Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Acoustic Emission Sensors in Superconducting Magnets

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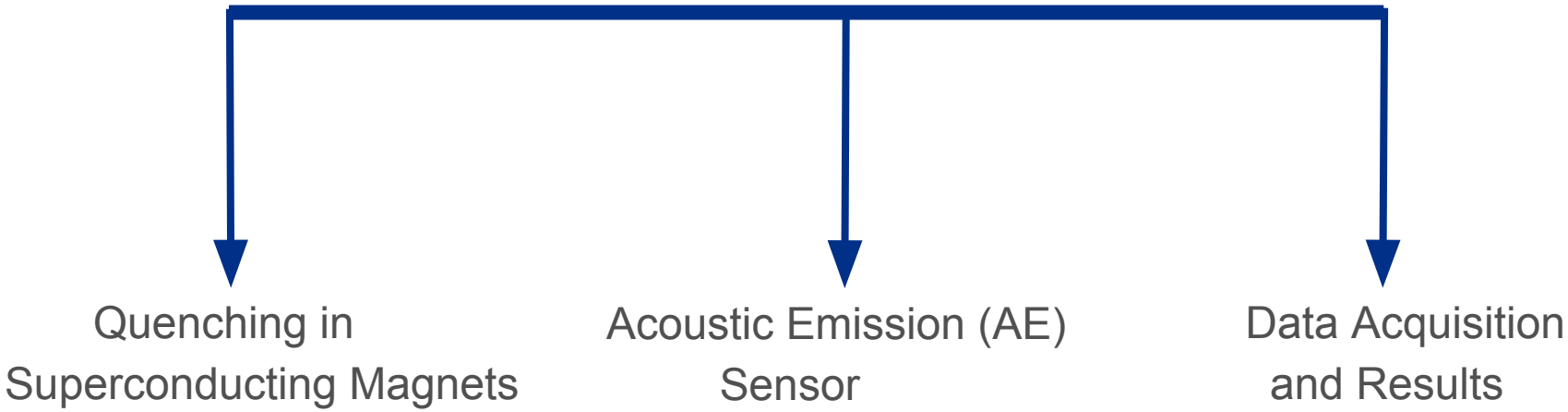
SIST/GEM Final Presentation

6 August 2018

Acoustic Emission Quench Detection Sensors in Superconducting Magnets



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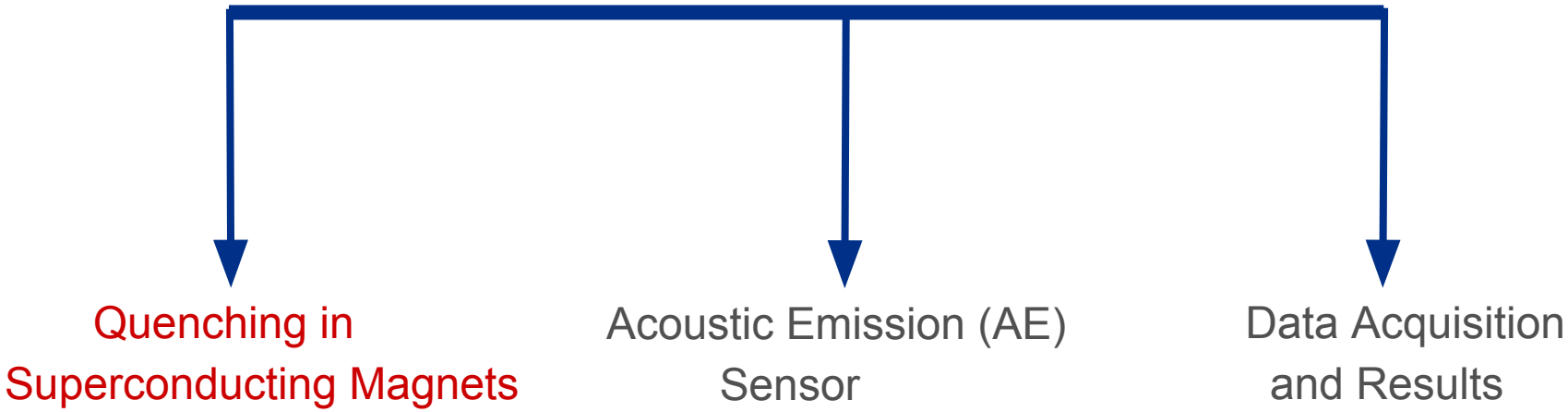


Superconducting Magnets

Electromagnets made of superconducting wire

Zero Resistance → More Current →
Stronger Magnetic Fields → Higher Energy Beams

Superconducting Magnets

Careful design and maintenance required

- Appropriate stress applied
- Must remain superconducting
- Quench - Sudden loss of superconductivity in part of a coil

Quenching

Factors that cause quenching include:

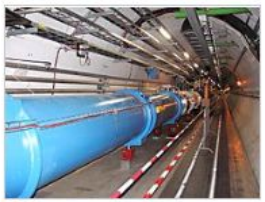
- Mechanical disturbances (microcracks)
- Electrical disturbances/ faults
- Magnetic field strength/ rate of change
- Defects in magnet

Magnets “trained” to withstand higher quenching currents by gradually increasing operating current (ramp)

Quenching

CERN says repairs to LHC particle accelerator to cost US$21 million

Wednesday, November 19, 2008



A view of the LHC tunnel.

Map of the LHC (the large circle) and the area underneath which it lies.

The European Organization for Nuclear Research (CERN) said on Monday that repairing the Large Hadron Collider (LHC) will cost up to €16.6 million or US$21 million.

The LHC, which is the world's largest and highest-energy particle accelerator, is located near the border of France and Switzerland and crosses the border four times. It has a diameter of 27 km (17 miles). It is designed to simulate the conditions shortly after the Big Bang, but it broke down on September 19 due to an electrical failure.

Most of the repair time is covered by previously scheduled maintenance time, and CERN originally hoped to have the machine up and running again by early May. However, CERN officials now believe that it may take until the end of July or longer.

CERN spokesman James Gillies said: "If we can do it sooner, all well and good. But I think we can do it realistically by early summer."

The machine operates at temperatures colder than outer space and must be gradually warmed up for experts to assess the damage, causing much of the delay. CERN expects the repair cost to fall within the annual budget for the project.

Have an opinion on this story? Share it!

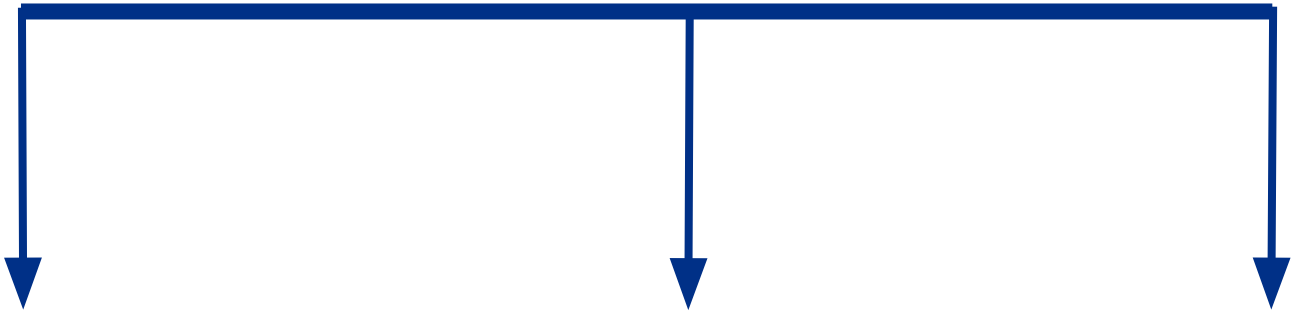
Quenching

Quench detection and diagnostic techniques:

- Strain gauges
- Quench antenas
- Coil voltage taps
- **Acoustic Emission sensors**

Sensors trigger heat sink to the magnet to more evenly distribute heat from a quench

Acoustic Emission Sensor



Quenching in Superconducting Magnets

Acoustic Emission (AE) Sensor

Data Acquisition and Results

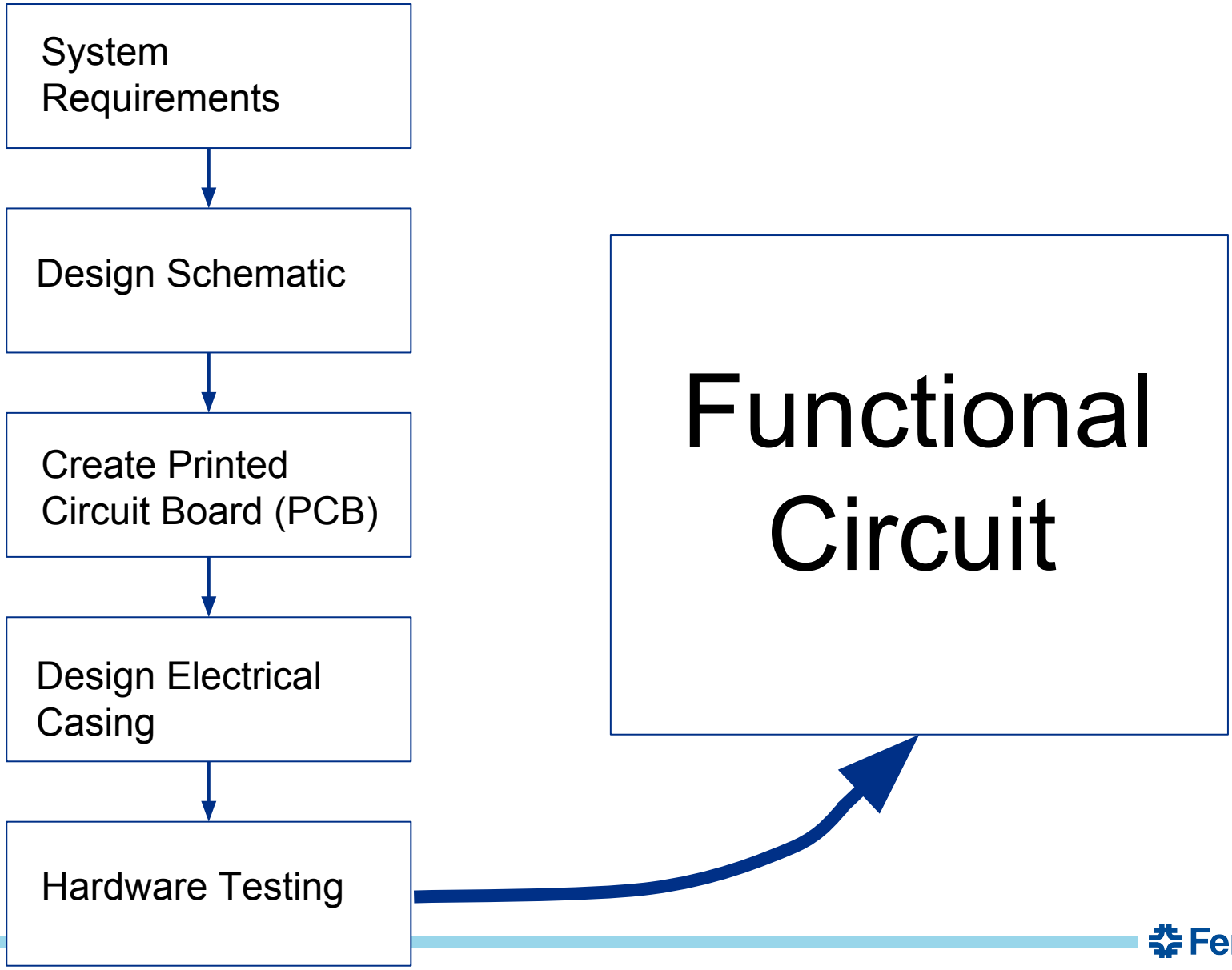
Acoustic Emission Sensor

Advantages of AE sensors:

- Comparable or faster signal detection (millisecond timescale)
- Isolated measurement system external to the magnet
- Negligibly affected by magnetic fields
- Inexpensive

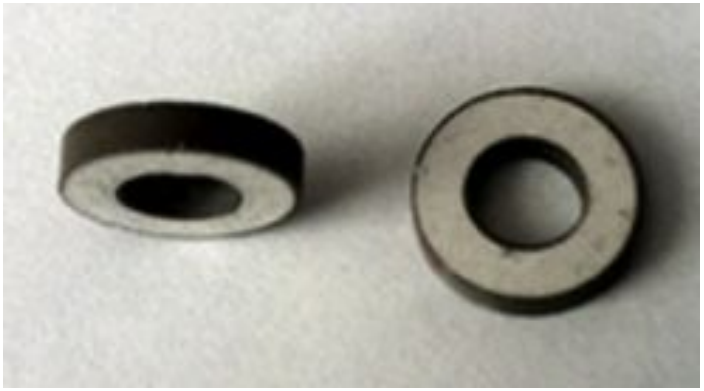
How are they designed?

Engineering Design Process



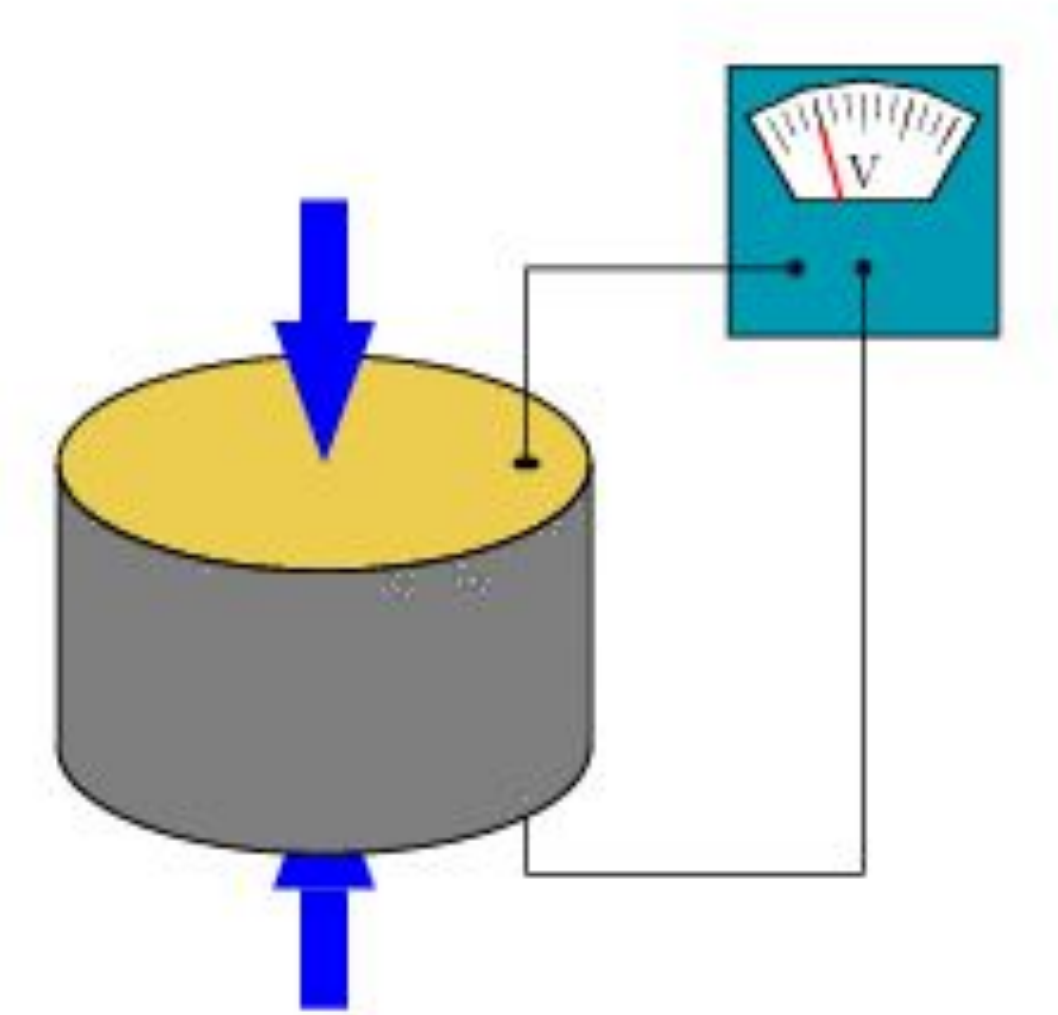
AE Sensor

Piezoelectric Ceramic
5 mm Inner Diameter
10 mm Outer Diameter

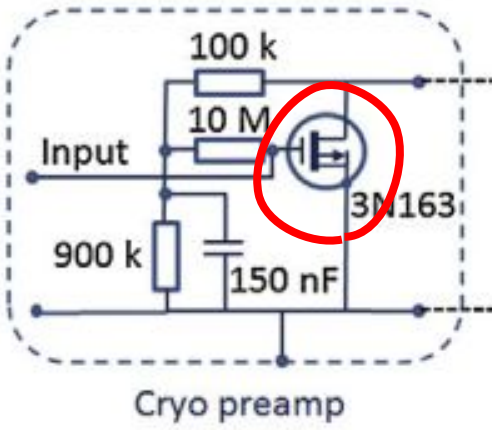


Transducer: converts mechanical stress into an electrical signal (voltage) and vice versa

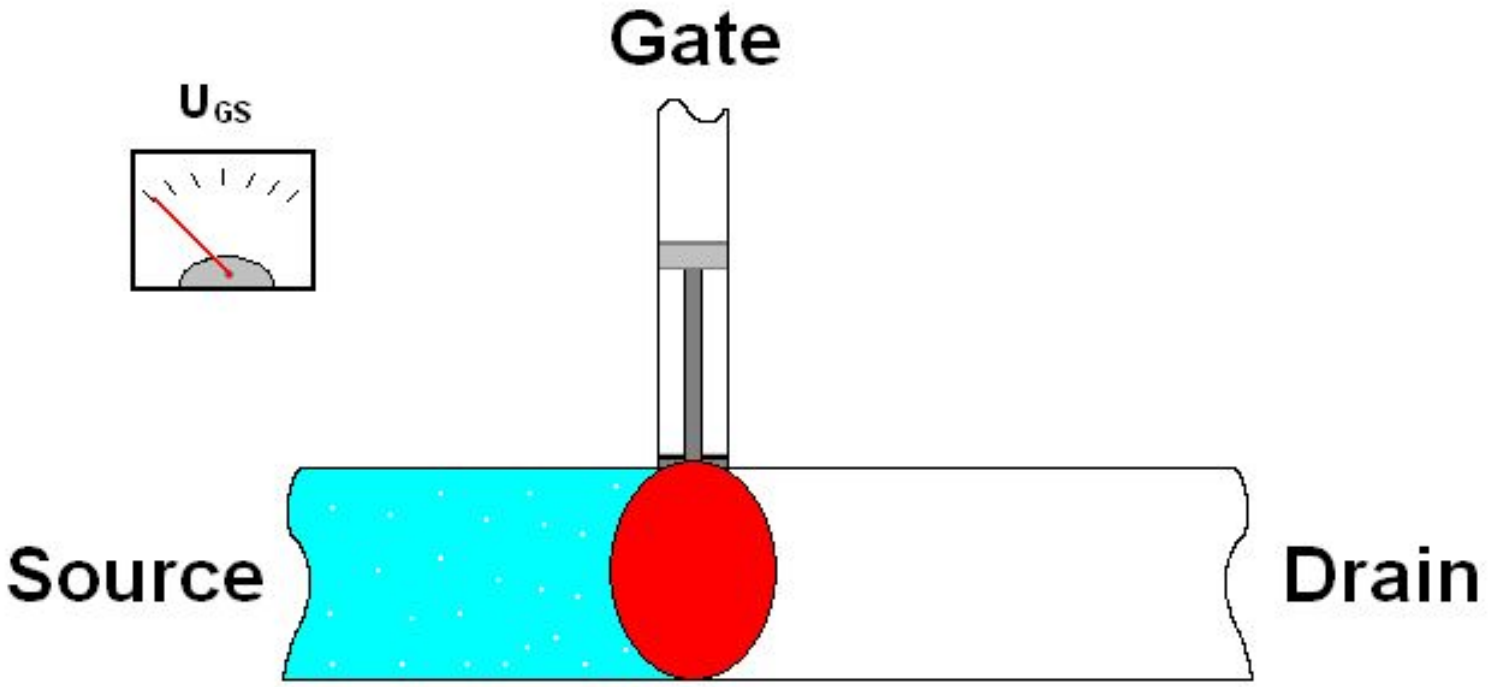
Entire circuit is designed to optimize this signal


V

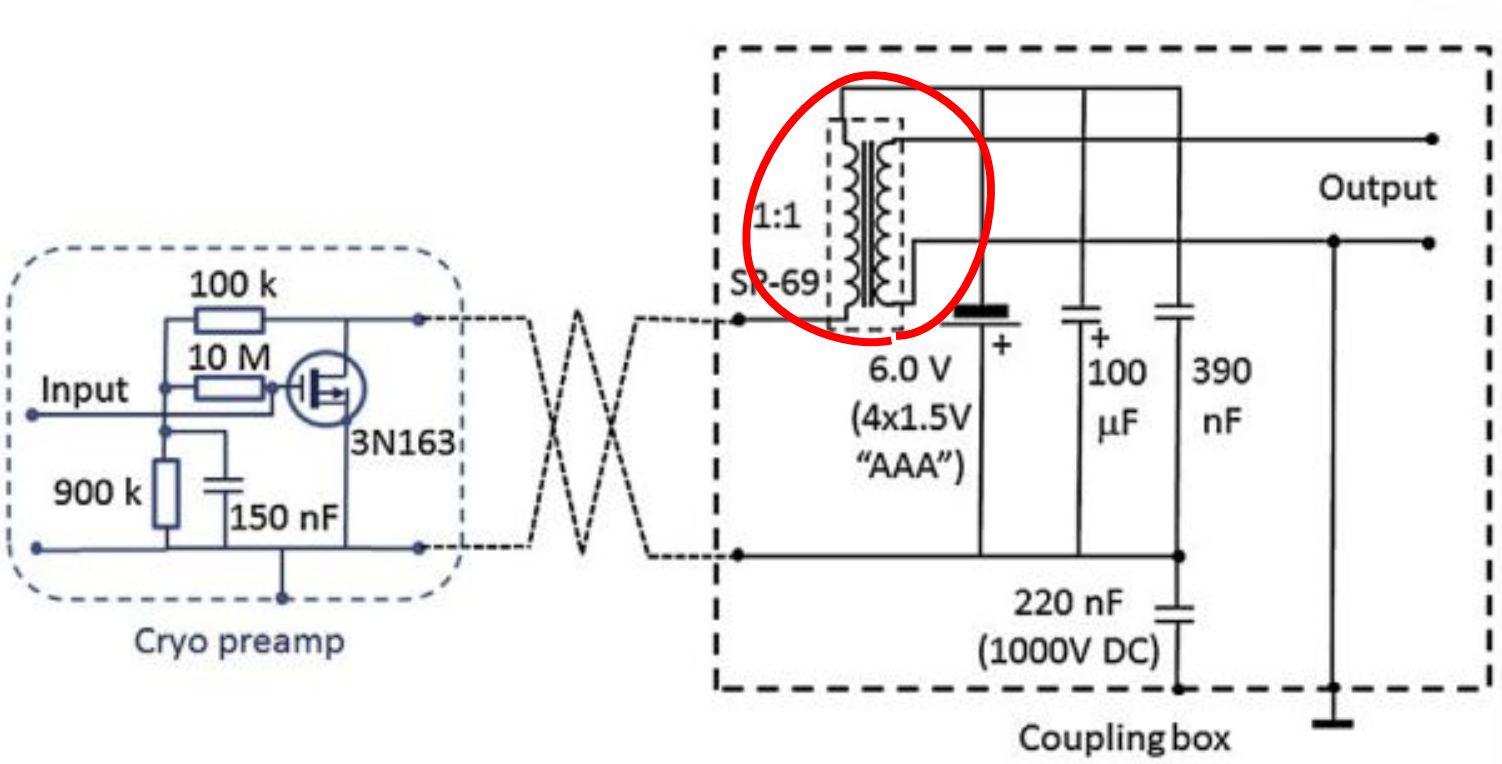
Schematic



Amplifies signal using MOSFET amplifying circuit


Gate
U_{GS}
Source
Drain

Schematic



Decouples power signal from AE signal and strengthens output signal

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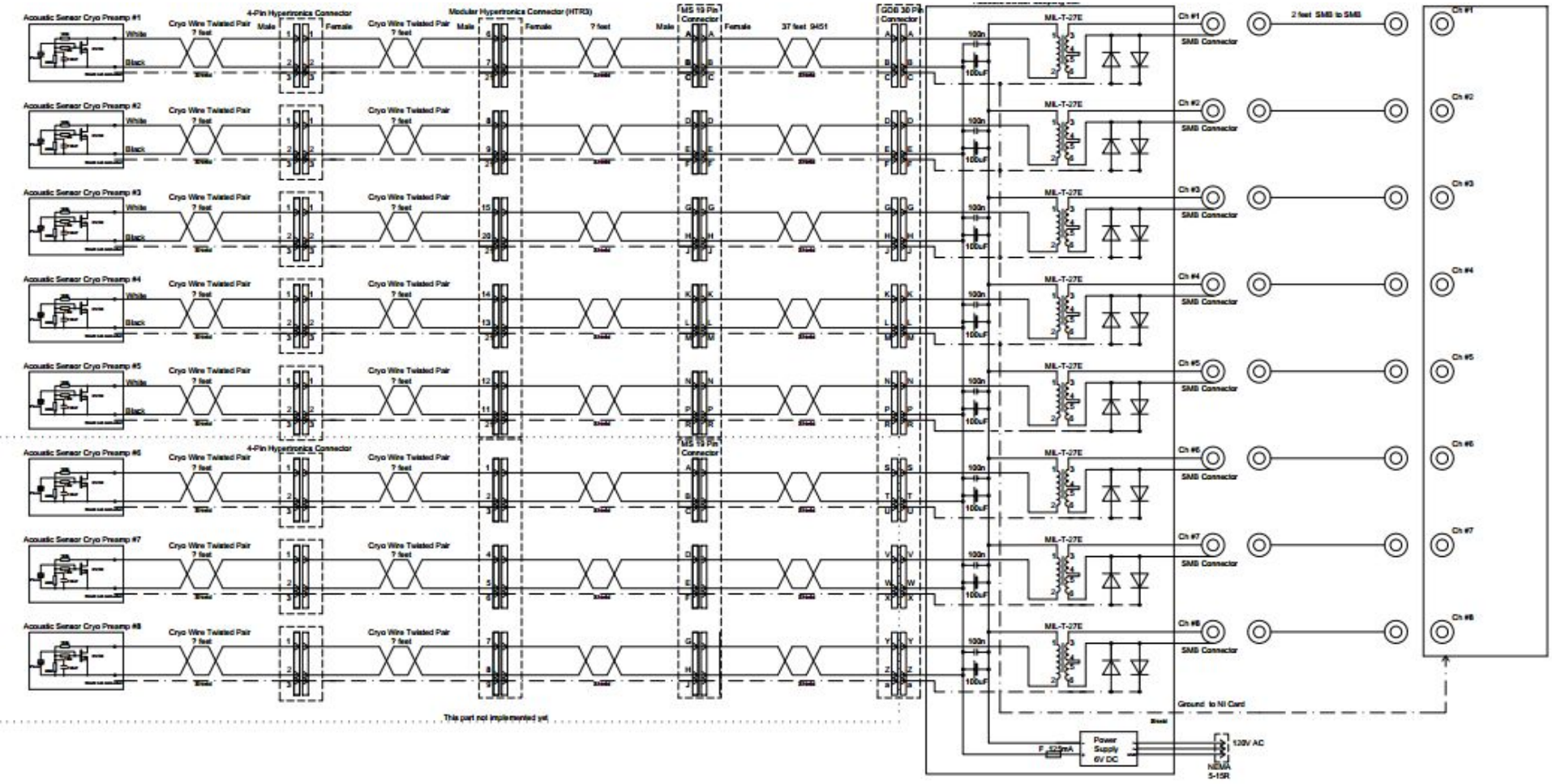
Schematic



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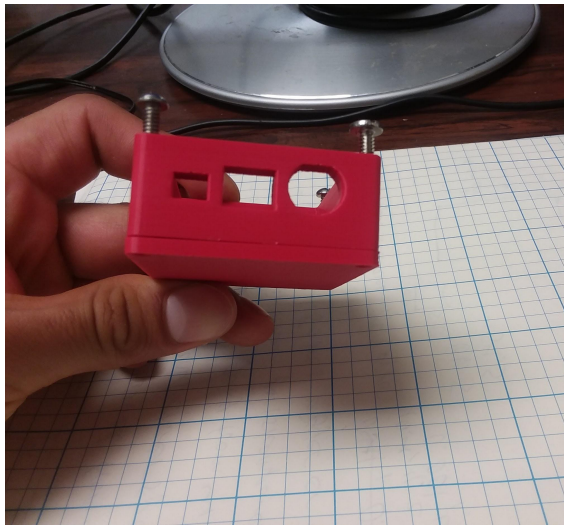
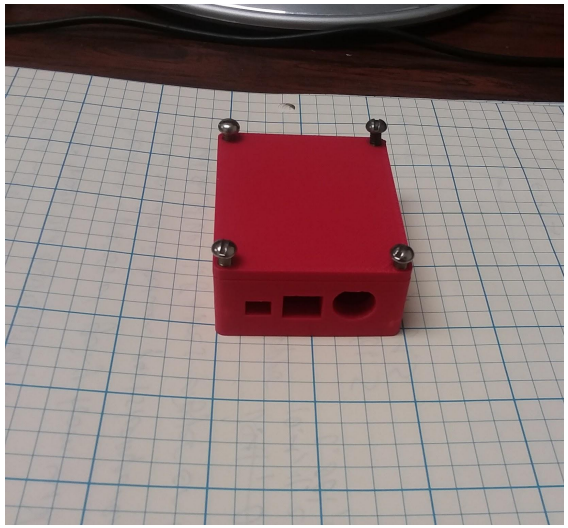
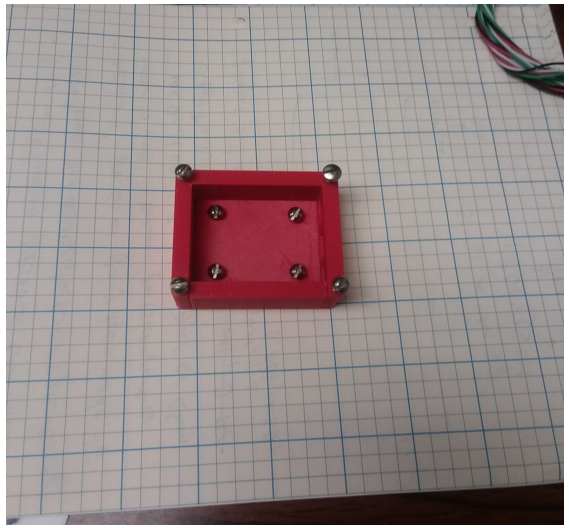
Electrical Casing

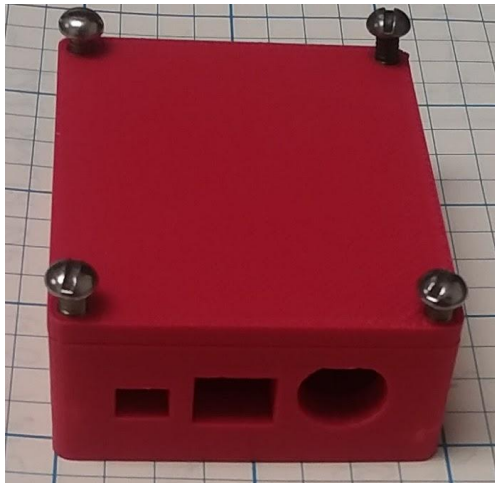




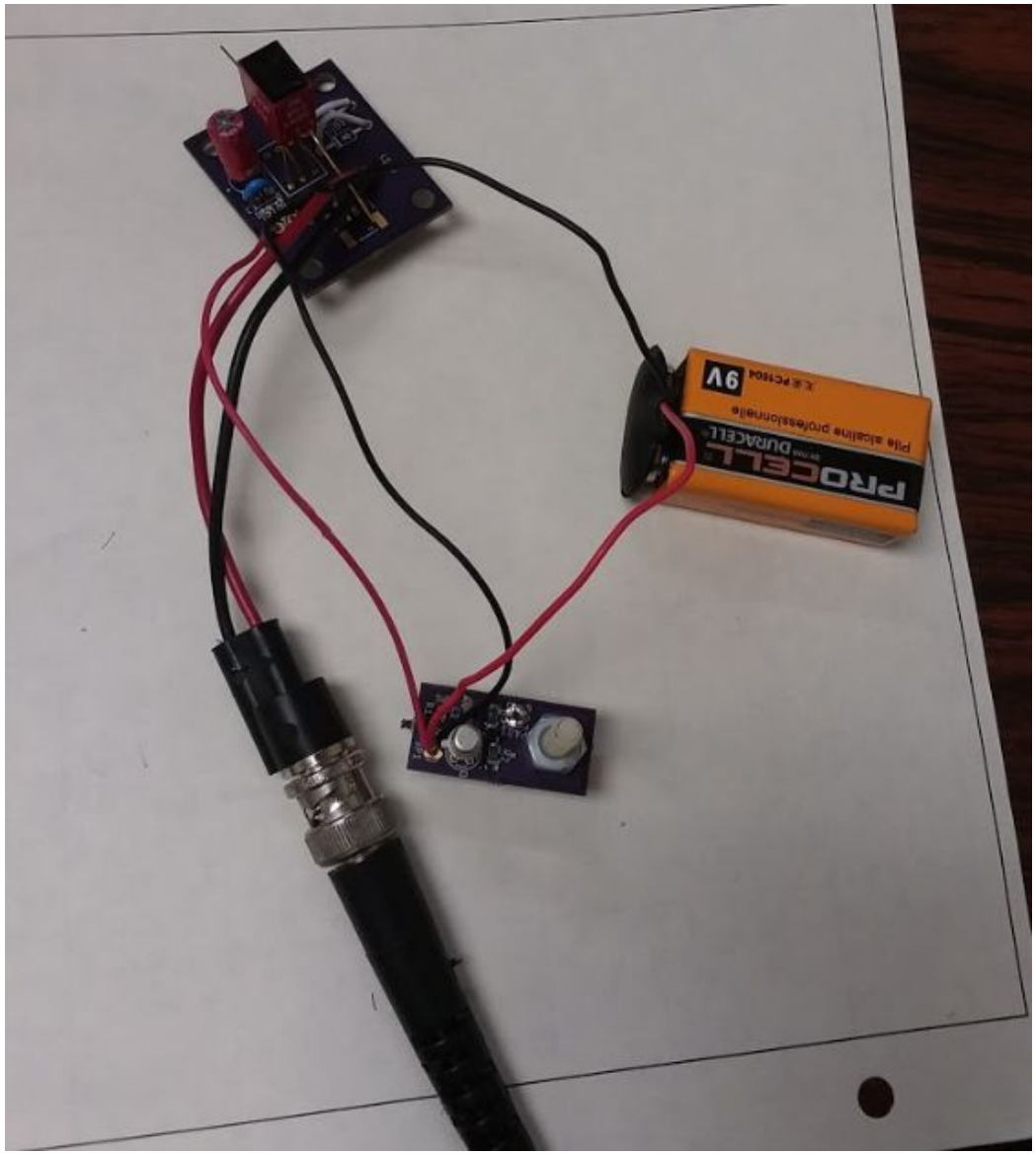


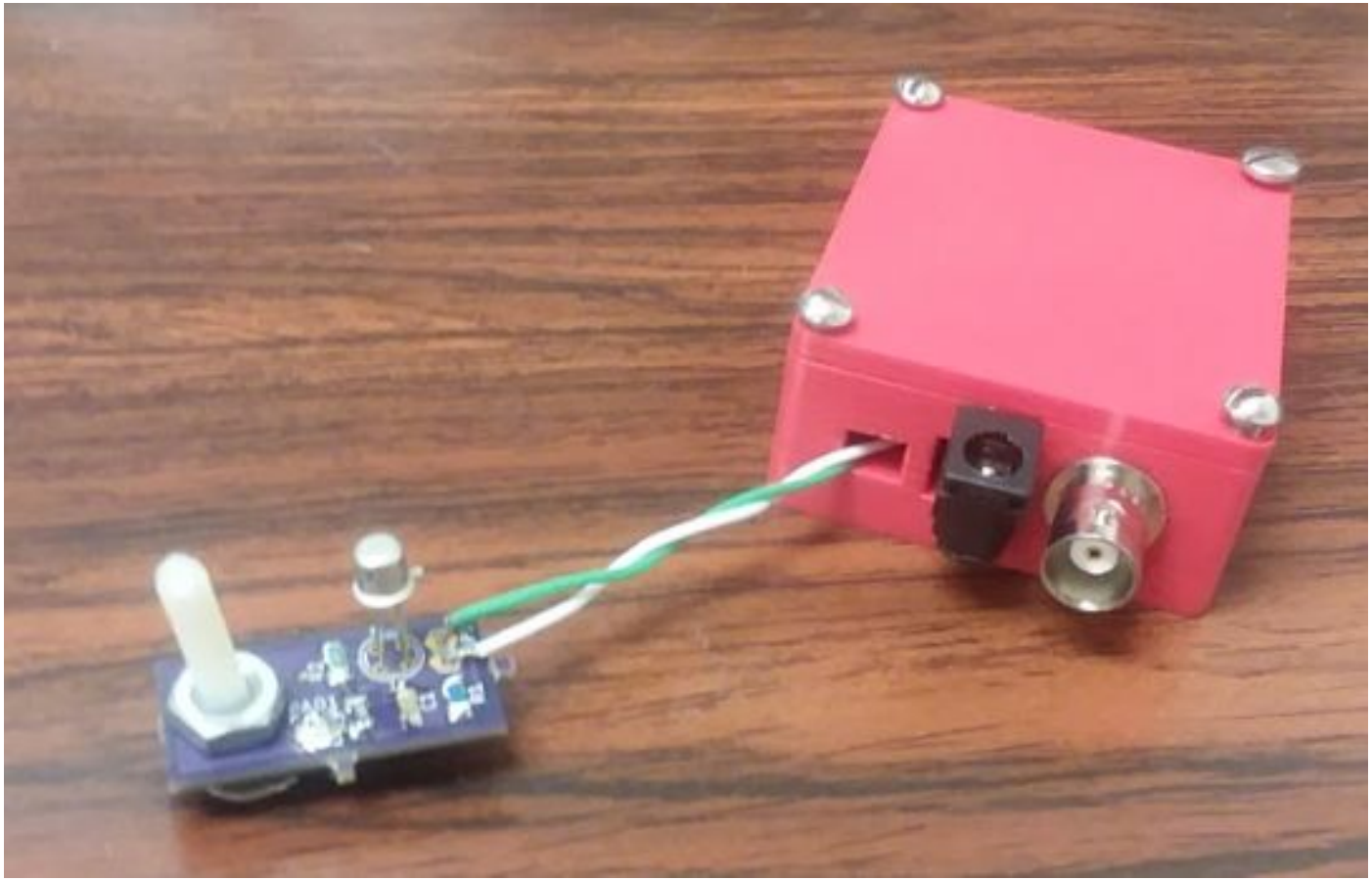
Electrical Casing

Electrical Casing (Junction Box)



- Maintains solid, reliable connections
- Protects circuit
- Reduces defects over time


9V
PROCELL
DURACELL



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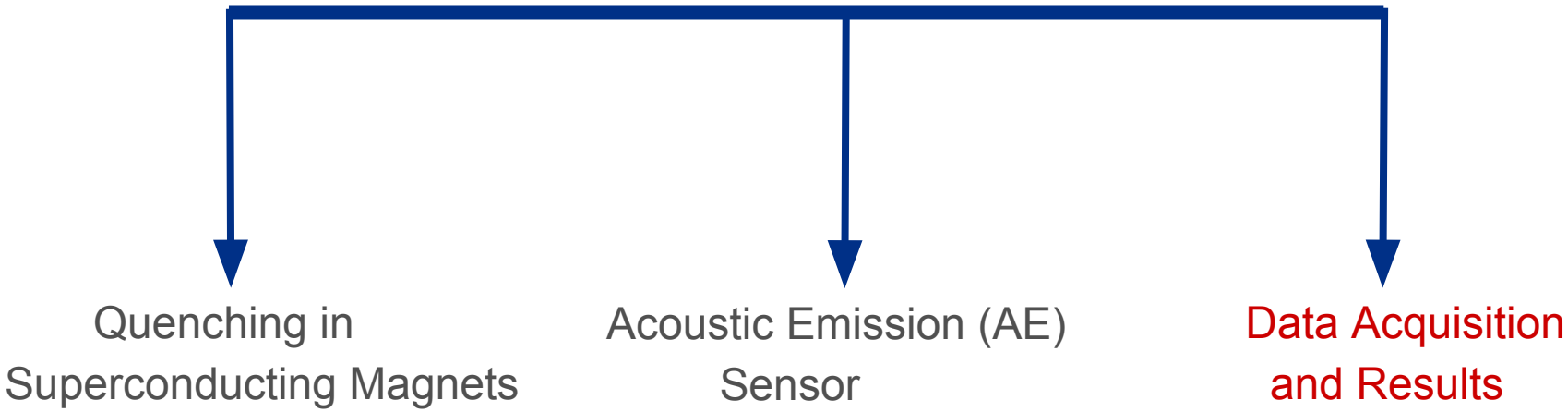
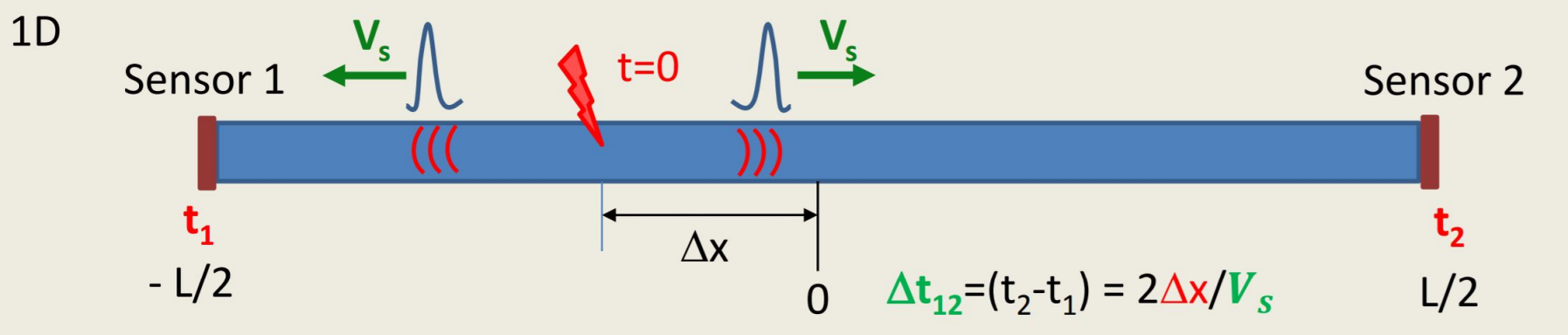


Data Acquisition

Data collection of sensors in 1 dimension:

- 33 x 2 x 1 inch aluminum bar
- AE sensors mechanically screwed in on both ends
- Bar tapped with a hammer at various points



1-dimensional source localization:

Time difference
Velocity of sound in bar → AE source location

Results

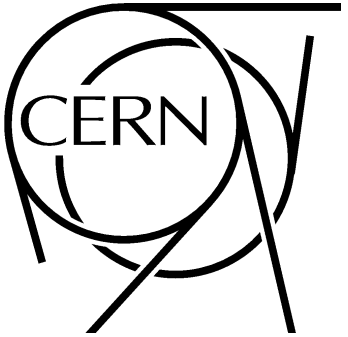
- Velocity of sound in bar determined to be 1.989 km/s
- Standard deviation: 2.34 cm
- Standard error: 0.33 cm

Next Steps

1. Conduct 2 dimensional localization
2. Improve sensor/experiment accuracy (COMSOL simulation, more sensors)
3. Test on prototype magnets

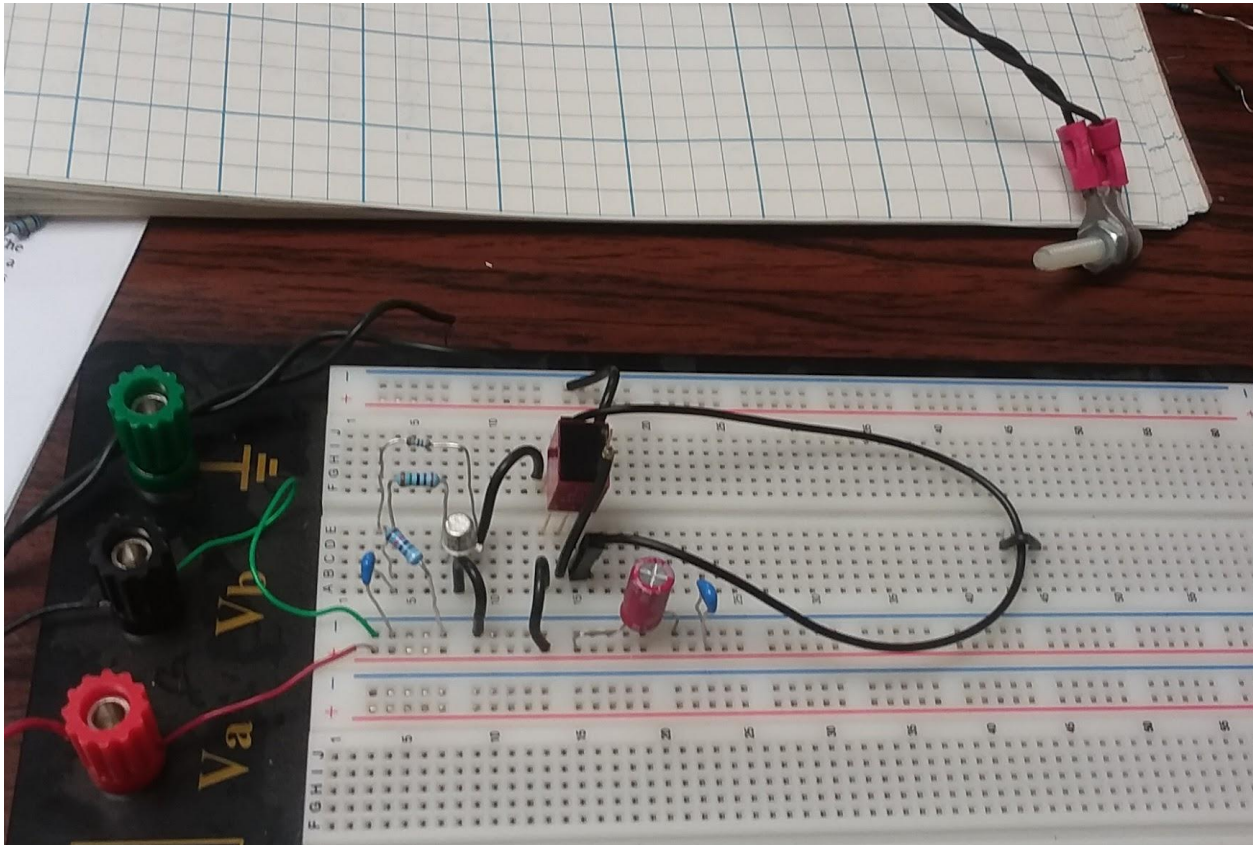
Questions?

Collaborations / Partnerships / Members

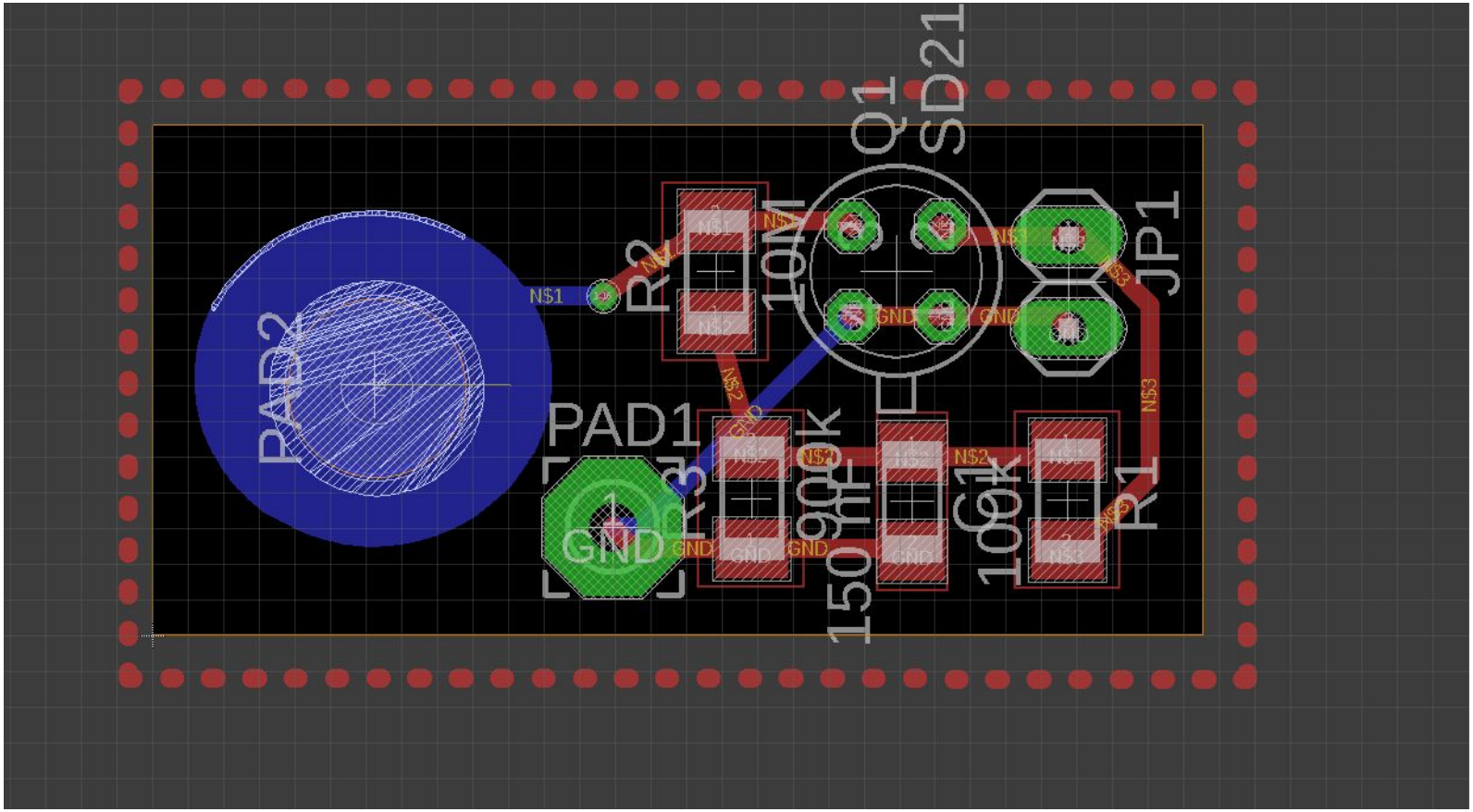


Appendix

Circuit on Breadboard



Cryo Amplifier PCB



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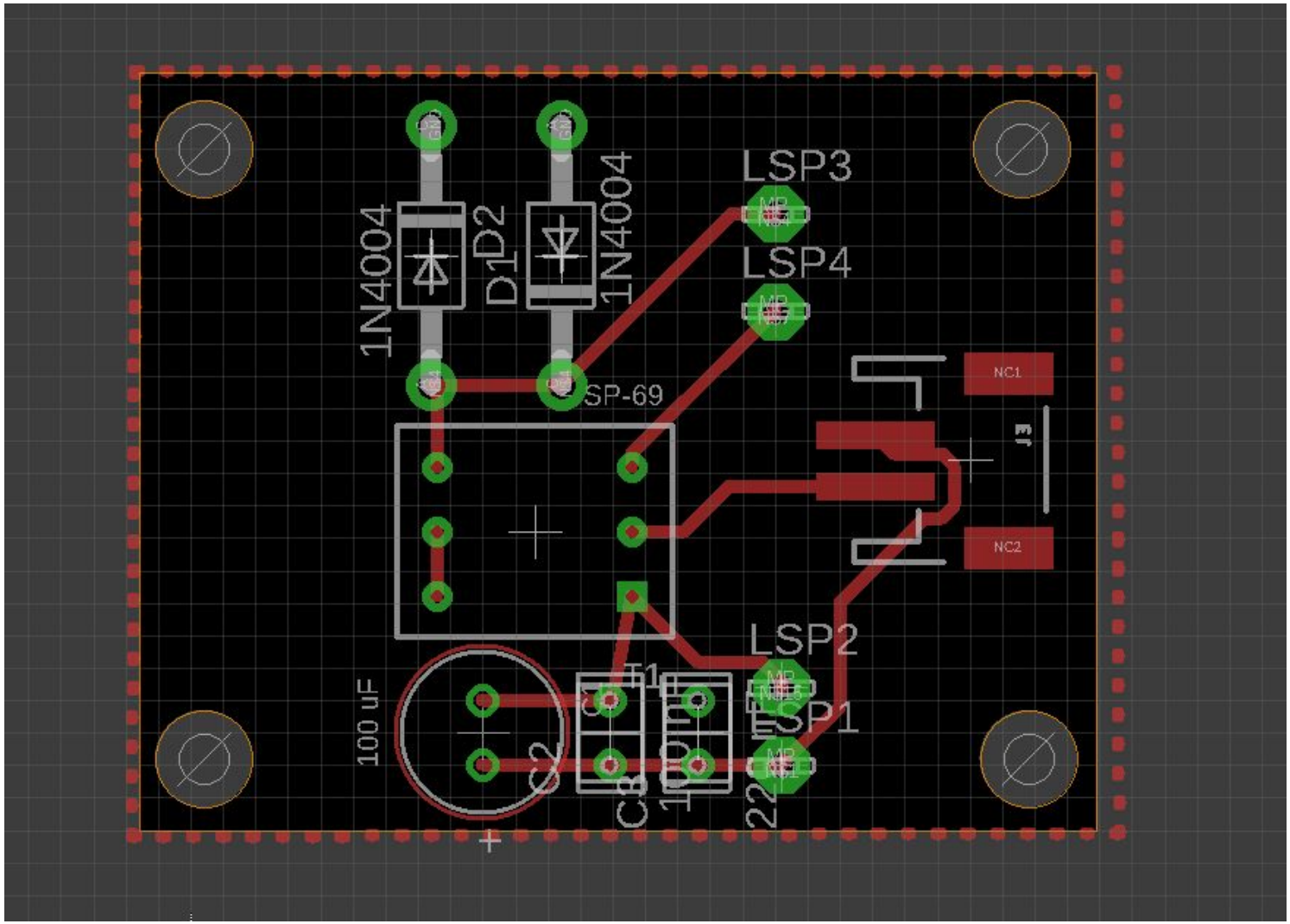
Coupling Box PCB



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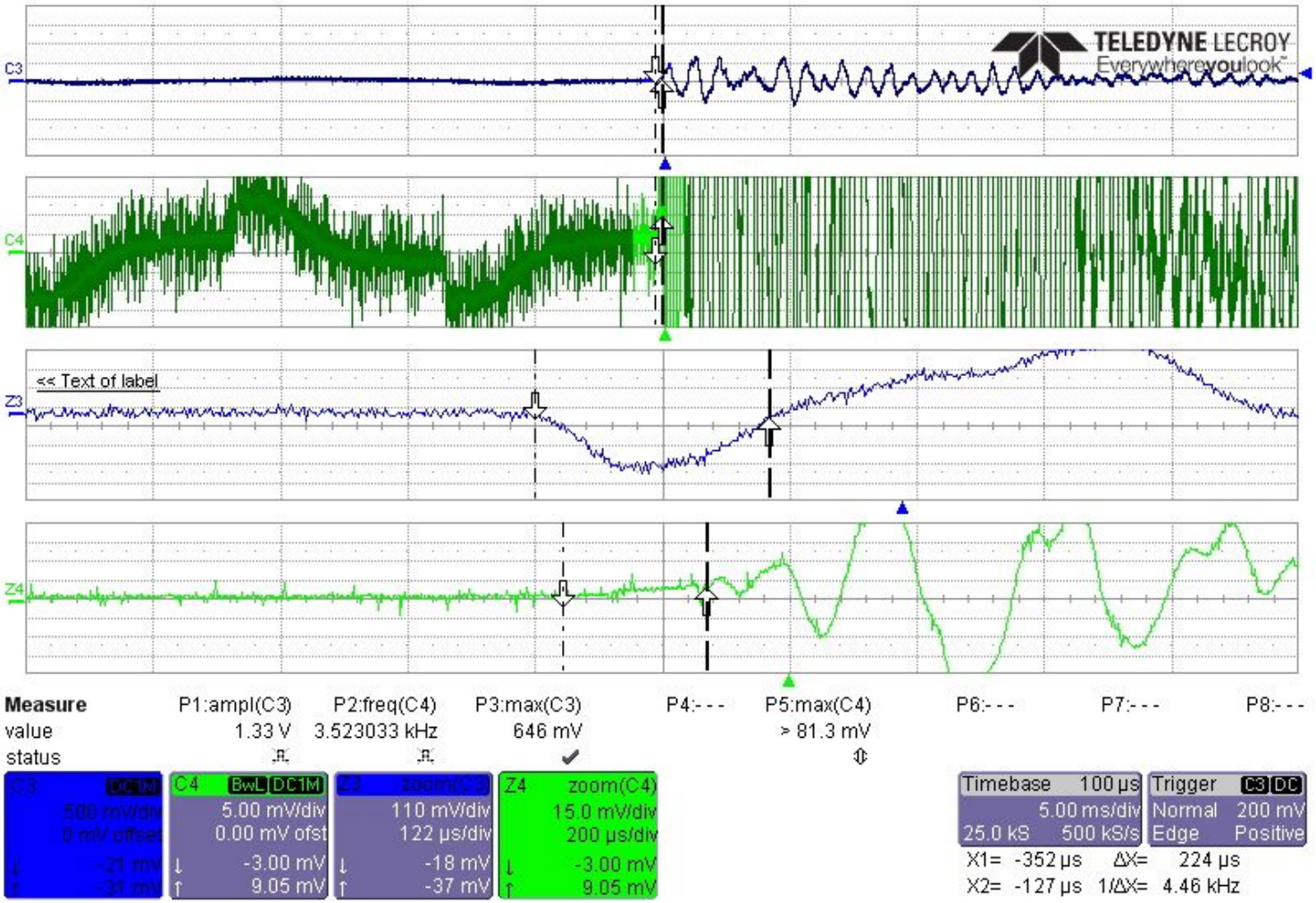
Sample Data for 1-D AE localization



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References

MOSFET animation:
https://upload.wikimedia.org/wikipedia/commons/2/2f/FET-Ani.gif

Transducer animation:
https://www.teachengineering.org/content/uoh_/lessons/uoh_piezo/uoh_piezo_lesson01_figure1.gif

Marchevsky, M., et al. “Acoustic Emission during Quench Training of Superconducting Accelerator Magnets.” Cryogenics, Science Direct, 31 Mar. 2015, www.sciencedirect.com/science/article/pii/S0011227515000399.