Metamaterials in FEKO

A description of how metamaterials may be modeled in FEKO followed by guidelines regarding the different simulation options.

Problem Description

The numerical simulation of metamaterials with negative permittivity or permeability raises a number of questions regarding meshing principles and the applicability of CEM techniques. This article aims to establish FEKO's ability to simulate problems involving metamaterials and to provide guidelines as to which meshing principles to follow and CEM techniques to apply when simulating metamaterials.

Results of these investigations will be presented along with guidelines for metamaterial simulation in FEKO and a simulation of utilising these principles.

Empirical Investigation: Fields in an Illuminated Sphere of Negative Index Material

A simple canonical sphere structure with variable radius and dielectric parameters is used for experimentation. This structure is well suited to this investigation as it can be solved analytically using a special Green's function or other series expansion technique. The sphere is excited by a plane wave in the z-direction and the electric field is sampled along a line passing near the centre (analytical singularities exist at the centre) of the sphere is considered in the various solutions.

Four metamaterial applications are considered using three different FEKO simulation techniques (VEP, SEP, FEM-MoM):

1. Electrically small sphere with low index values ($R = \lambda/4$ with ε_r and $\mu_r = \pm 1.5$)
2. Medium sphere with medium index values ($R = 2\lambda$ with ε_r and $\mu_r = \pm 1.5$)
3. Electrically large sphere with low index values ($R = 8\lambda$ with ε_r and $\mu_r = \pm 1.5$)
4. Electrically large sphere with high index values ($R = \lambda/4$ with ε_r and $\mu_r = \pm 8$)

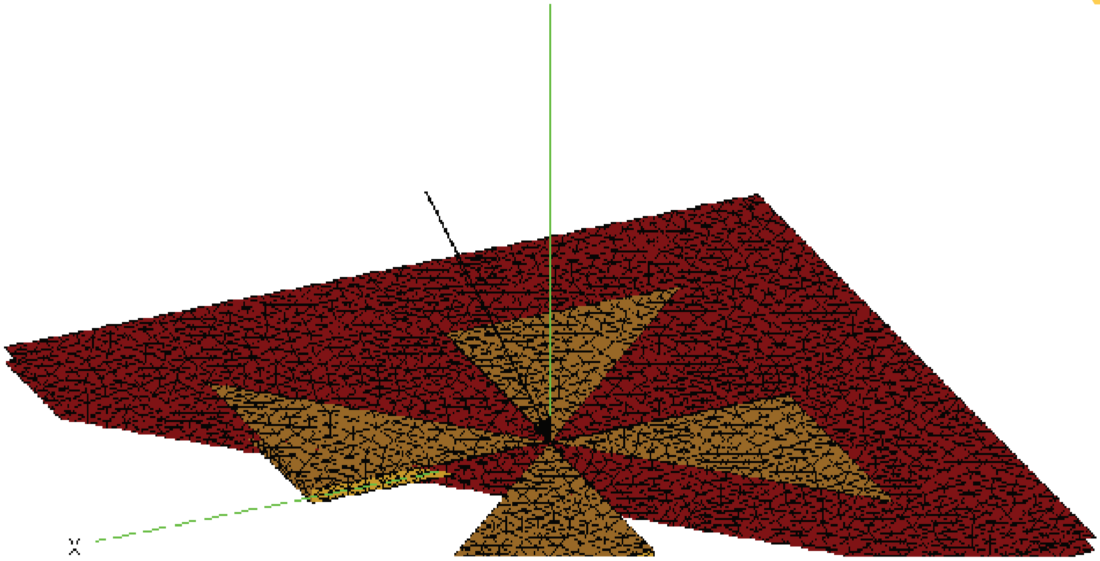
Various simulations involving these scenarios were performed to draw a comparison between simulation techniques. These comparisons are used to extract some basic guidelines for the simulation of negative index materials for problems of varying electrical size.

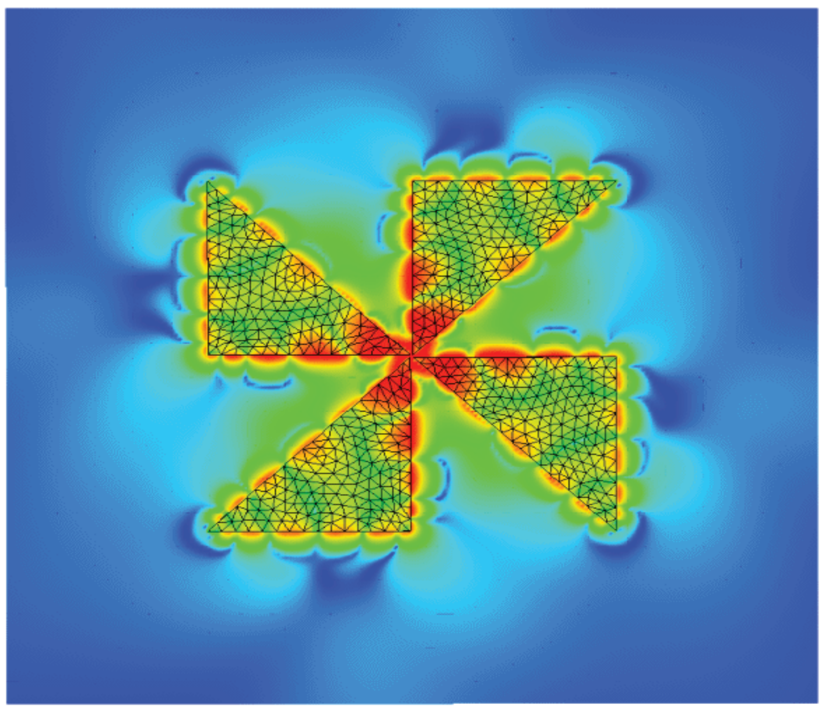
Guidelines Derived from These Experiments

- Electrically large negative index regions generally deliver poor results for all techniques.
- VEP should be avoided, specially for negative permittivity materials ($\varepsilon_r<0$). The mesh is often not accurate enough for general geometries resulting in imprecise near-field computation.
- SEP and FEM are both applicable to electrically small geometries. The SEP is generally better suited to this application because of smaller resource requirements. It should be noted that
  - If $\varepsilon_r * \mu_r < 0$ poor convergence and stability may be observed with the SEP and the FEM is the better solution method. The most stable solutions are realised when using the "Direct Sparse Solver" for the FEM solution.
  - If $\varepsilon_r * \mu_r > 0$ the SEP convergence and stability is acceptable and the SEP is then better suited to the problem because it requires less resources than the FEM.
- SEP and FEM both result in accurate solutions for electrically small to medium sized structures.
- Excessively fine meshes may reduce iterative solution stability for the FEM and the refinement of meshes beyond the point of convergence will not necessarily improve solution accuracy.

Example: A Metamaterial Resonator

A meta-material resonator structure from [1], as shown in the figure below was modeled in FEKO using hybrid FEM/MoM. In [2] this structure was modeled between two infinite PEC plates to force the TM mode. Finite plates were used in the FEKO model shown below. The resonator was excited by placing a z-directed elementary dipole element at the centre of the structure. The electric near-field in the metamaterial resonator central plane was computed at 4.545 GHz and is presented below the model.





References

[1] Costas D. Sarris, „Periodic FDTD Characterization of Guiding and Radiation Properties of Negative Refractive Index Transmission Line Materials,“ ACES 2006.

[2] A. Rennings, S. Otto, C. Caloz, and I. Wolff, „CRLH extended equivalent circuit (EEC) FDTD method and its application to an open metamaterial- loaded resonator,“ in Proc. 22nd International Review of Progress in Applied Computational Electromagnetics (ACES), Special session Computational Electromagnetics for Metamaterials, Miami, FL, USA, March 2006, pp. 763-770.