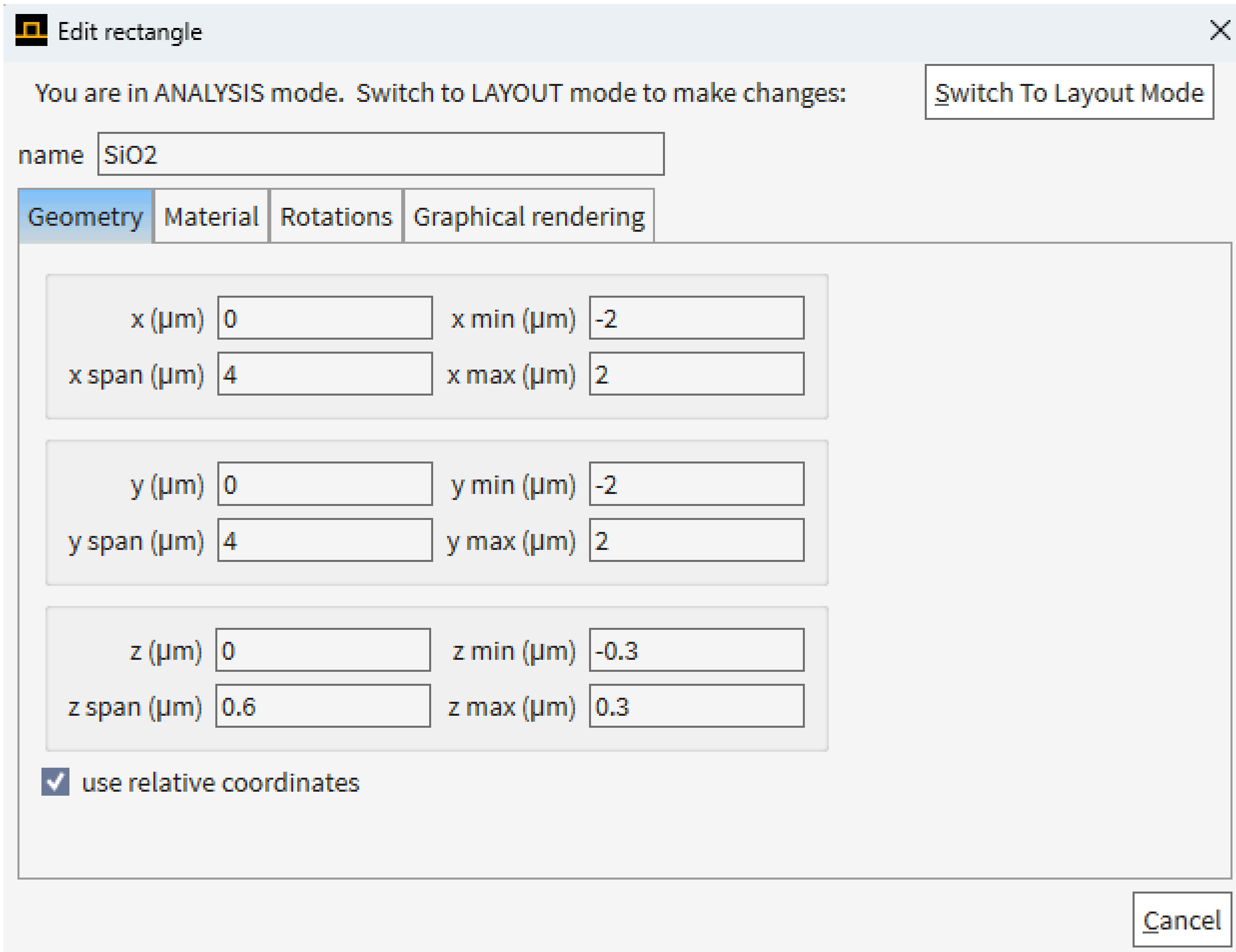
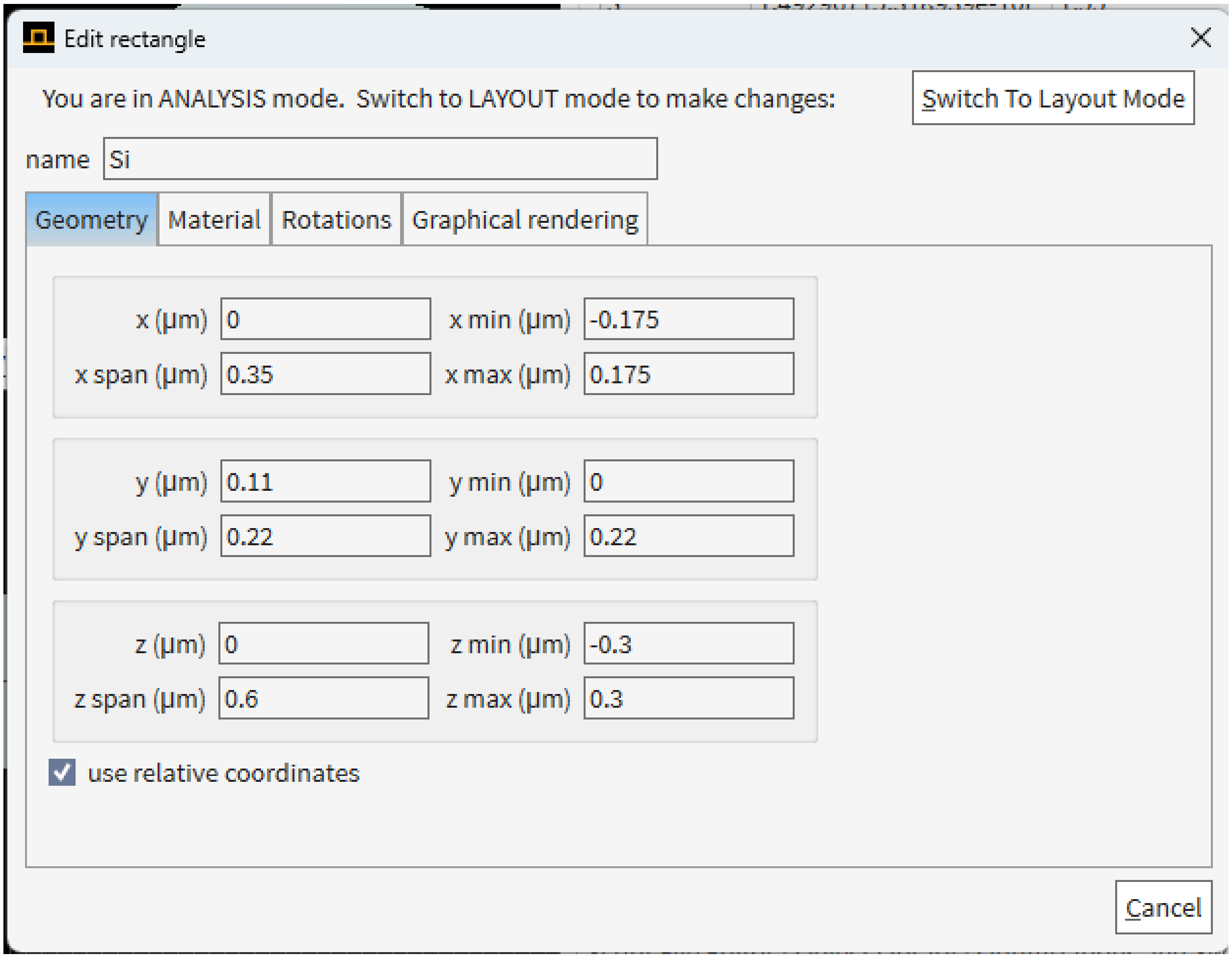
Lumerical Mode Simulation

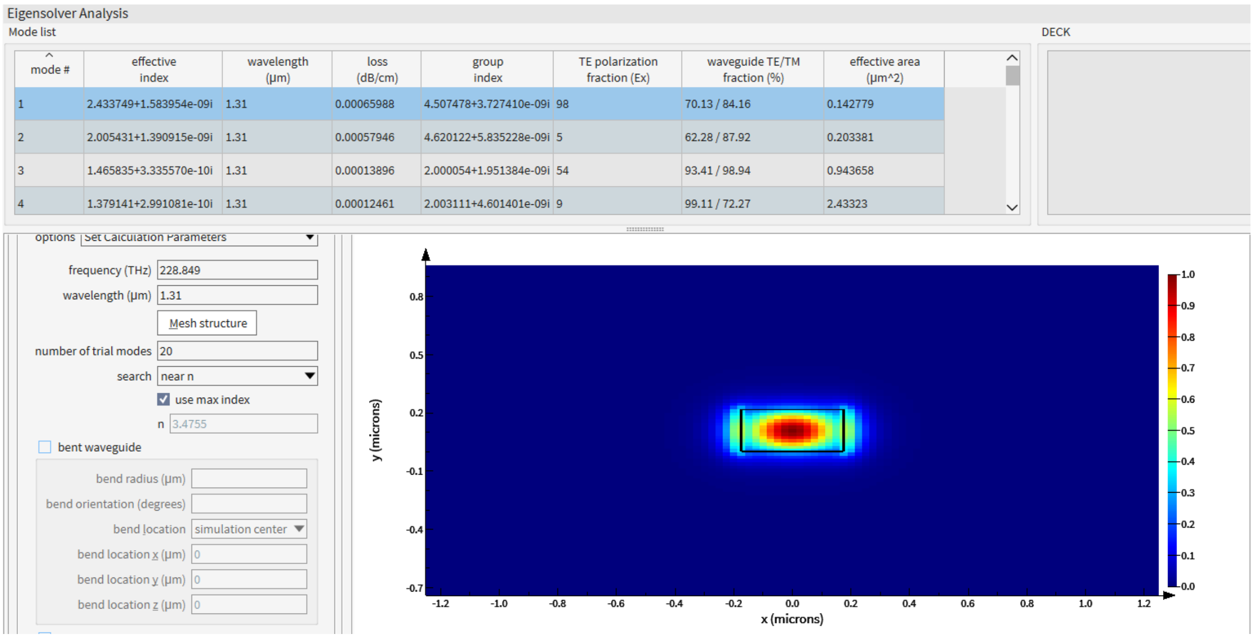
I kept the SiO2 material to be the same size with the settings from the videos on MODE.



Because our project deals with a 350 nm waveguide rather than a 500nm waveguide, I changed the Si geometry to have a 350nm x span. I kept the y span the same as we are not changing the waveguide thickness, just its width.

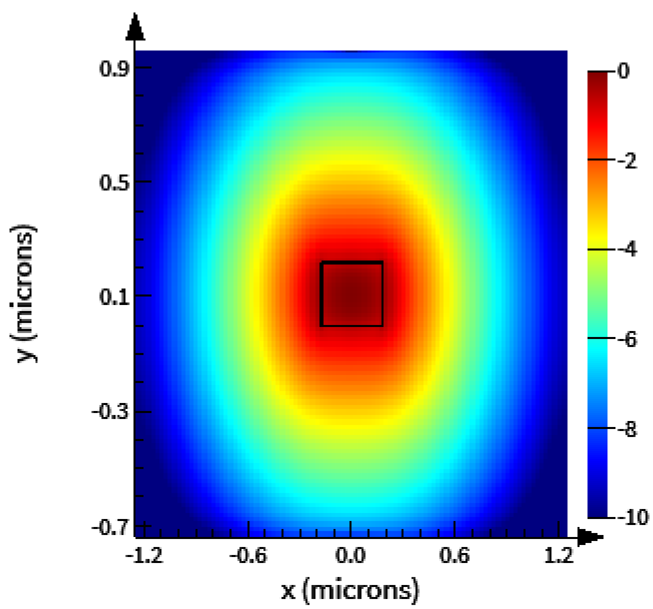


When simulating with the 1310 nm wavelength, we need to change the wavelength parameter in the modal analysis tab.

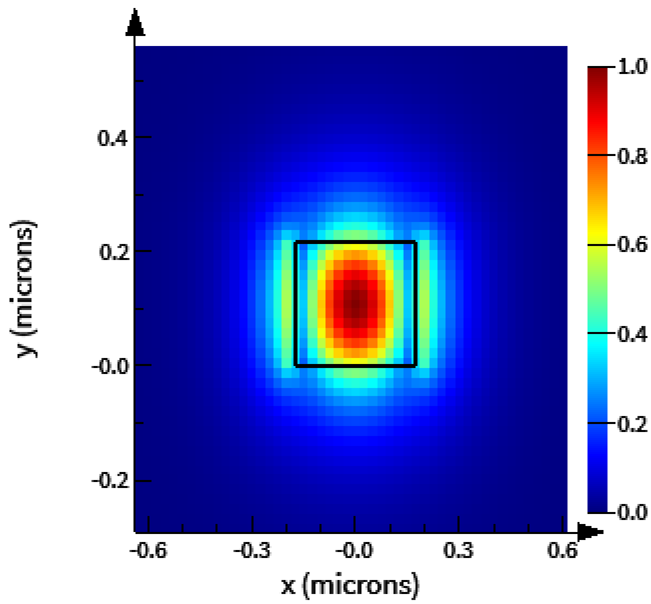


The effective Index after simulation is 2.434. With a group index of 4.507.

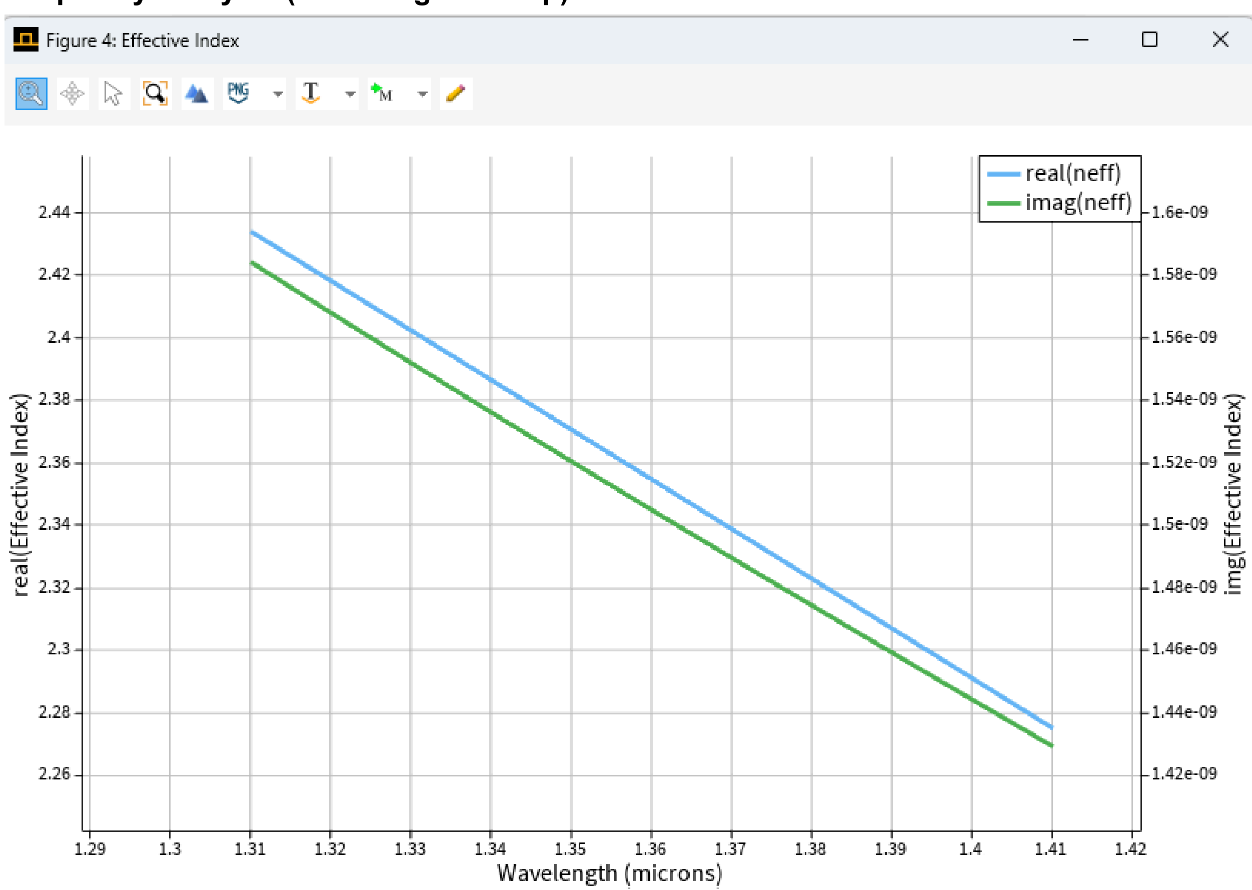
Here is the electric field intensity plotted on the log scale.



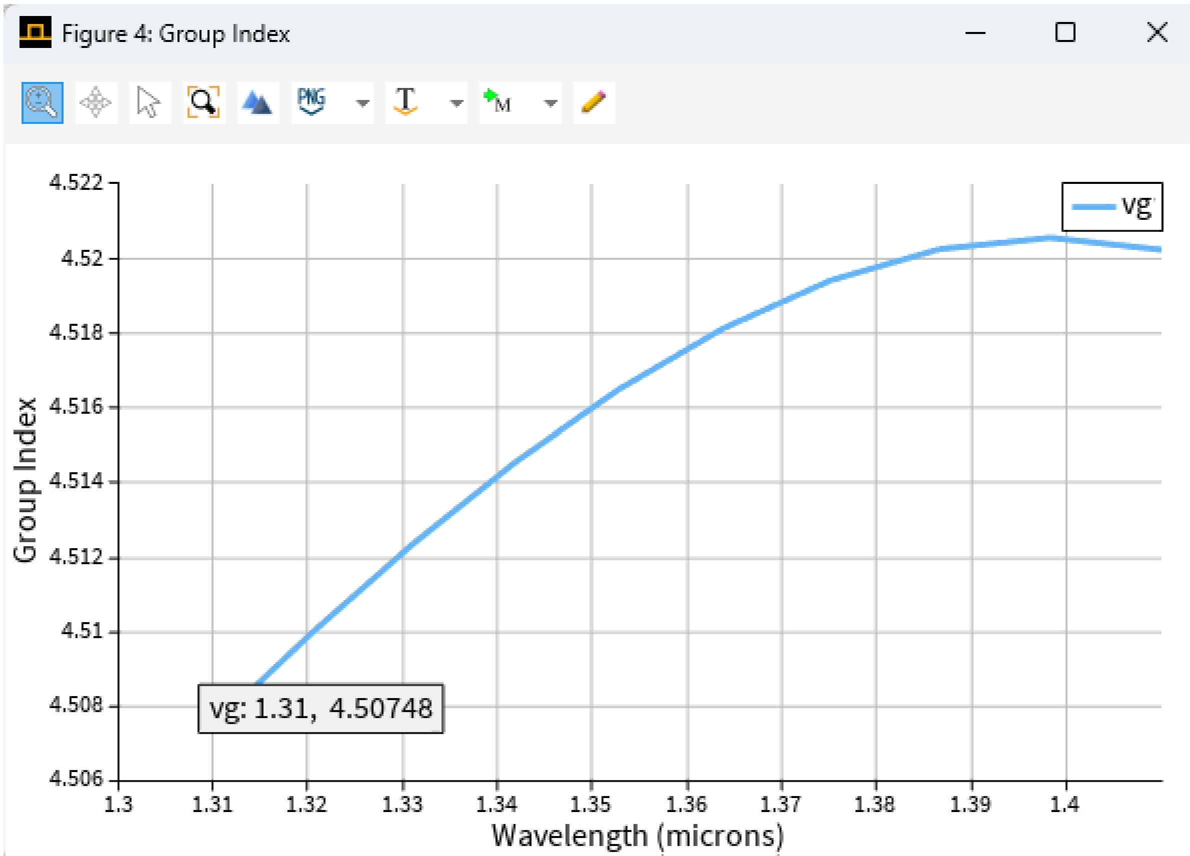
And here is the X component of the electric field.



Frequency Analysis (Wavelength Sweep)

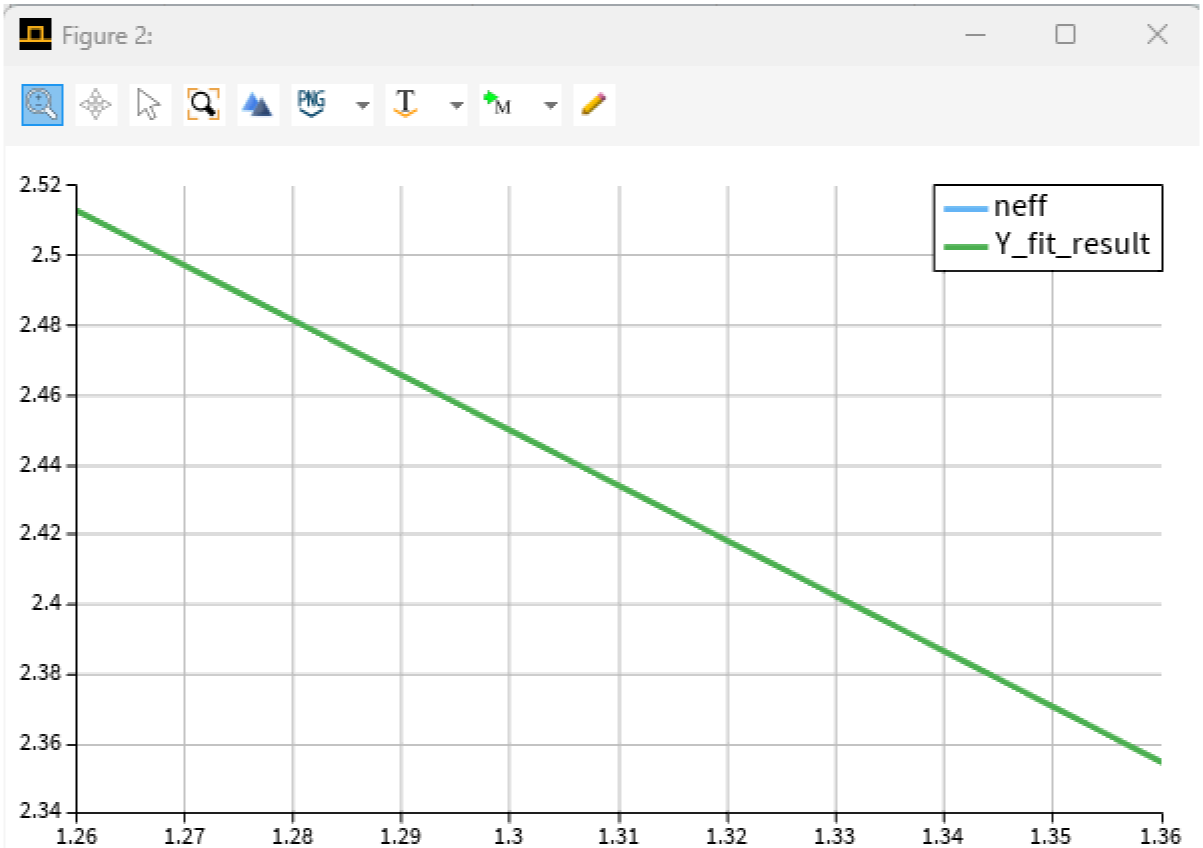


The effective index at 1310 nm for this waveguide is about 2.434, and the group index increases with wavelength and is approximately 4.50.

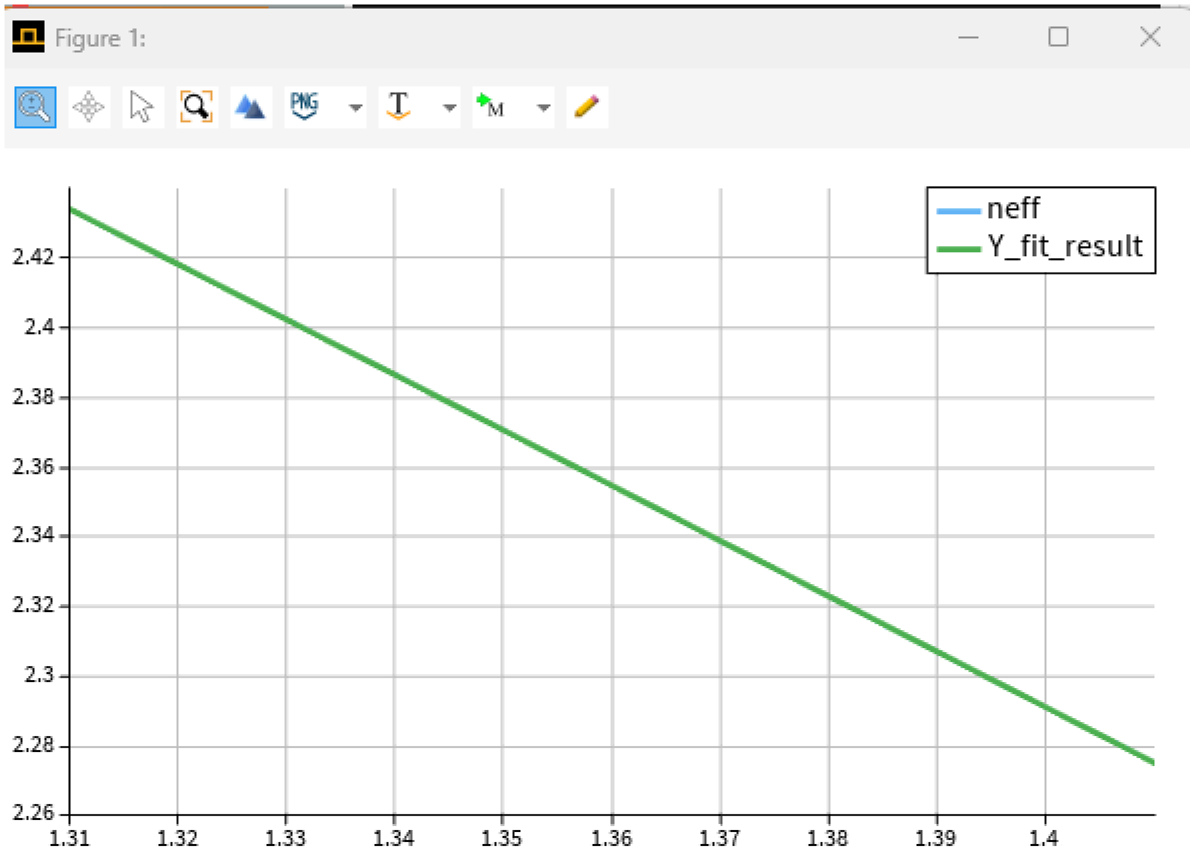


After running the script to model the wave guide's effective index, I got the following equation.

```
plot (lambda, neff, Y_fit_result);  # plot the result;
result:
2.0505
-1.60896
-0.0501316
```

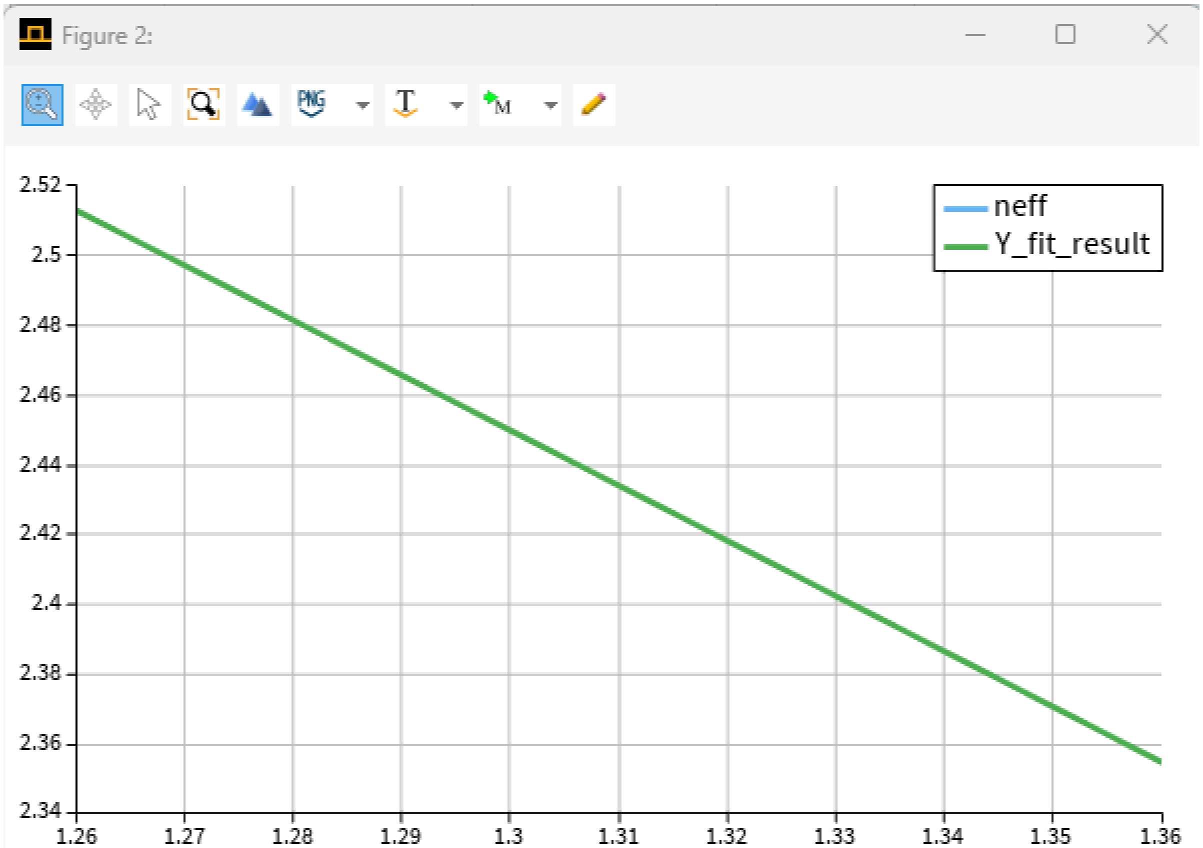


When using this method, the effective index is 2.04861, which varies quite substantially from the direct situation at 1310 nm.



Since we are operating at 1310 nm, I am also going to do a test from a 1260-1360 nm in order to double check the effective index.

```
plot (lambda, neff, Y_fit_result);  # plot the result;
result:
2.04861
-1.62683
-0.0920119
>
```



The effective index is around 2.04861 at the wavelength of 1.31nm.

Given a group index of 4.507, we can calculate the path length difference from the FSR, using the equation:

Delta L = c / (ng * FSR)

$c = 299\,792\,458$

-10 2.997925×10^8

$n_g = 4.507$

-10 10

$F_{SR} = 25 \cdot 10^6$

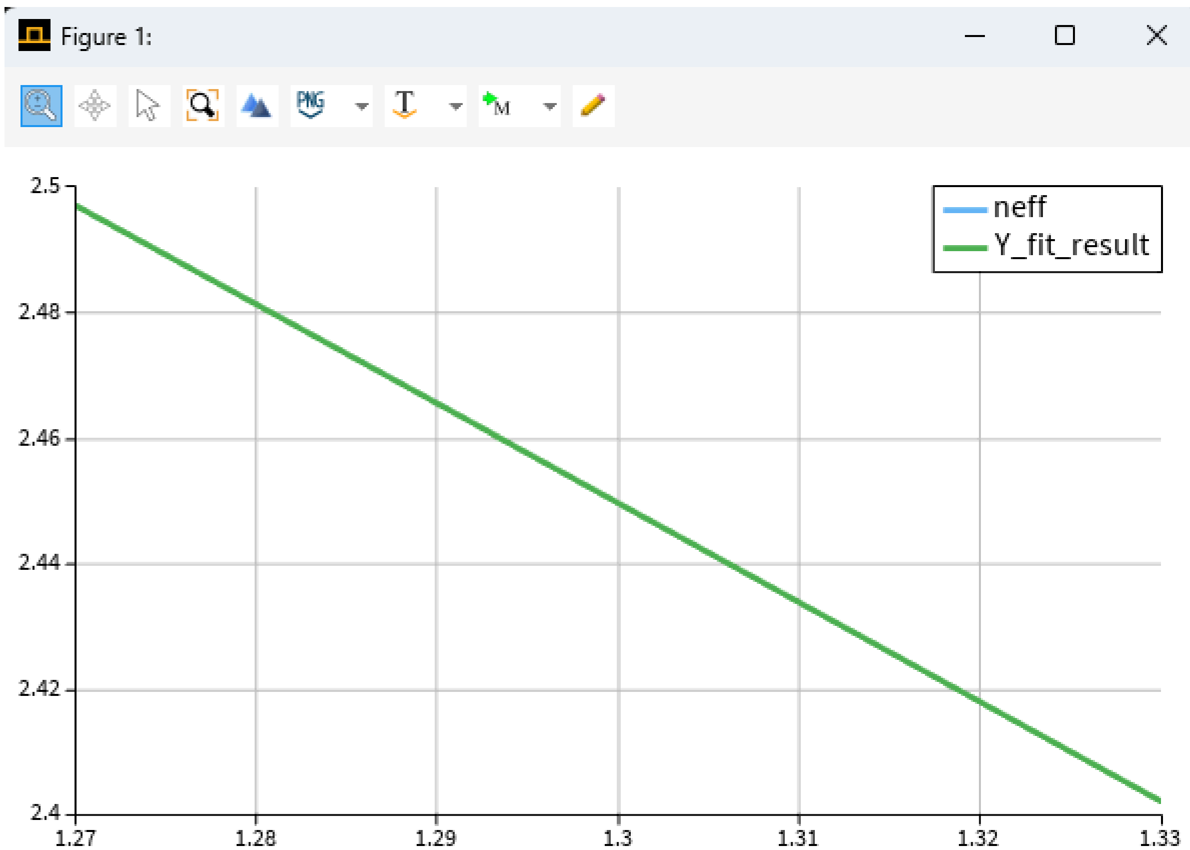
$= 25\,000\,000$

$L = \frac{c}{n_g \cdot F_{SR}}$

$= 2.66068300865$

I calculate that the path length difference of the interferometer needs to be 2.66 mm. Now I will make this in KLayout.

I also did a frequency sweep from 1270-1330 nm, as this aligns with the range that we are testing in, and
The effective index sweep looked like this:



And the equation for effective index was:

```
plot (lambda, neff, Y_fit_result);  # plot the result;
result:
2.04818
-1.63017
-0.0984098
>
```

And at 1.27nm, the group index was 4.49.

So using a group index of 4.5 in my calculations is good and I will aim for a path difference of 2.66mm.

I made this design in KLayout.

$L_1 = 155.254$

−10 155.254

$L_2 = 90.285$

−10 90.285

$L_{SPIRAL} = 2578.429$

−10 2578.429

$L_3 = 151.971$

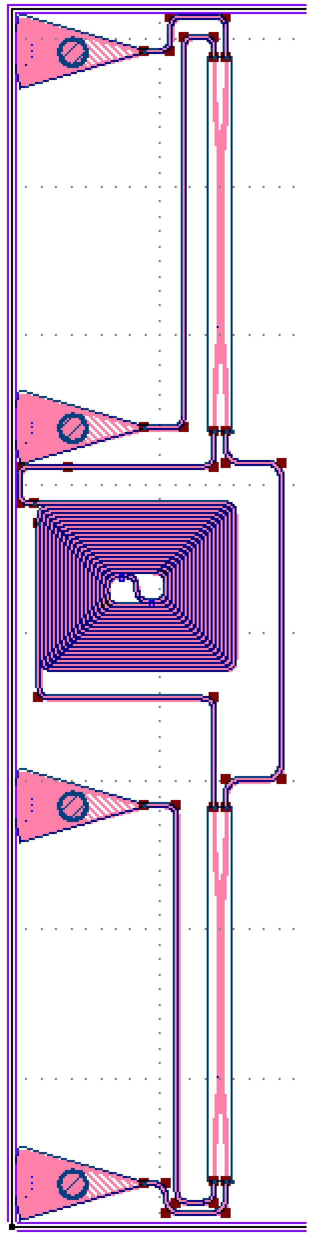
−10 151.971

$L_{Total} = L_2 + L_3 + L_{SPIRAL}$

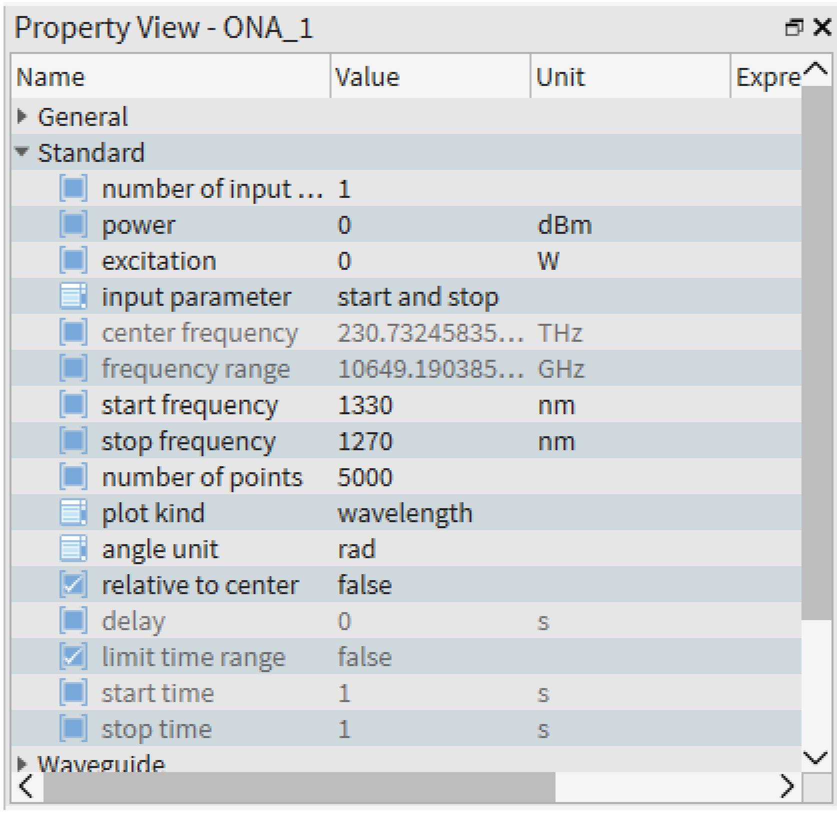
$= 2820.685$

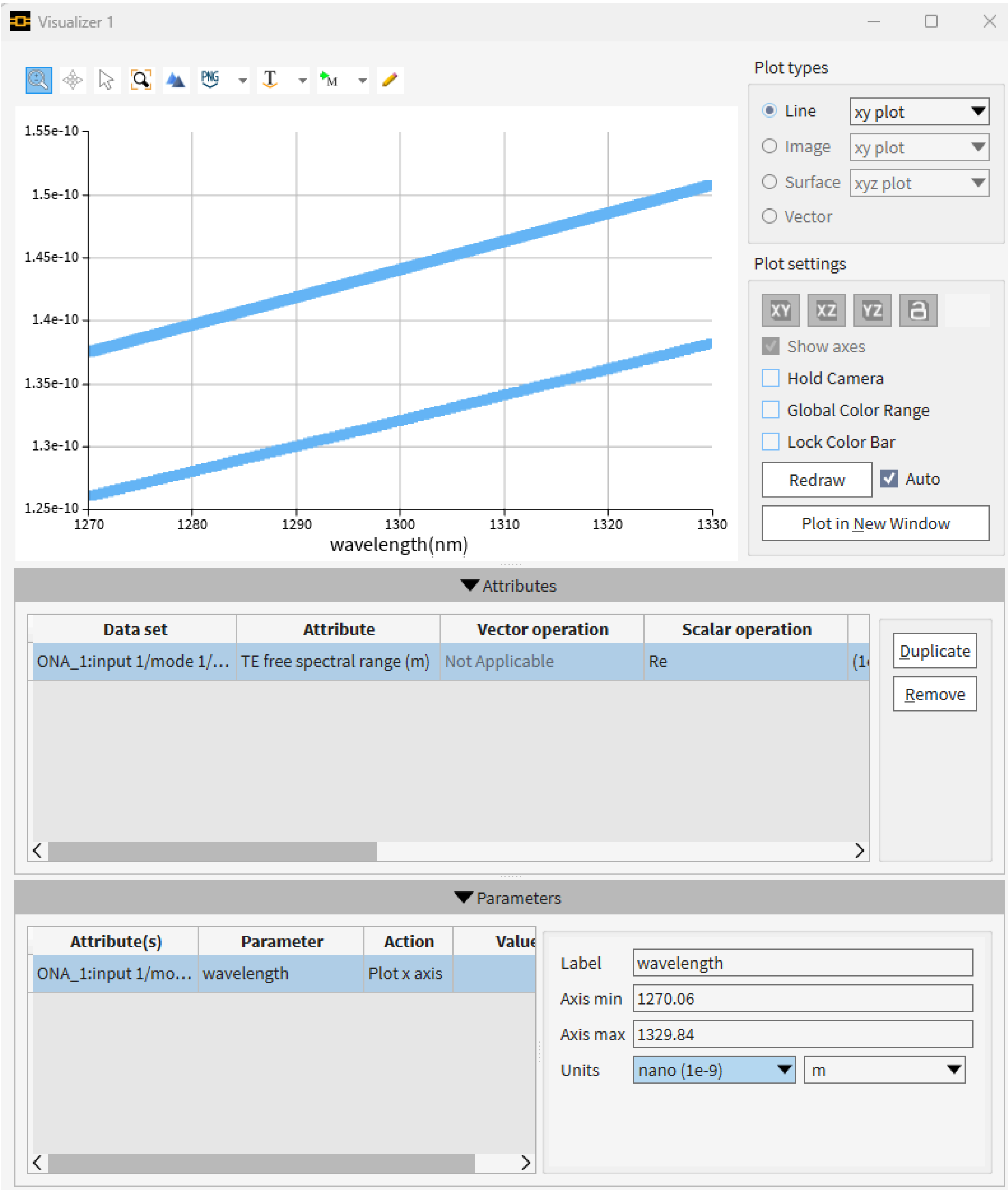
$D = L_{Total} - L_1$

$= 2665.431$

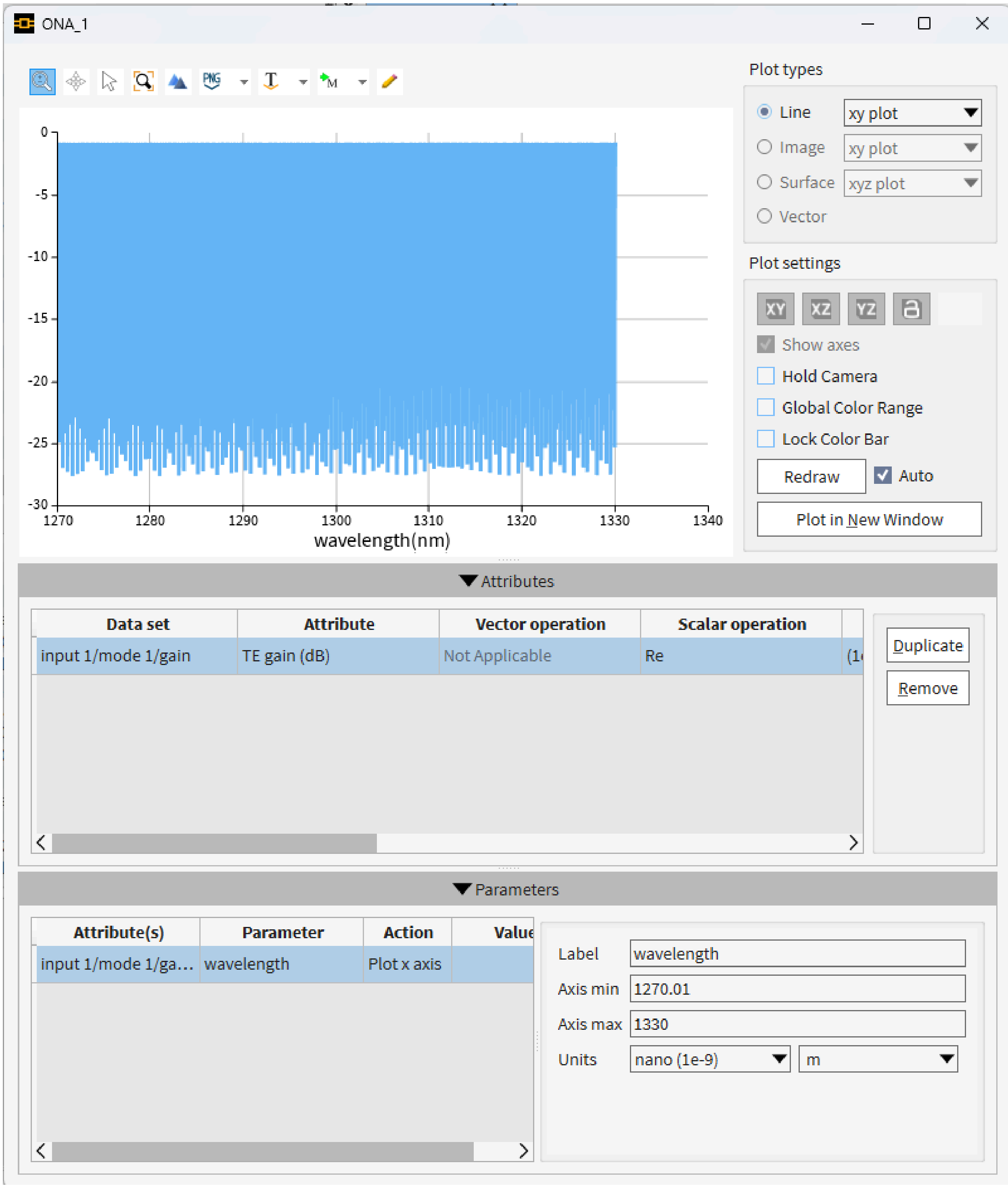


I am running the network analyzer from 1270nm to 1330nm

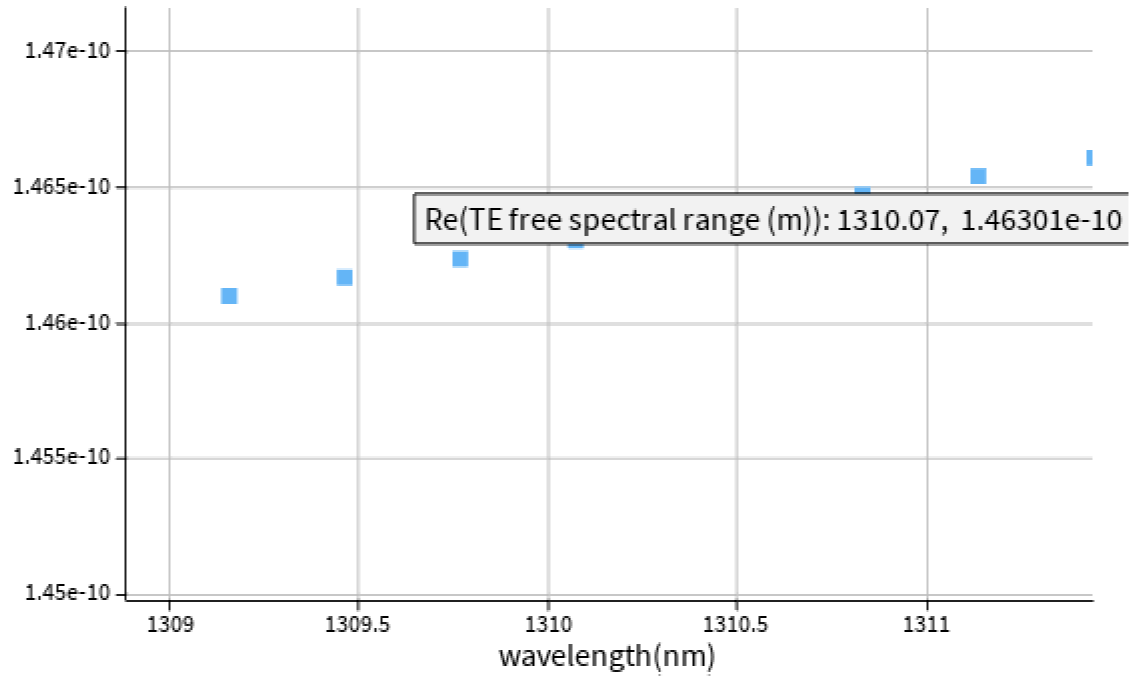




Above is the plot of the free spectral range.



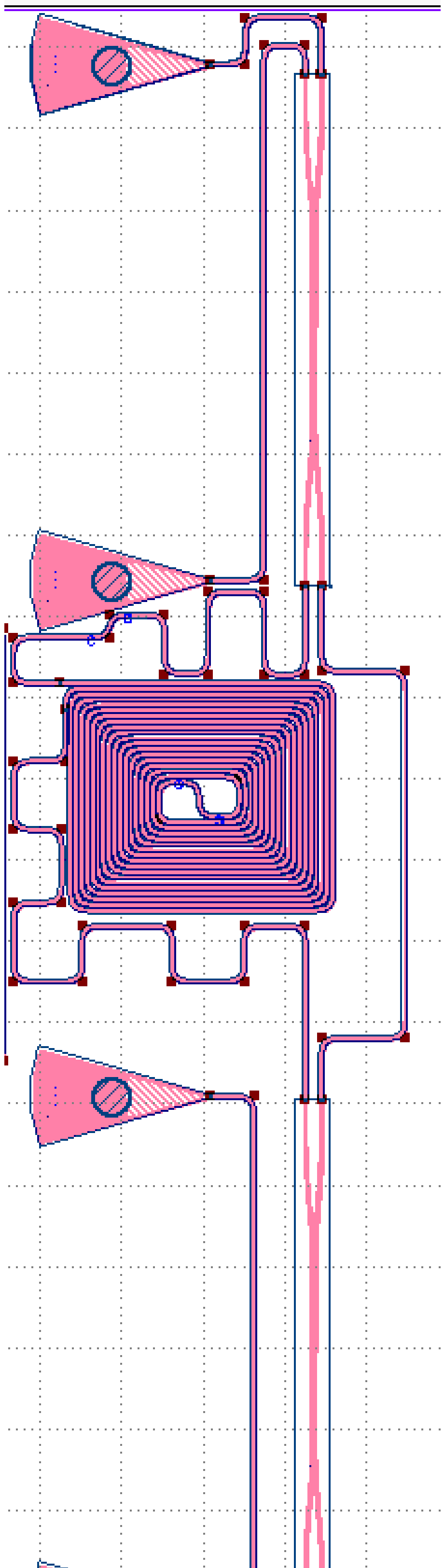
This was the plot for the output of the interferometer.



Here the FSR is 0.14nm, which is what it should be, as this is a 25 GHz FSR. To convert from nm to hertz of the FSR you use the equation:

$$\boxed{\Delta\nu \approx -\frac{c\Delta\lambda}{\lambda^2} = \frac{c}{\Delta L n_g}}$$

I was able to simulate these expected output frequencies for different path lengths as well, and I made a chip design with a 23GHz spacing.



```python
c = 299792458 # m/s
ng = 4.507478

FSR_GHz = 25.0e9 # GHz

wavelength = 1310e-9 # nm

FSR_wavelength_spacing = FSR_GHz * wavelength**2 / c
# Print spacing to 2 decimal places
print("Wavelength Spacing = {:.2f}".format(FSR_wavelength_spacing * 1e9), "nm")
```

✓ 0.0s

```
Wavelength Spacing = 0.14 nm
```

```python
path_length_difference_1 = c / (FSR_GHz * ng)
# Print path length difference to 2 decimal places
print("Path Length Difference = {:.2f}".format(path_length_difference_1*1e3), "mm")
```

✓ 0.0s

```
Path Length Difference = 2.66 mm
```

```python
def calc_path_diff_from_spacing(desired_spacing):
    L = wavelength**2 / (desired_spacing*1e-9 * ng)
    return L

lambda_diff = 0.8 # nm
for lambda_diff in [0.08, 0.10, 0.12, 0.14, 0.16]:
    print(f"Path Length Difference for {lambda_diff}nm = " + "{:.2f}".format(calc_path_diff_from_spacing(lambda_diff) * 1e6), "um")
    print(f"Resulting FSR = "+"{:.2f}".format(c / (calc_path_diff_from_spacing(lambda_diff) * ng) * 1e-9), "GHz")
```

✓ 0.0s

```
Path Length Difference for 0.08nm = 4759.04 um
Resulting FSR = 13.98 GHz
Path Length Difference for 0.1nm = 3807.23 um
Resulting FSR = 17.47 GHz
Path Length Difference for 0.12nm = 3172.69 um
Resulting FSR = 20.96 GHz
Path Length Difference for 0.14nm = 2719.45 um
Resulting FSR = 24.46 GHz
Path Length Difference for 0.16nm = 2379.52 um
Resulting FSR = 27.95 GHz
```

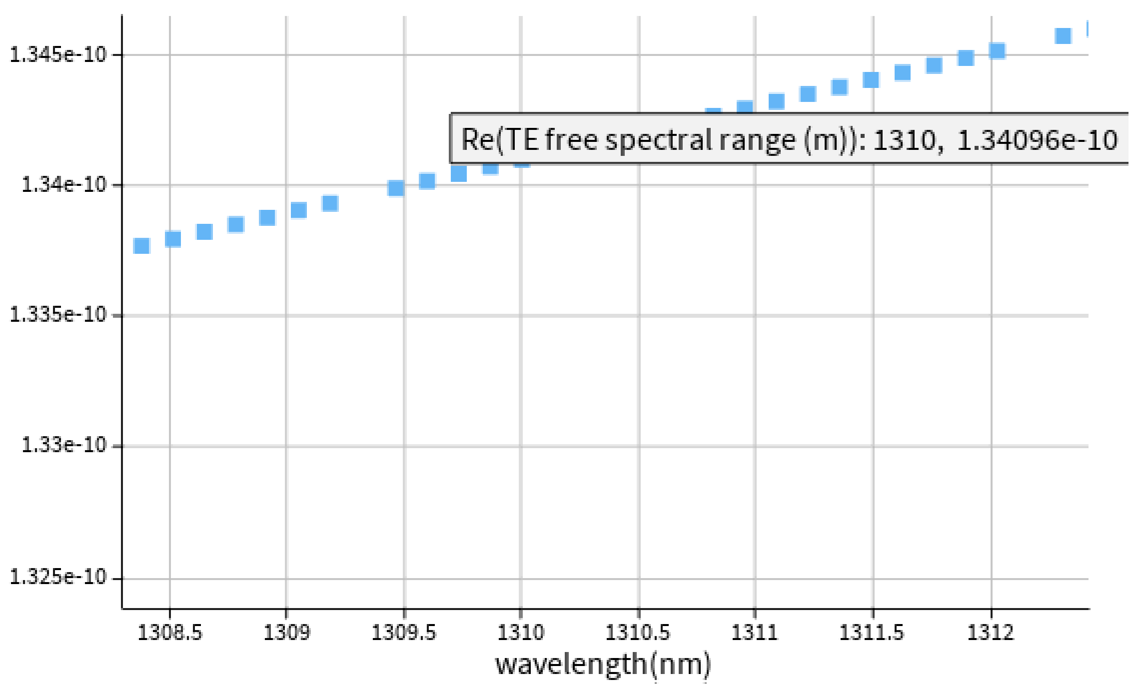
```python
def calc_FSR_from_path_diff(path_diff):
    return c / (path_diff * ng)

L1 = 160.693e-6
L2 = 237.315e-6
L_Spiral = 2578.429e-6
R1 = 161.323e-6

LTotal = L1 + L2 + L_Spiral
R_Total = R1

L_Diff = LTotal - R_Total
FSR = calc_FSR_from_path_diff(L_Diff)
print("FSR_GHz = ", FSR * 1e-9, "GHz")
print("FSR_nm = ", FSR * wavelength**2 / c * 1e9, "nm")
```

✓ 0.0s

```
FSR_GHz =  23.626049014977255 GHz
FSR_nm =  0.1352424373351062 nm
```

The function above calculated the expected FSR in GHz for the path length difference that I had in the second circuit.

This matches the INTERCONNECT simulation.



- Consider fabrication variations (width +/- 10 nm, thickness +/- 10 nm, process bias Δw, range of propagation loss values) and how they will impact the filter performance. Start with identifying the process corners, simulating the waveguide for each corner, then simulating the circuit for each corner.

Corners:

Design #	Waveguide Size	Group Index	Path Difference	File_name
1	350 x 220	4.507478	2660.40	350x220_wg.ldf
2	360 x 230	4.469343	2683.10	360x230_wg.ldf
3	360 x 210	4.466558	2684.77	360x210_wg.ldf
4	340 x 230	4.525866	2649.59	340x230_wg.ldf
5	340 x 210	4.518220	2654.08	340x210_wg.ldf

```python
def calc_necessary_path_diff(ng):
    FSR = 25e9 # GHz
    return c / (FSR * ng)

print("Path Length Difference for ng = 4.5: ", calc_necessary_path_diff(4.5) * 1e6, "um")
```

✓ 0.0s Python

```
Path Length Difference for ng = 4.5:  2664.821848888889 um
```

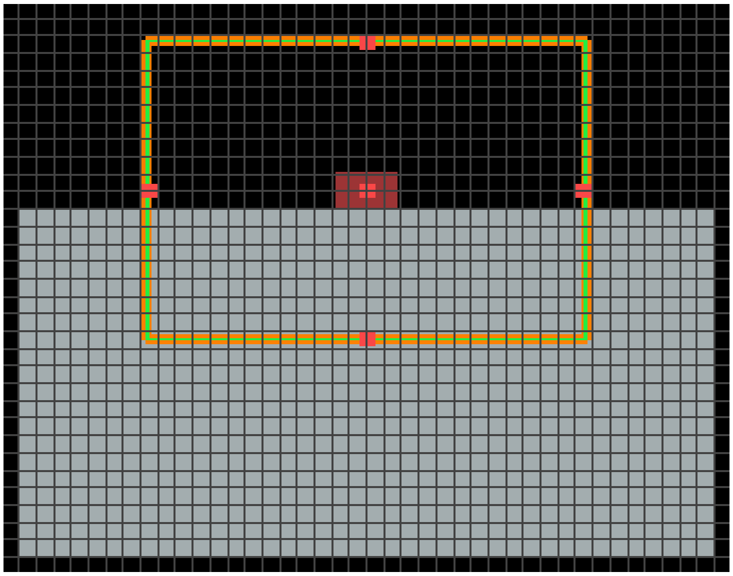
Now I am going to simulate different sized waveguides in lumerical mode to get a variation in group indexes, and then try to make a variety of designs with those size variations.

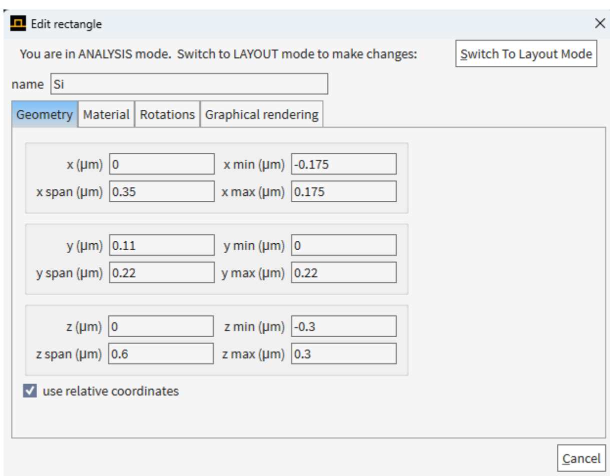
```python
ngth Difference for ng = 4.507478: " + "{:.2f}".format(calc_necessary_path_diff(4.507478) * 1e6), "um")
ngth Difference for ng = 4.469343: " + "{:.2f}".format(calc_necessary_path_diff(4.469343) * 1e6), "um")
ngth Difference for ng = 4.466558: " + "{:.2f}".format(calc_necessary_path_diff(4.466558) * 1e6), "um")
ngth Difference for ng = 4.525866: " + "{:.2f}".format(calc_necessary_path_diff(4.525866) * 1e6), "um")
ngth Difference for ng = 4.518220: " + "{:.2f}".format(calc_necessary_path_diff(4.518220) * 1e6), "um")
```

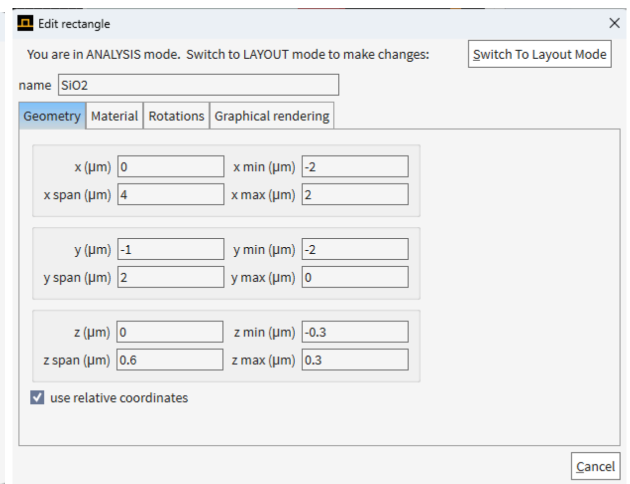
✓ 0.0s Python

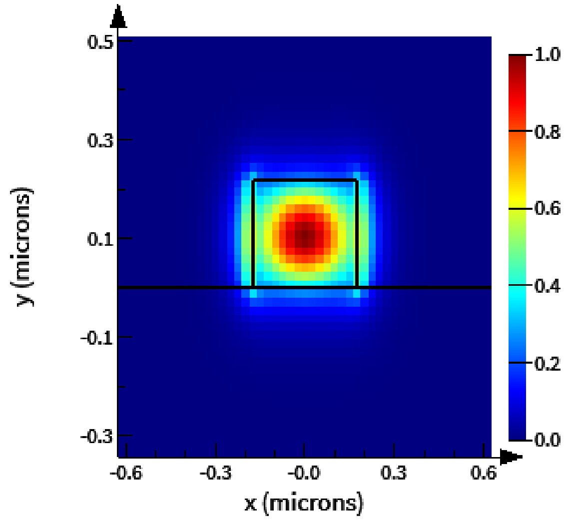
```
Path Length Difference for ng = 4.507478: 2660.40 um
Path Length Difference for ng = 4.469343: 2683.10 um
Path Length Difference for ng = 4.466558: 2684.77 um
Path Length Difference for ng = 4.525866: 2649.59 um
Path Length Difference for ng = 4.518220: 2654.08 um
```

For Chip 2 I began by simulating the waveguide.







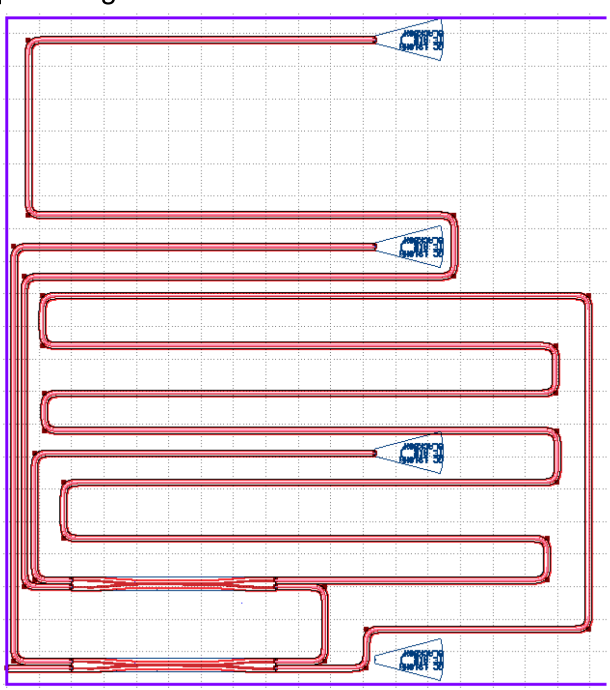


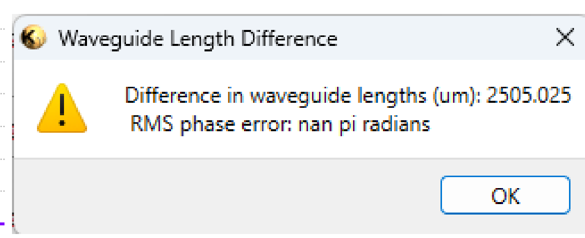
Eigensolver Analysis

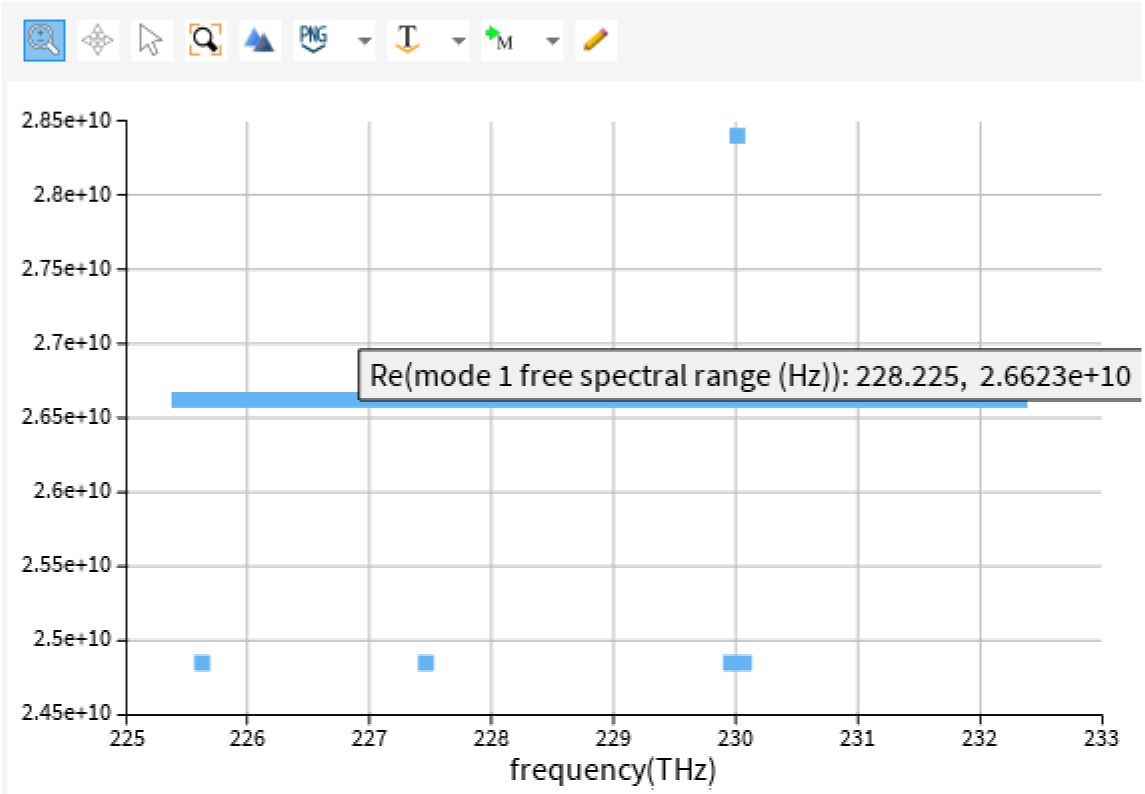
Mode list

mode #	effective index	wavelength (µm)	loss (dB/cm)	group index	TE polarization fraction (Ex)	waveguide TE/TM fraction (%)	effective area (µm^2)
1	2.355116+1.723409e-09i	1.31	0.00071798	4.786668+3.484210e-09i	97	65.47 / 84.16	0.140897
2	1.845431+1.543339e-09i	1.31	0.00064296	5.028435+7.395737e-09i	6	59.66 / 87.37	0.200235

The group index is 4.786668, and from my python calculations, this means there is a required path length difference of 2505.22 um.







Based on my simulation of chip 2, the FSR was about 26 GHz. This is slightly larger than I wanted, however I am confident in my path length difference calculation and so will keep the same pathlength.

Having the correct path difference is resulting in the wrong FSR.

Chip 2 Design

```
print("Path Length Difference for ng = 4.78668: ", calc_necessary_path_diff(4.78668) * 1e6, "um")
ng = 4.78668
L2 = 100.219e-6
L1 = 2605.244e-6

LTotal = L1
R_Total = L2
print("Path 1", LTotal * 1e6, "um")
print("Path 2", R_Total * 1e6, "um")

L_Diff = LTotal - R_Total
print("Path Length Difference = {:.2f}".format(L_Diff*1e6), "um")
FSR = calc_FSR_from_path_diff(L_Diff, ng)
print("FSR_GHz = ", FSR * 1e-9, "GHz")
print("FSR_nm = ", FSR * wavelength**2 / c * 1e9, "nm")
```

```
Path Length Difference for ng = 4.78668:  2505.222475703411 um
Path 1 2605.244 um
Path 2 100.219 um
Path Length Difference = 2505.03 um
FSR_GHz =  25.001970795734678 GHz
FSR_nm =  0.14311861735547823 nm
```