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Electrical and information technology

Projects in microwave theory 2017

Write a short report on the project that includes a short abstract, an introduction, a theory section, a section on the results and conclusions.

Some projects require that you have a discussion with Anders before you start. The deadline for the report is Tuesday, May 16. You can get help from Anders anytime. Just send him an e-mail and ask for a meeting

The plan is to have oral presentations Friday May 19 and Tuesday May 23. You sign up for this on the web page. You should attend all presentations. The allocated time for each presentation is 15 minutes, including questions.

1 SIW-antenna

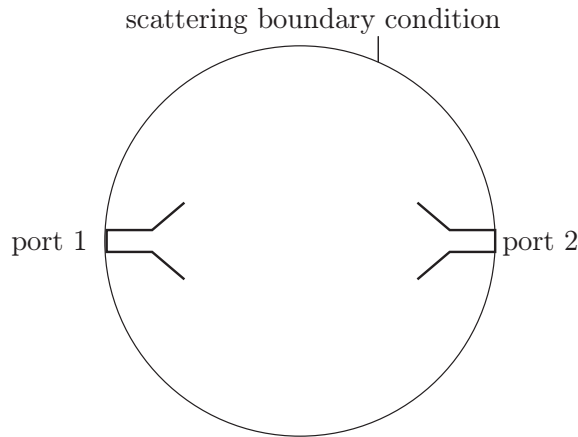


Figure 1: SIW horn antennas.

For simplicity you can do this project in a two-dimensional setting. Construct two horn antennas by using SIW, see section 5.13 in the book. The main frequency is 27 GHz, but the antenna should be able to transmit in the frequency band 20-30 GHz. The vias have radius 0.25 mm. You need to determine a suitable distance between vias centers. Both the length and width of the horn should be approximately 15 mm. The power is fed through one of the ports and received by the other. Calculate the S-parameters. Check that the S-matrix is symmetric (reciprocity). You need to determine a suitable width of the feeding SIW. Also estimate the bandwidth of the antenna. Use a circle to truncate the computational domain, as in the figure. Use scattering boundary condition with circular waves on the circle.

Present a graph of S_{21} in dB scale for the frequency band 20-30 GHz.

2 Whispering gallery modes

Read about the history of whispering gallery modes (WGM) on internet. Today WGM is a quite hot topic in nano-optics. Try to find some papers that describe applications.

Analytic and numerical examples

Start with a cylindrical cavity with perfectly conducting walls. Let the radius be 10 cm and the height one cm. Find the whispering gallery modes analytically for the azimuthal n -indices 20, 40 and 80. Determine the resonance frequencies for the corresponding whispering gallery modes and try to plot the electric field in Matlab. How is the wavelength related to the wavenumber and n ? Then solve the corresponding problems in Comsol and see how accurate the solution is.

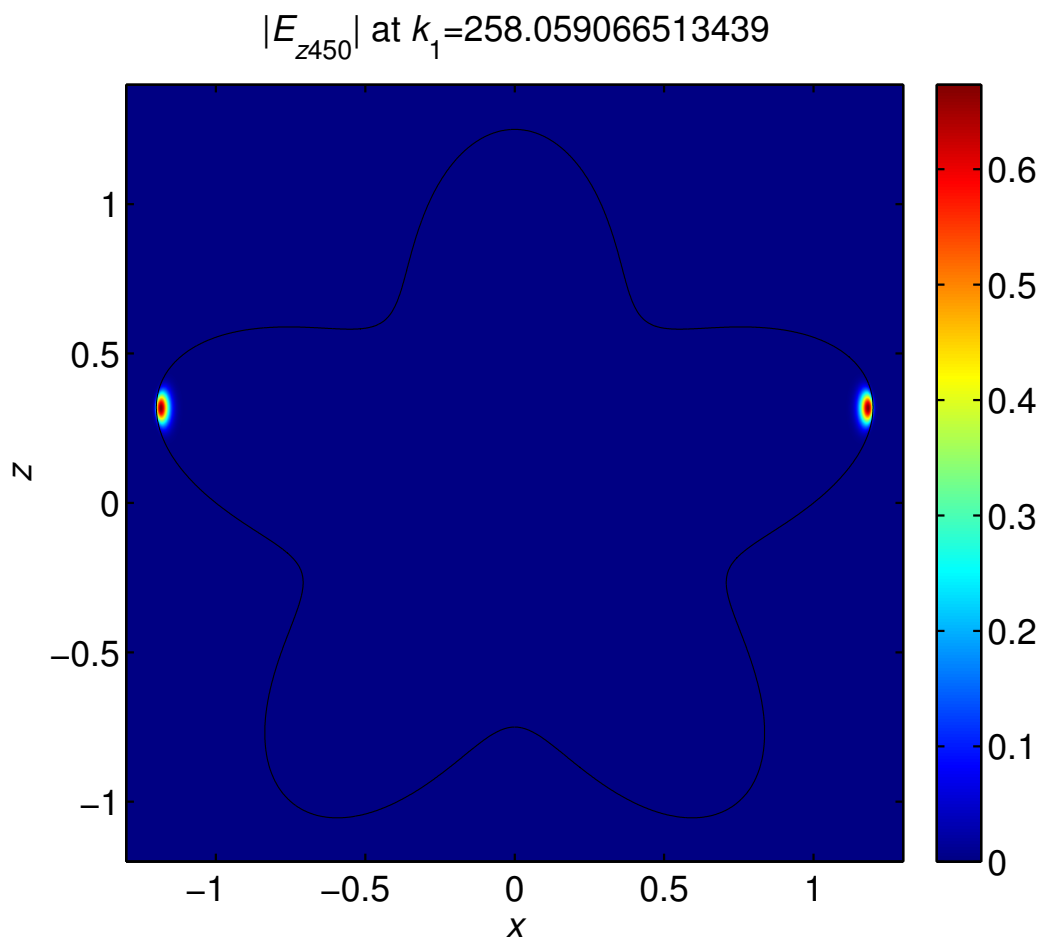


Figure 2: An example of a whispering gallery mode in a dielectric resonator.

Now turn to a dielectric resonator for optical wavelengths. Use an oblate spheroid with half axis ratio 10 and made of quartz glass with index of refraction 1.5. The wavelength in vacuum is $1.55 \mu\text{m}$. Try to find whispering gallery modes for as high azimuthal indices as possible with Comsol. The larger the major half axis is, the higher azimuthal index you can use. Since the WGM has a wave that is confined in a small region one can truncate the computational domain. Try this in order to find WGM at very high azimuthal indices.

3 Bandstop SIW-filter

Construct a bandstop filter by using a substrate integrated waveguide with a notch filter. The vias are vertical circular copper rods that go through the substrate between two horizontal ground planes. The radius of the vias is $a = 0.5 \text{ mm}$. The distance between the centers of two vias should be 2 mm. The substrate has a relative permittivity of approximately $\varepsilon = 2.3$. The length of the waveguide is approximately 40 mm and the thickness of the substrate is 3 mm.

a) Find the width of the waveguide such that the fundamental mode is the only propagating mode in the interval 15-30 GHz (approximately).

b) Design a bandstop filter using vias such that the frequency $f = 20 \text{ GHz}$ is rejected.

b) What is the smallest S_{12} you can achieve at 20 GHz? Plot the S-parameters in the whole frequency band where the fundamental mode, but no other modes, propagate.

c) Estimate the bandwidth of your filter.

d) Analyze the losses in your structure. How much are the ohmic losses in the vias and how much are the losses due to leakage?

Help: Before you do the bandstop filter for the SIW it is wise to do it for a hollow waveguide first. You may try a waveguide filter similar to the one in figure 3. It consists of a resonator that is attached to the waveguide. The resonance frequency is stopped. There is a hole between the resonator and the waveguide. Use a rectangle with scattering boundary conditions as the boundary for the substrate. This means that wave that escapes from the SIW are not reflected at the boundary.

4 Microwave oven

Examine a microwave oven. In particular you may examine and describe the magnetron, the waveguide from the magnetron to the oven, the oven as a resonance cavity, and the microwave filter in the door.

Here are some things you may calculate by using COMSOL. It is enough if you pick one or two of these.

1. The magnetron is in fact a resonance cavity with a resonance frequency of 2.45 GHz. Try to make a 2-D copy of the geometry and calculate the resonance frequency in COMSOL. There are different resonances in the magnetron. At

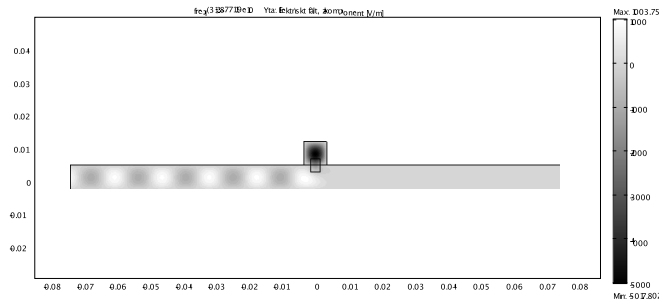


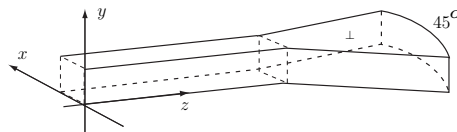
Figure 3: Waveguide with bandstop filter

<http://www.radartutorial.eu/08.transmitters/tx08.en.html> you find information on the one that is used in most magnetrons.

2. Simulate the quarter wave filter in the door of the oven.
3. Simulate the electromagnetic field in the oven. Here you can get help from the help desk of COMSOL. They have the microwave oven as an example.

Anders has a magnetron and a dismantled microwave oven that you can look at. Only one group can pick this project.

5 Horn antenna



Examine the electric field in a horn antenna with opening angle of 45° , cf figure. The horn is fed by the fundamental mode in a rectangular waveguide with dimension $a \times b$, where $a = 5$ cm and $b = 2.5$ cm. Notice that the distance between the horizontal plates is equal to b . The frequency is 4 GHz.

First determine the different TE-modes that the TE_{10} mode can generate in the horn by solving Helmholtz equation in cylindrical coordinates. Try to plot the different modes in the horn. You don't have to take the feeding waveguide into account and you may consider a horn with infinite extension in the radial direction.

The solutions you look for have to satisfy the radiation condition that the wave is an outward traveling wave for large value of $k\rho$. You might need some help from Anders here.

Next solve the same problem in COMSOL for a horn with length $R = 30$ cm. Use 2D→electromagnetic waves. Now take into account the feeding waveguide as well as the finite length of the horn. Set up a system with a transmitting and a receiving antenna as in Figure 1 in project 1. Make a movie of the the propagation of waves between the horns and save it for the presentation. It is illustrative, even if it is a 2D approximation of a 3D geometry. Also make a graph of S_{21} in the frequency range 3.5-5 GHz.

6 Photonic band-gaps

It is hard to guide light unless you are using an optical fiber or some other dielectric waveguide. During the last 14 years there have been efforts to create waveguides for light that propagates in air. This is done by using channels in a periodic structure of dielectric rods. The periodic structure should then have a band-gap for the wavelength used by the light. A band gap is a frequency interval where the light cannot propagate. Try to find some more information on band-gap structures on internet.

In the help-desk of COMSOL you may find a simulation of a photonic band gap structure. Go to RF and Users guide in the help desk. Pick Optics and photonics models. There you find photonic crystals. Instead of using gallium-arsenide you may use a material with constant index of refraction, say $n = 5$. First analyze the cut-off frequency and bandwidth of the photonic band gap structure. This is done by determining the leakage of power from the waveguide. Integrate the power transported through the surfaces that are not the input port or the output port. If this leakage is negligible compared to the power transported in the waveguide then you are in the frequency band of the waveguide. If the frequency is too small then there is no propagating mode in the waveguide and you are below the cut-off frequency.

a) Try to make a waveguide that splits up the wave in two parts that travel in opposite direction.

b) Make a notch filter, cf project *Bandstop SIW filter*.

c) Animate the wave in COMSOL and save the file so that it can be used at the presentation.

COMSOL

Use **2D axisymmetric solver**→ **RF** → **Electromagnetic waves frequency domain** → **Eigenfrequency**. Try to use different mesh sizes in order to get accurate values. Use the User-defined mesh in order to refine the mesh beyond the meshes given in Physics-controlled mesh.

7 Transatlantic cable

The first transatlantic cables had very small band width and it took several minutes to send a few letters with Morse code. Try to find information about the cable (estimate R , L , G , C) and explain why the bandwidth was so limited. Find the approximate equations that are relevant for the cable and solve these in both time and frequency domain. Use Matlab, or some other program, to simulate the received signal when a short word is sent by Morse code through the cable. You may also try to use the COMSOL solver for transmission lines.

8 Traveling wave cavity

The linear accelerator at MAX IV laboratory consists of several traveling wave cavities that operate at 3 GHz. The figure shows such a cavity. You will get the dimensions of the different parts of the cavity from Anders. From this you implement the geometry in COMSOL and then try to find the mode that is suitable for accelerating the electrons. If you choose this project you will get some more help from Anders.



9 Schumann resonances

An approximate theory for the Schumann resonances is described in the book on pages 148–149. Both the earth and the ground are then considered to be perfectly conducting. The approximation is fairly good since the frequencies are very low and the radius of the earth is very large. In this project the following spherical model is used:

- The earth has radius $R = 6367$ km and is considered to be perfectly conducting.
- The thickness h between the ground and the ionosphere is on the order of 50–90 km, and is filled with air ($\sigma_a = 0$, $\mu_r = \epsilon_r = 1$).
- The ionosphere is a spherical shell with inner radius $R + h$ and an outer radius that is very large. In the theoretical analysis it is convenient to consider the thickness of the ionosphere to be infinite. In COMSOL one may use a thickness of 500 km and apply a radiation condition on the outer sphere. The conductivity of the ionosphere is in the range $10^{-7} < \sigma < 10^{-4}$. Both ϵ_r and μ_r are one.

Try to find a thickness h and a conductivity σ such that the resonances are close to the measured ones ($f_1 = 7.83$ Hz, $f_2 = 14.3$ Hz, $f_3 = 20.8$ Hz and $f_4 = 27.3$ Hz).

Theory

Only examine the TM-waves. Use the following spherical wave expansions in the two regions

$$\mathbf{E}(\mathbf{r}) = \begin{cases} \alpha \mathbf{u}_{2l}(\mathbf{r}) + \beta \mathbf{w}_{2l}(\mathbf{r}), & R < r < R + h \\ \gamma \mathbf{v}_{2l}(\mathbf{r}) & r > R + h \end{cases} \quad (9.1)$$

The function $\mathbf{v}_{2l}(\mathbf{r})$ is the same as $\mathbf{u}_{2l}(\mathbf{r})$ but with $j_l(k_1 r)$ exchanged for $h_l^{(1)}(k_2 r)$ and k_1 exchanged for k_2 , where $k_1 = \omega/c_0$ is the wavenumber in air and $k_2 = \omega\sqrt{\mu_0(\epsilon_0 + i\sigma/\omega)}$ is the wavenumber in the ionosphere.

The boundary conditions are that the tangential component of \mathbf{E} is zero at $r = R$ and that the tangential electric and magnetic fields are continuous at $r = R + h$.