Microtechnique: 2025-2026 Master Semester 1
Fundamental of Integrated Photonic Components

Assignment #4
Coupled mode waveguides

IMPORTANT NOTE: Parametrize the geometry shown in Figures 1 and 2. You will need to adapt the geometry for Problem 1 and Problem 2.

Problem 1 (50 points):

Consider two coupled ridge waveguides (named $wg1$ and $wg2$ in the sketches) with the geometrical parameters indicated in Figure 1:

Parameter	Value
W	4 μm
H	3 μm
H_{top}	1 μm
L	3 μm
W_{wg1}	0.35 μm
W_{wg2}	0.35 μm
h_{wg}	0.25 μm
$dist$	0.12 μm/0.18 μm

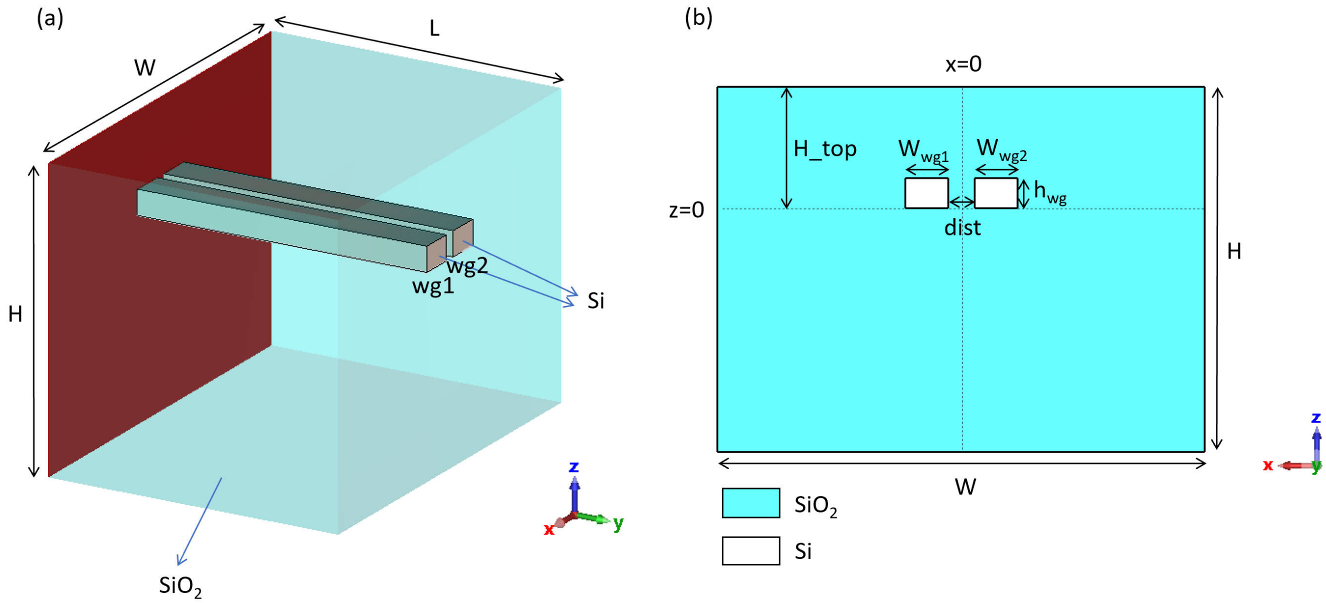


Figure 1: (a) Perspective view and (b) front view of two coupled waveguides $wg1$ and $wg2$.

Building the model:
(1) Units/Settings: "Dimension": µm; "Wavelength/Freq": µm/THz; "Settings defined": wavelength.
(2) Material: For silicon, use the material ***Silicon (lossy)*** *from CST material library. For silicon oxide use the attached file (****SiO2.txt****).*
(3) Align the coordinate system as in Figure 1. Before you start building the geometry, choose ***View/Select View/Use z-axis up views****.*

Place a port on the face marked red in Figure 1a) and solve a) for the two distances below.

1. dist = 0.12 μm
2. dist = 0.18 μm

a) Run a simulation in the frequency domain to obtain possible port modes at a single wavelength of 1550 nm (set the wavelength range 1.55 um to 1.551 um in CST; mesh:automatic, model set to 30, background set to 1; choose adaptive mesh refinement). Report the 2D mode profiles of the first two modes (display the x component of the electric field in arrow and x component contour visual mode in the x–z plane) and their effective refractive index (n_{eff}). Calculate the beating length (L_{beat}) for the extracted n_{eff} (**30 points**).

In the following we will simulate light coupling from $wg1$ to $wg2$. In order to avoid reflection from the end of the waveguides, we need to refine the model to contain bends at the end of each waveguide, as shown in the top view in Figure 2 with $\delta = 0.5\ \mu m$. *Check the tutorial at the end of the document for suggestions on placing the spacing δ and the bend at the end of the waveguides.*

Construct a second geometry with L = $2L_{beat}$ and place two ports as shown in Fig. 2. Run a simulation in the time domain in a wavelength range of 1500-1650 nm (set 1 mode for both waveguide ports, accuracy to -30 dB, mesh: near to model to be 5, others to be 1, unclick "adaptive mesh refinement"). Plot the following for the two distances below:

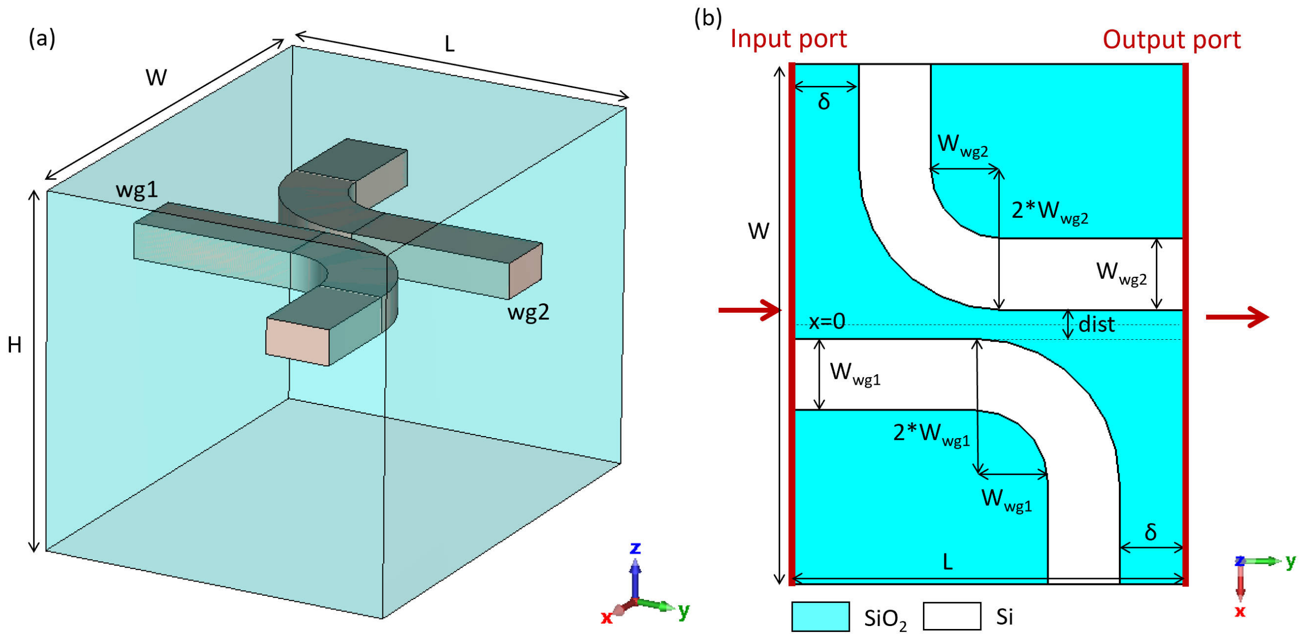


Figure 2: (a) Perspective view and (b) Top view of two coupled waveguides with a configuration to couple into $wg1$ and couple out from $wg2$.

1. dist = 0.12 μm
2. dist = 0.18 μm

b) S21 or transmission from port 1 to port 2 as a function of frequency. What is the frequency at which the transmission is maximum? Name it f_{Tmax}. (**10 points**)

c) Z-cut of the electric field (x-component, real part) at f_{Tmax} at the center of the waveguides ($z = \frac{h_{wg}}{2}$) (**10 points**)

Solution

a) The port modes for distances of $0.12\mu m$ and $0.18\mu m$ are shown in figures 3 and 4, respectively.

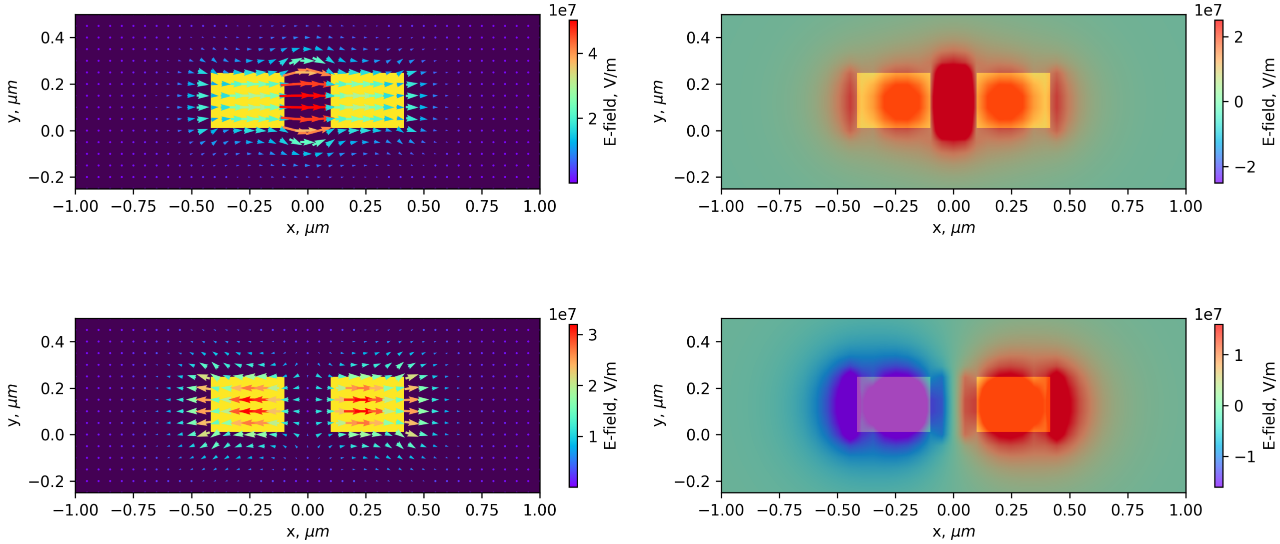


Figure 3: First row: arrow (left panel) and contour (right) plots of the mode 1 (with effective refractive index $n^{(1)}_{eff} \approx 2.099$) for a distance of $0.12\mu m$. Second row: the same for mode 2 ($n^{(1)}_{eff} \approx 1.956$).

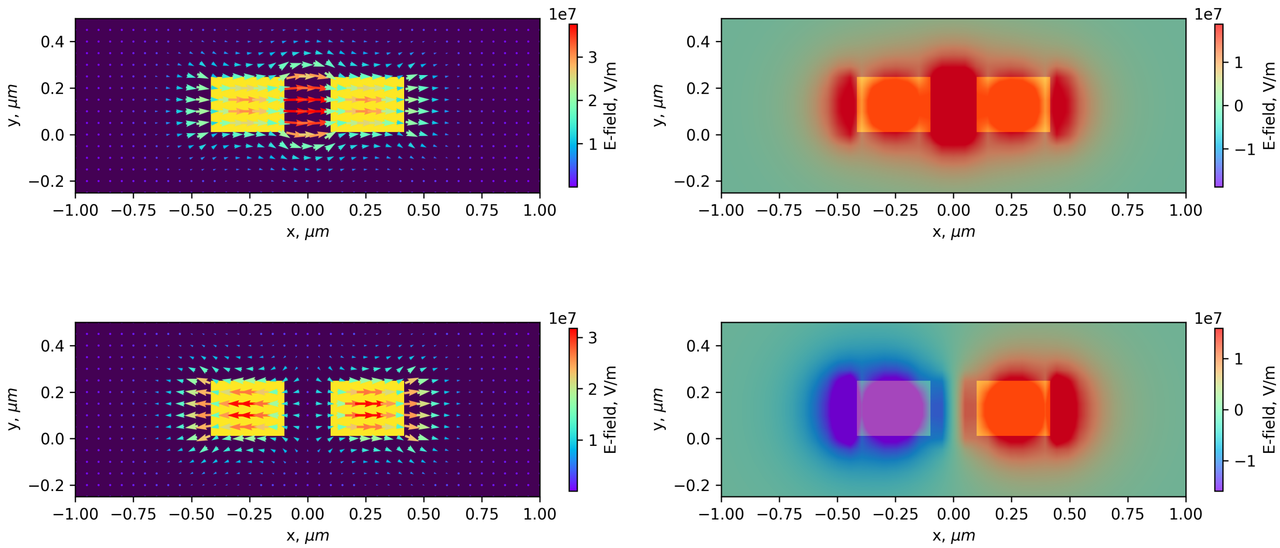


Figure 4: First row: arrow (left panel) and contour (right) plots of the mode 1 (with effective refractive index $n^{(1)}_{eff} \approx 2.06$) for a distance of $0.18\mu m$. Second row: the same for mode 2 ($n^{(1)}_{eff} \approx 1.969$).

The beating length can be calculated using the formula below:

$$L_{beat} = \frac{\lambda}{2(n^{(1)}_{eff} - n^{(2)}_{eff})} \tag{1}$$

where $n_{eff}^{(i)}$ is the effective refractive index of the mode i. The calculated beating lengths are shown in figure 5.

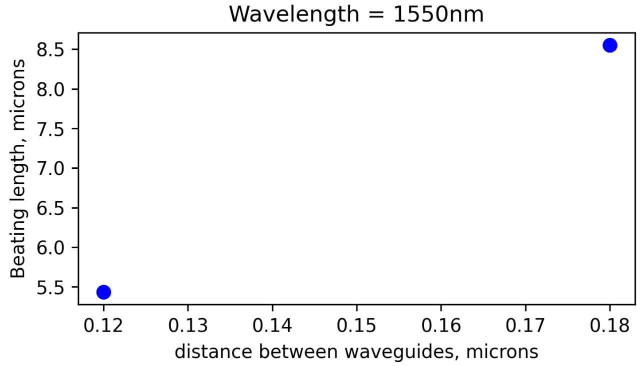


Figure 5: Calculated beating length L_{beat}

b) The simulated transmission (in dB units) is presented in figure 6.

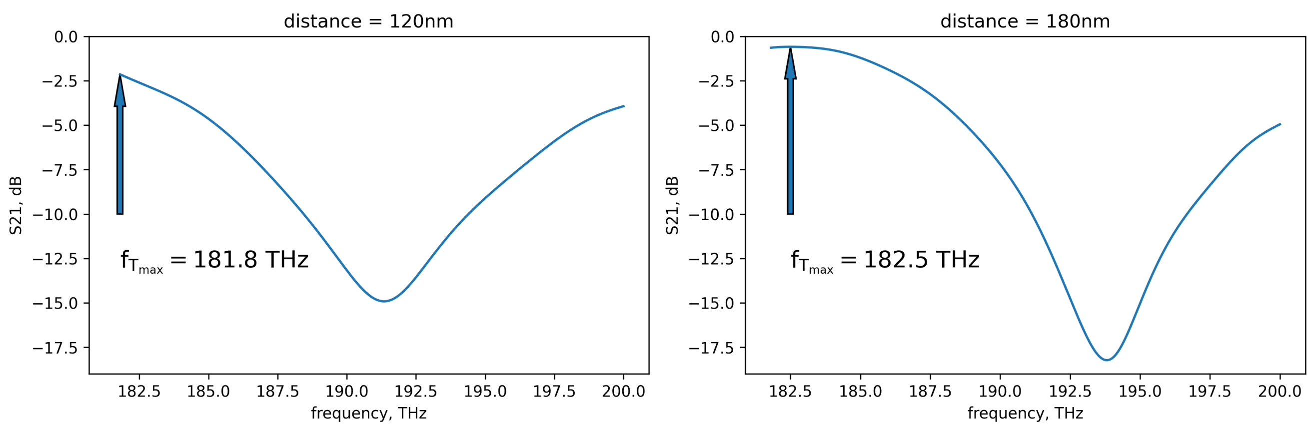


Figure 6: Simulated S21 parameter as a function of frequency for two distances. Arrows indicate the frequencies at which the S21 is maximum.

c) Z-cuts of the electric fields for both distances are presented in figures 7 and 8.

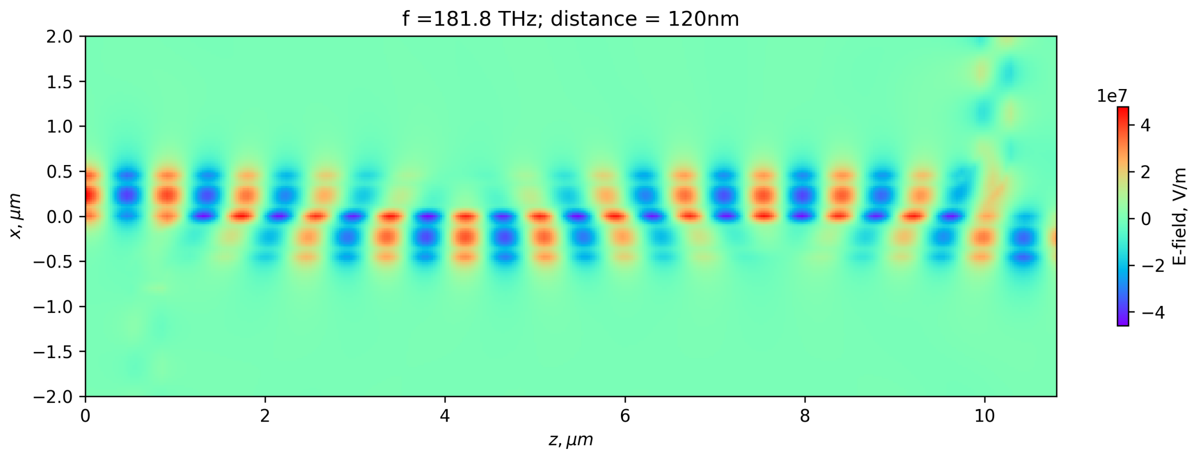


Figure 7: The Z-cut of the electric field (x-component, real part) for dist = 120 nm. The oscillation of the field between wg1 and wg2 happening with a period of $\approx 5.5\mu m$ matching the previously calculated L_{beat}.

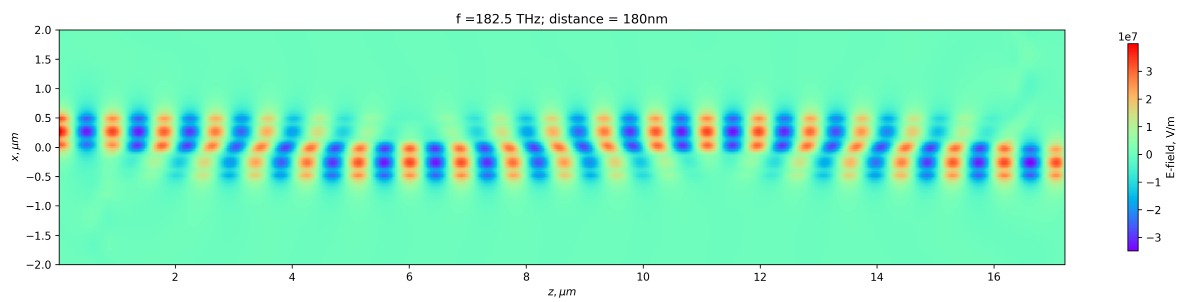


Figure 8: The Z-cut of the electric field (x-component, real part) for dist = 180 nm. The oscillation of the field between wg1 and wg2 happening with a period of $\approx 8.5\mu m$ matching the previously calculated L_{beat}.

Problem 2 (50 points):

Consider a similar structure as in problem 1, with geometry as shown in Figure 1, but where the two waveguides have different widths:

Parameter	Value
W	4 μm
H	3 μm
H_{top}	1 μm
L	3 μm
W_{wg1}	0.35 μm
W_{wg2}	0.73/0.85 μm
h_{wg}	0.25 μm
$dist$	0.12 μm

a) Run a simulation in the frequency domain for each waveguide separately (once only for $wg1$ and once only for $wg2$) at 1550 nm and calculate only the first three port mode for each waveguide. Report the corresponding

2D mode profiles (x component, contour visual mode) and their effective refractive indices (n_{eff}). Provided we want to couple the fundamental in $wg1$ to the first excited mode in $wg2$, which width of $wg2$ is more suitable and why? (**20 points**)

b) Run a simulation of the system containing the two waveguides, selecting the optimized waveguide width you found in a). Report the port modes (x component, contour visual mode) and their effective refractive index, similar to Problem 1a). Calculate the beating length (L_{beat}). (**10 points**)

Now we will simulate coupling of the fundamental in $wg1$ to the first excited mode in $wg2$. Using the same model you built for Problem 1 (Figure 2) and setting L = $10L_{beat}$, simulate the two coupled waveguides in the time domain (set 1 mode for both waveguide ports, set the accuracy and mesh the same as Problem 1b) and plot the following:

c) Launch the fundamental into $wg1$ and report the Z-cut of the electric field (x-component, real part) at 1550 nm at the center of the waveguides ($z = \frac{h_{wg}}{2}$). Plot the electric field profile at the end of the $wg2$ through field monitor at 1550 nm and compare with all modes calculated from the port and check the match. (**10 points**)

d) Launch the fundamental into $wg2$ and report the Z-cut of the electric field (x-component, real part) at 1550 nm at the center of the waveguides ($z = \frac{h_{wg}}{2}$). (**10 points**)

Solution

a) The 3 first three modes of each waveguide separately are shown in figure 9.

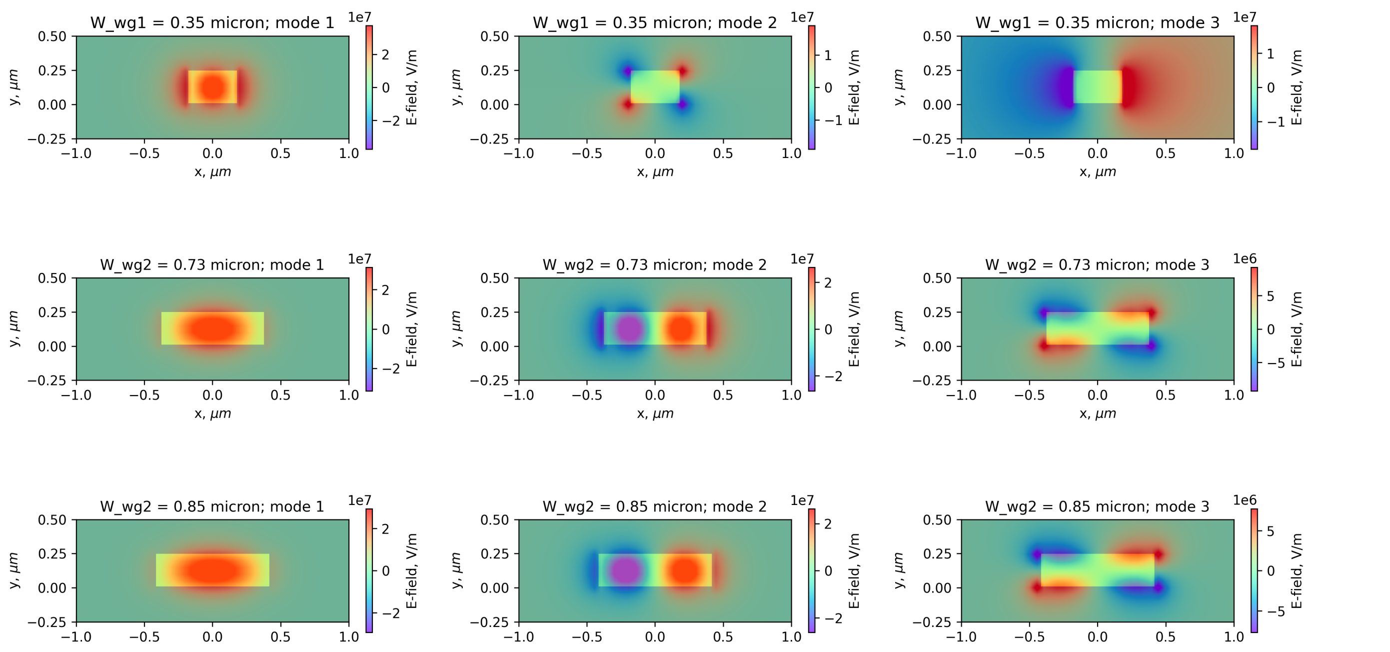


Figure 9: First row: contour plots of the first three excited modes of the wg1 (with a width of $0.35\mu m$). Second row: contour plots of the first three excited modes of the wg2 (with a width of $0.73\mu m$). Third row: contour plots of the first three excited modes of the wg2 (with a width of $0.85\mu m$).

To find out which width of the waveguide 2 is more suitable for coupling the 1st mode of the waveguide 1 to the 2nd mode of the waveguide 2, we plot the effective refractive indices of all modes shown in figure 10.

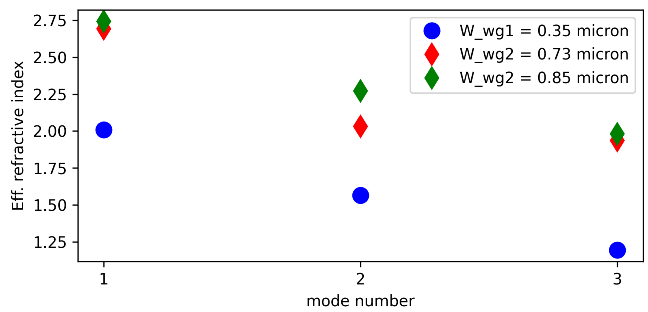


Figure 10: Effective refractive indices for the modes reported in figure 9.

The difference in the effective refractive indices between mode 1 of waveguide 1 and mode 2 of waveguide 2 is smaller for the width of $0.73\mu m$. Therefore, this width should be chosen for further simulations.

b) The mode profiles of the first three modes for the coupled system with a waveguide 2 width of $0.73\mu m$ is shown in figure 11. Note that the first mode corresponds to the fundamental mode of the waveguide 2 alone; therefore, we have to consider only modes 2 and 3 to calculate the beating length! The calculated beating length then is $L_{beat} = \frac{\lambda}{2(n_{eff}^{(2)} - n_{eff}^{(3)})} \approx 7.5\mu m$.

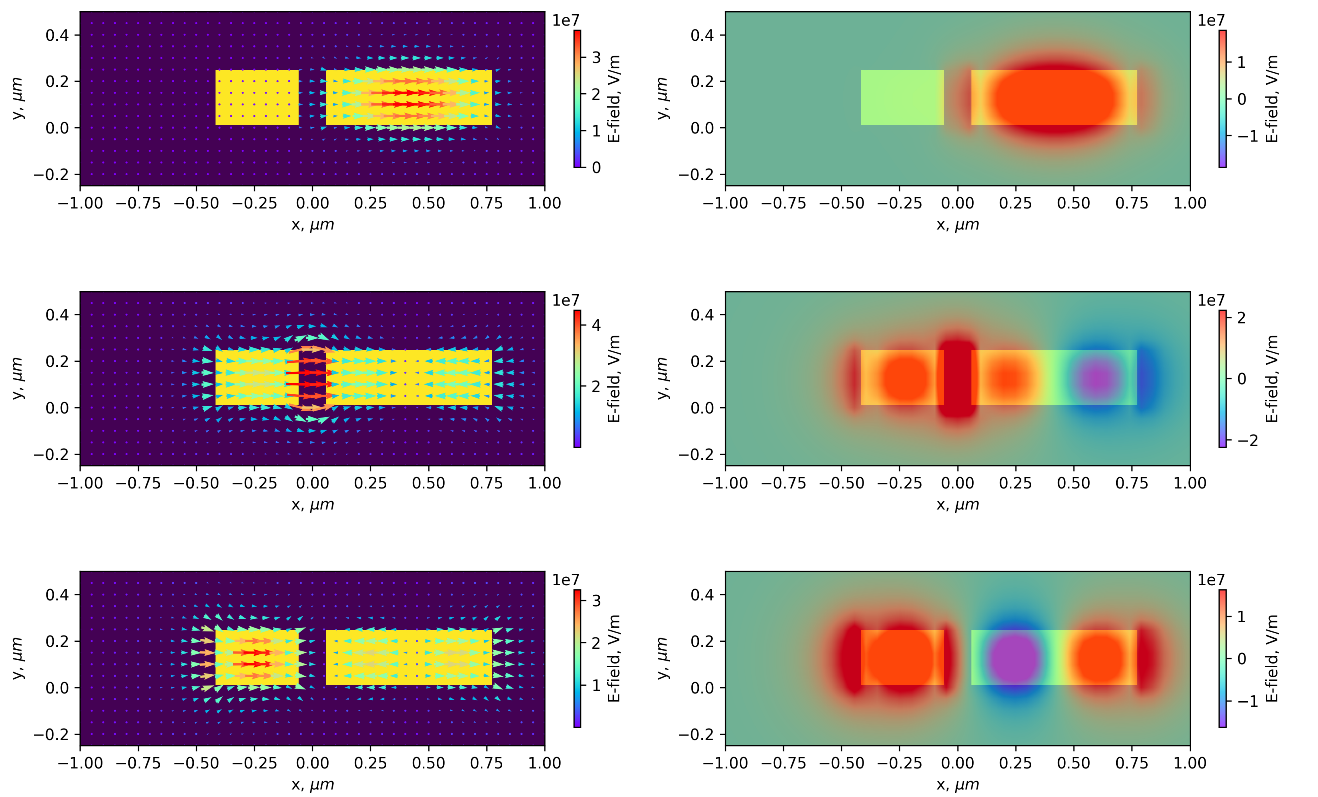


Figure 11: Mode profiles of the first three modes of the coupled system. Arrow plots (left) and contour plots (right) correspond to modes 1–3 shown from top to bottom.

c) The simulation results when $wg1$ was excited with the fundamental mode are shown in the figure 12. The power is oscillating between $wg1$ and $wg2$ with a period of $\approx 15\mu m$, in agreement with the calculation above.

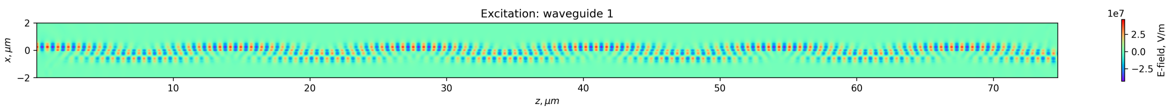


Figure 12: The Y-cut of the x component of the electric field while excited from $wg1$ with mode 1.

To further verify that the coupling indeed happened to the mode 2 of the $wg2$, the electric field distribution at the end of the $wg2$ is shown in the figure 13, matching the field distribution shown in figure 9.

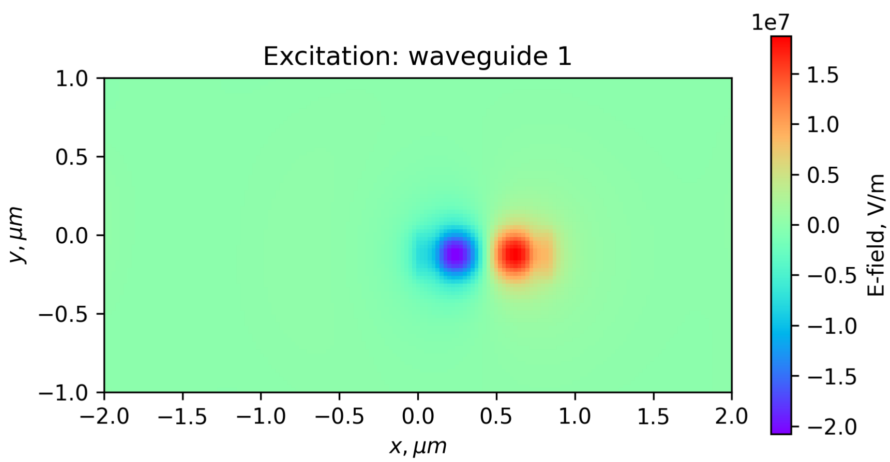


Figure 13: The Z-cut of the x component of the electric field while excited from $wg1$ with mode 1.

d) The simulation results when $wg2$ was excited with the fundamental mode are shown in the figure 14. Indeed, there is no coupling between waveguides in this case.

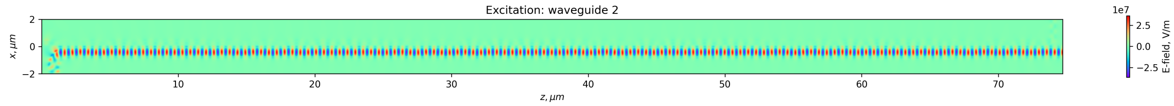
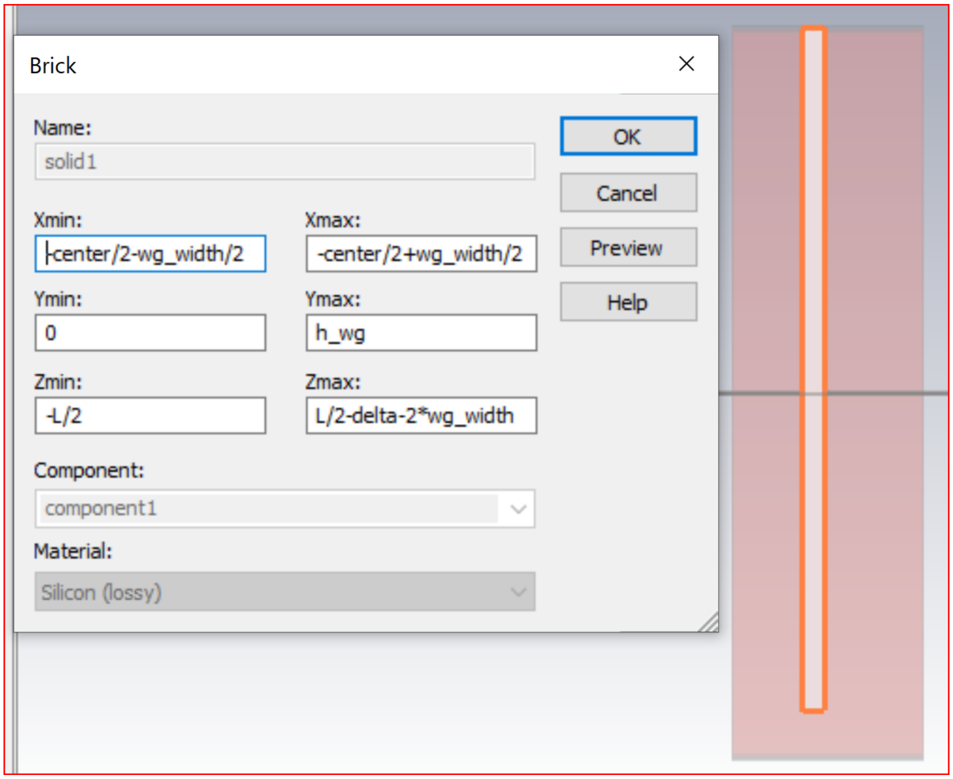


Figure 14: The Y-cut of the x component of the electric field while excited from $wg2$ with mode 1.

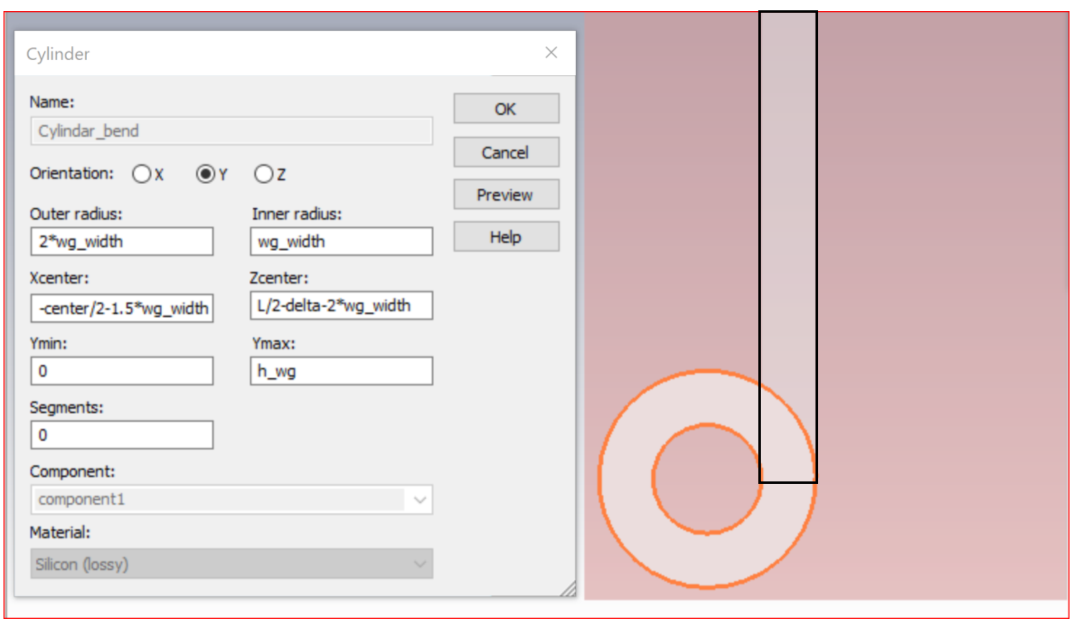
Tutorial to create the bend at the end of a waveguide

1-Make a waveguide. Put the end of the waveguide until $\frac{L}{2} - \delta - 2 \times W_{wg1}$

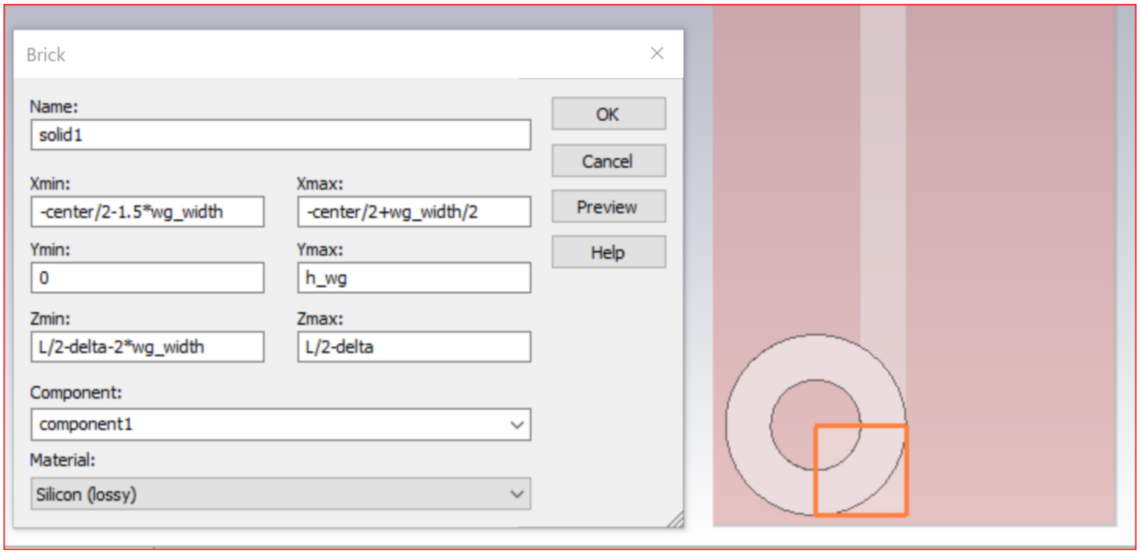
center is dist+W_{wg1}



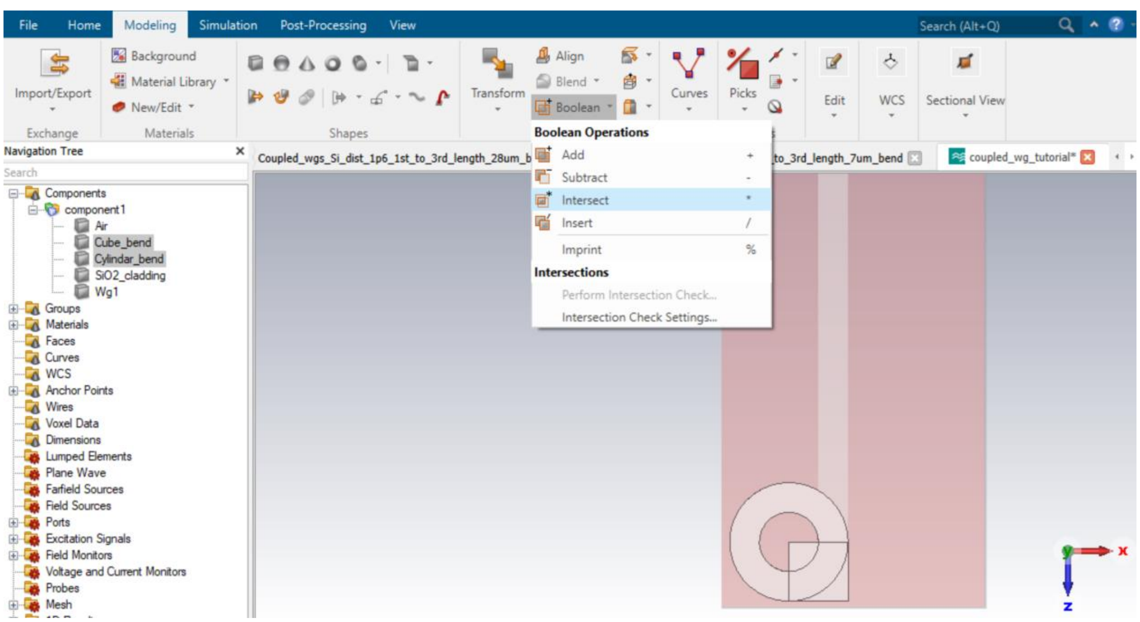
2-Create a Cylinder from Modeling>shapes>Cylinder with the following parameters:



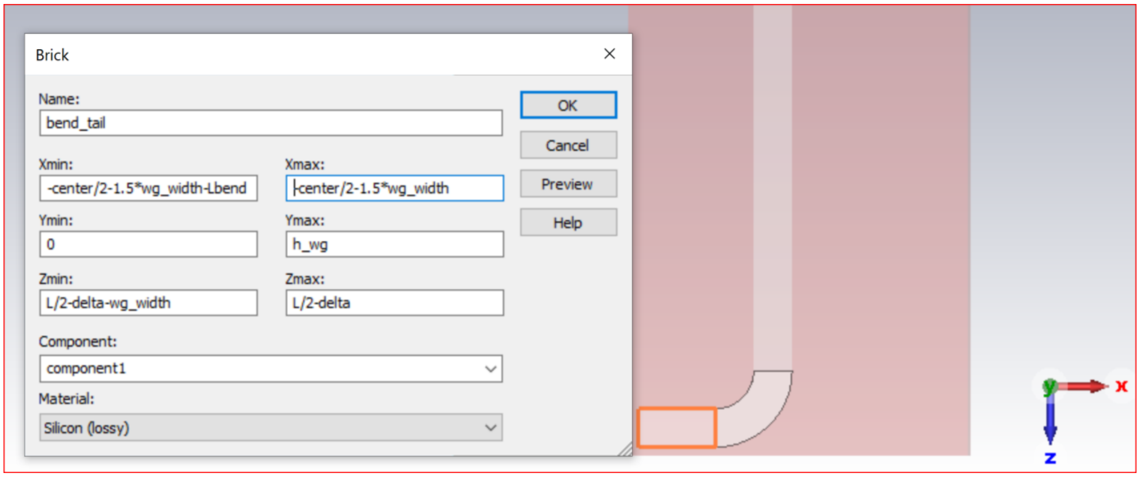
3-Create a Brick with the following parameter:



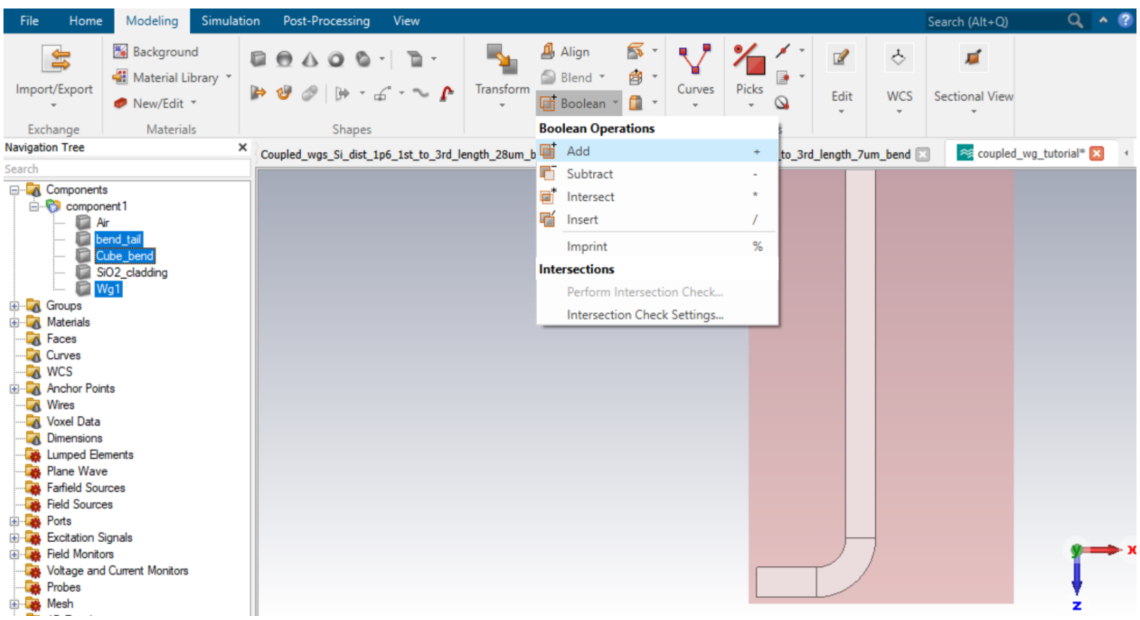
4- Intersect the cube and the cylinder via *Boolean Operations* in *Modeling* tab



5-Create another Brick for the tail of the bend with the following parameters:



6-Merge the waveguide, the curve, and the tail using *Add* in *Boolian Operations:*



7-To have the waveguide inside the cladding, make a copy of waveguide (Wg1_1 in figure). Then, use the *subtract* in *Boolean Operations*. First select the cladding, then choose subtract from the Boolean Operations and finally choose the waveguide (Wg1_1) and then press Enter for subtracting waveguide from the cladding.