EECE 5698: Terahertz Communication for 6G
Homework Assignment 2

Given: February 13, 2024
Due: March 3, 2024 (11:59 PM)

Submission Instructions:

Submit your assignment directly on Canvas

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Part 1: Analytical Terahertz Channel Modeling

In this problem, you will analytically explore the behavior of the Terahertz (THz) band channel, following the models introduced in class.

The file `molecular_absorption.mat` included with this assignment contains the following variables:

- *k:* Molecular absorption coefficient in [m^{-1}] as a function of frequency for the two most absorbing gases at THz frequencies that can be found in a standard atmosphere, namely, O_2 and H_2O.
- *f:* Frequency vector in [Hz]

In MATLAB,

a) Load the molecular absorption coefficient. Compute and plot the molecular absorption loss (in dB) as a function of frequency (from 100 GHz to 10 THz only) for three different distances (1, 10 and 100 meters), in the same figure. Label the axis with magnitude and units (Hint: remember the `xlabel` and `ylabel` commands), include a legend to distinguish the three lines (Hint: remember the legend command). Mark the absorption-defined transmission windows. If needed, adjust the vertical scale (Hint: remember the `xlim` and `ylim` commands)
   - In which cases would you utilize the absorption-free windows?
   - Would you ever consider communicating over the absorption lines instead? Justify your answer.
   - For the first transmission window above 1 THz, how much does the 3-dB bandwidth change when increasing the distance? Provide a quantitative answer.

b) Compute and plot the spreading loss (in dB) as a function of frequency for the same three distances, for an ideal isotropic omnidirectional antenna.
   - What would be the size of that antenna, if a dipole were considered?
   - What can you do to reduce the spreading losses?

c) By combining the two losses, compute the path loss as a function of frequency and for the same three distances.
   - How does the path-loss at 300 GHz compare to spreading loss at 2.4 GHz, 60 GHz and 200 THz (1500 nm or infra-red wavelength)?
   - Despite these results, why are we interested in moving towards higher frequencies?

Prepare a brief report INTEGRATING your scripts, figures and answers for each of the aforementioned questions, in one file.

Part 2: Experimental Terahertz Channel Modeling

In order to understand the response of different materials to THz signals, we proceed as follows:

- At the transmitter (Tx), with the Arbitrary Waveform Generator (AWG), we generate a chirp signal from 0 to 10 GHz, which we then up-convert to 130 GHz with the frequency-multiplier-based up-converter and radiate with a directional antenna.
- At the receiver (Rx), we down-convert the received signal from 130 GHz to IF and utilize the Digital Storage Oscilloscope (DSO) to digitize the received IF.
- We measure the response of a material in two different setups (see Figure 1):
    - Transmission: An obstacle is placed halfway on the line-of-sight path between the transmitter and the receiver
    - Reflection: An obstacle is placed off the line-of-sight path at an angle, and the Tx and the Rx are oriented towards it.
    - In both cases, the total distance that the signals travels is the same, i.e., 1.4 m.
- This is performed 1,000 times and then the received signal is averaged in time to reduce the noise.

Figure 1: Transmission and reflection scenarios utilized to characterize the response of different materials.

The following signals have been collected:

`transmission_air.mat`	Transmission without obstacle
`Reflection_air.mat`	Reflection from air: Not provided, there is no reflected signal
`transmission_plastic.mat`	Transmission through plastic
`reflection_plastic.mat`	Reflection from plastic
`transmission_metal.mat`	Transmission through metal: Not provided: there is no received signal
`reflection_metal.mat`	Reflection from metal
`transmission_glass.mat`	Transmission through glass
`reflection_glass.mat`	Reflection from glass
`transmission_wood.mat`	Transmission through wood
`reflection_wood.mat`	Reflection from wood

Each file has been sampled at 160 Giga-Samples-per-second (GSaps).

To facilitate the processing of each file, the `compute_power.m` file is included with this assignment. In this file:

- The time-domain data from the DSO is loaded and converted to the frequency domain with the Fast Fourier Transform (FFT) algorithm.
- The power spectrum is computed.
- Time and frequency domain plots are shown.
- The total power is computed.

Now,

a) Utilizing the provided script and data files, complete the following table:

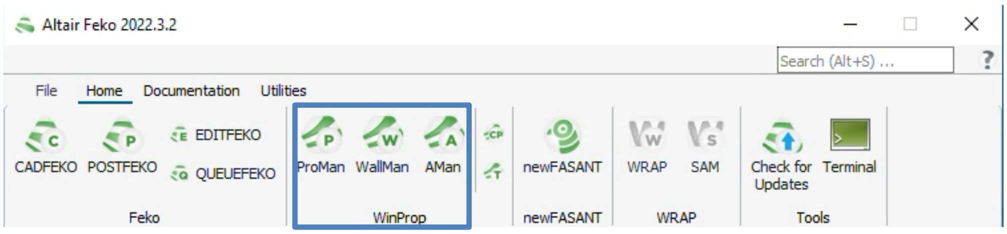
Material	Power in Transmission	Power in Reflection	Material type (e.g., mostly transparent, mostly reflecting, highly absorbing, etc.)
Air			
Plastic			
Metal			
Glass			
Wood			

b) Based on your obtained information, qualitatively explain how multi-path propagation at THz frequencies might look like in both indoor and outdoor scenarios.

Prepare a brief report INTEGRATING the table and your answer to the question above. No need for scripts or figures.

Part 3: Ray Tracing

In this problem, we will model the wave propagation and analyze indoor and outdoor environments using WinProp, a ray tracing-based propagation software included within the Feko Installation. Using this software, we will compare the propagation characteristics of electromagnetic waves at 2.4 GHz and 130 GHz frequencies.



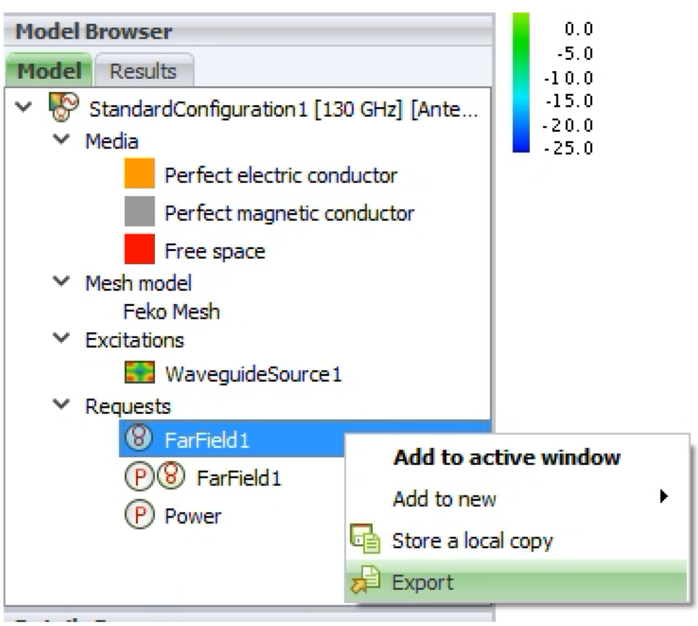
For 2.4 GHz, we will use an omnidirectional antenna, but we will design a directional 130 GHz antenna.

a) Antenna Design on Feko

Using CADFEKO, following the same steps as in the previous assignment, design a 130 GHz antenna with the following parameters:

- WR7 waveguide
- Waveguide length (in the z-axis) = 3 mm
- Square horn antenna of side length = 9.58 mm
- Flare length (in the z-axis) = 10 mm

From POSTFEKO, generate a 2D polar plot and a 3D radiation diagram showing the gain in dB. Then export the far field .ffe file, and choose Gain from the Result settings dropdown menu. Name the pattern and save it to be used later in the following steps.



In your deliverables, attach a screenshot of the antenna CAD model, 3D radiation pattern and the polar plot.

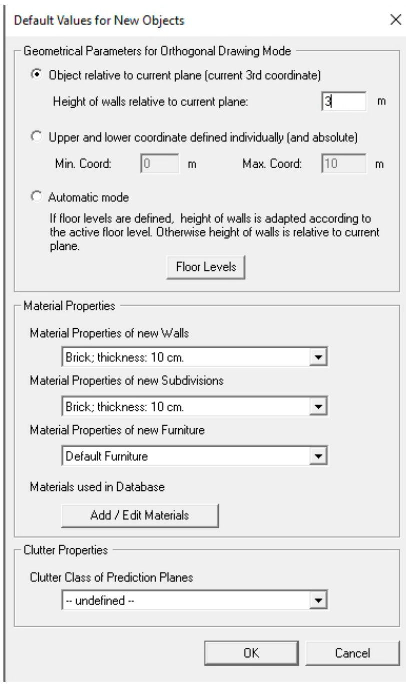
Among other modules in WinProp, we will focus on WallMan to model the environment and Proman to configure simulation scenarios and manage results.

b) Now, design an indoor model of an office floor plan using WallMan (short for Wall Manager)

From File, click on New Database. Make sure the type is set to Indoor database and the mode of operation in Draw manually, then browse to open the GlobalMaterialCatalogue.mcb attached with the assignment.

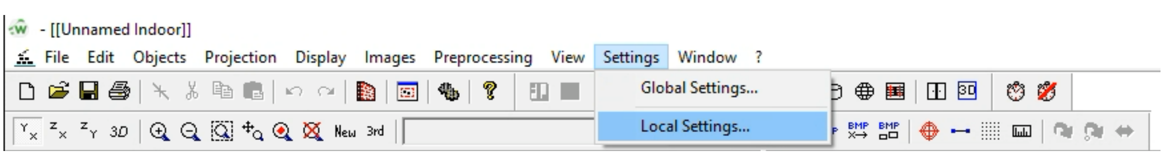
At this step, we are ready to set the default values for the material will use.

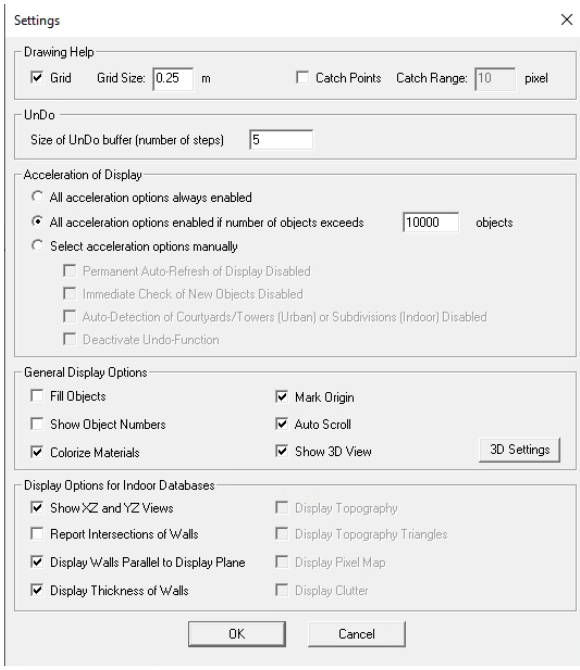
- Set the height of walls to 3 m
- Select Brick of 10 cm thickness for the material properties of new walls
- Click Ok



From Settings, Local Settings

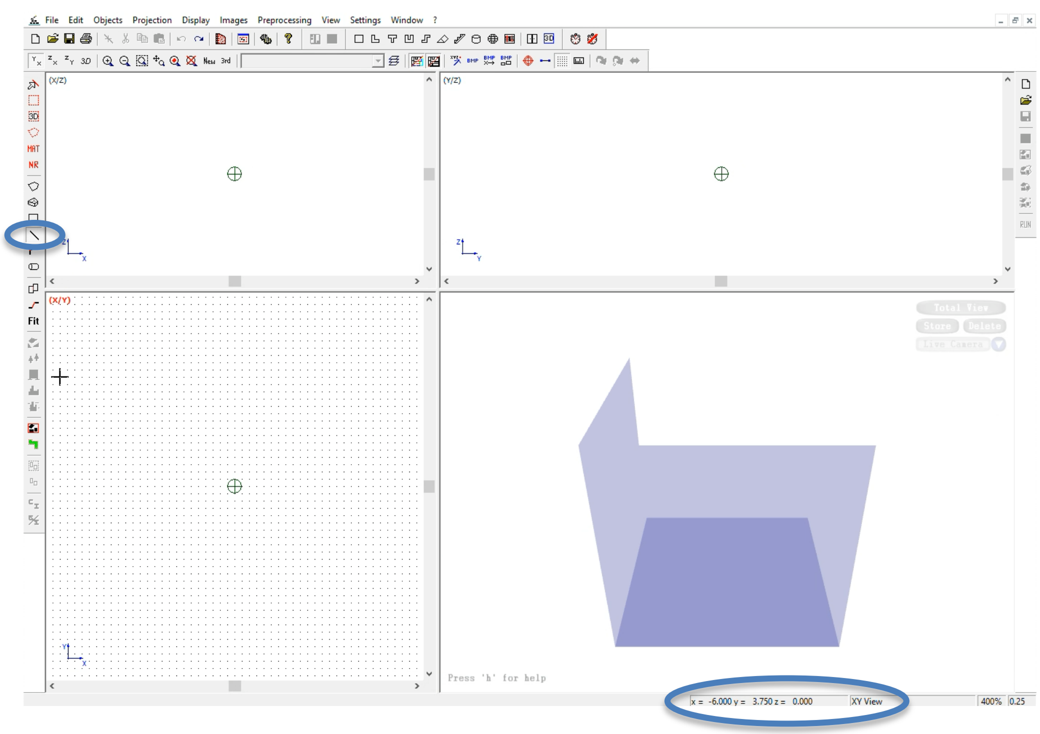
- Set the Grid Size to 0.25 m
- Check the Colorize Material box, to easily differentiate between the used materials
- Check the Display Thickness of Walls box



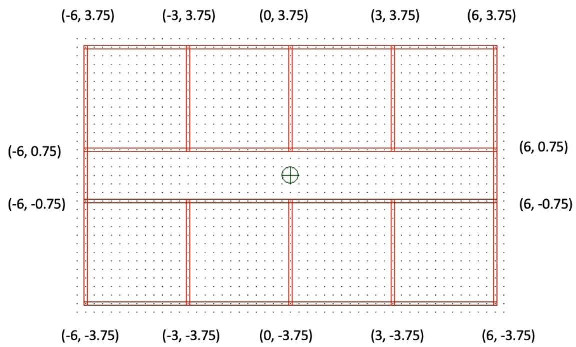


We will add orthogonal objects in the (X/Y) Plane.

- Zoom in till you are able to see the grids
- Click on the orthogonal object button from the left side and navigate to point (x = -6, y = 3.75), then draw a line till point (x = 6, y = 3.75). (Hint: You need to left clicks to start drawing and one left click to finish it).
- Select the other planes and zoom in to be able to see the model.

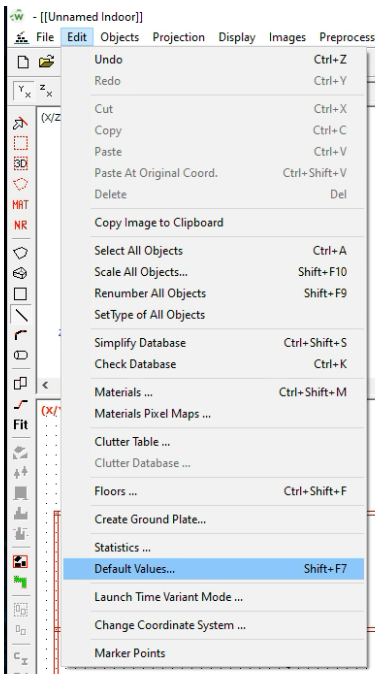


Using the same approach, draw the following structure:

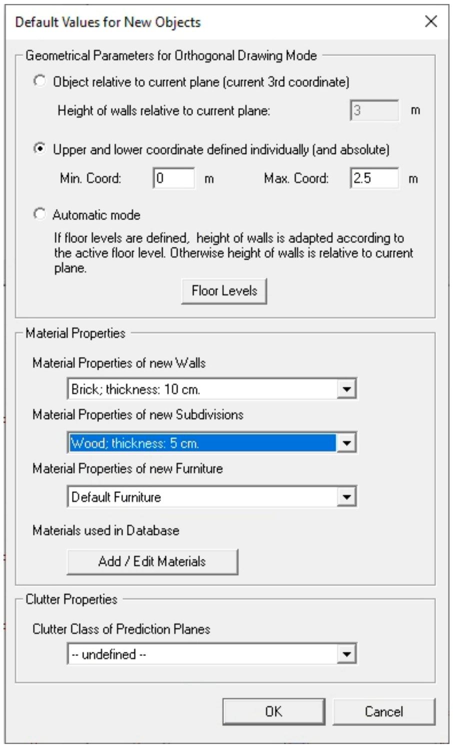


Add doors:

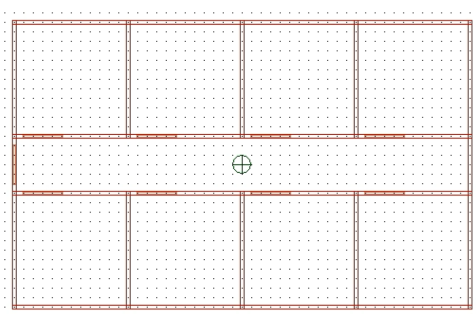
- From Edit, select Default Values



- The door will start from the floor with a height of 2.5 m, so we can set the upper and lower coordinates to be 0 and 2.5 m respectively. Then make sure to select the material of the subdivision to be Wood; thickness: 5 cm.

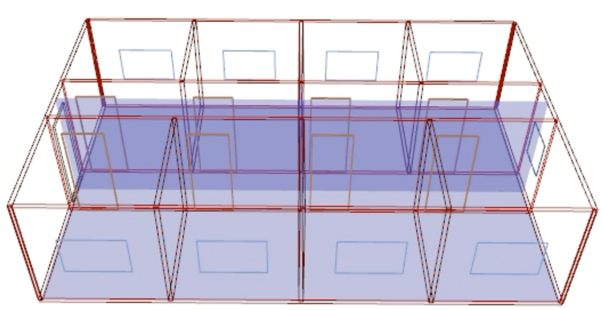


- Start drawing doors by creating subdivisions using the same approach as that used for building the walls. The door width is assumed to be 1 m. Add a door to the left side of the corridor and a door for each room as follows.



Add windows:

- From Edit, select Default values. Set the lower coordinates to 1 m and the upper coordinated to 2 m. Then, select the subdivision material to be Glass; thickness: 5mm.
- Add window to each room and a window to the right side of the corridor.



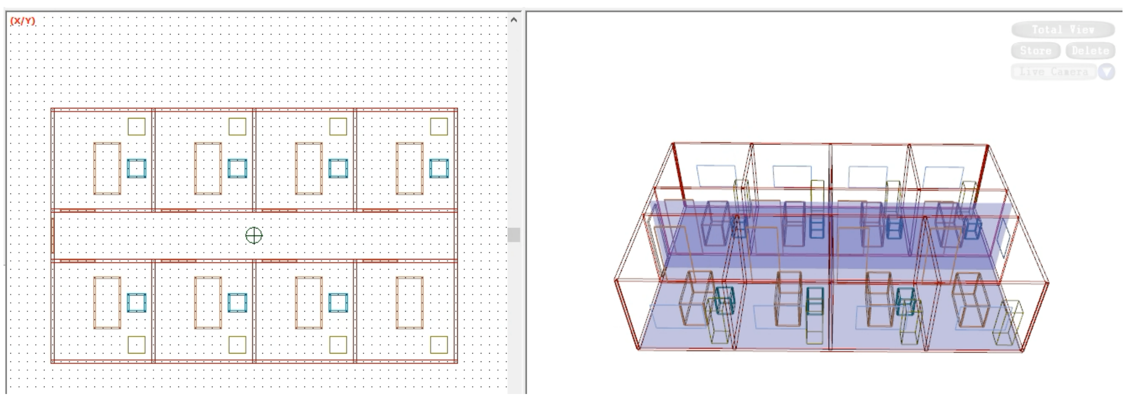
Let’s add some furniture in each room:

- Metal Drawers
    - Min. Coord: 0 m
    - Max. Coord: 1.5 m
    - Material properties of new Walls: Metal; thickness: 5 mm
    - Dimensions: 0.5 m x 0.5 m

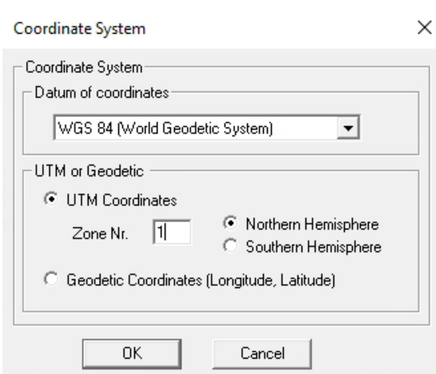
- Table
    - Min. Coord: 0 m
    - Max. Coord: 1 m
    - Material properties of new Walls: Wood; thickness: 5 cm
    - Dimensions: 1.5 m x 0.75 m

- Chair
    - Min. Coord: 0 m
    - Max. Coord: 0.75 m
    - Material properties of new Walls: Plastic (Polystyrene); thickness: 5 cm
    - Dimensions: 0.5 m x 0.5 m

The model should look similar to this. (Hint: The windows are not shown in the X/Y as the default is that the third coordinate (i.e., z-axis) is 0, and the windows start from z = 1 m to z = 2 m). To change the third coordinate, click on 3d and change the value to view different altitude.



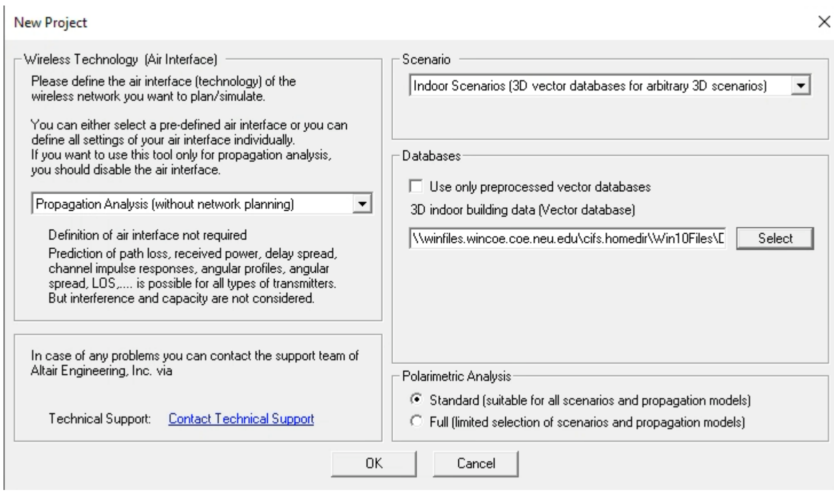
Save the database, give the model a name, and set the Zone Nr. To 1



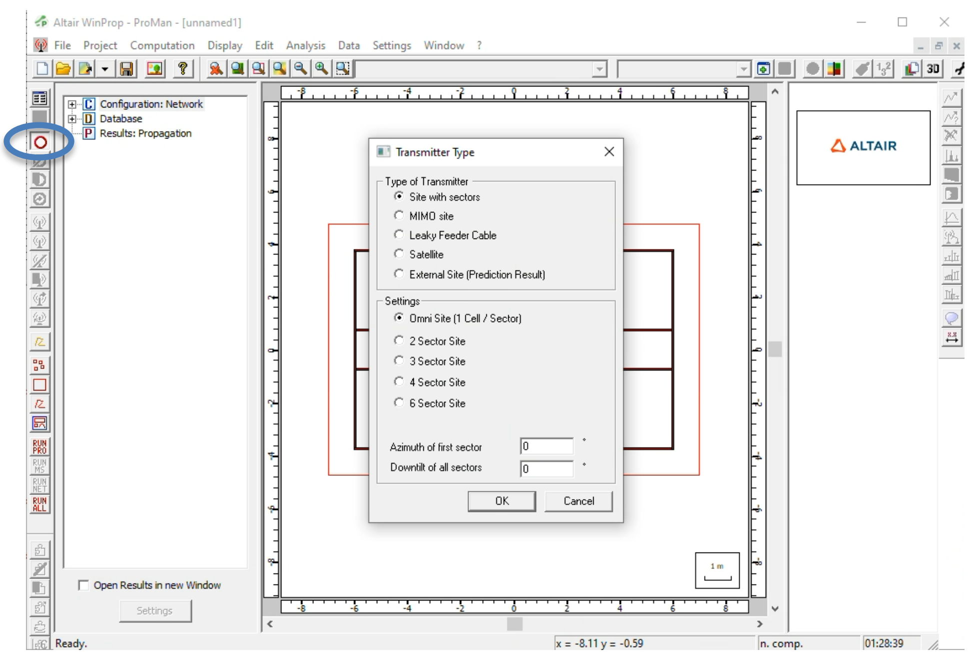
In your deliverables, attach a screenshot of the indoor model.

c) Using ProMan (short for Propagation Manager), we will simulate propagation scenarios to better design and optimize wireless communication systems. Using the indoor model developed in part b, we will compare the propagation of an omnidirectional 2.4 GHz antenna and the directional 130 GHz antenna designed in part a.

From File, choose New Project.
Ignore the Default settings for now.
From Scenario dropdown menu choose Indoor Scenarios.
Browse to the database created in part b.
Click Ok.
Finally, set the height to 3 m.

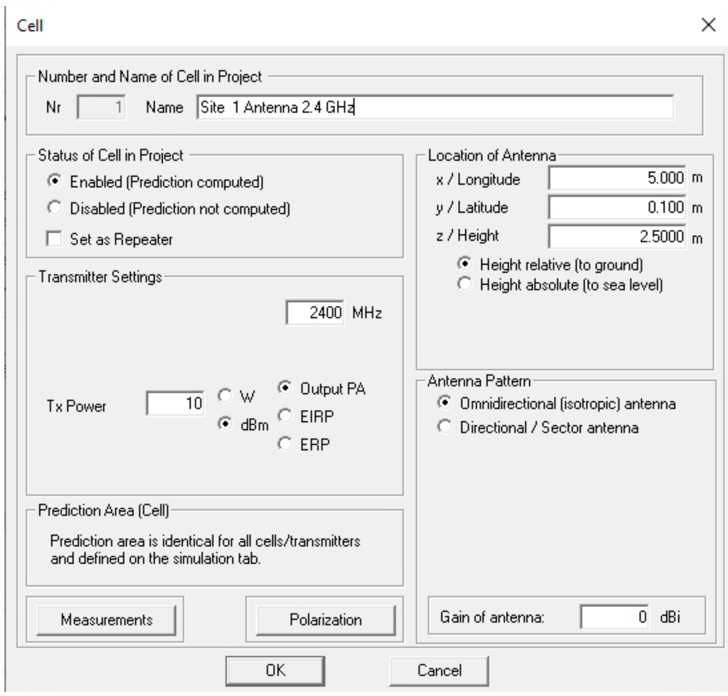


Add a transmitter by clicking on Set Side then select Side with sectors.



Place the site in the corridor in front of the window
- Site x = 5 m
- Site y = 0.1 m

- Click on the antenna and set the parameters.
    - x = 5 m
    - y = 0.1 m
    - Frequency = 2400 MHz
    - Tx Power = 10 dBm
    - Omnidirectional antenna (Gain = 0 dBi)
    - Name the antenna
    - Click Ok



From Project, Click on Edit Project Parameters

- From the Simulation tab, set the resolution to 0.01 m
- From the Propagation tab, check Field Strength, Path Los, and LOS Analysis
- Click Ok

Save the model and give it a name.

From Computation, Click on Propagation: Compute All

This shows the signal propagation at height = 3 m

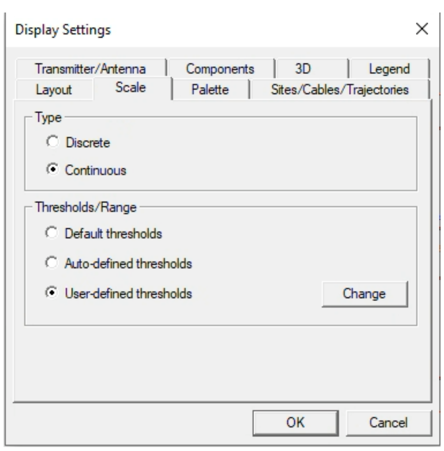
To see the furniture effect:

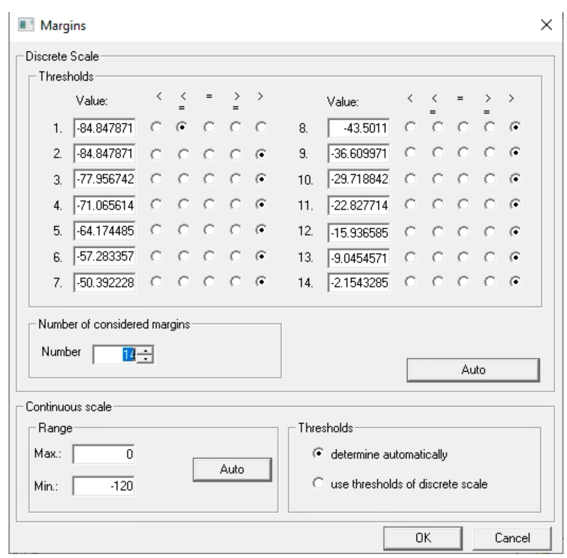
- From Project, click on Edit Project Parameters
- Set the Height to 0.3 m
- From Computation, click on Propagation: Compute All.

To compare between to cases, ensure that the colormap range is the same.

From Settings, choose Local Settings then click on the Scale tab.

Choose user-defined thresholds and change the max to be 0 and the minimum to be -120





Now, Add the 130 GHz antenna designed in part a.

From Project, Click on Edit Project Parameters

- From the Sites tab, click on the Site 1 previously added.
- Click on Add to add another antenna.
- Set the frequency to 130 GHz.
- Tx Power = 10 dBm
- For the Antenna Pattern, Click on Directional/ Sector Antenna
    - Navigate to the exported antenna pattern.
- Click Ok

Site 1 is now updated with 2 antennas. After the computation,

d) Answer the following:

- What are the main obstacles of the signal?
- How does each material (i.e., brick, wood, metal, ...) affect the signal? Which material is causing more losses?
- Save a copy of the database developed in Part b. Change the thickness of one of the walls and repeat Part c. Does that affect the signal?
- How does the height of the antenna affect the signal?
- Mention at least two factors to consider when optimizing antenna placements for maximizing coverage in the given scenario.
- Compare the propagation characteristics (i.e., wall penetration, path loss, coverage area, …) of 2.4 GHz and 130 GHz waves.

Prepare a brief report INTEGRATING the table and your answer to the question above. No need for scripts or figures.

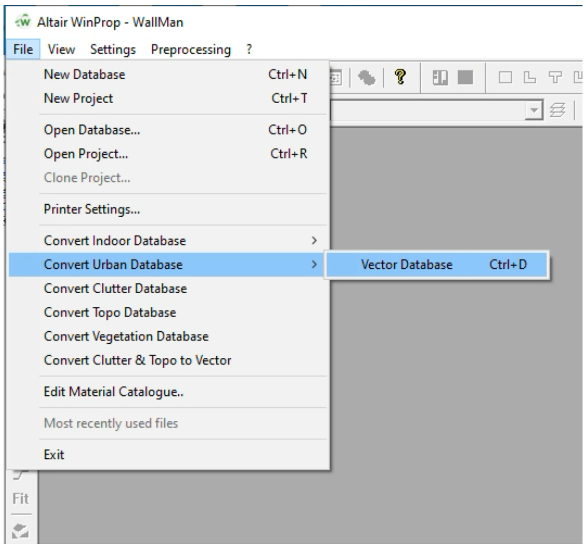
e) Outdoor Model **(Optional)**

In this step, we will extract the dataset from OpenStreetMap, a mapping project that provides free world map.

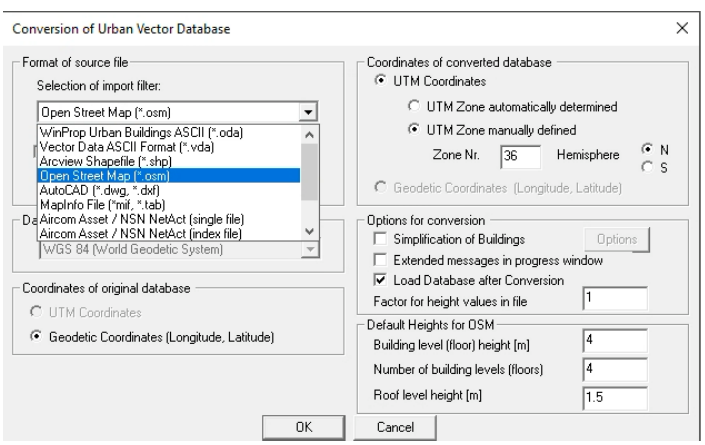
- Navigate to openstreetmap.org
- Find Northeastern on the map (North = 42.3411, South = 42.3358, East = -71.0848, and West = -71.0936)
- Export the map and download .osm file

Using WallMan, the database (.osm) will be transformed into a format compatible with Proman for further analysis.

- Open WallMan
- From File, Click on Convert Urban Database, then click on Vector Database.



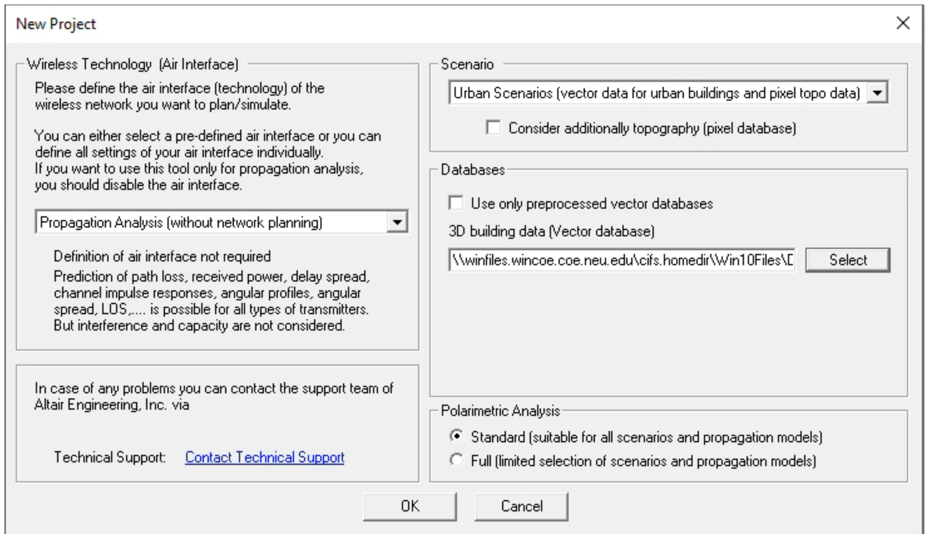
- From the format dropdown menu, select Open Street Map (*.osm), then click OK.



- Load the (.osm) exported file, then choose a location to save the converted (.odb) file.

After the conversion is complete, open ProMan.

- From File, select New Project
- Choose Urban Scenario
- Browse to the converted (.odb) map
- Click Ok



- Set the Height to 3 m. This will let you see almost the first floor of all the available buildings in the map.
- Pick a location and build a site as previously done in Part C, then add the 2.4 GHz and the 130 GHz transmitter antennas.
- Answer the following:
  - Can this site cover the whole campus?
  - Is there any difference between the propagation of both waves?
  - How does distance affect path loss in outdoor environments, and how can it be mitigated?
  - Mention at least 2 strategies for optimizing antenna placements to maximize coverage and signal quality.