The Effects of a Superparamagnetic Ground on the EMI Response of a Target

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Introduction:

Electromagnetic induction (EMI) sensors have a long history of success in finding visually obscured metal objects [1]. The electromagnetic properties of soils adversely affect the performance of EMI sensors and if conditions are severe enough, render them useless. A simple circuit model is often used to express the EMI response of a target analytically. This analytic model produces a response function that contains unique characteristics based on the target's electromagnetic properties. This work uses the analytic model for validation, then investigates the effects of a super-paramagnetic half-space on the response of a target.

Figure 1: Pfc. Nikko Williams using an advanced EMI sensor called the VMR2 Minehound [2].

Computational Methods:

The Magnetic Fields interface from the AC/DC Module is used to compute the magnetic fields and induced currents by solving Maxwell's equations using the following formulation:

$$(j\omega\sigma - \omega^2\varepsilon_0\varepsilon_r)A + \nabla \times (\mu_0^{-1}\mu_r^{-1}B) = J_e \qquad B = \nabla \times A$$

Figure 2 depicts the modeling environment. **Figure 3** shows the concentric and coplanar transmit and receive coils used to model an EMI sensor along with a concentric ring target.

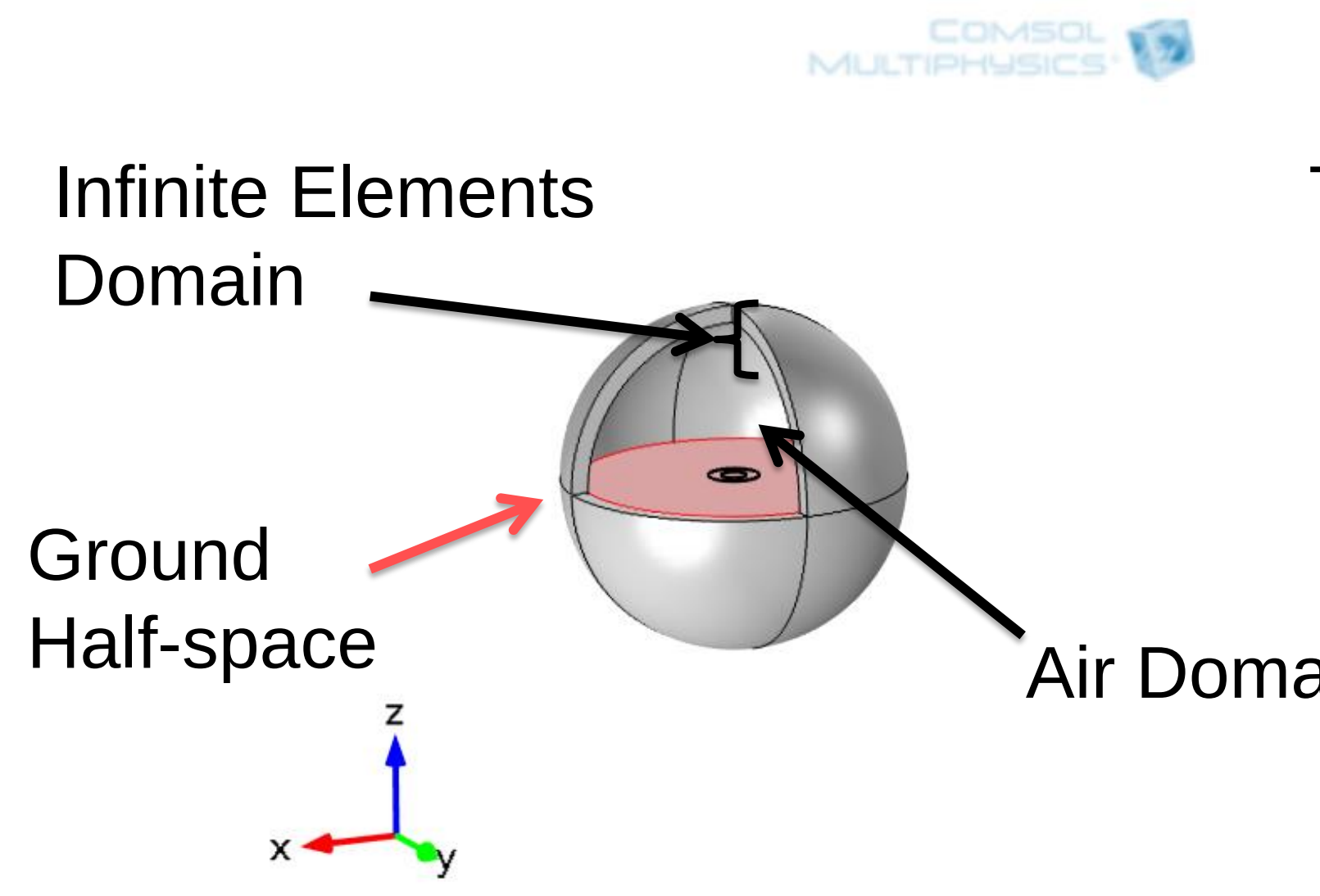

Figure 2: The modeling environment.

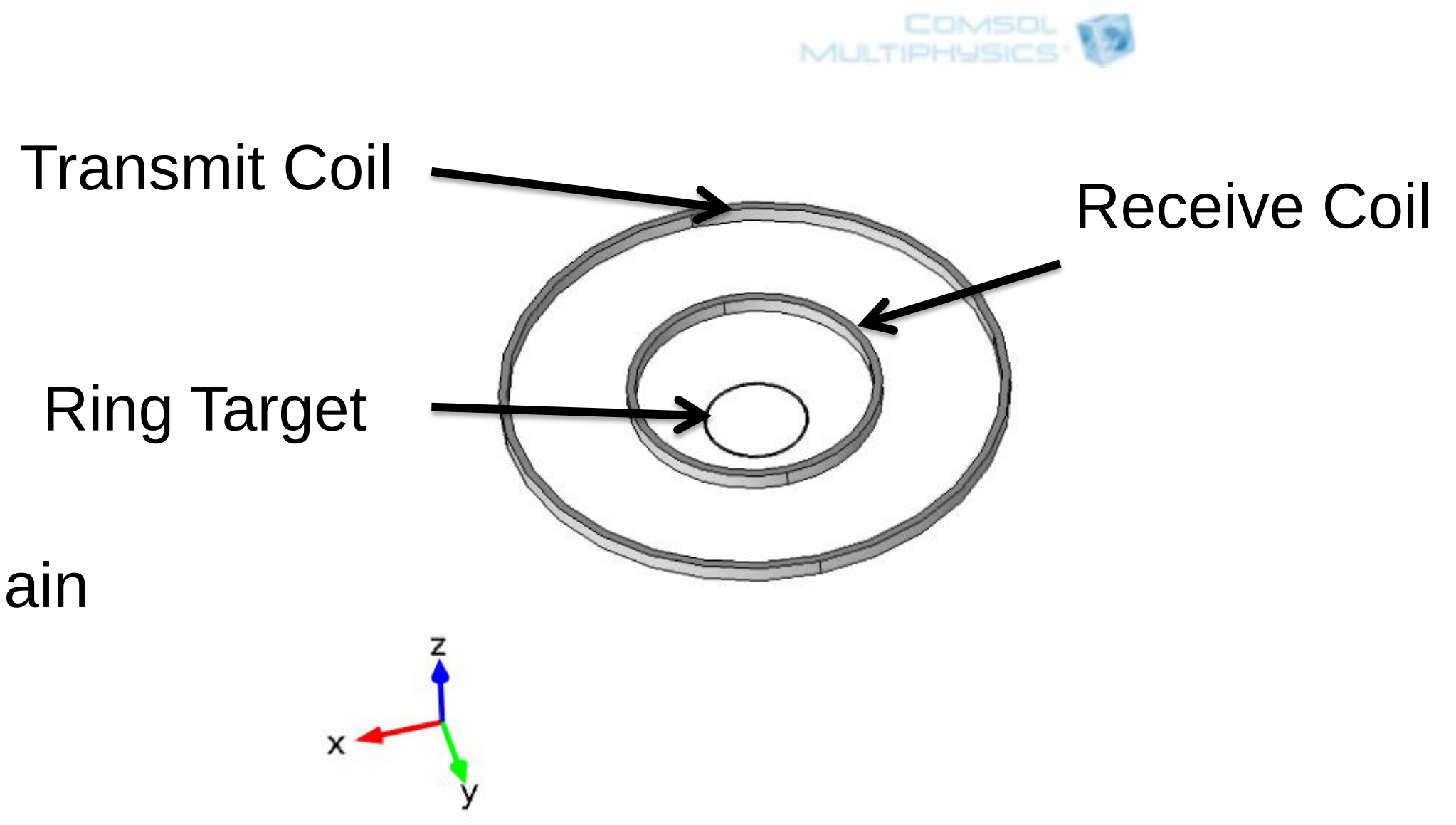

Figure 3: Transmit and receive coils with a ring target.

A well-established model for super-paramagnetic ground assumes a log-uniform distribution of magnetic relaxation constants resulting in a magnetic susceptibility (MS) of the form [3]:

$$\chi_{(\omega)} = \chi_{dc}\left(1 - \frac{1}{\ln\left(\tau_2/\tau_1\right)} \cdot ln\frac{i\omega\tau_2 + 1}{i\omega\tau_1 + 1}\right)$$

Where χ_{dc} is the static (dc) value of the MS, ω is the angular frequency, $i = \sqrt{-1}$ and τ_1 and τ_2 are the lower and upper bounds of the magnetic relaxation time constants, respectively. This model is used for the MS with a 10% volumetric variability applied to the soil half-space as shown in **Figure 4**.

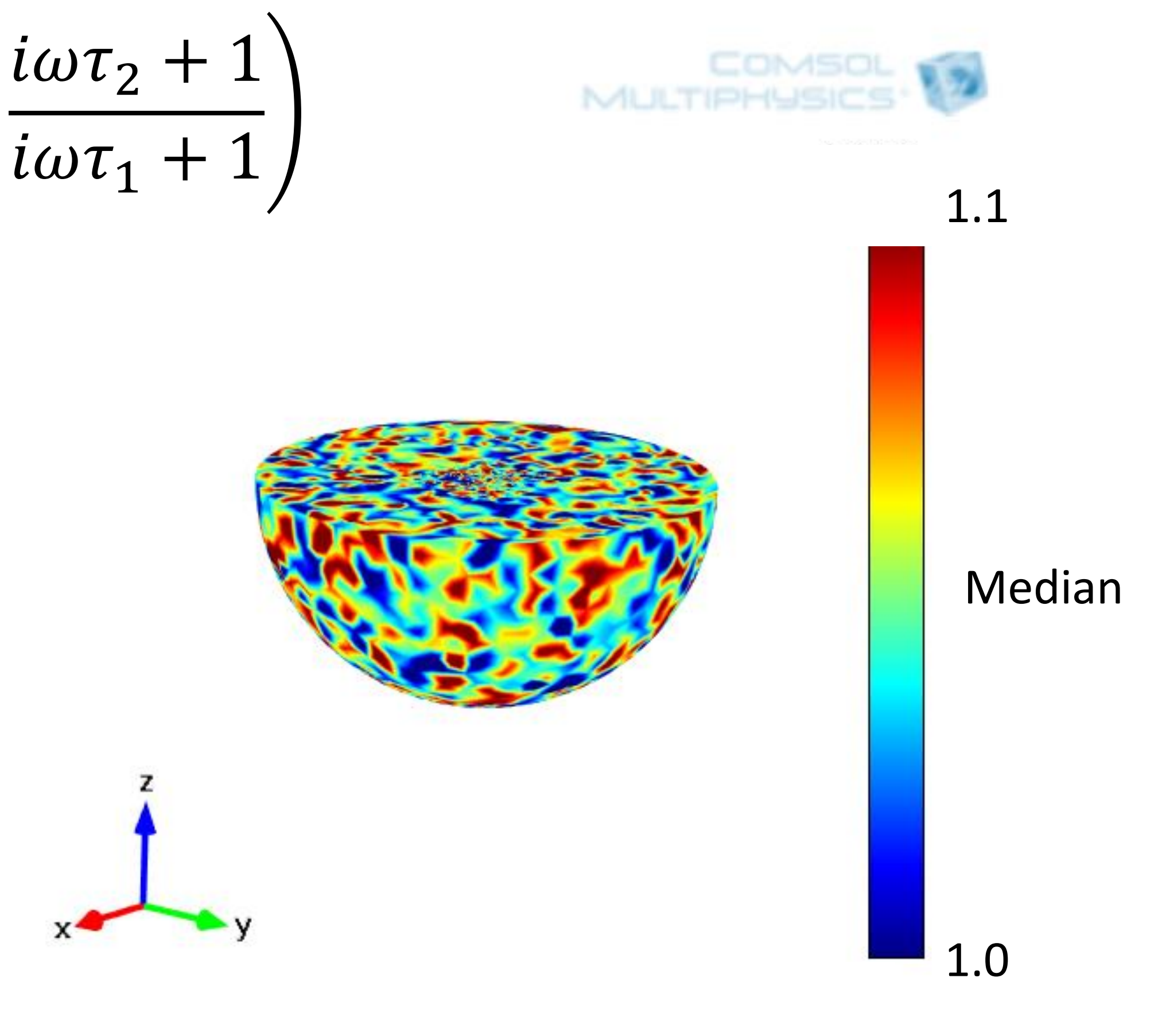

Figure 4: Modeled magnetic soil half-space with a volumetric variability in magnetic susceptibility of 10%.

Model Verification:

Model verification is an important step to ensure that the model environment is properly set up and that the physics is correct. A ring target without the soil half-space was tested against published results to validate the model.

A ring of AWG 22 wire with a 3 cm loop diameter has a single imaginary peak at 10.1kHz. **Figure 5** depicts the COMSOL results for this ring. The imaginary peak is located at 9.5 kHz which is in agreement with both the theoretical value and with Scott's measured value [4].

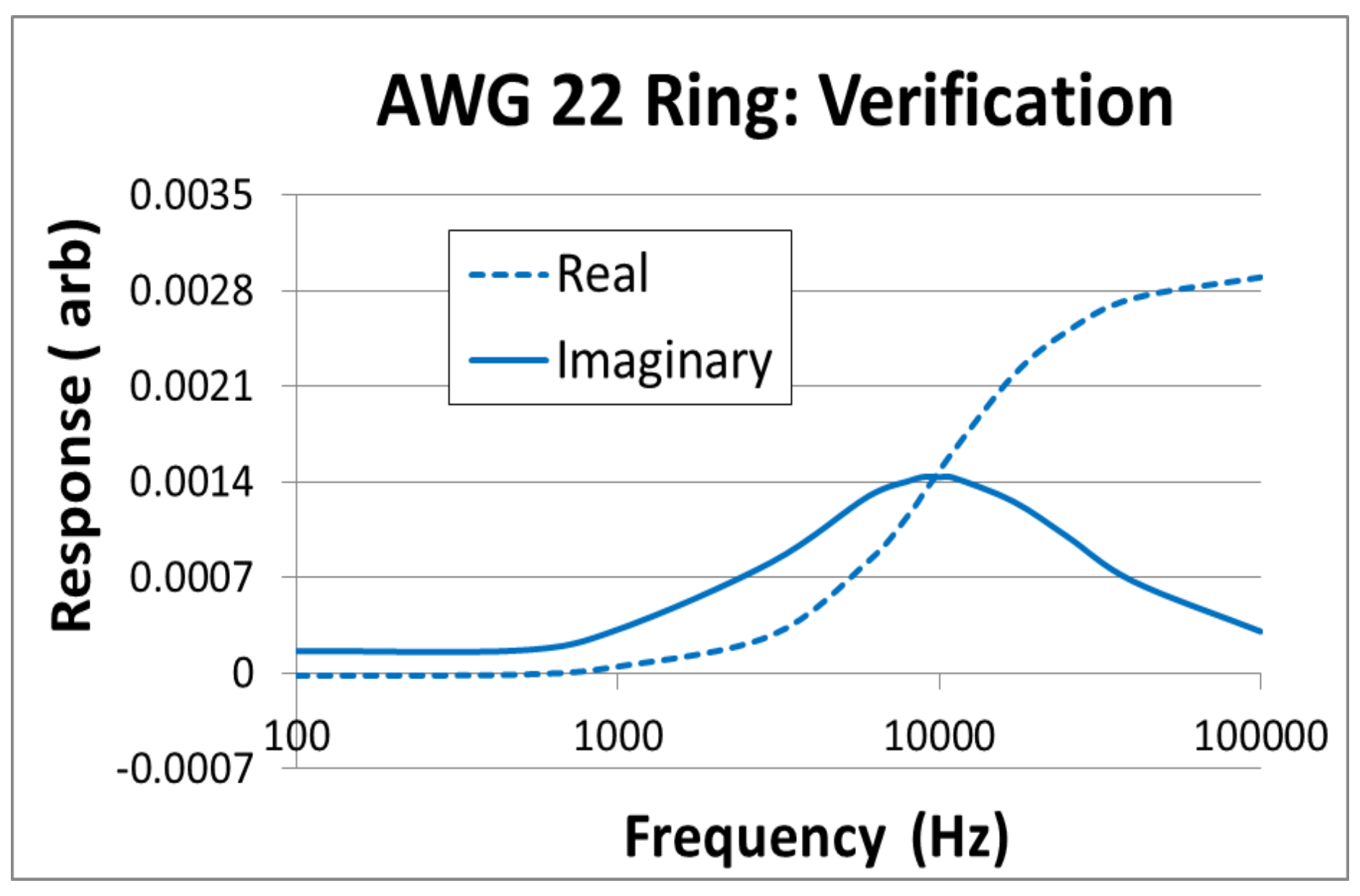

Figure 5: Measured response function from COMSOL simulation used to validate the model.

Results:

The ground half-space was added after the model was validated for a ring target in air. Various levels of static MS were chosen based on standards for soil severities developed by the European Committee for Standardization [5]. **Figure 6** shows that the real portion of the response is most affected by the super-paramagnetic ground. As the frequency increases the soil effects begin to diminish as expected since the real and imaginary components of the frequency dependent MS approach zero with increasing frequency.

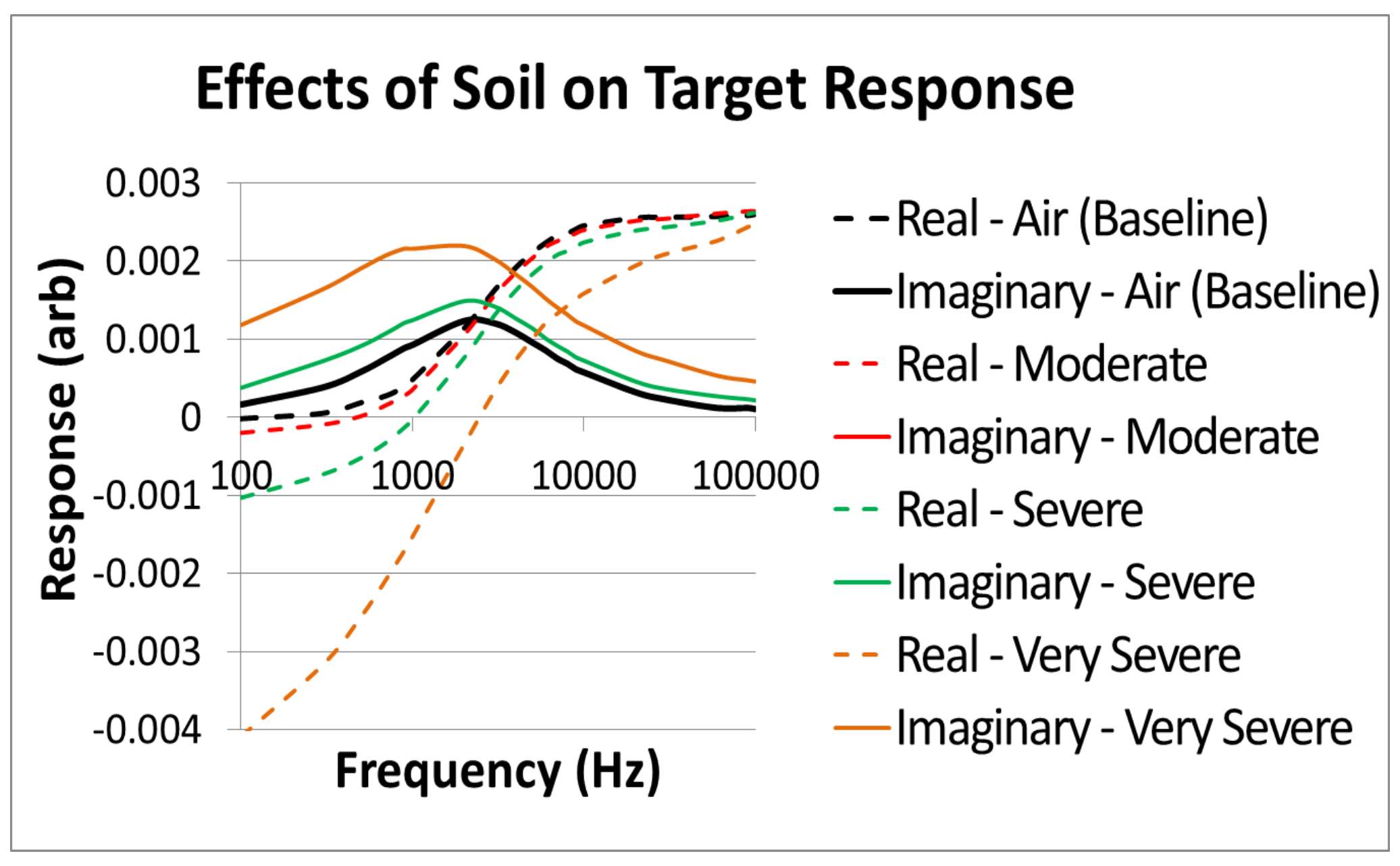

Figure 6: Measured EMI response of a ring target in various levels of super-paramagnetic ground.

Conclusion:

The modeling results give insight into how magnetic soil couples with the response of a target. The effects of the super-paramagnetic ground adversely affect the response of an EMI sensor diminishing its ability to find visually obscured objects. Future work aims to incorporate the electric circuits physics to model transient effects and modeling ground penetrating radar using the RF module.

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