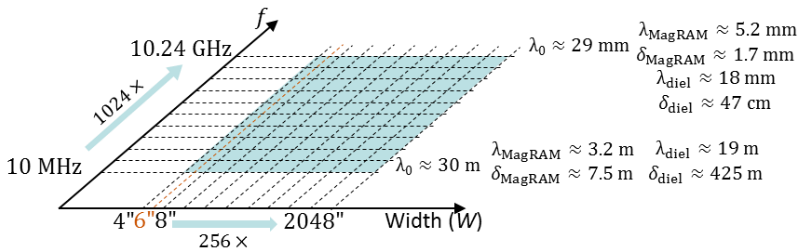
Description of Scattering Object

A homogeneous low-loss dielectric plate of size $W \times 7W/4 \times 1.5$ mm coated with a 1.5 mm thick lossy magneto-dielectric material.

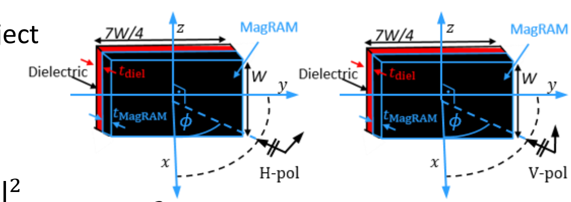
Length Scale and Frequency Range



The problems of interest cover a range of 512x in physical length scale and 1024x in frequency; the ranges are logarithmically sampled to yield 110 scattering problems. Because of the extra data for the $W = 6$ in plate, there are 110 + 12 unique scattering problems in Problem Set IIF. In these problems, the plate sizes are in the range $0.0033 \le W/\lambda_0 \le 1776$, $2.4 \times 10^{-4} \le W/\delta_{\mathrm{diel}} \le 111$, and $1.3 \times 10^{-2} \le W/\delta_{\mathrm{MagRAM}} \le 3.2 \times 10^{4}$, where λ_0 is the free-space wavelength, δ_{diel} is the penetration depth in the dielectric, and δ_{MagRAM} is the penetration depth in the magnetic radar absorbing (MagRAM) material. The length and width of the dielectric plates were chosen to approximately match the plate targets in [1], while the thickness of the plate and of the coating were chosen to match an available sample of ARC Technologies' DD-13490, a flexible silicone rubber microwave absorber [2].

Interesting Features

1. The logarithmic sampling is distorted along the length axis and an extra plate of $W = 6$ in is introduced because of publicly available measurement data corresponding to this size [3]. The sampling is also distorted along the frequency axis: scattering from the plate of $W = 6$ in at frequencies $f \in$ {10, 20, 40, 80, 160, 320, 640, 1280, 2560, 5120, 7000, 10240} MHz are included in the problem set because of publicly available measurement data [3]. These distortions add 12 unique scattering problems to the set.
2. The thin side wall presents meshing and accurate integration challenges.
3. The lossy magneto-dielectric material introduces extra uncertainties and sensitivities to RCS measurements and simulations [4].
4. The material diversity and junction in the composite object present challenges for RCS simulations [3].



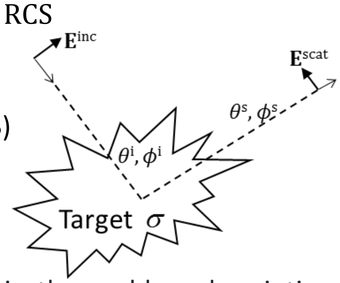
Quantities of Interest

Radar cross section (RCS) definition

$$\sigma_{vu}(\theta^{\mathrm{s}},\phi^{\mathrm{s}},\theta^{\mathrm{i}},\phi^{\mathrm{i}}) = \lim_{R\to\infty} 4\pi R \frac{|\hat{v}(\theta^{\mathrm{s}},\phi^{\mathrm{s}}) \cdot \mathbf{E}^{\mathrm{scat}}(\theta^{\mathrm{s}},\phi^{\mathrm{s}})|^2}{|\hat{u}(\theta^{\mathrm{i}},\phi^{\mathrm{i}}) \cdot \mathbf{E}^{\mathrm{scat}}(\theta^{\mathrm{i}},\phi^{\mathrm{i}})|^2} \quad : \text{ RCS } (\mathrm{m}^2)$$

$$\sigma_{vu,\mathrm{dB}}(\theta^{\mathrm{s}},\phi^{\mathrm{s}},\theta^{\mathrm{i}},\phi^{\mathrm{i}}) = 10\log_{10}\sigma_{vu} \quad : \text{ RCS in dB (dBsm)}$$

$$\sigma_{vu,\mathrm{dB}}^{TH}(\theta^{\mathrm{s}},\phi^{\mathrm{s}},\theta^{\mathrm{i}},\phi^{\mathrm{i}}) = \max\left(\sigma_{vu,\mathrm{dB}}, TH_{vu,\mathrm{dB}}\right) - TH_{vu,\mathrm{dB}} \quad : \text{ Thresholded RCS}$$



1. Set $\theta^{\mathrm{i}} = 90^{\mathrm{o}}$. Vary $0^{\mathrm{o}} \le \phi^{\mathrm{i}} \le 180^{\mathrm{o}}$ (every 0.5^{o} in the interval).
2. Compute back-scattered $\sigma_{\theta\theta,\mathrm{dB}}$ and $\sigma_{\phi\phi,\mathrm{dB}}$ (the VV- and HH-pol RCS in dB) at $N_\phi = 361$ scattering directions.

Material Properties

The material properties of the dielectric and the MagRAM may be found in the problem description documents for Problem Set IIC-Thin Dielectric Plates and Problem Set IID-Thin MagRAM Plates.

Performance Measures

Error Measure: Simulation errors shall be quantified using

$$avg.err_{uu,\mathrm{dB}}^{TH} = \frac{1}{2\pi}\int_0^{2\pi}\left|\sigma_{uu,\mathrm{dB}}^{TH}(\phi^s) - \sigma_{uu,\mathrm{dB}}^{\mathrm{ref},TH}(\phi^s)\right|d\phi^s \approx \frac{1}{N_\phi}\sum_{n=1}^{N_\phi}\left|\sigma_{uu,\mathrm{dB}}^{TH}(\phi_n^s) - \sigma_{uu,\mathrm{dB}}^{\mathrm{ref},TH}(\phi_n^s)\right| \ \ (\mathrm{dB}) \ \text{ for } u \in \{\theta,\phi\}$$

where

$$TH_{uu,\mathrm{dB}} = \max_{\phi^s} \sigma_{uu,\mathrm{dB}}^{\mathrm{ref}} - 80 \ (\mathrm{dB})$$

This error measure discounts errors in RCS values smaller than TH.

Cost Measure: Simulation costs shall be quantified using observed wall-clock time and peak memory/process

$$t^{\mathrm{wall}}(\mathrm{s}) \text{ and } mem^{\mathrm{maxproc}}(\mathrm{bytes})$$

as well as the "serialized" CPU time and total memory requirement

$$t^{\mathrm{total}} = N_{\mathrm{proc}} \times t^{\mathrm{wall}}(\mathrm{s}) \text{ and } mem^{\mathrm{max}} = N_{\mathrm{proc}} \times mem^{\mathrm{maxproc}} \ (\mathrm{bytes})$$

Here, N_{proc} denotes the number of processes used in a parallel simulation. It is expected that results will be reported for at least 2 runs: "Efficient" (small N_{proc}) and "Fast" (large N_{proc}).

Study 1: Error vs. Cost Sweep

Fix frequency and fix plate dimensions. Simulate many error levels (proxy: mesh densities) for 4 cases:

Case 1: *f*=10 MHz, *W*=6 in

Case 2: *f*=7 GHz, *W*=6 in (measurement frequency)

Case 3: *f*=10 MHz, *W*=128 in

Case 4: *f*=320 MHz, *W*=128 in

It's recommended to simulate as many error levels (mesh densities) as possible. 3-5 error levels is typical. A typical error-vs.-cost study will consist of 4x3-5=12-20 simulations.

Study 2: Frequency Sweep

Fix plate dimensions and error level (proxy: mesh density). Simulate many frequencies for 4 cases:

Case 1: *W*=6 in, error level 1 (coarsest mesh)

Case 2: *W*=128 in, error level 1 (coarsest mesh)

Case 3: *W*=6 in, error level 2 (finer mesh)

Case 4: *W*=128 in, error level 2 (finer mesh)

Frequencies shall be chosen as $f \in \{10, 20, 40, \ldots, 5120, 10240\}$ MHz. It's recommended to simulate as many frequencies as possible. A full frequency-sweep study will consist of 4x11=44 simulations.

Study 3: Size Sweep

Fix frequency and error level (proxy: mesh density). Simulate many sizes for 4 cases:

Case 1: *f*=10 MHz, error level 1 (coarsest mesh)

Case 2: *f*=320 MHz, error level 1 (coarsest mesh)

Case 3: *f*=10 MHz, error level 2 (finer mesh)

Case 4: *f*=320 MHz, error level 2 (finer mesh)

Dimensions shall be chosen as $W \in \{4, 8, 16, \ldots, 1024, 2048\}$ in. It's recommended to simulate as many sizes as possible. A full size-sweep study will consist of 4x10=40 simulations.

Reference Quantities of Interest

The following RCS data are made available in the benchmark to enable participants to calibrate their simulators:

4 RCS measurement results corresponding to the *W*=6 in plate at frequencies $f \in \{2560, 5120, 7000, 10240\}$ MHz. They are provided for ϕ^{i} sampled every 0.25°. The HH-polarized data are the same as those plotted in Fig. 8 of [3].

References

[1] A. C. Woo, H. T. G. Wang, M. J. Schuh and M. L. Sanders, "EM programmer's notebook-benchmark radar targets for the validation of computational electromagnetics programs," *IEEE Ant. Propag. Soc. Mag.*, vol. 35, no. 1, pp. 84-89, Feb. 1993.

[2] ARC Technologies, “Technical Data Sheet DD-13490. [Online]. Available: http://arc-tech.com/pdf/DD-13490%20Rev%20C.pdf

[3] J. T. Kelley, D. A. Chamulak, C. Courtney, and A. E. Yilmaz, “Increasing the material diversity in the Austin RCS Benchmark Suite using thin plates,” in *Proc. Ant. Meas. Tech. Assoc. (AMTA) Symp.*, Nov. 2020.

[4] J. T. Kelley, B. MacKie-Mason, D. A. Chamulak, M. Martin, K. Crouch, C. C. Courtney, and A. E. Yilmaz, “Towards quantifying the effect of material uncertainty on RCS predictions of composite targets,” in *Proc. ACES Symp.*, May 2024.