RCS of Targets due to Excitation with Structured Waves

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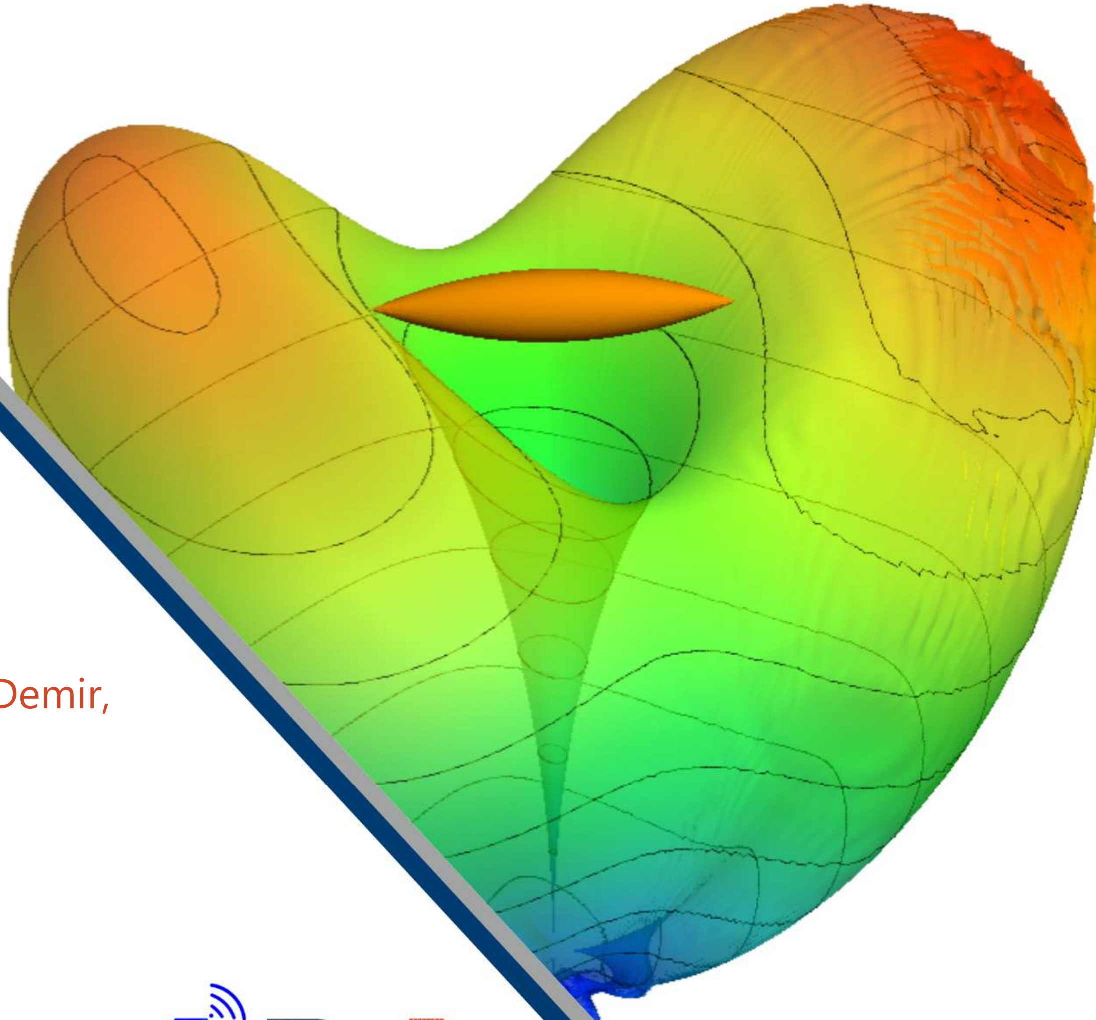

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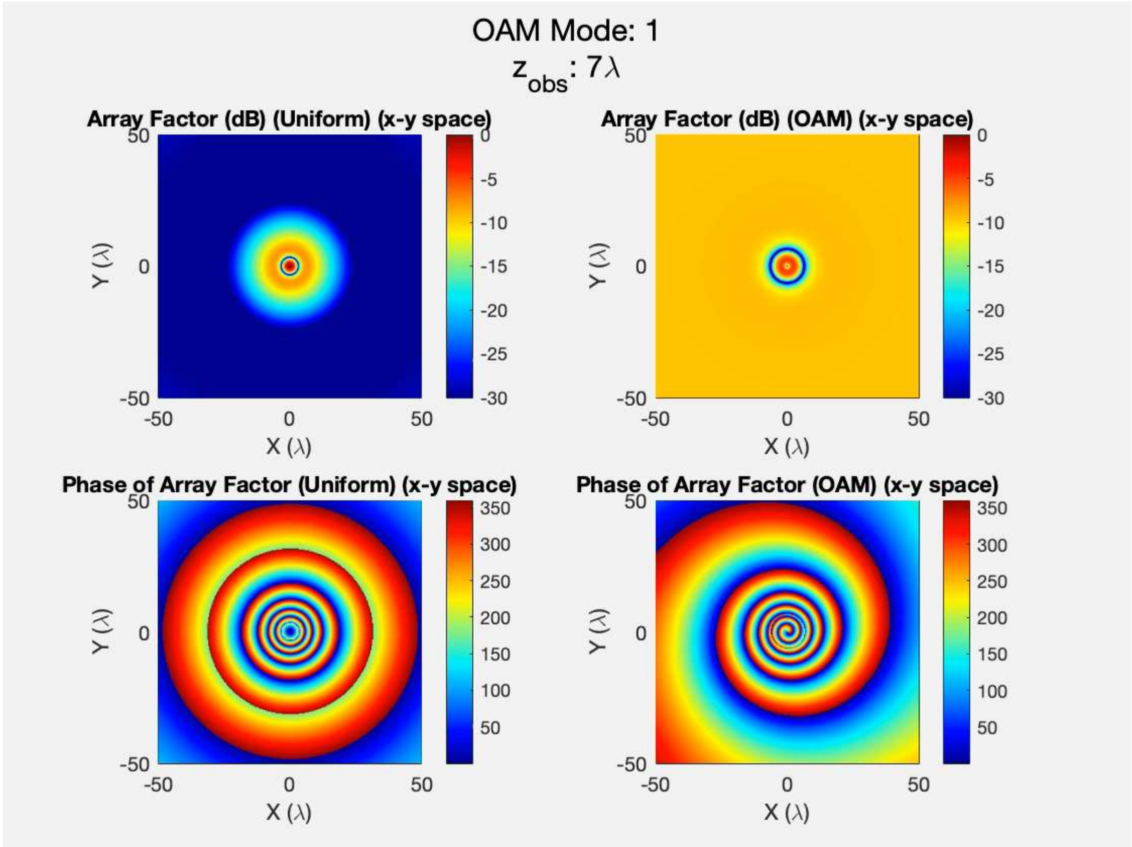
Antenna, RFID, and Computational EM Group

Motivation

- Spatially Variant Waveform (SVW) are a class of propagation modes where the fields tangential to propagation direction are not uniform
- In particular, SVW beams with orbital angular momentum have potential applications in radar as well as communications, atomic physics, and more.
- **Goal of this work:**
  - *Develop a comparison for RCS of targets due to excitation by OAM beams relative to RCS due to traditional plane wave illumination*
  - *Develop a method to compute RCS from physical sources (antenna) as well as analytical expression generating such beams such as Laguerre-Gaussian, Hermite-Gaussian, etc.*



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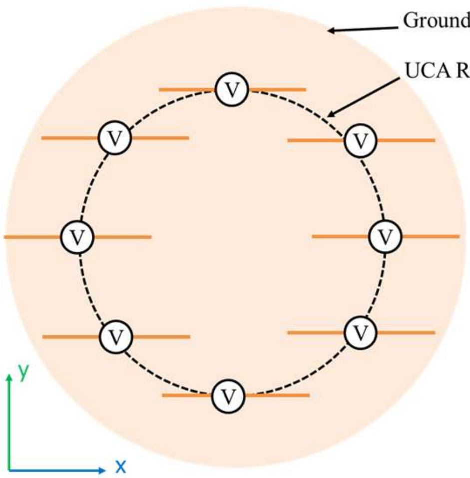
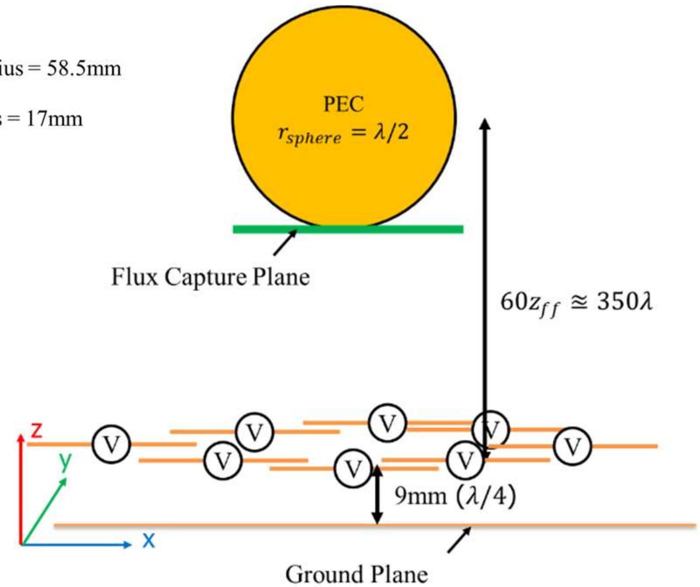
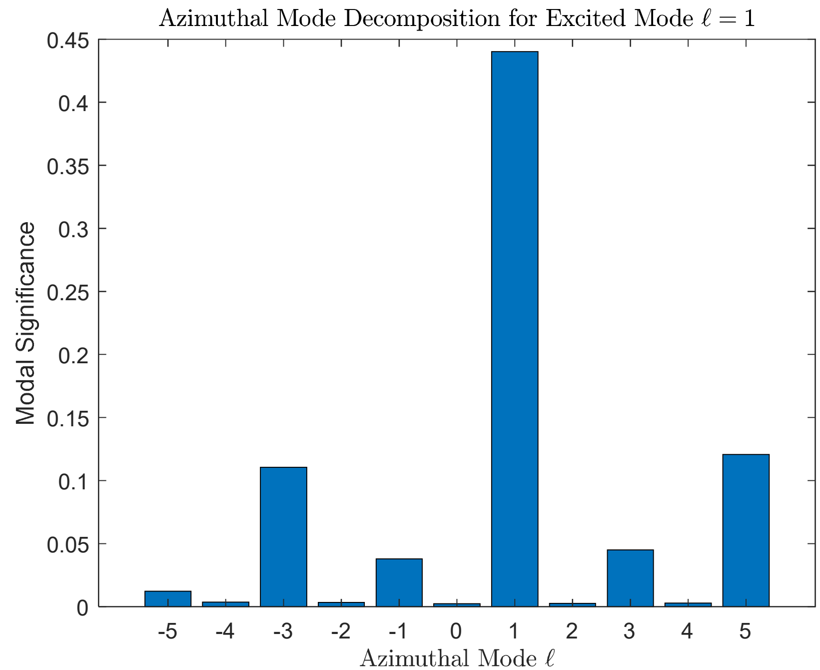
OAM Modes from a Uniform Circular Array





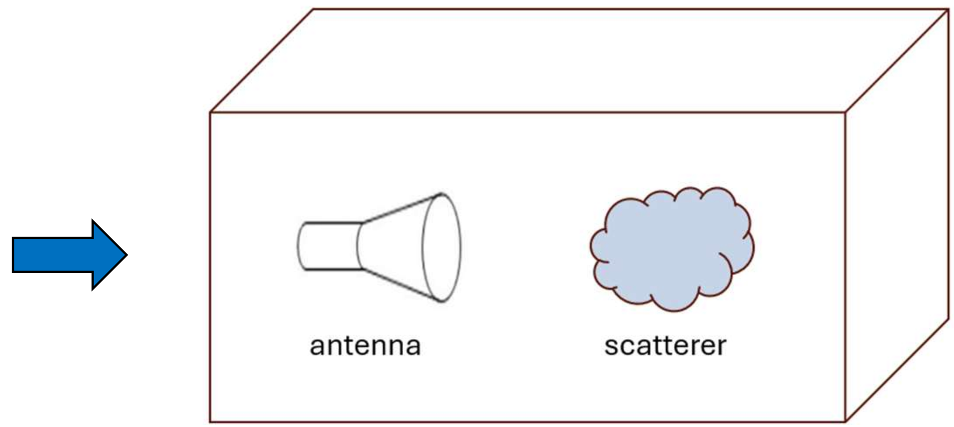


RCS of Scatterers Placed in the Vicinity of Spatially Varying Waveform

- For a problem space containing local sources (antennas) which radiate spatially varying waveforms as well as scattering objects, the resulting far field radiation is the **sum of:**
  - Radiated fields from the local antennas
  - Scattered fields from the scatterers
- We would like to calculate the scattered field from the scatterers **only** neglecting the radiation from the sources
- **Therefore, we propose a two-step simulation process**

Computational domain with local sources such as antenna arrays exciting different OAM beams

Single or multiple scatterers can be present in the same computational domain.



RCS of Scatterers Placed in Near Field of Local Sources

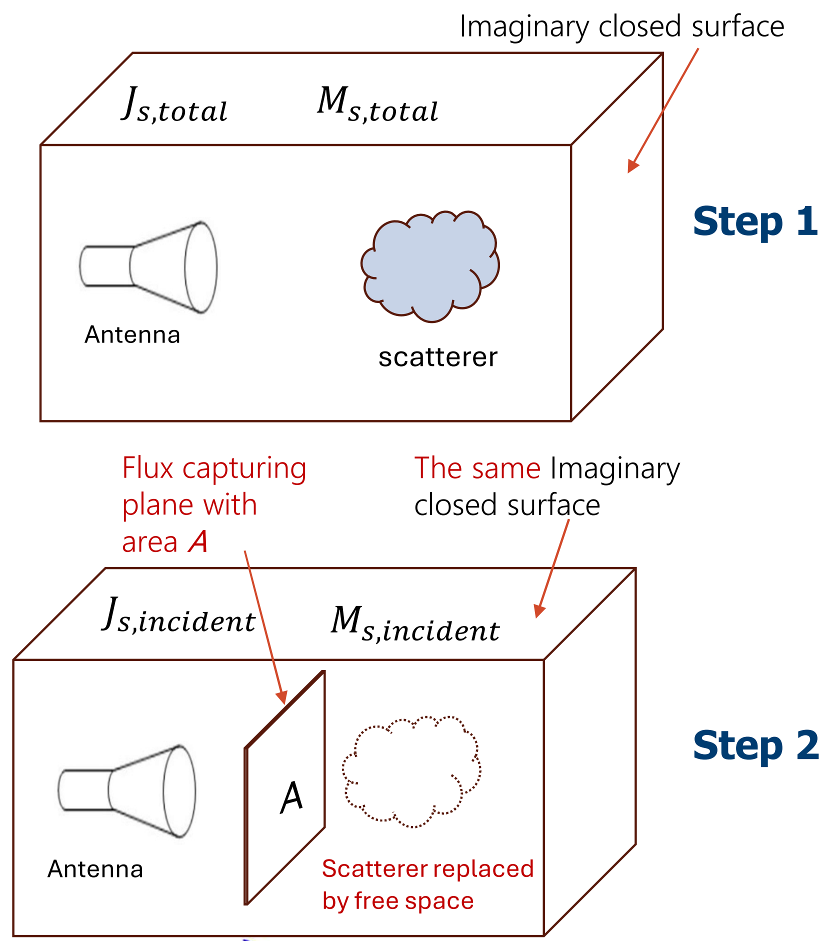
- **Step 1**
  - Simulate the problem space including the sources and the scatterers
  - Capture currents $J_{s,total}$ *and* $M_{s,total}$ on closed imaginary surface
- **Step 2**
  - Simulate the problem space with the presence of the sources only
  - Capture currents $J_{s,incident}$ and $M_{s,incident}$ on the same closed imaginary surface
- Use the currents from the two steps above to calculate the fictitious currents due to the scattered fields from the scatterers only

$$J_{s,scattered} = J_{s,total} - J_{s,incident}$$

$$M_{s,scattered} = M_{s,total} - M_{s,incident}$$

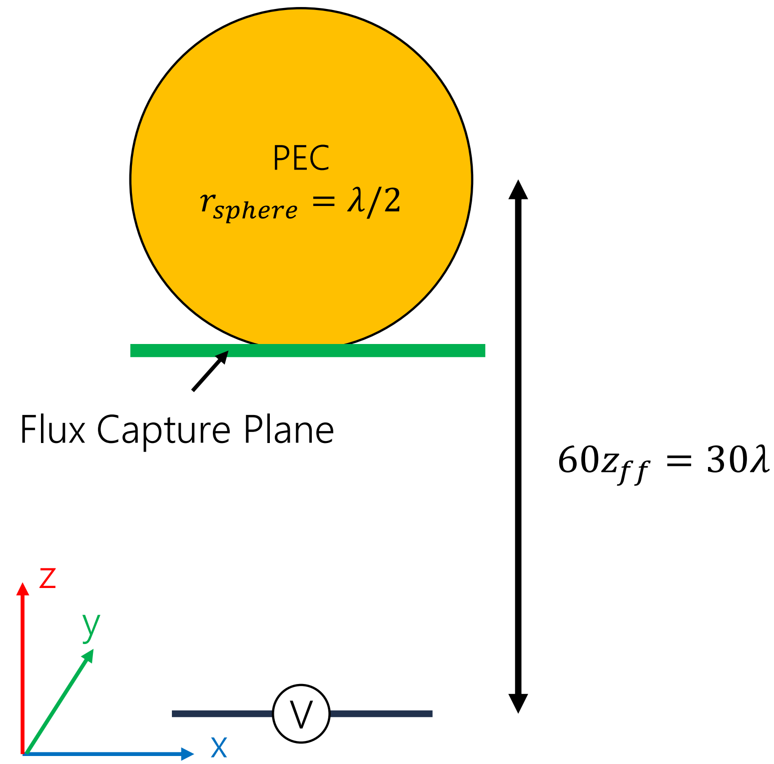
- Use these scattered currents to calculate the far scattered fields power density from the scatterers
- Capture the incident power density on the flux capturing plane
- Normalize the scattered fields to obtain the RCS.

$$RCS(\theta,\phi) = \lim_{r\to\infty}\left(4\pi A r^2 \frac{P_{scat}}{P_{inc}}\right)$$

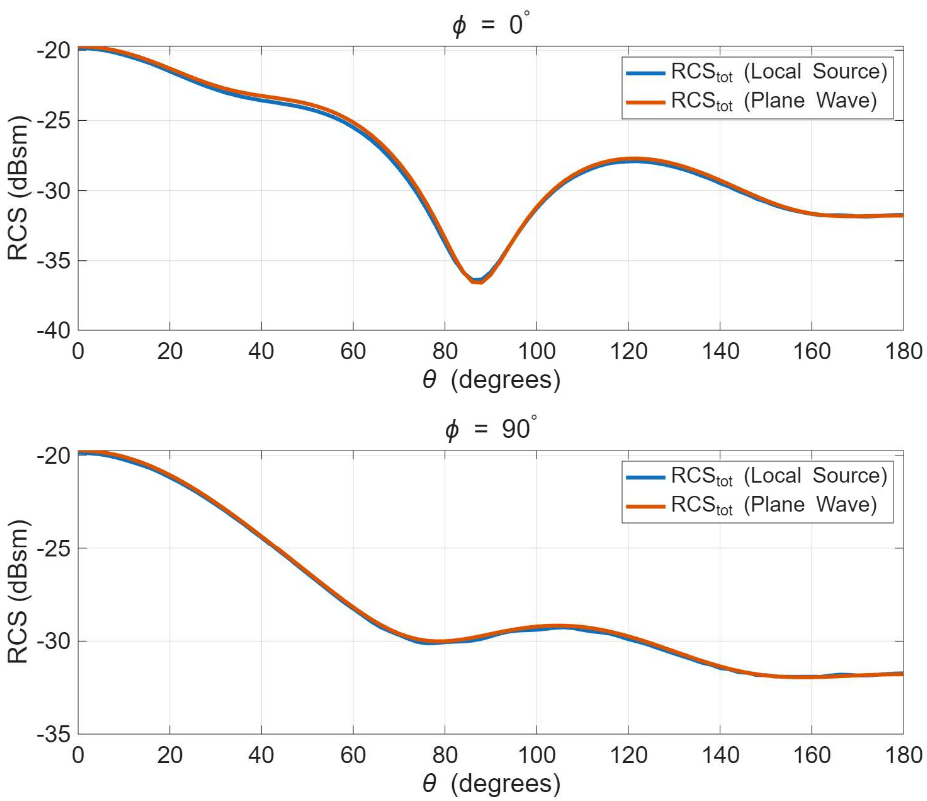


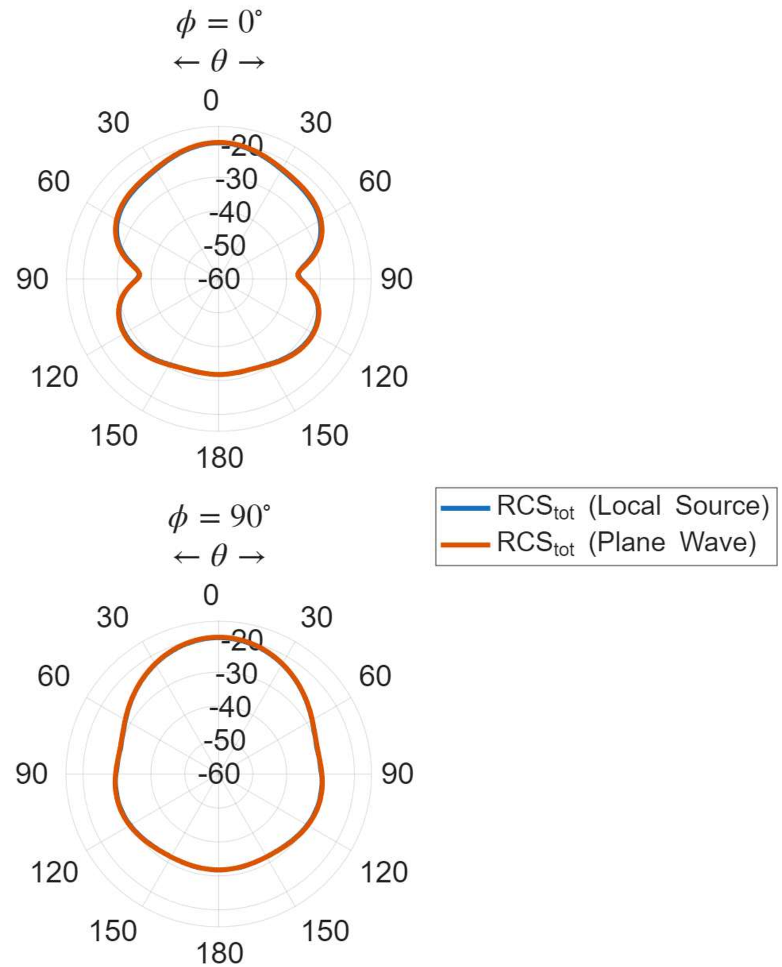
Results Validation against Traditional Plane Wave RCS

- We compared results obtained from the local source two step method with traditional plane wave RCS
- The local source is a dipole with length $D = \lambda/2$ parallel to the x-axis
- PEC sphere with diameter 1λ is located at $60z_{ff}$ where $z_{ff} = \frac{2D^2}{\lambda}$. A large distance is chosen to approximate a plane wave
- These results are to demonstrate that the two-step method with sources at such a far distance from the scatterer is in good agreement with traditional RCS based on plane wave incidence



RCS of a PEC Sphere due to Dipole vs. Plane Wave





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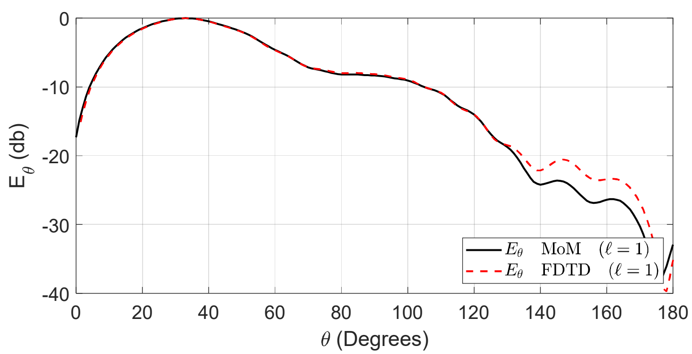
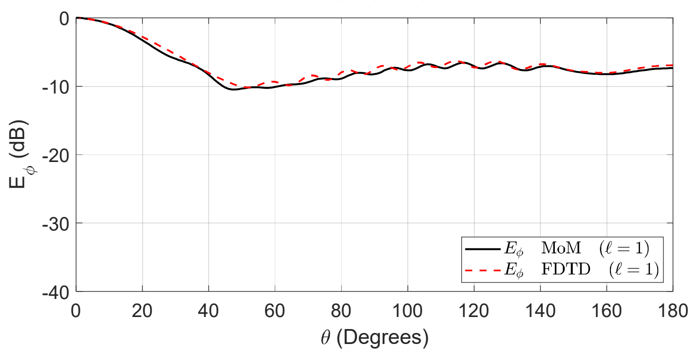
Simulation Method Comparison

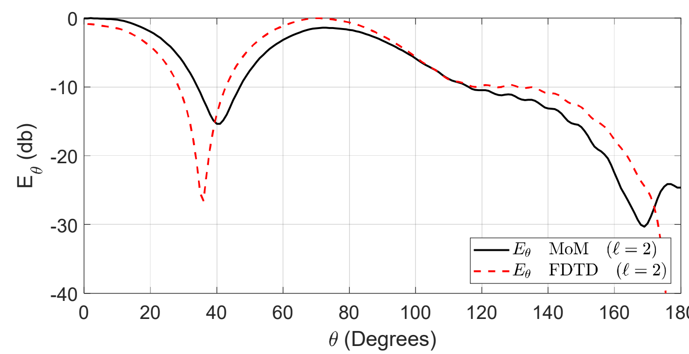
- The two-step technique is applicable to any simulation method
- Results are shown comparing scattered fields from a PEC Sphere using method of moments (MoM) and finite difference time domain (FDTD)

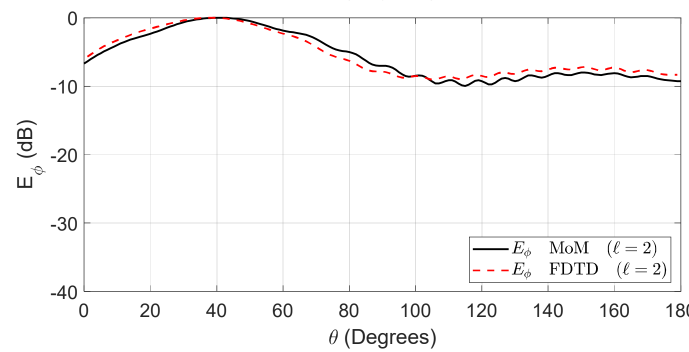
OAM mode $\ell = 1$





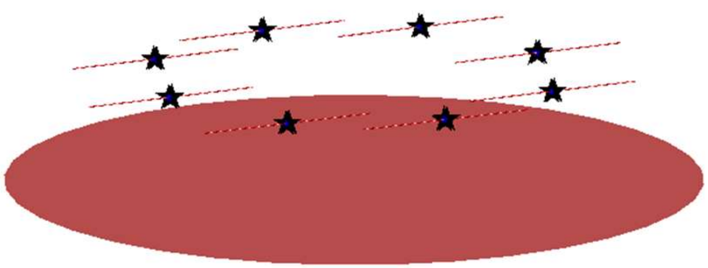
OAM mode ℓ =2

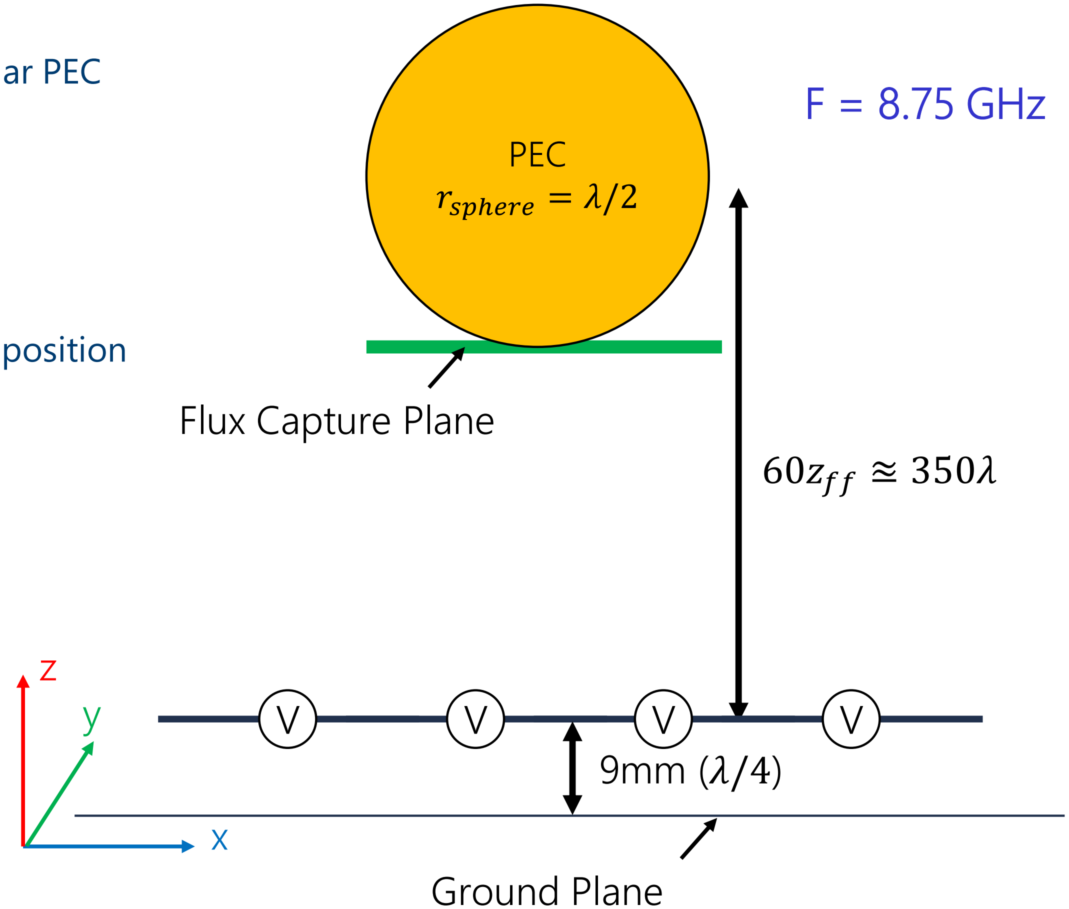




RCS of a PEC Sphere due to Radiation from a Circular Array of Dipole Antennas

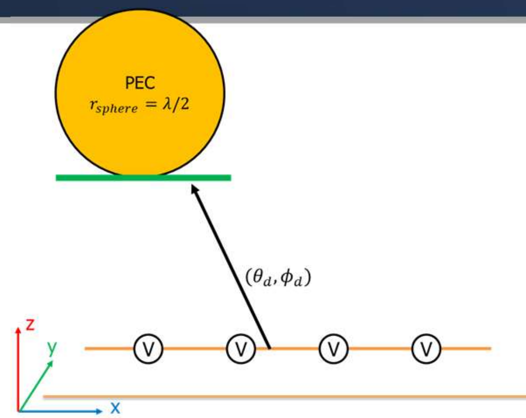
- UCA of *N* dipoles parallel to the x-axis backed by a circular PEC ground plane. Producing x-polarized SVW wave
- *N*=8 dipoles, arranged in circular array of radius 17mm
- Circular ground plane of radius 58.5mm
- Dipole height above ground plane is 9mm
- Dipole *n* excitation phase (Ψ_n) determined by element *n* position
- Azimuth position $\phi_n = \tan^{-1}\left(\frac{y_n}{x_n}\right), n = 0, 1, \dots, N$
- Excitation Phase $\Psi_n = e^{jl\phi_n}$



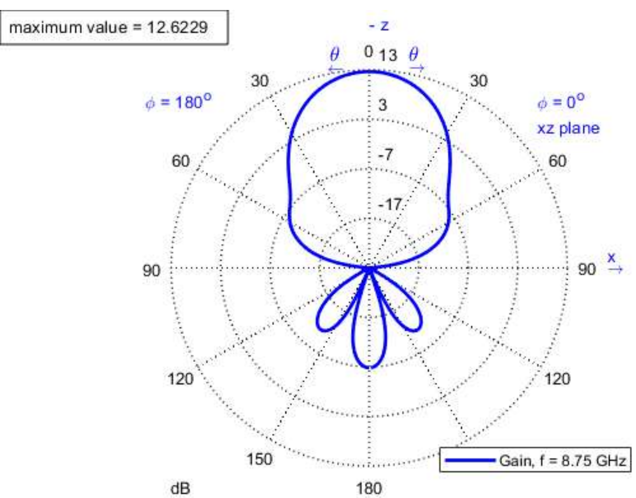


UCA Radiation Patterns

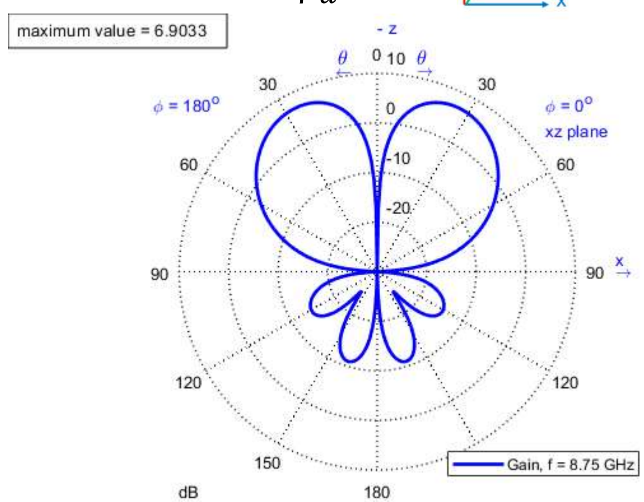
Far Field patterns of modes 0-2 are shown without the scatterer
We estimate the peak intensity direction $[\theta_d, \phi_d]$ to determine where to place the scattering object



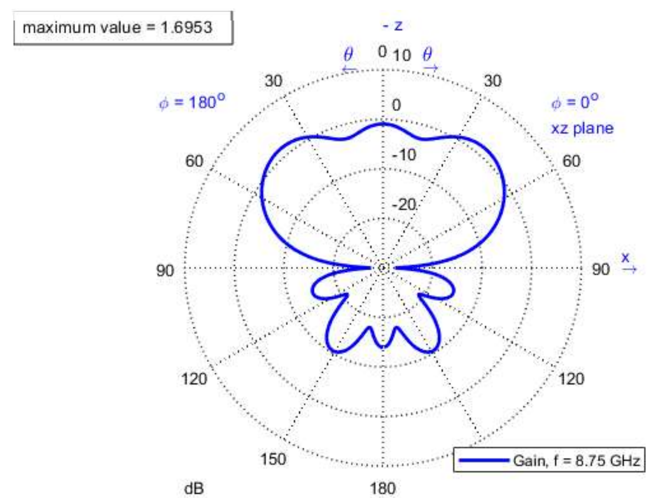
$\ell = 0$
$\theta_d = 0°$
$\phi_d = 0°$



$\ell = 1$
$\theta_d = 30°$
$\phi_d = 0°$

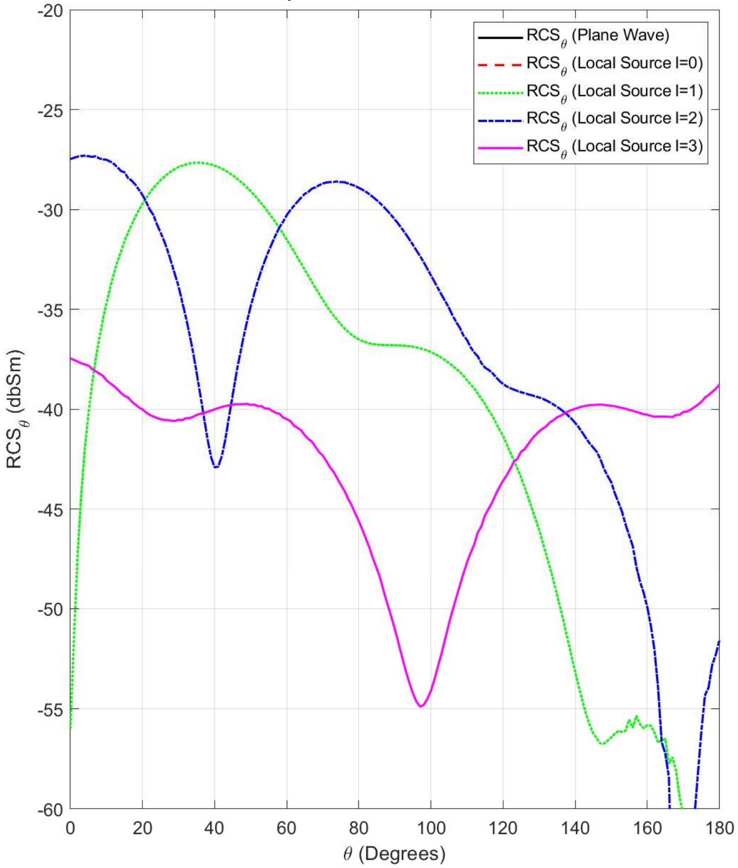


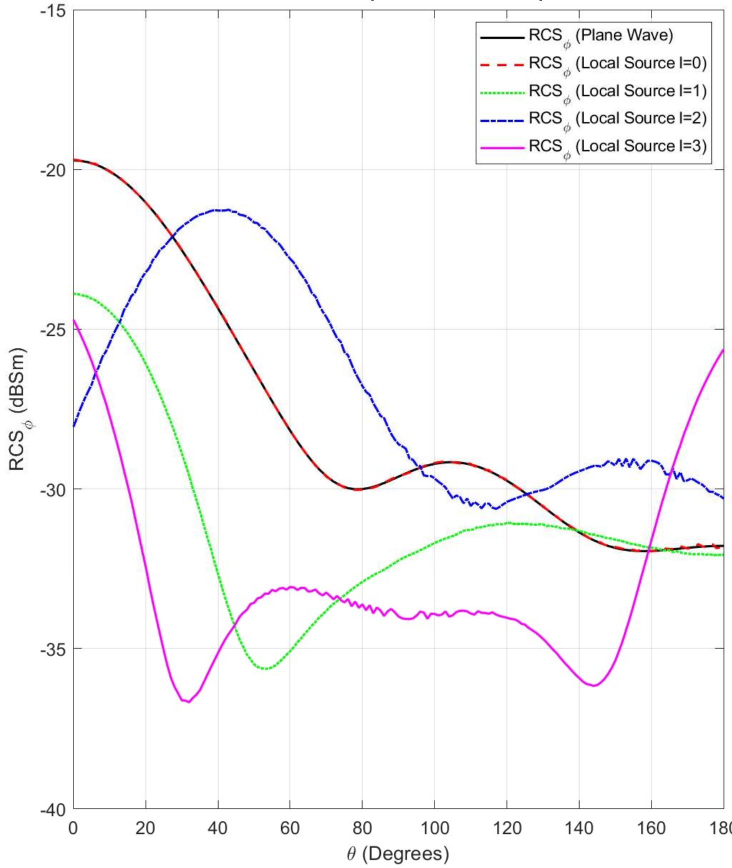
$\ell = 2$
$\theta_d = 45°$
$\phi_d = 120°$

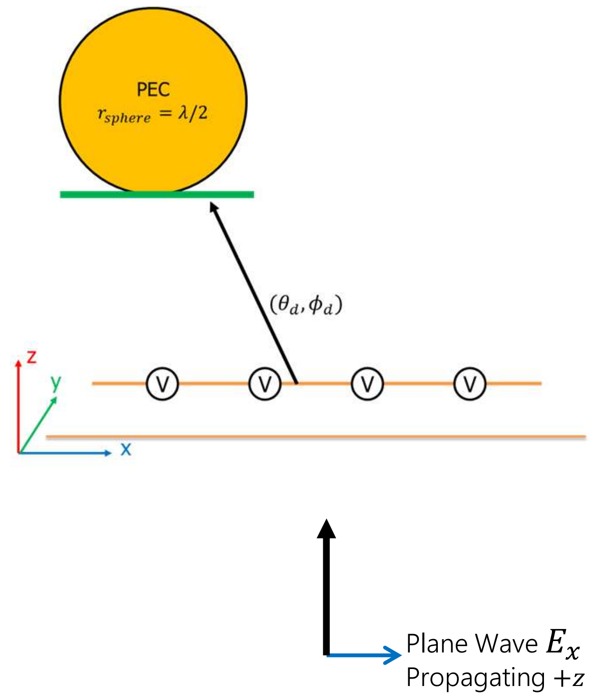


RCS of a PEC Sphere in the YZ Plane for Modes 0-3 and Plane Wave

The ϕ-component of the RCS from mode 0 and from the x-polarized plane wave are in good agreement.

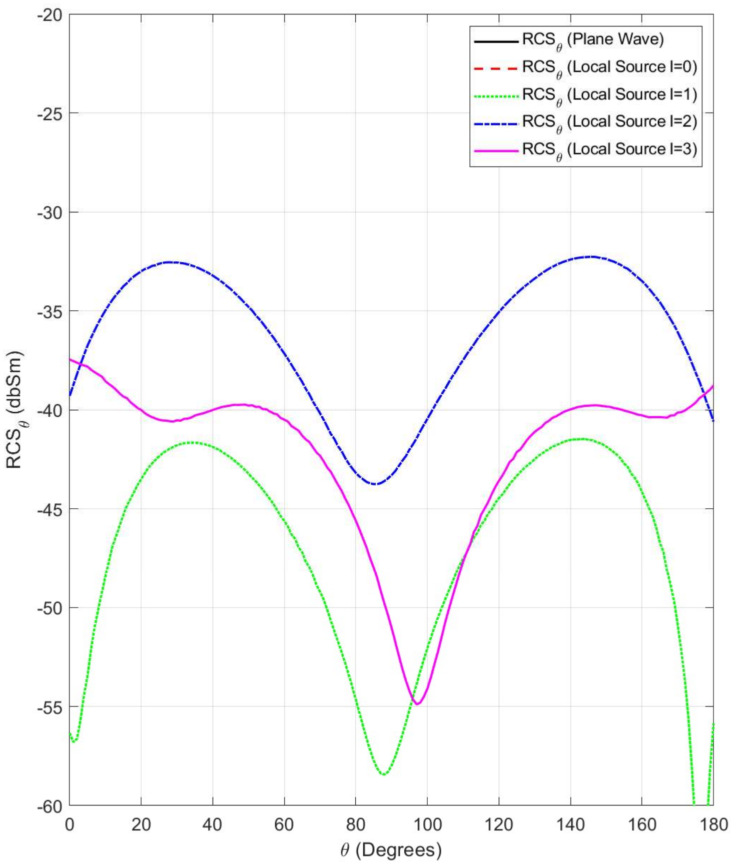


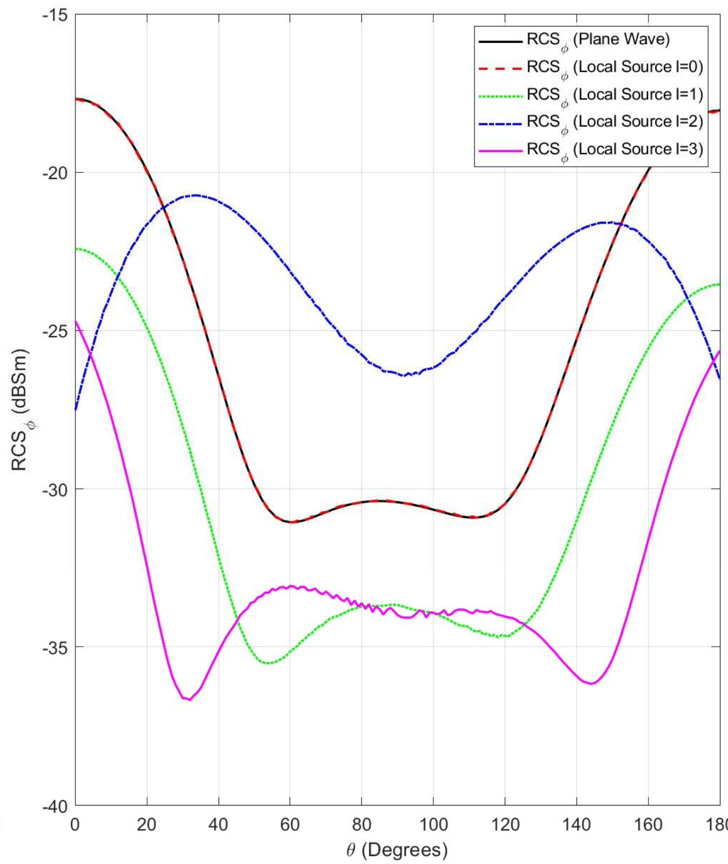


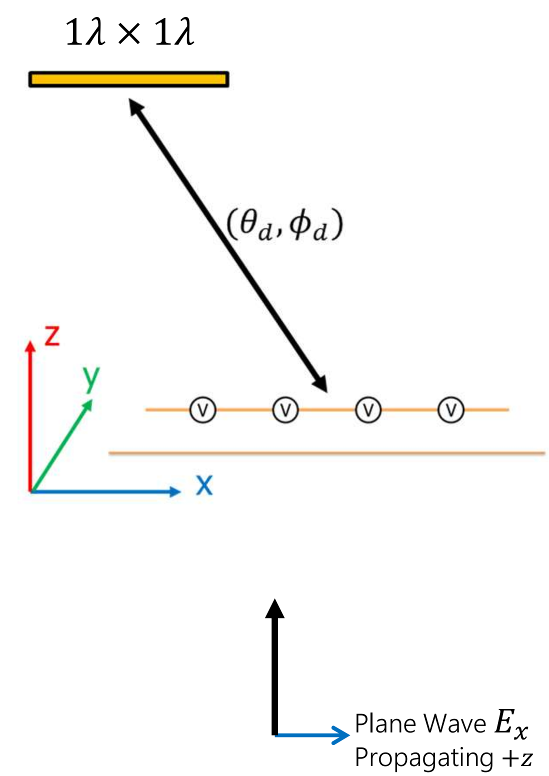


RCS of a PEC Plate in the YZ Plane for Modes 0-3 and Plane Wave

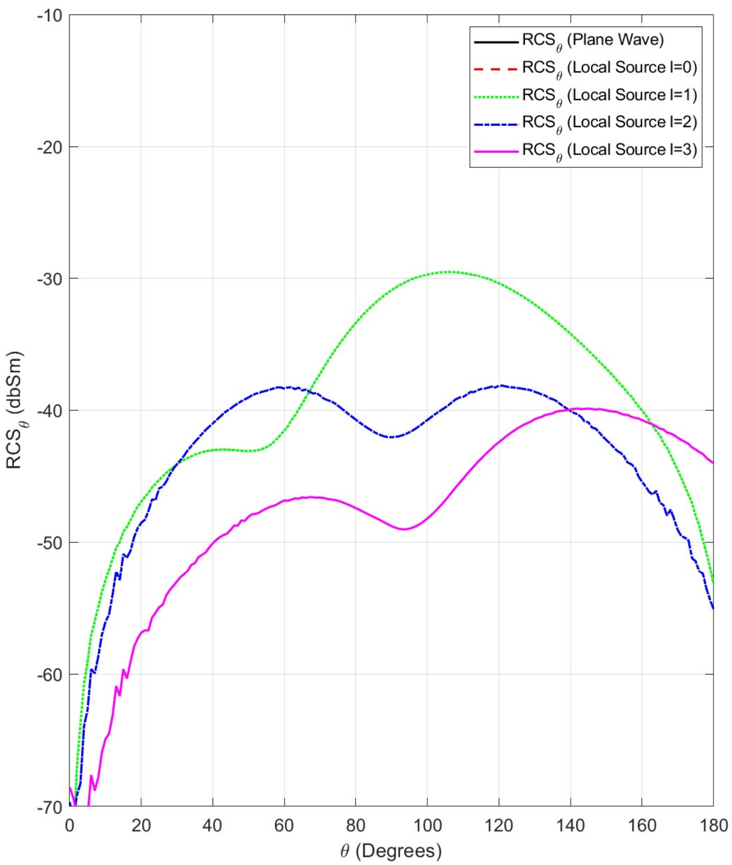
The direction of the maximum RCS for mode 2 is different than those of modes 0, 1, and 3.

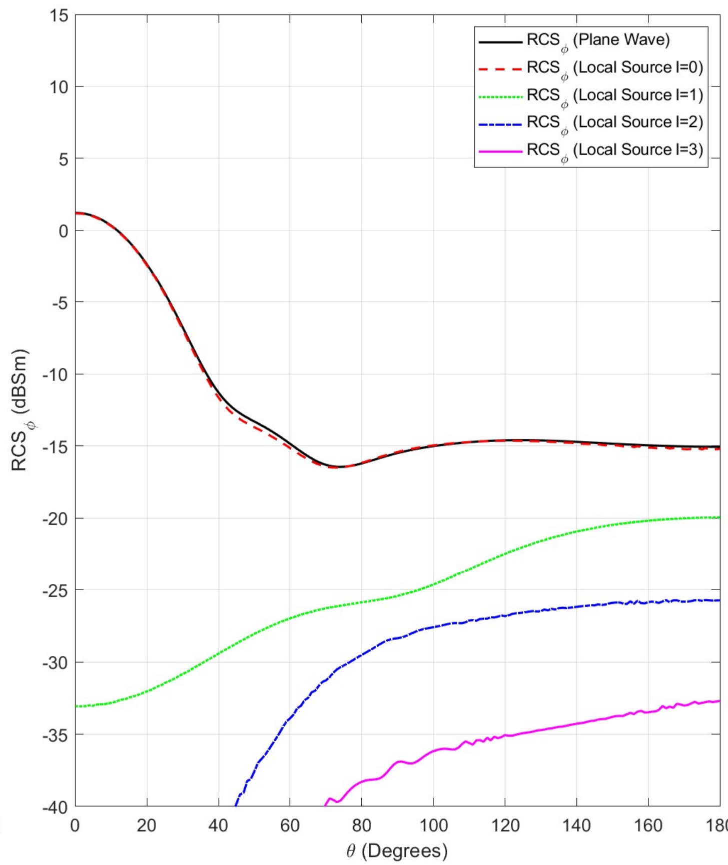


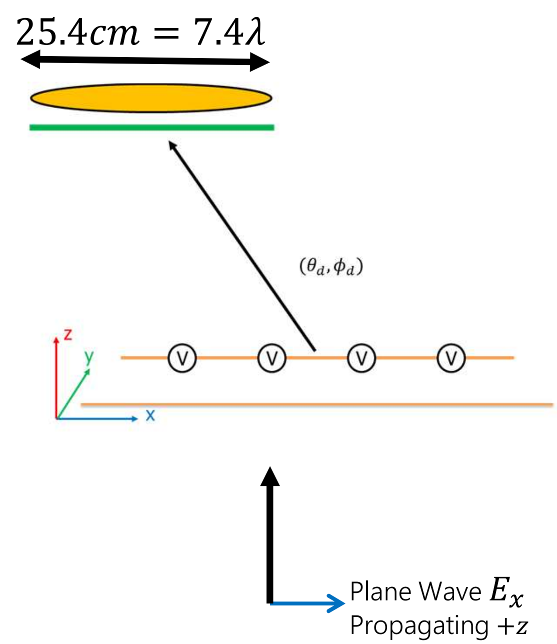




RCS of a PEC Ogive in the YZ Plane for Modes 0-3 and Plane Wave







Ogive dimensions from: 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 Antennas and Propagation Magazine*, vol. 35, no. 1, pp. 84–89, Feb. 1993, doi: 10.1109/74.210840.

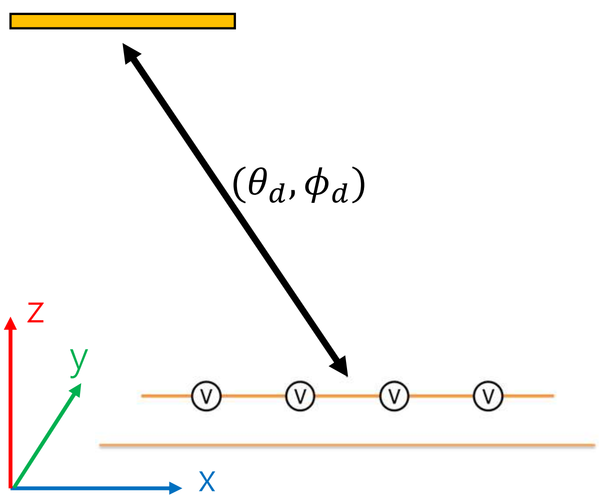
Conclusions and Future Work

- The presented method is effective for computing the RCS from local excitation sources
- The results were compared with those of a plane wave illumination when the sources are distanced away from the scatterer.
- The results of RCS of targets due to structured SVW beams provide some opportunities for extracting new features from Target's RCS data.

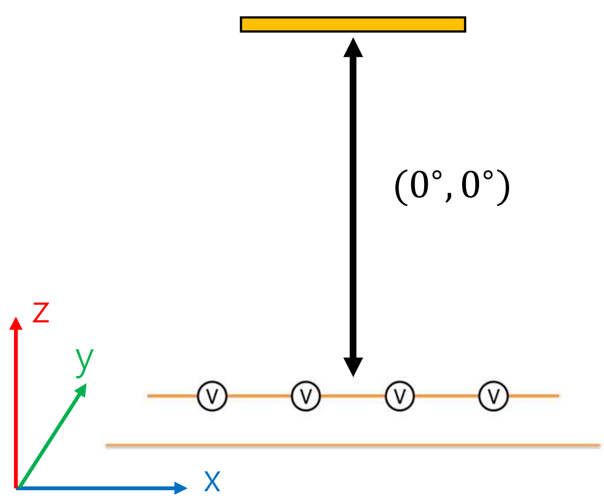
Backup Slides

PEC Plate in Different Far Field Positions

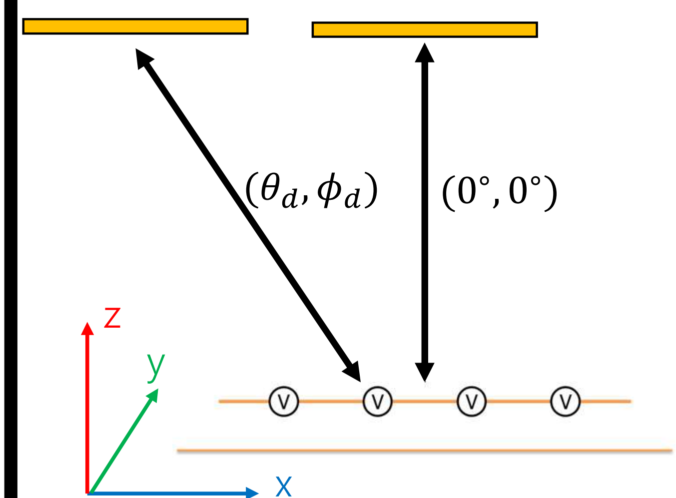
Max Intensity Direction (Previous Results)



Normal Direction

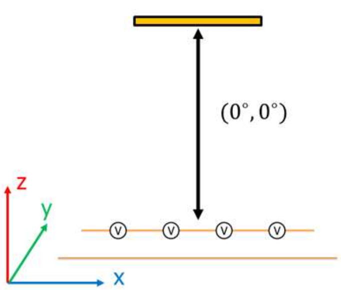


Normal Direction + Max Intensity Direction

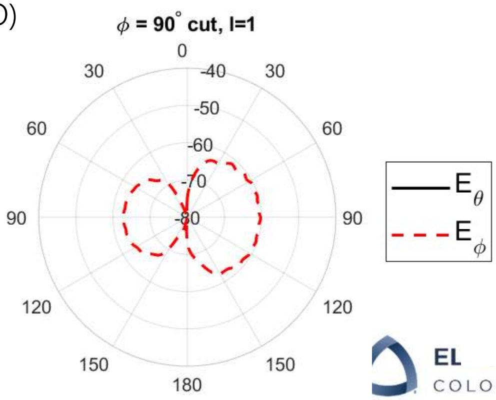


PEC Plate in Normal Direction – OAM Mode $\ell = 1$

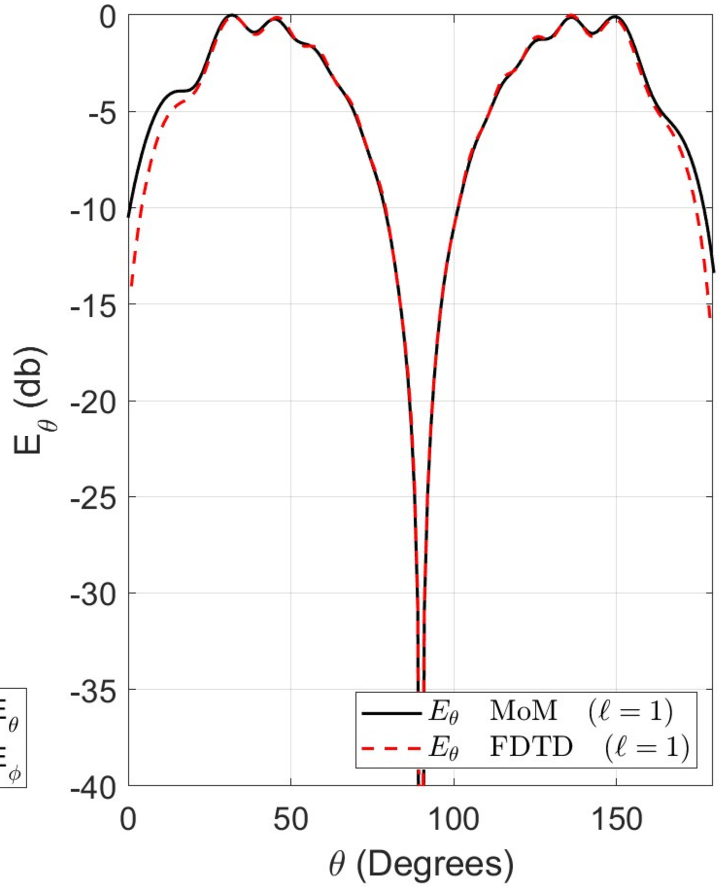
Normal Direction

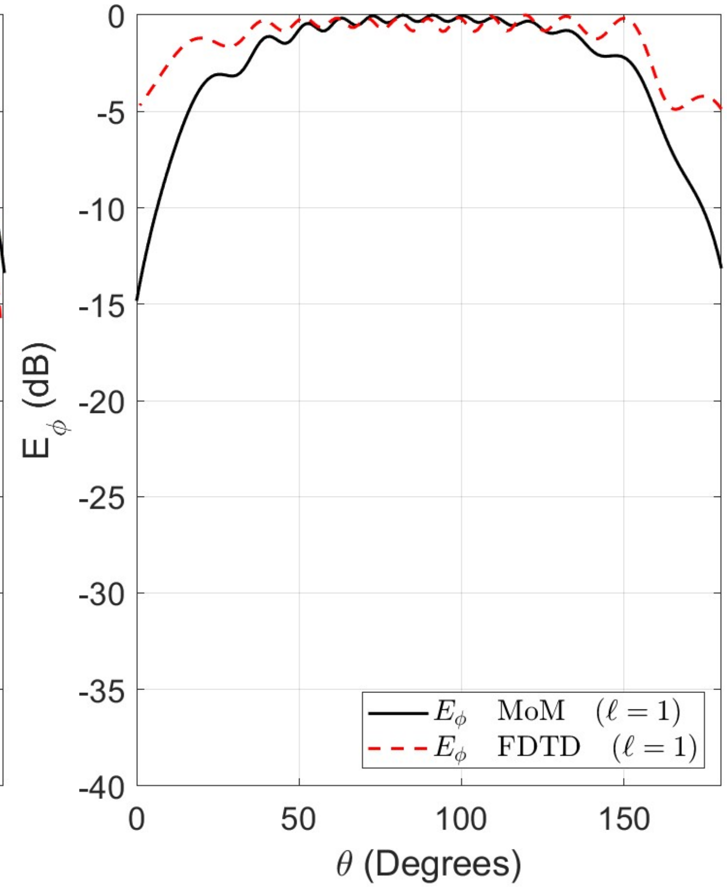


Unnormalized Scattered Fields (FEKO)

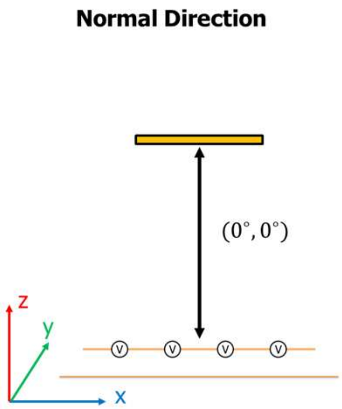


$\phi = 90°$

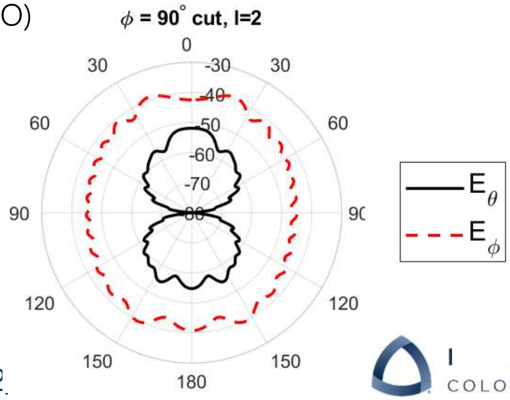




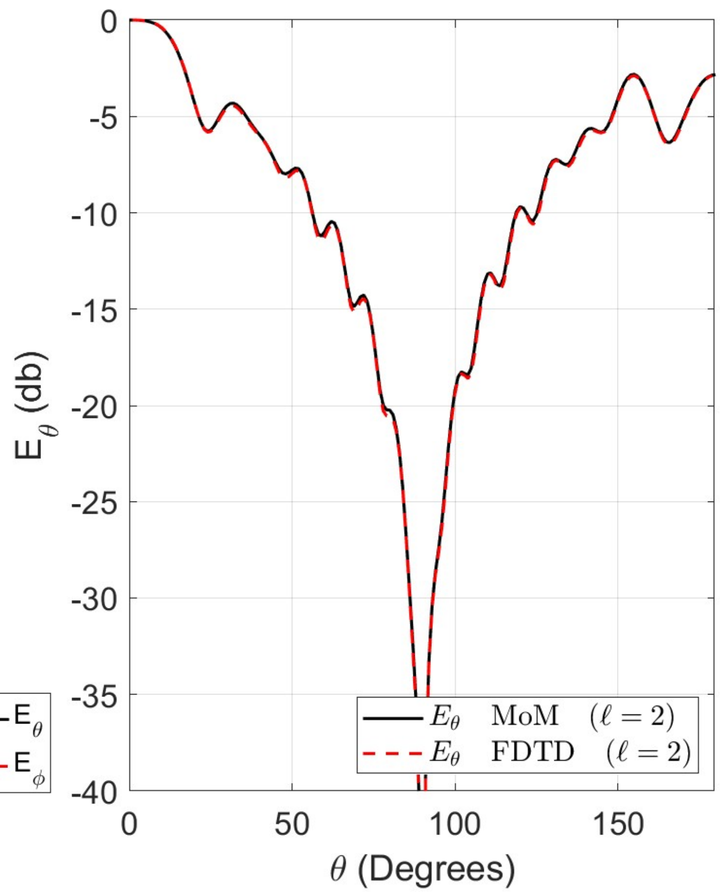
PEC Plate in Normal Direction – OAM Mode ℓ =2

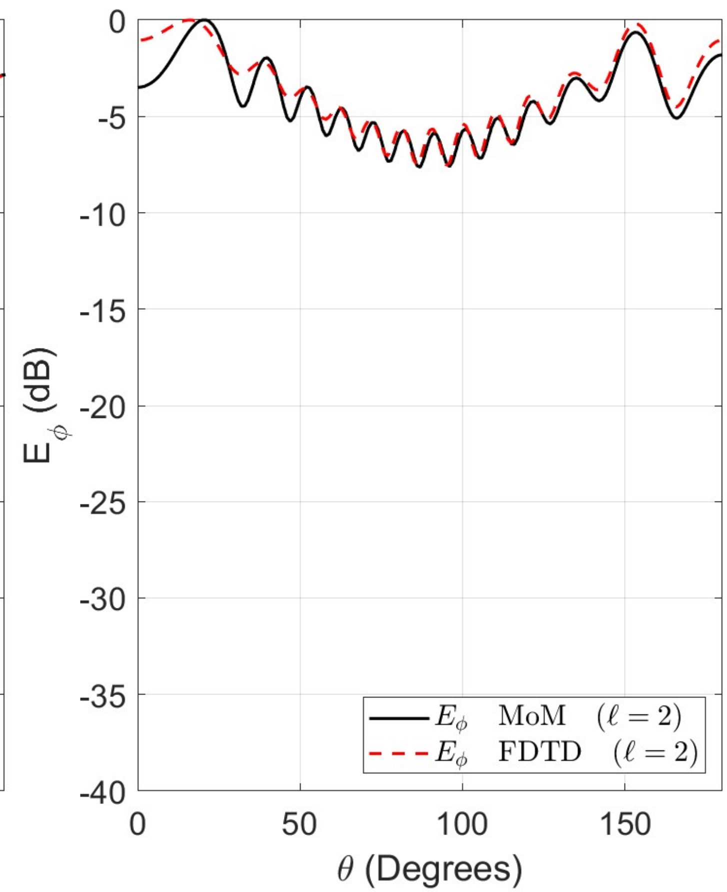


Unnormalized Scattered Fields (FEKO)



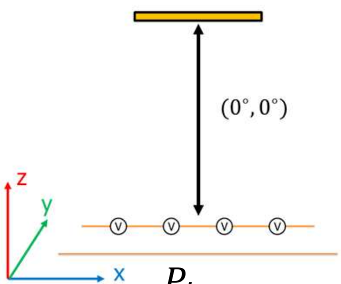
$\phi = 90°$





PEC Plate in Normal Direction – MoM RCS compared to Plane Wave

Normal Direction



$$\ell = 0, \frac{P_{inc}}{A} = 3.5 \times 10^{-4} \frac{W}{m^2}$$

$$\ell = 1, \frac{P_{inc}}{A} = 6.6 \times 10^{-9} \frac{W}{m^2}$$

$$\ell = 2, \frac{P_{inc}}{A} = 9.57 \times 10^{-6} \frac{W}{m^2}$$

$$\ell = 3, \frac{P_{inc}}{A} = 5.98 \times 10^{-8} \frac{W}{m^2}$$

Very small scattered fields, very small $\frac{P_{inc}}{A}$ ➔ numerical precision issues.

Illumination near the phase singularity seems to resemble a plane wave

$\phi = 90°$