A Conformal 2D FDFD Eigenmode Method for Wave Port Excitation and S-Parameter Extraction in 3D FDTD Simulation

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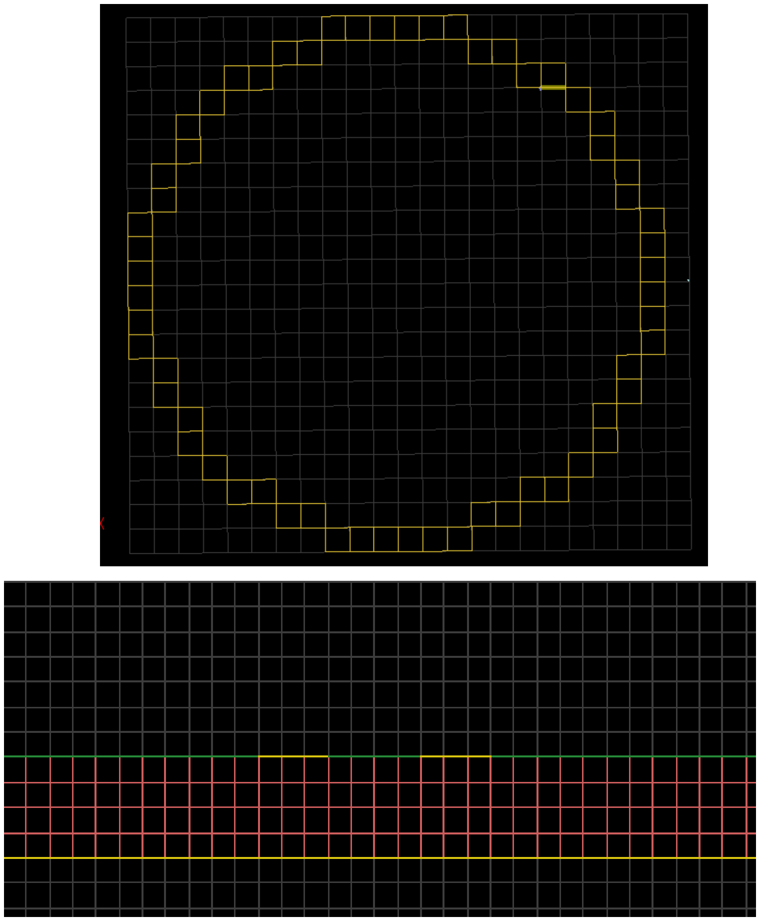
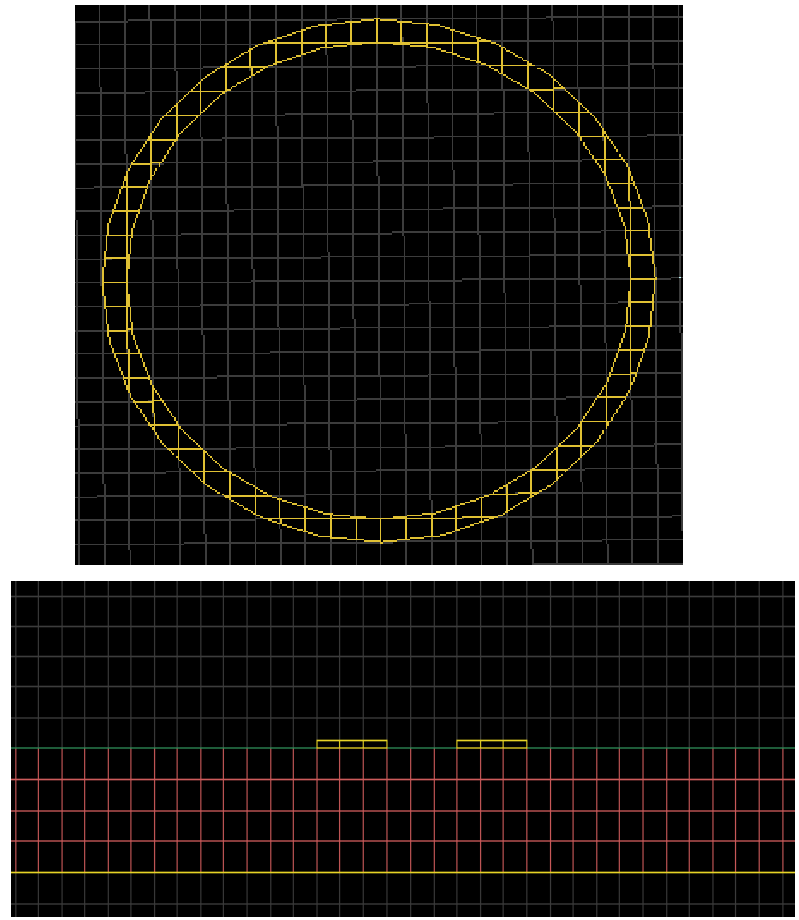
Motivation of This Work



Staircased meshes

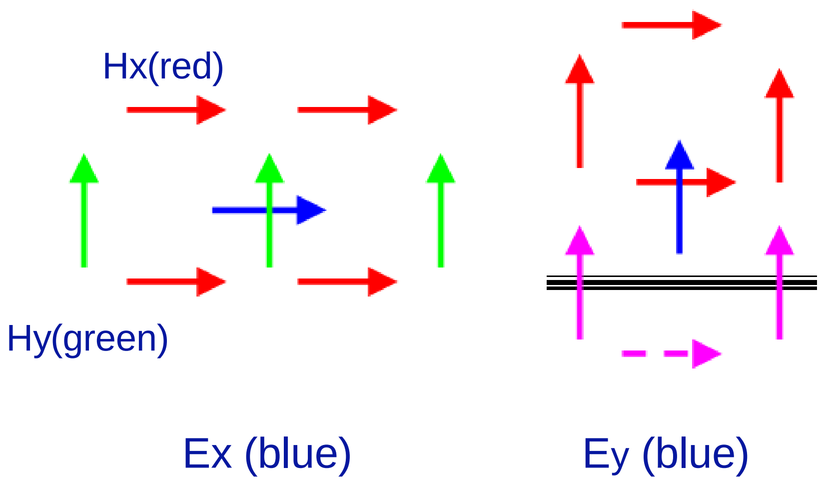


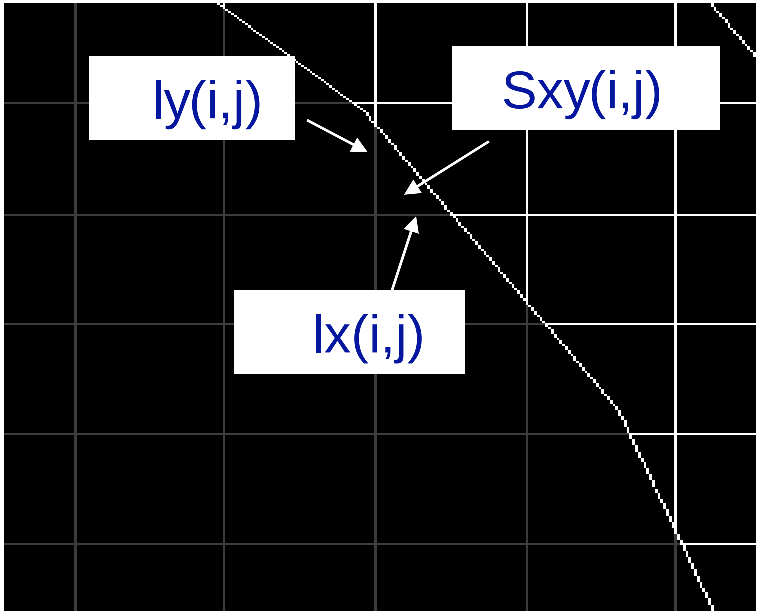
Conformal meshes

2D FDFD Eigenmode Method and 3D Conformal FDTD Method

Y.Zhao, K.L.Wu and K.M.Cheng, “A compact 2D full-wave finite difference frequency domain method for general guided wave structure,” IEEE Trans. on Microwave Theory Tech., vol. 50, no.7, 1844-1848, 2002.

S. Benkler, N. Chavannes and N. Kuster, “A new 3-D conformal PEC FDTD scheme with user-defined geometric precision and derived stability criterion,” IEEE Trans. on Antennas and Propagation, vol. 54, no. 6, 1843-1849, June 2006.





Conformal cell edges and areas

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Conformal 2D FDFD Eigenmode Method

$$\frac{\beta}{k_0} E_x(i,j) = -\frac{1}{k_0^2 \varepsilon_{zz} l_x(i,j) h_y} \left[H_x(i,j-1) - H_x(i+1,j-1) - H_x(i,j) + H_x(i+1,j) \right] +$$

$$\frac{1}{k_0^2 \varepsilon_{zz} l_x(i,j) h_x} H_y(i-1,j) + \left(1 - \frac{2}{k_0^2 \varepsilon_{zz} l_x(i,j) h_x} \right) H_y(i,j) + \frac{1}{k_0^2 \varepsilon_{zz} l_x(i,j) h_x} H_y(i+1,j)$$

$$\frac{\beta}{k_0} E_y(i,j) = \frac{1}{k_0^2 \varepsilon_{zz} l_y(i,j) h_x} \left[H_y(i-1,j) - H_y(i-1,j+1) - H_y(i,j) + H_y(i,j+1) \right] +$$

$$\frac{1}{k_0^2 \varepsilon_{zz} l_y(i,j) h_y} H_x(i,j-1) - \left(1 - \frac{2}{k_0^2 \varepsilon_{zz} l_y(i,j) h_y} \right) H_x(i,j) - \frac{1}{k_0^2 \varepsilon_{zz} l_y(i,j) h_y} H_x(i,j+1)$$

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Conformal 2D FDFD Method (Cont'd)

$$
\begin{aligned}
\frac{\beta}{k_0} H_x(i, j) = \frac{1}{k_0^2 h_x} \Big[& E_x(i-1, j) l_x(i-1, j) S_{xy}(i-1, j) - E_x(i, j) l_x(i, j) S_{xy}(i, j) - \\
& E_x(i-1, j+1) l_x(i-1, j+1) S_{xy}(i-1, j) + E_x(i, j+1) l_x(i, j+1) S_{xy}(i, j) \Big] \\
& - \frac{l_y(i-1, j)}{k_0^2 S_{xy}(i-1, j) h_x} E_y(i-1, j) + \left(\varepsilon_{yy} - \frac{l_y(i, j)}{k_0^2 h_x} \big(1/S_{xy}(i-1, j) + 1/S_{xy}(i, j) \big) \right) E_y(i, j) \\
& - \frac{l_y(i+1, j)}{k_0^2 S_{xy}(i, j) h_x} E_y(i+1, j)
\end{aligned}
$$

$$
\begin{aligned}
\frac{\beta}{k_0} H_y(i, j) = -\frac{1}{k_0^2 h_y} \Big[& \big(E_y(i, j-1) l_y(i, j-1) - E_y(i+1, j-1) l_y(i+1, j-1) \big) / S_{xy}(i, j-1) - \\
& E_y(i, j) l_y(i, j) S_{xy}(i, j) + E_y(i+1, j) l_y(i+1, j) S_{xy}(i, j) \Big] \\
& + \frac{l_x(i, j-1)}{k_0^2 S_{xy}(i, j-1) h_y} E_x(i, j-1) + \left(\varepsilon_{xx} - \frac{l_x(i, j)}{k_0^2 h_y} \big(1/S_{xy}(i, j-1) + 1/S_{xy}(i, j) \big) \right) E_x(i, j) \\
& + \frac{l_x(i, j+1)}{k_0^2 S_{xy}(i, j) h_y} E_x(i, j+1)
\end{aligned}
$$

Eigenmode Equation

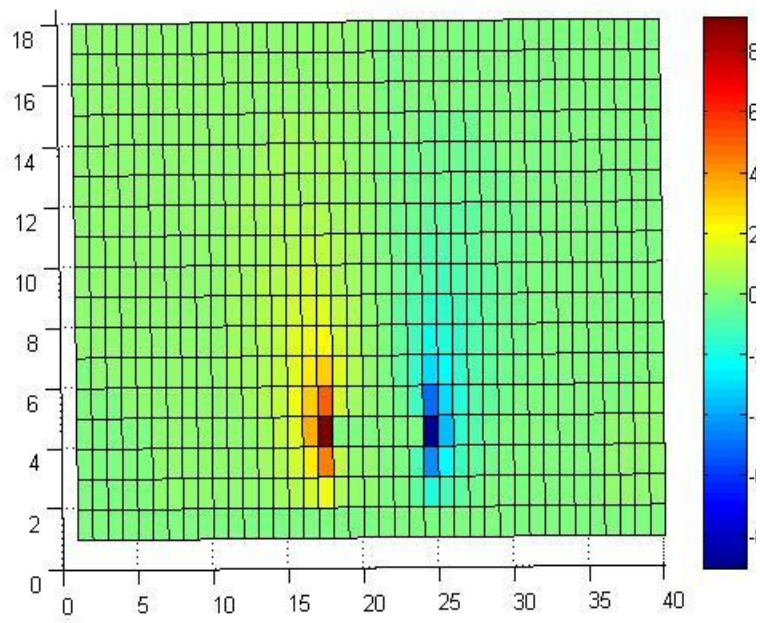
Linear equation: $[\mathbf{A}]\{f\} = \lambda \{f\}$

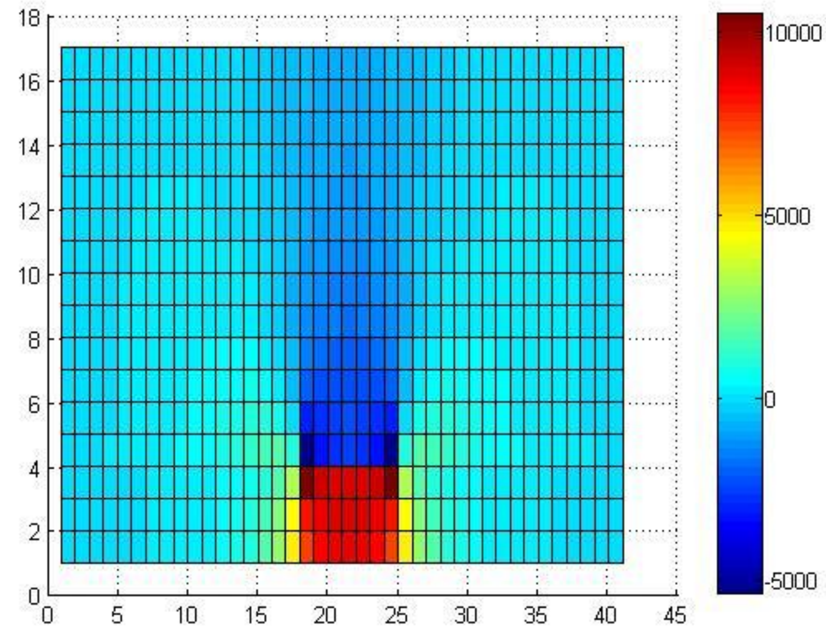
Eigenvalue: $\lambda = \beta / k_0$

Eigenmode: $\{f\} = \{E_x, E_y, H_x, H_y\}^T$

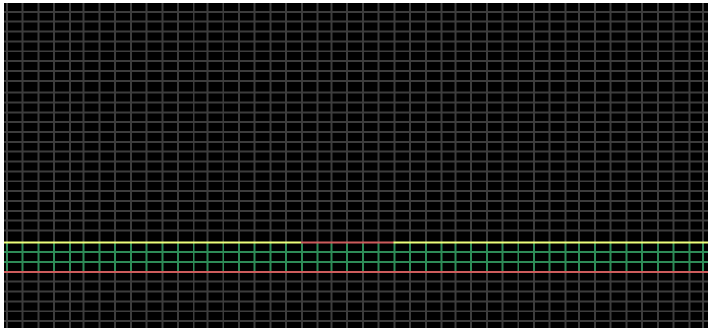
Boundary Conditions: PEC/PMC/ABC

Microstrip Electric Field Profile





E_x

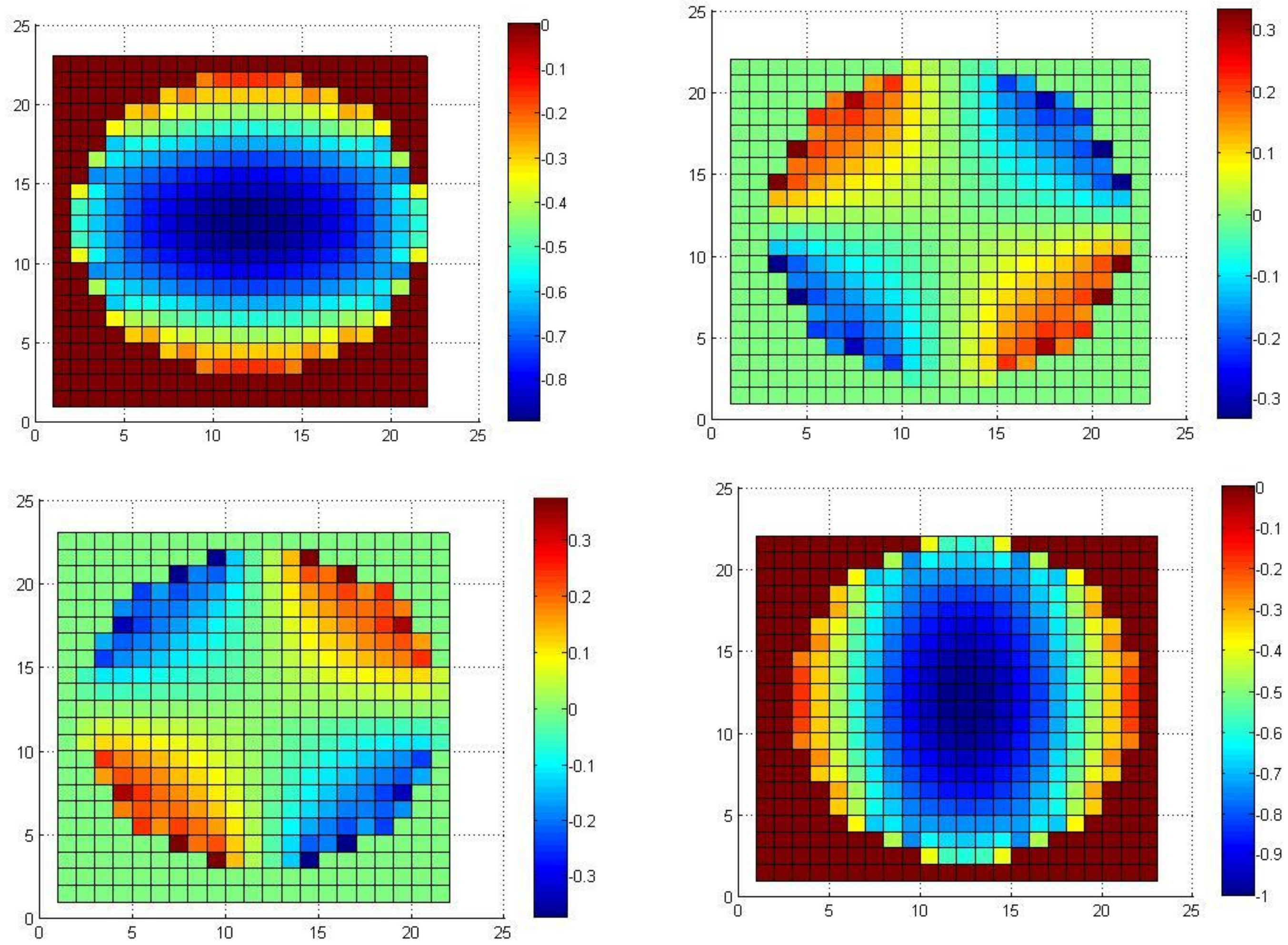


E_y

TE_{11} Mode of Circular Waveguide

TE_{11}

TE_{11}



E_x E_y

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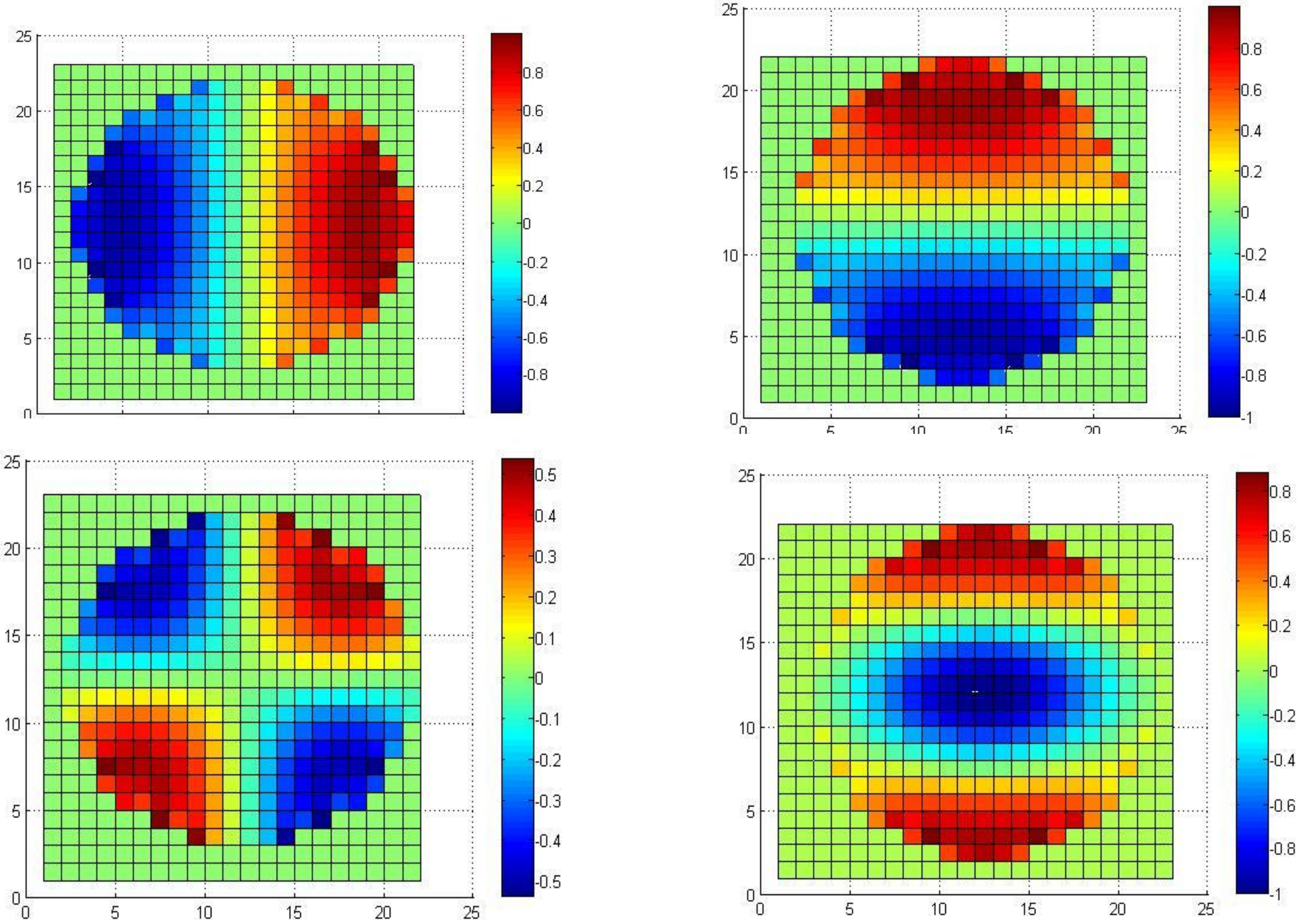
TM_{01}/TM_{11} Mode of Circular Waveguide

TM_{01}

TM_{11}



E_x E_y

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Propagation Constants

Circular Waveguide

	Analytical	Staircased	Conformal
TE_{11}	0.8882	0.8913	0.8969
TM_{01}	0.7998	0.7866	0.7997
TM_{11}	0.2920	0.3070	0.2901

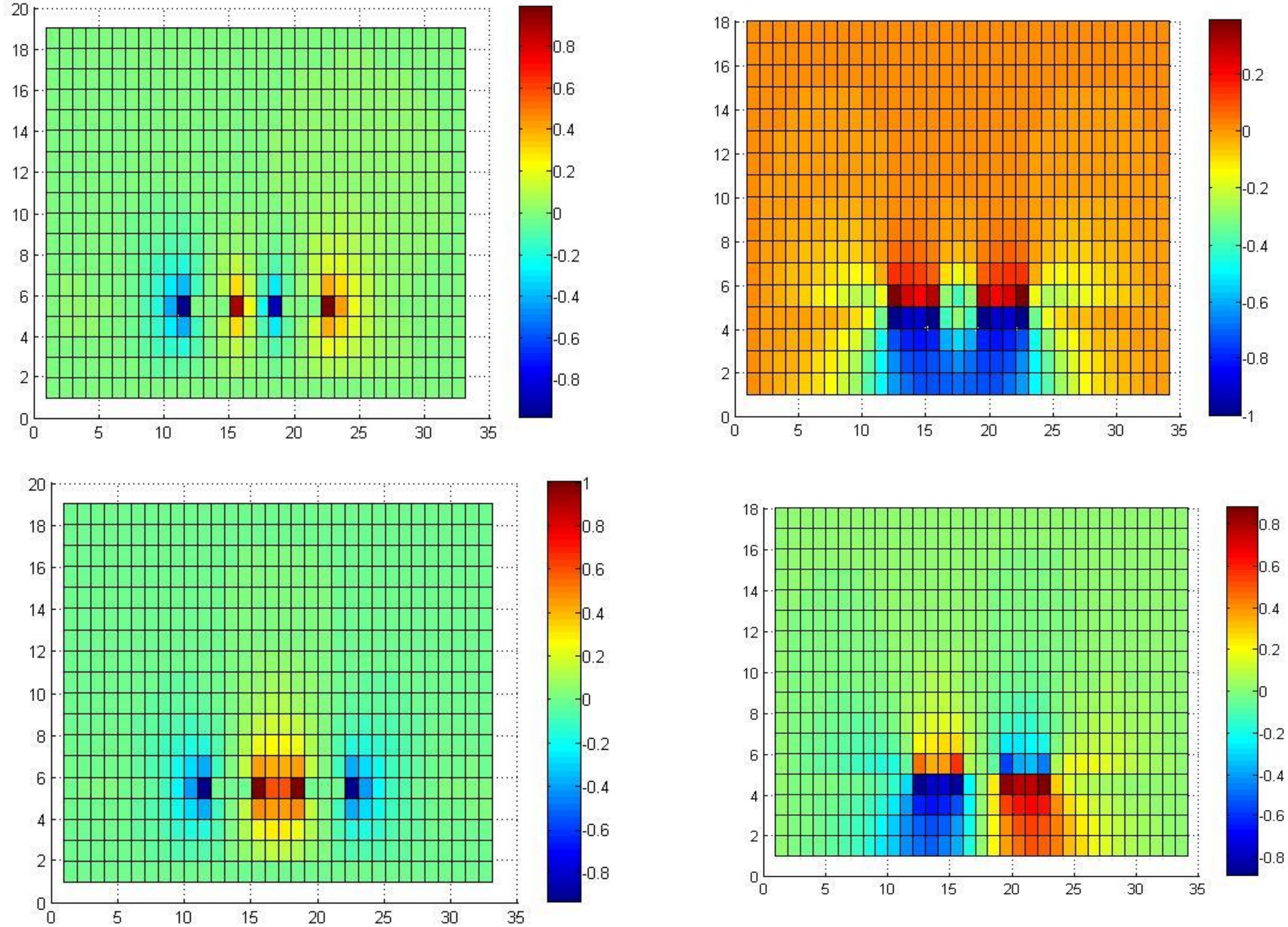
Differential Pair

	0.0 mm	0.1 mm	0.2 mm	0.3 mm
Even mode	2.9089	2.9095	2.9102	2.9109
Odd mode	2.6051	2.6039	2.6026	2.6011
Even (ADS)	2.8719	2.8732	2.8744	2.8758
Odd (ADS)	2.5902	2.5743	2.5611	2.5493

Even/Odd Modes of Differential Pair

Even mode

Odd mode



E_x E_y

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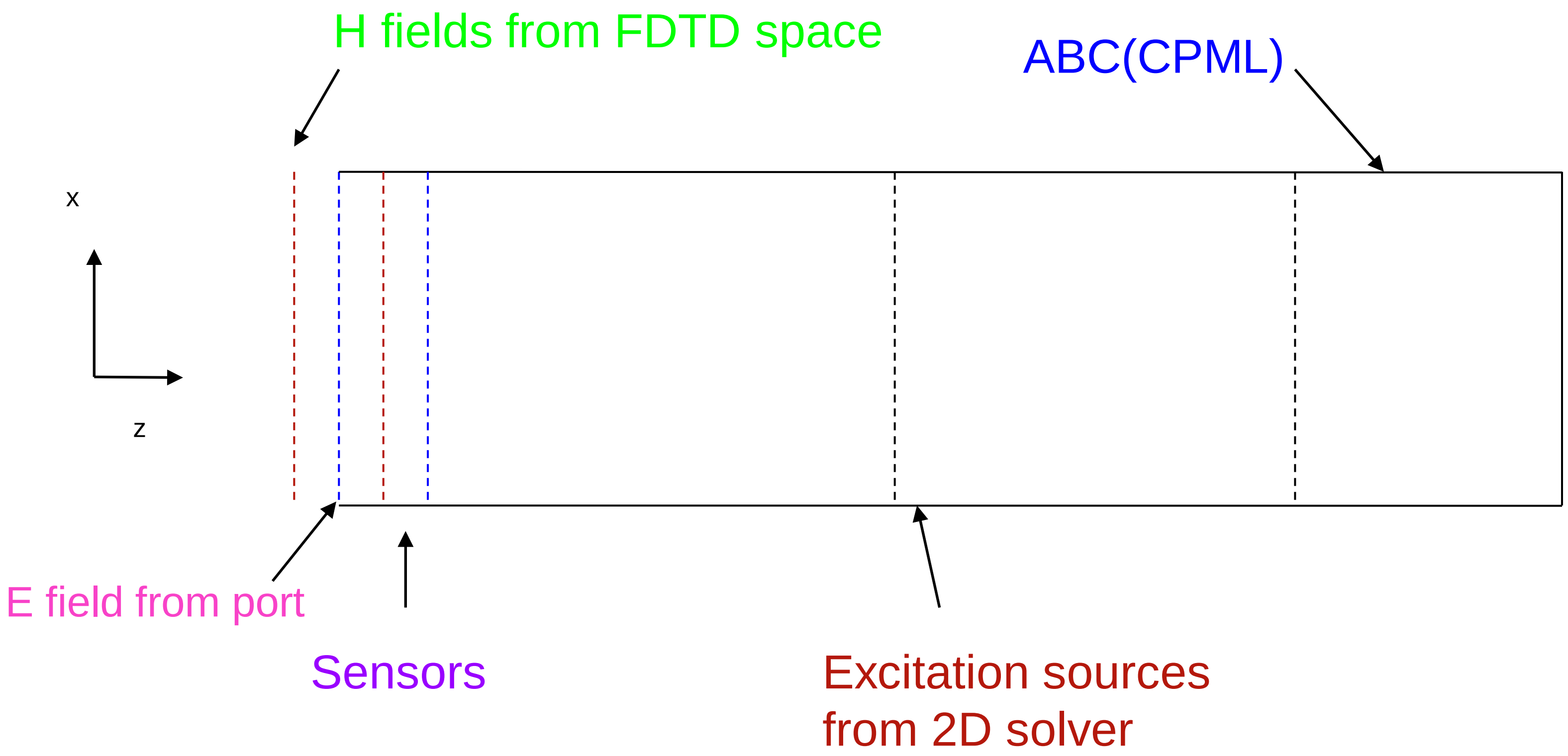
Designed Waveguide Port



Y. Wang and S. Langdon, "Design of wave ports in FDTD and its application to microwave circuits and antennas," IEEE Antennas and Propagation Symposium, Toronto, Canada, 2010.

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S-Parameter Extraction

$$V_i(\omega) = \iint_S E(x, y, z_p, t) \times h_{T,i}(x, y, \omega_T) \cdot ds \qquad I_i(\omega) = \iint_S e_{T,i}(x, y, \omega_T) \times H(x, y, z_p, t) \cdot ds$$

$$Z_i(\omega) = \sqrt{\frac{V_i(\omega)V_i^{'}(\omega)}{I_i(\omega)I_i^{'}(\omega)}}$$

$$a_i(\omega) = \frac{V(\omega) + Z_i(\omega)I_i(\omega)}{2\sqrt{Z_i(\omega)}} \qquad b_i(\omega) = \frac{V(\omega) - Z_i(\omega)I_i(\omega)}{2\sqrt{Z_i(\omega)}}$$

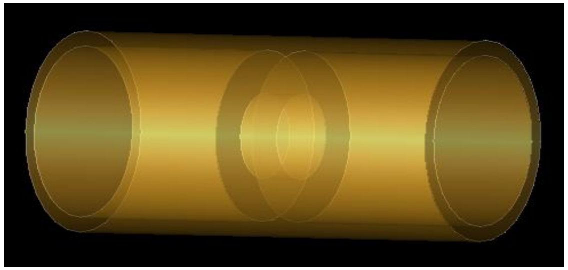
W. Gwarek and M. Celuch-Marcysiak, “Wide band S-parameter extraction from FDTD simulation for propagating and evanescent modes in inhomogeneous guides,” IEEE Trans. on Microwave Theory Tech., vol. 51, no. 8, 1920-1928, 2003.

Comparison of Simulated and Measured Results

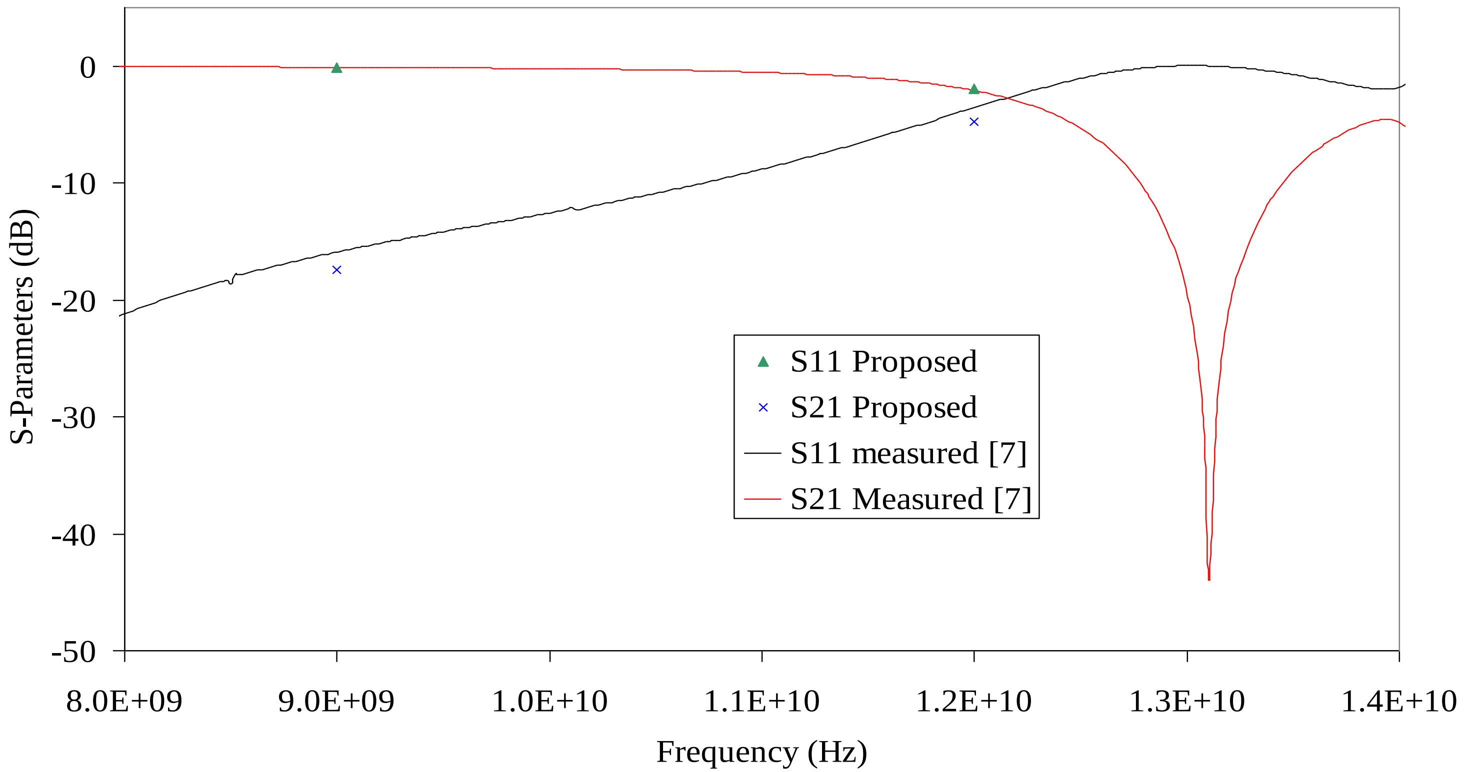
Return loss and transmission loss of the circular waveguide with a circular iris calculated vs. measurement

	Calculated[7]	Measured[7]	Conformal
S_{11} (9 GHz)	-0.087	-0.166	-0.111
S_{21}(9GHz)	-16.832	-17.458	-15.938
S_{11} (12 GHz)	-1.873	-1.906	-2.419
S_{21}(12 GHz)	-4.539	-4.800	-3.671

[7] R.W. Scharstein and A.T. Adams, “Thick circular iris in a TE_{11} mode circular waveguide,” IEEE Trans. Microwave Theory Tech., vol. 36, 1529–1531, 1988.



A Circular Waveguide With a Circular Iris



S-parameters of the circular waveguide with a circular iris calculated by the proposed method vs. measured data

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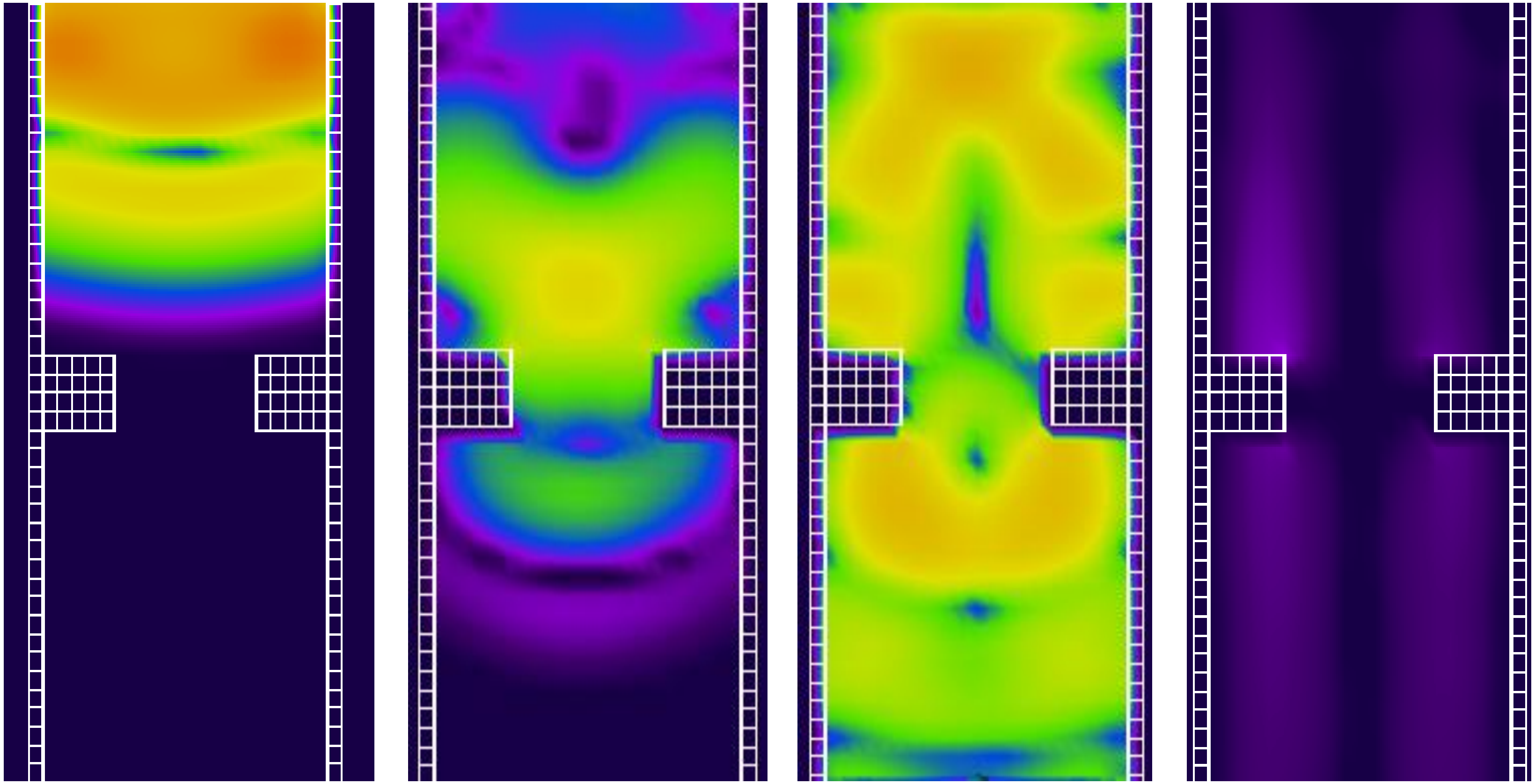
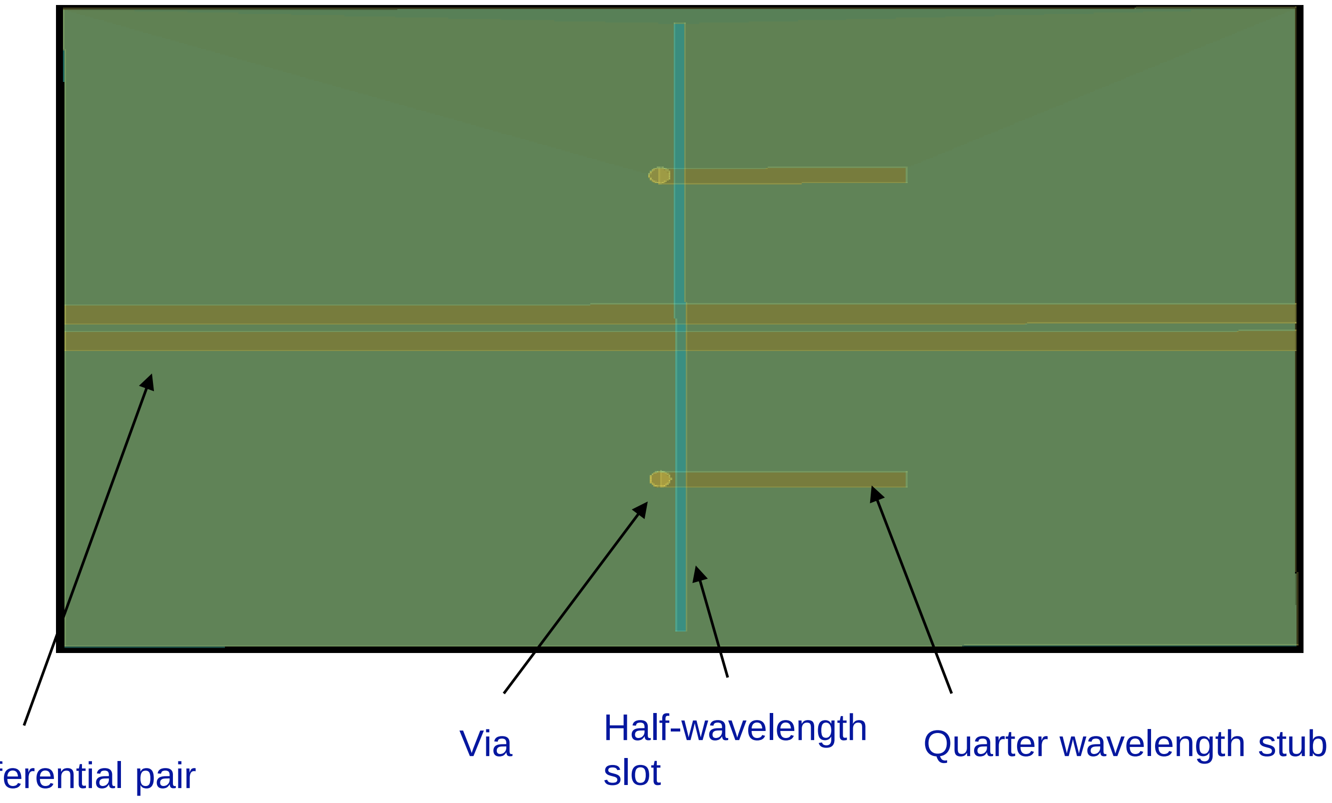
Field Snapshot of the Circular Waveguide with a circular Iris



Exciting from port | Propagating | Reflection and transmission | Convergence

Differential Pair with Slot Line and Stubs



[9] H. H. Chuang; T. L. Wu, “A new common-mode EMI suppression technique for GHz differential signals crossing slotted reference planes,” IEEE International Symposium on Electromagnetic Compatibility, July 2010.

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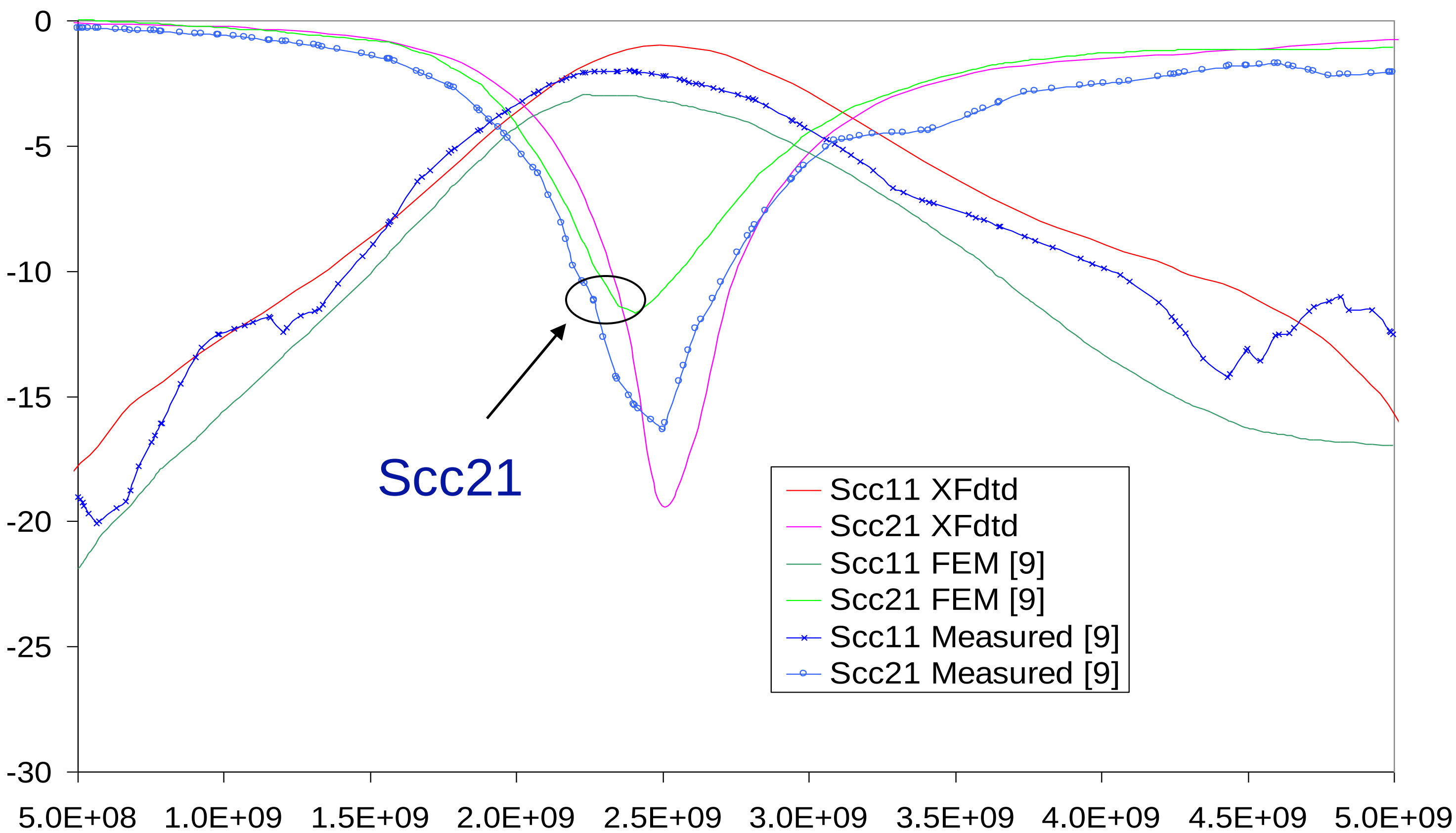
Common Mode S-Parameter



Insertion and return loss of common mode for the differential pair without stubs compared with measurement

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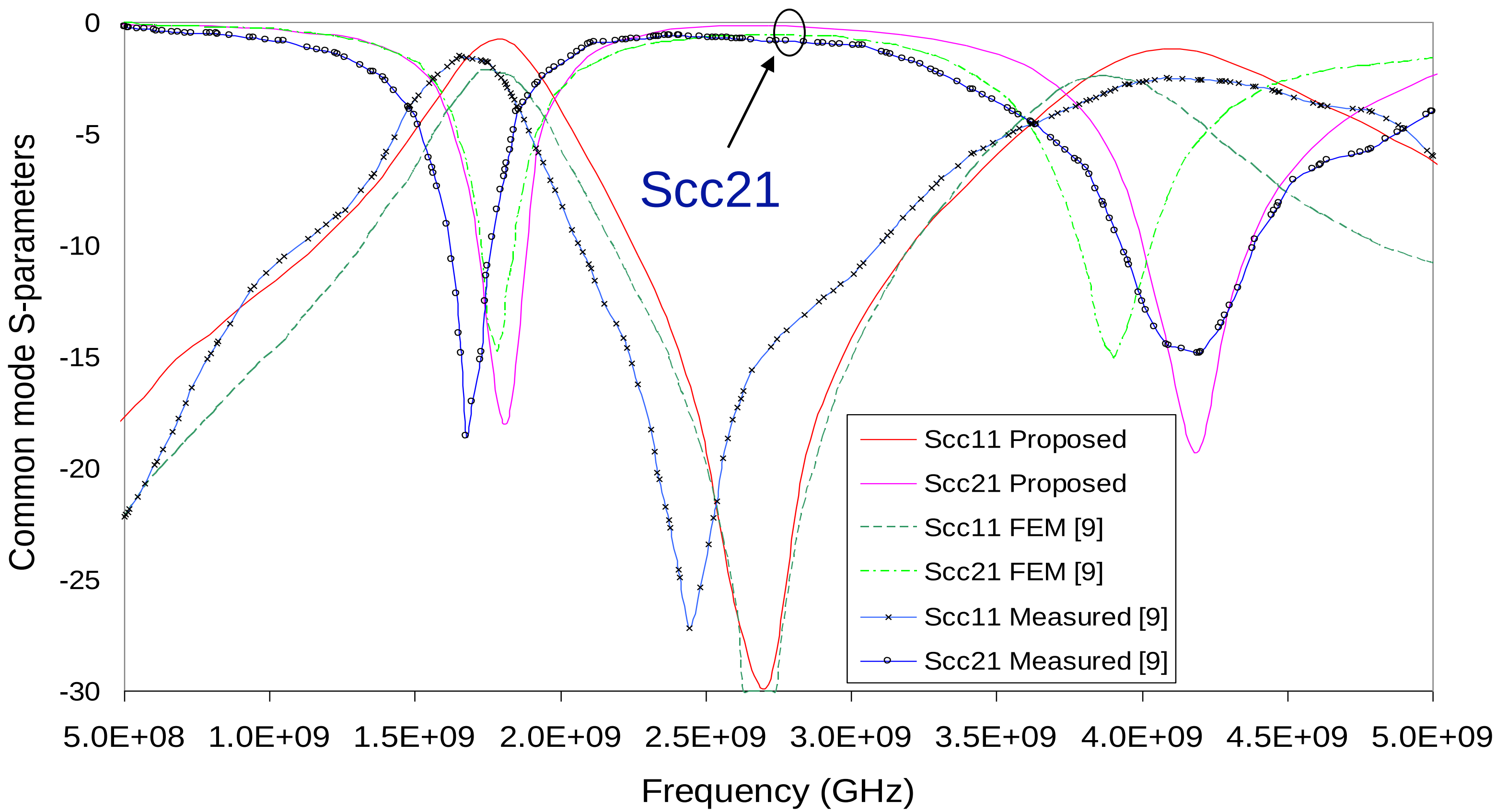
Common Mode S-Parameter (cont'd)



Insertion and return loss of common mode for the differential pair with stubs compared with measurement

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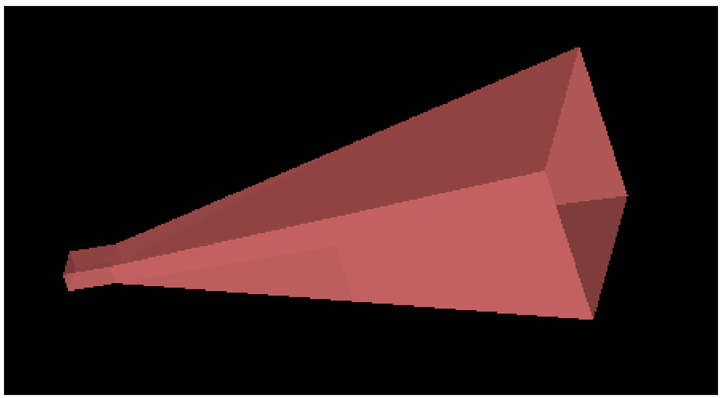
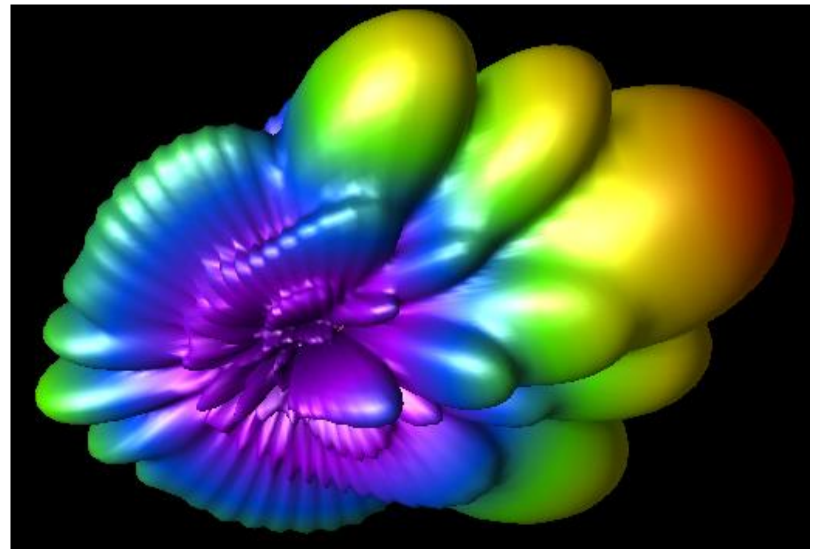
Radiation Pattern of Horn Antenna





The calculated 3D radiation pattern of the horn antenna at 10 GHz by the proposed method

[10] K. Liu, C.A. Balanis, C.R. Birtcher, and G.C. Barber, "Analysis of pyramidal horn antennas using moment methods," IEEE Trans. on Antennas and Propagation, vol. 41, no. 10, 1379-1389, 1993.

Rectangular Waveguide and Horn Antenna

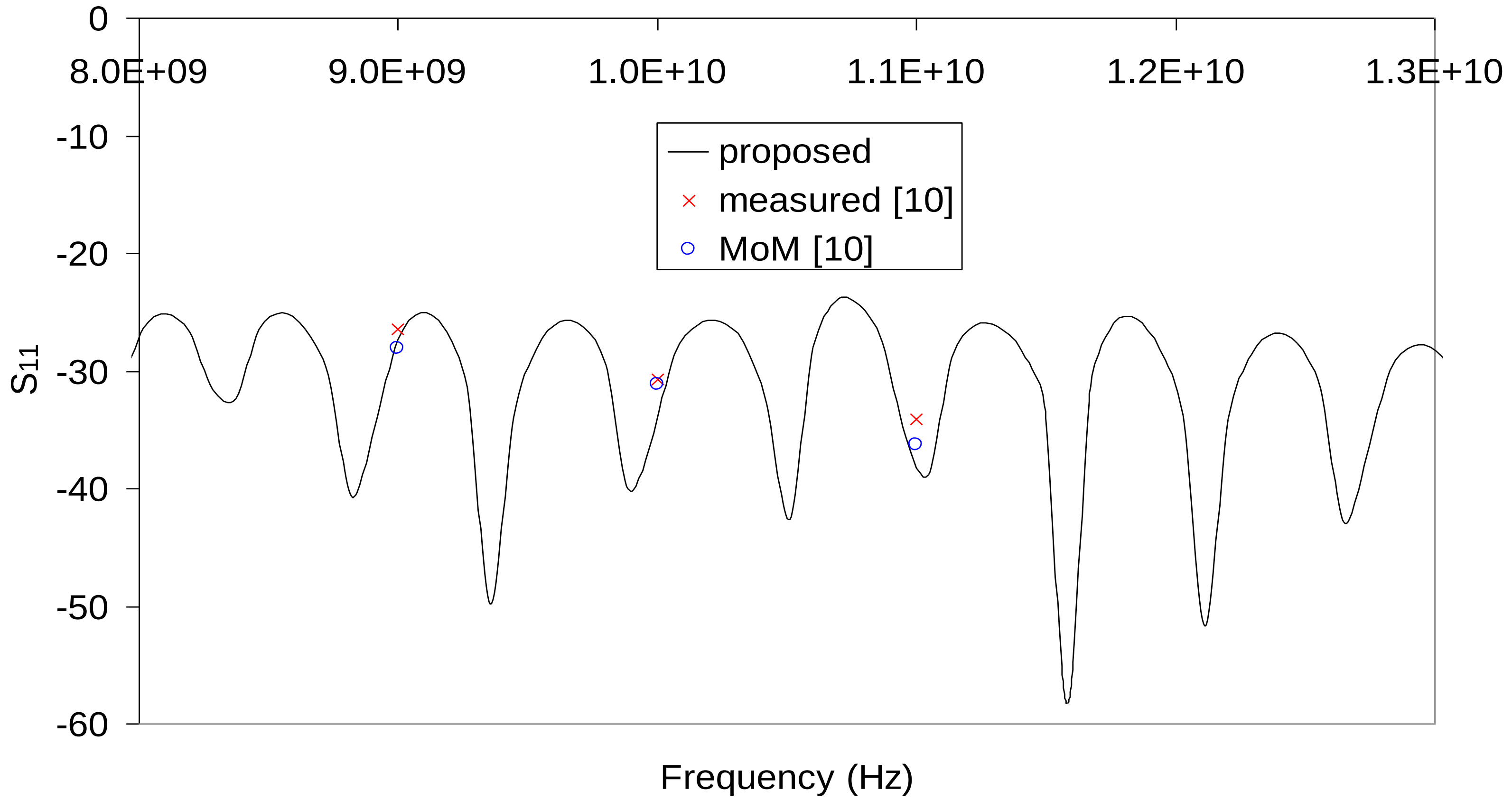
Propagation constants of propagation modes of rectangular waveguide

	TE_{10}	TE_{20}	TE_{01}	TE_{11} TM_{11}
Analytical	0.9226	0.6363	0.4968	0.3131
Proposed	0.9228	0.6395	0.5030	0.3232

The gain of the horn antenna calculated vs. MoM and measurement

	9 GHz	10 GHz	11 GHz
Proposed	19.43	20.18	20.95
MoM[10]	19.98	20.63	21.46
Measured[10]	19.72	20.46	21.24

Return Loss of the Horn Antenna



The broadband return loss of the horn antenna vs. MoM and measured results

Comparison of Return Loss of the Horn Antenna

Proposed vs. MoM and Measurement

	9 GHz	10 GHz	11 GHz
Proposed	-27.348	-32.378	-37.184
MoM [10]	-28.093	-31.147	-36.327
Measured [10]	-26.444	-30.714	-34.151

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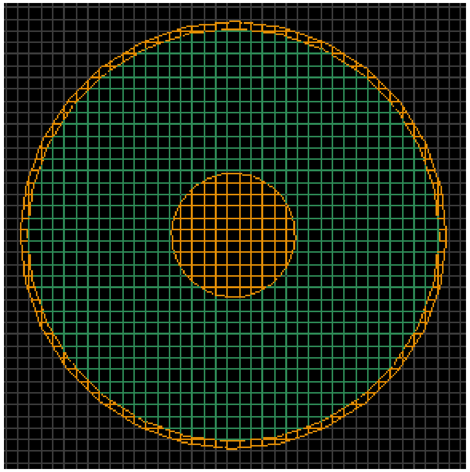
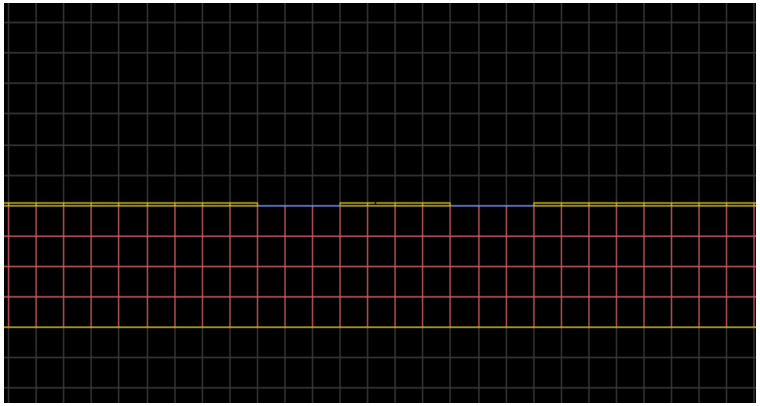
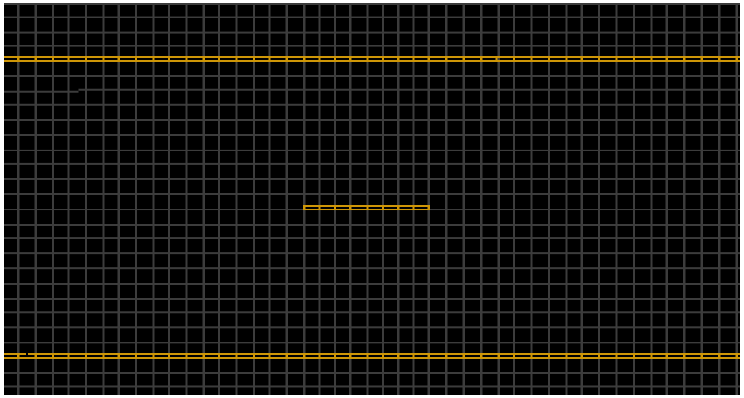
Other Applications

- Coax, CPW, stripline / other waveguides
- Connect to any circuits/ antennas







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Conclusion

- A conformal 2D FDFD Eigenmode solver was developed for arbitrarily shaped inhomogeneous waveguides.

- The propagation constants obtained by the conformal 2D solver agree well with those calculated by the analytical solutions, staircased 2D FDFD and other circuit solvers.

- The eigenmodes obtained by the conformal 2D FDFD solver can be used to excite various transmission lines and extract the modal S-parameters for conformal 3D FDTD solvers.

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