Exercises

Mach-Zehnder Interferometer with Ansys Lumerical Software

Dr. Prabhav Gaur, Dr. Andrew Grieco, Karl Johnson, Dr. Peter Ilinykh, Prof. Saharnaz Baghdadchhi, Prof. Yeshaiahu Fainman, University of California San Diego

Edited by Harriet Parnell in the Ansys Academic Development Team

education@ansys.com

Ansys Software Used

This resource uses Ansys Lumerical MODE™ optical waveguide design tool.

Summary

This exercise explores the Mach-Zehnder Interferometer using Ansys Lumerical MODE tool. It was originally developed by Dr. Prabhav Gaur, Dr. Andrew Grieco, Karl Johnson, Dr. Peter Ilinykh, Prof. Saharnaz Baghdadchhi, Prof. Yeshaiahu Fainman for the *ECE 184: Optical Information Processing and Holography* course at the University of California San Diego.

Table of Contents

1. Objective

Design a Mach-Zehnder interferometer and analyze its performance using Ansys Lumerical software.

2. Background

A Mach-Zehnder interferometer is a device that converts phase modulation into intensity modulation using interference. A schematic of a device is shown in Figure 1.

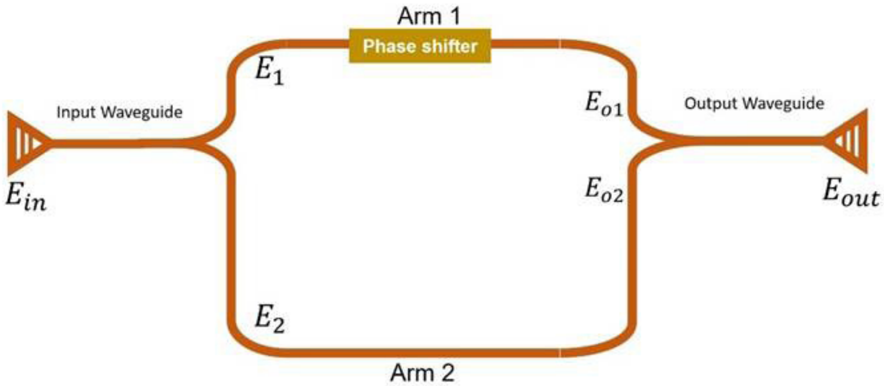


Figure 1. Schematic of MZI

MZI is formed by first using a Y-branch to split the light wave into two optical paths. One of the arms has a phase shifter. The two branches are combined using a second Y-branch to interfere the two fields. Assume a propagating mode in the input waveguide characterized by an electric field E_{in}. After the Y-branch beam splitter, the mode is split into two fields, E_1 in arm 1 and E_2 in arm 2. The intensity of each field is half of the intensity at the input waveguide. Both fields propagate along the arms, acquiring corresponding phase before the output:

$$E_{oi} = E_1 e^{i\beta_i L_i} = \frac{E_{in}}{\sqrt{2}} e^{i\beta_i L_i} \;\; with \;\; i = \{1,2\}$$

where $\beta_i = kn_{effi} = (2\pi/\lambda)n_{effi}$ is the propagation constant of the mode in the arm i of length L_i with an effective index n_{effi}. Note that the propagation constant can be a complex value in the presence of loss (which experimentally is always the case):

$$\beta(\lambda) = \frac{2\pi}{\lambda} n_{eff_i} + i\frac{\alpha}{2}$$

where α is the propagation loss per unit length.
The field at the output waveguide is:

$$E_{out} = \frac{1}{\sqrt{2}}(E_{o1} + E_{o2}),$$

And the intensity is therefore:

$$I_{out} = \frac{1}{2}|E_{o1} + E_{o2}|^2 = \frac{I_{in}}{2}\left[1 + \cos\left(\frac{2\pi}{\lambda}\left(n_{eff1}L_1 - n_{eff2}L_2\right)\right)\right]$$

Thus, the output intensity of MZI varies sinusoidally as function of a wavelength and optical path difference between the interferometer's arms, $n_{eff1}L_1 - n_{eff2}L_2$.

The period of oscillation is called the free-spectral range (FSR) and reads in the spectral domain as:

$$\Delta\lambda_{FSR} = \frac{\lambda^2}{n_g|L_1 - L_2|},$$

where $n_g = \partial\beta/\partial k \approx n_{eff} - \lambda(\partial n_{eff}/\partial\lambda)$ is the group index. It is interesting to note that the more the MZI is unbalanced ($L_1 \neq L_2$), the more sensitive it will be to the wavelength as the FSR becomes smaller.

3. Ansys Lumerical Simulation Part

You will analyze MZI performance using Lumerical software; the corresponding files will be provided.

3.1 Step 1.

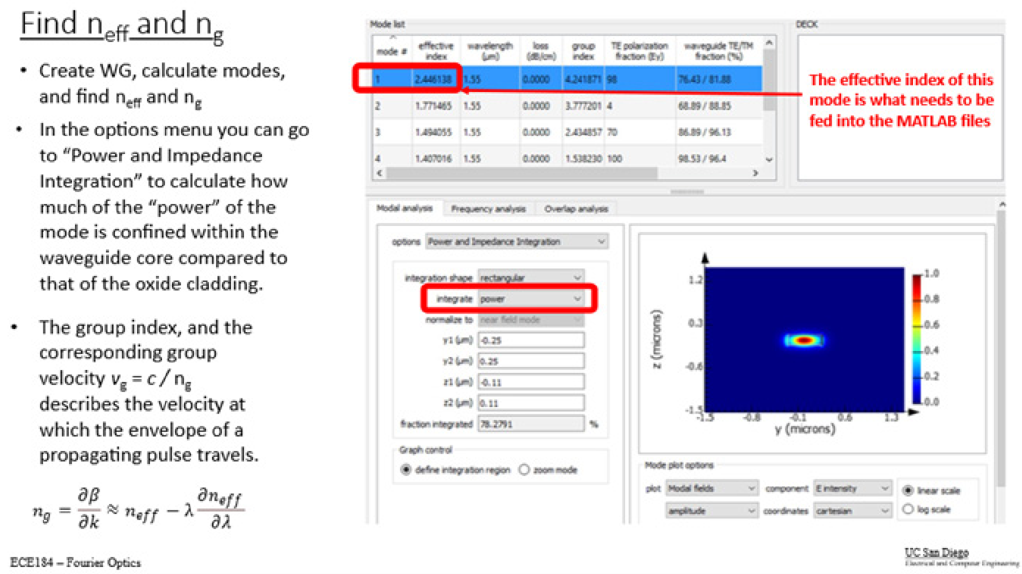
(simulation file: “CalculatingEffectiveIndexGroupIndex.lms”)
In order to calculate the propagation constant of the MZI arms, you need to know the effective index of the waveguides used to create the MZI arms.

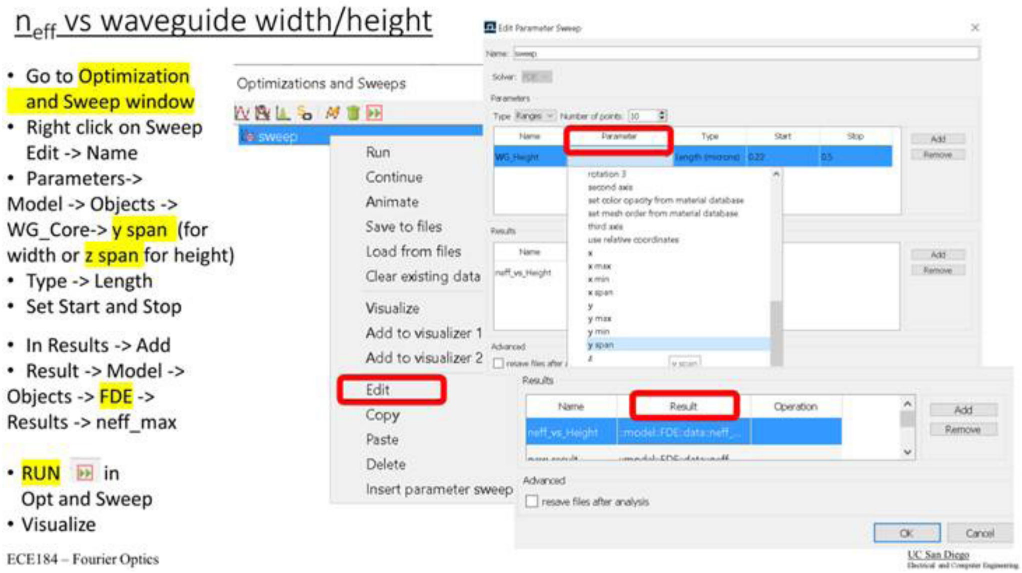
In this file, you can calculate the *effective index*, *group index*, and the *confinement factor* of the mode in the waveguide core compared to that of the cladding oxide. Additionally, you can run a sweep to change the waveguide width and height to see their effect on the effective index.

Questions:

1. For the fundamental TE mode, what is the effective index of a 220nm tall and 500nm wide waveguide at λ=1550nm? at 1510nm? How does the effective index behave vs. wavelength?
2. What is the mode confinement factor of the fundamental TE mode at =1550nm? What happens to the confinement factor if we choose a smaller wavelength?
3. What is the group index for λ=1550nm? for 1510nm?
4. Does your waveguide geometry support a TM fundamental mode? If so, what is the effective index at λ=1550nm?
5. Plot the relationship between group index (n_g) and effective index (n_{eff}).
6. Does changing the width of the waveguide affect the effective index?
   What about the group index?

Note: Use sweep in Optimization and the Sweep window (see snapshots below).





7. Do you see an increase/decrease in the effective index by increasing the width?
8. Do the same by changing the height of the waveguide. How does the effective index behave when changing the waveguide height?

3.2 Step 2.

(simulation file: "ECE184_MZI_Transmission.lsf"):

In this numerical simulation, you can plot the transmission spectra of a lossless Mach-Zehnder interferometer for a given FSR and group index.

Questions:

1. Use the group index found in Step 1 and L1 = 610µm, L2 = 710µm to calculate FSR for λ=1550nm.
2. Plot the transmission spectrum for this FSR. Use wavelength range 1500 – 1550 nm.
3. What is the mean value of the extinction ratio (Tmax/Tmin) ?
4. Plot the relationship between ΔL and FSR?
5. Plot the relationship between neff and beta for a wavelength range of 1500 to 1550nm
6. How does the transmission spectrum change as a function of FSR?

3.3 Step 3.

(simulation file: “ECE184_MZI_Transmission_withLoss.lsf”):

In this numerical simulation, you can choose the lengths of the MZI arms, and additionally, you can introduce loss into the system and see the effect of that on FSR, extinction ratio, and transmission spectra.

Questions:

1. Choose loss values of 1dB, 10dB, 1000dB, and plot transmission spectra.
2. What happens to the transmission spectra when you introduce loss?
3. What is the effect of loss on the extinction ratio?
4. Plot the transmission spectrum for a balanced MZI when L1 = L2.
5. How does the plot of the beta vs neff change when you introduce loss?
6. What happens to the transmission spectrum if the y-branch split of the MZI is not 50-50?
7. What happens if you introduce loss only to one arm of MZI but not to another?

Use and Reproduction

The content used in this resource may only be used or reproduced for teaching purposes; and any commercial use is strictly prohibited. The full Academic Terms & Conditions can be found using this link.

Document Information

This case study is part of a set of teaching resources to help introduce students to topics related to fluids.

Ansys Education Resources

To access more undergraduate education resources, including lecture presentations with notes, exercises with worked solutions, microprojects, real life examples and more, visit www.ansys.com/education-resources.

Feedback

Here at Ansys, we rely on your feedback to ensure the educational content we create is up-to-date and fits your teaching needs.

Please click the link here out a short survey (~7 minutes) to help us continue to support academics around the world utilizing Ansys tools in the classroom.

ANSYS, Inc.
Southepointe
2600 Ansys Drive
Canonsburg, PA 15317
U.S.A.
724.746.3304
ansysinfo@ansys.com