Application example: Plane wave towards a scatterer

SIM5G: FDTD toolbox

One important application of FDTD simulations is in studying electromagnetic wave scattering, which has broad implications in fields such as radar cross-section analysis, optical device development, and metasurface characterization. This example focuses on modeling the scattering of a plane electromagnetic wave by a metallic cubic scatterer. The objective is to simulate the interaction between the incident plane wave and the metallic object to extract the scattered field. This scenario provides a fundamental example of how electromagnetic waves interact with conductive objects, revealing insights into scattering behavior, including reflection, diffraction, and radar cross-section evaluation.

An overview of the application example is the following

- **Model**: A metallic cube scatterer of side dimension $a = 45$ mm. Copper is selected as the material of the scatterer with bulk conductivity $6 \cdot 10^7$ S/m.
- **Computational Domain**: A cubic FDTD simulation domain of side dimension 200 mm with absorbing boundary conditions (Perfectly Matched Layers, PML) to simulate an open environment. The cell-to-wavelength ratio is selected 40.
- **Excitation**: A linearly polarized plane wave propagating in free space with azimuth angle $\phi = 45°$ and elevation $\theta = 90°$. The plane wave is modeled using the Total-Field/Scattered-Field formulation.
- **Operating Frequency**: A broadband analysis is conducted from 2 to 4 GHz.
- **Objective**: Computation of the scattered electric and magnetic fields at 3 GHz and visualization of the far-field pattern.

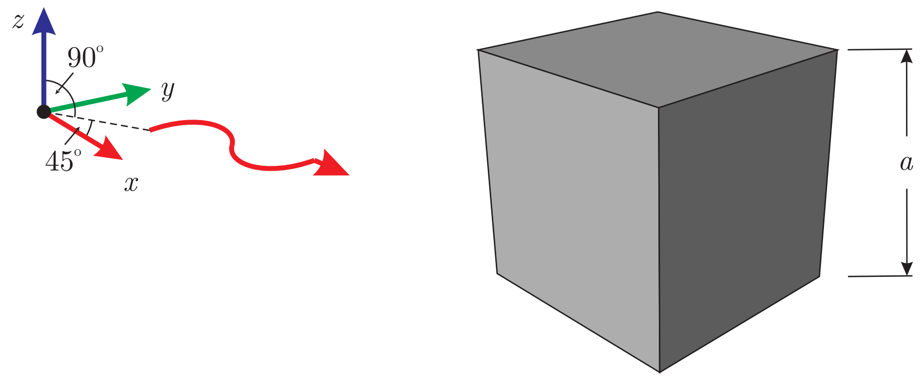

Figure 1: Plane wave propagation towards a metallic cube scatterer.

1 Setup of the FDTD simulation

To address the described scenario effectively, the SIM5G FDTD toolbox provides a versatile framework for simulating electromagnetic phenomena. All electromagnetic interactions can be simulated with precision by systematically applying its modules, as depicted in Fig. 2. The following sections outline the specific steps used in each analysis stage.

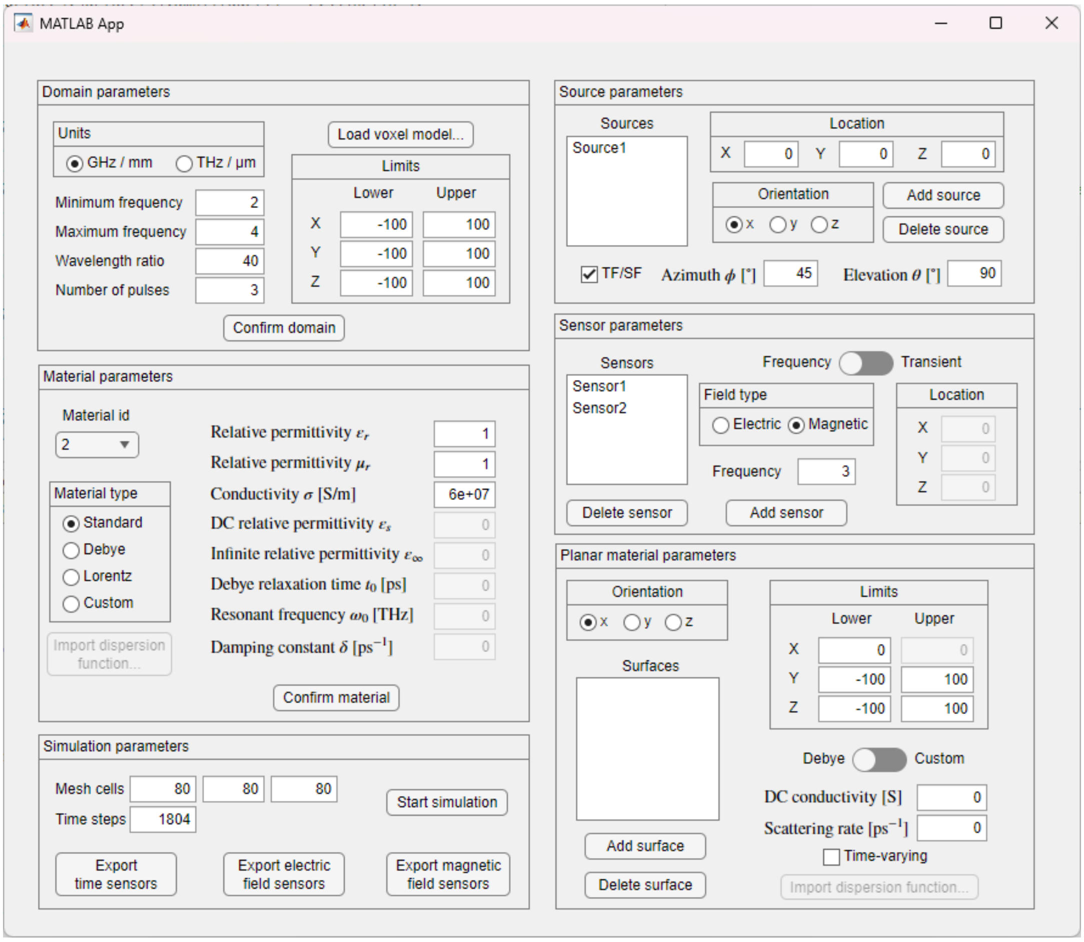

Figure 2: Overview of the SIM5G FDTD toolbox for the simulation of the scatterer.

1.1 Domain parameters

- **Load voxel model**: A file dialog opens, and ".\Models\voxel_model_scatterer.mat" shall be selected to load the model to be simulated.
- **Units**: The option "GHz/mm" shall be selected.
- **Minimum frequency**: It shall be set to 2 GHz (the unit is automatically applied).
- **Maximum frequency**: It shall be set to 4 GHz (the unit is automatically applied).
- **Number of pulses**: Normally, more than 3 shall be selected. However, 3 is adequate for this problem.
- **Limits**: The lower limit shall be set -100 mm and the maximum 100 mm for all the directions (the unit is automatically applied).

- **Confirm domain**: After setting all the parameters, the domain shall be confirmed with this button. This will enable the material selection for the model and initiate the simulation parameters.

1.2 Material parameters

For material with id$= 1$:

- This material is air, which has the default parameters. For this reason, no further action is required.

For material with id$= 2$:

- **Material type**: The option "Standard" shall be selected.
- **Relative permittivity**: The default value ($\varepsilon_r = 1$).
- **Relative permittivity**: The default value ($\mu_r = 1$).
- **Conductivity**: The conductivity value of copper shall be selected, namely $\sigma = 6 \cdot 10^7$ S/m.
- **Confirm material**: After setting all the parameters, the material shall be confirmed with this button.

1.3 Source parameters

- **TF/SF**: The option shall be enabled to introduce the propagation of a plane wave using the Total-Field/Scattered-Field formulation.
- **Azimuth**: It shall be set to $\phi = 45°$.
- **Elevation**: It shall be set to $\theta = 90°$.
- **Add source**: After setting the TF/SF parameters, the source shall be confirmed with this button.

1.4 Sensor parameters

- **Frequency**: The toggle button shall be set to this option.
- **Field type**: Initially, the option "Electric" shall be selected.
- **Frequency**: It shall be set to 3 GHz (the unit is automatically applied).
- **Add sensor**: After setting the electric sensor parameters, it shall be confirmed with this button.
- **Field type**: Next, the option "Magnetic" shall be selected.
- **Frequency**: It shall be set to 3 GHz (the unit is automatically applied).
- **Add sensor**: After setting the magnetic sensor parameters, it shall be confirmed with this button.

1.5 Planar material parameters

No planar materials are utilized in this application example. As a result, no further action is required.

1.6 Simulation parameter

- The "Mesh cells" and the "Time steps" shall be automatically retrieved by confirming the previous steps.
- **Start simulation**: The FDTD simulation will start with this button.
- After the simulation is completed, the results can be exported with the buttons "Export electric field sensors" and "Export magnetic field sensors".

2 Results of the FDTD simulation

The results are saved inside the application's folder with the name "FDTDxxfieldSensor.txt", where "xx" corresponds to the field component, namely "FDTDexfieldSensor.txt" corresponds to E_x. The results are saved into a vector form using two columns per monitor, one for the real and one for the imaginary part. Initially, the complex form shall be retrieved, while to acquire the voxel-based values one shall use the command:

```
B = reshape(A, N, M, K)
```

where `A` is the complex values in vector form, `B` the desired complex values in the voxel-based form and `N, M, K` are mesh cells along each direction, which can be derived by the FDTD toolbox under the "Simulation parameters" tab. Finally, the field monitor results of both the electric and magnetic components can be imported into a near-to-far field transformation algorithm to extract the radar cross-section, as depicted in Fig. 3.

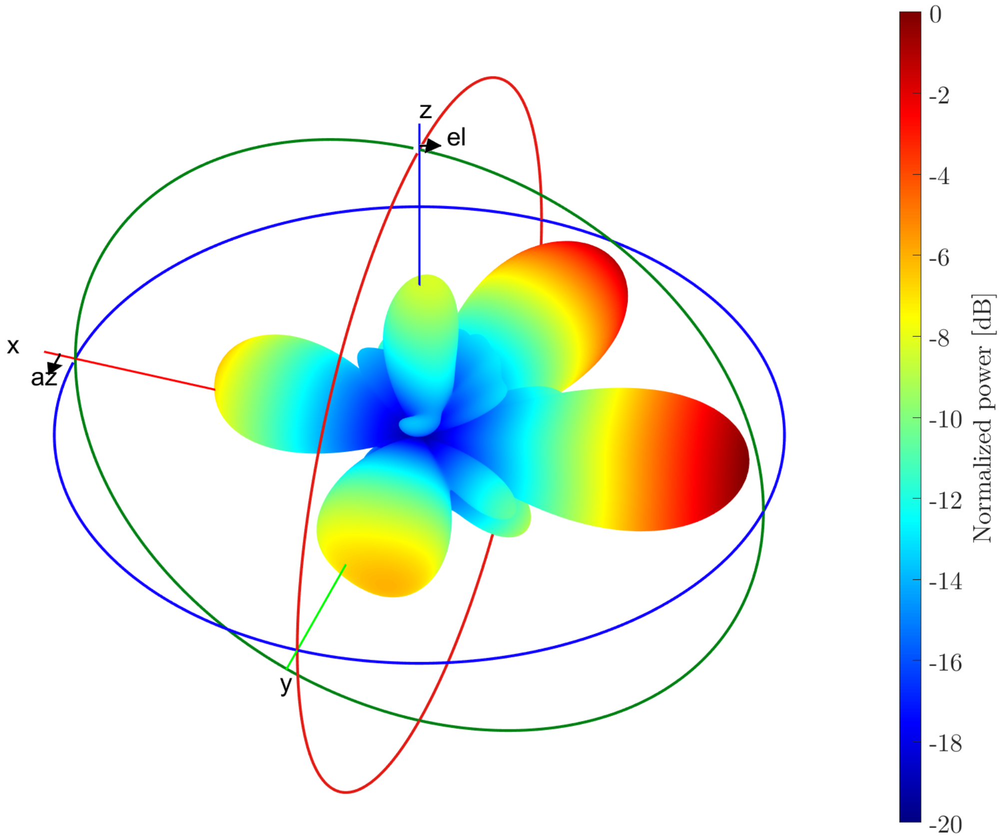

Figure 3: Radar cross-section of the metallic cube scatterer at 3 GHz under the illumination conditions of Fig. 1.