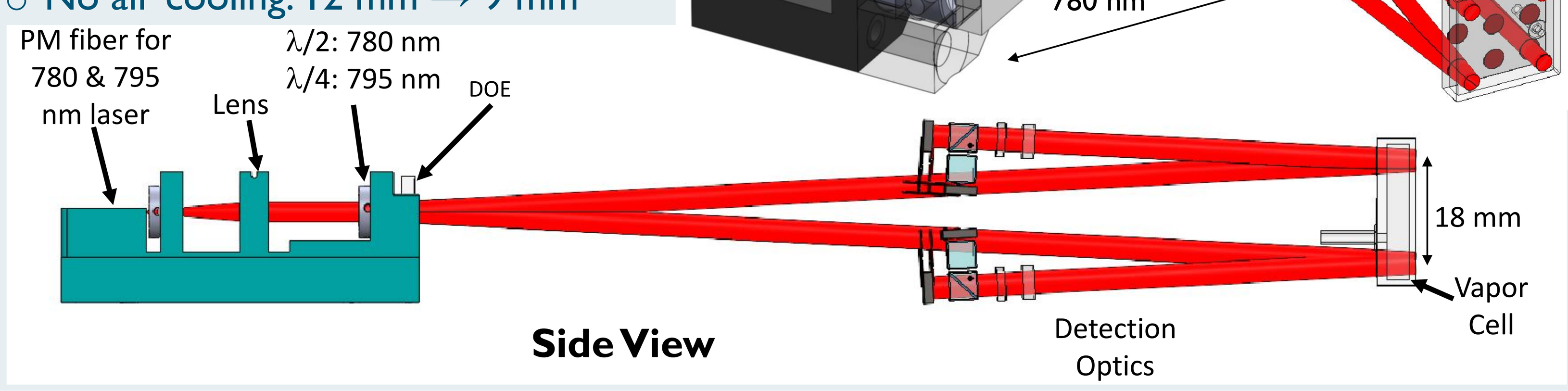
Result:

- Reduced cell temperature: 145 °C → 130 °C
- Reduced optical power:
  - Pump: 38 mW → 4 mW
  - Probe: 14 mW → 4 mW

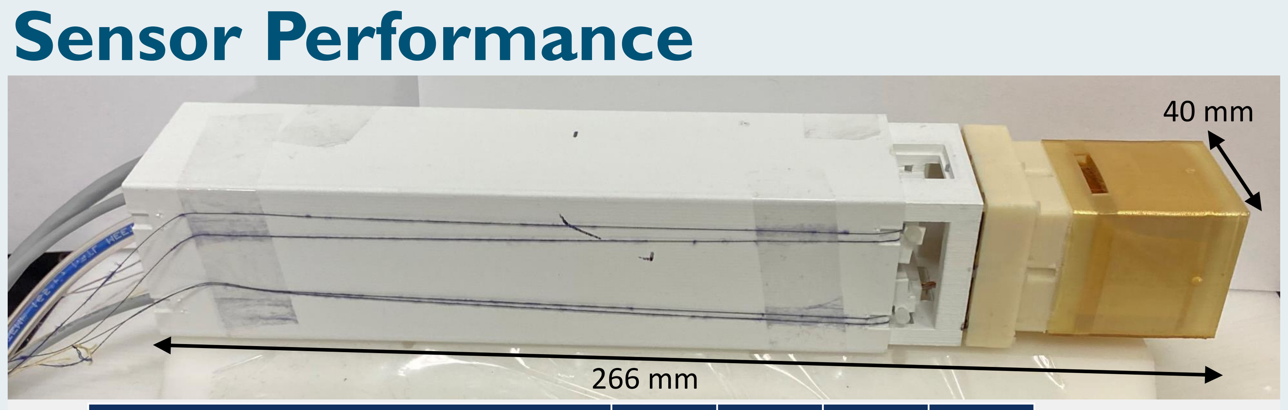
Increase 3 mm → 5 mm insulation

- Oven power: 6.1 W → 3 W
- No air cooling. 12 mm → 9 mm

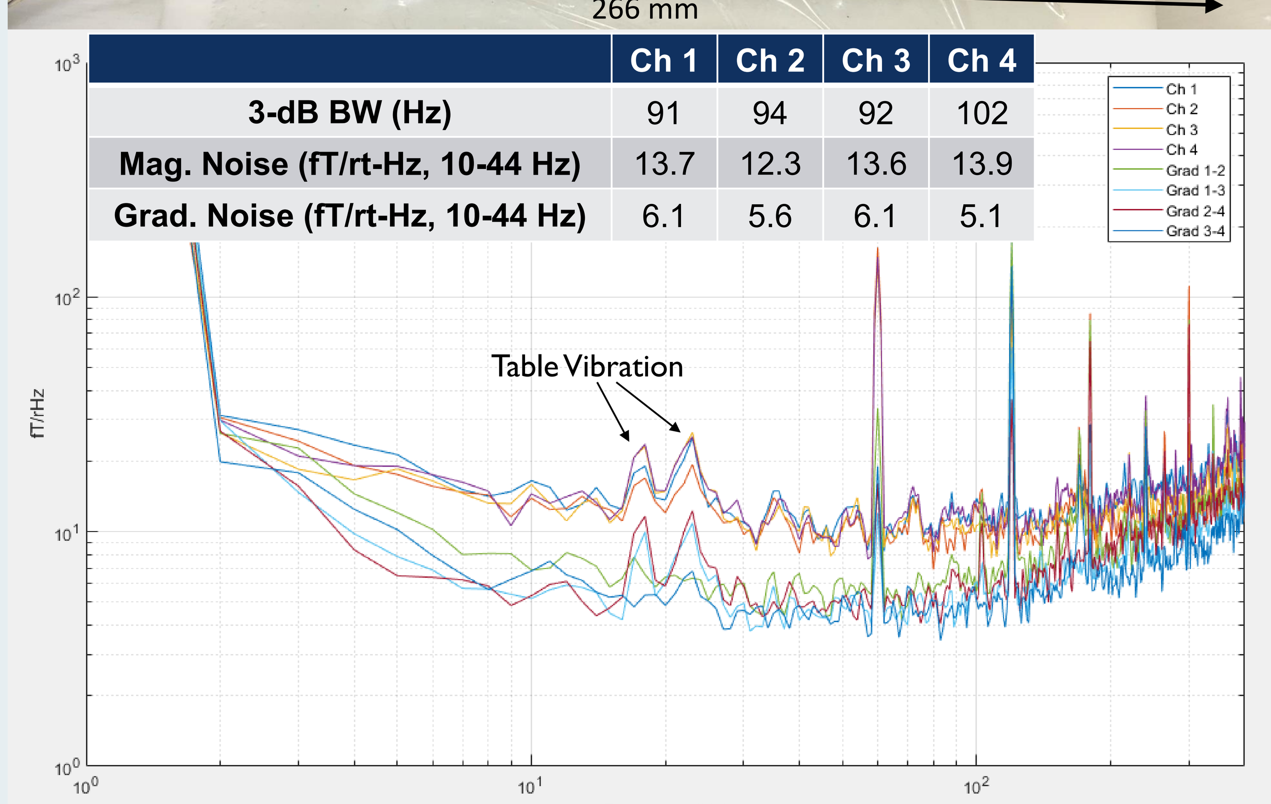


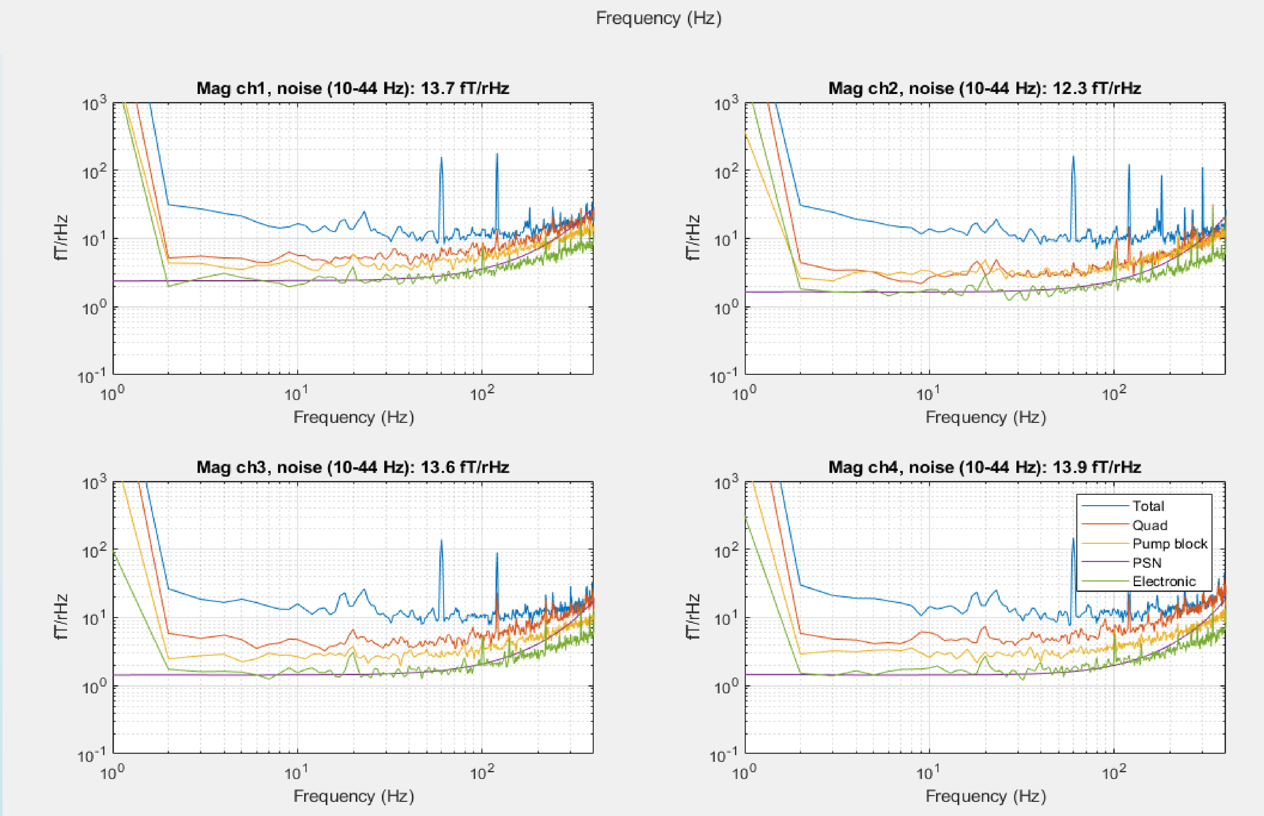


Sensor Performance



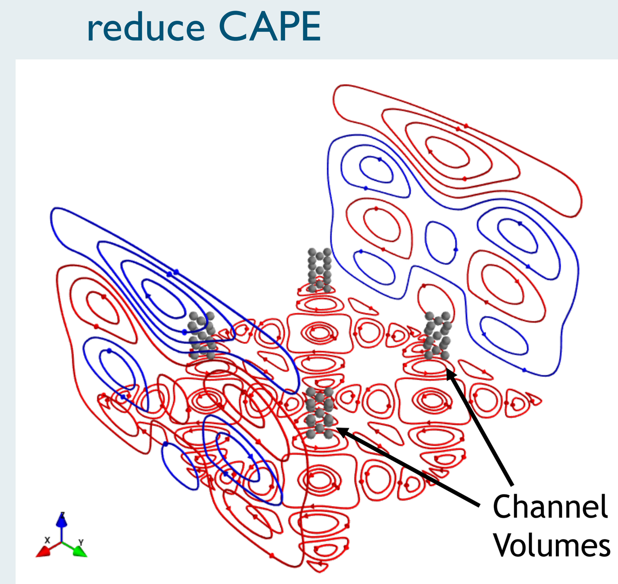
	Ch 1	Ch 2	Ch 3	Ch 4
3-dB BW (Hz)	91	94	92	102
Mag. Noise (fT/rt-Hz, 10-44 Hz)	13.7	12.3	13.6	13.9
Grad. Noise (fT/rt-Hz, 10-44 Hz)	6.1	5.6	6.1	5.1

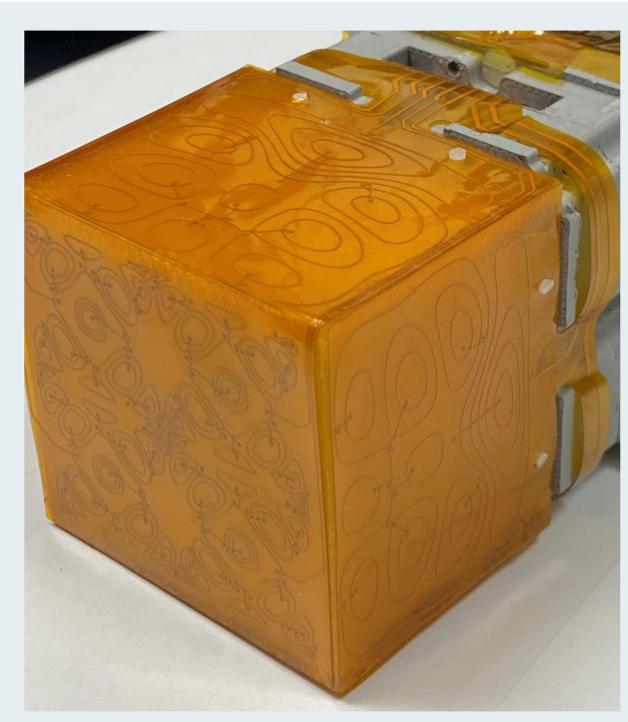




On-Sensor coils

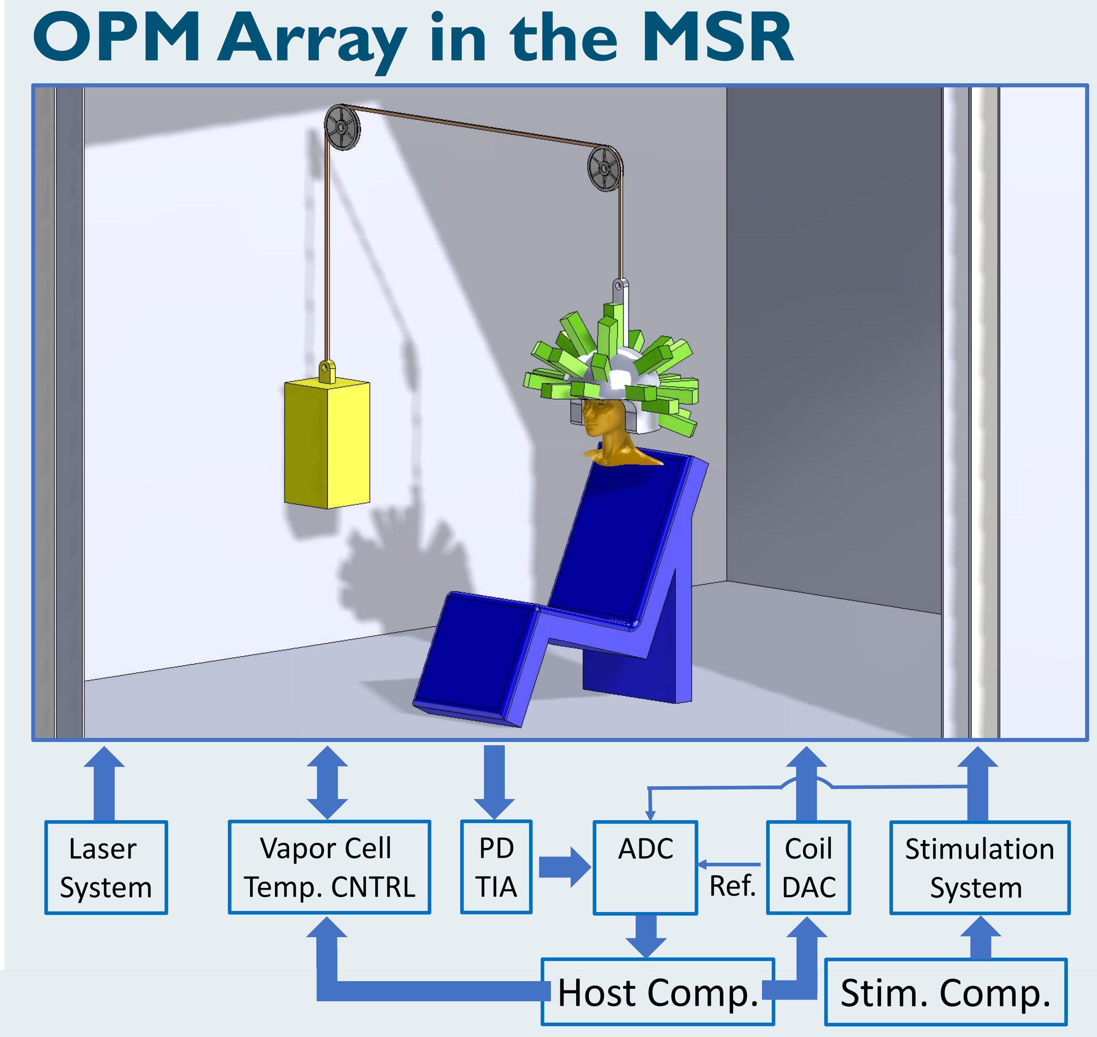
- Designed by Joonas Iivanainen with *bfieldtools* [3]
- Coils: X Y Z
  2 coils 2 coils 4 coils
- Control B_z for each channel to reduce CAPE





Field uniformity across the channel volume: 26% → 11%

OPM Array in the MSR



Above: Drawing of OPM array in the MSR and block diagram of the control and data acquisition systems. PD TIA: photodiode transimpedance amplifier, ADC: analog to digital converter, DAC: digital to analog converter.

OPM-Based MEG system

- Plan 27 sensors: 108 (216) channel single (dual) axis
- Position in a magnetically shielded room (MSR)
- Field cancellation coils in the MSR
- Allow modest movement

Control Electronics

Each daughterboard contains analog circuits and FPGA board for:

- Temp. CNTRL PID
- Laser monitoring (possible active power control)
- Signal detection and demodulation
- Arbitrary waveform generator for the on-sensor coils
- Communication with the host computer

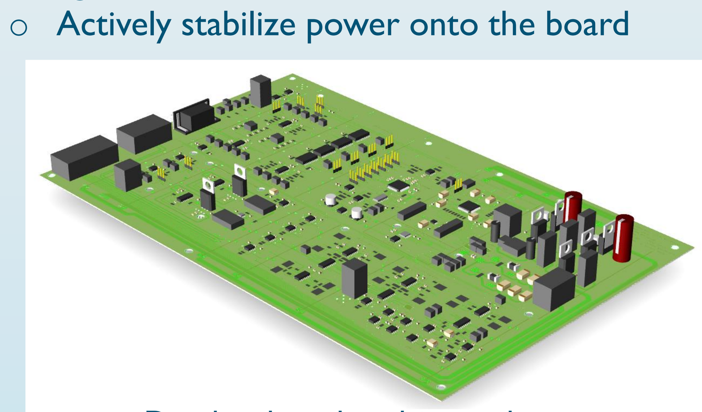
Laser system

Laser Sources:

- Probe: Toptica amplified DFB laser: 4 W
- Pump: Moglabs amplified cateye laser: 3.5 W
  - Two seed lasers separated by ~10 GHz

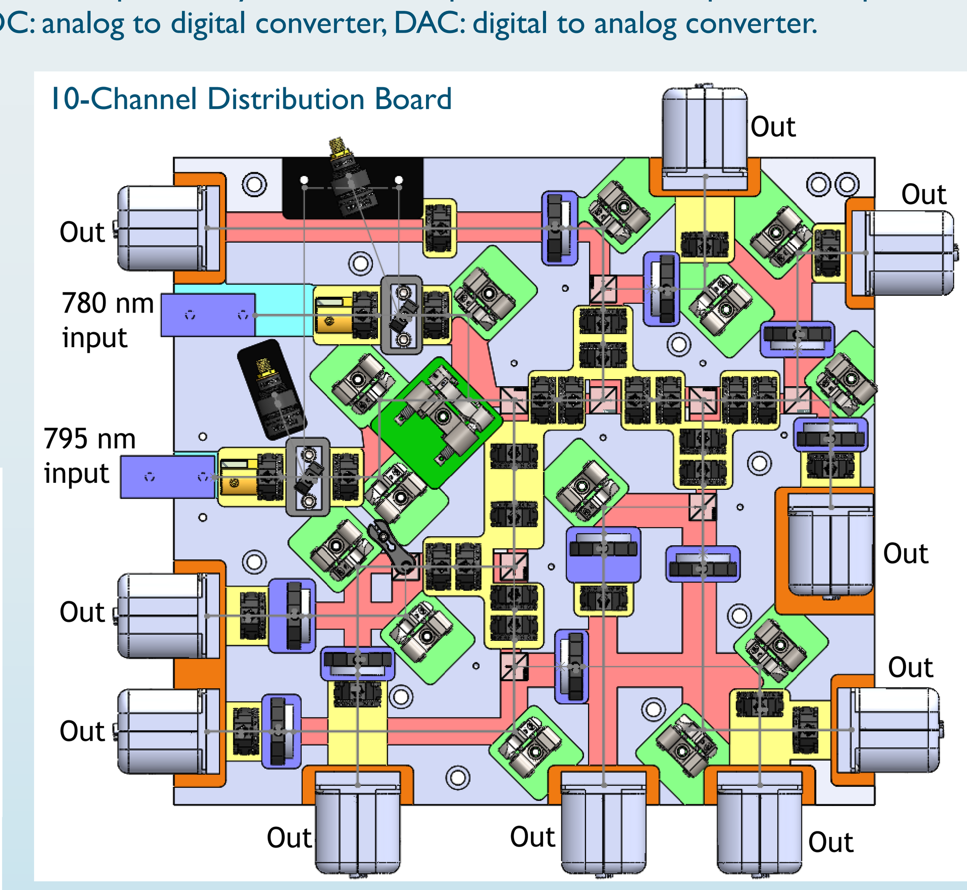
Light distribution boards:

- Solid aluminum construction
- Commercial optical mounts
- Combine and distribute 780 and 795 nm light
- Actively stabilize power onto the board



Daughterboard to drive each sensor
- FPGA board mounted above

10-Channel Distribution Board



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[1] A. P. Colombo, *et al.*, Optics Express, **24**, 15403 (2016)
[2] A. Borna, *et al.*, Phys Med Biol, **62**, 8909 (2017). Amir Borna, *PLoS One*, **15**(1), e0227684 (2020).
[3] *https://bfieldtools.github.io/*
[4] Amir Borna, *NeuroImage*, **247**, 118818 (2022).

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