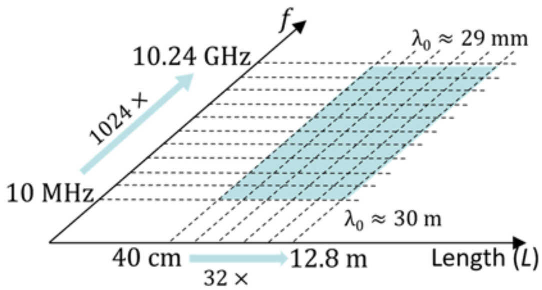
Description of Scattering Object

A perfect electrically conducting (PEC) hexagonal prism with a "cramped cobra" shaped duct.

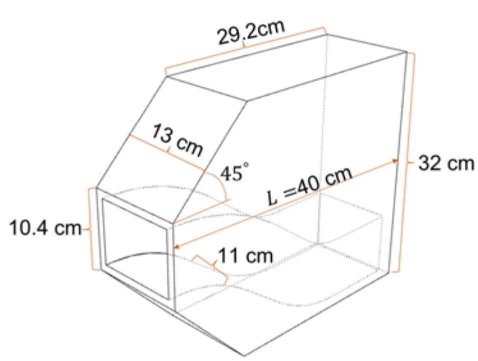
Length Scale and Frequency Range

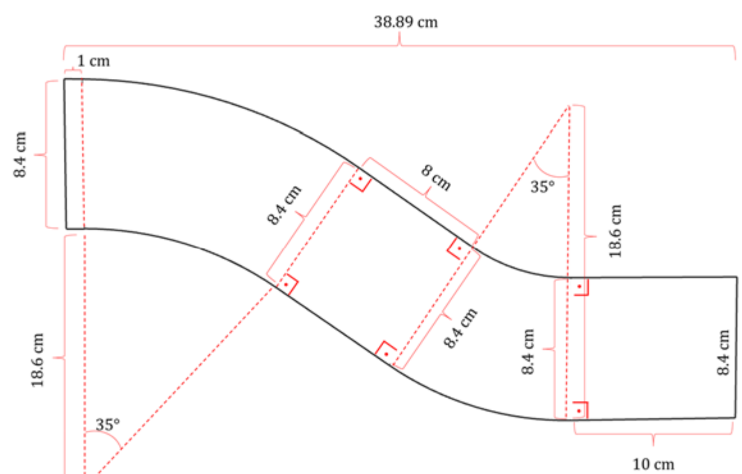


The problems of interest cover a range of 32x in physical length scale and 1024x in frequency; the ranges are logarithmically sampled to yield 66 scattering problems. Because the camera boxes are PEC, there are only 16+1 unique scattering problems in Problem Set IIISB. In these problems, the model sizes 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]. Unlike Problem Set IIISA, the front aperture is open to reveal a "cramped cobra" shaped duct[1], whose precise dimensions are given in the diagram below.
2. The diagram below shows the dimensions of the smallest cobra-ducted camera box in the problem set. 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 other 5 cobra-ducted camera boxes in the problem set IIISB are obtained by scaling all dimensions of the geometry proportionally.

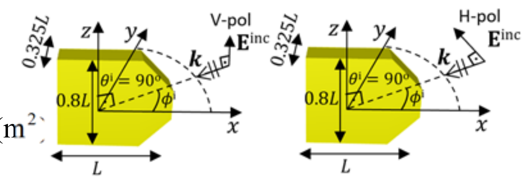




[1] The duct is referred to as the "cramped cobra duct" because its dimensions are similar but not identical to the COBRA cavity described in [2] and related publications.

Quantities of Interest

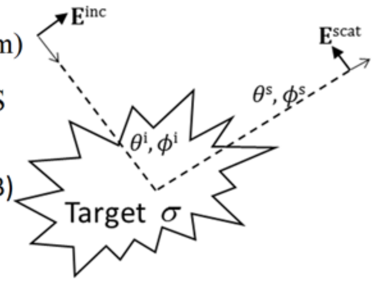
Radar cross section (RCS) definition



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

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

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



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-RCS in dB) at $N_\phi = 361$ scattering directions.

Performance Measures

Error Measure: Simulation errors shall be quantified using

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

where

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

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

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

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

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

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 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 $f\in\{10, 20, 40, \dots, 5120, 10240\}$ 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 $L\in\{40, 80, 120, \dots, 640, 1280\}$ 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 cobra-ducted 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}. Note that the high return at $\phi^{\mathrm{i}} = 90^{\mathrm{o}}$ saturated the instrumentation radar at 10240 MHz; thus, the measured RCS values near that look angle are inaccurate. The same phenomenon can be observed in Fig. 3 in [1].

4 RCS simulation results for the smallest cobra-ducted 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] A. E. Yilmaz, E. Smith, S. Cox, B. MacKie-Mason, C. C. Courtney, and G. Burchuk, "Camera boxes: a set of complex scattering problems to test EM simulations and measurements," in *Proc. IEEE Antennas Propag. Soc. Int. Symp.*, July 2022.

[2] J.-M. Jin, J. Liu, Z. Lou, and C. S. T. Liang, “A fully high-order finiteelement simulation of scattering by deep cavities,” *IEEE Trans. Antennas Propag.*, vol. 51, no. 9, pp. 2420–2429, Sep. 2003.

[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.