# Extracting Images and Displacements from Raw Spectral Domain Optical Coherence Tomography Data

Prof. Brian Frost

ECE-435, Spring 2025

## Introduction

In class, we discussed the processing pipeline for spectral domain optical coherence tomography (SD-OCT). The "raw data" from an SD-OCT A-Scan is given in the number of electrons stored on each CCD pixel of a line camera. There are $N = 2048$ such pixels. In hardware, this camera comes right after a diffraction grating, meaning each pixel corresponds to a *wavelength* of light present in the interference pattern between the reference and the reflected sample beams.

The raw data in `BScan_Layers.raw` is a matrix consisting of $N$ rows and $M + D$ columns. The first $D$ columns are the background samples (recall what these are from our discussion in lecture) and the remaining $M$ correspond to A-Scans. A-Scans are taken at $M$ points along a line segment in optical coordinates. I will tell you that the full B-Scan is 1 mm wide.

The files titled `MScanX.raw`, where `X` is 1 or 40 contain samples from a speaker playing `X` tones at 80 dB SPL. The first $D$ columns of each data set are background, and the next $R$ are A-Scans taken at one location with a sampling rate of $f_s$ – that is, spaced $\Delta t = 1/f_s$ apart.

Data is taken on a ThorLabs Telesto 3, which uses an SLD with center wavelength $\lambda_0 \approx 1300$ nm and bandwidth $\Delta\lambda \approx 100$ nm. Axial pixel size $dz = 3.6$ $\mu$m. Data is taken using an LSM-03 objective lens, which has numerical aperture $NA = 0.055$. The data is taken in air, which has $n = 1$.

In all cases, recall the mirror image effect and the fact that spurious high-value DC components should not contribute to your image significantly (but may appear)

## I. Guiding computations

Given the information in the introduction, compute the following:

1. The lateral resolution of the system. What limits the lateral resolution?

2. The axial resolution of the system. What limits the axial resolution?

3. The B-Scan "pixel" aspect ratios. What will the B-Scan's aspect ratio be, with/without accounting for the "mirror image" artifact of OCT.

## II. The A-Scan function

Write a function that generates a complex A-Scan in the spatial domain. It should include background subtraction as well as windowing and deconvolution. For deconvolution, smooth your background using a polynomial fit (you will want to toy around with the order of this fit by looking at the average background vs the fit). Do not use the smoothed background for background subtraction, but instead use the regular average background. This should not require any for loops at all.

This function may take a bit of time to run. Add time markers to your function and either return or print the amount of time each step takes. Comment on these values in your report.

Display the magnitude (in dB) of 2 A-Scans from `BScan_Layers.raw`, and one from each of the `MScan` files. The M-Scan ones should look pretty similar to one another.

For your report, I would like a brief summary of how the function works, a discussion of the time taken by different steps in the function, and the plots of these A-Scan magnitudes. I want you to then try to run the same code on any single A-Scan you found looked nice a) *without* deconvolution or background subtraction, and b) without deconvolution but with background subtraction. In your report, compare these to the signal processed with the full pipeline, and explain the differences you see.

## III. The B-Scan

Create an image from all of the scans in `Bcan_Layers.raw`. You might just want to use the function from above, but then you will be doing many redundant computations. Instead, write a new B-Scan function of a similar form to your A-Scan function that avoids any redundant computation. This should not require any for loops at all. You may have to use some cropping, scaling or basic contrast enhancement to make the image look OK. Specifically, recall the mirror image effect. To determine the best contrast enchancement method, look at A-Scans. Filter the B-Scan in the way that gives the clearest image. There is no "right" answer to how to process this image, but you should have some intuition. In your report, provide:

1. The B-Scan, unprocessed and processed, presented in grayscale with an aspect ratio corresponding to the true physical distances.
2. A discussion of the pixel sizes and how you determined the proper aspect ratio
3. A discussion of how you processed the image, and why you chose the steps and filters you chose. Do not just say "this looked nice," but instead give a possible mechanism for why it looks nice.
4. A comparison with a B-Scan created without using deconvolution (with background subtraction, however).

As a hint – the B-Scan is of a few layers of Scotch tape stacked on top of one another. Can you count the layers? How thick is each sheet of tape, and how far are they from one another?

## IV. The M-Scan

To begin, produce the *average* of the A-Scan magnitudes from the 1-tone M-Scan. There are a LOT of data A-Scans here, so this will take a while. There should be a band of high intensity where the speaker's membrane is. Take note of the indices of two particular high-intensity points in this A-Scan average. The speaker is rather close to the scanner here.

Write a script which performs spectral domain phase microscopy (SDPM) given a time series of complex A-Scans, $\Delta t$, and a pixel at which to track sub-pixel motion. It should return a vector of time-domain data in units nm. Remember to unwrap the angle.

Present the data in the time domain and in the frequency domain for both pixels. Does the time domain data look about right? What if you zoom in? Does the frequency domain data look about right? What tone did I play through the speaker (in kHz)?

Do the same for the other M-Scan. Present these outputs in time and frequency. Tell me which 40 frequencies make up this tone complex (in kHz). You may list the tones by using MATLAB functions (or by hand if you have that much time).

Briefly comment on the amplitude difference between frequencies and between SPLs. Is the speaker all-pass? Is the speaker approximately linear? How would you know?