Efficient Implementation of BOR FDTD Algorithms in the Engineering Design of Reflector Antennas

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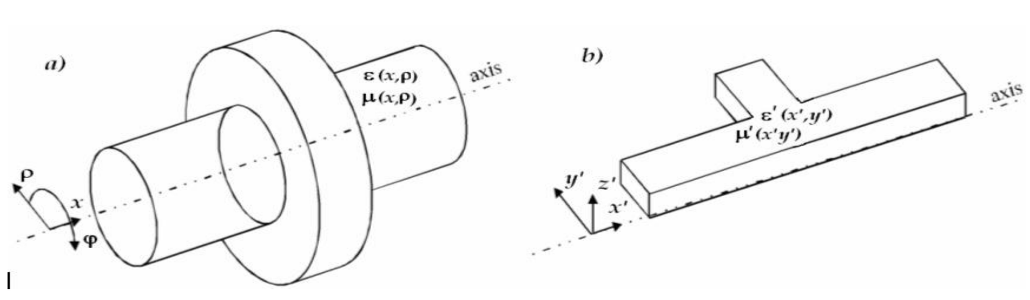
ABSTRACT This work presents a modelling-based methodology for the design and evaluation of axi-symmetrical antennas, including horns, compact and large dual-reflector antenna systems. The starting concept of the antenna is an educated guess stemming from the engineer's experience; however, further evaluation and optimization of that concept continue in a **computational loop that involves a conformal FDTD algorithm in a BOR formulation**. Our **BOR FDTD retains the advantages of general-purpose 3D FDTD software**, providing full-wave solutions and delivering key engineering parameters of antenna systems together with an insight into the distribution of the electromagnetic near-field, a useful feature to assess the mismatch of the horn due to the subreflector interaction. At the same time, the **unique BOR formulation accelerates the analysis by orders in magnitude**, making it practical to evaluate many designs within a manual or automatic optimisation loop. We also show that **BOR FDTD compares favourably with the Mode Matching Technique**, being computationally fast while obviating the MMT inherent structural assumptions.

The concept of BoR FDTD

Reduce 3D axisymmetrical problem (a) to planar 2D (b):



Apply Maxwell equations in cylindrical coordinates:

- **numerical** FDTD discretisation in 2D plane ($x\rho \rightarrow x'y'$)
  → economies in computer effort by 2-3 orders in magnitude

- angular $\cos(n\varphi)$ / $\sin(n\varphi)$ field dependence enforced **analytically**
  → expected higher accuracy for high-n modes

Discretisation and computer requirements:

Variable meshing enforcing basic cel size of λ/20:

- Workstation equipped with 64 GB of RAM
  1300 x 1300 λ simulation project
  Antenna diameter of at least **2600λ**

- Video game nVidia GeForce GTX 1080 Ti card with 11 GB of memory
  Antenna diameter of at least **1200λ**

Optimisation of the horn

X-band: Rx: 7.25 – 7.75 GHz, Tx: 7.9 – 8.4 GHz

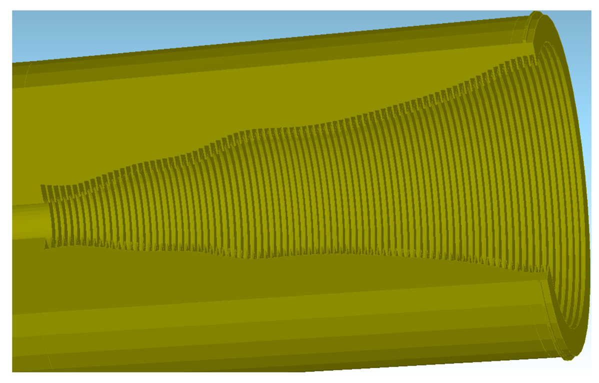
Length: 1320 mm: 920 mm long circular „feed-tube" 400 mm long corrugated horn section

Diameter: 40 mm in the feed tube; 252 mm at the aperture

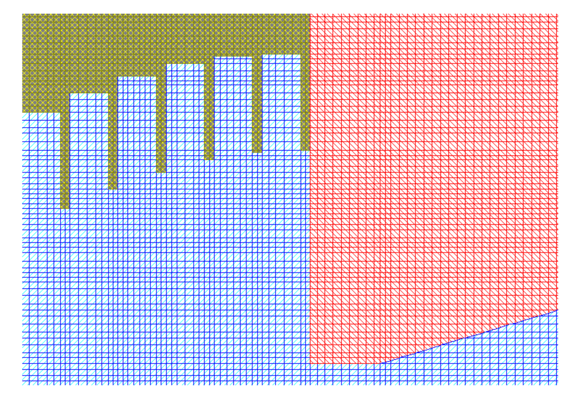
Corrugations: 82

Configuration: part of dual-reflector system

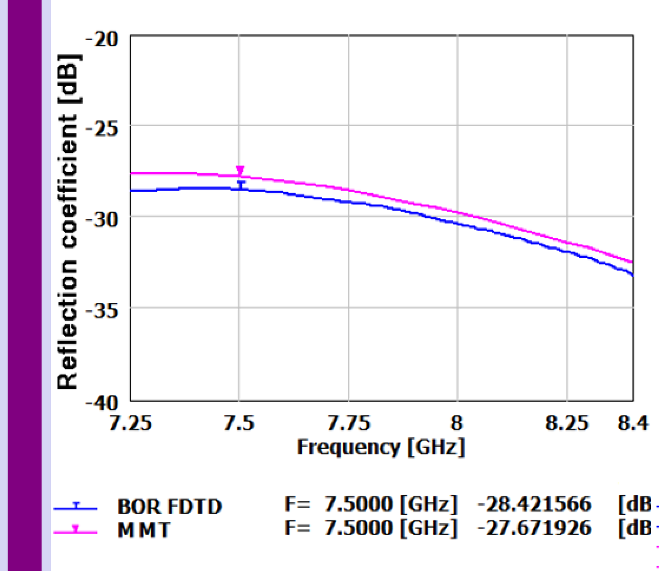
Meshing: λ/40 → 1 milion FDTD cells

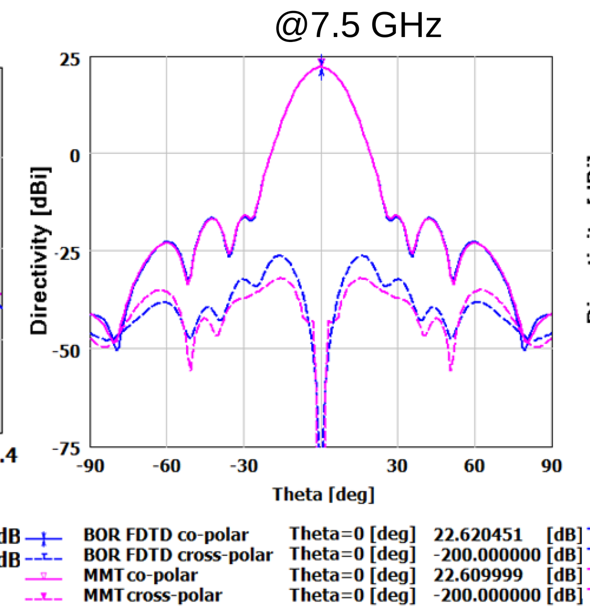


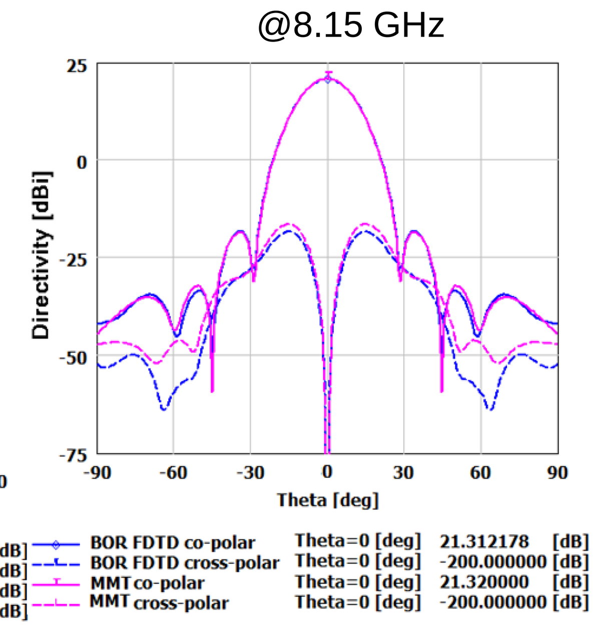
Conformal BOR FDTD



Corrections for field singularities at metal edges/corners







Computation speeds:
21 s @ nVidia GeForce GTX 1080 Ti
1 min 57 s @ Intel i7 4930-K
49 s @ Intel Xeon Silver 4116

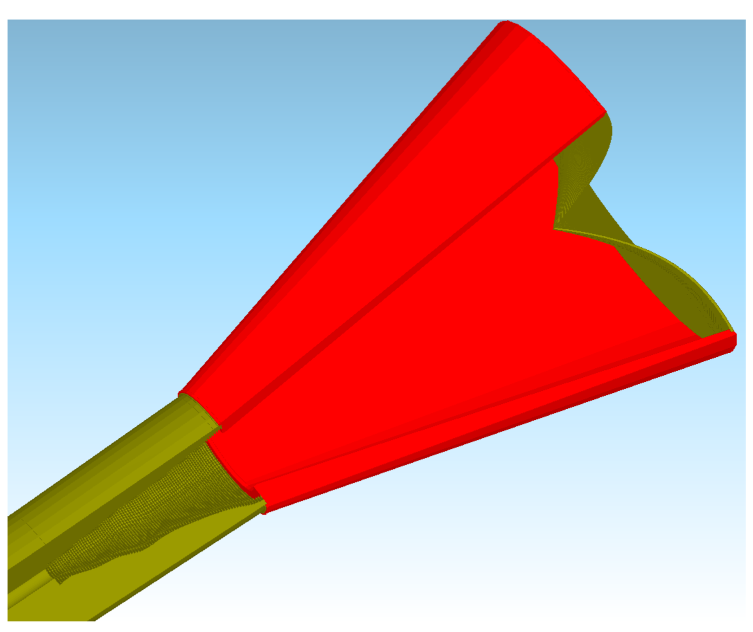
Optimisation loop:
- Objective: reflections & radiation patterns
- **120** design iterations within **1 hour**

Comparison of the BOR FDTD[1] and MMT[2] for accuracy validation

[1] QuickWave V2D software, [2] AXIAL software

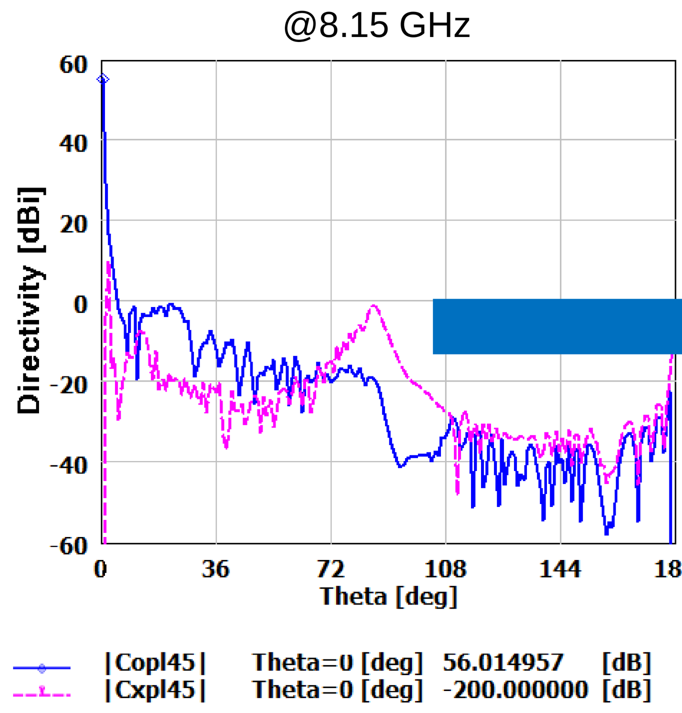
Design of the dual-reflector antenna system

- Optimised horn as a feeding horn in dual-reflector antenna system
- **9 m**-diameter main reflector
- **0.7 m** –diameter subreflector
- Subreflector attached to feeding horn with low-loss structural foam
- **250 wavelengths** in diameter



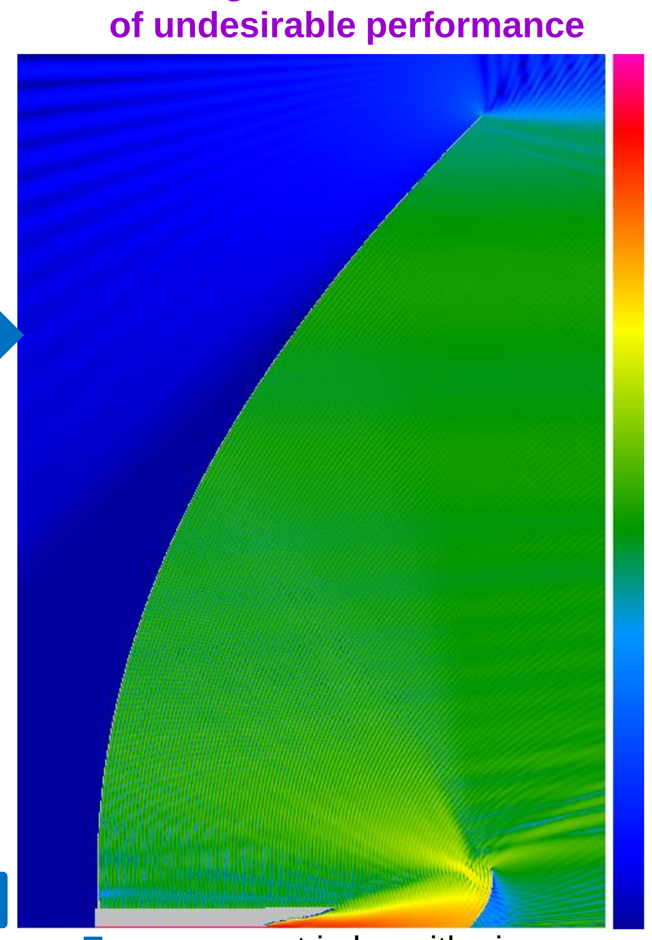
Meshing: λ/40; 33 milion FDTD cells
Memory occupation: 2 GB
Computation time: 8 minutes
Radiation patterns: 24 frequencies, Δθ= 1 deg, 5 sec

Efficient optimisation loop: **YES**



Insight into EM near-field

Investigation of the cause of undesirable performance



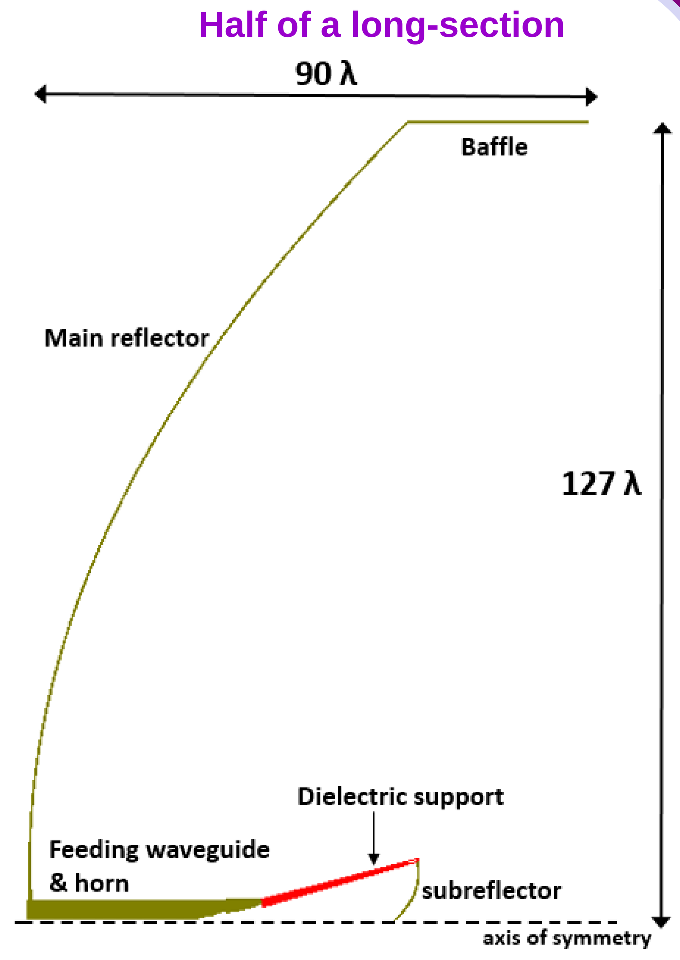
Ep component in logarithmic scale for dual-reflector antenna

Consideration of possible improvements to e.g. decrease the leakage

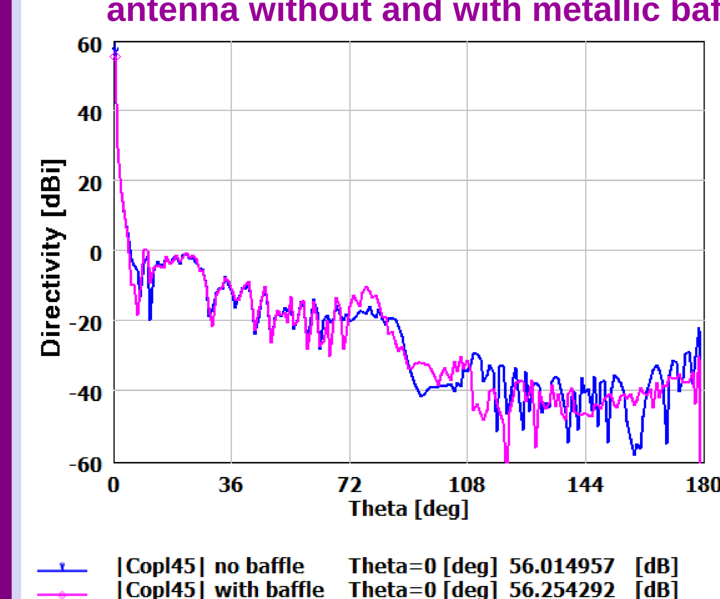
Geometry modifications and adjustments

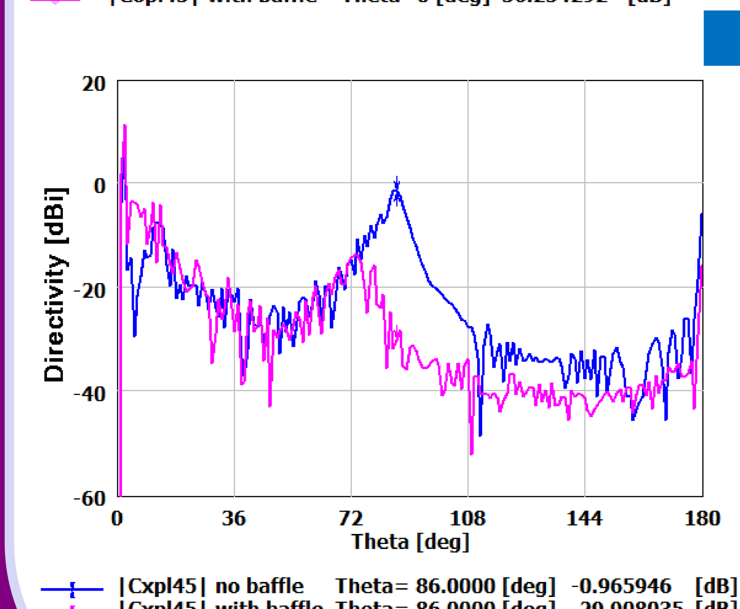
- EM near-field displays provide guidelines to consider possible improvements to decrease the leakage
- Introducing 1m – long metal baffle at the edge of main reflector
- EM analysis with BOR FDTD

Half of a long-section

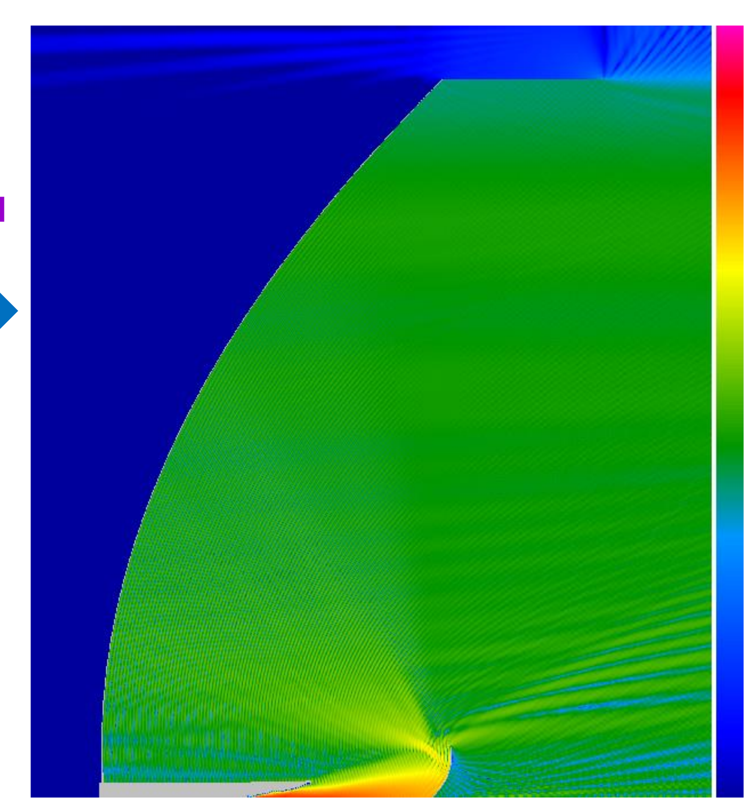


Comparison of radiation pattern of antenna without and with metallic baffle





Insight into EM near-field



Ep component in logarithmic scale for dual-reflector antenna with 1m-long metallic baffle

Conclusions:

- Design of axi-symmetrical antennas can be accurately and efficiently performed with **BOR FDTD**.
- With a single analysis of feeding horn being completed within 1 minute and 10 minutes for analysis of dual-reflector system, BOR FDTD allows for completing an optimisation proces within hours.
- **BOR FDTD** retains the advantages of 3D FDTD in terms of wide-frequency-band modeling of complex geometries and inhomogeneous and lossy materials.
- Efficiency of BOR FDTD stems from reducing the simulation of axi-symmetrical structure to half of its long-section, whereas in the 3D approach at least one quarter of the volume needs to be considered
- Enginnering experience is irreplaceable in proposing initial design, interpreting EM field displays and proposing improvements so as to eliminate misperformances

Acknowledgement

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