SAND2019-3876PE

Magnetic Induction Tomography for National Security Applications

Project Number (SL17-EDUG-FastNeutronImaging-PD3Jb)

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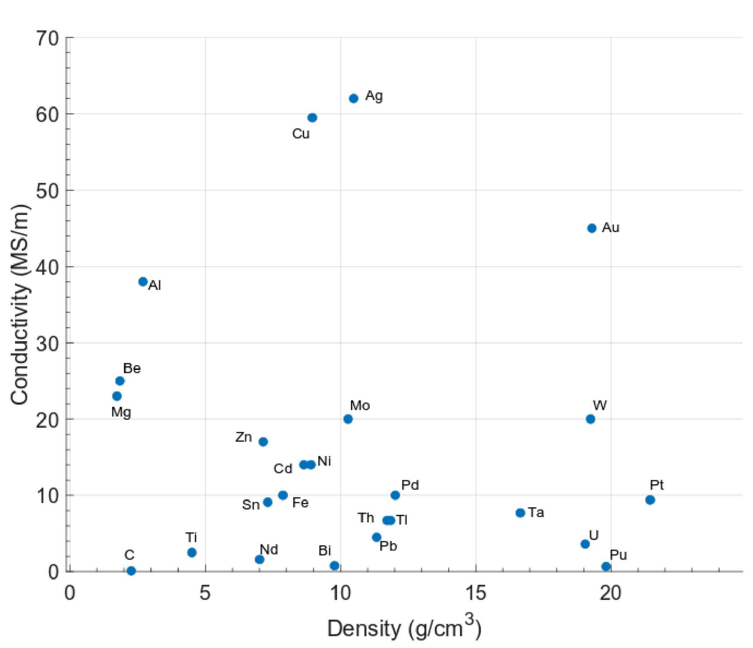
Goals and Objectives

- Develop an alternative signatures technique to provide information complementary to radiography in support of security applications
- Identify materials based on their conductivity (σ) profile and response to an applied AC electromagnetic field in accordance with Faraday's law of induction $\boldsymbol{\nabla} \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$

Introduction

A novel detection technique is emerging based on magnetic induction tomography (MIT). This technique is sensitive to material conductivity and can be used to penetrate high-density, low-conductivity shielding materials (e.g. lead).



Conductivity vs density for a selection of materials

This screening technique can be used to generate conductivity maps of screened objects to help identify concealed threat objects including firearms and special nuclear materials.

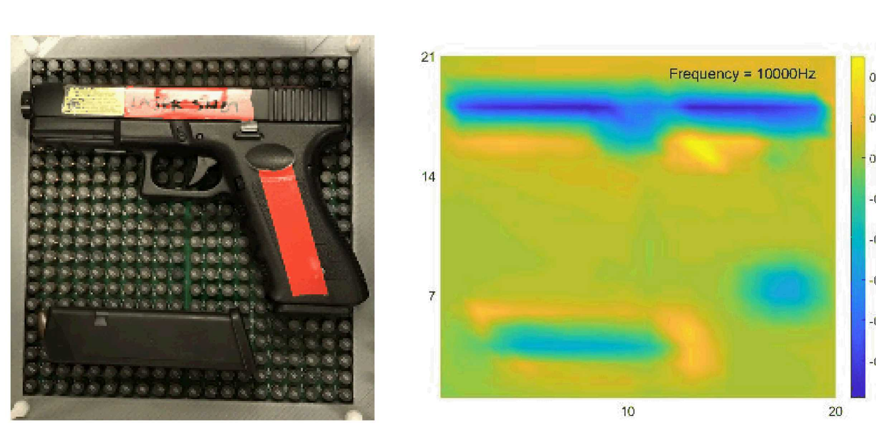
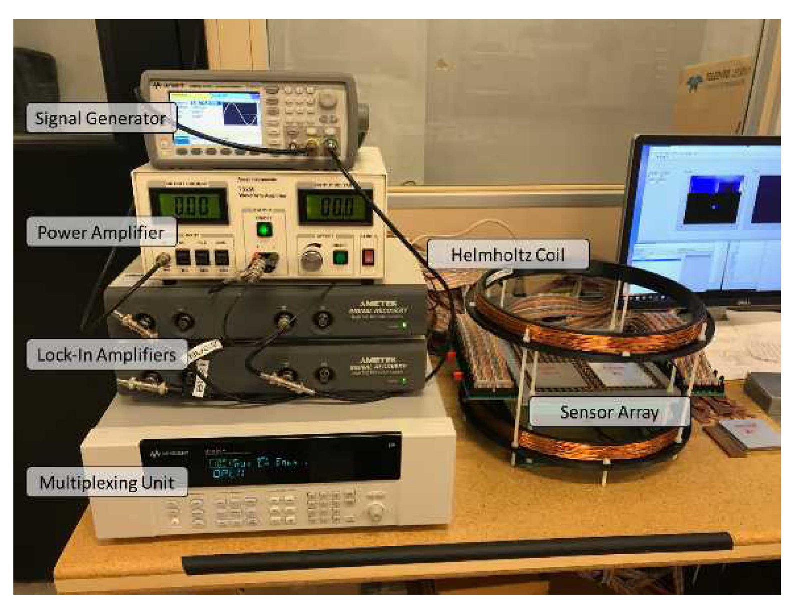


Image of Glock training pistol and loaded magazine

Methods

Image Acquisition

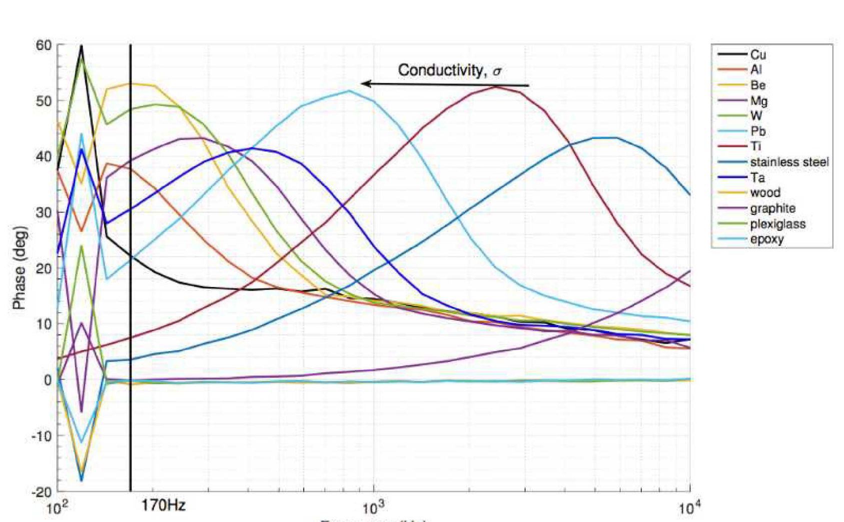
- Helmholtz coil with AC driving signal generates uniform field across plane
- Eddy currents induced in a conductive object generate secondary fields that perturb the applied field
- Lock-in amplifiers are used to compare the measured magnitude and phase to the driving signal
- A multiplexer is used to read each sensor sequentially allowing for a 21×20 conductivity map to be measured in ~30 seconds



Equipment used for MIT imaging array benchtop demonstrator

Material Characterization

Frequency-sweeps can be used to generate a response that is characteristic of the conductivity and the thickness of the material

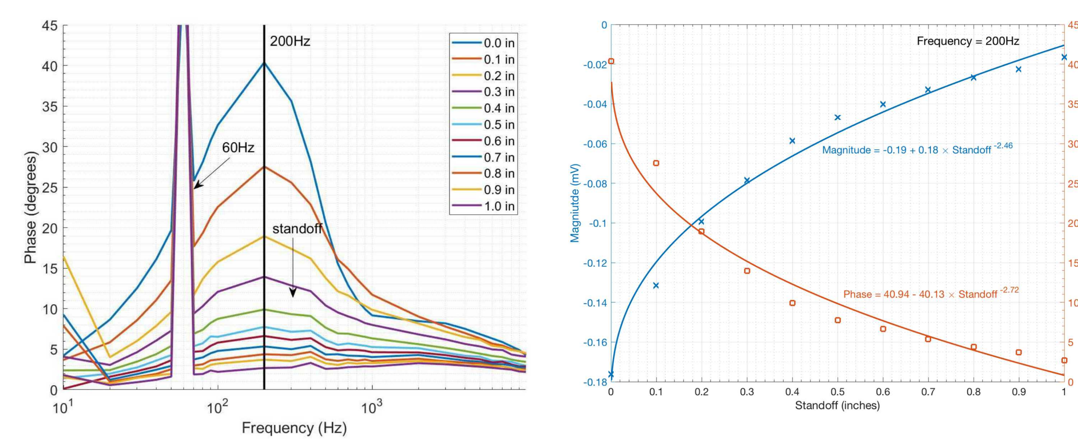


Relative phase as a function of frequency for a selection of materials, each with a thickness of 0.4"

Results

Dependence on standoff

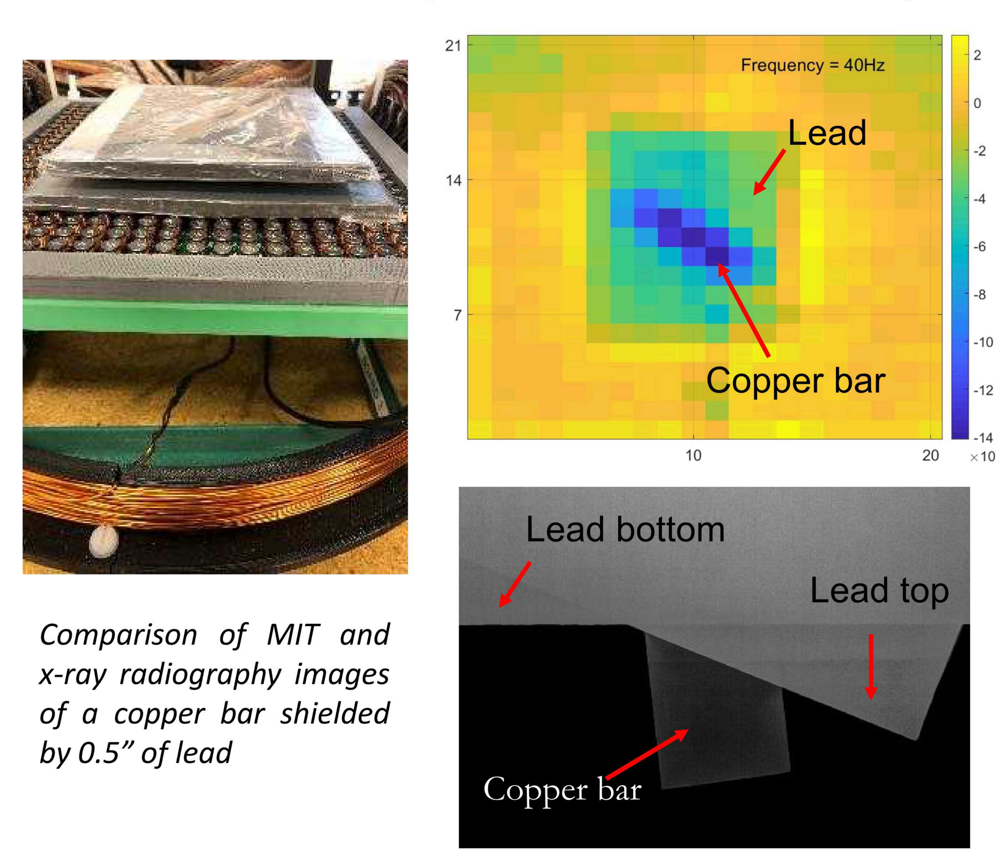
- A 0.2"-thick copper bar was measured at standoff distances between 0" and 1" in 0.1" steps
- The driving frequency was swept between 10 Hz and 10 kHz
- Results show that the frequency of maximum phase shift remains constant but signal strength falls of as $1/r^3$



Frequency-dependent phase response as a function of standoff. Both the phase and magnitude response follow the expected $1/r^3$ falloff

Penetration through shielding

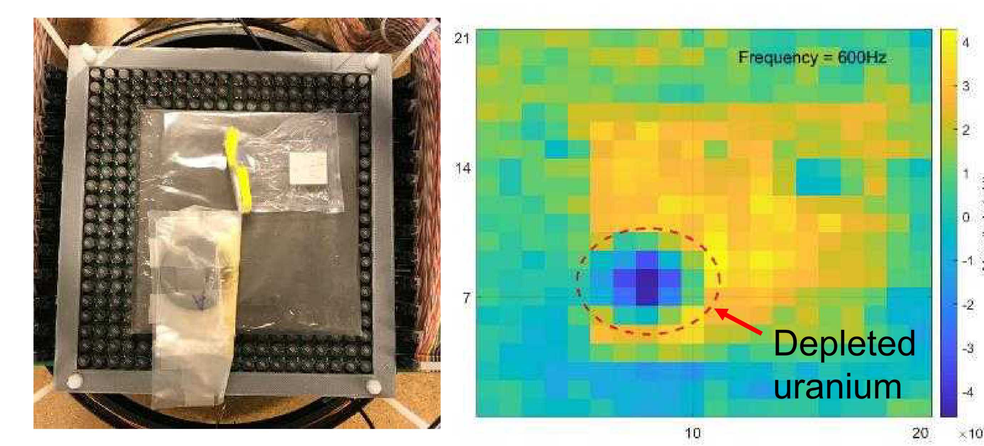
- Penetration ability is determined by a material's skin depth, which is related to the material's conductivity and and frequency; $\delta = \sqrt{\frac{2}{\omega\sigma\mu}}$.
- A comparison between MIT and x-ray radiography demonstrates the utility of detecting objects shielded by lead
- An MIT image acquired at 40Hz reveals a copper bar through 0.5" of lead. Compare this with a 3 minute exposure at 450keV X-ray



Comparison of MIT and x-ray radiography images of a copper bar shielded by 0.5" of lead

Discussion and Next Steps

- In support of Nuclear Threat Reduction, we would like to be able to detect and identify shielded special nuclear material. We were able to detect a 0.15"-thick depleted uranium disc through 0.25" of lead.
- While this image was generated using an implicit background-subtraction, the result motivates further development in hardware and reconstruction algorithms



Detection of lead-shielded depleted uranium using implicit background subtraction

Hardware Improvements

- Moving from coils to Hall-effect sensors offer a cost-effective route to increase sensitivity and also adds the ability to make DC measurements for improved material characterization
- Development of ASICs to handle on-board multiplexing, lock-in analysis and digitization
- Improved mechanical ruggedization for use in an operational environment

Improved Analysis Techniques

- Realistic operating scenarios will present challenges such as
  - Object standoff
  - Multiple layers of material
  - Inhomogeneous applied fields
- Inverse reconstruction algorithms can help reduce image artifacts and improve material characterization capabilities
- Fusion of MIT and radiography images may provide improved material characterization capabilities

Conclusion and Relevance to Program Objectives

- MIT presents an alternative method for detecting concealed objects that provides complementary information to radiography
- Low-frequency interrogation pulses can be used to penetrate through conductive shielding material
- Frequency-dependent response demonstrates the potential to characterize detected material
- This technique has been used to successfully locate depleted uranium concealed by lead, demonstrating its potential utility as an alternative signature for detection of shielded special nuclear material

Collaboration with AWE

- This work is part of an ongoing collaboration between Sandia National Laboratories and The Atomic Weapons Establishment
  - Multiple visits between SNL and AWE
  - Six-month secondment of Robert Ward (AWE) to SNL/CA

Rob Ward, Kyle Polack, and Joe Watson at SNL in June 2017

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References

1. R. Ward, et al., "Magnetic induction tomography of objects for security applications," SPIE Proceedings Vol. 10438: Emerging Imaging and Sensing Technologies for Security and Defence II (2017). DOI: 10.1117/12.2278888
2. B. J. Darrer, et al., "Magnetic Imaging: A new tool for UK National Nuclear Security," Nature Scientific Reports Vol 5, Num 7944 (2015). DOI: 10.1038/srep07944

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