

Electromagnetic Metagrating Absorbers

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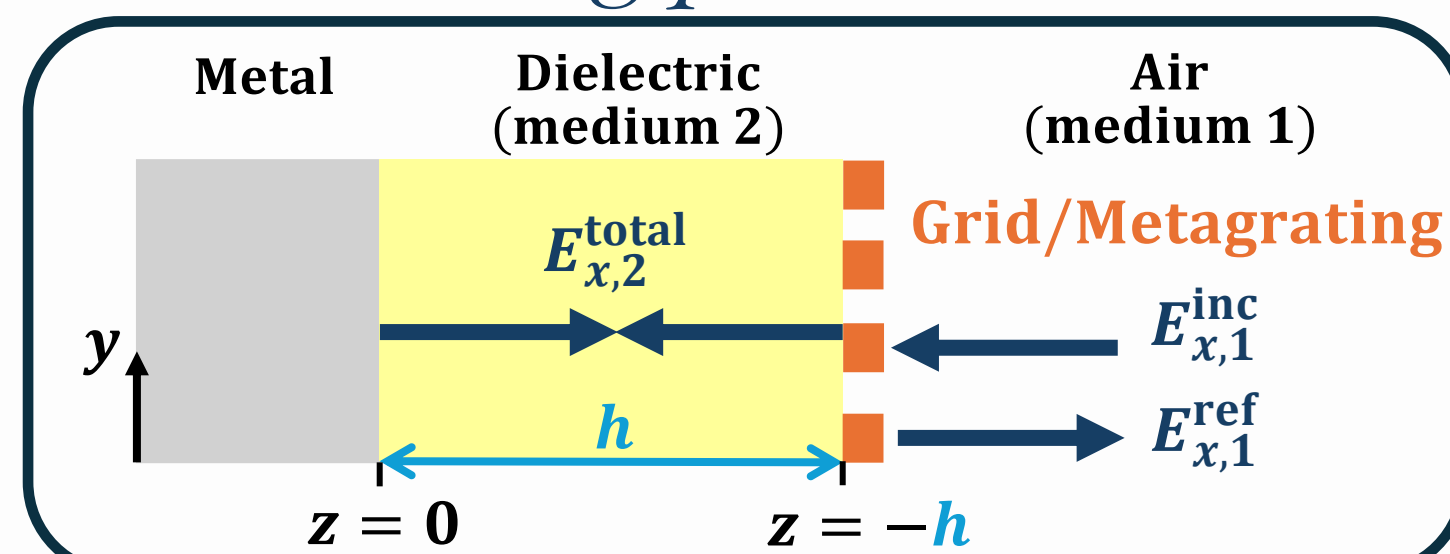
1. Introduction

- Absorption of electromagnetic waves in thin planar structures which are passive, linear, and time-invariant is desirable in many applications, ranging from radar-cross-section reduction and stealth, through solar cells and detectors for sensing, to harvesting of radiated RF power. In many of those, one would like to maximize the absorption band – a wideband device.
- In metal-backed dielectric planar structures, excited by normally incident plane-waves, an inherent trade-off between the thickness and bandwidth is found [1]. In other words, a thin absorber would limit the absorption bandwidth, and vice-versa.
- In this project, we apply rigorous semianalytical models associated with metagratings (MGs, periodic arrangements, patterned on substrates, of sparsely packed distributed loaded lines acting as secondary sources via Floquet-Bloch theorem, dictating radiation of discrete FB modes [2]), coupled with recently devised *abstract* guidelines [3], to derive closed-form and semianalytical expressions for the required constitutive distributed load parameters and metagrating (MG) geometry.

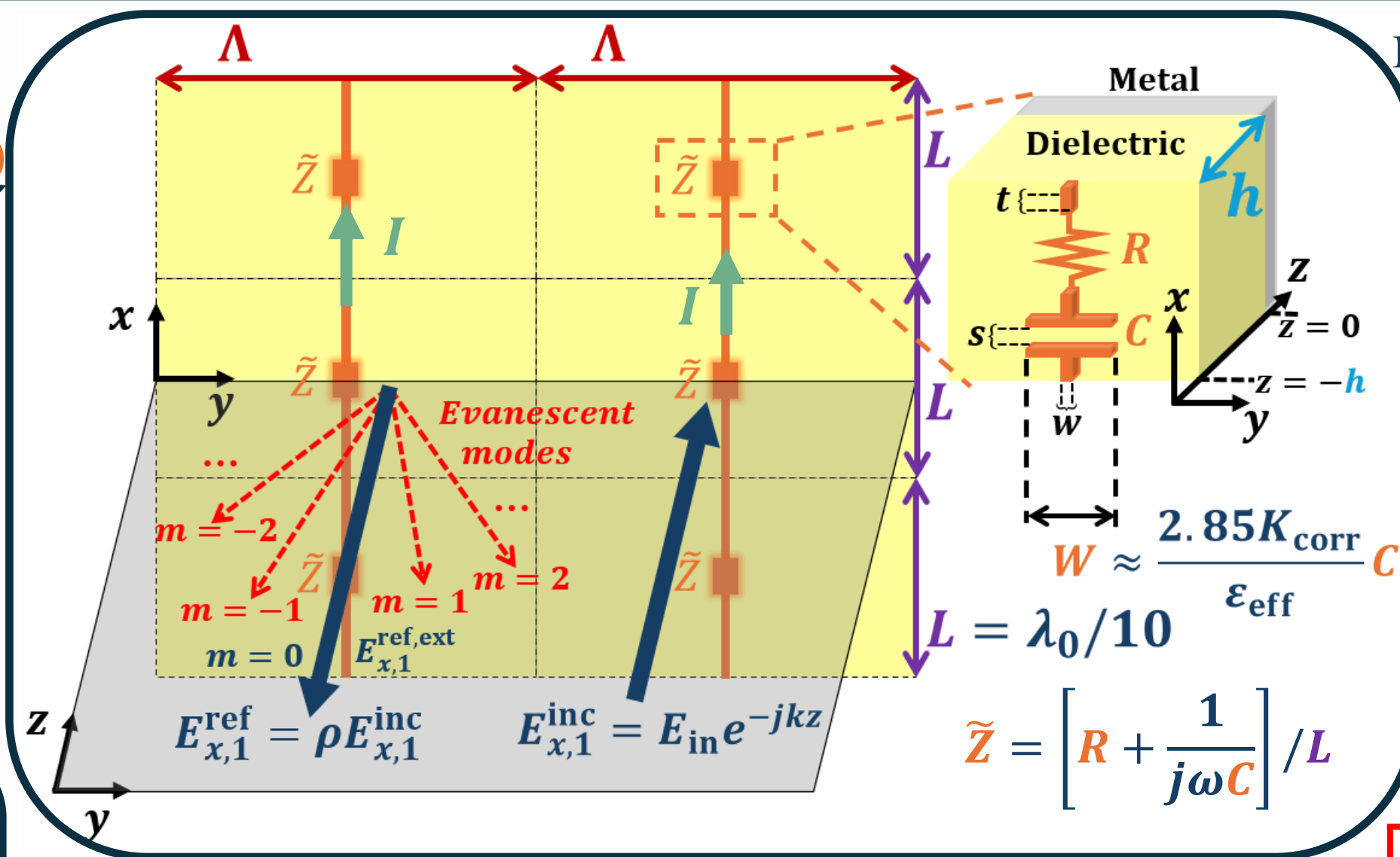
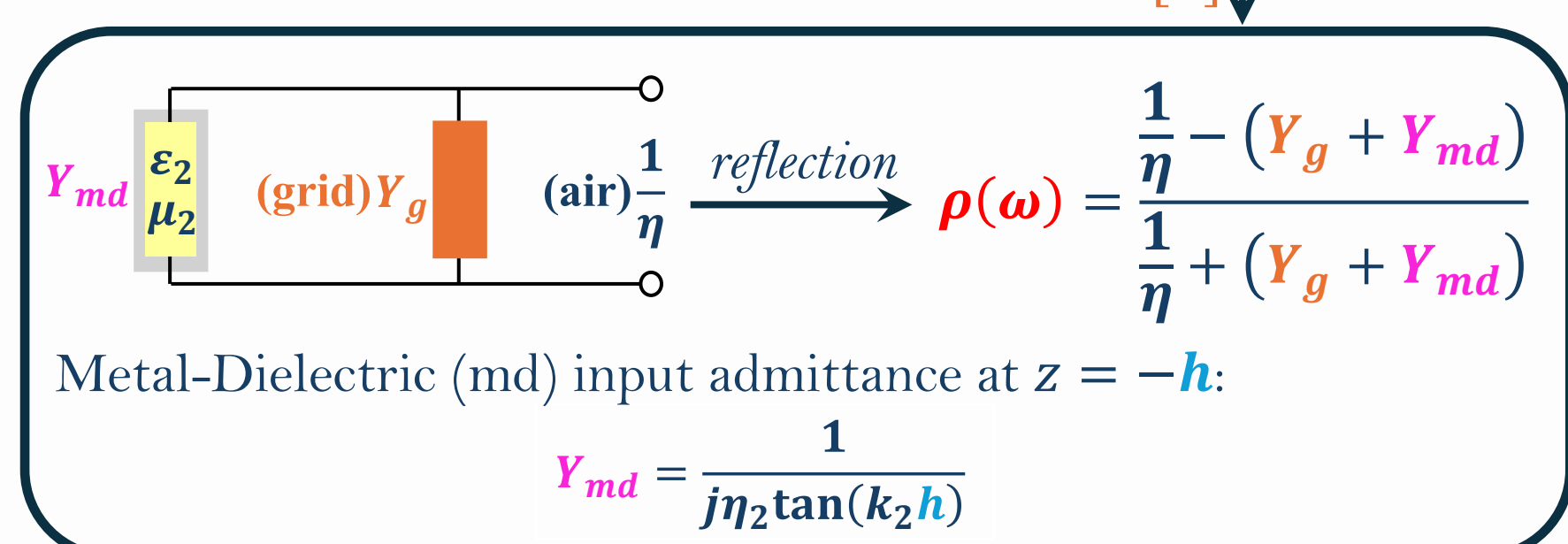
2. Theory – Analytical Formalism

A. Scattering problem

Metagratings (MGs)



Grid: *abstract* Transmission Line Model [3]



Equivalent MG grid admittance:

$$Y_g = \left[\frac{(1 - R_0)(\tilde{Z} - \tilde{Z}_0) + \frac{\eta T_0^2}{2\Lambda R_0}}{(1 + R_0)(\tilde{Z} - \tilde{Z}_0) + \frac{\eta T_0^2}{2\Lambda R_0}} \right] \frac{1}{\eta} - Y_{md}$$

Resolving
Fields

Propagating fields ($\Lambda < \lambda_{\min}$):

$$E_{x,1}^{\text{inc}} = E_{\text{in}} e^{-jkz}$$

$$E_{x,1}^{\text{ref}} = R_0 E_{\text{in}} e^{jk(z+2h)} - \frac{\eta}{2\Lambda} I T_0 e^{jk(z+h)}$$

Floquet-Bloch reflection & wavenumber:

$$R_m = \frac{j\beta_{m,1} \tan(\beta_{m,2}h) - \beta_{m,2}}{j\beta_{m,1} \tan(\beta_{m,2}h) + \beta_{m,2}} = T_m - 1$$

$$\beta_{m,i} = \sqrt{k_i^2 - (2\pi m/\Lambda)^2}; \alpha_{m,i} = j\beta_{m,i}$$

Ohm's Law: $E_{x,1}^{\text{tot}}(z = -h, y = 0) = I\tilde{Z}$

Metagrating (MG) reflection coefficient:

$$\rho(\omega) = \frac{E_{x,1}^{\text{ref}}}{E_{x,1}^{\text{inc}}} \Big|_{z=-h} = \frac{R_0(\tilde{Z} - \tilde{Z}_0)}{\frac{\eta T_0^2}{2\Lambda R_0} + \tilde{Z} - \tilde{Z}_0}$$

Perfect absorption MG load:

$$\tilde{Z}_0 = \frac{\eta T_0}{2\Lambda R_0} - j \frac{k\eta}{2\pi} \ln \left(\frac{\Lambda}{2\pi r_{\text{eff}}} \right) - j \frac{k\eta}{2\Lambda} \sum_{m \neq 0} \left\{ \frac{T_m}{\alpha_{m,1}} - \frac{\Lambda}{2\pi|m|} \right\}$$

Degrees-of-freedom:

$$\{R, C, \Lambda, h\}$$

Metagrating (MG) absorption coefficient:

$$A(\omega) = \sqrt{1 - |\rho(\omega)|^2}$$

B. Rozanov's bound [1]

C. Grid admittance conditions [3]

$$\text{Absorption Bandwidth} = \Delta\lambda < \frac{2\pi^2 \mu_s^2}{|\ln \rho_0|} h$$

ρ_0 - maximally allowed reflection magnitude

We can't simultaneously decrease h and increase $\Delta\lambda$ as desired!

Compact wideband absorption is limited.

Perfect absorption grid admittance ($\rho(\omega) = 0$): $Y_g^{\text{opt}} = \eta^{-1} - Y_{md}$

$$\begin{aligned} 1 \quad & |\rho(\omega_0)| = \rho_0 \\ 2 \quad & \text{Im}\{Y_g\} \Big|_{\omega_0} = \text{Im}\{Y_g^{\text{opt}}\} \Big|_{\omega_0} \\ 3 \quad & \frac{\partial \text{Im}\{Y_g\}}{\partial \omega} \Big|_{\omega_0} = \frac{\partial \text{Im}\{Y_g^{\text{opt}}\}}{\partial \omega} \Big|_{\omega_0} \\ 4 \quad & \frac{\partial \text{Re}\{Y_g\}}{\partial \omega} \Big|_{\omega_0} = 0 \end{aligned}$$

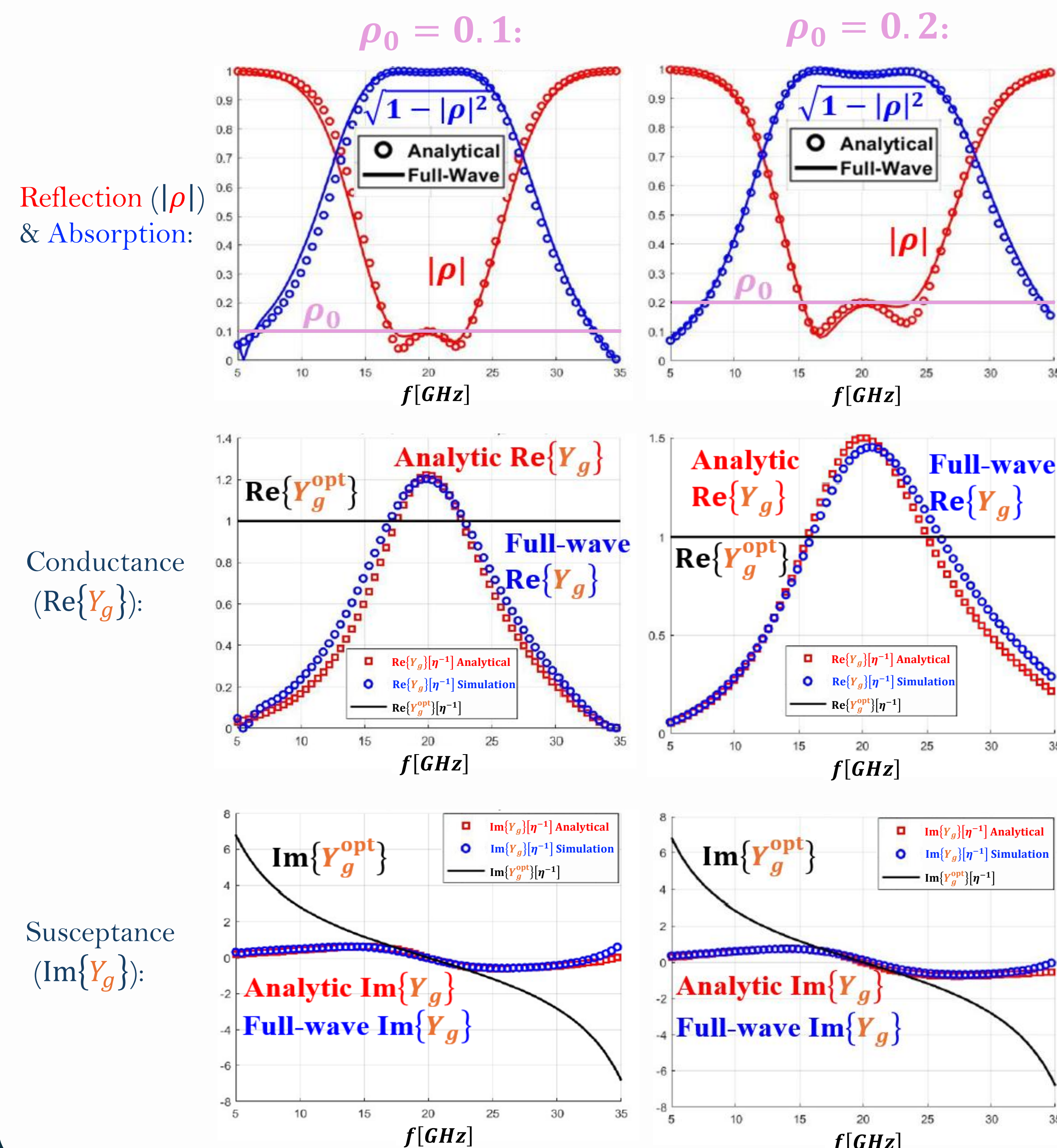
Rigorous
MG model

Closed-form (R, C, h) & semianalytical (Λ) formulas:

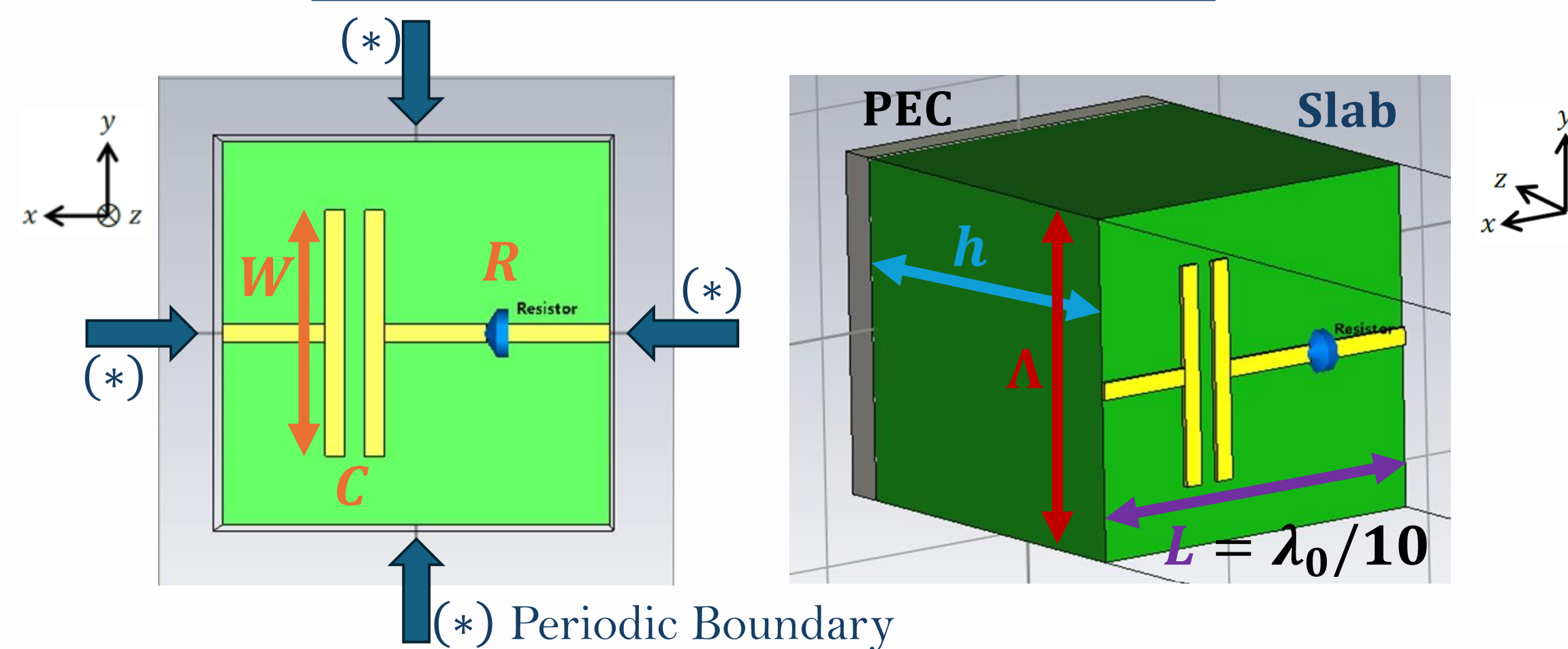
$$C = \frac{2\epsilon_0}{k_0^2 L} \left[\frac{1}{\pi} \ln \left(\frac{\Lambda}{2\pi r_{\text{eff}}} \right) + \frac{1}{\Lambda} \sum_{m \neq 0} \left\{ \frac{T_m}{\alpha_{m,1}} - \frac{\Lambda}{2\pi|m|} \right\} \right]^{-1}$$

$$R = \frac{\eta L}{\Lambda} \left(\frac{1 - \rho_0}{1 + \rho_0} \right) \quad h = \frac{\lambda_0}{4\sqrt{\epsilon_{r,2}}} \quad \Lambda = \Lambda(\omega_0, h, \rho_0)$$

3. Validation (20GHz)



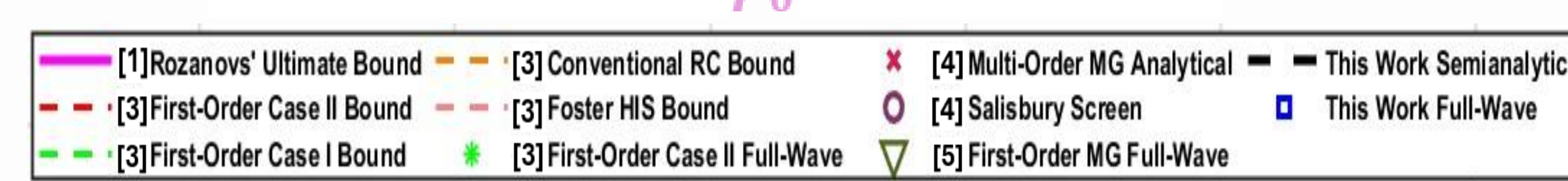
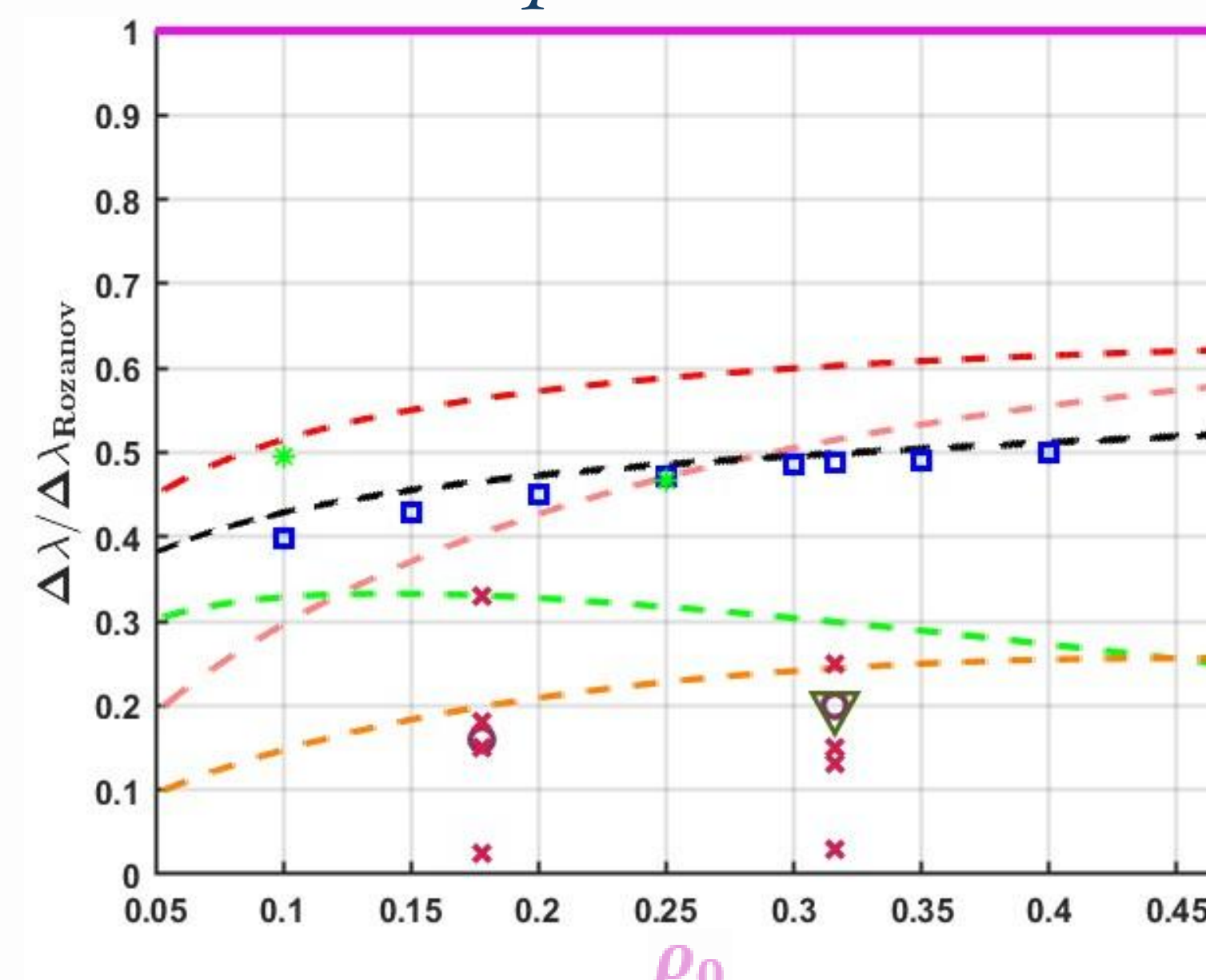
Full-Wave Validation in CST



Synthesis for Rogers RO3006 ($\epsilon_{r,2} = 6.15$) & $\rho_0 = 0.1$:

$$W = 1.04[\text{mm}] \quad R = 99.06[\Omega] \quad \Lambda = 0.311\lambda_0 \quad h \approx \lambda_0/10$$

Absorption Bandwidth



4. References

- [1] K. N. Rozanov, *IEEE Trans. Antennas Propag.*, **48**, 8 (2000).
 [2] A. Epstein and O. Rabinovich, *Phys. Rev. Appl.*, **8**, 054037 (2017).
 [3] P. S. Nayani, M. Moradi, P. Salami, and Y. Radi, *Nat. Commun.*, **16**, 905 (2025).
 [4] F. Boust, T. Lepetit, and S. N. Burokur, *Opt. Lett.*, **47**, 20 (2022).
 [5] Z. Tan, J. Yi, Q. Cheng, and S. N. Burokur, *IEEE Trans. Antennas Propag.*, **71**, 2 (2023).