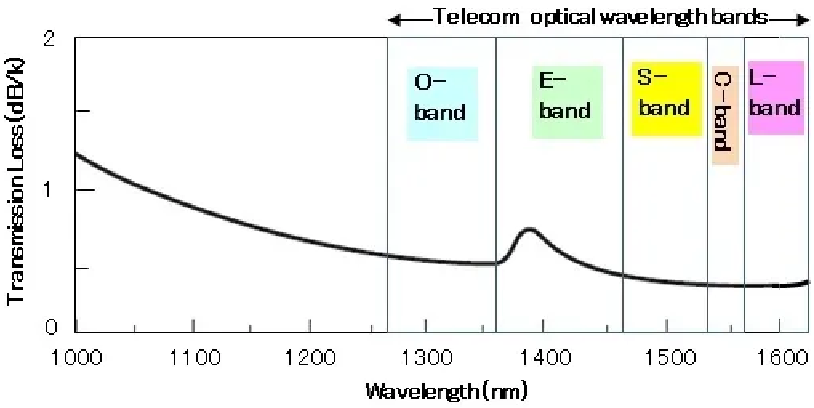
ELEC 413 - Chip 1 and 2 Design Document

Abstract

This document outlines the design of an demux interferometer operating in the 1270–1330nm bandwidth (O-band). It includes design details for both the multiplexer and demultiplexer circuits. This is a work in progress.



- https://www.fiberlabs.com/glossary/optical-communication-band/

Information

- Chip Projects
- Fabrication Process Details

Design Requirements

General

- 605µm by 410µm floor plan
- Simulate fabrication variation of $\pm$ 10nm in width/thickness
- Maximum SNR is 60dB
- Aim for a high extinction ratio

Chip 1

- https://github.com/SiEPIC/openEBL-2025-02
- https://www.appliednt.com/nanosoi-fabrication-service/
- ANT process bias of 15nm (*i.e.* expect width of 335nm)

Chip 2

- https://github.com/SiEPIC/SiEPICfab-EBeam-ZEP-PDK
- https://github.com/SiEPIC/UBC-ELEC413-2025
- https://docs.google.com/document/d/1HpU0Z95oETRH_fx-z4YNDfZ5-b3SPxWYZX6zVMYroiM/
- Connects to a DFB laser
- Single full etch with positive resist
- Air cladding

- 220nm $\pm$ 12.5nm thickness
- 3.5µm oxide on 725µm handle
- Minimum feature size: 100nm (thickZEP), 50nm (thinZEP)
- Process bias: 35nm (thickZEP), ~0nm (thinZEP)
- Approx. 1 nm of native oxidation on silicon

Equations

- Compact model of a waveguide:

$$n_{\text{eff}}(\lambda) = n_1 + n_2(\lambda - \lambda_0) + n_3(\lambda - \lambda_0)^2$$

- The compact model is used to determine the propagation constant of the waveguide, as a function of frequency:

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

  - The propagation loss α is determined by the imaginary part of the effective index:

$$\alpha(\lambda) = \frac{4\pi}{\lambda}\text{Im}\{n_{\text{eff}}\}$$

- Mach-Zender interferometer transfer function:

$$T_{\text{MZI}}(\lambda) = \frac{1}{4}\left|1 + e^{-i\beta\Delta L}\right|^2$$

  - ΔL is the path length difference of the two arms of the interferometer
  - In decibels,

$$T_{\text{MZI-dB}}(\lambda) = 10\log_{10}(T_{\text{MZI}}(\lambda))$$

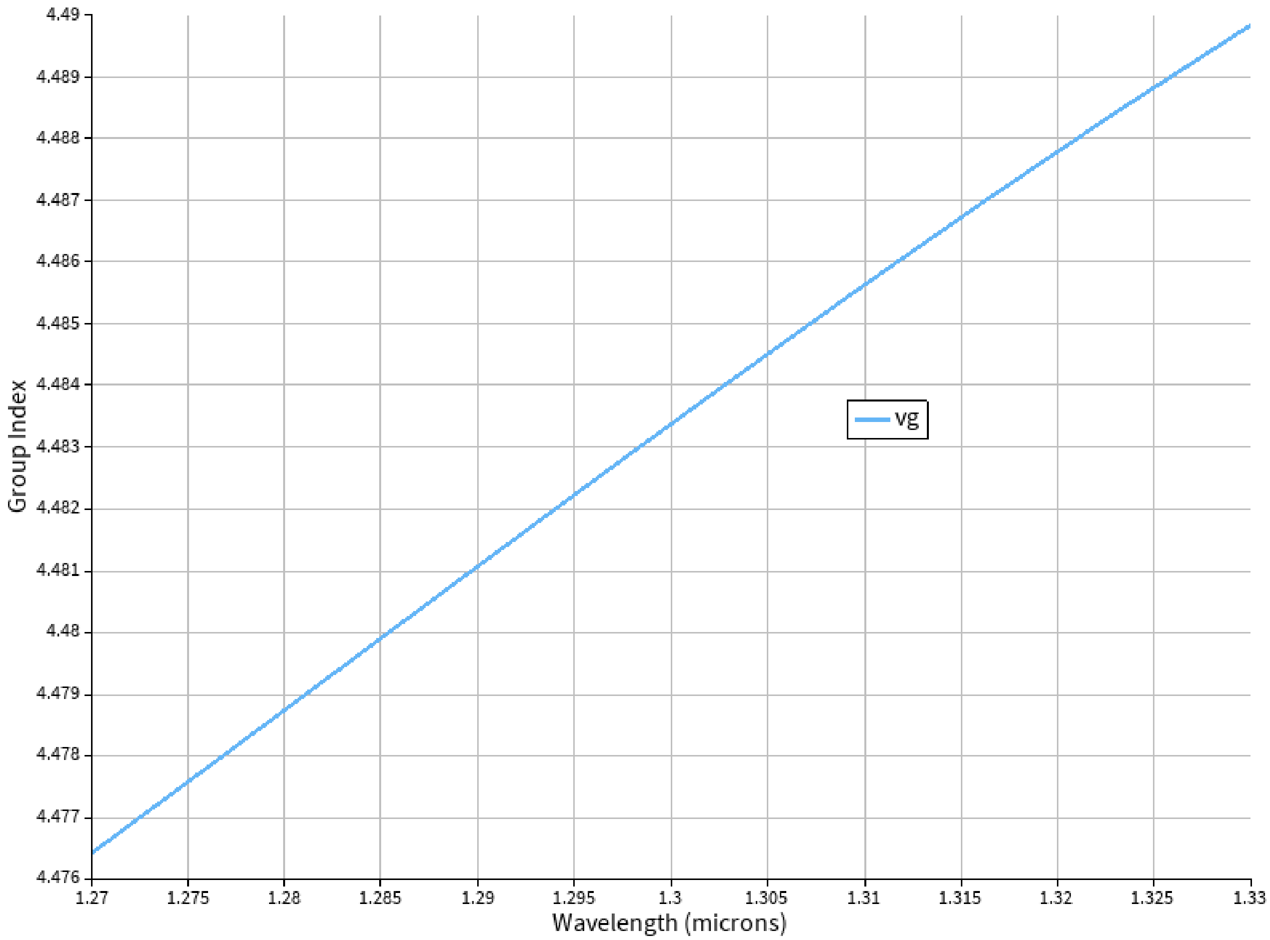
- Equation for the free spectral range:

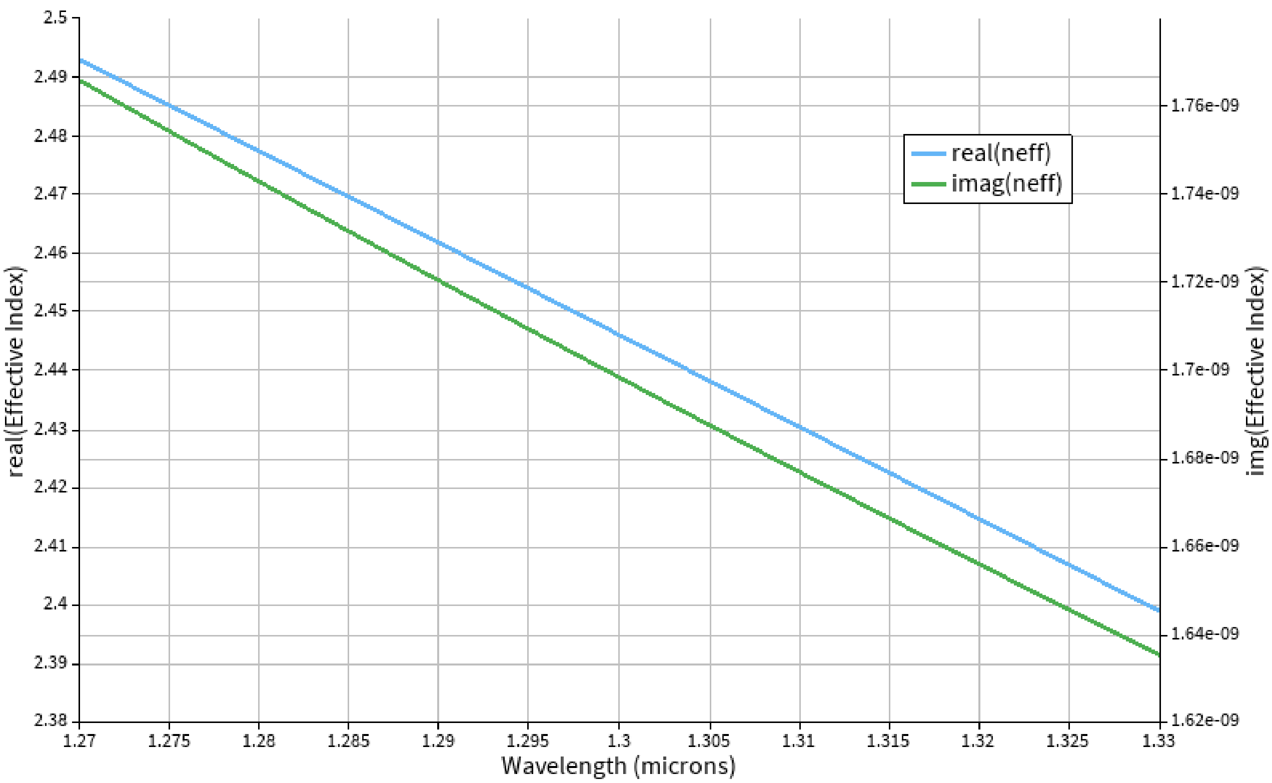
$$\Delta L = \frac{c}{n_g \Delta\nu}$$

Chip 1

Modelling

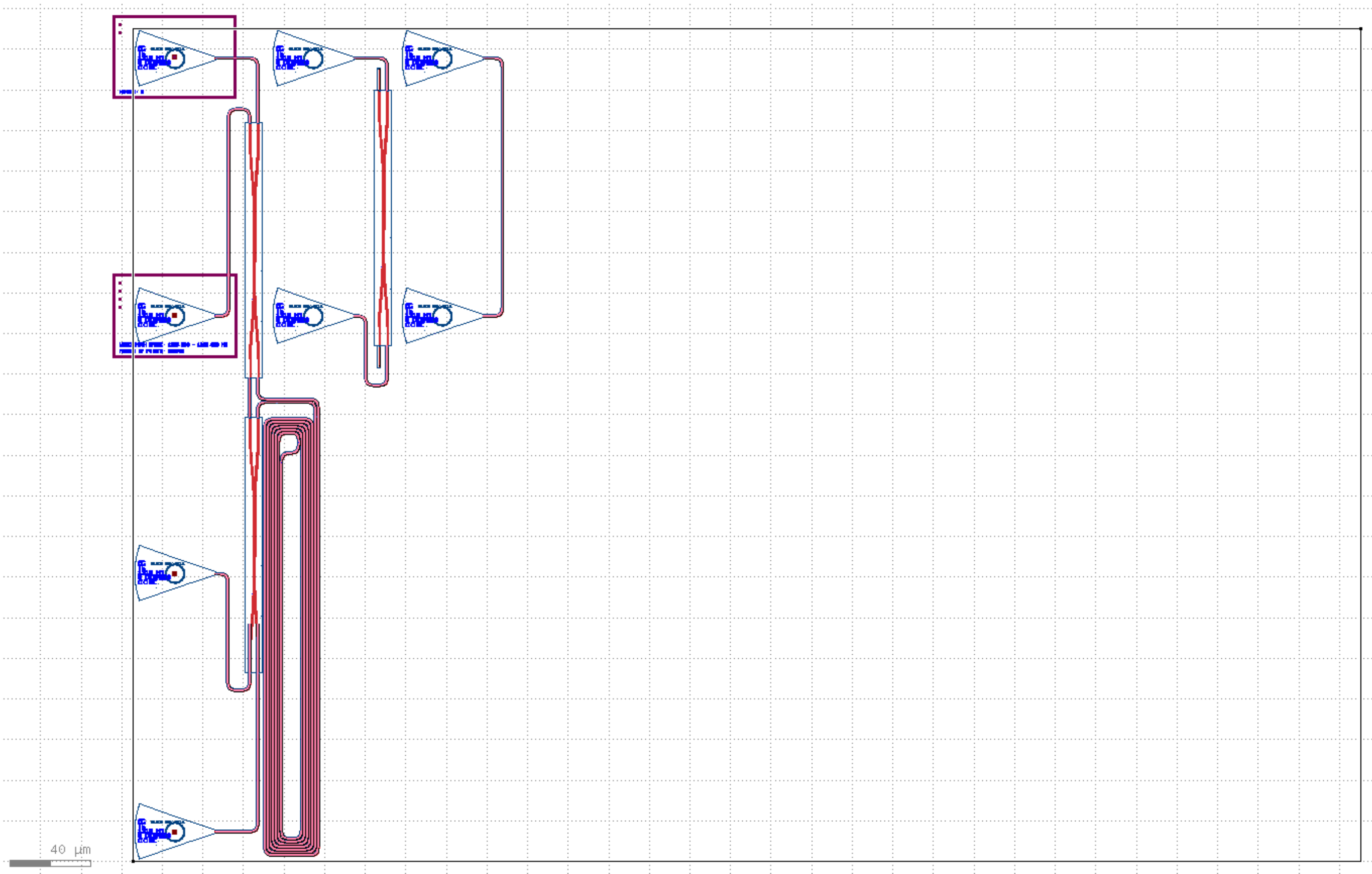
- A silicon waveguide with width 350µm and thickness 220µm was modelled in Lumerical MODE. Using a frequency sweep from 1270 to 1330nm, data on the effective and group indices was collected:





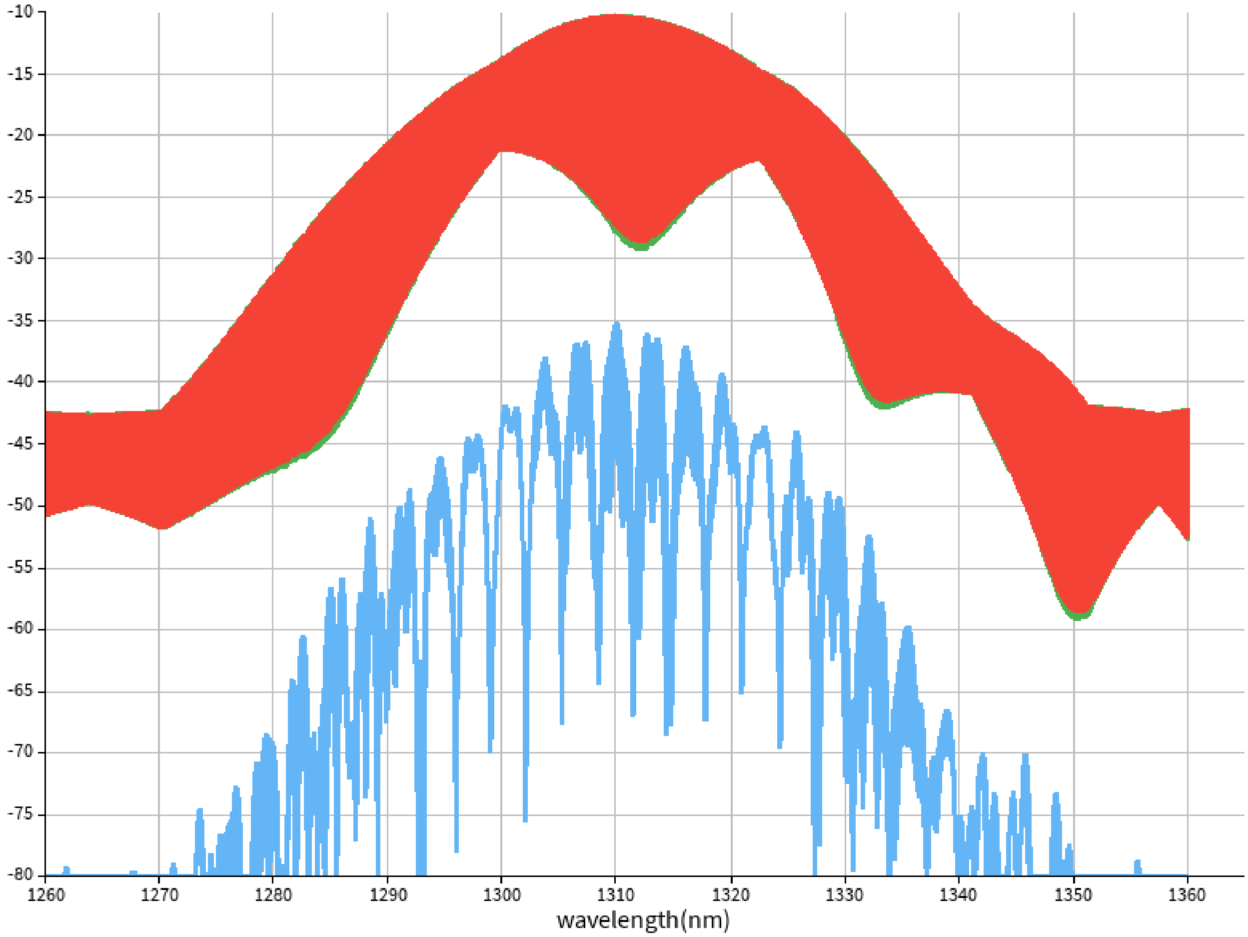
- From Lumerical MODE modelling, the group index of the first mode of the waveguide was found to be 4.486 at 1310nm. Thus, the required path length difference is 2666µm.

KLayout and INTERCONNECT



- The chip contains an MZI and two additional circuits to test the 50/50 splitter and determine the insertion loss from the grating couplers.

- The MZI circuit was modelled in Lumerical INTERCONNECT. The gain at the three outputs is shown below:



  - The blue plot shows the transmission at the first optical port, indicating that there is negligible backscatter.
  - The red and green plots show the transmission at the two outputs. At 1310nm the free spectral range is 0.14nm, which corresponds to the desired 25Ghz.

TODO

- Calculate group index at corners (*i.e.* with some variation in waveguide width/thickness)
  - Add additional circuits with a path length difference that corresponds to these indices
- Rotate paperclip waveguide and extend to reduce number of bends
- Add variations
- Account for process bias by increasing feature size by 15µm and remodelling

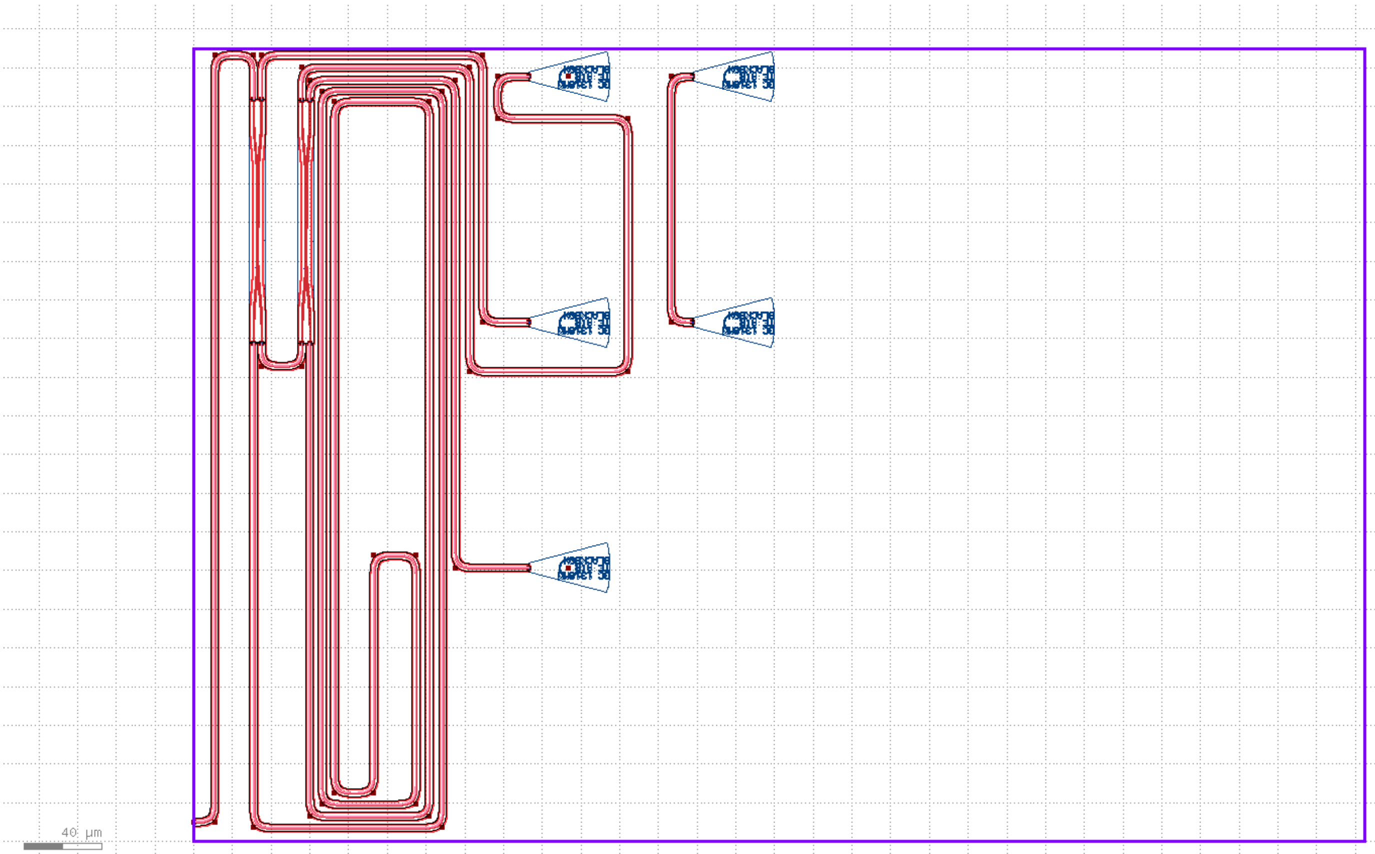
Chip 2

Modeling

Thickness	Width	Group index	ΔL (µm)
220	350	4.789046	2503.98
210	340	4.870387	2462.16
210	360	4.742660	2528.48
230	340	4.844723	2475.21
230	360	4.719026	2541.14

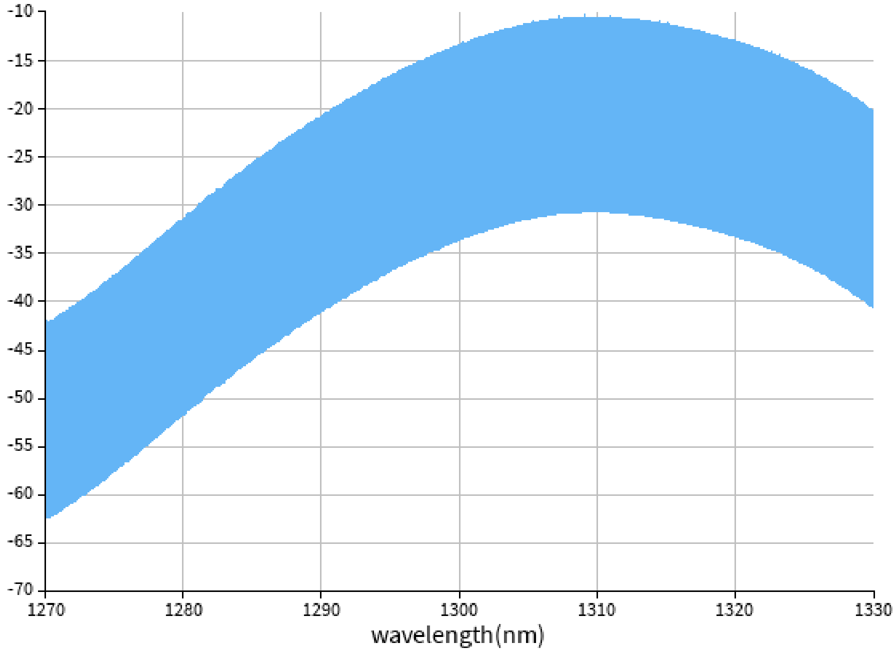
The width of the waveguide has a stronger effect on the group index than the thickness. The difference in group index is approximately $\pm$ 0.08, corresponding to a path length difference of $\pm$ 42µm. The maximum possible error in FSR due to the fabrication process is $\pm$ 1.67%. One strategy is choosing the halfway point between the smallest and largest ΔL, which would be 2501.65. A better strategy would be to a) assume a Gaussian distribution for deviation in dimensions, and b) take into account the inverse relationship between group index and FSR, which means that a *smaller* group index produces a larger error.

KLayout and INTERCONNECT

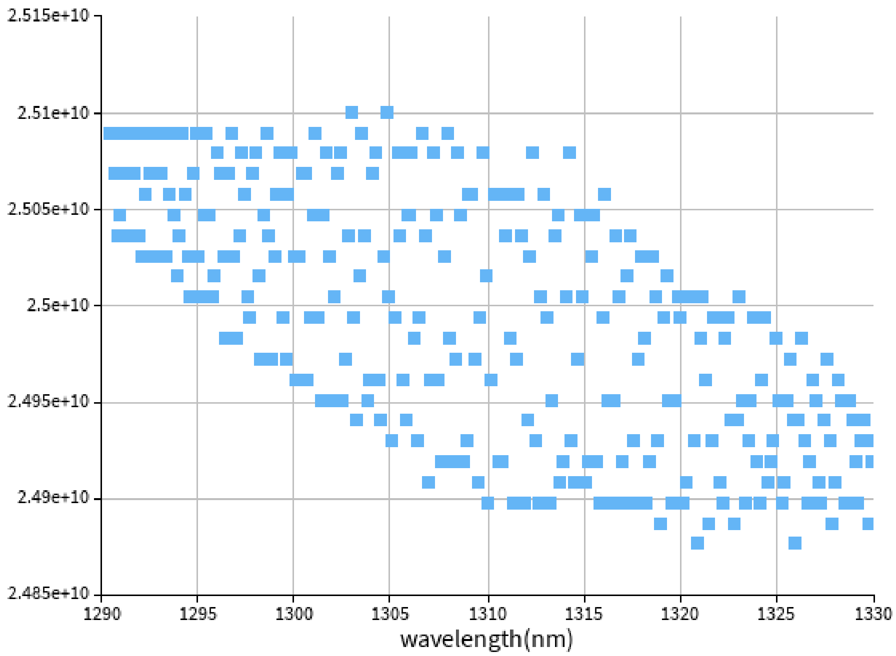


Design notes:

- The circuit layout was designed to minimize differential mode error (by keeping waveguides close together, in the same vertical area) and propagation loss (by keeping the first interferometer path short and having as many straight waveguides as possible, while keeping the overall footprint small.)
- The path length difference can be adjusted by shortening or lengthening the innermost waveguide segment, for a total range of roughly 2287–2960µm.
- A small de-embedding circuit was included. The output from this circuit will be subtracted from the output of the interferometer to cancel-out insertion loss.
- The interferometer was designed for a group index of 4.79 and corresponding path length difference of 2503.8µm.
- The width of the waveguide cladding mask in KLayout was reduced from 4.35 to 4.00µm in order to avoid errors caused by overlapping waveguides at splitter inputs/outputs.



The circuit was simulated in Lumerical INTERCONNECT over the O-band range. The graph above shows the gain at the output.



The free spectral range is 25GHz as expected, with an error of less than 0.5%. The sinusoidal pattern of the FSR is most likely due to the spacing of test wavelengths in the simulation.