

## Microwave theory 2016: Computer session

### 1. Coaxial cable

A coaxial cable has an inner conductor with radius  $a = 1$  mm and an outer conductor with inner radius  $b$ . The region between the conductors are filled with a lossless plastic material with  $\epsilon_r = 4$  and  $\mu_r = 1$ . The radius  $b$  is chosen such that the characteristic impedance is  $50 \Omega$ .

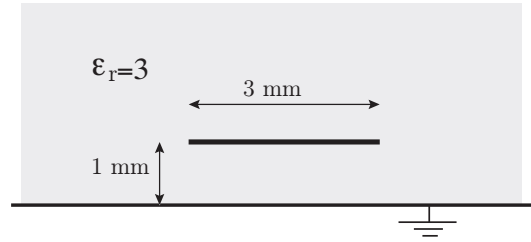
a) Use the formulas on page 45 in the book to determine  $b$ . Also calculate the capacitance  $C$  with format long in Matlab.

b) Find the capacitance  $C$  from Comsol. Use the scheme described on page 47 in the book. Compare your result with the analytic expression. How many digits do you get?

c) Find the bandwidth of the cable. The bandwidth is defined as the width of the frequency band where only the TEM mode can propagate in the cable. To find out the frequency of the second mode you may start from scratch again. Do the following steps:

- Choose 2D and choose Electromagnetic waves frequency domain under Radio Frequency. Then press study, click on choose eigenfrequency and done.
- Draw the coaxial cable and fill it with the material, as in b)
- Right click on Electromagnetic waves and choose perfectly conducting boundary conditions for all surfaces (it is probably already chosen).
- 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. We will look at this next week but you can do it in Comsol without knowing the details. Click on Step 1:Eigenfrequency under Study. Choose 10 eigenfrequencies and give a starting value. You may pick 10 GHz (1e10) as a starting value.
- Click Compute and find the bandwidth by finding the lowest eigenfrequency. Comsol often find non-physical solutions (spurious solutions). These fake solutions reveal themselves by having very cluttered field maps. A real resonance has a very nice looking field map. Experiment with the different options Comsol has for plotting the fields. Look at field maps of different components for the electric and the magnetic field.

## 2. Parallel plate transmission line



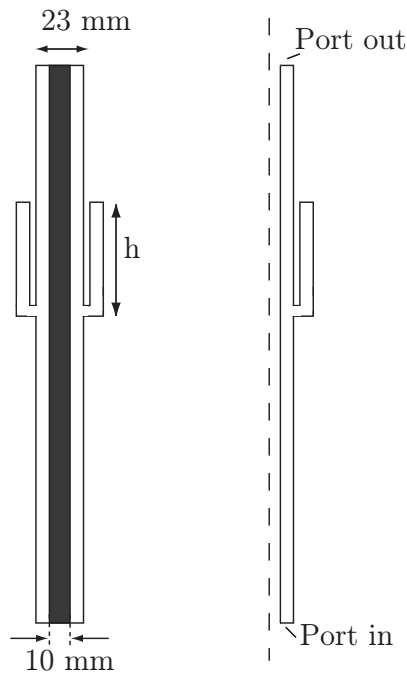
Use at least two different mesh sizes when you do your calculations in order to see that the solution has converged.

a) Find the line parameters  $L$  and  $C$ , and the characteristic impedance  $Z_0$  for a parallel plate above a ground plane as given by the figure. The thickness of the plate is 0.1 mm. Follow the steps given on page 47 in the book. Notice that the medium around the microstrip is a dielectric material with  $\epsilon = 3$ . The capacitance can be calculated by two methods and you should try both of them. You will find that there is a difference between the two methods. This indicates that for a structure with corners the finite element method gives good, but not extremely good results. Compare your results with the approximate expressions given on page 44. You will find that the approximate expression is not accurate for this structure.

- Method 1:  $C = Q/V$  where  $Q$  is the charge per unit length  $\rho_\ell$  of the plate. You have two options to calculate  $\rho_\ell$ ; by integrating the surface charge density over borders of the the plate, or by integrating it over the borders of the large rectangle. One gives a result that is closer to what you get in method 2. Why?
- Method 2:  $C = 2W_E/V^2$  where  $W_E$  is the electric energy per unit length. The electrostatic energy is a predefined quantity that you find under **Results**→**Derived results**→**Global evaluation**. Integrate over the area between the two rectangles.

b) Decrease the distance between the plates from 1 mm to 0.1 mm and calculate the capacitance again. Compare with the expressions on page 44. Is the agreement better?

### 3. S21 and S11 for a notch filter



**Figure 1:** The notch filter. The structure is axially symmetric and the figure shows the cross section.

If you have time you may do this example:

Build a coaxial cable with a notch filter (bandstop filter) with a stop frequency at 3 GHz. The dimensions are as in the figure. Find the height  $h$  such that the frequency 3 GHz is stopped. Let Comsol plot the S21 parameter in dB scale. Also plot the S11 parameter in dB scale.

Do the following steps:

1. Start Comsol and pick **2d-axisymmetric** → **Radio Frequency** → **Electromagnetic waves** → **Frequency domain**.
2. Draw the geometry. The dashed line is the axis of symmetry. You only draw the right half of the cross section. This is the part consists of the three rectangles in the right part of the figure. Let the total length be 25 cm and place the notch filter at the middle of the coaxial cable. When you have drawn the three rectangles you can use **Geometry** → **Boolean operations** → **union** to form the union of the three rectangles.
3. Choose air as material.
4. The default boundary condition on all lines is perfectly conducting. You should replace the lines at the inlet and outlet with ports. This is done by **electromagnetic waves** → **Port**. Use **Type of port** → **Coaxial**. Make sure that

you have added the selection. The lower port should be the input port (Wave excitation on) and the upper one the output port (Wave excitation off).

5. Choose the frequency range and frequency step by **Study 1** → **Step 1 Frequency domain** Click on range to the right of **Hz** and choose 1 GHz as start frequency, 5 GHz as stop frequency and 0.1 GHz as step. Once you have the bandstop frequency at the right place you may narrow the frequency range and step size.
6. You may refine the mesh if you like.
7. Compute (right click on Study)
8. You can now look at the norm of the electric field for different frequencies (or some other quantity).
9. In order to get the curves for the S parameter you click **Results** → **1 D Plot Group** and the **1 D Plot Group** → **Line graph** Let data set be **from parent**. In selection you use **Manual** and add the lines for the two ports. As y-axis data you choose **S21 dB** and for x-axis data **frequency**. Plot by clicking on **Plot** on top of the frame.
10. Change the dimension of the filter until you get a stop at 3 GHz. Remember to activate all rectangles and the union after you have made a change.