Design and Implementation of a Mach-Zehnder Interferometer for Wavelength Division Multiplexing

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Abstract

This project focuses on designing and implementing a Mach-Zehnder Interferometer (MZI) for wavelength division multiplexing (WDM) applications. The interferometer is designed for 25 GHz channel spacing and operation in the 1310 nm wavelength band. The project includes theoretical analysis, circuit simulation using Lumerical INTERCONNECT, chip layout design, and performance evaluation. Simulation and experimental results are compared to validate the design.

I. Introduction

With the growing demand for high-speed optical communication, WDM has become a critical technology for increasing data transmission efficiency. This project aims to design and characterize an MZI-based multiplexer for integrating multiple optical channels into a single fiber. The MZI is optimized to achieve minimal insertion loss and high transmission efficiency.

II. Theory and Simulation

A. Theoretical Background

The MZI is an essential component in WDM systems, enabling optical signal filtering and multiplexing. It operates based on interference between two optical paths with different lengths. The free spectral range (FSR) of the interferometer is given by:

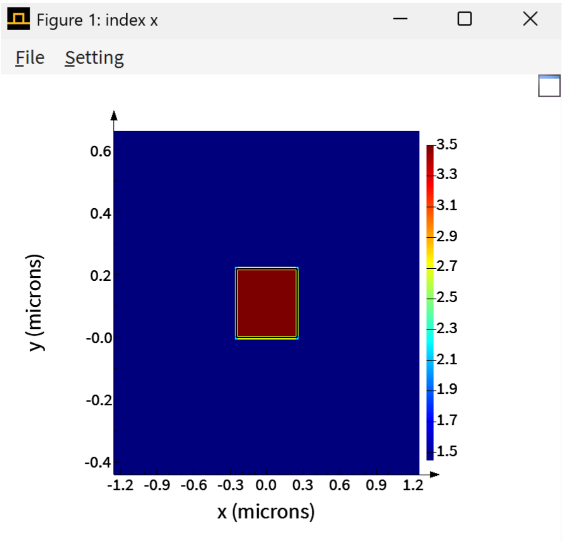
$$FSR = \frac{c}{n_g \Delta L}$$

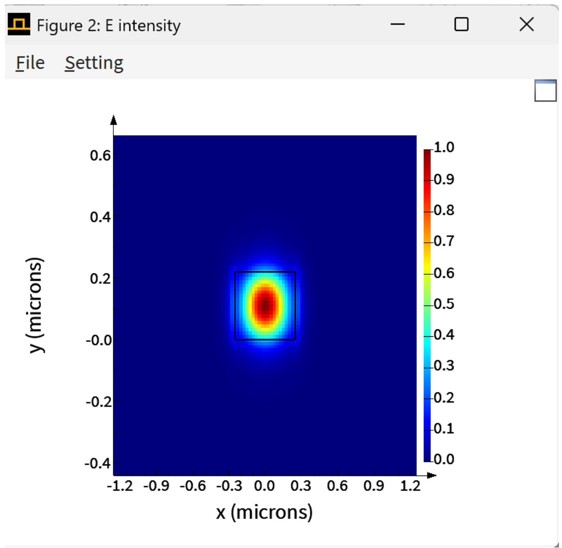
where cc is the speed of light, ngn_g is the group index of the waveguide, and ΔL\Delta L is the path length difference.

B. Simulation Approach

Simulations were conducted using Lumerical INTERCONNECT to model the transmission characteristics of the MZI. Key parameters include:

- Waveguide properties (effective index, group index, propagation loss)
- Directional coupler splitting ratio (50/50)
- Path length difference ΔL\Delta L to achieve 25 GHz channel spacing
- Mask layout design constraints

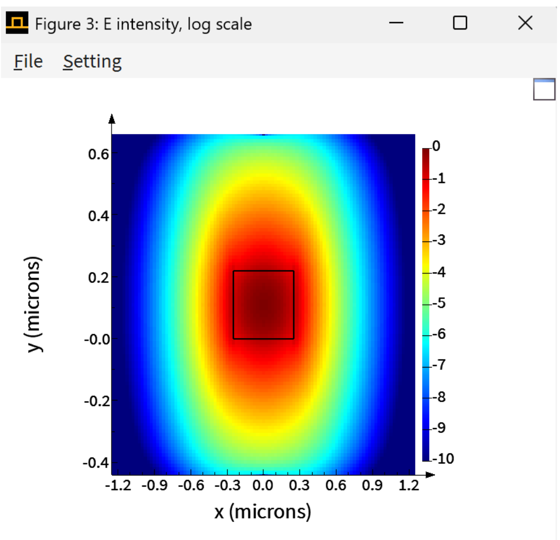




Eigensolver Analysis

Mode list

mode #	effective index	wavelength (µm)	loss (dB/cm)	group index	TE polarization fraction (Ex)	waveguide TE/TM fraction (%)	effec (µ
1	2.716522+1.529197e-09i	1.31	0.00063707	4.181021+3.462133e-09i	99	82.54 / 83.82	0.134173
2	2.164928+1.480281e-09i	1.31	0.00061669	4.695887+4.949953e-09i	4	60.18 / 91.08	0.230239
3	1.823261+1.507214e-09i	1.31	0.00062791	4.717190+7.920606e-09i	87	60.99 / 90.58	0.27606



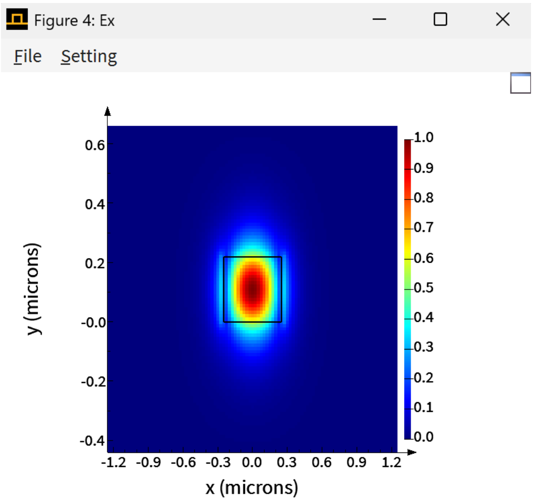


Figure 4: Ex
File Setting
y (microns)
x (microns)
0.6 0.4 0.2 -0.0 -0.2 -0.4
-1.2 -0.9 -0.6 -0.3 0.0 0.3 0.6 0.9 1.2
1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0

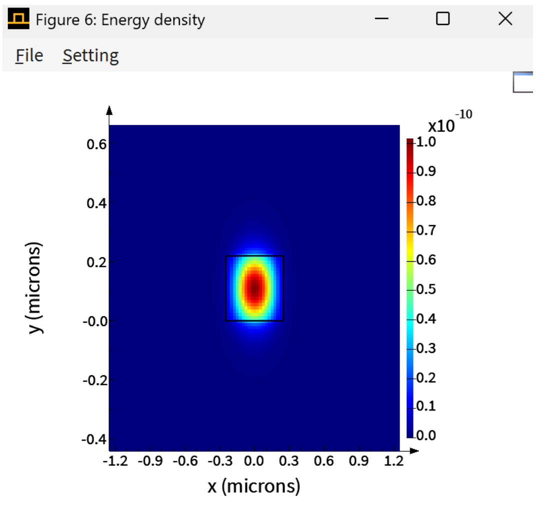


Figure 6: Energy density
File Setting
x10^-10
y (microns)
x (microns)
0.6 0.4 0.2 -0.0 -0.2 -0.4
-1.2 -0.9 -0.6 -0.3 0.0 0.3 0.6 0.9 1.2
1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0

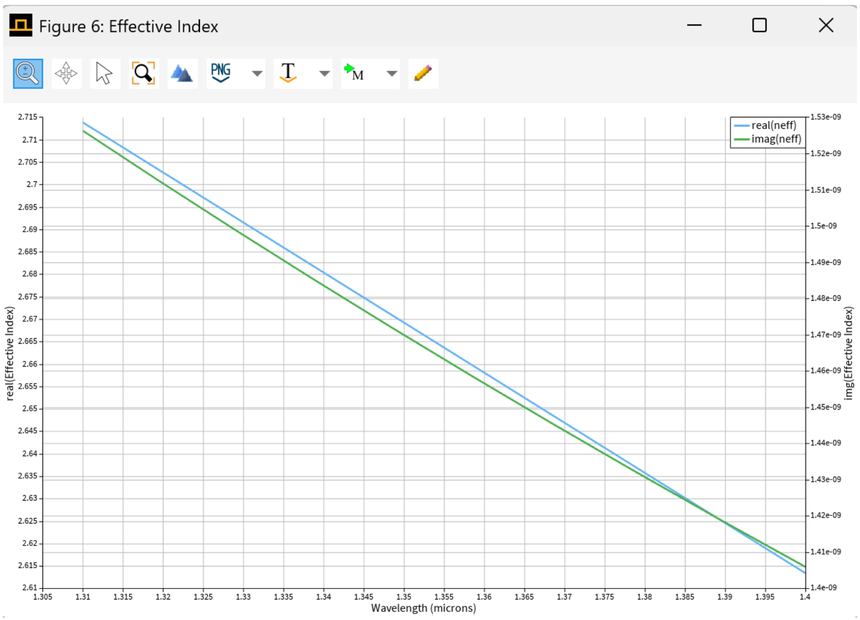


Figure 6: Effective Index
real(neff)
imag(neff)
real(Effective Index)
imag(Effective Index)
Wavelength (microns)

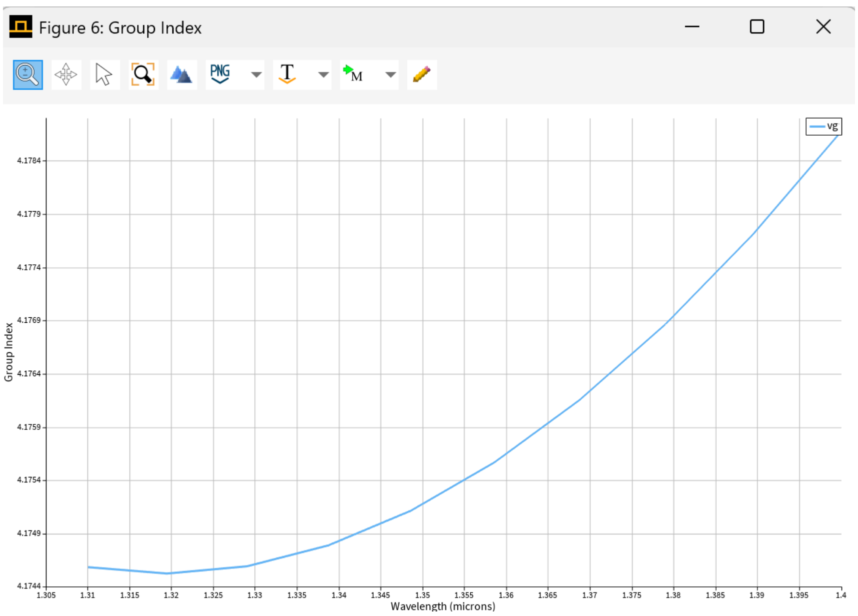
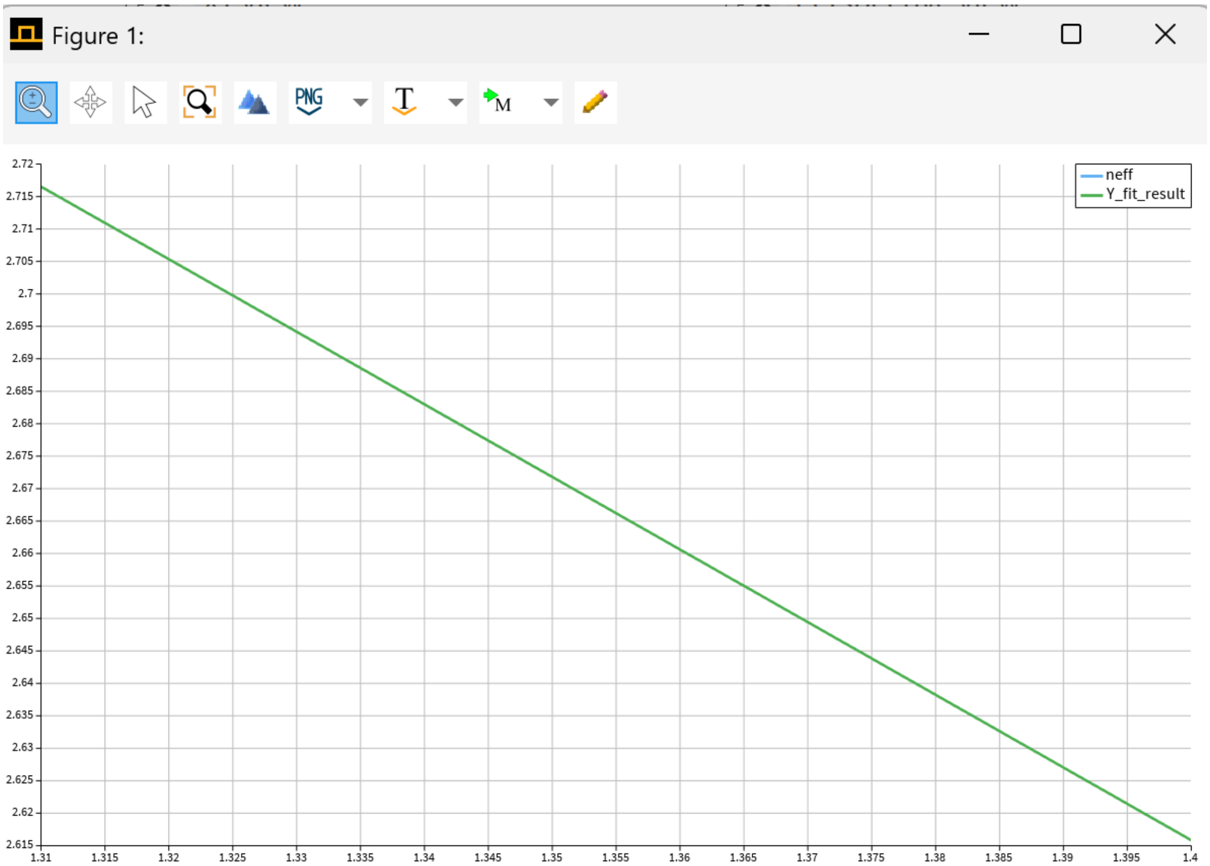


Figure 6: Group Index
vg
Group Index
Wavelength (microns)



III. Design and Implementation

A. Design Objectives

B. Design Methodology

C. Chip1 Layout

The preliminary layout of Chip 1 is shown in below figure. It features multiple grating couplers for optical input and output, as well as an optimized waveguide structure designed to support efficient signal processing.

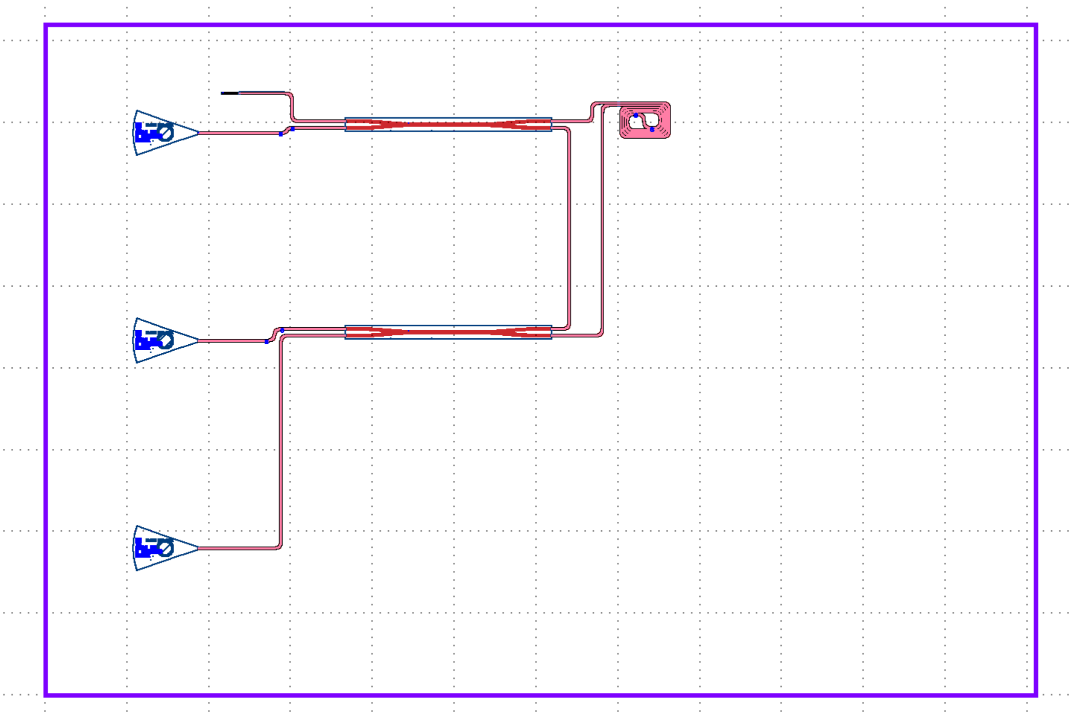


Figure: Draft layout of Chip 1 designed for the ELEC413 Project

D. Chip2 Layout

The draft layout of Chip 2 is shown in below figure. It consists of multiple waveguides with carefully designed bends and couplers to minimize optical loss while maintaining a compact footprint. One input waveguides on the left receive laser signals, and three output grating couplers are used to extract the processed signals.

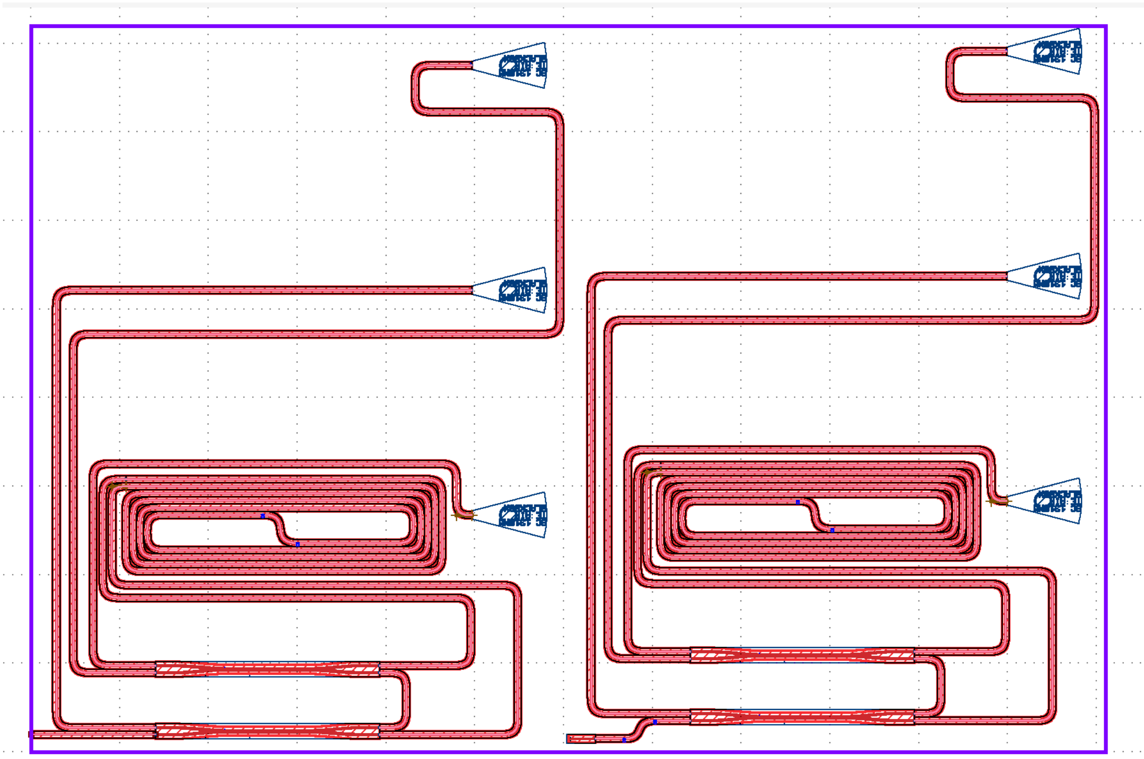
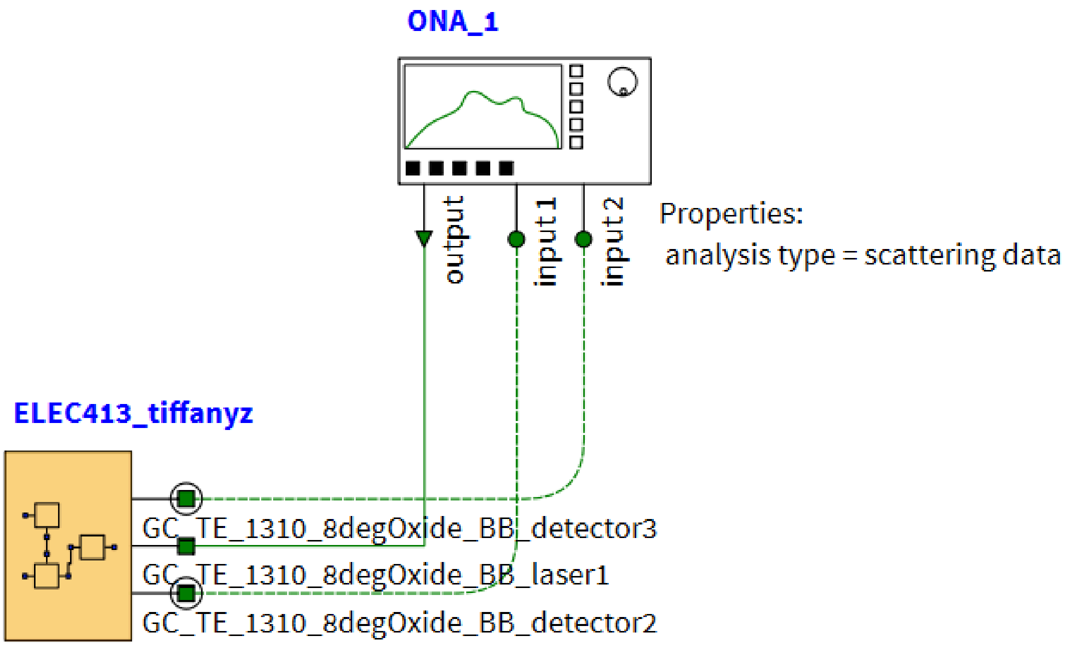


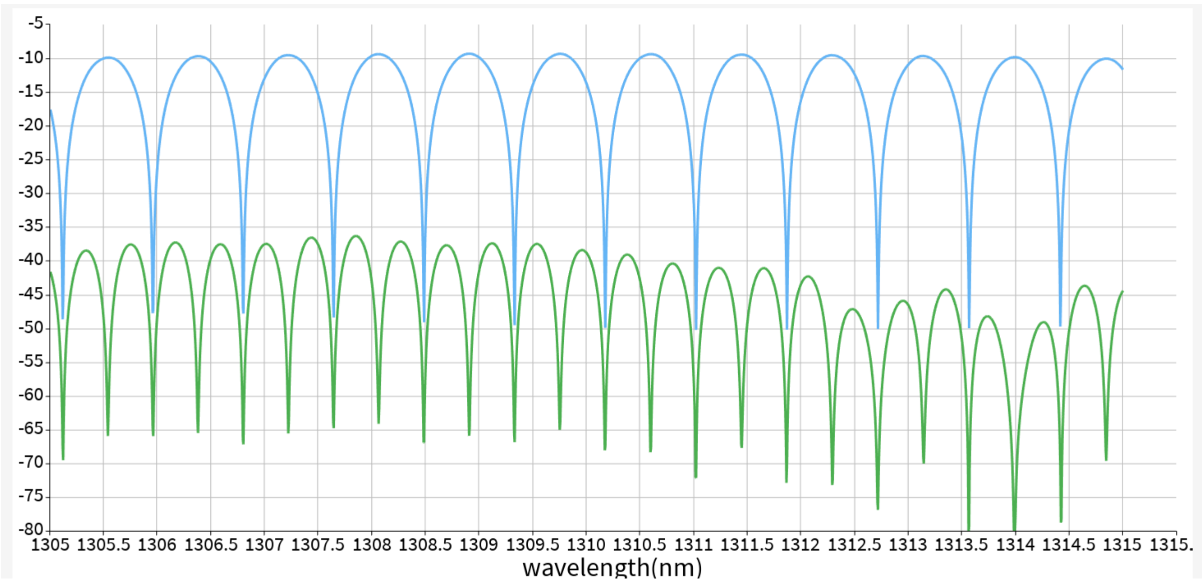
Figure: Layout of Chip 2 designed for the ELEC413 Project

IV. Results and Analysis

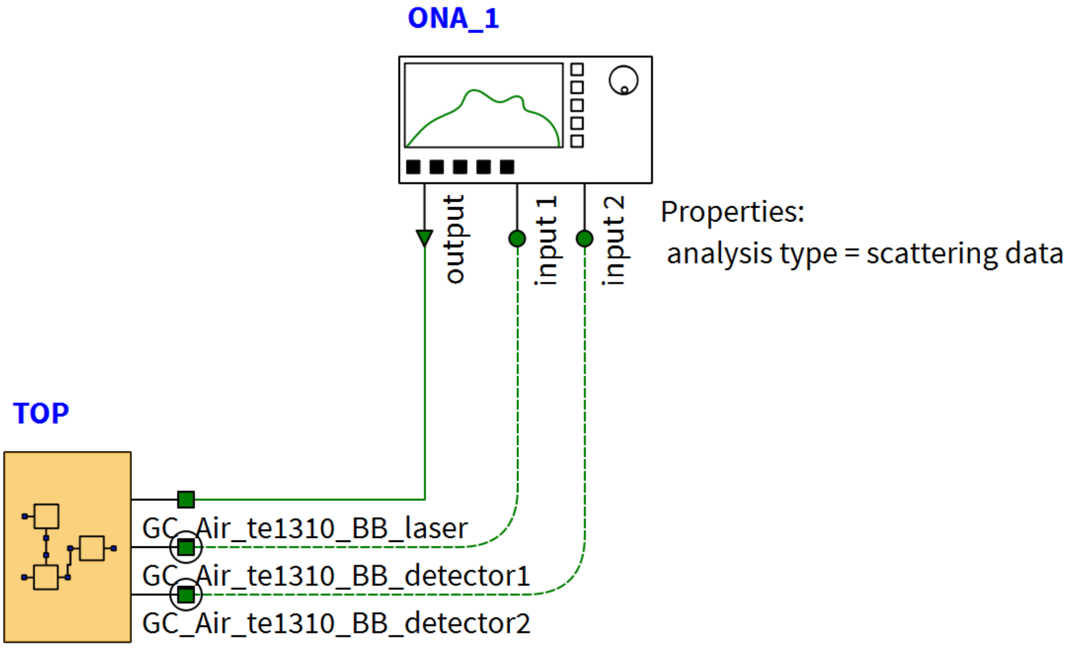
A. Simulation Results

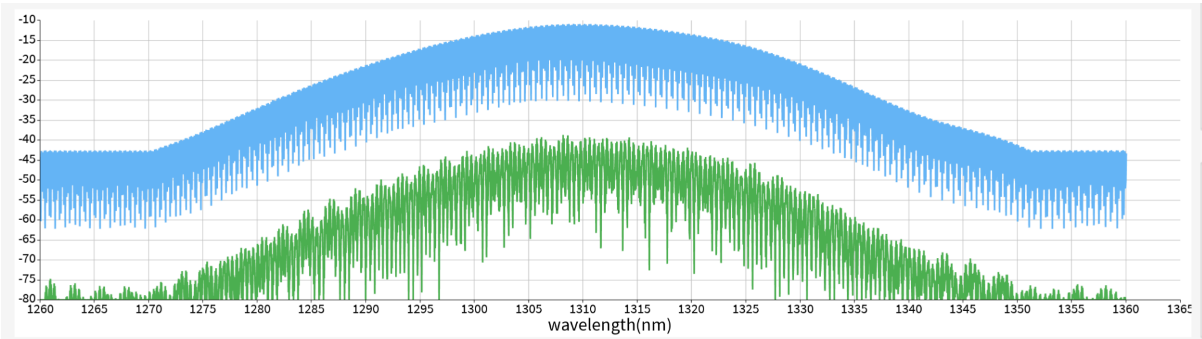
Chip1





Chip2





B. Experimental Results

C. Discussion

V. Conclusion

Acknowledgment

References