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A pulsed vector optically pumped magnetometer operating in the SERF regime

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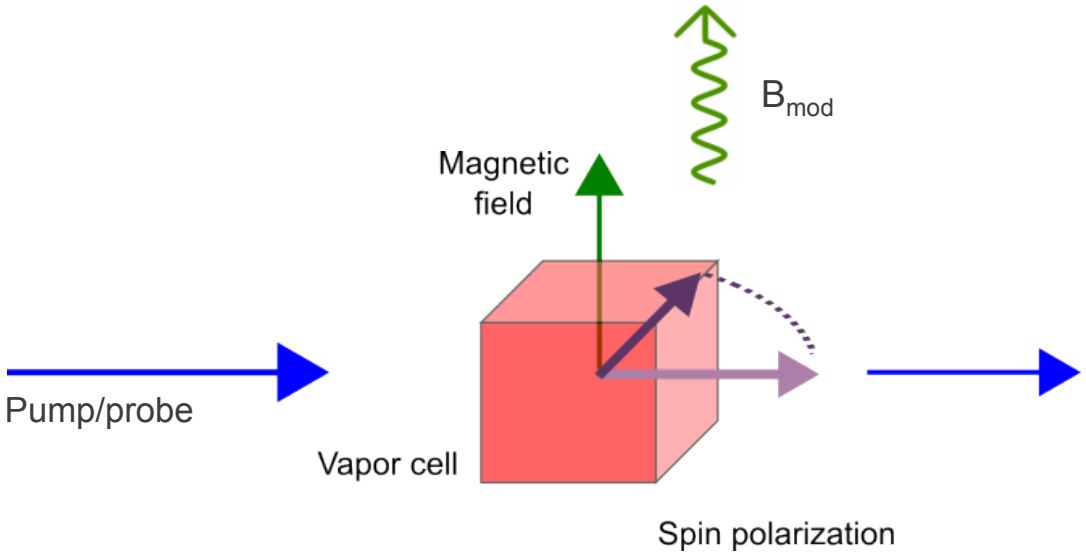
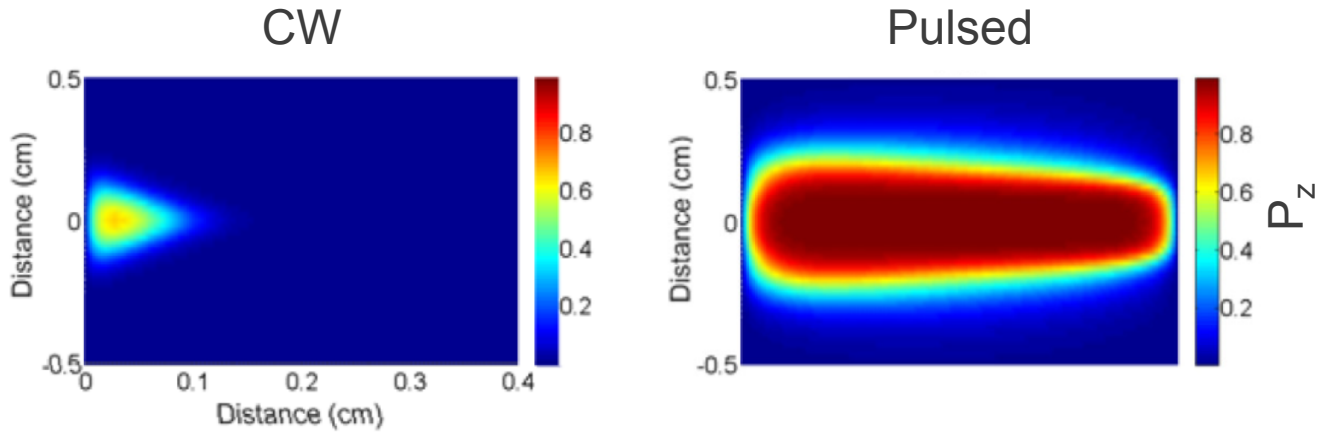
CW vs. pulsed pump magnetometer for MEG

- "Traditional" spin-exchange relaxation free (SERF) magnetometer
  - CW pump
  - CW magnetic field modulation (~1 kHz) to define the sensitive axis



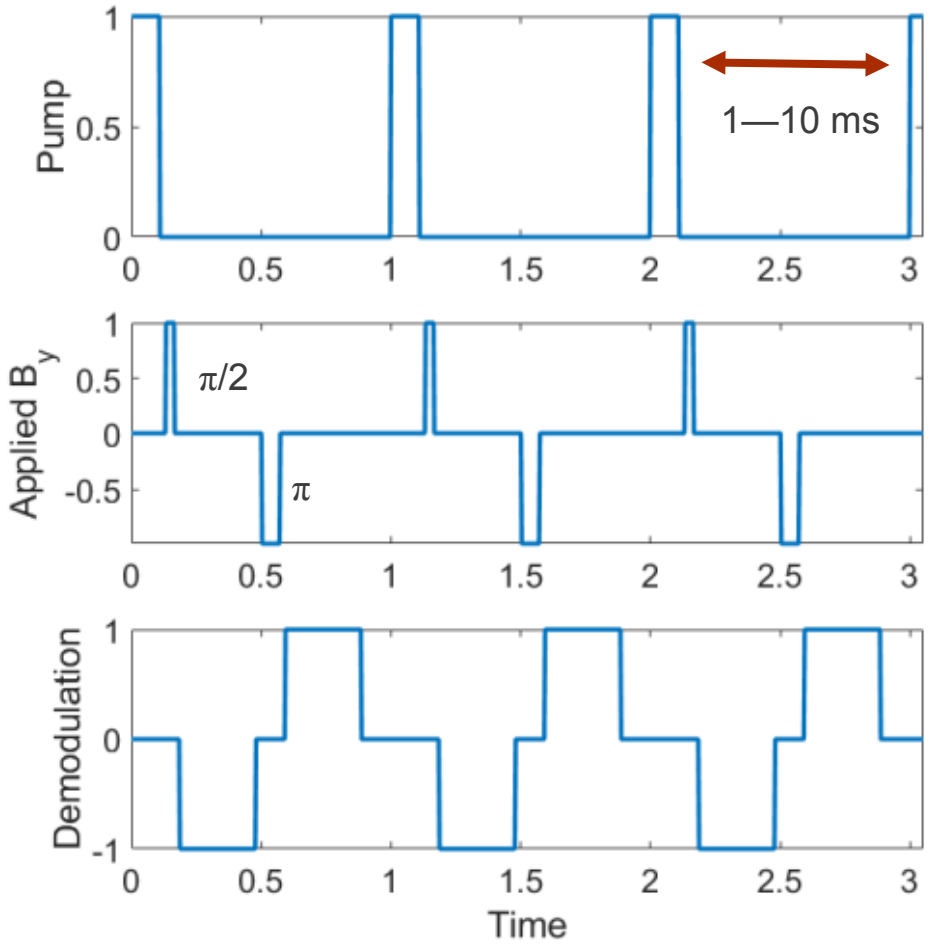
Motivation for a pulsed pump

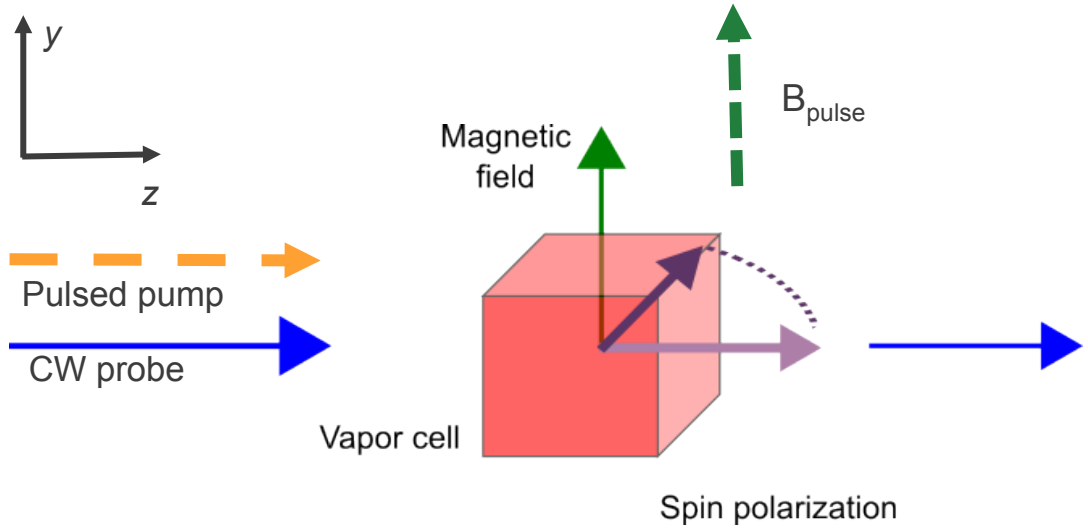
- Integrate pump laser into the sensor head
- Allows to use large-power pump
  - Complete optical pumping throughout the cell
  - Larger signal size compared to a CW magnetometer
- Eliminates problems with pump light power distribution and pump light shift

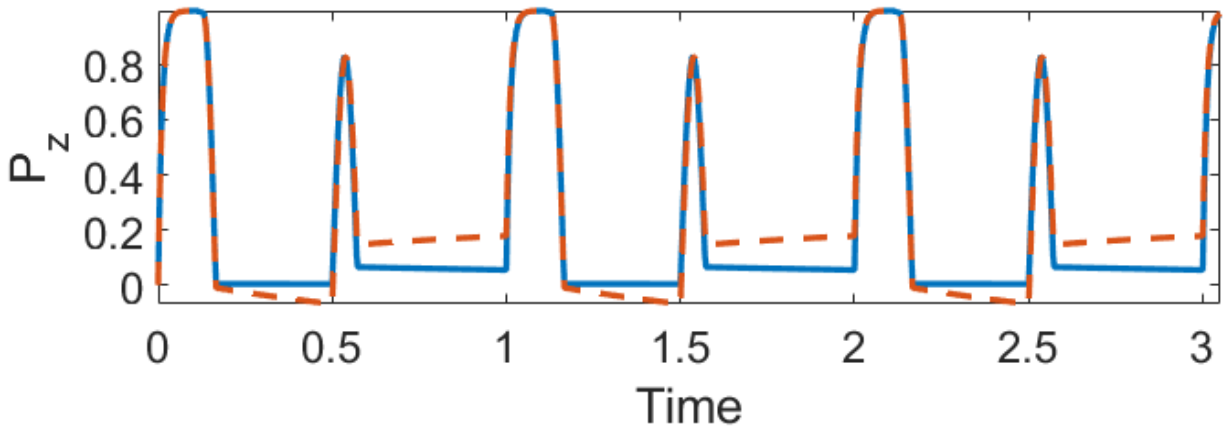


Measurement of a single field component

- Pulse sequence to measure B_y

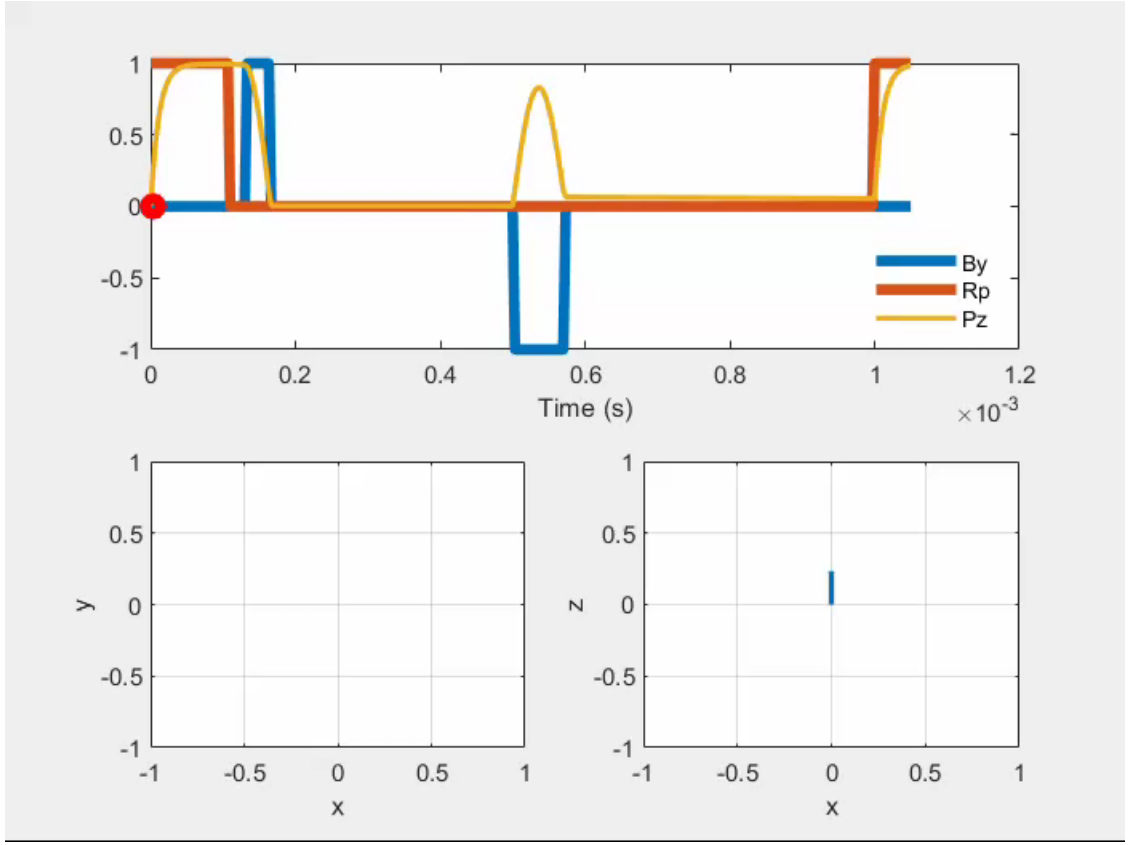




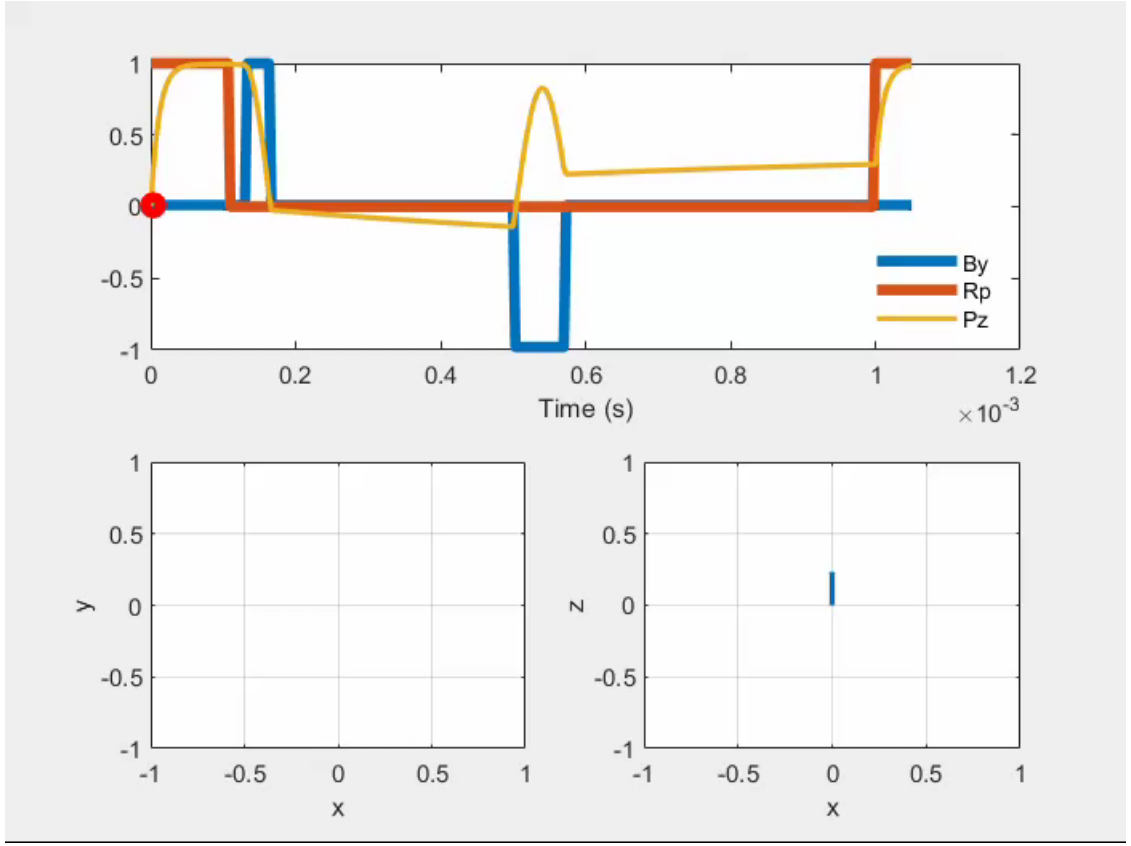


Measurement of a single field component

Zero B_y



Non-zero B_y



Magnetometer signal

- Polarization component as a function of time after π/2 pulse

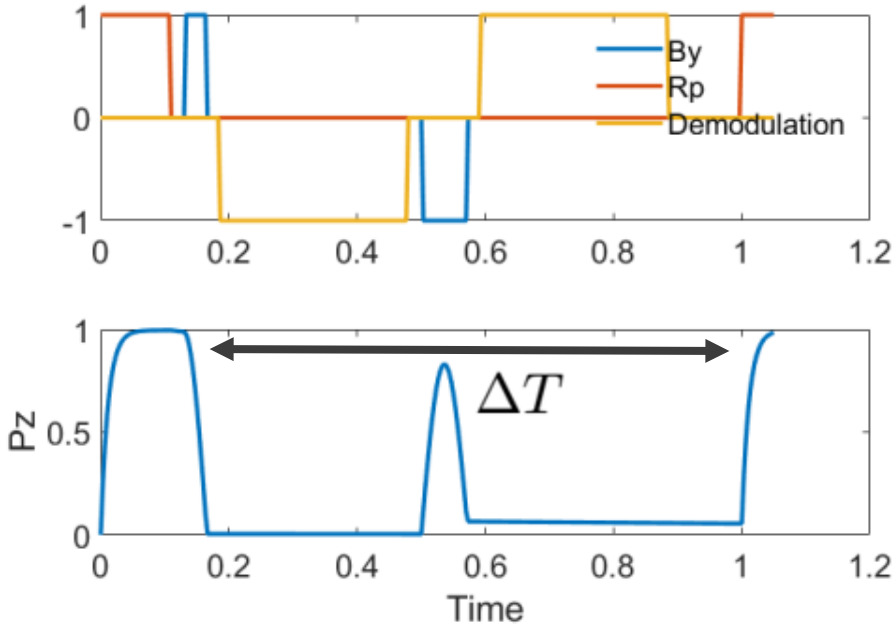
$$P_z(t) = P_0 e^{-t/T_2} \sin(\gamma B t)$$

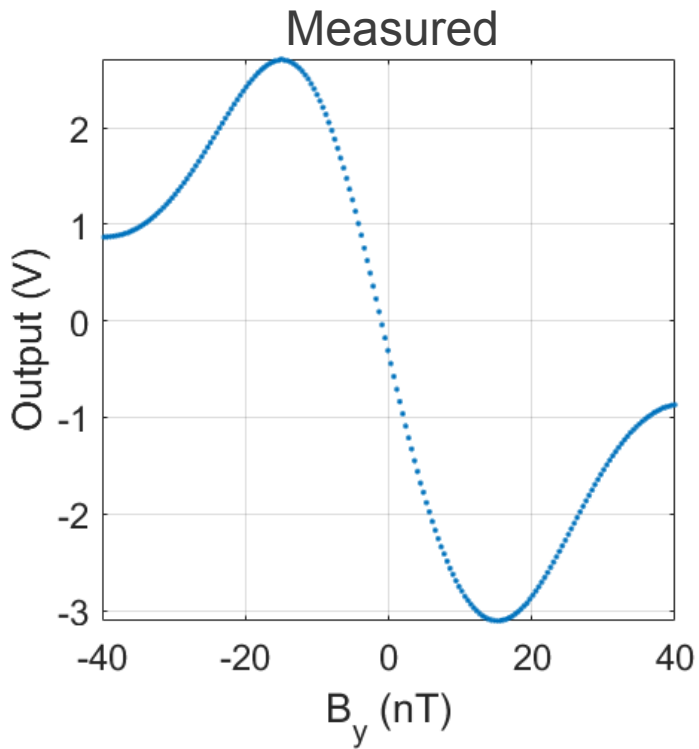
- Assuming a short π pulse, the signal after demodulation is

$$S = -\frac{1}{\Delta T}\int_0^{\Delta T} P_0 e^{-t/T_2} \sin(\gamma B t) dt$$

$$= P_0 \frac{\left(T_2 - e^{-\Delta T/T_2}(T_2 + \Delta T)\right)}{\Delta T} \frac{T_2 \gamma B}{(T_2 \gamma B)^2 + 1}$$

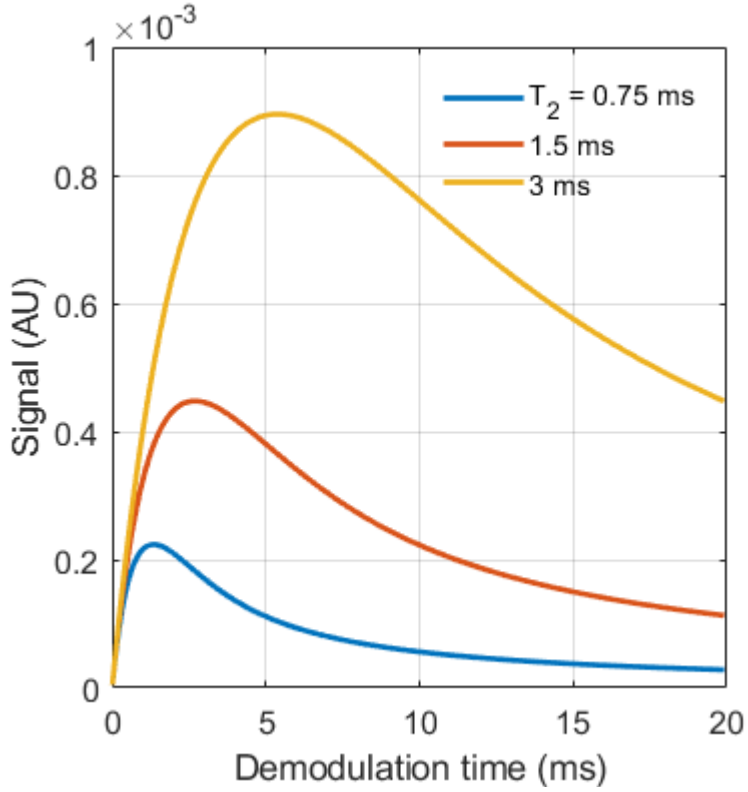
$$\approx P_0 \frac{\left(T_2 - e^{-\Delta T/T_2}(T_2 + \Delta T)\right)}{\Delta T} T_2 \gamma B$$

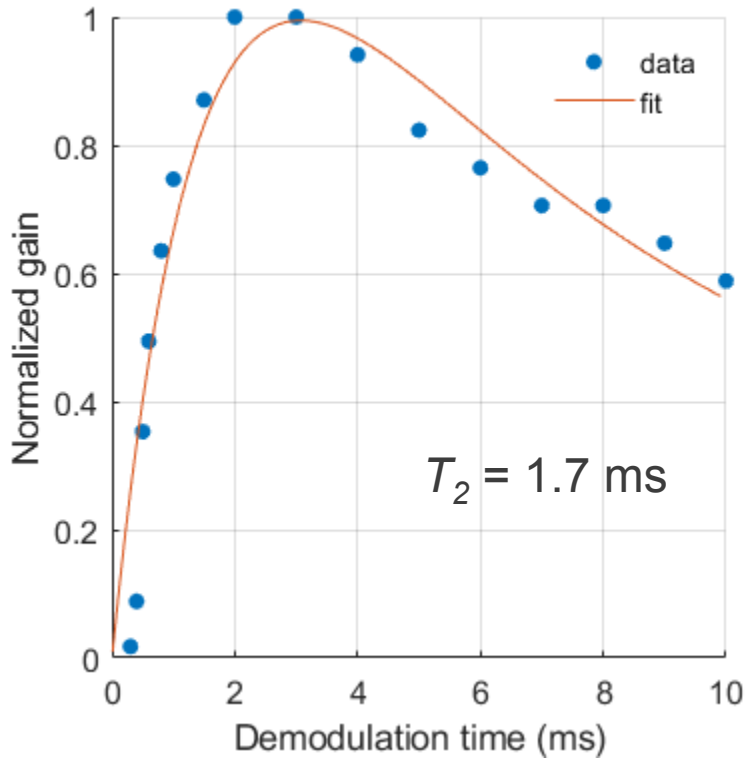




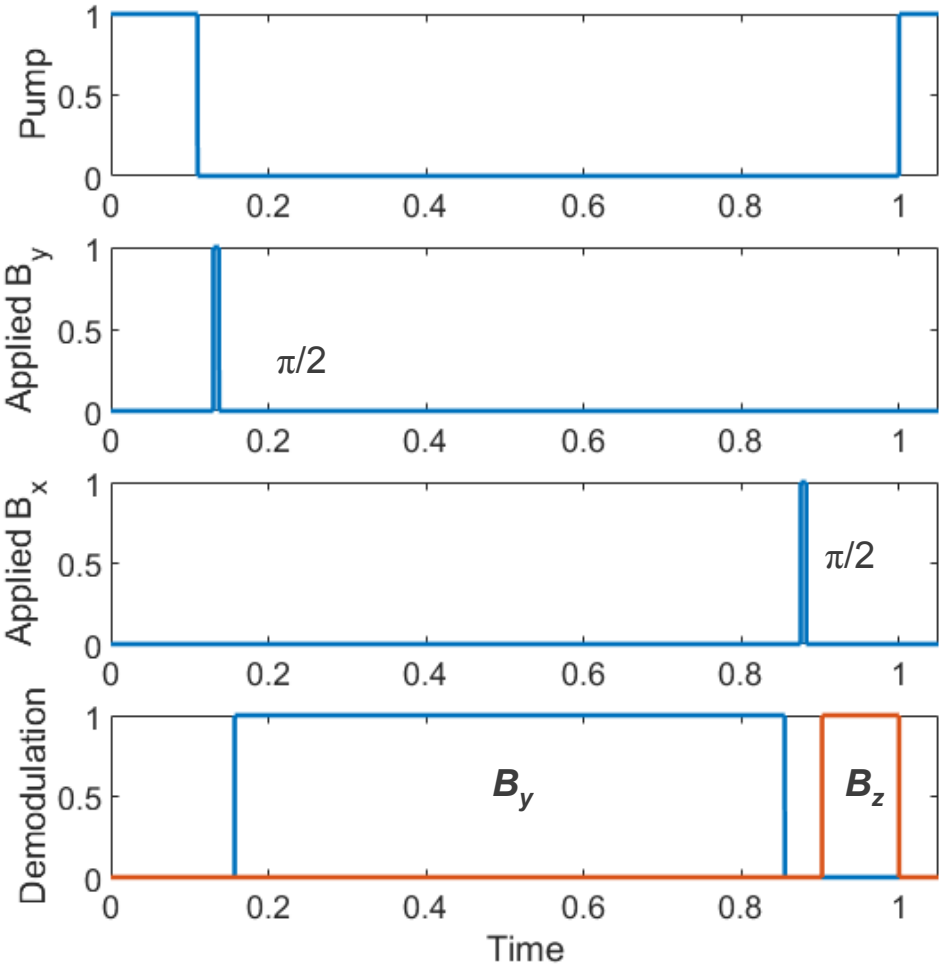
Signal dependence on demodulation time

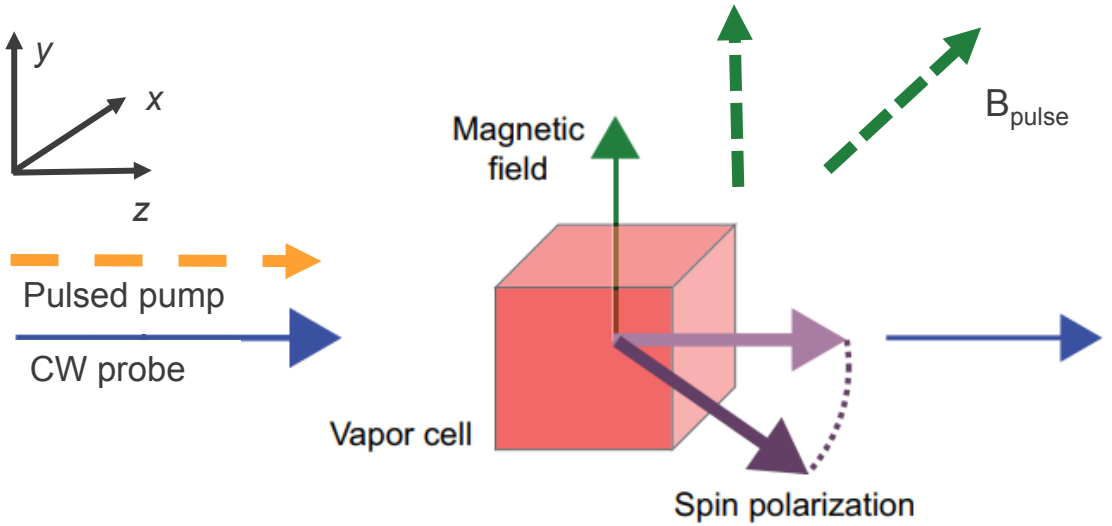
$$S \approx P_0 \frac{\left(T_2 - e^{-\Delta T/T_2}(T_2 + \Delta T)\right)}{\Delta T} T_2 \gamma B$$

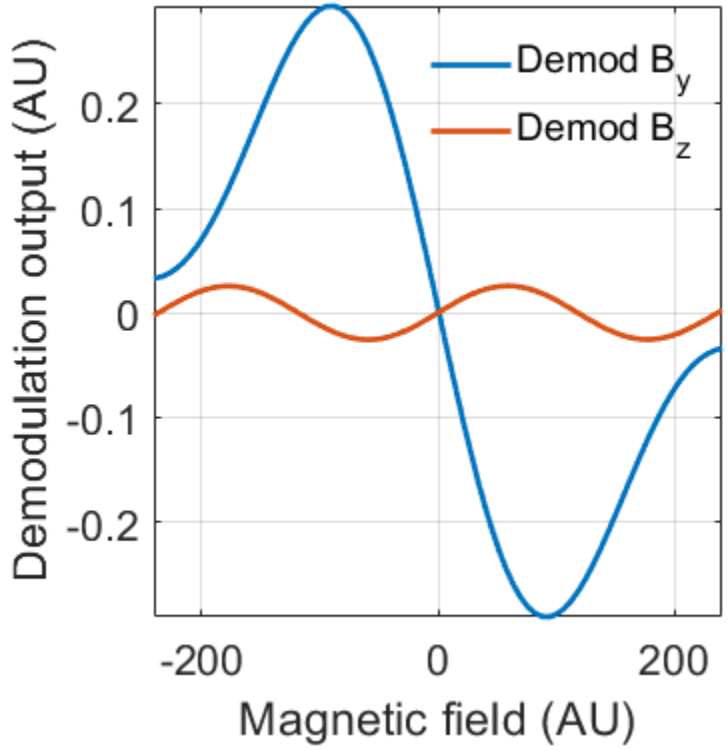




Dual-axis measurement

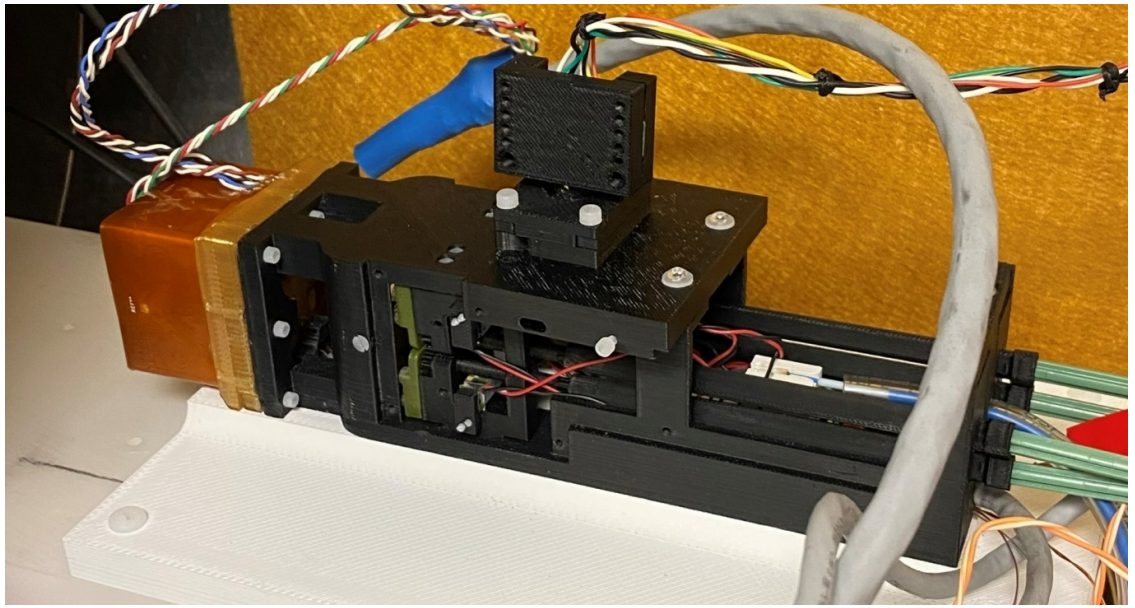


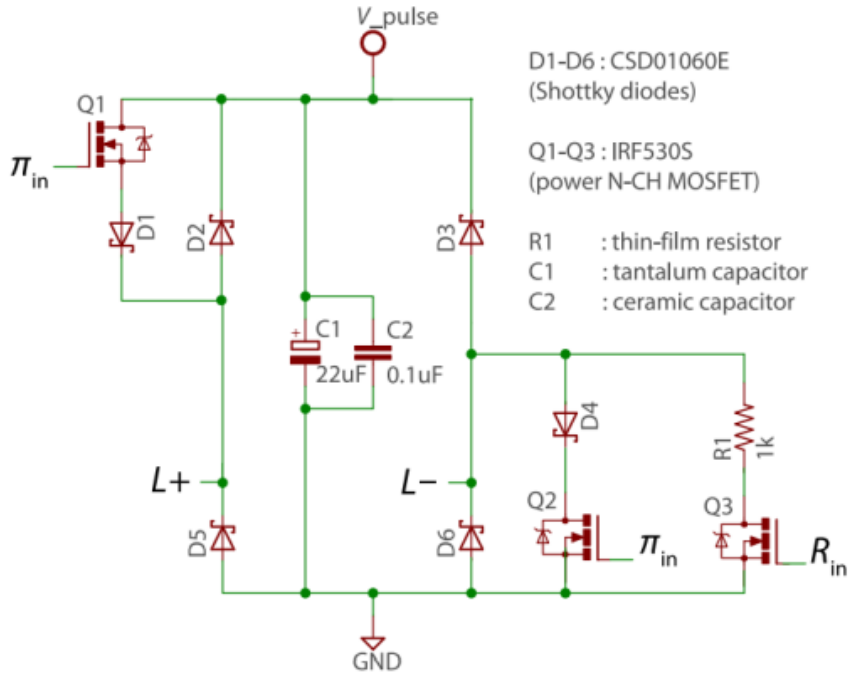




Sensor implementation

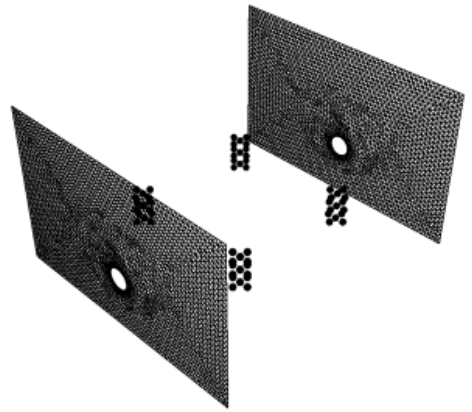
- Built a sensor prototype based on Sandia 4-channel OPM
- High-power multimode laser diode for 795 nm
- CW 780-nm probe
  - Faraday rotation
- Full H-bridge circuit for generating short magnetic field pulses (*Zhivun et al. 2019*)
  - π/2 pulse duration 4—40 μs
- New on-sensor coil design using bfieldtools
- NI USB-6289 DAQ with Labview software for pulse-sequence control



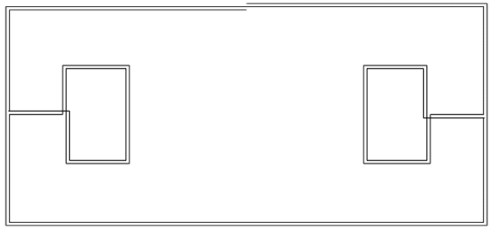


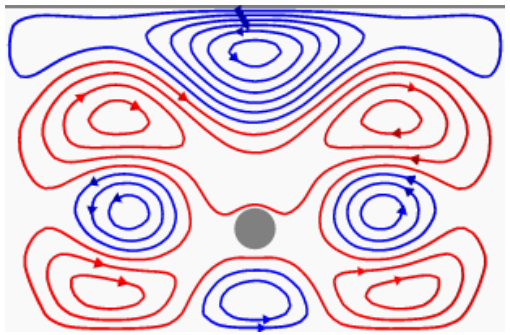
Zhivun et al. 2019

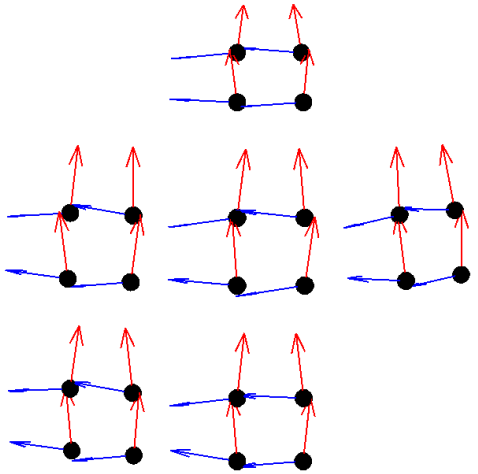
On-sensor coil design with bfieldtools

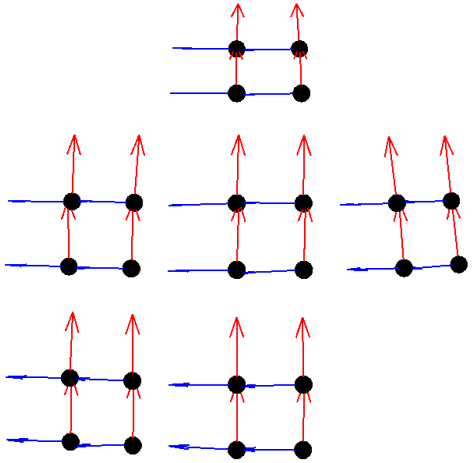


- Old B_y coil
  - Field inhomogeneity < 20%
  - Array sensing angle deviation ~10°
- New B_y coil
  - Field inhomogeneity < 13%
  - Array sensing angle deviation ~5°

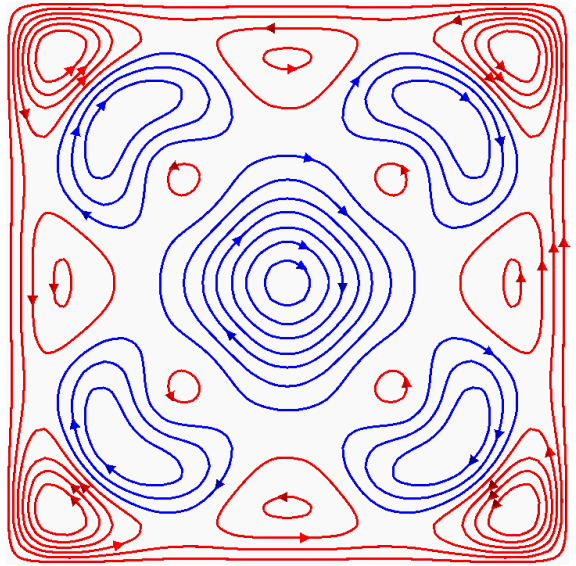




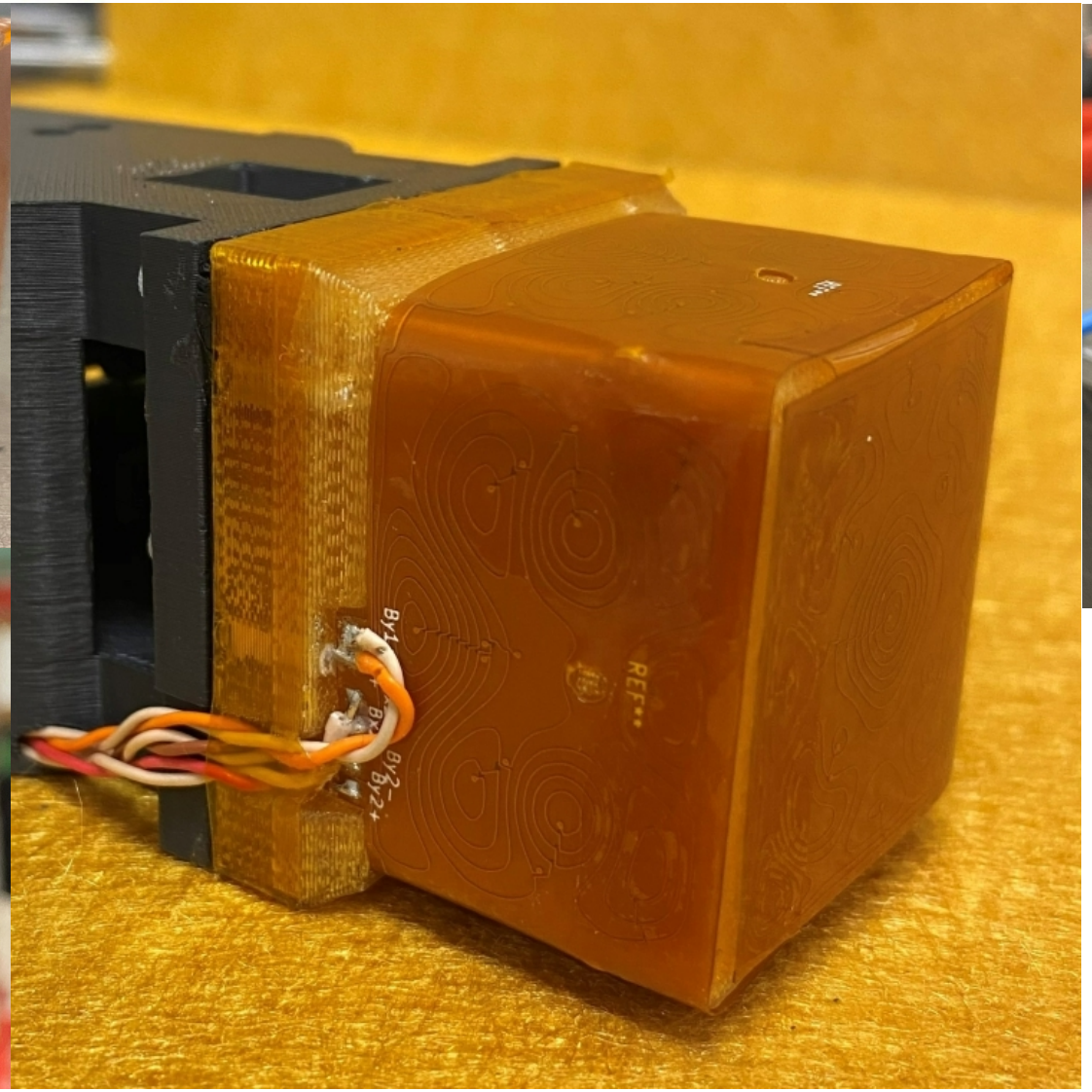


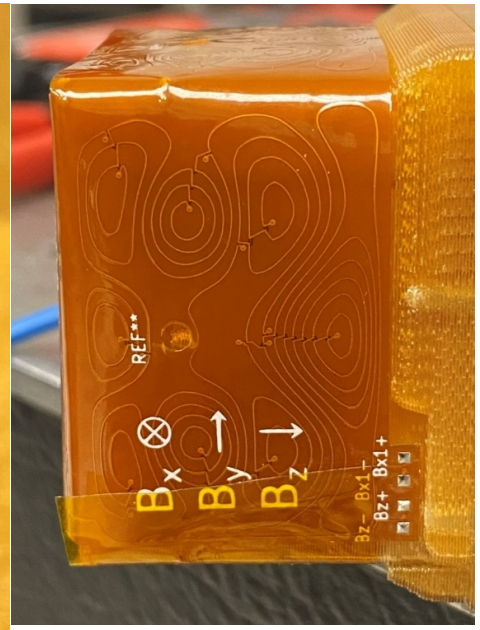


- B_z coil
  - Field inhomogeneity < 11%



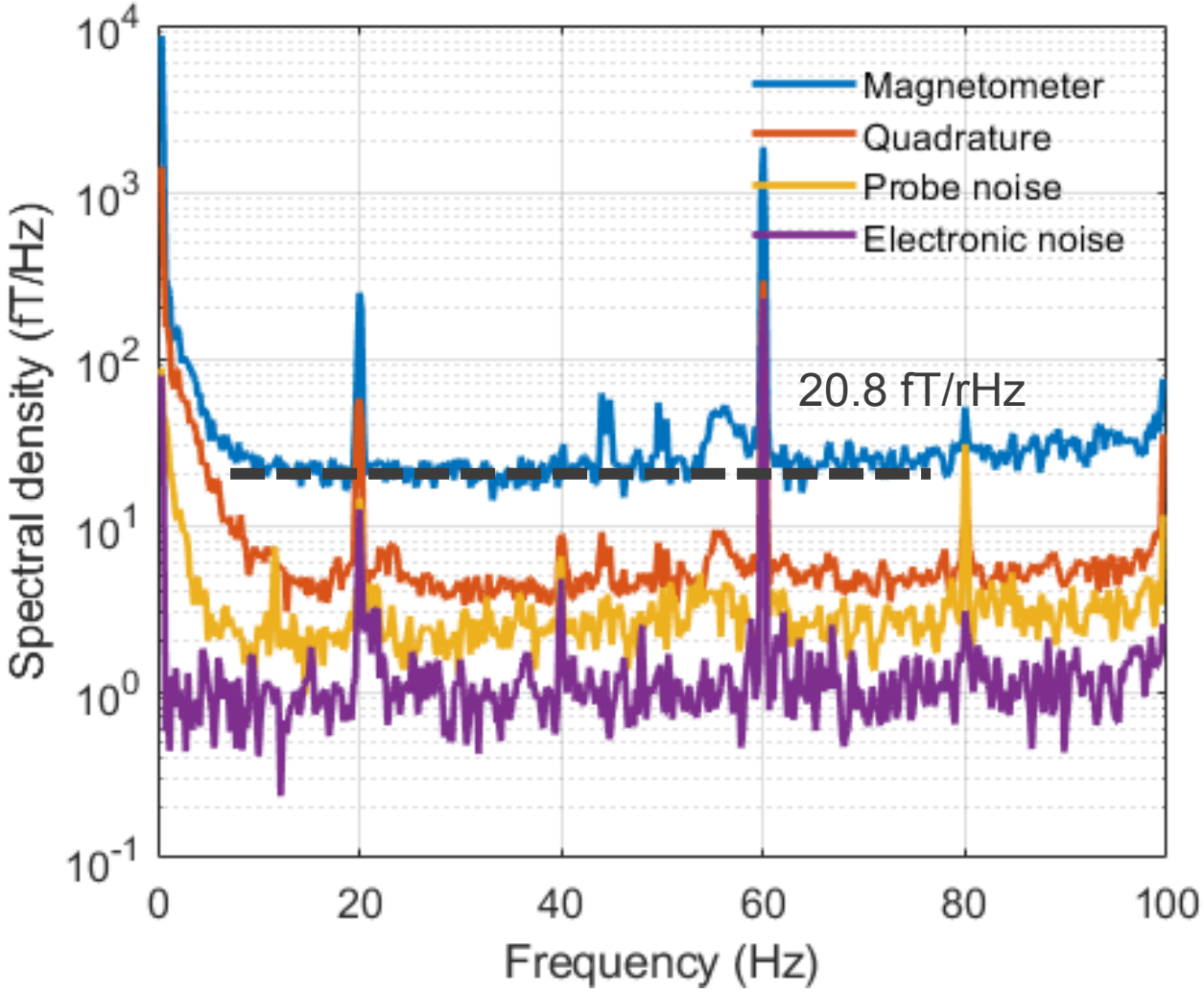
On-sensor coil design with bfieldtools





Bandwidth-normalized sensitivity

- Single-axis measurement
- Pump period = 5 ms
  - Fs = 200 Hz
- π/2 pulse duration 24 μs
- Magnetic sensitivity ~21 fT/rHz



Conclusion

- We have demonstrated a single-axis pulsed OPM operating in the SERF regime
  - Sensitivity ~20 fT/rHz
  - Bandwidth 100 Hz
- Reduce the noise floor of the magnetometer
  - Magnetic pulse noise
  - Timing jitter
  - Spin polarization fluctuations
- Increase the sensor bandwidth
  - Shorter pump period
- Measurement of multiple field components simultaneously
  - Dual- / tri-axis

Acknowledgments

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