

EE3109 Lab 1 | Reflection and Transmission from an Interface

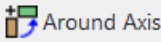
Objective

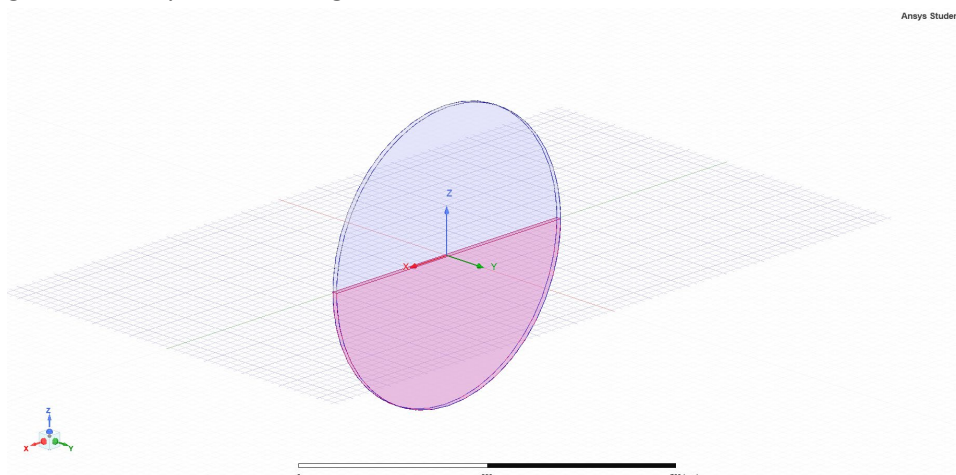
- Learn the basics on how to perform electromagnetic simulation with HFSS
- Explore and verify EM wave reflection and transmission off an interface between two materials
- Explore and verify EM wave reflection and transmission at an air-metamaterial boundary

Preparation

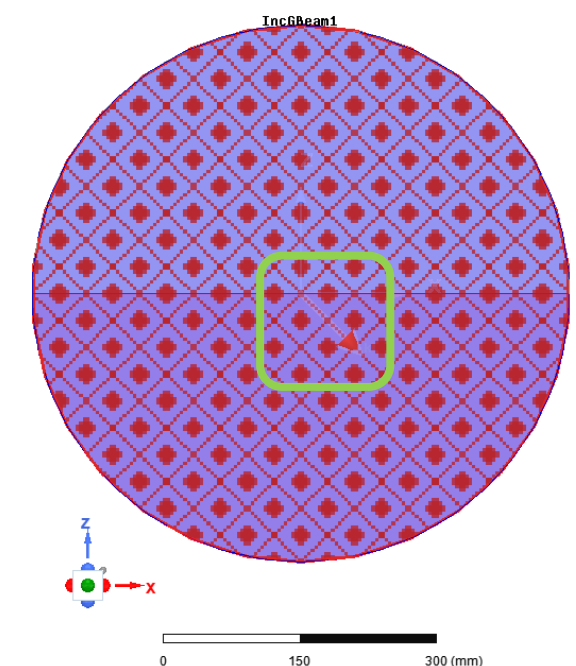
- Download and Install the Ansys Electronics Desktop from <https://www.ansys.com/academic/students/ansys-electronics-desktop-student>
- Upon opening the program, select the EM model from the open screen, to access a slightly simplified interface.
- Come to the lab and listen to the in-class explanation prior to conducting the lab activity

Instruction

1. **Geometry Settings:** Open a new simulation file at a frequency of 3 GHz. The wavelength is approximately 10 cm in air.
2. Set the simulation area by drawing the cylinder with the circular base on the xz-plane, with a radius of 3λ and a height (in the y-direction) of 0.1λ . Place the centre of the cylinder at the origin. Call this shape the “SimBox”
3. Fill the bottom half of the simulation area (the half-space with $z < 0$) with a shape by the name “Dielectric”. You can do this by drawing a rectangular box that covers the volume $z < 0$, and using the Model > Boolean > Intersect operation (accessible from the top tab) to get the “intersection” between the rectangular box and the cylinder. If the “Intersect” function removes the cylinder you will need to redraw it.
4. Fill the top half of the simulation area (the half-space with $z > 0$) with a shape by the name “Air”, either by following a similar procedure as Step 3 above, or by duplicating the shape “Dielectric” and rotating by 180 degrees above the origin, using the “Duplicate along axis” button in the Draw tab. It looks like this: 
5. After all this your simulation geometry setup should look like this (feel free to colour your regions so that you can distinguish them well).



6. **Material Settings:** By default, all materials are assigned as vacuum. For this exercise, add two materials to the database: “Material A” with $(\mu_r, \epsilon_r, \sigma) = (1, 3, 0)$ and “Material B” with $(\mu_r, \epsilon_r, \sigma) = (-1, -3, 0)$. To do this, go to the panel to the left of your geometric diagram, right-click on the vacuum material and select “Properties”, which should take you to the material library. Choose the function “Add Material” below the material table. Name the material and insert its $(\mu_r, \epsilon_r, \sigma)$ as listed above. Leave the other quantities unchanged. After filling in the material properties table, click “Validate Material” and observe the check mark to see that your material is valid. Then click “OK” to add the material.
7. Select the shape “Dielectric”, right-click and choose “Assign Material”. Choose “Material A” as the material for this dielectric.
8. **Boundary Settings:** select the curved outer boundaries in the +z and -z directions, and set each one as a “Radiation” boundary. This simulates a boundary which allows waves to exit the SimBox smoothly without back reflection.
9. Select the $\pm y$ -sides of the SimBox and set them as Perfect Electric conductors. This effectively simulates a 3D environment where propagating electromagnetic quantities are invariant in the y-direction. Furthermore, in this environment only the TE mode is allowed. The benefit of doing this is that the y-dimension of this domain is rendered very small, such that the simulation can be performed efficiently.
10. **Excitation Settings:** Define θ_i (theta_i, unitless) as a project variable. Set the variable to 0 for the time being.
11. Select the SimBox, and set up a Gaussian beam excitation. The Gaussian beam is like a plane wave, but the wave amplitude decreases away from a central axis, such that simulation of an infinitely large space will not be required. Let the phase center be located at the origin. Let the width of the beam waist be 1λ . Set the electric field to be along the y-direction, and the wavevector be pointed such that the plane wave incidence comes at $\theta_i = 45^\circ$ with respect to the interface normal, hitting the interface from the top (i.e. from air). Let k_x be positive for $\theta_i \in (0^\circ, 90^\circ)$. After setting up the Gaussian beam excitation, selecting the Gaussian beam from the left-most panel should display the following picture of the setup (note the arrow in the middle (boxed in green) which denotes the Gaussian beam’s travel direction).



12. **Simulation Settings:** Set up a driven simulation for the frequency of 3 GHz. Require that the simulation runs for at most 15 iterations; and that it should converge to 1% change or lower in successive simulations for 2 or more times before the simulation is considered to have converged. (If the computational resource of your computer does not allow this simulation, you can experiment with relaxing one or more of the above criteria.)
13. **Analysis:** Use the “Validate: function to verify that the simulation is in order. Then perform the simulation!
14. **Viewing your results:** Here we learn a few ways of viewing the simulation results
 - **Mag_E Field Overlay Plot:** Select the top face (let’s say, the -y-directed face) of SimBox. Right click the phase, and choose Plot Field > E > Mag_E, to plot the magnitude of the electric field at one phase point. This is called an “overlay” plot because it directly lays the plot over the geometric region.
 - **Poynting Vector Overlay Plot:** Select a face, right-click choose Plot Field > Other > Vector_RealPoynting to plot a Poynting Vector Overlay Plot over the region.
 - **Animation:** Right-click the Mag_E Field Overlay plot and choose animation to show how the electric-field magnitude changes at different phase points. The default phase goes from 0° to 170° degrees because Mag_E for phase point ϕ and phase point $\phi+180^\circ$ will look exactly the same.
 - **Changing between incident, scattered and total waves:** Accessing HFSS > Fields > Edit Sources from the top panel allows one to change between incident, scattered and total waves. Selecting “Incident” will show only the incident wave; selecting “total” will show the incident wave as well as the reflected and transmitted waves.

Results and Discussion

0. Please show all overlay plots from the +y perspective. This can be shown by choosing the Model tab and choosing Orient > Left (+Y). Experiment with other perspectives.

I. Scattering off an Air-Dielectric Interface

1. Show the Mag_E and Poynting vector overlay plots of the incident Gaussian beam. Show the electric field overlay plot, and include the screen capture in your report.
2. Which way is the Gaussian beam propagating with time? View the animation to determine the propagation direction, and denote this direction on your overlay plot in Step 1 above.
3. Show the Mag_E and Poynting vector overlay plots (total) showing field reflection and transmission. From the animation, which way is each of those three waves propagating (towards or away from the interface)? From the Poynting vector, which way are the waves propagating?
4. Use the help of a picture editing program (eg. Paint, Word or Powerpoint) to determine θ_i , θ_r and θ_t from the plots shown in Step 3. Show your work in determining these angles.
5. Compare θ_r and θ_t obtained in Step 4 with values as calculated from Snell’s laws. Do the calculated and simulated values agree or disagree? How well is the agreement, and what may be the reason if there is any disagreement?

II. Scattering off an Air-Metamaterial Interface

6. Change the “Dielectric” from “Material A” to “Material B”.
7. Repeat Steps 2-5 for this new situation of Air-metamaterial interface.
8. **BONUS:** How can one eliminate reflection at an air-metamaterial boundary? Change Material B into Material C, such that both materials have the same refractive index, the same θ_t is

achieved, and the reflected wave vanishes. Give the material parameters ($\mu_r, \epsilon_r, \sigma$) for Material C and show how these material parameters are obtained. Show the simulated Mag_E and Poynting Vector overlay plots for this case.

Lab Report

Please prepare an individual lab report, showing

- A diagram of the simulation geometry similar to the one after Step 5 of the Instruction section.
- A diagram of the excitation source similar to the one after Step 11 of the Instruction section.
- A display and discussion of the results, in answer to Steps 1-8 of the Results and Discussion section.

Further Exploration

Time permitting, feel free to perform further exploration with this simulation set up! Some interesting things to try include: varying the angle of the incident wave, simulating phenomenon with critical and Brewster angles and simulating a transmission line. If you run out of ideas, try following some of the built-in tutorials and follow ones that are offered online.