# ENSC 476/895 - Biophotonics

## Lab 2 - Optical Coherence Tomography

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## Purpose

The reason we are doing this lab is to learn about Optical Coherence Tomography using a wavelength swept laser. During this lab we should be able to compare our experimental measurements with the expected values of measurements. We will align the objective lens and the mirrors to get light re-coupled to the detector and then align the optical path so that we can use our knowledge and acquire interferometric fringes.

## Methods

To acquire our data, we had to align the mirrors to get light re-coupled to the detector and we also aligned the optical path to get fringes. This data is obtained using a high speed digitizer, ATS 660 AlazarTech 125 MSPS, which is connected to a computer via PCIe bus. We are able to control and easily obtain our data using that software because it functions like an oscilloscope.

The light source uses a wavelength swept laser that operates in the 1310nm wavelength. Therefore, the laser light was invisible. To observe if the optical path of the laser was aligned we used an IR card to see the Near IR (NIR) laser. This card enabled us to see two red dots. The first dot was the dimmer red dot and it was the light going through the detector. The second dot was the brighter red dot and it was the light deflected back by the mirror.

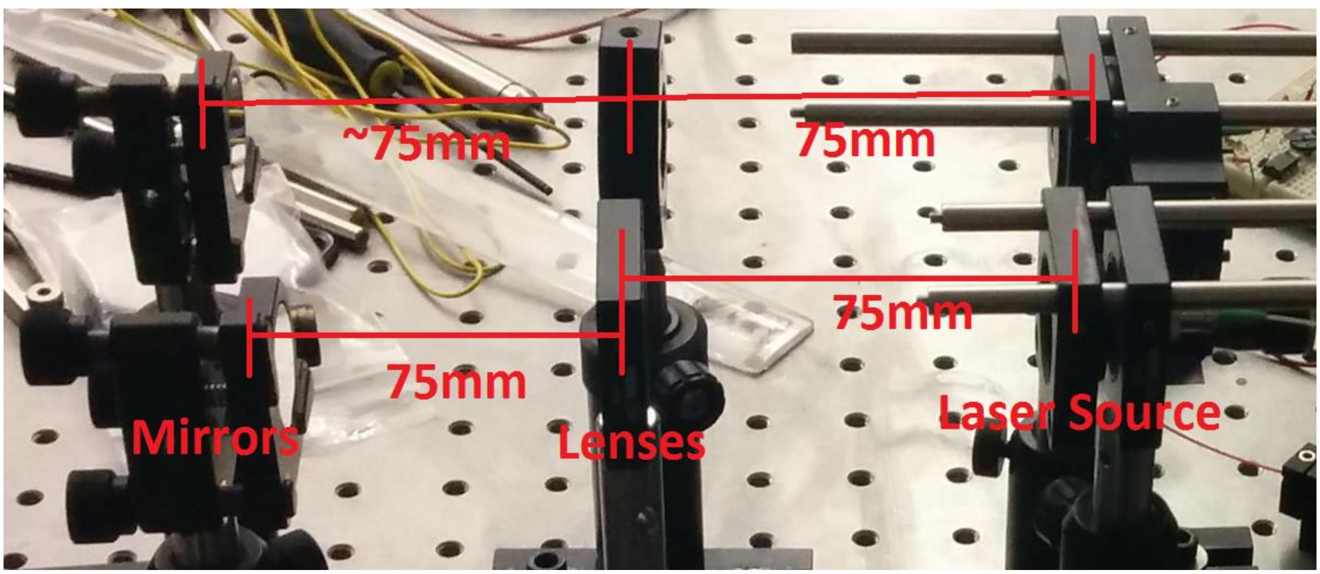


Figure 1: Aligned mirrors and lenses to get fringes

We knew we had to align these two dots on both the reference arm and the sampling arm. The lenses we were given had 75mm focal length therefore from the laser source there was a 75mm distance to the lenses and then another 75mm distance to the mirrors as shown in figure 1 above.

To demonstrate that our optical paths were aligned and that we had lights coupled from both the interferometer arms back to the detector we set up the reference arm and the sampling arm separately. We did so by covering the laser of one arm using a piece of paper (just made sure the laser was blocked) and then aligned the two red dots using the IR card. This method is also backed up by looking at the data acquired from the oscilloscope like software as we would only acquire a fringe if the light was coupled properly back to the detector.

For the quantitative part, we assumed that the optical path length difference (OPLD) was already at 0mm. The TA told us that one revolution of the mirror attachment-adjusting wheel was 0.5mm, therefore we turned that wheel twice to get a difference of 1mm and then measured the data we acquired from that new OPLD. We made two revolutions and collected data and stopped at the tenth revolution or at 5mm. Similarly, for the external clock we followed the same method as the internal clock except we started at 5mm then went down to 0mm.

**Results**

We are assuming that this upper part is the reference arm while the bottom part is the sample arm. Looking at figure 1 above, looking at the reference arm, the distance between the upper mirror and the upper lens is not exactly 75mm. This was because we could not get fringes when the upper mirror was at exactly 75mm from the upper lens. So we had to move the upper mirror back a bit to align the reference arm optical path and get the fringes.

**Part 1:**

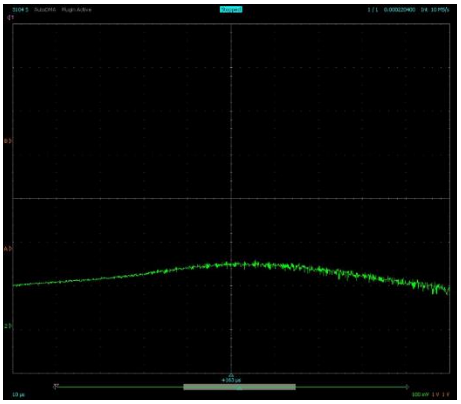

Figure 2: Shows the sampling arm data

We acquired the image above, Figure 2, from the data of the oscilloscope software when we covered the reference arm with a piece of paper. Similarly, Figure 3 was acquired when the sampling arm was covered.

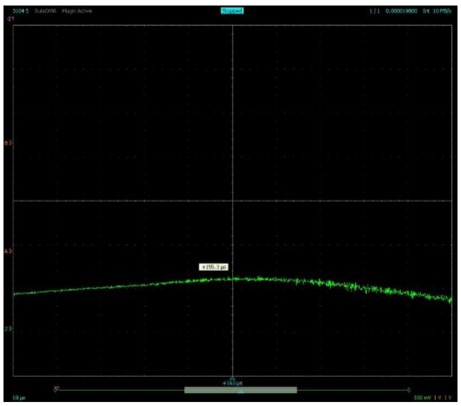

Figure 3: Shows the reference arm data

**Part 2:**

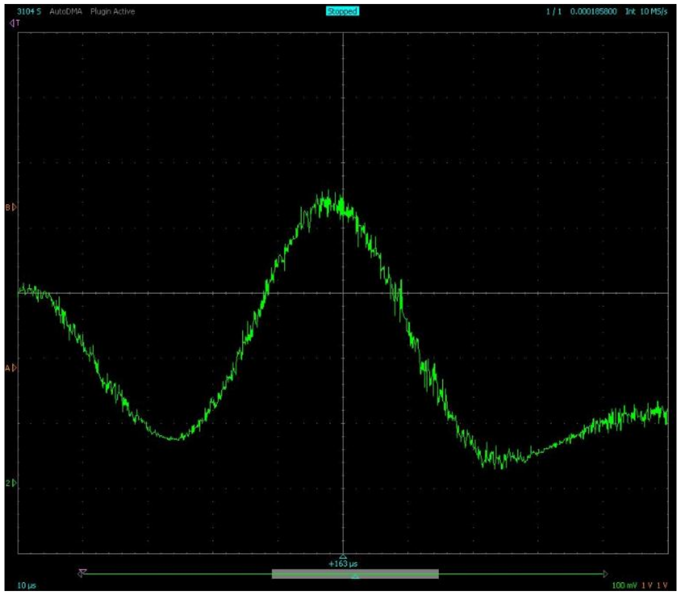


Figure 4: Data from the generated interference fringes

Above shows Figure 4 and it is the data acquired when both the interferometer arms have light coupled back to the detector. No arms were covered so we generated interference fringes as seen above.

Looking at Figure 2 and Figure 3 the frequencies were not very high because we had to make sure that the interference fringes would not overshoot when they were combined. If they were higher instead then the data that would have been in Figure 4 would be too big and cut off from the top. Also, the light coupled from each interferometer arm had to be as similar as possible to generate the interference fringes. This can be easily seen by how similar the wave patterns are in Figures 2 and 3.

**Part 3:**

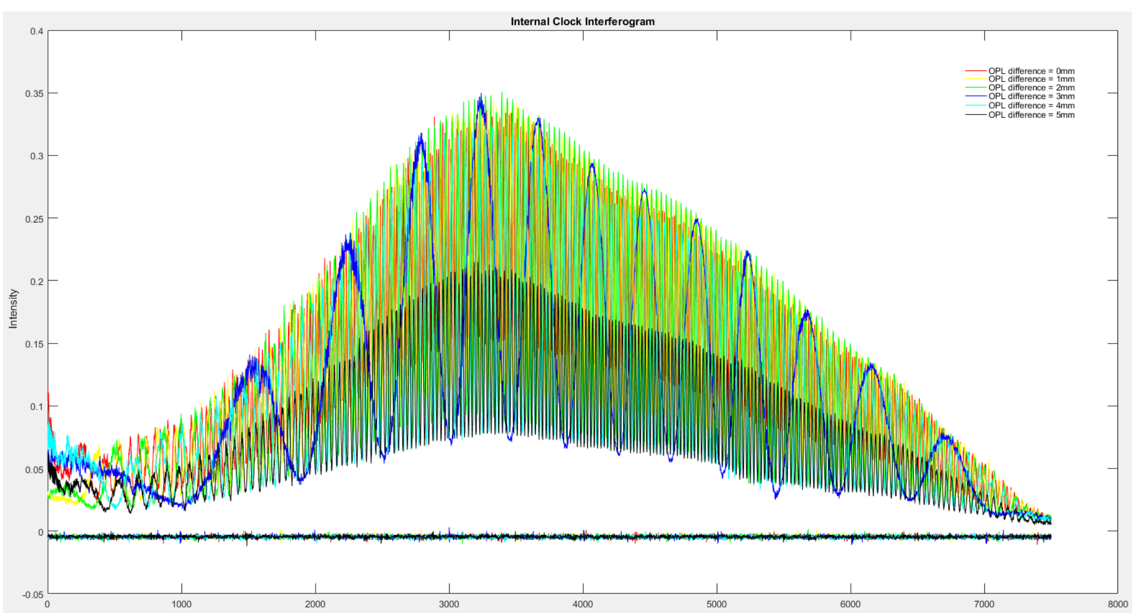


Figure 5: Internal Clock with OPLD ranging from 0mm to 5mm

Figure 5 above shows the data in one graph of the internal clock interferograms with the optical path length difference ranging from 0mm to 5mm. Figures 6 to Figure 11 below show each internal clock interferogram with OPLD from 0mm increasing by 1mm up to 5mm.

a. Before we opened the data after acquiring our interfering fringes, we changed the frequency from 2000 to 4000 and stopped at 6000. Then for the internal clock source, we used a length of 7500 and clock rate of 50MS/s. Dividing those two numbers we then get a sampling rate of 0.00015s or 150µs. We used this sampling rate because of the 7500 length and that is because any less than 7500 and the data would be cut off short and any more than 7500 then the data would repeat again.

b. @ 1mm

$$FWHM_{Envelope} = x_2 - x_1$$

= 5653.26 – 1749.52

= 3903.74

@ 2mm

$$FWHM_{Envelope} = x_2 - x_1$$

= 5649.76 – 1745.96

= 3903.80

@ 3mm

$$FWHM_{Envelope} = x_2 - x_1$$

= 5650.14 – 1750.82

= 3899.32

@ 4mm

$$FWHM_{Envelope} = x_2 - x_1$$

= 5650.57 – 1749.24

= 3901.33

@ 5mm

$$FWHM_{Envelope} = x_2 - x_1$$

= 5656.40 – 1804.25

= 3852.15

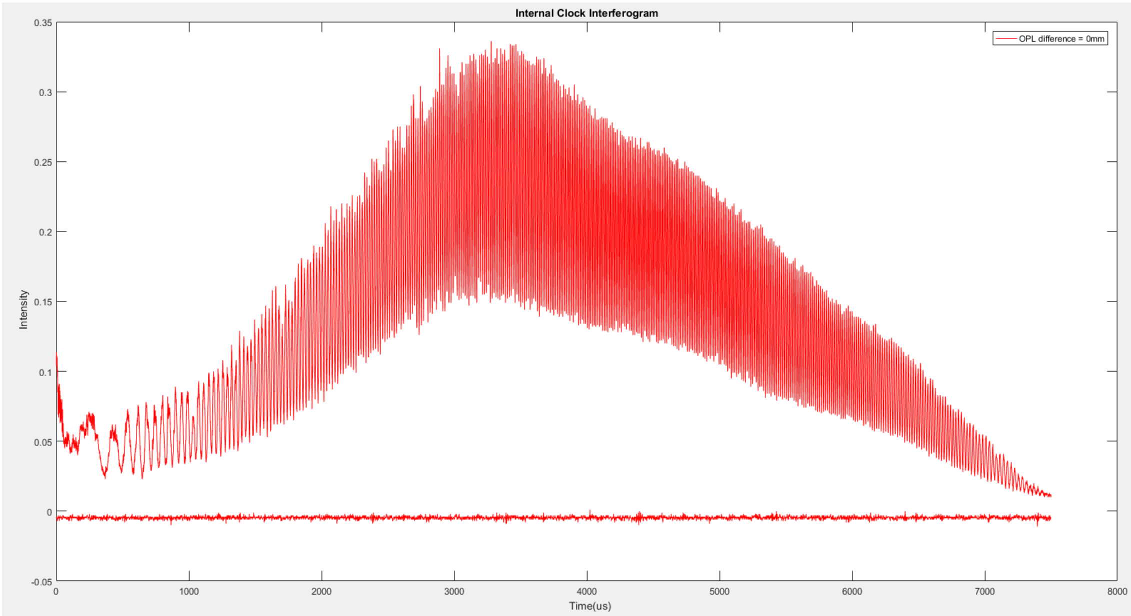


Figure 6: Internal Clock with OPLD of 0mm

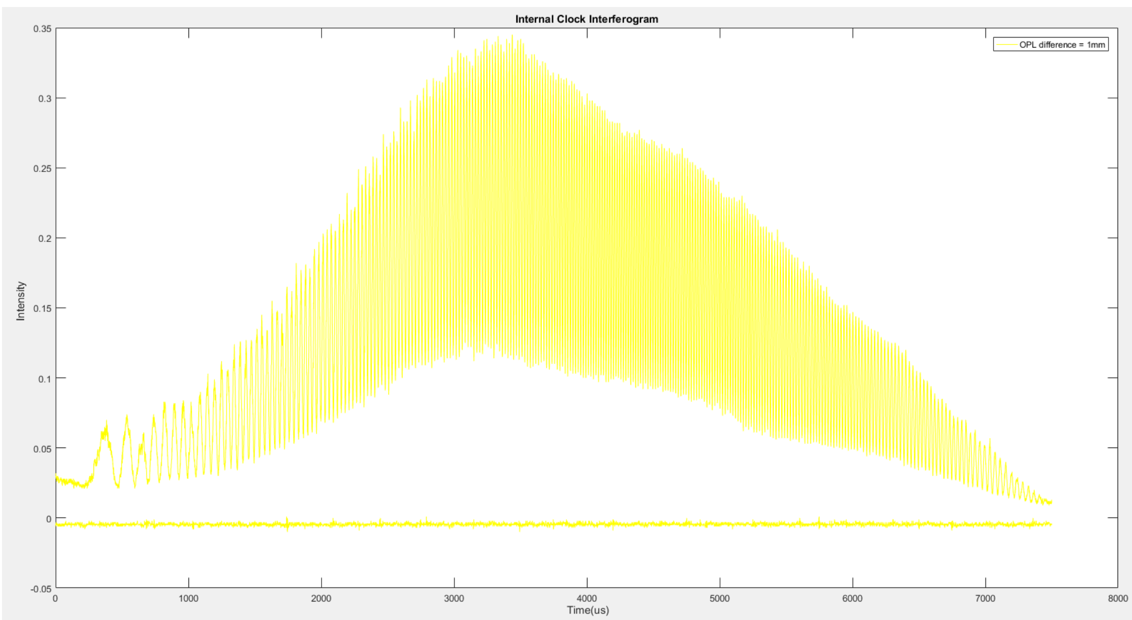


Figure 7: Internal Clock with OPLD of 1mm

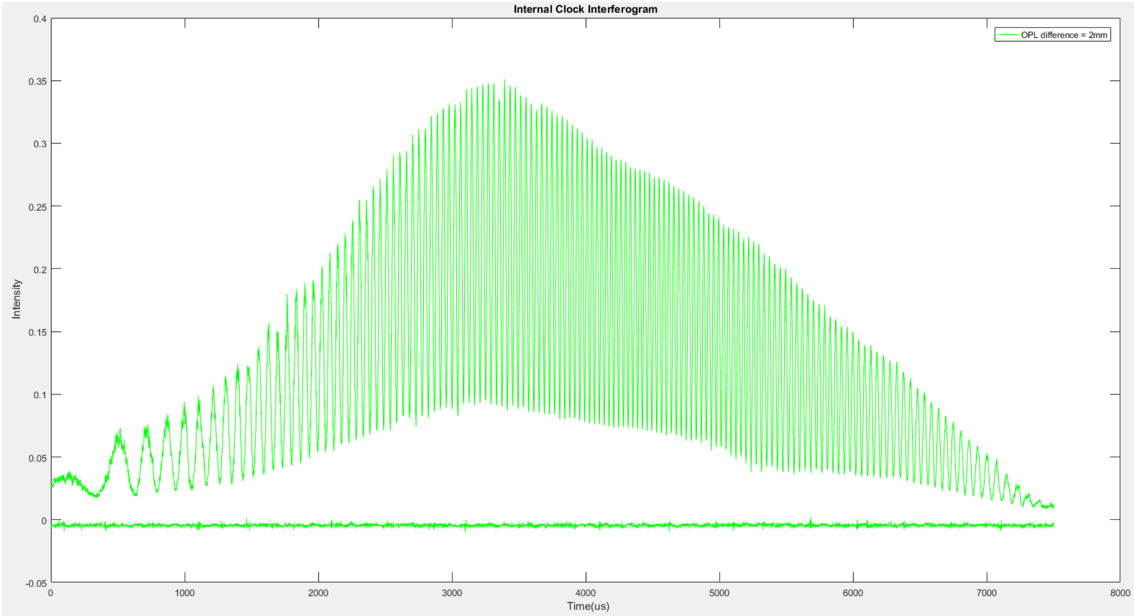


Figure 8: Internal Clock with OPLD of 2mm

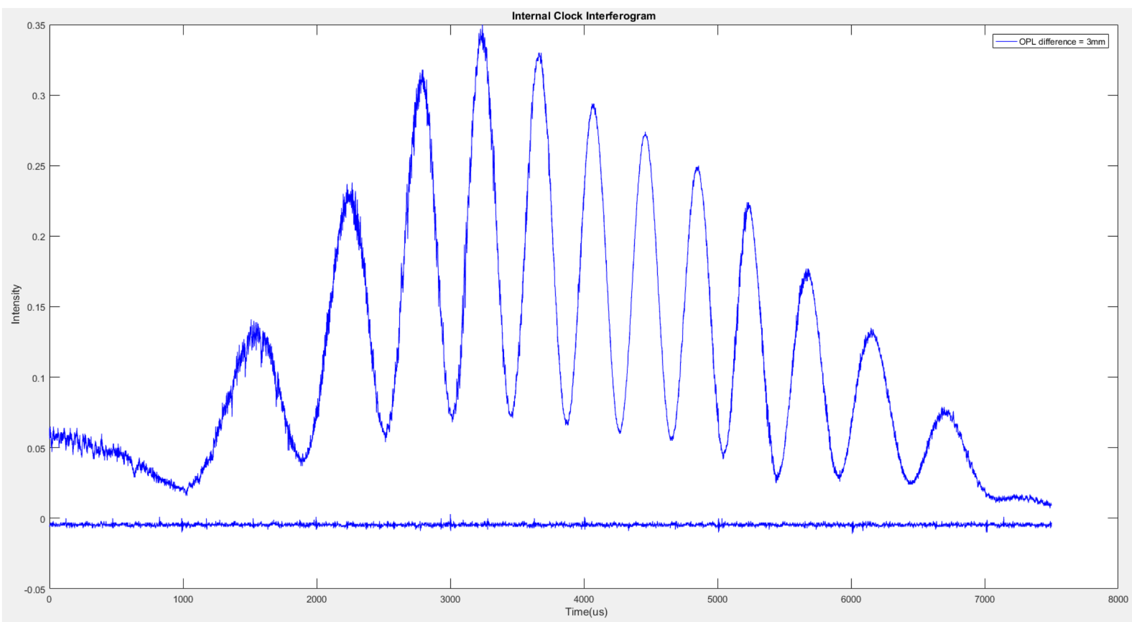


Figure 9: Internal Clock with OPLD of 3mm

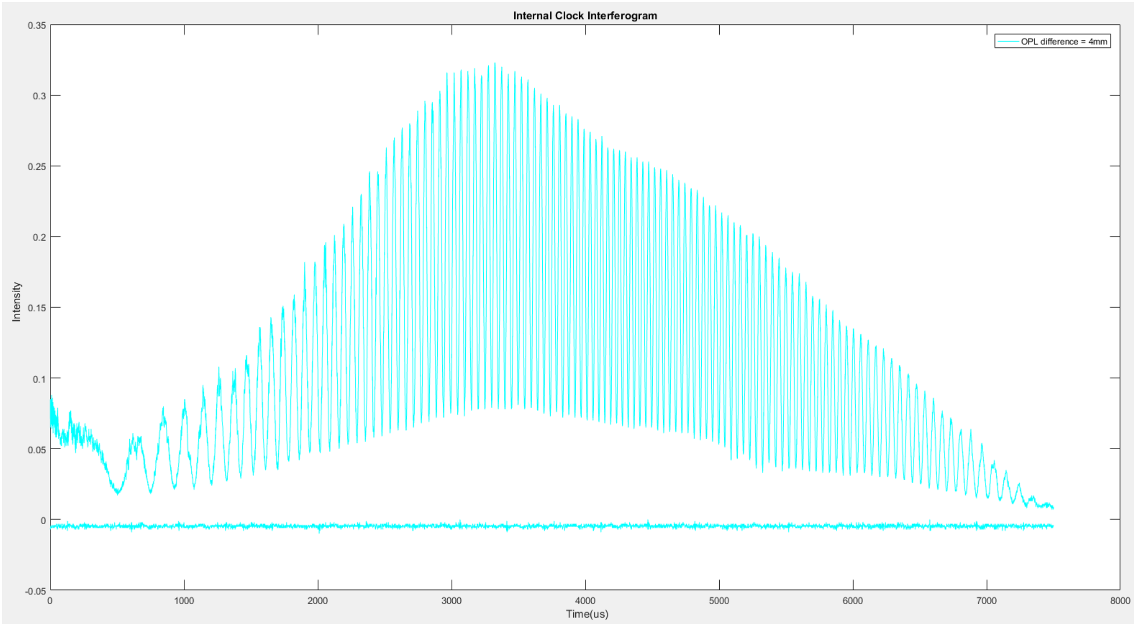


Figure 10: Internal Clock with OPLD of 4mm

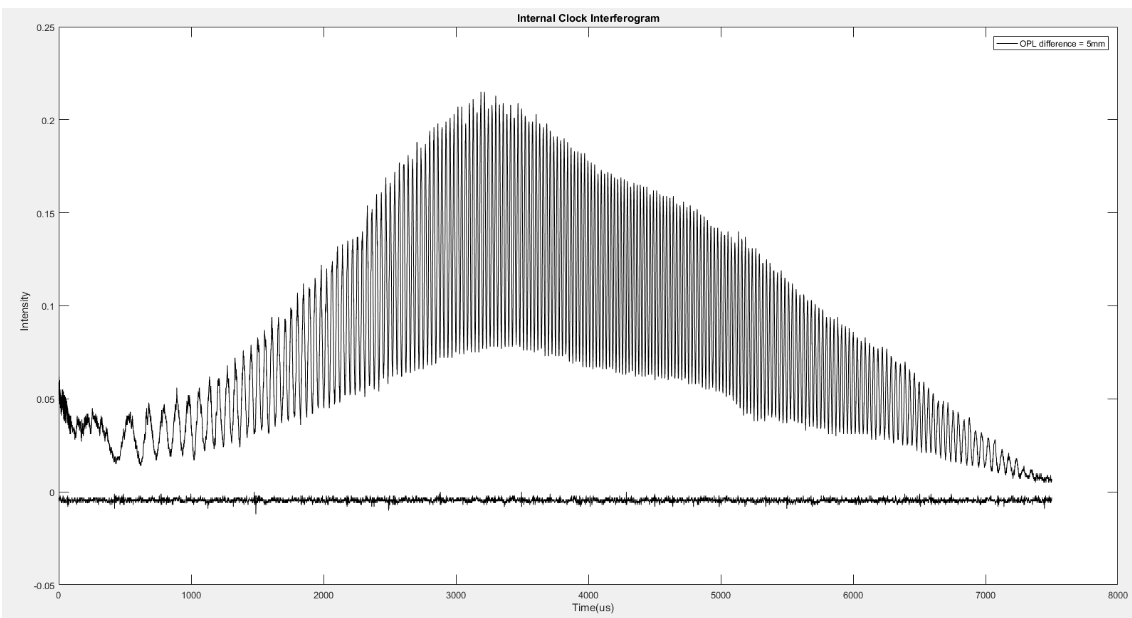


Figure 11: Internal Clock with OPLD of 5mm

**Part 4:**

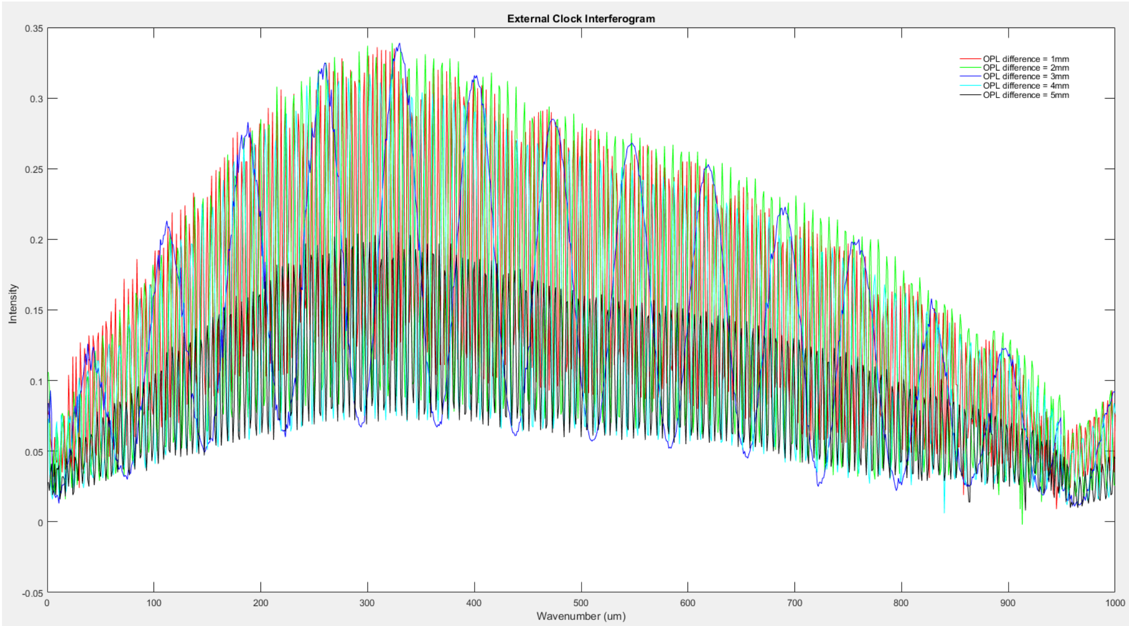


Figure 12: External Clock with OPLD ranging from 0mm to 5mm

Figure 12 above shows the data in one graph of the external clock interferograms with the optical path length difference ranging from 1mm to 5mm. Figures 13 to Figure 17 below show each external clock interferogram with OPLD from 1mm increasing by 1mm up to 5mm.

a. For the external clock source we used a length of 1000 and clock rate of 50MS/s. Dividing those two numbers we then get a sampling rate of 0.00002s or 20µs. We used 1000 because similar to the internal clock source reason, any less than 1000 then the data would be cut off short and any more than 1000 then the data would repeat again in the negative values.

b. @ 1mm

$$FWHM_{Envelope} = x_2 - x_1$$

= 766.14 – 96.57

= 669.57

@ 2mm

$$FWHM_{Envelope} = x_2 - x_1$$

= 765.70 – 96.25

= 669.45

@ 3mm

$$FWHM_{Envelope} = x_2 - x_1$$

= 766.84 – 96.17

= 670.67

@ 4mm

$$FWHM_{Envelope} = x_2 - x_1$$

= 766.64 – 96.13

= 670.51

@ 5mm

$$FWHM_{Envelope} = x_2 - x_1$$

= 802.56– 96.12

= 706.44

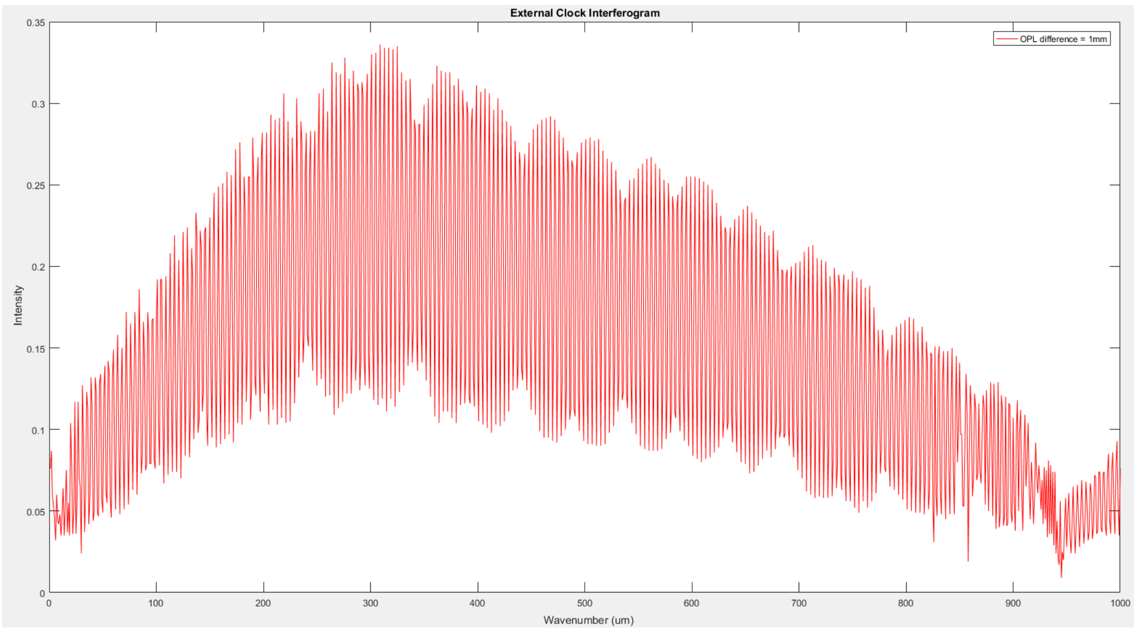


Figure 13: External Clock with OPLD of 1mm

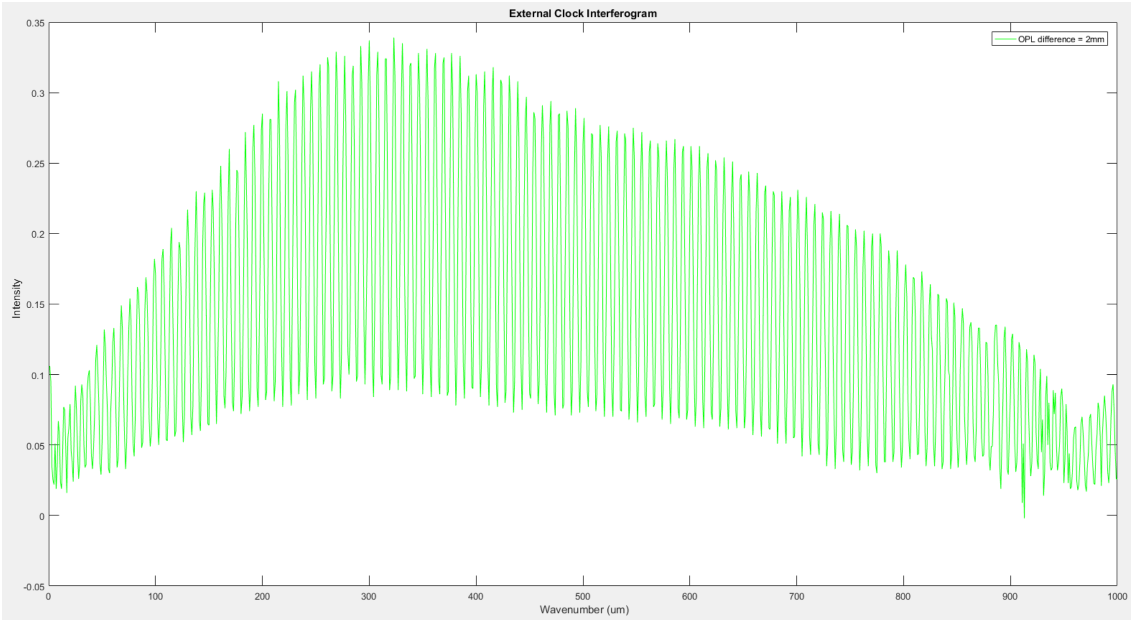


Figure 14: External Clock with OPLD of 2mm

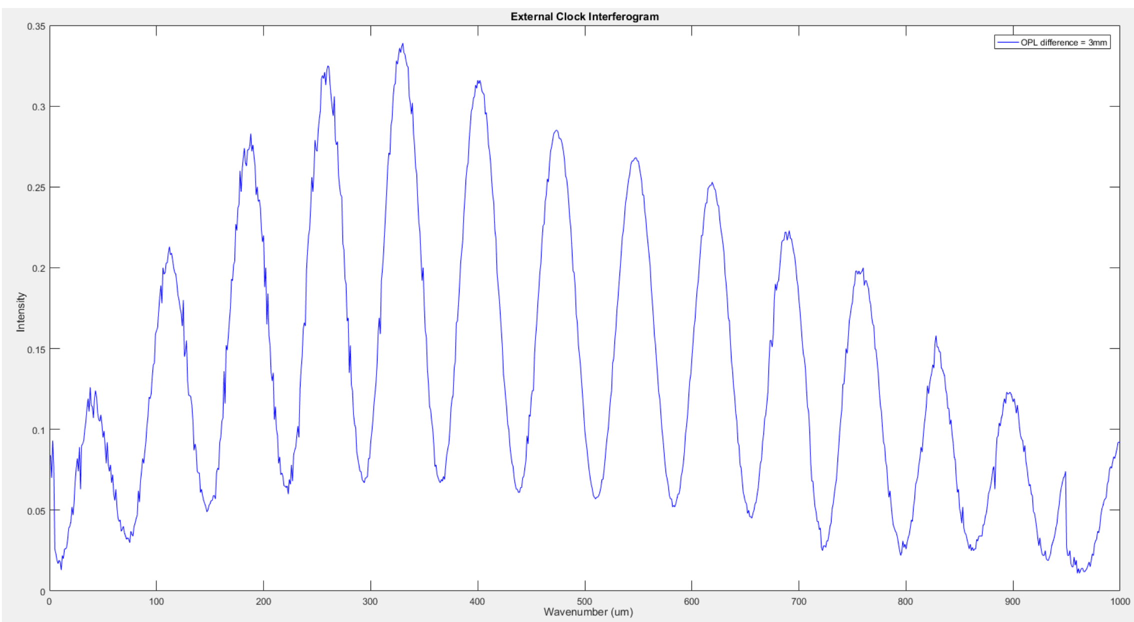


Figure 15: External Clock with OPLD of 3mm

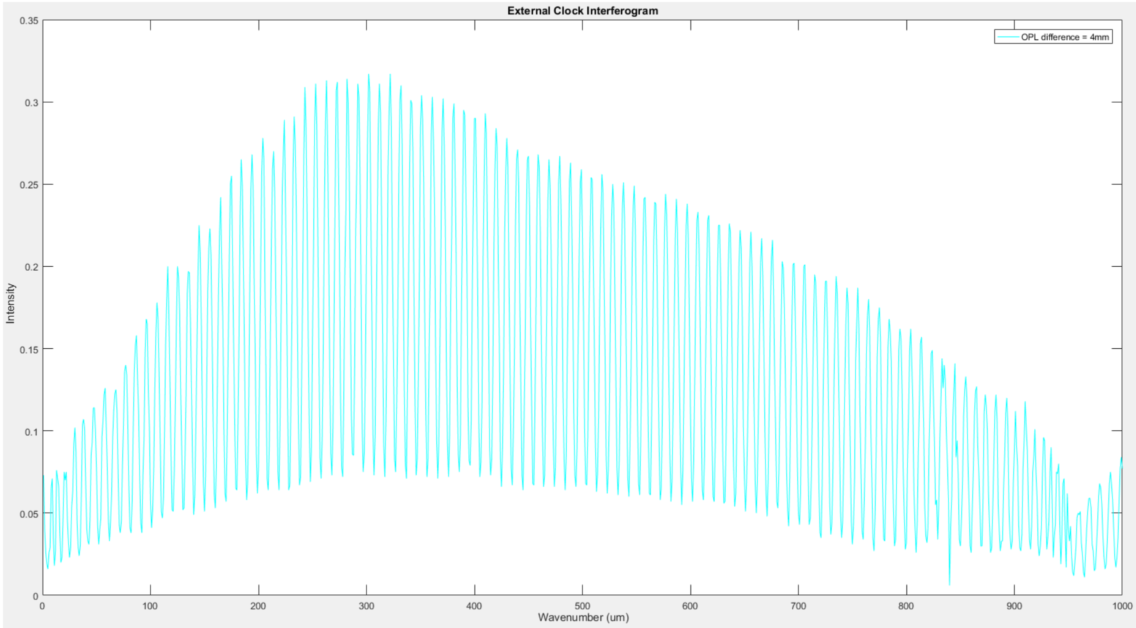


Figure 16: External Clock with OPLD of 4mm

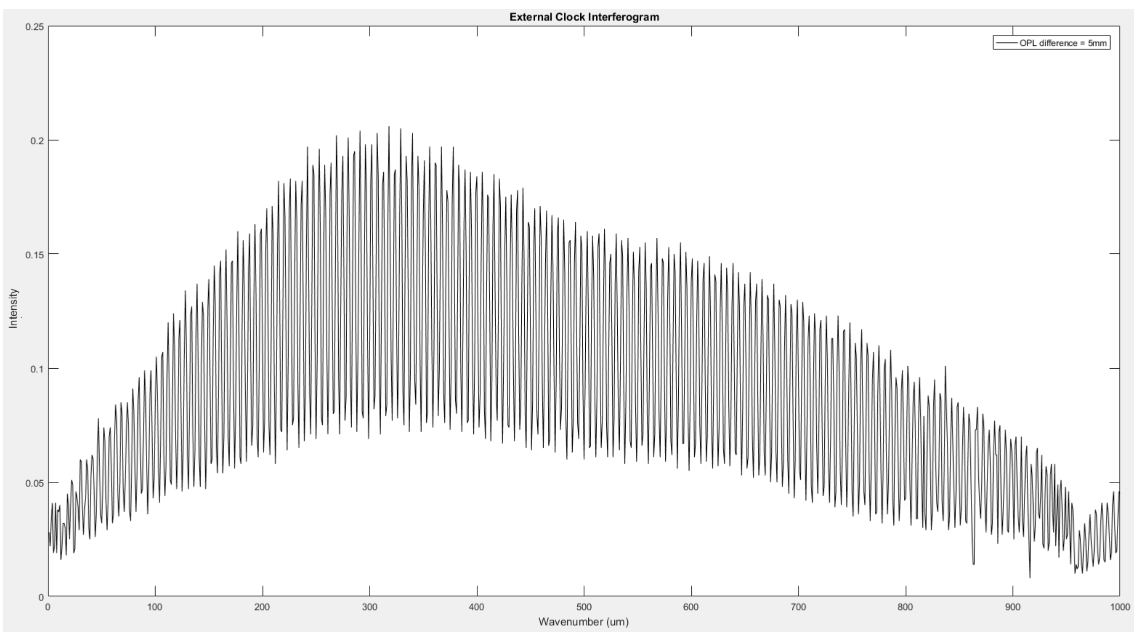


Figure 17: External Clock with OPLD of 5mm

**Part 5:**

Figures 18 to Figure 23 are plots we obtained by numerically resampling the data we acquired from part 3 to be approximately linear in wavenumber. We can observe that only the resampled data of OLPD 1mm and 2mm stayed upright. The plots with OLPD 0mm, 3mm, 4mm, and 5mm were inverted.

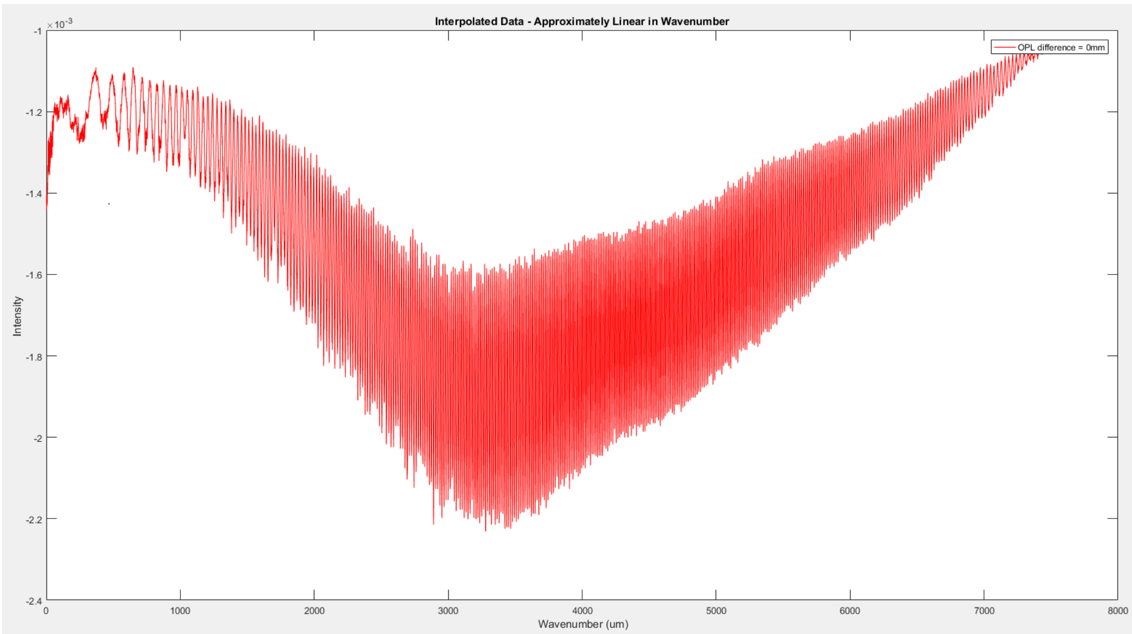


Figure 18: Numerically resampled data of part 3 with OPLD of 0mm

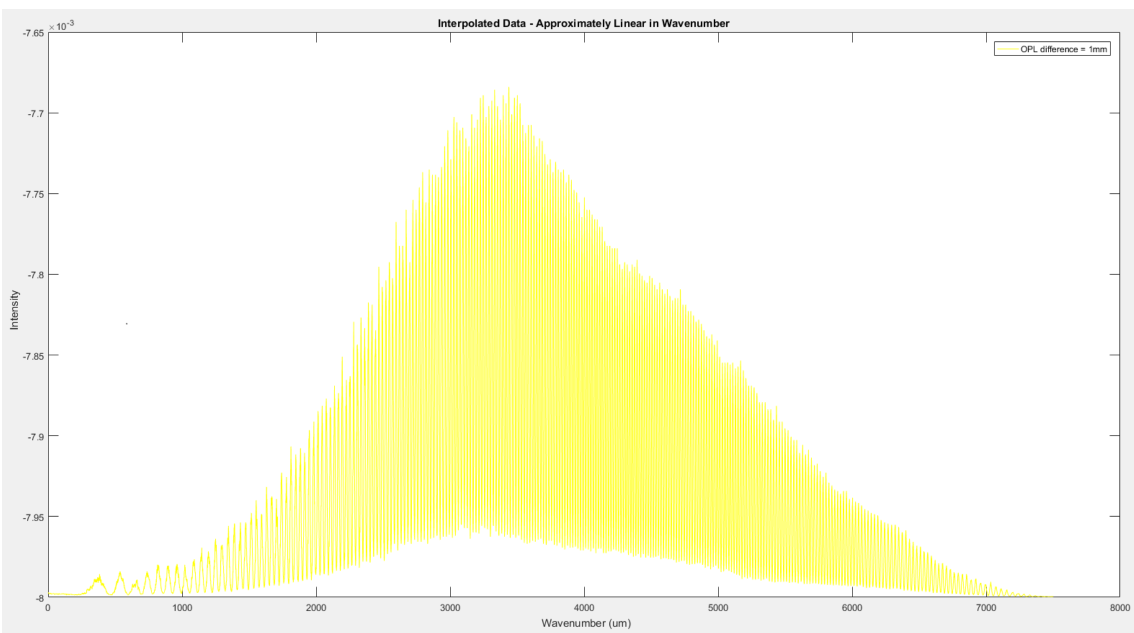


Figure 19: Numerically resampled data of part 3 with OPLD of 1mm

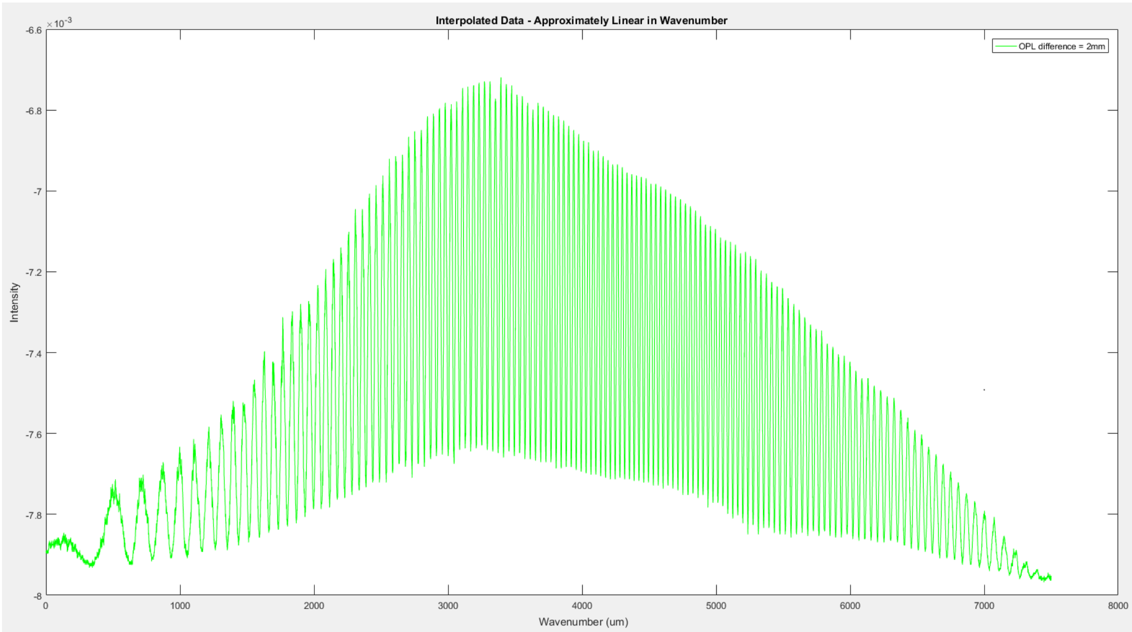


Figure 20: Numerically resampled data of part 3 with OPLD of 2mm

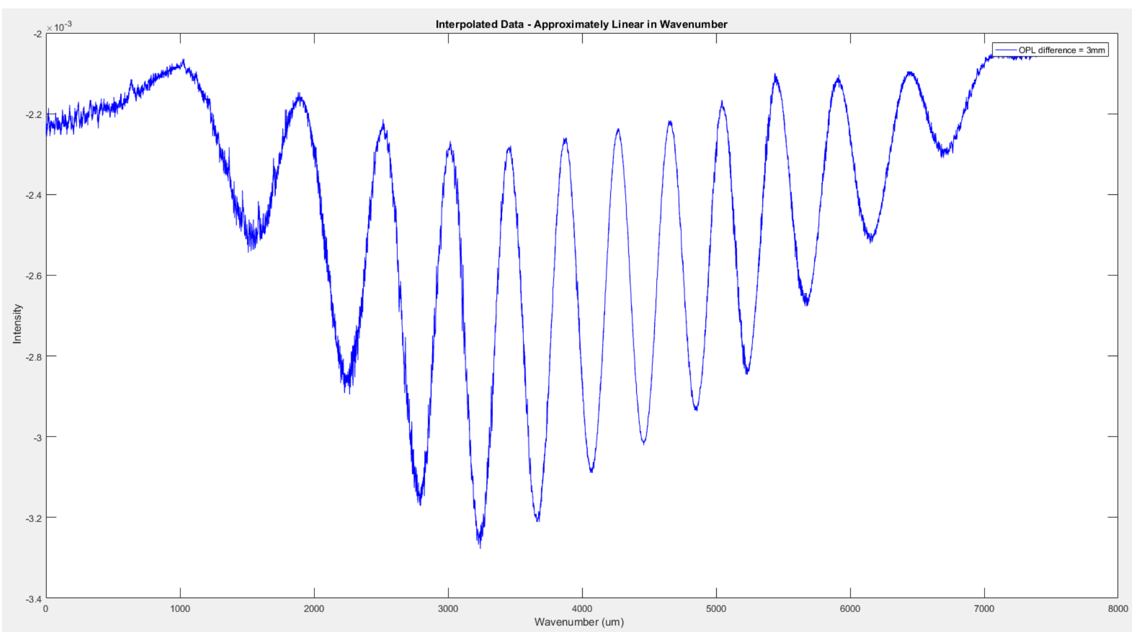


Figure 21: Numerically resampled data of part 3 with OPLD of 3mm

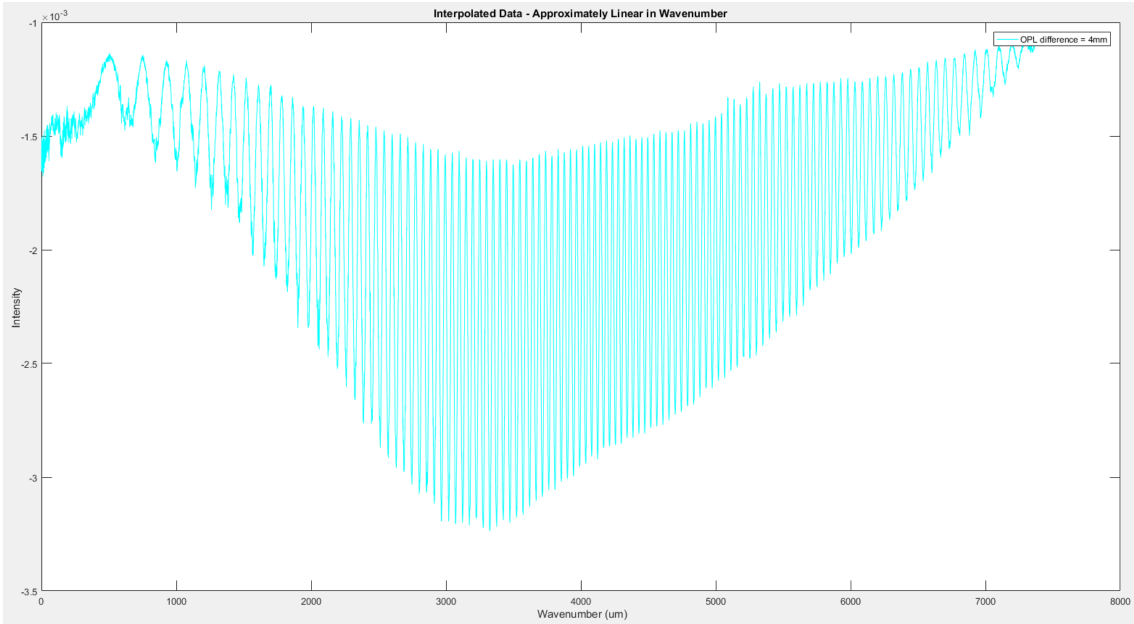


Figure 22: Numerically resampled data of part 3 with OPLD of 4mm

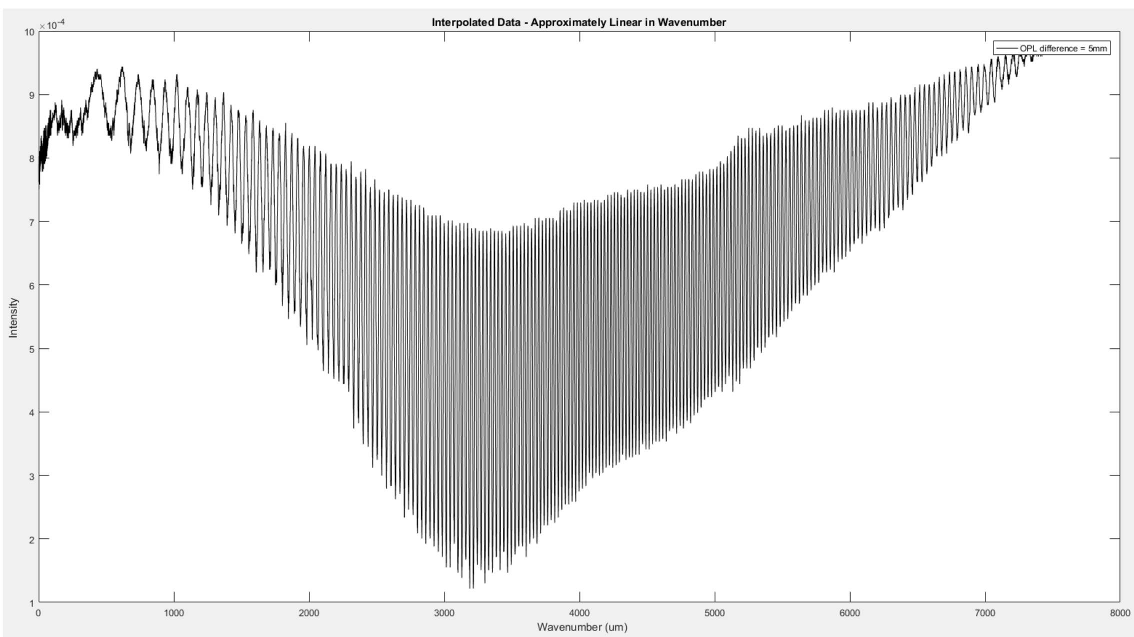


Figure 23: Numerically resampled data of part 3 with OPLD of 5mm

## Discussion

The axial point spread function (PSF) theoretically does not change as we change the distance. In our lab, we observed that the axial PSF does not change when we use an envelope on the signal and find the FWHM. However, if we zoom into a single fringe and find the axial PSF, it changes slightly. This could be due to the distorted signal as we are going over the sampling resolution leading to an incorrect conclusion.

Looking at the combined plots of the internal clock and external clock interferograms (Figure 5 and Figure 12) we can see that the height of the PSF does not change as a function of distance.

We can tell from looking at the plots above that sampling the signal uniformly in time versus uniformly in wavenumber affects the shape of the cosine. The signal uniform in time is very sharp and not really spread evenly. While the signal uniform in wavenumber resembles a clearer cosine shape and its waves are spread out more evenly.

There is only a slight difference between positive and negative values of the optical path length difference. The difference is that the negative values are the inverted version of the positive values. We can see this if we increased our sampling rate to include mode samples into our data. For the internal clock interferogram if we used a length of 15000 instead then we would see the negative values of the optical path length difference, i.e. we would see two plots that are inverts of each other.

**Conclusion**

In this lab, we used a wavelength swept laser that is invisible and can only be viewed with an IR Card which helped us to track the optical path and align the beam through the lenses, mirrors and fiber collimators. This was a good opportunity for us to be exposed in hands-on experience with Optical Coherence Tomography. Most importantly, the lab observation and calculation concluded that the axial optical PSF and the height is independent of the distance (i.e. moving the reference mirror). The sampling rate was also accountable in the observation as it provides the limitation after which point we cannot come to proper conclusion. For our case, we couldn’t conclude our observation if we find the FWHM from a single fringe.

**Index**

**MATLAB code:**

s.m

```
plot(int_0mm,'red')
hold on;
plot(int_1mm,'yellow')
hold on;
plot(int_2mm,'green')
hold on;
plot(int_3mm,'blue')
hold on;
plot(int_4mm,'cyan')
hold on;
plot(int_5mm,'black')
hold off;

title('Internal Clock Interferogram')
xlabel('Time')
ylabel('Amplitude')
```

s2.m

```
plot(int_0mm,'red')
legend('OPL difference = 0mm')
%hold on;
%{
plot(int_0mm,'red')
legend('OPL difference = 0mm')
hold on;
plot(int_1mm,'yellow')
legend('OPL difference = 1mm')
hold on;
plot(int_2mm,'green')
legend('OPL difference = 2mm')
hold on;
plot(int_3mm,'blue')
legend('OPL difference = 3mm')
hold on;
plot(int_4mm,'cyan')
legend('OPL difference = 4mm')
hold on;
plot(int_5mm,'black')
legend('OPL difference = 5mm')
hold off;
%}
title('Internal Clock Interferogram')
xlabel('Time')
ylabel('Amplitude')
```

s3.m

```
plot(ext_0mmy,'red')
hold on;
plot(ext_2mmy,'green')
hold on;
plot(ext_3mmy,'blue')
```

```
hold on;
plot(ext_4mmy,'cyan')
hold on;
plot(ext_5mmy,'black')
hold off;

title('External Clock Interferogram')
xlabel('Time')
ylabel('Amplitude')
```

s4.m

```
plot(ext_0mm,'red')
legend('OPL difference = 0mm')
%hold on;
%{
plot(ext_0mm,'red')
legend('OPL difference = 0mm')
hold on;
plot(ext_2mm,'green')
legend('OPL difference = 2mm')
hold on;
plot(ext_3mm,'blue')
legend('OPL difference = 3mm')
hold on;
plot(ext_4mm,'cyan')
legend('OPL difference = 4mm')
hold on;
plot(ext_5mm,'black')
legend('OPL difference = 5mm')
hold off;
%}
title('External Clock Interferogram')
xlabel('Path Length Difference (um)')
ylabel('Intensity')
```

**PART 5: PROCESSING - INTERPOLATION**

s5.m

```
x0 = xlsread('int_0mmx');
y0 = xlsread('int_0mmy');
yp = interp1(x0,y0,'cubic');
plot(yp, 'red')
legend('OPL difference = 0mm')
%hold on;
%{
x0 = xlsread('int_0mmx');
y0 = xlsread('int_0mmy');
yp = interp1(x0,y0,'cubic');
%yp = griddedInterpolant(x0,y0,xp, 'linear')
plot(yp)

x0 = xlsread('int_0mmx');
y0 = xlsread('int_0mmy');
yp = interp1(x0,y0,'cubic');
plot(yp, 'red')
legend('OPL difference = 0mm')

x1 = xlsread('int_1mmx');
```

```
y1 = xlsread('int_1mmy');
yp = interp1(x1,y1,'cubic');
plot(yp, 'yellow')
legend('OPL difference = 1mm')

x2 = xlsread('int_2mmx');
y2 = xlsread('int_2mmy');
yp = interp1(x2,y2,'cubic');
plot(yp, 'green')
legend('OPL difference = 2mm')

x3 = xlsread('int_3mmx');
y3 = xlsread('int_3mmy');
yp = interp1(x3,y3,'cubic');
plot(yp, 'blue')
legend('OPL difference = 3mm')

x4 = xlsread('int_4mmx');
y4 = xlsread('int_4mmy');
yp = interp1(x4,y4,'cubic');
plot(yp, 'cyan')
legend('OPL difference = 4mm')

x5 = xlsread('int_5mmx');
y5 = xlsread('int_5mmy');
yp = interp1(x5,y5,'cubic');
plot(yp, 'black')
legend('OPL difference = 5mm')

%}
title('Interpolated Data - Approximately Linear in Wavenumber')
xlabel('Wavenumber')
ylabel('Amplitude')
```

s6.m

```
exx5 = xlsread('ext_5mmx');
%exy5 = xlsread('ext_5mmy');
plot(exx5, 'black')
legend('OPL difference = 5mm')

%hold on;
%{
exx1 = xlsread('ext_0mmx');
exy1 = xlsread('ext_0mmy');
plot(exy1, 'red')
legend('OPL difference = 1mm')

exx2 = xlsread('ext_2mmx');
exy2 = xlsread('ext_2mmy');
plot(exy2, 'green')
legend('OPL difference = 2mm')

exx3 = xlsread('ext_3mmx');
exy3 = xlsread('ext_3mmy');
plot(exy3, 'blue')
```

```
legend('OPL difference = 3mm')

exx4 = xlsread('ext_4mmx');
exy4 = xlsread('ext_4mmy');
plot(exy4, 'cyan')
legend('OPL difference = 4mm')

exx5 = xlsread('ext_5mmx');
exy5 = xlsread('ext_5mmy');
plot(exy5, 'black')
legend('OPL difference = 5mm')
%}
%}
title('External Clock Interferogram')
xlabel('Wavenumber')
ylabel('Amplitude')
```

s7.m

```
plot(exy1,'red')
hold on;
plot(exy2,'green')
hold on;
plot(exy3,'blue')
hold on;
plot(exy4,'cyan')
hold on;
plot(exy5,'black')
hold off;

title('External Clock Interferogram')
xlabel('Time')
ylabel('Amplitude')
```