Increasing the Material Diversity in the Austin RCS Benchmark Suite Using Thin Plates

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Outline

- ❑ Motivation
  - The Austin RCS Benchmark Suite
- ❑ Material Characterization
  - Material description
  - Measurement process
- ❑ Target Preparation
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- ❑ Monostatic RCS Measurement
  - Measurement setup and data collection
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- ❑ RCS Results and Analysis
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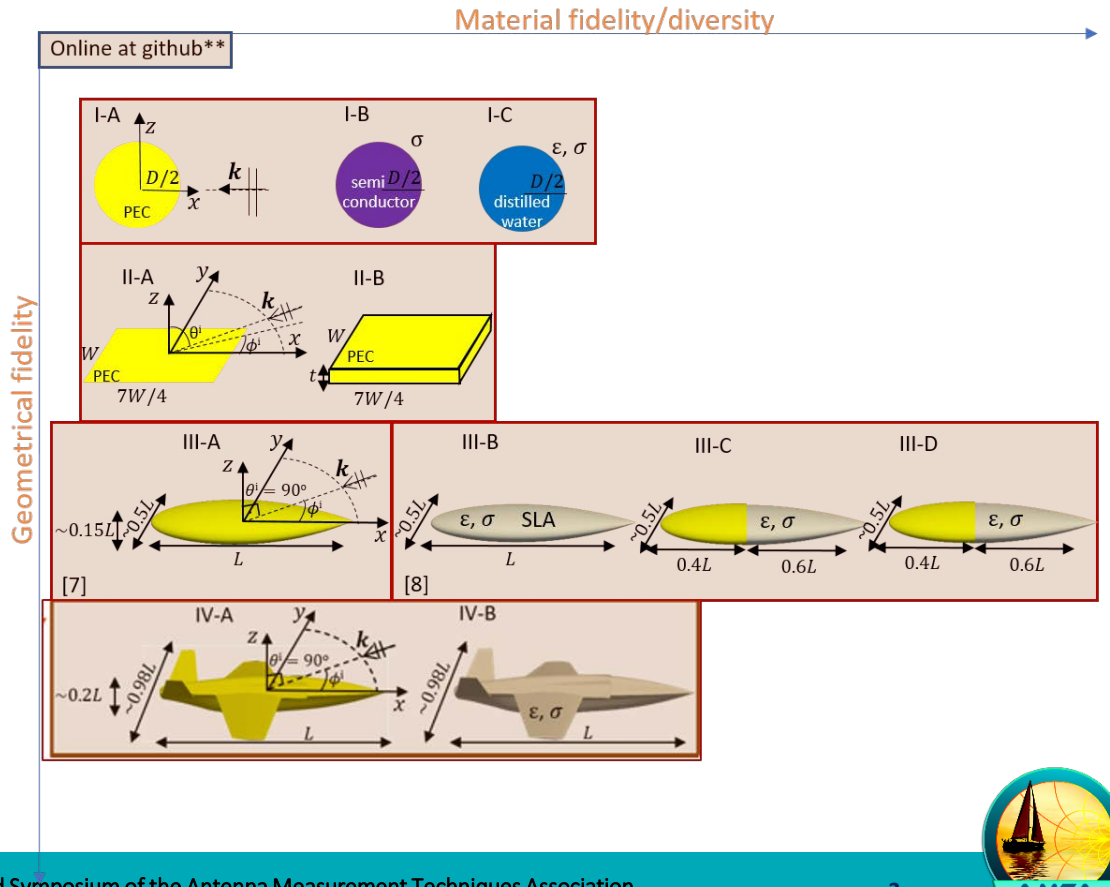
  - Material uncertainty quantification
- ❑ Public Release
- ❑ Conclusion

Motivation

- The Austin RCS Benchmark Suite
  - Contains well-defined scattering problems ranging from easy to difficult



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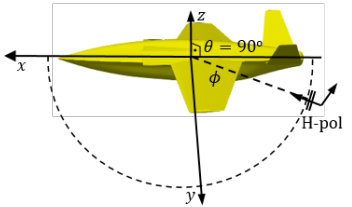
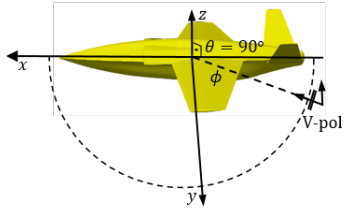
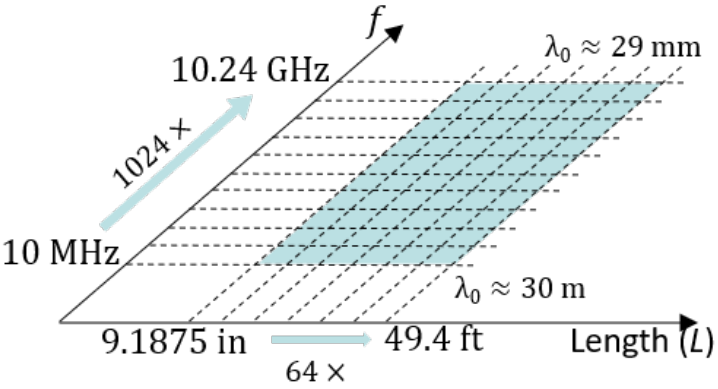


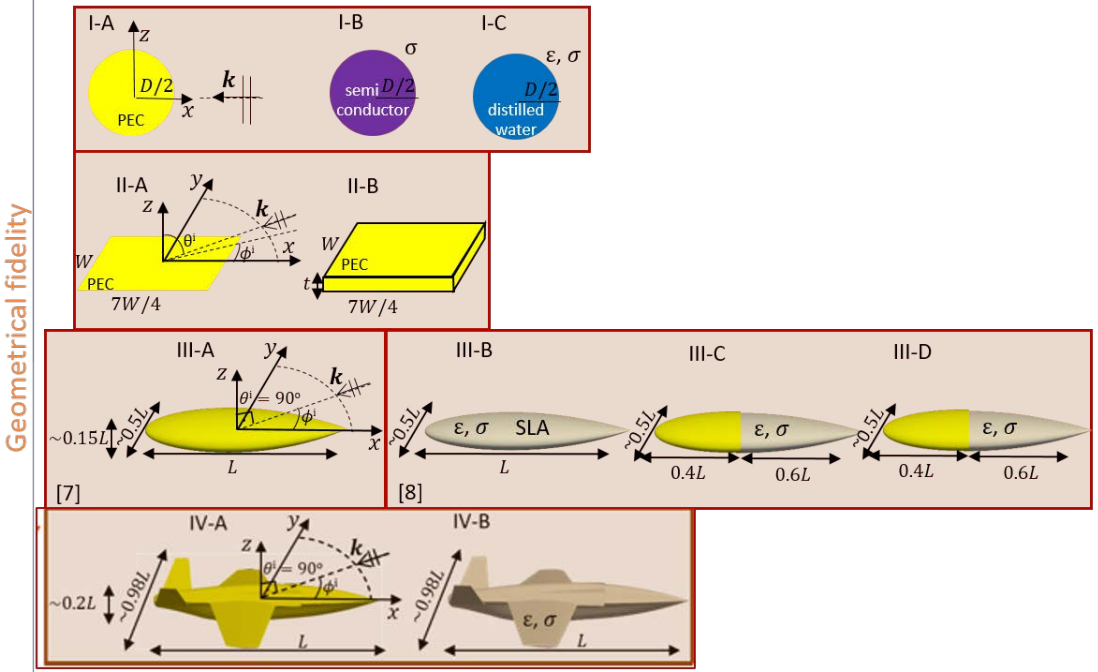




Material fidelity/diversity

Online at github**

Geometrical fidelity



Motivation

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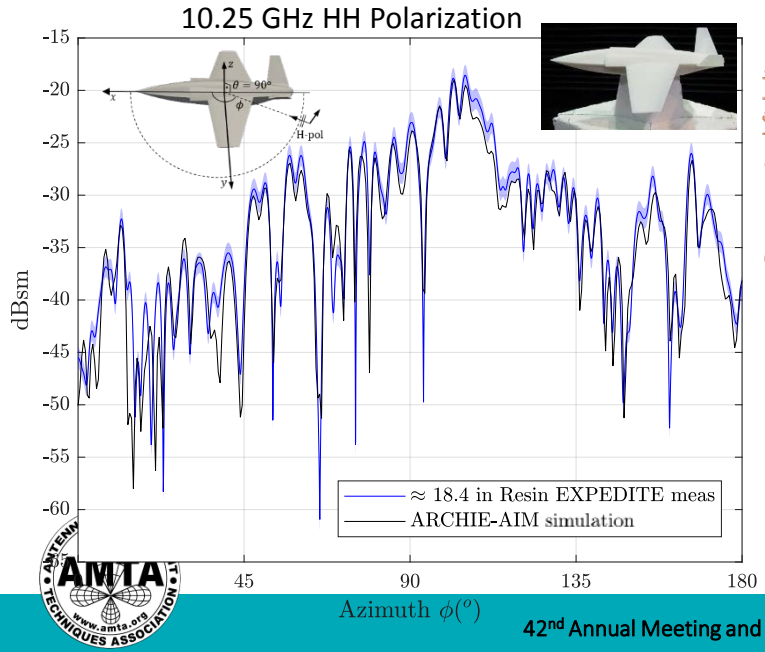
  - Contains well-defined scattering problems ranging from easy to difficult
  - Contains analytical, measurement, and simulation reference data



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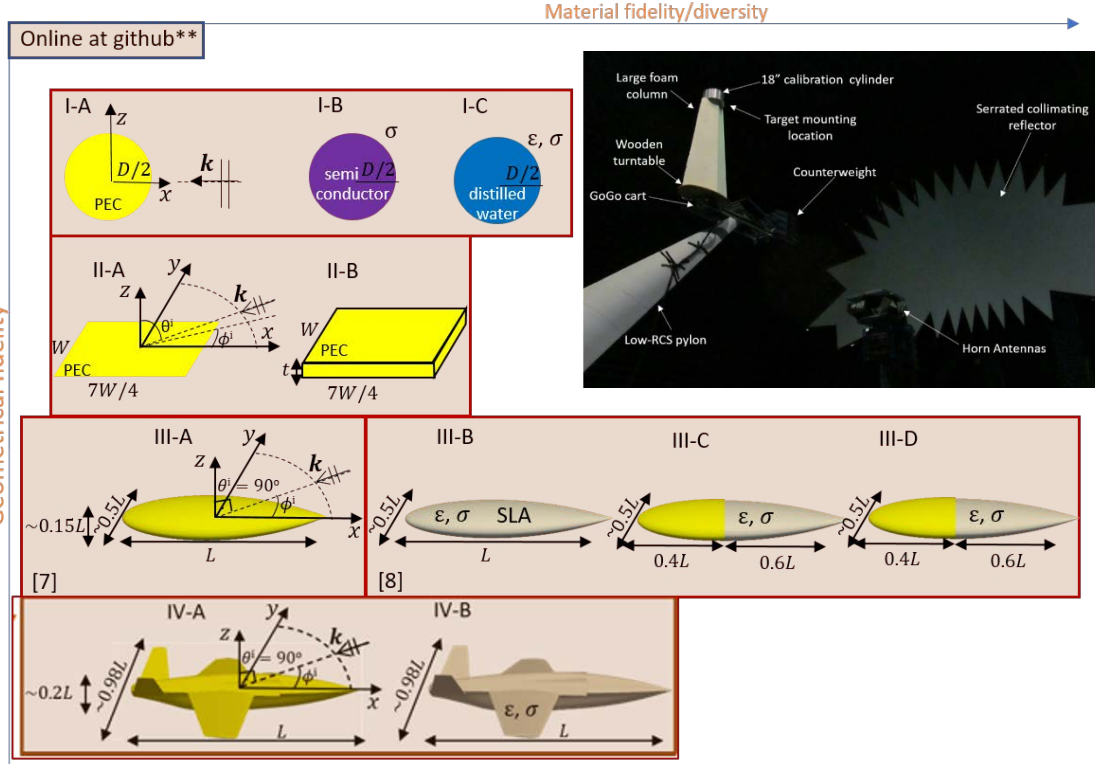

Motivation

- The Austin RCS Benchmark Suite
  - Contains well-defined scattering problems ranging from easy to difficult
  - Contains analytical, measurement, and simulation reference data
  - Emphasis on replicability, public availability

master ▾ AustinCEMBenchmarks / Austin-RCS-Benchmarks /

UTAustinCEMGroup EXPEDITE UNV Meshes

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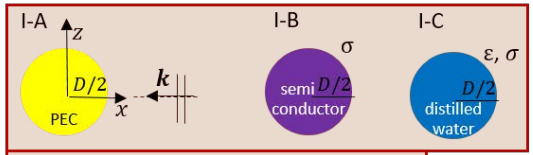
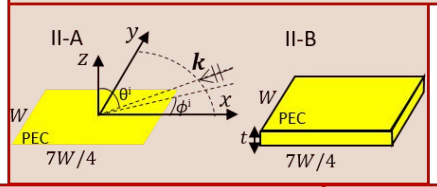
Problem I-Spheres	2020 ACES Update
Problem II-Plates	Updated reference data
Problem III-Almonds	2020 ACES Update
Problem IV-EXPEDITE-RCS Aircrafts	EXPEDITE UNV Meshes
ACES2020Presentation.pdf	2020 ACES Update
AMTA2019presentation.pdf	2019 AMTA update
HowToParticipate.md	Populating placeholder messages

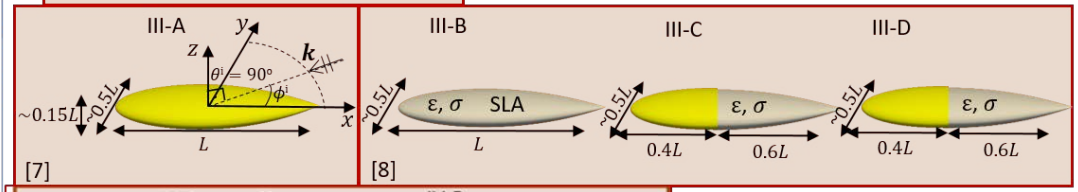
Online at github**

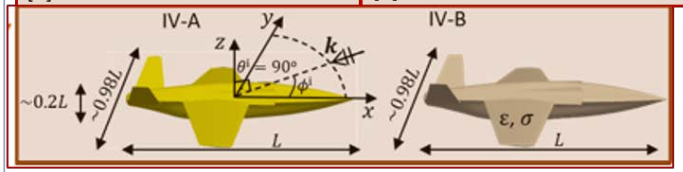
Material fidelity/diversity

Geometrical fidelity

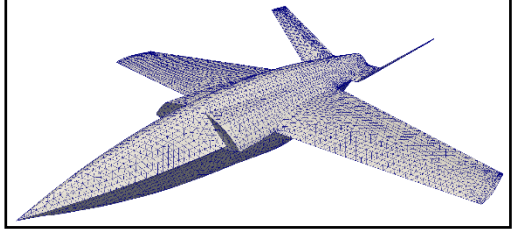






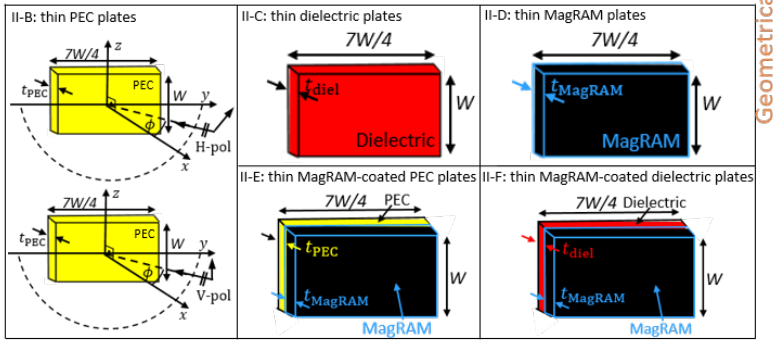


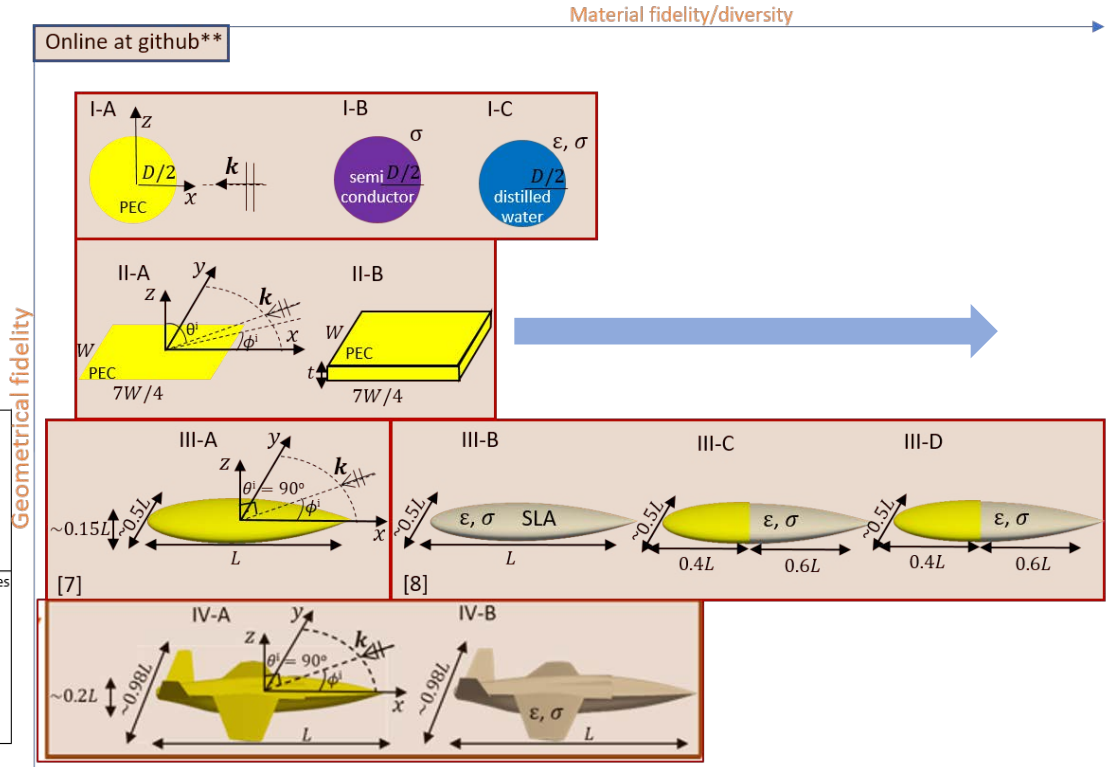
EXPEDITE-RCS Model "Mesh A"



Motivation

- The Austin RCS Benchmark Suite
  - Contains well-defined scattering problems ranging from easy to difficult
  - Contains analytical, measurement, and simulation reference data
  - Emphasis on replicability, public availability
  - Extend Material fidelity/Diversity dimension of Suite with five thin plate targets

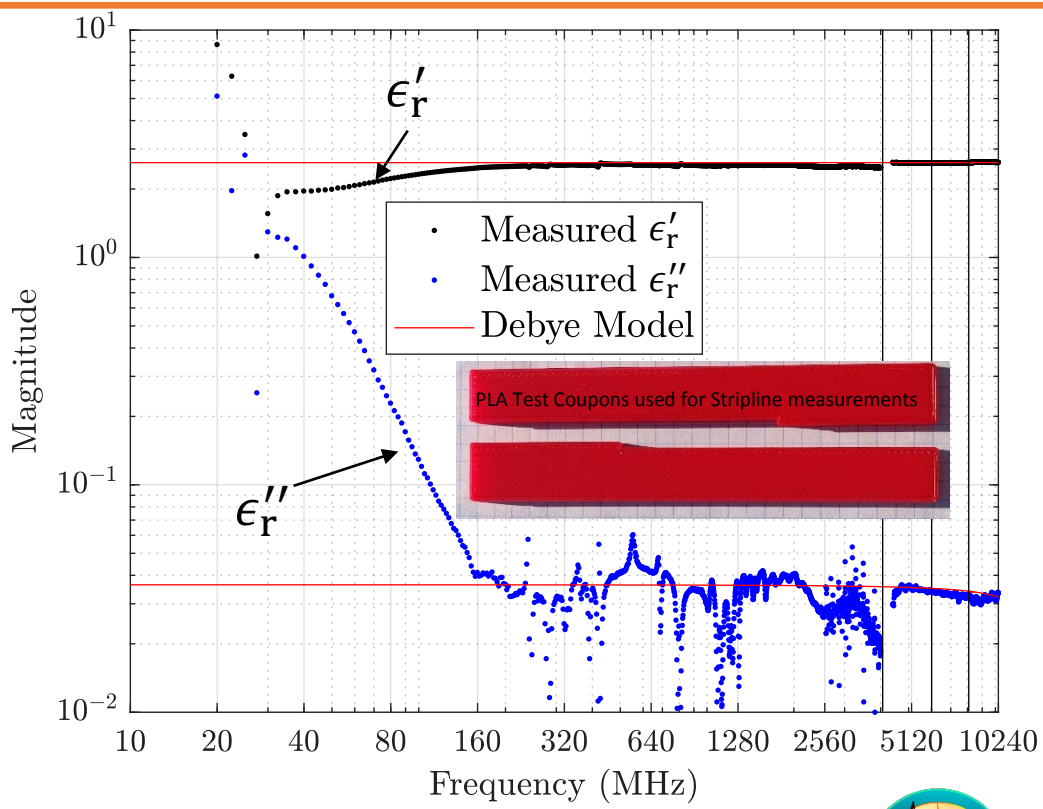




Material Characterization

- Material Description
  - Metal: 6061-T6 aluminum
  - Low-loss dielectric: PolymaxTM polylactic acid (PLA) [1]
  - Magnetic radar absorbing material (MagRAM): ARC Technologies' DD-13490 [2]
- Measurement Process
  - Measured PLA's S-parameters and inverted using NRW algorithm to determine material properties

$$\epsilon_r(f) = A + \frac{B}{1 - jfC}$$



References:
[1] Polymaker, "PolyMaxTM PLA." [Online]. Available: https://polymaker.com/product/polymax-pla/
[2] ARC Technologies, "Technical Data Sheet DD-13490. [Online]. Available: http://arc-tech.com/pdf/DD-13490%20Rev%20C.pdf

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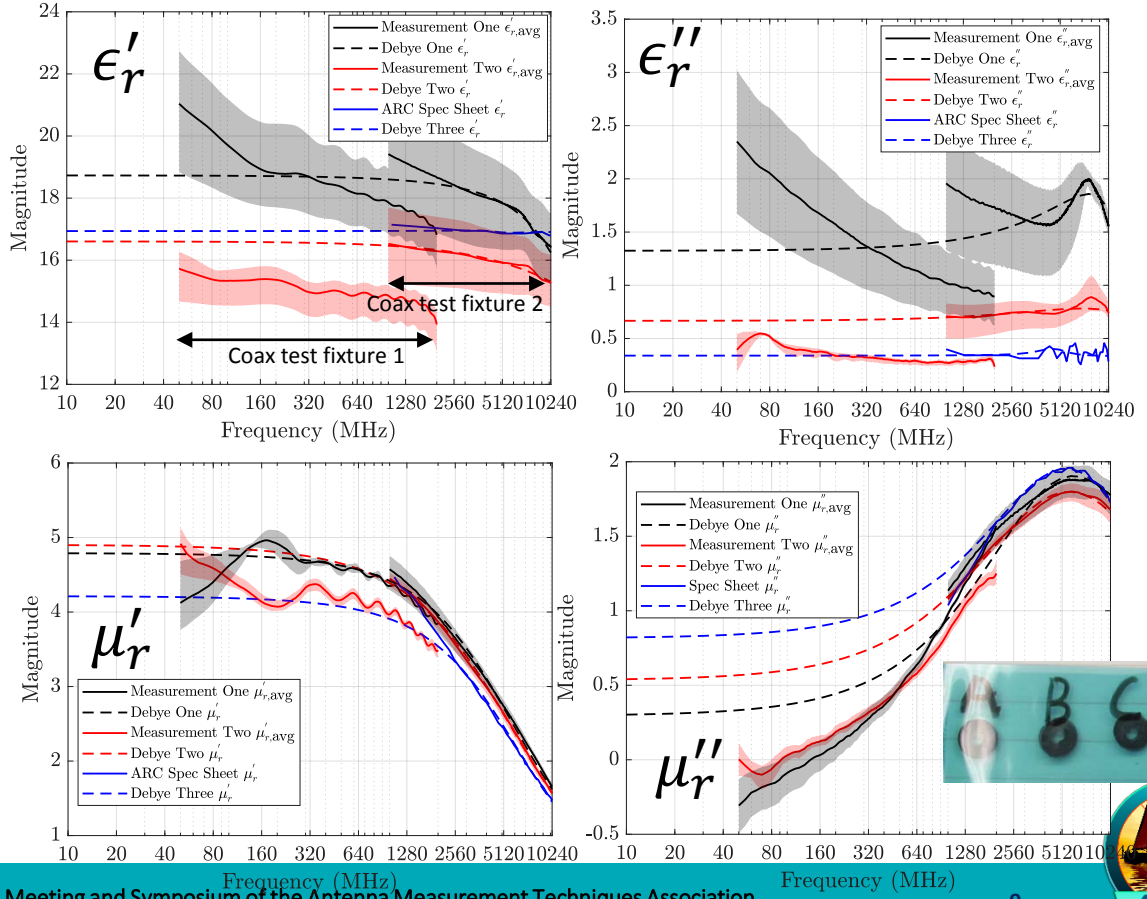
- Measurement Process
  - Two Debye models were fit to independent measurement campaigns and one model was fit to spec sheet data provided by ARC Technology.

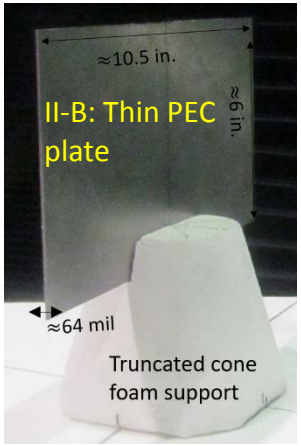
$$\epsilon_r(f) = A_1 + \frac{B_1}{1 - jfC_1}$$

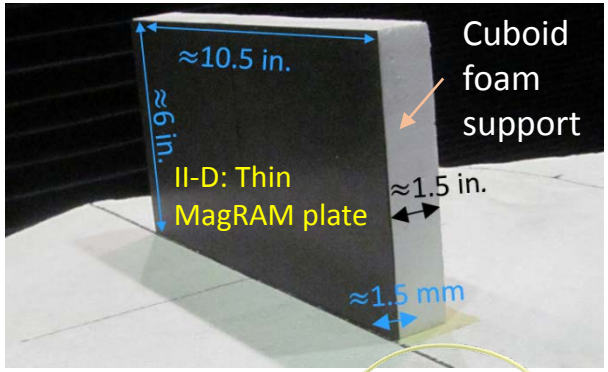
$$\mu_r(f) = A_2 + \frac{B_2}{1 - jfC_2}$$

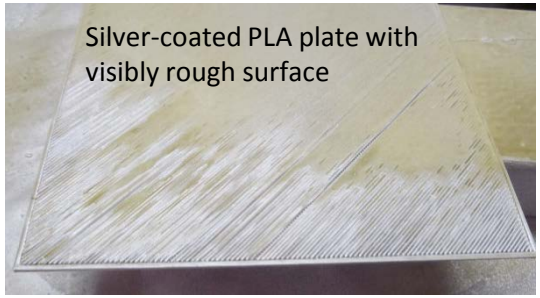


Target Preparation

- Target Descriptions
  - II-B: Thin PEC plates
  - II-C: Thin dielectric plates
  - II-D: Thin MagRAM plates
  - II-E: Thin MagRAM-coated PEC plates
  - II-F: Thin MagRAM-coated dielectric plates
- Target Preparation
  - Aluminum plate cut from larger sheet of 6061-T6 aluminum
  - PLA plate additively manufactured with Lulzbot Taz 6 3D printer
  - MagRAM plate cut from sample of ARC DD-13490 material



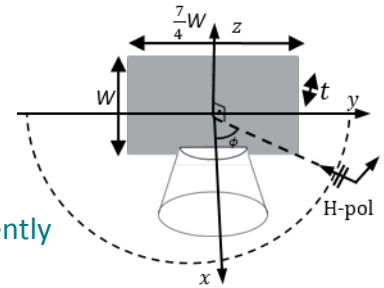


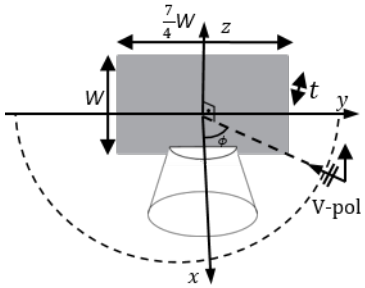


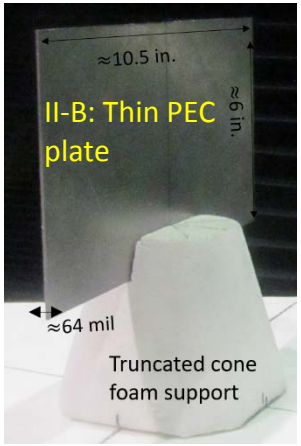
Original Images from:
https://profound3d.com/products/lulzbot-taz-workhorse-3d-printer?utm_medium=cpc&utm_source=google&utm_campaign=Google%20Shopping&gclid=EAIaIQobChMIn9XdptmF5QIVUdbACh1-hQ87EAQYBCABEgIXgfD_BwE

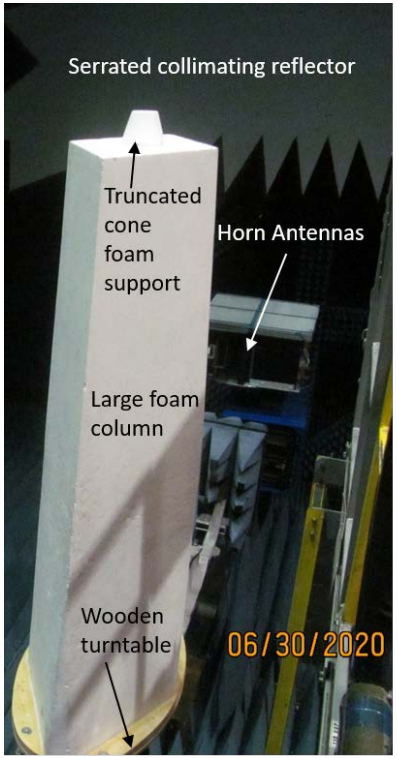
Monostatic RCS Measurement

- Measurement Setup
  - LMA Rye Canyon Anechoic Chamber
  - Dual Calibration Technique
    - 18” and 15” NIST squat cylinders
- Data Collection
  - Background measurements taken frequently
    - Included small foam mounts
  - Data collected from $\phi \in [10°, 370°]$ azimuthal range
  - Rotation rate of $0.28°/s$ for a total of $\approx$ 23 minutes per polarization per target
  - Radar sampling rate of 0.5° in azimuth



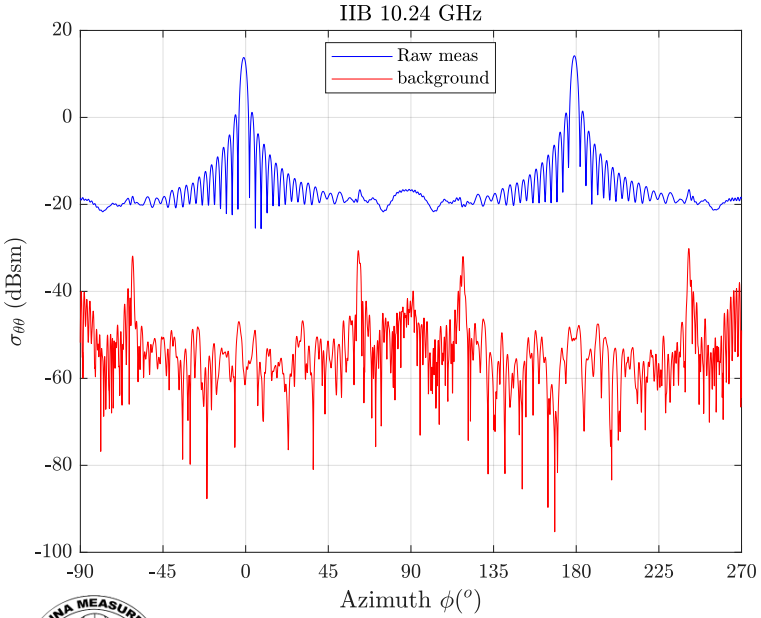


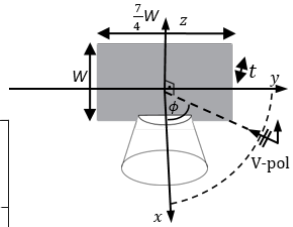


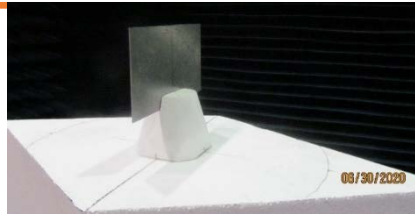


Measurement Post-Processing

- Measurement Post-Processing
  - Cubic spline interpolation to resample measurement data at increments of 0.1°







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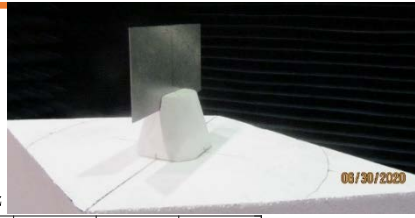
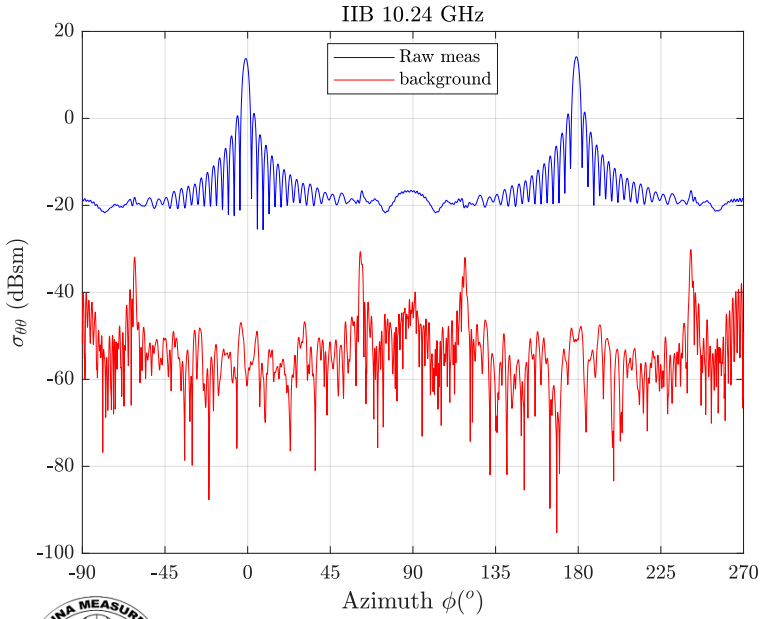
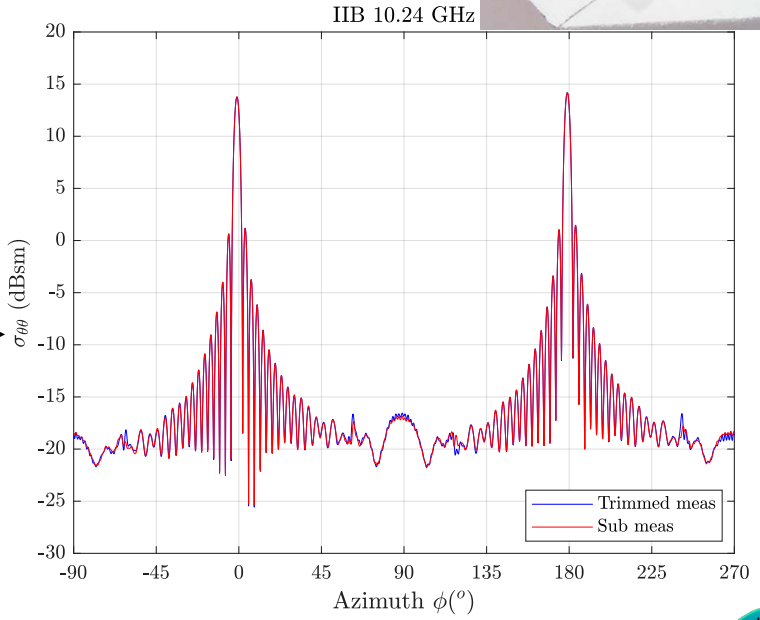
  - Background subtraction





Background Subtraction



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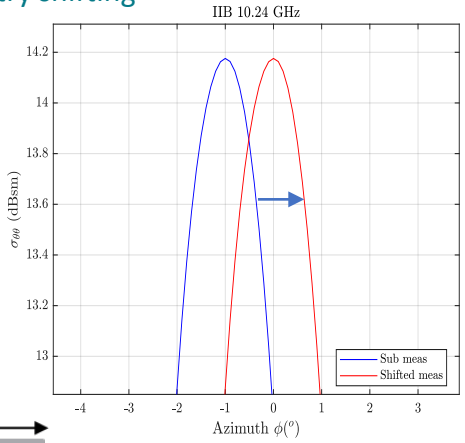
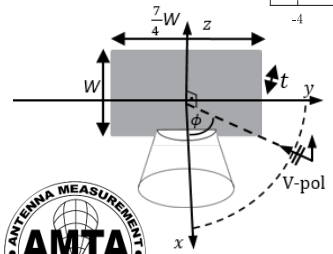
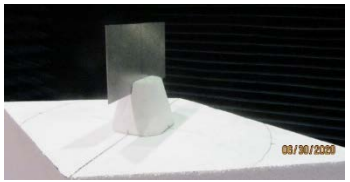
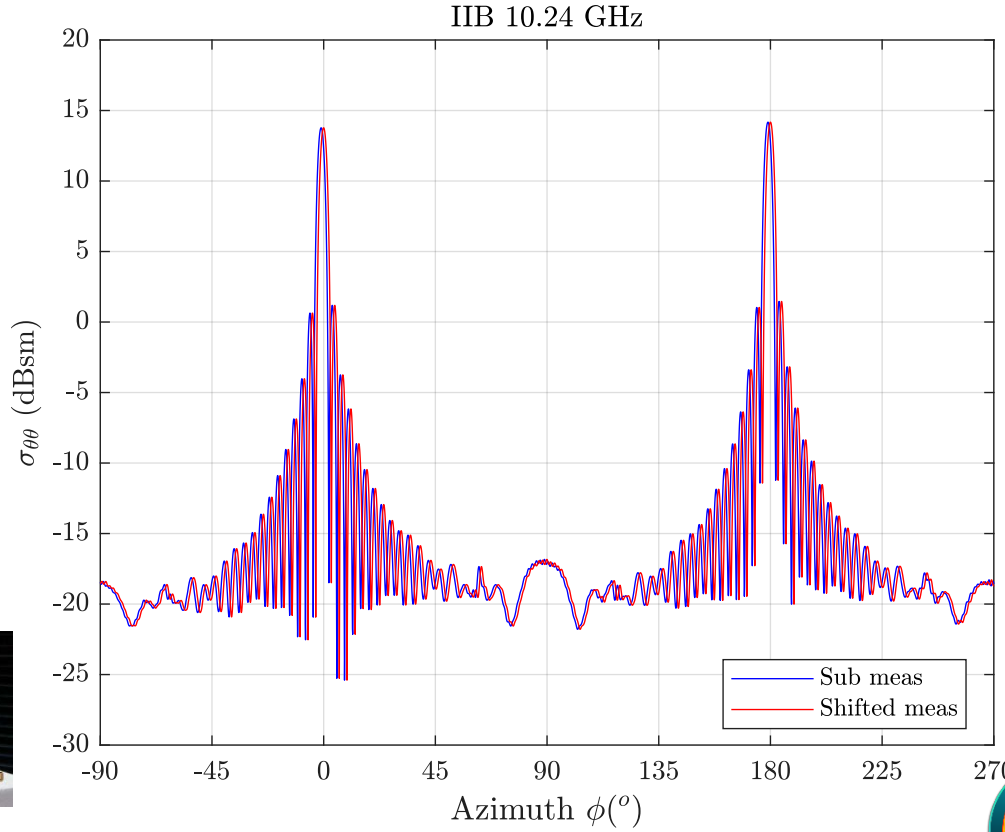
  - Background subtraction
  - Symmetry shifting









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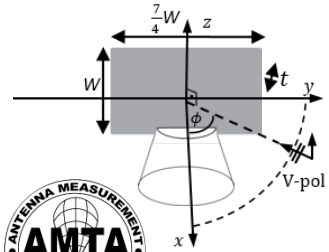
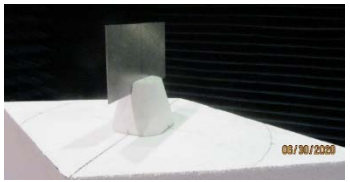
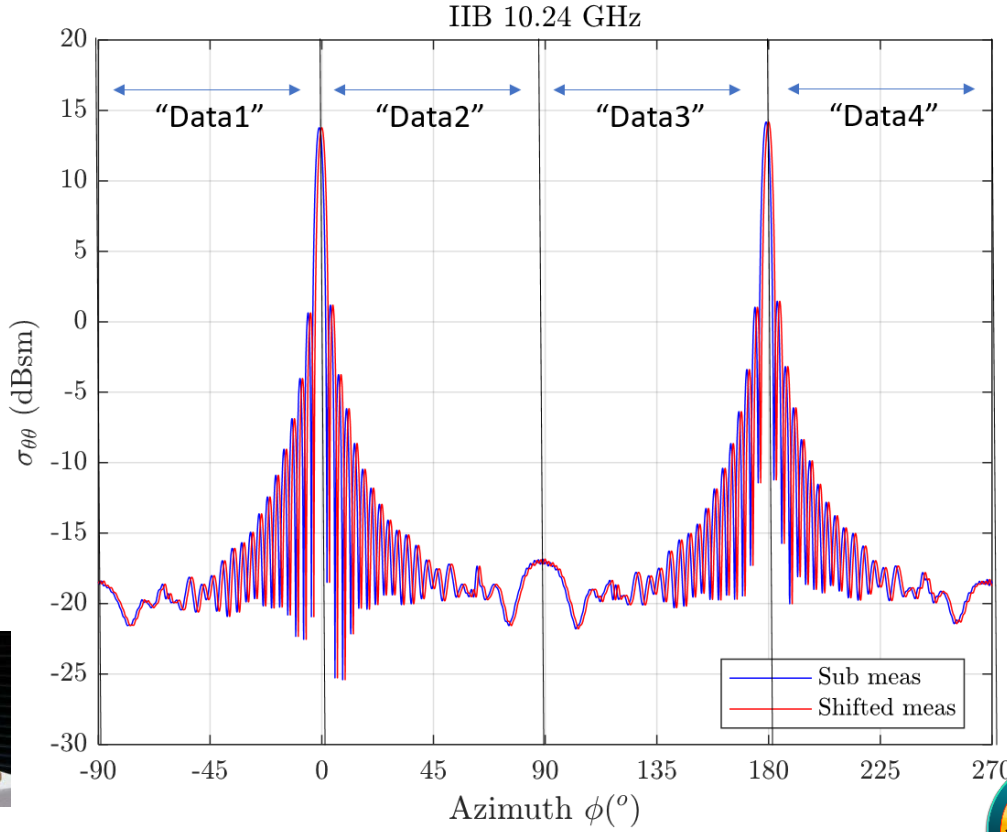
  - Background subtraction
  - Symmetry shifting
  - Data averaging







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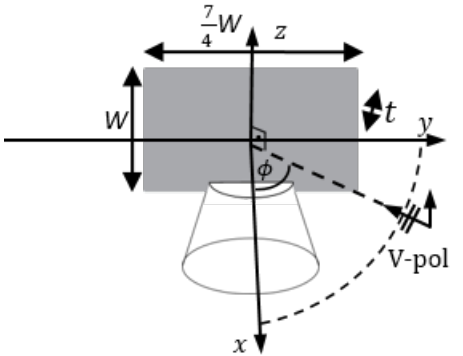
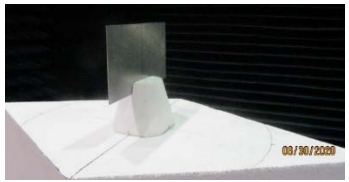
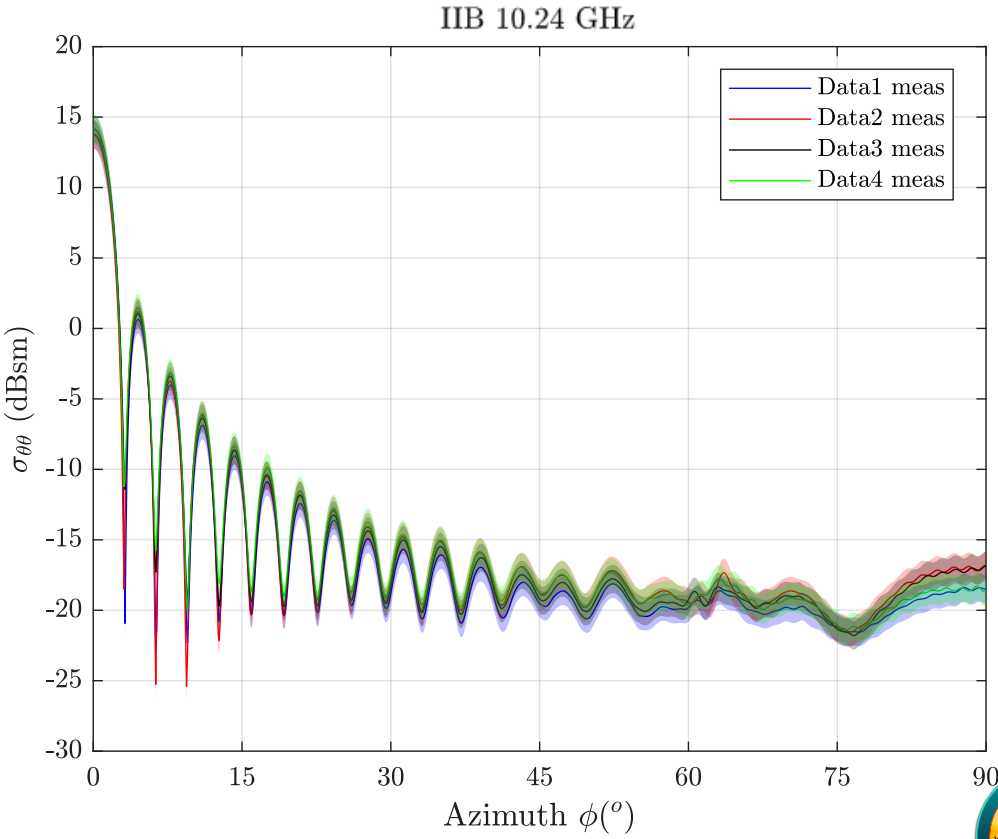
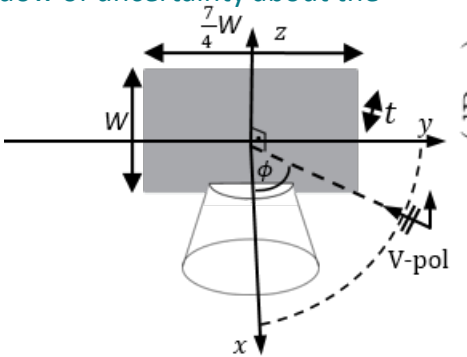


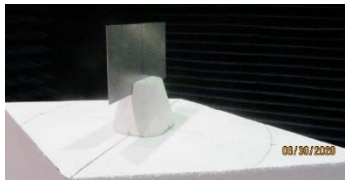


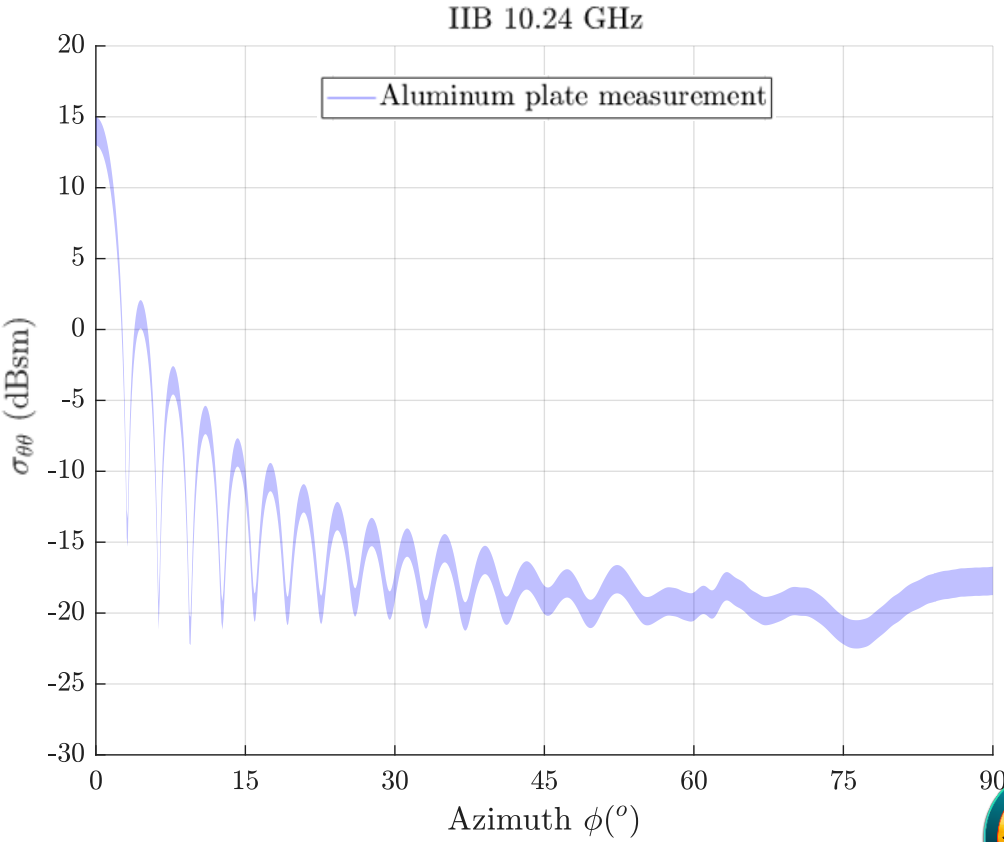


Measurement Post-Processing

- Measurement Post-Processing
  - Cubic spline interpolation to resample measurement data at increments of 0.1°
  - Background subtraction
  - Symmetry shifting
  - Data averaging
  - ± 1 dB window of uncertainty about the average

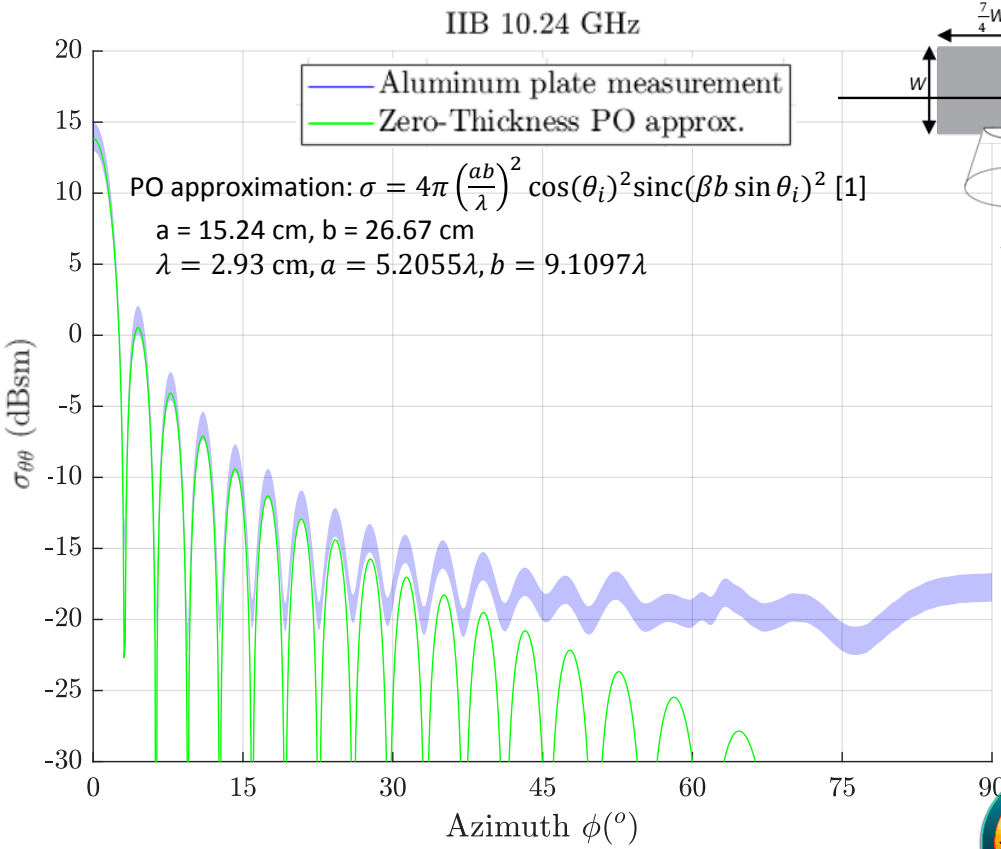




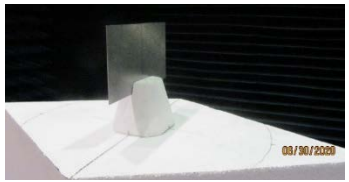


RCS Predictions/Simulations

- Prediction method comparison and measurement validation
  - Physical Optics (PO) Approximation: Computationally "free", but not very accurate



Reference: [1] Balanis, C., 1989. *Advanced Engineering Electromagnetics*. New York [etc.]: J. Wiley & sons.



RCS Predictions/Simulations

- Prediction method comparison and measurement validation
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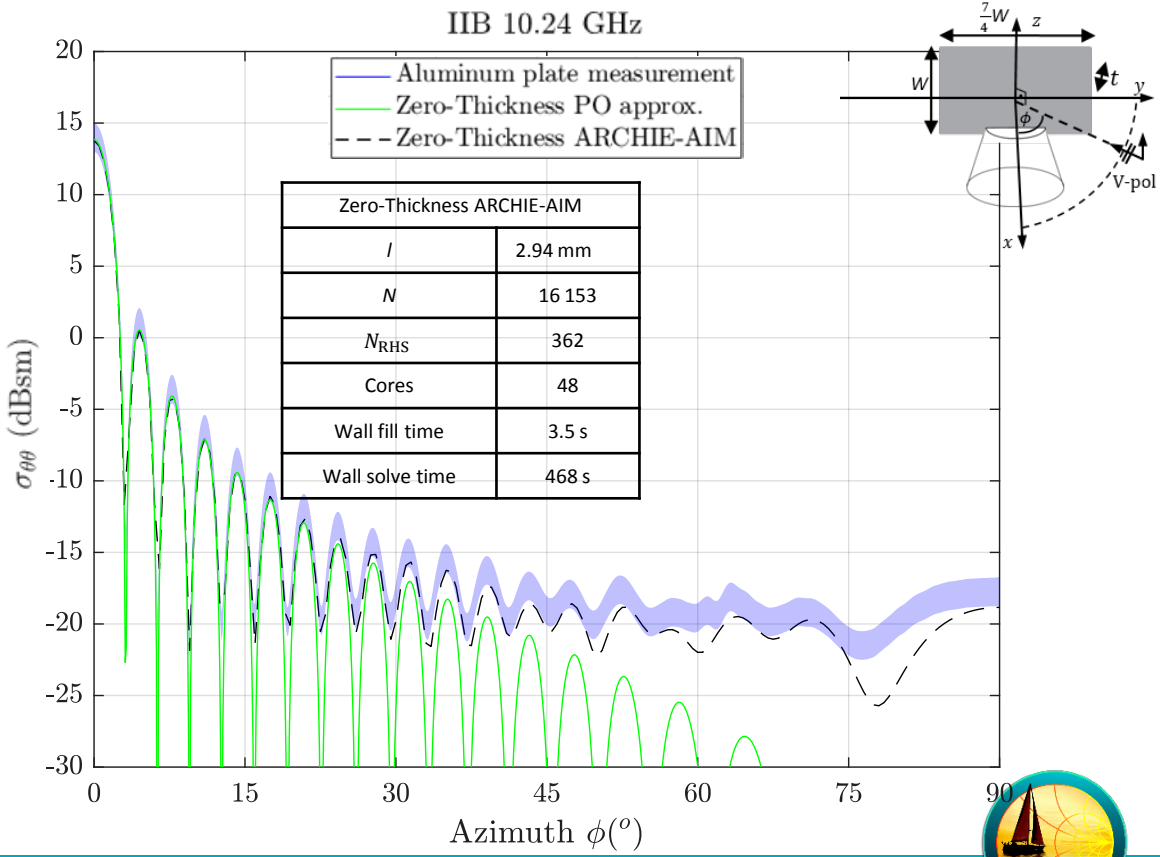
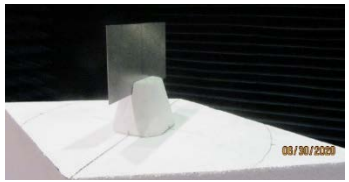
  - Modeling thin (64 mil thick) PEC plate as a zero-thickness PEC plate increases accuracy over PO



Zero-Thickness ARCHIE-AIM	
l	2.94 mm
N	16 153
N_{RHS}	362
Cores	48
Wall fill time	3.5 s
Wall solve time	468 s

Reference: [1] Balanis, C., 1989. *Advanced Engineering Electromagnetics*. New York [etc.]: J. Wiley & sons.



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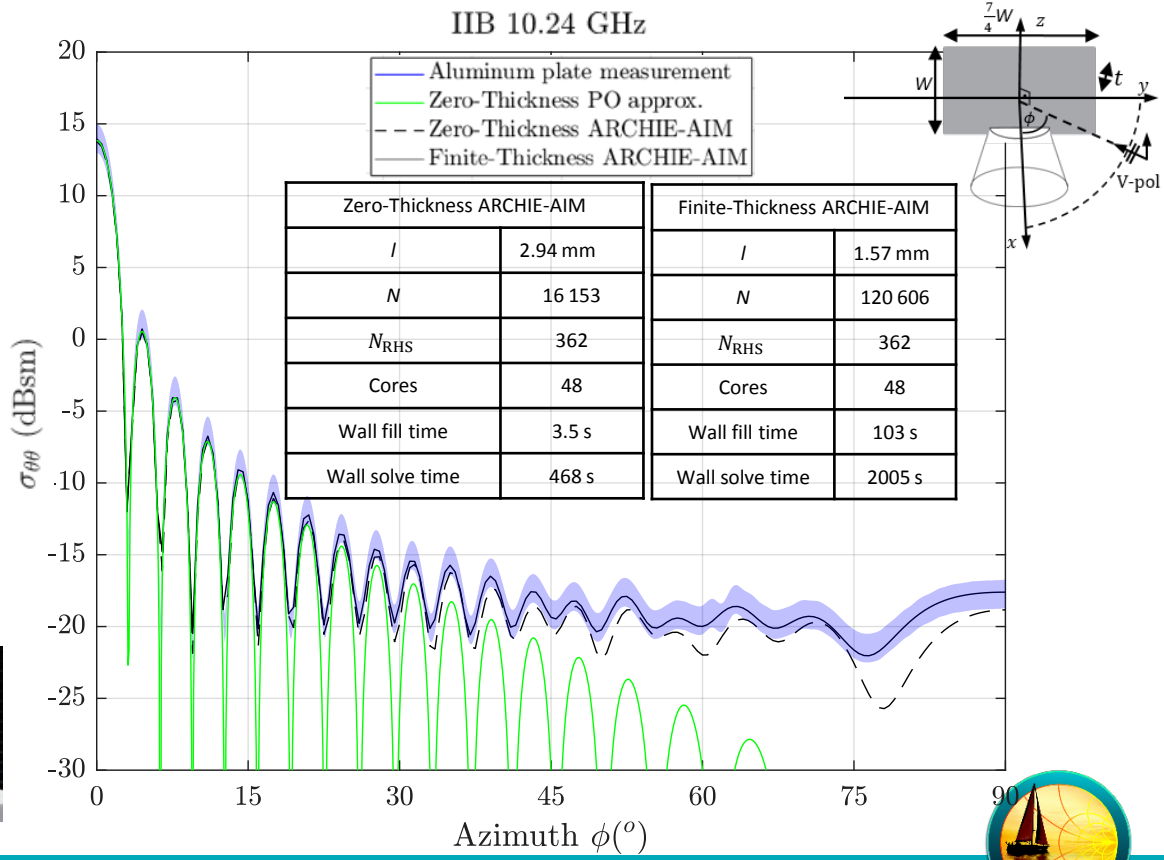
  - Modeling thin (64 mil thick) PEC plate with actual thickness yields highly accurate RCS results



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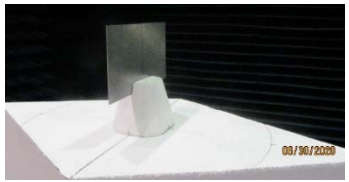
N_{RHS}	362
Cores	48
Wall fill time	3.5 s
Wall solve time	468 s

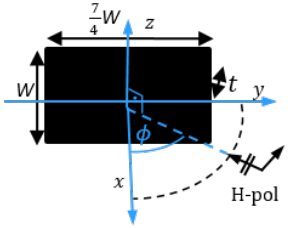
Finite-Thickness ARCHIE-AIM	
l	1.57 mm
N	120 606
N_{RHS}	362
Cores	48
Wall fill time	103 s
Wall solve time	2005 s

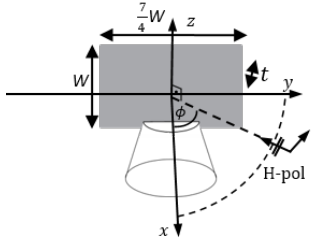
Reference: [1] Balanis, C., 1989. *Advanced Engineering Electromagnetics*. New York [etc.]: J. Wiley & sons.

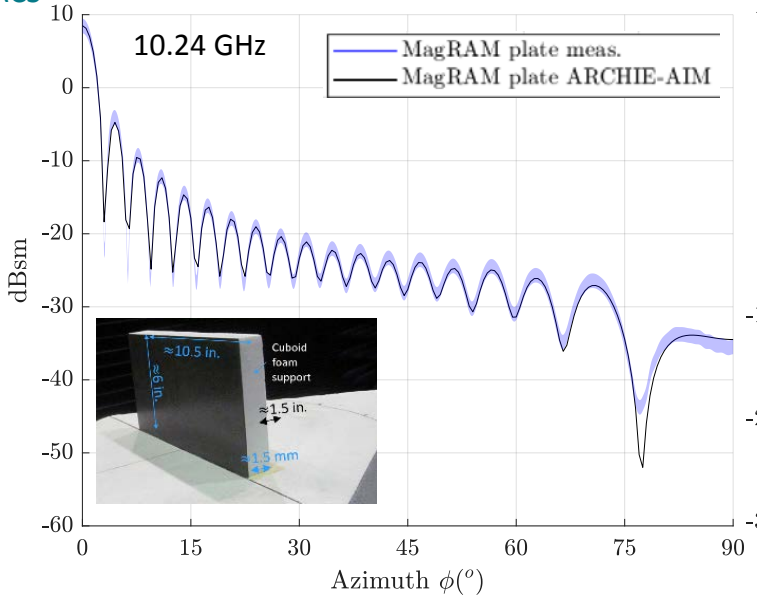


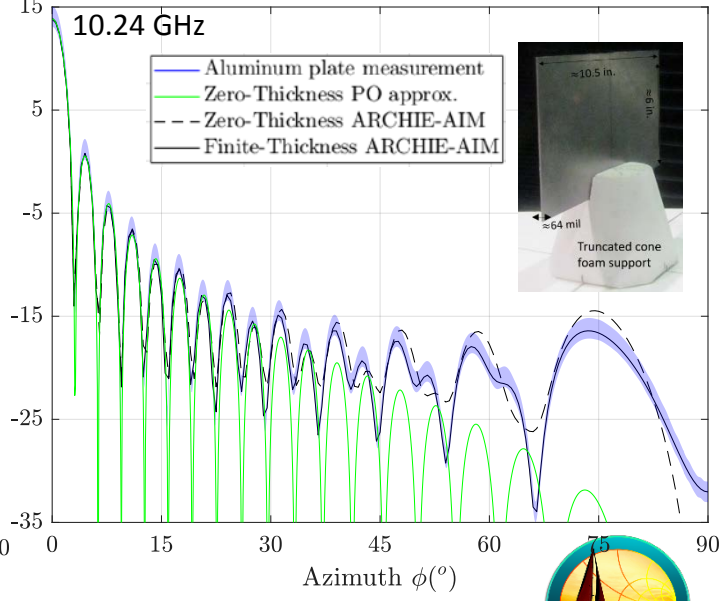
RCS Predictions/Simulations

- Prediction method comparison and measurement validation
  - Finite thickness modeling for aluminum and MagRAM plate targets yields accurate RCS results



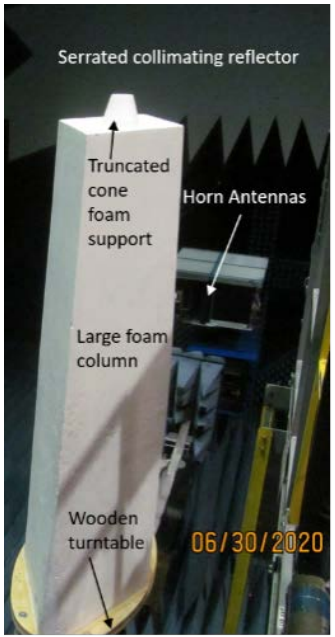


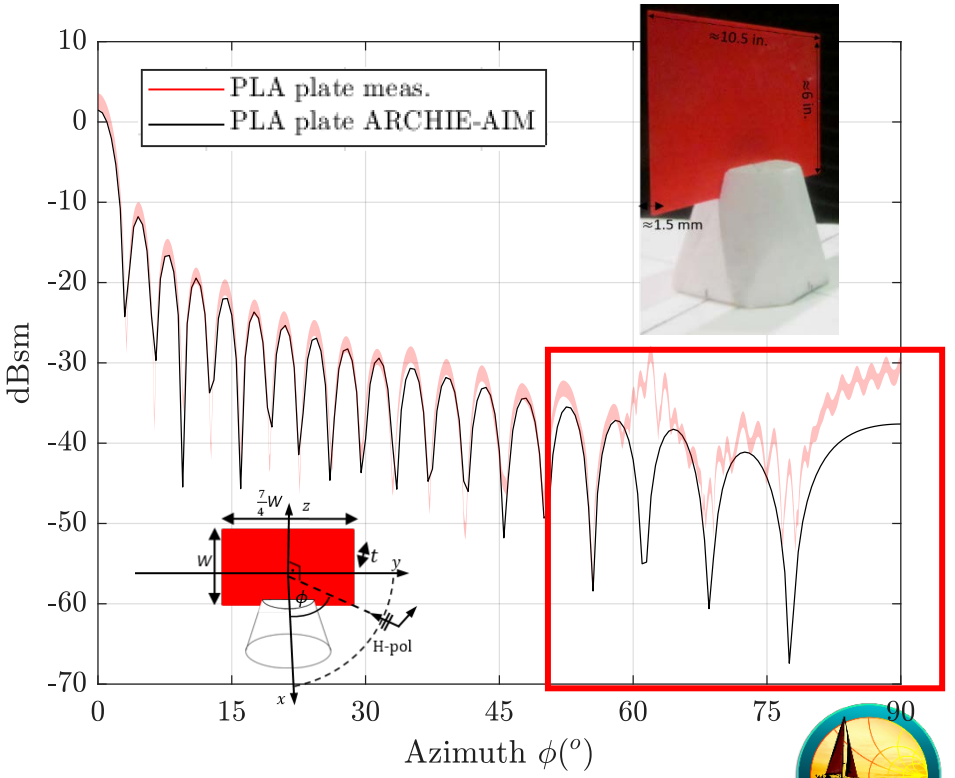




RCS Predictions/Simulations

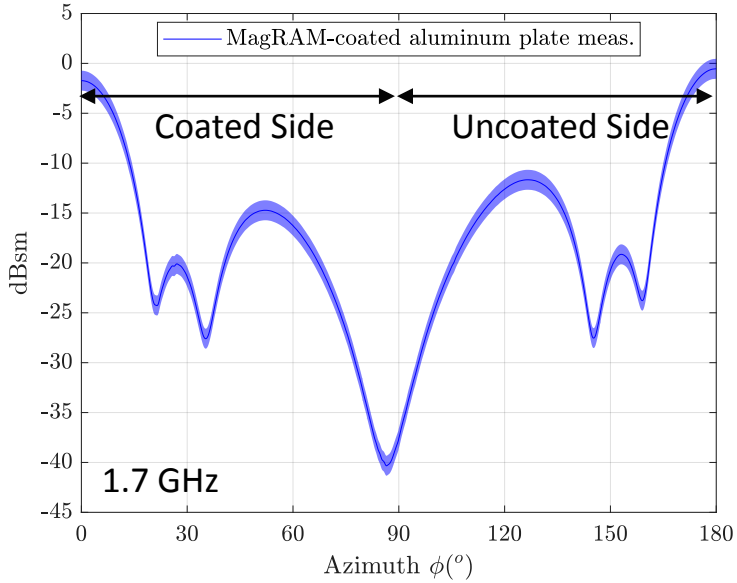
- Prediction method comparison and measurement validation
  - Finite thickness modeling for aluminum and MagRAM plate targets yields accurate RCS results
  - Background interference produces less accurate RCS measurements for PLA plate target

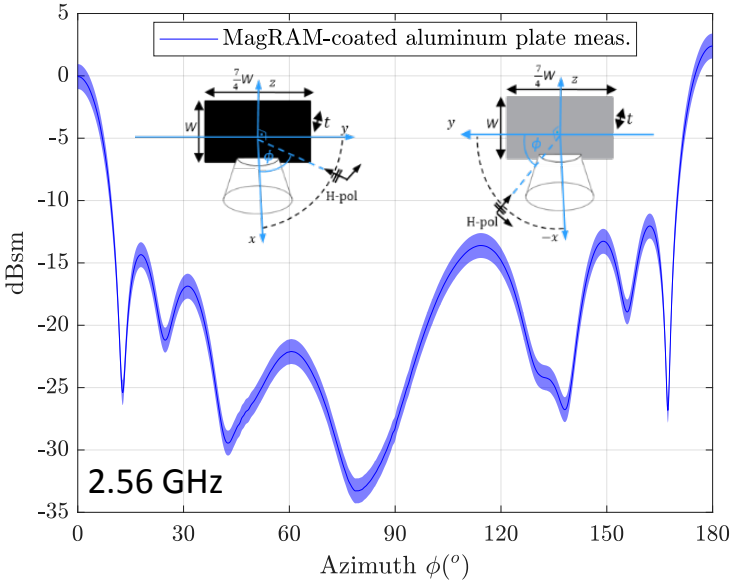




RCS Predictions/Simulations

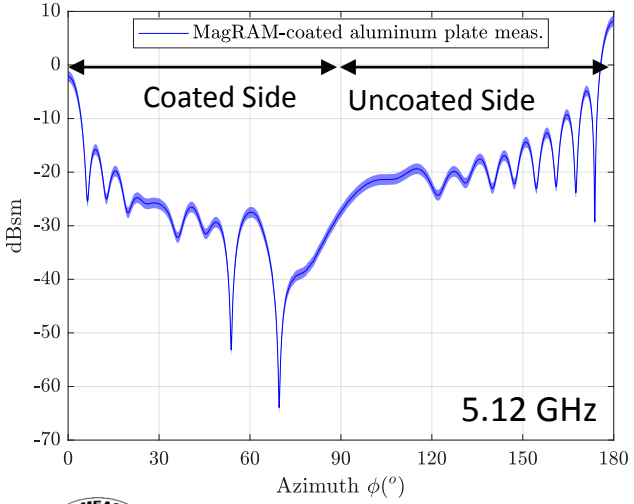
- Coated plate
  - At lower frequencies, MagRAM does not appreciably reduce RCS

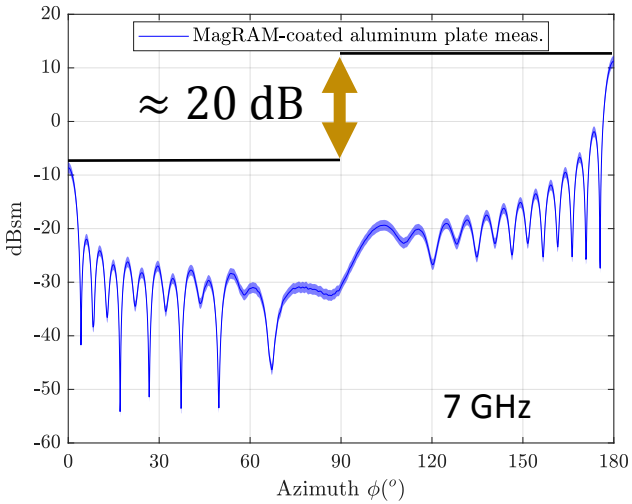


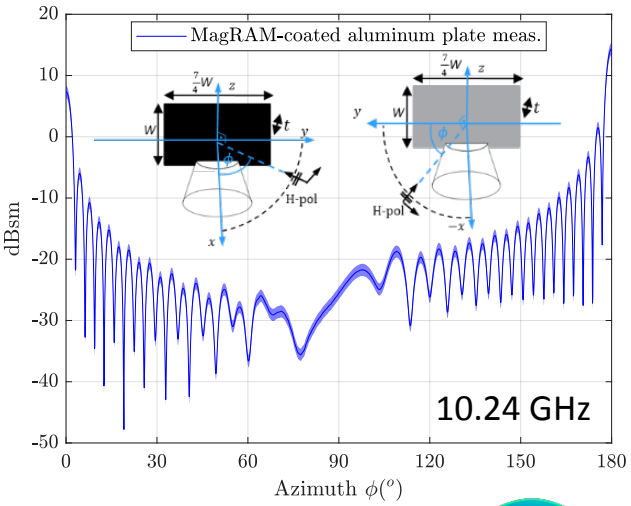


RCS Predictions/Simulations

- Coated plate
  - At lower frequencies, MagRAM does not appreciably reduce RCS
  - As frequency increases, the MagRAM begins to act as an absorber

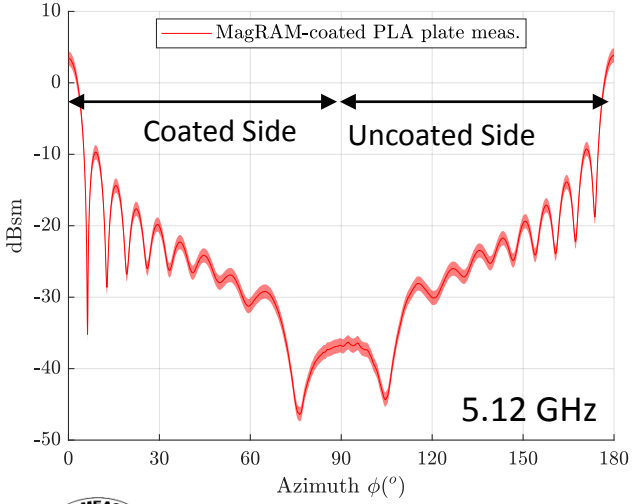


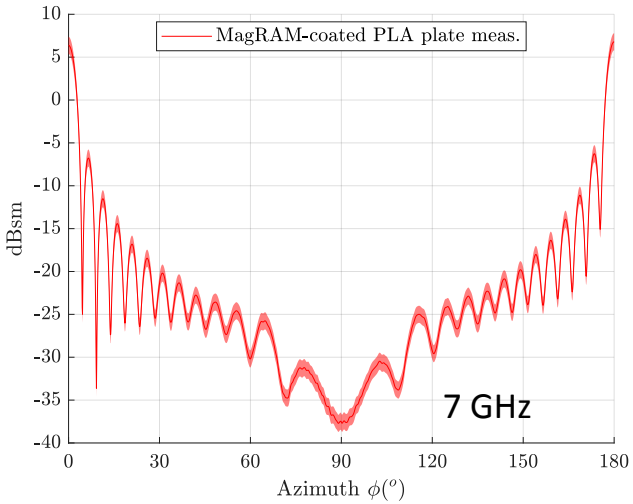


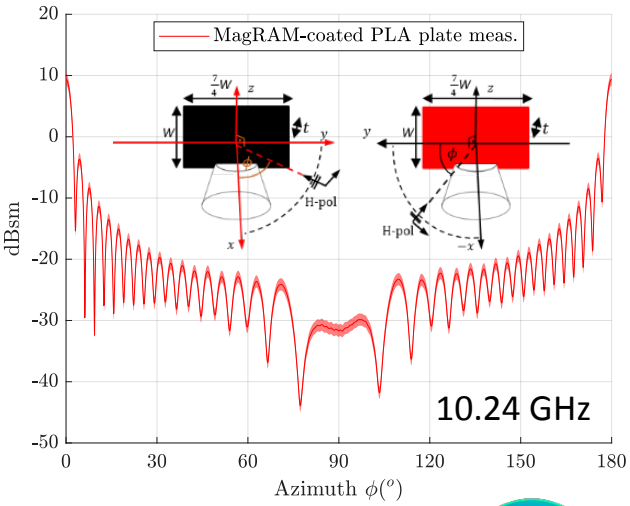


RCS Predictions/Simulations

- Coated plate
  - RCS for MagRAM-coated PLA plate is fairly symmetric for coated vs. uncoated sides

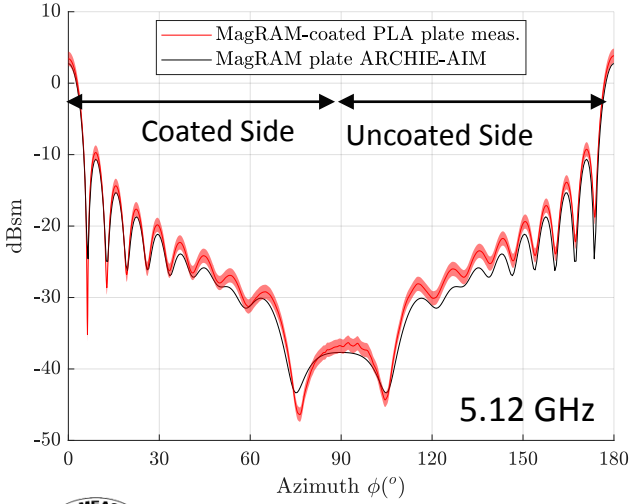


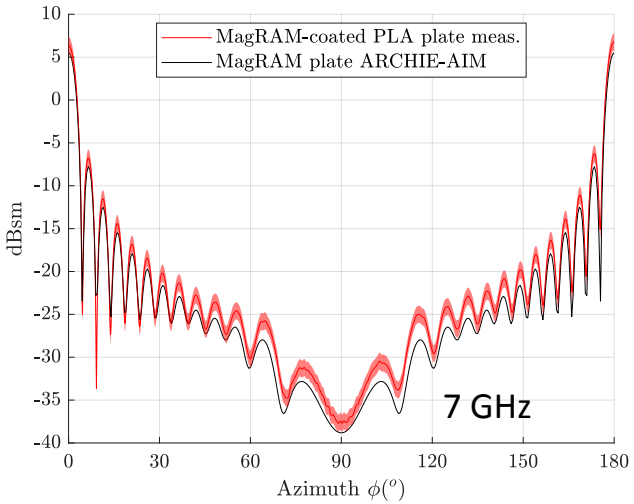


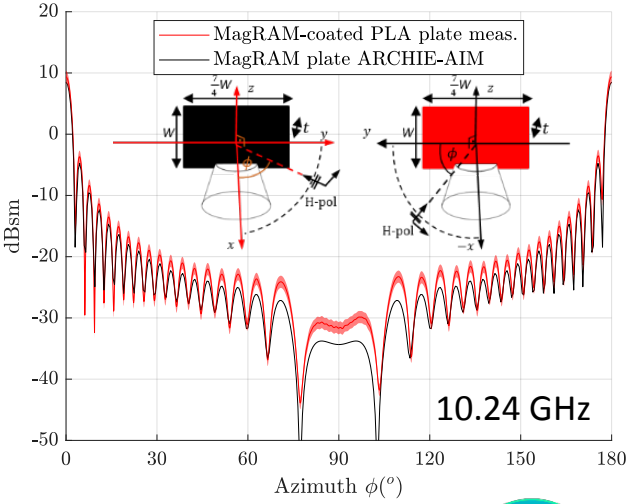


RCS Predictions/Simulations

- Coated plate
  - RCS for MagRAM-coated PLA plate is fairly symmetric for coated vs. uncoated sides
  - PLA supports may not significantly impact RCS measurements of targets with sufficiently high return

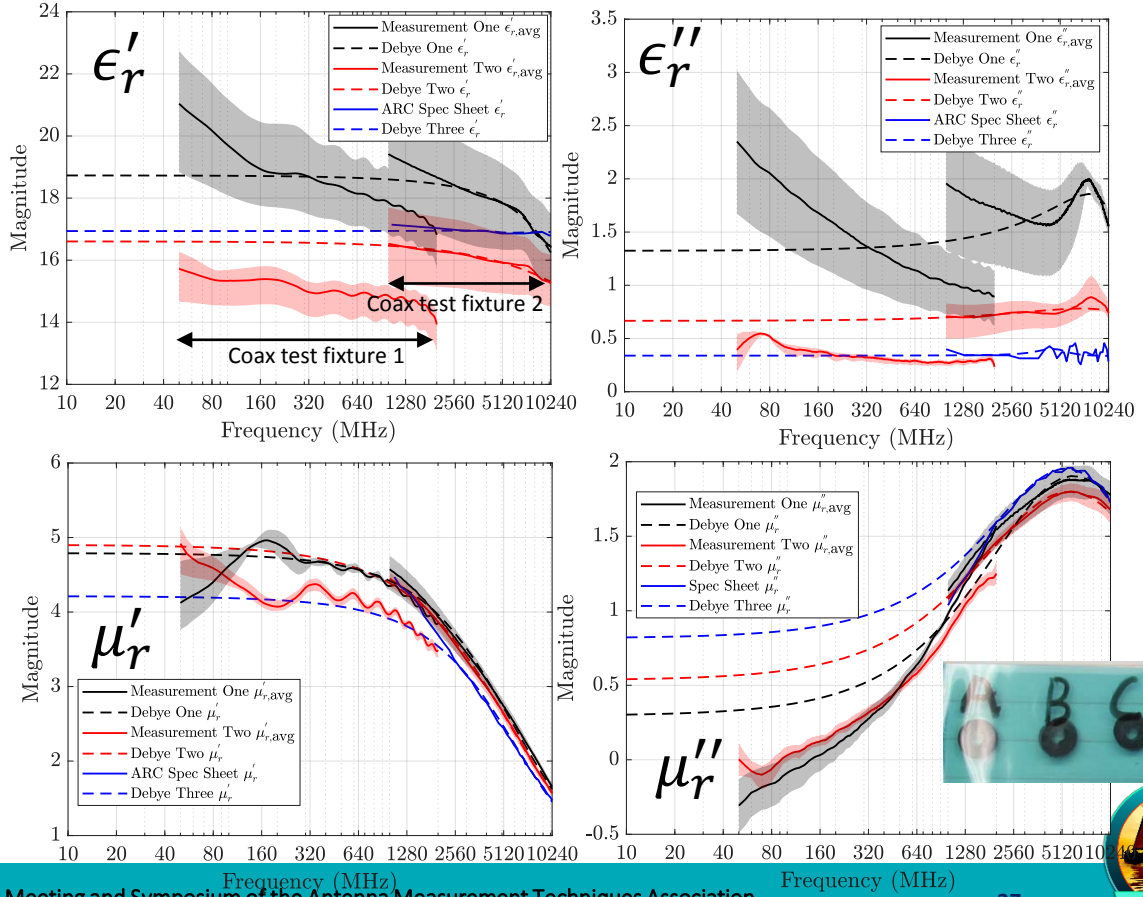






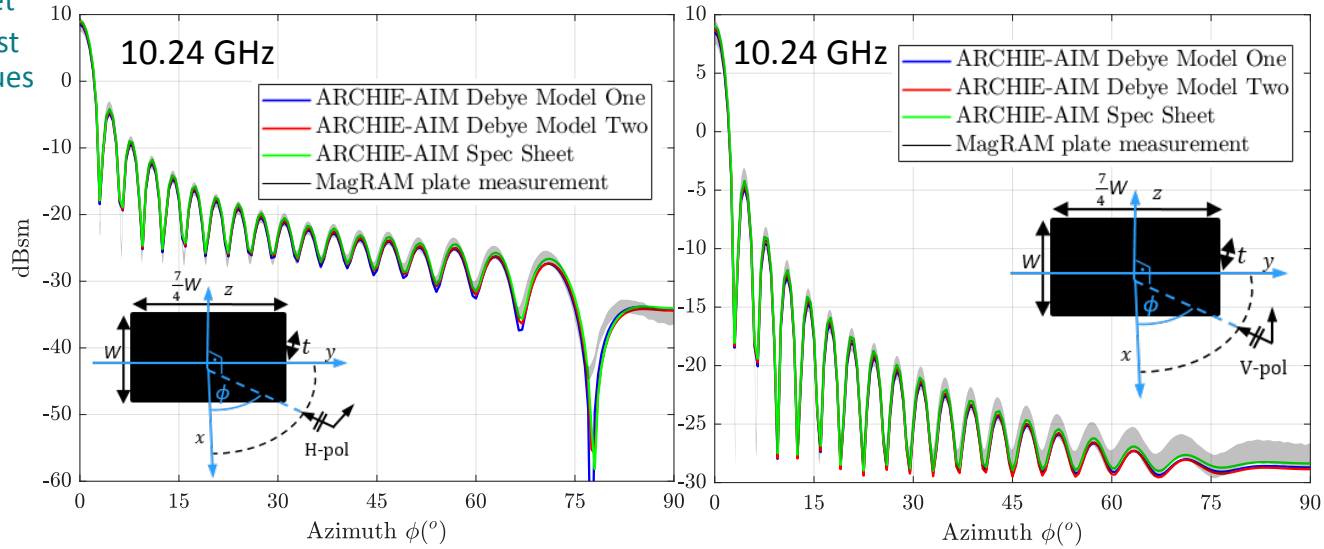
RCS Predictions/Simulations

- Material uncertainty quantification
  - Significant disagreement in MagRAM's material properties (especially permittivity) between measurements and ARC spec sheet



RCS Predictions/Simulations

- Material uncertainty quantification
  - Significant disagreement in MagRAM's material properties (especially permittivity) between measurements and ARC spec sheet
  - However, at frequencies of interest simulations different material values yield quite similar RCS



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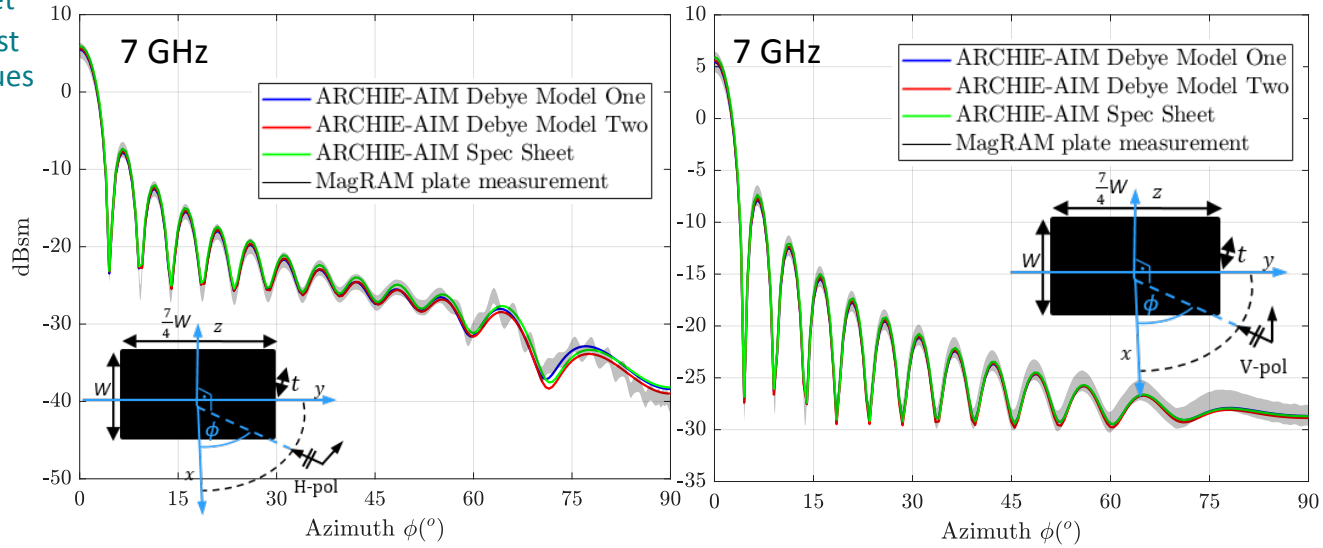

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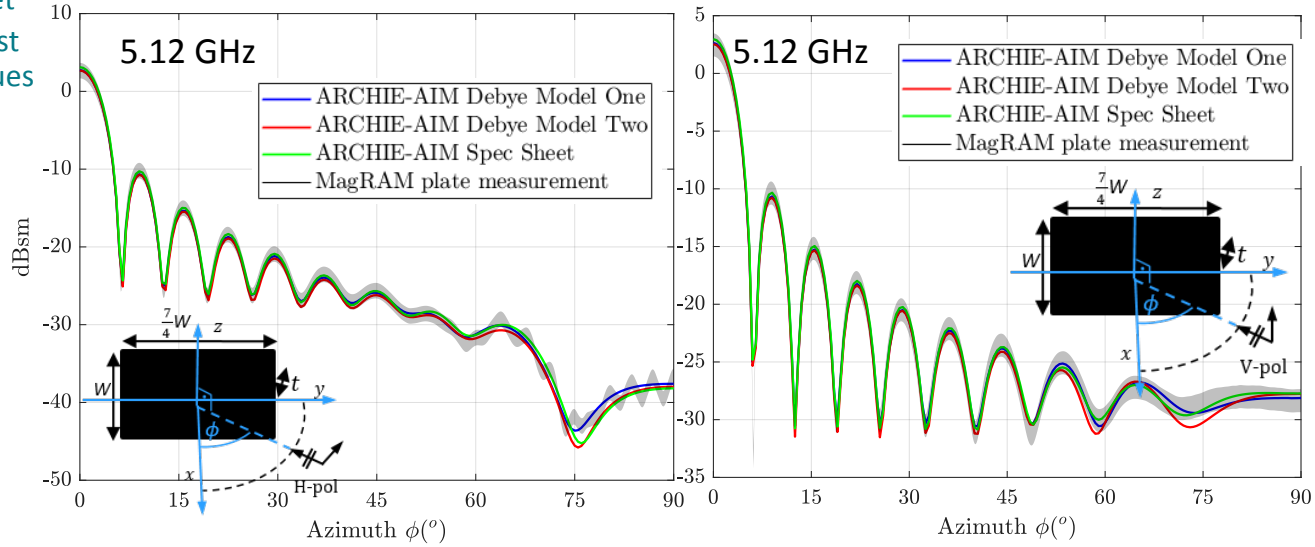
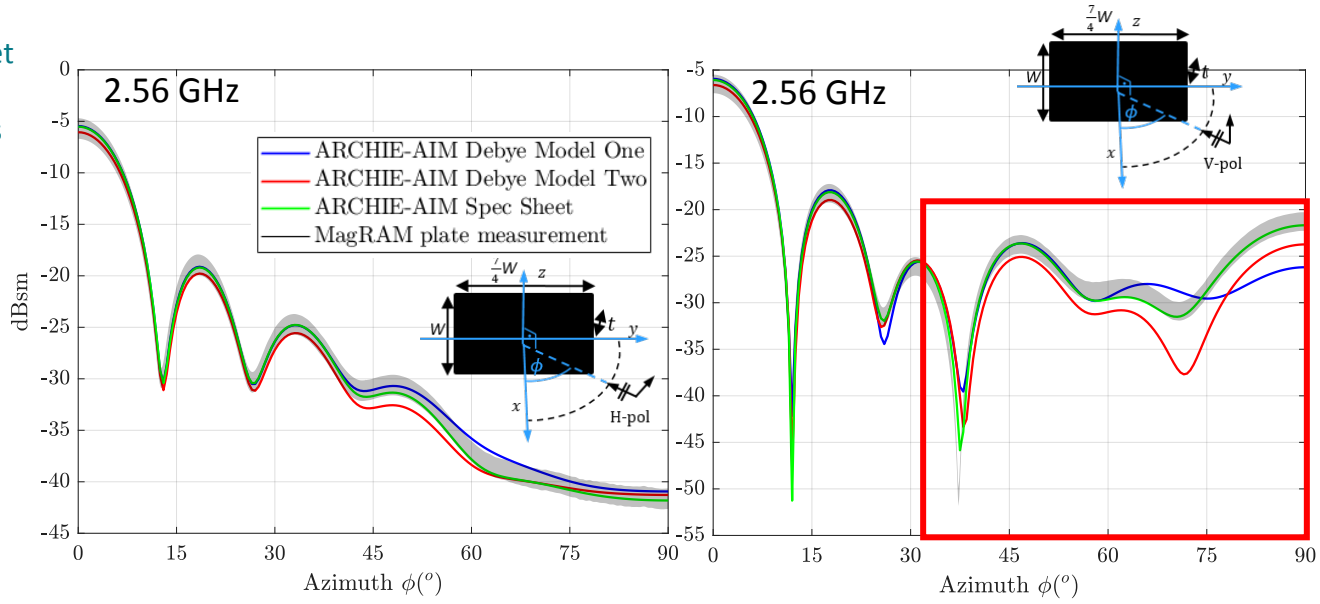


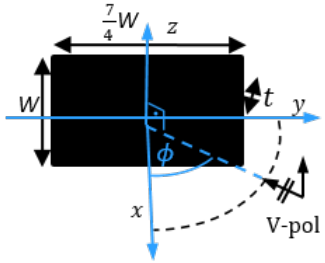
RCS Predictions/Simulations

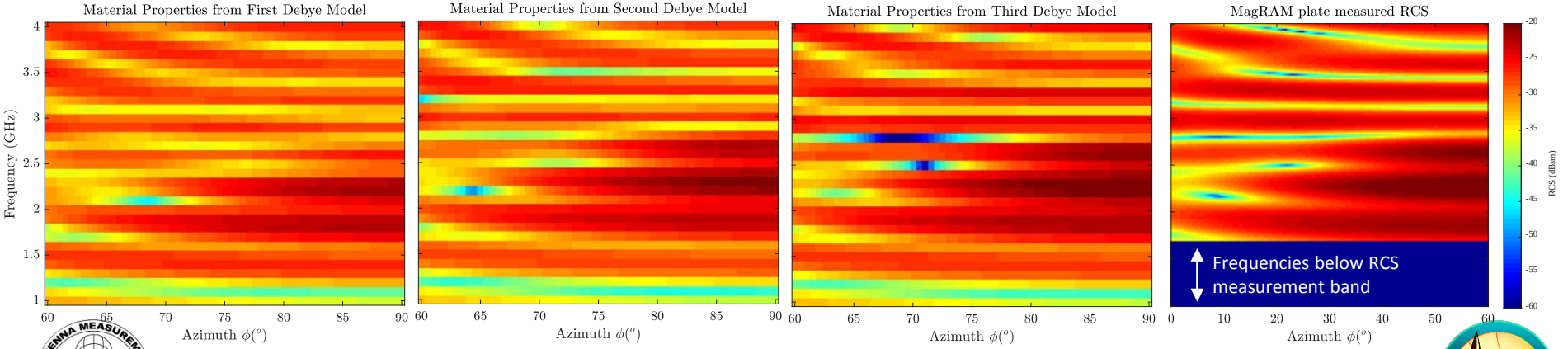
- Material uncertainty quantification
  - Significant disagreement in MagRAM's material properties (especially permittivity) between measurements and ARC spec sheet
  - BUT, at 2.56 GHz for V-pol we see notable difference in RCS patterns



RCS Predictions/Simulations

- Material uncertainty quantification
  - Significant disagreement in MagRAM's material properties (especially permittivity) between measurements and ARC spec sheet
  - BUT, at 2.56 GHz for V-pol we see notable difference in RCS patterns
  - Sweeping through the frequency band, V-pol is much more sensitive than H-pol





RCS Predictions/Simulations

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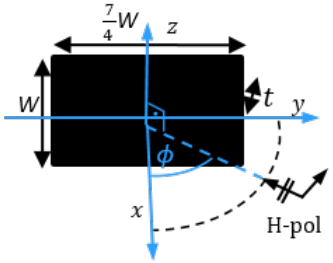
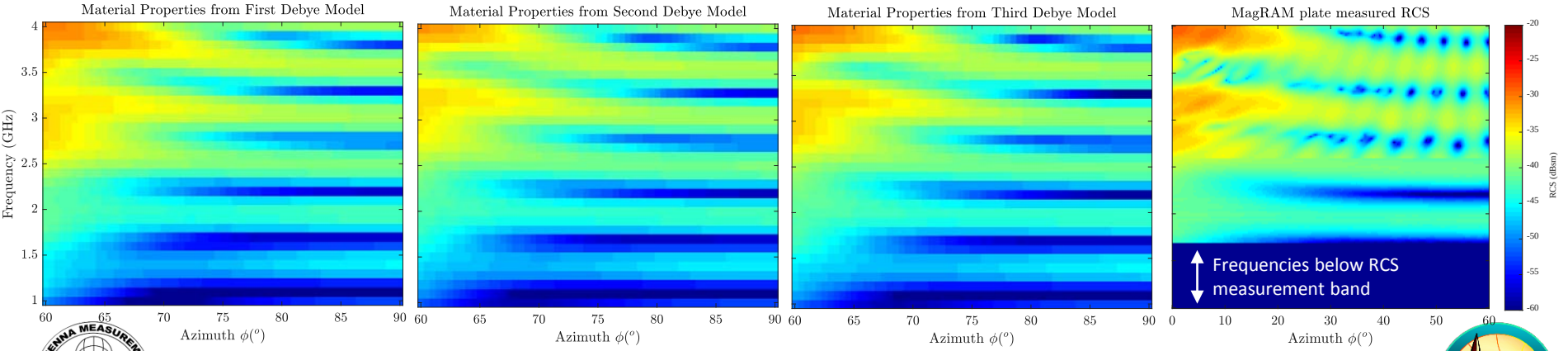
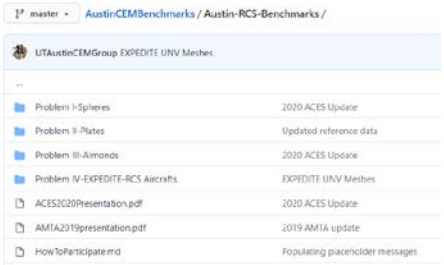
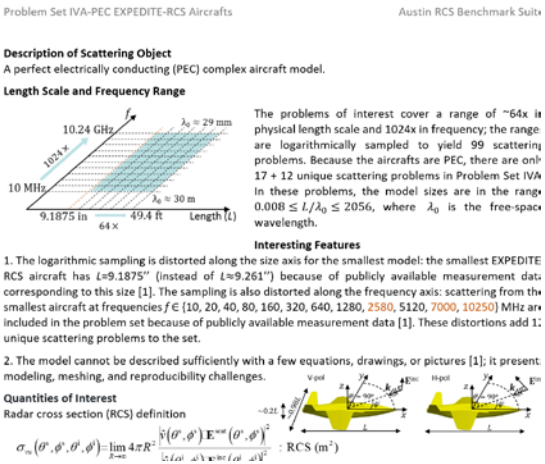


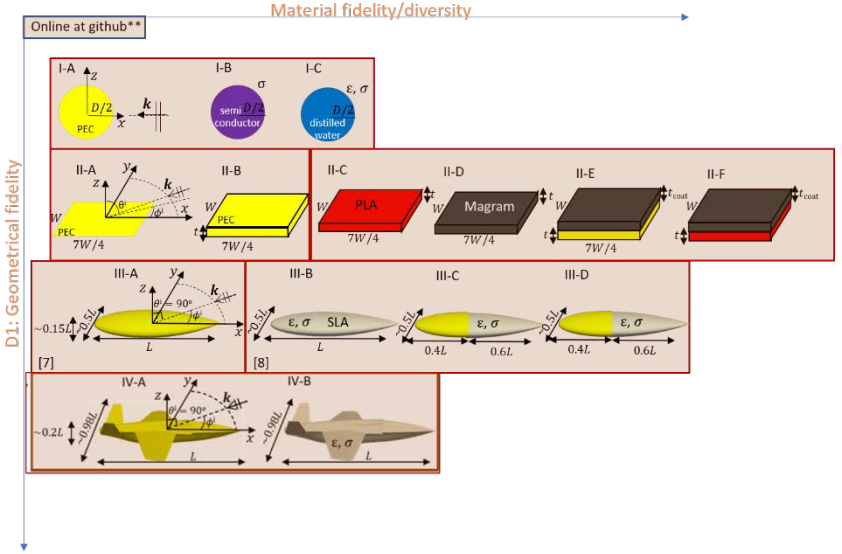


Public Release

- Austin RCS Benchmark Suite
  - Features Available:
    1. Problem Descriptions
    2. Reference Data
    3. Simulation Data
    4. Models
    5. Meshes



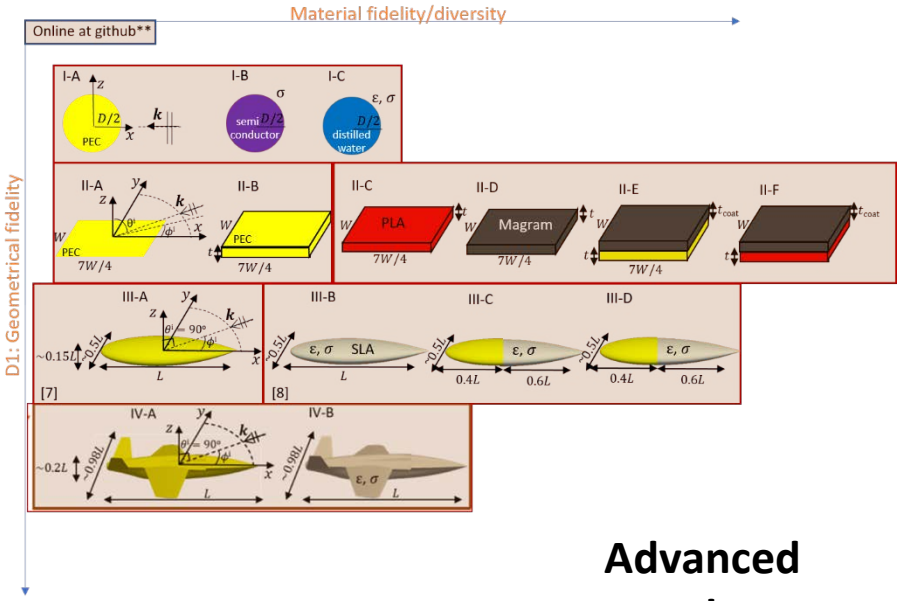




Website:
https://github.com/UTAustinCEMGroup/AustinCEMBenchmarks/tree/master/Austin-RCS-Benchmarks

Conclusion

- Plate Benchmark Problems
  - Enable validation, quantitative comparison, improve prediction methods
  - Highly accurate RCS measurements even for grazing incidence
- RCS Measurements of Complex Targets
  - 3D printed PLA supports may be used to help ensure reproducible measurements
- Material Uncertainty
  - RCS may be highly sensitive to small perturbations in material properties only for a narrow frequency band or for a particular polarization



Advanced Development Programs

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