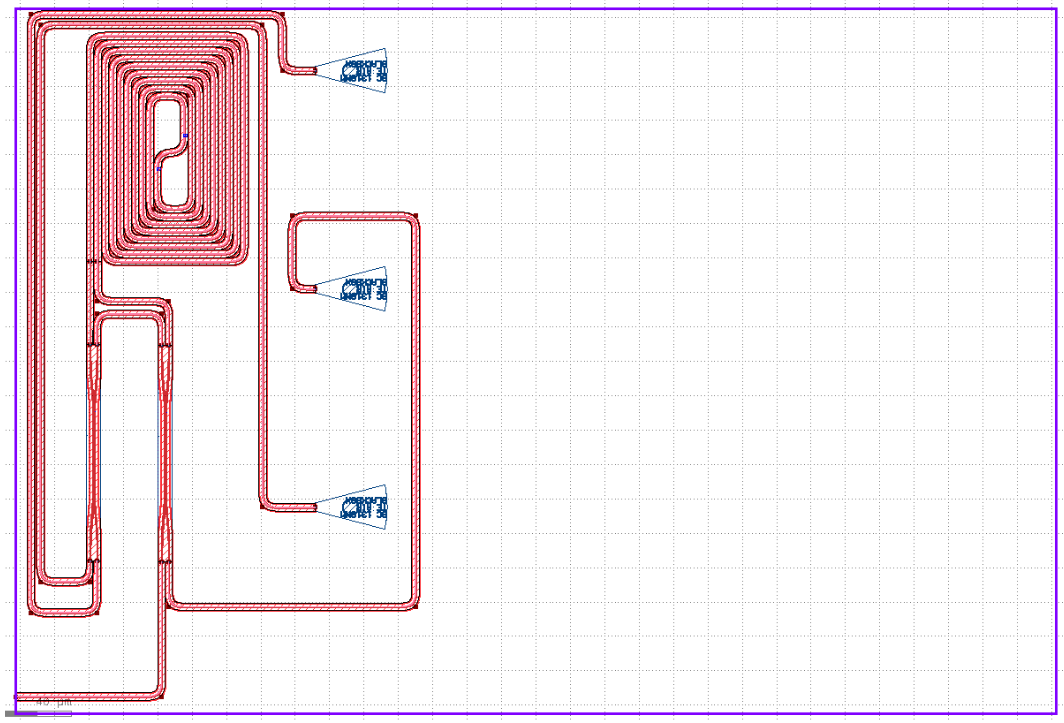
Design Document
Project 1: MZI (Updated Chip 2)

Kai Asaoka

ELEC 413

IMPORTANT: CHIP 2 UPDATE NOTE

- **Chip 2 contents start on slide 20** (requirements are identical to chip 1 and are laid out in the following slides).



Design Requirements

The MZI was designed in accordance with the design requirements as outlined as a part of the course project:

- 2 outputs, minimal loss
- 25 GHz Spacing
- 1310nm wavelength
- Si core, SiO_2 Cladding
- Floorplan: 605 μm x 410 μm

Calculations

From the design requirements, we know:

- FSR = 25GHz

Using the equation,

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

Where c is the speed of light (3E8m/s), ng is the group index, we can calculate ΔL, representing the path length difference between the two paths of the MZI.

Waveguide Design

Basing the design on the specifications provided by Applied Nanotools, I used the following specifications for waveguide simulation:

350nm waveguide width

220nm waveguide height

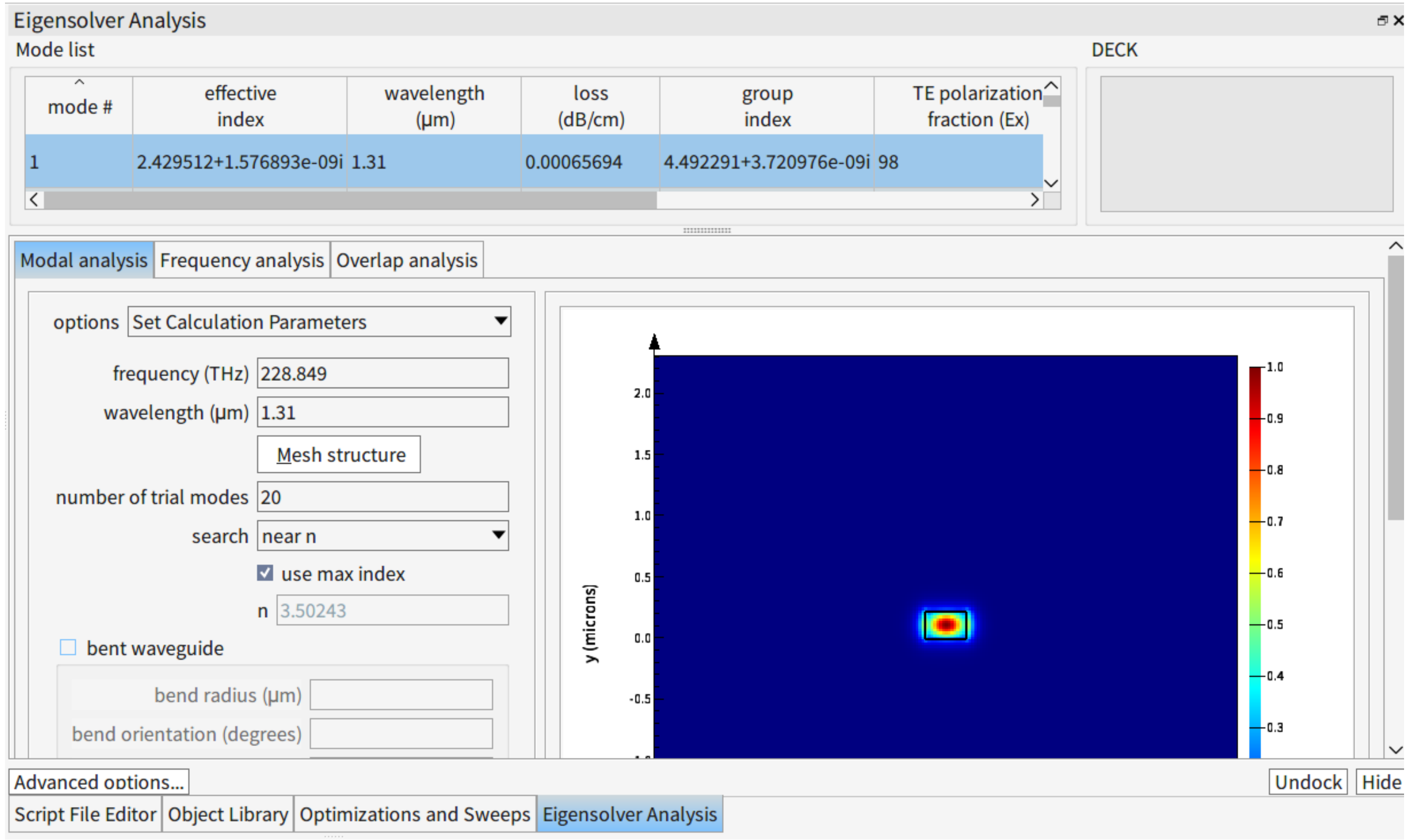
440nm cladding height

500nm cladding width (arbitrary)

https://www.appliednt.com/nanosoi-fabrication-service/

Waveguide Design

Simulating the waveguide in Lumerical MODE, I obtained the group index (ng) for the waveguide (4.49), along with theoretical values for the effective index (2.43), using 1310nm wavelength.



Calculations

We now know that for our system:

- FSR = 25GHz
- ng = 4.49
- c = 3E8m/s

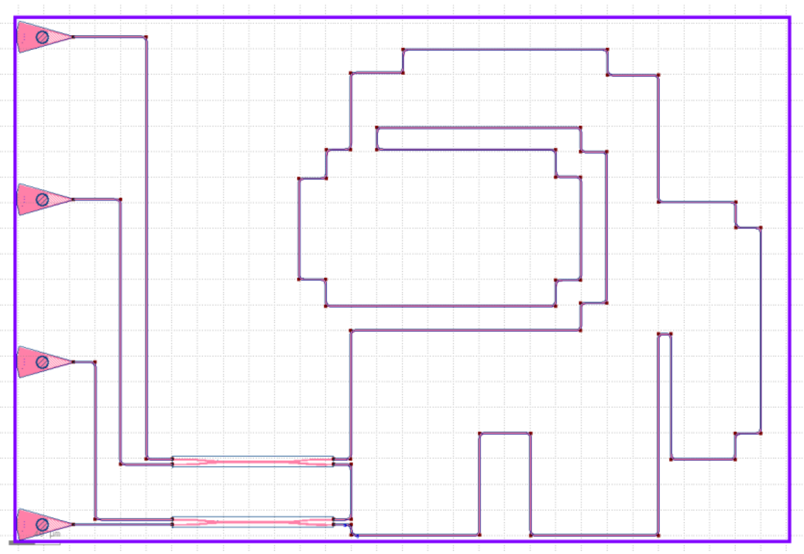
Plugging these values into our previous FSR equation,

$$25E9 = \frac{3E8}{4.49\Delta L}$$

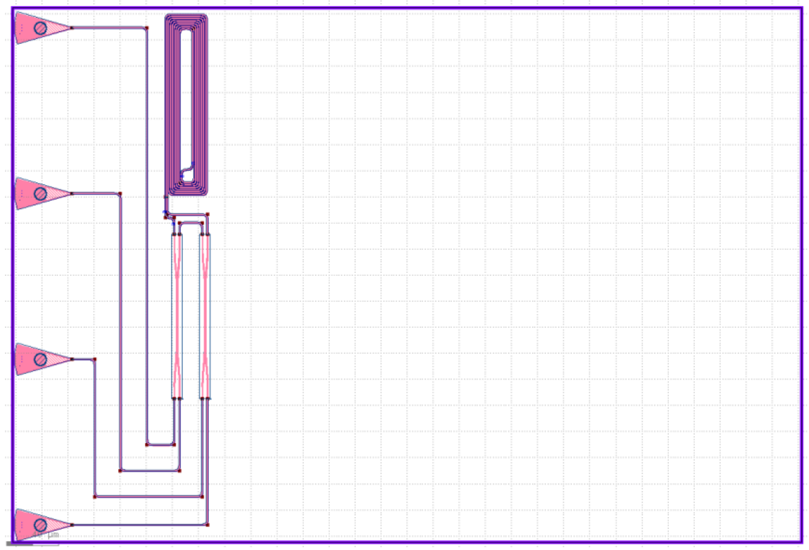
We obtain a ΔL of 2.6707mm.

Calculations

Using this value of ΔL, two variations of the MZI circuit were drafted using Klayout, one artistic design making use of mostly straight waveguides, and a second compact design using a paperclip structure.



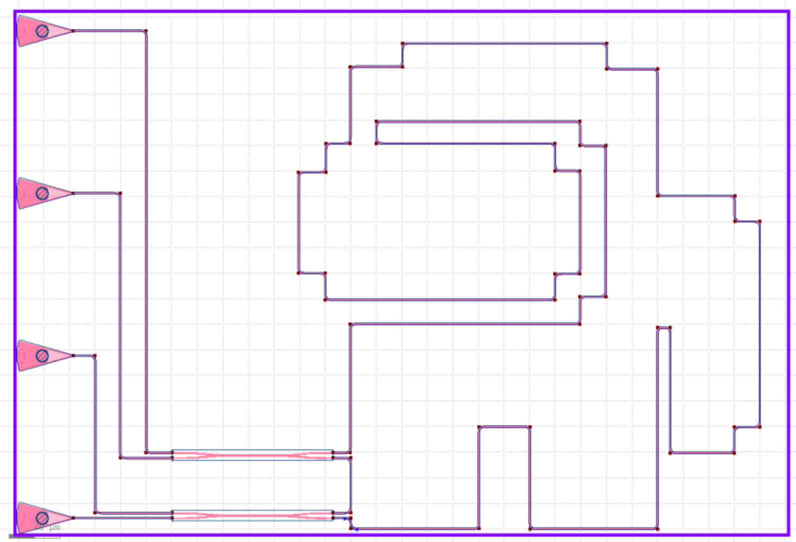
Straight waveguide design



Compact paperclip design

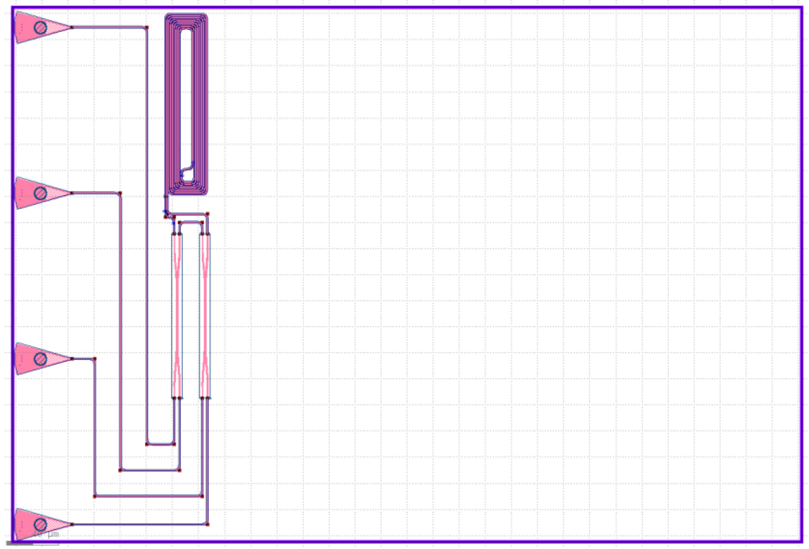
Detailed Specifications

Straight waveguide design



$$L1 = 67.465\ (microns)$$
$$L2 = 2738.219$$
$$\Delta L = 2670.754$$

Compact paperclip design

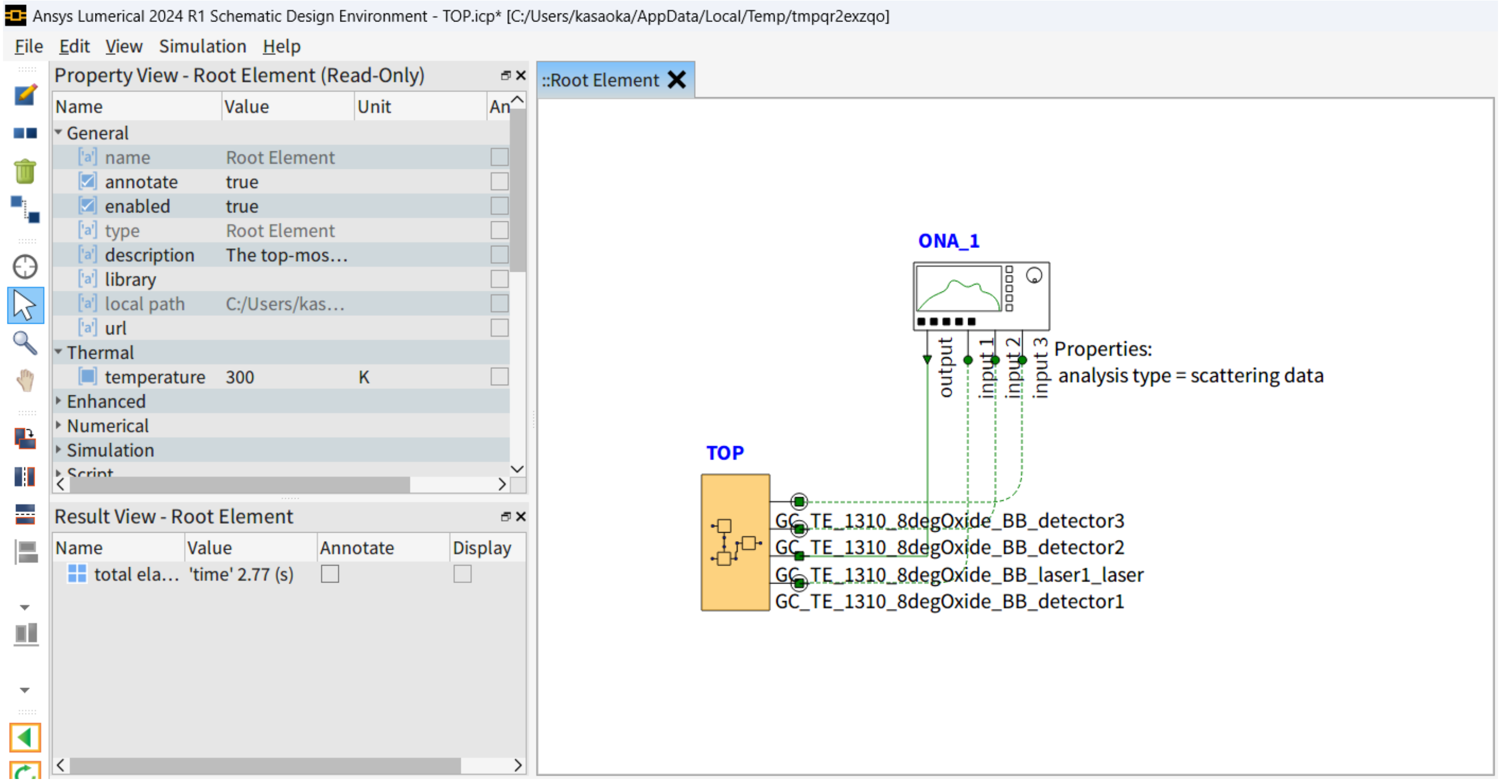


$$L1 = 32.305\ (microns)$$
$$L2 = 2703.071$$
$$\Delta L = 2670.766$$

Both designs meet target ΔL of 2.6707 microns.

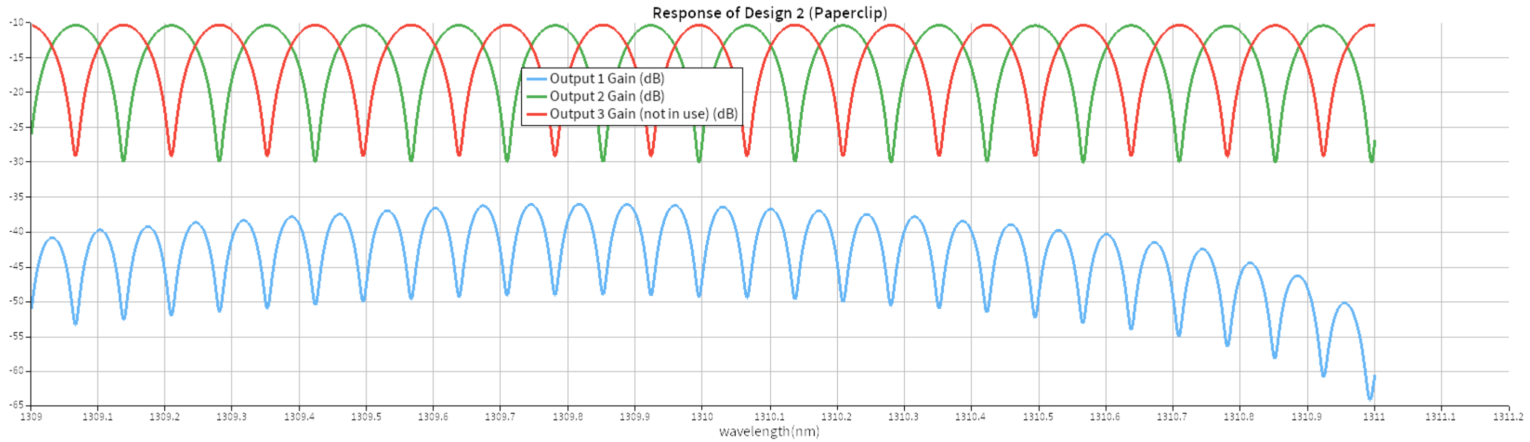
Simulation

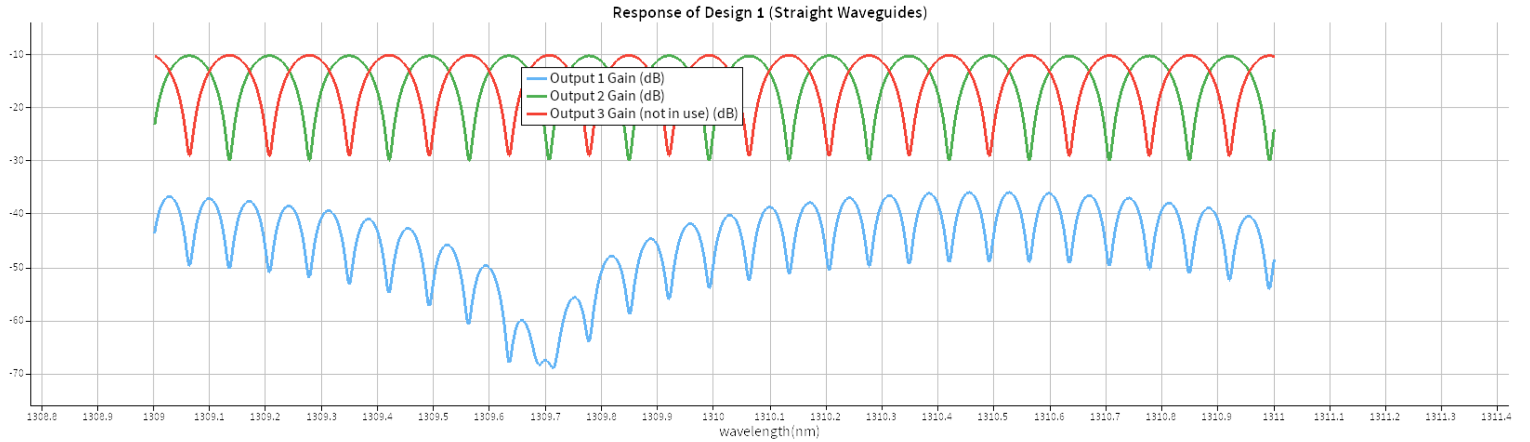
- Using Lumerical INTERCONNECT, both designs were tested to identify if differences between the outputs of the designs could be identified.



Simulation

Taking response measurements of both designs, there were no significant difference in results.



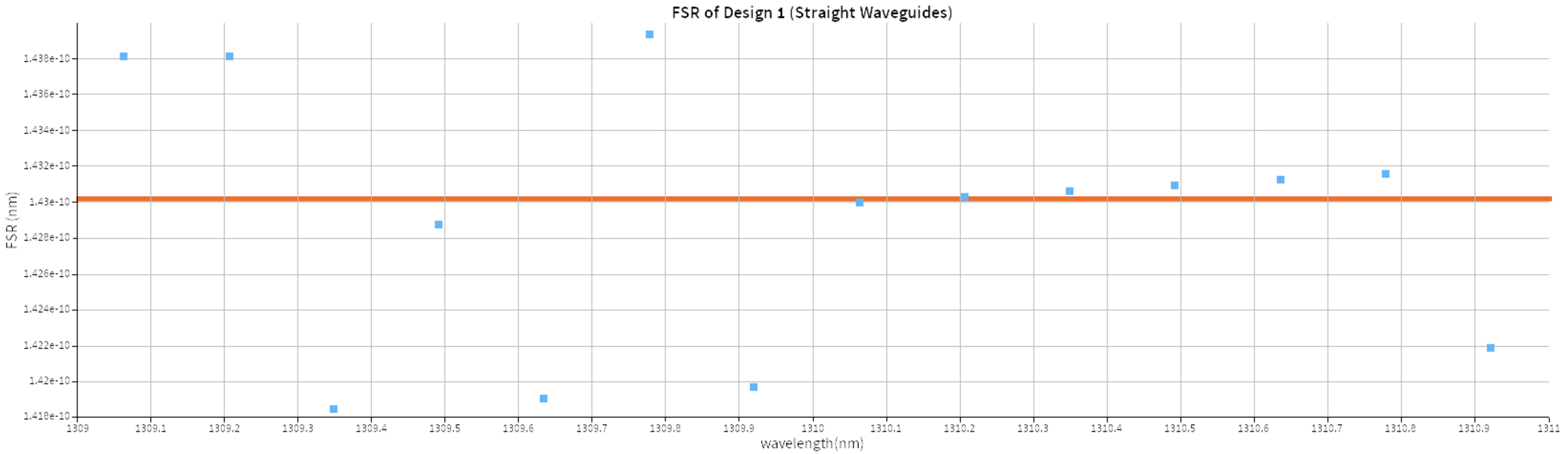


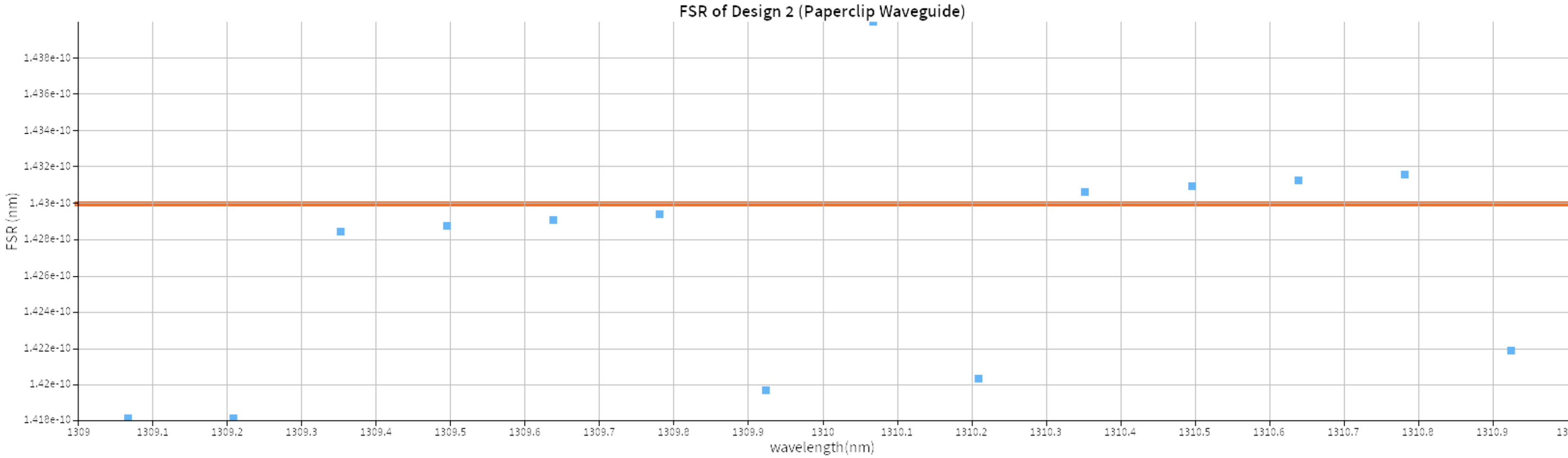
Simulation

Taking FSR response measurements of both designs, there were also no significant difference in results.

The recorded $\Delta\lambda$ was ~1.43e-10m for both designs, ignoring outliers in data

(Further investigation into outliers may be necessary. **Outliers are speculated to relate to additional modes, namely the TM mode**).





Simulation

Recalculating FSR based on our experimental measurements, we use the equation:

$$FSR = -\frac{c\Delta\lambda}{\lambda^2}$$

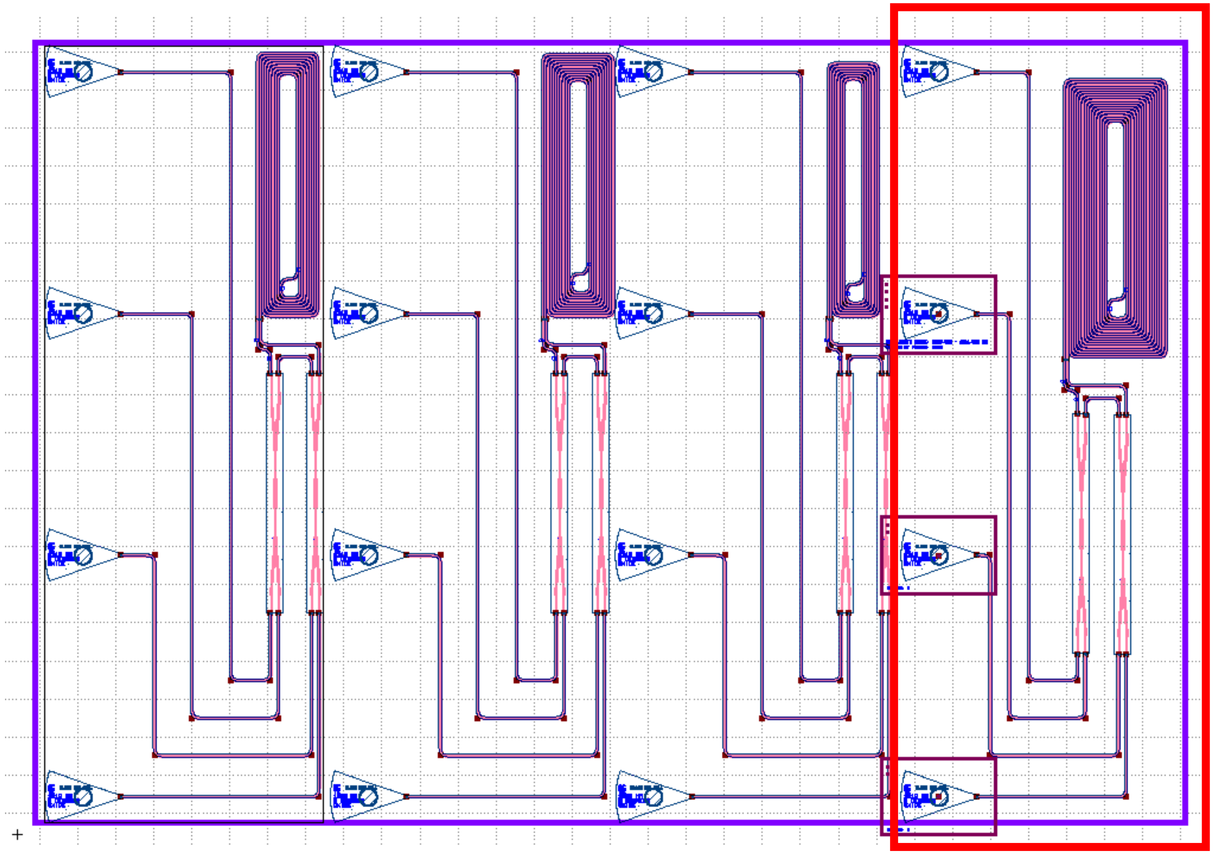
As we have determined $\Delta\lambda$ to be 1.43E-10, we can use this in our equation, along with $\lambda = 1310\mathrm{E} - 9$ and $c = 3E8$ to recalculate our experimental FSR.

We obtain 24.4998GHz, sufficiently close to our target FSR of 25GHz.

Design Specifications (Change in dL)

- Following this, more variations of MZI 2 were created to test how changing dL would affect the FSR.

- For the sake of demonstration, we will focus on analyzing the MZI on the right, with approx. 2 x dL of the previous design.



Previous:

$L1 = 32.305\ (microns)$

$L2 = 2703.071$

$\Delta L = 2670.766$

New:

$L1 = 32.305\ (microns)$

$L2 = 5283.99$

$\Delta L = 5251.68$

Calculations

Through the previous FSR Equation,

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

We expect doubling ΔL should halve the previous FSR:

$$FSR = \frac{25GHz}{2} = 12.5GHz$$

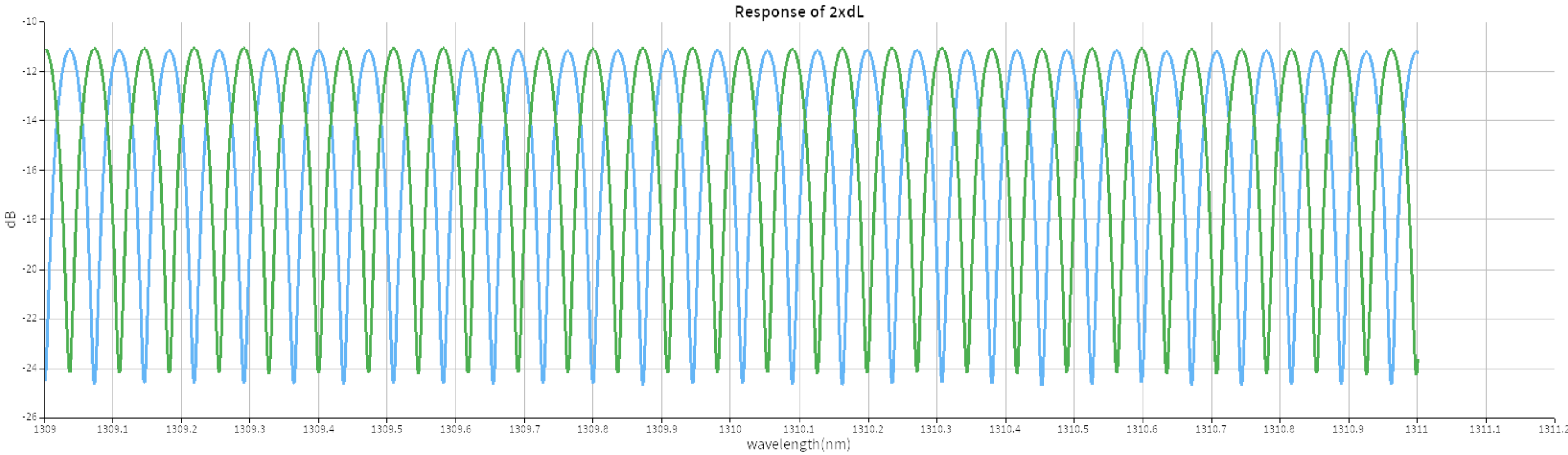
Simulation (2xdL)

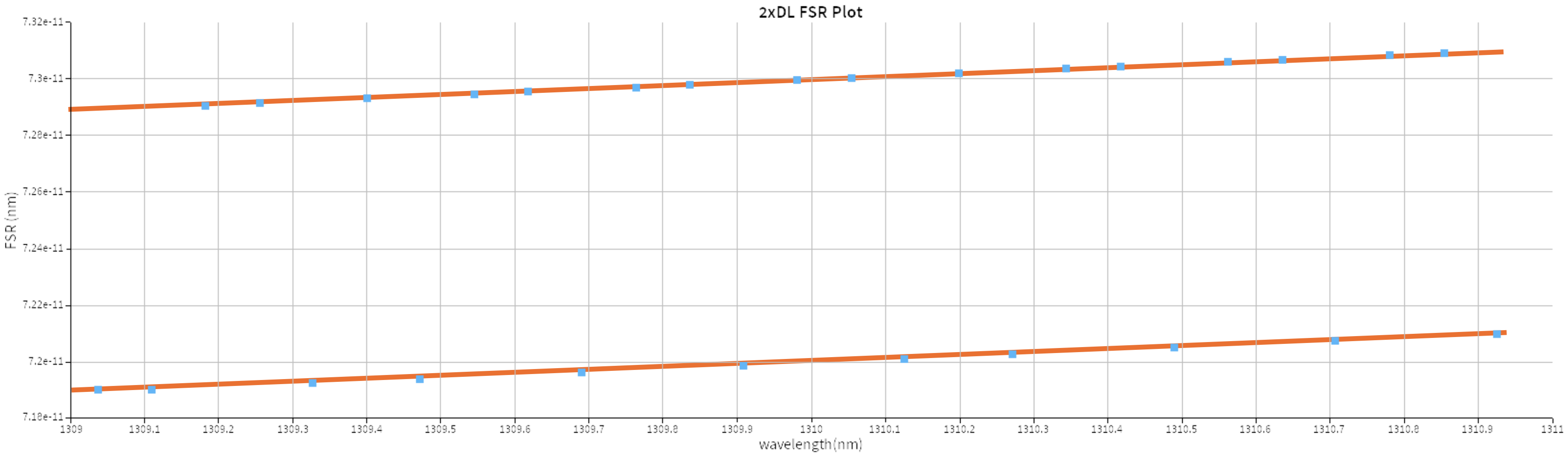
Testing this circuit in Lumerical INTERCONNECT, we obtain a $\Delta\lambda$ of approx. 7.3E-11 and 7.2E-11, where two distinct trends can be seen in the data.

Using the following equation:

$$FSR = -\frac{c\Delta\lambda}{\lambda^2}$$

We can obtain an FSRs of 12.76GHz, and 12.58GHz respectively, which line up with our calculated expectations.





Modal analysis (Investigating TM Mode)

Observing that there are two distinct trendlines, we investigate the identity of the second trendline. One hypothesis that was investigated was that the TM mode could be contributing to the FSR, thus producing a second trendline.

Taking the TM mode into account, we observe an ng of 4.63.

Using the dL ($5251.68\mu m$) from the previous result,

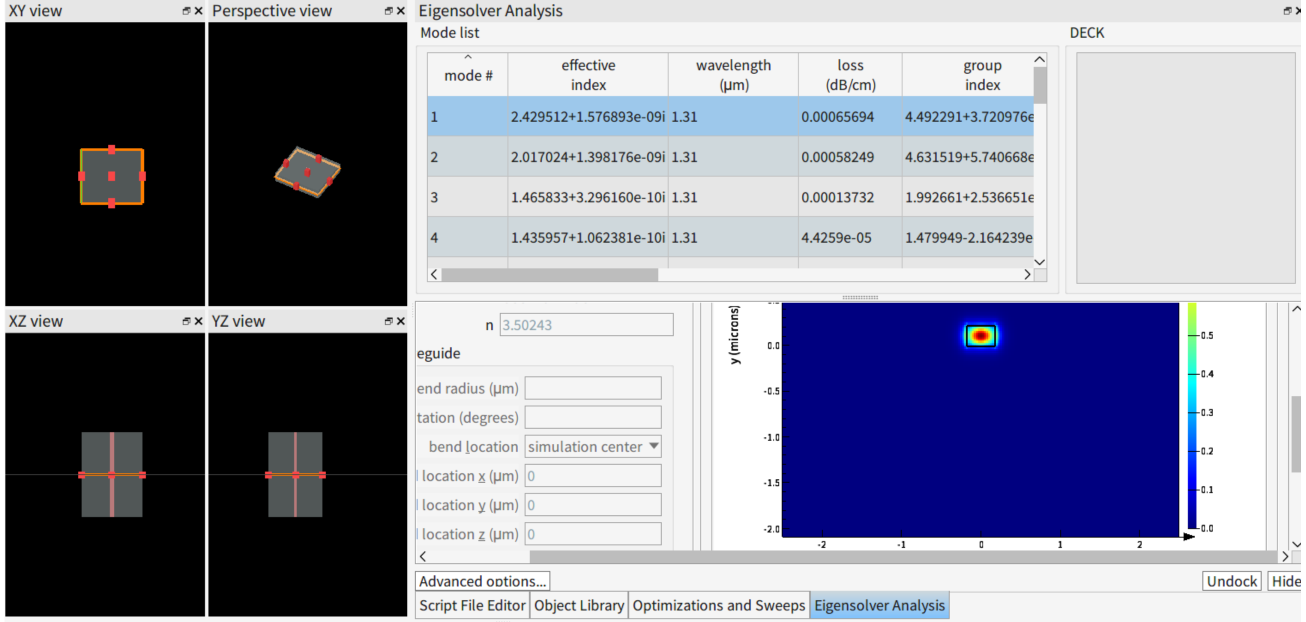
$$FSR = \frac{c}{n_g \Delta L}$$

Using ng = 4.49 (TE Mode),

We calculate FSR = 12.71GHz, which lines up with our previous result.

Using ng = 4.63 (TM Mode),

We calculate FSR = 12.329 GHz, which is close to, but not exactly our second result of 12.58GHz.



While not a conclusive result, this motivates us to investigate the identity of the second trend in data as seen on the previous slide.

Conclusion

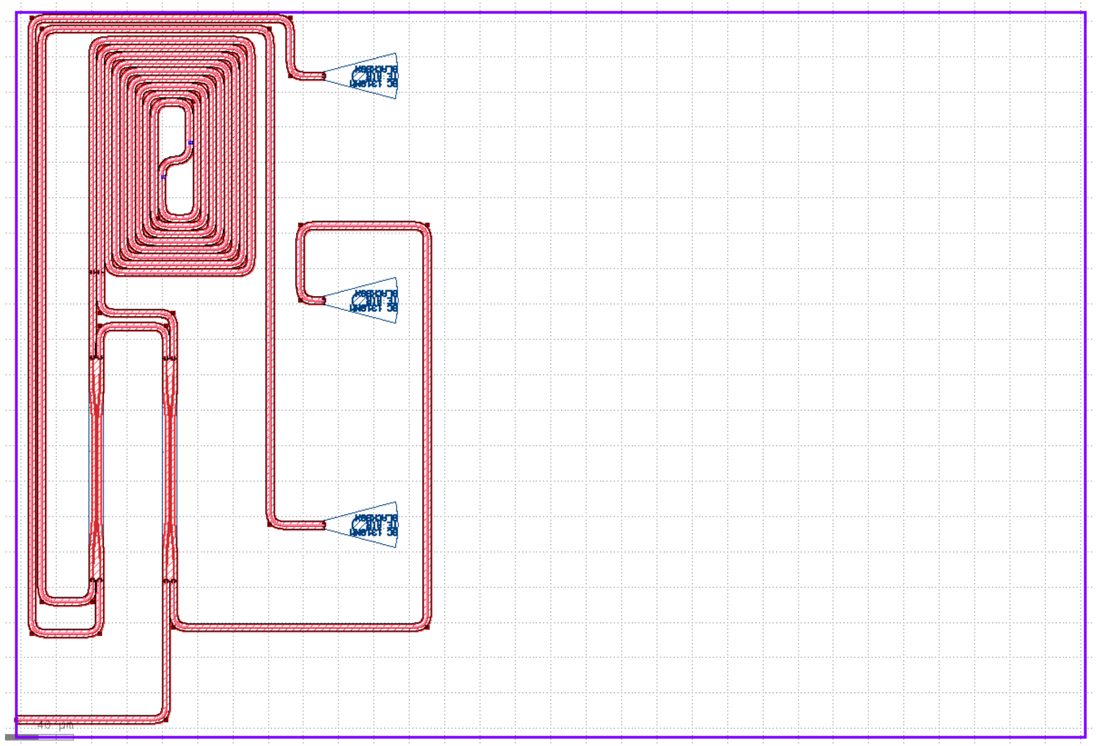
- Both straight waveguide and paperclip waveguide resulted in similar experimental results.
- We conclude that using straight waveguides and curvy waveguides, as seen in the paperclip, are equally viable without any significant downside to making designs more compact.
- Observed FSR and dL are inversely proportional to each other, and we can design around this by adjusting dL accordingly.

Future Direction

- Attempt to couple waveguides of different widths (410nm) to the system and observe results.
- Investigate outliers in FSR graph.

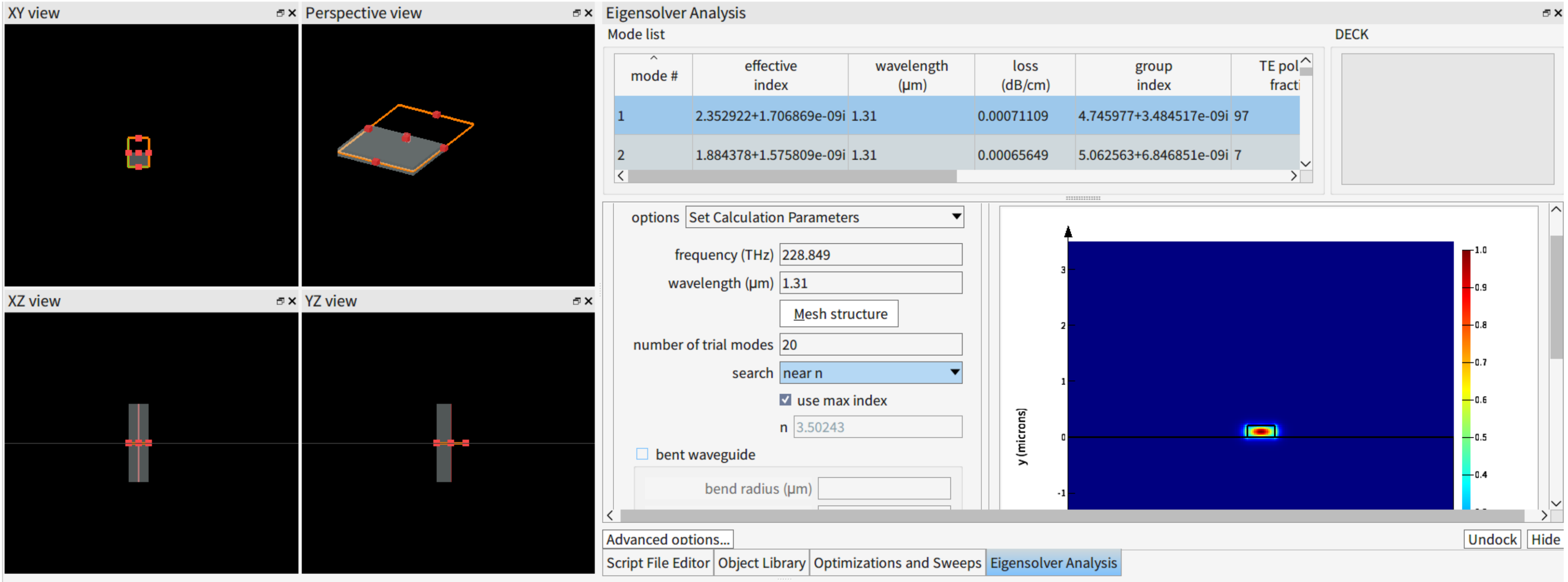
Chip 2: Shuksan

- To compare the usage of an external laser to an on-chip laser, a chip compatible with on-chip laser fabrication was constructed (air cladding instead of SiO2).



Waveguide Design (air cladding)

Simulating the new air cladding waveguide in Lumerical MODE, I obtained a new group index (ng) for the waveguide (4.746) using 1310nm wavelength and air cladding.



Calculations

We now know that for our system:

- FSR = 25GHz
- ng = 4.49
- c = 3E8m/s

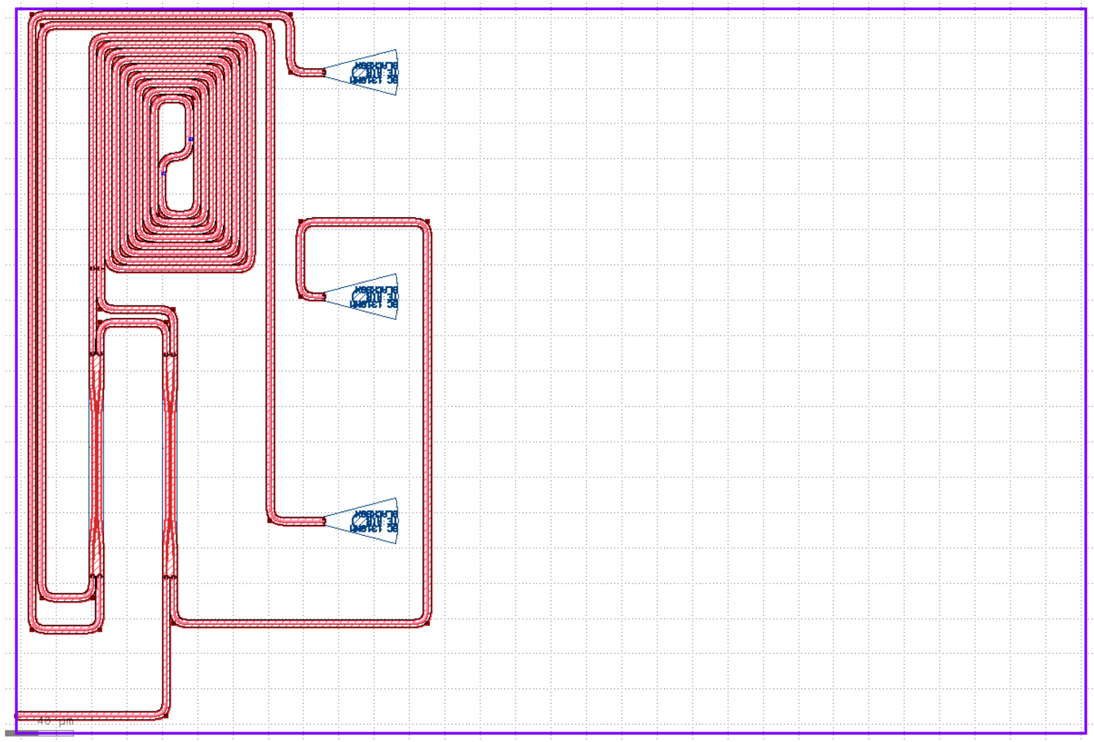
Plugging these values into our previous FSR equation,

$$25E9 = \frac{3E8}{4.746\Delta L}$$

We obtain a ΔL of 2.5284mm.

Chip 2: Shuksan

- To compare the usage of an external laser to an on-chip laser, a chip compatible with on-chip laser fabrication was constructed.

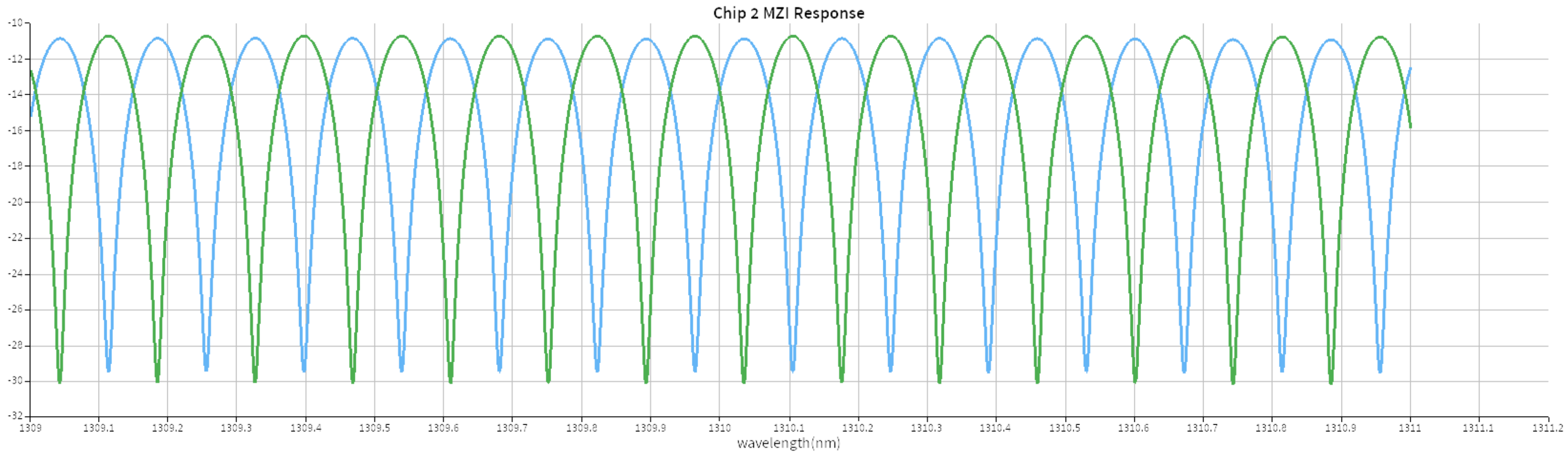


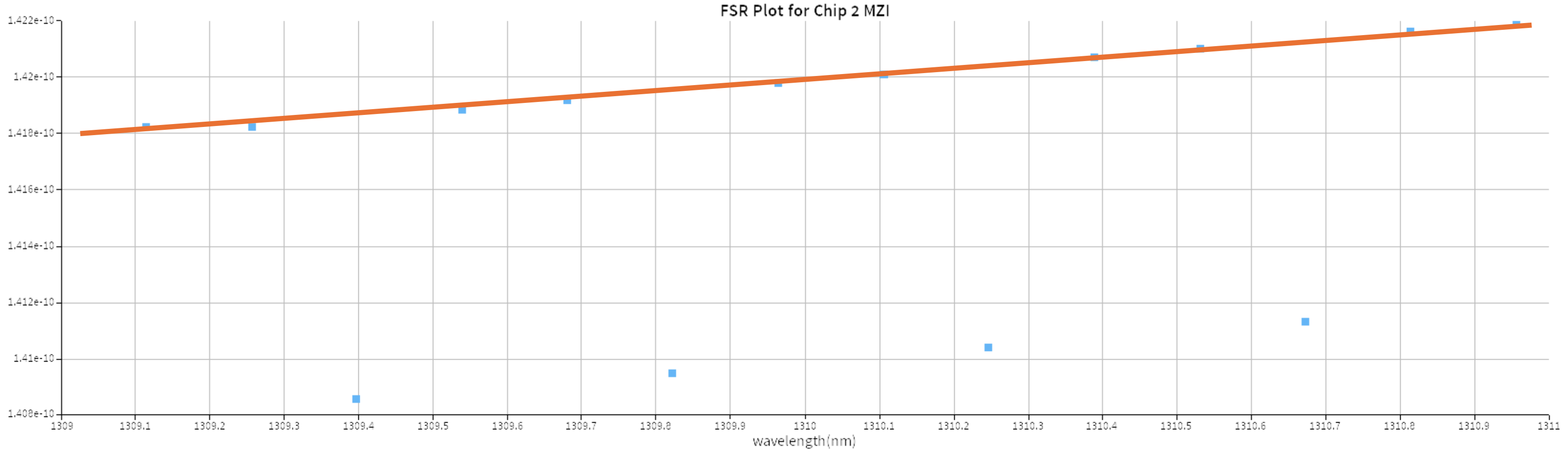
$$L1 = 60.288\ (microns)$$
$$L2 = 2588.73$$
$$\Delta L = 2528.45$$

Simulation (Chip 2)

Testing this circuit in Lumerical INTERCONNECT, we obtain a $\Delta\lambda$ of approx. 1.42E-10, very close to that of chip 1.

The response also looks identical to that of chip 1.





Simulation (Chip 2)

Recalculating FSR based on our experimental measurements, we use the equation:

$$FSR = -\frac{c\Delta\lambda}{\lambda^2}$$

As we have determined $\Delta\lambda$ to be 1.42E-10, we can use this in our equation, along with $\lambda = 1310\mathrm{E} - 9$ and $c = 3E8$ to recalculate our experimental FSR.

We obtain 24.4824 GHz, sufficiently close to our target FSR of 25GHz, and identical to our previous result for chip 1.

Conclusion

- While we have simulated the result of a laser inputted to the grating coupler, we have not tested the input on the lower left of the chip, meant for an embedded laser.
- Testing this is our next step, after fabrication of the chip, to compare against chip 1 in a real-world scenario.