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Overview of Sensing Technologies

PRESENTED BY

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Resonator technologies for high sensitivity detection of biological targets

Sponsors: LDRD, CRADA

<u>Purpose:</u> Develop a next generation microfluidic point of care diagnostic platform that rapidly identifies and determines a pathogen's antimicrobial susceptibility.

<u>Problem Addressed:</u> Transform the way bloodborne infections are identified and treated by rapidly speeding up the identification and susceptibility profiling process.

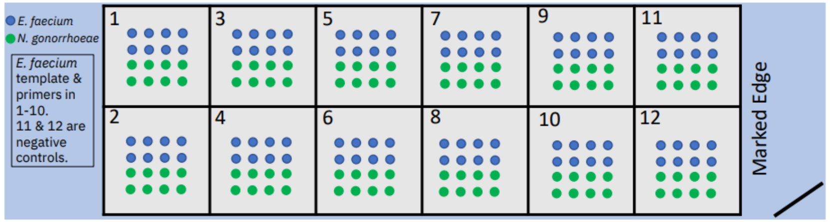
<u>Approach:</u> We have developed technology to extract and identify genomic targets within minutes. The susceptibility profile uses machine learning to help a clinician rapidly determine if a patient has an infection, then predicts if a patient is at risk of developing sepsis and then rapidly, ~30 minutes, identify the pathogen (bacterial or fungal) and then rapidly determine the pathogen's antimicrobial susceptibility, ~30 minutes.

<u>Impact:</u> In 2019, there were over 2.8 million antibiotic-resistant infections, a 40% increase from 2013. Leveraging multiple pieces of intellectual property as the base of the platform, our aim is to reduce the time from days to hours that it takes to get doctors the information they need to treat patients with antibiotic-resistant infections. The end goal is to transform the way bloodborne infections are identified and treated.

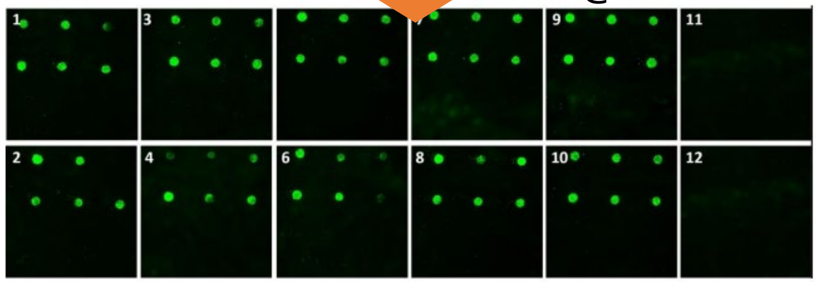
2nd Generation DNA/RNA Extraction System

ssDNA/ssRNA

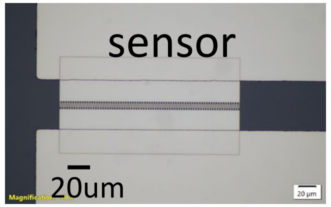
Isothermal solid-phase RPA enables simultaneous detection of multiple pathogens in ~ 30 minutes

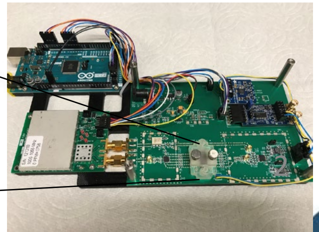


20 min @ 35°C



Susceptibility profiling sensor and reader hardware





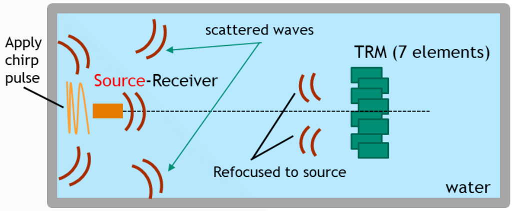
Asset Monitoring using Time-Reversal Acoustics (TRA). Sponsors: GS/LDRD

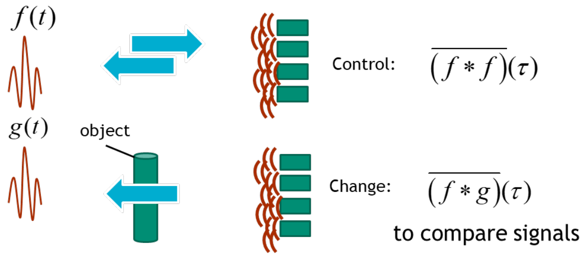
Purpose: How do we better safeguard assets in busy/complex or dangerous environments in air or water?

Problem Addressed: Current optical Containment/Surveillance (C/S) measures suffer from line-of-sight, inadequate lighting or obscurants in the air (i.e., smoke), leading to lengthy time-consuming and resource-intensive nondestructive assay (NDA) measurements and ID verification. Adversarial skills improve with each iteration when they know the method. Camera CCDs also degrade in high-rad environments.

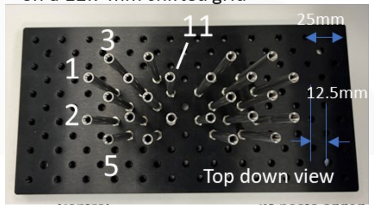
Approach: When acoustic waves interact with the structural features of an object and environment, they form a set of complex cryptographic signature of their previous interaction history in time. When the acoustic signals are played in reverse by a time reversal mirror (TRM) the original acoustic pulse is reconstructed at the original source if no changes occurred. However, if a change occurred such as removing and/or moving an object or even replacing it with a decoy, the signals will not reconstruct, indicating a change has occurred.

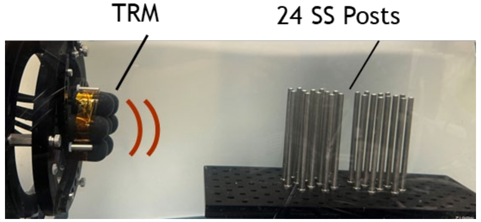
Impact: Time reversal acoustics has cryptographic strength and is ideal for busy/complex environments such as non-line of sight. The method does not require high-density recording or image comparison techniques. We can also determine the location where the change occurred.

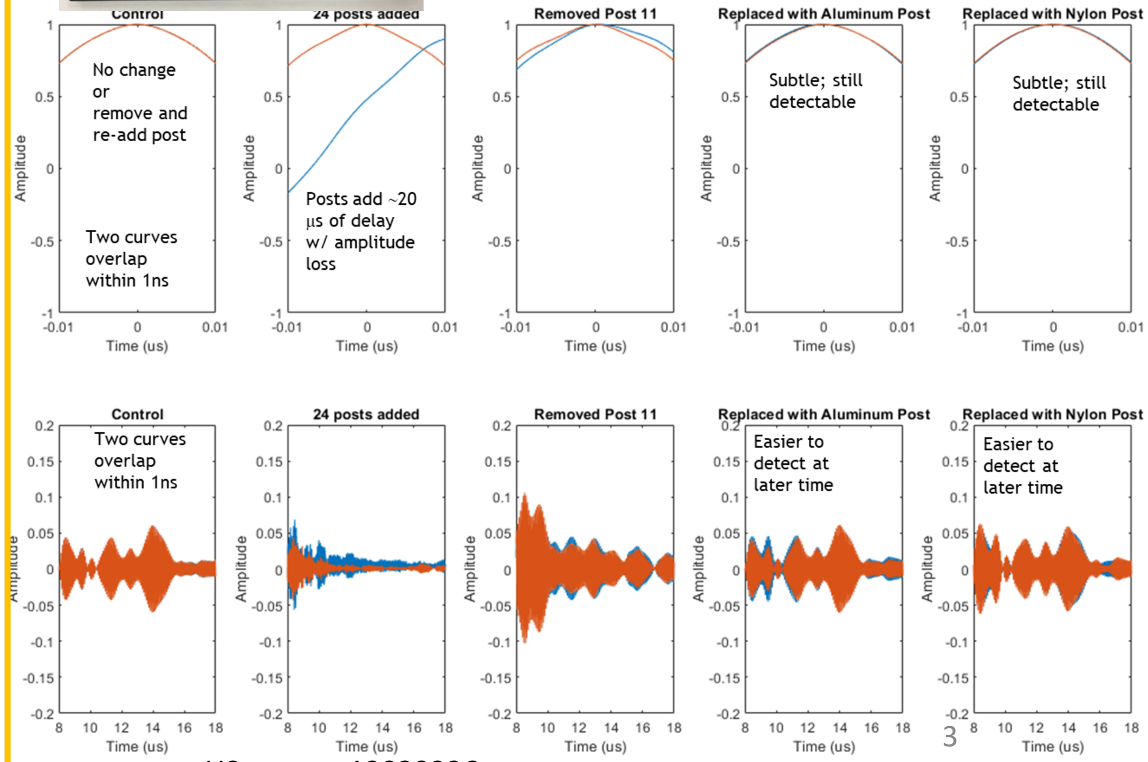




Array of 24 stainless steel (SS) posts on a 12.7 mm shifted grid







US patent: 12039226

Dynamic State Classification of Objects in Closed Environments using Time Reversal Acoustics (TRA)

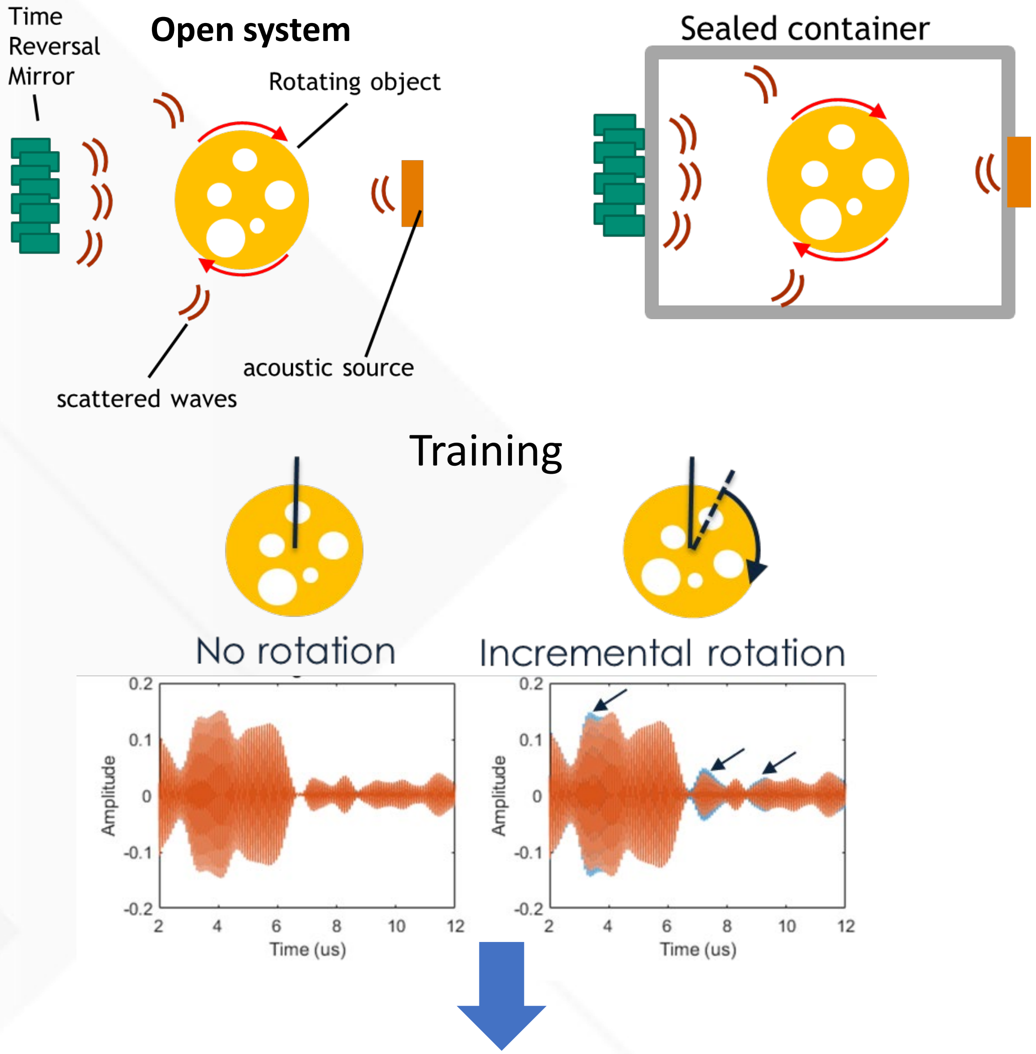
<u>Purpose:</u> How do we track the dynamic state of objects non-destructively in closed environments in real-time?

<u>Problem Addressed:</u> Current optical and electric/magnetic-field methods struggle with metal boundaries and sealed containers.

<u>Approach:</u> TRA detects subtle structural features behind barriers and through lossy boundaries. Reverse propagation causes acoustic waves to self-focus, overcoming inhomogeneities. The use of a convolutional neural network (CNN) to analyze TRA signals introduces a novel approach to identifying subtle and distinctive signatures, enhancing the accuracy and reliability of state detection.

<u>Impact:</u> TRA leverages the invariant properties of wave propagation equations under time reversal, allowing for precise detection of changes in complex environments. The ability of acoustic waves to self-focus in reverse-time propagation overcomes the challenges posed by inhomogeneous media, making this approach superior in handling lossy interfaces and variations in density and temperature.

<u>Mission Relevance:</u> Detects contraband, unauthorized changes in valued containers, the supply-chain, and monitor wear conditions.



Prediction for Actual System State

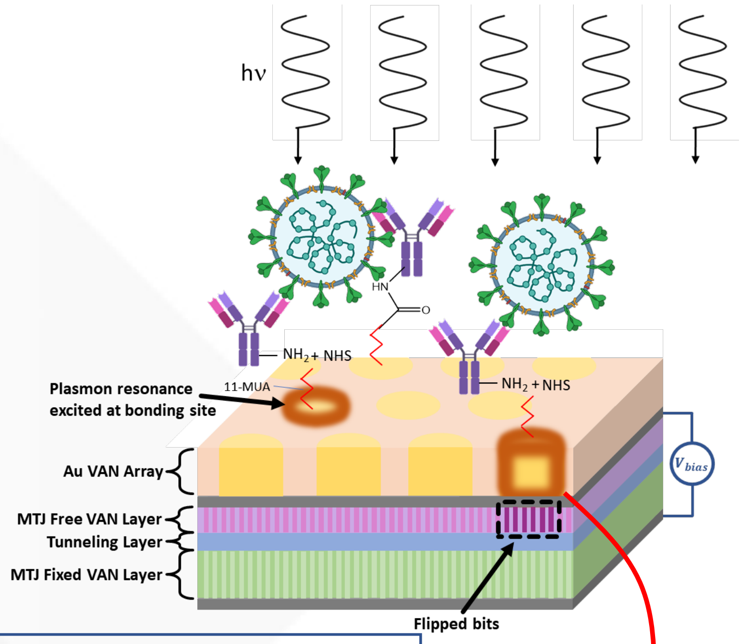
Plasmonic Heterostructures with Integrated Localized Magnetic Memory (PHILMM), HDTRA1-16-24-FRCWMD-Call – DTRA Awarded –In Progress

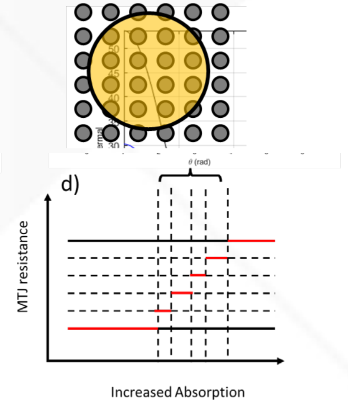
Purpose: How do we realize *a plasmonic sensor as a memory element?*

Problem Addressed: Current chemical and biological sensor technologies lack the ability to smartly detect and store data local the device itself. To date, detection and storage are performed separately which fails to meet lower size, weight, and power (SWaP) microsensors to detect CB threats.

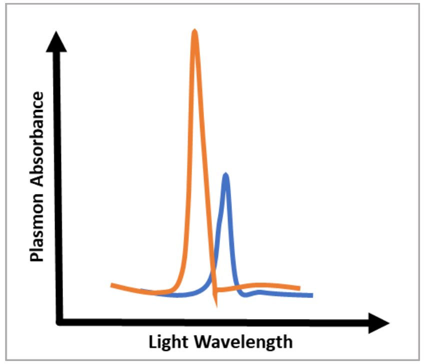
Approach: Under a recently funded DTRA proposal, we are developing a plasmonic detector with nonvolatile memory elements by leveraging a new class of multiferroics with tailored functionalities. When a pathogen binds to the detector surface, it induces a local plasmonic response that flips the local magnetization through a novel transduction mechanism and then records the sensing event in nonvolatile memory. The memory state can be nondestructively read using a magnetic tunnel junction (MTJ) integrated with the sensing region. The complete sensor operates as an array of individual detection elements, which uses averaging to achieve high resolution in a single measurement cycle. Thus, every measurement constitutes a binning event for an ensemble average which is retained in nonvolatile memory.

Impact: Employing a data storage capability that enables magnetoelectrically-coupled multiferroic materials to write electrically and read magnetically into a sensor provides a means to significantly advance SWaP needs, resulting in a smaller bit size and reducing the applied external fields required within the sensor.





VAN enabled detection through "ensemble" averaging



A bonding event causes a shift in local plasmon absorbance, so a plasmon is now excited by the incident light, which flips the local magnetic bits.

Microwave Magneto-Resistive Gradiometer

Objective/Problem:

- Finding small defects in the presence of large background fields (such as Earth's field, power supplies, machinery, electrical traces, etc.) is difficult. *By measuring magnetic field gradients instead, previously obscured features can now be detected.*
- We propose a novel micro-scale magnetic field gradiometer for the imaging of small sub-surface defects.

Limitations of Current Technology

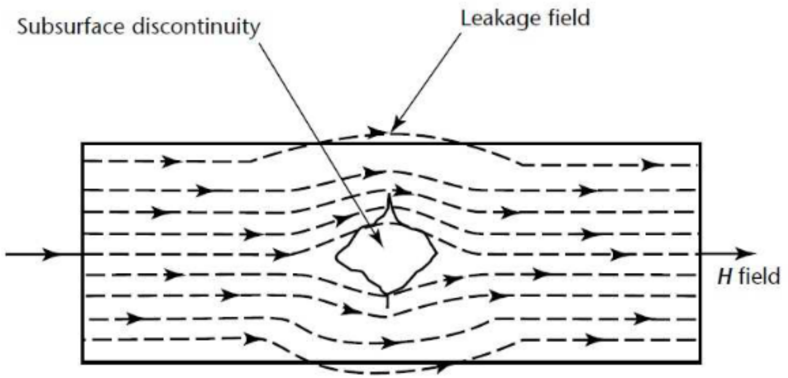
- *Small-scale magnetometers (GMR, AMR) have issues with hysteresis, nonlinearity, and saturation*. This limits their application as their response can easily be washed out by large fields.
- Resonant detectors do not have issues with hysteresis and saturation, but *need to be driven by oscillators which limits how many can be arrayed due to system complications.*

Technical Approach

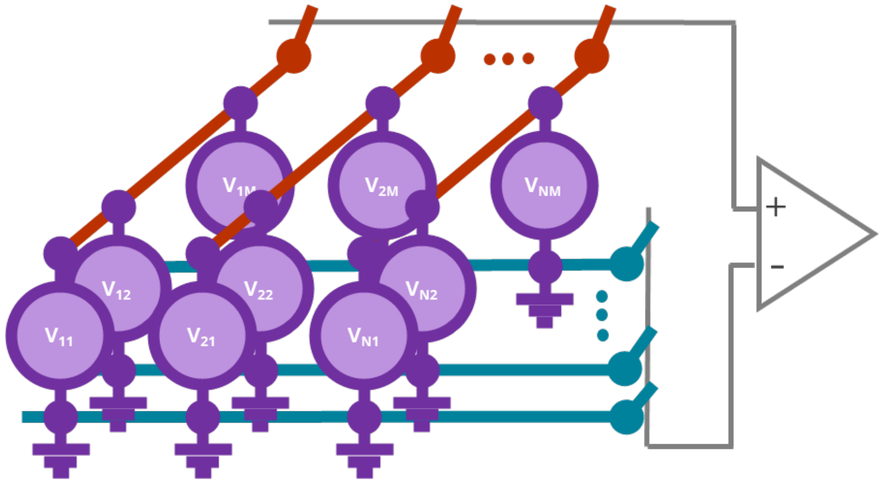
- We propose a novel approach using micro-scale magnetic resonators, whose *resonance frequency shift is measured by a DC voltage* through nonlinear magneto-resistive coupling.
- Measured voltage difference between adjacent resonators will be proportional to the local magnetic field gradient, allowing *direct measurement of magnetic field gradient.*
- "Inverse problem" algorithms will be used to reconstruct the defect in real time.

Impact

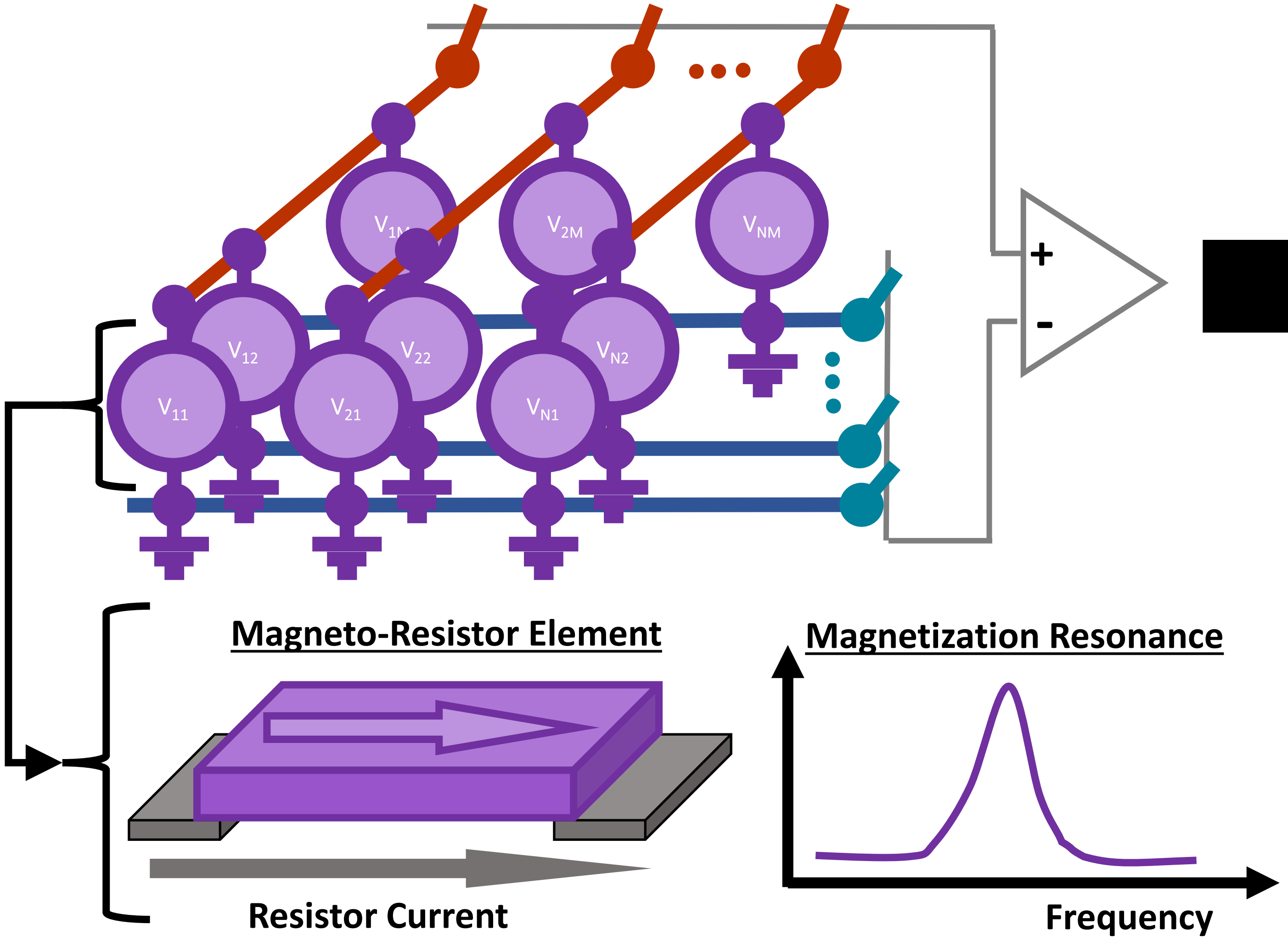
- Project success would enable applications in the nondestructive evaluation of integrated circuits and heterogeneously integrated systems, tamper detection, unique ID verification, and position tracking.
- Technology from this LDRD could also be applied to nonvolatile memory, qubit manipulation, and RF devices.
- Source reconstruction methods could be reapplied to GPS-less navigation and antenna beam-forming.

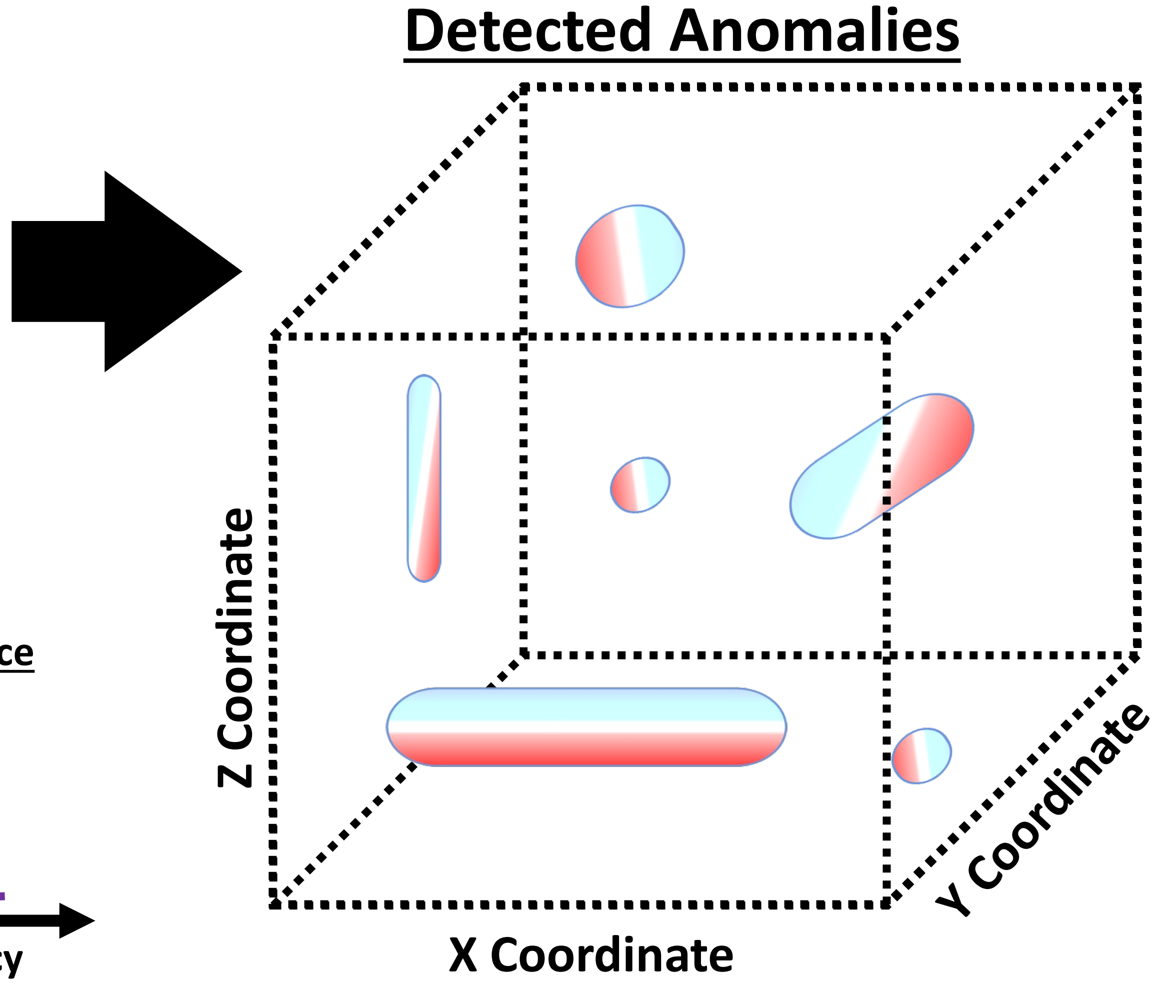


P. O. Moore and S. S. Udpa, Nondestructive Testing Handbook: Electromagnetic testing, vol. 5. American Society for Nondestructive Testing, 2004



Microwave Magneto-Resistive Gradiometer, cont'd





We propose a novel sensor leveraging nonlinear magnetization dynamics for 3D imaging of small (~1 μm) defects through magnetic field gradients.