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Modeling complex structures in electromagnetics using hybrid algorithm

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Presentation Outline

- Introduction
- Research motivation
- Common CEM techniques
- Problem definition
- Past research work
- Novel hybrid technique
- Numerical examples and simulation results
- Observations
- Future research
- References

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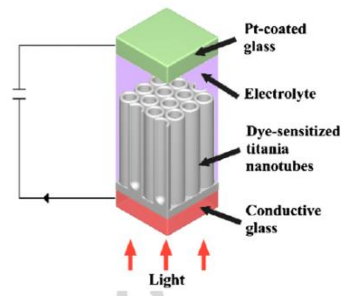
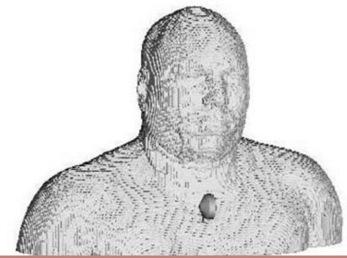
Introduction: Modeling Challenges in Current Technologies

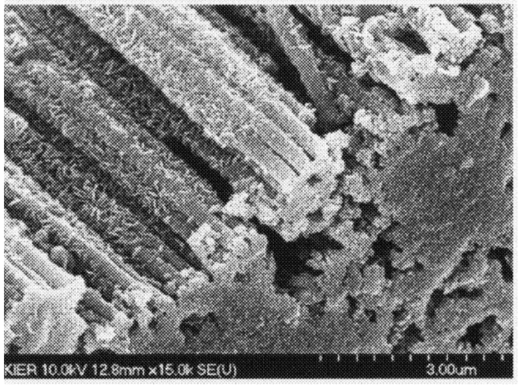


A cartoon drawing of the titania nanotube dye-sensitized solar cell.

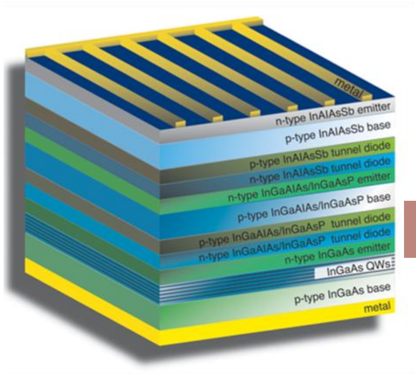


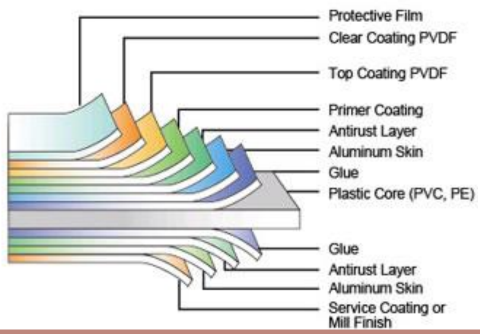
Embedded Antenna (Multiscale)

Nano Rods (Thin and Long)

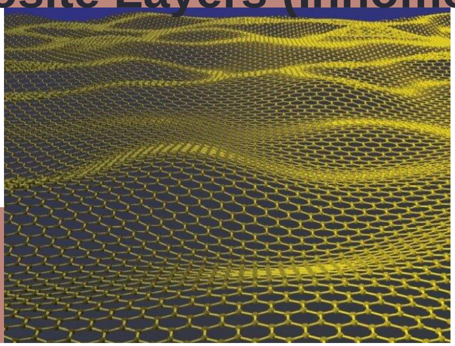


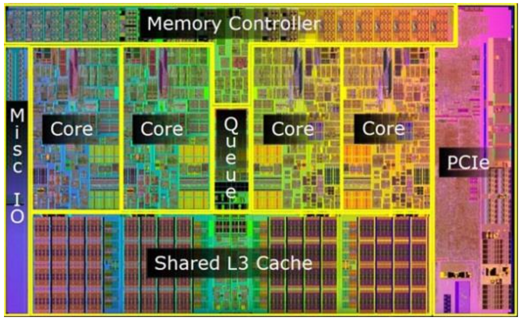
Solar Cells (Plasmonics)





Composite Layers (Inhomogeneous)





Graphene
(Fine Thickness)

Sub micron Die (Signal Integrity)

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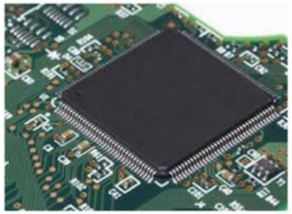
Research Motivation

- Ubiquity of complex multi-scale problems in numerical electromagnetics

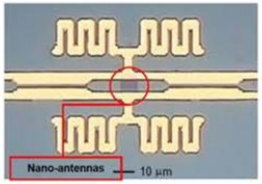
Body area networks

Conformal printed antennas and circuits

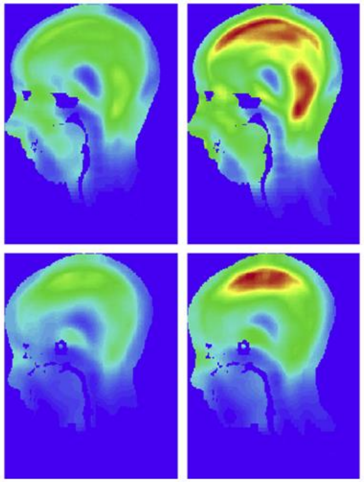
High-speed interconnects



Integrated circuits



Nano-antennas



MRI scanning using rapid 7T coil

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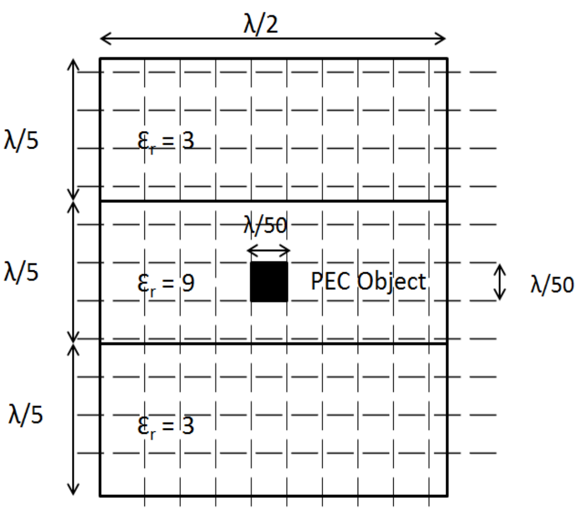
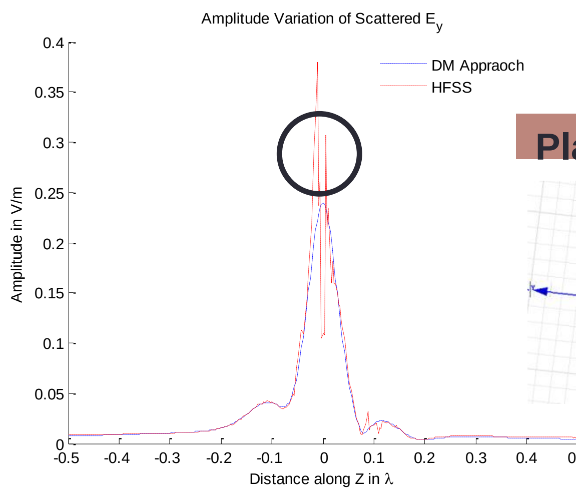
Research Motivation

- Simulation of structures with multi-scale features is highly challenging

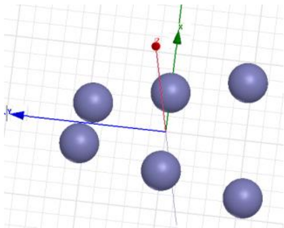


Fine feature captured by conventional FDTD mesh

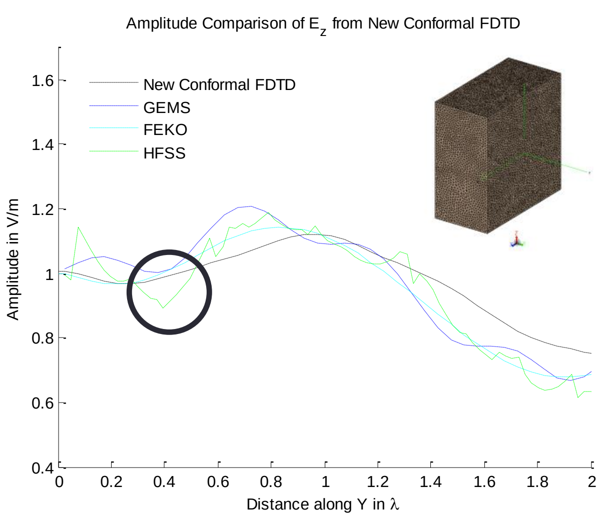


Spurious Ripples!

Plasmonic Nano-spheres



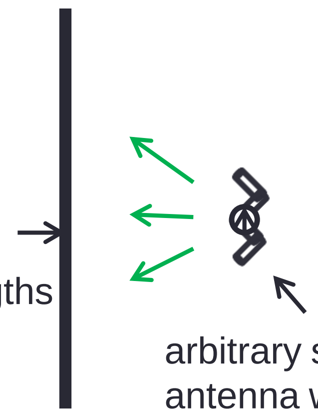
Dielectric Cuboid



Common CEM techniques

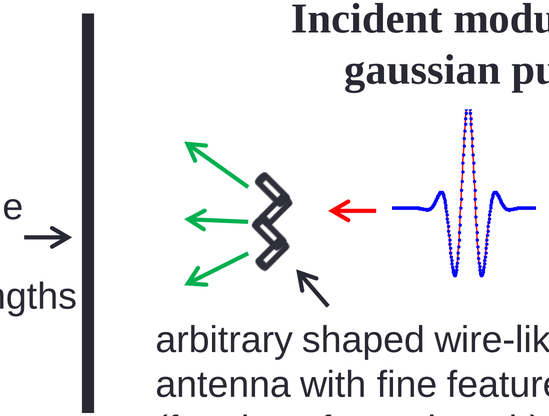
- FDTD
  - Solves for a wide frequency range
  - Computationally expensive when handling fine structures, resonant structures, and dispersive media
- MoM
  - Solves at a single frequency
  - Singularity extraction requires special treatment
  - Handles dispersive media well, but computationally expensive when handling fine structures
- FEM
  - Solves at a single frequency
  - Computationally expensive for fine and resonant structures
- FIT
  - Solves for a wide frequency range
  - Computationally expensive when handling fine structures, resonant structures, and dispersive media

Problem definition: Example of a multi-scale problem in numerical electromagnetics



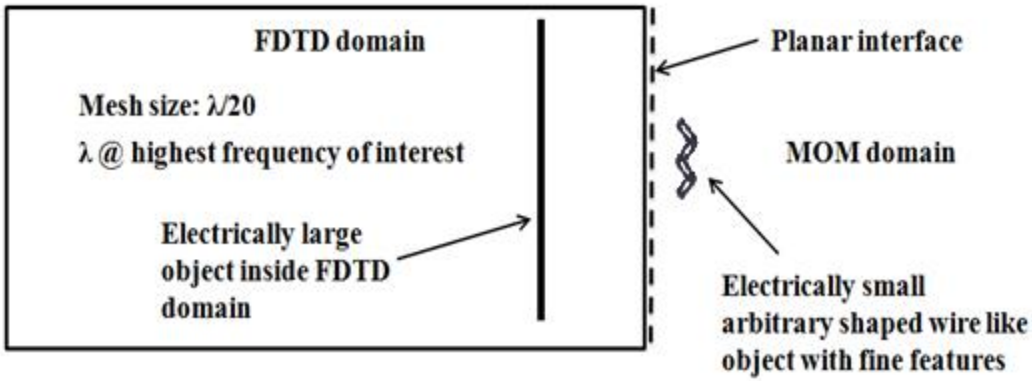
Transmit case
(wire-like antenna is the source)

OR



Receive case
(external plane wave is the source)

Proposed hybrid technique



The novel hybrid FDTD technique combines the MoM and FDTD techniques directly in the time domain

Fine features are handled by MOM code

⇓

Special basis functions are used to represent current on wire-like geometries with fine features

⇓

Time domain scattered fields are sampled at a planar interface

⇓

Sampled time domain scattered fields are then combined with the conventional FDTD update equations

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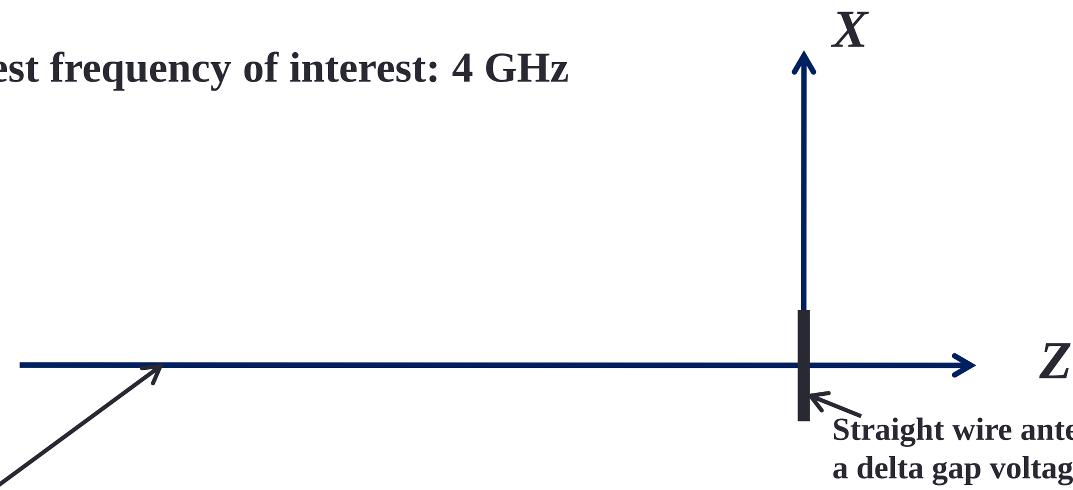
Problem Definition – validation of MoM code

λ @ highest frequency of interest: 4 GHz



Straight wire antenna of length 0.75 cm with a delta gap voltage source

Observation Line

Wire antenna radius = 0.005*length

A straight wire is directed along x.
Length of the straight wire is 0.75 cm

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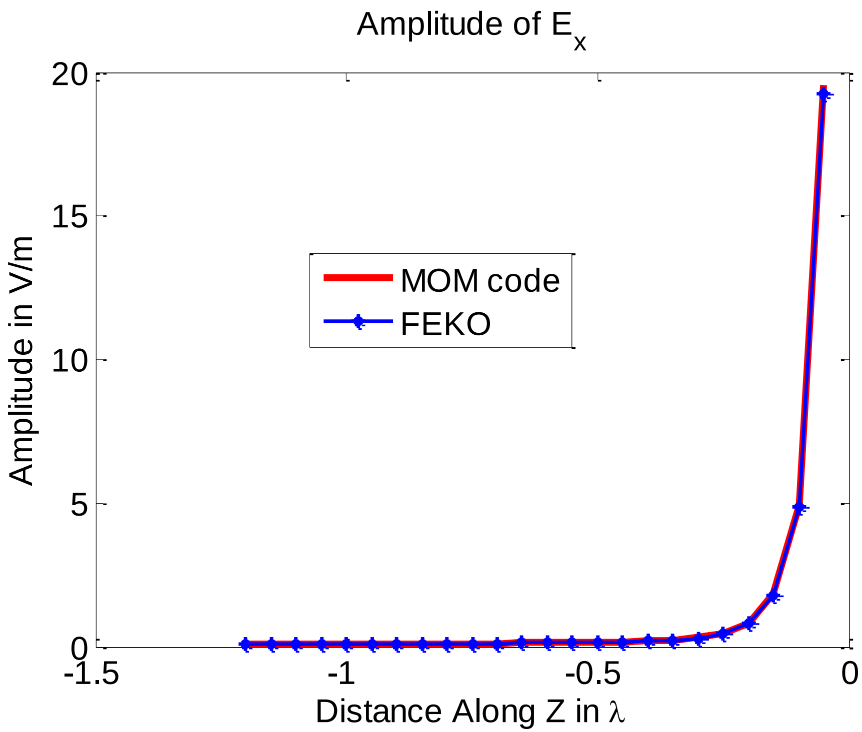
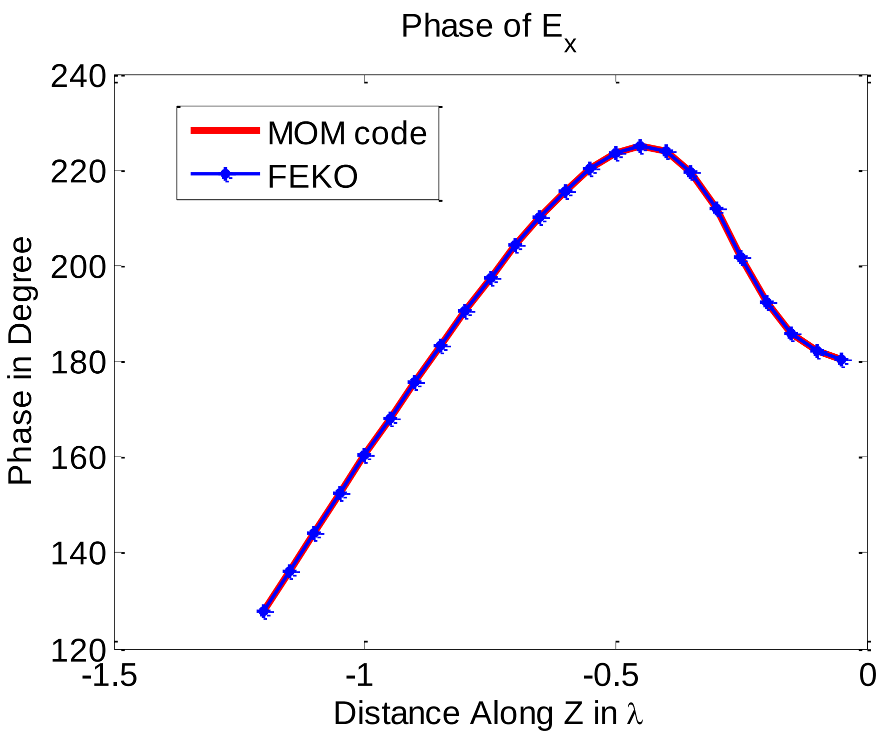
MoM code vs FEKO results



Magnitude comparison



Phase comparison

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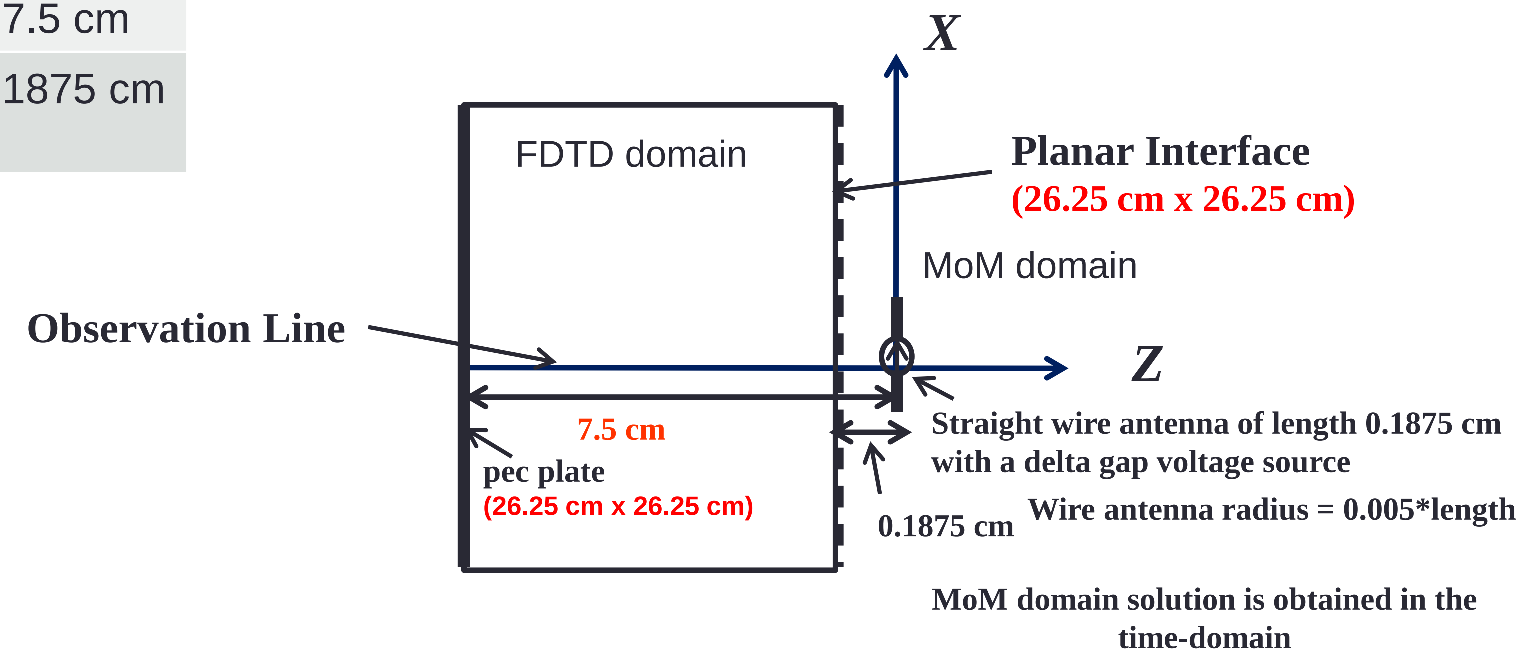
Transmit Case: Example 1

Variable	Value
λ	3.75 cm
λ_0	7.5 cm
$\lambda/20$	0.1875 cm

FDTD domain mesh size: $\lambda/20$

λ @ highest frequency of interest: 8 GHz
λ_0 @ center frequency of interest: 4 GHz



A straight wire antenna is directed along x at a distance of 7.5 cm from a pec plate
Length of the straight wire antenna is 0.1875 cm from the wire antenna

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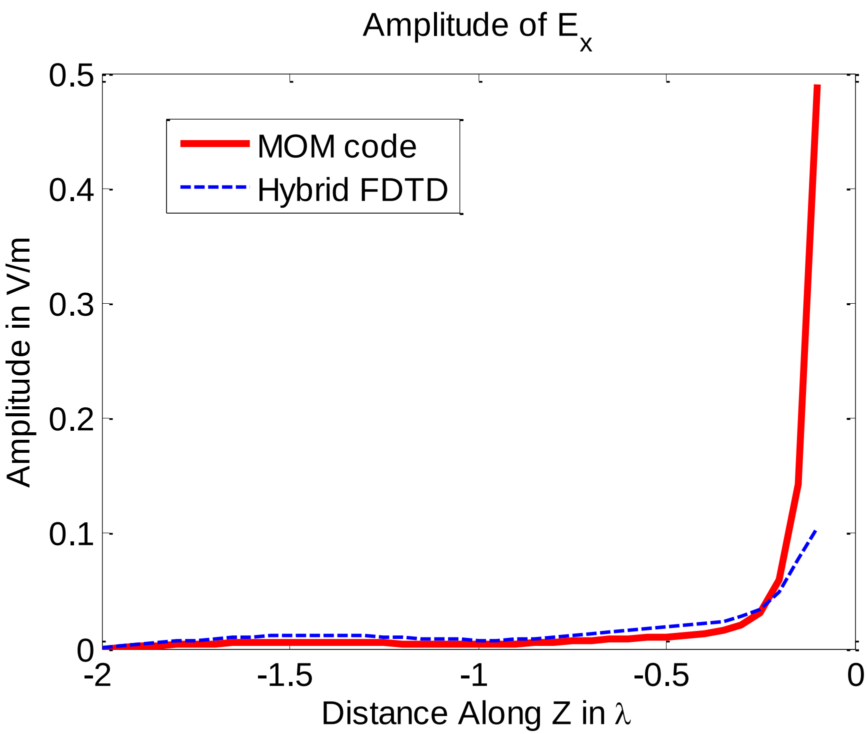
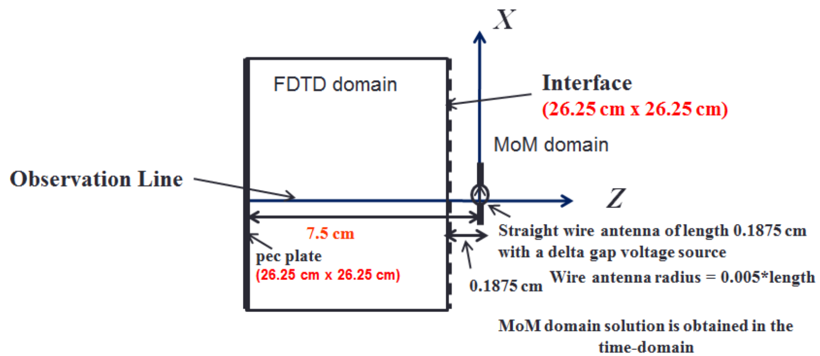
E_x amplitude comparison at 4 GHz





Results are in close agreement when the wire antenna length is 0.1875 cm

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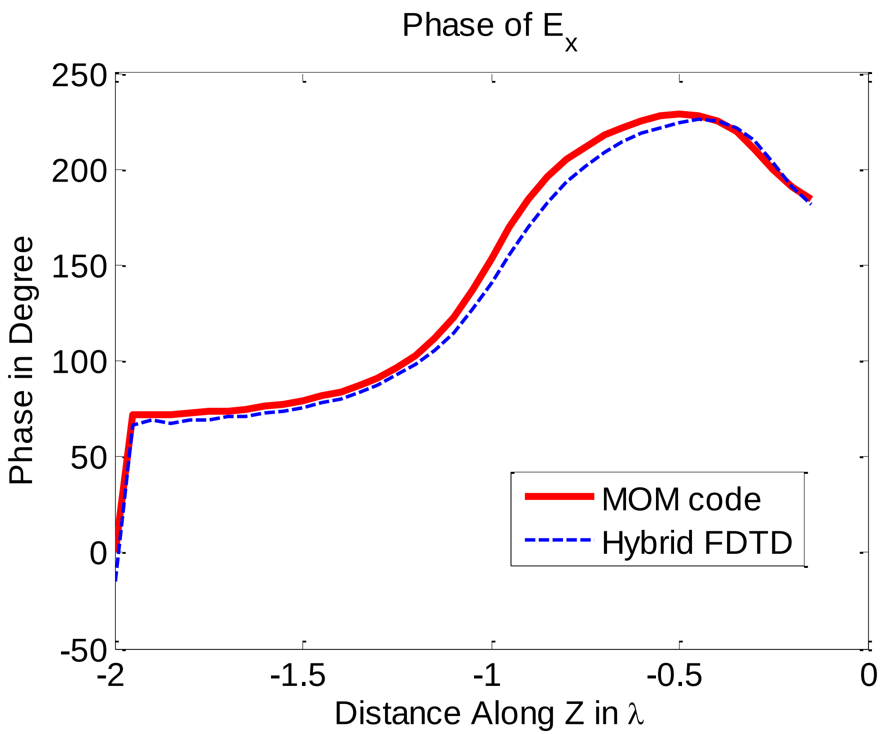
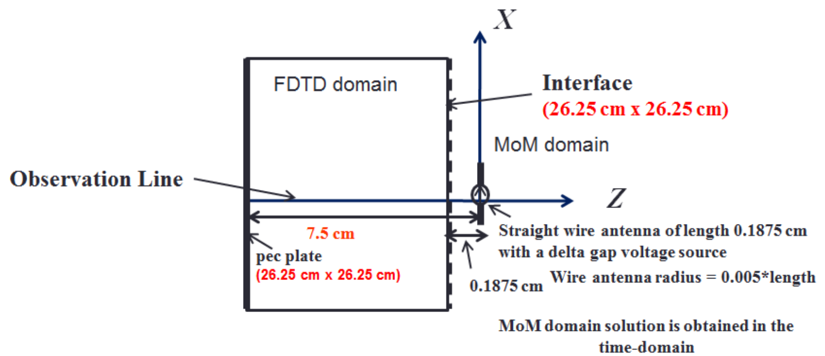
E_x phase comparison at 4 GHz





Results are in close agreement when the wire antenna length is 0.1875 cm

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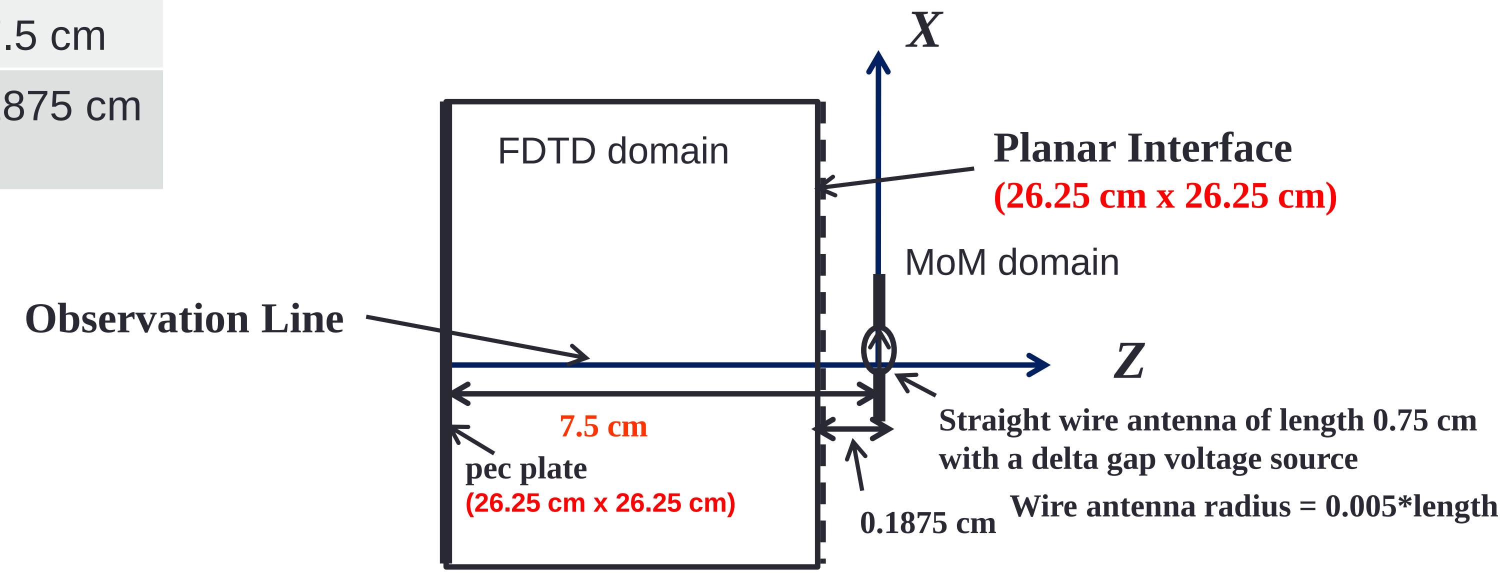
Transmit Case: Example 2

Variable	Value
λ	3.75 cm
λ_0	7.5 cm
$\lambda/20$	0.1875 cm

FDTD domain mesh size: $\lambda/20$

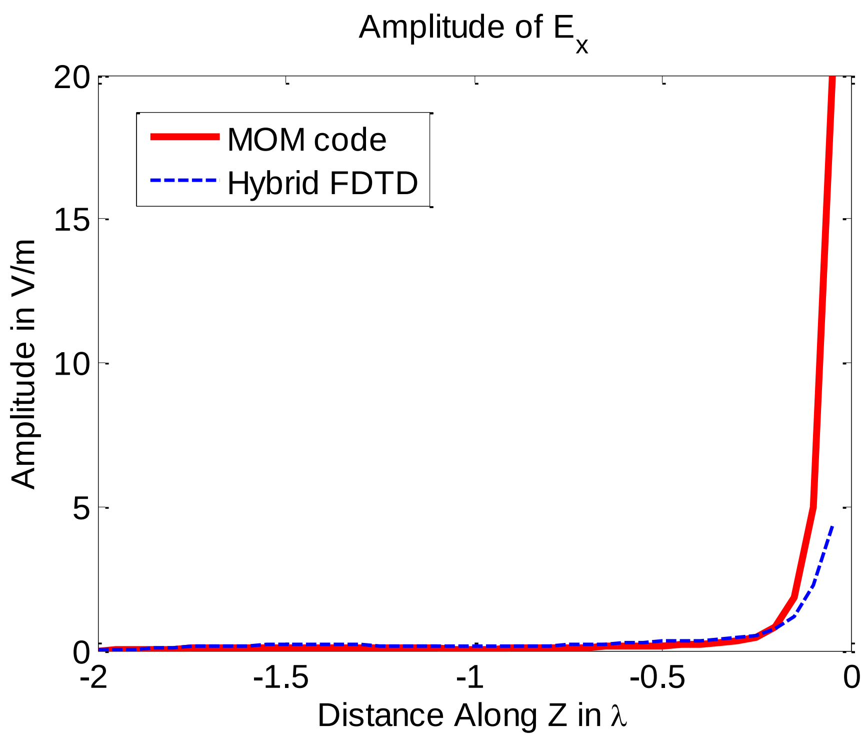
λ @ highest frequency of interest: 8 GHz
λ_0 @ center frequency of interest: 4 GHz



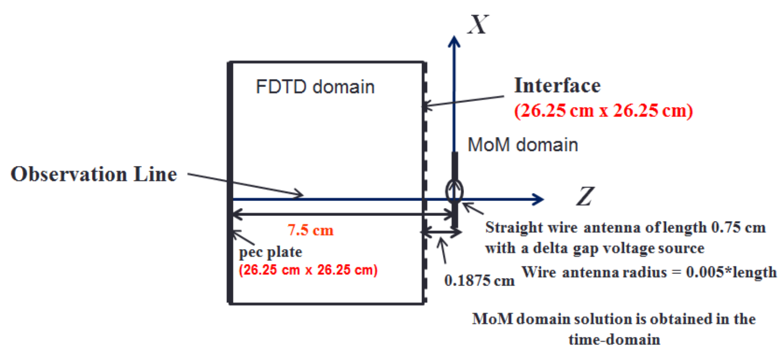
MoM domain solution is obtained in the time-domain

A straight wire antenna is directed along x at a distance of 7.5 cm from a pec plate
Length of the straight wire antenna is 0.75 cm from the wire antenna

E_x amplitude comparison at 4 GHz



Results are in close agreement when the wire antenna length is increased to 0.75 cm



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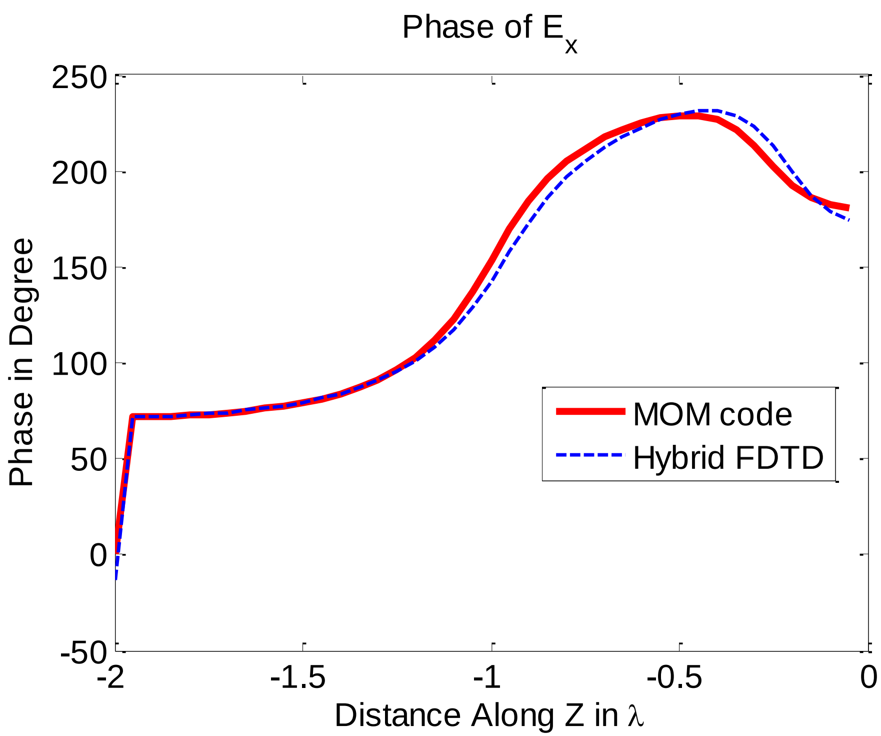
E_x phase comparison at 4 GHz



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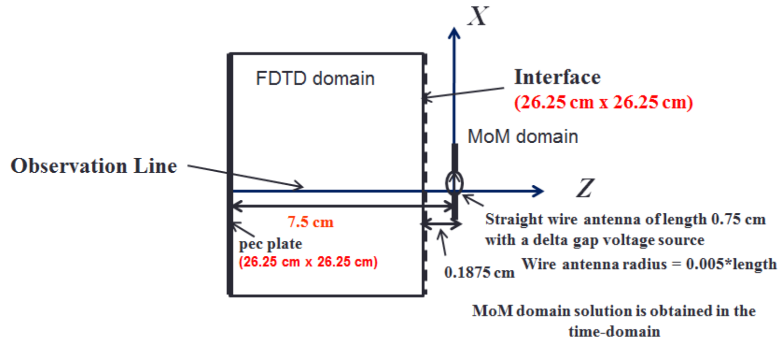

Receive Case: Example 1

Variable	Value
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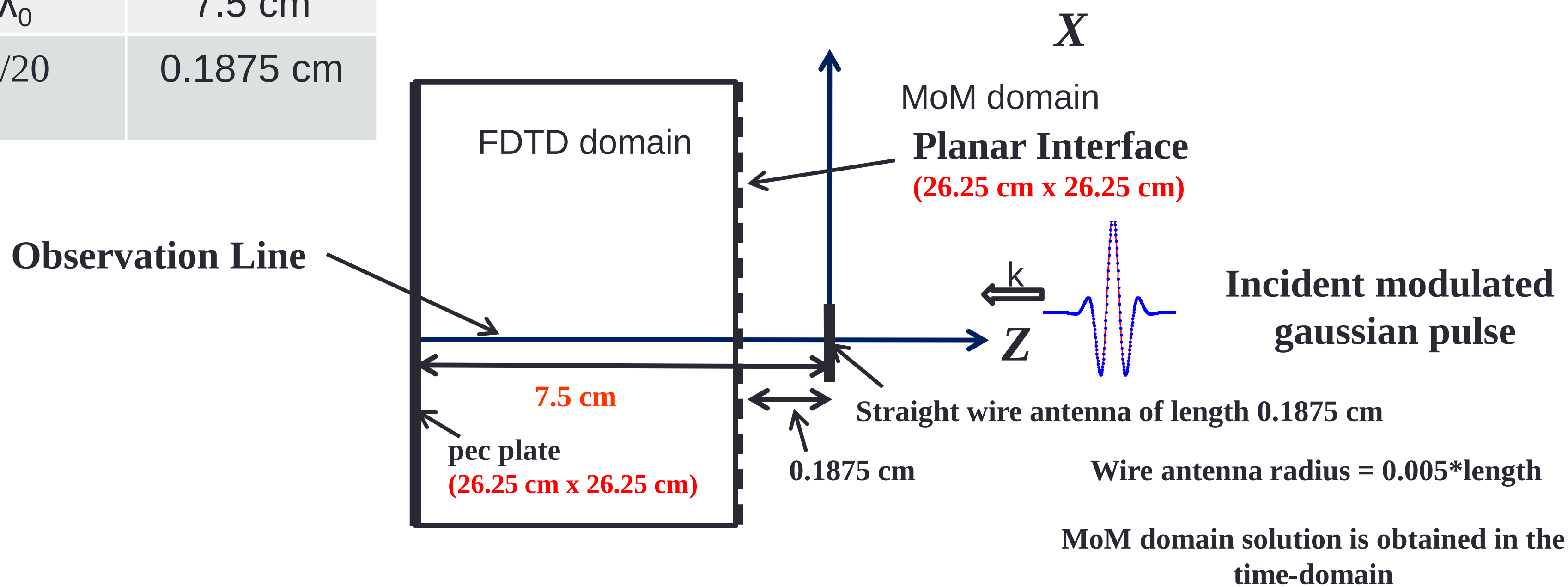
$\lambda/20$	0.1875 cm

Mesh size: $\lambda/20$

λ @ highest frequency of interest: 8 GHz
λ_0 @ center frequency of interest: 4 GHz



A straight wire antenna is directed along x at a distance of 7.5 cm from a pec plate
Length of the straight wire antenna is 0.1875 cm
Planar Interface is at a distance 0.1875 cm from the wire antenna

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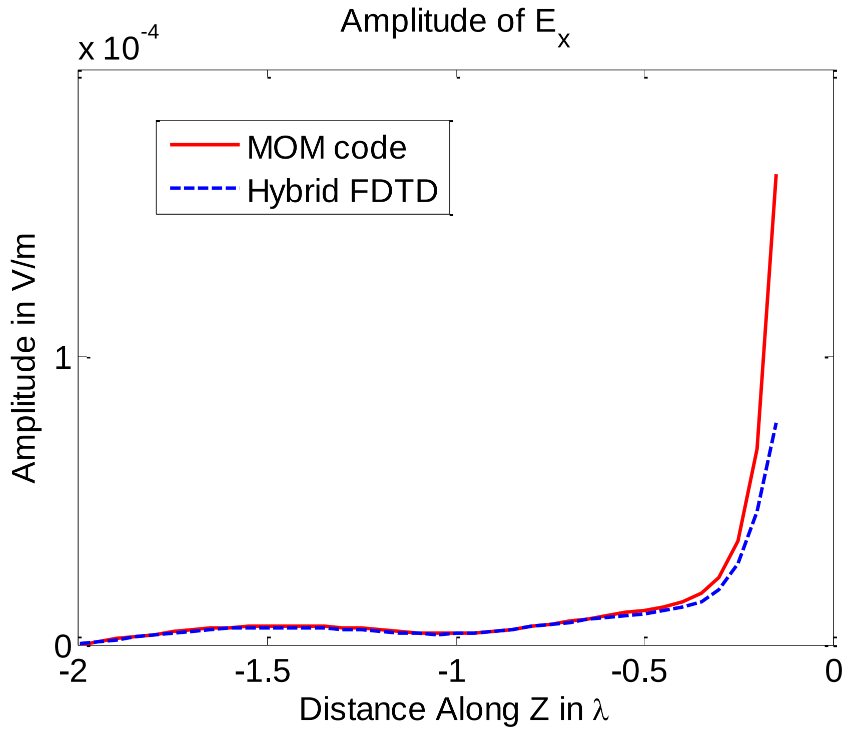
E_x amplitude comparison at 4 GHz



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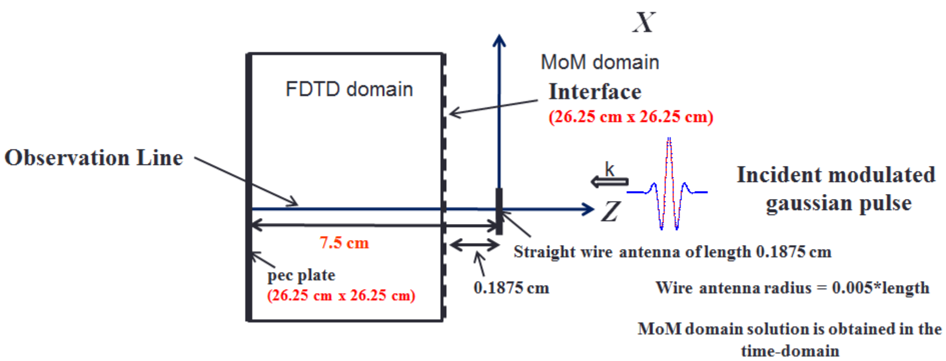

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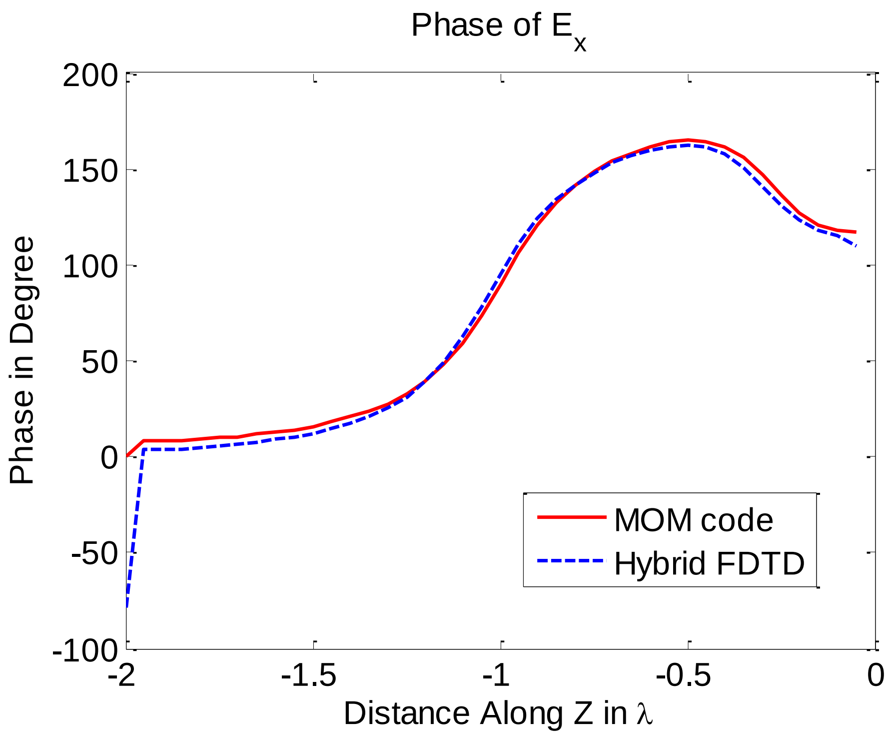
E_x phase comparison at 4 GHz



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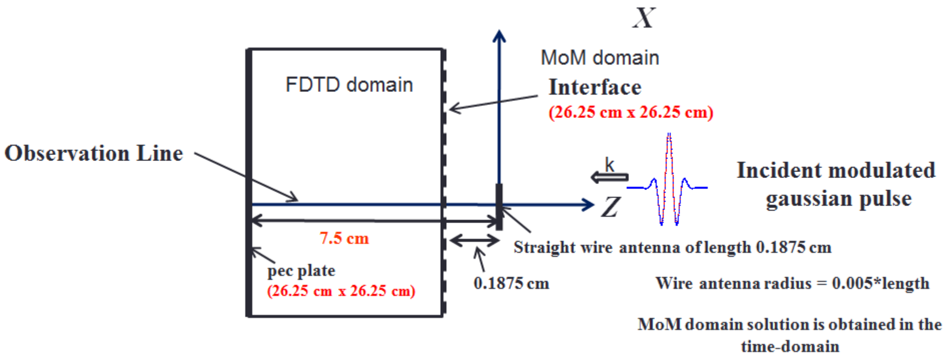
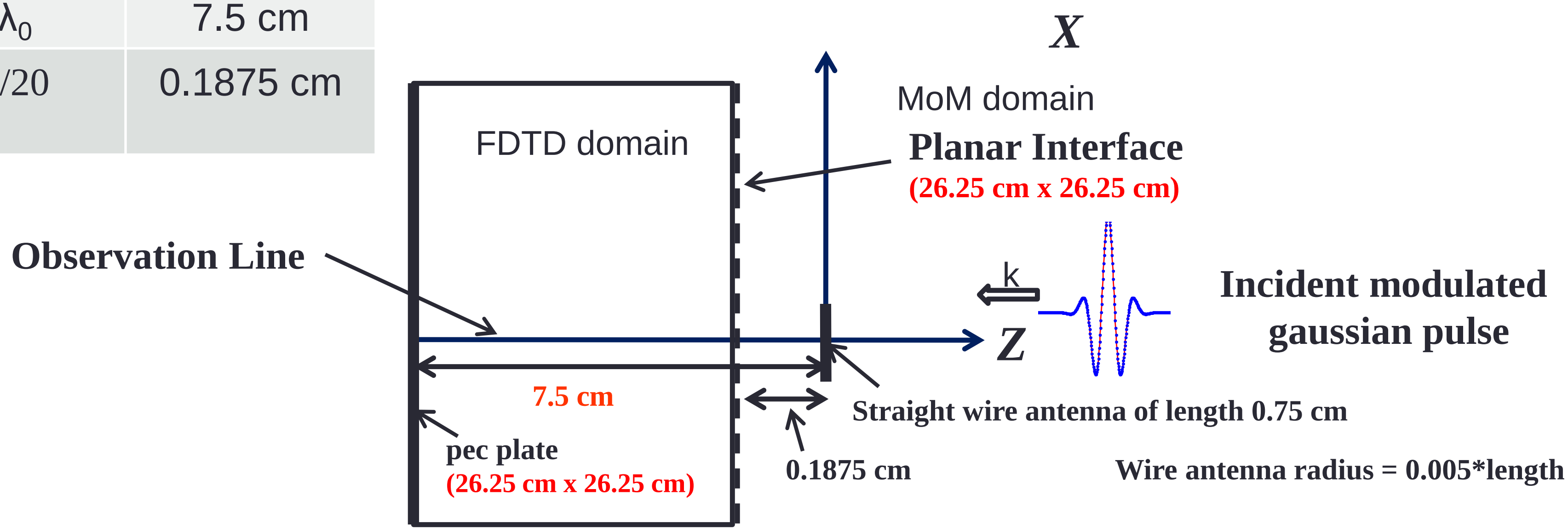


Receive Case: Example 2

Variable	Value
λ	3.75 cm
λ_0	7.5 cm
$\lambda/20$	0.1875 cm

Mesh size: $\lambda/20$

λ @ highest frequency of interest: 8 GHz
λ_0 @ center frequency of interest: 4 GHz



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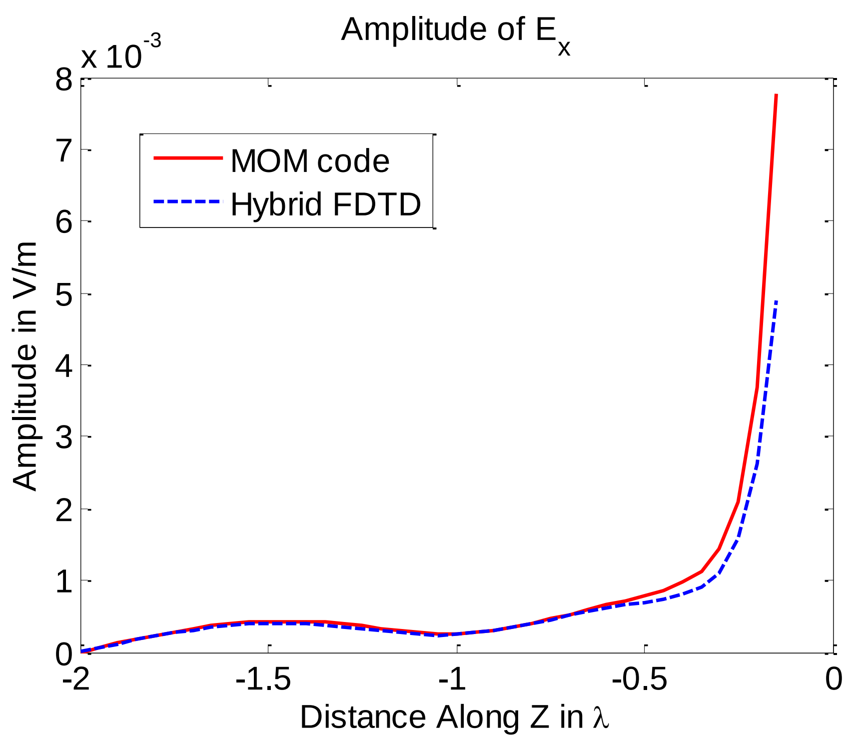
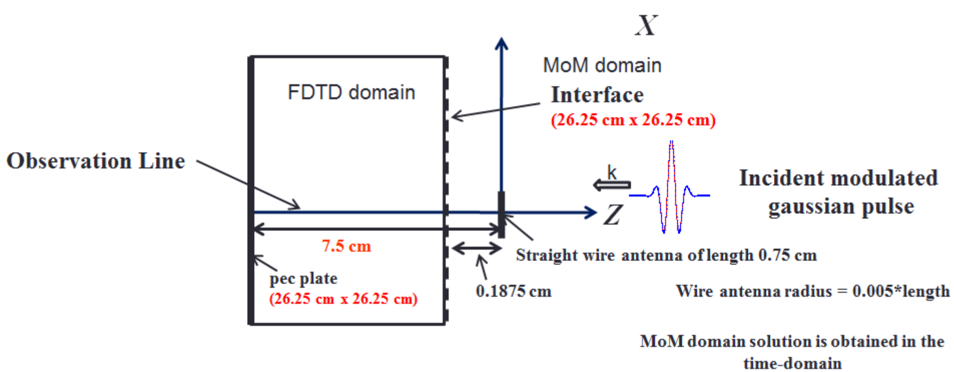
E_x amplitude comparison at 4 GHz



Results are in close agreement when the wire antenna length is increased to 0.75 cm



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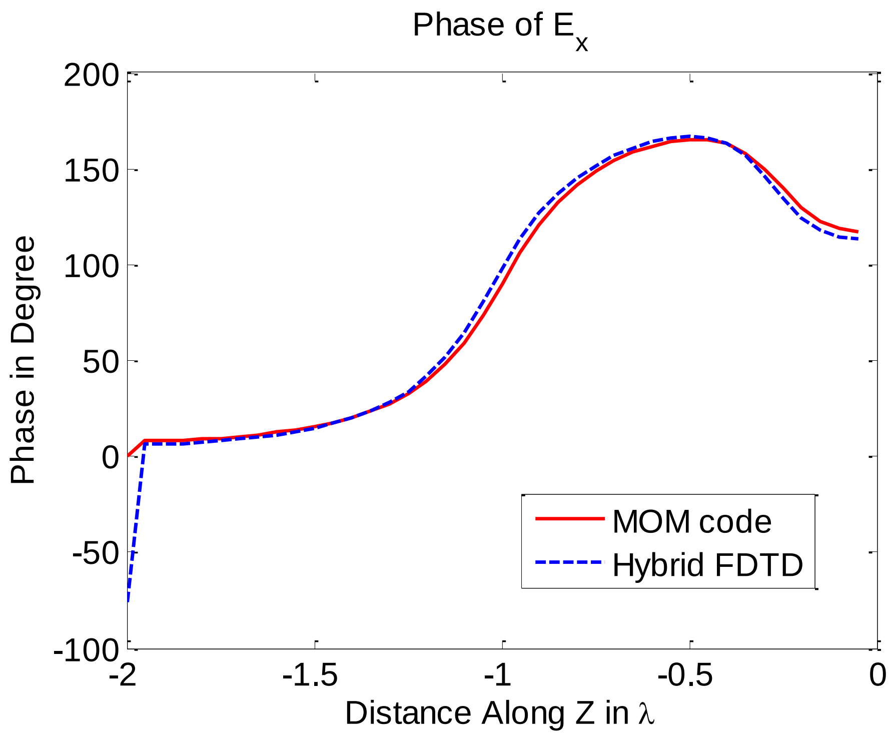
E_x phase comparison at 4 GHz



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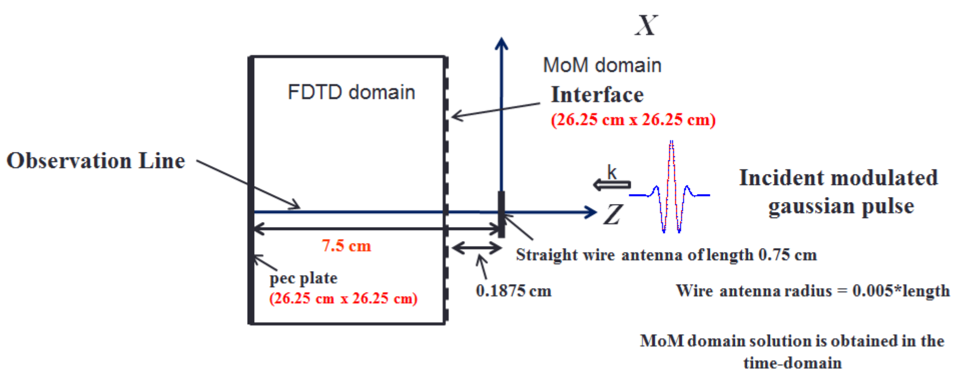

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Observations

- Amplitude and phase of the scattered field along the observation line obtained using the proposed hybrid method are in close agreement to that obtained using the method of moments code

- Accurate results are obtained using the proposed novel hybrid technique for the cases when the scatterer size is small as well as large

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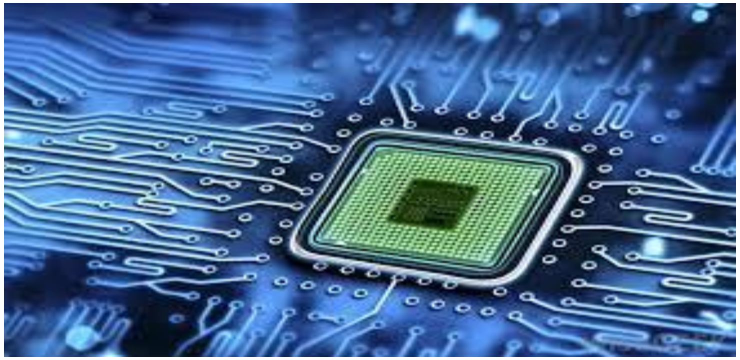
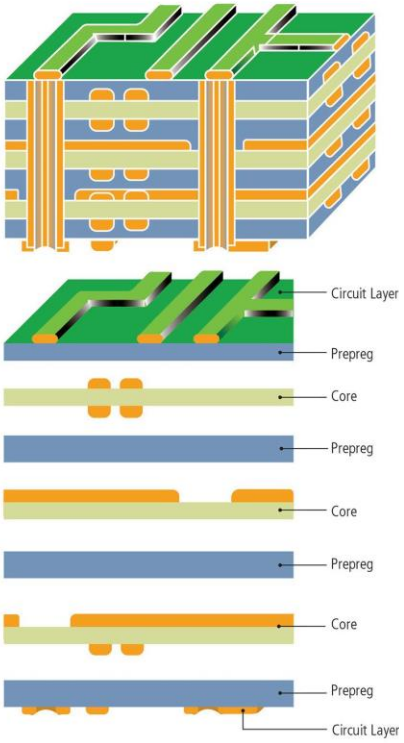
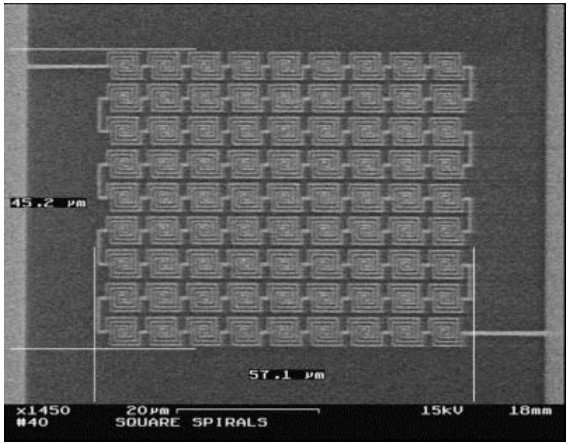
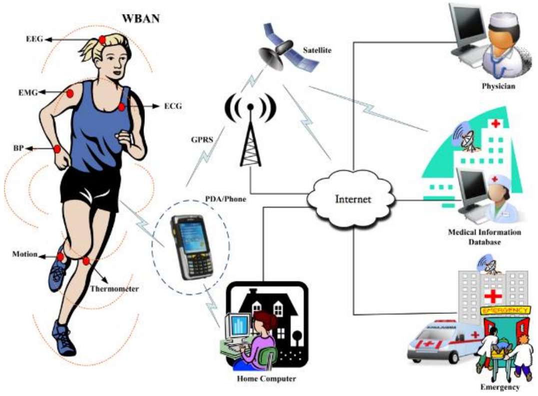
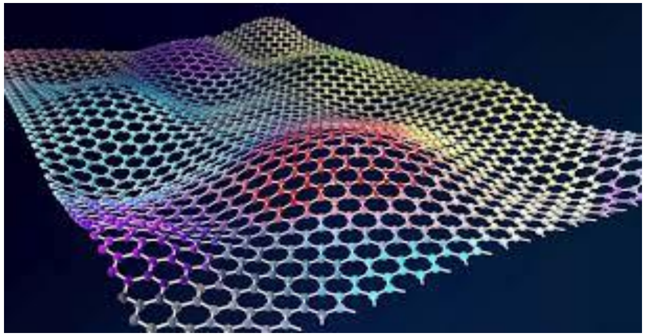
Applications











Numerous other applications … !!

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References

- [1] Kane S. Yee, "Numerical Solution of Initial Boundary Value Problems Involving Maxwell's Equations in Isotropic Media," IEEE Trans. On Antennas and Propagation, vol.14, no.3, pp. 302-307, May 1966.
- [2] Jean-Pierre Berenger, "A Perfectly Matched Layer for the Absorption of Electromagnetic Waves", Journal of Computational Physics 114, 185-200 (1994).
- [3] Wenhua Yu, Xiaoling Yang, Yongjun Liu and Raj Mittra, Electromagnetic Simulation Techniques Based on the FDTD Method, John Wiley & Sons, Inc., 2009.
- [4] Raj Mittra, J.N. Bringuier, "A Technique for Solving Multiscale Problems in CEM Utilizing Dipole Moments and Macro Basis Functions," Proceedings of the Fourth European Conference on Antennas and Propagation (EuCAP), 2010.
- [5] Raj Mittra, Jonathan Bringuier, Chiara Pelletti, Kadappan Panayappan, Ozlem Ozgun, Agostino Monorchio, "On the Hybridization of Dipole Moment (DM) and Finite Methods for Efficient Solution of Multiscale Problems", Proceedings of the Fifth European Conference on Antennas and Propagation (EuCAP), 2011.
- [6] E.C. Jordan and W.L. Everitt, "Acoustic Models of Radio Antennas", Proc. IRE, 29, 4, 186 (1941).

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Thank You

Questions