A Overview of Implementation, Findings, Late-Time Instabilities analysis in the Orthogonalized Integral-Based Subgridding Algorithm in FDTD

Union Radio Scientific International Portugal
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MATERIAIS INTELIGENTES PARA A RADIOCIÊNCIA

17º CONGRESSO DO COMITÉ PORTUGUÊS DA URSI

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- **Miguel D. Ruiz-Cabello N.**
- Amelia Rubio Bretones.
- Salvador G. García.

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OUTLINE

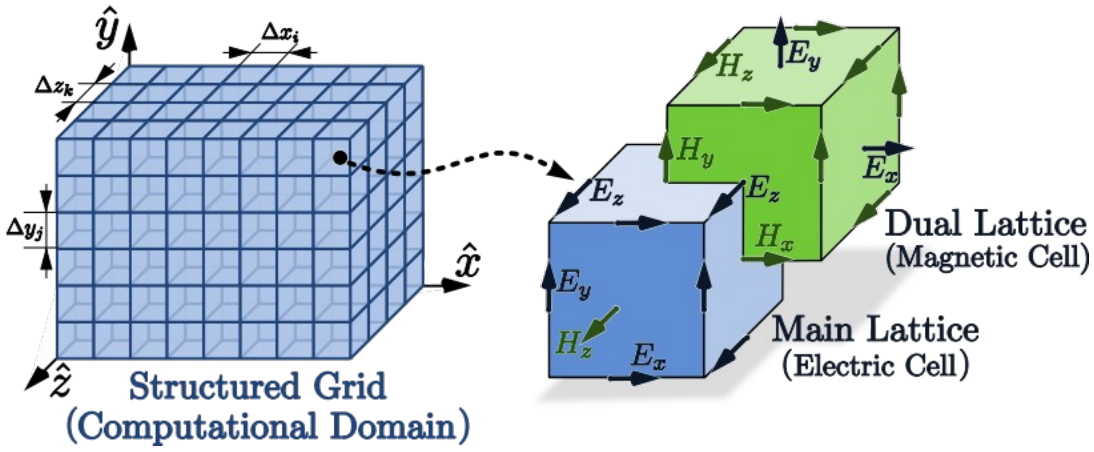
1- Introduction and Motivation: FDTD main features

2- Conformal technique

3- Subgridding technique (Subgridding+Conformal)

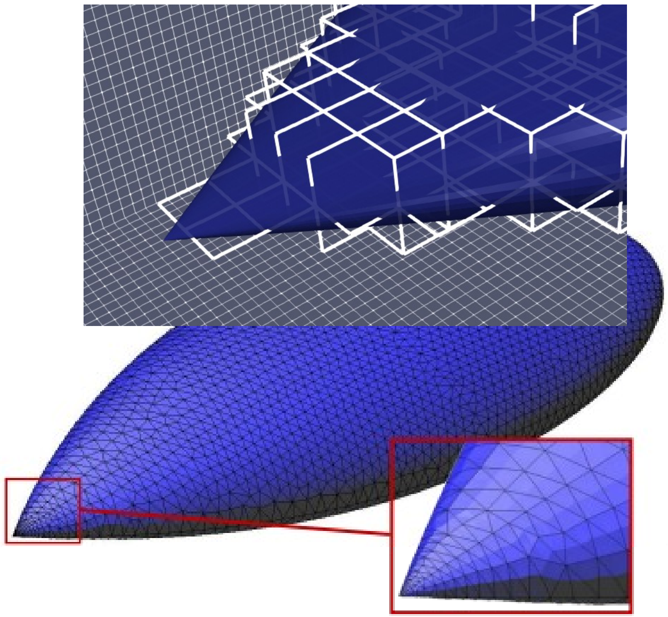
4- Results

5- Conclusion



$$E_i^{n+1} = C_{a,i} E_i^n + C_{b,i} \left(H_{i-1/2}^{n+1/2} - H_{i+1/2}^{n+1/2} \right)$$

$$H_{i+1/2}^{n+1/2} = D_{a,i+1/2} H_{i+1/2}^{n-1/2} + D_{b,i+1/2} \left(E_i^n - E_{i+1}^n \right)$$



- ✔ **Pros:** The method is computationally efficient because, the fields are implicitly indexed on a Grid.

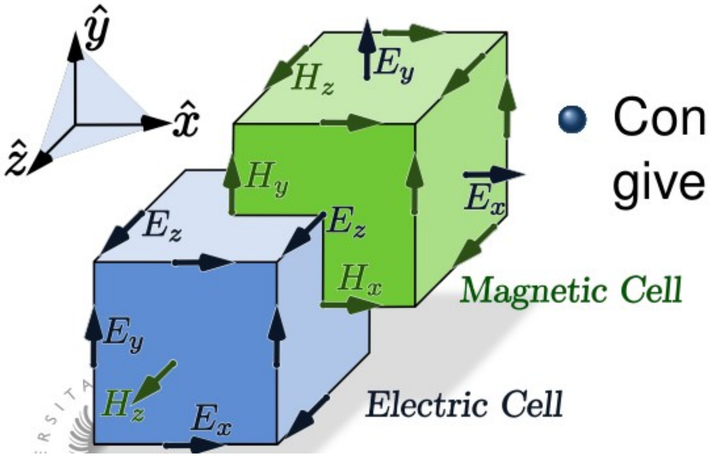
- ✗ **Cons:** Unlike other methods (Finite Elements, MoM), FDTD meshes are constrained to the discrete elements on the grid, such as voxels, surfels, and linels; consequently, the adaptability of the mesh is limited.

- It's an explicit method: (Centered Finite Differences, second-order formulation)

$$H_z\Big|_{i+1/2,j+1/2,k}^{n+1/2} = H_z\Big|_{i+1/2,j+1/2,k}^{n-1/2} + \frac{\Delta t}{\mu_0}\left(\frac{E_y\big|_{i,j+1/2,k}^{n} - E_y\big|_{i+1,j+1/2,k}^{n}}{\Delta x} - \frac{E_y\big|_{i+1/2,j,k}^{n} - E_y\big|_{i+1/2,j+1,k}^{n}}{\Delta y}\right)$$

$$E_z\Big|_{i,j,k+1/2}^{n+1} = E_z\Big|_{i,j,k+1/2}^{n} + \frac{\Delta t}{\varepsilon_0}\left(\frac{H_x\big|_{i,j-1/2,k+1/2}^{n+1/2} - H_x\big|_{i,j+1/2,k+1/2}^{n+1/2}}{\Delta y} - \frac{H_y\big|_{i-1/2,j,k+1/2}^{n+1/2} - H_y\big|_{i+1/2,j,k+1/2}^{n+1/2}}{\Delta x}\right)$$

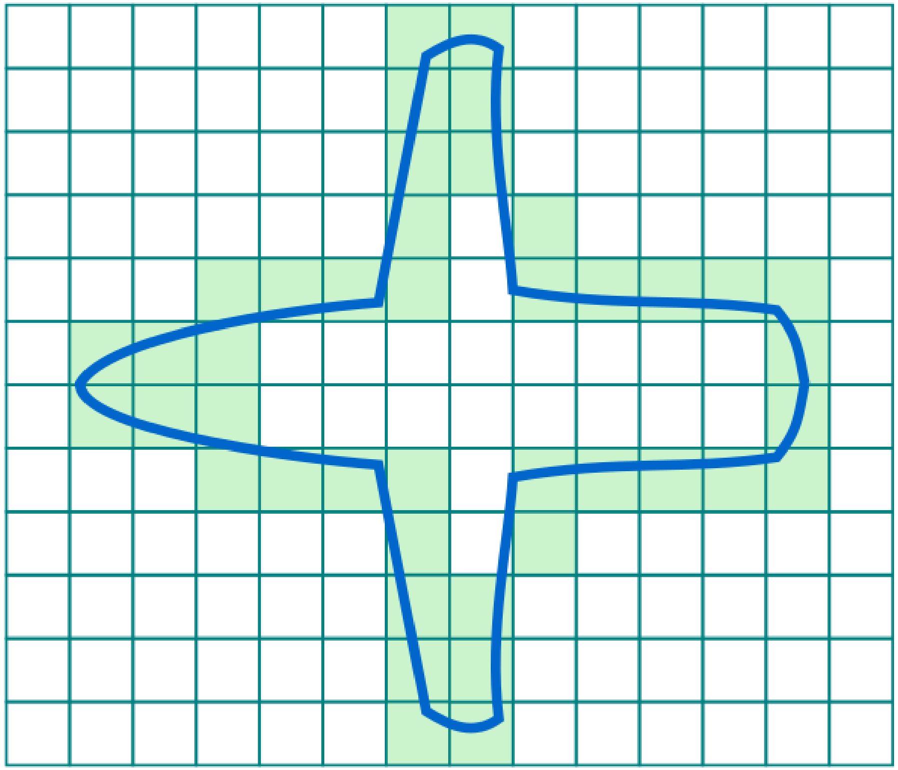
- The field are placed according to a Grid.



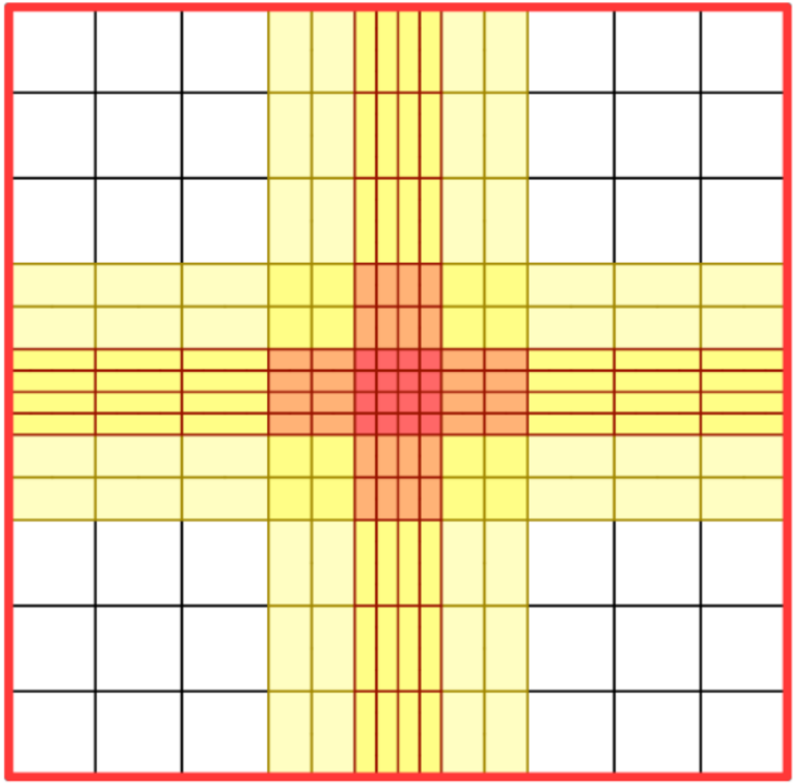
- Conditionally stable: The stability condition is given by the Courant-Criterion :

$$\Delta t = \mathrm{CFLN}\frac{\Delta s}{c_0\sqrt{3}} \qquad \mathrm{CFLN} \leq 1.0$$

Requies to advance the whole space

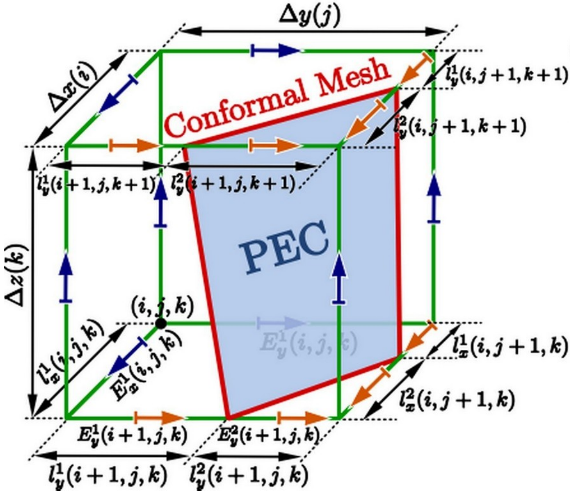


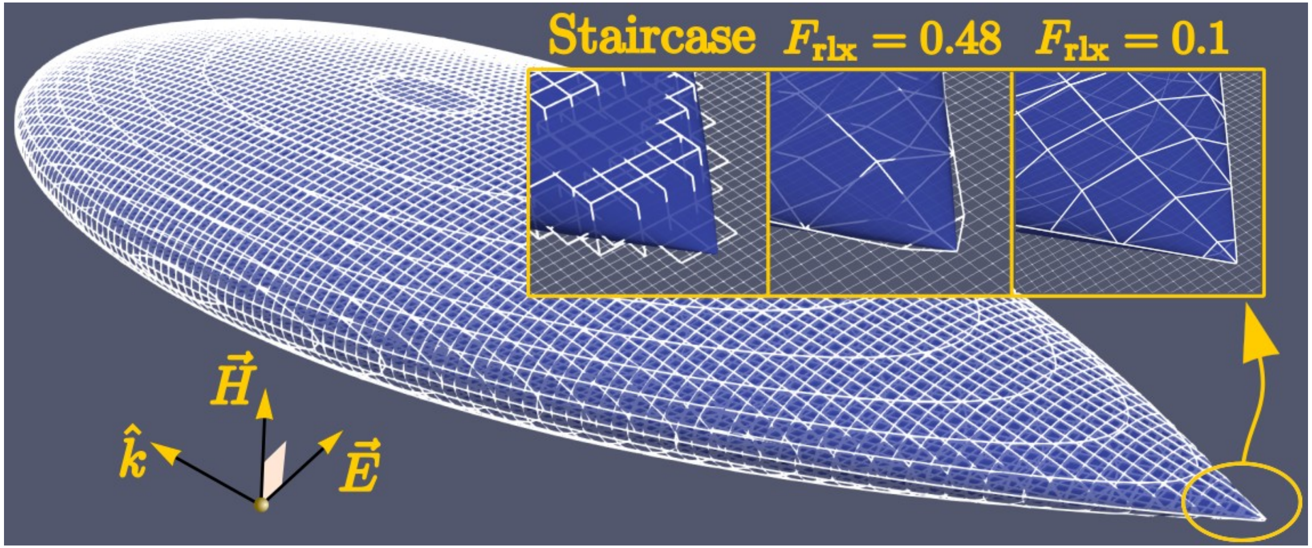
Cannot deal with multiscale problems

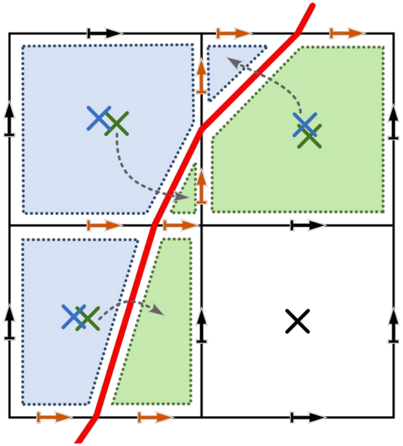


2- Conformal technique

- FDTD conformal algorithm are methods to deal with curved surfaces.
- Conformal methods provide with a high adaptability of the mesh and reduces the anisotropies inherent in staircased mesh.
- The conformal algorithm used is based on Dey-Mittra method. This conformal approach uses fractional cell.
- We use techniques to guaranty the stability, based on LECT and using relaxed meshed.



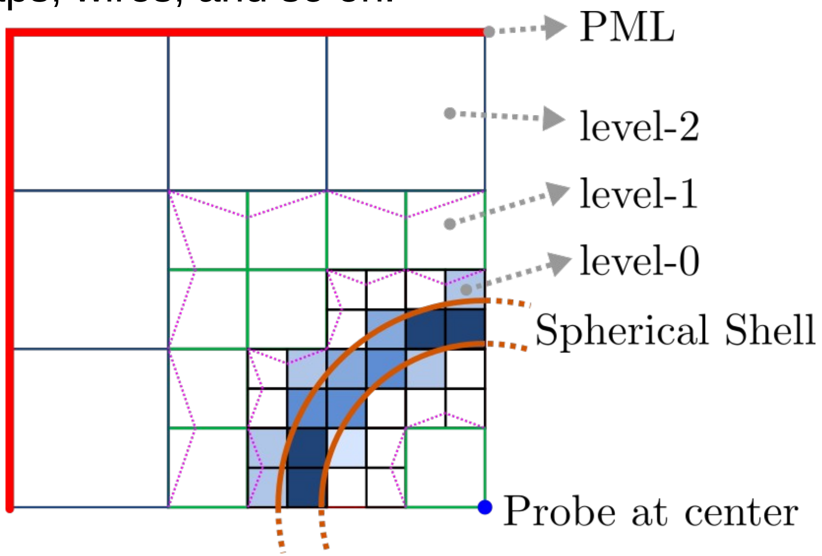


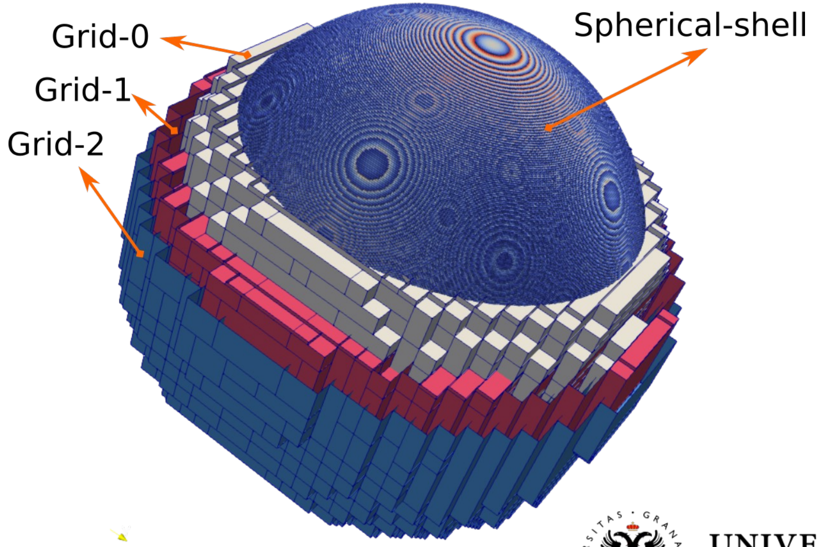


3- Subgridding technique

The subgridding is highly accurate numerical algorithm to deal with multi-scale problem of general purpose in FDTD.

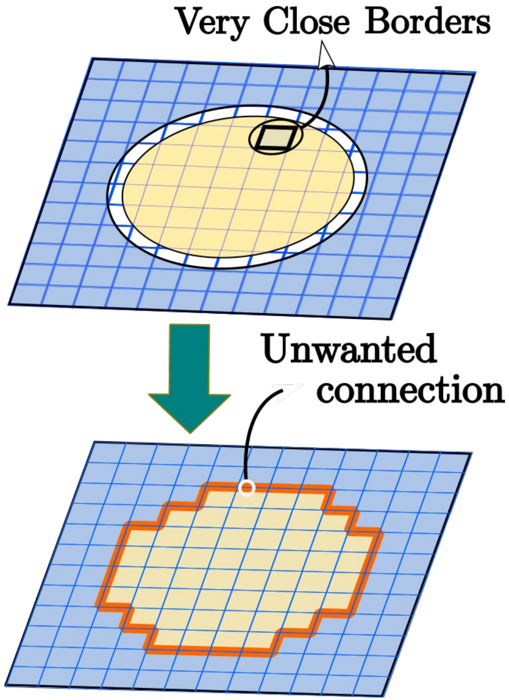
- This method is based on nested grids.
- The size of the nested grids have a 1:2 ratio recursively.
- The finest cells are used in areas with intricate fine/small details, such as panels, apertures, gaps, wires, and so on.
- The coarse cells are used in the rest of the space (free-space and region with irrelevant details)
- The goals of the subgridding method is reduces the number of cells to be processed, and in turn, improves CPU and memory performance.

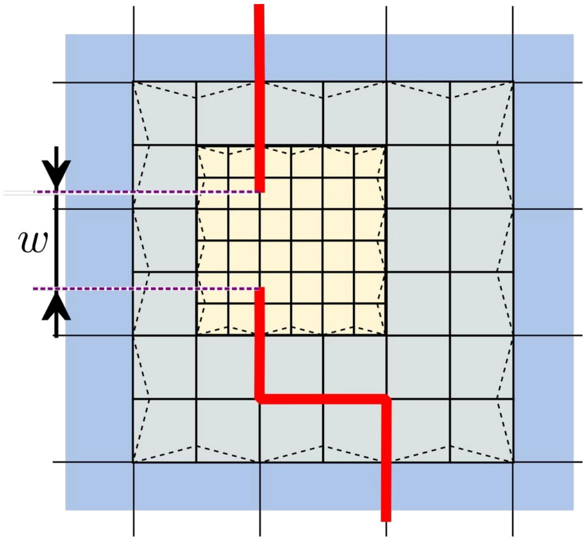




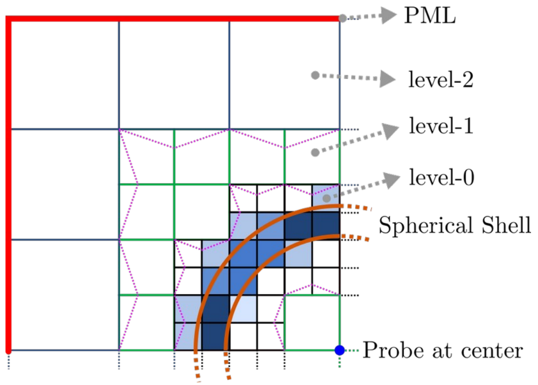
Multiscale Problems of general purpose

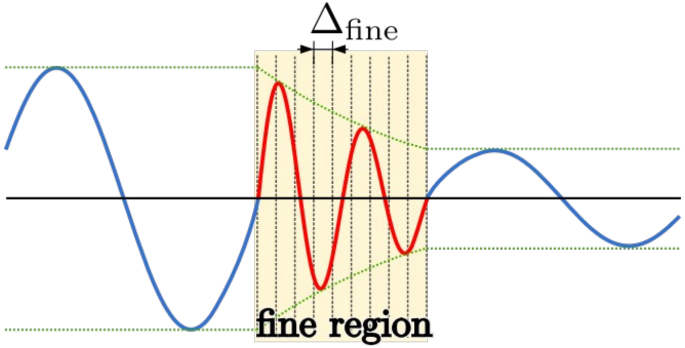
Small Geometrical Details





Small wavelength

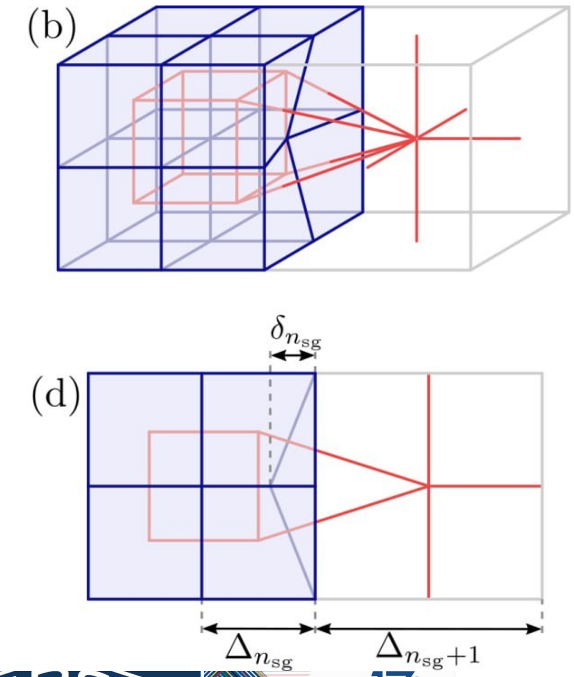


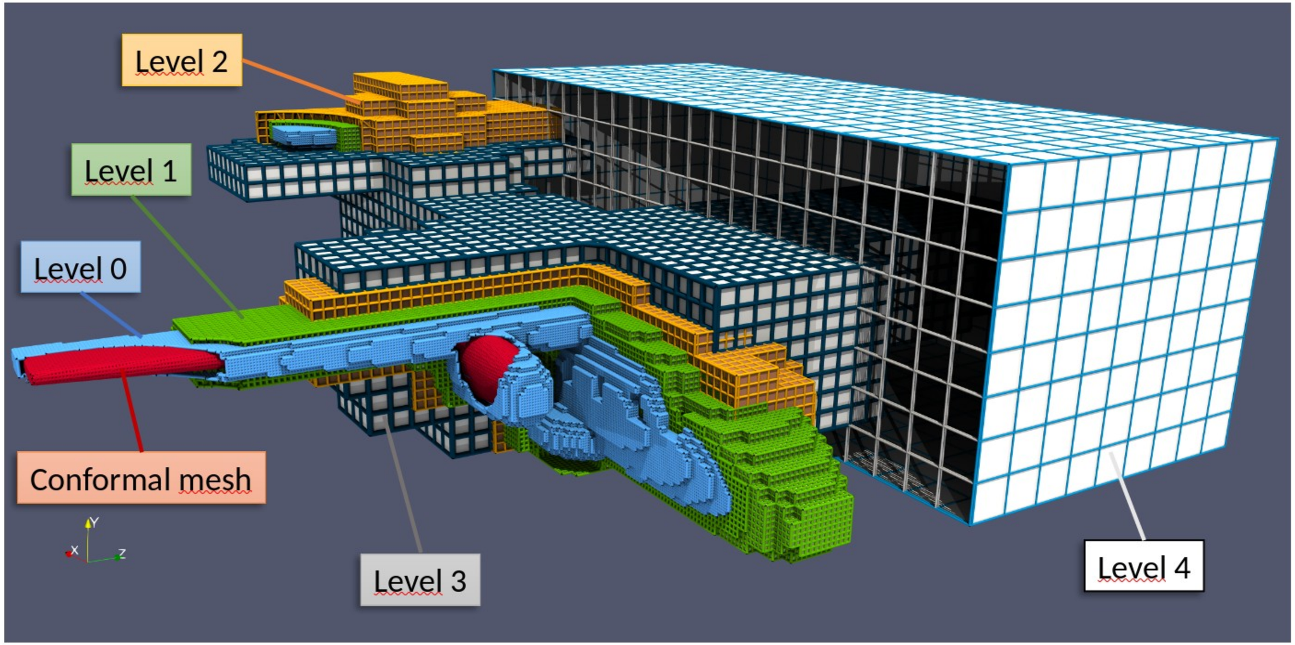


3- Subgridding technique

Spurious Reflection, are mitigated **orthogonalization method** and a **1:2 factor** of transition.

- Among the several subgrid methods that we have tested, we have found a good trade-off between accuracy and performance in using 1:2 transition and an orthogonalization technique.
- The orthogonalization method consists of deforming the cell in the transition to preserve the orthogonality between the E and H vectors.

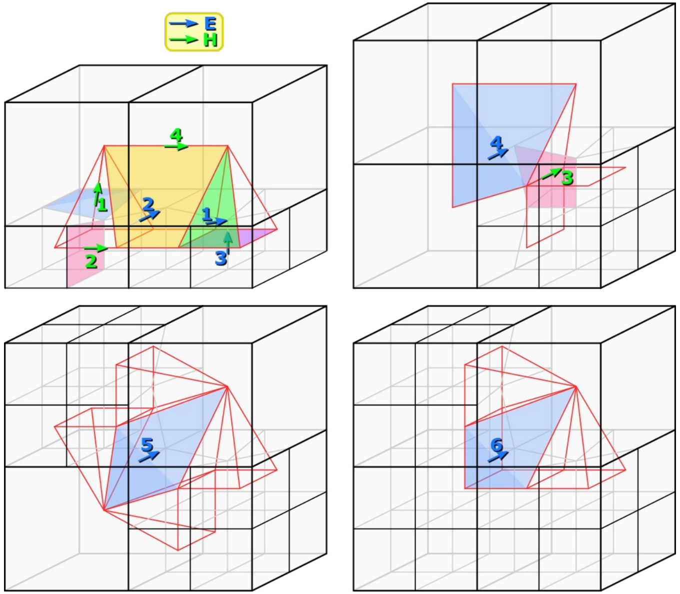


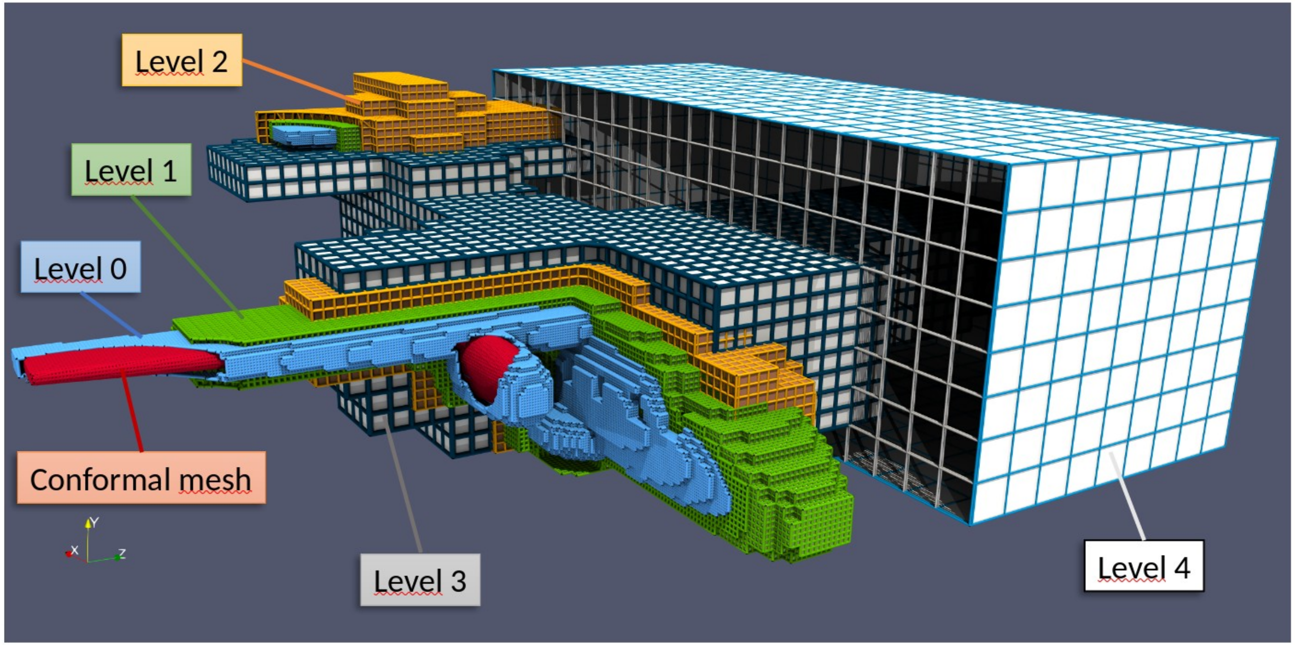


3- Subgridding technique

Spurious Reflection, are mitigated **orthogonalization method** and a **1:2 factor** of transition.

- Deformed cells in different scenarios in the transition of two subgrid levels.
- The method used to update the deformed cell is based on the FIT method.





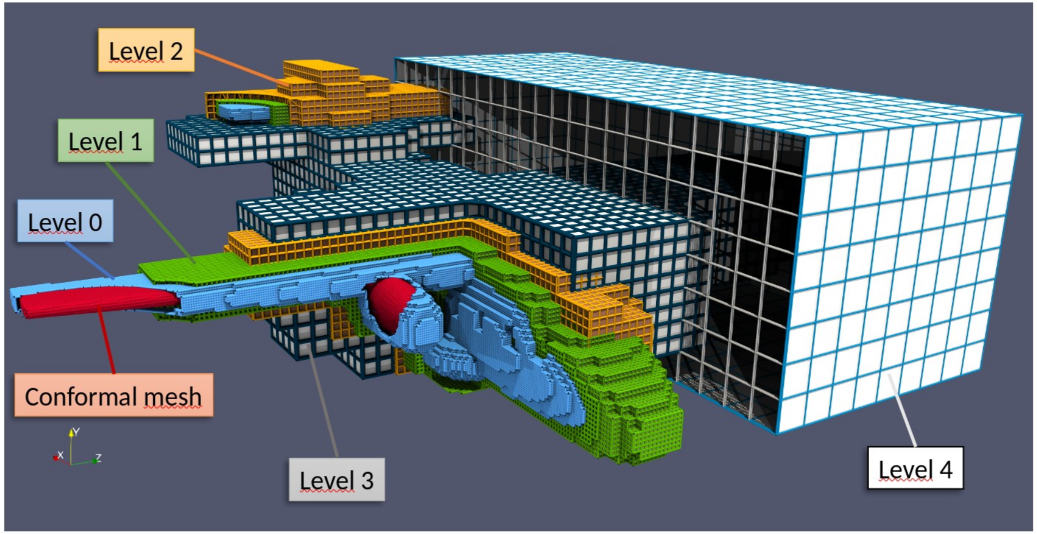
3-Subgridding technique

Orgonalization and Local time stepping (LTS) scheme

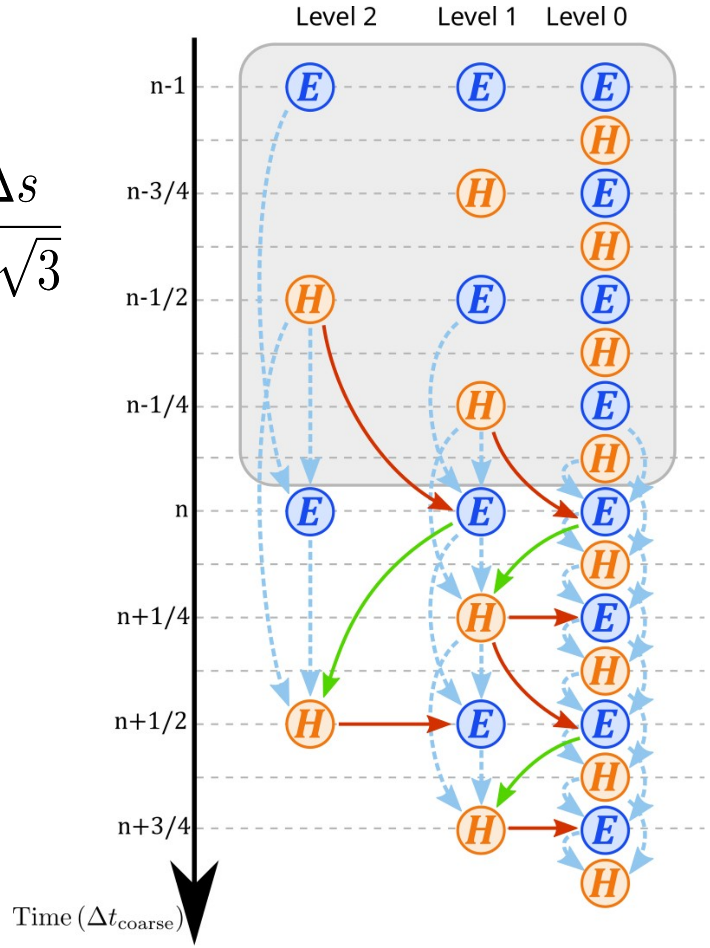
IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 70, NO. 11, NOVEMBER 2022 10769

On the Effect of Grid Orthogonalization in Stability and Accuracy of an FDTD Subgridding Method

Antonio M. Valverde, Miguel Ruiz Cabello, Clemente Cobos Sánchez, Amelia Rubio Bretones, and Salvador G. Garcia, *Senior Member, IEEE*



$$\Delta t = \text{CFLN}\frac{\Delta s}{c_0\sqrt{3}}$$

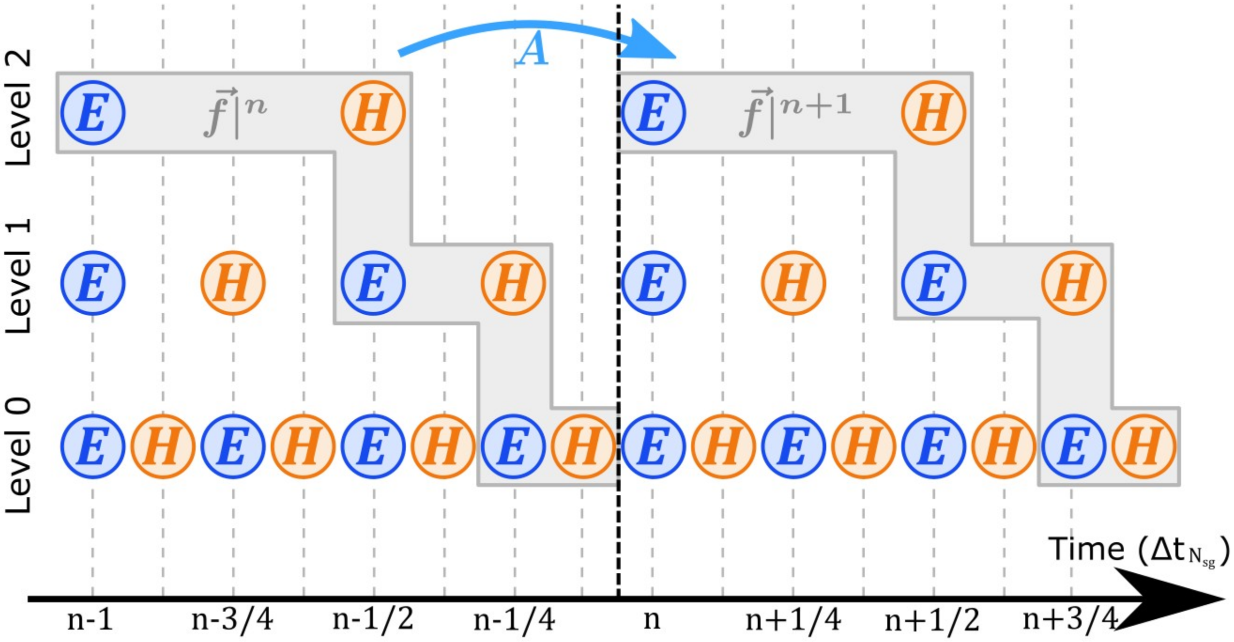


Stability study: using spectral analysis

Researchers in the area of time domain methods are aware that this kind of techniques (LTS, and deformed cells) can lead to instabilities.

$$f|^{n+1} = A\, f|^{n} + S|^{n}$$

$$\begin{pmatrix} E|^{n}_{N_{sg}} \\ H|^{n+1/2}_{N_{sg}} \\ E|^{n+1/2}_{N_{sg}-1} \\ H|^{n+3/4}_{N_{sg}-1} \\ \vdots \end{pmatrix} = A \begin{pmatrix} E|^{n-1}_{N_{sg}} \\ H|^{n-1/2}_{N_{sg}} \\ E|^{n-1/2}_{N_{sg}-1} \\ H|^{n-1/4}_{N_{sg}-1} \\ \vdots \end{pmatrix}$$



Stability study: using spectral analysis

Time evolution operator

$$f\big|^{n+1} = A\, f\big|^{n}$$

$$\begin{pmatrix} E\big|^{n}_{N_{sg}} \\ H\big|^{n+1/2}_{N_{sg}} \\ E\big|^{n+1/2}_{N_{sg}-1} \\ H\big|^{n+3/4}_{N_{sg}-1} \\ \vdots \end{pmatrix} = A \begin{pmatrix} E\big|^{n-1}_{N_{sg}} \\ H\big|^{n-1/2}_{N_{sg}} \\ E\big|^{n-1/2}_{N_{sg}-1} \\ H\big|^{n-1/4}_{N_{sg}-1} \\ \vdots \end{pmatrix}$$

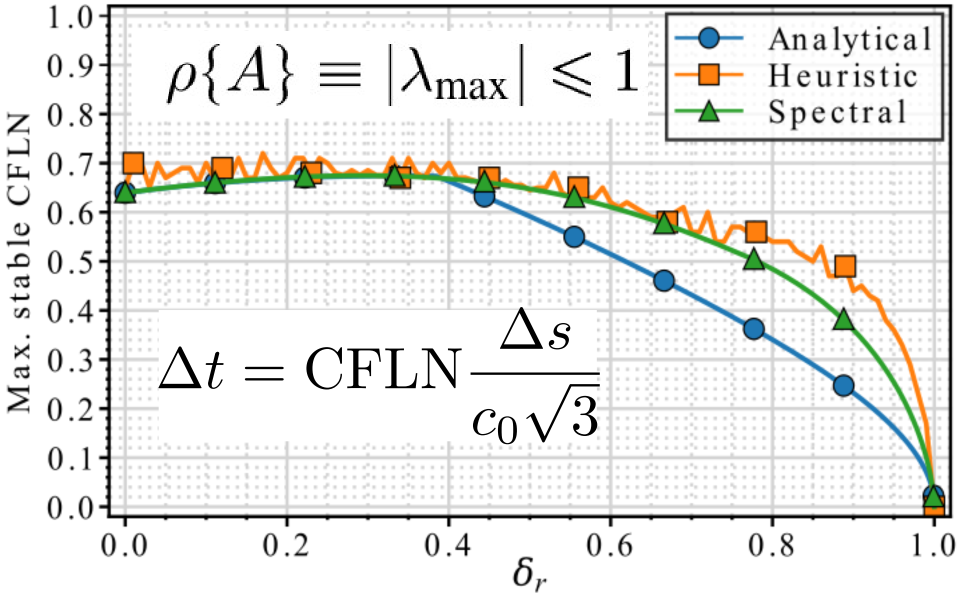
$$\vec{f}\,\big|^{0} = \sum_{i=1}^{n_{\text{fields}}} f_i\, \hat{e}_i$$

$$\vec{f}\,\Big|^{n} = A^n\, \vec{f}\,\Big|^{0} = \sum \lambda_i^n\, f_i\, \hat{e}_i$$

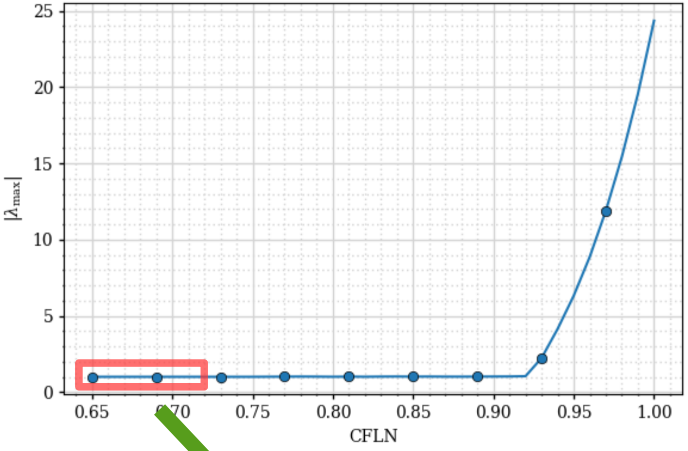
$n \rightarrow \infty$

?? Bounded Constant

$$\left\|\vec{f}\,\right|^{n}\Big\|^2 = \sum_{\substack{i=1\\k=1}}^{N} |\lambda_i|^n |\lambda_k|^n\, e^{jn(\theta_k-\theta_i)} f_i^* f_k (\hat{e}_i \cdot \hat{e}_k)$$

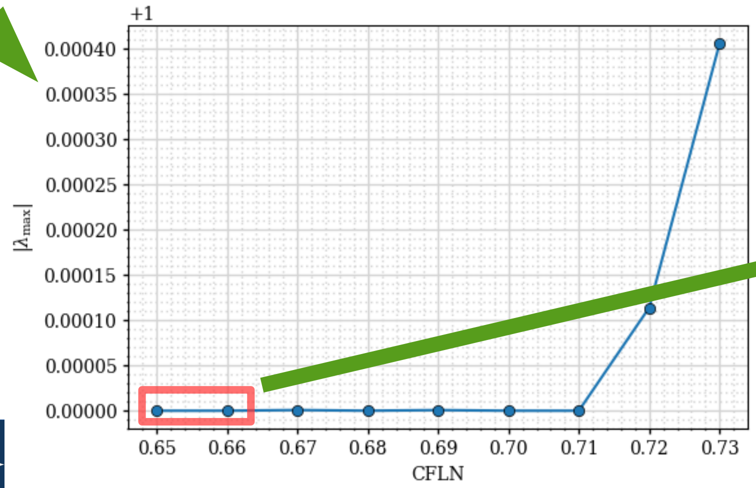


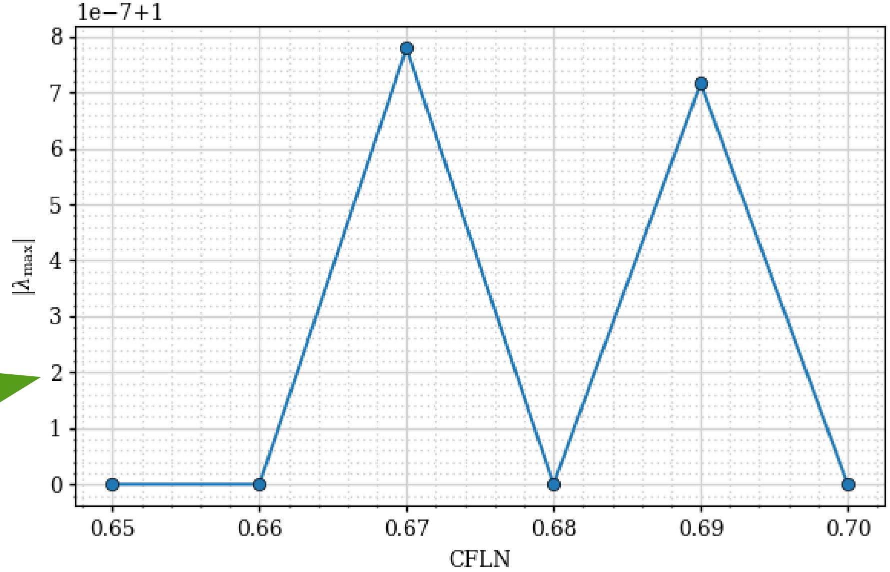
Stability study: Late-Time



$$f|^{n+1} = A\, f|^{n} + S|^{n}$$

$$\rho\{A\} \equiv |\lambda_{\max}| \leqslant 1$$





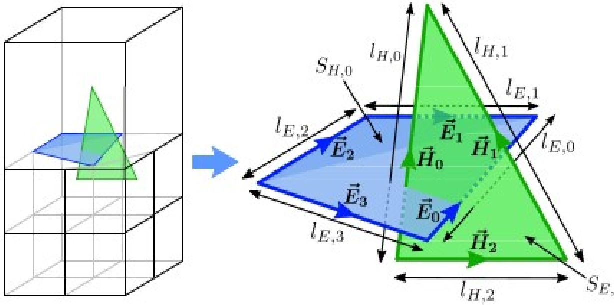
3-Subgridding technique

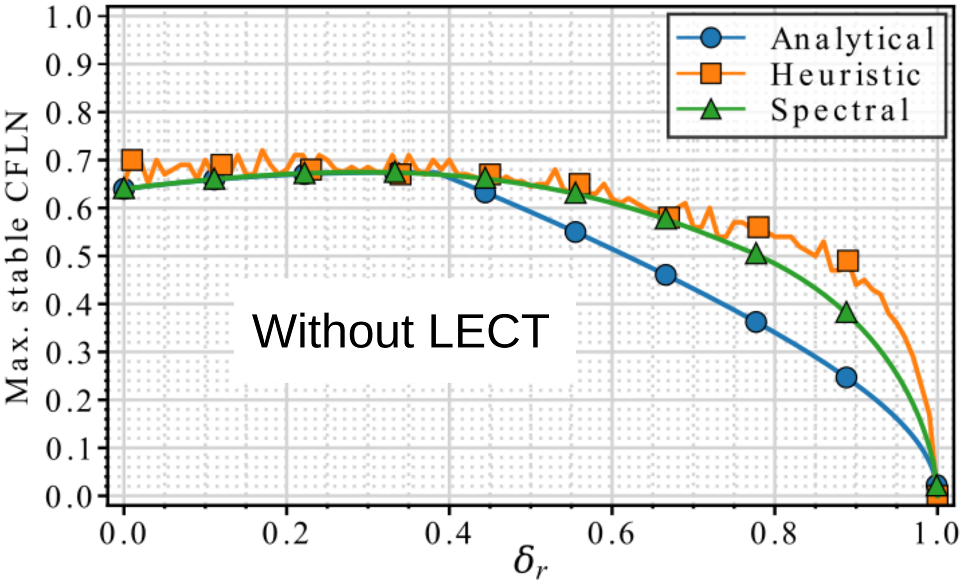
LECT to improve the stability

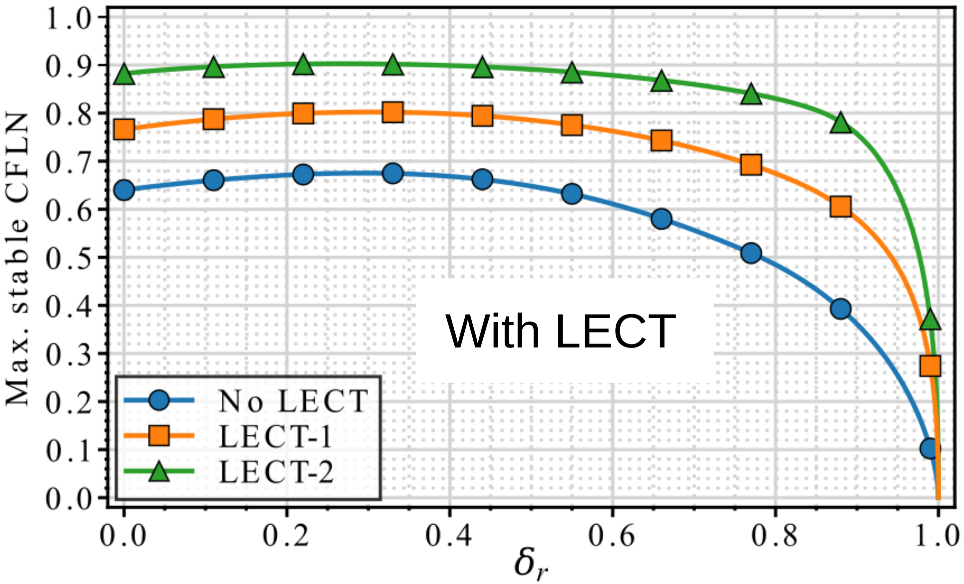
IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION,

Analysis and Improvement of the Stability of a 3D FDTD Subgridding Method by Applying a LECT-based Technique

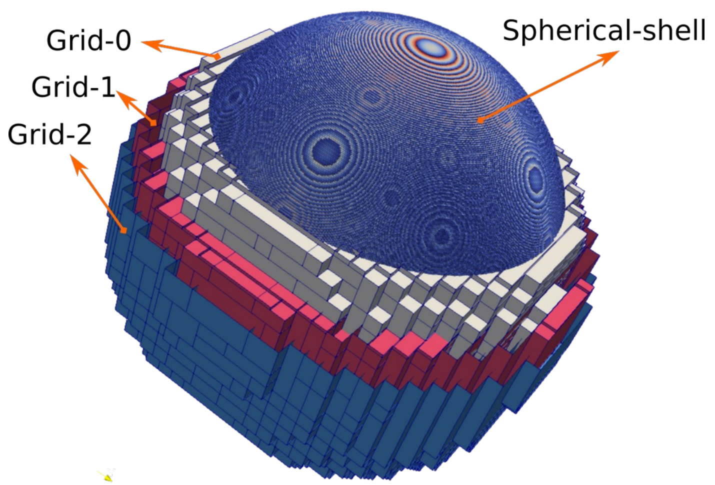
Antonio J. Martín Valverde, Miguel Ruiz-Cabello N., Amelia Rubio Bretones, Alberto Gascón Bravo, Salvador Gonzalez García *IEEE, Senior Member*

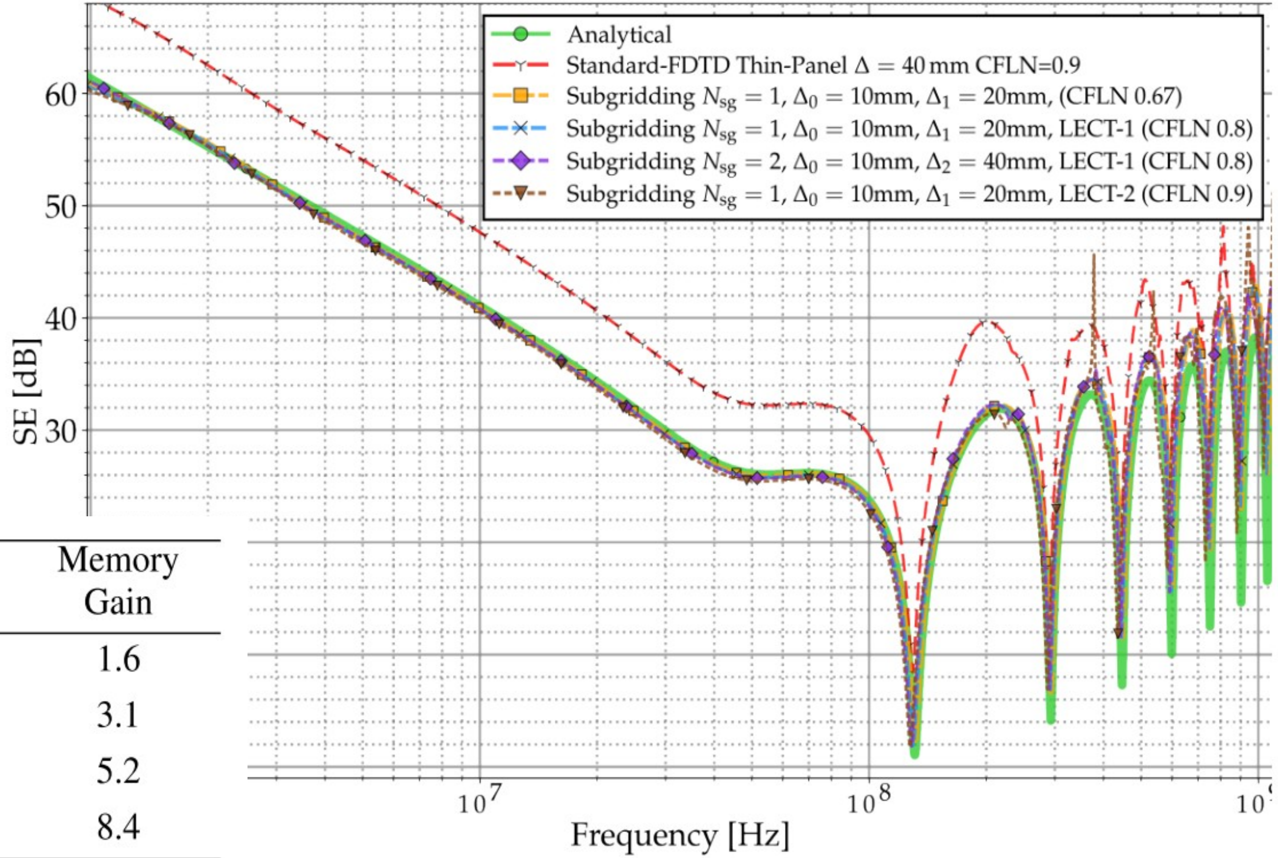






Shielding effectiveness

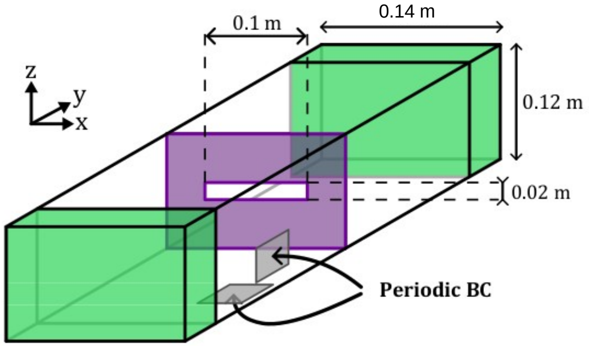


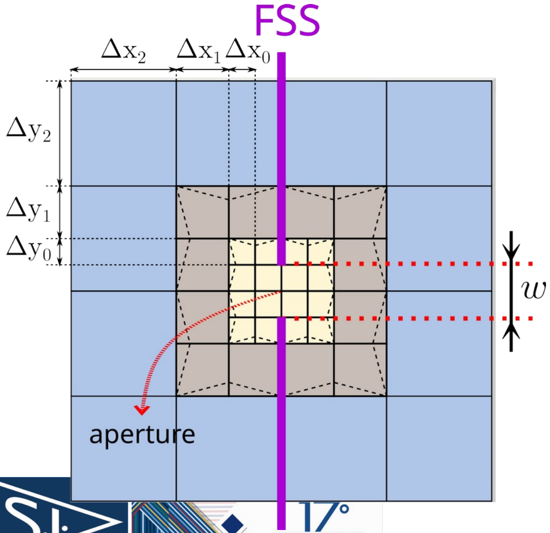


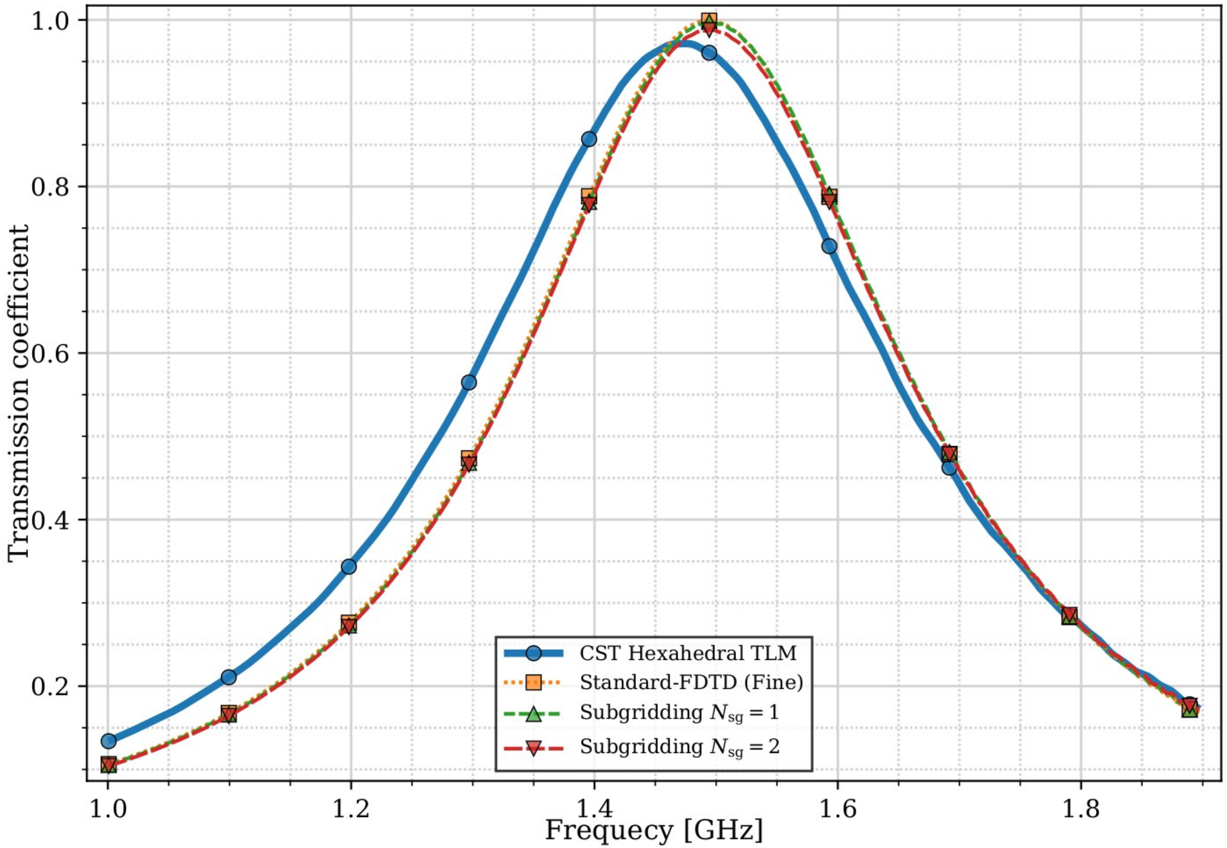
Method	CFLN	Δ_{min} [mm]	Δ_{max} [mm]	CPU Gain	Memory Gain
FDTD N_{sg}=1	0.67	20	40	2.8	1.6
FDTD N_{sg}=2	0.67	10	40	5.1	3.1
FDTD N_{sg}=3	0.67	5	40	7.9	5.2
FDTD N_{sg}=4	0.67	2.5	40	11.5	8.4

4. Results: Basic FSS

FSS: Based on periodical unit-cell 0.14x0.12m with a slot of 0.1mx0.02m







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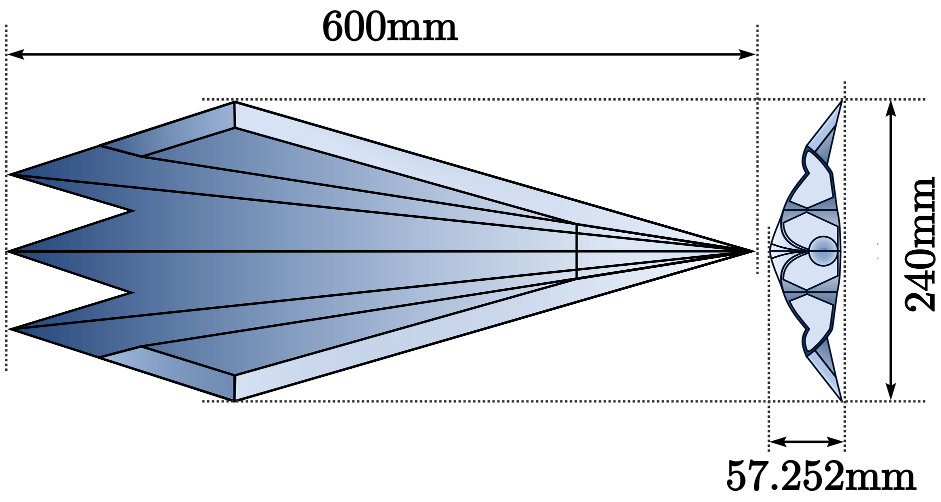
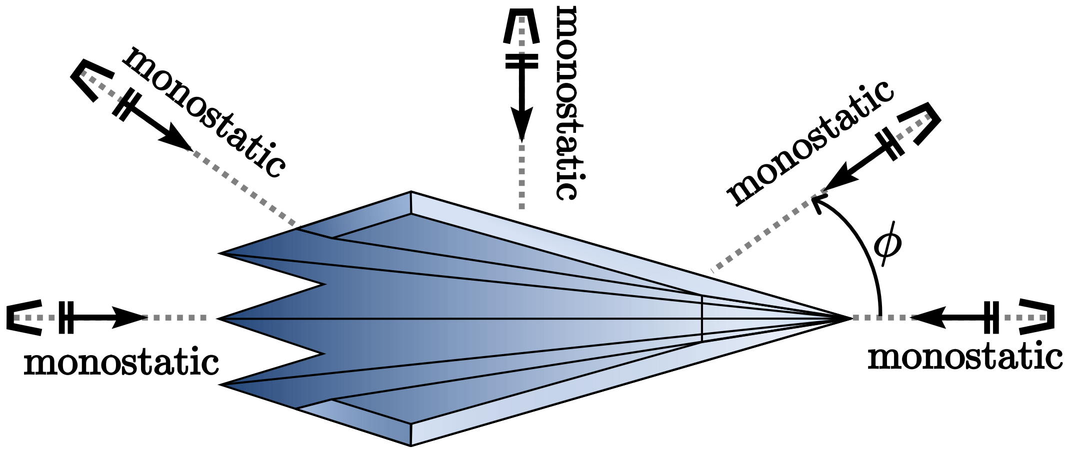
Backscattering angle depended at 2.714Ghz, both Copolar and Crosspolar

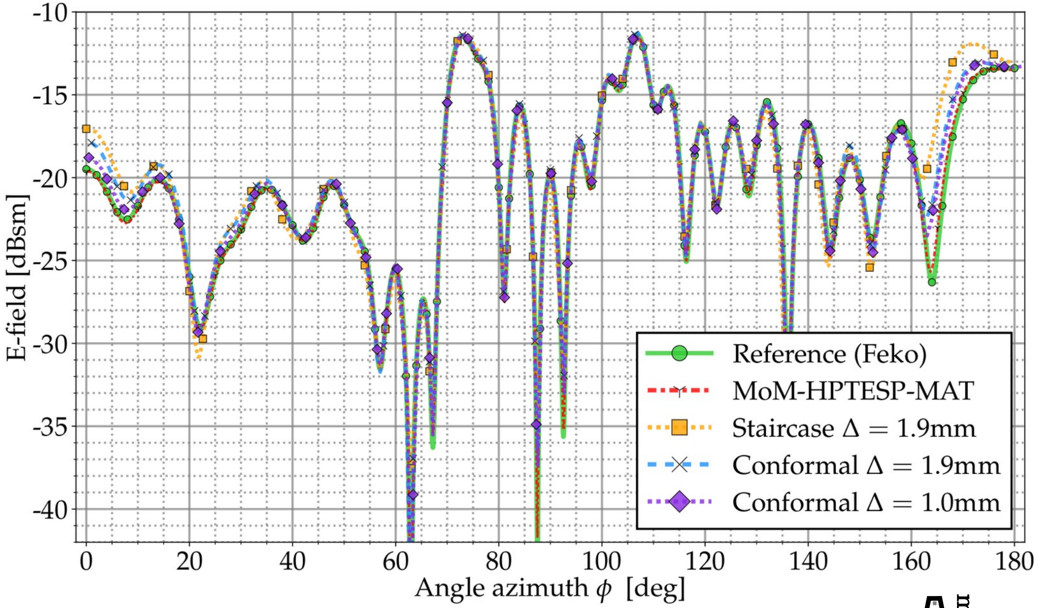




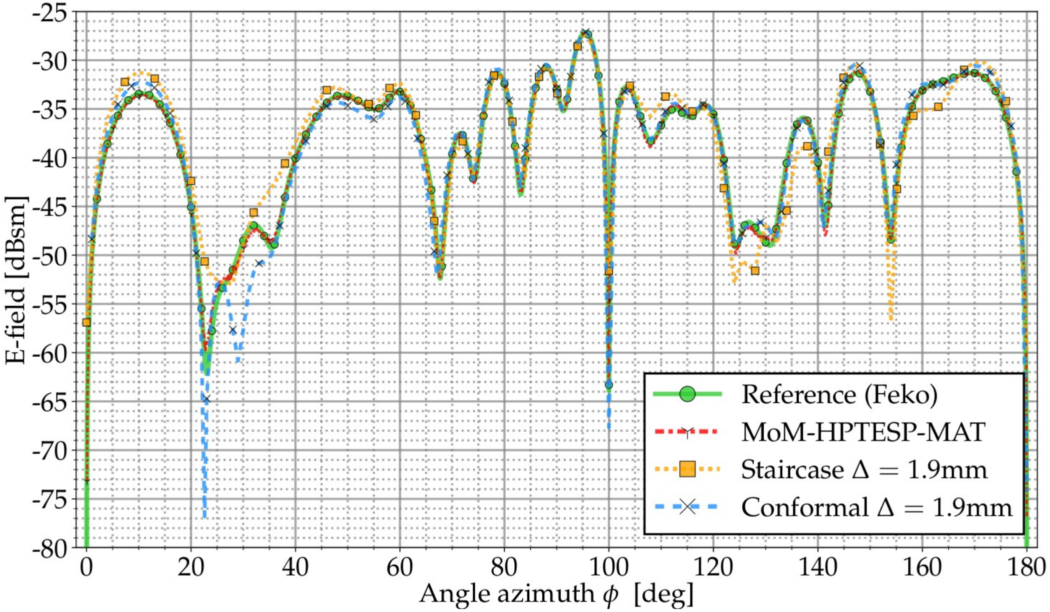
4-Results: RCS Flamme PEC

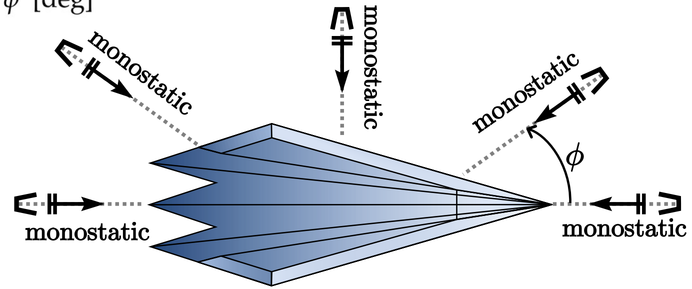
Backscattering angle depended at 2.714Ghz, both Copolar and Crosspolar

Copolar Component

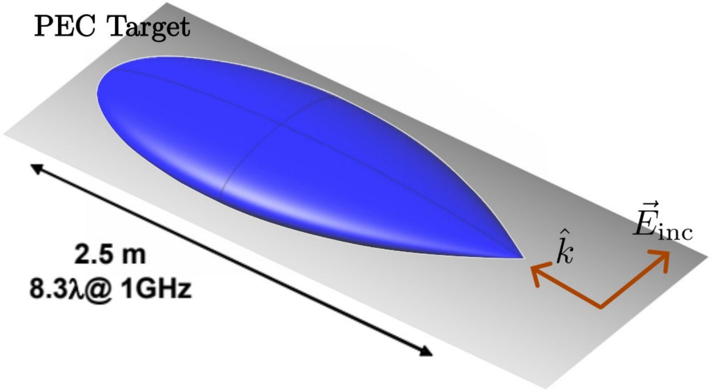


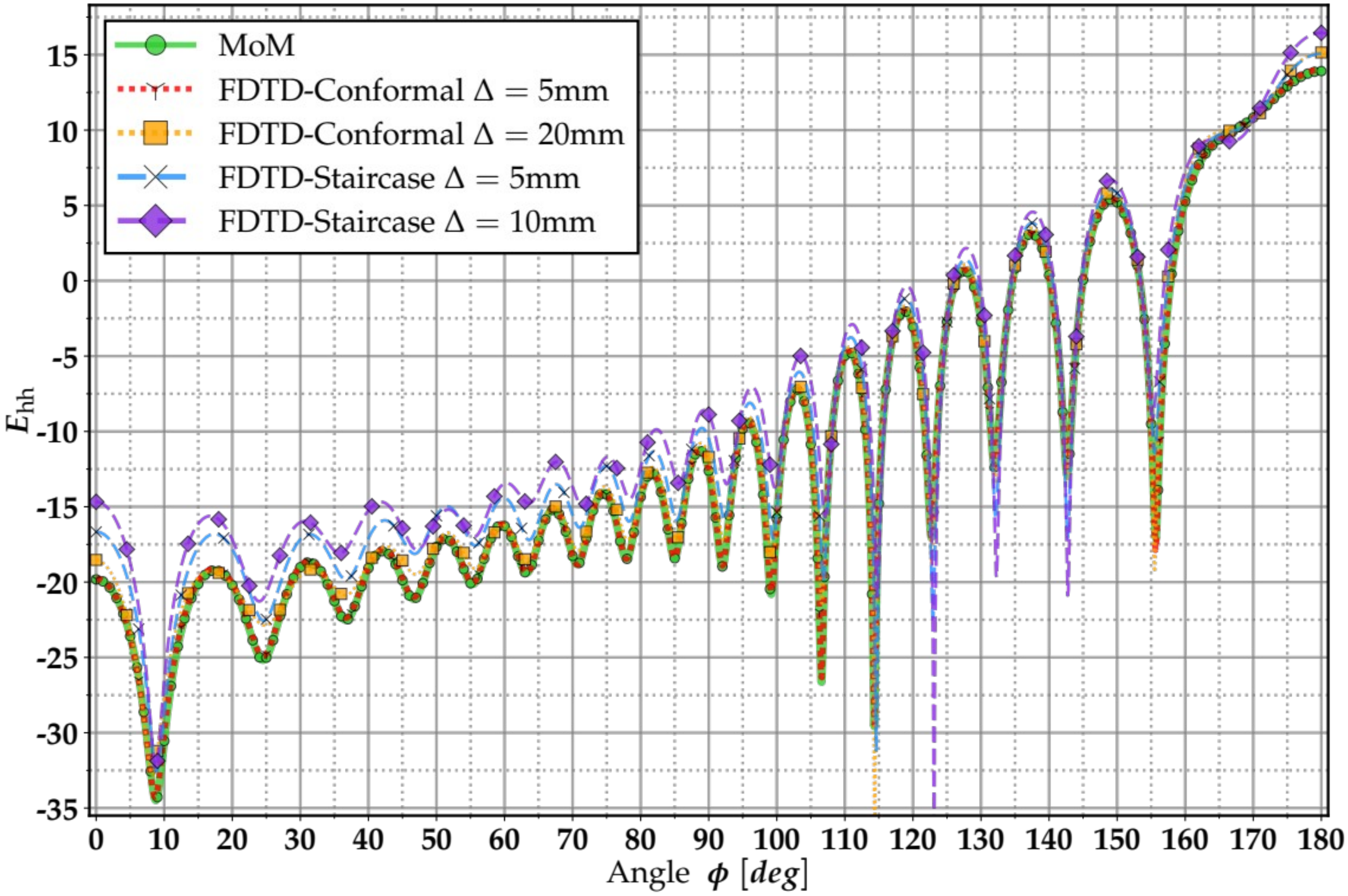
Crosspolar component





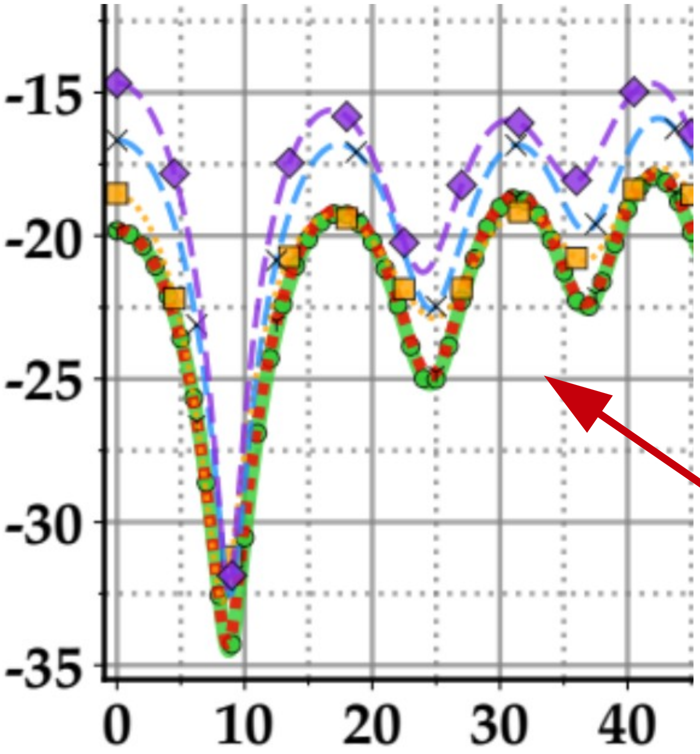
Bistatic copolar at 1GHz

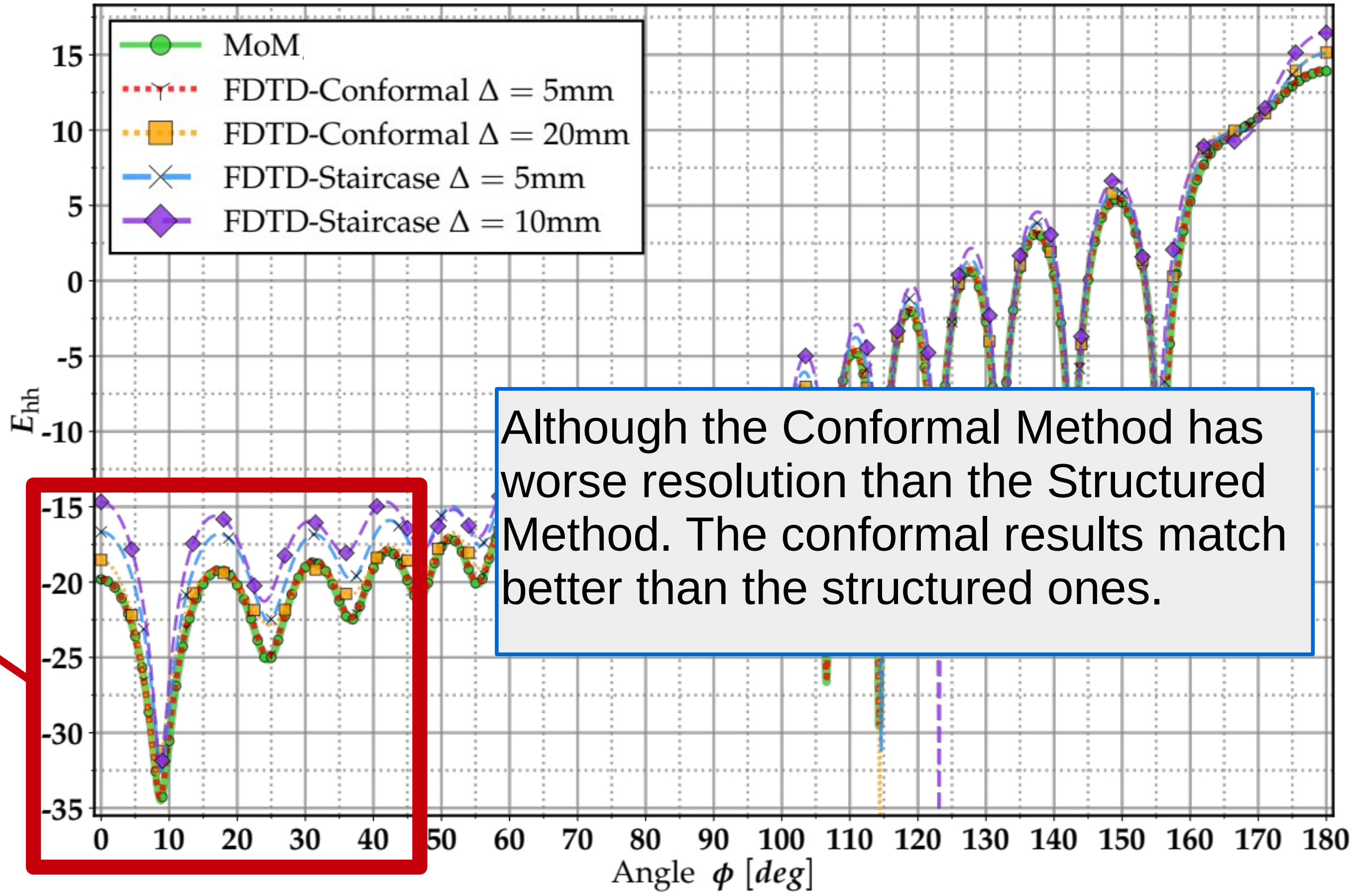




4-Results: Nasa Almond PEC

Bistatic copolar at 1GHz

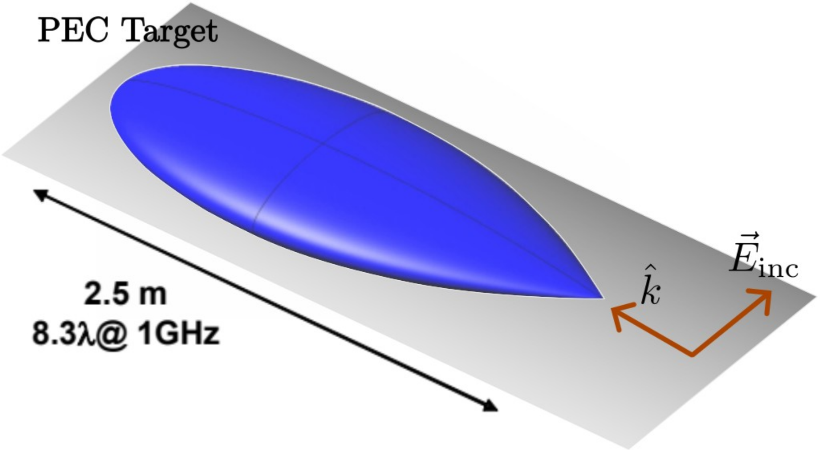


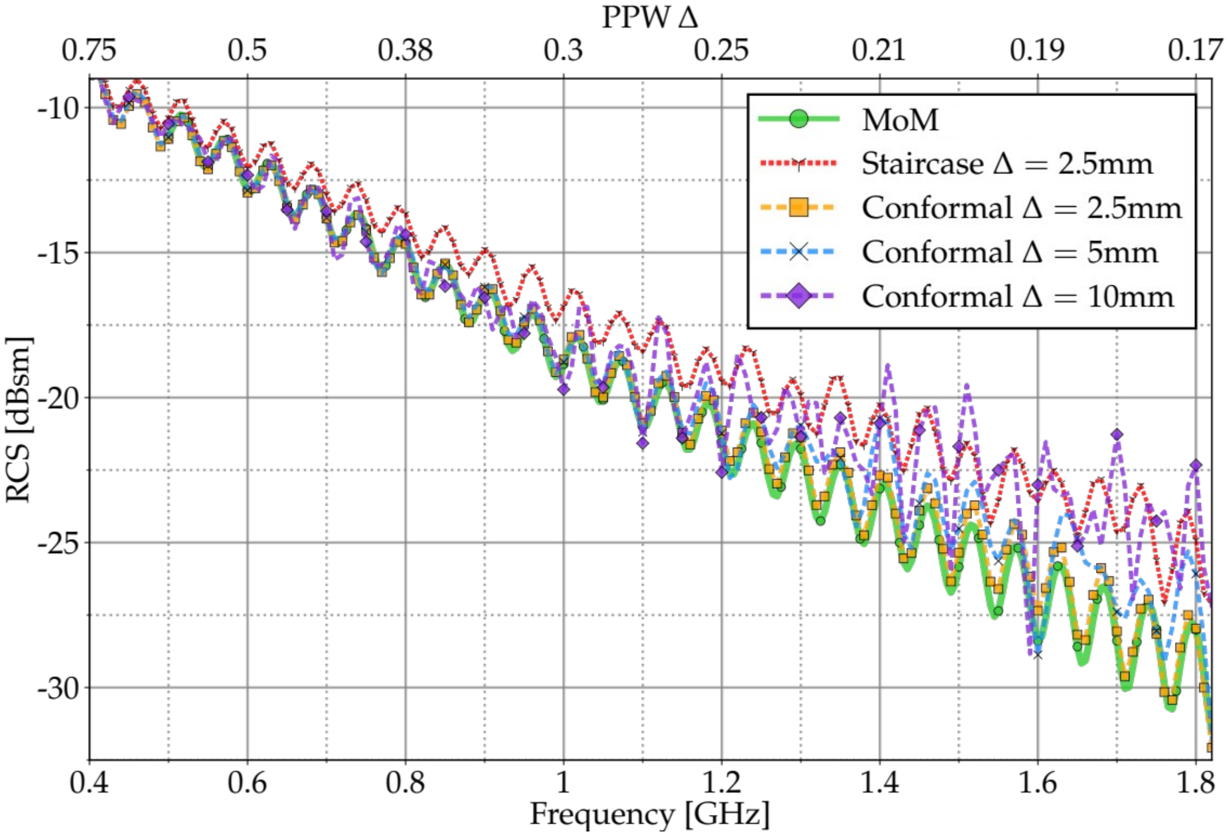


Although the Conformal Method has worse resolution than the Structured Method. The conformal results match better than the structured ones.

4. Results: Nasa Almond PEC

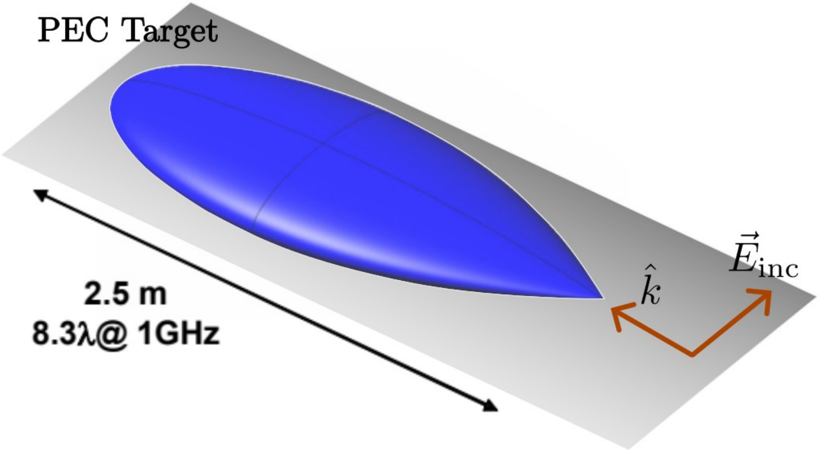
Backscattering in frequency

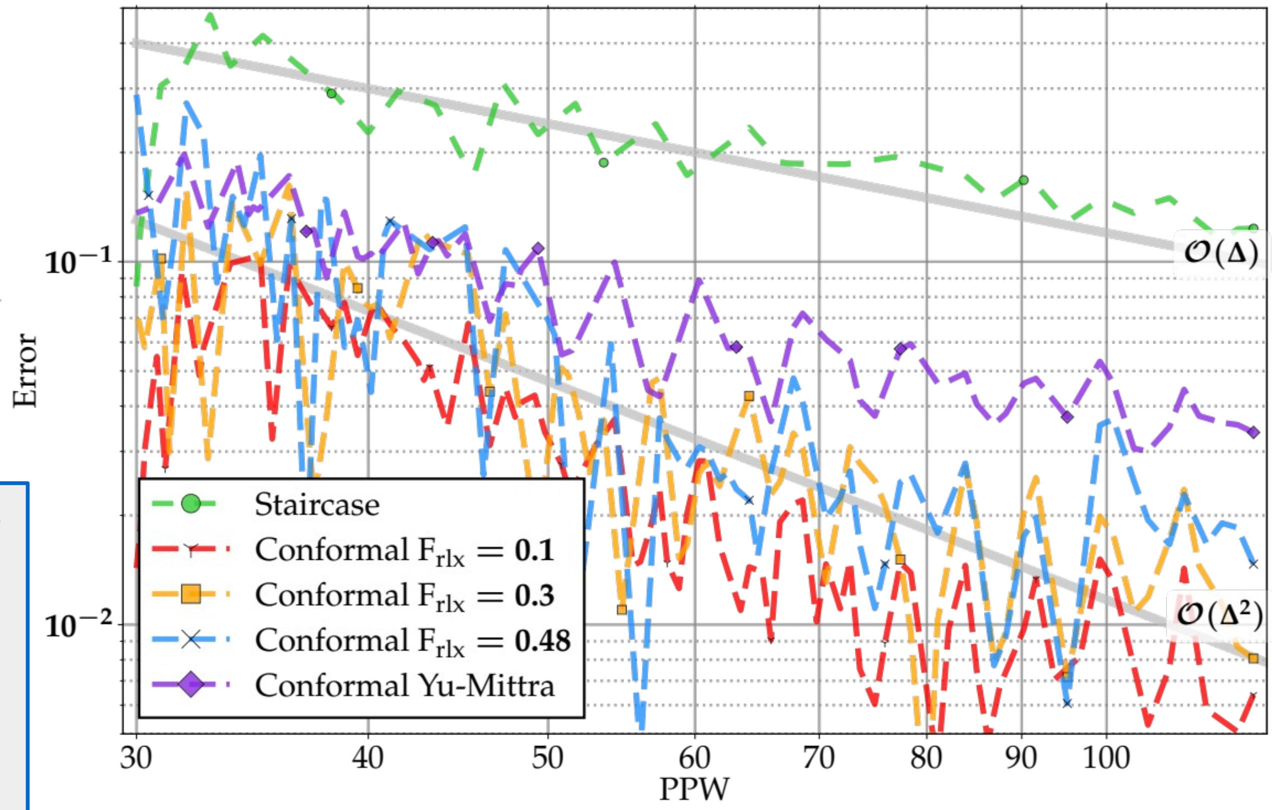




4-Results: Nasa Almond PEC

Backscattering in frequency: convergence study





The FDTD is formulated in second but the error of the structured mesh reduces it to one order.

The conformal mesh preserves the second order of the original formulation.

- **FDTD-Staircases** exhibit poor accuracy and low convergence.
- The **FDTD-Conformal** demonstrates improved accuracy and convergence.
- The combination of the **FDTD-subgridding** technique (with LTS, 1:2 ratio and orthogonal transition) with **conformal methods** offers a stable solution with favorable trade-off between efficiency and accuracy for addressing multiscale problems of a general purpose.

Thanks for your attention

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