# Electrodynamics 2019: Computer session

## 1. Cut-off frequencies for modes in rectangular waveguide

Consider a rectangular waveguide with cross section $0 < x < 10$ cm and $0 < y < 4$ cm

- Choose first 2D and then **Radio Frequency** → **Electromagnetic waves frequency domain**. Then press study and click on **Eigenfrequency** and then **done**.
- Draw the cross section of the rectangle and fill it with air.
- Right click on **Electromagnetic waves** and choose **perfectly conducting boundary conditions** for all surfaces (this is default).
- Choose extremely fine mesh.
- Now it is time to find the frequencies where higher order modes will start to propagate. This is done by solving an eigenvalue problem. The problem is similar to the one used for getting the analytic expressions. However, Comsol gives both TE and TM waves at the same time.

  Click on **Step 1:Eigenfrequency** under **Study**. Choose 20 eigenfrequencies and give a starting value. You may pick 1 GHz as a starting value.
- Click Compute and find the lowest eigenfrequencies. The eigenfrequencies are the same as the cut-off frequencies (Why?) Note: Comsol often finds non-physical solutions (spurious solutions). These false solutions reveal themselves by having very cluttered field maps and complex eigenfrequencies. A real resonance has a very nice looking field map.
- Try different options for plotting the fields. Look at field maps of different components for the electric and the magnetic field.
- Check out the animation.
- Check the accuracy by comparing with the analytic expressions for the cut-off frequencies. Use 299792458 m/s as the speed of light.
- How can you find out if a mode is TE or TM? Test this.

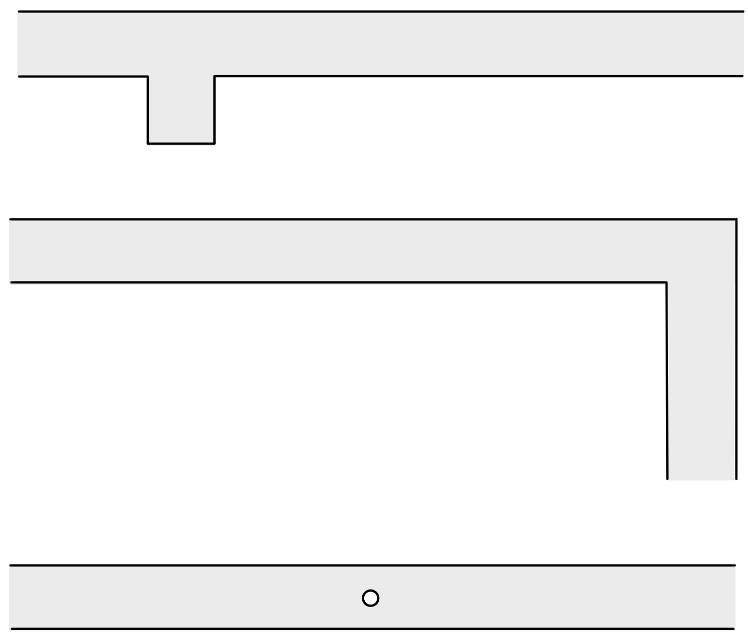

**Figure 1**: Geometries of waveguides.

## 2. Propagation of waves in rectangular waveguide

1. Take a look at the propagation of some $TE_{m0}$ modes along the waveguide in COMSOL. Again go to **2D** and **Electromagnetic waves frequency domain** under **Radio Frequency**. As a study you choose **Frequency domain**, or (even better) **Adaptive Frequency Sweep**.

2. We look at the waveguide from above (what we call the $xz$-plane). Let the width of the waveguide be 5 cm. The lengths you can choose as you like.

3. Try out the geometries in the figure. Use **Booleans and Partitions** under **Geometry** to form these geometries. To add two pieces you choose **Union** and to take the difference between two objects you choose **Difference**.

4. Fill the domain with air.

5. Right click on **Electromagnetic waves** and choose **Port**. Mark the input in your geometry. Choose **Rectangular** under **Type of port**. Then let the power be on and choose **Transverse electric** as **Mode type** and 1 as **Mode number**. That will generate the fundamental mode at this port.

6. Choose again **Port** and let that be the output. Use the same as the other port with the exception that the power is off.

7. Define a suitable frequency interval with 10 steps.

8. Compute.

9. Look at different components of the electric and magnetic fields to see the waves for some different frequencies. Don't use the norm use the field components!
10. Make a movie by Right click on **Export**. Choose **Animation** and **Player**. Choose **Dynamic data extension** under **Sequence type**.
11. Plot the S-parameters, see below.

## 3. Propagation of waves in circular waveguide in 3D and 2D axial symmetry

If you have time you may look at wave propagation along a circular waveguide by using 2D axial symmetry and also 3D. Ask for help if you get stuck.

## 4. S-parameters

If one has an input port and an output port in a system one is often interested the transmission of power from one port to another. Comsol automatically calculates such transmitted powers. It is represented by $S_{21}$, which is one of the S-parameters. The definition of the S-parameters is as follows:

- $S_{11}$ =the reflection coefficient for port 1. It is the given by $|S_{11}| = \sqrt{P_\mathrm{r}/P_\mathrm{in}}$, where $P_\mathrm{r}$ is the reflected power for port 1 and $P_\mathrm{in}$ the incident power at port 1
- $S_{21}$ =the transmission coefficient from port 1 to port 2. It is given by $|S_{21}| = \sqrt{P_\mathrm{t}/P_\mathrm{in}}$, where $P_\mathrm{t}$ is the transmitted power to port 2 and $P_\mathrm{in}$ the incident power at port 1.