

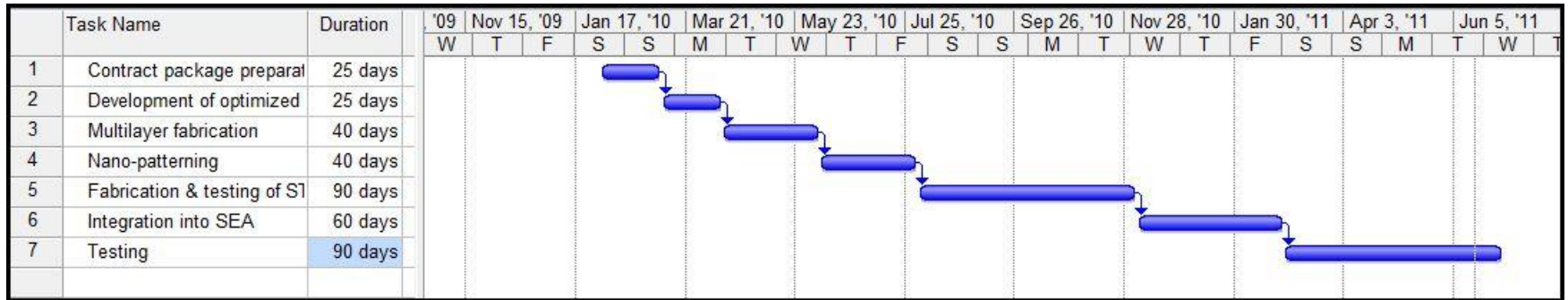


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Innovative Grant 2010 Report Spin Torque Nano Oscillator Detector and Antenna Characterization

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Total Funds

Innovation Grant \$100K

CERDEC matching Funds for novel embedded antenna research +50K

Total Cost:

\$150K

Fabrication of spintronics radar detectors \$100K

TARDEC, RDECOM PI Dr. Thomas Meitzler and Co-PI Dr. Elena Bankowski \$50K

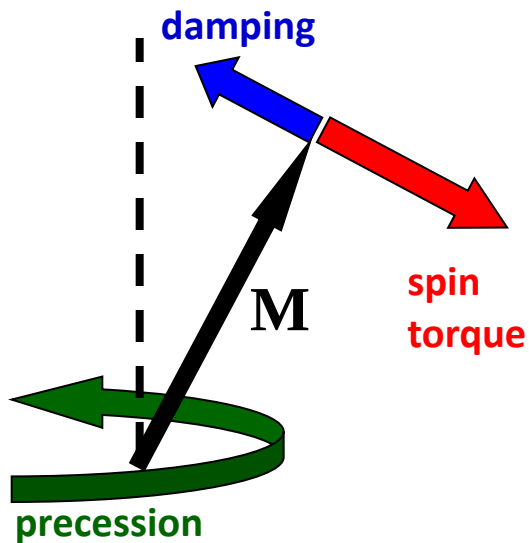
The full amount of the innovation grant dollars was disbursed .

- DC characterization of magnetic tunnel junctions (MTJ) completed.
- Circuit design including ESD protection completed.
- Microwave characterization of magnetic tunnel junctions completed.
- Completed putting together all enclosure and electronic components (inductors, ESD protection diodes, SMA flange connectors).
- Ferromagnetic Resonance Frequency (FMR) measurements of the metal junction diodes completed.
- Ten prototype devices fabricated by UC-Irvine and delivered to TARDEC.
- All ten antennas characterized in the Sensor Enhanced Armor lab anechoic chamber for signal gain versus frequency.
- Surrogate armor coupon modified to contain an antenna and MTJ detector.
- Measurements made of the antenna and detector embedded in armor.

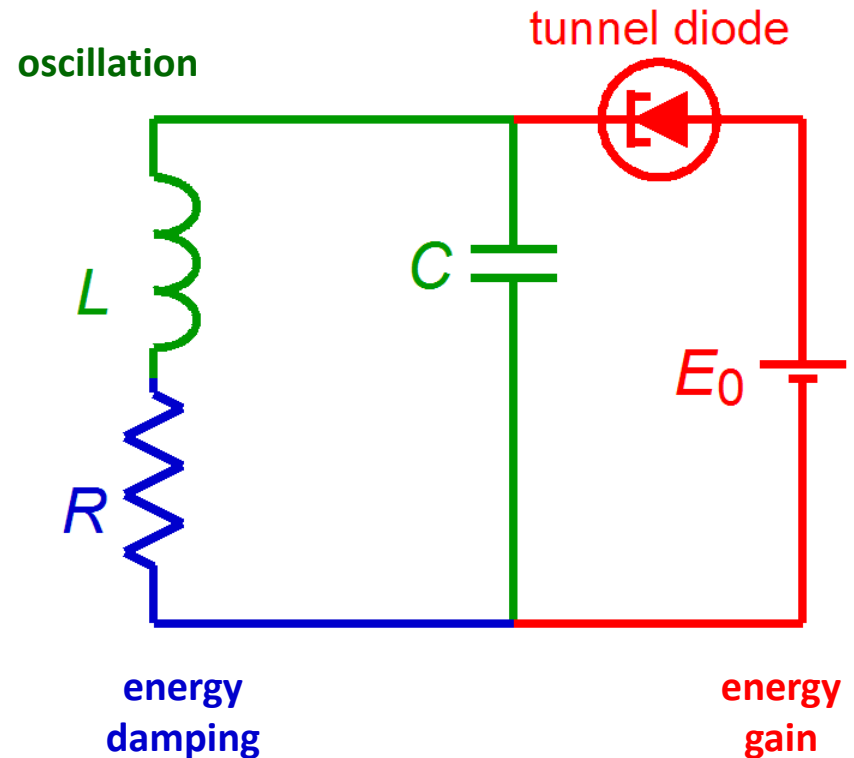
- 1 – 6 GHz initial scan to determine approximate resonance frequency
 - A group: focused scans at 4-6 GHz
 - B group: focused scans at 1-3 GHz
- 10 Detectors were tuned for maximum sensitivity from 0 to 3 turns at 1/2 turn increments
- Multiple peaks are present on some detectors
- B group devices typically have a higher voltage output (4B was the highest at approximately 1mV)
- Tuning the magnet on the B group changes both the sensitivity and resonance frequency. For the A group, it only changes the sensitivity

STNO and conventional oscillator

Spin-torque
nano-oscillator



Electrical oscillator



Nonlinear oscillator model

oscillation
(precession)

positive damping (Gilbert
torque)

negative damping (spin-
transfer torque)

$$\frac{dc}{dt} + i\omega(p)c + \Gamma_+(p)c - \Gamma_-(p)c = 0$$

C is the complex **amplitude** of oscillations

$p = |c|^2$ is the (dimensionless) oscillation **power**

$\phi = \arg(c)$ is the oscillation **phase**

Stochastic nonlinear oscillator model

Stochastic Langevin equation:

$$\frac{dc}{dt} + i\omega(p)c + \Gamma_+(p)c - \Gamma_-(p)c = f_n(t)$$

Random thermal noise:

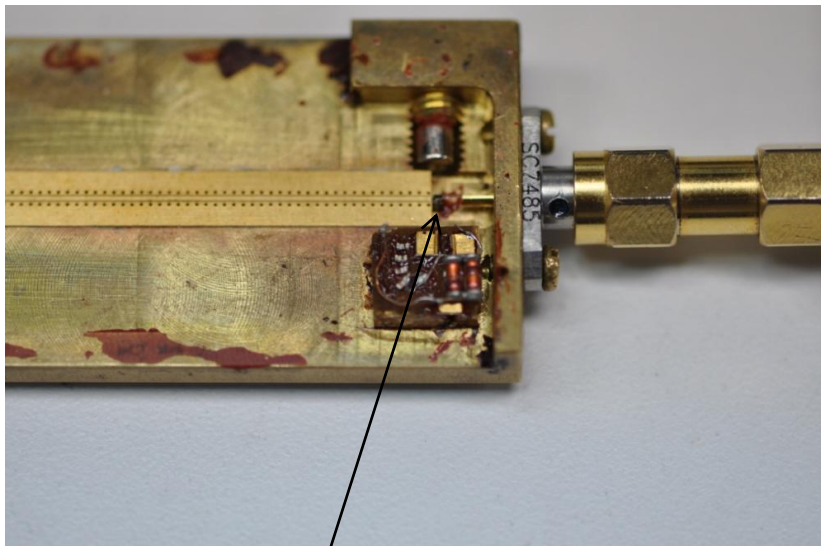
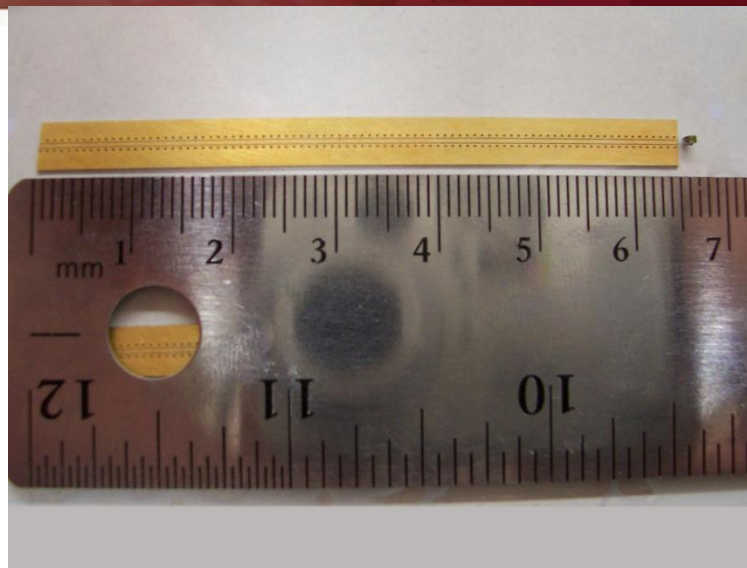
$$\langle f_n(t) f_n^*(t') \rangle = 2D_n \delta(t - t')$$

$$D_n(p) = \Gamma_+(p)\eta(p) = \Gamma_+(p) \frac{k_B T}{\lambda \omega(p)}$$

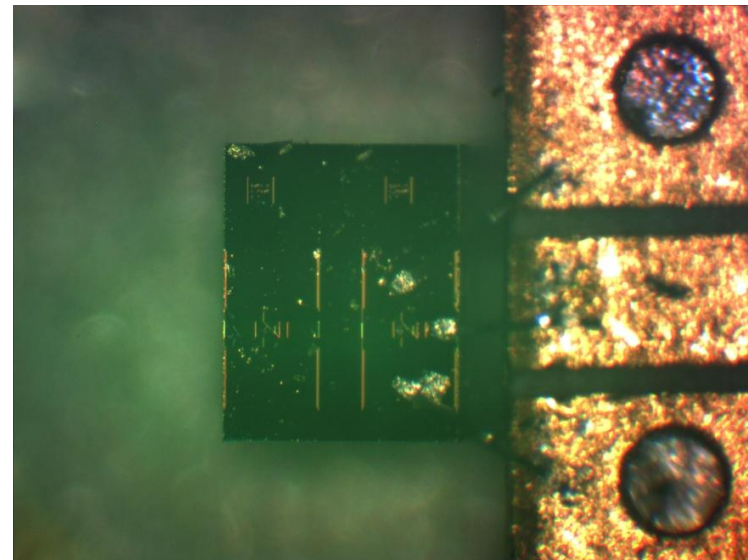
$$\eta = \frac{k_B T}{\lambda \omega(p)} \quad \text{-- thermal equilibrium power of oscillations:}$$

$$\langle |c|^2 \rangle_{\Gamma_-=0} = \langle p \rangle_{\Gamma_-=0} = \eta$$

Coplanar antenna

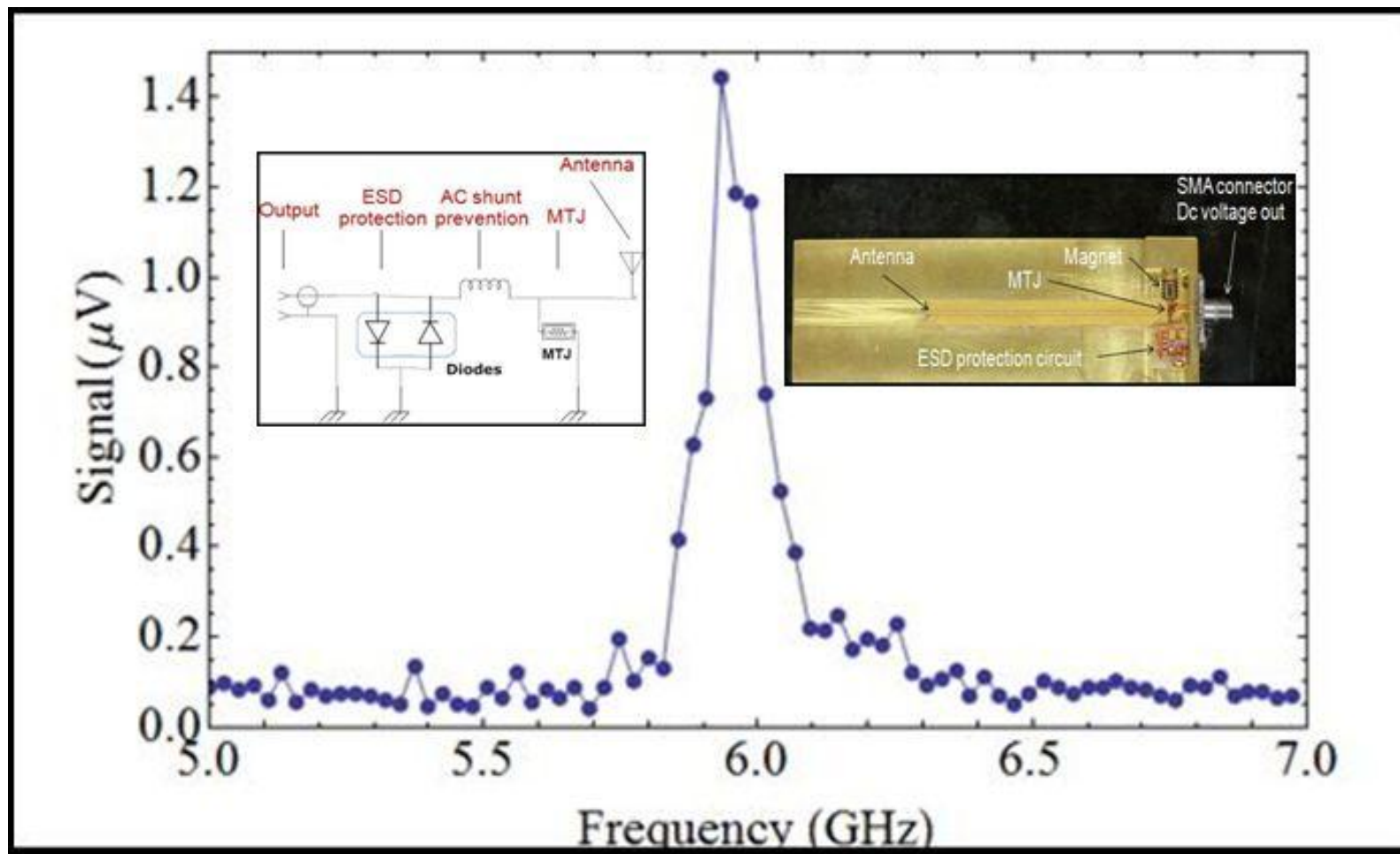


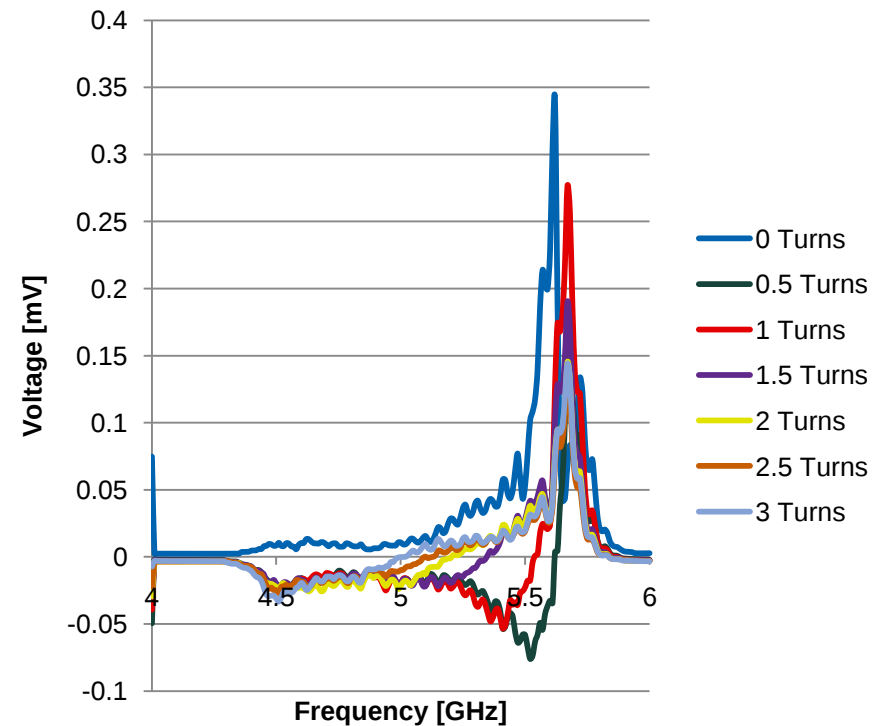
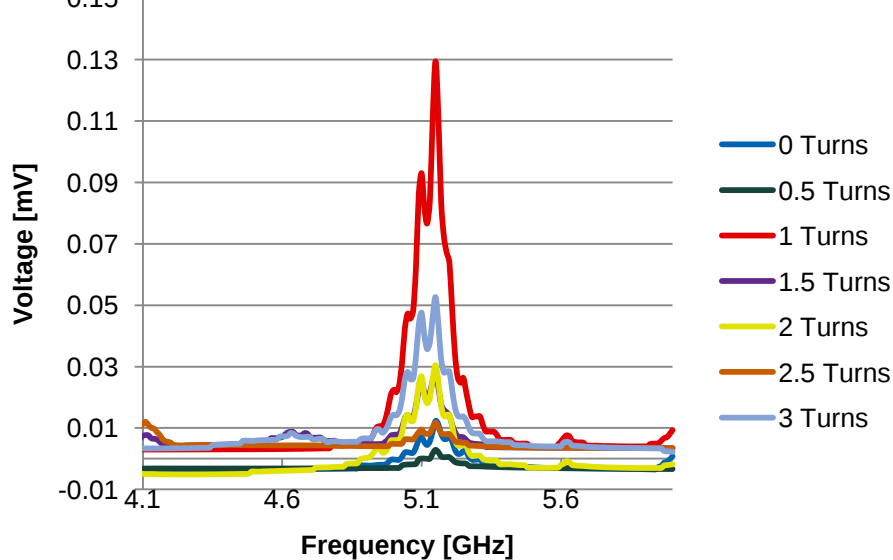
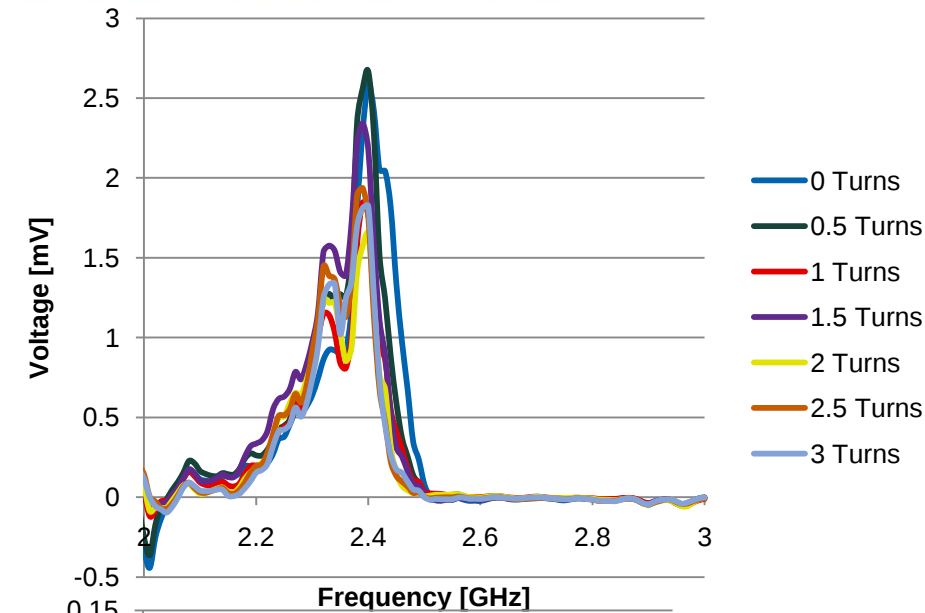
Metal tunnel junction detector



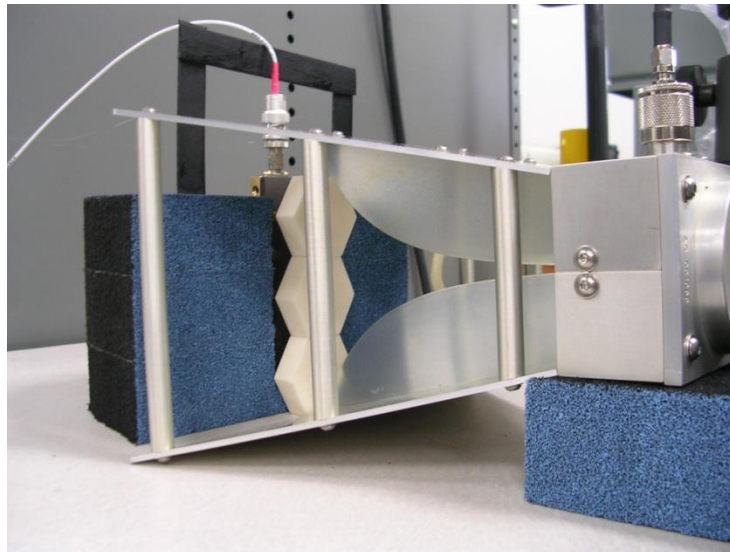
Antenna bonding to detector

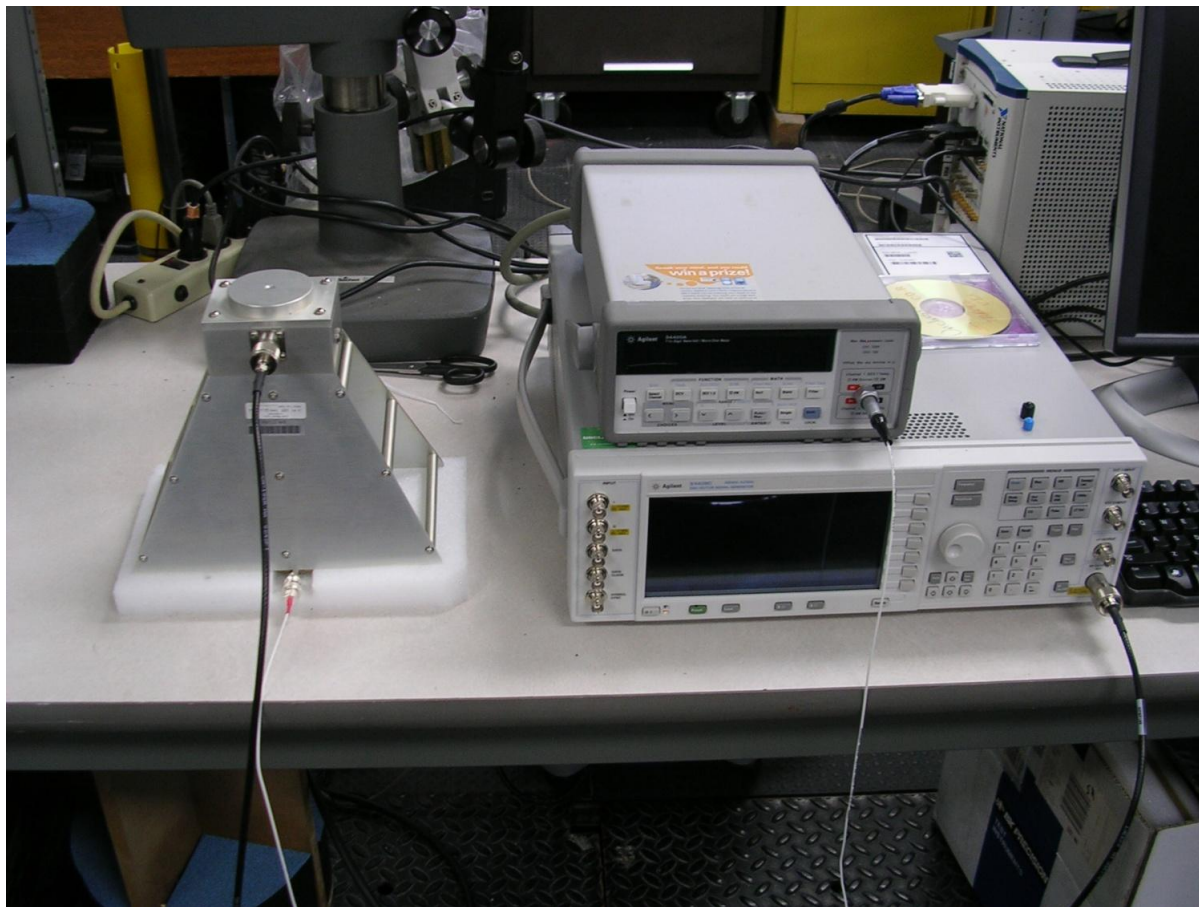
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- The detector was moved away from the antenna and tested at 0in, 6in, 12in, and 24in distances
- Tests performed both in the anechoic chamber and on the bench.
- Armor tiles placed in front of the detector to test material (ceramic, SiC) transmittance



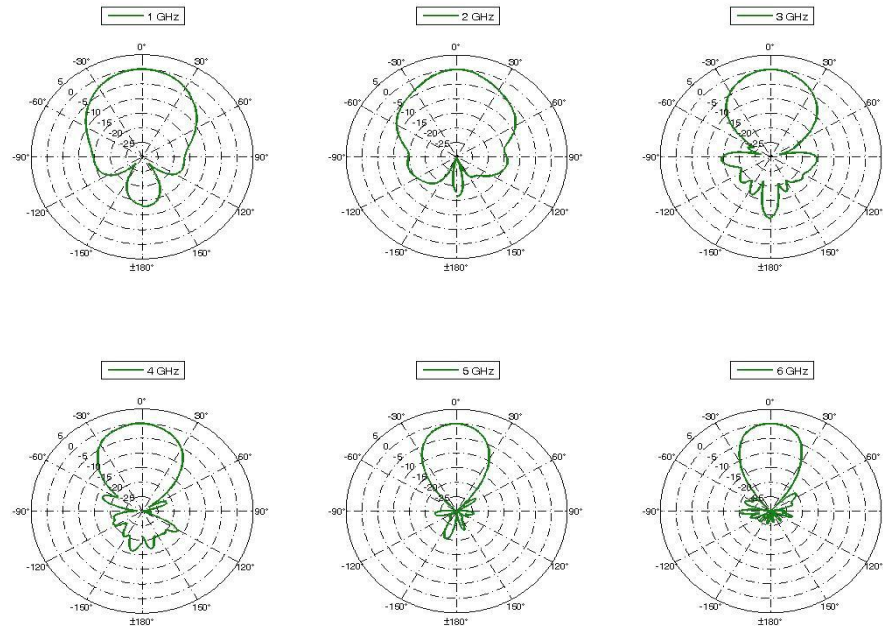


Horn antenna

Nano voltmeter

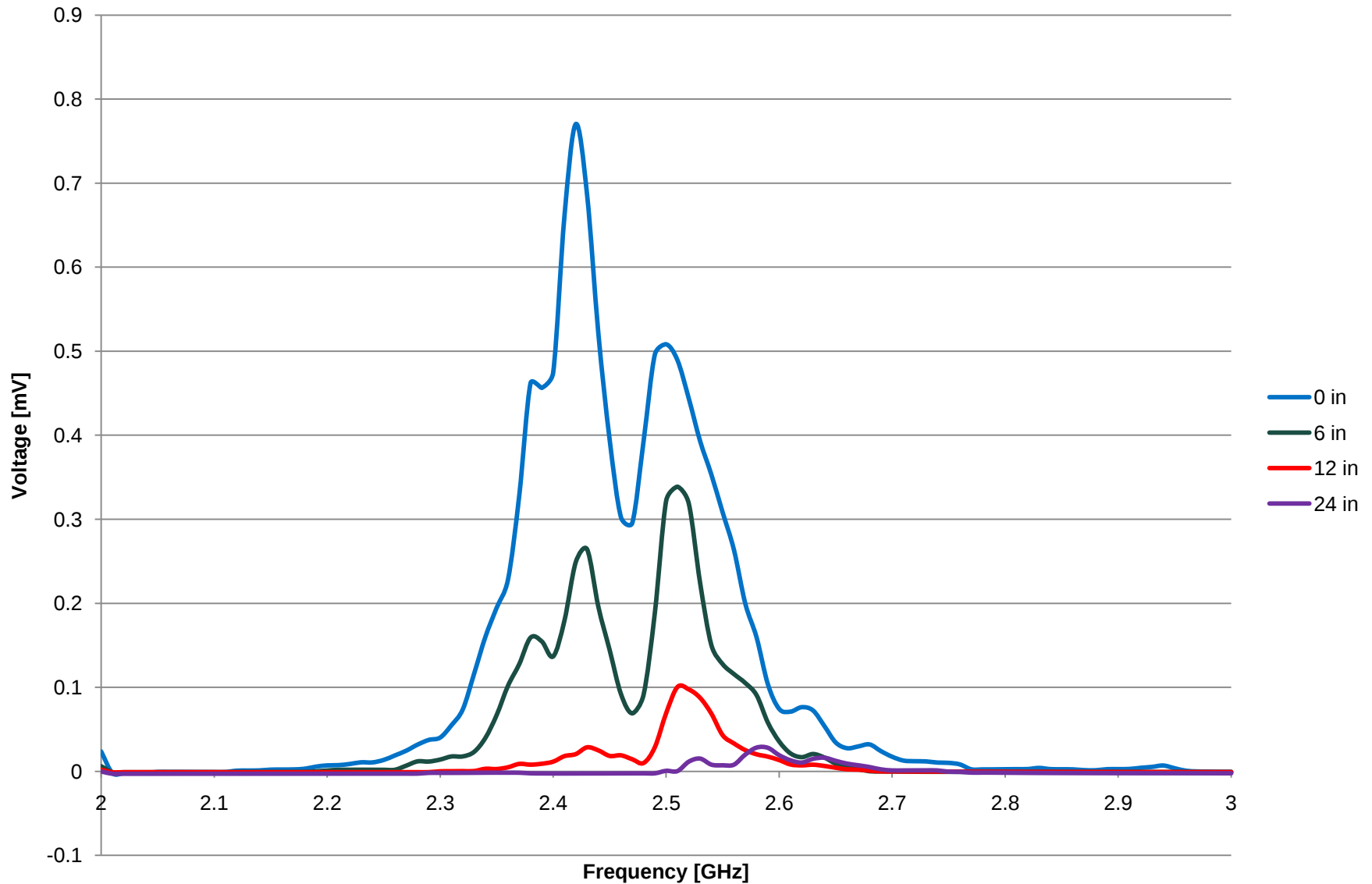
RF signal generator

- Horn radiation patterns taken using UC-I and TARDEC horn antennas
- Graphs represent accurate patterns, but not magnitudes due to normalization

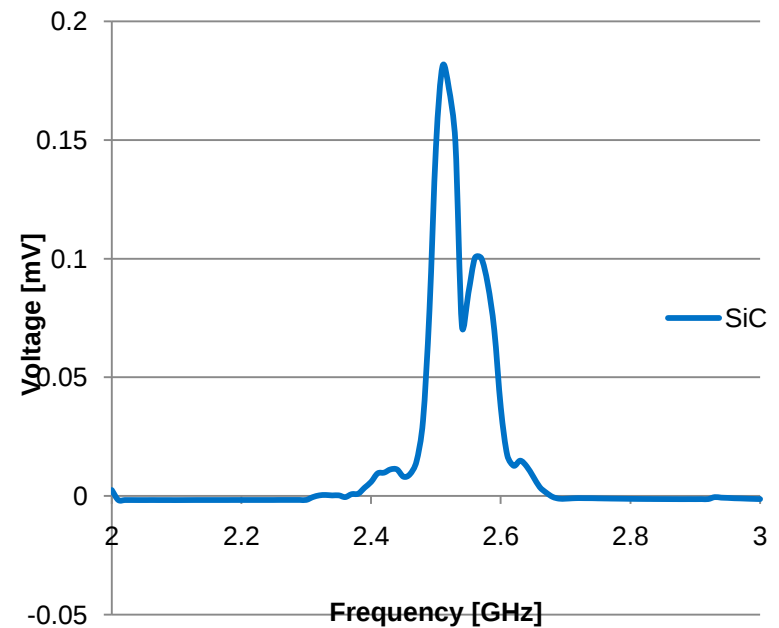
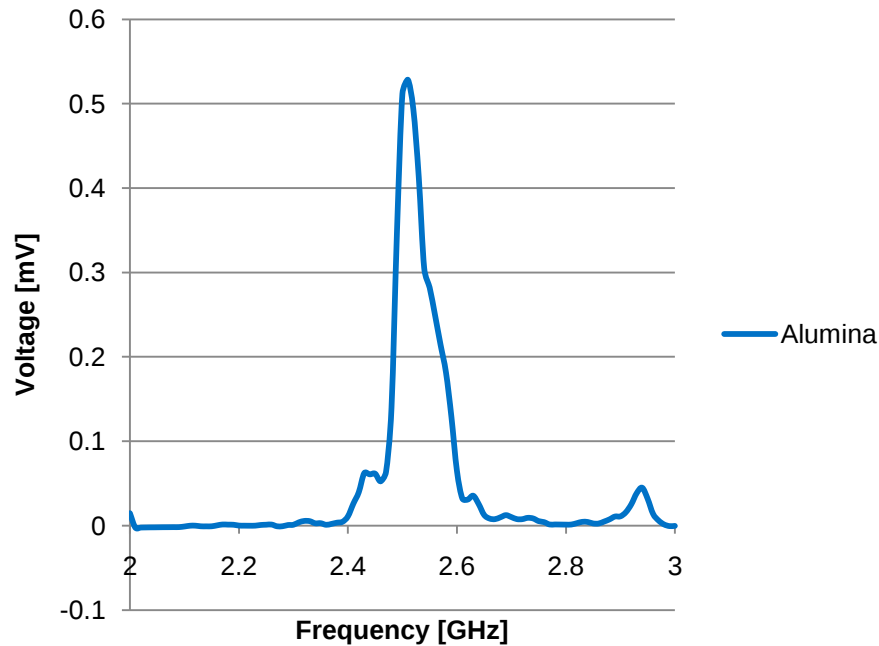




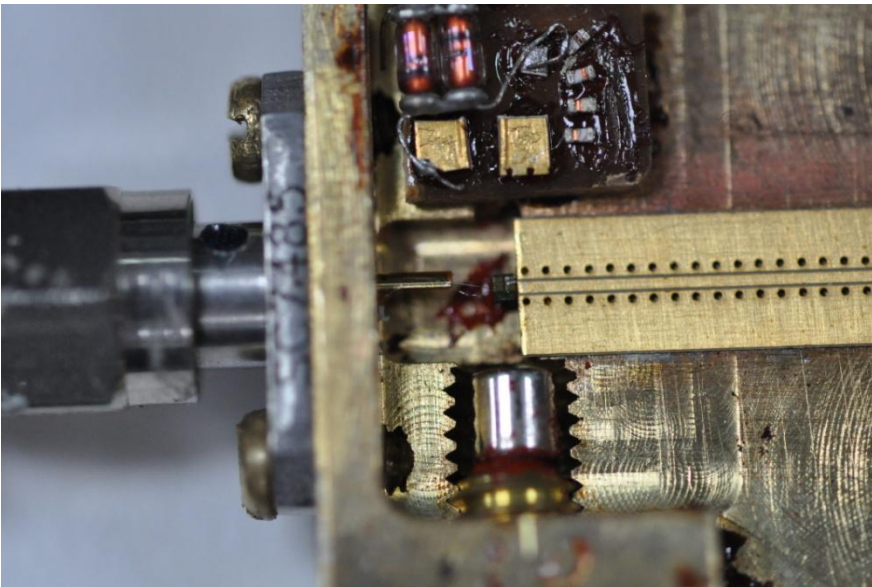
Detector Distance Testing: Bench

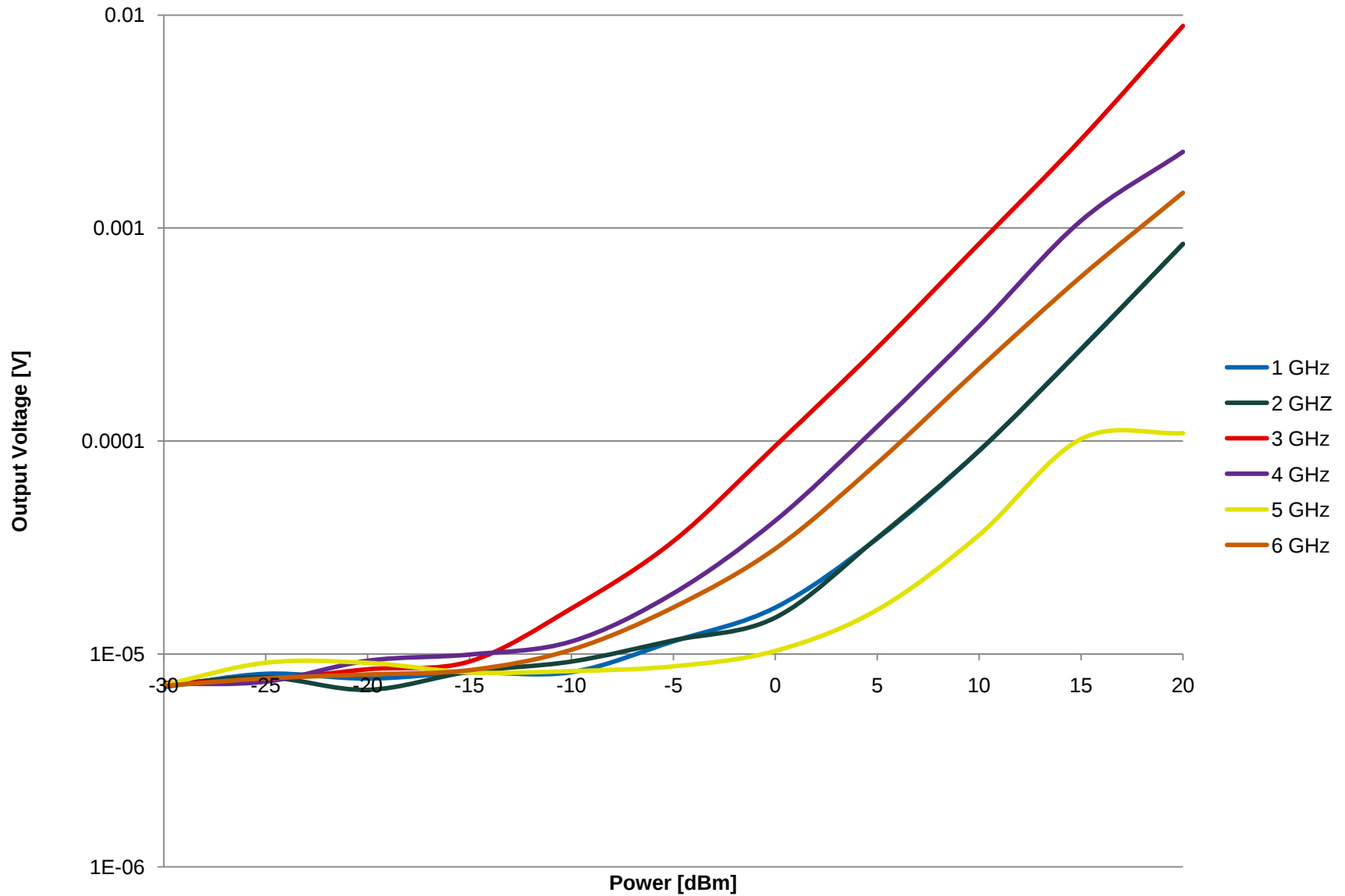


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- Effects of the Duroid Cover tested
- Duroid amplified some frequencies, but attenuated others

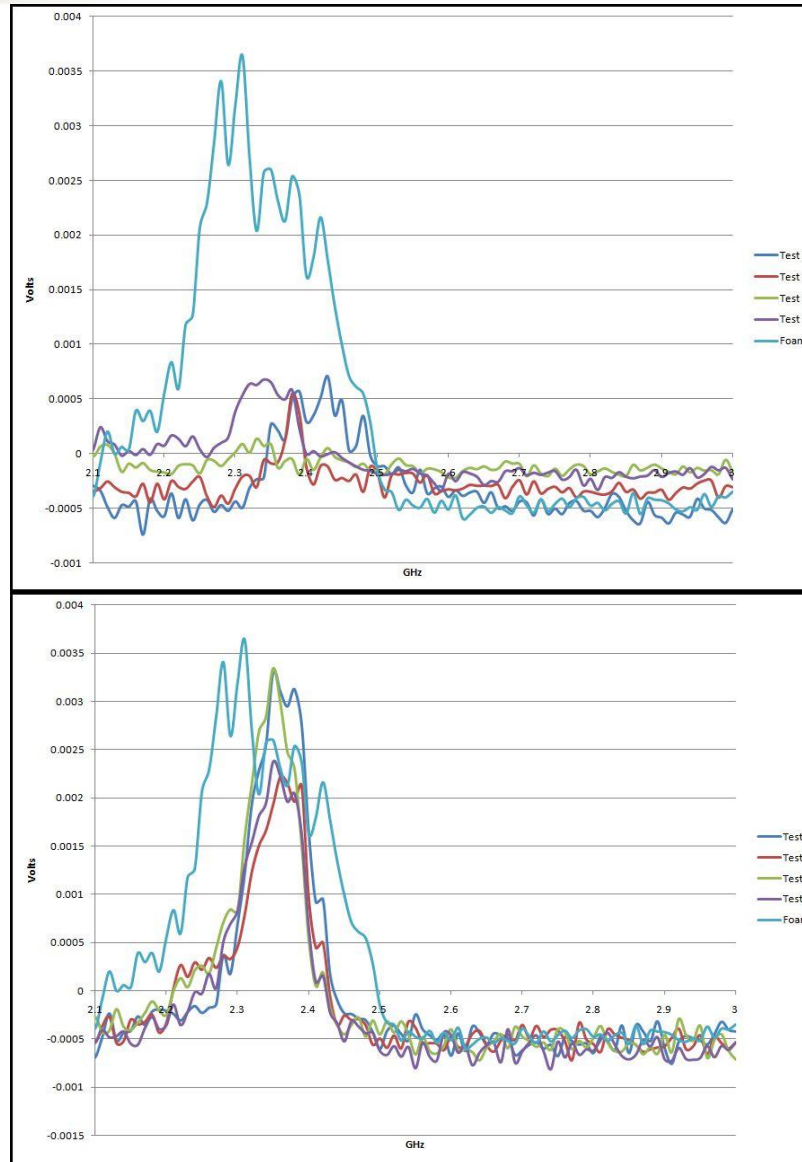






Front of
surrogate
armor

Back of armor



Small amount
of attenuation
by the armor
coupon in some
cases.

More stable
signal behind
the armor.

- We think that spintronic microwave sensors/detectors are an important nano technology that in the future will become an essential and vital part of the anti-radar and communications defense systems for military ground vehicles and aircrafts and that this technology will substantially increase system survivability.
- The successful completion of this project advances our understanding of the physical processes in nano-scale magnetic structures at microwave frequencies. Besides military and space-oriented applications, spintronics technology can also be used in commercial electronic devices, in particular, for the development of wireless intra- and inter-chip communication systems in nano-electronic integrated circuits.
- This research can fall under the future umbrella of Army metamaterials research and multifunctional armor.