WM-06

Advances in computational modelling of radar wave – material interactions

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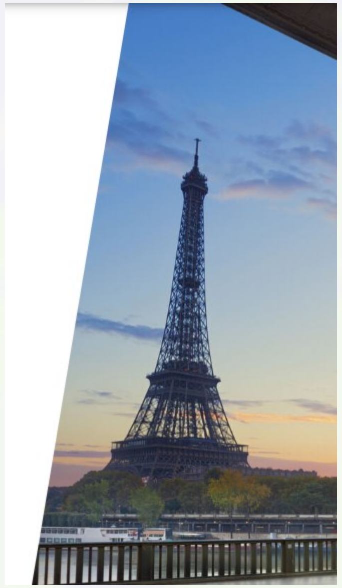

Outline

- I. Introduction
- II. Computational Regimes for Electromagnetic Modelling
    - Importance of Accurate Electromagnetic Modelling: Material characterisation scenarios, Radar antenna design acceleration
- III. Dedicated Computational Regimes
    - Vector 2D FDTD Algorithm for Axisymmetrical Horn Antennas
    - Near-to-Far Field Transformation in Lossy Tissues
    - Near-to-Near Field Transformation
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    - Quasi-Free-Space Millimetre-Wave Material Measurements
    - Near-Field Sensing
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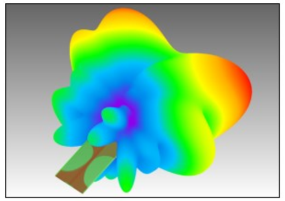
Introduction

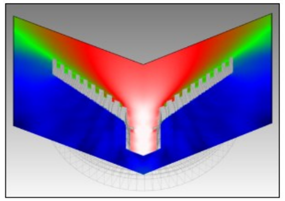
QuickWave

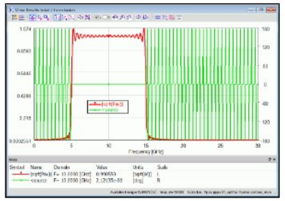
Software for electromagnetic design and simulations based on conformal FDTD method.

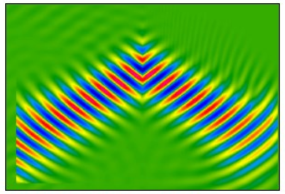
QuickWave is a general-purpose electromagnetic simulator based on the conformal FDTD method and supplemented with a range of unique models for curved boundaries, media interfaces, modal excitation, and parameter extraction. It has a well-established position on the worldâs market due to approaching specific, challenging problems specialists participation in the customerâs projects as consultants). That kind of approach causes that QuickWave has a very broad variety of information which can be extracted from the simulations in a form of different pre-processings, co-processings and post-processings.

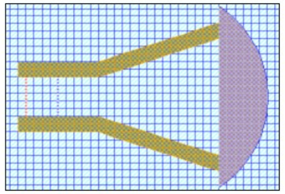
Functionalities

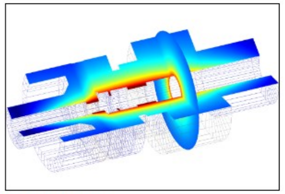

Full 3D EM solver


Vector 2D (V2D) solver for axisymmetrical structures (BOR - Bodies of Revolution)

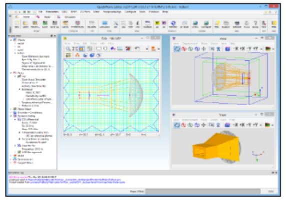

Co-processings & post-processings

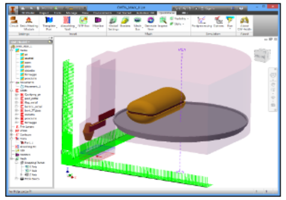

Materials, excitations & boundary conditions

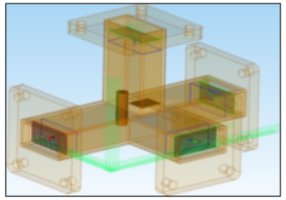

Conformal FDTD mesh


Special features

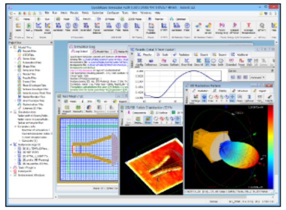
Input Interfaces

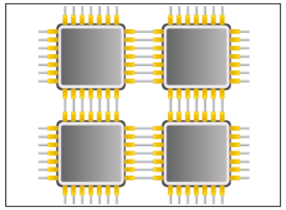

QW-Editor

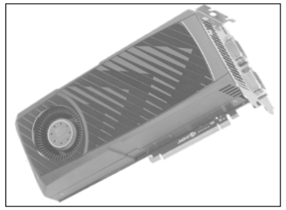

QW-AddIn for Autodesk® Inventor® Software


QW-Modeller

Simulation Engines


QW-Simulator


Multiprocessor / multicore computing

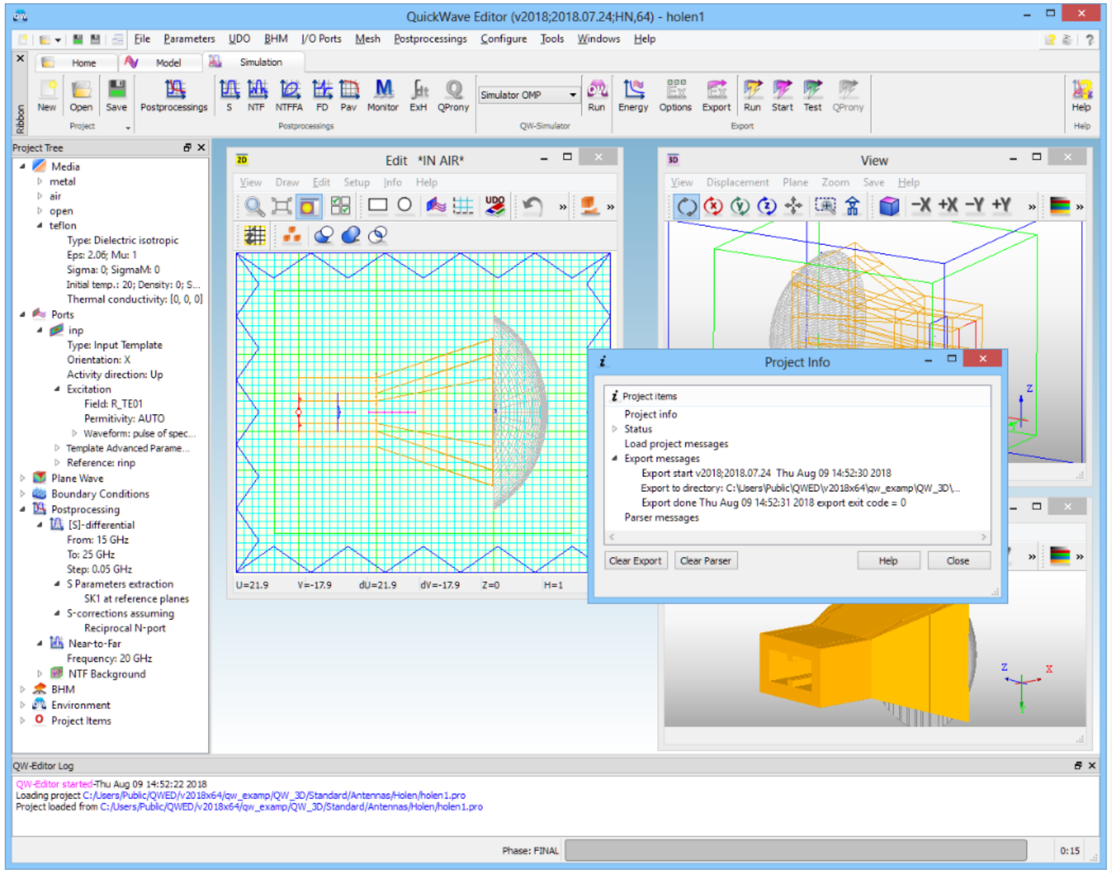

GPU / MultiGPU computing

Introduction

EuMA
European Microwave Association

QuickWave 3D can be applied to a variety of microwave and millimetre-wave problems including:

- accurate S-parameter calculations of shielded and open microwave and millimetre-wave circuits, also in cases involving dispersion, multimodal propagation, and evanescent modes, covering in particular the circuits manufactured in microstrip, coplanar, coaxial, cylindrical waveguide, and dielectric guide technologies
- calculations of radiation patterns, gain, radiation efficiency, radiation resistance, and return loss of antennas of various types (patch, horn, rod), rigorously taking into account irregular geometry, complicated corrugations, and inhomogeneous filling
- calculations of input impedance of mobile phone antennas and of specific absorption rate in human tissues
- calculations of heating patterns for microwave power applications, with accurate and fast display of instantaneous, time-maximum, and time-averaged patterns of fields and dissipated power
- determination of eigenfrequencies, Q-factors, and pure modal field patterns for shielded and open inhomogeneous resonators, also in cases involving closely-spaced modes
- calculations of embedding impedance for lumped elements
- calculation of scattering patterns with plane wave excitation



Computational Regimes for Electromagnetic Modelling

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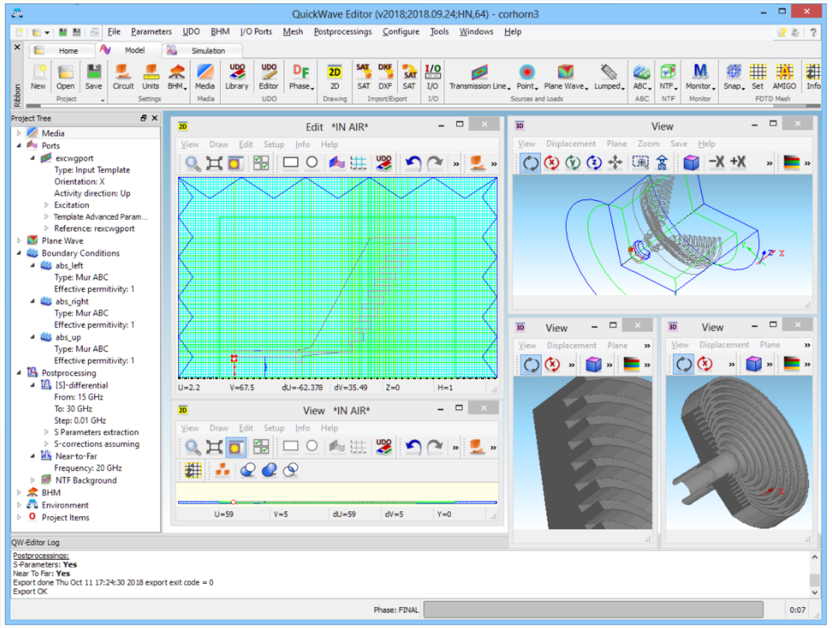
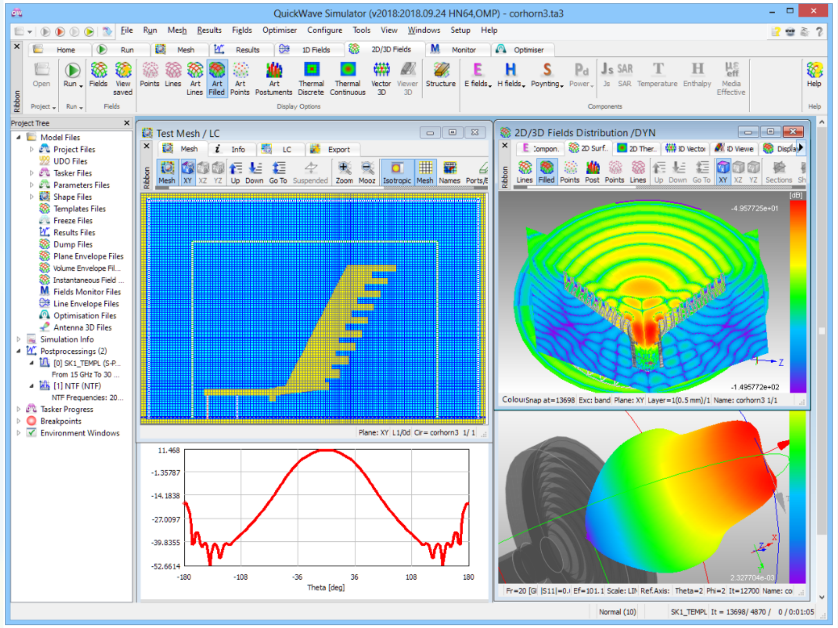
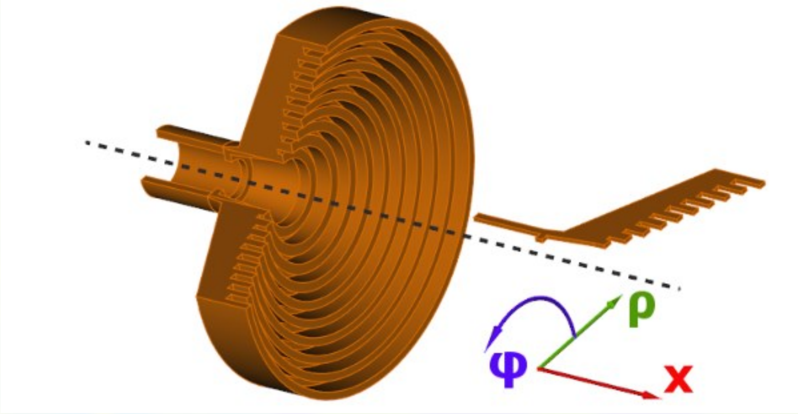
Vector 2D (V2D) solver for axisymmetrical structures (BOR - Bodies of Revolution).

QuickWave V2D is a unique on the market and ultra fast Vector 2D (QW-V2D) electromagnetic solver is applicable to the analysis of axisymmetrical devices (which are also called Bodies Of Revolution) as large as 2100 wavelengths, including antennas (horns, rods, biconical), circular waveguide discontinuities, and resonators. It is based on the Maxwell equations re-expressed in cylindrical coordinates. Definition of a 2D long-section of the structure allows for hundreds times faster simulation than brute force 3D analysis.





It has been proven [8] that the structures, which maintain axial symmetry of boundary conditions, belong the class of vector two-dimensional (V2D) problems. The total electromagnetic field in such structures can be decomposed into a series of orthogonal modes, of different angular field dependence of the cos(n*Phi*) or sin(n*Phi*) type, where *Phi* is angular variable of the cylindrical coordinate system and n=0,1,2... Each n-mode is analysed separately in QW-V2D. Under such assumptions the numerical analysis can be conducted in two space dimensions, over one half of the long-section of the structure, with n predefined as a parameter. Let us note that the n-mode defined above should not be confused with one mode of a circular waveguide. For example, one QW-V2D analysis with n=1 takes into account a composition of all circular waveguide modes TE_{1k} and TM_{1m} where k and m are arbitrary natural numbers.



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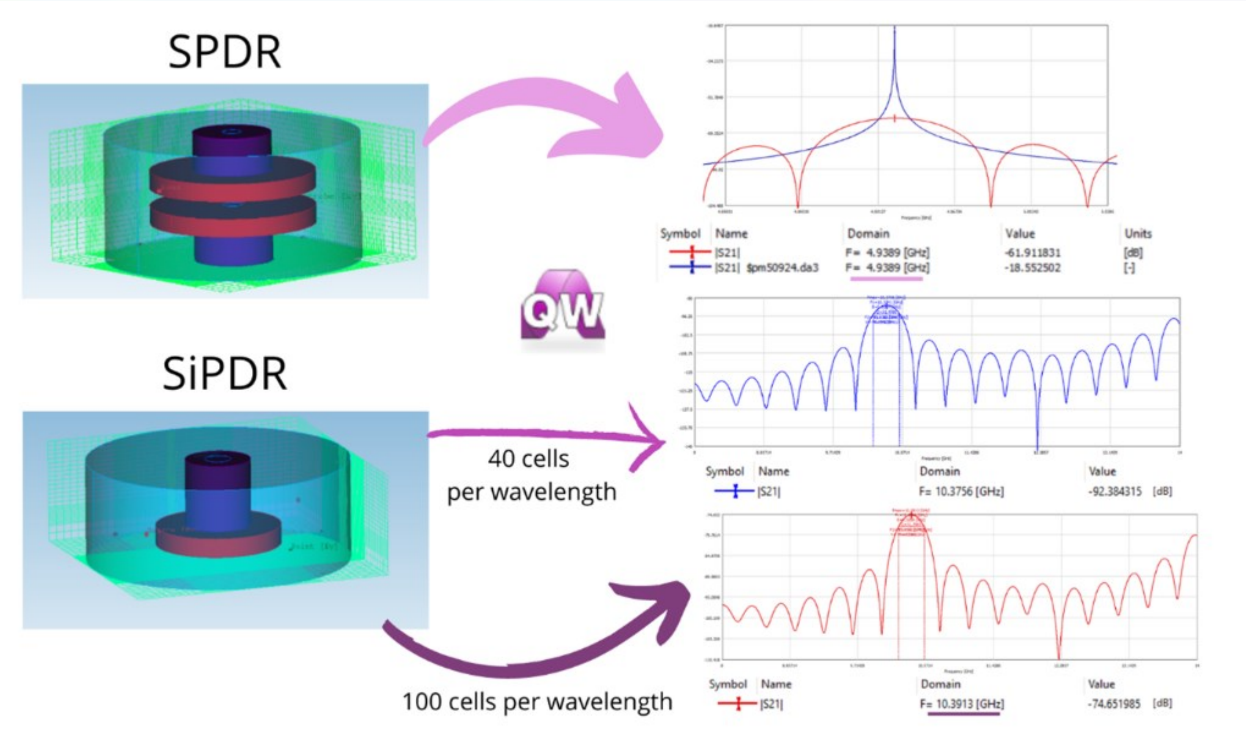
Computational Regimes for Electromagnetic Modelling

The split-post dielectric-resonators (SPDR) are intended for the contactless measurements of the complex permittivity of laminar dielectric materials including LTCC substrates, but also thin ferroelectric films deposited on low loss dielectric substrates. SPDRs and SiPDRs can be used for the measurements of the surface resistance and conductivity of various conducting materials such as commercial resistive layers, thin conductive polymer films or high resistivity semiconductors. The SPDR technique is applicable to high-resistivity semiconductors having the resistivity from 100 Ωâ�m to 10 000 Ωâ�m. When materials with lower resistivity need to be measured, single-post dielectric-resonator (SiPDR) is used, whose sensitivity range is from 10-5 Ωâ�m to 100 Ωâ�m. For this reason, it is used to study metamaterials as well as semiconductor wafers. The combination of both measurement methods allows for a large range of absolute resistivity determination. These techniques allow resistivity mapping and measurements of material properties versus temperature.

The above resonators were designed in QW-Modeller software freely available as examples. In both models there are no samples placed. Using the latest version of the QuickWave simulator, the Direct Fourier Transforms of the signals at the ports have been calculated in post-processing called S-Parameters. From these results the S21 parameter was selected from which the maximum was determined. At this point the 3dB bandwidth on the decibel scale was calculated and shown. The results obtained from QuickWave have been compared with Vector Network Analyzer (VNA) and are in agreement with each other.



Computational Regimes for Electromagnetic Modelling

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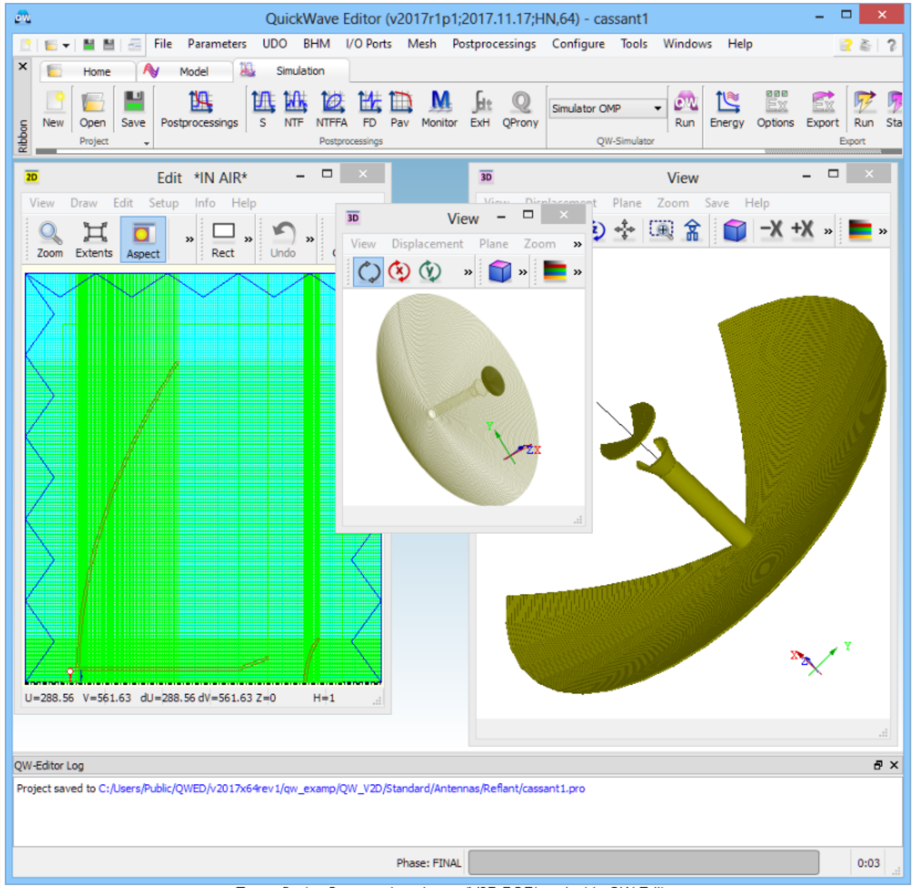
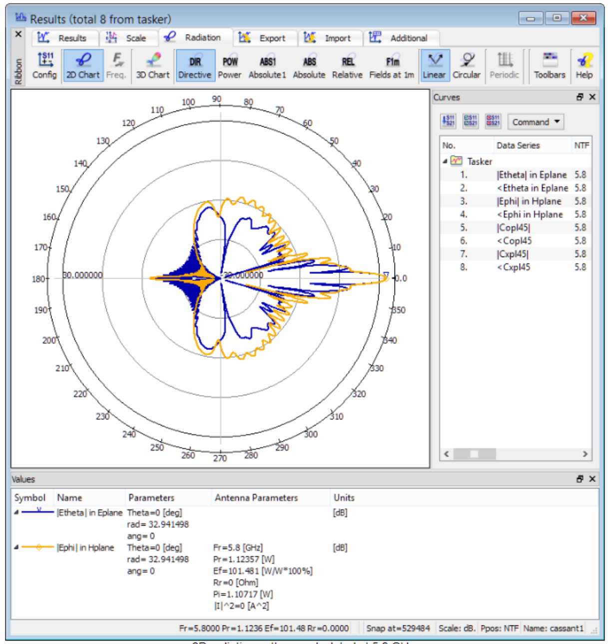


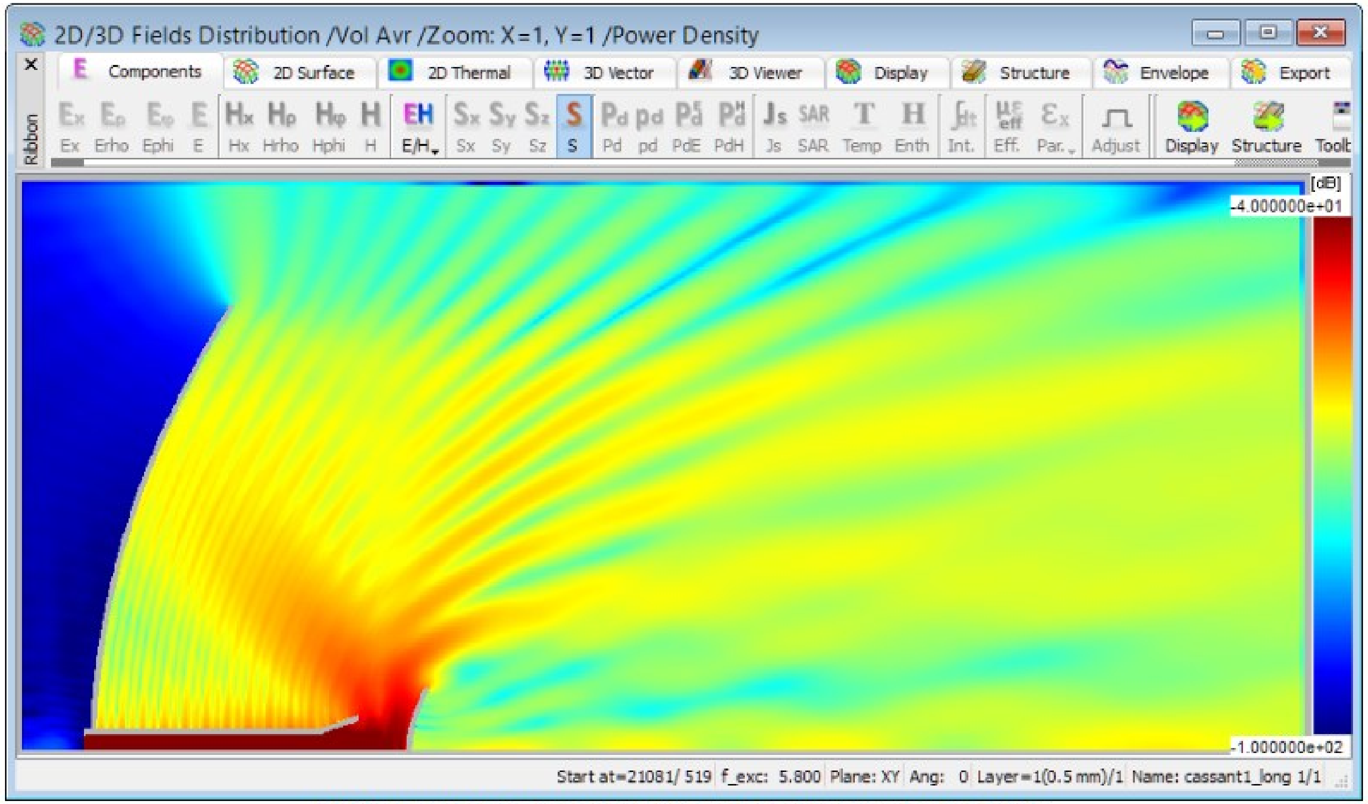
Two-reflector Cassegrain antenna (V2D BOR) project in QW-Editor.



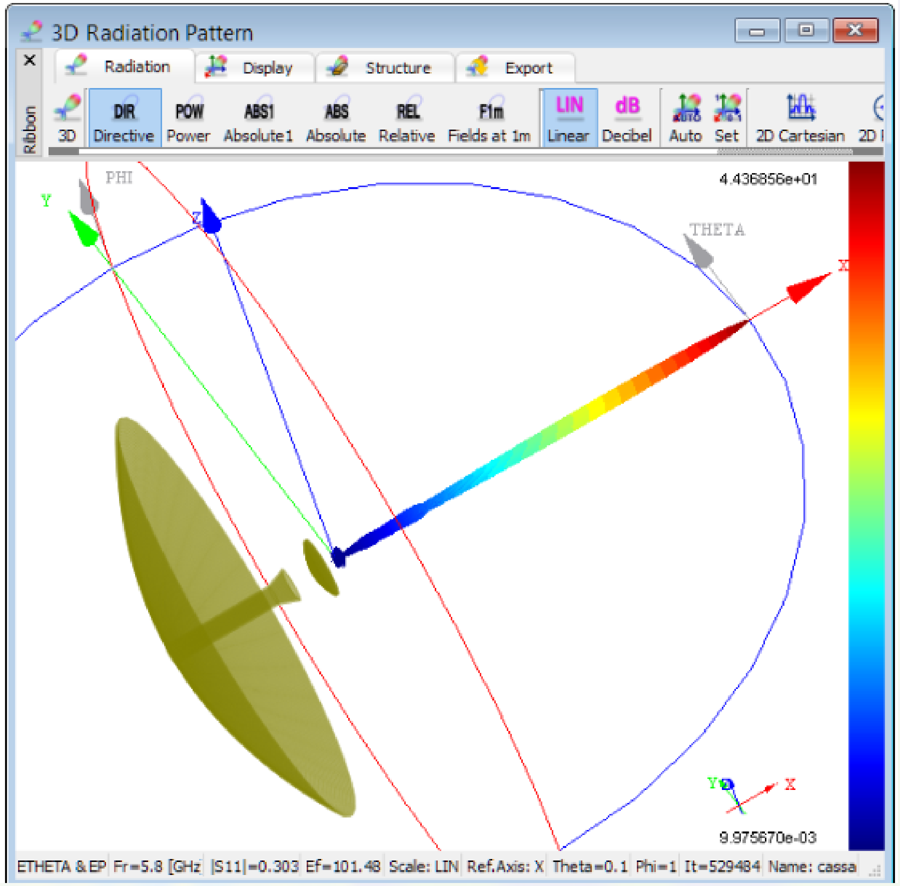
2D radiation patterns calculated at 5.8 GHz.

The structure that is analysed herein is an axisymmetrical horn antenna. Axial symmetry allows for performing the antenna analysis with ultra-fast vector 2D Bessel and FDTD hybrid solver (V2D BOR) designated for Bodies of Revolution (BOR) structures. This solver allows for analysing only half of structure's long-section, which results in its extremely fast performance. The structure should be drawn in a way that its symmetry axis coincides with project symmetry axis ρ=0 (in the QW-Editor and QW-Simulator referred as y=0).

Computational Regimes for Electromagnetic Modelling

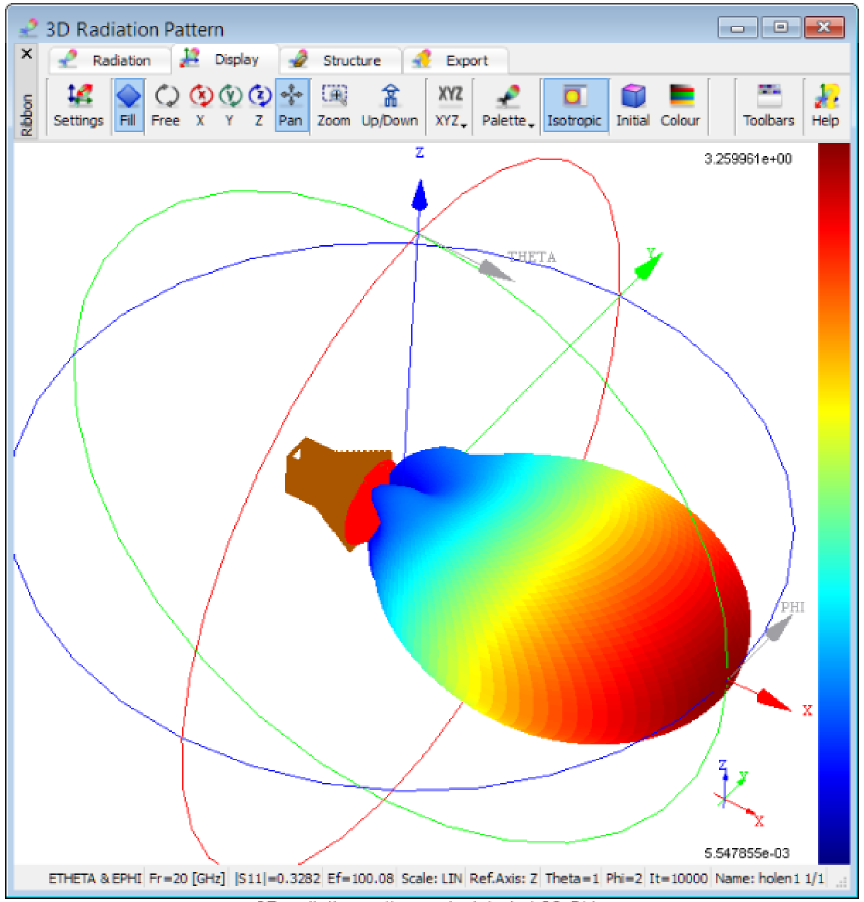


Distribution of time average envelope of the Poynting vector at 5.8 GHz.



3D radiation pattern, with both Phi and Theta varying in steps, can be calculated in the 3D Radiation Pattern window. The 3D Radiation Patterns dialogue allows setting the reference axis and steps for angles Phi and Theta, defined with respect to that axis in the same way as for the 2D radiation pattern case. A single calculation frequency is also selected.

Dedicated Computational Regimes



3D radiation pattern calculated at 20 GHz.

Vector 2D FDTD Algorithm for Axisymmetrical Horn Antennas

The reference axis can be set to X, Y or Z by clicking respective radio buttons in the Axis column of the dialogue. There is also an option to define an **arbitrary reference axis**. For an example of application of this option, please refer to the **Two dipoles in free space excited in phase**.

We can set the reference point or in other words the origin of the coordinate system for the NTF transformation. The position of the reference point does not influence the absolute values of the radiation patterns (in lossless NTF background medium) but it does influence their phase characteristics. Moving the reference point can be helpful in a search for the antenna electrical centre. The reference point position is expressed in the same coordinates and units as those used in the project and defined in user input interface. To recall what units have been used, we can just take a look at the title bar of the window. In the considered example we see Units: mm.

Dedicated Computational Regimes

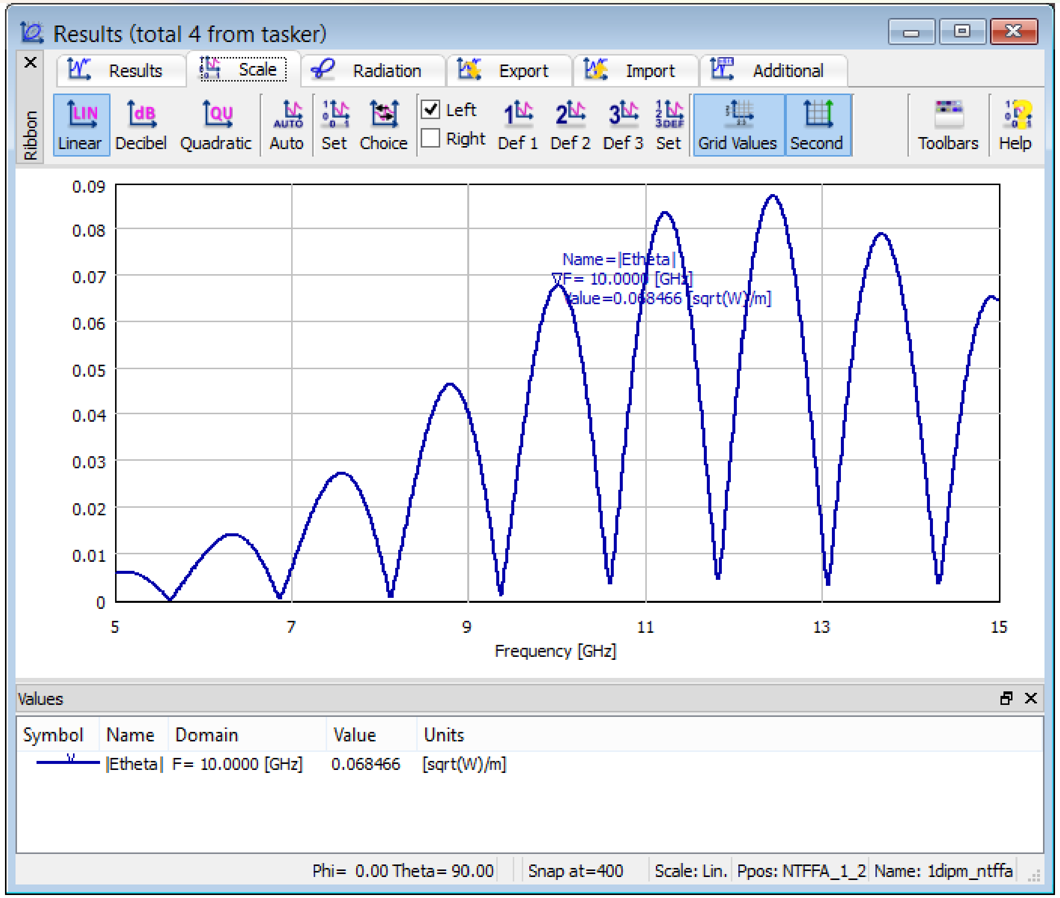
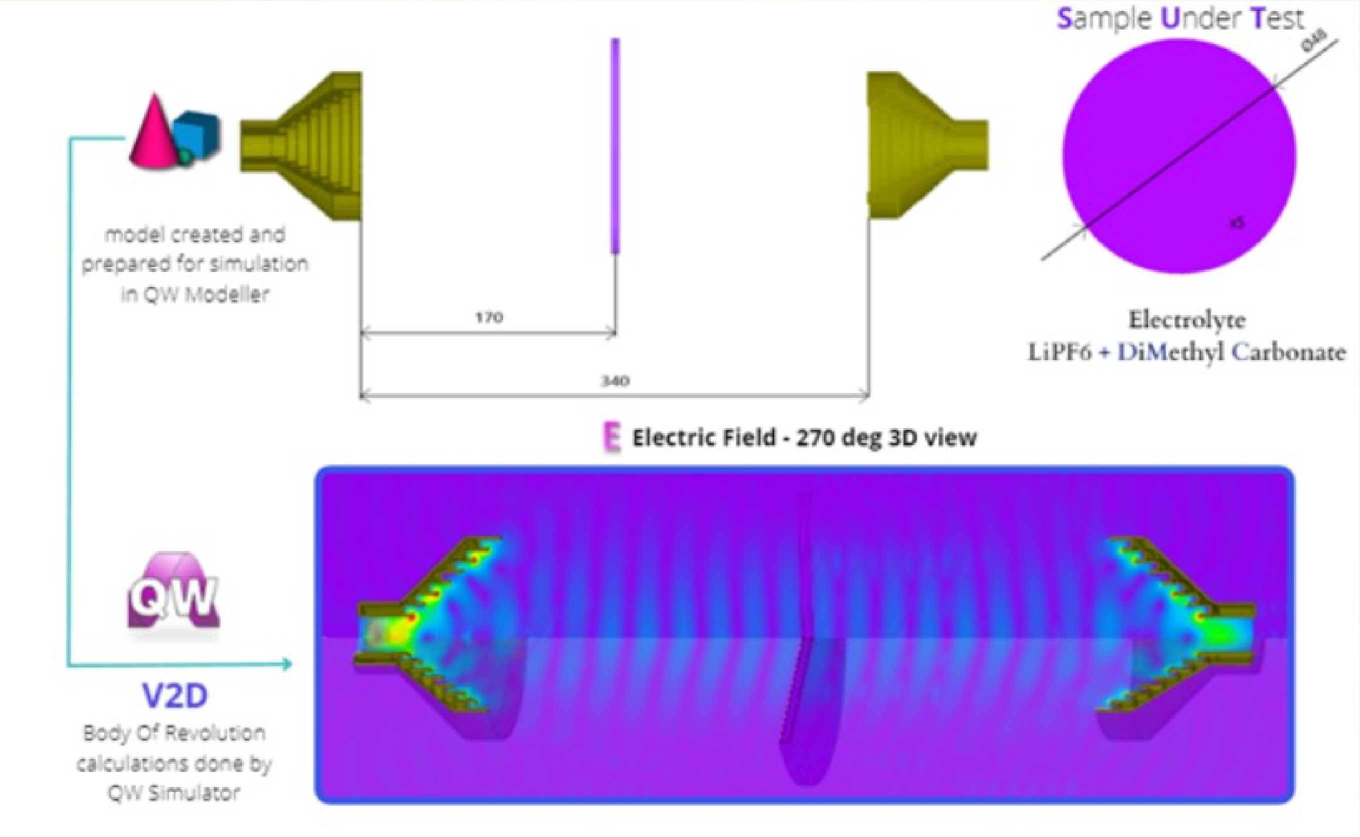


Fig. 2.3.9-6 *Antenna Fixed Angle Results* window in the example *1dipm_ntffa.pro* (it = 165, 420).

Near-to-Far Field Transformation in Lossy Tissues

The NTFFA post-processing, like *NTF*, may operate with magnetic and/or electric symmetries in –*X*, -*Y* and –*Z* direction. Open ..*\Antennas\Dipoles\1dipe_ntffa.pro*. The dipole is excited near the electric wall located on the left boundary of the *project*. In excitation settings in Edit Point/Probe dialogue, we may see that the dipole is excited with a Gaussian pulse of finite duration and frequency spectrum around 10 GHz.
Regarding *NTFFA* post-processing, we have set the observation direction to (*φ*, θ) = (0deg, 90deg) to watch the far field response perpendicularly to the ground plane.

Applications



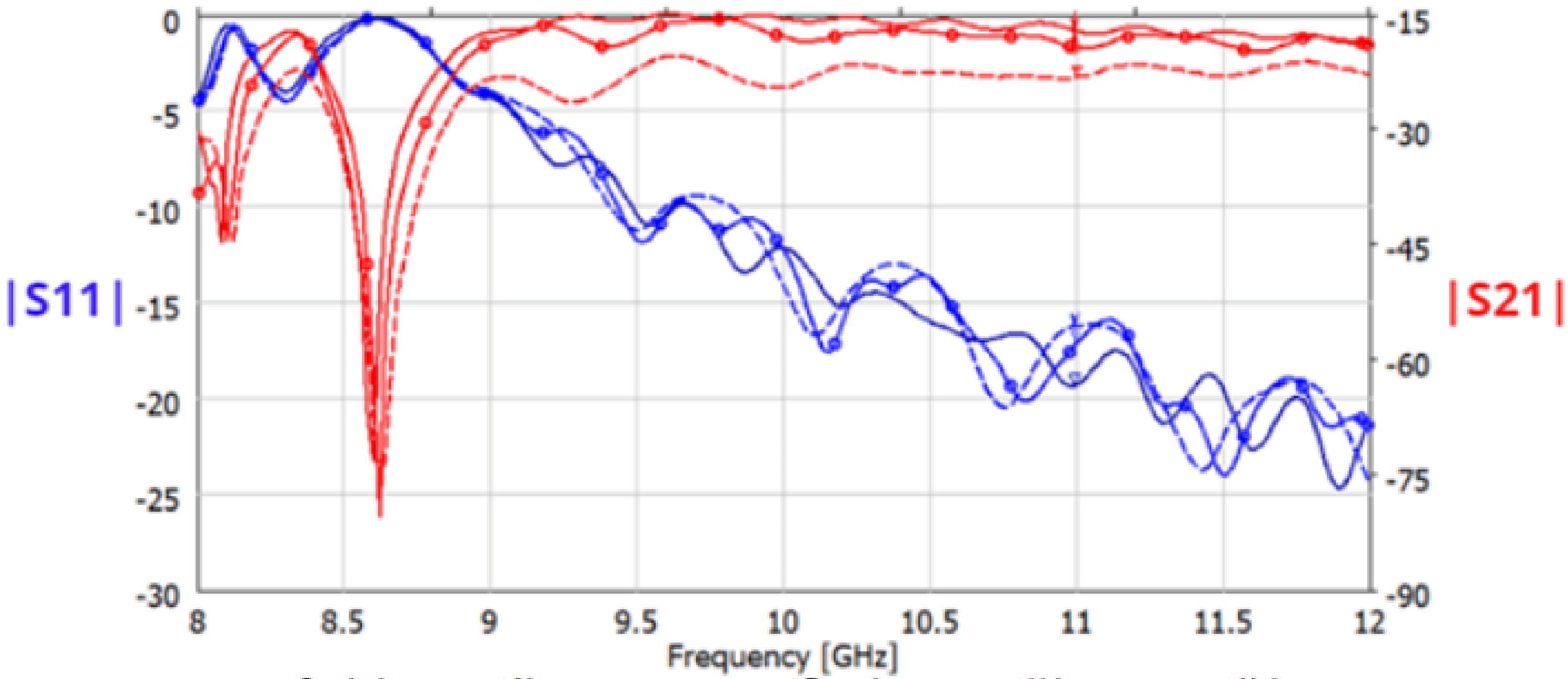
Quasi-Free-Space Millimetre-Wave Material Measurements

The method is mainly adapted to the measurement of solid samples, however, it is possible to adapt the liquid sample to the system under consideration. It must be placed in a sealed container with low permittivity and as low losses. This is important so that it affects the measurement system as little as possible. In this case, there comes another step to the measurement procedure herein, the thickness and dielectric properties of the container must be measured.

Using an axisymmetrical corrugated horn antenna (V2D BOR), a free-space measurement model was created. Thanks to the corrugations, the antenna focuses electromagnetic waves on the sample eliminating the need for lenses. Model is considered in cylindrical coordinates x,ρ,φ under the assumption that the dependence of the fields on the coordinate φ is analytically known. Thus, in reality, we consider the structure in two dimensions x and ρ. In terms of the FDTD grid, we have only one layer of FDTD cells reproducing the shape of the structure in the x, ρ plane. The operating frequency of the antenna is 11 GHz. In the model, the source is excited by a TE_{11} mode. A LiPF6 + DiMethyl Carbonate electrolyte with a permittivity of 3.1075 F/m and a conductivity of 1.04 S/m was selected as the sample under test (SUT).

A mesh of 151728 cells was applied to the layout along with boundaries. Using 14 MB of RAM, a simulation was run that reached convergence after 27000 iterations lasting 20 seconds

Applications



Symbol	Name	Domain	Value	Units
	|S11| Air	F= 11.0000 [GHz]	-19.321751	[dB]
	|S21| Air	F= 11.0000 [GHz]	-16.689428	[dB]
	|S11| Teflon	F= 11.0000 [GHz]	-17.193642	[dB]
	|S21| Teflon	F= 11.0000 [GHz]	-18.832634	[dB]
	|S11| Electrolyte	F= 11.0000 [GHz]	-16.175905	[dB]
	|S21| Electrolyte	F= 11.0000 [GHz]	-22.809902	[dB]

Conclusion

In this work, we have explored various computational regimes and their significant applications in the field of electromagnetic modeling. Accurate electromagnetic modeling is crucial for material characterization, especially in scenarios involving complex materials and designs, such as radar antennas. We discussed the importance of precision in these models to ensure the reliability and efficiency of designs and processes. We delved into specific computational regimes, including the Vector 2D FDTD algorithm tailored for axisymmetrical horn antennas, which facilitates more accurate and efficient design processes. Furthermore, we examined the transformations necessary for effective modeling in different fields: Near-to-Far Field Transformation, particularly in lossy tissues, and Near-to-Near Field Transformation, both essential for realistic and applicable modeling scenarios. The applications of these computational techniques are vast, and we highlighted a couple of key areas. Quasi-Free-Space Millimeter-Wave Material Measurements demonstrate how these models can be applied in practical measurement scenarios, providing accurate data that is critical for various engineering applications. Additionally, Near-Field Sensing showcases the utility of these models in detecting and analyzing near-field electromagnetic phenomena. In conclusion, the integration of these advanced computational regimes in electromagnetic modeling not only enhances the accuracy and reliability of material characterization and antenna design but also opens up new possibilities in various applied fields. Future work could further refine these models and explore additional applications, ensuring that the field of electromagnetic modeling continues to evolve and support technological advancements.

Thanks!

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