# Improving sensitivity in contactless conductivity measurements
## Applications to superconductors, metals, and magnetic systems

Morgan Walker[1,2], William Coniglio[2]
[1]University of Florida, [2]National High Magnetic Field Laboratory

NATIONAL MAGLAB

## Introduction

We are interested in what happens to materials under high magnetic field, high pressure, and low temperature. We put samples in a solenoid to measure conductivity and magnetic susceptibility. The amount of sample penetrated by field, and hence the skin depth, determines measurement sensitivity. The more the inductance changes as the skin depth changes, the more sensitive our measurements are to changes in conductivity and susceptibility.

f, σ, μ ➡ Skin Depth ➡ Sample Penetration ➡ Inductance

Shows how inductance depends on frequency, conductivity, and susceptibility

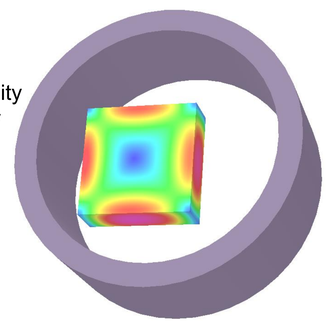
$$\delta = \sqrt{\frac{2}{\mu\omega\sigma}}$$

Equation 1.

The skin depth equation
Symbols: μ is permeability ω is frequency σ is conductivity

## Goals

- Determine if sample position inside coil affects sensitivity
- Investigate how sample size compared to its skin depth affects measurement sensitivity
- Understand why some past experiments were successful and why others were not
- Learn how to better design future experiments.



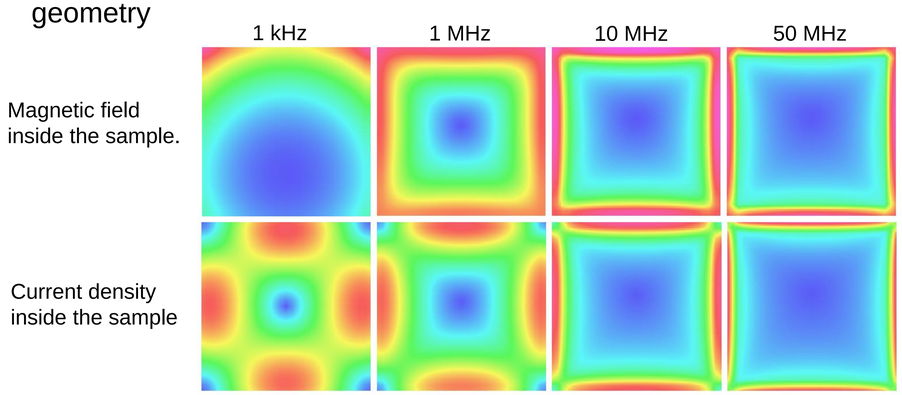
Sample inside the coil at 1MHz:
Warm colors → high current density
Cool colors → low current density

## Simulation

I used finite element analysis software[1] to determine how the skin depth of a material affects inductance. I varied the ratio of skin depth to sample size by changing conductivity, susceptibility, frequency, sample size, and total system size. The sample is placed near the edge of the coil, rather than in the center.

## Results

- At1 kHz the field fully penetrates the sample. As frequency increases skin depth decreases, and field only penetrates sample edges.
- The interesting current density pattern is caused by the sharp sample geometry




- Measurements are most sensitive to changes in conductivity at moderate frequencies and moderate conductivities.

Figure1.

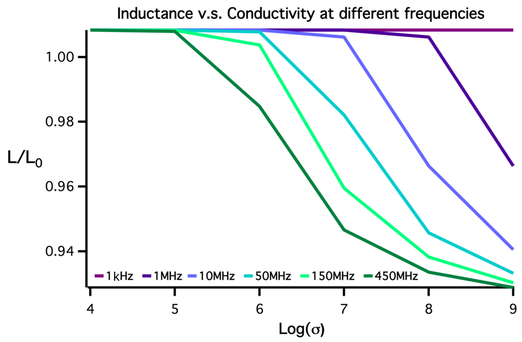



Figure 1. shows how conductivity and frequency affect the inductance. Areas with a larger slope are more sensitive.

- Measurements are most sensitive to changes in magnetic susceptibility at low frequency and low conductivity

Figure 2.

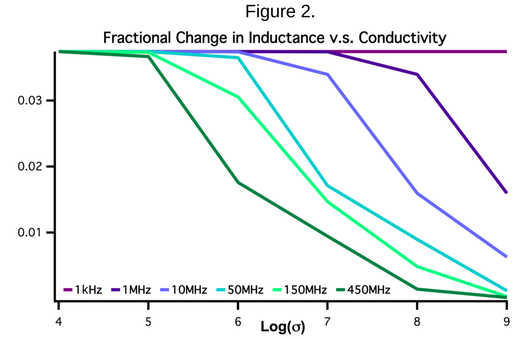


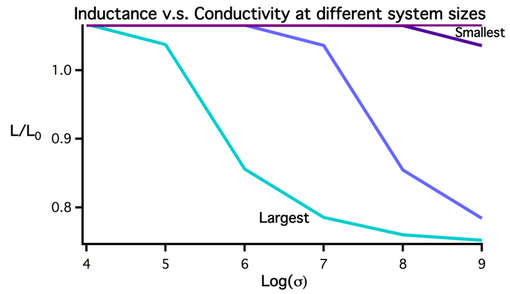

Figure 2. shows how a 10% change in magnetic susceptibility affects inductance. Larger values mean more sensitivity.

## References

- [1]OPERA-3d/ELEKTRA-SS Version 17.0, Vector Fields Ltd, Oxford, UK
- Griffiths, D. J. *Introduction to Electrodynamics*. 4th ed. NJ: Prentice Hall, 1999. Print.

- Increasing the size of the entire system has the same effect as increasing frequency and increasing conductivity

Figure 3.




Each line is a different system size at 1 kHz, starting at the original size and increasing by a factor of ten each time

- Larger samples in the same coil give more sensitivity. Sample cross-section is more important to sensitivity than sample height.

Table 1.

| Sample Radius | $\frac{L_{max}}{L_{min}}$ |
|---|---|
| 30 μm | 1.00 |
| 40 μm | 1.20 |
| 50 μm | 1.45 |

Table 2.

| Sample Height | $\frac{L_{max}}{L_{min}}$ |
|---|---|
| 10 μm | 1.09 |
| 20 μm | 1.11 |
| 40 μm | 1.16 |

Table 1. and Table 2. show the ratio of the largest inductance to the smallest inductance at different sample sizes.
Table 1: Vary sample radius
Table 2: Vary sample height

## Conclusions

- Confirmed that sensitivity is improved when the sample is placed close to coil, rather than in the center
- Measurements have little sensitivity to changes in conductivity when a sample is fully or minimally penetrated by field
- Measurements have the most sensitivity to changes in susceptibility when a sample is fully penetrated by field
- Figures 1, 2, and 3 can be used to understand the outcome of previous experiments and to design future experiments

## Future Work

- Determine if the skin effect in the coil affects measurement sensitivity
- Investigate a flat coil with the sample on top configuration

## Acknowledgements

- Thanks to Jose Sanchez for organizing the REU program, William Coniglio for supervision, and Andy Gavrilin for help with Vector Fields.
- This research was funded by DMR 1157490 and NNSA SSAA DE-NA0001979