



**LUNDS**  
UNIVERSITET

Electrical and information technology

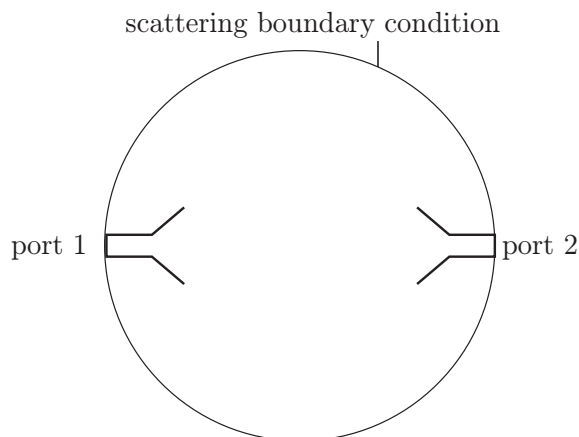
## **Projects in microwave theory 2014**

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 Wednesday, May 14. The lecture on Tuesday, May 13, 8-10 is devoted for the assignments and projects. You can then get help from Anders.

The plan is to have oral presentations Tuesday May 20 and Wednesday May 21. You sign up 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.

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 at least in the frequency band 20-30 GHz. The vias have radius 0.25 mm. You need to determine a suitable distance between vias centers. The length and width of the horn is 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 size of the feeding SIW. Also estimate the bandwidth of the antenna. You need the circle in order to limit the computational domain. 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 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  $a = 0.5$  mm. The distance between the centers of two vias should be 2 mm. The substrate has a relative permittivity of approximately  $\epsilon = 2.3$ . 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).

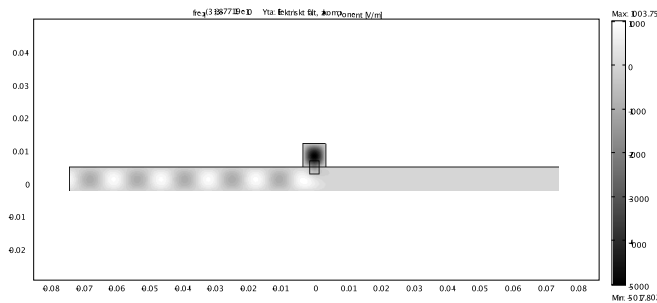
b) Design a bandstop filter using vias such that the frequency  $f = 20$  GHz is rejected.

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 2. 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.



**Figure 2:** Waveguide with bandstop filter

### 3 Silica on silicon waveguides: leakage in bends

In photonics it is possible to make integrated circuits for light directly on silicon. Instead of using microstrips, as in ordinary integrated circuits, one uses silica waveguides embedded in silicon glass. The silica waveguides have rectangular cross section. The waves are confined to the waveguide, just like it is for an optical fiber. On a circuit it is often necessary to bend waveguides in order to send signals from one point to another. The drawback is that there is a leakage of power at the bends.

Use a rectangular silica on silicon waveguide and try different radius of curvature (measured in wavelengths) for bends and different widths of the waveguide to find the ratio between the power loss by leakage and the power transported in the waveguide. In order to get simple calculations in COMSOL you can consider that the waveguide is between two perfectly conducting horizontal plates. In that case you can use 2D→Electromagnetic waves→frequency domain in COMSOL. Use the material browser in COMSOL for silica glass and silicon. The vacuum wavelength is  $1.55 \mu\text{m}$ . However, it is easier if you build a structure that should be suitable for  $1.55 \mu\text{m}$  and then change the wavelength. You are only interested in propagation

of the fundamental  $TE$  wave. At the entrance and exit of the waveguide you should use ports as boundary condition.

Help: Let the silica glass region be a square and have the entrance and exit of the waveguide at the border of the square. Let the boundary of the silica region be scattering boundary condition. It means that waves that hit that boundary will not be reflected. The entrance and exit are ports where you can use User defined port with the  $z$ -component of  $\mathbf{E}$  equal to one and the wavenumber be equal to the wavenumber in silicon. Use rectangles and circles when you build your structure. The Boolean operations are very useful.

## 4 Determination of transmission line parameters for microstrips

Analyze how to achieve the line parameters  $R$ ,  $L$ ,  $G$ , and  $C$ , as well as the characteristic impedance  $Z_0$ , by COMSOL for a microstrip line on a substrate above a ground plane. The substrate should have a low, but non-zero, conductivity and the micro strip and ground plane have large but finite conductivity. Try to find realistic values for the substrate and the microstrip. Consider micro strips with thickness much larger than the skin depth. You may also discuss how to find the line parameters when the thickness is on the order of the skin depth.

In the book there are two different methods described how to determine the line parameters (see pages 63–68 and 135–139). Use both methods and try to improve the results obtained in the book.

## 5 Microwave oven

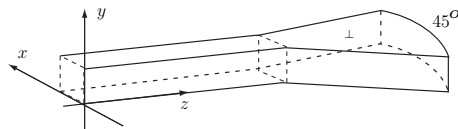
Examine a microwave oven. In particular you may examine and describe the magnetron, the waveguide from the magnetron to the oven, the oven as a resonance cavity, and the microwave filter in the door.

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 <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.

## 6 Horn antenna



Examine the electric field in a horn antenna with opening angle of  $45^\circ$ , 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.

## 7 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.

## 8 Schumann resonances

An approximate theory for the Schumann resonances is described in the book on pages 147–148. 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 region between the ground and the ionosphere has height  $h$ , which 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 use a radiation boundary. The conductivity of the ionosphere is in the range  $10^{-7} < \sigma < 10^{-4}$ . Both  $\epsilon_r$  and  $\mu_r$  are one.

Try to find a thickness  $h$  and a conductivity  $\sigma$  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

$$\mathbf{E}(\mathbf{r}) = \begin{cases} \alpha \mathbf{u}_{2l}(\mathbf{r}) + \beta \mathbf{w}_{2l}(\mathbf{r}), & R < r < R + h \\ \gamma \mathbf{v}_{2l}(\mathbf{r}) & r > R + h \end{cases} \quad (8.1)$$

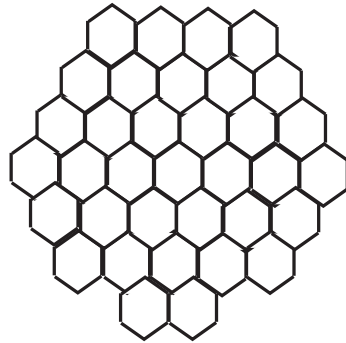
The function  $\mathbf{v}_{2l}(\mathbf{r})$  is the same as  $\mathbf{u}_{2l}(\mathbf{r})$  but with  $j_l(k_1 r)$  exchanged for  $h_l^{(1)}(k_2 r)$  and  $k_1$  exchanged for  $k_2$ , where  $k_1 = \omega/c_0$  is the wavenumber in air and  $k_2 = \omega \sqrt{\mu_0(\epsilon_0 + i\sigma/\omega)}$ 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

## 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 mech beyond the meshes given in Physics-controlled mesh.

## 9 Microwave lens



The company Telewide in Skellefteå manufactures a special kind of microwave lens antenna (<http://www.telewide.se/pdf/Techpres.pdf>). The lens consists of a large number of metallic waveguides with identical cross-sections. When the wave passes through the waveguide it is phase shifted  $k_z L$  where  $L$  is the length of the waveguide. This phase shift is used to compensate the extra path length from the opening of the waveguide to the focal point. All of the waves from the different waveguides should be in phase at the focal point, in order to receive a strong signal, a.

Design a microwave lens with a diameter of 50 cm and a focal length of 68 cm. The lens is made of thin plastic sheets with a thin metallic coating. The lens is used in the interval 10.7–12.75 GHz. Try to design the lens such that the focal length is 68 cm at the frequency 11.5 GHz. You may try two different type of cross sections of the waveguides; squares and hexagons. In that way they can be densely packed and the antenna performance is independent of polarization. Use COMSOL to determine  $k_z$ . Also examine the other frequencies in the frequency band. Is there a well defined focal length for each frequency?

Give a detailed description of your antenna and attach a picture of the electromagnetic field in the waveguide.

Also make a 2-D version of the antenna in COMSOL. Send in a plane wave and see if you can get a focusing effect.