Benchmarking Conformal BoR FDTD Algorithm for Efficient mm-Wave Design of Multiflare Antennas

Lukasz Nowicki [1], Lucas Polo-López[2], Juan Córcoles[3], Jorge A. Ruiz-Cruz[3], Malgorzata Celuch [1]

[1]QWED Sp. z o.o., 02078 Warsaw, Poland; lukasznowicki@qwed.eu

[2] Institut d'Electronique et des Technologies du numéRique (IETR), INSA, 35700 Rennes, France

[3]Escuela Politécnica Superior, Universidad Autónoma de Madrid, 28049 Madrid, Spain

This work is concerned with the assessment of accuracy and efficiency of FDTD algorithms for the design of millimetre-wave horn antennas. Specific interest is in smoothwalled multiflare horns, which at such frequencies appear as promissing alternatives to corrugated horns, due to lower sensitivity to manufacturing tolerances and lower costs. Yet their modelling poses new challenges due to inclined or curved walls. We demonstrated that a conformal FDTD method in the Bodies-of-Revolution 2D formulation in cylindrical coordinates is specifically suitable for the task, retaining the geometrical flexibility of FDTD with the computational efficiency dedicated Method-of-Moment solvers.

Multiflare horn antenna as benchmarking example...

Horn antennas are, basically, a waveguide whose transverse section increases progressively along its longitudinal axis. Therefore, horns share the main advantages that waveguides present, like low power losses, great mechanical robustness and high-power handling capabilities. Additionally, they can achieve high directivity values and also present low return loss levels. All these characteristics make them especially suited for critical applications where high performance is required.

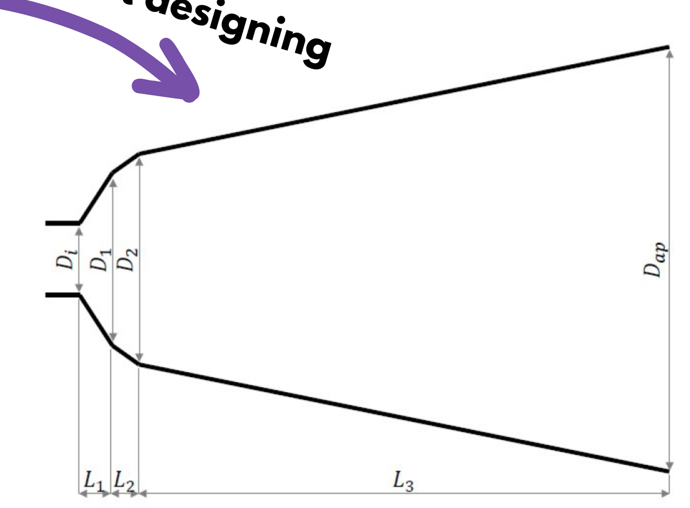
Mode-matching modelling

A horn-type antenna can be viewed as a two-port waveguide device, where one of the ports corresponds to the radiating aperture. The mode-matching technique is a well-known approach to analyze a horn antenna, which is done in three steps. In the first step, the horn profile is discretized in a high-number of very small two-port waveguide sections cascaded along the longitudinal axis. These partial problems are characterized by their Generalized Scattering Matrix (GSM), which are cascaded retaining the high-order mode interaction between sections. Second, the electromagnetic field at the aperture is obtained after solving the resultant problem of the GSM cascading. Finally, in the third step, that computed field is inserted into the radiation integrals to obtain the far field with the field equivalence principle.

Conformal BoR FDTD modelling

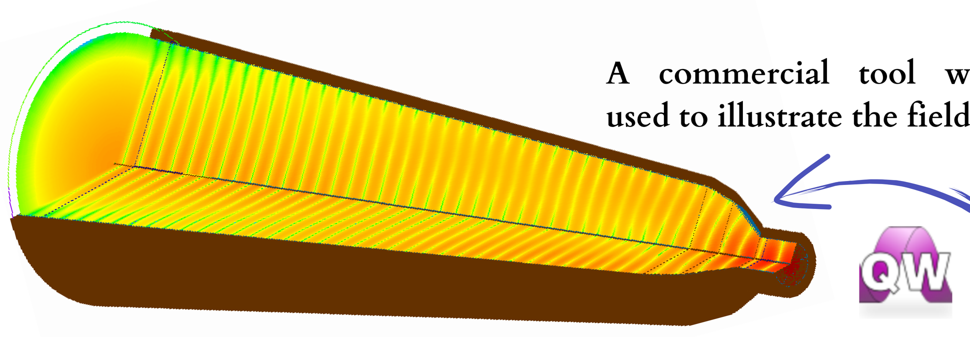
The most popular variant is 3D FDTD in Cartesian coordinates, but for structures preserving the axial symmetry of boundary conditions another FDTD variant, namely the Bodies-of-Revolution (BoR) FDTD is advantageous. It incorporates the angular field dependence (angular mode number) analytically and restricts the spatial discretisation to half of the longitudinal long-section of the antenna. It has been broadly used for corrugated horns and now tested for the multiflare horn herein. In contrast to the fixed rectangular grid used in the FDTD method, conformal FDTD makes the computational domain consistent with the boundary of the object being modeled. This approach allows for more accurate modeling of objects with curved surfaces and complex shapes, making it a valuable tool in a variety of applications.

Let's start designing



	Diameters [mm]				Lengths [mm]		
Symbol	D_i	D_1	D_2	D_{ap}	L_1	L_2	L_3
Value	0.406	0.976	1.19	2.4	0.487	0.398	7.886

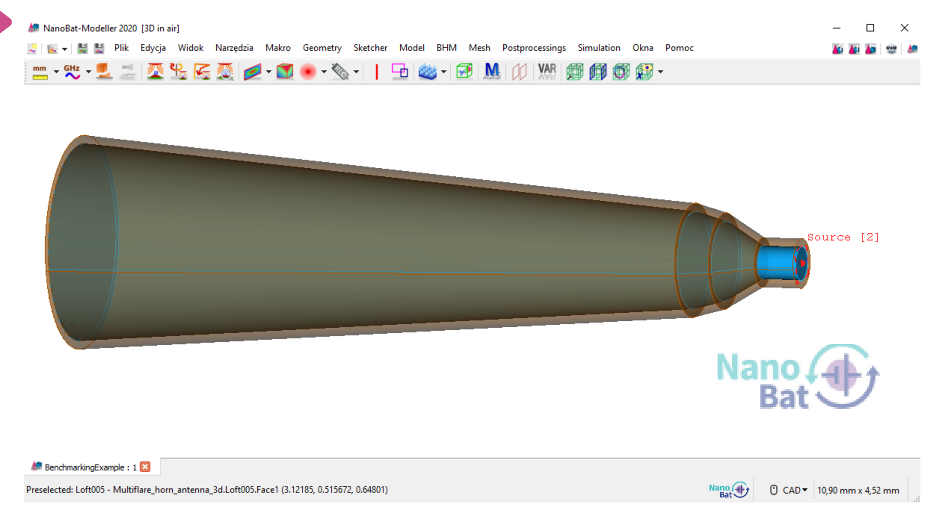
Dimensions of the modeled antenna



A commercial tool was used to illustrate the fields.

Electric Field distribution

Modeling Procedure



NanoBat Modeller

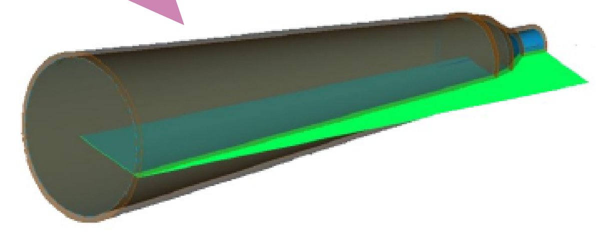
licence-free CAD modeller developed within the NanoBat project.

Simulation parameters

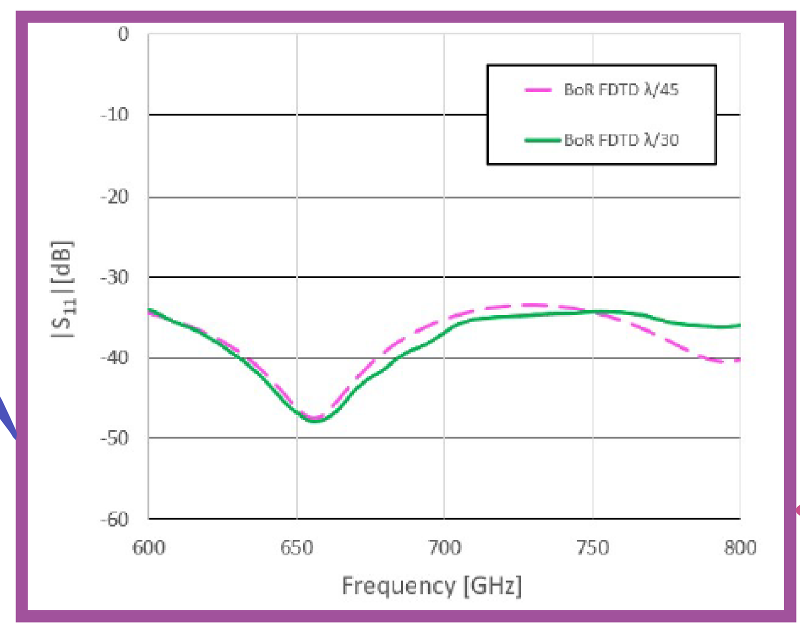
Setting up the source

Source is excited by Circular TE_{11} field mode at matching frequency equal 700 GHz.

Create a mesh



3D view of the considered multiflare antenna in NanoBat Modeller, which automatically generates 2D BoR mesh.



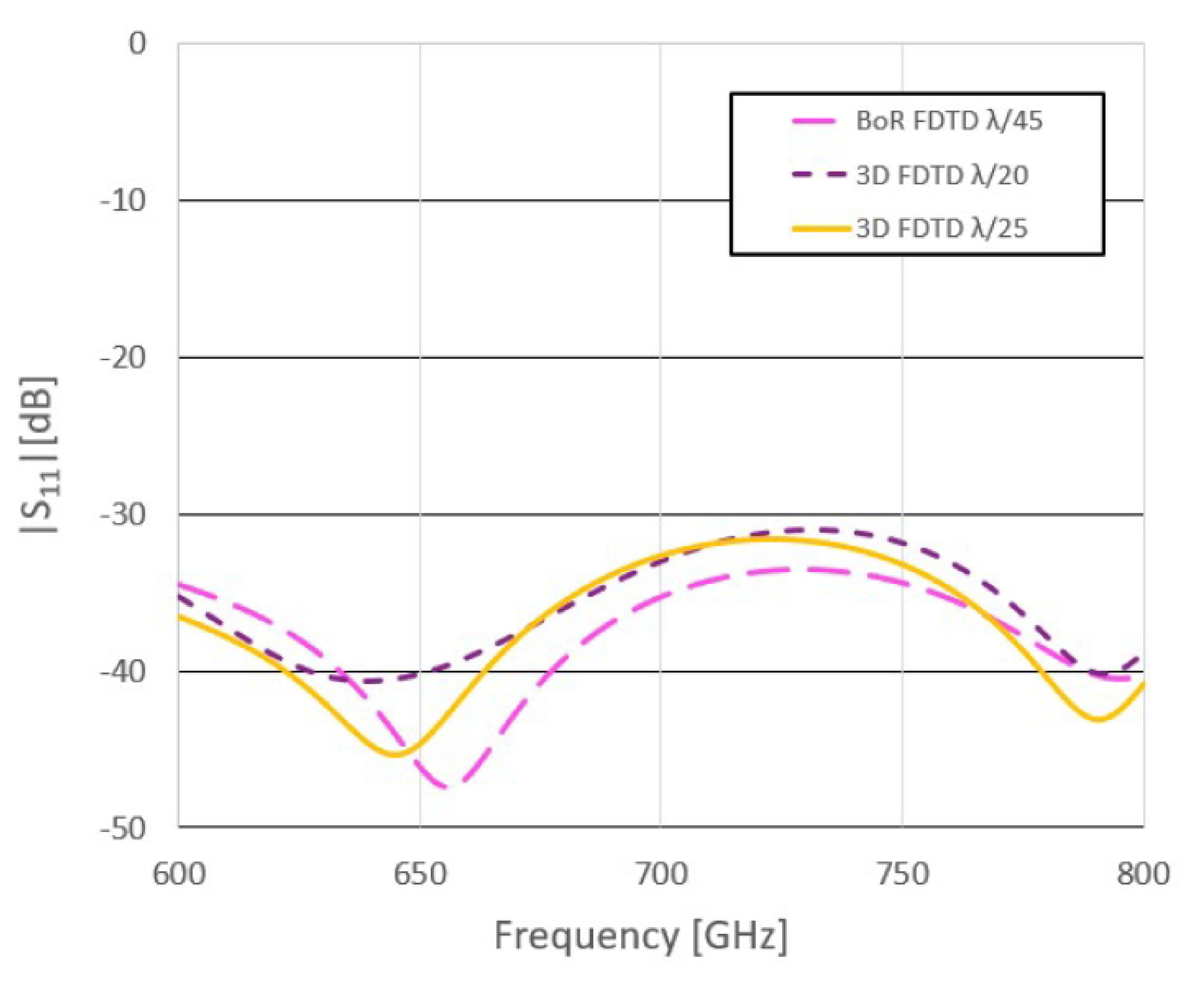
Return loss.calculated by BoR FDTD at meshing of λ/30 (CPU time 3 seconds) and λ/45 (10 seconds).

Getting results

The mesh is imported into the BoR FDTD NanoBat software and as one of the results of such a simulation, we get the return loss.

3D FDTD vs BoR FDTD

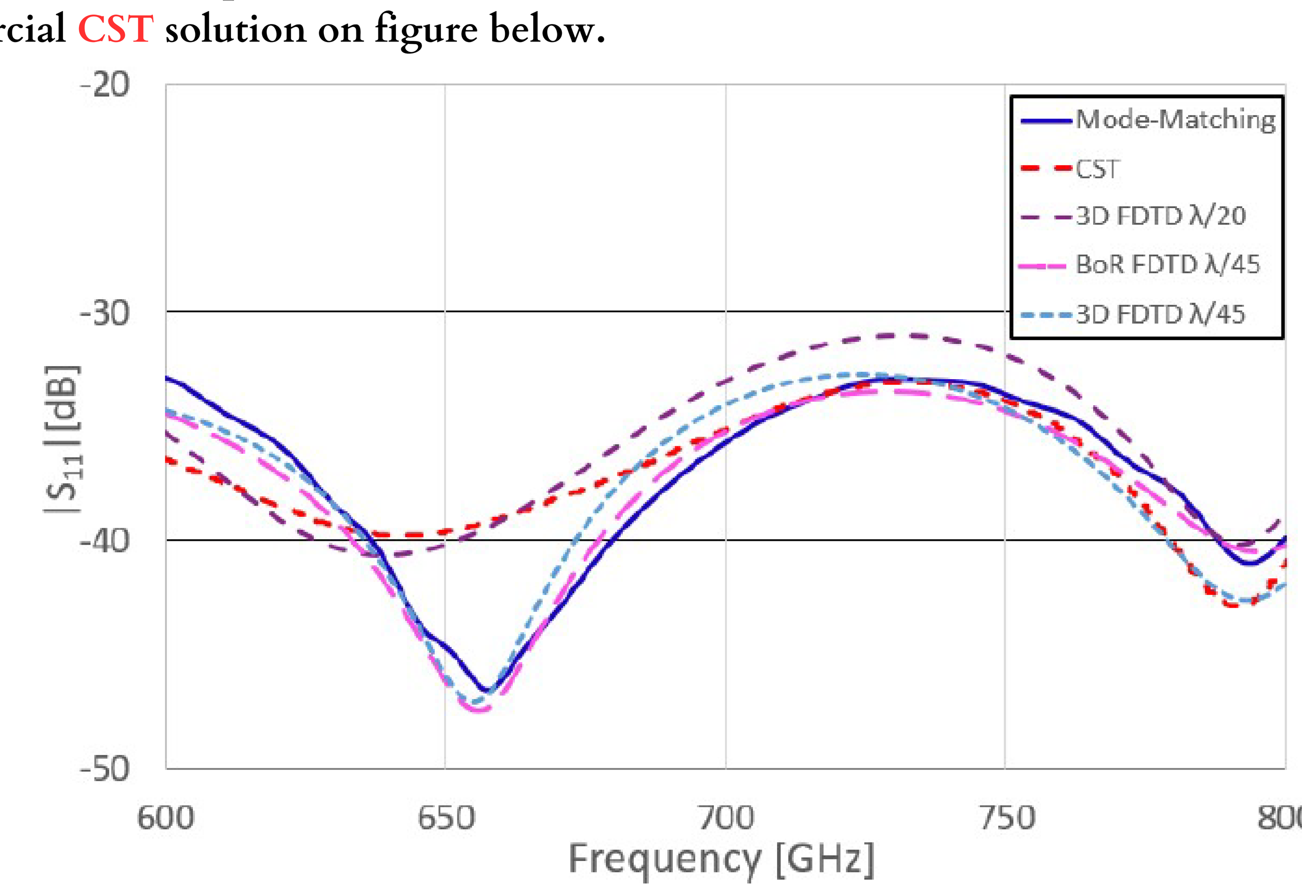
When considering 3D FDTD calculations from 31 MB of RAM, as much as 4 GB should be allocated if λ /20 resolution is set, which is equivalent to 50789508 cells. Increasing the resolution to λ/25 results in an increase in the order of an additional 4 GB of memory. However, it can be seen that as the resolution increases, the results of the S11 scattering matrix approach the BoR FDTD solution which is shown above on Fig.3. The increased amount of resources is associated with an increase in calculation time to 02:07:45 hours for λ/20 and 2:48:17 hours for λ/25. With higher resolution Both 3D FDTD and BoR FDTD methods were performed on a standard computer with parameters: i7-8700, 16 GB RAM and AMD Radeon Pro WX 3100. A change of computer was required to get results for 3D FDTD with the λ/45 resolution. This was needed because the 3D mesh uses a huge amount of RAM equal to 45.856 GB. Calculation time tooks 11:59:41 hours.



Return loss calculated by 3D FDTD of meshing λ/20 (CPU 02:07:45) and λ/25 (2:48:17) compared with BoR FDTD of λ/45 (10 seconds).

Benchmarking

For the Mode-Matching method, 140 mods are considered for this type of antennas, where the number of modes at each discontinuity is assigned in terms of the surface ratio between such discontinuity and the aperture. With this method, the calculations were completed in 686.1 seconds on the computer i7-4790 CPU and 31.8 GB RAM. All methods were compared to the commercial CST solution on figure below.



Return loss calculated using different methods: Mode-Matching, 3D FDTD (CST and NanoBat software) and BoR FDTD with conformal mesh generated by NanoBat Modeller.

Conclusions

We have demonstrated that a conformal BoR FDTD algorithm combines the speed of dedicated mode-matching algorithms for horn antennas with the generality and geometrical flexibility of popular 3D FDTD solvers. This is because the BoR approach uses, in fact, the modal expansion in one (angular) space dimension, reducing the discretisation to 2D and thereby reducing memory and computing time by over 2-3 orders of magnitude, and making even large and complex structures tractable on a laptop or desk-top computer. The locally conformal approach additionally contributes to the accurate modelling of curved boundaries of multiflare antennas, while the time-domain approach makes simulation time practically independent of the number of calculated frequency points.

Acknowledgement

The work of QWED team currently receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreement NanoBat No. 861962 and the Polish National Centre for Research and Development under M-ERA.NET3/2021/83/I4BAGS/2022.

This work was partially supported by the Spanish Government under grant PID2020-116968RB-C32 (DEWICOM) and TED2021-130650B-C21 (ANT4CLIM) funded by MCIN/AEI/ 10.13039/501100011033 (Agencia Estatal de Investigación) and by UE (European Union) "NextGenerationEU"/PRTR.