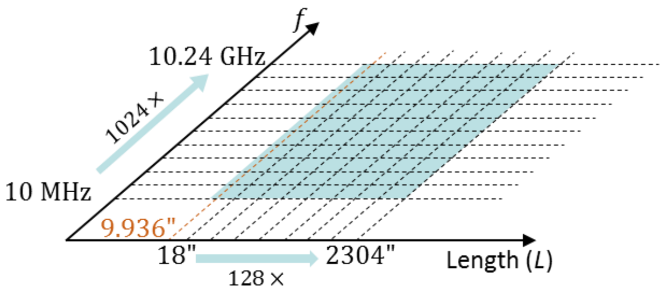
Description of Scattering Object

A perfect electrically conducting (PEC) almond proportional to the dimensions in [1].

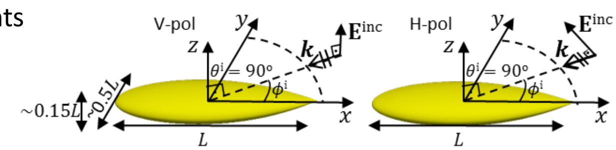
Length Scale and Frequency Range



The problems of interest cover a range of ~256x in physical length scale and 1024x in frequency; the ranges are logarithmically sampled to yield 99 scattering problems. Because the almonds are PEC, there are only 19 + 12 unique scattering problems in Problem Set IIIA. In these problems, the almond sizes are in the range $0.0076 \le L/\lambda_0 \le 1998$, where λ_0 is the free-space wavelength.

Interesting Features

1. The logarithmic sampling is distorted along the length axis for the smallest almond: the smallest almond has L=9.936'' (instead of L=9 in) because of publicly available measurement data corresponding to this size [1],[2]. The sampling is also distorted along the frequency axis: scattering from the smallest almond at frequencies $f \in$ {10, 20, 40, 80, 160, 320, 640, 1280, 3500, 5125, 7000, 10250} MHz are included in the problem set because of publicly available measurement data [2]. These distortions add 12 unique scattering problems to the set.
2. The non-trivial shape and tip of the almond presents modeling and meshing challenges.



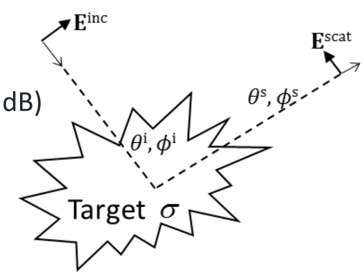
Quantities of Interest

Radar cross section (RCS) definition

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

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

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



1. Set $\theta^{\mathrm{i}} = 90°$. Vary $0° \le \phi^{\mathrm{i}} \le 180°$ (every 0.5° 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.

Performance Measures

Error Measure: Simulation errors shall be quantified using

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

where

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

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^{wall}(s) and mem^{maxproc}(bytes)

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

$t^{\mathrm{total}} = N_{\mathrm{proc}} \times t^{\mathrm{wall}}$(s) and $mem^{\mathrm{max}} = N_{\mathrm{proc}} \times mem^{\mathrm{maxproc}}$ (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 almond dimensions. Simulate many error levels (proxy: mesh densities) for 4 cases:

Case 1: *f*=10 MHz, *L*=9.936 in
Case 2: *f*=7 GHz, *L*=9.936 in
Case 3: *f*=10 MHz, *L*=288 in
Case 4: *f*=320 MHz, *L*=288 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 almond dimensions and error level (proxy: mesh density). Simulate many frequencies for 4 cases:

Case 1: *L*=18 in, error level 1 (coarsest mesh)
Case 2: *L*=288 in, error level 1 (coarsest mesh)
Case 3: *L*=18 in, error level 2 (finer mesh)
Case 4: *L*=288 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 $L \in \{9.936, 18, 36, \ldots, 1152, 2304\}$ in. It's recommended to simulate as many sizes as possible. A full size-sweep study will consist of 4x9=36 simulations.

Reference Quantities of Interest

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

8 RCS measurement results corresponding to the smallest almond (*L*=9.936 in) at frequencies $f \in \{3500, 5125, 7000, 10250\}$ MHz. These measurements were made using two almonds [2]: One was of size *L*=9.936 in and the other was scaled up 2x in all dimensions. These data are the same as those plotted in Figs. 11-12 of [2]; they are provided for ϕ^{i} sampled every 0.25^{o}.

4 RCS simulation results for the smallest almond at the above 4 frequencies found by using the ARCHIE-AIM code, a frequency-domain FFT-accelerated integral-equation solver developed at UT Austin [3]-[5]. These data are the same as the finest mesh (≈0.6-mm average edge length) results in [2].

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] J. T. Kelley, D. A. Chamulak, C. C. Courtney, and A. E. Yılmaz, "Rye Canyon radar cross-section measurements of benchmark almond targets," *IEEE Ant. Popag. Soc. Mag.*, Feb. 2020.

[3] M. F. Wu, G. Kaur, and A. E. Yılmaz, "A multiple-grid adaptive integral method for multi-region problems," *IEEE Trans. Antennas Propag.*, vol. 58, no. 5, pp. 1601-1613, May 2010.

[4] F. Wei and A. E. Yılmaz, "A more scalable and efficient parallelization of the adaptive integral method part I: algorithm," *IEEE Trans. Antennas Propag.*, vol. 62, no. 2, pp. 714-726, Feb. 2014.

[5] J. W. Massey, V. Subramanian, C. Liu, and A. E. Yılmaz, "Analyzing UHF band antennas near humans with a fast integral-equation method," in *Proc. EUCAP*, Apr. 2016.