



INTERNSHIP-M1

OBSERVATIONS

*OPTICAL FIBER REFRACTOMETER: FROM THE DESIGN
INTO GAS SENSING TECHNOLOGIES*

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M1-SATCOM

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DEFINITIONS

PHOTONIC CRYSTAL FIBER: A Fiber with a pattern of air holes with the central hole missing made of pure fused silica an arrangement of very tiny and closely spaced air holes which go through the whole length of the fiber.

SNELL'S LAW: Snell's Law is a fundamental principle that explains how light waves, change direction when passing from one medium to another.

Snells Law expressed as

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

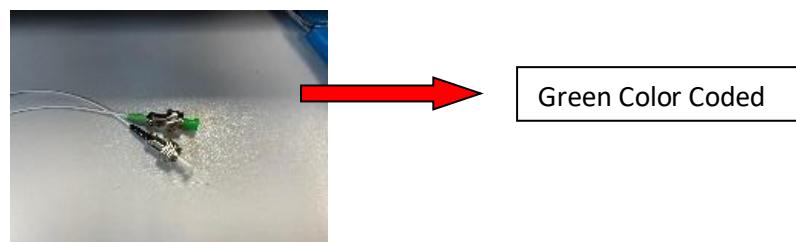
Critical Angle (θ_c):

The critical angle is the angle of incidence beyond which total internal reflection occurs. For total internal reflection to occur, the angle of incidence of the light must be greater than the critical angle, which depends on the refractive indices of the core and cladding. It is expressed as

$$\sin(\theta_c) = n_{cl} / n_{co}$$

Return Loss: Return loss is a measurement of the light reflected back to the source at an optical interface.

Angled-polished connectors: Fiber connector that minimizes back-reflection due to a 8° angle-polish applied to end faces.



EXPERIMENTAL PROCEDURE

WEEK 1:

PREPARATION OF LIQUID FOR EQUIVALENT CLADDING:

Mixed Glycerol with Water and measured in digital refractometer to get below Brix values

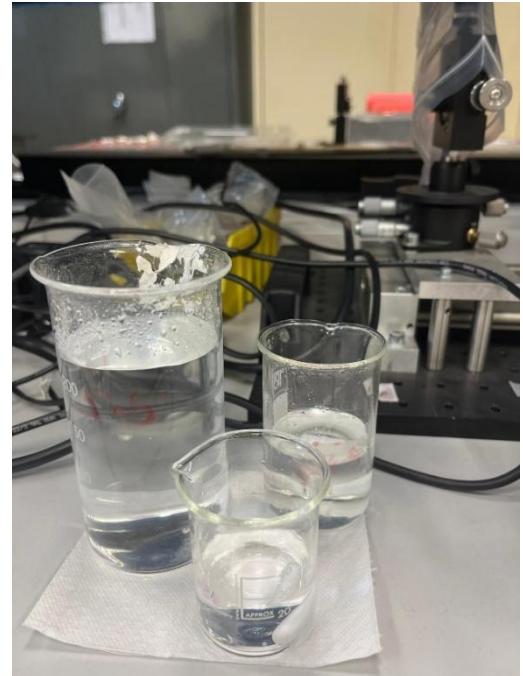
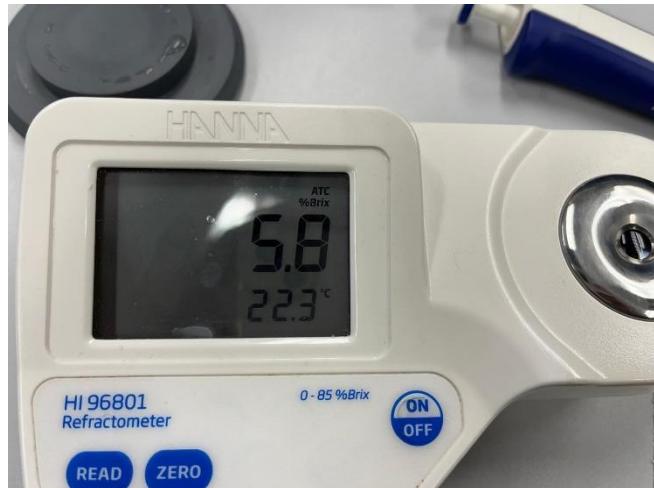
APPARATUS: Digital Refractometer for Brix value

5.5% 1.34026 RIU

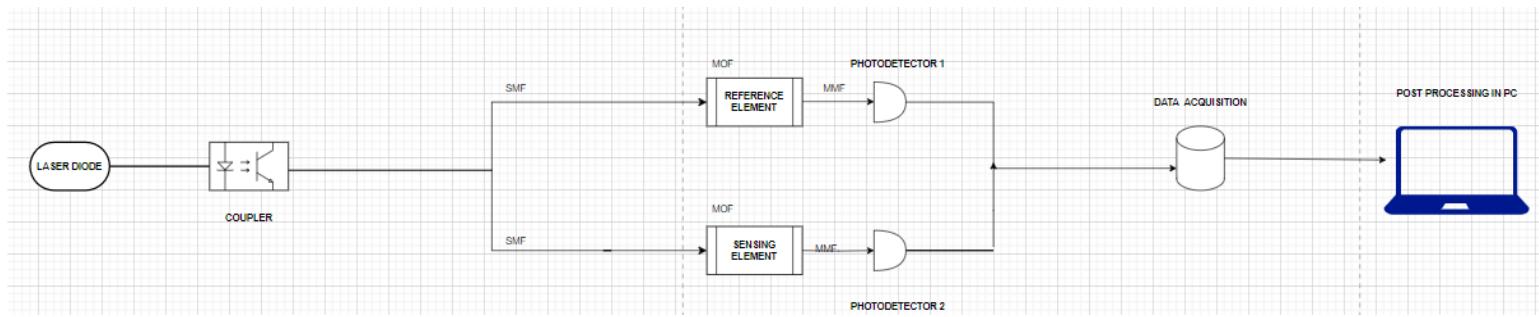
14.8% 1.35408 RIU

15.1% 1.35568 RIU

Results:



EXPERIMENTAL SETUP:



Post preparing the liquid, the experimental is setup and offset of the photodetector is calculated before recording the power measurements.

1.OFFSET CALCULATION OF PHOTODETECTOR

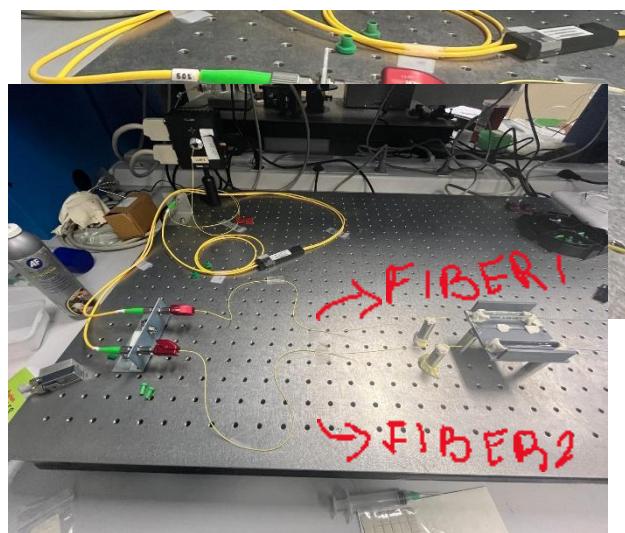
LASER	P1(mW)	P2(mW)	P3(mW)	Average	Ratio
Laser1	2.025	2.026	2.017	2.022667	1.1257885
laser2	1.792	1.798	1.8	1.7966667	
Fiber1	1.926	1.928	1.925	1.926333	1.18860551
Fiber2	1.619	1.621	1.622	1.62066667	

Cross verify value	P1(mW)	P2	P3
Laser	1.982097	2.011903	2.073999
Fiber	1.92435232	1.92672954	1.92791814

Photodetector	Gain-0dB	Gain-10dB
PD1	2.68V	8.43V
PD2	2.38V	7.45V

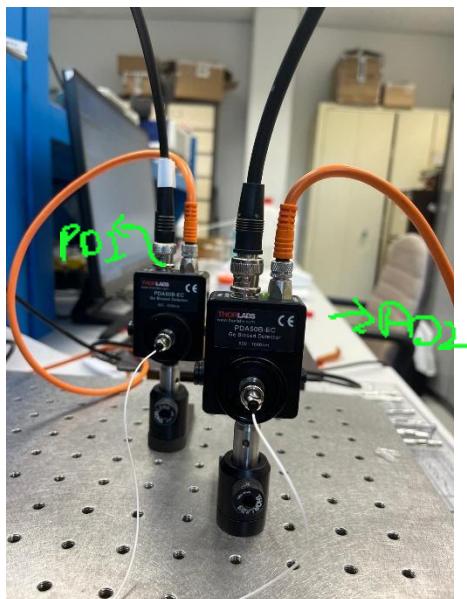
Three values of power are measured using power meter at the end of each laser using a APC Connector and using ideal SMF fiber end point and ratio of the average value is calculated

Power measured at Laser1 and Laser2:



Power measured at Fiber1 and Fiber2:

Power measured at Photodetector1 and Photodetector2:



The photodetector used is PDA50B-EC from Thorlabs is a Germanium gain amplifier that detects light in the range 800 to 1800 nm and variable gain from 0-70 dB.

Checking the datasheet, for the Gain of the Photodetector 60dB, the Bandwidth given is 705 Hz, hence sampling frequency should be 1.4KHz in accordance to the Shannon-Nyquist Theorem, and Input signal from the function generator is modulated at 350Hz.

2. The SMF-Capillary Fiber of thickness 20 microns is spliced with MMF by removing the cladding, cleaved, and then joined using the splicer. The sensing element and the reference element of length 5 cm are placed inside a tube filled with water of Refractive index 0 on the Reference side and another filled with a Glycerol-water mixture of various refractive indexes to study the variation of power.
3. The spliced Fiber is placed on the test bench connected to the laser source and photodetector which is in turn connected to Data Acquisition System and Oscilloscope.
4. The refractive index used for the measurement is 5.8 and 3 sets of readings were taken to ensure stability of the setup.
5. Laser source is given at 40mA and sampling frequency should be 1.4KHz

Result:

	A	B	C	D	E	F	G	H	I	J
1	Ref	SM	Ref	SM	Ref	SM	Ref	SM	Ref	SM
2	0	0	0	5.8	0	0	0	16.2	0	
3	2.49599961	2.13429769	2.44922143	2.11013914	0.13270439	2.11411469				
4	2.49971706	2.12136083	2.45098703	2.1098698	0.13284159	2.11572913				
5	2.50118422	2.12890476	2.45103963	2.10920189	0.13222155	2.11597053				
6	2.50004402	2.1274385	2.45145911	2.10894154	0.13250694	2.1158254				
7	2.50351768	2.12507845	2.44906501	2.10879878	0.13238483	2.11562876				
8	2.49814359	2.1232926	2.4506889	2.10799759	0.13261436	2.11564798				
9	2.49379454	2.12206763	2.44867643	2.10761954	0.13278808	2.11546586				
10	2.49359821	2.12140778	2.4497615	2.10702527	0.13283554	2.11505919				
11	2.48826568	2.12126854	2.45023385	2.1072199	0.13290253	2.11443389				
12	2.60041686	2.12143799	2.45069154	2.10732741	0.13289247	2.1144207				
13	2.59707188	2.12145856	2.45301301	2.10793007	0.13310585	2.11424932				
14	2.59403545	2.12061287	2.45426024	2.10871223	0.1331611	2.11377869				
15	2.5881954	2.11989053	2.45514864	2.10855898	0.1331832	2.11304091				
16	2.58795445	2.11945322	2.45294451	2.10832393	0.1331894	2.11248329				
17	2.58628569	2.11919367	2.4542637	2.10871804	0.13302648	2.11225421				
18	2.57945585	2.11794471	2.45370643	2.10843536	0.13240229	2.11201637				
19	2.57603356	2.11802259	2.45438796	2.10842656	0.13011729	2.11171045				
20	2.57878273	2.11804163	2.45482314	2.1087791	0.12719145	2.11162315				
21	2.5747255	2.11795107	2.45521163	2.10908128	0.1240261	2.11167441				
22	2.5733838	2.11756463	2.45628685	2.10930959	0.11590092	2.11127922				
23										
24	2.54553029	2.12233441	2.45229353	2.1085208	0.13109984	2.11382229	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
25	1.000000		1.031264		19.338855		#DIV/0!		#DIV/0!	
26	LD 25 C; 40 mA; Modulation: 1 KHz, 1 Vpp sampling rate 25 kHz				10dBpd					
27										

12June:

Observations for the experiment were carried out for solvents with Brix values 6.2, 20.1, 29.5, 36.1 for 35um of capillary fiber.

Below is the screenshot of the reading recorded. Ref column indicates the power in terms of mV for the Reference element and SM indicates for sensing element, two sets of readings were taken to ensure the stability of the setup.

Analyzing the power of the sensing element, it is concluded that power gradually reduces when the viscosity of the liquid increases.

Result:

C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Ref	SM	Ref	SM	Ref	SM	Ref	SM	Ref	SM	Ref	SM	Ref	SM	Ref	SM	Ref	SM	Ref
5620071	0.10986449	1.5850309	5.5930386	1.575585	0.5999009	1.5667358	4.6508166	1.5631016	8.1249275	1.5486586	8.43961	1.5480212	5.736081	1.5452928	5.4706281	1.5417389	5.042668	
5617594	8.0397275	1.5653559	5.5841481	1.5753356	5.60128	1.5667943	4.6564379	1.5619378	8.1332351	1.5488141	8.4409384	1.5481723	5.7274347	1.5454209	5.4756786	1.5416838	5.0356734	
5613794	0.1088051	1.5655118	5.5921691	1.5753085	5.6056442	1.5668634	4.6511981	1.5620198	8.1410202	1.5490076	8.4420647	1.5479237	5.713762	1.5460511	5.4756908	1.5414852	5.0301152	
1.561718	8.110526	1.5651667	5.6020374	1.5753465	5.6078319	1.5671751	4.6543784	1.5619971	8.1483748	1.5493153	8.4469381	1.5480496	5.7099507	1.54603	5.4824923	1.5412073	5.0249792	
5620996	8.1234428	1.5648512	5.6130538	1.5752217	5.6094884	1.5671134	4.6547819	1.5628981	8.1521062	1.5493566	8.4487587	1.548775	5.7101236	1.5460816	5.48942	1.5412684	5.0212629	
5622278	8.1216322	1.5649021	5.5989026	1.5746651	5.6155996	1.5670785	4.6568602	1.5622798	8.1514012	1.5488757	8.453235	1.5489521	5.7075252	1.5460429	5.4965529	1.5417576	5.0153493	
5620695	8.1205991	1.5647608	5.6126203	1.5746041	5.6255986	1.5674244	4.666091	1.5627719	8.1547465	1.5466674	8.4571158	1.5492345	5.686289	1.5455481	5.5019254	1.5417784	5.0017033	
5615078	8.1130261	1.5647024	5.6164554	1.5747607	5.6136344	1.5674247	4.6570709	1.5630837	8.1508256	1.54892	8.46070942	1.5492275	5.6862469	1.5459878	5.5008267	1.5419991	4.9951944	
5612344	8.1161329	1.5646599	5.6064945	1.5745652	5.6539861	1.5671373	4.6539763	1.5628626	8.1630269	1.5493149	8.462615	1.5479278	5.6702467	1.5466091	5.4984429	1.5416397	4.9886774	
5615102	8.1415772	1.5646599	5.6064945	1.5745652	5.6539861	1.5671373	4.6539763	1.5628626	8.1630269	1.5493149	8.462615	1.5479278	5.6702467	1.5466091	5.4984429	1.5416397	4.9886774	
5618245	8.4097172	1.5648297	5.5846896	1.5742007	5.6389389	1.5674589	4.6502389	1.5629116	8.1624418	1.549754	8.467688	1.5483391	5.6627064	1.5469339	5.5009369	1.5414471	5.0212629	
1.561615	8.1415772	1.5646219	5.6011497	1.5741445	5.6064338	1.5672556	4.6446579	1.5628504	8.1795375	1.5497449	8.4655537	1.5486906	5.6647765	1.5469339	5.5009369	1.5414471	5.0212629	
5618528	8.1446284	1.5646555	5.6050395	1.5739374	5.6369431	1.5678149	4.6510815	1.5635461	8.1789956	1.5503102	8.4641924	1.5490088	5.6584805	1.5460922	5.5132486	1.5421068	4.9626065	
56151028	8.1392792	1.5646157	5.6094441	1.5739467	5.6420045	1.5684158	4.6550915	1.5620654	8.1951395	1.5501692	8.467609	1.5480439	5.6544297	1.5459384	5.5090912	1.5419551	4.9574719	
5612586	8.1318128	1.5641244	5.6142041	1.5740546	5.6403649	1.5680872	4.648414	1.5620302	8.1998361	1.5496975	8.4720191	1.5487747	5.6525429	1.5459061	5.5075687	1.5419963	4.9510074	
5616749	8.1402115	1.5639101	5.6228962	1.5739167	5.6369379	1.5691256	4.6399192	1.5624349	8.1994041	1.5496975	8.4722027	1.5480599	5.6556384	1.5459768	5.5105725	1.5416341	4.9449276	
5616082	8.1464195	1.5646729	5.6015633	1.5736093	5.6422912	1.5675665	4.6387684	1.562268	8.2008618	1.5499439	8.4725984	1.5482359	5.6531281	1.5460645	5.5087705	1.5414975	4.9937327	
5611229	8.142085	1.5646591	5.5997255	1.5729591	5.6493324	1.5676448	4.639587	1.5624628	8.1957058	1.5500821	8.473408	1.5477773	5.6467627	1.5456943	5.5132932	1.5411454	4.9520682	
5606828	8.141207	1.5644283	5.6042212	1.5736786	5.6500753	1.5673114	4.6367409	1.5623776	8.1994977	1.5498112	8.4732289	1.5476078	5.64392933	1.5462994	5.5093598	1.5415104	4.9273518	
5616551	8.1274128	1.5647659	5.6031126	1.5744485	5.6280813	1.5674082	4.6500704	1.5624047	8.1689957	1.5495021	8.4579873	1.5482876	5.6766633	1.5460402	5.499366	1.5417235	4.9856159	
1.001820	0.0689291	0.688104	0.571084	1.006463	1.050968	1.0706144	0.684726	1.006463	1.050968	1.0706144	0.684726	1.006463	1.050968	1.062493	#DIV/0!	#DIV/0!	#DIV/0!	
1 KHz	V	1 V	sampling rate 25 kHz	10dB pd														

CHARACTERIZATION OF NOISE:

The SNR can be calculated by considering the ratio of signal values in first cell of PSD to the average of noise values in same column. The SNR is calculated for each set of readings. The snippet of the program below.

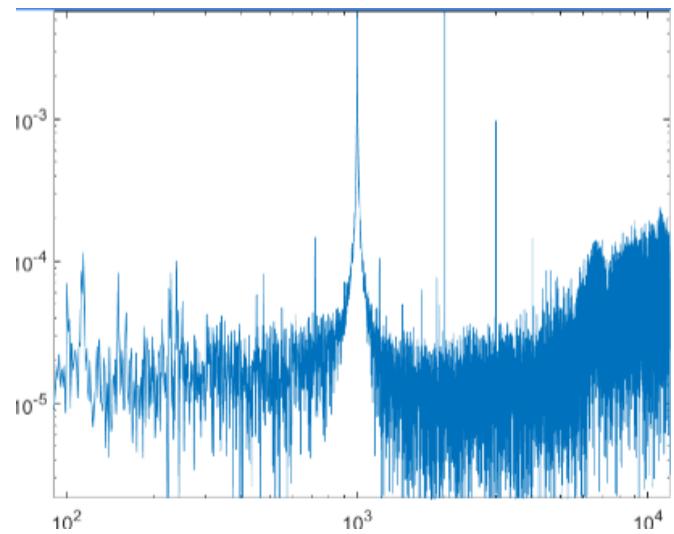
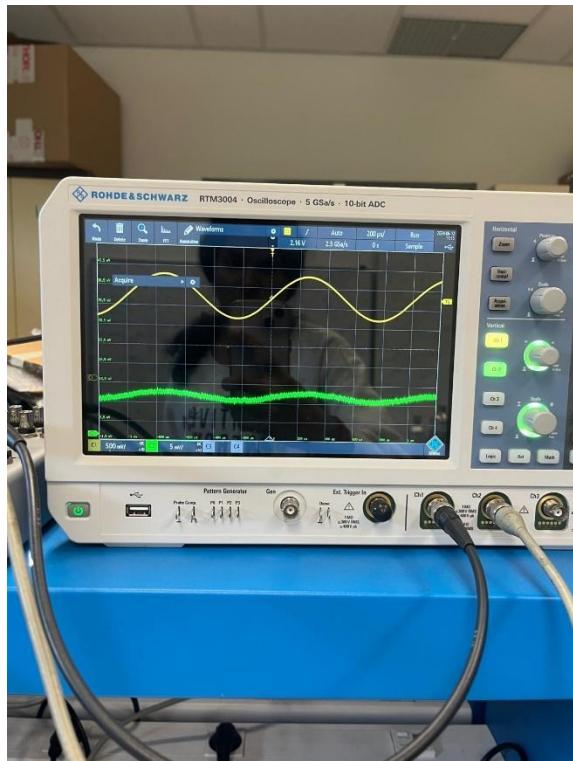
MATLAB CODE:

```
i=0;
for i=1:N/20:N
    [freq1(i,:),psdx0(i,:)] = PSD_simple(freq,ai_00(:,i));
    [freq2(i,:),psdx1(i,:)] = PSD_simple(freq,ai_01(:,i));
end

a0=nonzeros(psdx0);
a1=nonzeros(psdx1);
psd0=reshape(a0,[],12501)';
psd1=reshape(a1,[],12501)';

signal=(psd1(1,:))'; %data in 1st row
r=(psd0(2:end,1:end))'; %excluding 1st cell for noise
```

```
i=psd0(2:end,1:20)  
noise=(mean(i))';  
  
signal_tonoise=10*log10(signal./noise) %SNR for each column
```



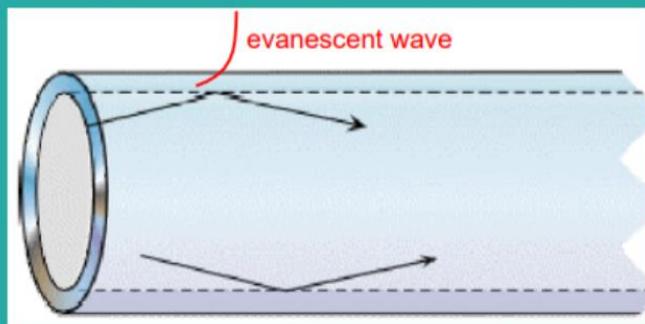
WEEK 2:

COMSOL APPLICATION

DEFINITION:

What is an EVANESCENT WAVE?

- Occurs at the boundary between two media with different refractive indices
- Interact with the surrounding medium, allowing for the development of fiber optic sensors



GOAL: To design a Photonic Crystal Fiber of 3 Layer HEXAGON SHAPE using COMSOL Application

PARAMETERS:

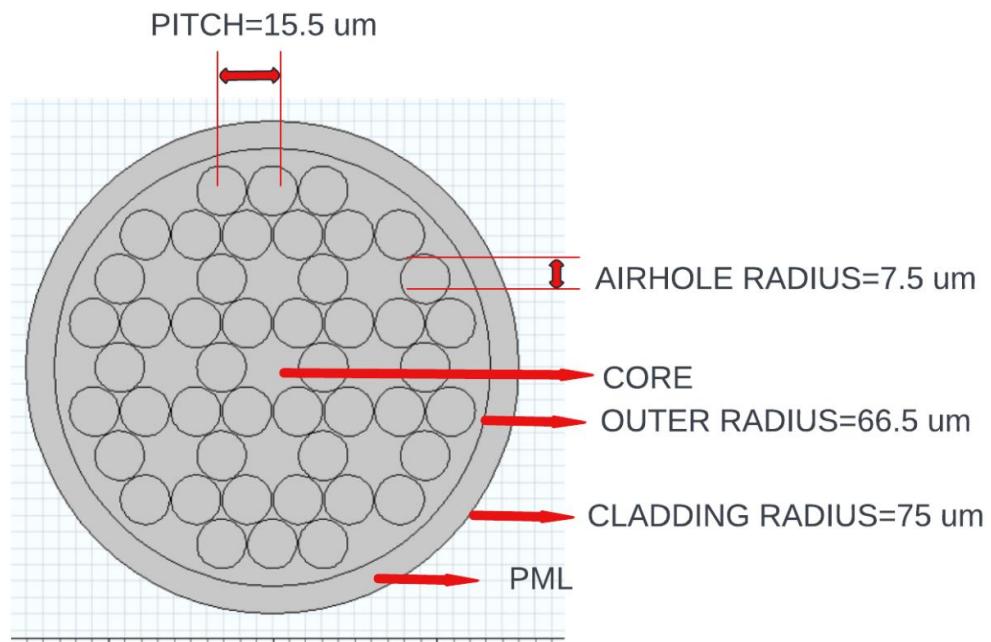
Airhole radius: 2.2 um

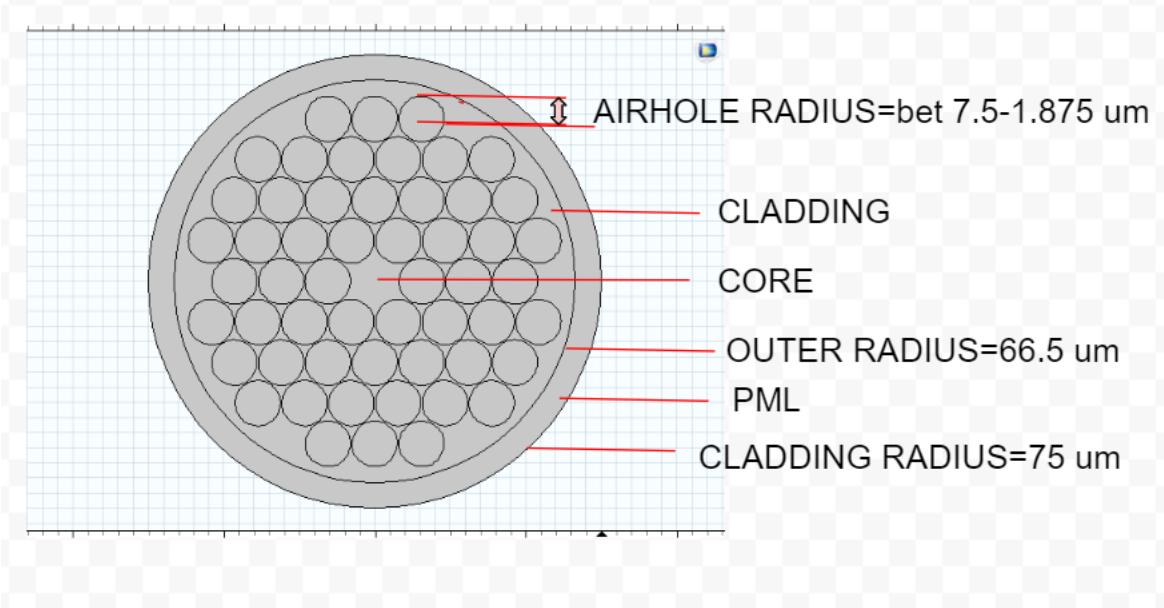
Pitch: 10 um Distance between 2 airholes

Outer Diameter: 105 um

PHOTONIC CRYSTAL FIBER: A Fiber with triangular pattern of air holes with the central hole missing. An optical fiber made of pure fused silica and obtains its waveguide properties not from a spatially varying glass composition but from an arrangement of very tiny and closely spaced air holes which go through the whole length of the fiber.

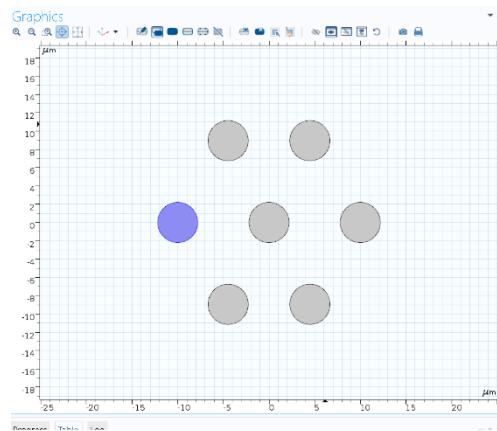
STRUCTURE DESIGN:



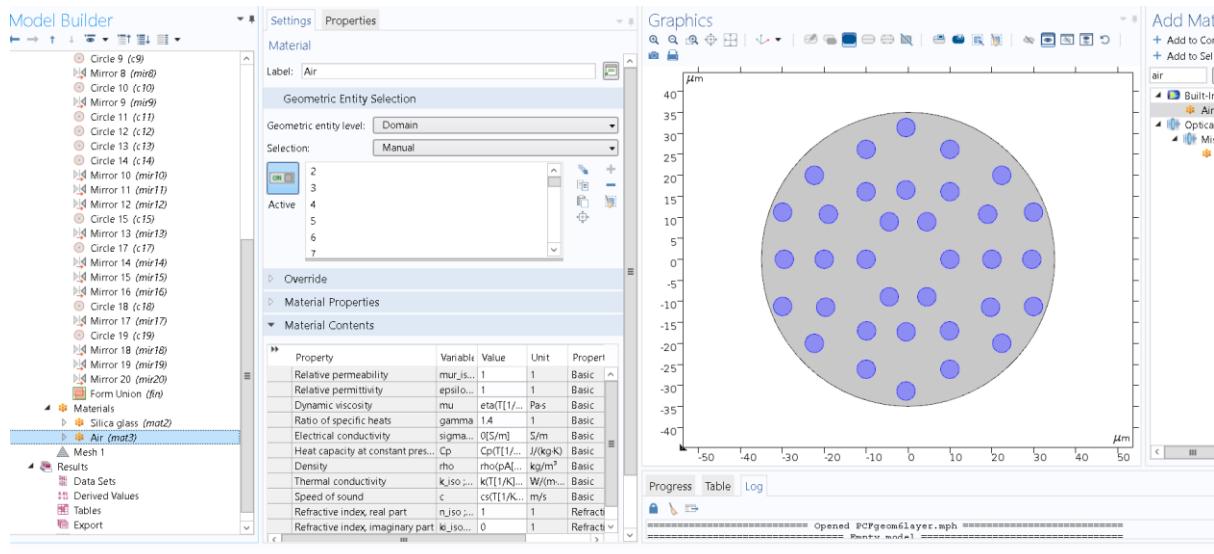


Results:

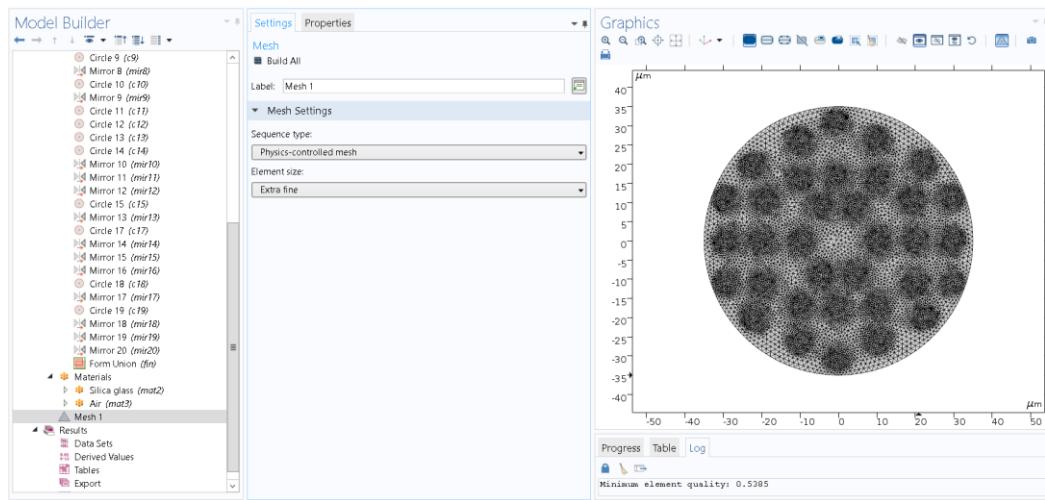
LAYER 1:



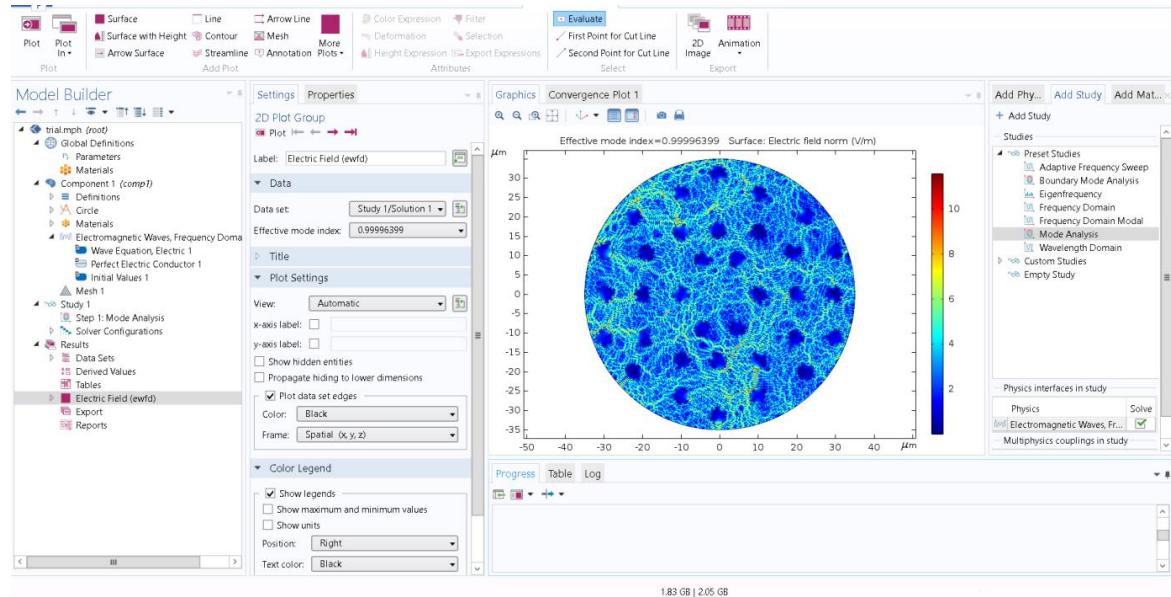
MATERIALS:



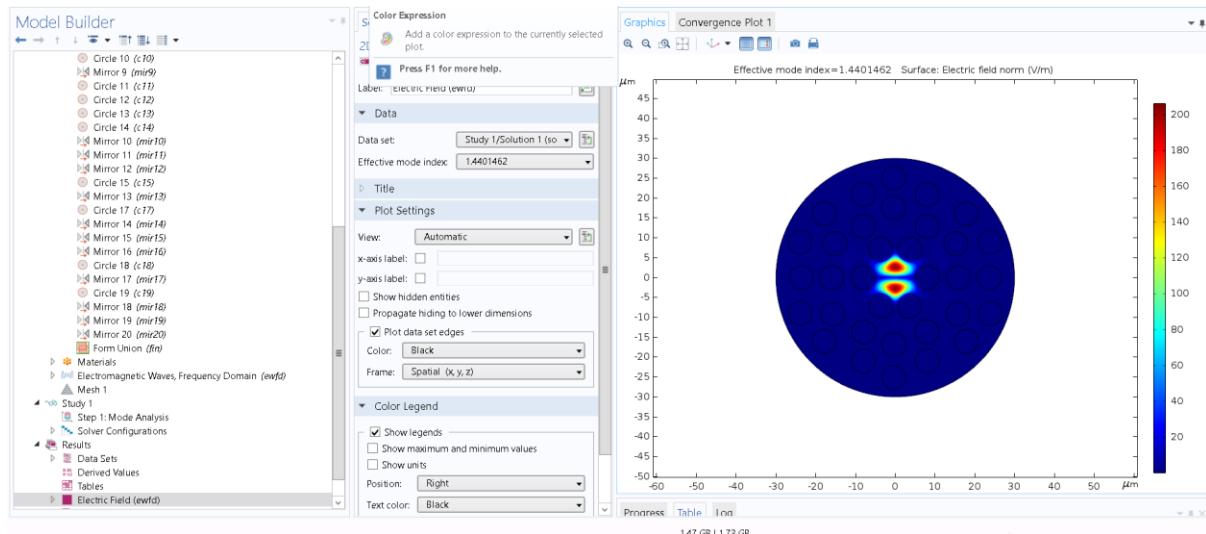
MESH:



Adding PHYSICS: EMF



STUDY:



COMSOL:

GOAL: To design a Photonic Crystal Fiber of 2 Layer CIRCLE SHAPE using COMSOL Application

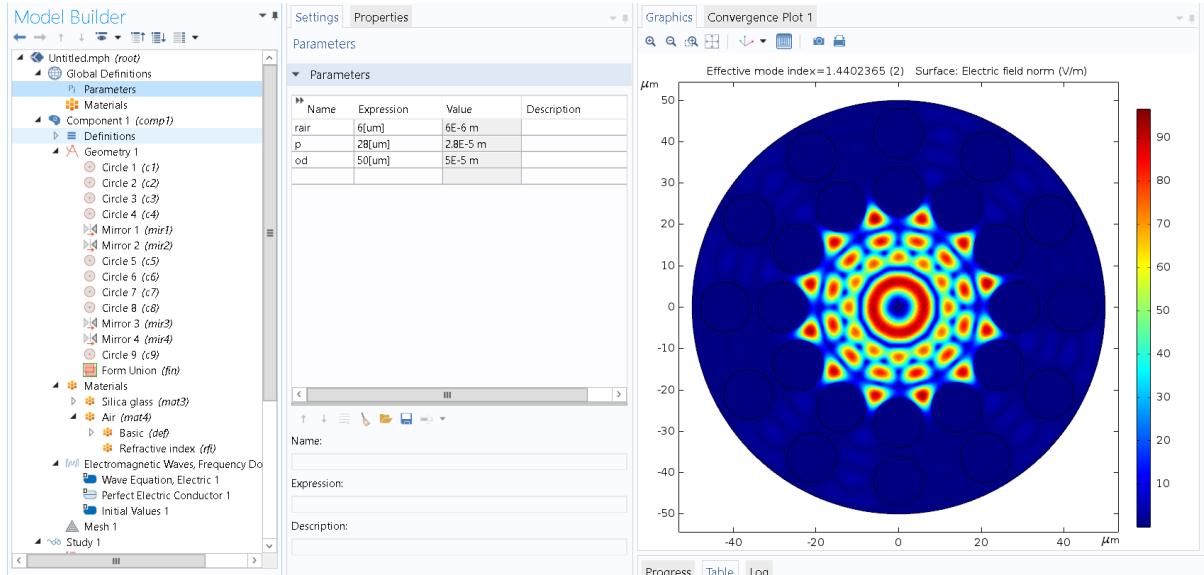
PARAMETERS:

Airhole radius: **6 um**

Pitch: 28 um Distance between 2 airholes

Outer Diameter: 50 um

RESULT:



LP modes, or Linearly Polarized modes, are specific types of modes in optical fibers, particularly in single-mode and multi-mode fibers. These modes describe the distribution of the electromagnetic field within the fiber and how light propagates through it.

In the above simulation result, the electric fields of the light wave are linearly polarized and appears to be leaky modes.

In fiber optics, polarization refers to the orientation of the electric field vector of the light wave. In LP modes, the electric field is linearly polarized, and an optical fiber supports various modes, which are distinct patterns of light propagation.

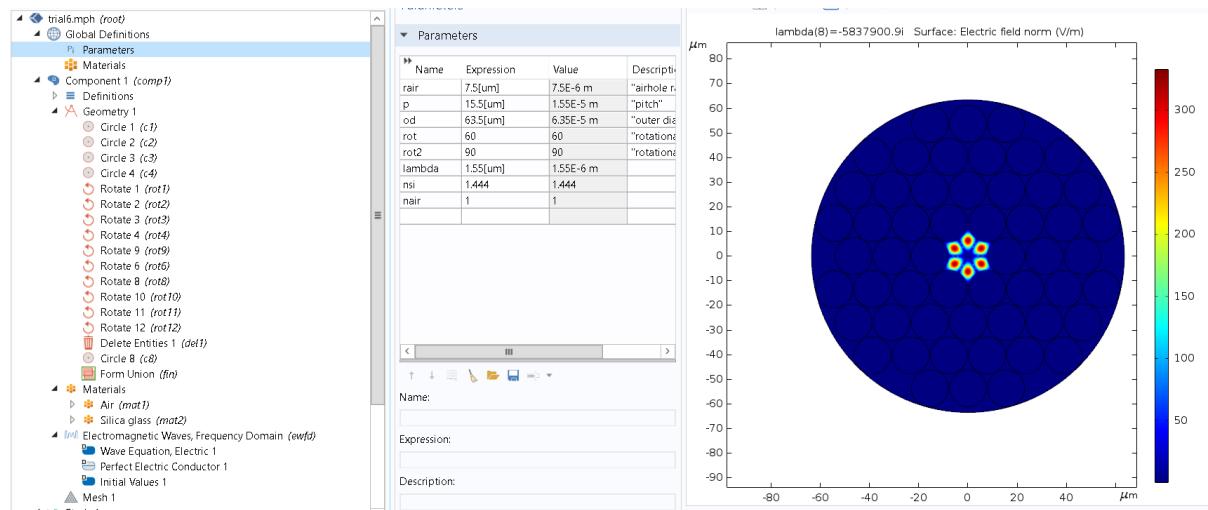
The mode numbers:

LP modes are typically denoted as LP_{l m} where l and m are mode numbers. In modes l=0, the power propagating in the core vanishes at the cut-off.

l ↗ the azimuthal number,

m ↗ the radial number.

- **Single-Mode Fibers:** These fibers are designed to support only the LP01 mode, ensuring minimal dispersion and high bandwidth over long distances.
- **Multi-Mode Fibers:** These fibers support multiple LP modes. They are used for shorter distances due to modal dispersion, where different modes travel at different speeds.



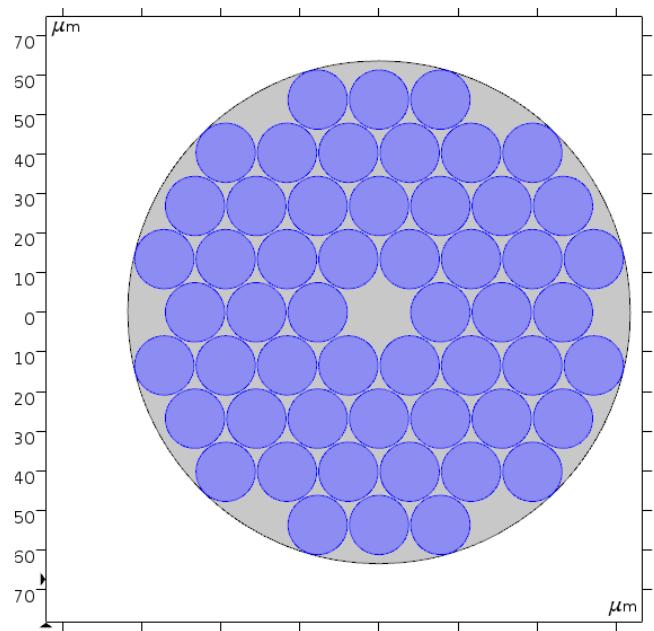
Further, altering the parameters of the geometry we get, mode LP31

Parameters:

Name	Expression	Value	Description
rair	7.5[um]	7.5E-6 m	"airhole radius"
p	15.5[um]	1.55E-5 m	"pitch"
od	63.5[um]	6.35E-5 m	"outer diameter"
rot	60	60	"rotational angle1"
rot2	90	90	"rotational angle2"
lambda	1.55[um]	1.55E-6 m	
nsi	1.444	1.444	
nair	1	1	

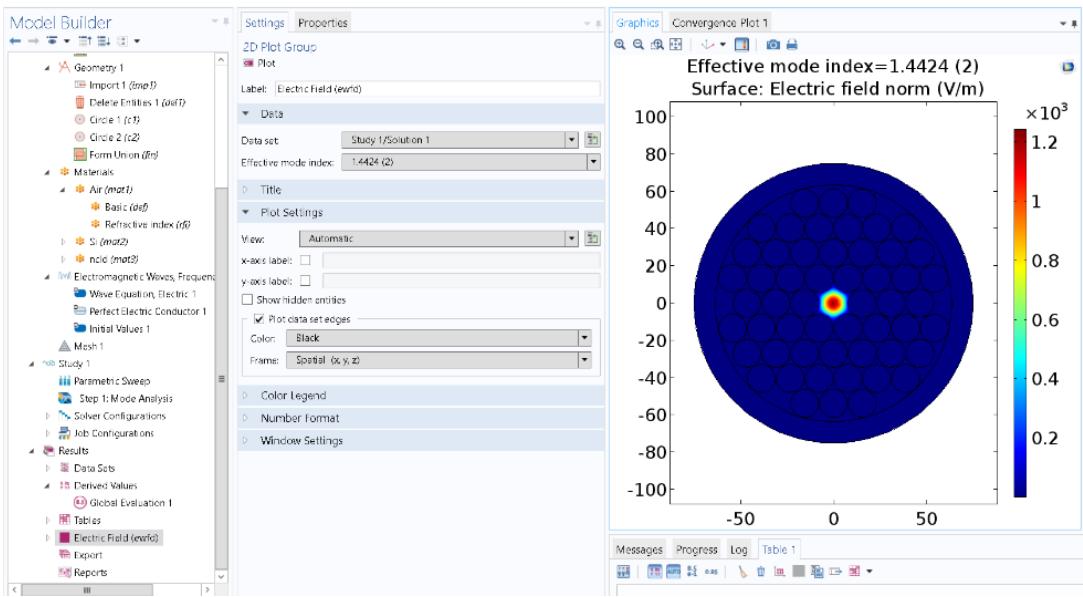
WEEK 3:

Further modifying the geometry by removing corner airholes and decreasing the outer diameter as below and increasing the number of modes to 16, we get modes without losses

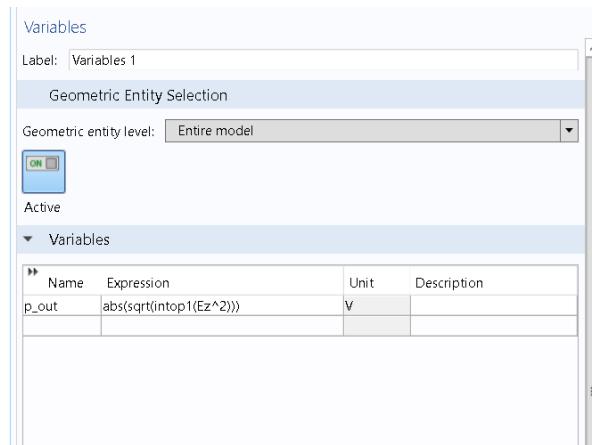


OBSERVING POWER VARIATION IN CLADDING AREA:

Adding cladding layer, of diameter as Perfectly Matched Layer (PML) and running the parametric sweep we get,

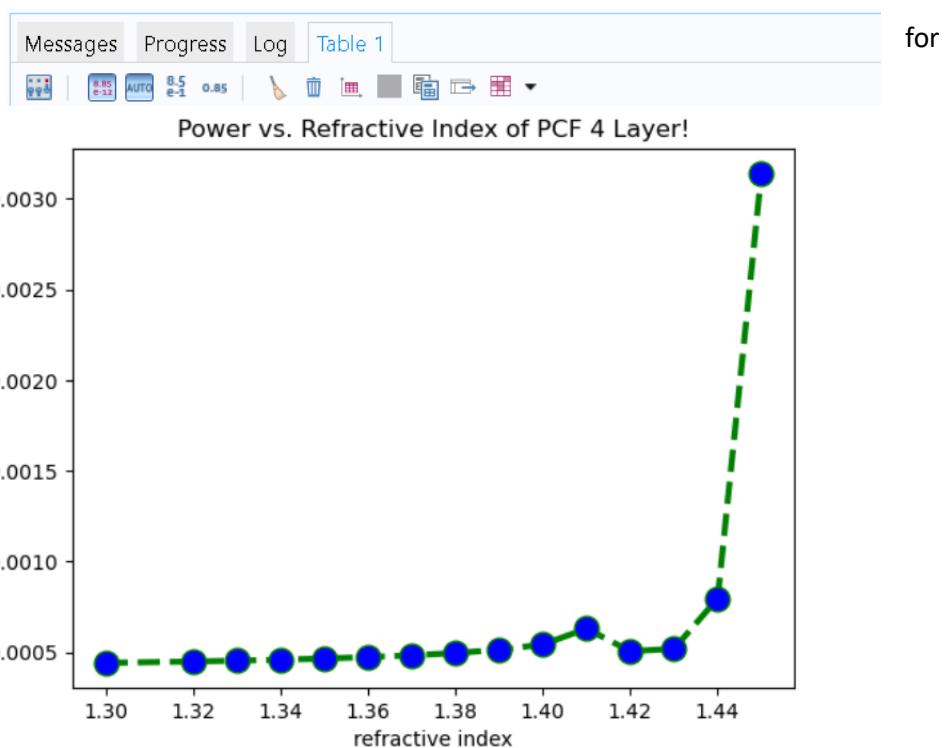


And the power was calculated using the formula under variables option:



Post running the parameter sweep and calculated power is tabulated below.

Using Python
graphical



representation of the output

Python code:

```

import matplotlib.pyplot as graph
import numpy as py

# data
ncl = [1.3,1.32,1.33,1.34,1.35,1.36,1.37,1.38,1.39,1.4,1.41,1.42,1.43,1.44,1.45]
power = [0.000441887,0.000449271,0.000453858,0.000459252,0.00046569,0.000473526,0.000483316,0.0004

# plotting the points
graph.plot(ncl, power,color='green', linestyle='dashed', linewidth = 3,marker='o', markerfacecolor
graph.xlabel('refractive index')
graph.ylabel('power')
graph.title('Power vs. Refractive Index of PCF 4 Layer!')

# function to show the plot
graph.show()

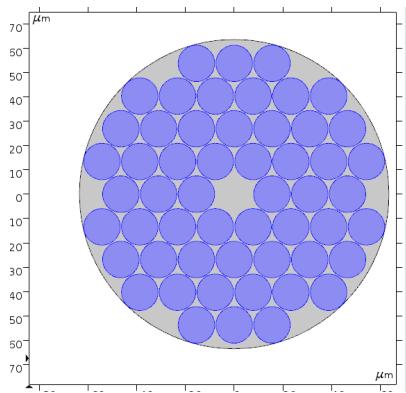
```

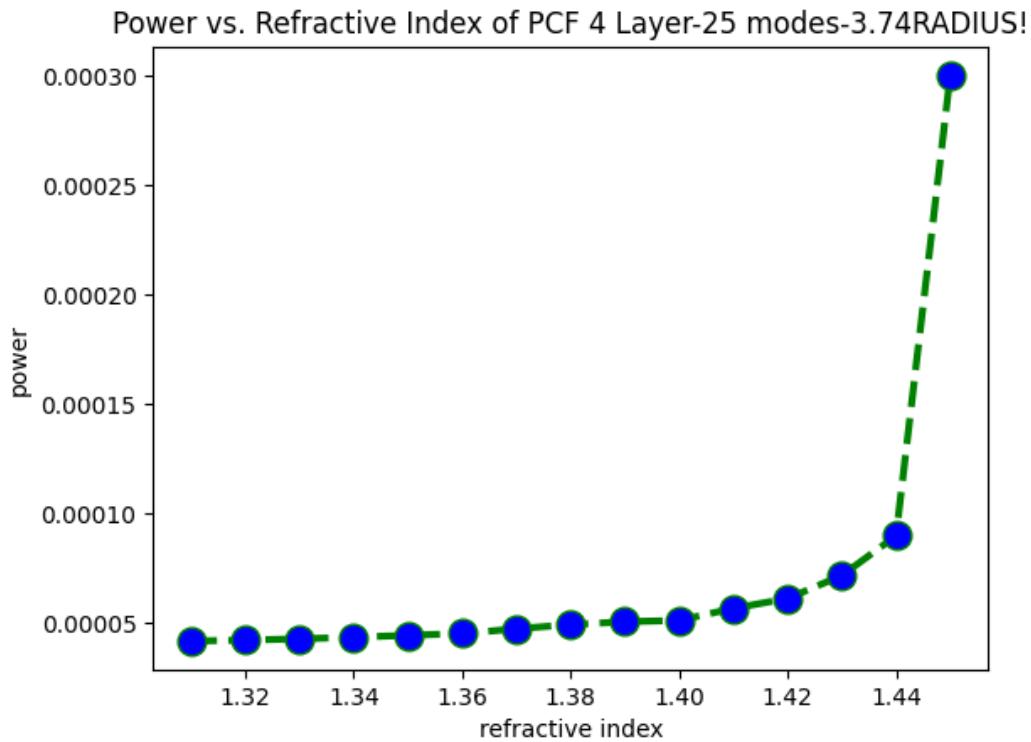
WEEK 4:

Altering the parameters and analysing the change of power of Evanescent fields

Rair:3.75 um

Geometry: PERIODIC NO AHC





CODE:

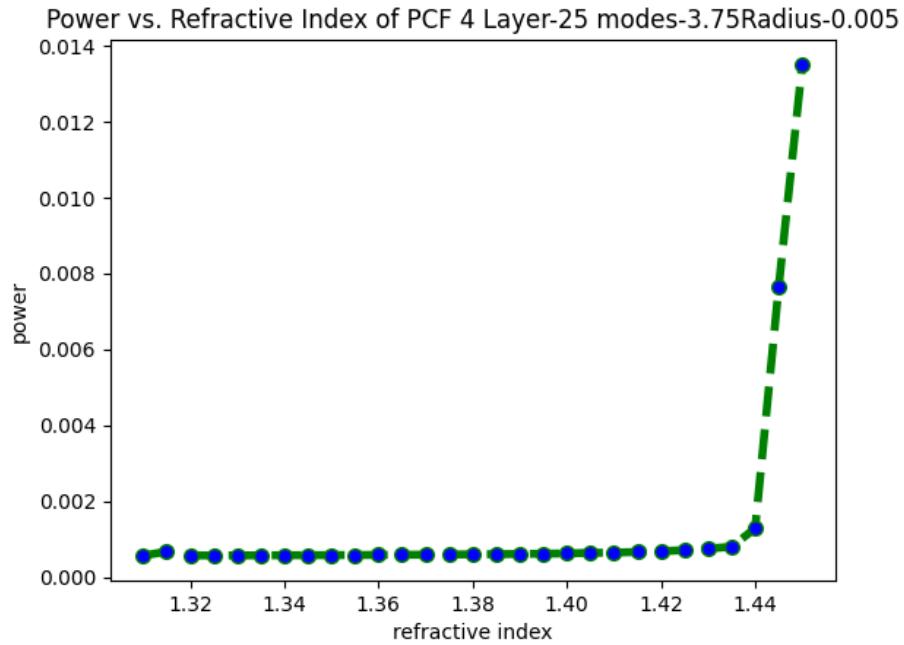
```
import matplotlib.pyplot as graph
import numpy as py

# data
ncl = [1.31,1.32,
1.33,1.34,1.35,1.36,1.37,1.38,1.39,1.4,1.41,1.42,1.43,1.44,1.45]
power = [4.18E-05,4.22E-05,4.28E-05,4.35E-05,4.44E-05,4.52E-05,4.74E-
05,4.93E-05,5.06E-05,5.12E-05,5.67E-05,6.12E-05,7.17E-05,8.98E-05,3.00E-04]

# plotting the points
graph.plot(ncl, power,color='green', linestyle='dashed', linewidth =
3,marker='o', markerfacecolor='blue', markersize=12)
graph.xlabel('refractive index')
graph.ylabel('power')
graph.title('Power vs. Refractive Index of PCF 4 Layer-25 modes-
3.74RADIUS!')

# function to show the plot
graph.show()
```

Result of 3.75 radius with 0.005 step size



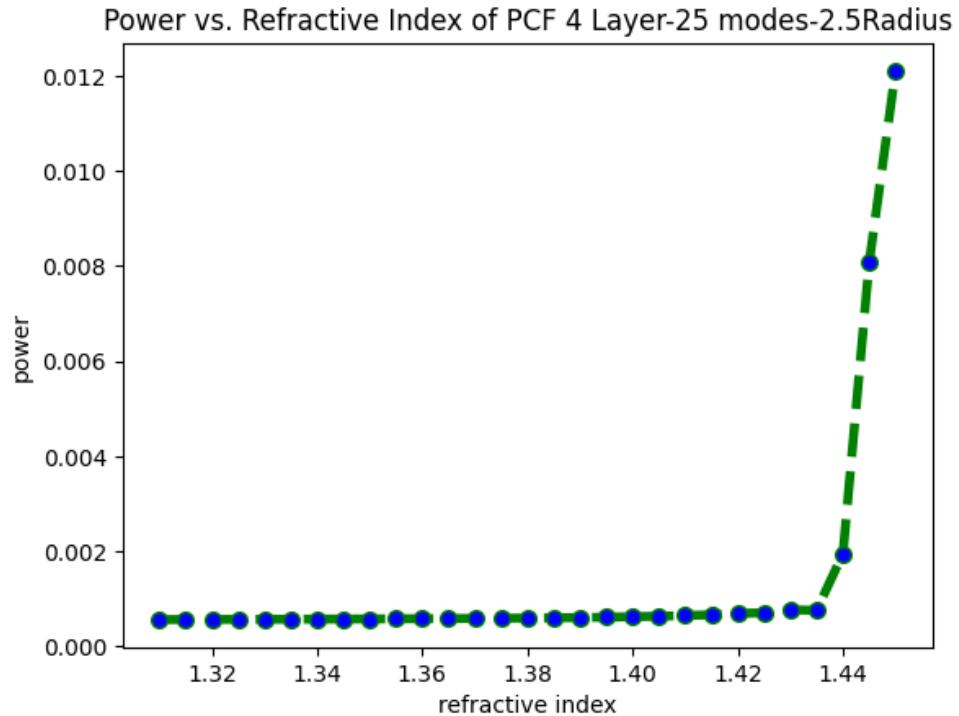
```
import matplotlib.pyplot as graph

# data
ncl =
[1.31, 1.315, 1.32, 1.325, 1.33, 1.335, 1.34, 1.345, 1.35, 1.355, 1.36, 1.365, 1.37, 1.375, 1.38, 1.385, 1.39, 1.395, 1.4, 1.405, 1.41, 1.415, 1.42, 1.425, 1.43, 1.435, 1.44, 1.445, 1.45]
power = [5.63E-04, 6.67E-04, 5.66E-04, 5.67E-04, 5.68E-04, 5.70E-04, 5.72E-04, 5.74E-04, 5.76E-04, 5.78E-04, 5.81E-04, 5.83E-04, 5.86E-04, 5.91E-04, 5.95E-04, 6.00E-04, 6.05E-04, 6.12E-04, 6.20E-04, 6.35E-04, 6.42E-04, 6.58E-04, 6.78E-04, 7.06E-04, 7.47E-04, 7.96E-04, 1.28E-03, 7.64E-03, 1.35E-02]

# plotting the points
graph.plot(ncl, power,color='green', linestyle='dashed', linewidth = 4,marker='o', markerfacecolor='blue', markersize=7)
graph.xlabel('refractive index')
graph.ylabel('power')
graph.title('Power vs. Refractive Index of PCF 4 Layer-25 modes-3.75Radius-0.005')

# function to show the plot
graph.show()
```

Result of Radius 2.5:



```
import matplotlib.pyplot as graph

# data
ncl25 =
[1.31, 1.315, 1.32, 1.325, 1.33, 1.335, 1.34, 1.345, 1.35, 1.355, 1.36, 1.365, 1.37, 1.375, 1.38, 1.385, 1.39, 1.395, 1.4, 1.405, 1.41, 1.415, 1.42, 1.425, 1.43, 1.435, 1.44, 1.445, 1.45]
power25 = [5.63E-04, 5.64E-04, 5.66E-04, 5.67E-04, 5.69E-04, 5.70E-04, 5.72E-04, 5.74E-04, 5.76E-04, 5.79E-04, 5.81E-04, 5.84E-04, 5.88E-04, 5.91E-04, 5.95E-04, 5.99E-04, 6.07E-04, 6.12E-04, 6.23E-04, 6.33E-04, 6.48E-04, 6.63E-04, 6.94E-04, 7.06E-04, 7.67E-04, 7.57E-04, 1.95E-03, 8.08E-03, 1.21E-02]

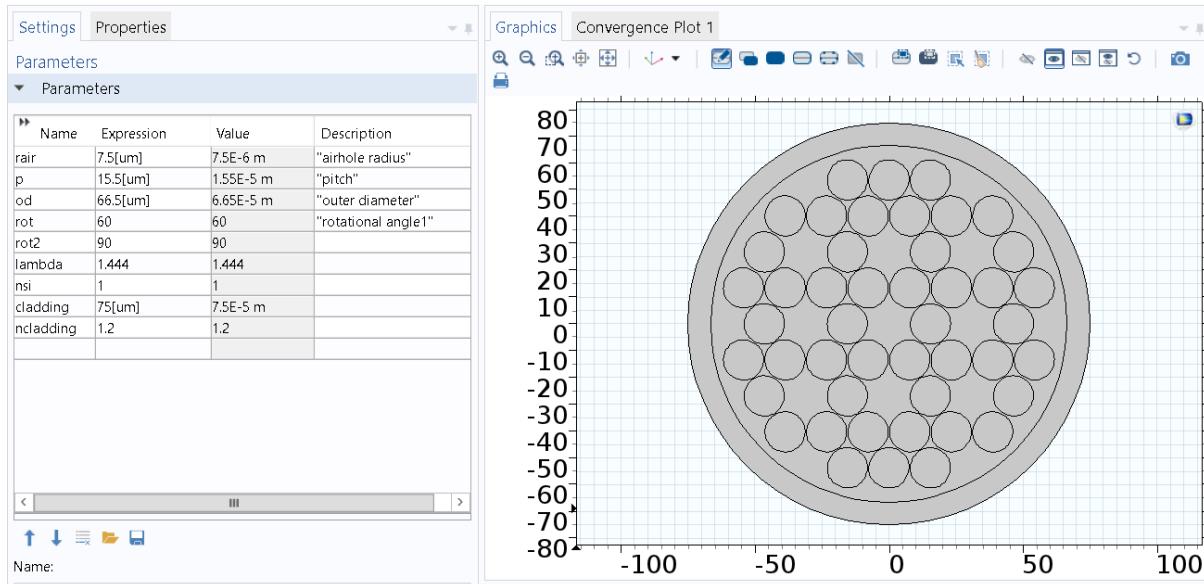
# plotting the points
graph.plot(ncl25, power25,color='green', linestyle='dashed', linewidth = 4,marker='o', markerfacecolor='blue', markersize=7)
graph.xlabel('refractive index')
graph.ylabel('power')
graph.title('Power vs. Refractive Index of PCF 4 Layer-25 modes-2.5Radius')

# function to show the plot
graph.show()
# %%
```

3rd July:

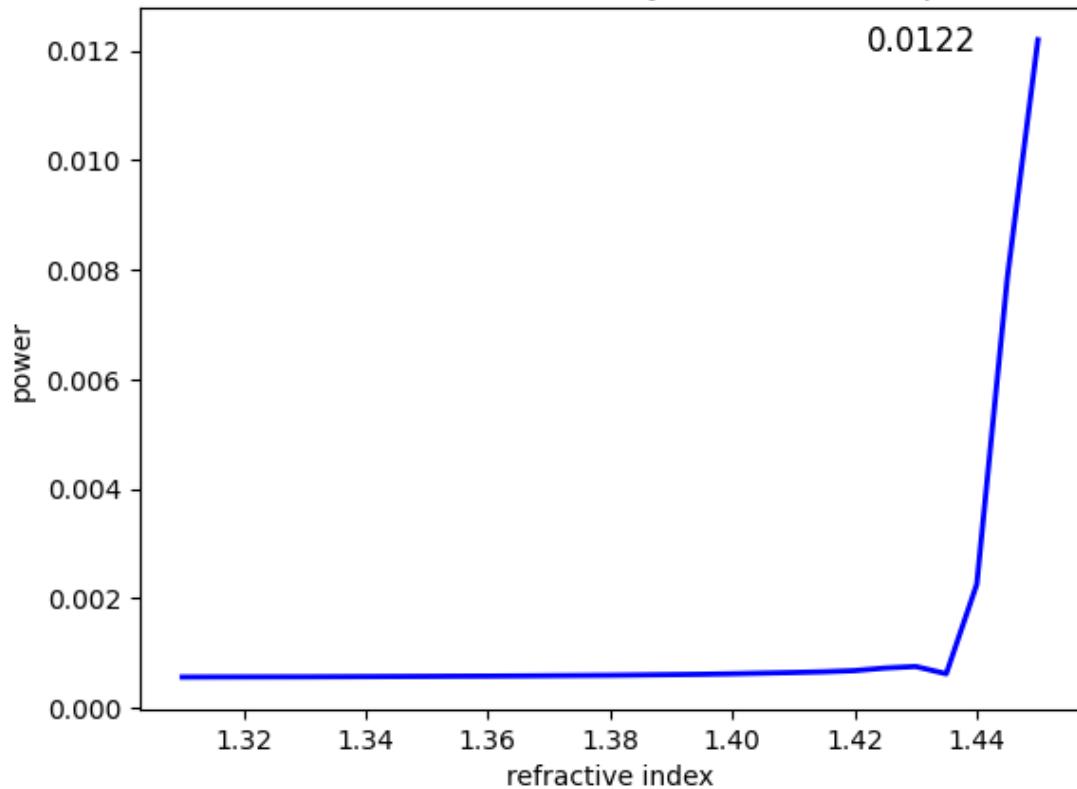
Airhole Radius: 7.5 um

Geometry: Semi Periodic with No Centre Airhole



RESULT:

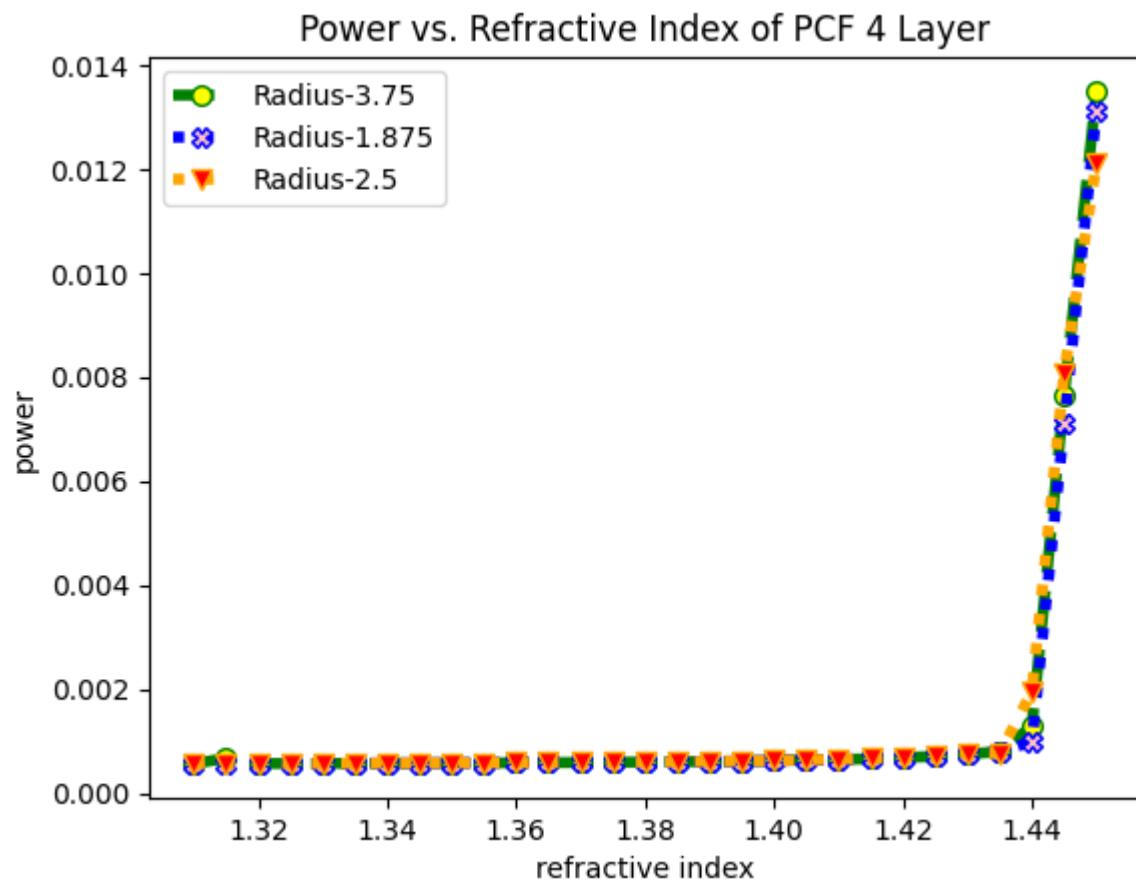
Power vs. Refractive Index of PCF 4 Layer Periodic-Semiperiodic no AHC



PARAMETER:

Airhole Radius: 3.25, 2.5, 1.875 um

Geometry: Semi Periodic with no Centre Airhole



In a well-designed hexagonal PCF, most of the power is confined within the core region.

4th JULY

PARAMETER:

AIRHOLE RADIUS: 7.5 um

GEOMETRY: PERIODIC NO AHC

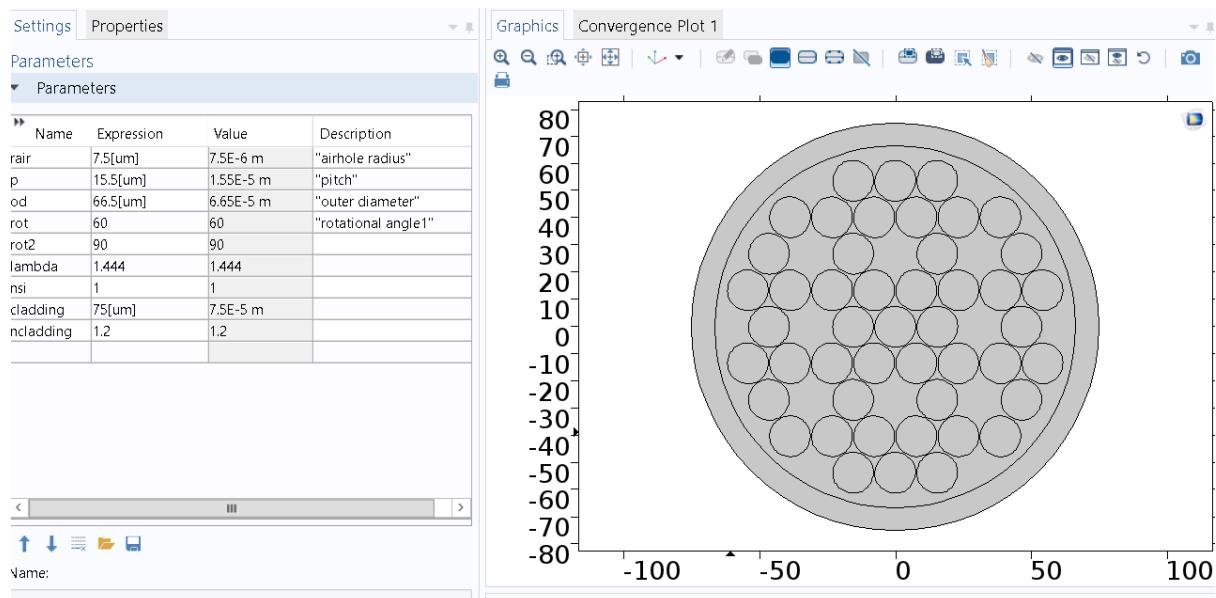
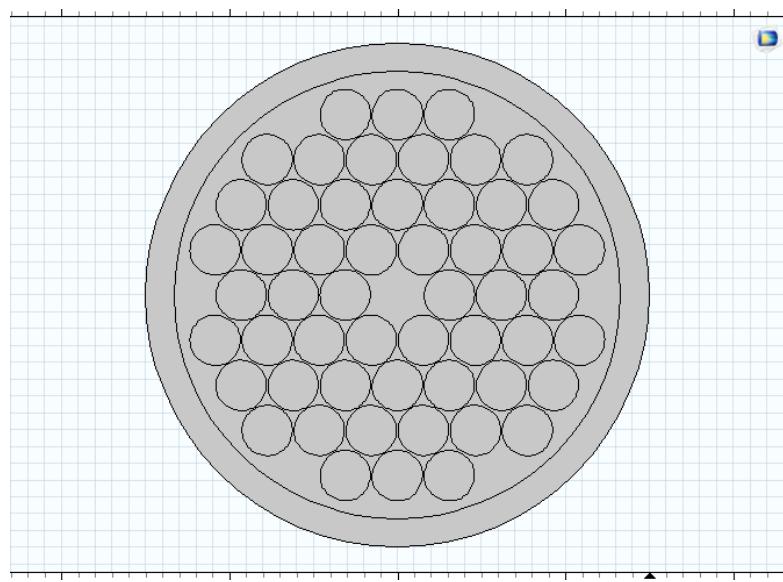
PARAMETER:

AIRHOLE RADIUS:

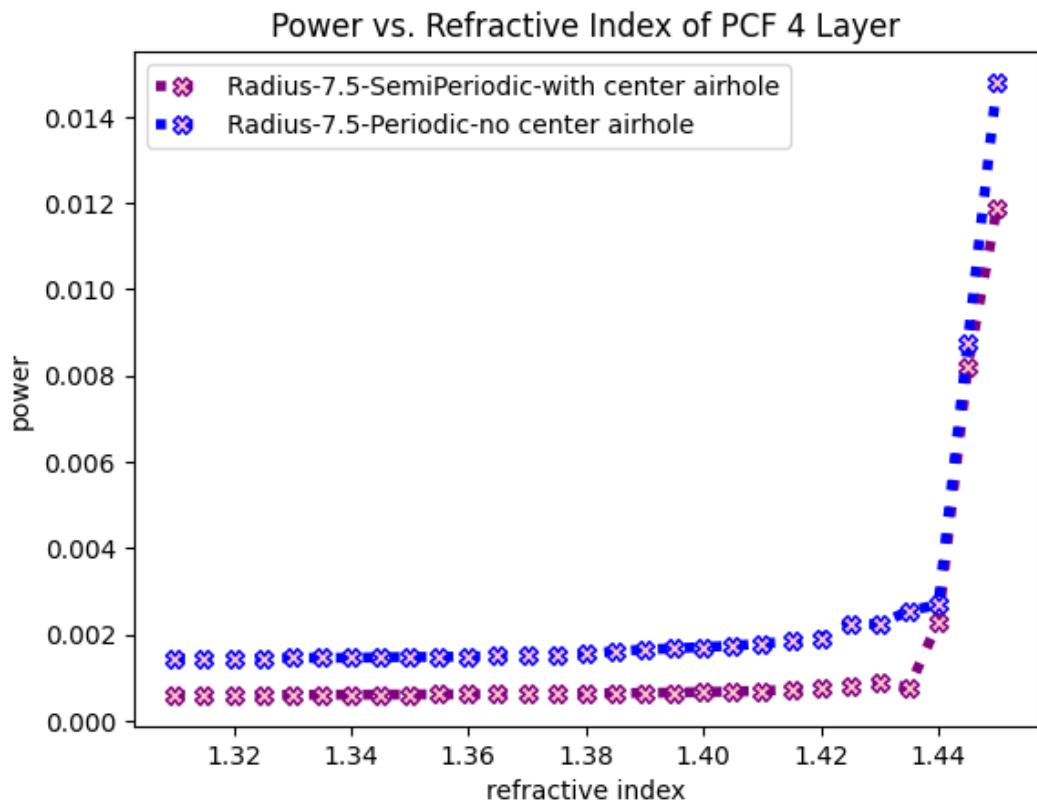
GEOMETRY: SEMI
with AHC

7.5 μm

PERIODIC



RESULT:

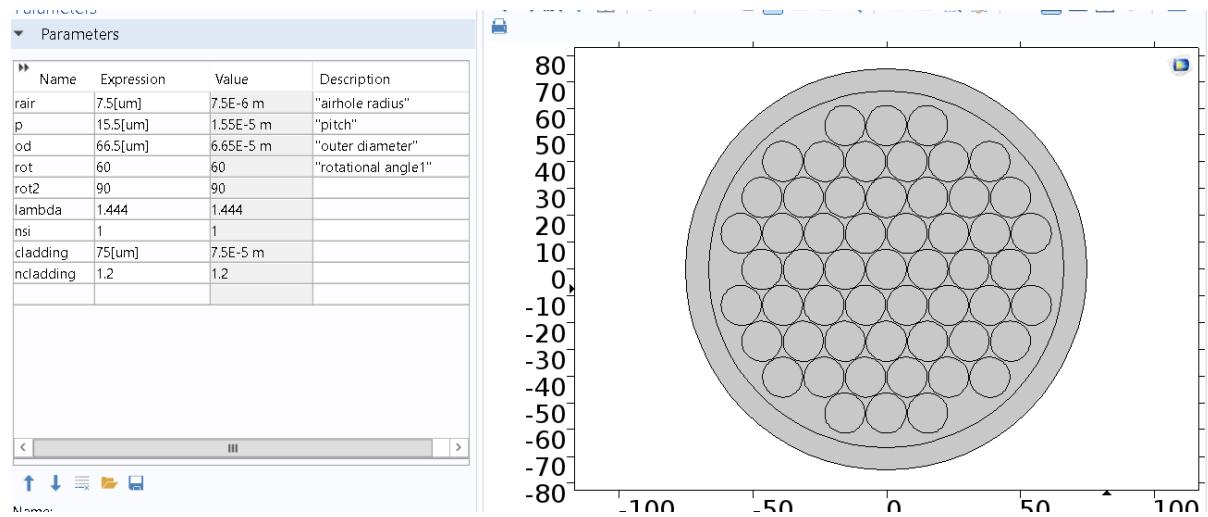


5TH JULY

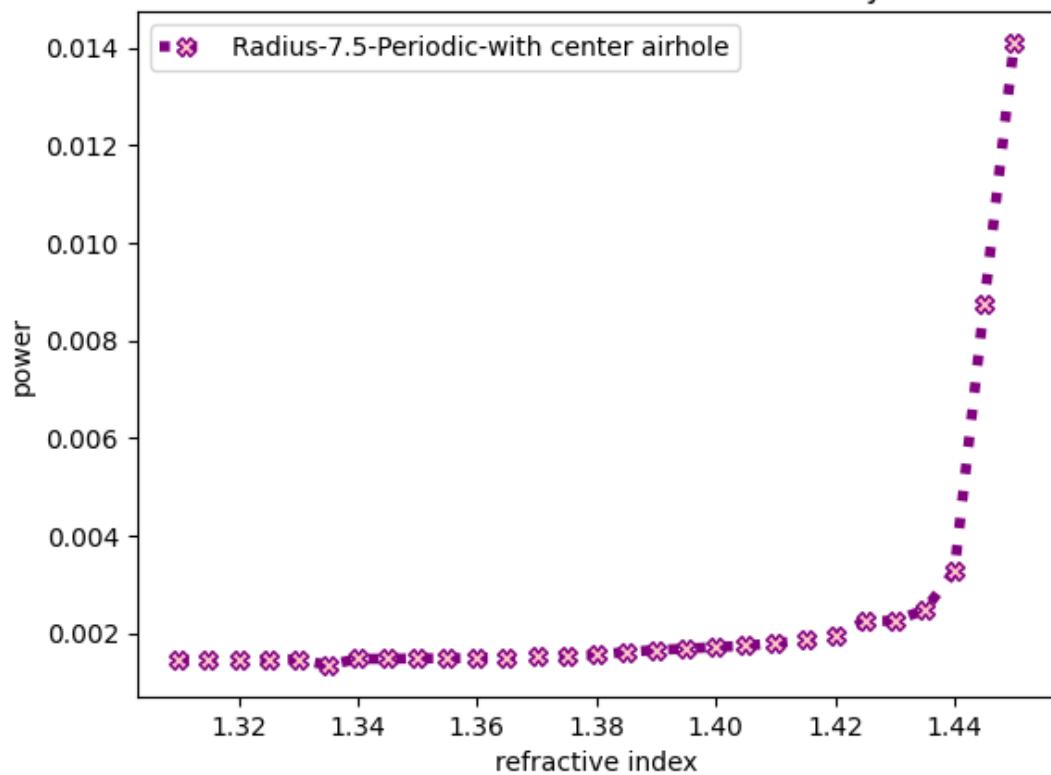
PARAMETER:

AIRHOLE RADIUS: 7.5 μm

GEOMETRY: **PERIODIC with AHC**



Power vs. Refractive Index of PCF 4 Layer

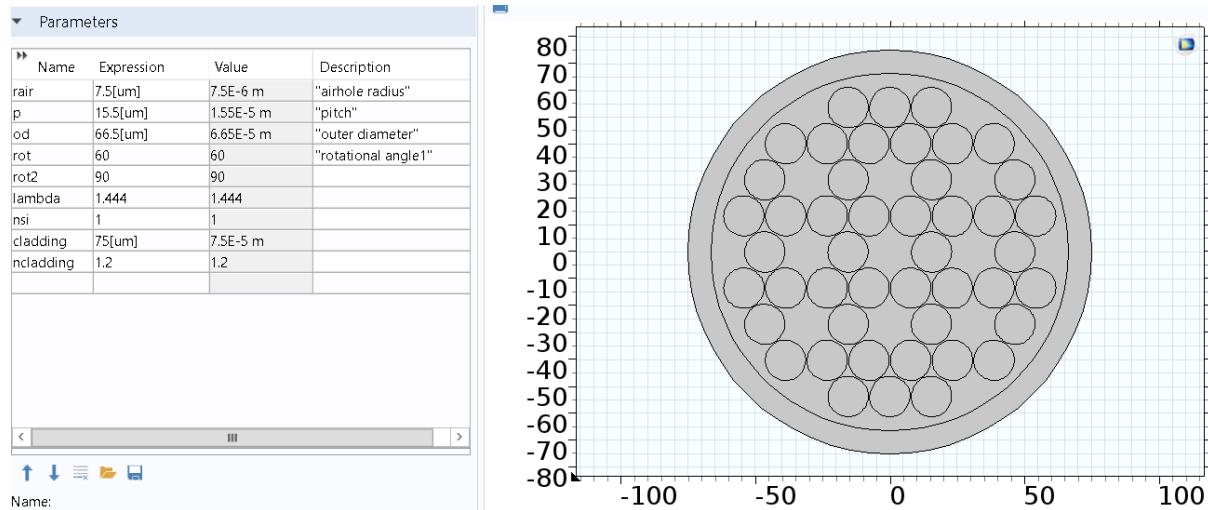


WEEK 5:

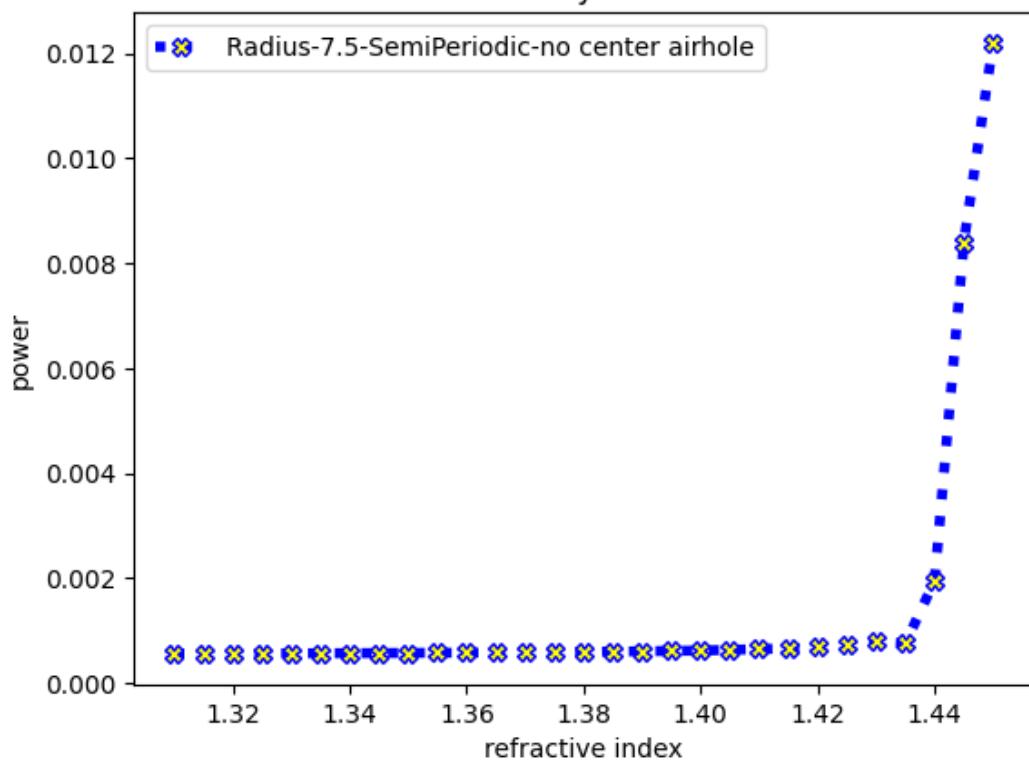
PARAMETER:

AIRHOLE RADIUS: 7.5 um

GEOMETRY: SEMI PERIODIC with no AHC



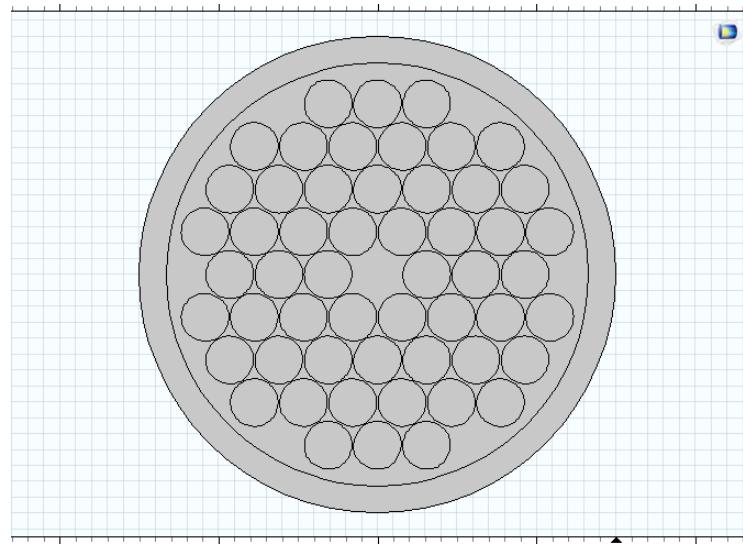
Power vs. Refractive Index of PCF 4 Layer semiPeriodic-with no center airhole



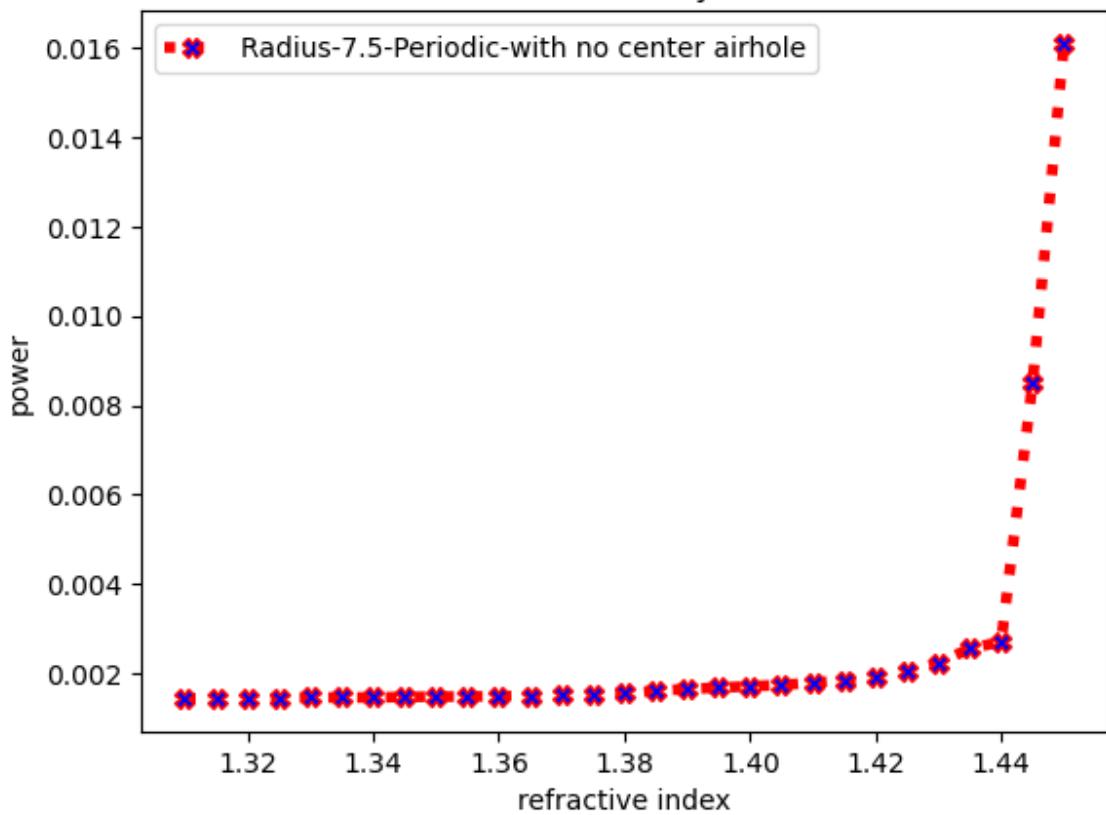
PARAMETER:

AIRHOLE RADIUS: 7.5 um

GEOMETRY: PERIODIC with no AHC



Power vs. Refractive Index of PCF 4 Layer Periodic-no center airhole



PARAMETER:

AIRHOLE RADIUS: 7.5 um

GEOMETRY:

PERIODIC—With AHC + without AHC

SEMIPERIODIC—with AHC + without AHC

WORKING PRINCIPLE:

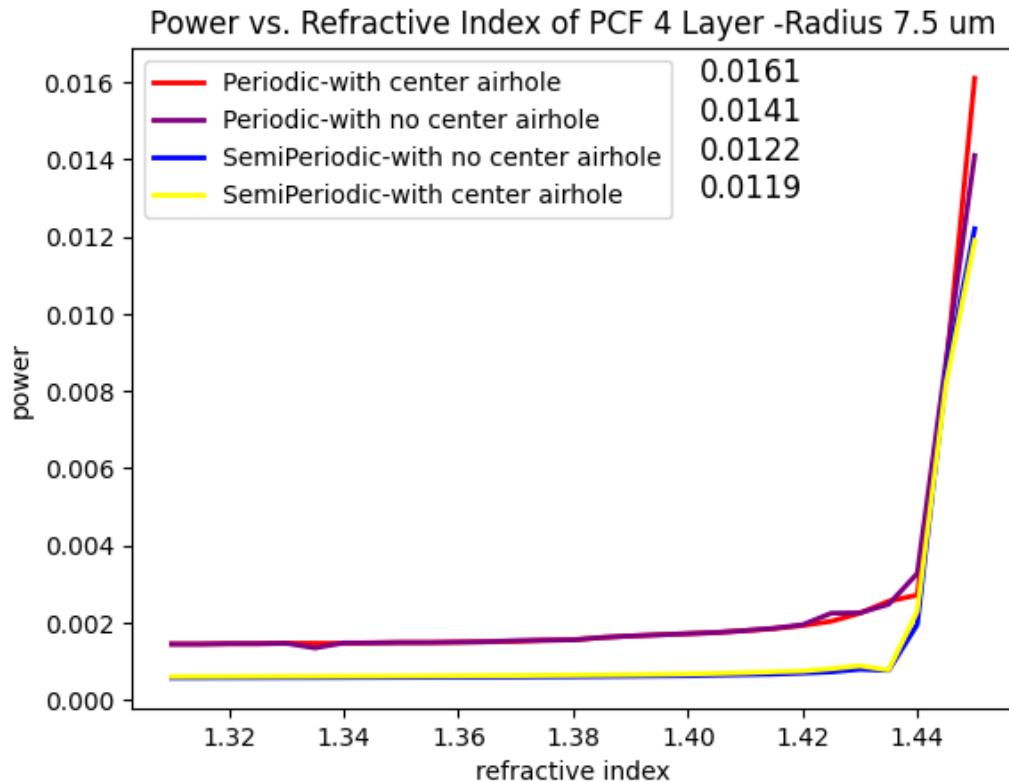
In a photonic crystal Fiber, Total Internal reflection is required to guide the light into the core and this can be achieved if n_{cl} (Refractive Index of cladding) is less than n_{co} (Refractive Index of core)

CASE 1: $n_{co} > n_{cl}$ Total Internal reflection of light at core-cladding boundary.

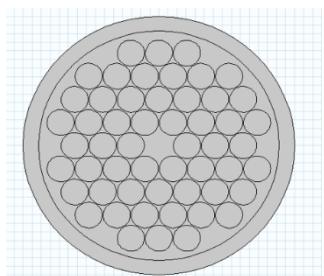
If the Refractive Index of Cladding is higher than the Refractive Index of the Core, then light will not be confined to the core. Instead, it will refract out of the core and into the cladding. This causes significant signal loss.

CASE 2: $n_{co} < n_{cl}$ No Total Internal reflection or Leakage of light into cladding

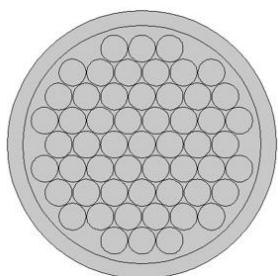
Below is the plot of COMSOL Multiphysics simulation of a PCF of Total thickness 66.5 um and Airhole radius of 7.5 um and analyzing the dispersion of light injected in Periodic and Semi periodic arrangement of Airhole



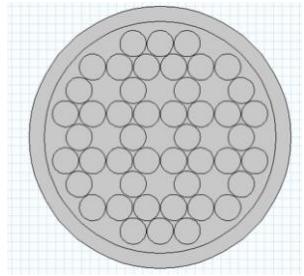
PERIODIC with no AHC



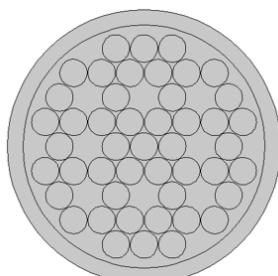
PERIODIC with AHC



SEMI PERIODIC with no AHC



SEMI PERIODIC with AHC



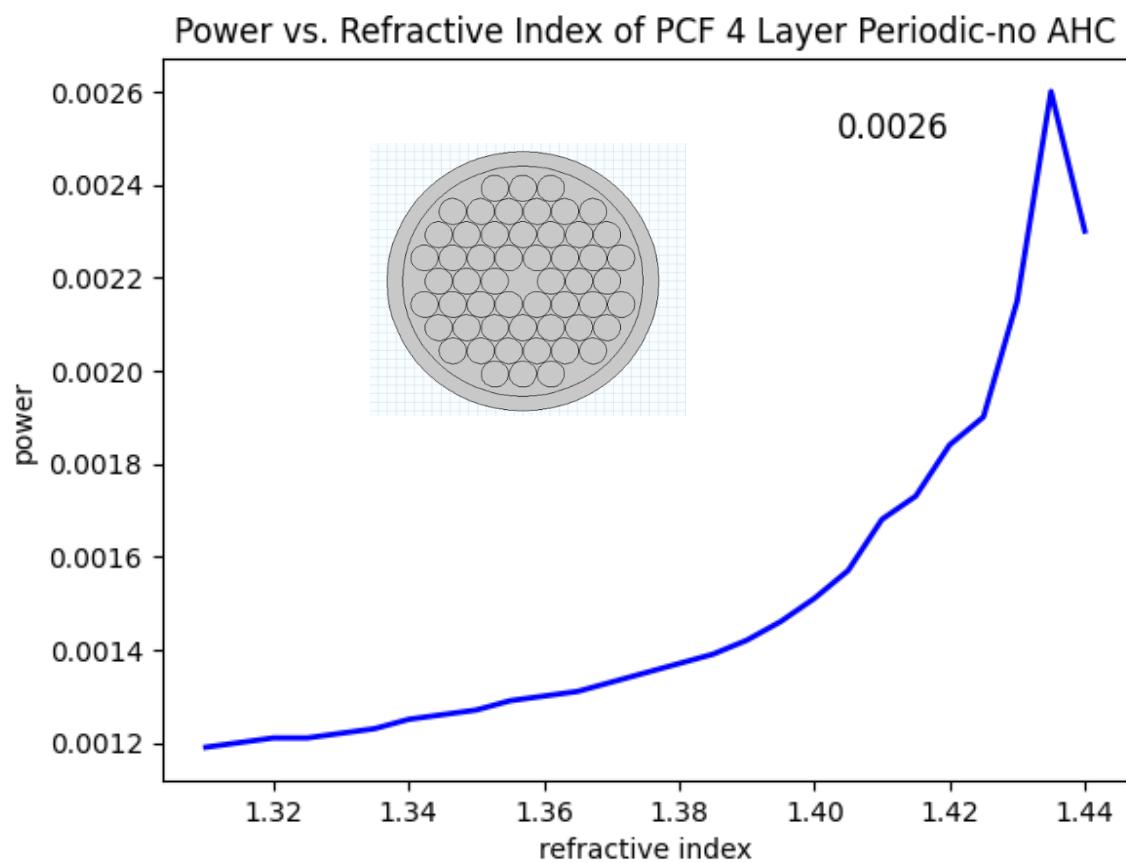
8th Jul

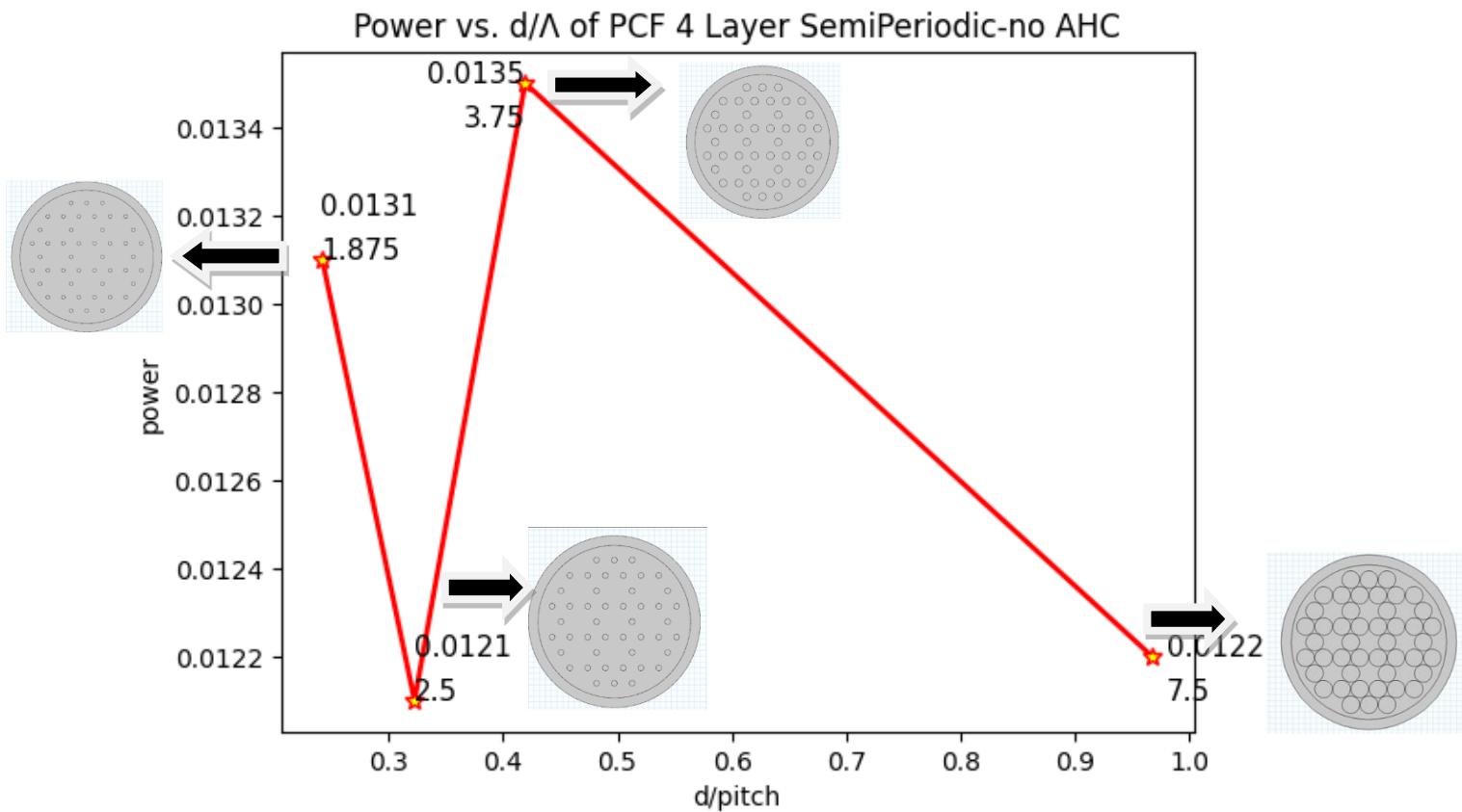
PARAMETER:

AIRHOLE RADIUS: 7.5 um

GEOMETRY:

PERIODIC—without AHC





PLOT IN DIAMETER/ PITCH FOR SEMIperiodic GEOMETRY

CODE:

```
import matplotlib.pyplot as graph

#SemiperiodicnoAHC
xaxis=[0.967741935, 0.419354839, 0.322580645, 0.241935484]

power75semiperiodic=[5.63E-04, 5.65E-04, 5.66E-04, 5.67E-04, 5.68E-04, 5.70E-04, 5.72E-04, 5.74E-04, 5.76E-04, 5.78E-04, 5.81E-04, 5.84E-04, 5.88E-04, 5.92E-04, 5.96E-04, 6.02E-04, 6.08E-04, 6.14E-04, 6.23E-04, 6.35E-04, 6.46E-04, 6.60E-04, 6.81E-04, 7.28E-04, 7.56E-04, 6.23E-04, 2.26E-03, 7.86E-03, 1.22E-02]
r1=7.5
pmax75SP=max(power75semiperiodic)
graph.text(0.98,0.0122,pmax75SP, fontsize=11, ha='left')
graph.text(0.98,0.0121,r1, fontsize=11, ha='left')

power375SP = [5.63E-04, 6.67E-04, 5.66E-04, 5.67E-04, 5.68E-04, 5.70E-04, 5.72E-04, 5.74E-04, 5.76E-04, 5.78E-04, 5.81E-04, 5.83E-04, 5.86E-04, 5.91E-04, 5.95E-04, 6.00E-04, 6.05E-04, 6.12E-04, 6.20E-04, 6.35E-04, 6.42E-04, 6.58E-04, 6.78E-04, 7.06E-04, 7.47E-04, 7.96E-04, 1.28E-03, 7.64E-03, 1.35E-02]
pmax375=max(power375SP)
r2=3.75
graph.text(0.419,0.0135,pmax375, fontsize=11, ha='right')
```

```

graph.text(0.419,0.0134,r2, fontsize=11, ha='right')

power25SP = [5.63E-04,5.64E-04,5.66E-04,5.67E-04,5.69E-04,5.70E-04,5.72E-
04,5.74E-04,5.76E-04,5.79E-04,5.81E-04,5.84E-04,5.88E-04,5.91E-04,5.95E-
04,5.99E-04,6.07E-04,6.12E-04,6.23E-04,6.33E-04,6.48E-04,6.63E-04,6.94E-
04,7.06E-04,7.67E-04,7.57E-04,1.95E-03,8.08E-03,1.21E-02]
pmax25SP=max (power25SP)
r3=2.5
graph.text(0.322,0.0122,pmax25SP, fontsize=11, ha='left')
graph.text(0.322,0.0121,r3, fontsize=11, ha='left')

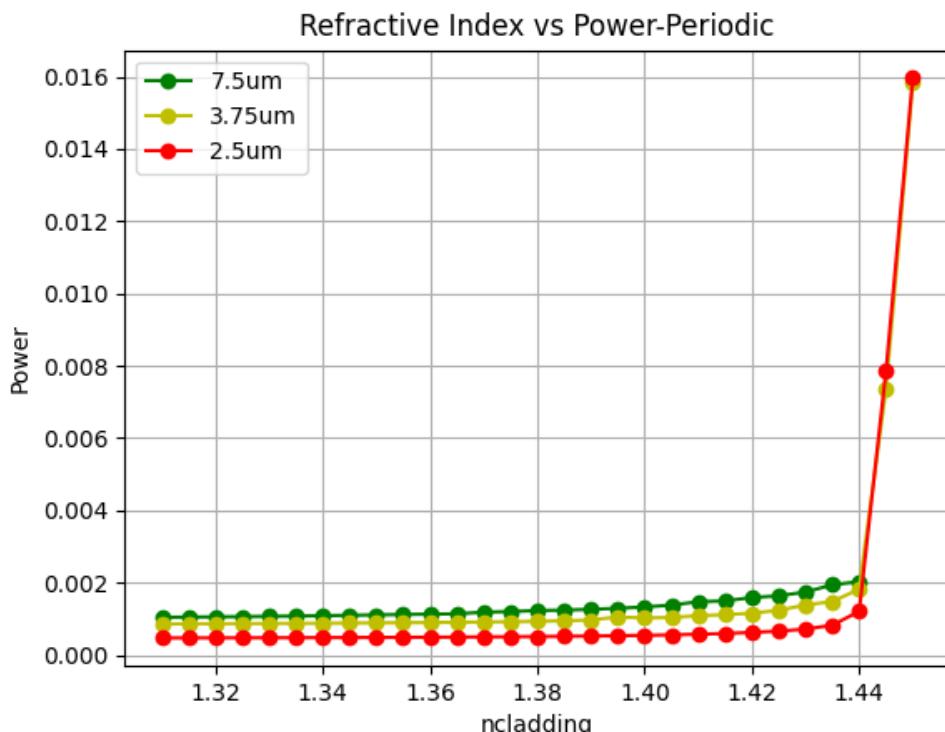
power18SP= [5.63E-04,5.64E-04,5.66E-04,5.67E-04,5.68E-04,5.70E-04,5.72E-
04,5.74E-04,5.76E-04,5.79E-04,5.82E-04,5.84E-04,5.88E-04,5.91E-04,5.94E-
04,6.00E-04,6.06E-04,6.12E-04,6.21E-04,6.30E-04,6.43E-04,6.60E-04,6.89E-
04,7.06E-04,7.47E-04,7.96E-04,9.85E-04,7.10E-03,1.31E-02]
pmax18SP= max(power18SP)
r4=1.875
graph.text(0.24,0.0132,pmax18SP, fontsize=11, ha='left')
graph.text(0.24,0.0131,r4, fontsize=11, ha='left')

pmax=[pmax75SP,pmax375,pmax25SP,pmax18SP]
#plot
graph.plot(xaxis, pmax, color='red', linestyle='solid', marker='*', linewidth=2, markerfacecolor='yellow', markersize=7)

graph.xlabel('d/pitch')
graph.ylabel('power')
graph.title('Power vs. d/ $\Lambda$  of PCF 4 Layer SemiPeriodic-no AHC')
# function to show the plot
graph.show()

```

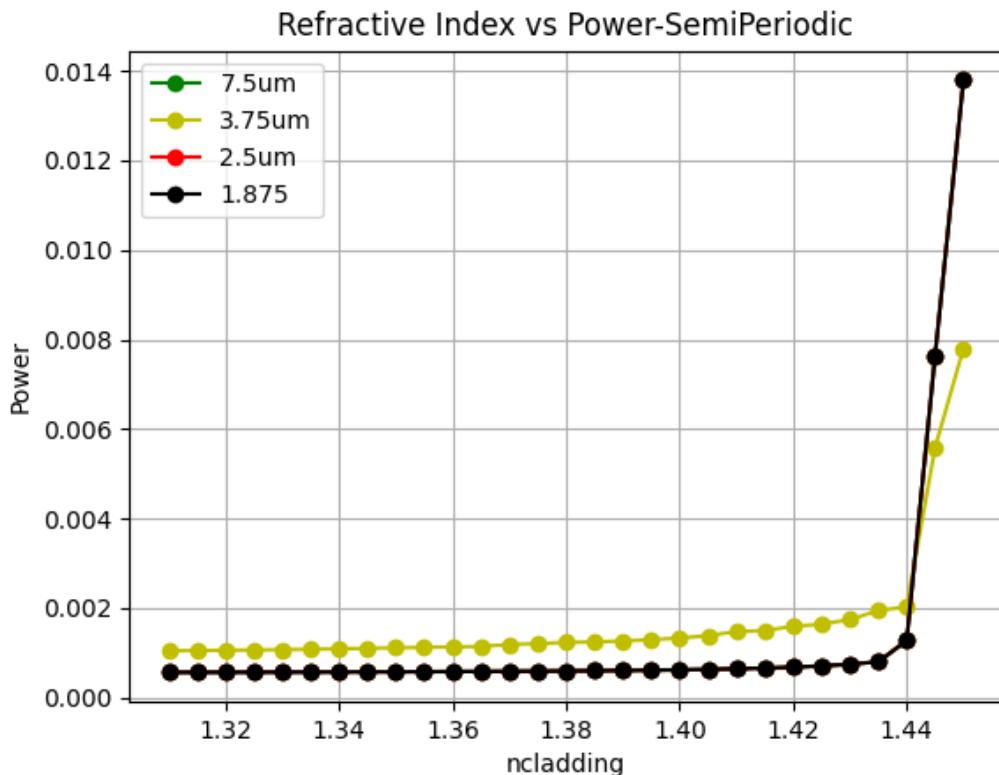
9th JUL



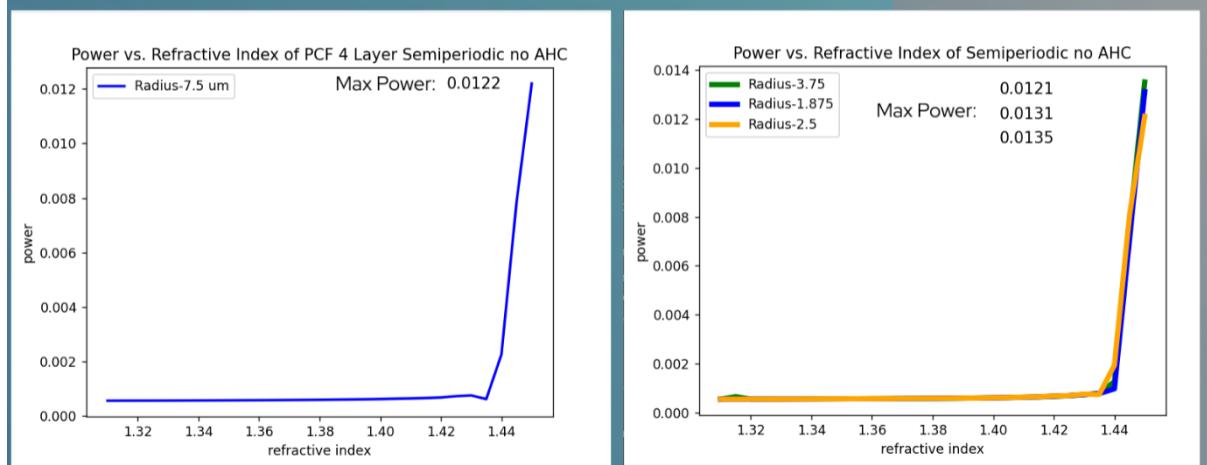
PERIODIC RESULTS:

The data for the plot is in Excel sheet "MOF"

SEMIPERIODIC RESULTS:



Power Variation Plot of SEMI PERIODIC Structure



CODE:

```
import matplotlib.pyplot as graph

#periodicnoairhole
ncl75periodic=[1.31, 1.315, 1.32, 1.325, 1.33, 1.335, 1.34, 1.345, 1.35,
1.355, 1.36, 1.365, 1.37, 1.375, 1.38, 1.385, 1.39, 1.395, 1.4, 1.405, 1.41,
1.415, 1.42, 1.425, 1.43, 1.435, 1.44, 1.445, 1.45]
power75periodic=[1.44E-03, 1.44E-03, 1.45E-03, 1.45E-03, 1.46E-03, 1.34E-
03, 1.47E-03, 1.47E-03, 1.48E-03, 1.48E-03, 1.49E-03, 1.50E-03, 1.53E-03, 1.54E-
03, 1.55E-03, 1.61E-03, 1.65E-03, 1.68E-03, 1.71E-03, 1.74E-03, 1.79E-03, 1.85E-
03, 1.94E-03, 2.24E-03, 2.25E-03, 2.47E-03, 3.27E-03, 8.76E-03, 1.41E-02]
pmax75noAHC=max(power75periodic)
graph.text(1.44,0.014,pmax75noAHC, fontsize=12, ha='right')
#plot
graph.plot(ncl75periodic, power75periodic, color='blue', linestyle='solid',
linewidth=2, markersize=7)

ncl375periodic=[1.31, 1.315, 1.32, 1.325, 1.33, 1.335, 1.34, 1.345, 1.35,
1.355, 1.36, 1.365, 1.37, 1.375, 1.38, 1.385, 1.39, 1.395, 1.4, 1.405, 1.41,
1.415, 1.42, 1.425, 1.43, 1.435, 1.44]
power375periodic=[1.42E-02, 1.37E-02, 1.33E-02, 1.29E-02, 1.24E-02, 1.20E-
02, 1.15E-02, 1.11E-02, 1.06E-02, 1.02E-02, 9.71E-03, 9.24E-03, 8.78E-03, 8.31E-
03, 7.85E-03, 7.36E-03, 6.88E-03, 6.38E-03, 5.90E-03, 5.39E-03, 4.86E-03, 4.32E-
03, 3.77E-03, 3.20E-03, 2.58E-03, 1.90E-03, 1.06E-03]
pmax375noAHC=max(power375periodic)

#plot
graph.plot(ncl375periodic, power375periodic, color='red',
linestyle='solid', linewidth=2, markersize=7)
graph.text(1.44,0.001,pmax75noAHC, fontsize=12, ha='left')

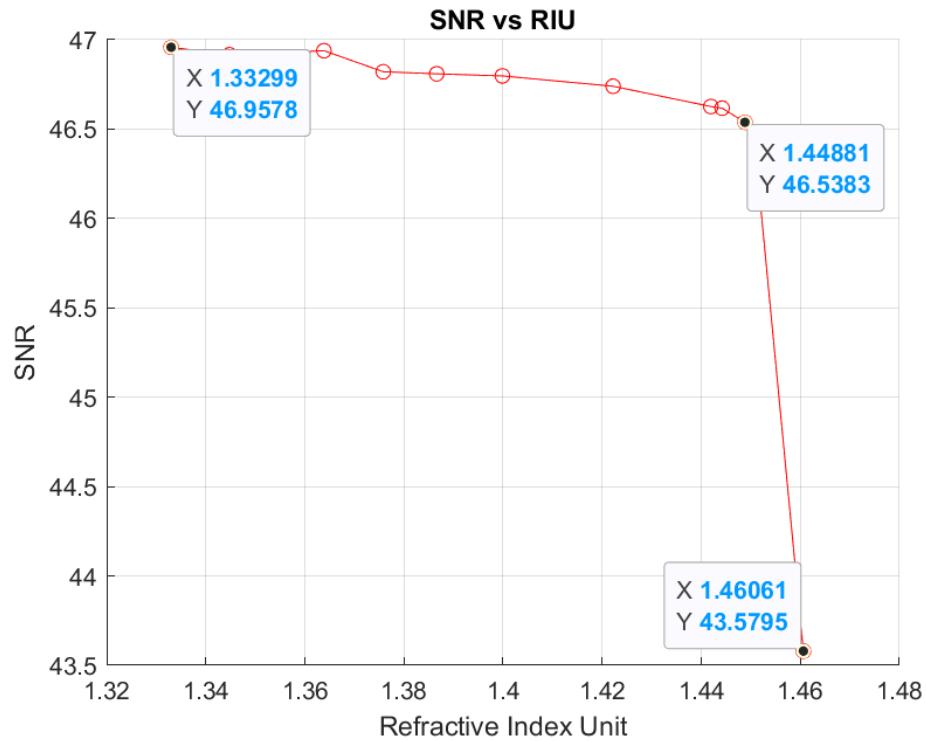
ncl25periodic=[1.31, 1.315, 1.32, 1.325, 1.33, 1.335, 1.34, 1.345, 1.35,
1.355, 1.36, 1.365, 1.37, 1.375, 1.38, 1.385, 1.39, 1.395, 1.4, 1.405, 1.41,
1.415, 1.42, 1.425, 1.43, 1.435, 1.44]
power25periodic=[2.88E-03, 2.88E-03, 2.88E-03, 2.88E-03, 2.88E-03, 2.88E-03, 2.88E-
03, 2.88E-03, 2.88E-03, 2.88E-03, 2.88E-03, 2.88E-03, 2.88E-03, 2.88E-03, 2.88E-
03, 2.88E-03, 2.88E-03, 2.88E-03, 2.88E-03, 2.88E-03, 2.88E-03]
pmax25noAHC=max(power25periodic)
graph.text(1.42,0.005,pmax25noAHC, fontsize=12, ha='right')

#plot
graph.plot(ncl25periodic, power25periodic, color='green',
linestyle='solid', linewidth=2, markersize=7)

graph.xlabel('refractive index')
graph.ylabel('power')
graph.title('Power vs. Refractive Index of PCF 4 Layer Periodic-Periodic no
AHC')
graph.legend(['Radius-7.5 um', 'Radius-3.75 um', 'Radius-2.5 um'])
# function to show the plot
graph.show()
# %%
```

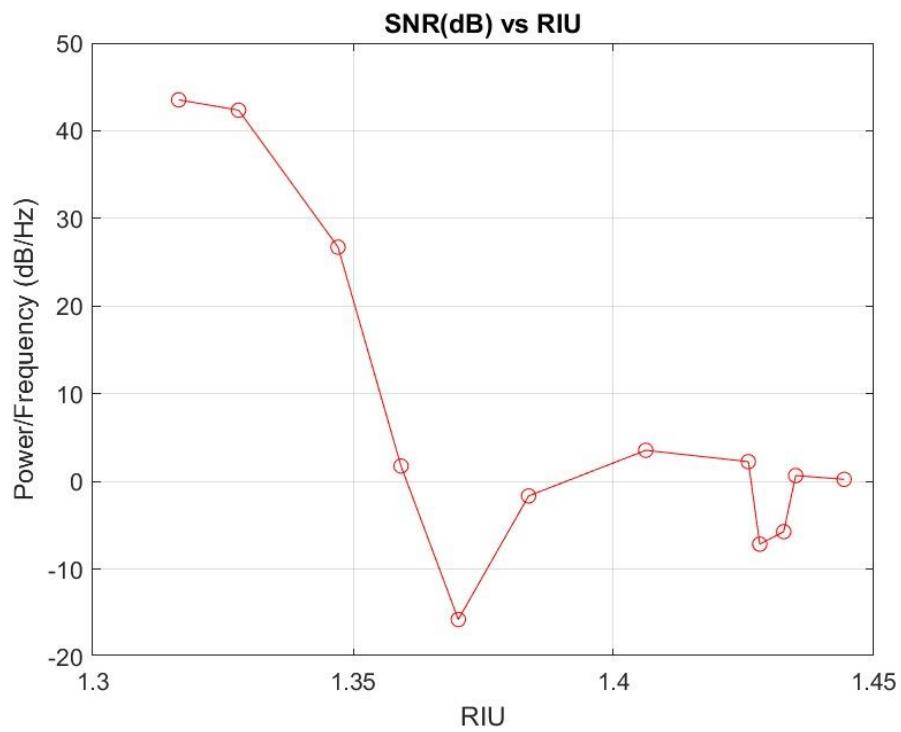
SNR vs RIU PLOT

As per ICUMSA(International Committee of Uniform Method of Sugar Analysis

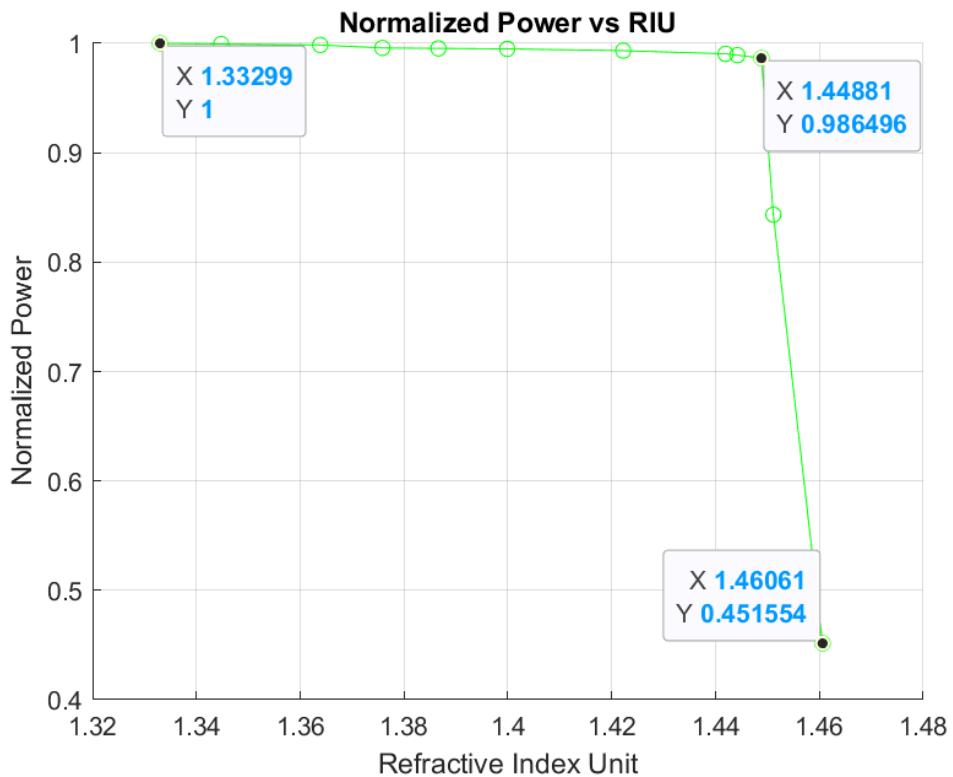


As my previous plot was not correct-The noise part was calculated from reference element while signal was calculated from sensing element Hence does not match

With the dataset i have, I tried to calculate the SNR but the plot does not look proper.
The program is in file 'psdtrial2.m' and 'psdtrial.m'



Normalised Power Plot

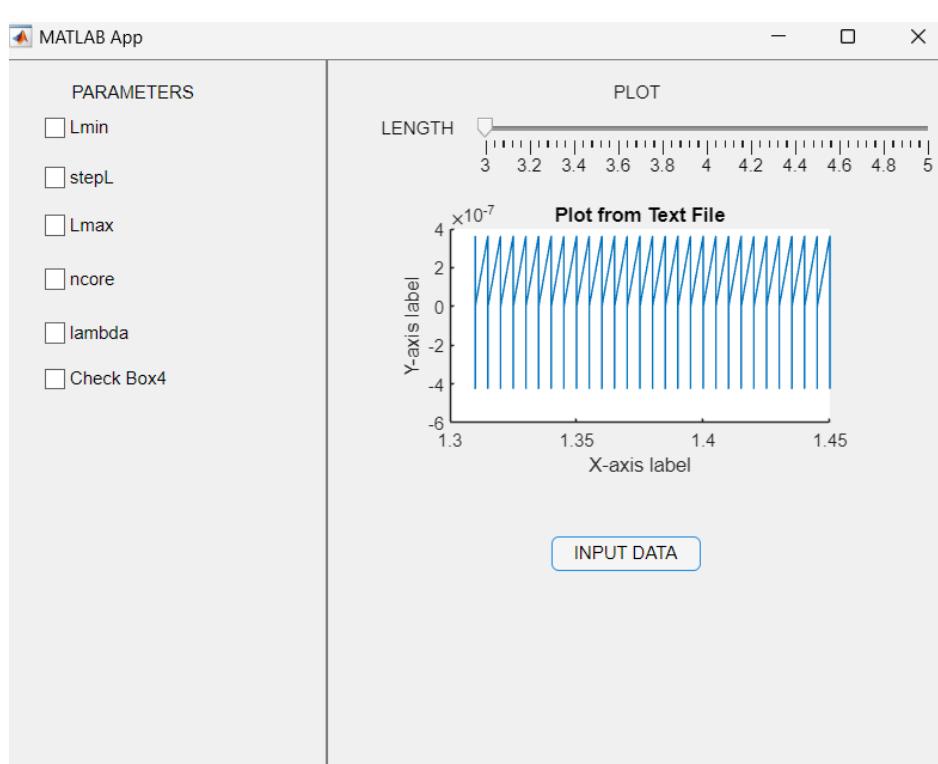
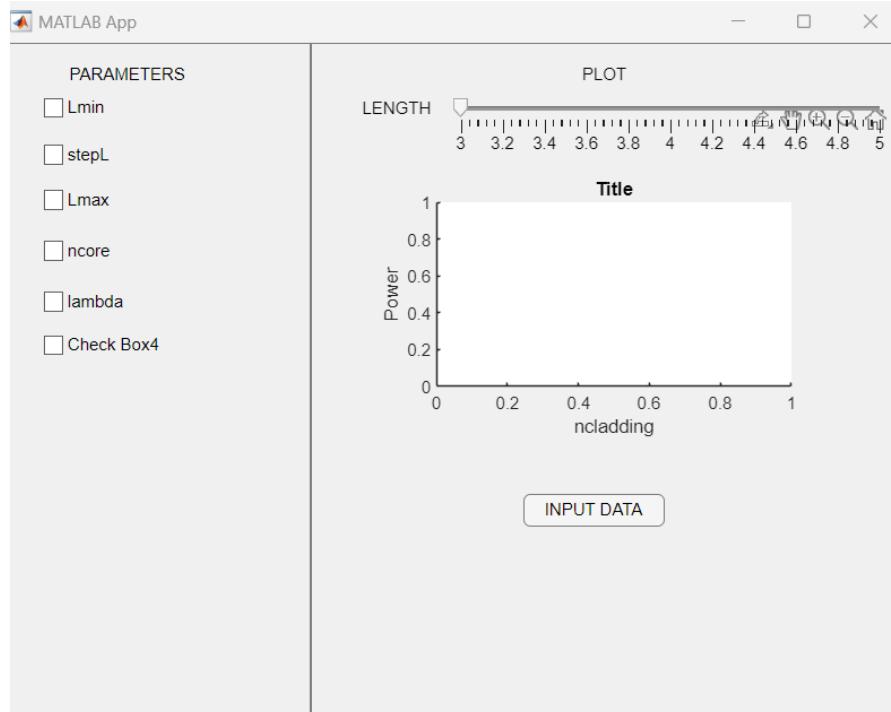


GUI

An attempt of creating a GUI was done. However, improvisations has to be done.

Clicking on the program PCF, opens the GUI box

select INPUT DATA button, to insert the .txt file for the plot



CONCLUSIONS

REFERENCES:

REFERENCES

Chiang, Jung-Sheng. (2018). Analysis of Leaky Modes in Photonic Crystal Fibers Using the Surface Integral Equation Method. Crystals. 8. 177. 10.3390/cryst8040177.

"The confinement losses are monotonically **decreased with the air-hole size and the number of air-hole rings**. It can be seen that both a **small air-hole size** and a smaller number of air-holes induce **a larger loss**, but reduce rapidly if the air-hole size is enlarged "

Chen, Ming-Yang & Zhou, Jun. (2014). Design of add-drop multiplexer based on multi-core optical fibers for mode-division multiplexing. Optics Express. 22. 1440-51. 10.1364/OE.22.001440.

Z. Liu and H.-Y. Tam, 'Fabrication and Sensing Applications of Special Microstructured Optical Fibers', Selected Topics on Optical Fiber Technologies and Applications. InTech, Feb. 14, 2018. doi: 10.5772/intechopen.70755.

M. Uthman, B. M. A. Rahman, N. Kejalakshmy, A. Agrawal and K. T. V. Grattan, "Design and Characterization of Low-Loss Porous-Core Photonic Crystal Fiber," in IEEE Photonics Journal, vol. 4, no. 6, pp. 2315-2325, Dec. 2012, doi: 10.1109/JPHOT.2012.2231939.

FURTHER PROGRESS:

01 Analyse Diameter by Pitch plot

02 Analyse more Fiber parameters

- Material Dispersion
- Effective Mode Area
- BireFringence
- Dispersion

03 Various Structures of PCF

LINK to the presentation: https://prezi.com/p/edit/qp_j4x80ceyy/