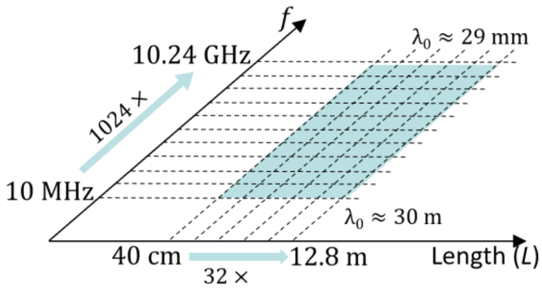
Description of Scattering Object

A perfect electrically conducting (PEC) hexagonal prism with a circle-cylinder shaped duct. A fan-blade assembly is inserted into the duct.

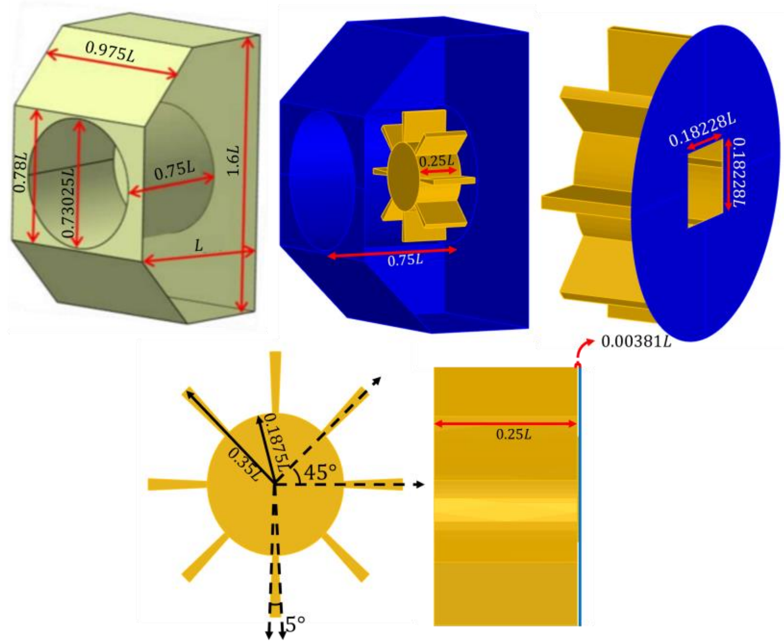
Length Scale and Frequency Range



The problems of interest cover a range of 32x in physical length scale and 1024x in frequency; the ranges are logarithmically sampled to yield 66 scattering problems. Because the camera boxes are PEC, there are only 16+1 unique scattering problems in Problem Set IIISD. In these problems, the model sizes are in the range $0.013 \leq L/\lambda_0 \leq 438$, where λ_0 is the free-space wavelength.

Interesting Features

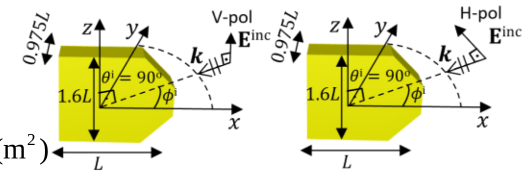
1. The camera box is designed as a host structure to enable reproducible RCS measurements of ducts. The flat-plate geometrical features of the housing promote strong backscattering in certain directions that are minimally affected by the scattering characteristics of any voids in the box [1],[2]. The camera box host structure used for Problem Sets IIISA and IIISB was modified in the following manner: its dimensions were scaled by 3× in the y-dimension and 2× in the z-dimension compared to that in [2] (see diagram for exact dimensions).



2. The diagram shows the dimensions of the straight-blade fan-loaded camera box. For the smallest problem in the problem set, a 2.88 in. × 2.88 in. × 0.06 in. metal plate connects the fan-blade assembly to the back-wall of the duct [1]; as a result, there is a 0.06-in. gap between the blades and the back wall of the duct. The sampling of the frequency range is distorted for this problem: scattering from the smallest camera box at frequencies $f \in \{10, 20, 40, 80, 160, 320, 640, 1280, 2560, 5120, 7000, 10240\}$ MHz are included in the problem set. This distortion is because of publicly available measurement data [1] and adds 1 unique scattering problem to the set.

3. The VV-polarized RCS pattern at 2.56 GHz was found to exhibit unusually high sensitivity to computational errors and simulation parameters in the $15^{\text{o}} \leq \phi^{\text{i}} \leq 30^{\text{o}}$ range. Methods and parameters that typically yield sufficiently accurate results may yield results that agree poorly with the reference simulation and measurement data for this part of the pattern.

Quantities of Interest

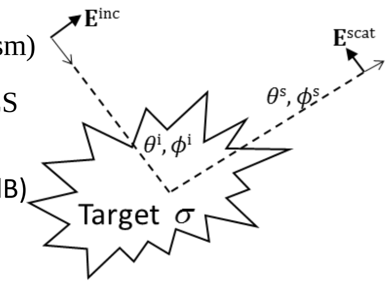


Radar cross section (RCS) definition

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

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

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



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

Performance Measures

Error Measure: Simulation errors shall be quantified using

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

where

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

This error measure discounts errors in RCS values below TH .

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

$$t^{\rm wall}_{\rm main}\text{ (s) and } mem^{\rm maxcore}_{\rm main}\text{ (bytes)}$$

as well as the “serialized” CPU time and total memory requirement

$$t^{\rm total}_{\rm main} = N_{\rm proc}\times t^{\rm wall}_{\rm main}\text{ (s) and } mem^{\rm max}_{\rm main} = N_{\rm proc}\times mem^{\rm maxcore}_{\rm main}\text{ (bytes)}$$

Here, $N_{\rm proc}$ 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 $N_{\rm proc}$) and “Fast” (large $N_{\rm proc}$).

Study 1: Error vs. Cost Sweep

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

Case 1: *f*=10 MHz, *L*=40 cm
Case 2: *f*=7 GHz, *L*=40 cm
Case 3: *f*=10 MHz, *L*=6.4 m
Case 4: *f*=320 MHz, *L*=6.4 m

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

Case 1: *L*=40 cm, error level 1 (coarsest mesh)
Case 2: *L*=6.4 m, error level 1 (coarsest mesh)
Case 3: *L*=40 cm, error level 2 (finer mesh)
Case 4: *L*=6.4 m, error level 2 (finer mesh)

Frequencies shall be chosen as $f \in$ {10, 20, 40, … , 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 $L \in \{40, 80, 120, \ldots, 640, 1280\}$ cm. It's recommended to simulate as many sizes as possible. A full size-sweep study will consist of 4x7=28 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 straight-blade fan-loaded camera box (*L*=40 cm) at frequencies $f \in \{2560\ 5120, 7000, 10240\}$ MHz. These data are provided for ϕ^{i} sampled every 0.5^{o}.

4 RCS simulation results for the smallest straight-blade fan-loaded camera box 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].

References

[1] J. T. Kelley *et al*., "Reproducible measurements of “fan blades in a pipe” CEM benchmark," in *Proc. Antenna Meas. Techn. Assoc. Symp.,* Oct. 2023.
[2] A. E. Yilmaz *et al*., "Camera boxes: a set of complex scattering problems to test EM simulations and measurements," in *Proc. IEEE Antennas Propag. Soc. Int. Symp.*, July 2022.
[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.