Application example: Resonance of a patch antenna

SIM5G: FDTD toolbox

Patch antennas are widely used in modern communication systems due to their low profile, light weight, and ease of integration with planar and non-planar surfaces. Accurate modeling and simulation of patch antennas are crucial for optimizing their performance characteristics, such as return loss, gain, and radiation pattern. In this example, the FDTD toolbox is utilized to simulate a microstrip patch antenna. The simulation provides insights into the broadband reflection coefficient to highlight the resonance frequency of the antenna.

An overview of the application example is the following

- **Model**: The substrate of the patch antenna has dimensions $l_s \times w_s = 50 \times 40\,\mathrm{mm}^2$ with height $h = 3.3\,\mathrm{mm}$ and relative dielectric permittivity 2.33. The patch has dimensions $l_p \times w_p = 16.5 \times 23.5\,\mathrm{mm}^2$, while a ground plane covers the entire bottom side of the substrate. These metallic parts are from copper with conductivity $6 \cdot 10^7$ S/m.

- **Computational Domain**: A cubic FDTD simulation domain of side dimension $190\,\mathrm{mm}$ with absorbing boundary conditions (Perfectly Matched Layers, PML) to simulate an open environment. The cell-to-wavelength ratio is selected 15.

- **Excitation**: A point dipole excitation is placed at the input of the patch antenna. The direction is towards the $z-$axis.

- **Operating Frequency**: A broadband analysis is conducted from 4 to $8\,\mathrm{GHz}$.

- **Objective**: Computation of the electric and magnetic components through time at the location of the excitation to evaluate the reflection coefficient.

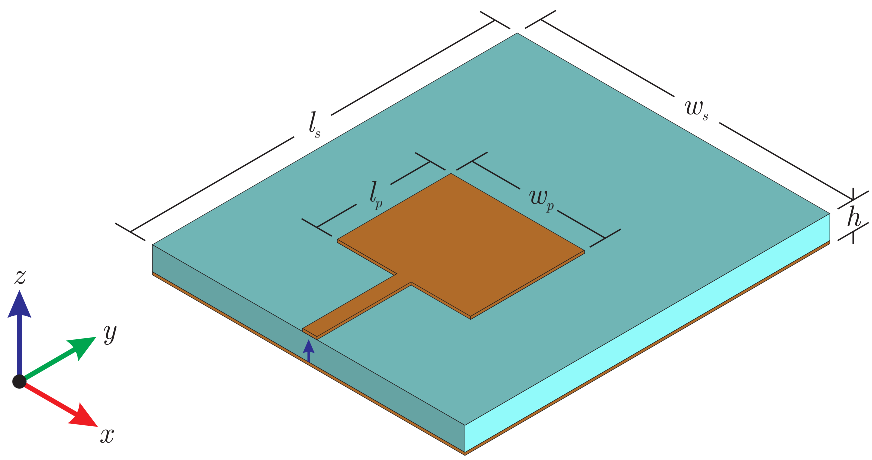

Figure 1: The patch antenna with its excitation at the microstrip input.

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.

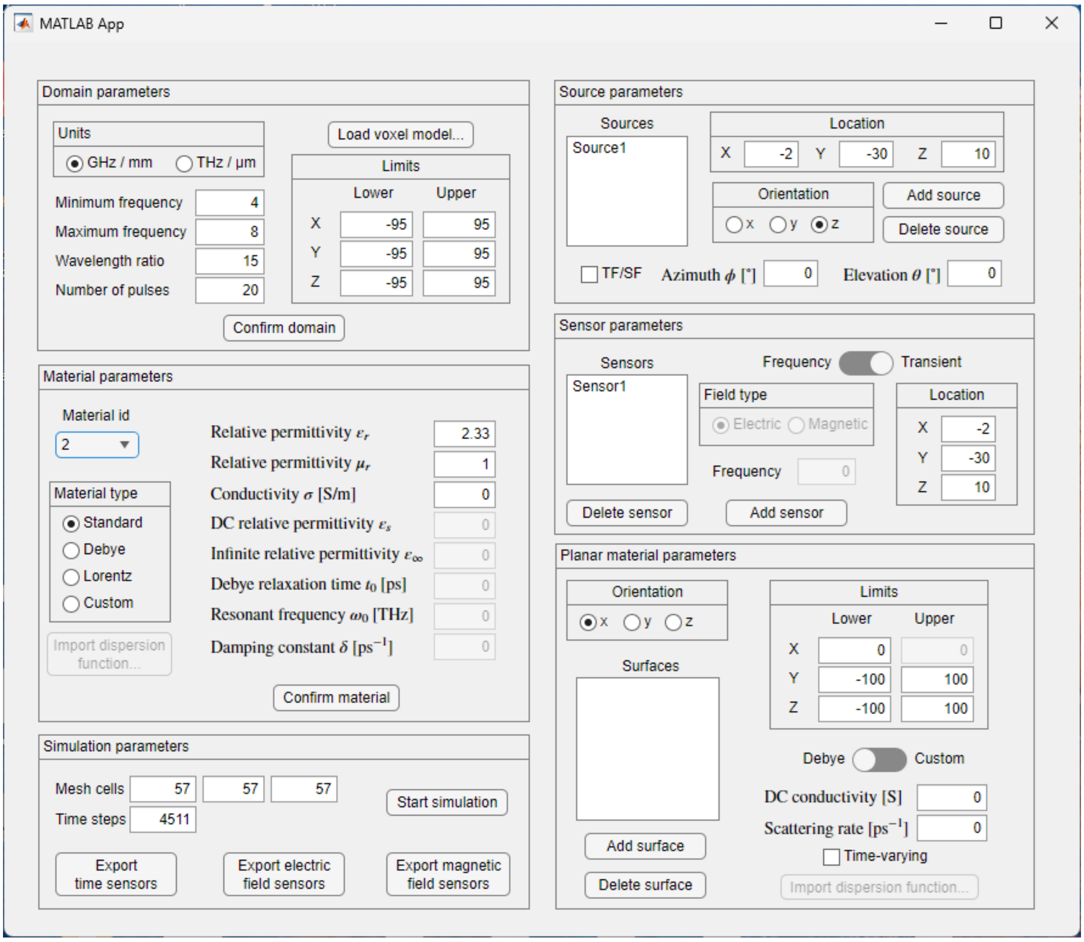

Figure 2: Overview of the SIM5G FDTD toolbox for the simulation of the patch antenna.

1.1 Domain parameters

- **Load voxel model**: A file dialog opens, and ".\Models\voxel_model_patch.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 4 GHz (the unit is automatically applied).
- **Maximum frequency**: It shall be set to 8 GHz (the unit is automatically applied).
- **Number of pulses**: Generally, the patch antenna has a deep resonance indicating that the electromagnetic fields remain inside the substrate for many cycles before fading. For this reason, this option shall be set to "20" to evaluate the interactions.

- **Limits**: The lower limit shall be set -95 mm and the maximum 95 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 relative dielectric permittivity of the substrate shall be selected, namely 2.33.
- **Relative permittivity**: The default value ($\mu_r = 1$).
- **Conductivity**: The default value ($\sigma = 0$).
- **Confirm material**: After setting all the parameters, the material shall be confirmed with this button.

For material with id$= 3$:

- **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

- **Location**: The input of the microstrip is at the position $x = -2$ mm, $y = -30$ mm and $z = 10$ mm (the unit is automatically applied).
- **Orientation**: The option "z" shall be selected.
- **Add source**: After setting the excitation parameters, the source shall be confirmed with this button.

1.4 Sensor parameters

- **Transient**: The toggle button shall be set to this option.
- **Location**: The sensor is placed again at the input of the microstrip, as the source, namely at the position $x = -2$ mm, $y = -30$ mm and $z = 10$ mm (the unit is automatically applied).
- **Add sensor**: After setting the location of the sensor, 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 button "Export time sensors".

2 Results of the FDTD simulation

The results are saved inside the application's folder with the name "FDTDtimeSensor.txt". They are saved in a vector form, with the first column corresponding to the time-steps, the second to the reference signal and the next six columns to the electromagnetic components (E_x, E_y, E_z, H_x, H_y and H_z). Initially, the input impedance can be retrieved as the ratio of the voltage to the current. The former can be evaluated as the line integral of E_z (in practice the E_z component multiplied by the cell size Δx), while the latter as the loop integral around the source (in practice the summation of H_x and H_y multiplied by the cell area $\Delta x \times \Delta y$)[1]. Then, the reflection coefficient can be calculated, as in Fig. 3 for $Z_0 = 75\,\Omega$.

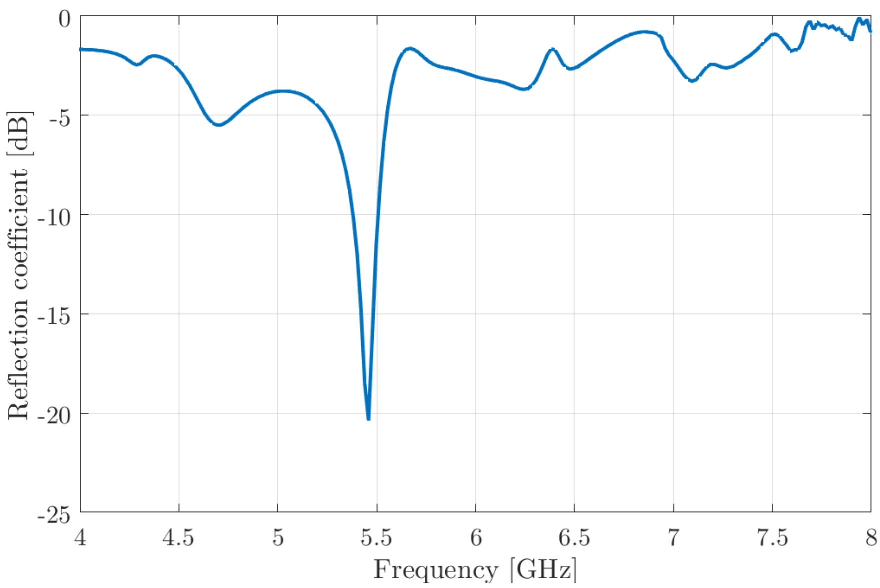

Figure 3: Reflection coefficient of the patch antenna in Fig. 1 for input impedance $Z_0 = 75\,\Omega$.

[1]The cell size Δx can be retrieved by the ratio of the computational domain to the number of mesh-cells along the $x-$axis. The size of the cell's other sides can be calculated correspondingly.