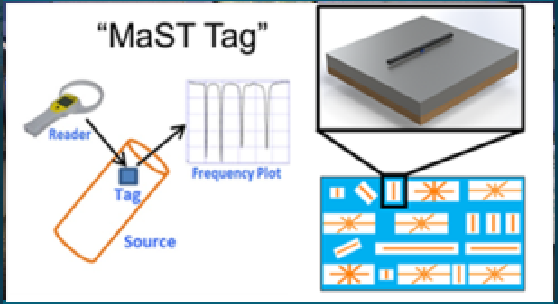
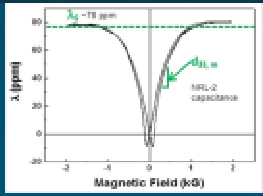
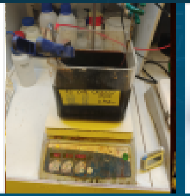
SAND2021-9426C

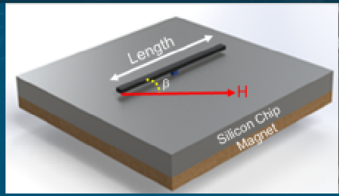
Sandia National Laboratories

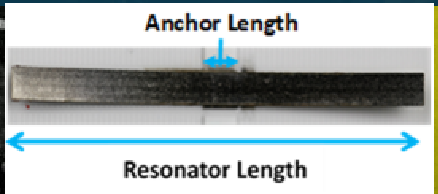
Magnetic Smart Tag (MaST) for Unique Identification











PRESENTED BY

Eric Langlois, Ph.D., Org. 5219, MEMS Technologies

U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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Goals and Objectives

Uniquely identify nuclear materials and other high value assets, particularly for International Nuclear Safeguards and Arms Control regimes

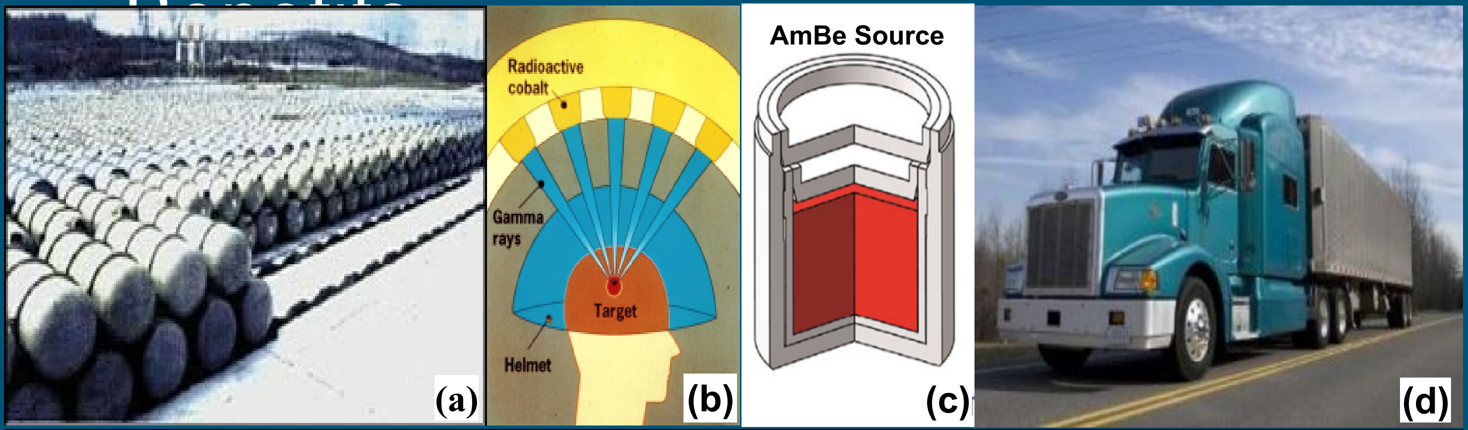
- Primary need is to prevent tampering and substitution of original component
- Passive (no battery required; zero standby power consumed)
- Wireless
- Distinctive, low frequency (< 10 MHz), magnetic signature
- Can be unobtrusively attached externally or intrinsically incorporated into the walls of new and existing nuclear fuel containers and equipment

Identifier Uniqueness is achieved with random, multi-bit (i.e., multi-resonator) arrays

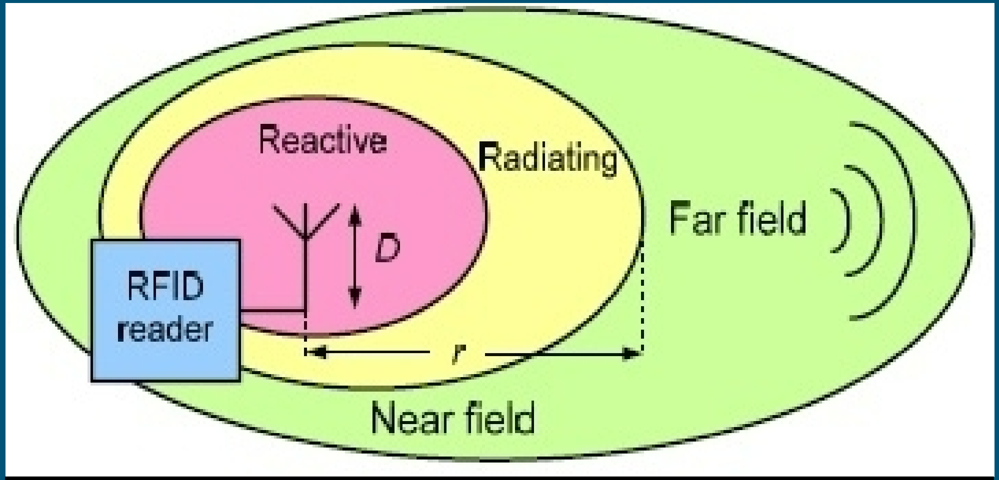
Anti-Counterfeit Properties making this technology nearly impossible to replicate:

- Proprietary CoFe alloy electroplating
- Multi-bit arrays
- Unique array patterning
- Post-processing randomness (e.g., patterned thin film coatings)

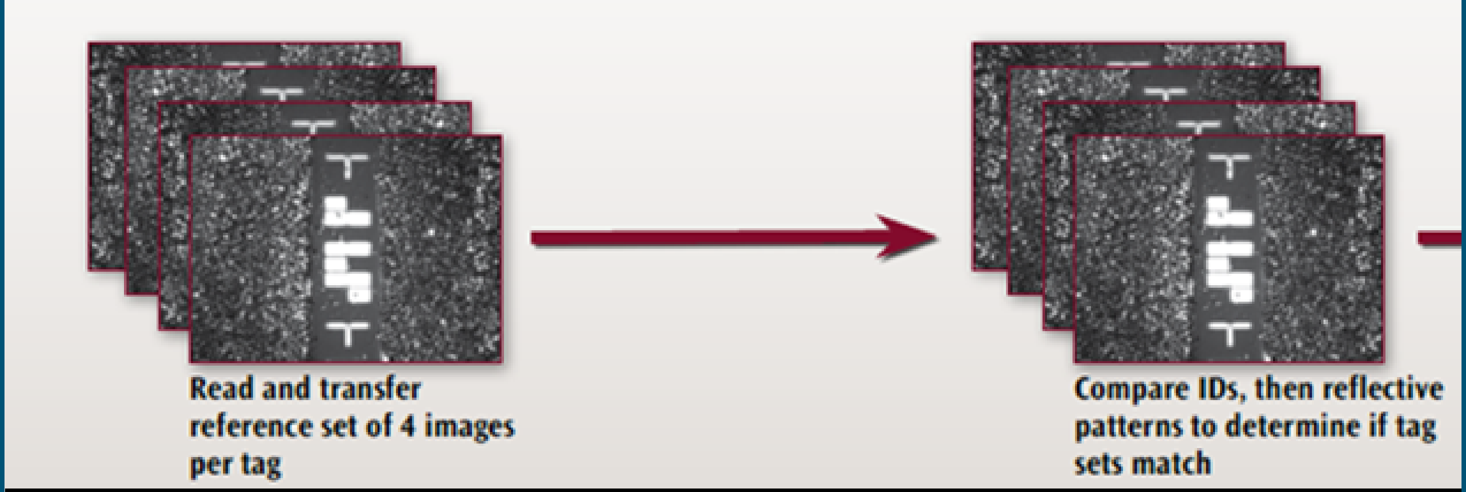
MaST Applications, Competition, Tagging Physics, & Safety



(a) UF6 cylinders, (b) Gamma Knife cobalt sources, (c) AmBe neutron source, (d) ND transportation trucks



Antenna near and far field regions



Reflective particle (RPT) tag

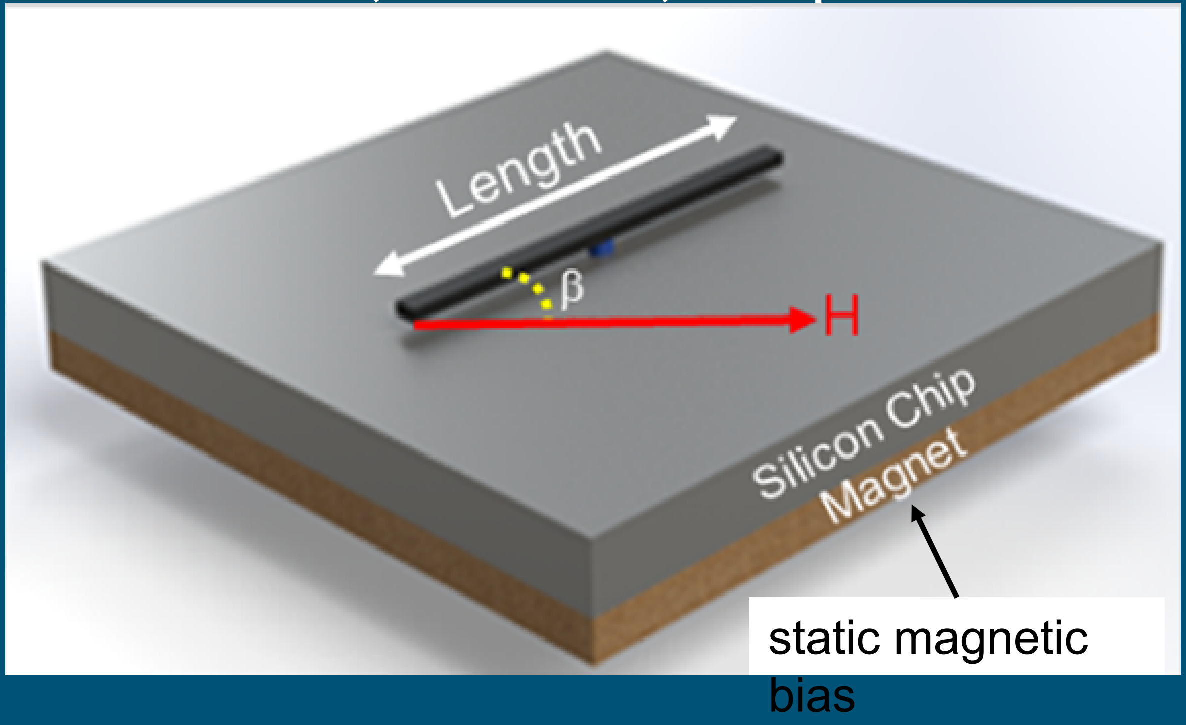
MaST

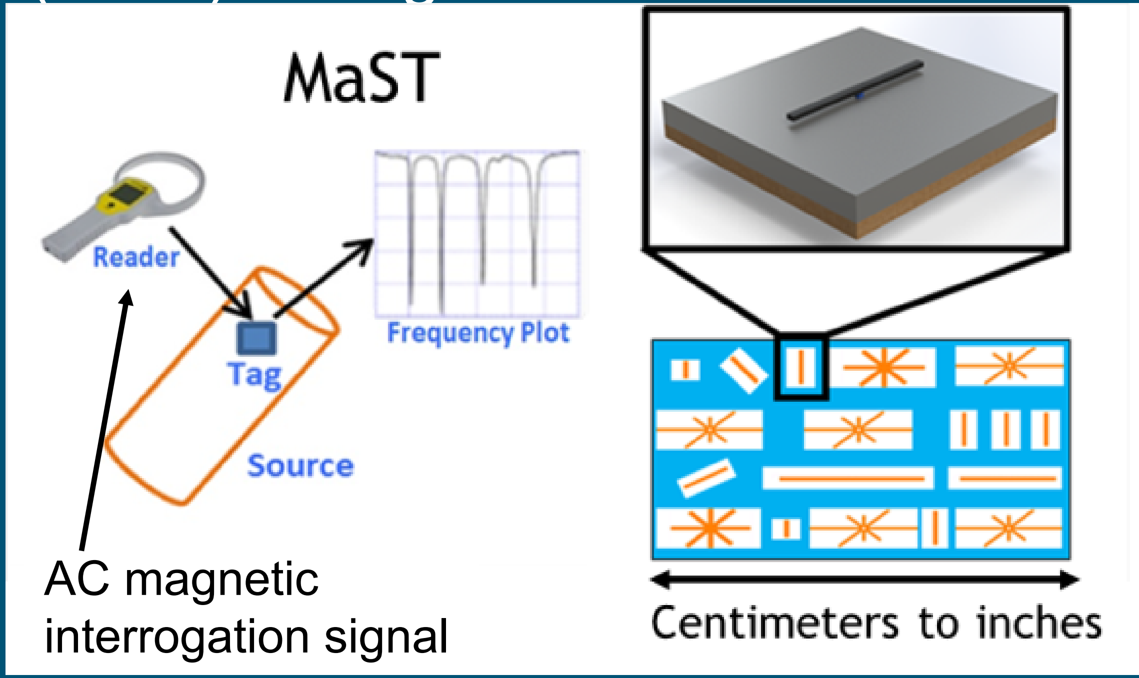
- LF (50 kHz – 5 MHz), near field technology
- No image comparison for verification
- No detuning caused by metal, water, etc.
- No integrated circuit chip
- Safe around high explosives
- Won't interfere with RF communications!

https://www.rfcafe.com/references/electrical/near-far-

MaST Theory of Operation

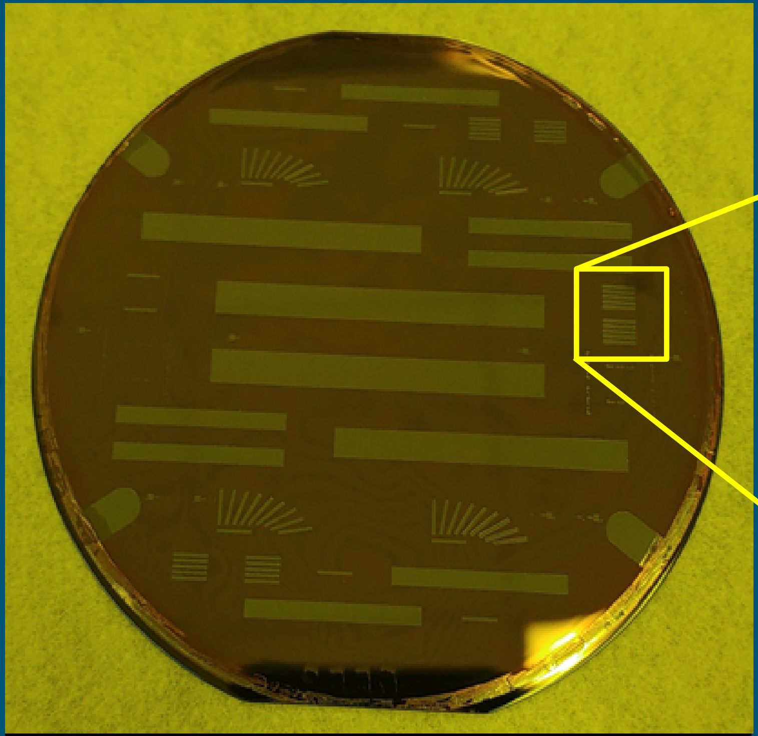
- MaST is comprised of an array of magnetic resonators and a bias magnet
- Operates by the Joule magnetostriction effect
- Passive, wireless, unique identifiers (UIDs) for high value assets



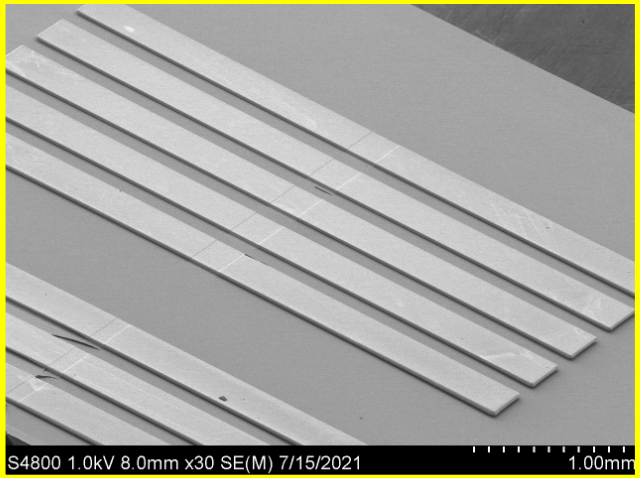


High Performance NiFeCo Alloy Electrodeposition

Plating setup



Resonator wafer

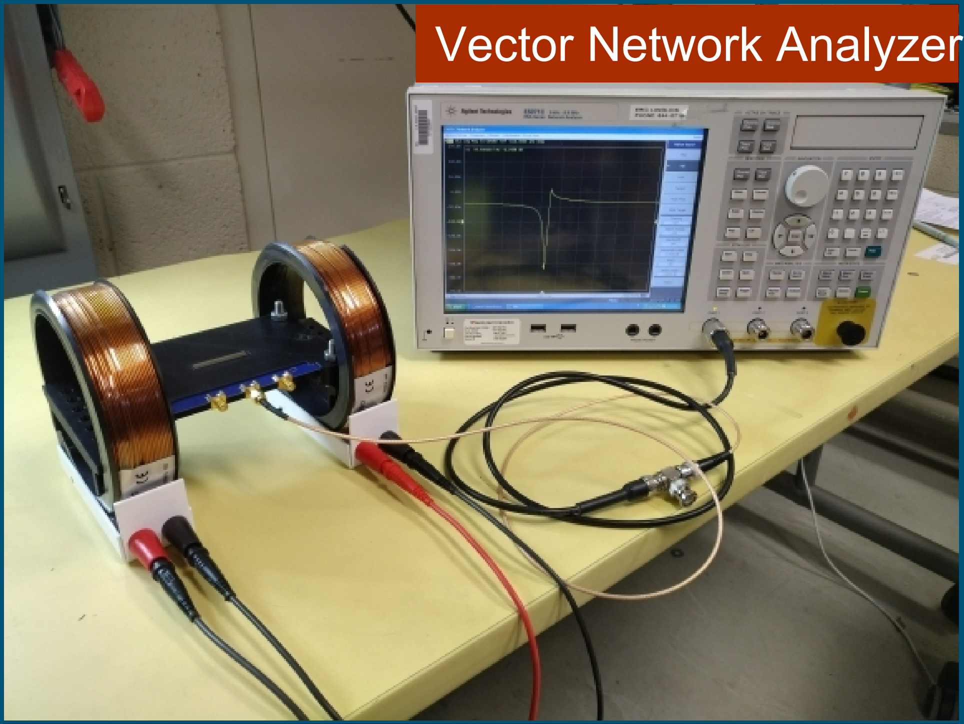


4.8 mm resonators

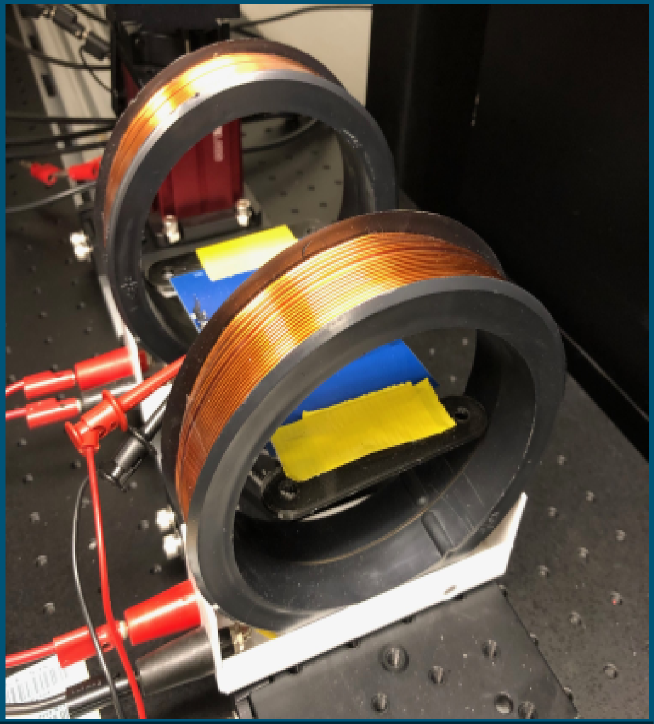
Bench Top Interrogation

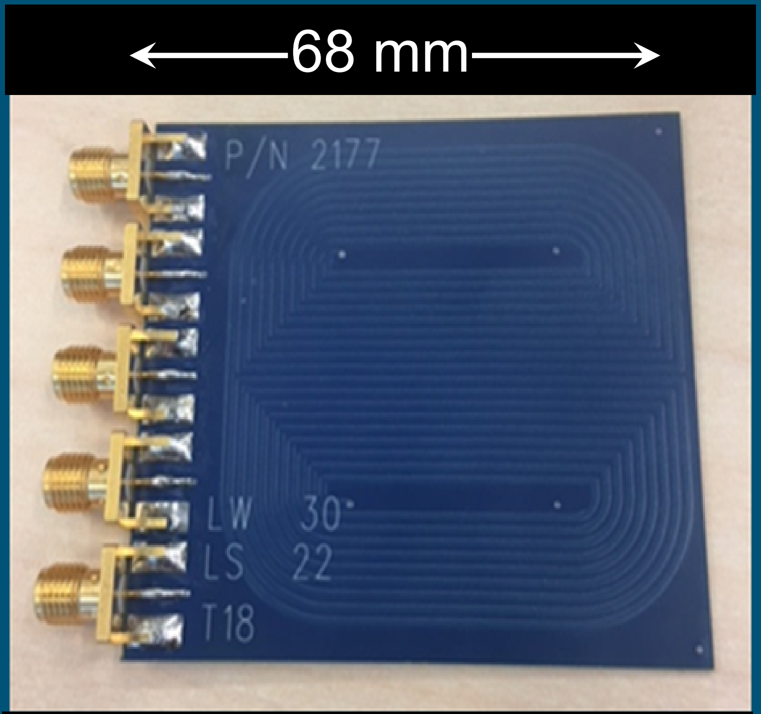
MaST is currently interrogated by:

- Static magnetic bias supplied by a Helmholtz coil
- AC magnetic field supplied by a planar loop antenna transceivers
- Vector network analyzer (VNA)



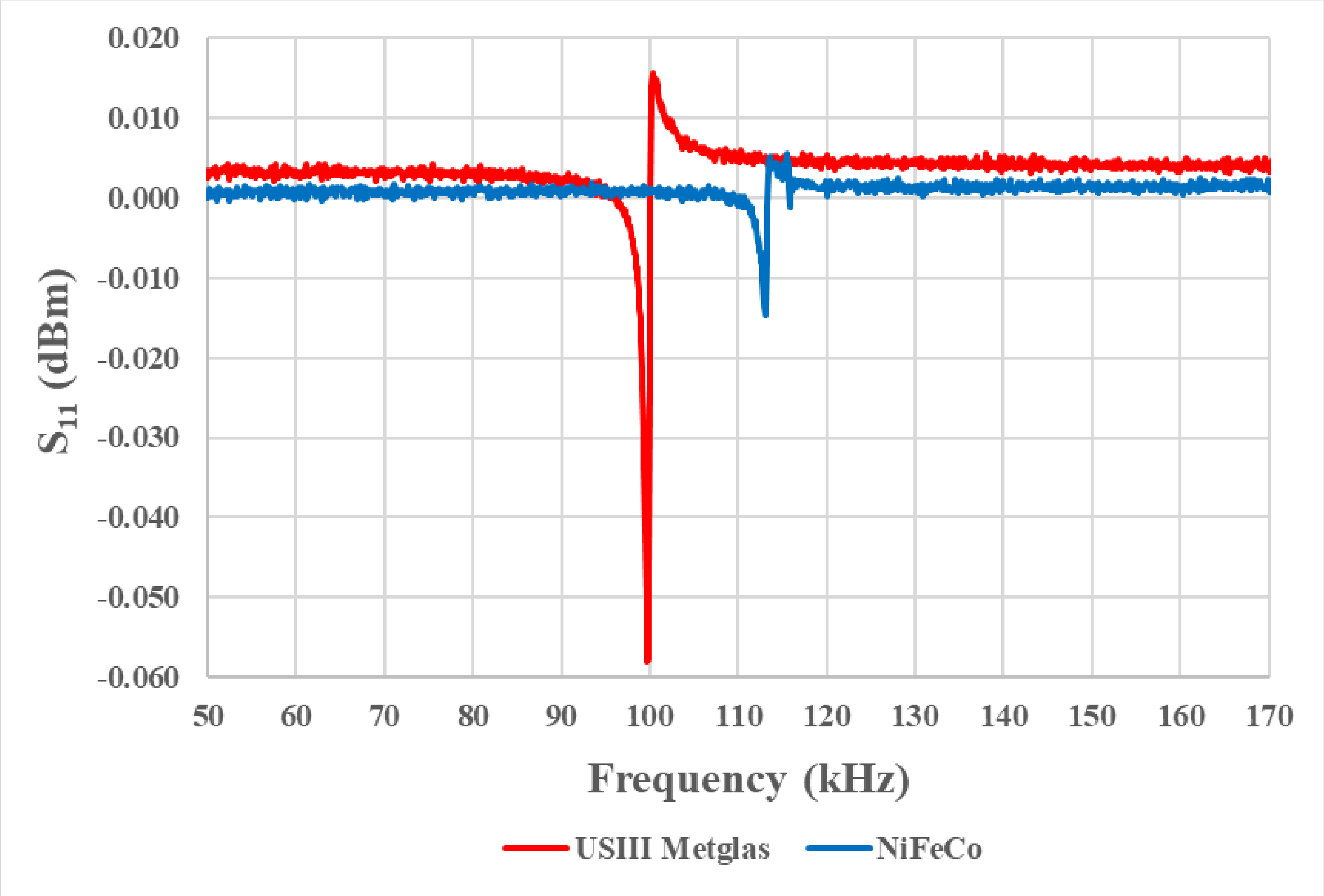
Bench setup


static bias field coils



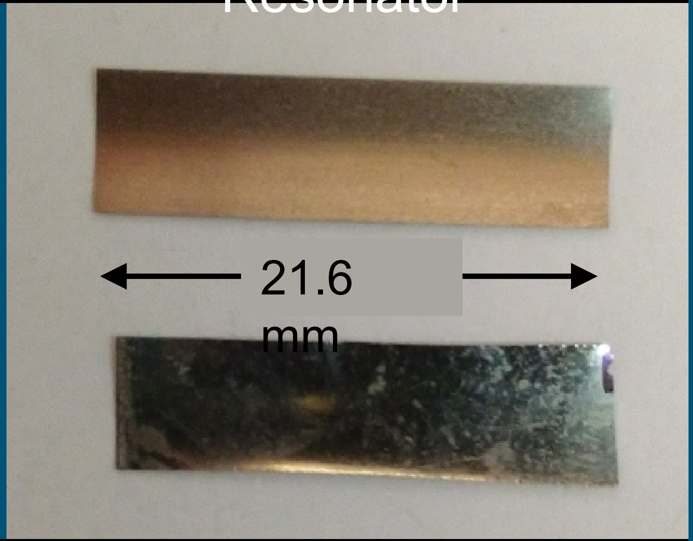
AC field planar antenna

NiFeCo Magnetic Resonance Achieved!



VNA measurement – USIII & NiFeCo

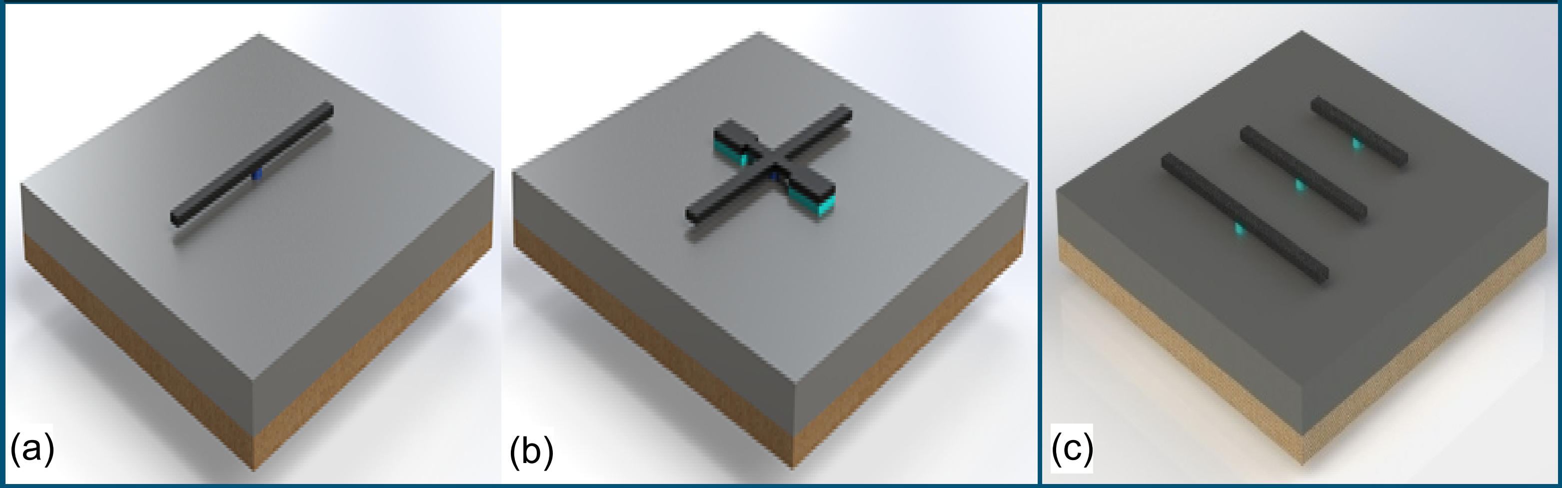
USIII Metglas Alloy Resonator



E-plated NiFeCo Resonator

Design Features

Resonator Anchoring



(a) Single frequency resonator with a central bottom anchor

(b) Single frequency resonator with side tethers and anchors

(c) Multifrequency resonator array (three frequencies)

Identification

$$N_K = \frac{N_T!\,(N_W - 1)!}{2N_R!\,(N_T - N_R)!\,(N_W - N_R)!}$$

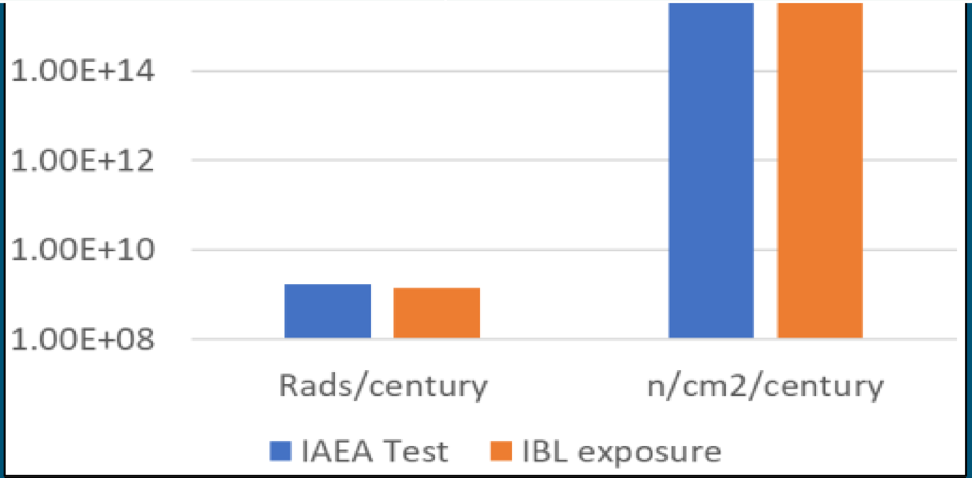
- N_T : number of resonator types
- N_R : number of resonators present
- N_W : number of possible angles
- N_K : number of coded tags possible.
- e.g., $N_T = 5$, $N_R = 12$, $N_W = 18$ gives a total of $N_K = 22{,}619{,}520$ different possible codes
- Code complexity established by end users for targeted application spaces

100 Year Accelerated Radiation Hardness Determined

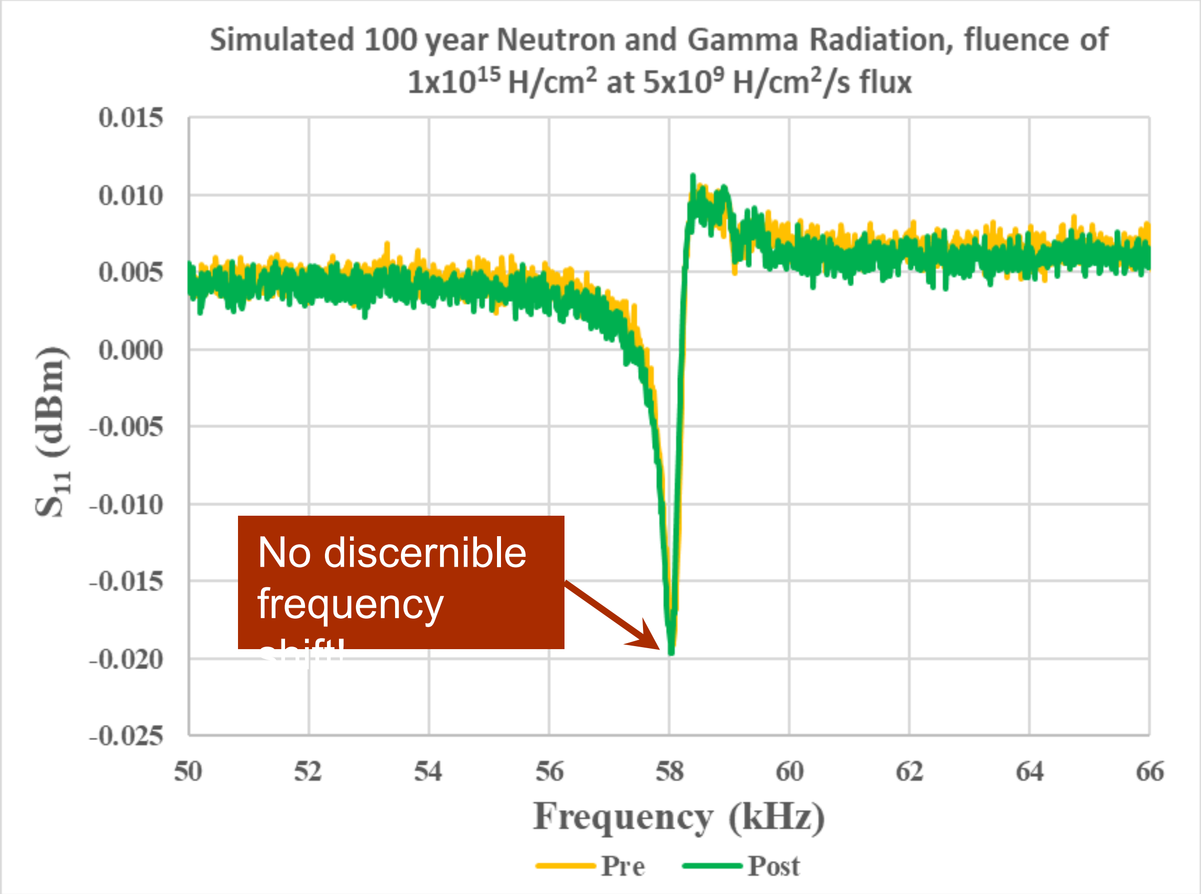
2.8 MeV H+ Pelletron Accelerator Equivalent Testing

- 2.5-day exposure - produces century level equivalent doses of both gammas and fast neutrons
- **No discernible frequency shift detected post exposure!**

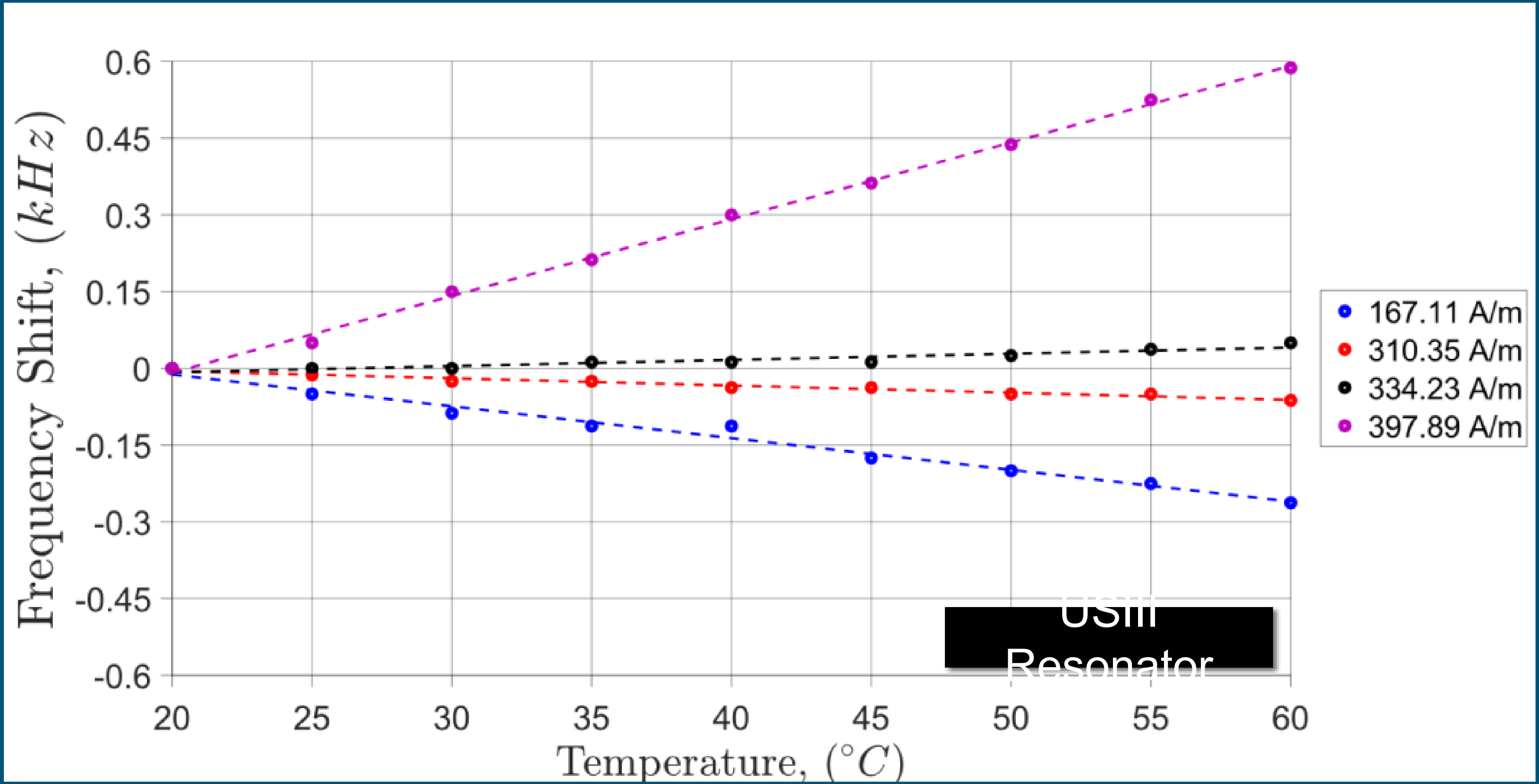
	Rads/century	n/cm^2 /century
IAEA Test	$1.75x10^9$	$3.15x10^{16}$
2.8 MeV Proton Exposure	$1.38x10^9$	$4.16x10^{16}$



Pelletron exposure vs. IAEA test



Future Temperature Dependence Cancellation Testing



- **An applied static biasing field of ~320 A/m can be used to cancel the temperature dependence!**
- **Further experiments needed to determine the static bias field for NiFeCo resonators**

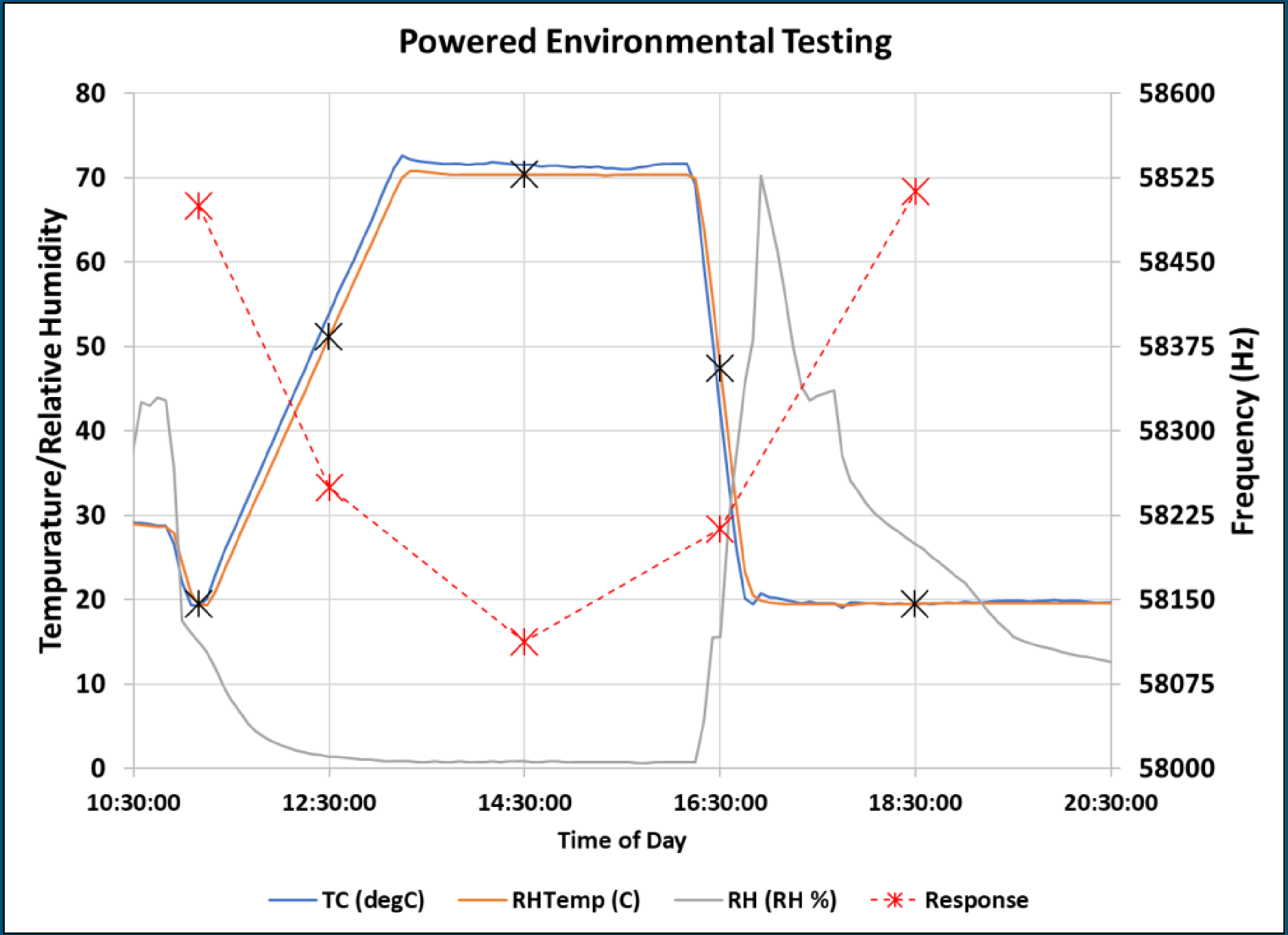
Summary and Acknowledgments

- **Goal: Create Magnetic Smart Tags (MaSTs) for identifying nuclear materials and other high value assets, particularly for International Nuclear Safeguards and Arms Control regimes**
- Advantages: passive, wireless, safe, will work with existing nuclear fuel containers and equipment
- Possesses anti-counterfeit properties making this technology nearly impossible to replicate
- Identifier Uniqueness is achieved with random, multi-bit (i.e., multi-resonator) arrays
- Novel high performance NiFeCo alloy electrodeposition – fabrication friendly!
- Proof of radiation hardness up to 100 years total dose using accelerated equivalent testing
- Temperature-induced frequency shifts can be canceled out using DC magnetic biasing

This work was funded by DOE/NNSA Office of Defense Nuclear Nonproliferation/Office of Proliferation Detection (NA-22). MaST team members are Jamin Pillars, Todd Monson, Patrick Finnegan, Barney Doyle, LaRico Treadwell, Heidi Smartt, Nick Gurule, and Ben Lehman.

Back Up Slides

Operational Temperature and Humidity Testing Performed

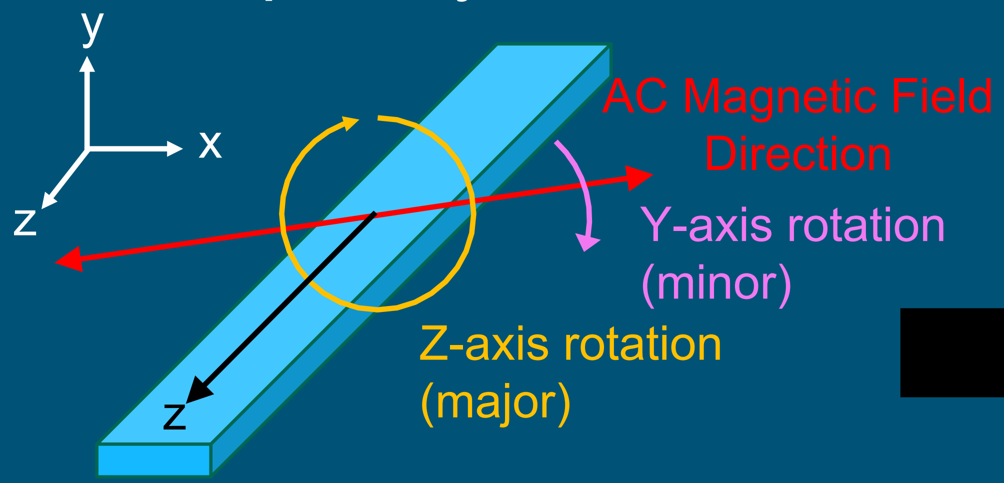


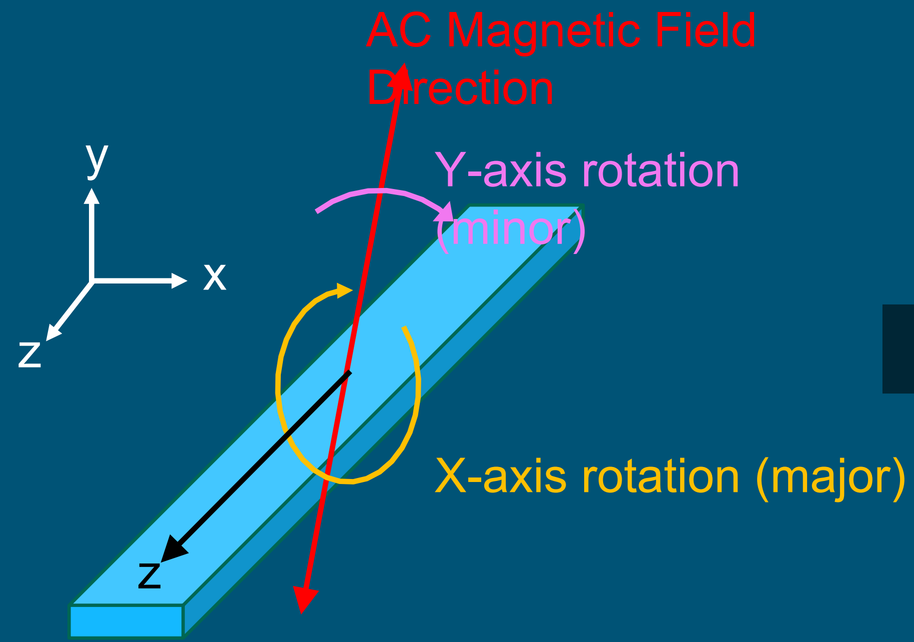
Resonant frequency was analyzed during elevated temperature cycle

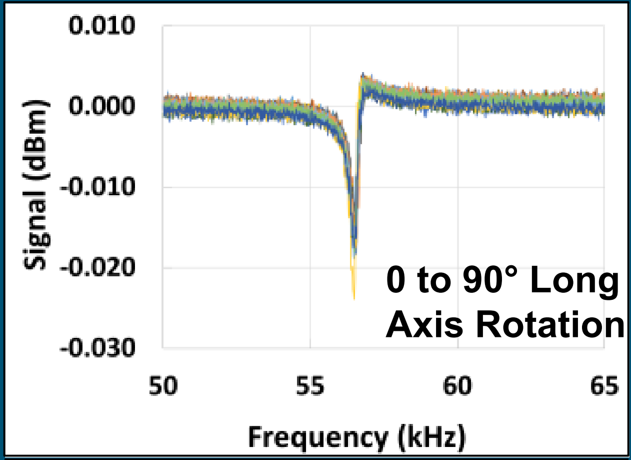
- Same DC bias field present during entire cycle
- **At temperatures above 50°C there was a less than 400Hz shift in resonant frequency!**
- Humidity spikes in future tests will be resolved by adjusting the profile to allow RH to stabilize

Zero Antenna (AC Field) Angular Dependence on Frequency

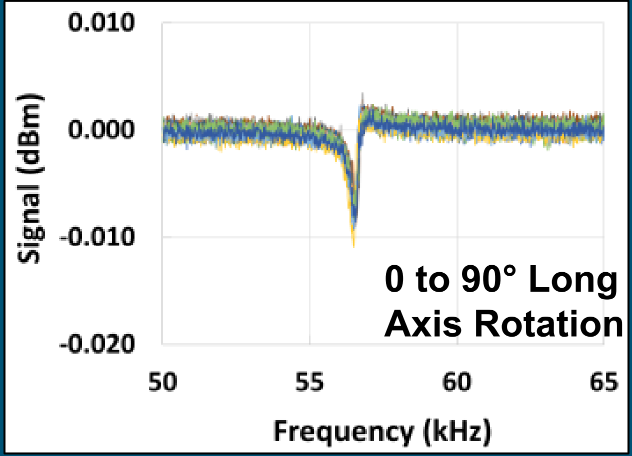
- Zero angular dependence on signal frequency
- Angular dependence on signal amplitude
- Stronger, more omnidirectional antennas



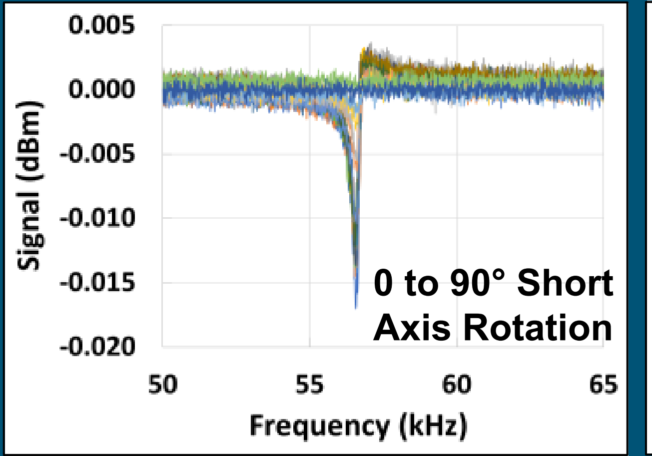




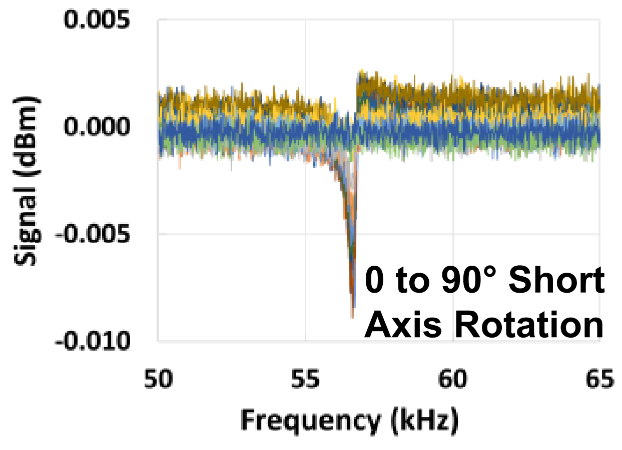
0° Minor Rotation



45° Minor Rotation



0 ° Minor Rotation

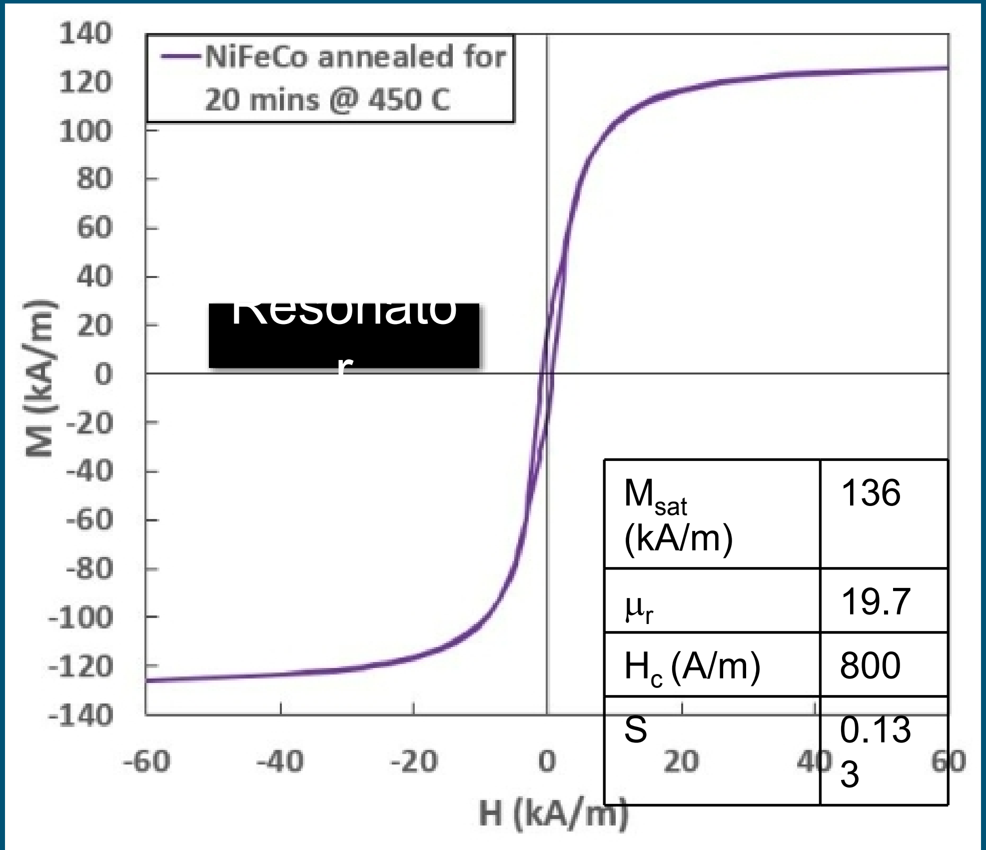


45° Minor Rotation

Magnetic Testing Critical for MaST Performance

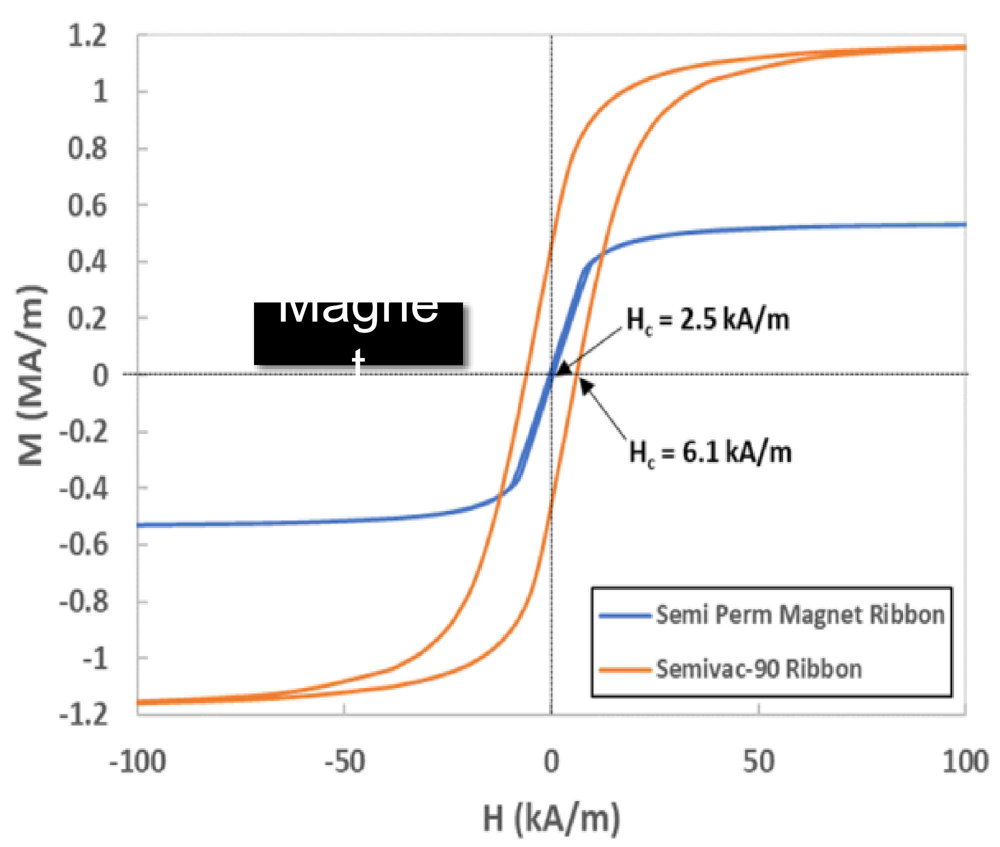
Commercial Semivac-90 ribbon will be used for future DC magnetic biasing

- reduces MaST size and power
- has sufficient magnetic saturation (M_{sat}) to bias resonator and coercivity (H_c) to hold the bias point



M_{sat} (kA/m)	136
μ_r	19.7
H_c (A/m)	800
S	0.133

NiFeCo M vs. H Plot



Semivac-90 vs. SPMR M vs. H Plot