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IEEE International Symposium on Antennas and Propagation and USNC/URSI National Radio Science Meeting
June 1-5, 2009
IEEE URSI

Green's Functions for High-Impedance Surfaces: A Comparison between Homogenized Models and Full-Wave Results

P. Baccarelli[(1)], P. Burghignoli[(1)], G. W. Hanson[(2)],
G. Lovat[(1)], S. Paulotto[(1),(3)], and A. B. Yakovlev[(4)]

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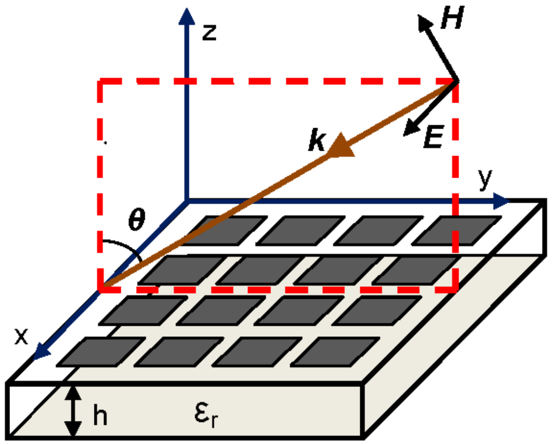
Outline

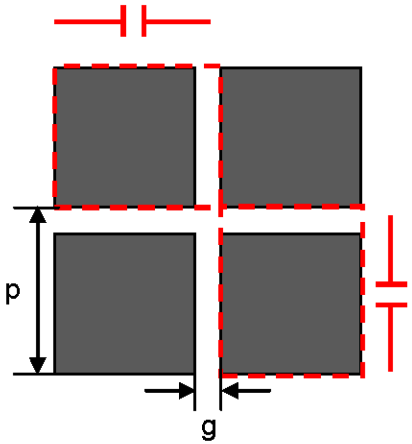
- **Motivation and Background**
  - High Impedance Surfaces and Artificial Magnetic Conductors
  - Plane-Wave Incidence
- **Excitation with an Electric Line Source**
  - Homogenized Model:
    - Green's function
    - Line source vs. plane-wave incidence
  - Periodic MoM Analysis: Array Scanning Method
- **Numerical Results**
- **Conclusions**

Motivation and Background

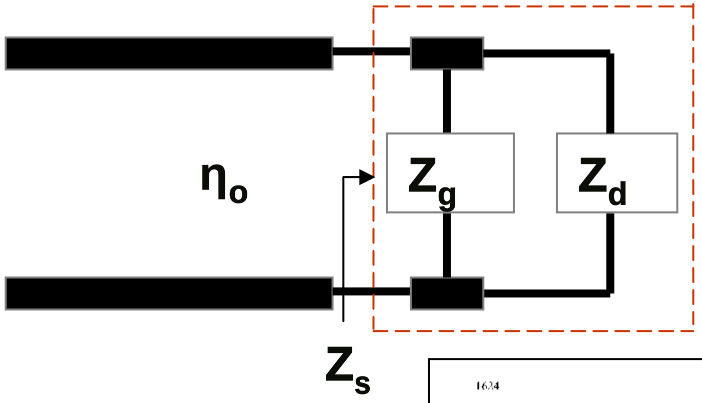
Plane-Wave Incidence
Analytical Modeling of HIS Structures

- Dynamic solution of 2D strip grid scattering problem
- Averaged impedance boundary condition
- Approximate Babinet principle





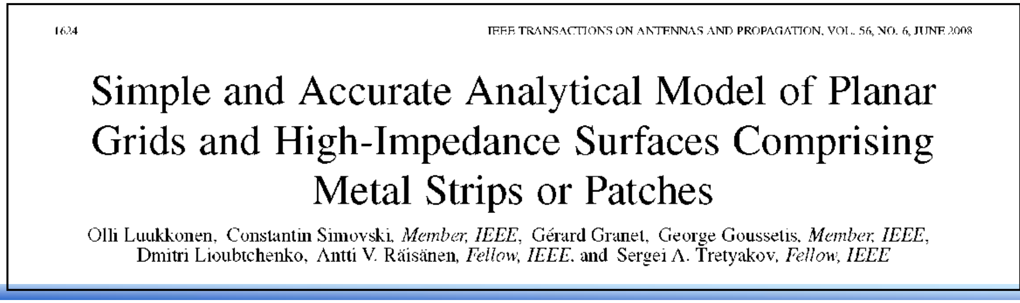
Transmission-line network



HIS

$$Z_s = \frac{Z_g Z_d}{Z_g + Z_d}$$

Parallel resonance $$Z_g(\omega) + Z_d(\omega) = 0$$

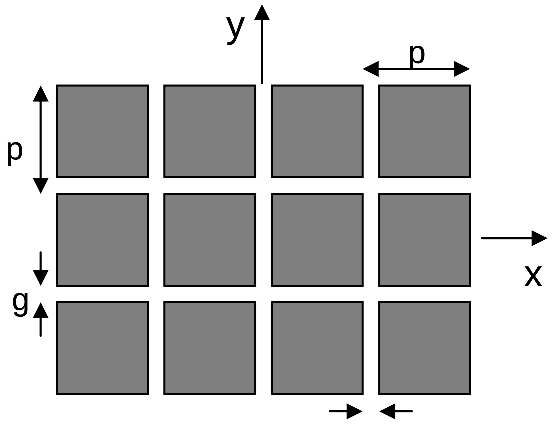


1624 IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 56, NO. 6, JUNE 2008

Simple and Accurate Analytical Model of Planar Grids and High-Impedance Surfaces Comprising Metal Strips or Patches

Olli Luukkonen, Constantin Simovski, *Member, IEEE*, Gérard Granet, George Goussetis, *Member, IEEE*, Dmitri Lioubtchenko, Antti V. Räisänen, *Fellow, IEEE*, and Sergei A. Tretyakov, *Fellow, IEEE*

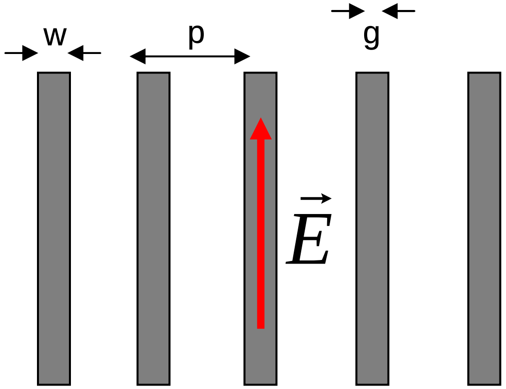
Grid Impedance



$$Z_g^{TE} = -j\frac{\eta_{eff}}{2\alpha}\frac{1}{\left(1-\frac{1}{2}\frac{k_0^2}{k_{eff}^2}\sin^2\theta\right)}$$

$$Z_g^{TM} = -j\frac{\eta_{eff}}{2\alpha}$$

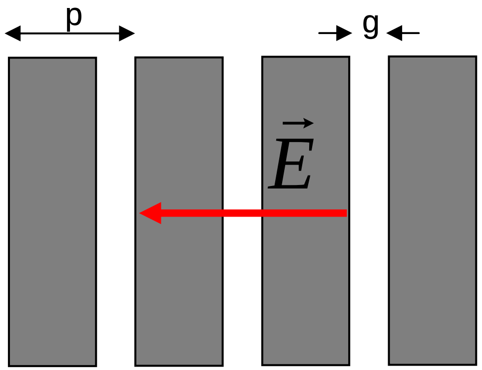
$$\alpha = \frac{k_{eff}\,p}{\pi}\ln\left(\csc\left(\frac{\pi g}{2p}\right)\right)$$



$$Z_g^{TM} = j\frac{\eta_{eff}}{2}\alpha\left(1-\frac{k_0^2}{k_{eff}^2}\sin^2\theta\right)$$

$$Z_g^{TE} = j\frac{\eta_{eff}}{2}\alpha$$

$$\alpha = \frac{k_{eff}\,p}{\pi}\ln\left(\csc\left(\frac{\pi w}{2p}\right)\right)$$



$$Z_g^{TE} = -j\frac{\eta_{eff}}{2\alpha}\frac{1}{\left(1-\frac{k_0^2}{k_{eff}^2}\sin^2\theta\right)}$$

$$Z_g^{TM} = -j\frac{\eta_{eff}}{2\alpha}$$

Surface Impedance of Grounded Slab

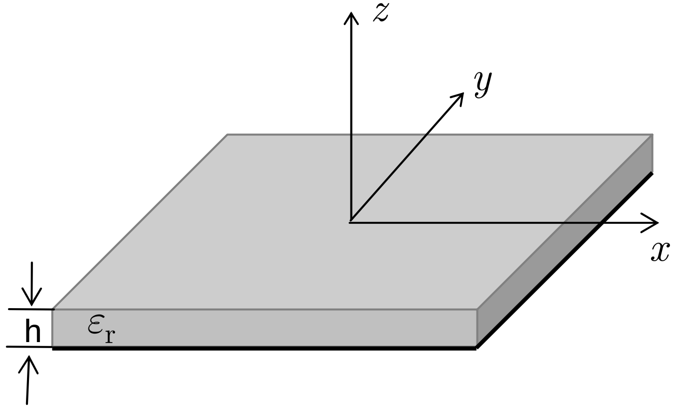
Dielectric Impedance

TM $$Z_d^{TM}(\omega,\theta) = \frac{j\eta_0}{\sqrt{\varepsilon_r - \sin^2\theta}} \tan(k_{zd}\, h)\left(1 - \frac{\sin^2\theta}{\varepsilon_r}\right)$$

TE $$Z_d^{TE}(\omega,\theta) = \frac{j\eta_0}{\sqrt{\varepsilon_r - \sin^2\theta}} \tan(k_{zd}\, h)$$

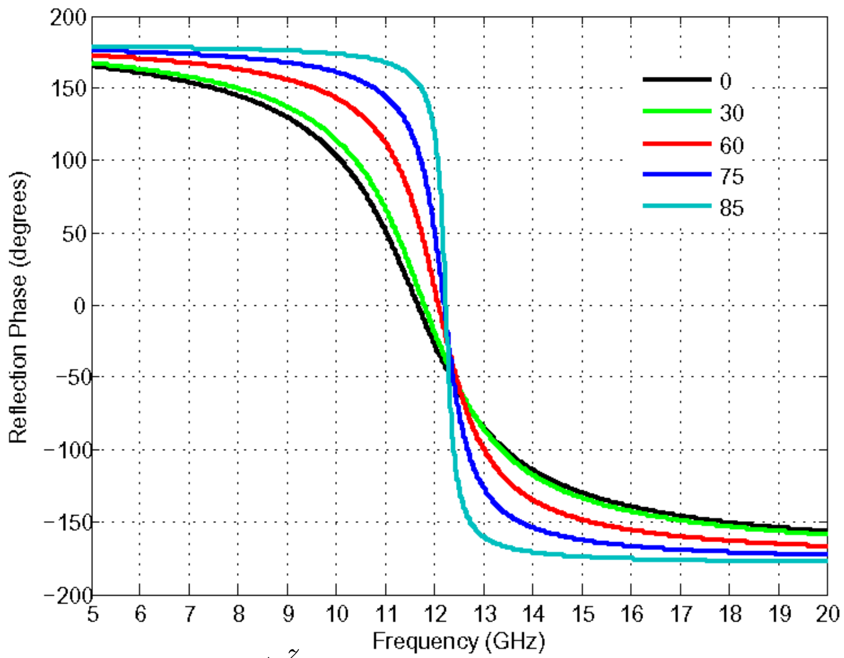
$$k_{zd} = \omega\sqrt{\varepsilon_0\mu_0}\sqrt{\varepsilon_r - \sin^2\theta}$$

vertical component of the wave vector of the refracted wave

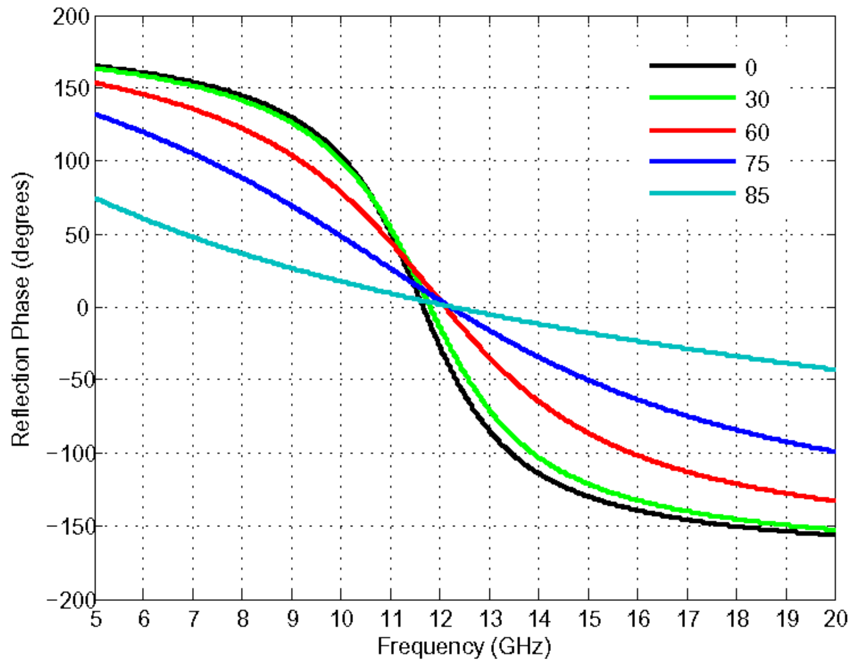


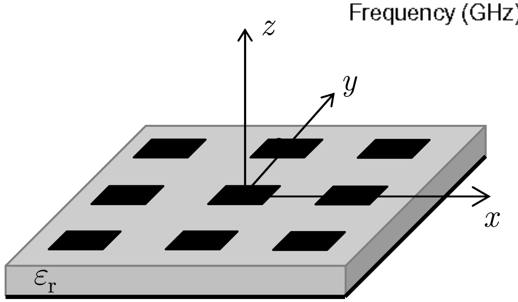
Patch Array HIS – Oblique Incidence

TE polarization

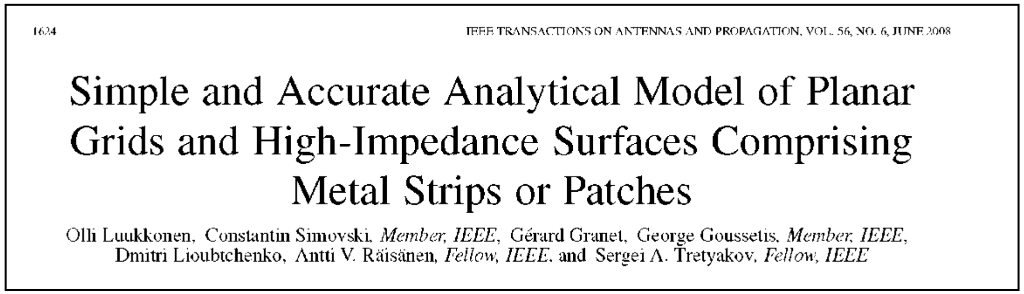


TM polarization





Substrate thickness: 1 mm
Period: 2 mm
Gap: 0.2 mm
Dielectric permittivity: 10.2



1624 IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 56, NO. 6, JUNE 2008

Simple and Accurate Analytical Model of Planar Grids and High-Impedance Surfaces Comprising Metal Strips or Patches

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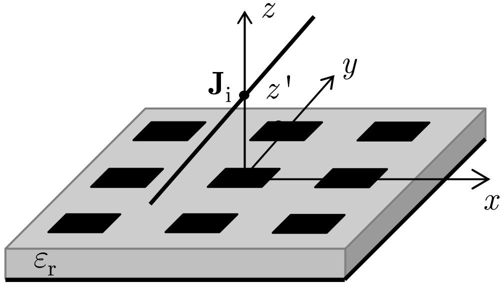
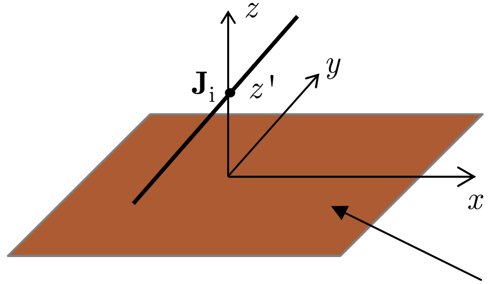
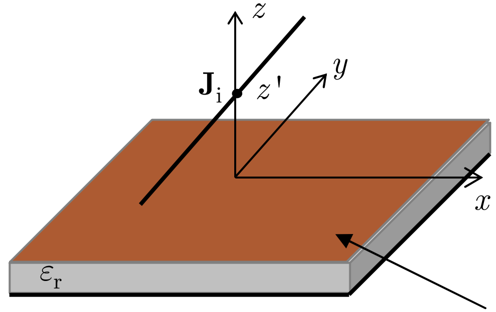
Excitation with a Line Source

Green's Function for Homogenized HIS

Original Problem	Homogenized Problem Method I	Homogenized Problem Method II
		

$Z_s = Z_{grid} || Z_{dielectric}$

Z_{grid}

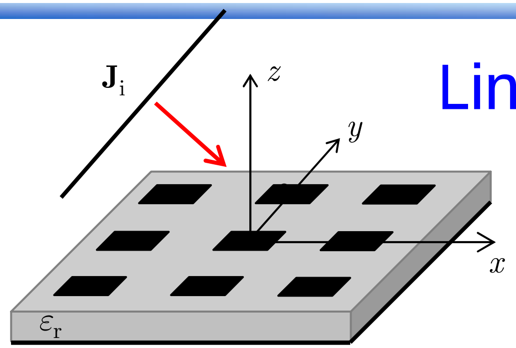
$$\mathbf{J} = \hat{\mathbf{y}} I_0 \delta(z - z_0)\delta(x)$$

$$\mathbf{E}(x,z) = \hat{\mathbf{z}} \frac{I_0 k_1^2}{j\omega\varepsilon_1} \left(\underbrace{\frac{1}{4j} H_0^{(2)}\left(k_1\sqrt{(z-z_0)^2 + x^2}\right)}_{\text{Direct Term}} + \underbrace{\frac{1}{2\pi}\int_{-\infty}^{\infty} R_t(k_x) e^{-p_1(z+z_0)} \frac{e^{jk_x x}}{2\sqrt{k_x^2 - k_1^2}}\, dk_x}_{\text{Scattered Term}} \right)$$

$$R_t^{\text{method I}}(k_x) = \frac{p_1 - j\omega\mu_1/Z_s}{p_1 + j\omega\mu_1/Z_s} \qquad p_i = \sqrt{k_x^2 - k_i^2} \qquad M^2 = \mu_2/\mu_1$$

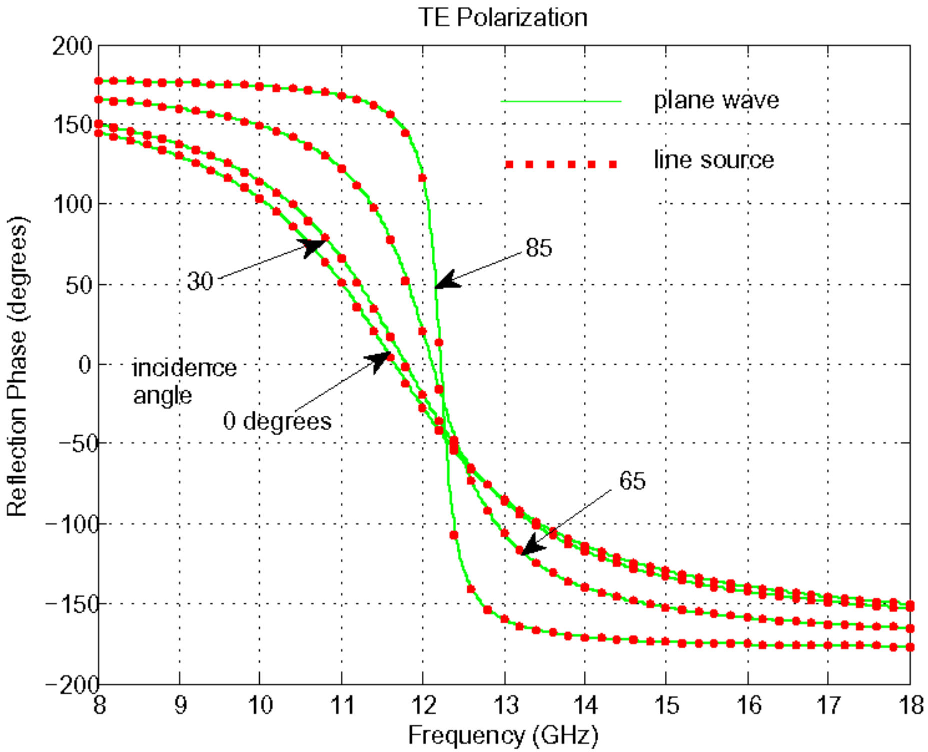
$$R_t^{\text{method II}}(k_x) = \frac{\left(1-e^{2p_2h}\right)(p_1 - j\omega\mu_1/Z_g)M^2 + \left(1+e^{2p_2h}\right)p_2}{\left(1-e^{2p_2h}\right)(p_1 + j\omega\mu_1/Z_g)M^2 - \left(1+e^{2p_2h}\right)p_2}$$

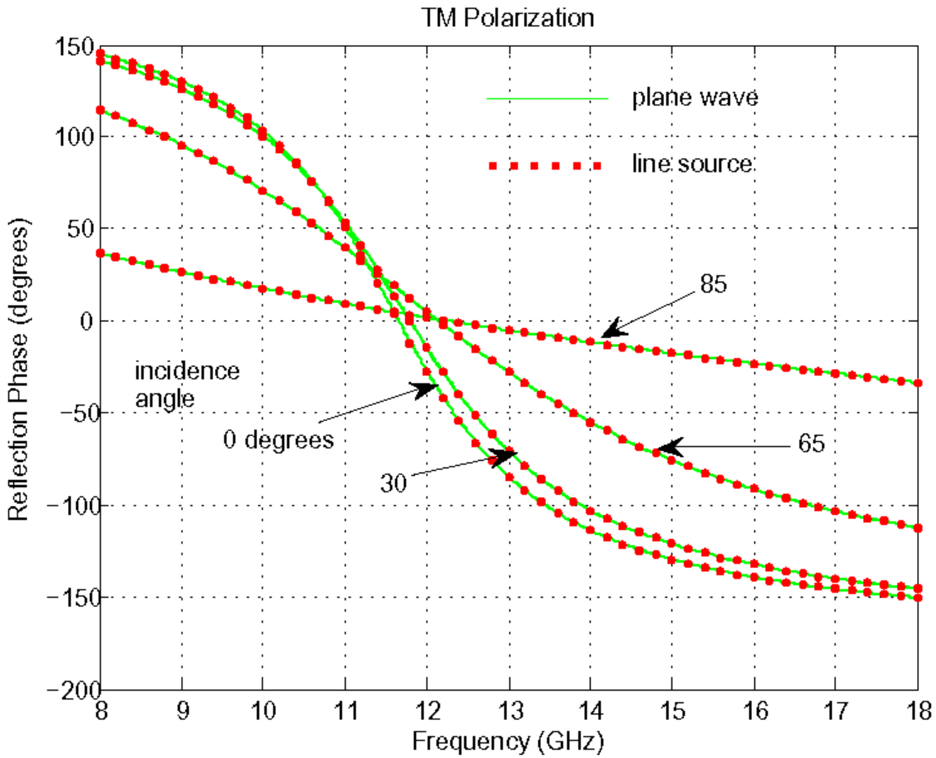
Line Source versus Plane-Wave Incidence (1)



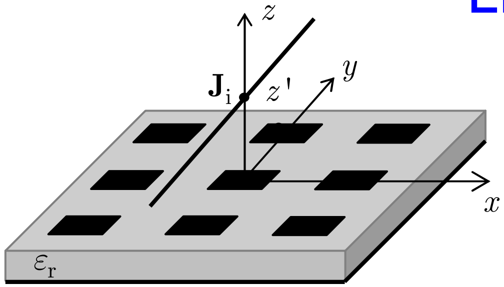
Line source in the far zone

Substrate thickness: 1 mm
Period: 2 mm
Gap: 0.2 mm
Dielectric permittivity: 10.2





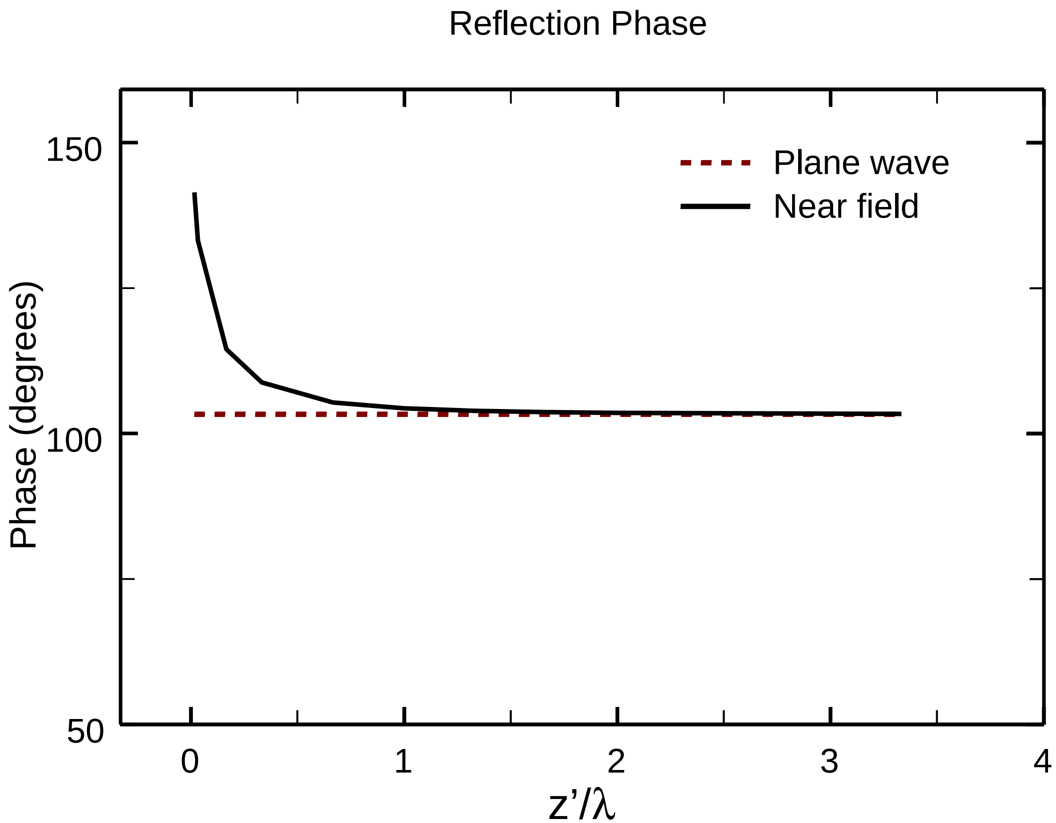
Line Source versus Plane-Wave Incidence (2)



Line source in proximity of homogenized HIS

f = 10 GHz

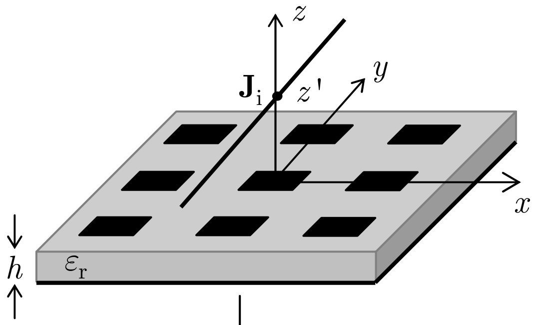
Normal incidence



The plane-wave and line-source results agree when the source is positioned about one wavelength above the HIS

Periodic Analysis: ASM 1D – 2D

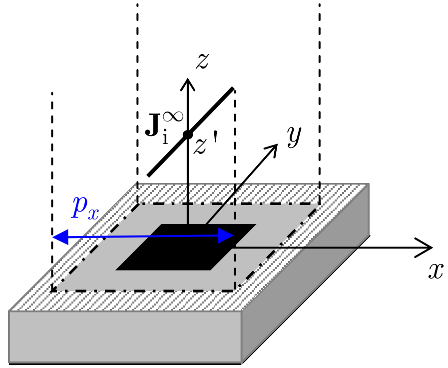
Original problem



$$\mathbf{J}_\mathrm{i}(x,z) = \mathbf{y}_0 I_0 \delta(x)\,\delta(z-z')$$

One-dimensional (1D) excitation

Auxiliary Floquet-Periodic (FP) problem



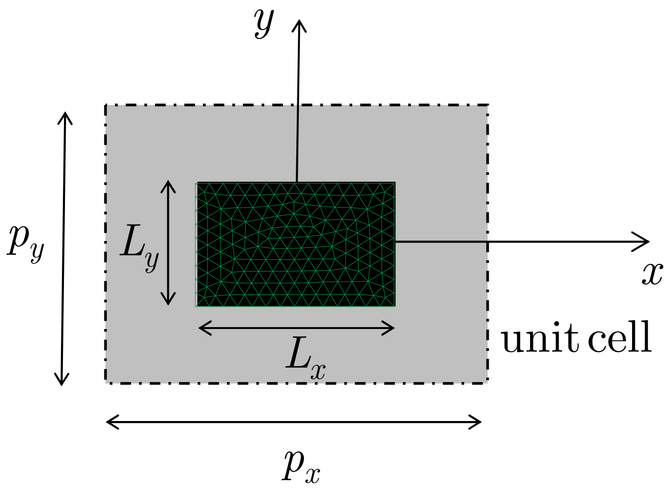
$$\mathbf{J}_\mathrm{i}^\infty(x,z) = \mathbf{y}_0 I_0 \left[\sum_{m=-\infty}^{+\infty} \delta(x - mp_x)\, e^{-jmk_x p_x}\right] \delta(z-z')$$

Two-dimensional (2D) periodicity

The ASM requires the efficient solution of a large number of auxiliary FP sub-problems

Periodic Analysis: The Auxiliary FP Problem

Mixed
Potential
Integral
Equations
(MPIE)



Rao
Wilton
Glisson
(RWG)

Discretization
of arbitrary planar
geometry
within the Unit Cell

Special Issue on Metamaterials EBG

Full-wave analysis of bound and leaky modes propagating along 2D periodic printed structures with arbitrary metallisation in the unit cell

P. Baccarelli, S. Paulotto and C. Di Nallo

IET Microw. Antennas Propag., Vol. 1, No. 1, February 2007

Acceleration techniques and interpolation schemes are required for the computation of the Mixed-Potential Multilayered
2-D Periodic Green's Functions

122 IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 57, NO. 1, JANUARY 2009

Regularization of Mixed-Potential Layered-Media Green's Functions for Efficient Interpolation Procedures in Planar Periodic Structures

Guido Valerio, *Student Member, IEEE*, Paolo Baccarelli, *Member, IEEE*, Simone Paulotto, *Member, IEEE*, Fabrizio Frezza, *Senior Member, IEEE*, and Alessandro Galli, *Member, IEEE*

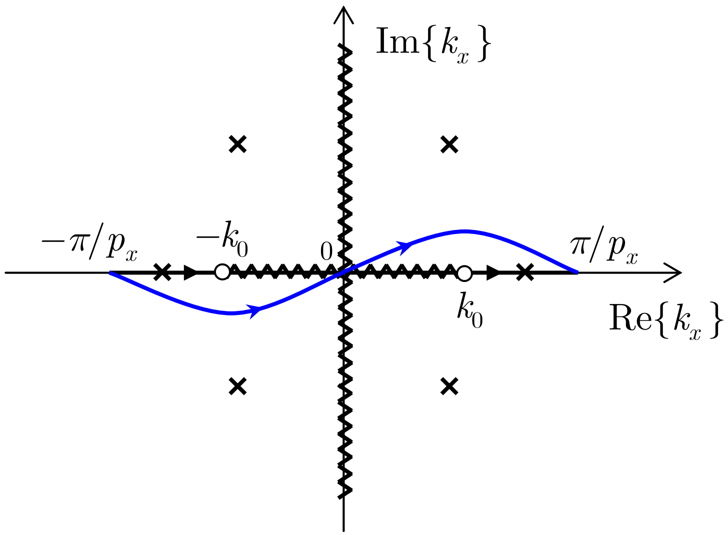
Periodic Analysis: ASM

$$\delta(x) = \frac{p_x}{2\pi} \int_{-\pi/p_x}^{+\pi/p_x} \sum_{m=-\infty}^{+\infty} \delta(x - mp_x) e^{-jmk_x p_x} \mathrm{d}k_x$$

Basic ASM identity

$$\mathbf{J}_\mathrm{i}(x,z) = \delta(z - z') \frac{p_x}{2\pi} \int_{-\pi/p_x}^{+\pi/p_x} \mathbf{J}_\mathrm{i}^\infty(x,z;k_x) \mathrm{d}k_x$$

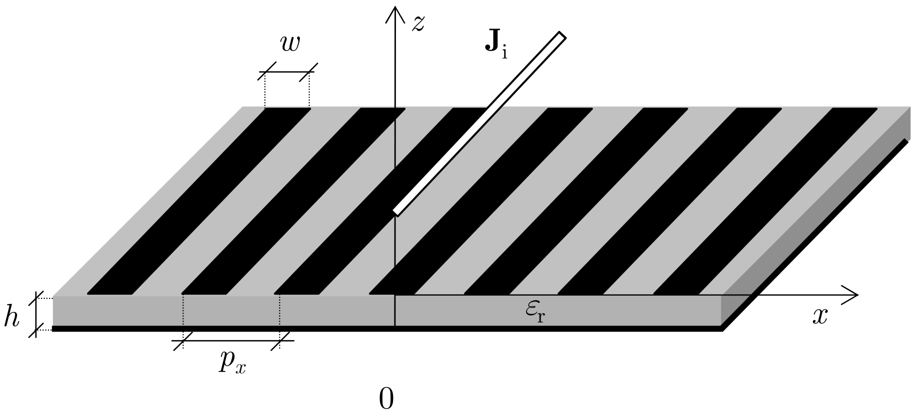
$$\mathbf{E}(x,y,z) = \frac{p_x}{2\pi} \int_{-\pi/p_x}^{+\pi/p_x} \mathbf{E}^\infty(x,y,z;k_x) \mathrm{d}k_x$$

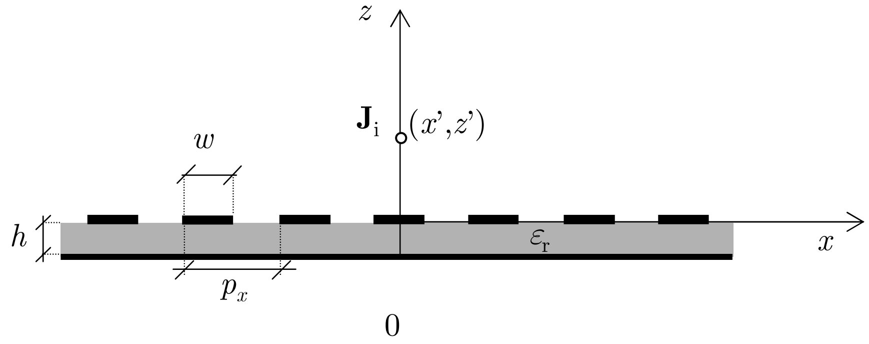


The field is represented as an integral superposition of FP fields. The integration is performed with respect to the phase shift k_x in the direction x over the entire first Brillouin zone.

Numerical Results
Comparison between Homogenized Model and Full-Wave Results

Validation: MSG-GDS





In this case both the structure and the source are independent of the y direction. The excited field is also independent of y and is purely TE$_{xz}$.

A one-dimensional (1D) ASM with 1D periodicity is implemented (ASM 1D-1D).

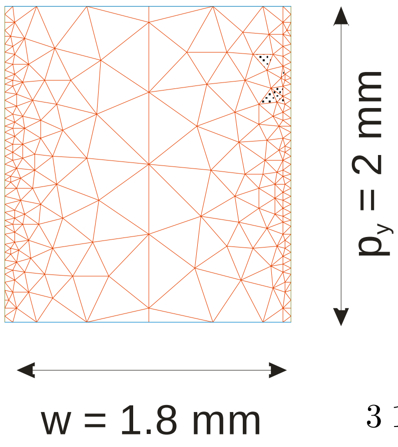
IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 53, NO. 1, JANUARY 2005 91

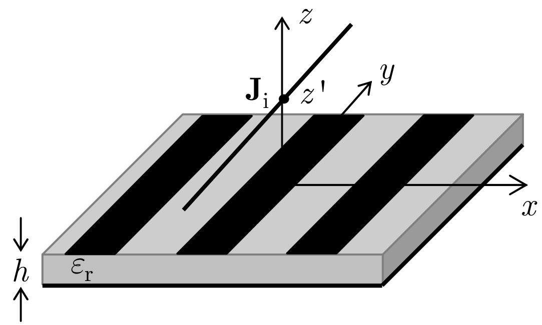
Fundamental Properties of the Field at the Interface Between Air and a Periodic Artificial Material Excited by a Line Source

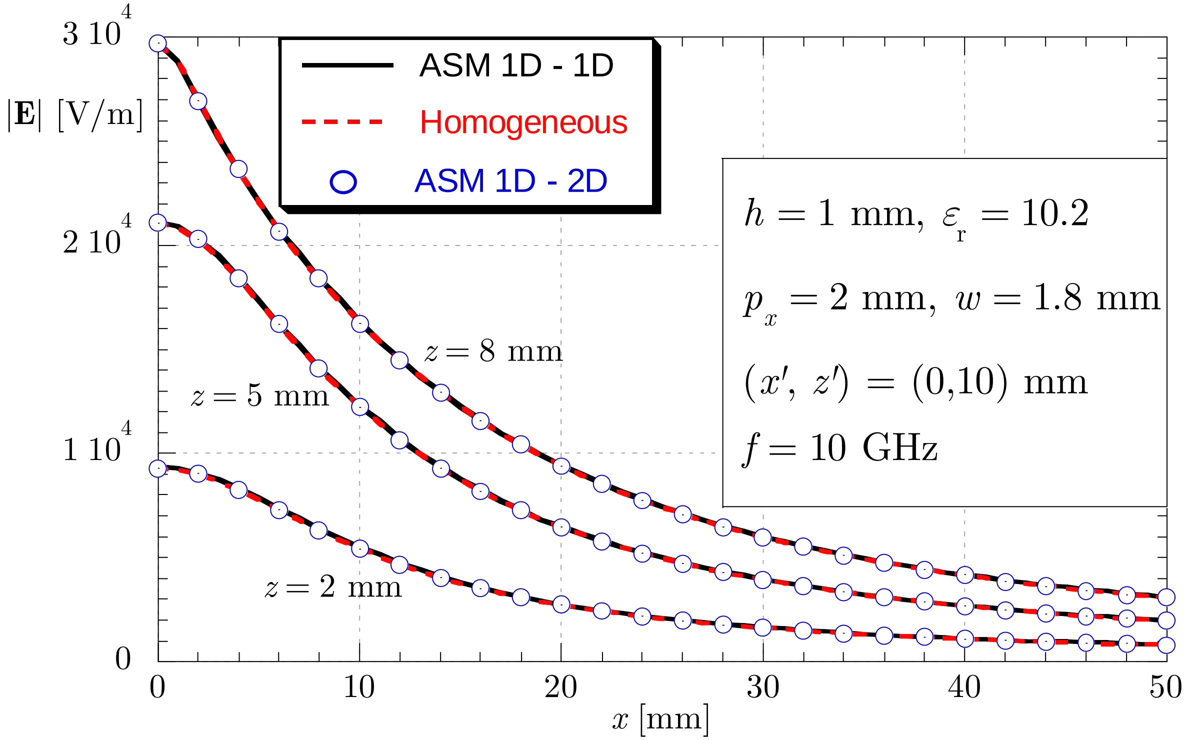
Filippo Capolino, *Senior Member, IEEE*, David R. Jackson, *Fellow, IEEE*, and Donald R. Wilton, *Fellow, IEEE*

The relevant EFIE is discretized in the unit cell expanding the current on the strips through entire-domain basis functions defined over the strip width and incorporating the appropriate edge singularity.

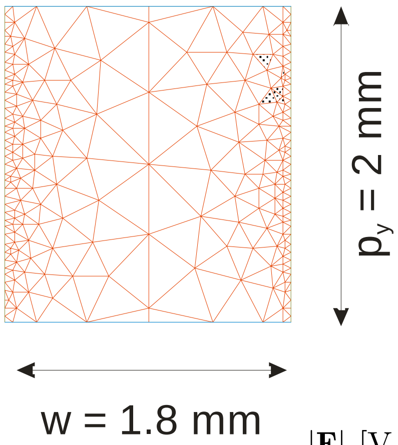
Validation: MSG-GDS parallel (1)

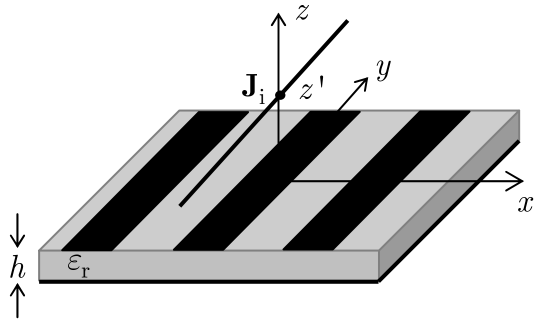


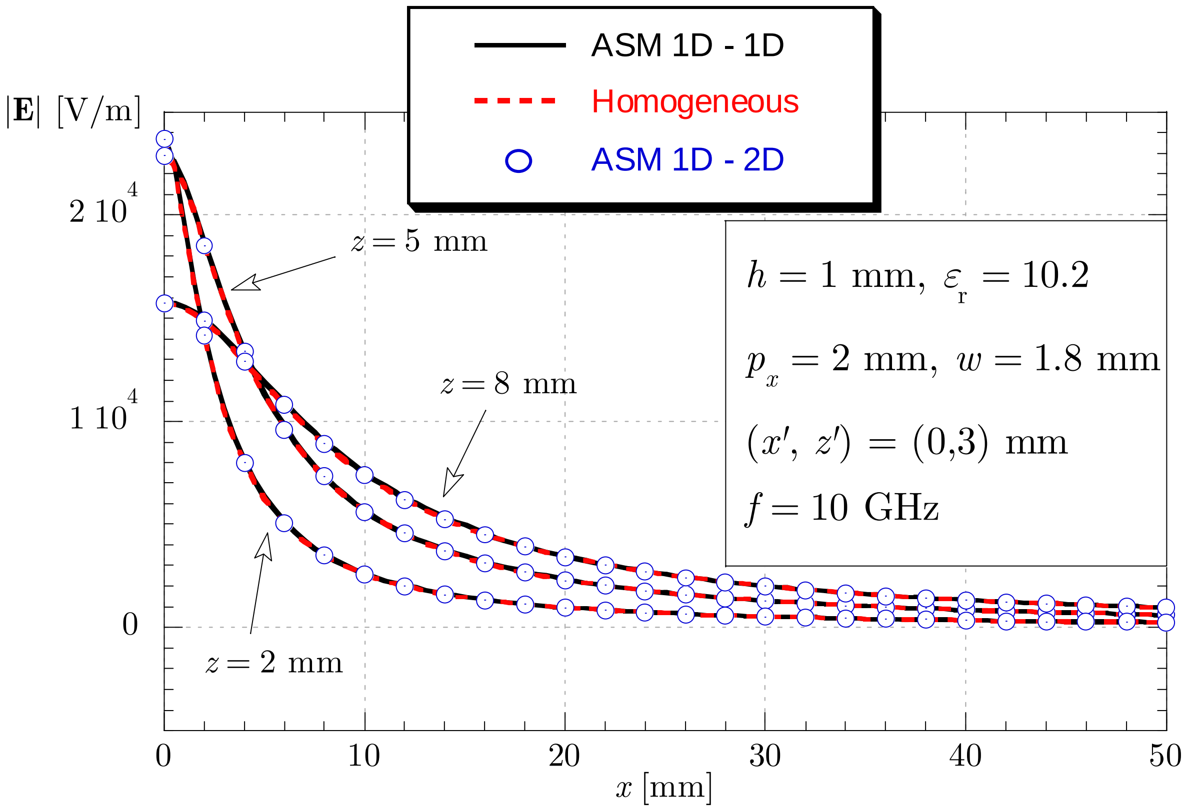




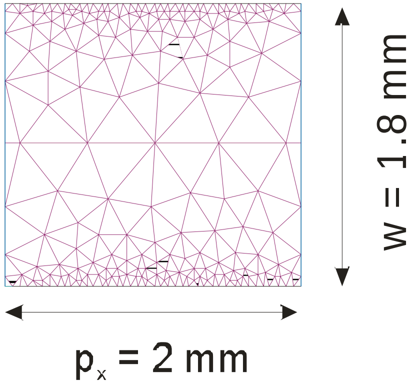
Validation: MSG-GDS parallel (2)

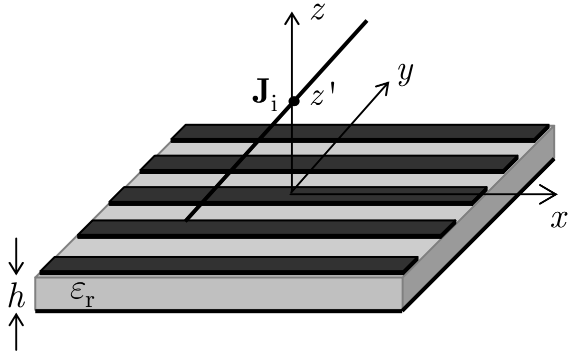


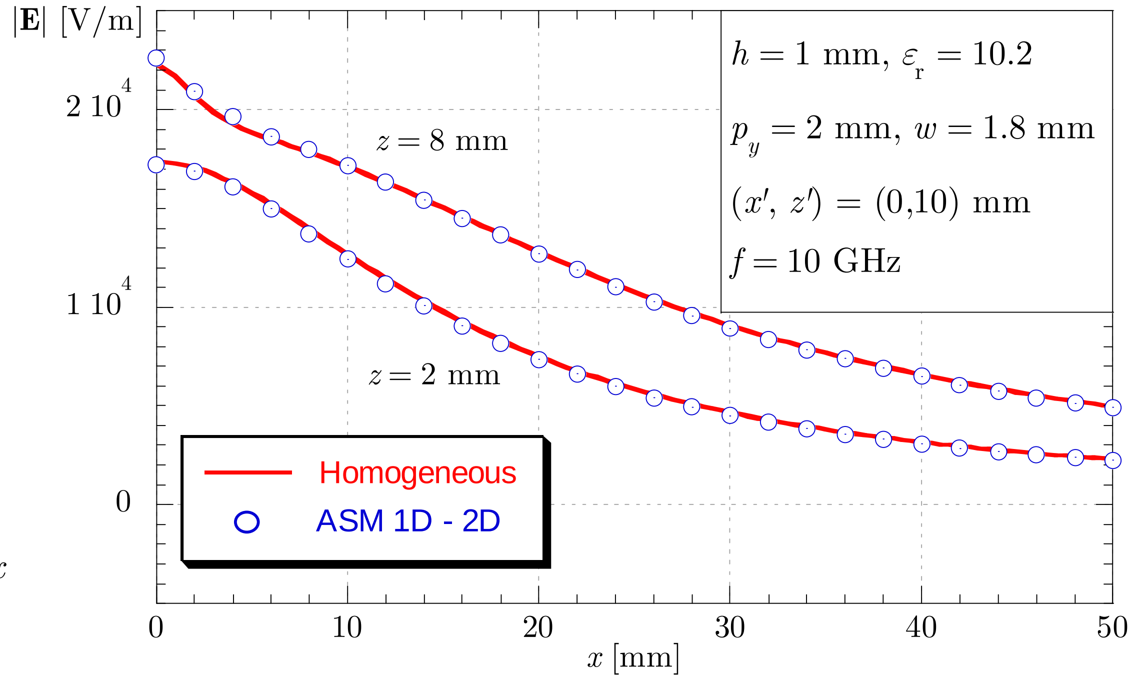




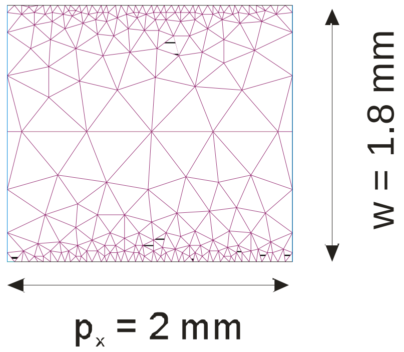
Case Study: MSG-GDS orthogonal (1)

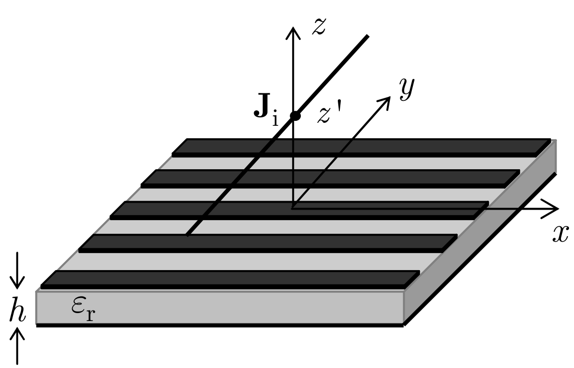


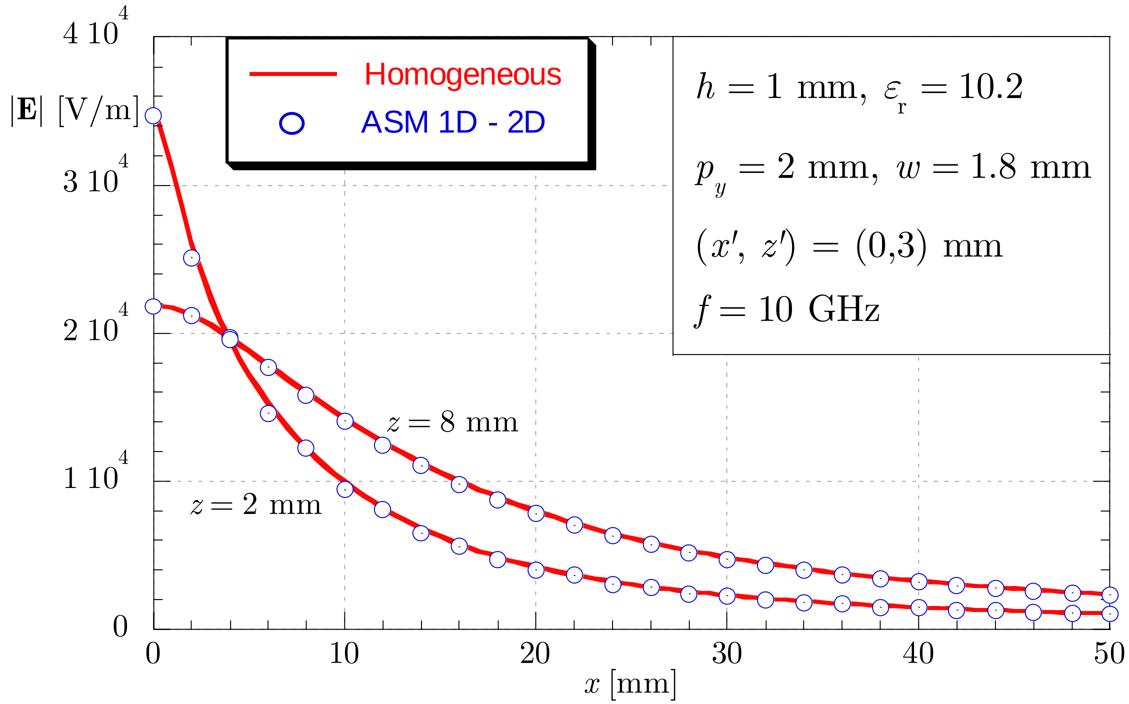




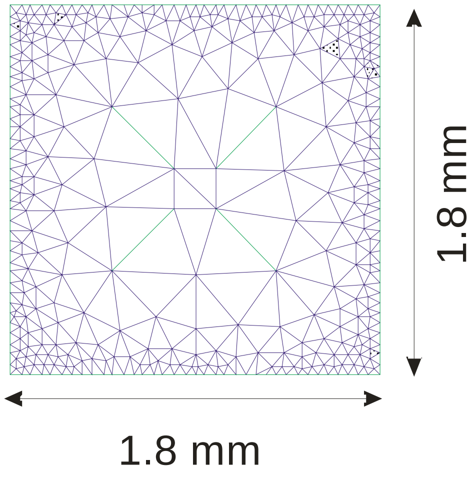
Case Study: MSG-GDS orthogonal (2)

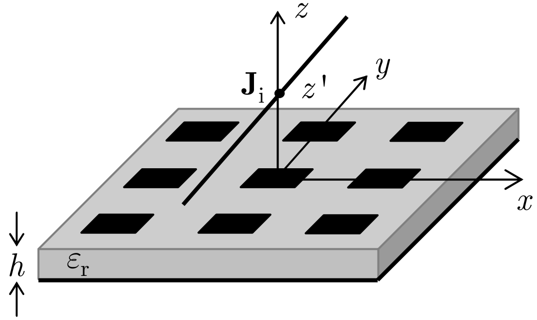


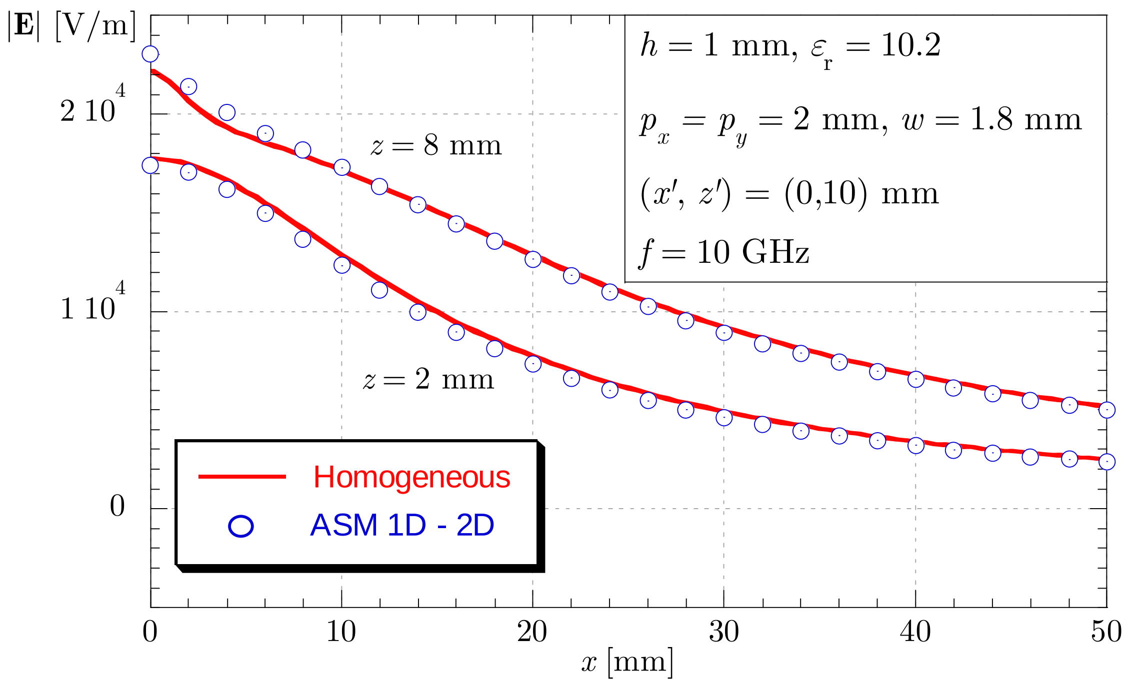




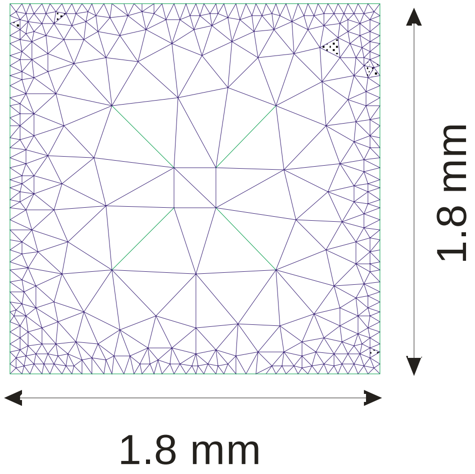
Case Study: Patch Array (1)

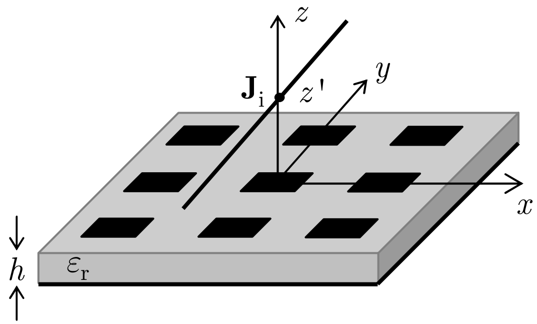


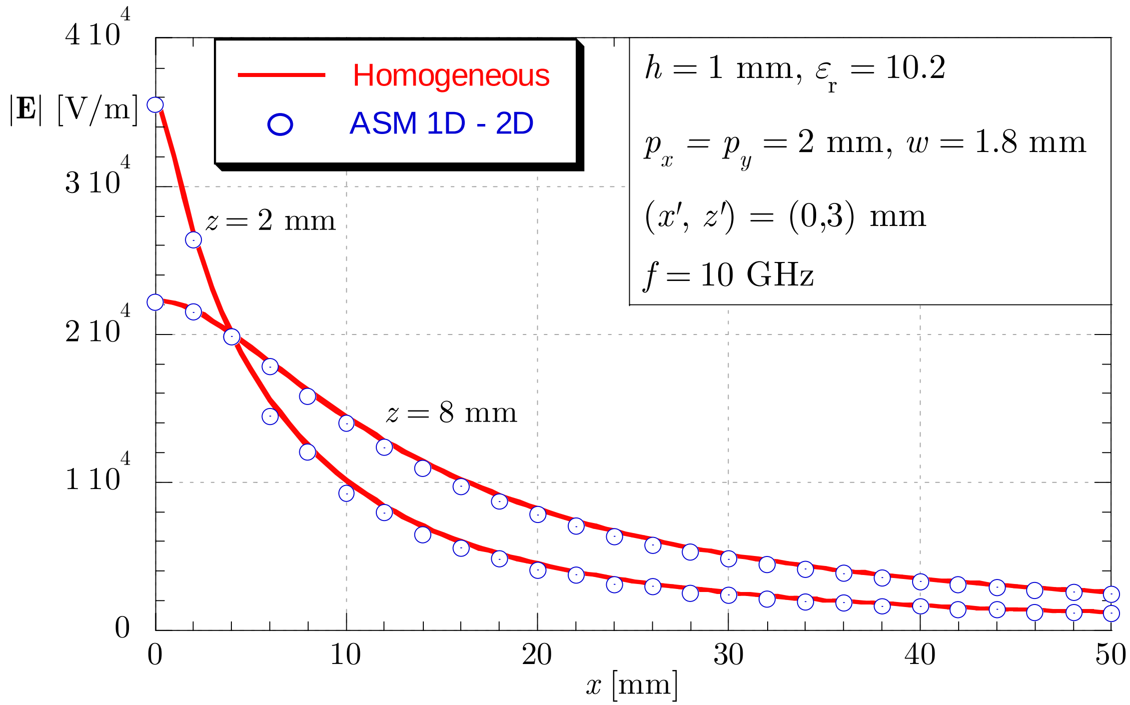




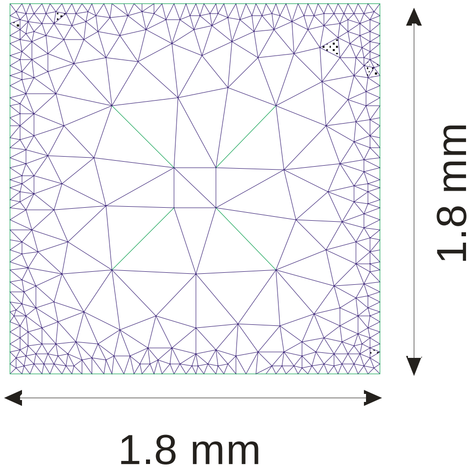
Case Study: Patch Array (2)

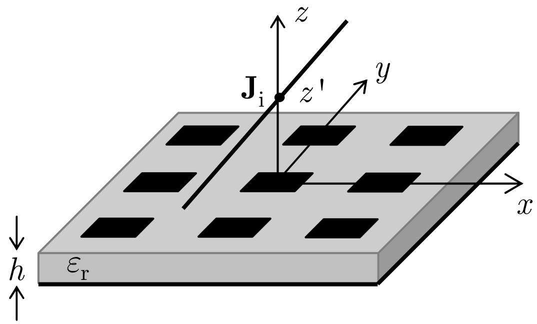


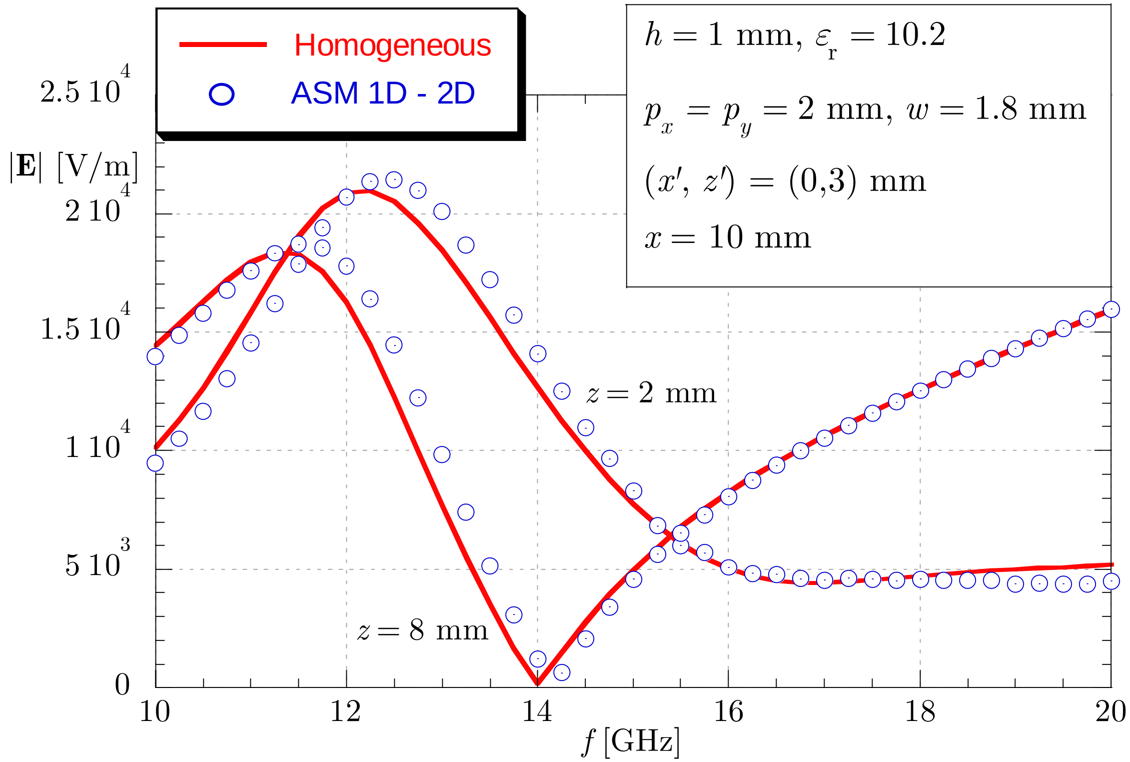




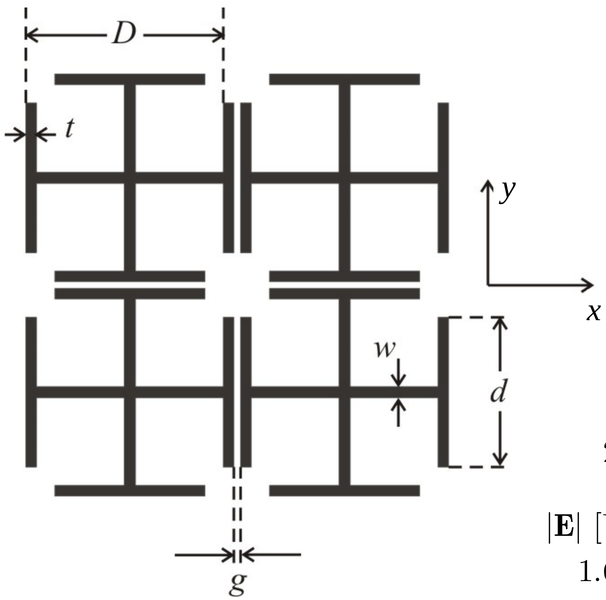
Case Study: Patch Array (3)



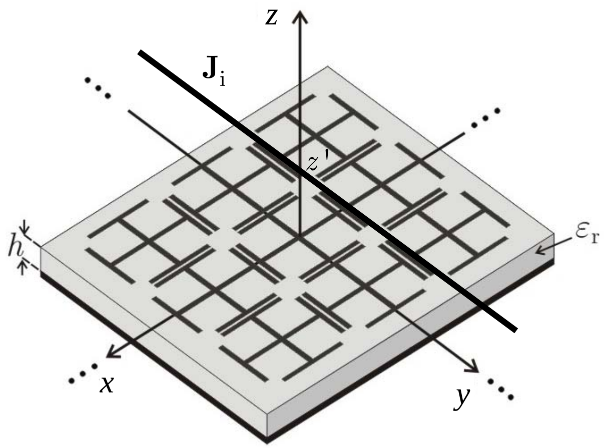


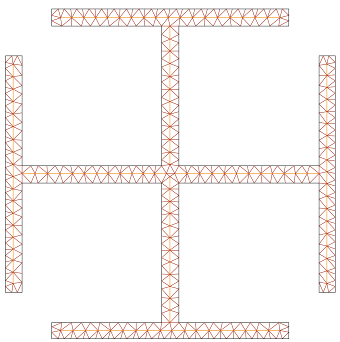


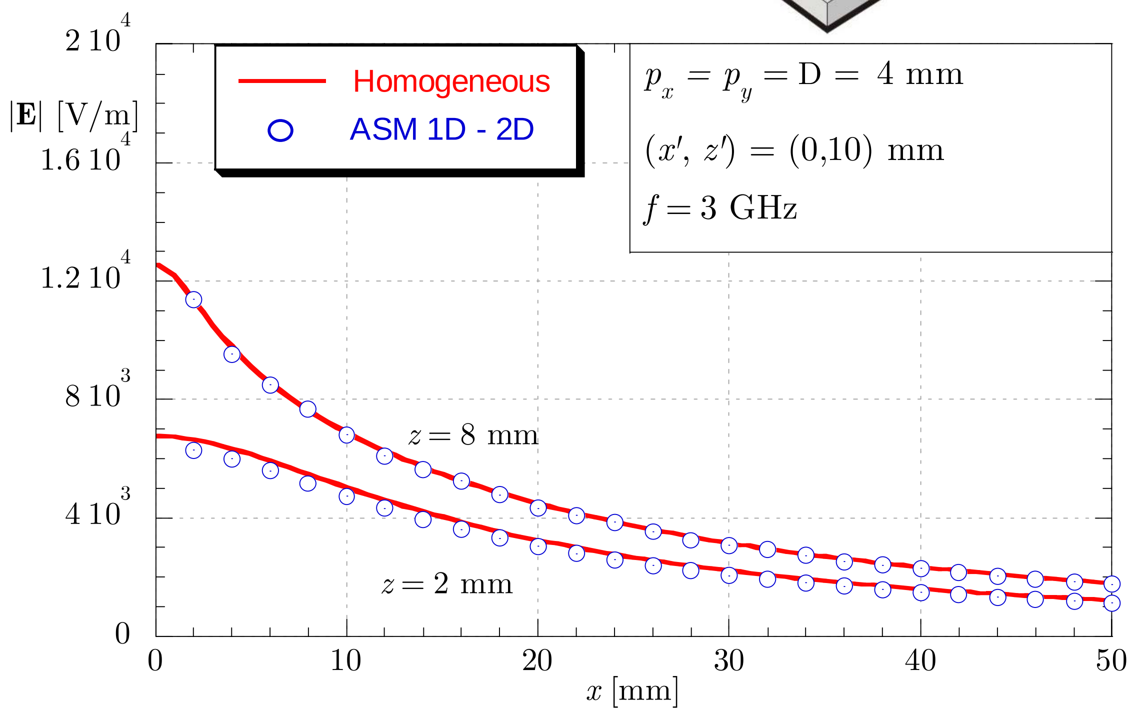
Case Study: Jerusalem Cross (1)



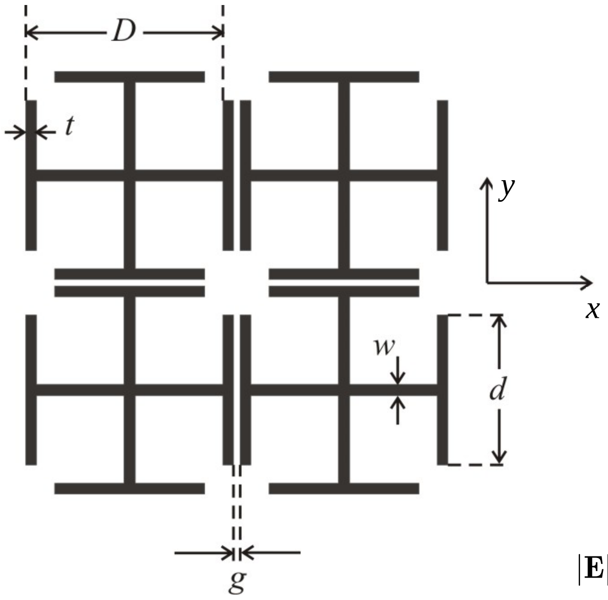
g = 0.1 mm
d = 2.8 mm
$t = w$ = 0.2 mm
D = 4 mm
h = 6 mm
ε_r = 2.7



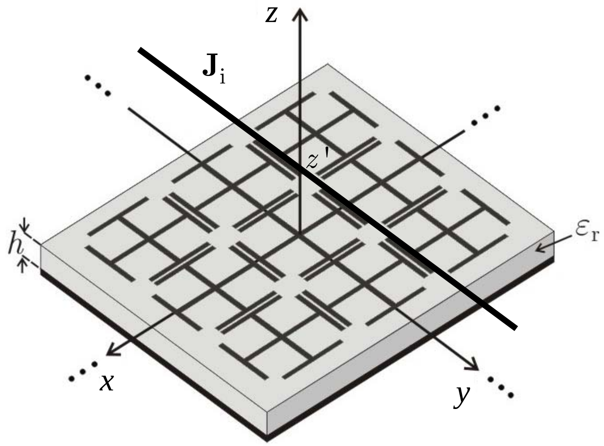


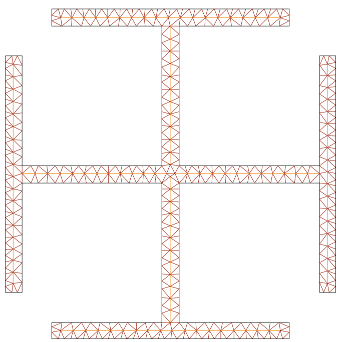


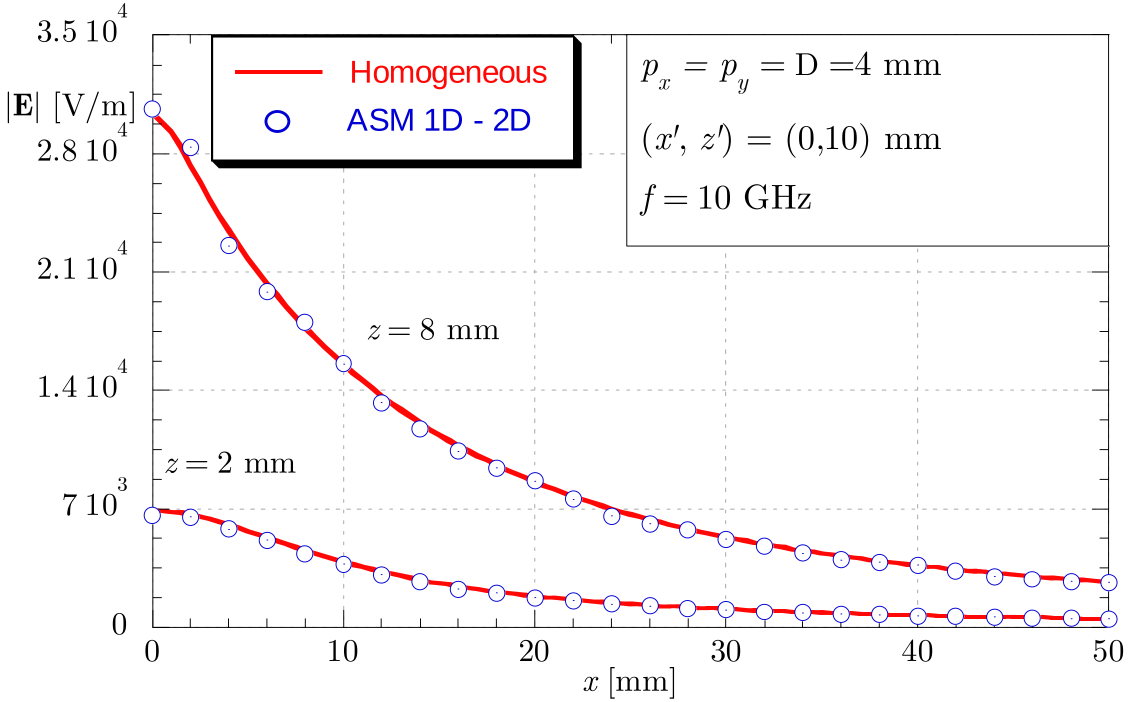
Case Study: Jerusalem Cross (2)



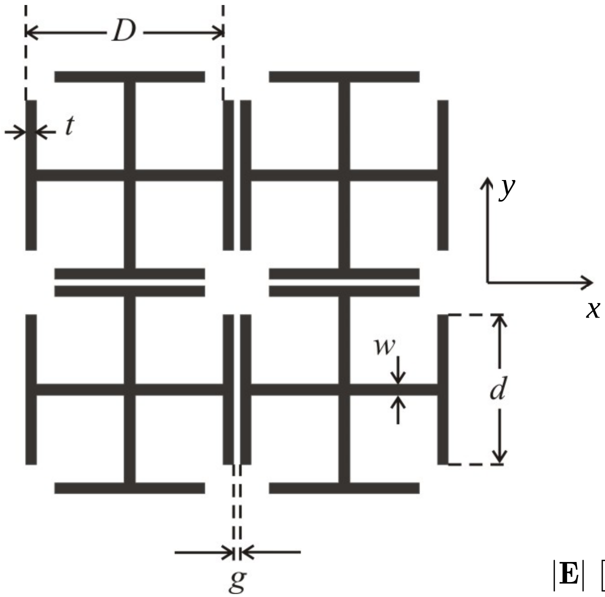
g = 0.1 mm
d = 2.8 mm
t = w = 0.2 mm
D = 4 mm
h = 6 mm
ε_r = 2.7







Case Study: Jerusalem Cross (3)



g = 0.1 mm
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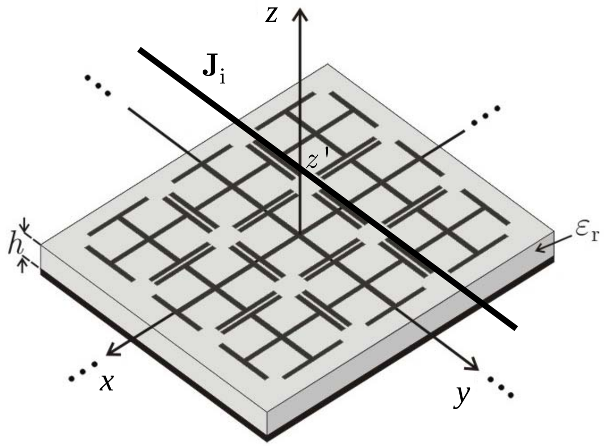
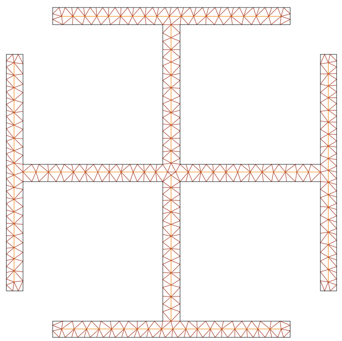
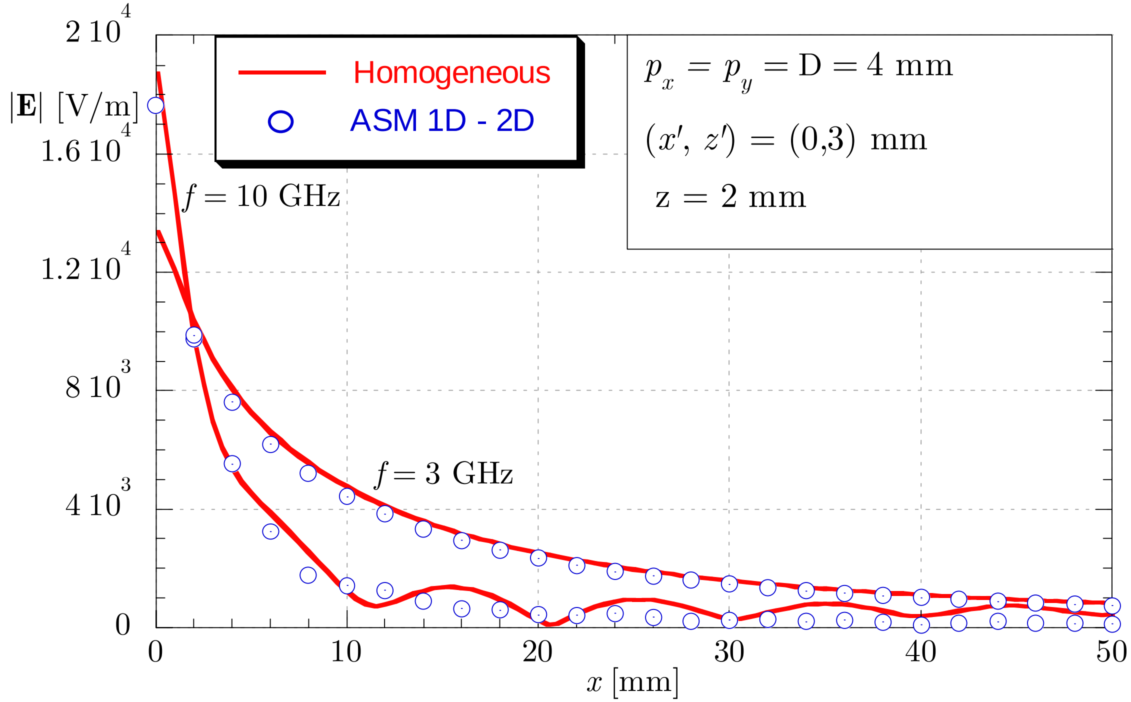
D = 4 mm
h = 6 mm
ε_r = 2.7







Conclusions

Conclusions

- **Array scanning method is developed for the full-wave analysis of HIS structures with 1D and 2D sub-wavelength grids and compared with the homogenized Green's function solution with the electric line source excitation**

- **Near field obtained with the homogenized model and full-wave Method is compared for different source and field points, showing an excellent agreement for several HIS structures**

- **Future work concerns the analysis of near and far fields due to realistic antennas placed in a proximity of HIS structures in order to characterize the conditions of applicability of homogenized Green's function**