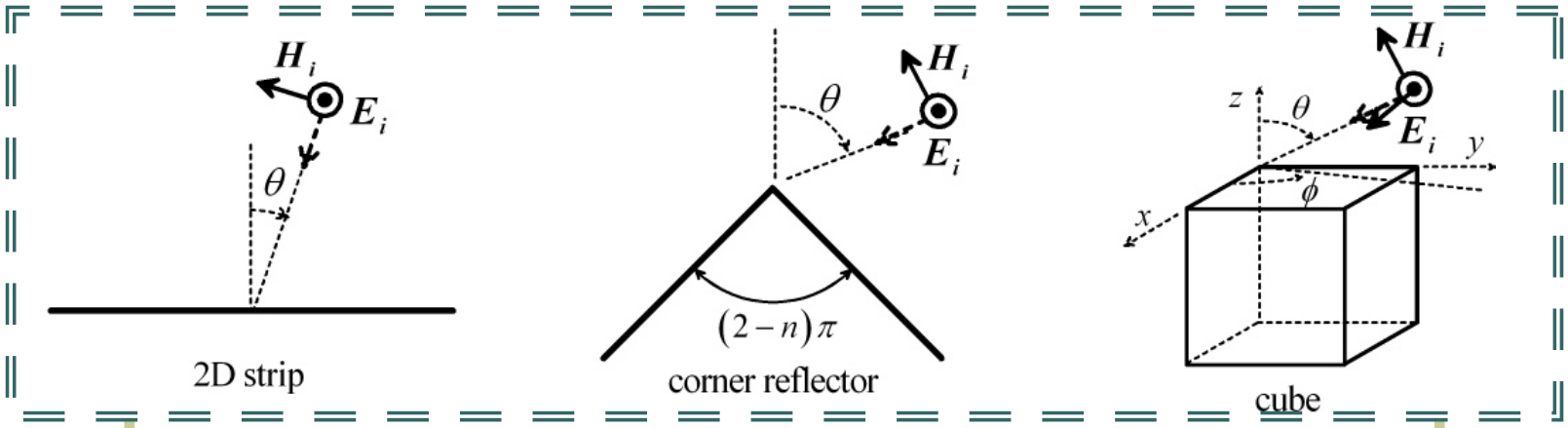
PO with Modified Surface-normal Vectors for RCS calculation of Scatterers with Edges and Wedges



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Tokyo Institute of Technology, Japan

Outline

i. Background

ii. PO with modified normal vector (Modified PO)

iii. Objective

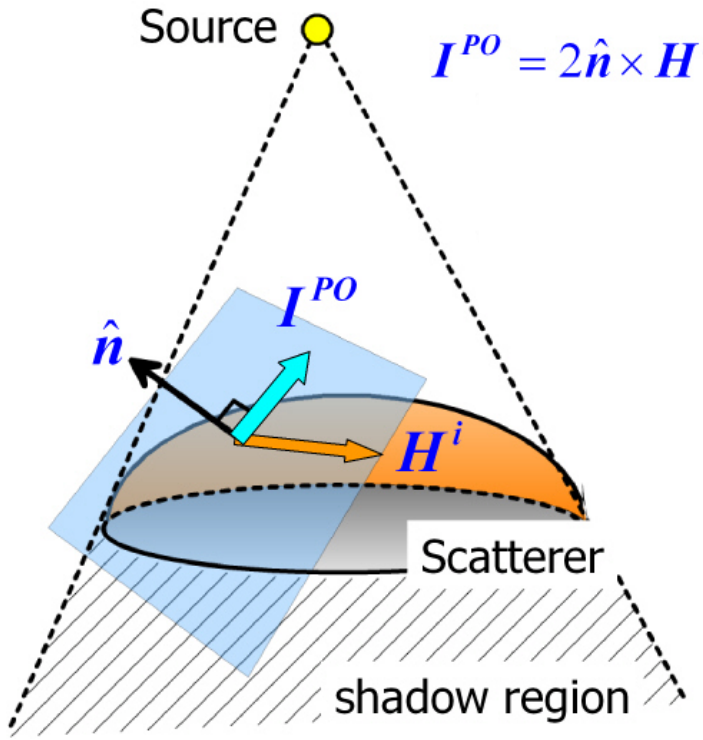
- *Simplified* surface-normal vectors for *RCS*
- Accuracy check
  - for *edge* (sample: 2D-strip)
  - for *wedge* (sample: corner reflector)
    - *Analytical explanation* of the accuracy
  - for *3-D objects* comparison with experiments and PTD (sample: Cubes)

iv. Conclusion

- *Higher accuracy* (GTD) than PO

Background

Physical Optics (PO)

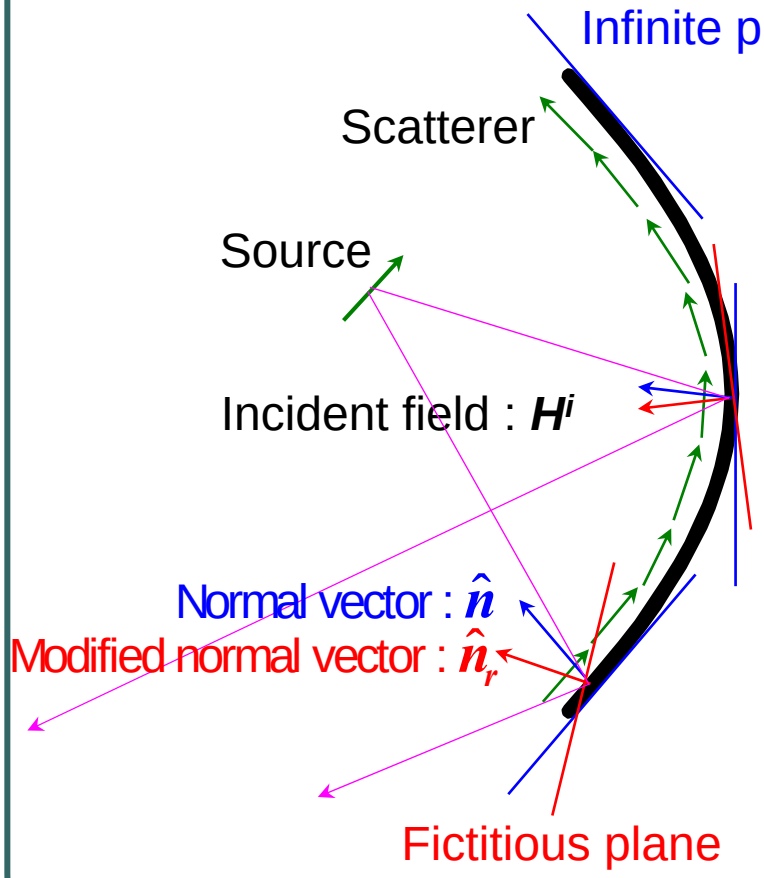


H^i : incident wave

$\hat{n}$: unit normal vector

- ○ **easy *algorithm***
- ○ ***no singularity***
- ✕ **error near edges**

The Empirical Idea to Introduce the Modified Surface-normal Vectors



PO diffraction error

$$E^d = E^i \left(D_i \, \text{m} \, D_r \right) \sqrt{\frac{1}{2\pi k \rho}} e^{-jk\rho - j\frac{\pi}{4}}$$

	PO	GTD
D_i	$\sin\left(\frac{\phi_d - \phi_i}{2}\right) \Big/ \cos\left(\frac{\phi_d - \phi_i}{2}\right)$	$1 \Big/ \cos\left(\frac{\phi_d - \phi_i}{2}\right)$
D_r	$\sin\left(\frac{\phi_d + \phi_i}{2}\right) \Big/ \cos\left(\frac{\phi_d + \phi_i}{2}\right)$	$1 \Big/ \cos\left(\frac{\phi_d + \phi_i}{2}\right)$

$$E^s_{PO} = \int_S J^{PO} \frac{\exp(-jkr_o)}{r_o} ds$$

$$J^{PO} = 2\hat{n} \times H^i$$

$$J^{Modified-PO} = 2\hat{n}_r \times H^i + 2\hat{n}_i \times \bar{H}^i$$

$$\left(\bar{H}^i = H^i - 2\hat{n}\left(H^i \cdot \hat{n} \right) \right)$$

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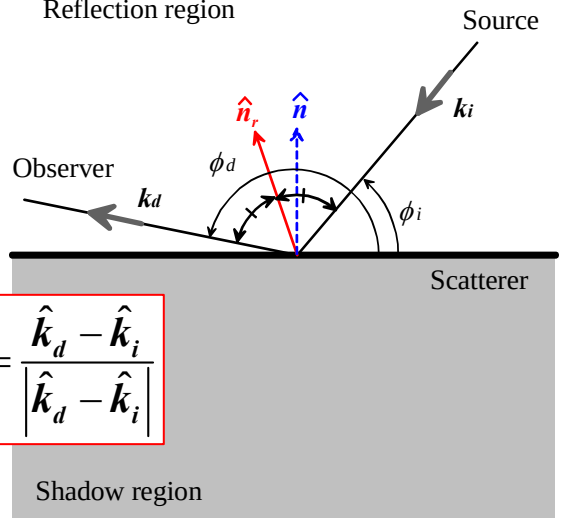
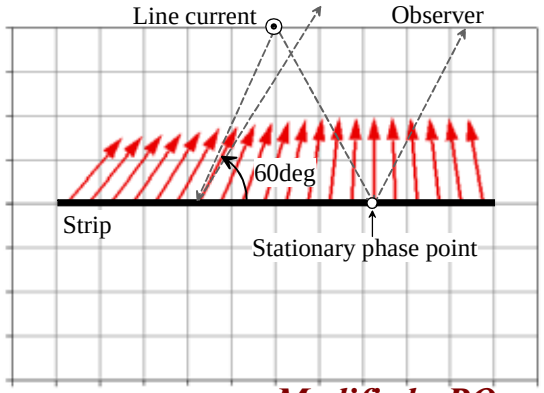
Definitions of the Modified Surface-normal Vectors

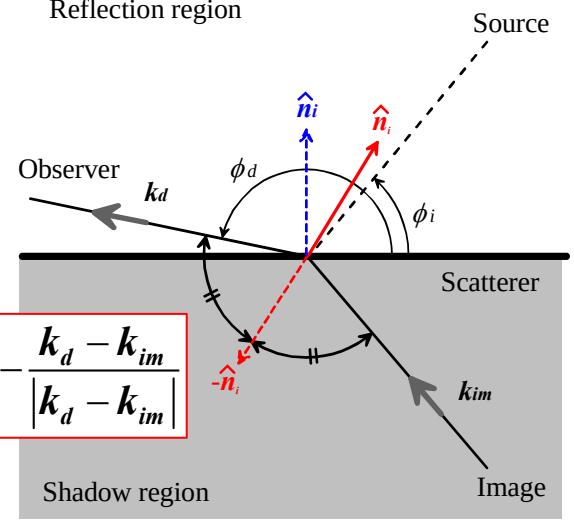
Reflection component



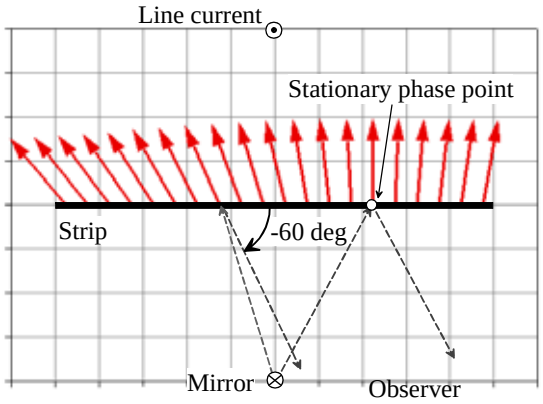
$$\hat{n}_r = \frac{\hat{k}_d - \hat{k}_i}{\left|\hat{k}_d - \hat{k}_i\right|}$$



Shadow component



$$\hat{n}_i = -\frac{k_d - k_{im}}{\left|k_d - k_{im}\right|}$$



$$J^{Modified-PO} = 2\hat{n}_r \times H^i + 2\hat{n}_i \times \bar{H}^i$$

$$\left(\bar{H}^i = H^i - 2\hat{n}\left(H^i \cdot \hat{n}\right)\right)$$

Procedure to introduce the modified surface-normal vectors in the PO

PO

Reflection component

Shadow component

Equivalent currents

$$\boldsymbol{I}^{PO} = 2\hat{\boldsymbol{n}} \times \boldsymbol{H}^{i} \Rightarrow \begin{Bmatrix} \boldsymbol{J}_r = \hat{\boldsymbol{n}} \times \boldsymbol{H}^{i} \\ \boldsymbol{M}_r = -\boldsymbol{E}^{i} \times \hat{\boldsymbol{n}} \end{Bmatrix} + \begin{Bmatrix} \boldsymbol{J}_i = \hat{\boldsymbol{n}} \times \boldsymbol{H}^{i} \\ \boldsymbol{M}_i = \boldsymbol{E}^{i} \times \hat{\boldsymbol{n}} \end{Bmatrix}$$

Diffraction coefficients

$$-\frac{\sin\frac{\phi_d+\phi_i}{2}}{\cos\frac{\phi_d+\phi_i}{2}} + \frac{\sin\frac{\phi_d-\phi_i}{2}}{\cos\frac{\phi_d-\phi_i}{2}} \qquad -\frac{\sin\frac{\phi_d+\phi_i}{2}}{\cos\frac{\phi_d+\phi_i}{2}} + \frac{\sin\frac{\phi_d-\phi_i}{2}}{\cos\frac{\phi_d-\phi_i}{2}}$$

Modified normal vector

GTD

Diffraction coefficients

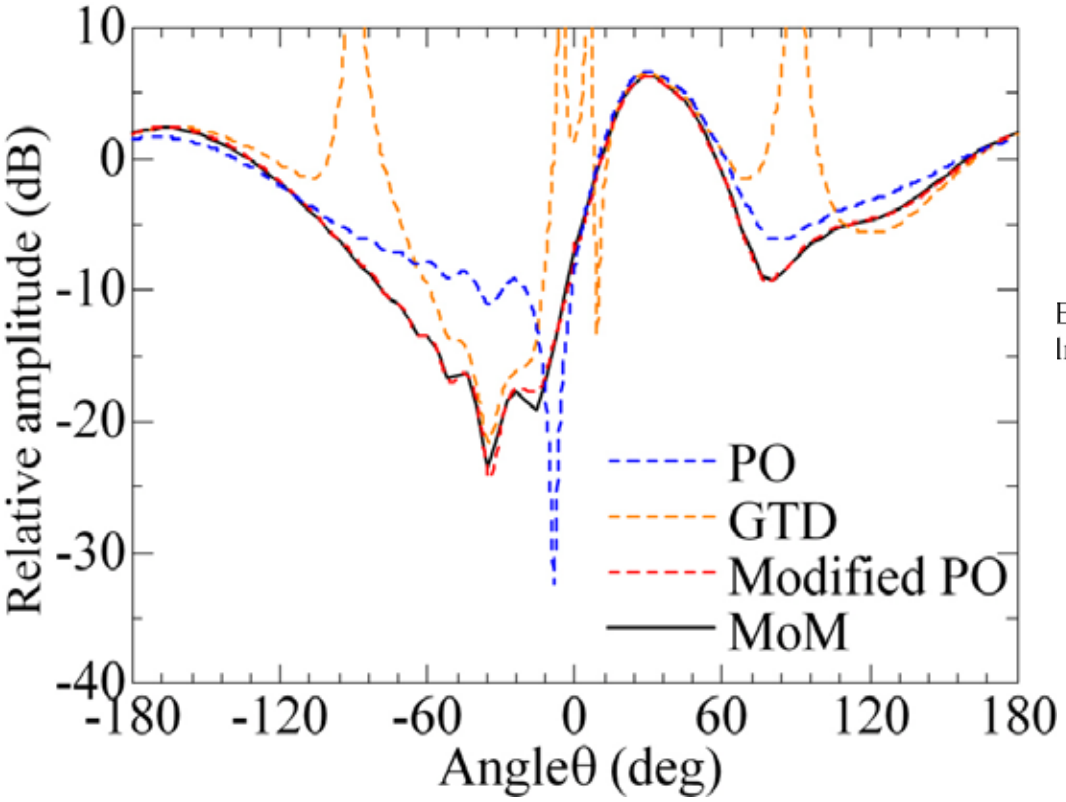
$$-\frac{1}{\cos\frac{\phi_d+\phi_i}{2}} + \frac{1}{\cos\frac{\phi_d-\phi_i}{2}} \Leftarrow -\frac{1}{\cos\frac{\phi_d+\phi_i}{2}} + \frac{1}{\cos\frac{\phi_d-\phi_i}{2}}$$

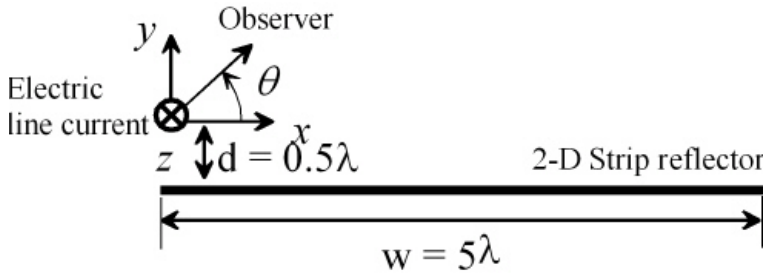
Equivalent currents

$$\boldsymbol{J}^{MPO} = \langle \hat{\boldsymbol{n}}_r \times \boldsymbol{H}^{i} + \hat{\boldsymbol{n}}_i \times \left[\boldsymbol{H}^{i} - 2\hat{\boldsymbol{n}}\left(\boldsymbol{H}^{i} \cdot \hat{\boldsymbol{n}}\right) \right] \rangle \times 2 \Rightarrow \begin{Bmatrix} \boldsymbol{J}'_r = \hat{\boldsymbol{n}}_r \times \boldsymbol{H}^{i} \\ \boldsymbol{M}'_r = -\boldsymbol{E}^{i} \times \hat{\boldsymbol{n}}_r \end{Bmatrix} + \begin{Bmatrix} \boldsymbol{J}'_i = \hat{\boldsymbol{n}}_i \times \bar{\boldsymbol{H}}^{i} \\ \boldsymbol{M}'_i = -\bar{\boldsymbol{E}}^{i} \times \hat{\boldsymbol{n}}_i \end{Bmatrix}$$

Modified PO

Error correction of PO





- Fine agreement at all angles

Reference from Shijo et al.[2])

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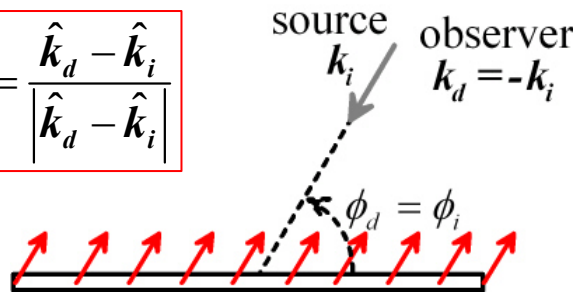
Simplification of the Modified Surface-normal Vectors in RCS

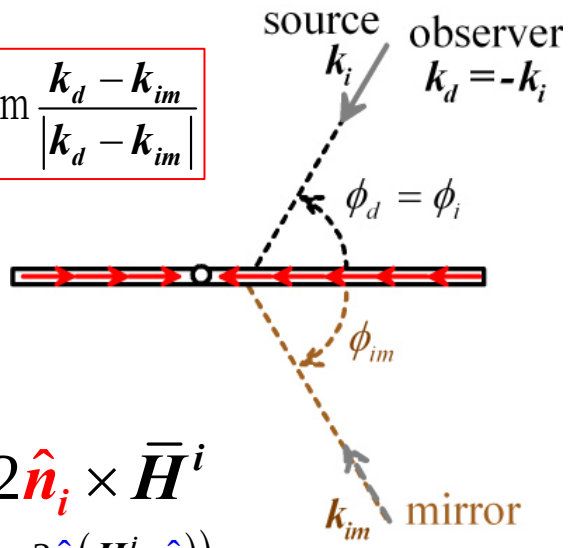
Reflection component

$$\hat{\boldsymbol{n}}_r = \frac{\hat{\boldsymbol{k}}_d - \hat{\boldsymbol{k}}_i}{\left|\hat{\boldsymbol{k}}_d - \hat{\boldsymbol{k}}_i\right|}$$



Shadow component

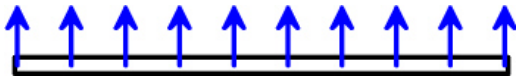
$$\hat{\boldsymbol{n}}_i = \mathrm{m}\frac{\boldsymbol{k}_d - \boldsymbol{k}_{im}}{\left|\boldsymbol{k}_d - \boldsymbol{k}_{im}\right|}$$



$$\boldsymbol{J}^{Modified-PO} = 2\hat{\boldsymbol{n}}_r \times \boldsymbol{H}^i + 2\hat{\boldsymbol{n}}_i \times \bar{\boldsymbol{H}}^i$$

$$\left(\bar{\boldsymbol{H}}^i = \boldsymbol{H}^i - 2\hat{\boldsymbol{n}}\left(\boldsymbol{H}^i \cdot \hat{\boldsymbol{n}}\right)\right)$$

Original surface-normal vectors



$$\boldsymbol{J}^{PO} = 2\hat{\boldsymbol{n}} \times \boldsymbol{H}^i$$

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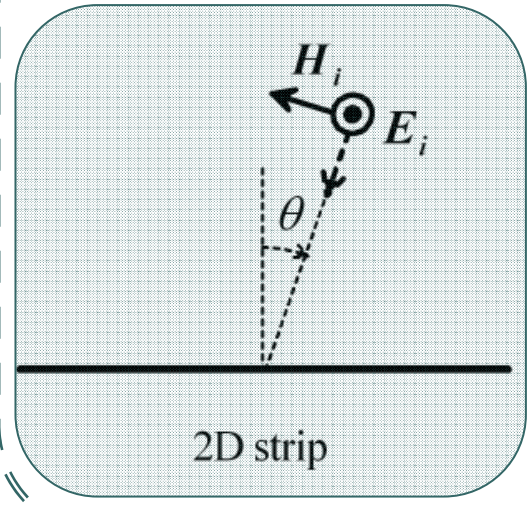
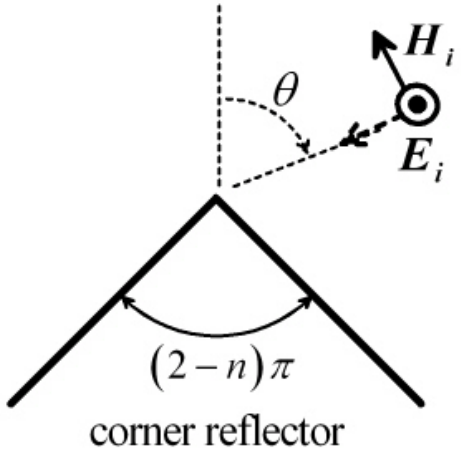
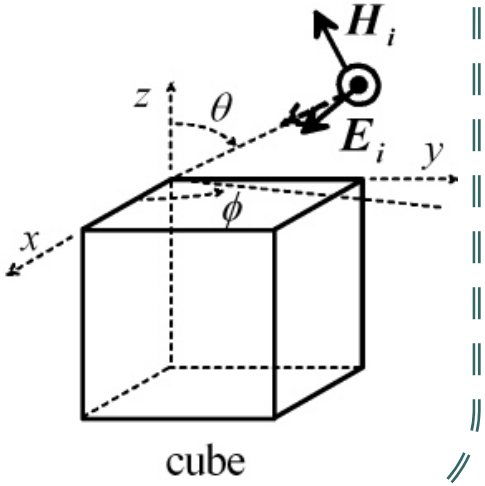
Samples

Application of ***the Modified PO*** to ***RCS (monostatic)***

TARGETS



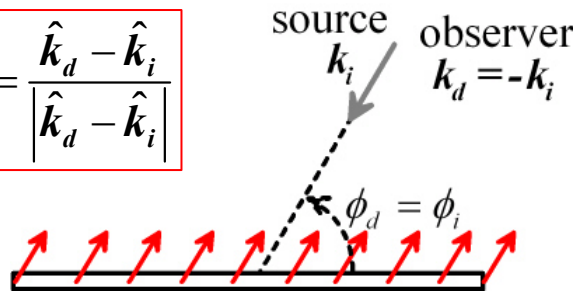




Simplification of the Modified Surface-normal Vectors in RCS

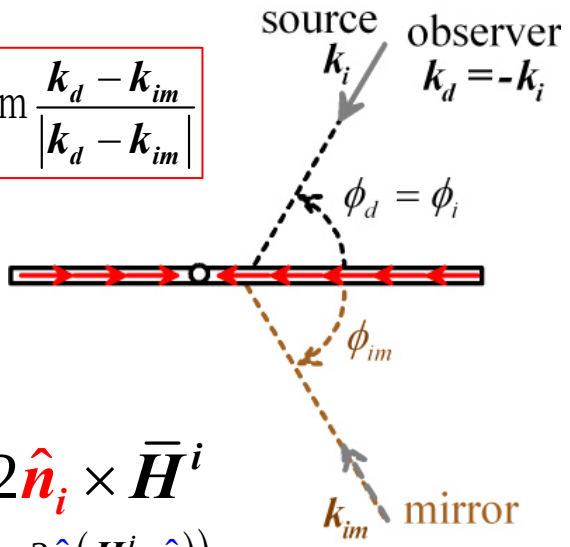
Reflection component

$$\hat{n}_r = \frac{\hat{k}_d - \hat{k}_i}{\left|\hat{k}_d - \hat{k}_i\right|}$$



Shadow component

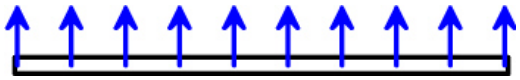
$$\hat{n}_i = \mathrm{m}\frac{k_d - k_{im}}{\left|k_d - k_{im}\right|}$$



$$J^{Modified-PO} = 2\hat{n}_r \times H^i + 2\hat{n}_i \times \bar{H}^i$$

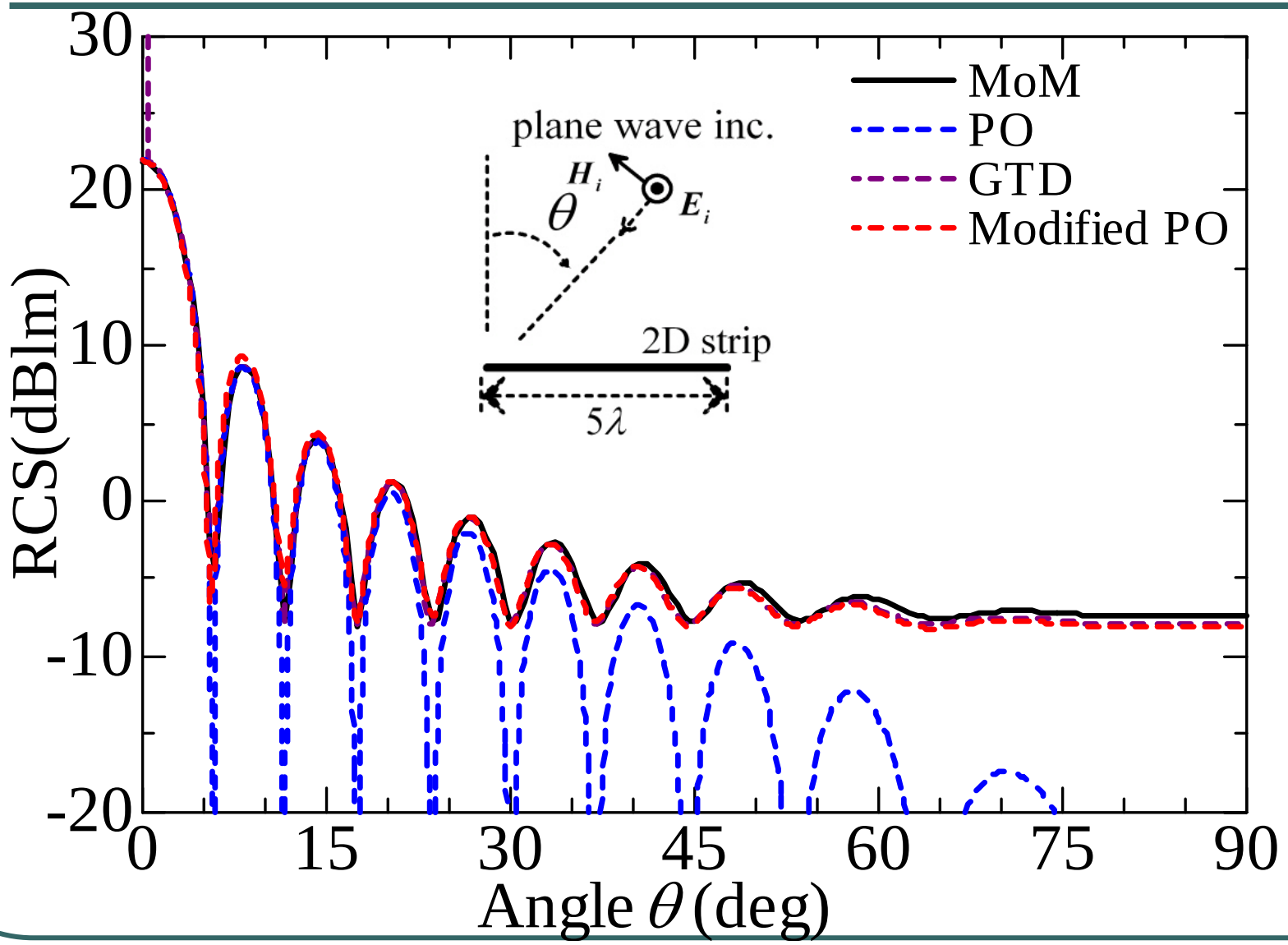
$$\left(\bar{H}^i = H^i - 2\hat{n}\left(H^i \cdot \hat{n}\right)\right)$$

Original surface-normal vectors

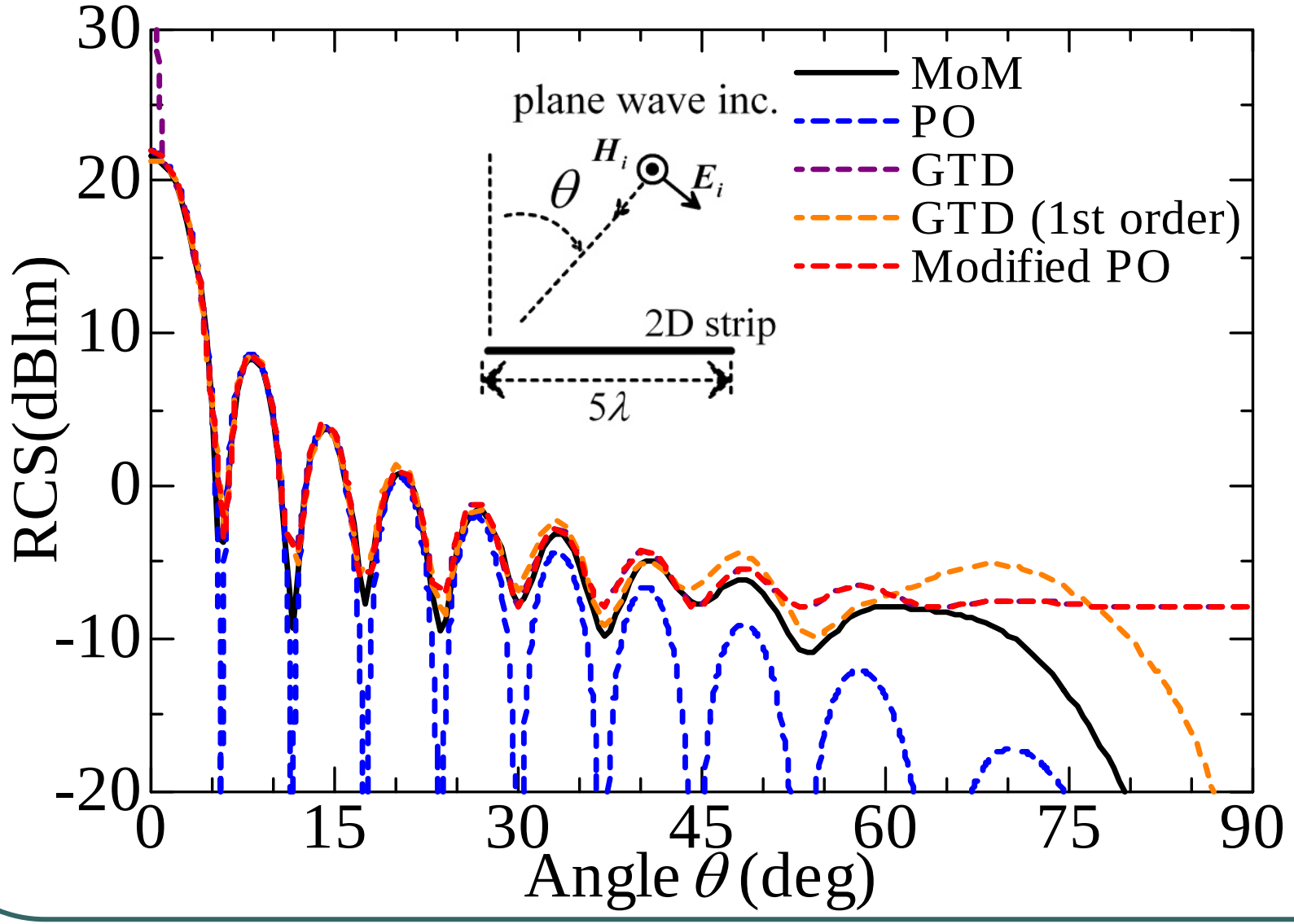


$$J^{PO} = 2\hat{n} \times H^i$$

Accuracy Check for a 2D strip (E polarization)



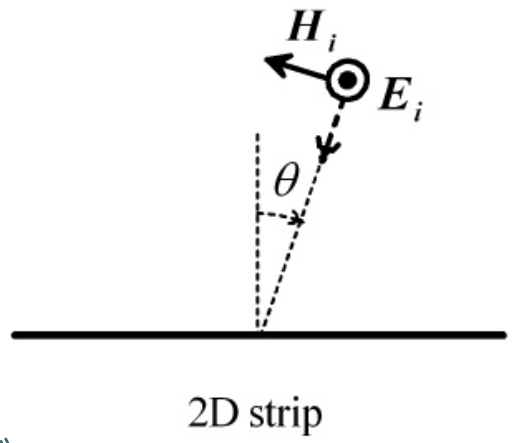
Accuracy Check for a 2D strip (H polarization)



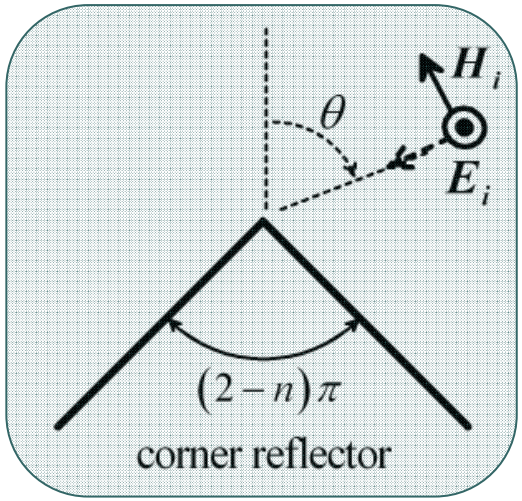
Samples

Application of ***the Modified PO*** to ***RCS (monostatic)***

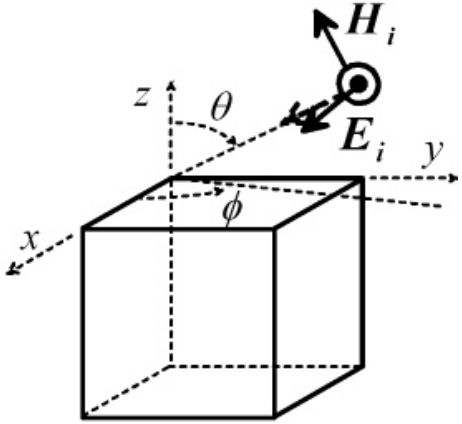
TARGETS



2D strip



corner reflector

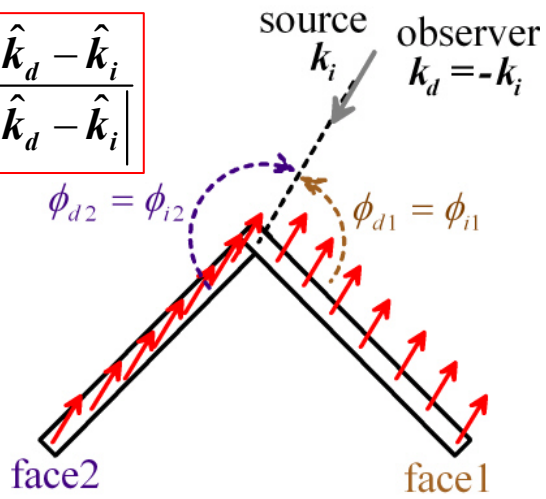


cube

Modified Surface-normal Vectors for a Corner Reflector in RCS

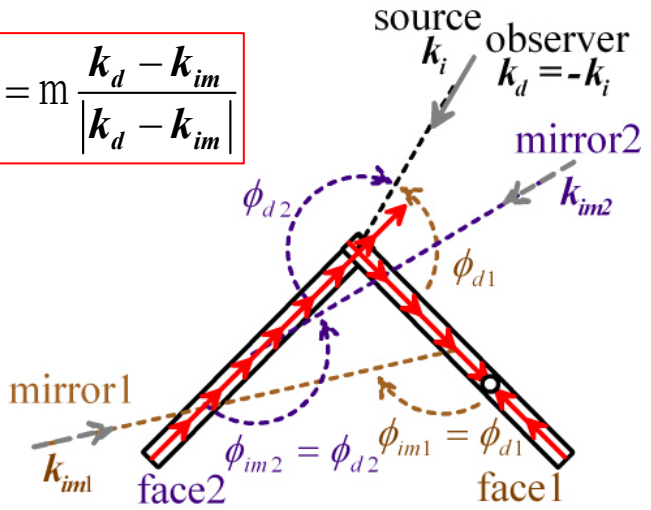
Reflection component

$$\hat{n}_r = \frac{\hat{k}_d - \hat{k}_i}{\left|\hat{k}_d - \hat{k}_i\right|}$$



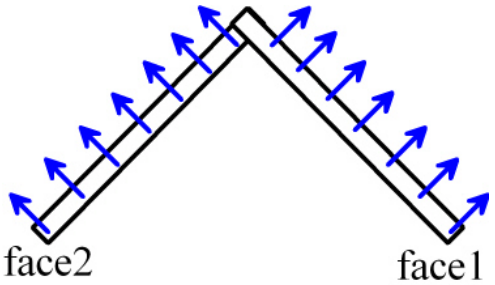
Shadow component

$$\hat{n}_i = \mathrm{m}\frac{k_d - k_{im}}{\left|k_d - k_{im}\right|}$$



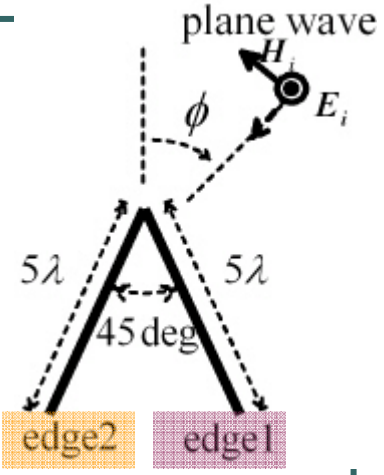
$$J^{Modified-PO} = 2\hat{n}_r \times H^i + 2\hat{n}_i \times \bar{H}^i \quad \left(\bar{H}^i = H^i - 2\hat{n}\left(H^i \cdot \hat{n}\right)\right)$$

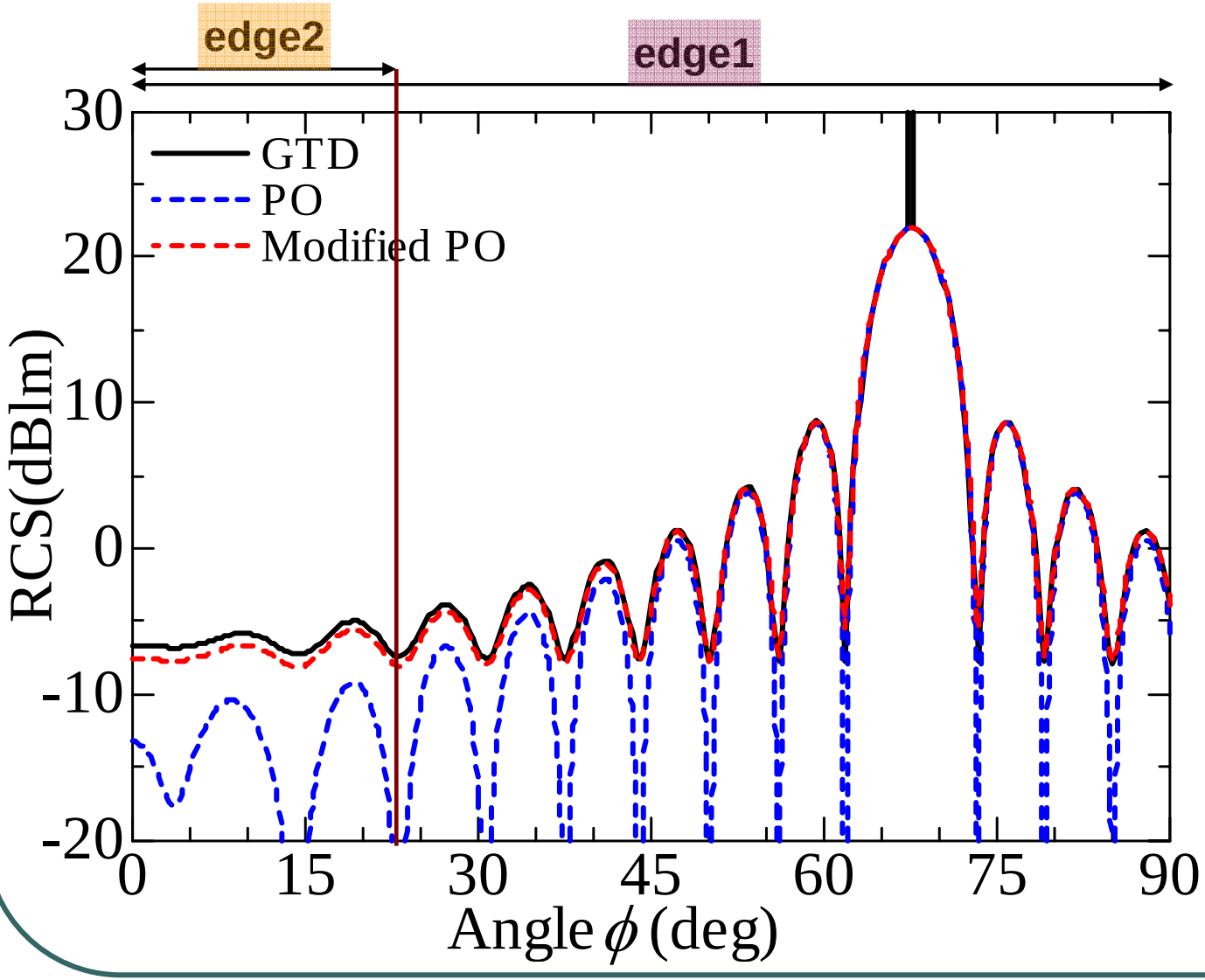
Original surface-normal vectors



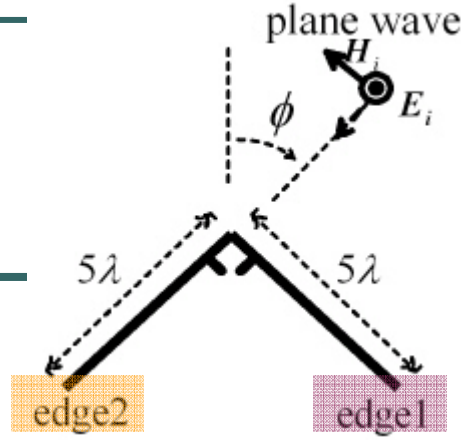
$$J^{PO} = 2\hat{n} \times H^i$$

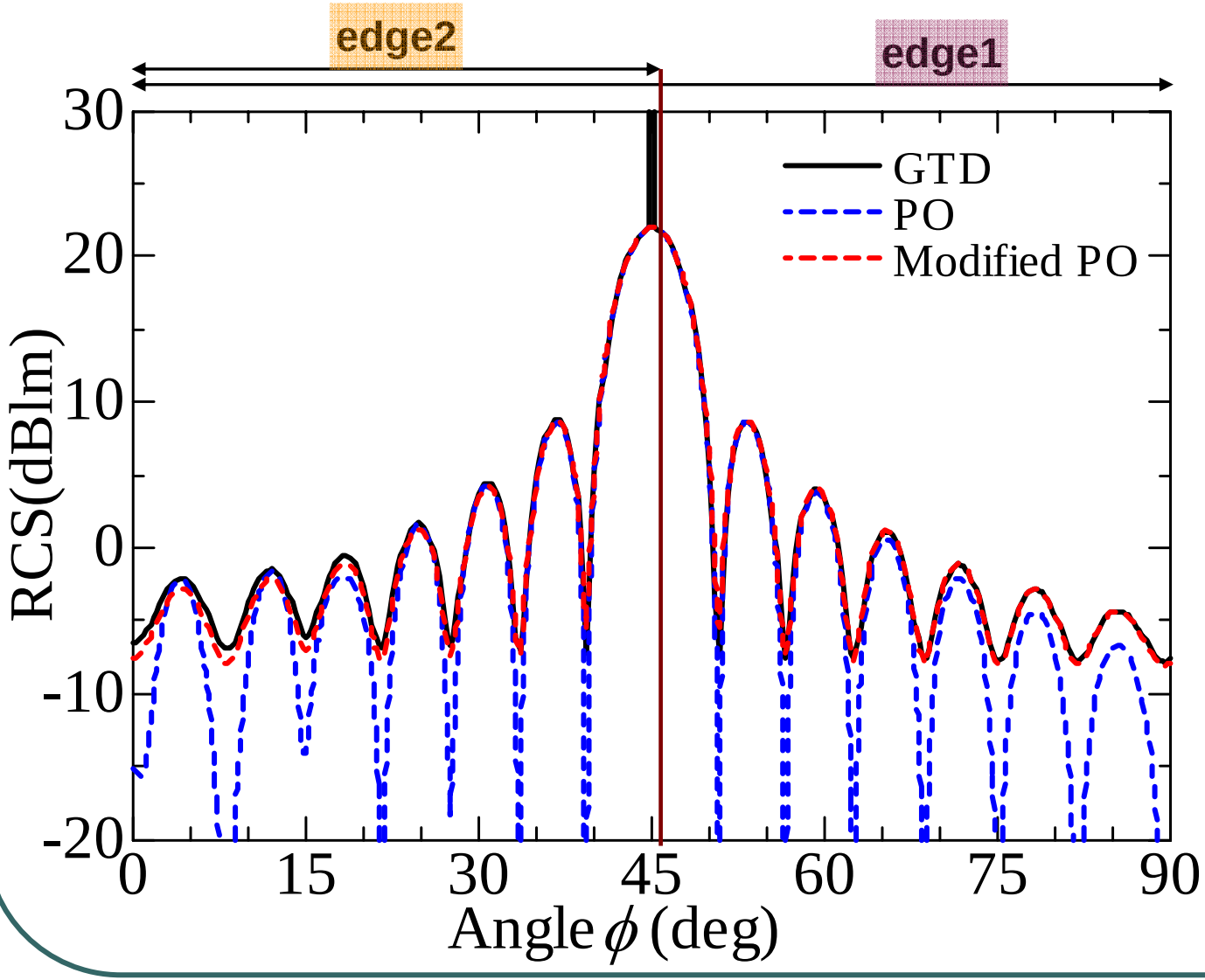
Accuracy Check for a Corner Reflector (E polarization)



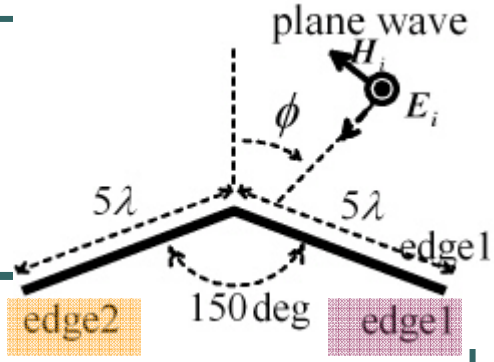


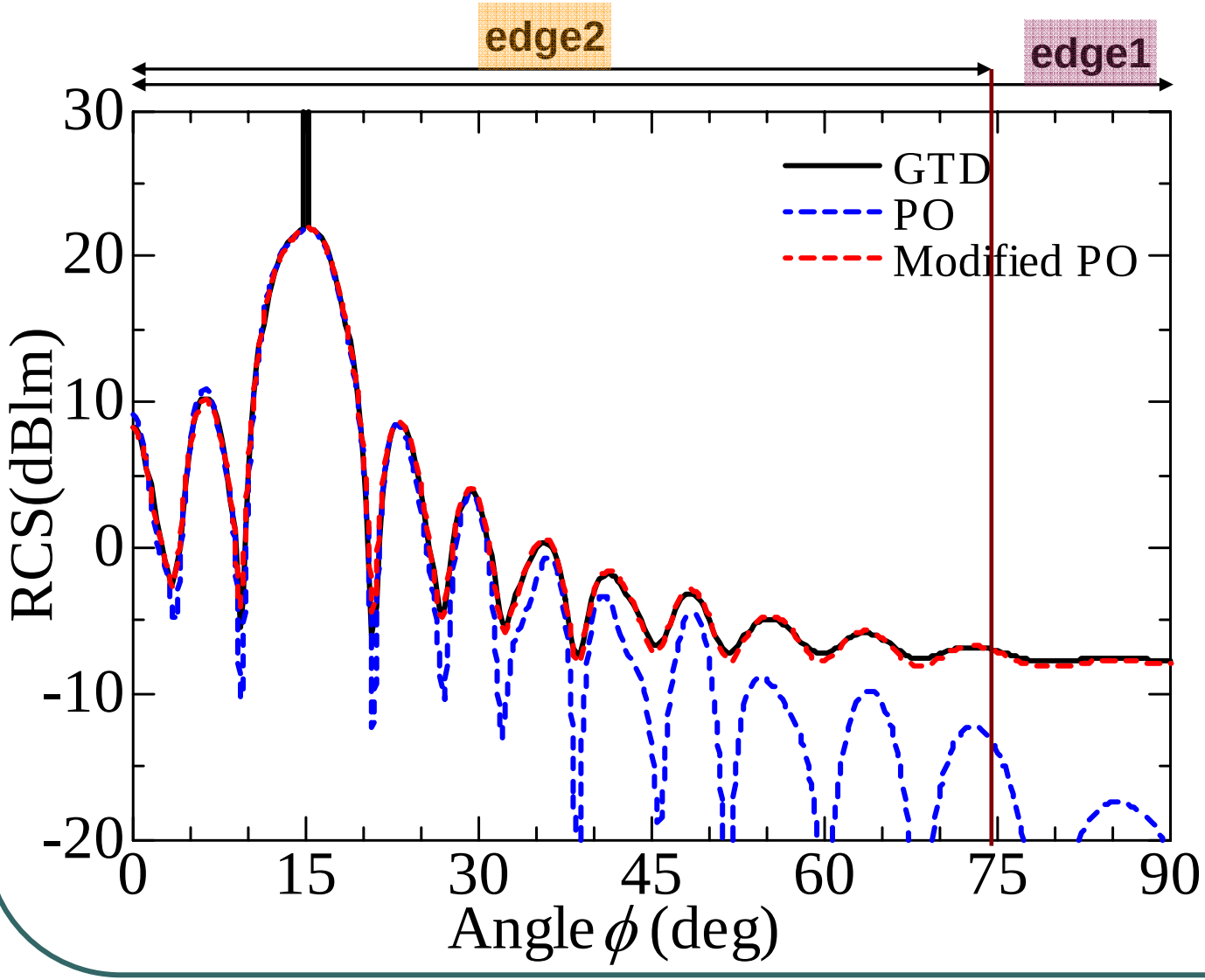
Accuracy Check for a Corner Reflector (E polarization)



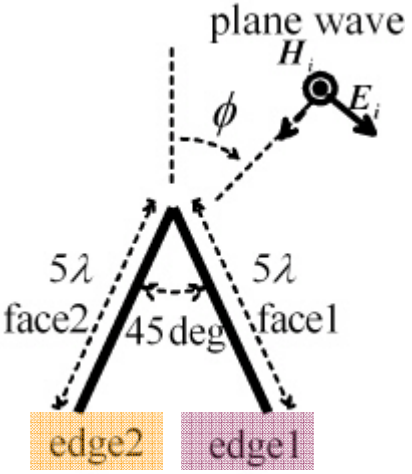


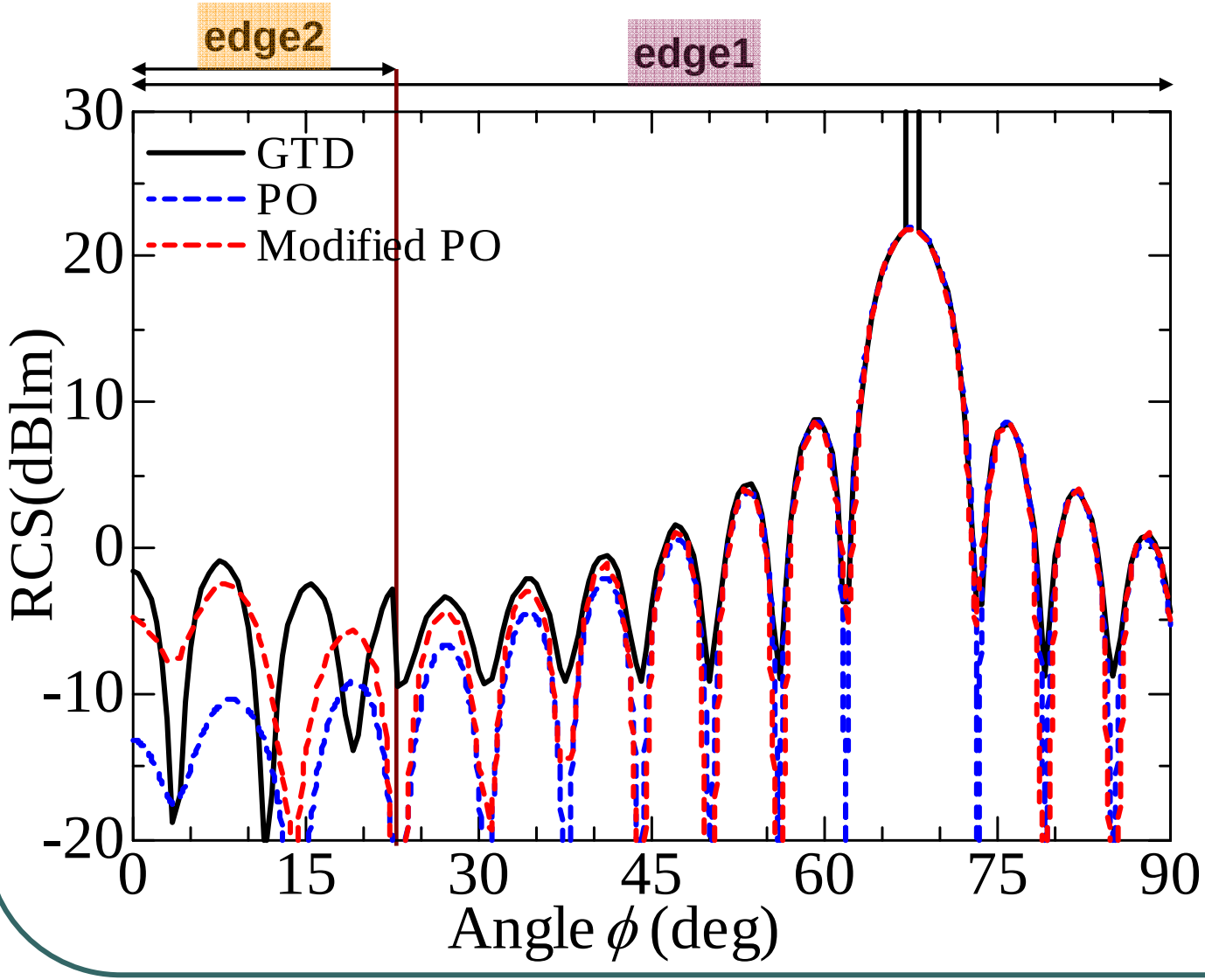
Accuracy Check for a Corner Reflector (E polarization)



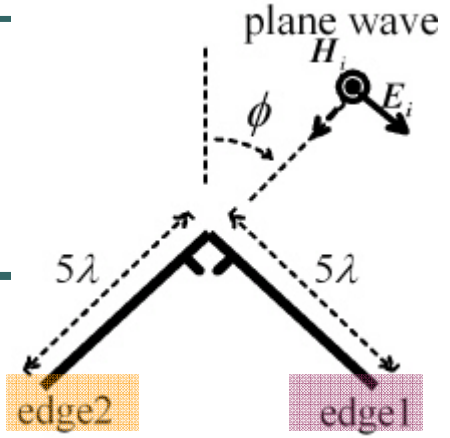


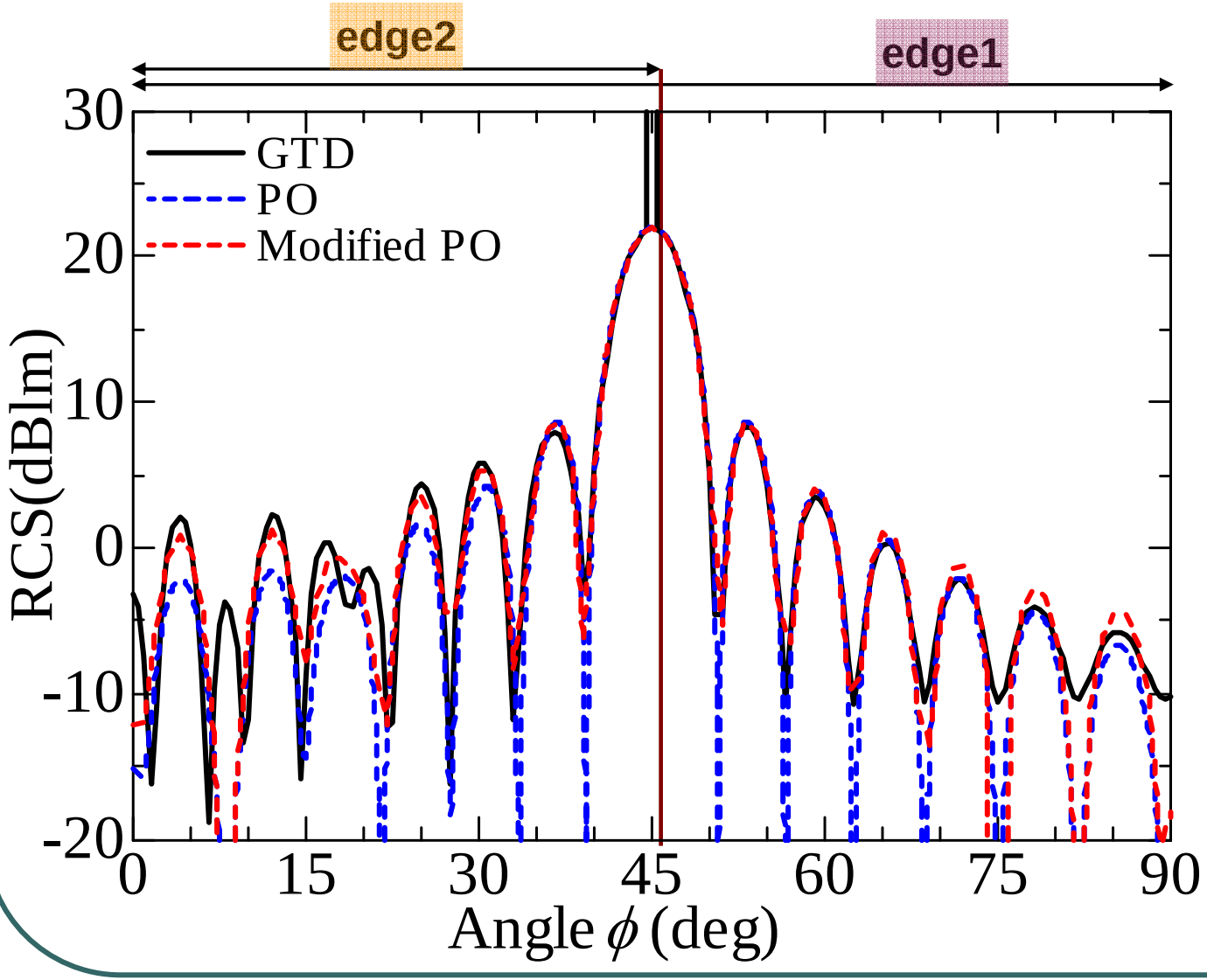
Accuracy Check for a Corner Reflector (H polarization)



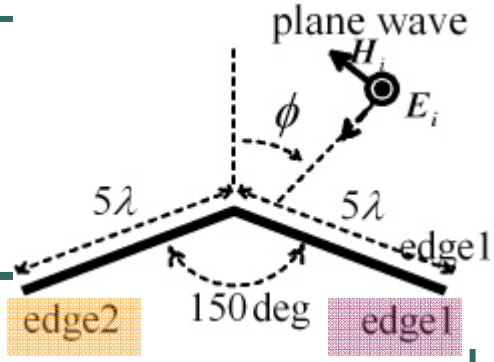


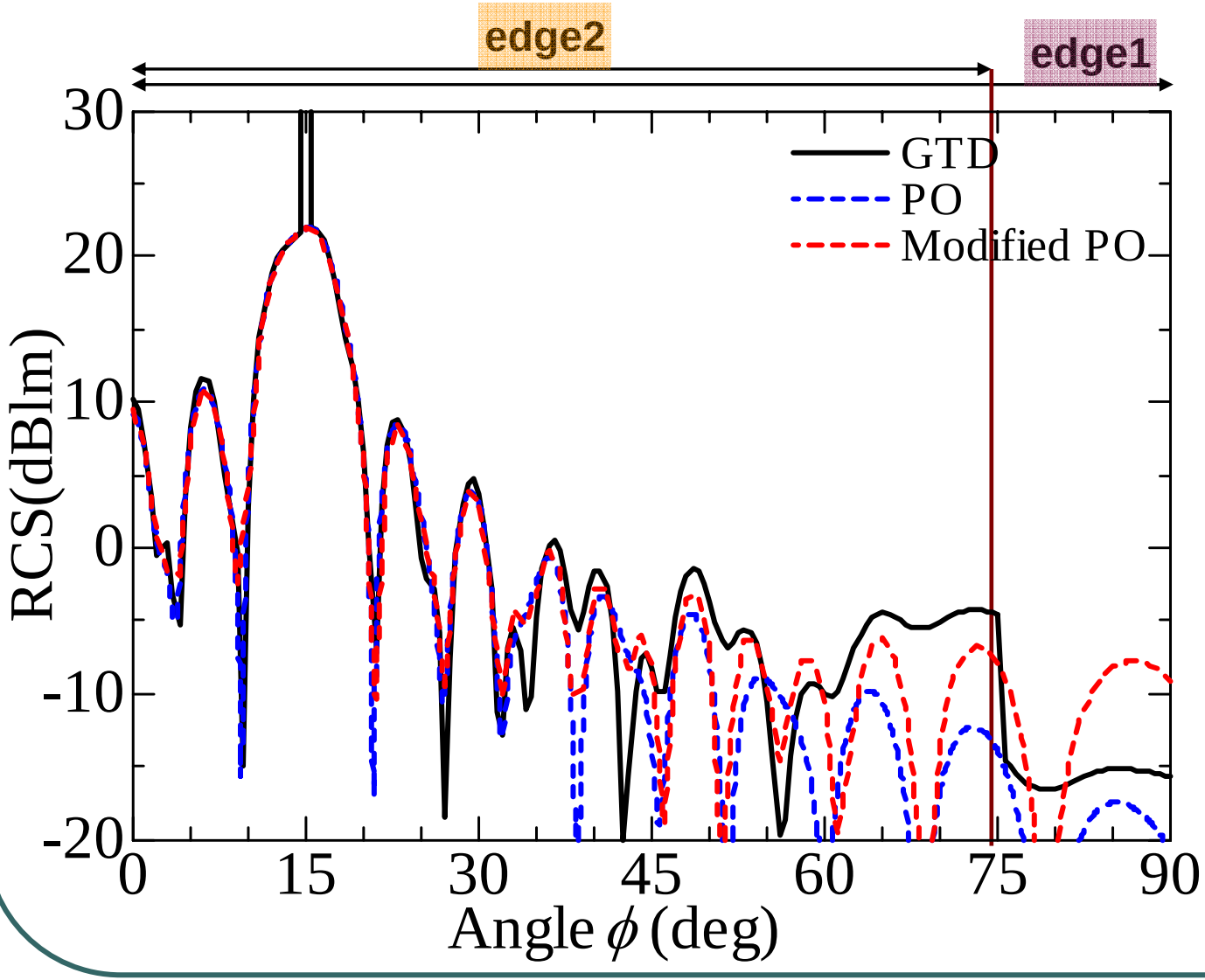
Accuracy Check for a Corner Reflector (H polarization)





Accuracy Check for a Corner Reflector (H polarization)

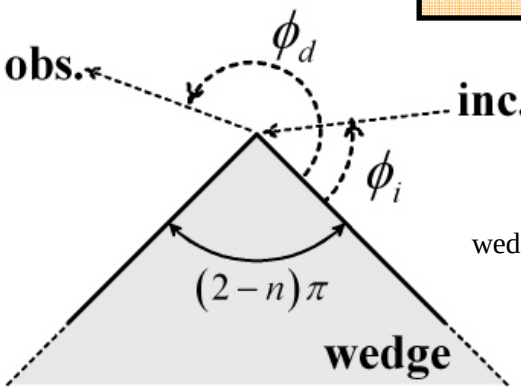




GTD diffraction coefficient

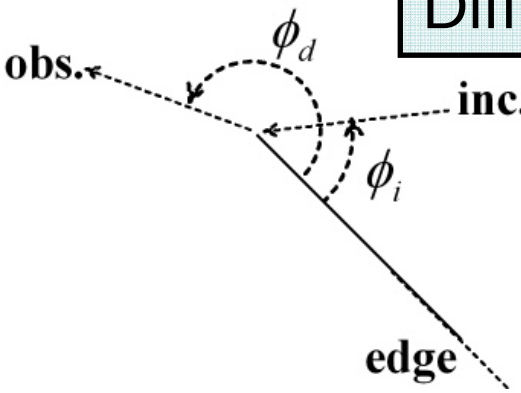
$$D^{\begin{bmatrix} s \\ h \end{bmatrix}} = D_i \, \text{m} \, D_r$$

Diffraction coefficient for *wedge*



$$_{\text{wedge}}D^{\begin{bmatrix} s \\ h \end{bmatrix}} = \frac{\sin\left(\frac{\pi}{n}\right)}{n}\left(\frac{1}{\cos\frac{\pi}{n} - \cos\frac{(\phi_d - \phi_i)}{n}} \, \text{m} \, \frac{1}{\cos\frac{\pi}{n} - \cos\frac{(\phi_d + \phi_i)}{n}} \right)$$

Diffraction coefficient for *edge*

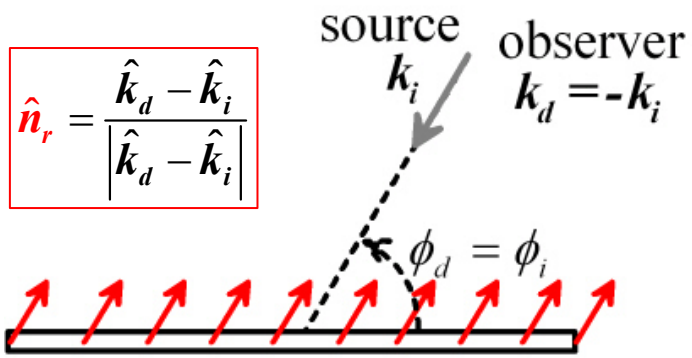


$$_{\text{edge}}D^{\begin{bmatrix} s \\ h \end{bmatrix}} = -\frac{1}{2}\left(\frac{1}{\cos\left(\frac{\phi_d - \phi_i}{2}\right)} \, \text{m} \, \frac{1}{\cos\left(\frac{\phi_d + \phi_i}{2}\right)} \right)$$

Simplification of the Modified Surface-normal Vectors in RCS

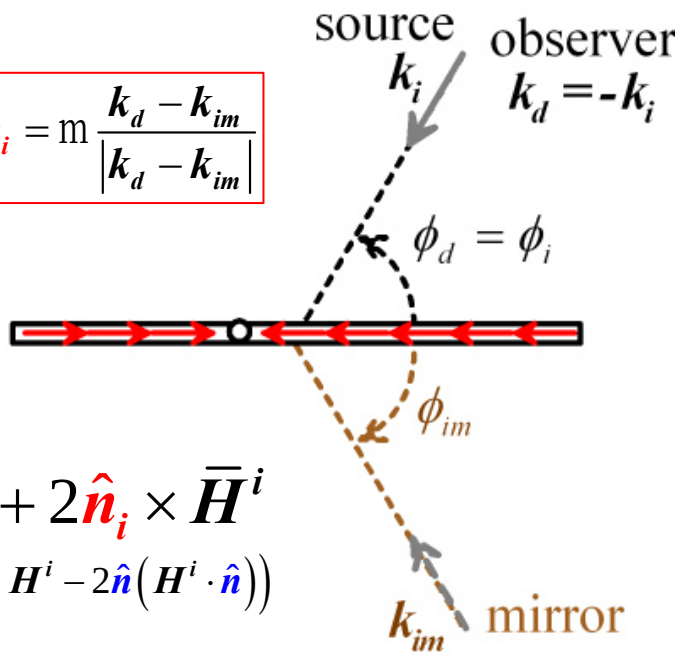
Reflection component

$$\hat{n}_r = \frac{\hat{k}_d - \hat{k}_i}{\left|\hat{k}_d - \hat{k}_i\right|}$$



Shadow component

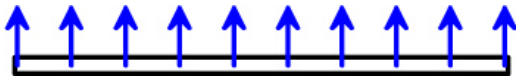
$$\hat{n}_i = \mathrm{m}\frac{k_d - k_{im}}{\left|k_d - k_{im}\right|}$$



$$J^{Modified-PO} = 2\hat{n}_r \times H^i + 2\hat{n}_i \times \bar{H}^i$$

$$\left(\bar{H}^i = H^i - 2\hat{n}\left(H^i \cdot \hat{n}\right)\right)$$

Original surface-normal vectors

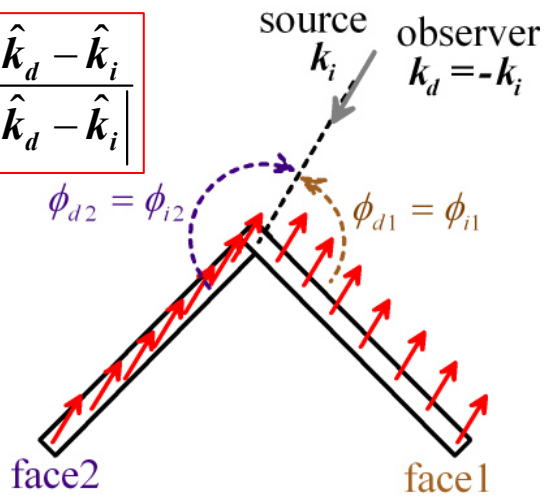


$$J^{PO} = 2\hat{n} \times H^i$$

Modified Surface-normal Vectors for a Corner Reflector in RCS

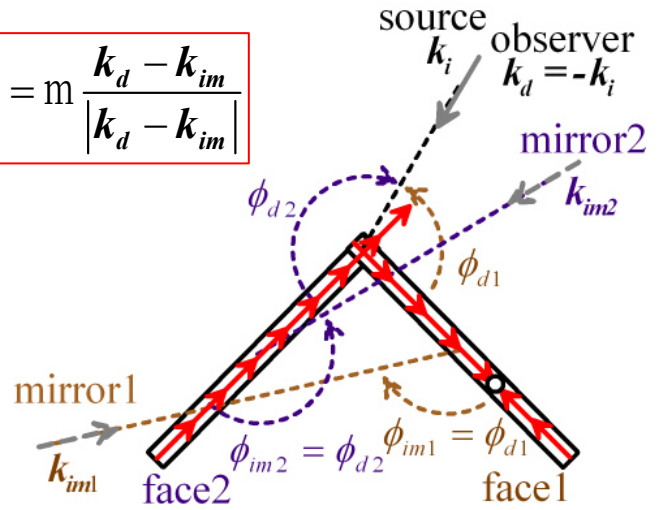
Reflection component

$$\hat{n}_r = \frac{\hat{k}_d - \hat{k}_i}{\left|\hat{k}_d - \hat{k}_i\right|}$$



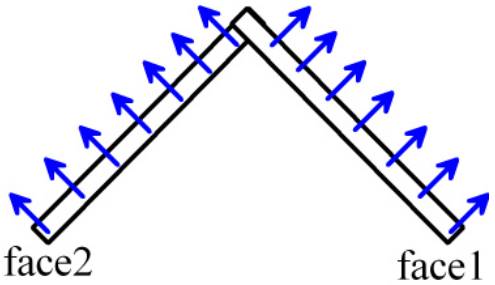
Shadow component

$$\hat{n}_i = \mathrm{m}\frac{k_d - k_{im}}{\left|k_d - k_{im}\right|}$$



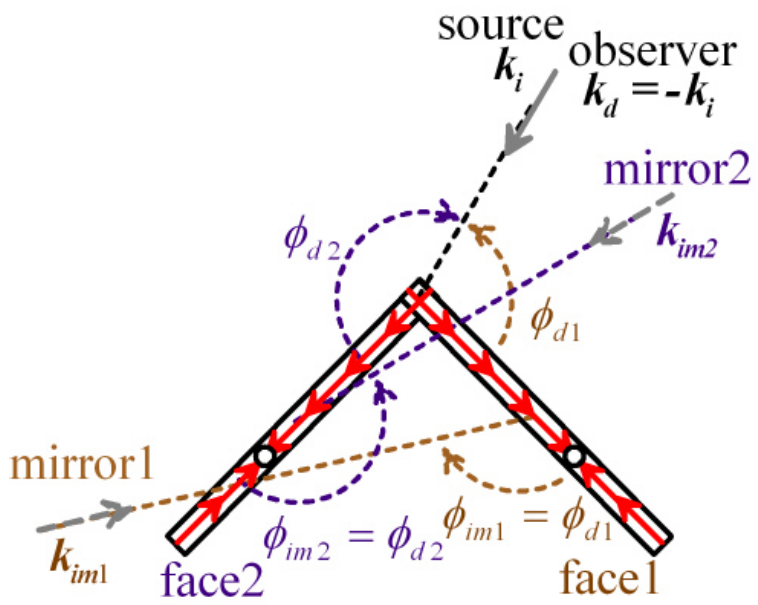
$$J^{Modified-PO} = 2\hat{n}_r \times H^i + 2\hat{n}_i \times \bar{H}^i \quad \left(\bar{H}^i = H^i - 2\hat{n}\left(H^i \cdot \hat{n}\right)\right)$$

Original surface-normal vectors

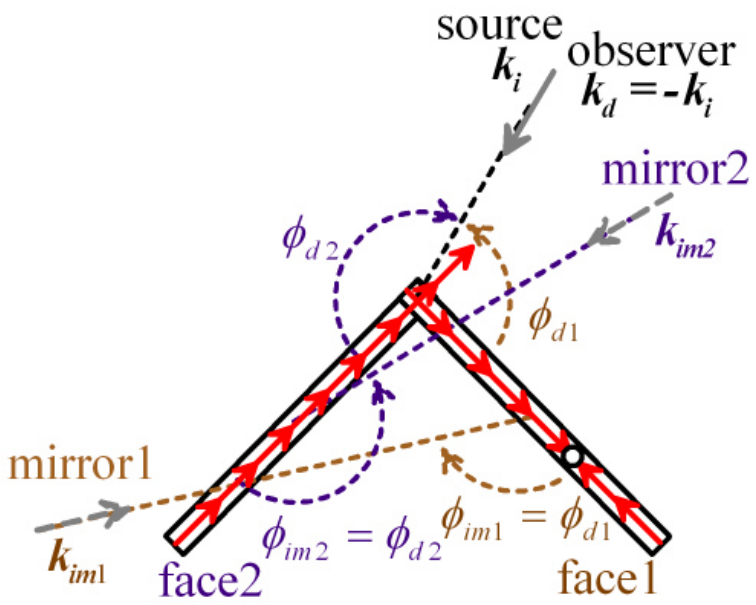


$$J^{PO} = 2\hat{n} \times H^i$$

Definition of ni Vectors for Shadow Component

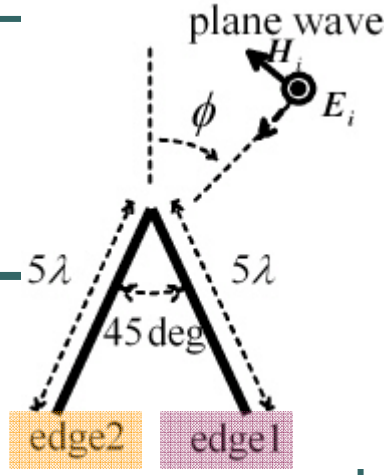


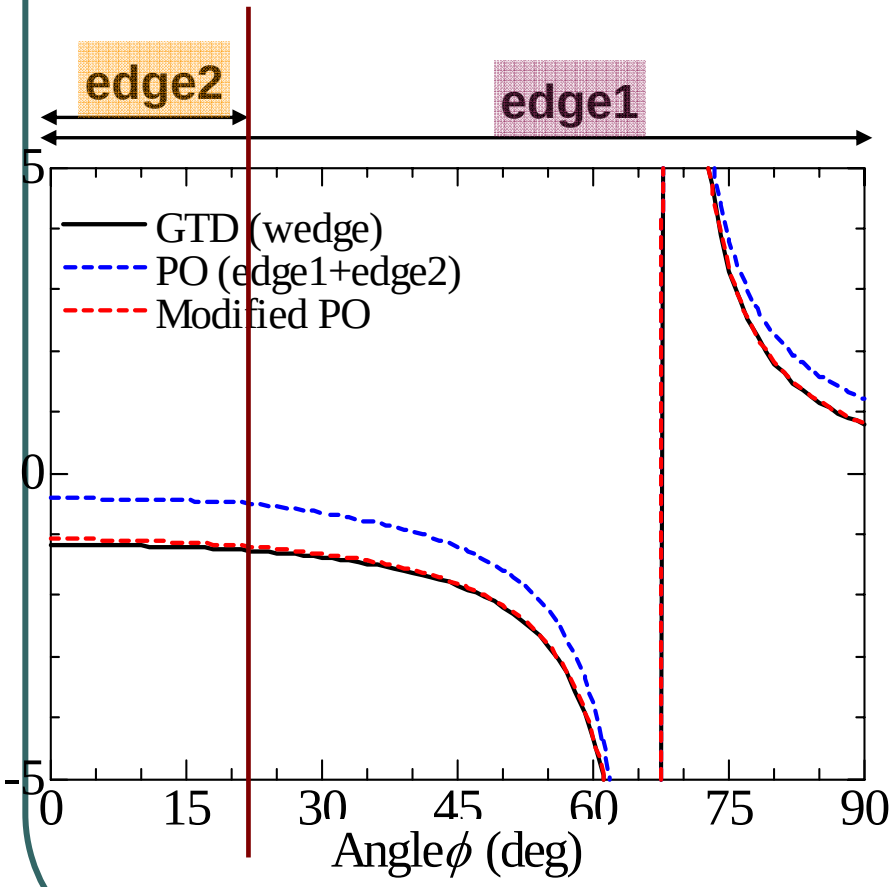
Pattern1



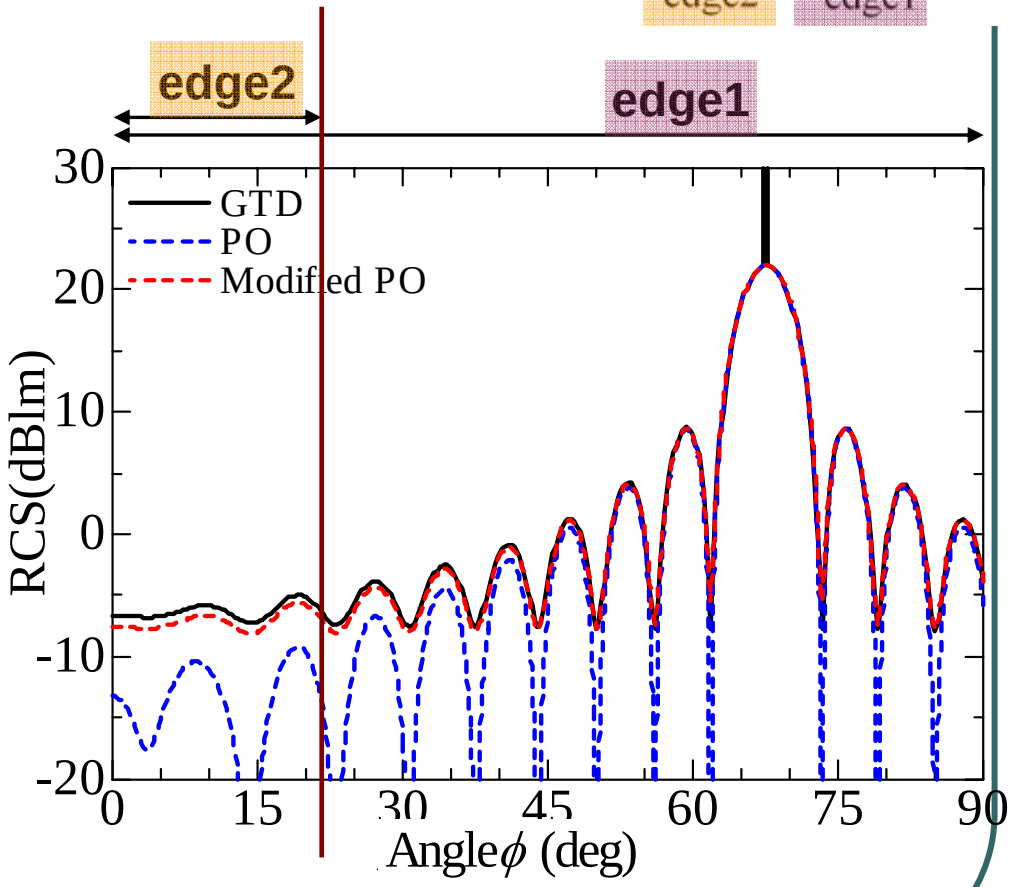
Pattern2

Accuracy Check for a Corner Reflector (E polarization)



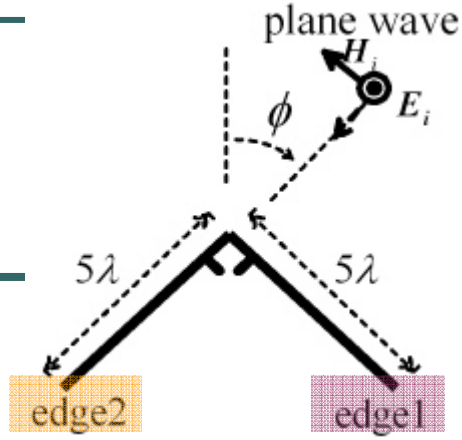


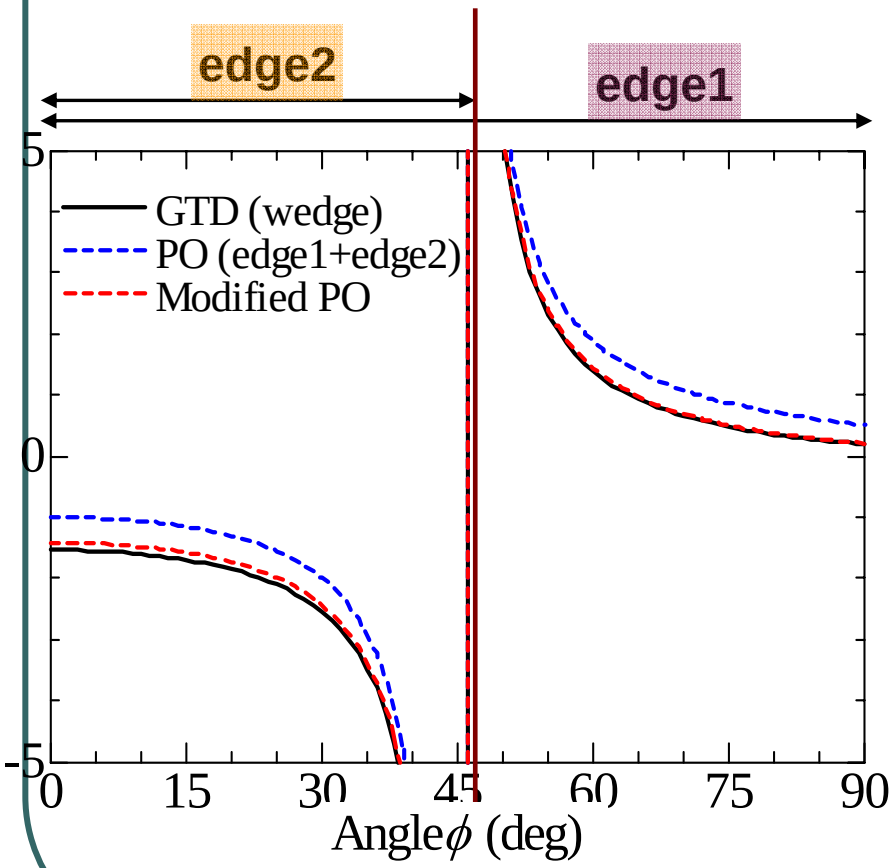
Diffraction coefficient



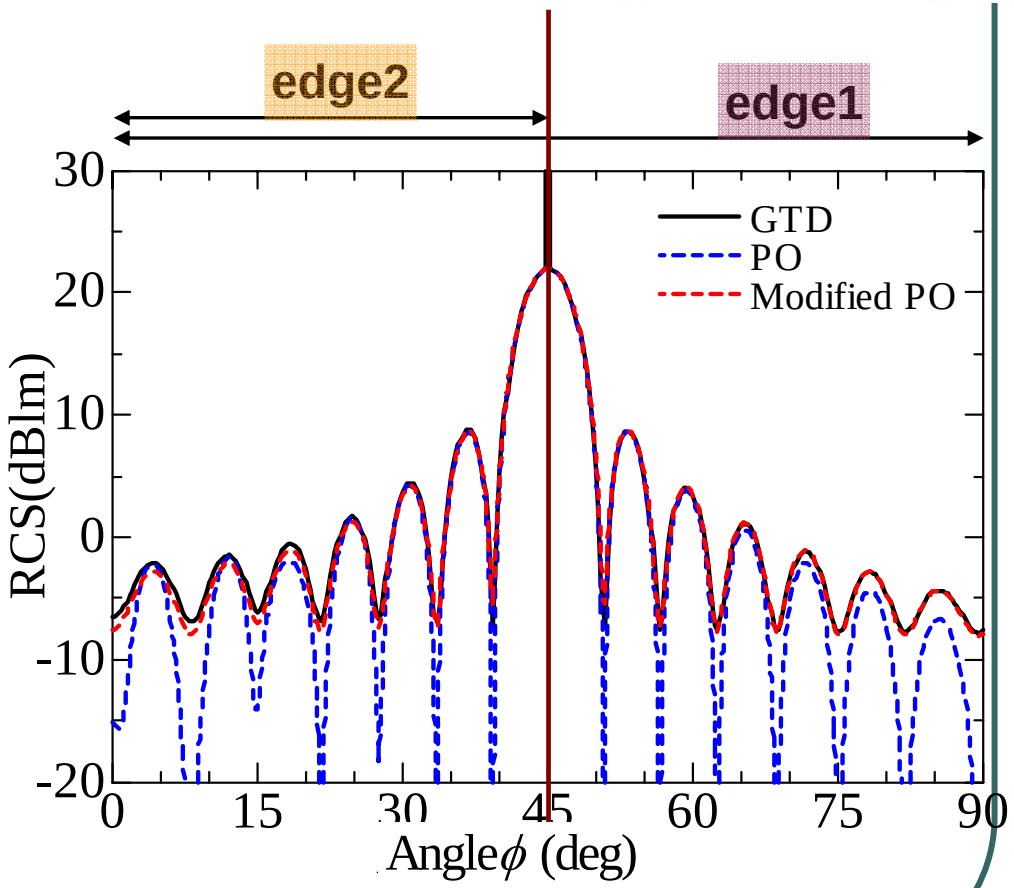
RCS analysis

Accuracy Check for a Corner Reflector (E polarization)



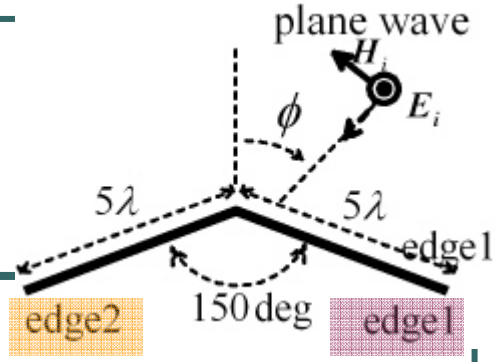


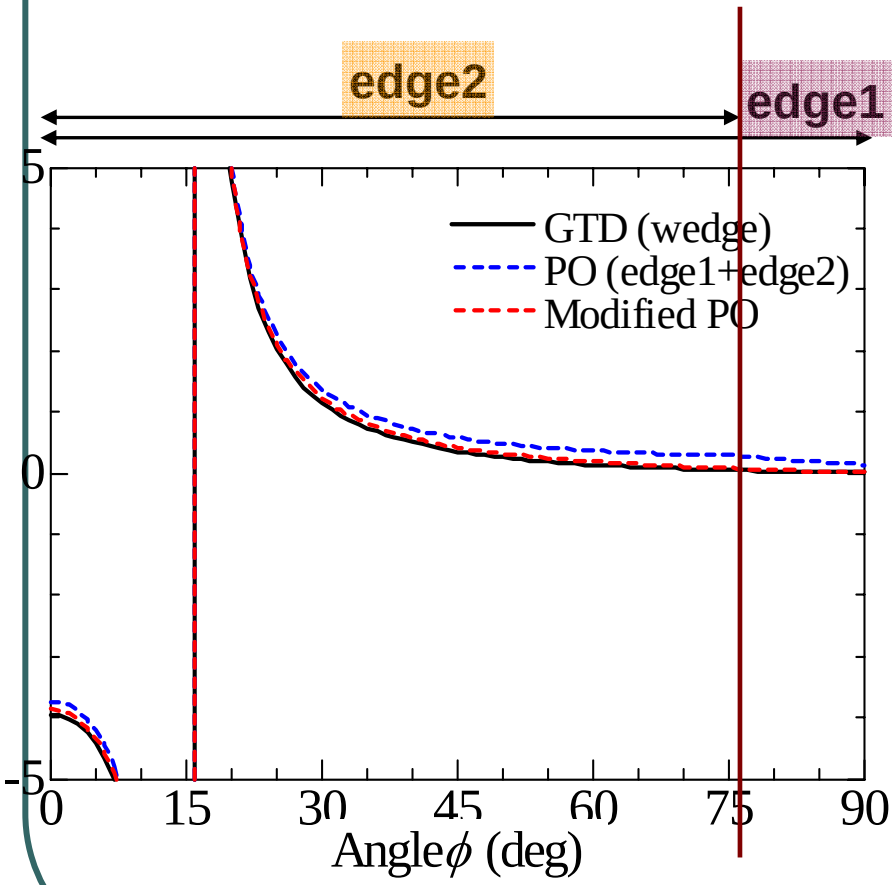
Diffraction coefficient



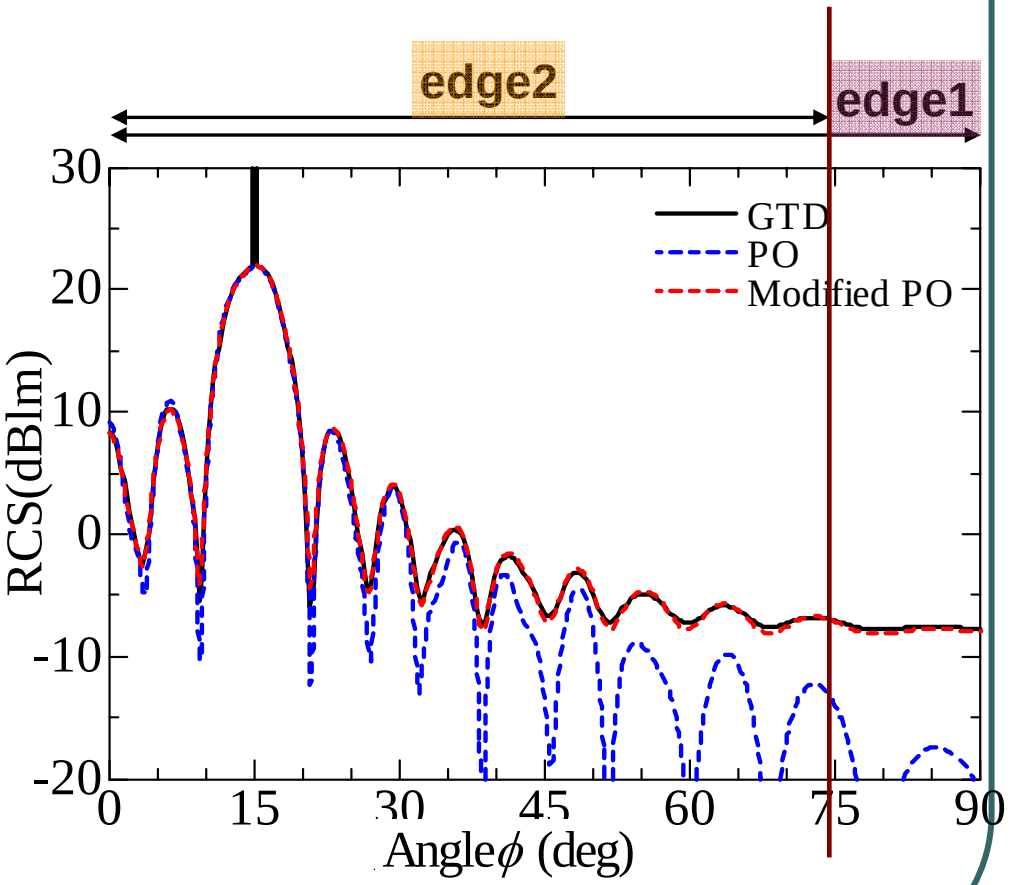
RCS analysis

Accuracy Check for a Corner Reflector



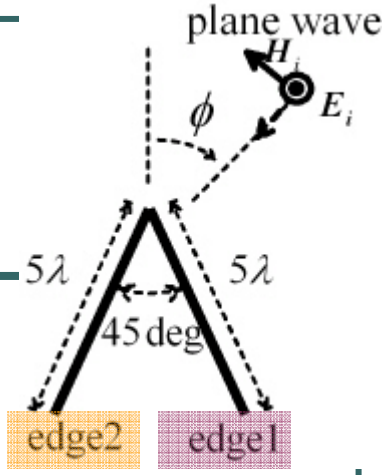


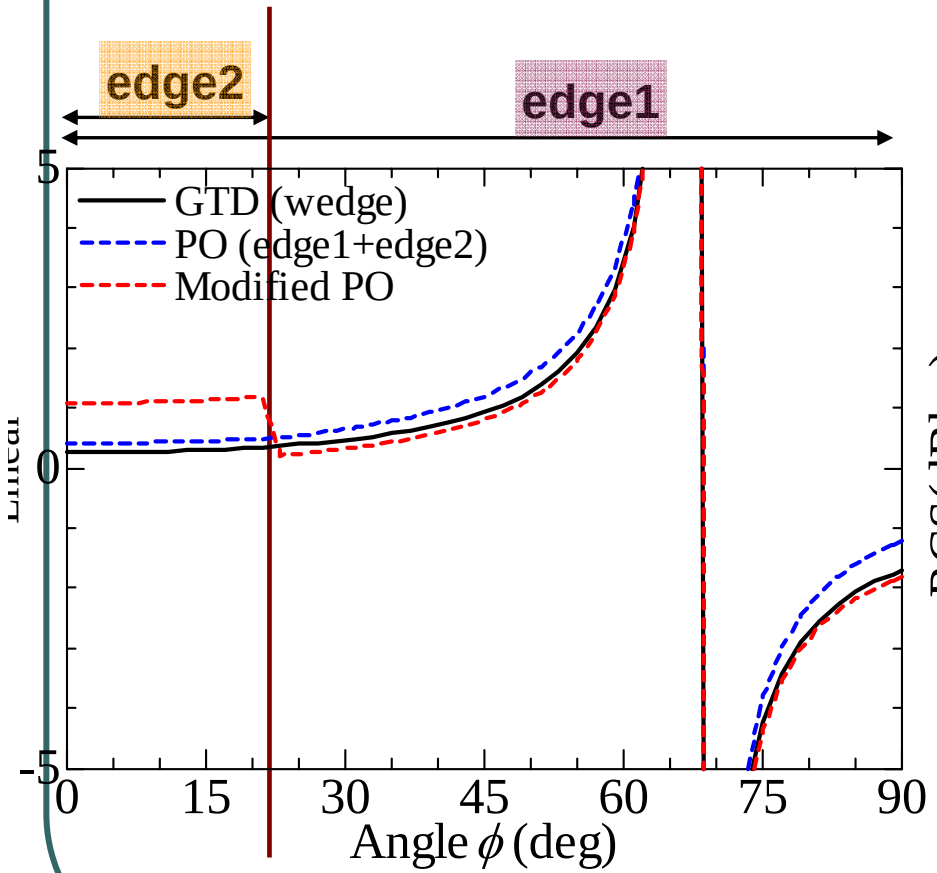
Diffraction coefficient



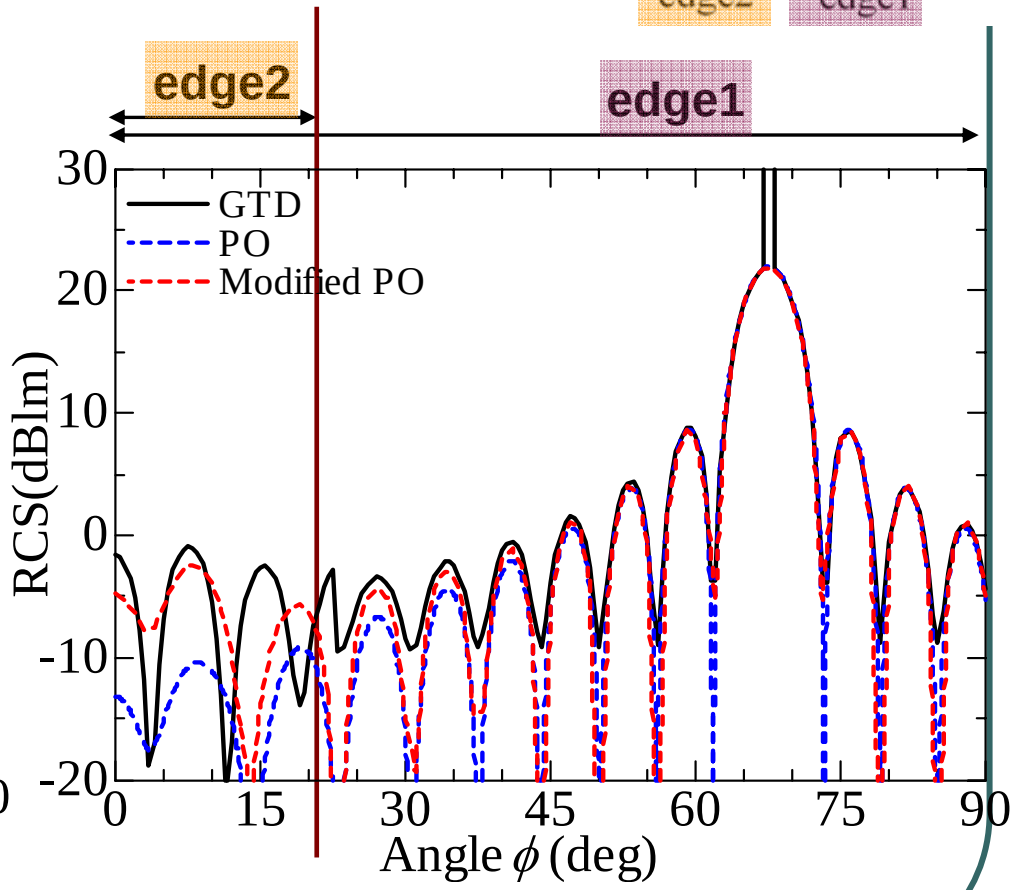
RCS analysis

Accuracy Check for a Corner Reflector (H polarization)



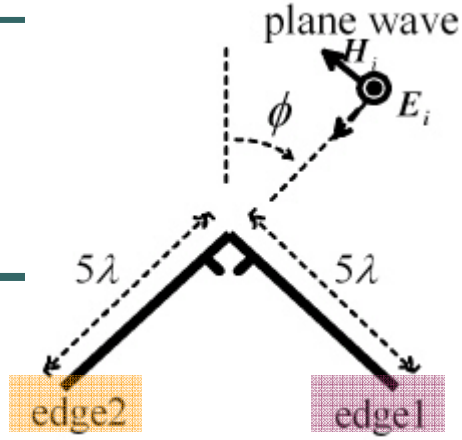


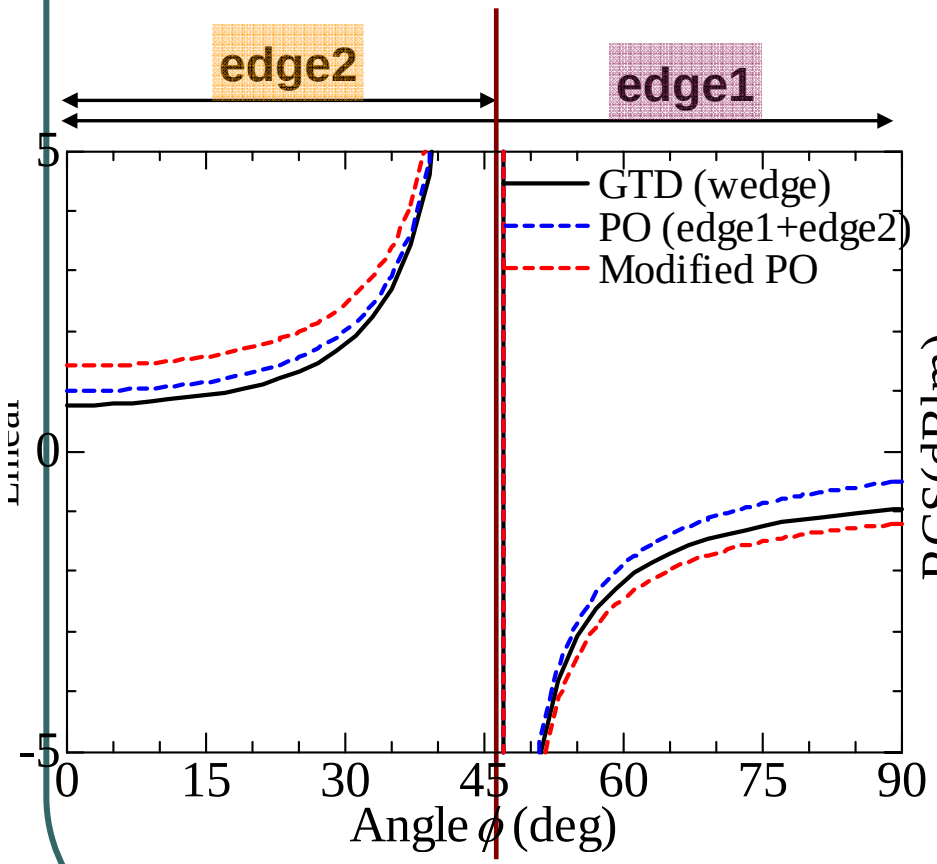
Diffraction coefficient



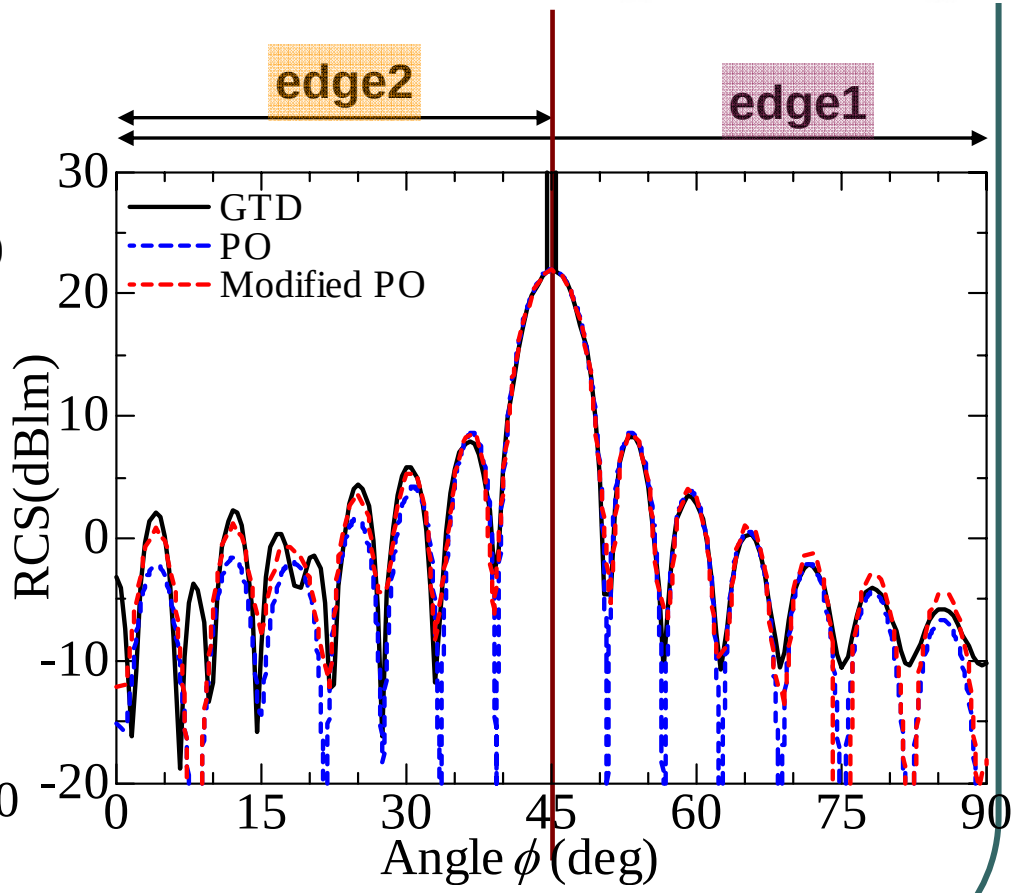
RCS analysis

Accuracy Check for a Corner Reflector (H polarization)



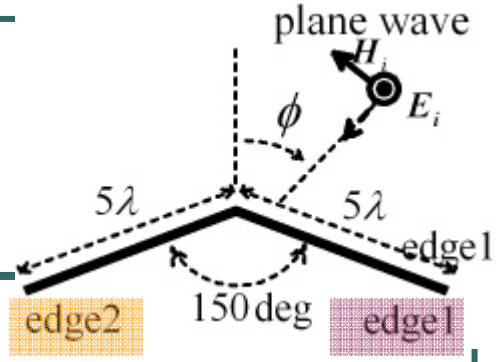


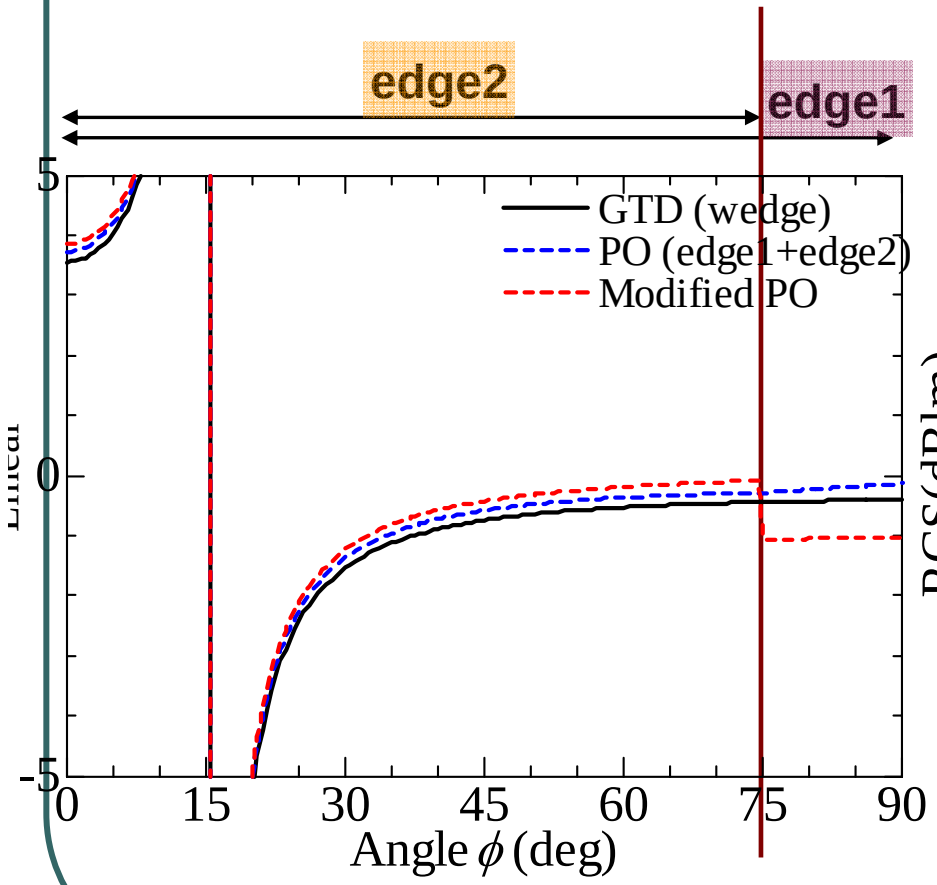
Diffraction coefficient



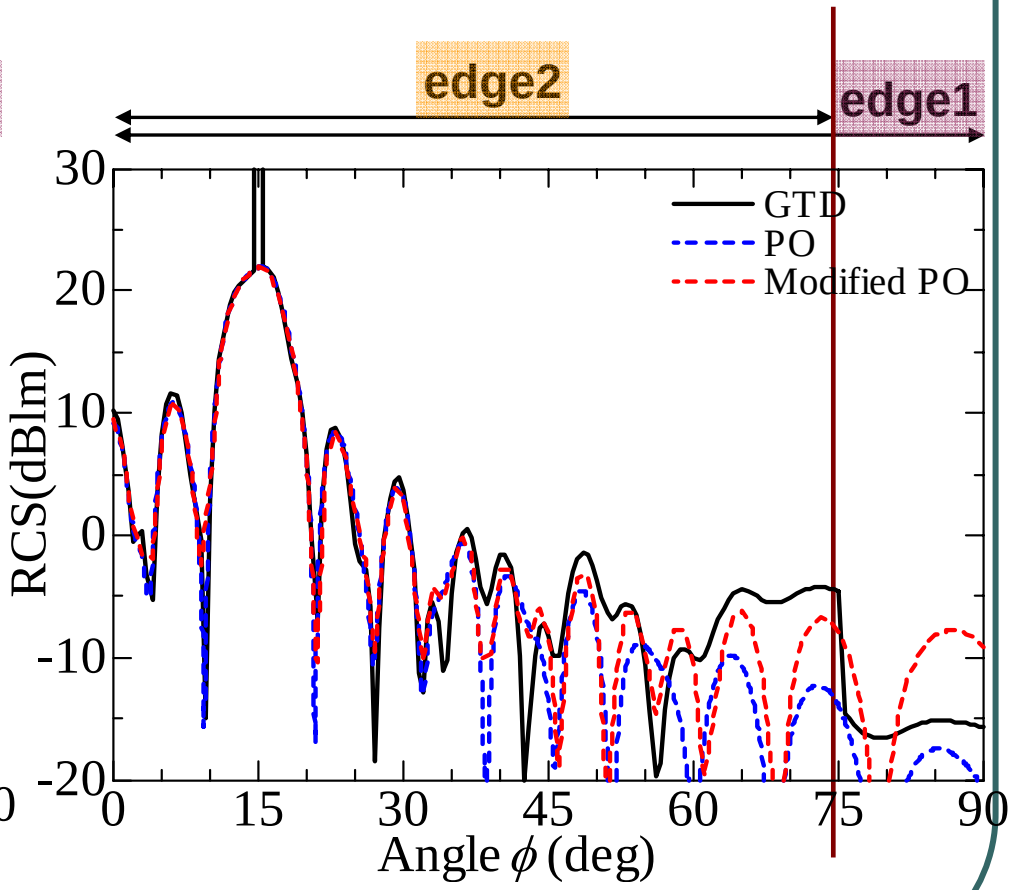
RCS analysis

Accuracy Check for a Corner Reflector (H polarization)





Diffraction coefficient

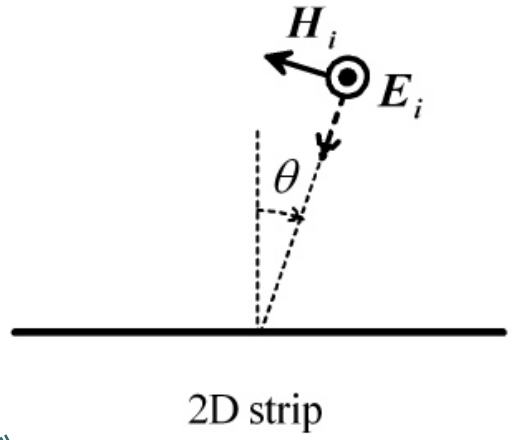


RCS analysis

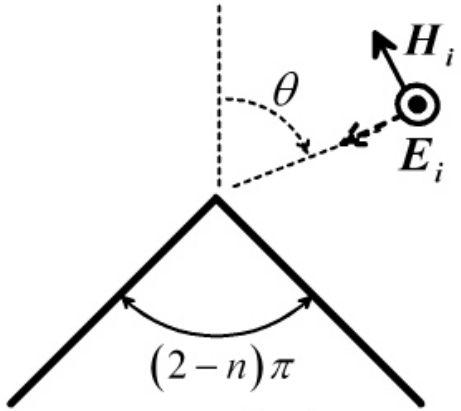
Samples

Application of ***the Modified PO*** to ***RCS (monostatic)***

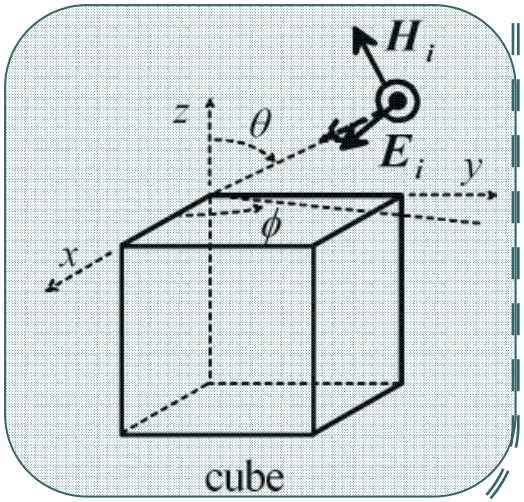
TARGETS



2D strip

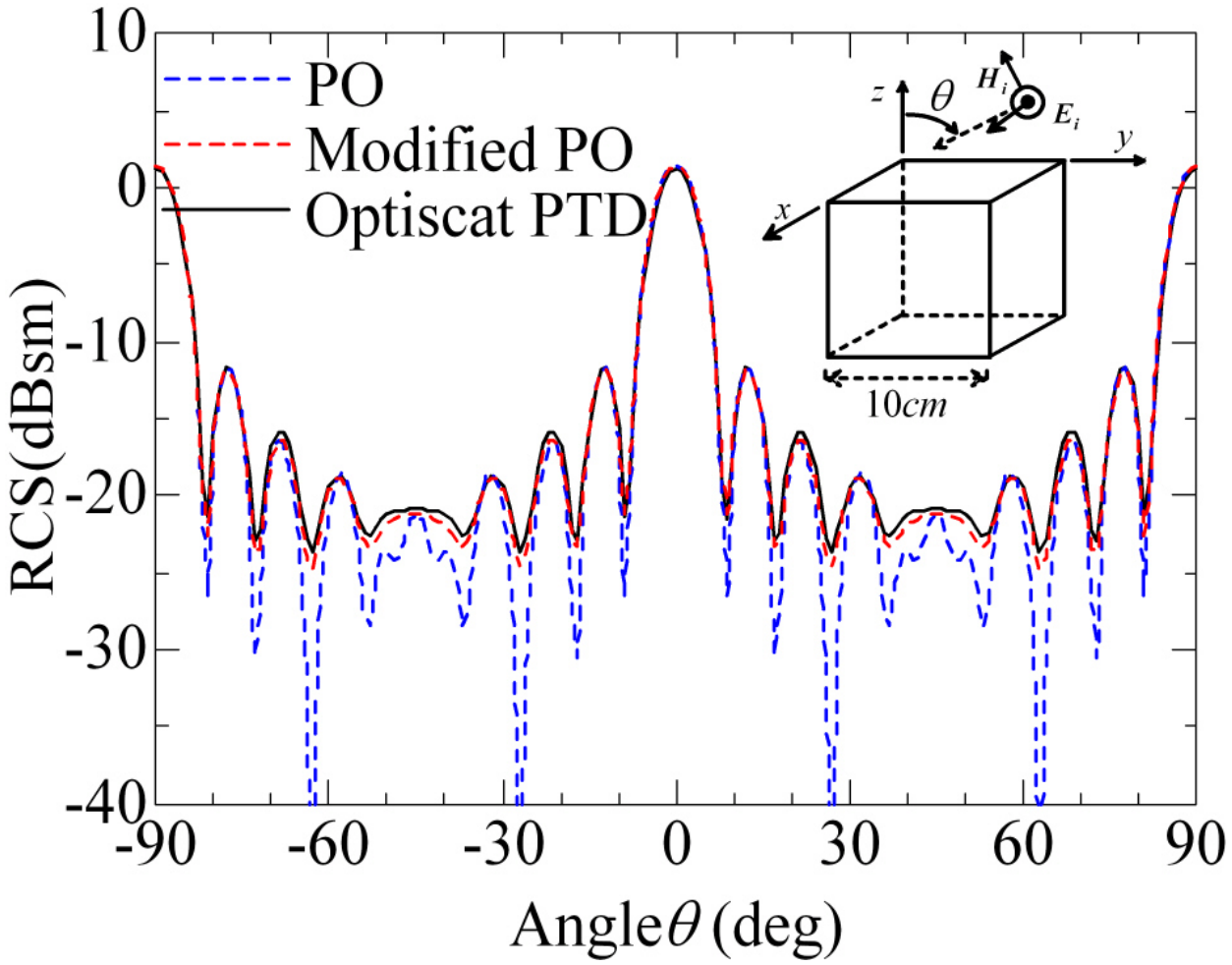


corner reflector

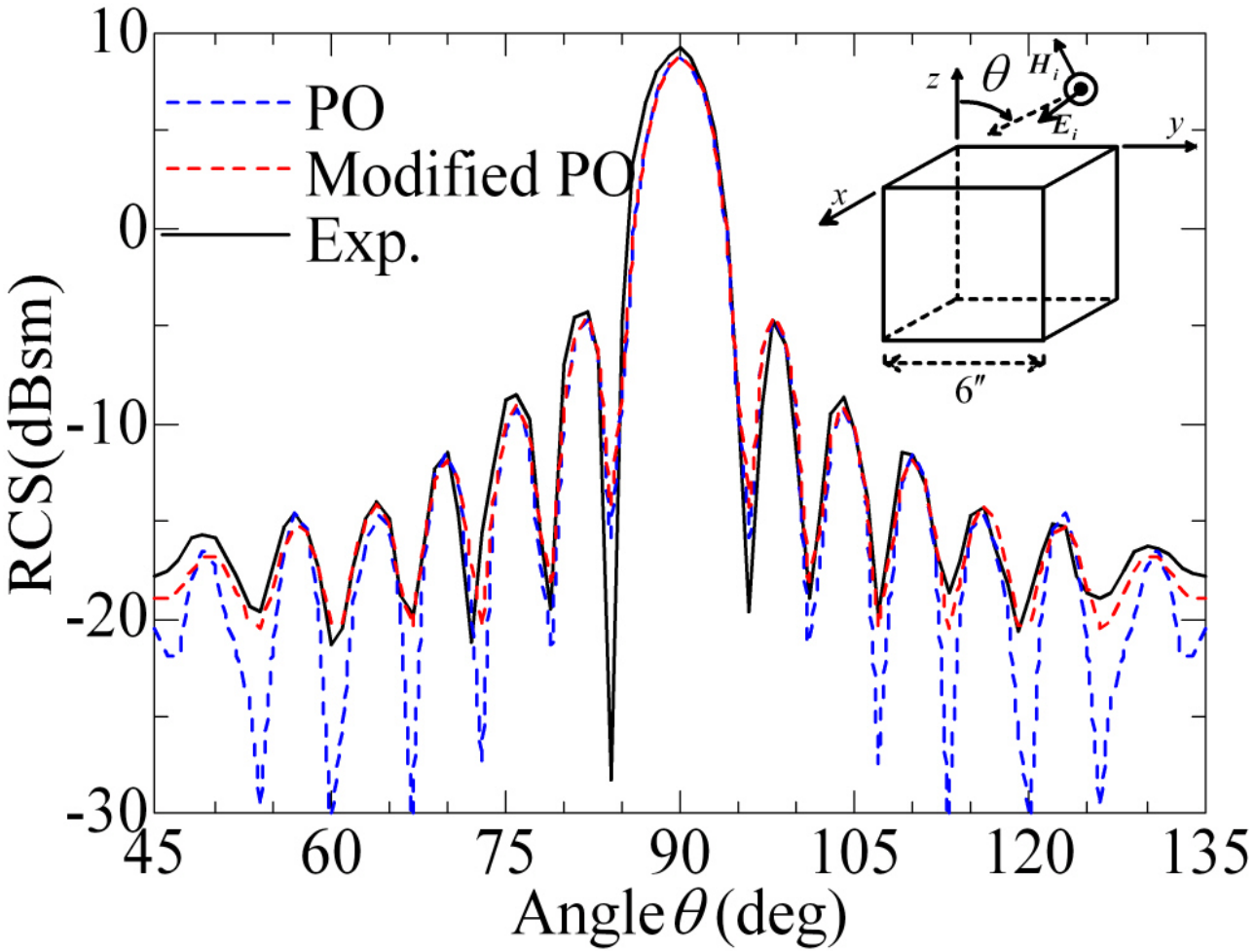


cube

RCS Comparison with PTD
10 cm Cube @ 10GHz (Ei // x incidence)

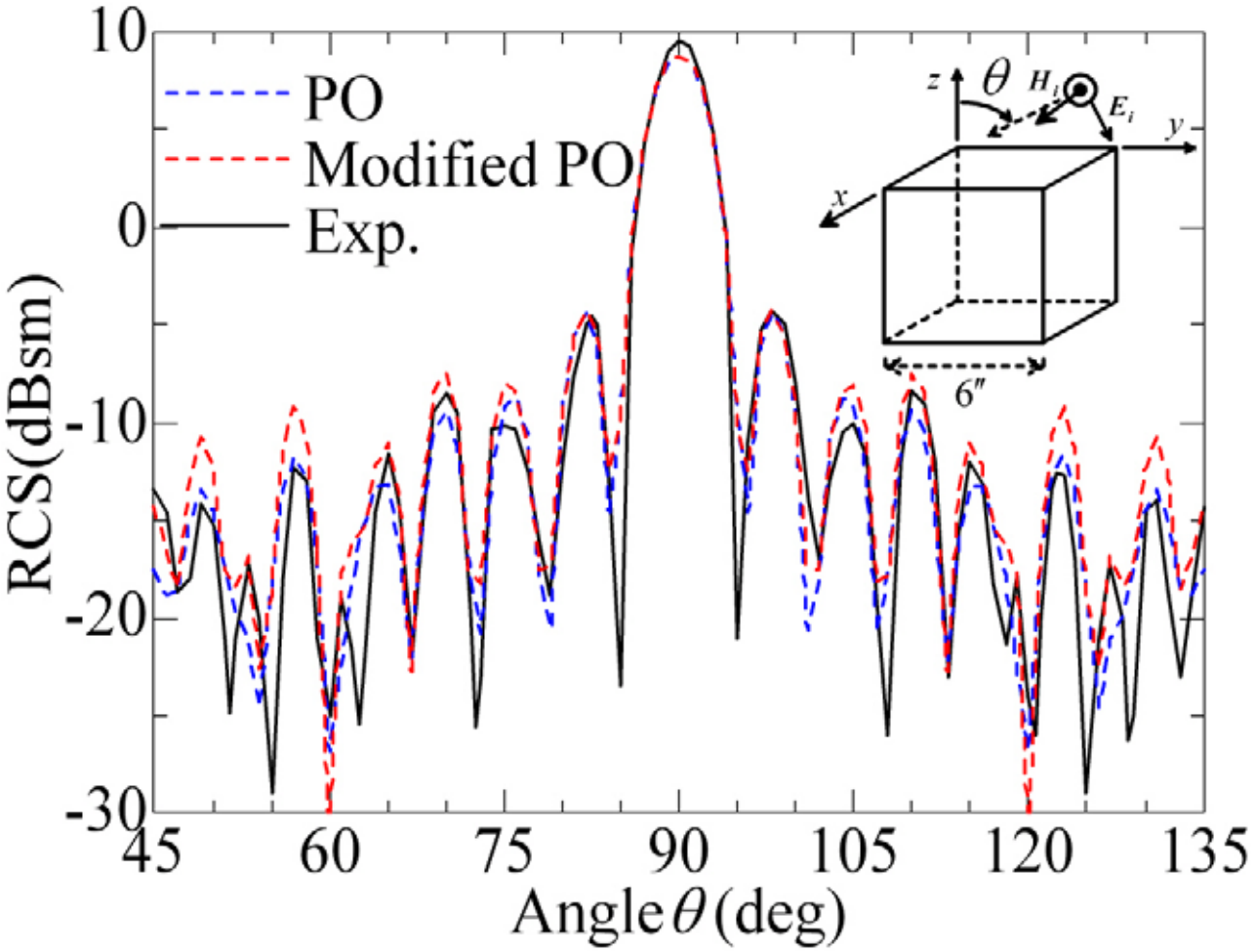


RCS Comparison with Experiments
6 inch Cube @ 10GHz (Ei // x incidence)



Exp. data from Natsuhara et al.[4])

RCS Comparison with Experiments
6 inch Cube @ 10GHz (Hi // x incidence)



Exp. data from Natsuhara et al.[4])

Outline

i. Background

ii. PO with modified normal vector (Modified PO)

iii. Objective

- ✓ *Simplified* surface-normal vectors for *RCS*
- ✓ Accuracy check for E wave incidence
  - ✓ for *edge* (sample: 2D-strip)
  - ✓ for *wedge* (sample: corner reflector)
    - ✓ *Analytical explanation* of the accuracy
  - ✓ for *3-D objects* comparison with experiments and PTD (sample: Cubes)

iv. Conclusion

- ✓ ***Higher accuracy*** (GTD) than PO

Conclusion

Application of ***the Modified PO*** to ***RCS (monostatic)***

- ✓ ***Simplified*** surface-normal vectors for ***RCS***
- ✓ ***Higher accuracy*** (GTD) than PO
- ✓ Analytical explanation to **wedge**

Future work

- ✓ Accuracy check to curved surface

References

[1] J. Goto, ‘’*Interpretation of high frequency diffraction based upon PO*,’’ bachelor thesis, Tokyo Institute of Technology, Tokyo, chap.3 (2003-3).

[2] Y. Z. Umul,”Modified theory of physical optics,” OPTICS EXPRESS, vol.12, no.20, Oct. 2004 Page(s) 4959-4972

[3] T. Shijo, L. Rodriguez, M. Ando, “*Accuracy demonstration of physical optics with modified surface-normal vectors*” *Antennas and Propagation Society International Symposium 2006, IEEE* , 9-14 July 2006 Page(s):1873 – 1876

[4] K. Natsuhara, T. Murasaki, and M. Ando “*Equivalent Edge Currents for Arbitrary Angle Wedges Using Paths of Most Rapid Phase Variation*”, IEICE Trans. Electron., Vol. E75-C, No.9 Sep. 1992

[5] Robert G. Kouyoumjian, senior member, IEEE, and Prabphakar H. Pathak, “A Uniform Geometrical Theory of Diffraction for an Edge in a Perfectly Conducting Surface”, Proceedings of IEEE, Vol. 62, No. 11 November 1974