OmniSim *for Nano-Photonics*

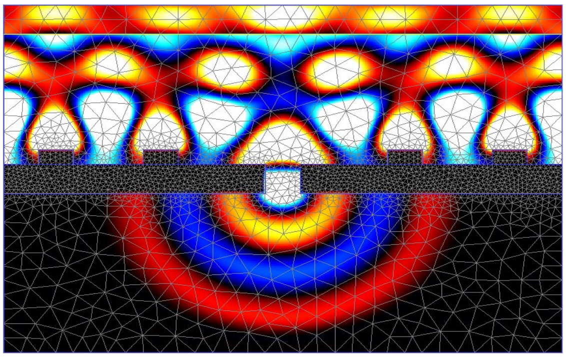
FETD, FDTD and RCWA for Metamaterials & Nonlinear Plasmonics

Modelling nano-photonics is challenging: it involves extremely high precision, complex geometries with dispersive nonlinear materials for periodic and aperiodic devices.

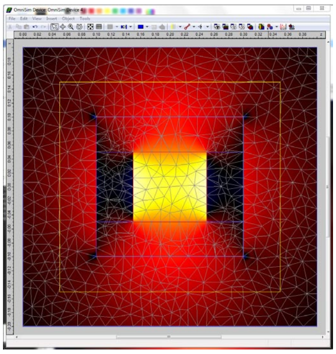
OmniSim offers a large variety of engines, allowing you to tackle these complex problems where one-method tools fail.

OmniSim is ideal for:
- **Metamaterials**
- **Plasmonics**
- **Nanoantennae**

OmniSim is a powerful simulation package for the **design and optimisation of non-linear plasmonics and metamaterials**.



Nano-plasmonics: a metal grating used as a light harvester simulated with FETD

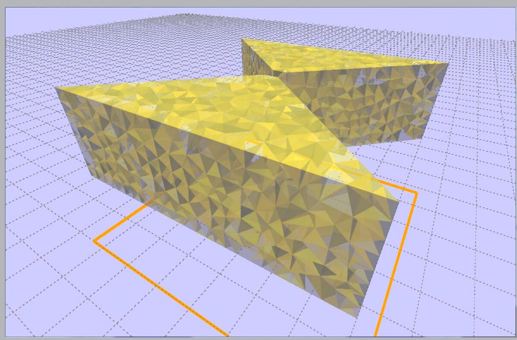


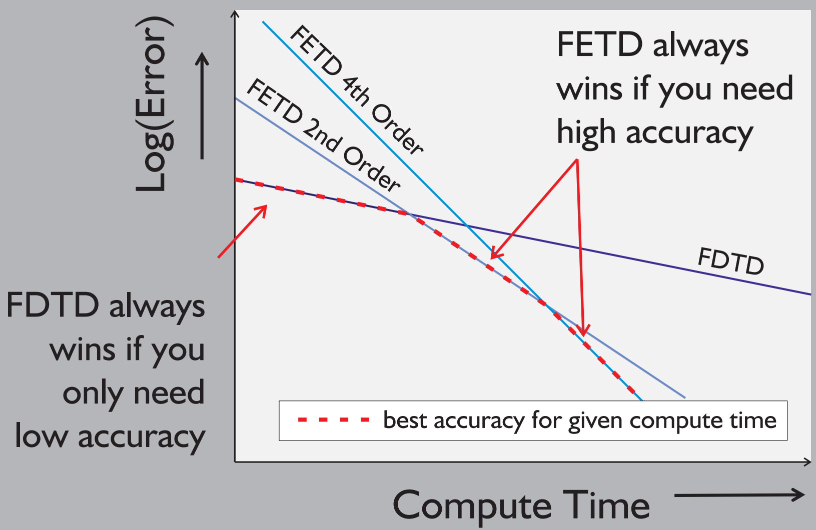
FETD: field enhancement in a gold hole nano-antenna

It features a very flexible layout editor and it is packed with a complete suite of high-performance 3D and 2D Maxwell solvers, including our unique **FETD** engine (Finite Element Time Domain), which is ideal for the modelling of metals, as well as **FDTD (**Finite Difference Time Domain) and **RCWA** (Rigorous Coupled-Wave Analysis).

What is FETD?

Finite element time domain (FETD) simulations are an alternative to the popular finite difference time domain (FDTD) method. Incorporating new state-of-the-art techniques, Photon Design presents an efficient, fully-functional FETD calculation engine, which will **complement FDTD** for simulations of photonic devices.





The FETD engine is designed to **address some of the specific shortcomings of FDTD**, in particular when modelling plasmonics: FDTD converges very slowly (1st order) when computing plasmonic devices. Our **FETD has up to 5th order convergence**.

Unlike conventional frequency domain implementations of the finite element method, FETD allows you to **model chi2 and chi3 nonlinearity**, which is often crucial for the modelling of plasmonics.

Photon Design®

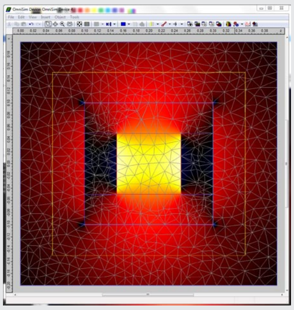
Photon Design Ltd
34 Leopold Street
Oxford, OX4 1TW
United Kingdom

Tel: +44 1865 324990
Fax: +44 1865 324991
Email: info@photond.com
Web: https://www.photond.com

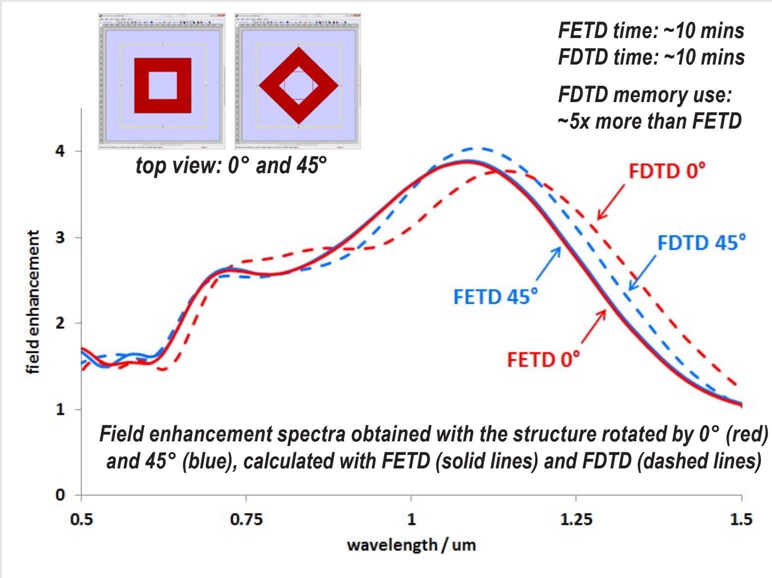
Modelling light interaction with metals: FETD vs FDTD

☑ Body-conformal meshing

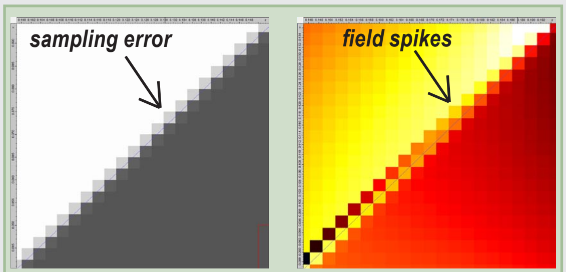
Thanks to its adaptive mesh, the FETD engine is much **less orientation-sensitive** than FDTD. This allows it to deal with slanted or curved interfaces with **no staircase approximation** and **no material averaging** at the surface. We simulated a gold nut structure with two different orientations and calculated the field enhancement in the centre of the hole. The FDTD engine displays erroneous discrepancies between the two orientations, caused by the staircase approximation of the diagonal interface at that resolution. For the same calculation time, the FETD engine gives almost identical results for both orientations for the entire spectrum.



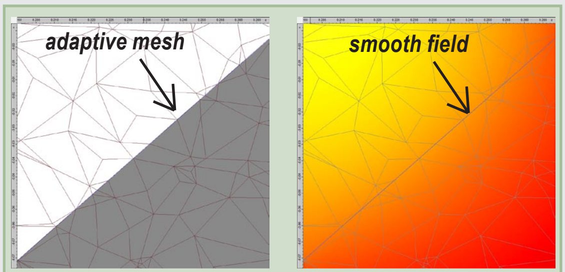
FETD: field in gold hole



Field enhancement spectra obtained with the structure rotated by 0° (red) and 45° (blue), calculated with FETD (solid lines) and FDTD (dashed lines)



FDTD: material alpha and Ez at interface

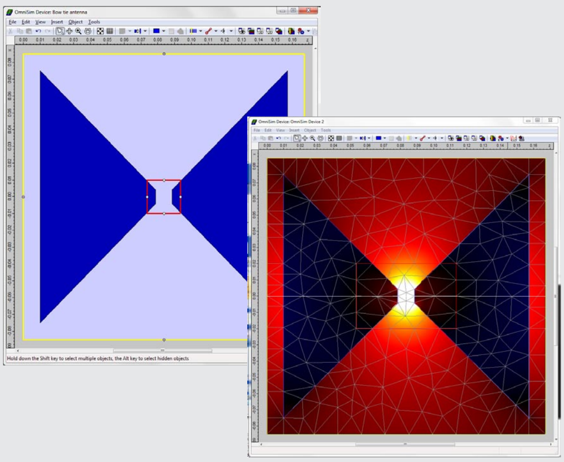


FETD: section of the 3D mesh and Ez at interface

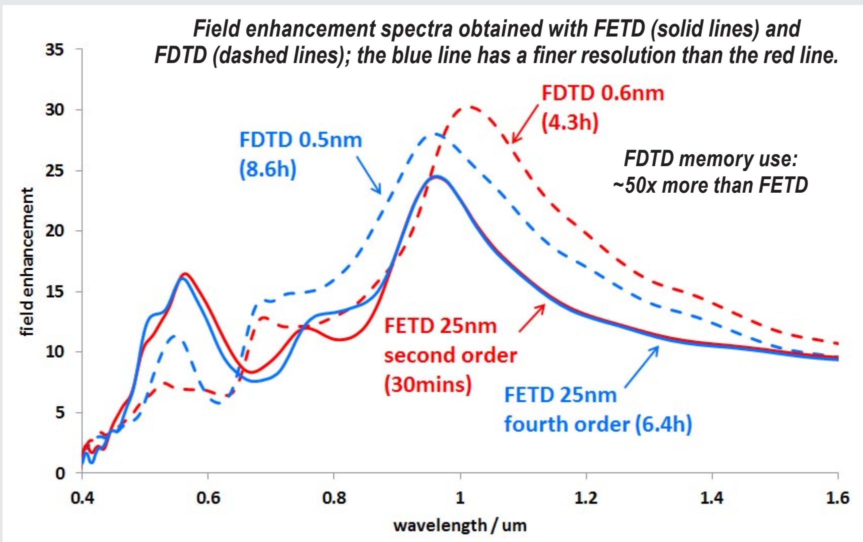
☑ Superior convergence: effects on modelling nano-antennae

Modelling an inclined metal surface in 3D can be a major challenge for FDTD, as extremely small grids are required to obtain accurate results. In this example we measured electric field enhancement in the hole of a bow-tie antenna. **The FDTD simulation still had not converged after an 8h30 simulation** on a i7-860 CPU (4 cores) and was unable to locate the resonant wavelength and the amplitude of the resonant peak with precision.

On the same computer **the FETD algorithm converged with a calculation time of only 30 minutes!** Such efficiency is made possible by the use of higher order elements in the finite-element mesh and by the FETD's ability to avoid staircasing at the metal surface.



Central section of the bow tie antenna: design and Ez field. The metal plates are shown in blue.

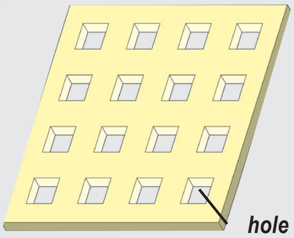


Field enhancement spectra obtained with FETD (solid lines) and FDTD (dashed lines); the blue line has a finer resolution than the red line.

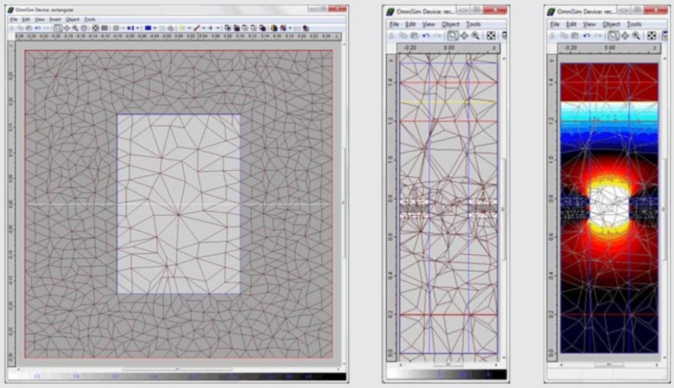
Simulating metamaterials with FETD and RCWA

☑ Bloch boundaries: modelling metamaterials with FETD

FETD is well-suited to producing highly accurate results for metamaterial structures; this can be used to model **negative-index or left-handed materials**. The structures are usually periodic in the transverse direction(s) and can be simulated at arbitrary incidence using the Bloch boundary condition of the FETD engine. The complex effective refractive index of the metamaterial layer can be retrieved from the coefficients of reflection and transmission (r and t) using the formula



$$\cos nk\Delta = \frac{1+t^2-r^2}{2t}$$

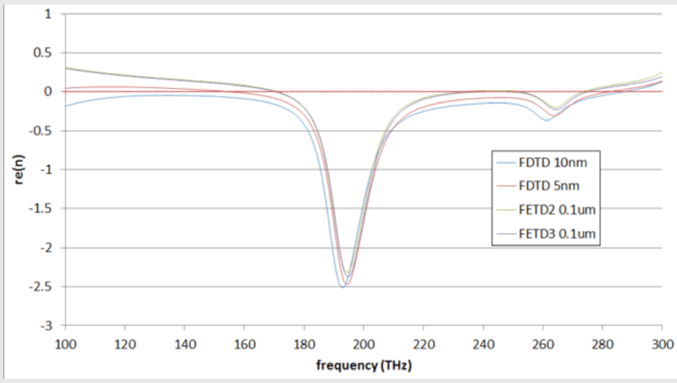


FETD mesh: top and side view *Ez field*

A three-dimensional “fishnet” structure was simulated. This consisted of a periodic array of rectangular subwavelength holes in a laminate consisting of magnesium oxide sandwiched between two gold layers.

This structure was simulated using FETD and FDTD; you can see here the real part of the refractive index plotted versus frequency. Negative index is around 200THz.

The FETD results converged much more quickly than FDTD: the two FETD resolutions give the same curve, whilst FDTD is still varying and tending towards FETD.



refractive index versus frequency for various FDTD and FETD resolutions: the negative index behaviour is shown below the red line

☑ Modelling metamaterials and diffraction gratings with RCWA

In addition to FETD and FDTD, OmniSim features a **state-of-the-art RCWA** engine which can be used to model **periodic metamaterials** as well as diffraction gratings and diffractive optical elements.

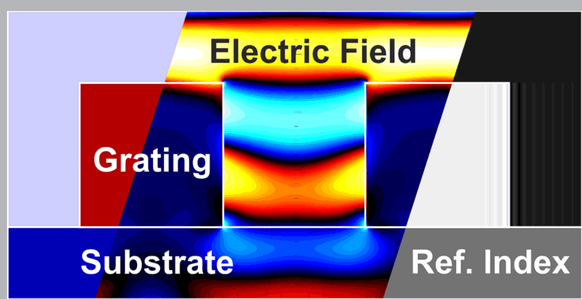
Our RCWA includes many proprietary features which allow it to converge more quickly than traditional algorithms, it supports metals and arbitrary geometries.

With FETD with Bloch boundaries and RCWA, **OmniSim offers two different methods to model metamaterials**; you can switch between the two in just one click and take advantage of the one which will be better suited to your geometry.

E field reflected by a diffraction grating modelled with RCWA

What is RCWA?

Rigorous coupled wave analysis (RCWA) is a frequency domain method which can be used to model the transmission and reflection of light incident on 1D and 2D periodic structures at arbitrary angles. RCWA can model the same type of structures as the FDTD/FETD engines with Bloch boundaries and provides complementary information such as power distribution in the diffraction orders.

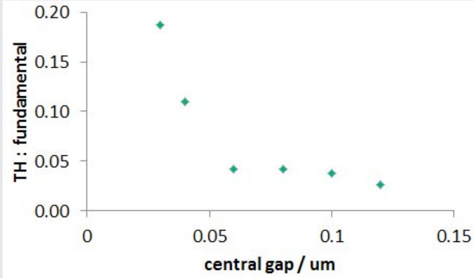


☑ Modelling nonlinear (chi3) plasmonics: nonlinearity in an bow-tie antenna

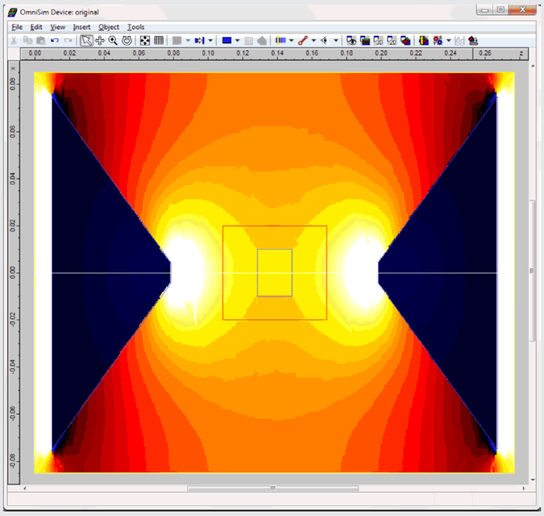
The FETD engine supports the modelling of chi2 (e.g. SHG) and chi3 (Kerr) nonlinear materials, including metals.

Here, a cuboid of chi(3) nonlinear material was placed between the plates of a gold bow-tie antenna and the structure was illuminated from above with a pulse centred on 1.55um. The ratio of the transmitted electric field at the third harmonic to the field at the central wavelength was recorded as a function of the distance separating the plates, which was varied. The field between the plates is enhanced by plasmonic effects, being greatest for small plate separation.

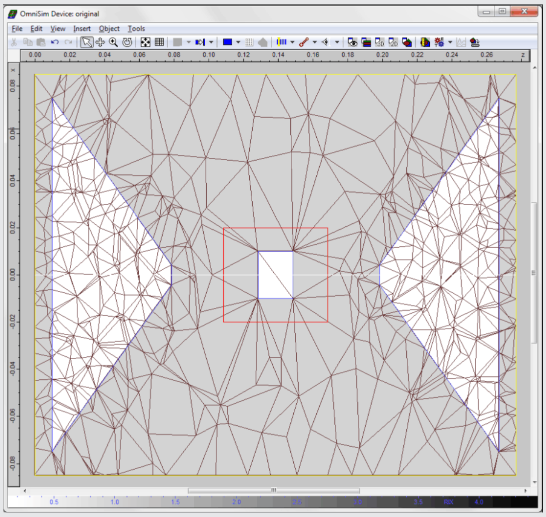
The graph to the right shows increasing power in the third harmonic as the gap is closed. This effect can form the basis of metamaterials with enhanced nonlinear optical response.



third harmonic generation versus gap



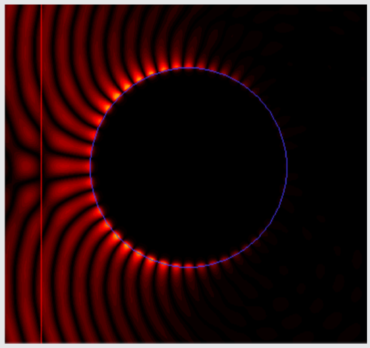
E-field top view



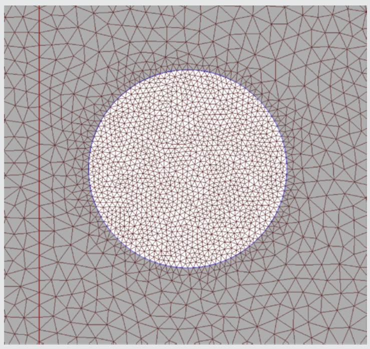
mesh top view

Features of the FETD Engine

- ☑ **Finite element time domain** calculation engine based on a new super-efficient method - **much faster than conventional finite element** time domain methods!
- ☑ **Finite element orders** from 1 to 5, allowing large efficient elements.
- ☑ **2D and 3D** versions.
- ☑ Automatic conformal tetrahedral (3D) or triangular (2D) meshing: **no staircasing or averaging of surfaces**.
- ☑ PML, Bloch, PEC and PMC boundary conditions.
- ☑ **Dispersive material** handling by Drude and Lorentz models.
- ☑ **Nonlinear** materials with chi2 and chi3.
- ☑ Full **multi-core** processor and **64-bit support.**
- ☑ **Variable mesh refinement** according to local refractive index – automatically uses a finer mesh where required.
- ☑ **Integrated with OmniSim and CrystalWave**'s user interface.
- ☑ Plane wave, Gaussian, waveguide-mode and dipole electromagnetic sources.
- ☑ A variety of sensors for measuring spatial, time-evolving and spectral responses.
- ☑ Intuitive **real-time field visualization** during simulations.



Mie scattering aroung gold sphere: field (high frequencies) and finite-elelement mesh



Photon Design®

Photon Design Ltd
34 Leopold Street
Oxford, OX4 1TW
United Kingdom

Tel: +44 1865 324990
Fax: +44 1865 324991
Email: info@photond.com
Web: https://www.photond.com