Streamlining Magnetoelectric Magnetic Field Sensor Testing

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Friday, July 30, 2021

Penn Engineering

Magnetometer Applications

Magnetoencephalography (MEG)

- Measuring magnetic fields produced by the brain
- Small amplitude magnetic fields (10 fT – 1 pT)

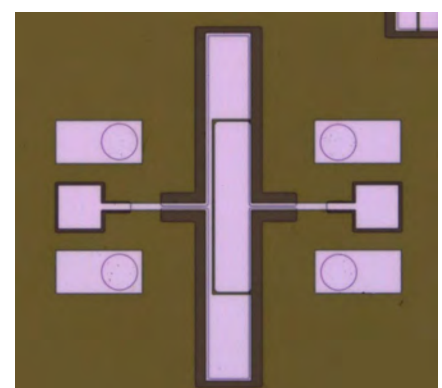
Current Devices for MEG

- Superconducting Quantum Interference Devices (SQUIDs)
- Optically Pumped Magnetometers (OPMs)

Magnetoelectric Magnetic Field Sensors

- Room temperature
- No lasers


Clockwise from left: SQUID, OPM[1], Magnetoelectric Magnetometer



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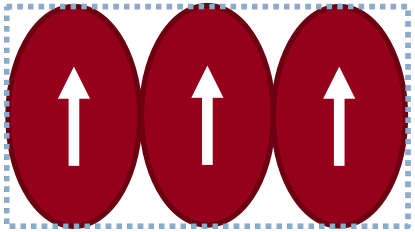
[1] Boto, Elena, et al. "Moving magnetoencephalography towards real-world applications with a wearable system." *Nature* 555.7698 (2018): 657-661.

Scientific Background

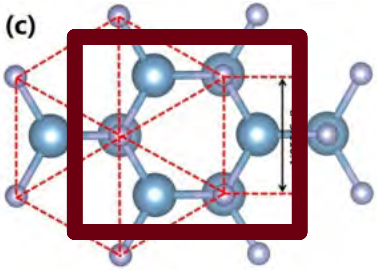
Magnetostriction

- Magnetostrictive materials strain in external magnetic field
- Magnetic dipoles align in DC field
  - Dipoles rotate and stretch
  - Produces strains
- Largest response desired for sensing an AC magnetic field
  - Bias field required for most strain per change in magnetic field



Piezoelectricity

- Piezoelectric materials produce a voltage in response to a strain
- Crystal structure deforms in response to external force
- Displacement of charges leads to a charge differential



Tetrahedral Structure of Aluminum Nitride [3]

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[2] R. Jahns *et al*, "Giant Magnetoelectric Effect in Thin-Film Composites," *Journal of the American Ceramic Society*, vol. 96, *(6)*, pp. 1673-1681, 2013. Available: https://api.istex.fr/ark:/67375/WNG-6NS5WS00-P/fulltext.pdf. DOI: 10.1111/jace.12400.

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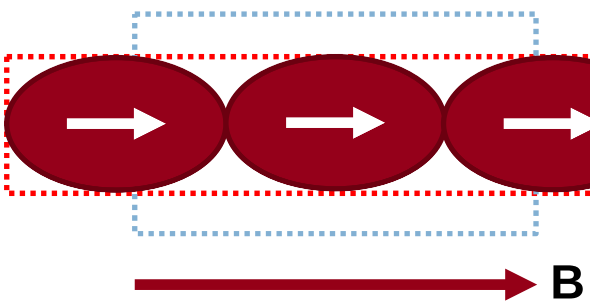

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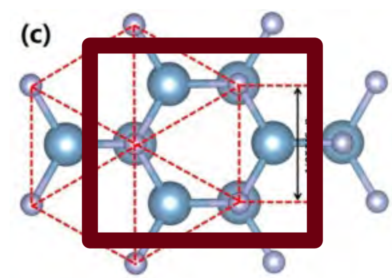

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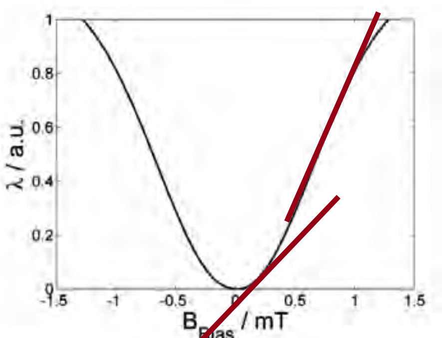

Strain vs Magnetic Bias Plot

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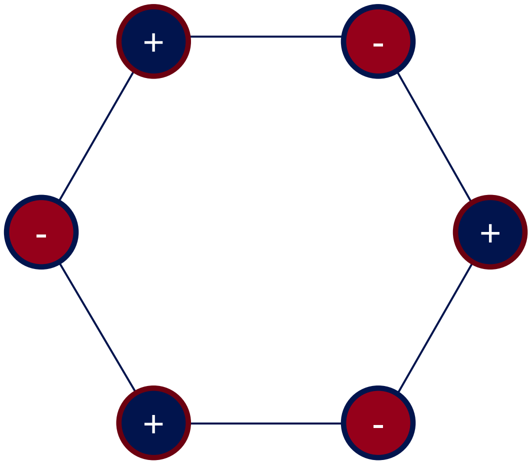

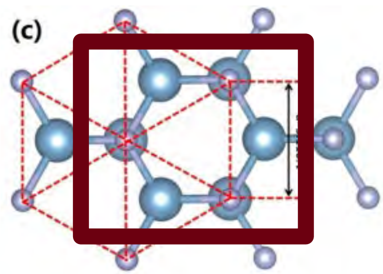

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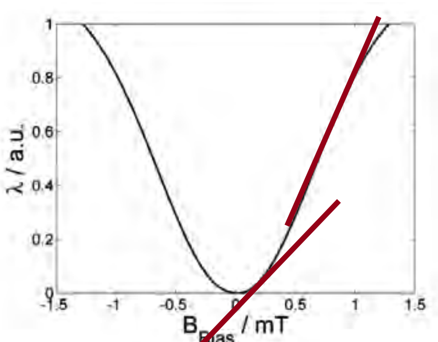

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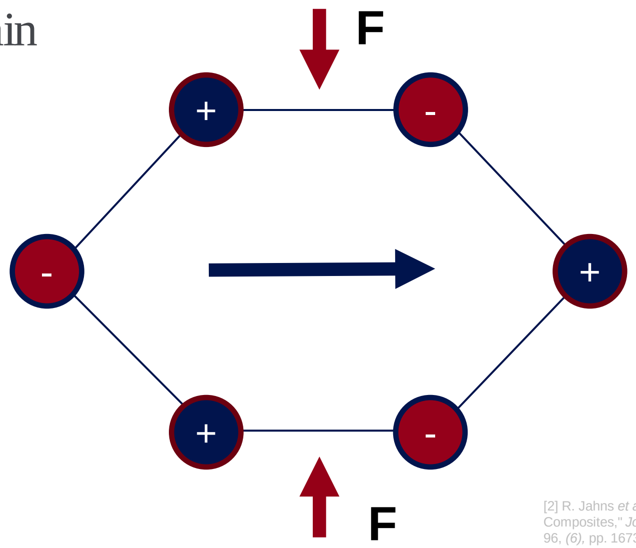

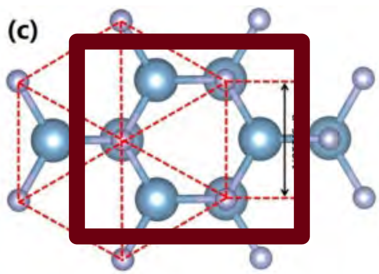

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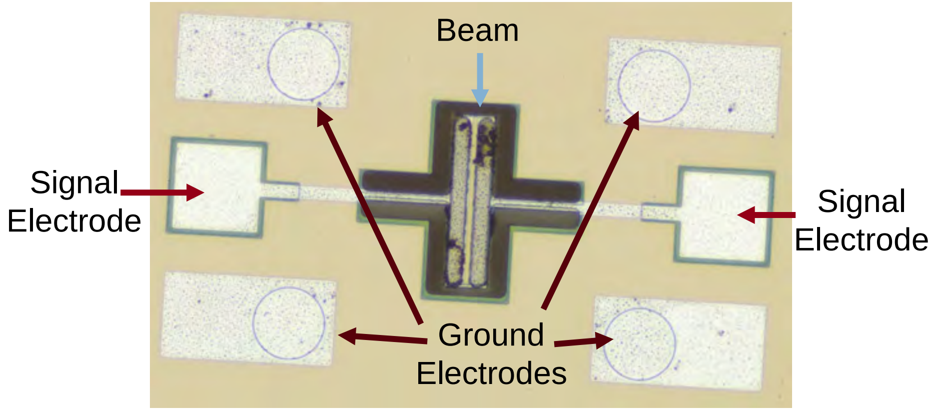
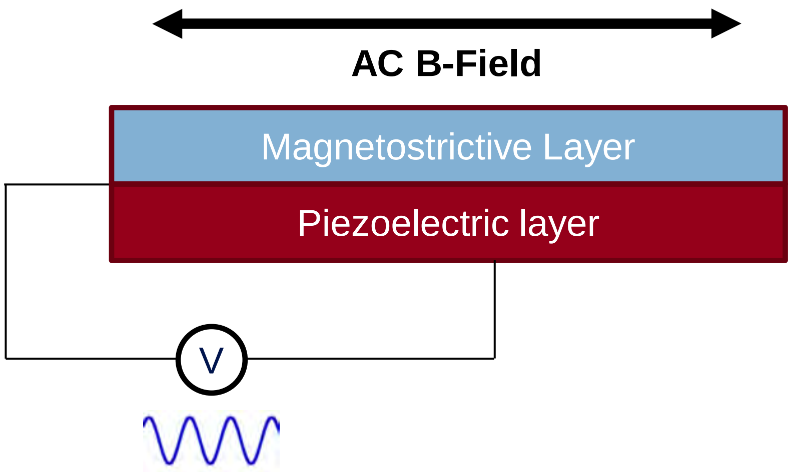
Magnetoelectric Sensors

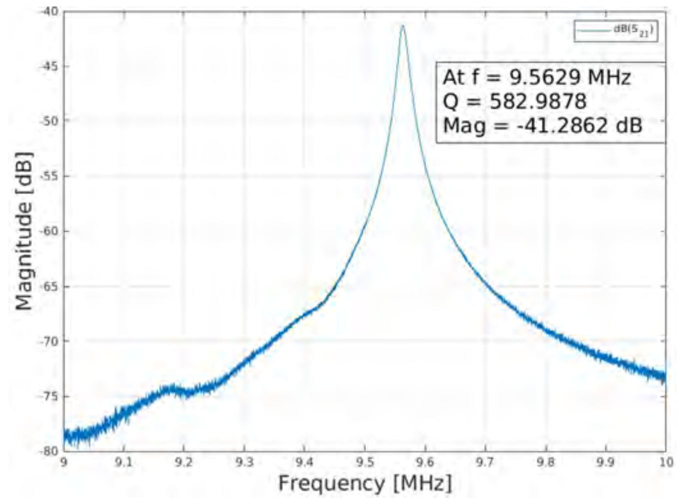
- Magnetoelectric effect: Transfer of energy between magnetic and electric fields
- Piezoelectric and magnetostrictive layers mechanically coupled
  - Magnetostrictive layer strains from magnetic field
  - Strains in magnetostrictive layer transferred to piezoelectric layer, creating detectable voltage



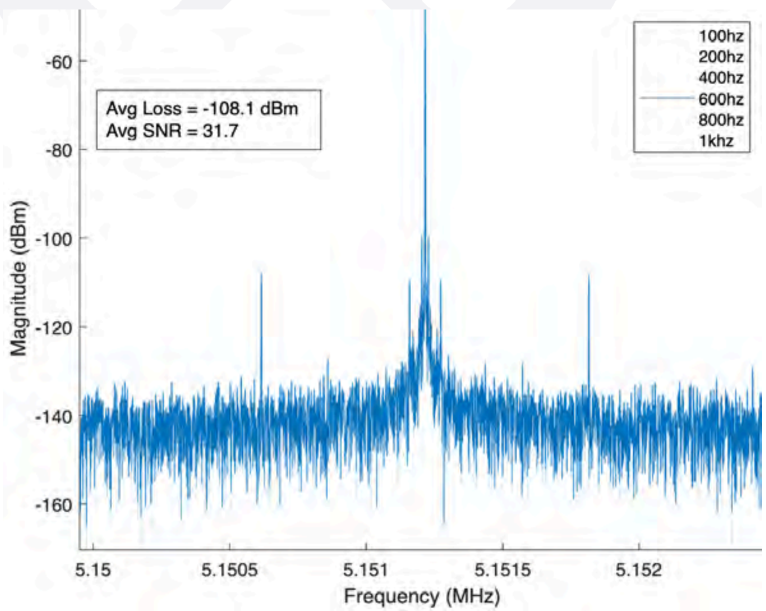


Testing ME Sensors

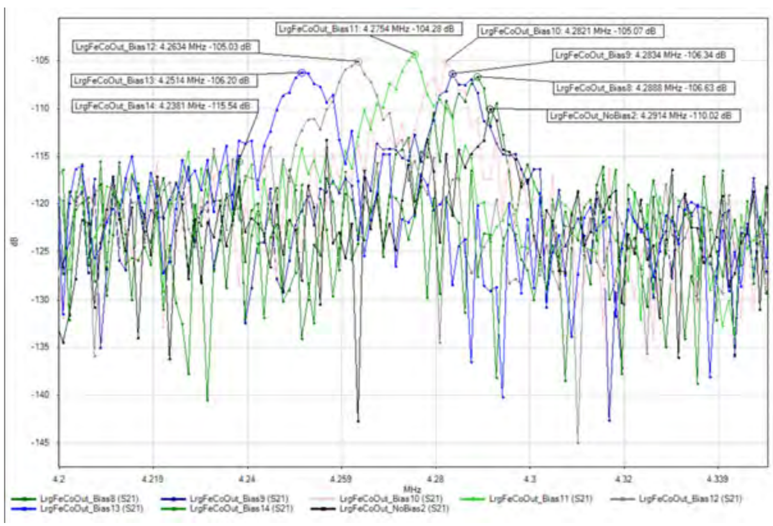
- Electrical
- Magnetic
- Modulation



Electrical Testing Results



Modulation Testing Results



Magnetic Testing Results

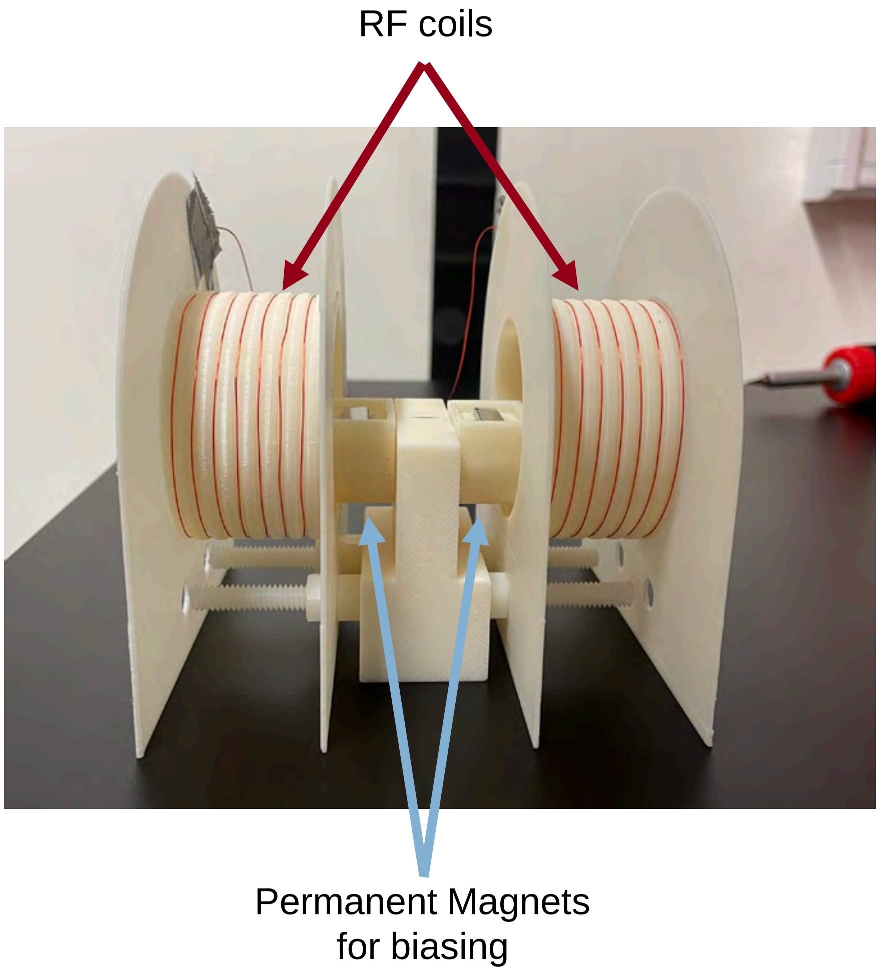
Current Testing Structure

Setup

- DC Bias
  - Permanent magnets
- RF Magnetic Field
  - Wound coils

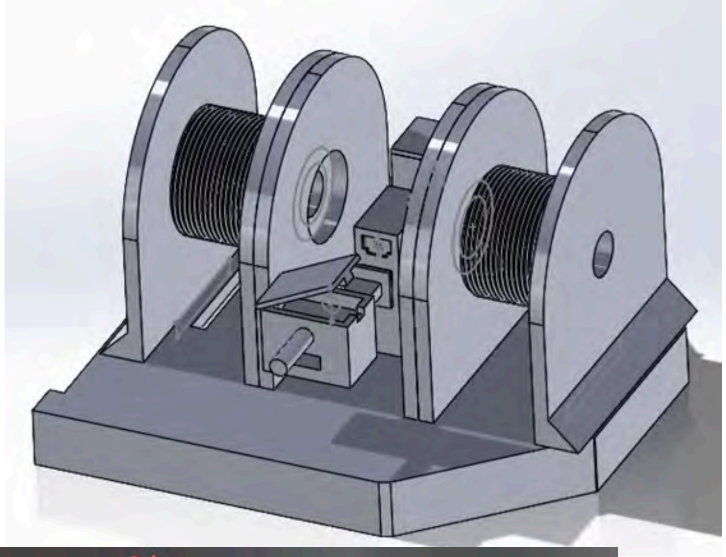
Drawbacks

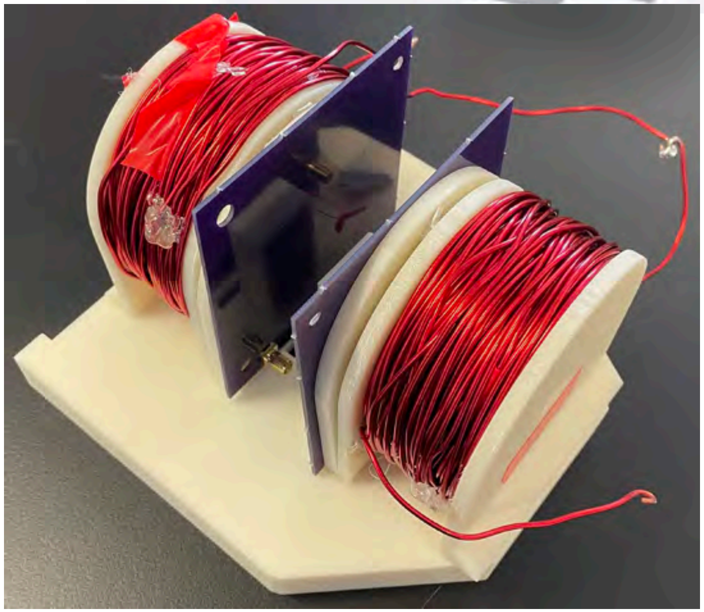
- Unstable
- Precision of bias field



Improved Design

- Designed in SolidWorks
  - 3D printed by Penn Biomedical Library 3D Printing
- PCBs designed in Eagle
  - PCBs fabricated at OshPark
- Component
  - Microscope stage cover
  - Electromagnets
  - RF PCB coil
  - Hall Effect Sensor
  - Perpendicular bias magnets





DC Electromagnet

Goals

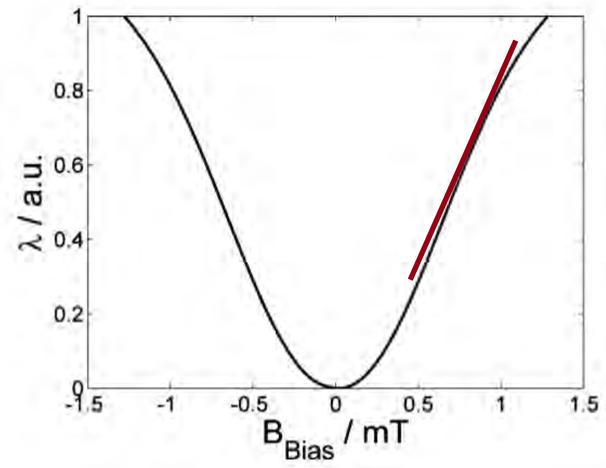
- 20 mT DC magnetic field

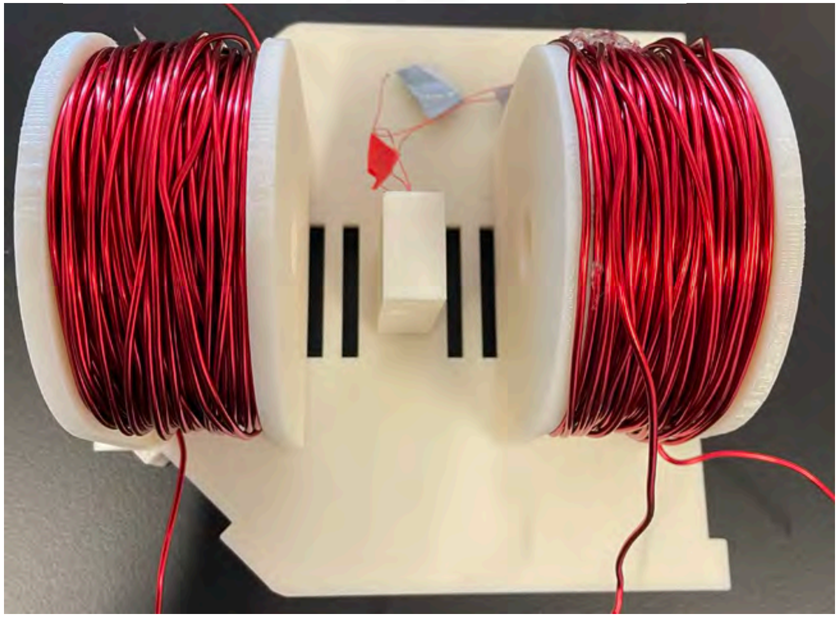
Considerations

- Optimize radius and length for magnetic field strength

Accomplished

- 240 turns, 5A
  - 11.6 mT with air core
  - 13.5 mT with magnetic core
- Current controllable magnetic field





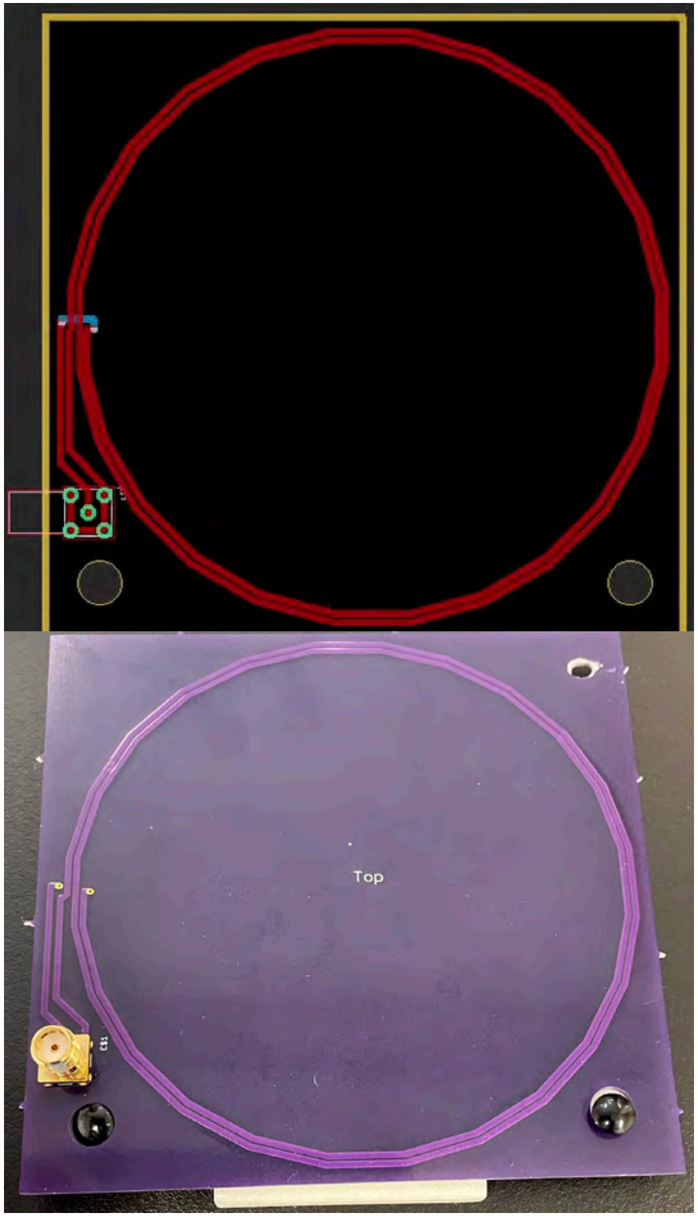
Printed Circuit Board RF Coils

Purpose and Goals

- Low frequency magnetic field
- High frequency magnetic testing
- Save space in testing structure for electromagnets

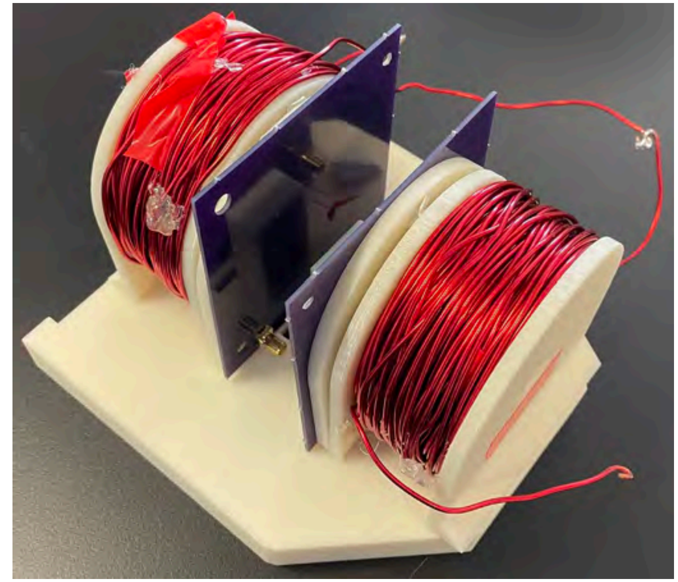
Considerations

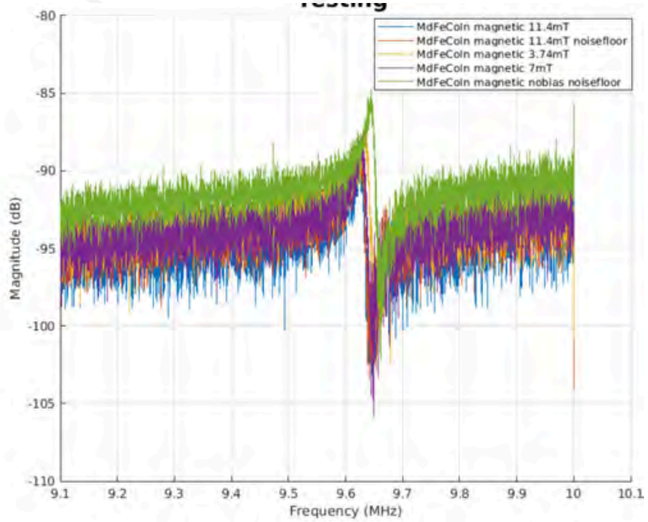
- Optimize coil turns, spacing between turns, inner/outer radius
- Inductive coils at high frequencies

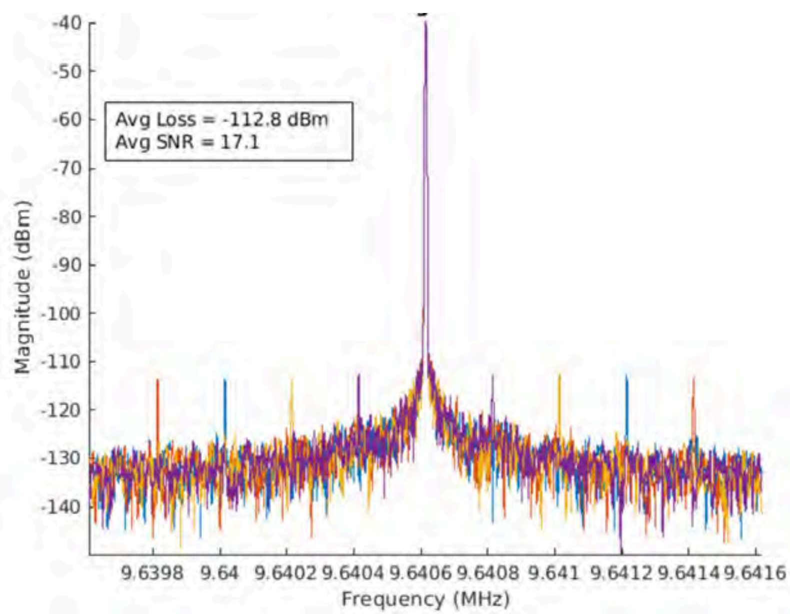


Final Testing Structure

- Successfully tested devices on designed structure
  - Electrical
  - Magnetic
  - Modulation







Acknowledgements

- The Olsson group
  - Dr. Troy Olsson
  - Sydney Sofronici and Michael D’Agati
- National Science Foundation
  - NSF REU grant no. 1950720
- University of Pennsylvania Libraries’ Biomedical Library

Questions?