Python Heterodyne Measurement Automation

Thomas Keyes

Computer Engineering, University of Virginia

axx2xu@virginia.edu

Program Highlights

1) Automatically adjusts the wavelength of lasers 3 and 4 to find the first measurement beat frequency as defined by the user
2) After calibrating the initial measurement state, the program determines the step size to loop from the user defined start and end beat frequency based on the input number of steps
3) Automatically selects the electrical spectrum analyzer for beat frequency measurements under 50 GHz
4) Automatically selects the wavelength meter for beat frequency measurements at or above 50GHz
5) Reads in data from user defined s2p files to add calibrated RF power data to the raw data
6) Reads in data from user defined excel sheet with beat frequency and RF loss to add calibrated RF power data to raw data

Equipment Used

- Anritsu ECL Lasers 3 and 4
  - The program adjusts the wavelength
- HP ESA 8565E/Newport Commercial PD
  - Program reads beat frequency < 50 GHz
- HP Wavelength Meter 86120C
  - Program reads beat frequency >= 50 GHz
- KEOPSYS Optical Amplifier (EDFA)
  - Program does not use
- Agilent Attenuator 81577A (VOA)
  - Program reads P actual
- Keithley Source meter 2400-C (High Power 3)
  - Program reads photocurrent
- Rohde & Shwarz Power Meter NRP-Z58
  - Program reads RF power up to 110GHz frequency

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Program Overview

Program Process

- Prompt user for input settings and loss files
- After pressing “START” prompts the user for save location
- Calibrates laser 3 and 4 to a user-specified threshold of starting beat frequency
- Iterates through a user-specified number of steps between start and stop beat frequency while measuring beat frequency, photocurrent, and RF power
- Updates live plots of beat frequency vs. step, photocurrent vs. beat frequency, and Raw RF power vs. beat frequency during the loop
- Saves data to .txt, .xlsx, and .png format for later use

Necessary Manual Inputs and Adjustments

- Turn on all equipment
- Turn on Delta WL mode on Wavelength Meter
- Zero R&S Power Meter using Power Viewer Software
- Enable lasers, set output power
- Enable Keithley Source meter – set output voltage and current threshold
- Enable optical amplifier and turn on pump
- Enable VOA and adjust attenuation to desired photocurrent

User Inputs in Program

- Starting wavelength for laser 3 and laser 4
- Start and end beat frequency (GHz)
- Number of steps to take between start and end beat frequency
- Delay time between updating lasers and taking new measurements (recommended minimum 3s)
- RF Link Loss data (.s2p)
- RF Probe Loss data (.xlsx)
- Save information
  - File name and location
  - Device number
  - Trial comments

- https://github.com/axx2xu/heterodyne

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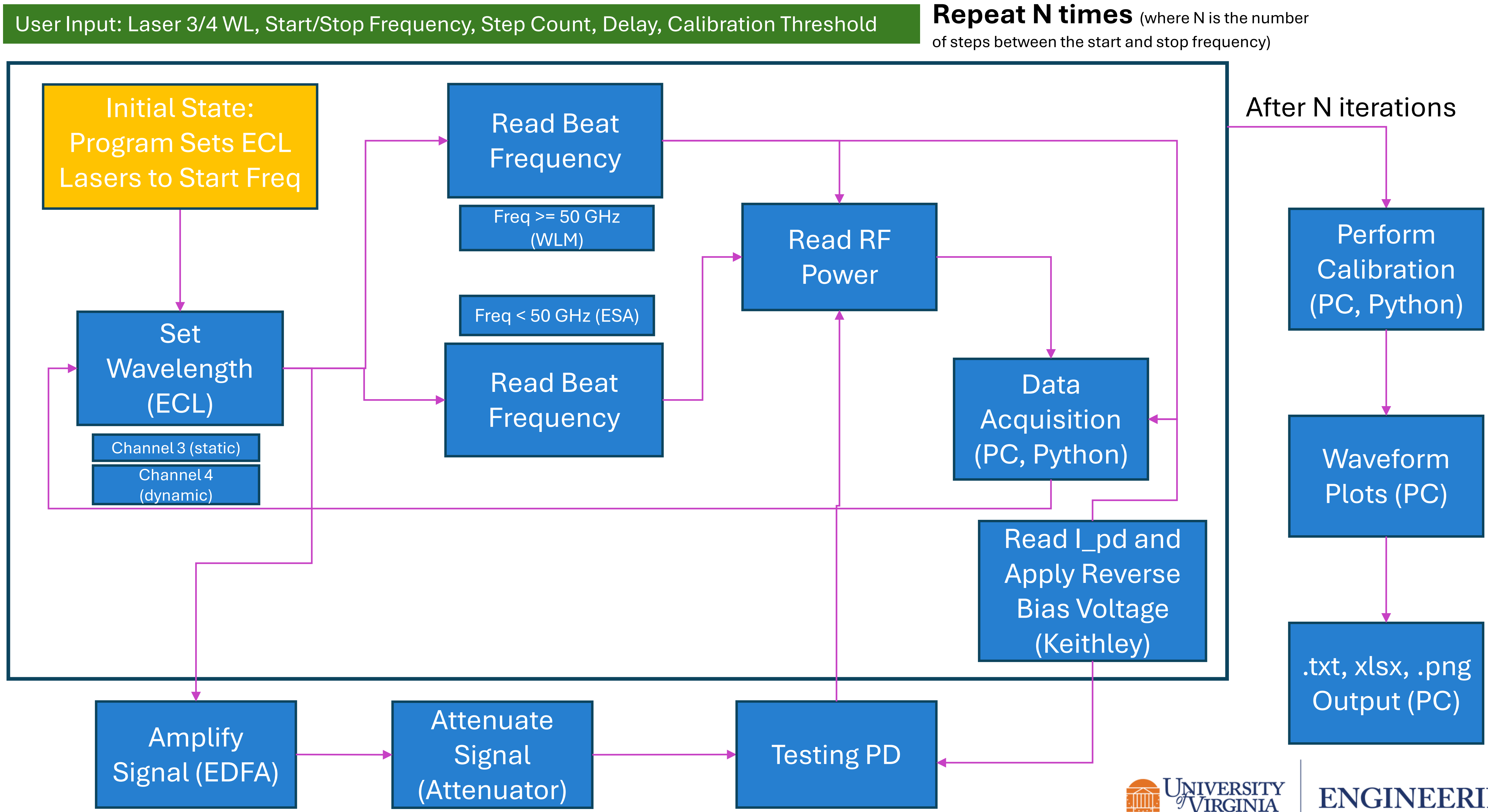
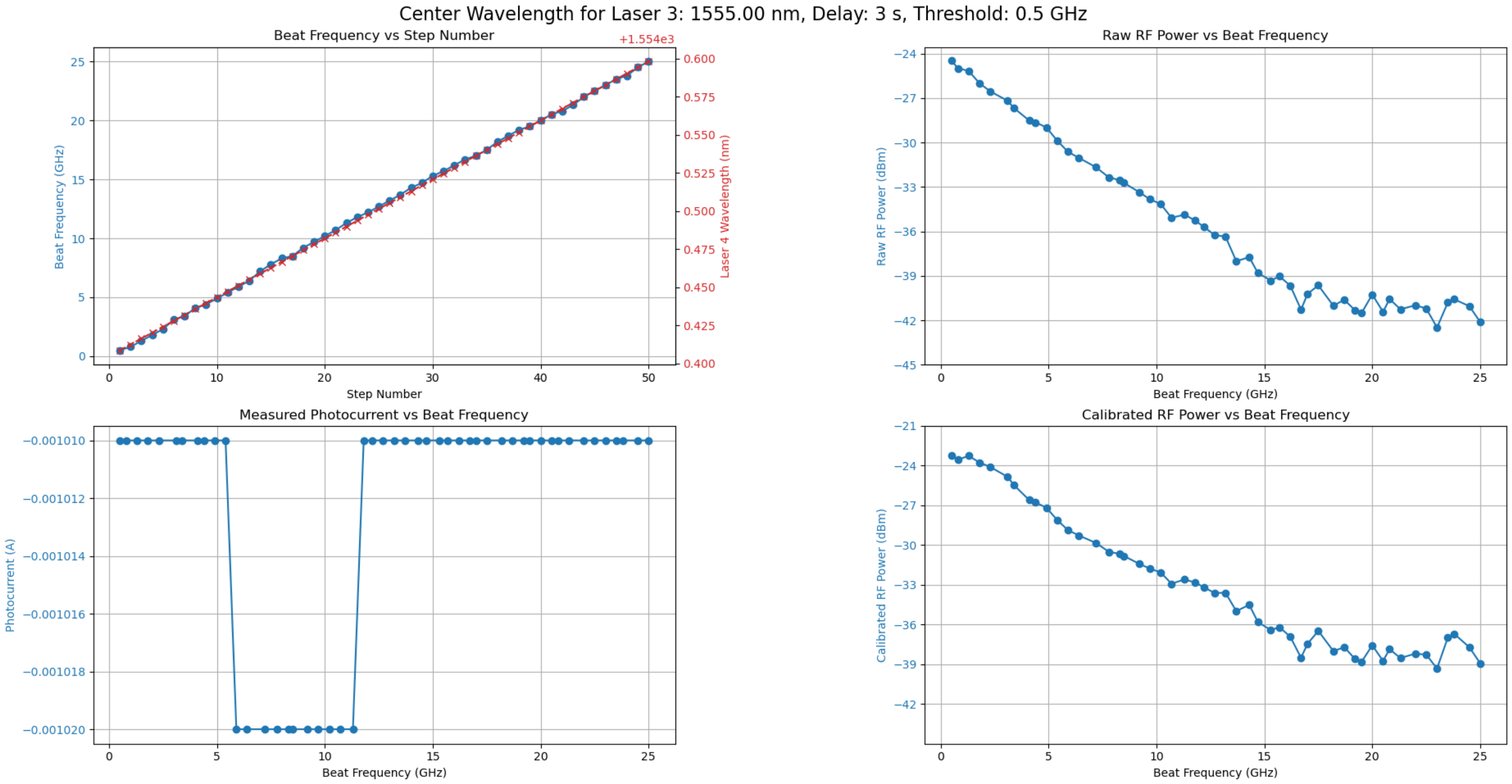

User Input: Laser 3/4 WL, Start/Stop Frequency, Step Count, Delay, Calibration Threshold
Repeat N times (where N is the number of steps between the start and stop frequency)
Initial State: Program Sets ECL Lasers to Start Freq
Set Wavelength (ECL)
Channel 3 (static)
Channel 4 (dynamic)
Read Beat Frequency
Freq >= 50 GHz (WLM)
Freq < 50 GHz (ESA)
Read Beat Frequency
Read RF Power
Data Acquisition (PC, Python)
Read I_pd and Apply Reverse Bias Voltage (Keithley)
After N iterations
Perform Calibration (PC, Python)
Waveform Plots (PC)
.txt, xlsx, .png Output (PC)
Amplify Signal (EDFA)
Attenuate Signal (Attenuator)
Testing PD

Program Output

Output Plots



The output plots contain four plots:

1) Beat frequency vs. step number – this is useful to see if the laser and steps and beat frequency measurements are updating reasonably
2) Measured photocurrent vs. beat frequency – used to visualize changes in the photocurrent reading from the Keithley
3) Raw RF Power vs. Beat Frequency – plots the rf power vs. beat frequency live as the measurement loop runs
4) Calibrated RF Power vs. Beat Frequency – once the measurement loop is finished the raw RF data is combined with the calibrated RF loss and re-plotted

*The red, right-side y-axis of the beat frequency vs. step number shows the wavelength at which laser 4 was set, as erratic points often occur in similar areas of wavelength. To get the value, add the value of the y-axis to the value at the top

Program Output

.txt Output Data

```
DEVICE NUMBER: 1
COMMENTS: BLAH
KEITHLEY VOLTAGE: -5.000e+00 V
INITIAL PHOTOCURRENT: -1.01e-03 (A)
STARTING WAVELENGTH FOR LASER 3: 1555.0 (nm) : STARTING WAVELENGTH FOR LASER 4: 1554.408 (nm) : DELAY: 2 (s)
DATE: 07/23/2024
TIME: 16:51:12

F_BEAT(GHz)     PHOTOCURRENT (A)        Raw RF POW (dBm)        Cal RF POW (dBm)        P Actual (dBm)
0.30            -1.0100e-03             -24.68                  -23.71                  7.811
0.80            -1.0100e-03             -25.26                  -23.82                  7.815
1.20            -1.0100e-03             -25.08                  -23.30                  7.820
1.70            -1.0100e-03             -25.52                  -23.35                  7.822
2.20            -1.0100e-03             -25.75                  -23.35                  7.824
2.70            -1.0100e-03             -25.52                  -23.05                  7.826
3.10            -1.0100e-03             -25.75                  -23.41                  7.830
3.80            -1.0200e-03             -25.95                  -23.91                  7.833
4.20            -1.0200e-03             -26.18                  -24.26                  7.836
4.80            -1.0100e-03             -25.91                  -24.09                  7.810
5.10            -1.0100e-03             -25.82                  -24.04                  7.809
5.80            -1.0100e-03             -26.43                  -24.65                  7.810
6.20            -1.0100e-03             -26.61                  -24.84                  7.808
6.80            -1.0100e-03             -26.76                  -24.99                  7.806
```

The .txt output data contains the measured data and a mix of user defined and automatically recorded information in the header:

1) File name is defined by the user
2) Device number and trial comments are defined by the user
3) Keithley voltage and initial photocurrent automatically queried from the instrument
4) Starting wavelength for laser 3 and 4 recorded after calibrating the first measurement beat frequency, initial user defined delay is added
5) Time and date automatically added
6) Data is sorted with the corresponding beat frequency and output in a structured text file format

*The starting wavelength for laser 3 and 4 indicate what wavelength the lasers were set to once the calibration finished and before beginning the measurement loop

Using the Program (Overview)

Steps of Use

1. Ensure setup is correct (cables, Bias-T, chip, etc)
2. Turn on all equipment, zero R&S Power Meter using Power Viewer software
3. Turn on Delta WL mode on Wavelength Meter
4. Enable lasers, set output power
5. Turn VOA Power on, **do not enable** (ensure α is set to 33)
6. Turn EDFA power switch and key to ON
7. Set Keithley voltage and current compliance, enable
   1. Ensure correct bias is applied
8. Turn on EDFA pump (**lasers must be enabled first**)
9. Enable the VOA, read the photocurrent on Keithley and adjust α until reaching the desired photocurrent
10. Enter user inputs and select loss files if applicable, then press the “START” button
    1. After pressing the “START” button, a new window will pop up, prompting the user to enter the device number, comments, and to select the file save path. The program will then begin.
    2. While the program is running, press the “STOP” button to stop measurements and save the data.
    3. At conclusion of the program, the plots will stay open and can be saved or closed.

Common Errors

- VISA Address not found
  - Ensure the GPIB hub is connected (blue USB connector) as well as the R&S power sensor is connected by USB (black USB connector)
  - Try the program again
- Calibration overstepped the threshold
  - Try the program again with different starting wavelength inputs
- Error reading network analyzer/excel file
  - Ensure the correct file paths are input for the .s2p and .xlsx loss data

Access Code and Related Files

- https://github.com/axx2xu/heterodyne

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Prior to Running the Program

Additional Requirements if First Time Use on Personal Computer

Driver and Software Installation

Required:

- Install NRP Toolkit (To connect with R&S NRP-Z58 power meter)
- Install VISA Library Passport for NRP (To connect with R&S NRP-Z58 power meter)
- Install R&S Power Viewer (To zero the power meter prior to turning on other equipment)

Optional:

- Install NI Max (To view what devices are connected to GPIB addresses)

* Some installation links can be found in the “drivers” file in the GitHub repository

Opening the Program (Ideal)

<u>Ideal Way to Open the Program</u>

- The designed and ideal way to run the program is to simply run the distributed .exe file named “heterodyne_automation.exe”
- If this runs successfully, the GUI should pop up as shown in the figure
- If this does not work, follow the steps on the following slide to run the program through python

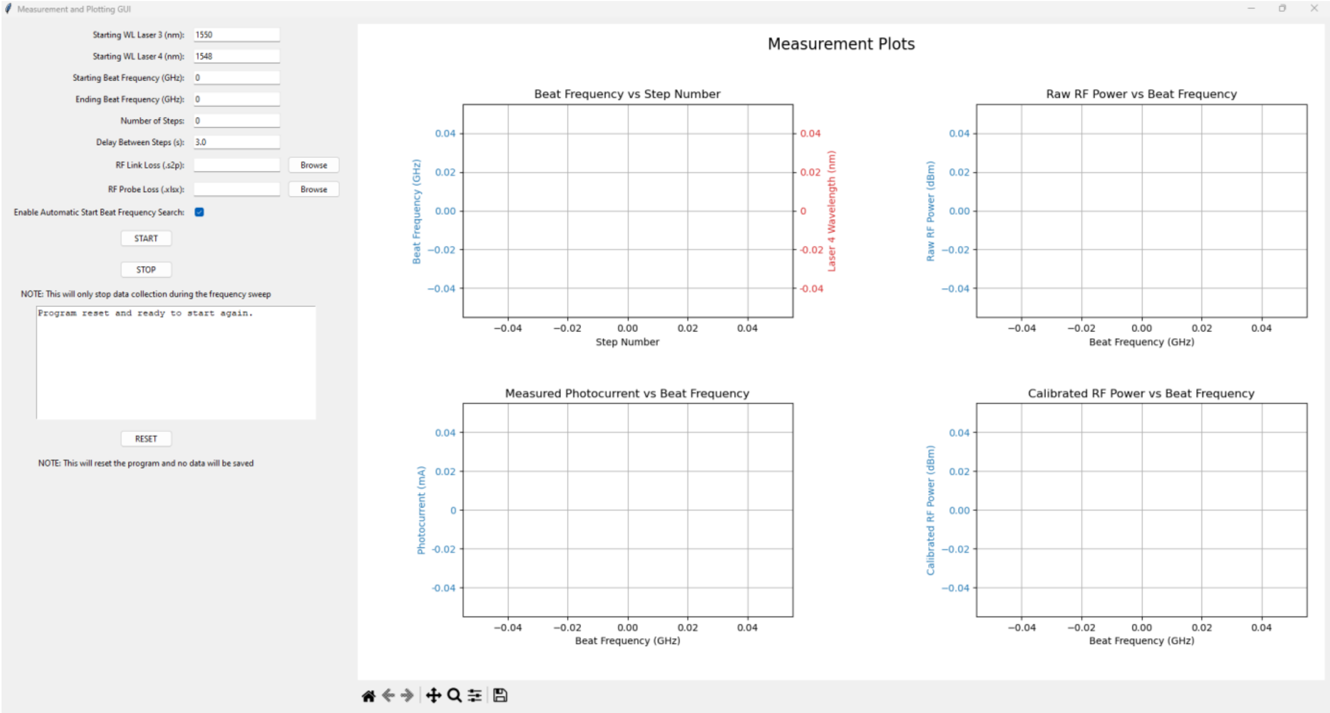

Figure: Program GUI When Initially Run

***Opening the program this way should not require installing Python or any dependencies**

Opening the Program (Backup)

<u>Backup Way to Open the Program</u>

- Ensure that Python is installed on your computer.
- Download the "heterodyne_automation.py" and "requirements.txt" files from the GitHub repository into a new project directory.
- Navigate to the project directory by opening a terminal and changing to the folder containing your project files.
- Create a virtual environment by running:
  python -m venv venv
- Activate the virtual environment:
  On Windows: .\venv\Scripts\activate
  On macOS/Linux: source venv/bin/activate
- Install the required packages with:
  pip install -r requirements.txt
- Run the program by executing:
  python heterodyne_automation.py

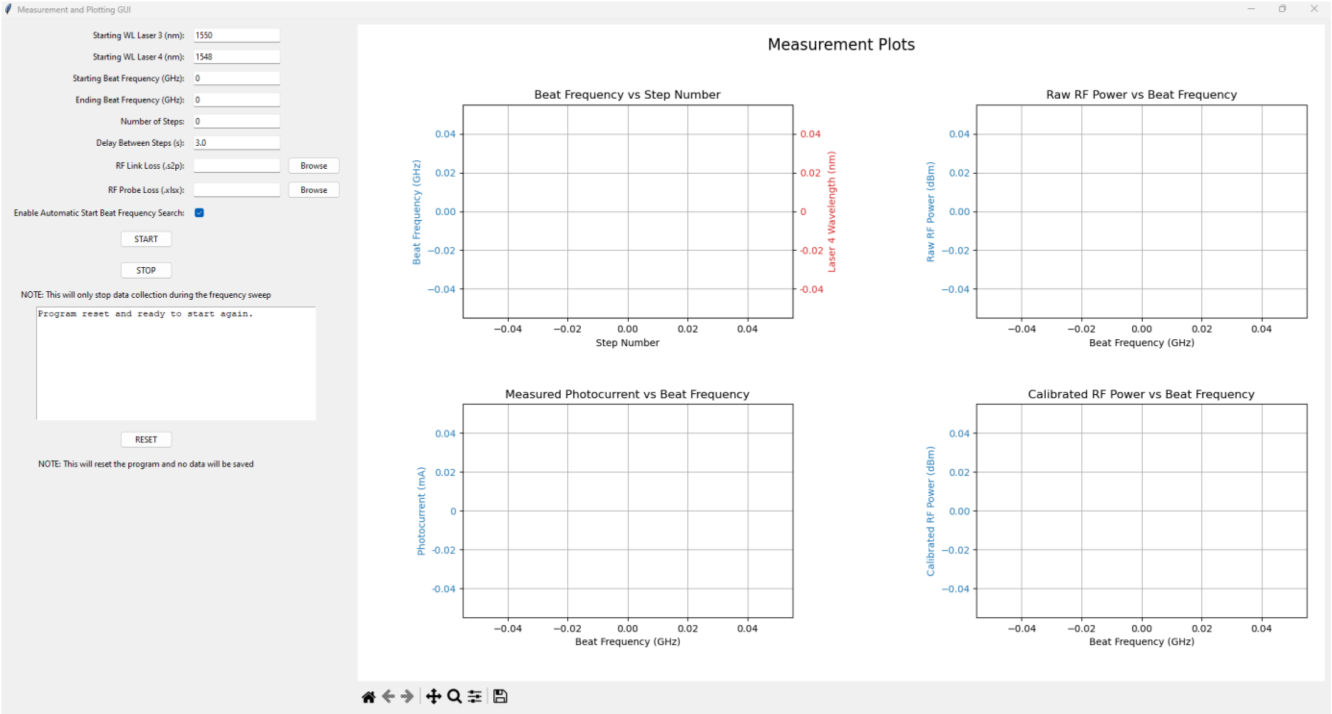

Figure: Program GUI When Initially Run

***It is important to create the virtual environment to prevent potentially overwriting existing python dependencies on your computer**

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How to Run Program

Input Initial Program Settings

1) Starting WL for Laser 3
   - This will be a stable wavelength and will not be changed by the program; it should be set to your desired wavelength.
2) Starting WL for laser 4
   - This output will be altered by the program to drive the beat frequency. The initial setting should be 2-3nm below that of Laser 3 unless you have already calibrated your starting wavelengths.
3) If you have already manually calibrated the starting beat frequency, enter the exact wavelengths from the ECL into the inputs of the program, and de-select the “automatic initial beat frequency search” check.

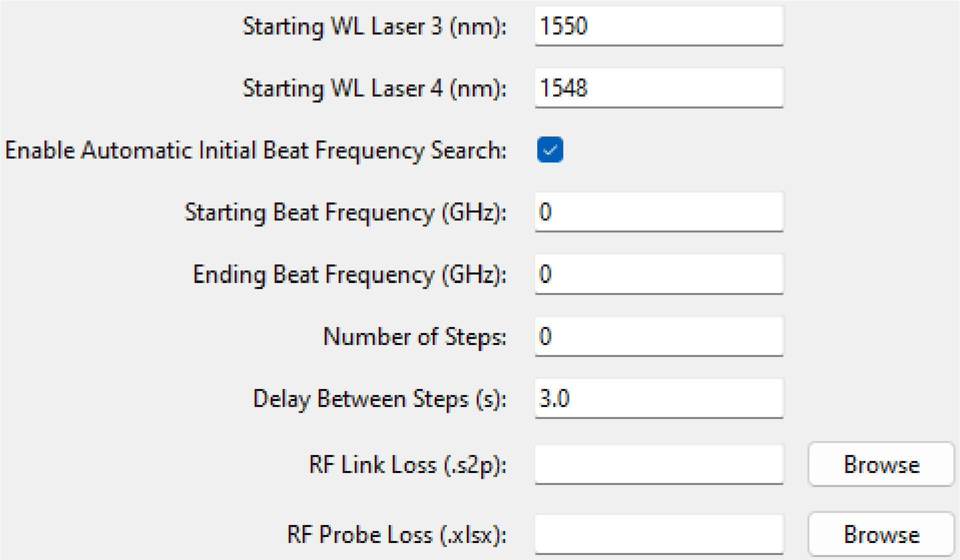


Figure: User Inputs in GUI before Running

How to Run Program (cont.)

<u>Input Initial Program Settings</u>

4) Starting and ending beat frequency set the range of beat frequencies that the program will parse and take measurements of.
5) Number of steps
   - This will determine the number of steps the program will take between the start and end beat frequency.
6) Delay between steps
   - This will set the delay the program takes between updating the lasers and taking the next measurements. I recommend at least a 3 second delay to ensure accurate measurements.
7) RF link loss file
   - If applicable include existing RF link loss file, it must have .s2p file formatting.
8) RF probe loss file
   - If applicable, include existing RF probe loss file, it must have .xlsx file formatting.

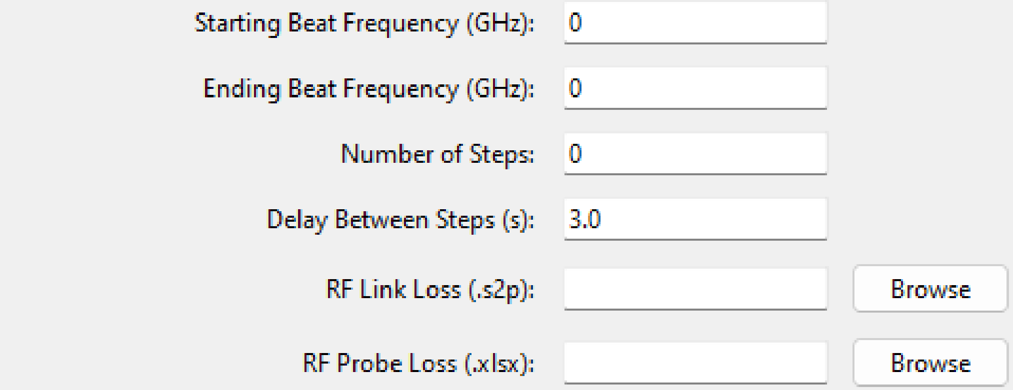


Figure: User Inputs in GUI before Running

How to Run Program (cont.)

Input Initial Program Settings

9) Press the “START” button
   - A new window will pop up prompting the user to enter the device number, user comments, and save file path
10) Device number
   - Enter the device number or another identification parameter (e.g., serial number).
11) Comments
   - Enter any additional user comments about the device or trial run
12) Choose file save path
   - Search the file directory for the desired save location, then select the save button.

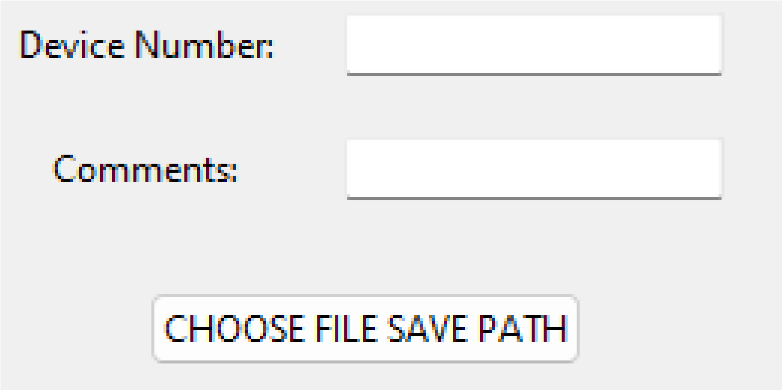
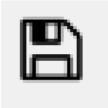


Figure: Pop-up After Selecting “START” button

While the Program is Running

<u>Options While Program is Running</u>

1) Once the measurement loop begins, current measurements will appear in the output window, such as photocurrent, RF power, etc.
2) To stop the loop during the measurement, press the “STOP” button. Any measurements that have been taken will be automatically saved.
3) To reset the program, press the “RESET” button. No data will be saved and the program should restart. If the program is not running correctly, it may need to be closed and re-opened.
4) The plots and data will automatically save to the path file selected during the initial program setup. If you would like to save the plots again, press the save button pictured to the right and select the desired file path.



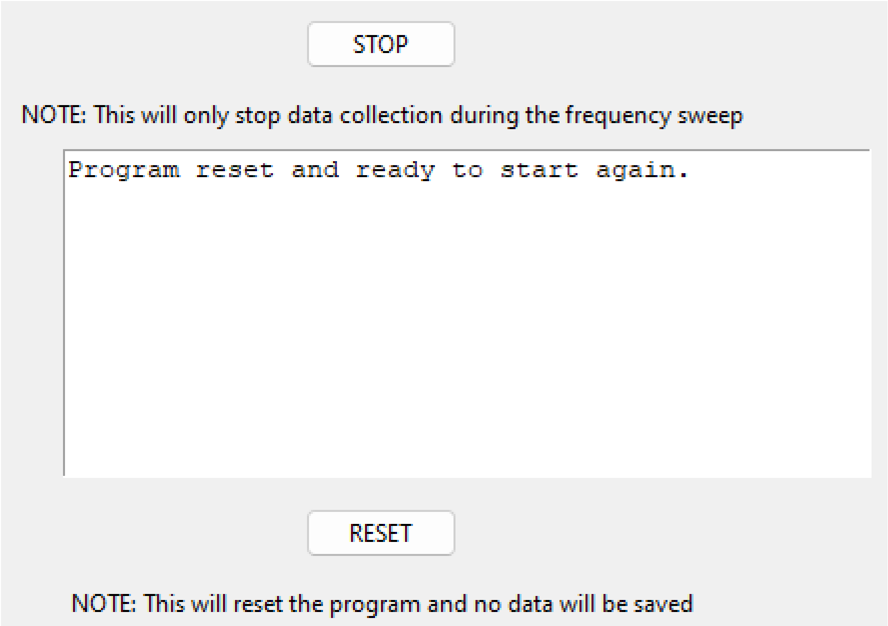


Figure: Output and buttons while running

Suggested Settings

<u>Wavelength and Delay Inputs</u>

- Over trials that have been run, center wavelength of 1555nm (laser 3 set to 1555nm and laser 4 calibrated to match) generally has best results
  - When lasers 3 and 4 are set near 1555nm, the wavelength meter typically reads near 1550nm, which indicates the lasers are ~ 5nm in wavelength lower than what they are set to on the ECL.
  - Laser 4 typically has an actual wavelength of ~ 1nm below that of laser 3. If you are using the calibration setting to search for the starting beat frequency, I suggest setting the laser 4 wavelength 1-2nm below laser 3 to avoid accidentally overstepping the calibration loop
- User-input delay between updating lasers and remeasuring of over 3 or more seconds typically offers best results
- Previous beat frequency vs. step plots are shown on following slides and highlight typical areas of issue, notably:
  - Common issues when laser 4 is set between <u>1544.1 – 1544.5nm</u>
  - Common issues when laser 4 is set between <u>1549.5-1549.9 nm</u>
  - Common issues when laser 4 is set between <u>1554.9-1555.2 nm</u>

Beat Frequency vs. Step Graphing for Different Center Wavelengths

- Center wavelength 1545nm: Inconsistency for all delay periods, less inconsistency with longer delay. Common issues when laser 4 is set between 1544.1 – 1544.5nm

- Center wavelength 1550nm: Inconsistency for all delay periods, less inconsistency with longer delay. Common issues when laser 4 is set between 1549.5-1549.9 nm

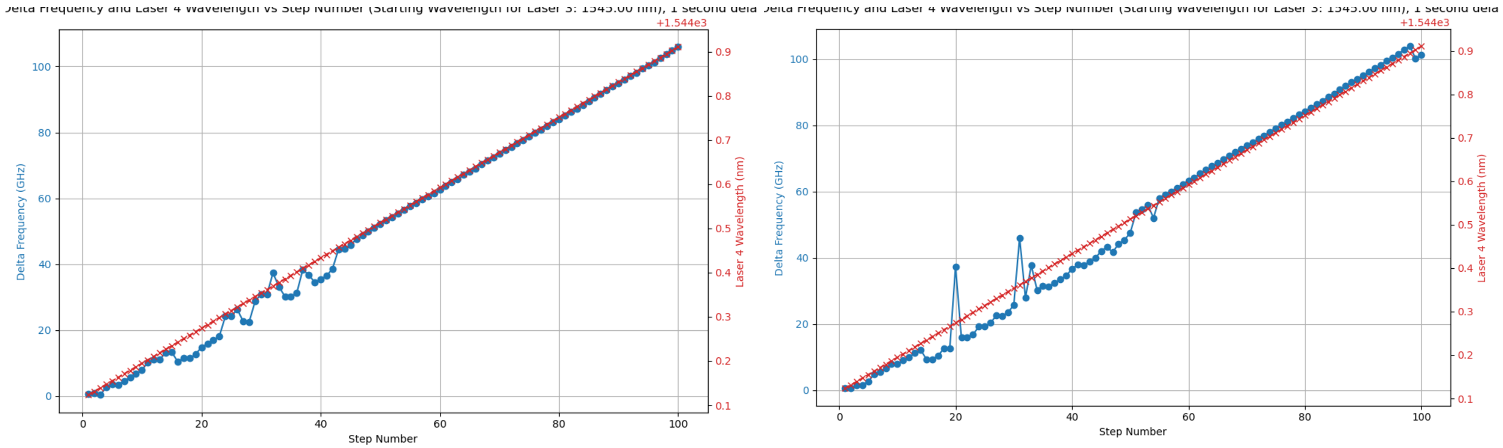
- Center wavelength 1555nm: Inconsistency for all delay periods, longer delay may have less consistency but were still inconsistent. Common issues when laser 4 is set between 1554.9-1555.2 nm

Conclusion

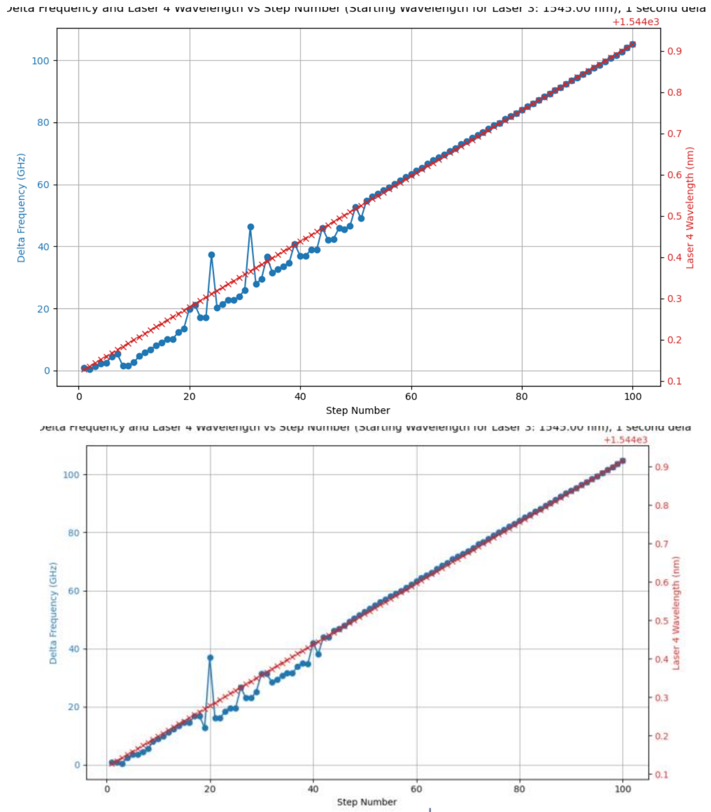
- Of the three tested center wavelengths, 1555nm appears to be the most consistent. Results may differ significantly between periods where the instruments have been turned off. Consecutive measurements may also be inconsistent with little delay between them. The measurements seem to be more accurate as the instruments have been on for longer periods of time. Recommend to test different center wavelengths and delays to find what is most accurate at the time before taking notable measurement recordings.

Beat Frequency vs. Step Graphing – 1545 nm

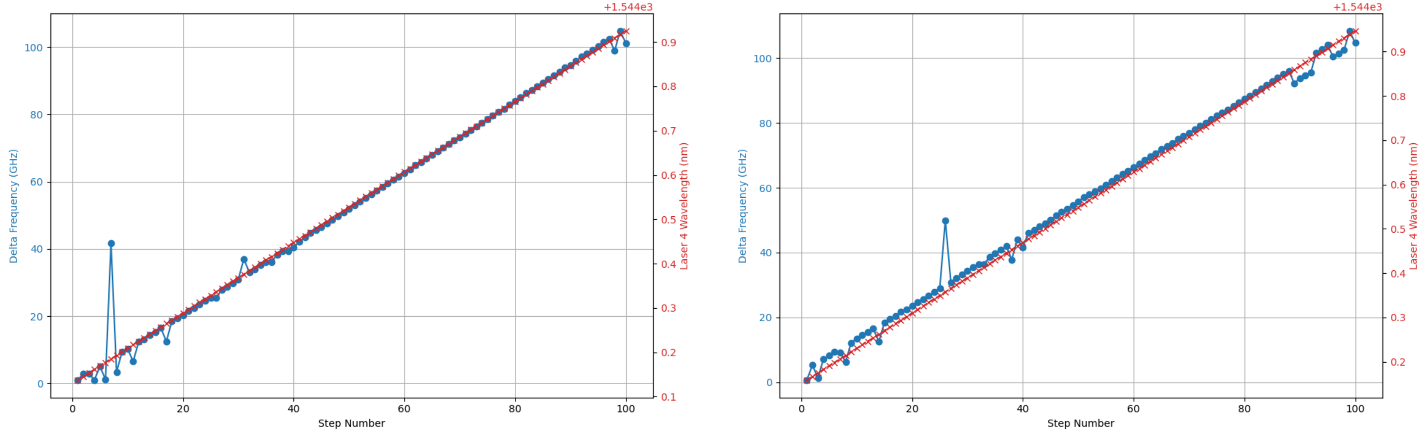
1s Delay



1.5s Delay



2s Delay



Issues common when laser 4 is set between 1544.1 – 1544.5nm

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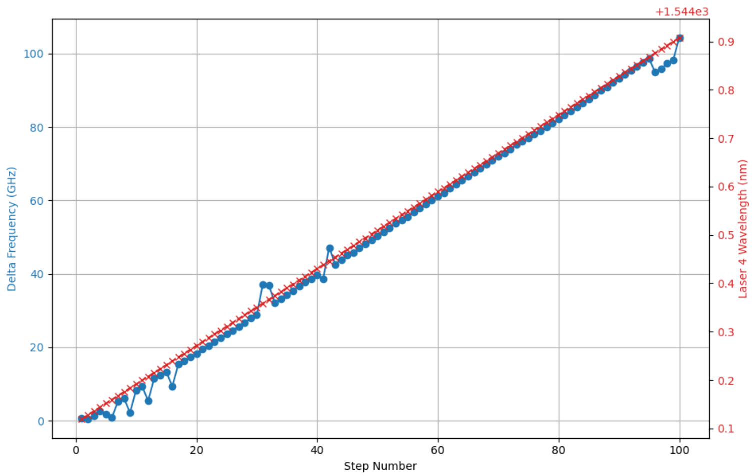
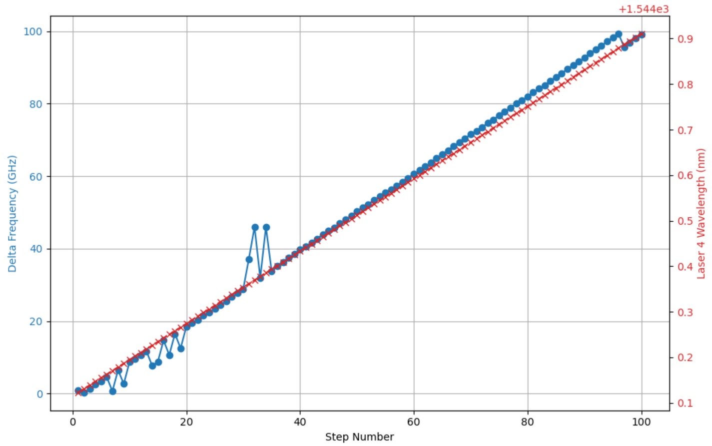
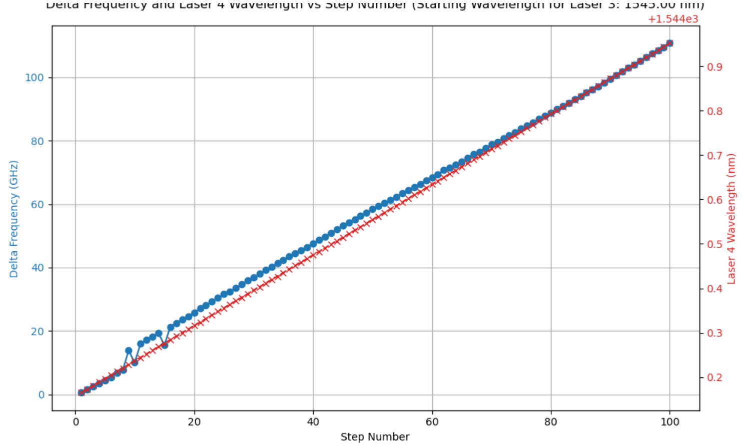
Beat Frequency vs. Step Graphing – 1545 nm

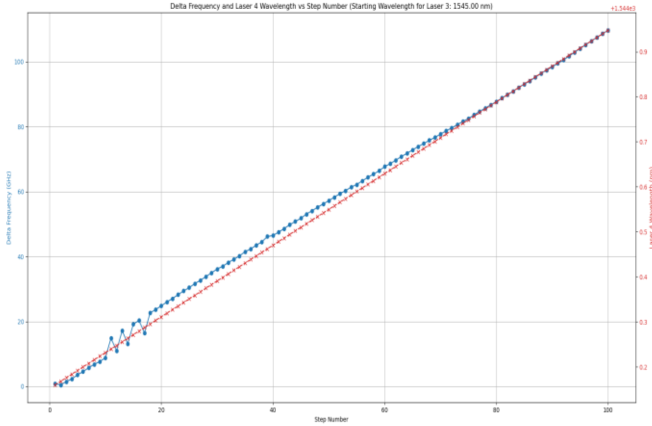
3s Delay





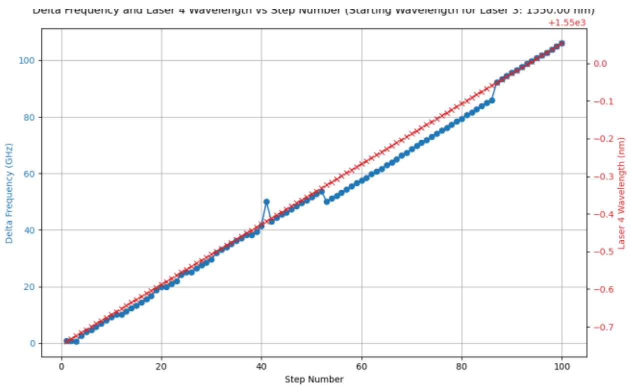
4s Delay

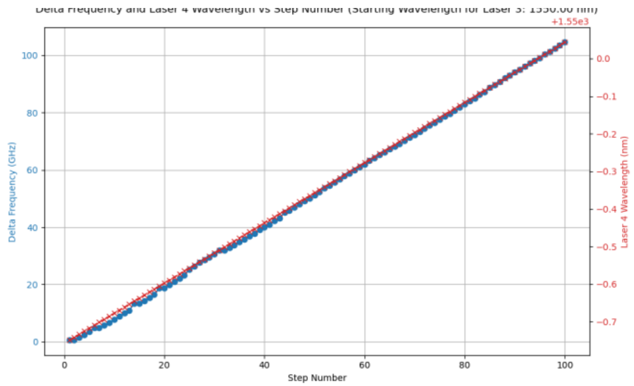




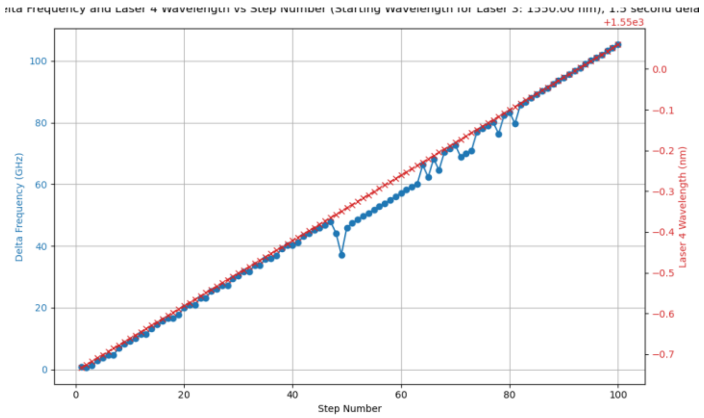
Beat Frequency vs. Step Graphing – 1550 nm

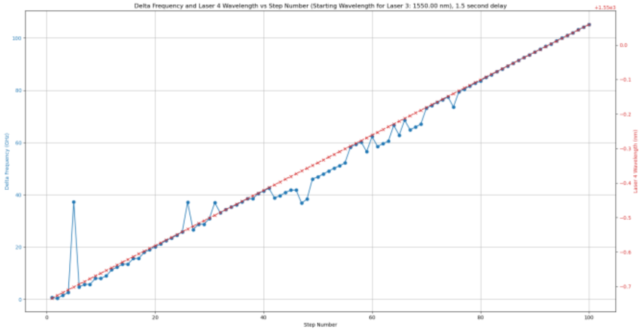
1s Delay



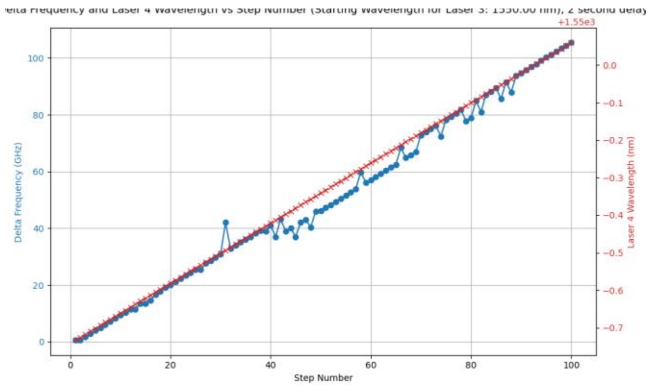


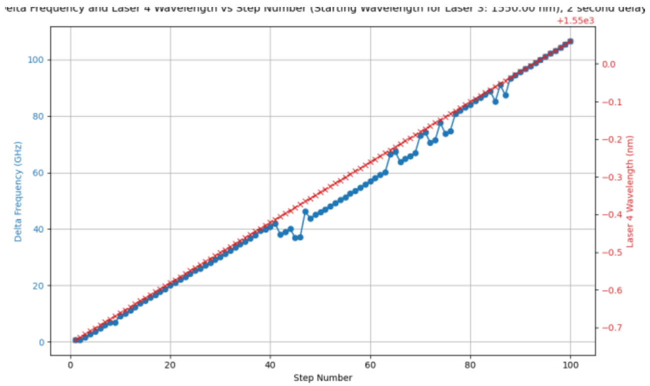
1.5s Delay





2s Delay

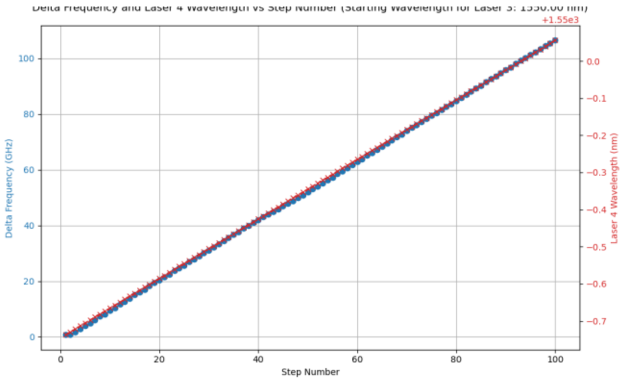


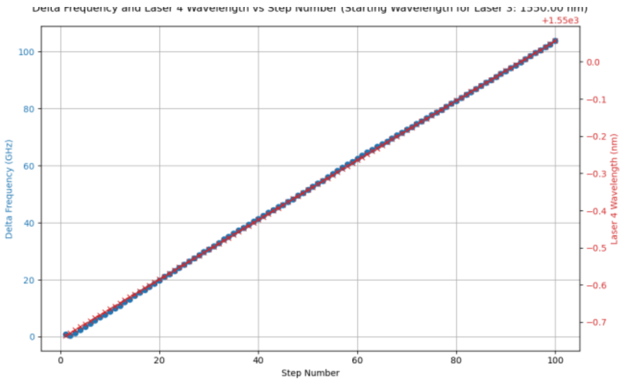


Issues common when laser 4 is set between 1549.5-1549.9 nm

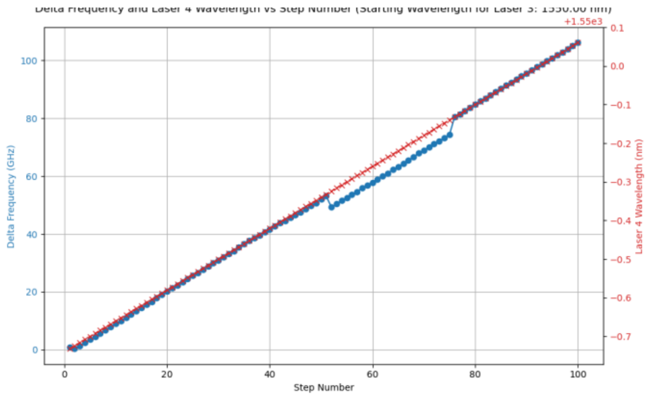
Beat Frequency vs. Step Graphing – 1550 nm

3s Delay

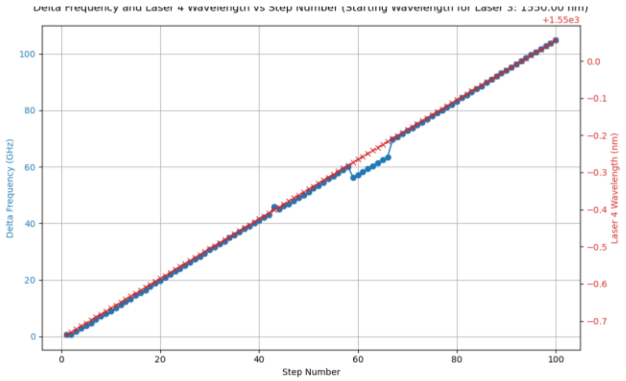


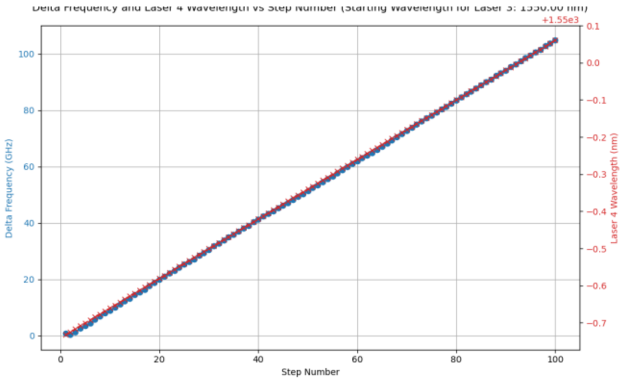


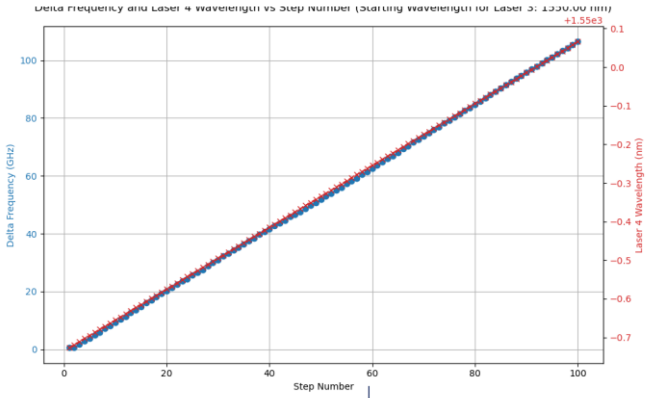
4s Delay



5s Delay



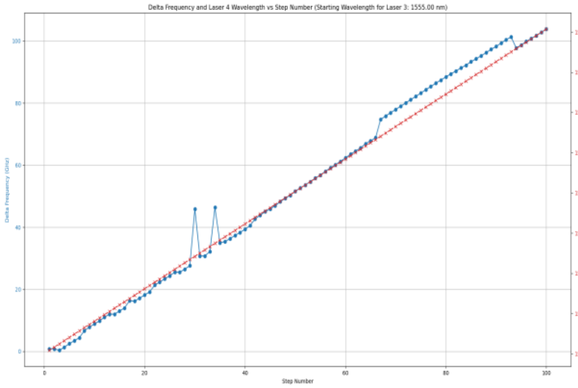


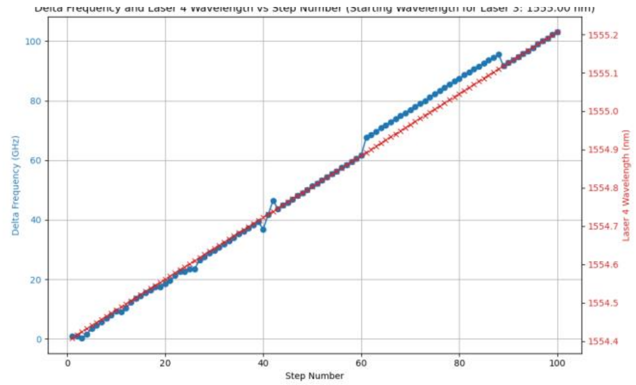


Issues common when laser 4 is set between 1549.5-1549.9 nm

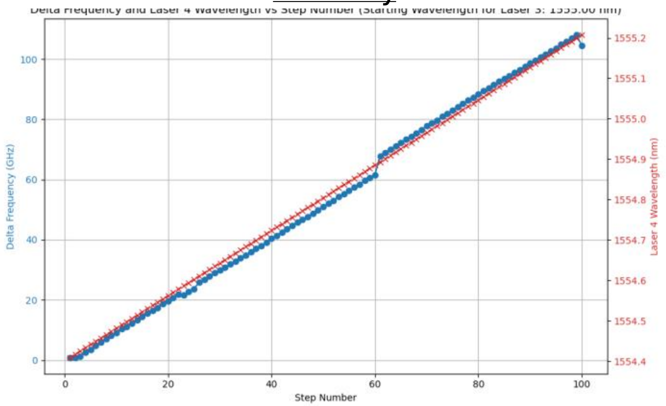
Beat Frequency vs. Step Graphing – 1555 nm

1s Delay

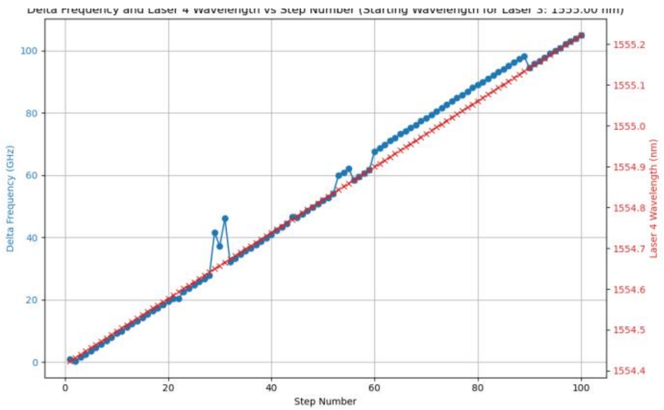


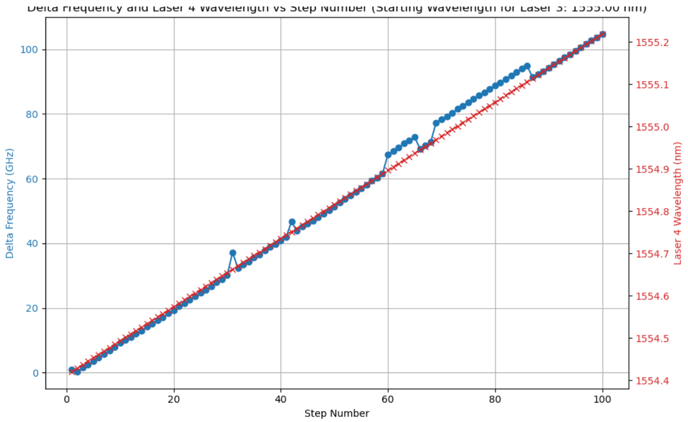


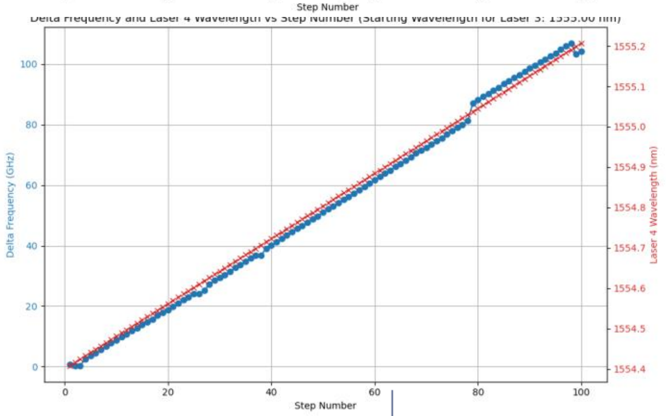
2s Delay



3s Delay



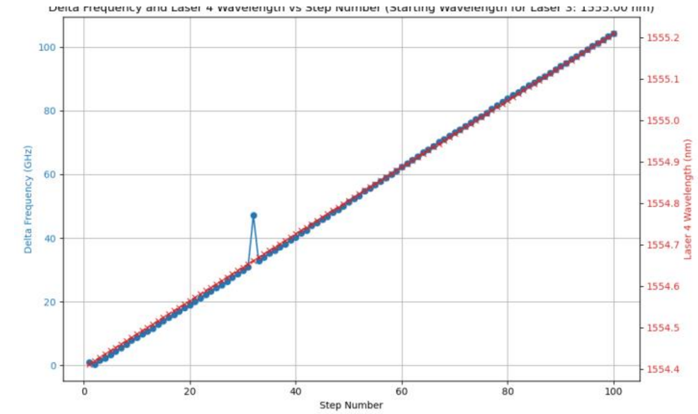


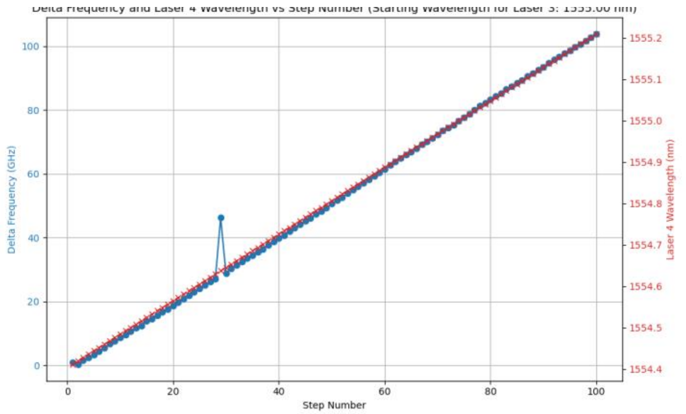


Issues common when laser 4 is set between 1554.9-1555.2 nm

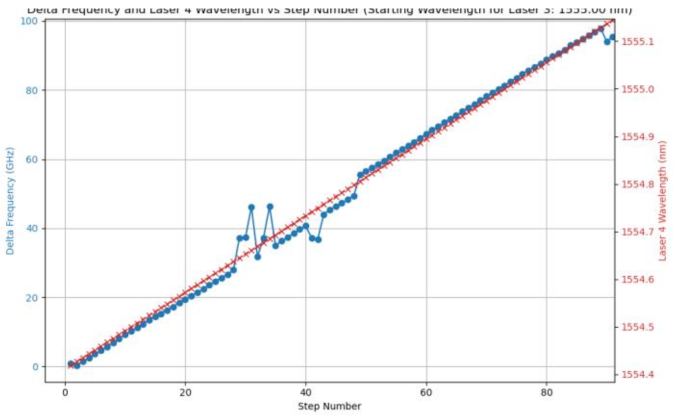
Beat Frequency vs. Step Graphing – 1555 nm

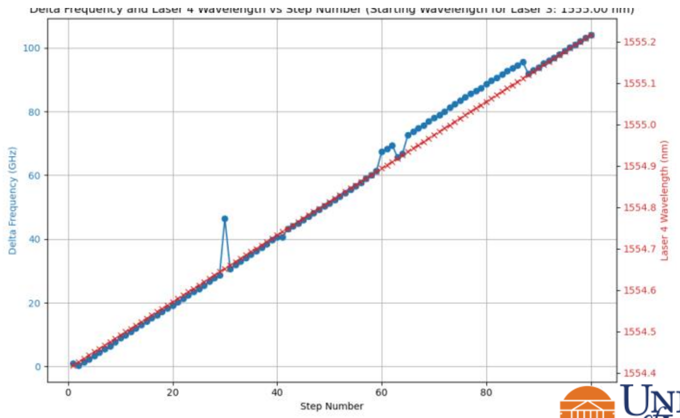
4s Delay





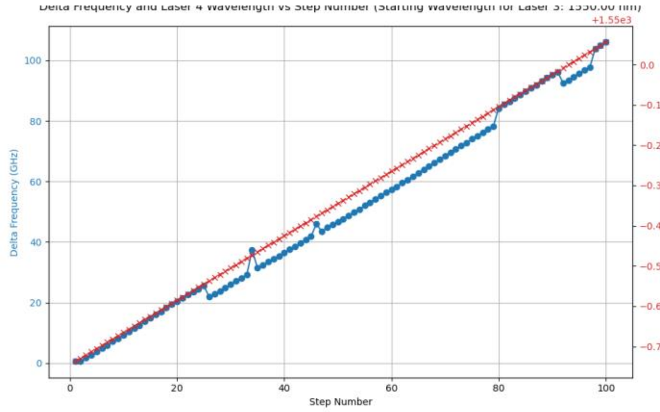
5s Delay

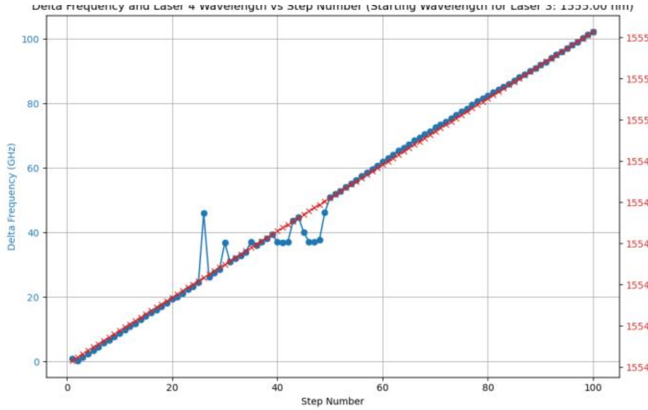


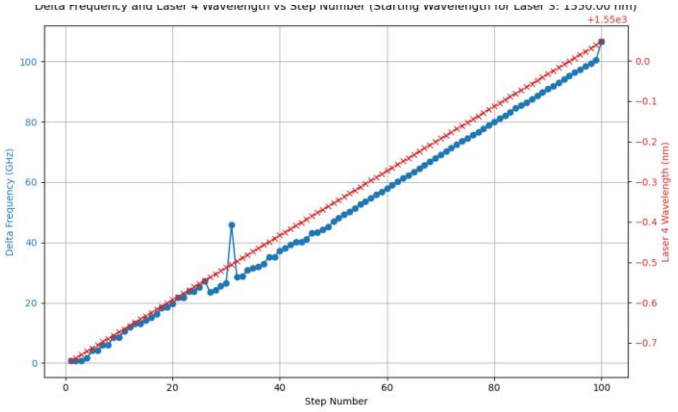


Single Point ESA vs. Averaged

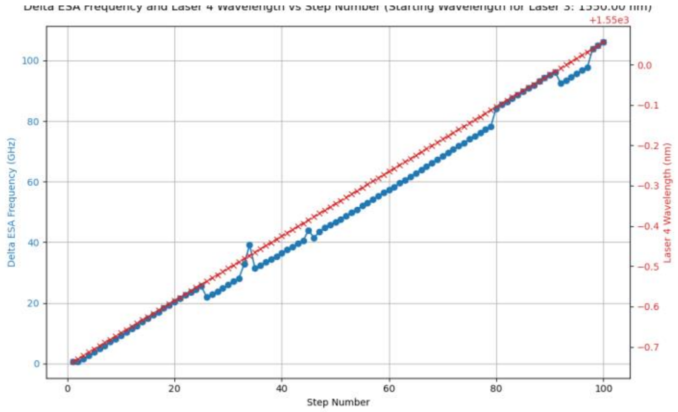
Single Point ESA Measurement

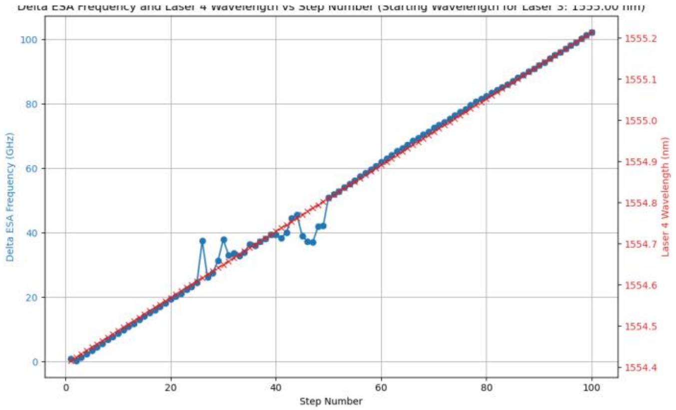


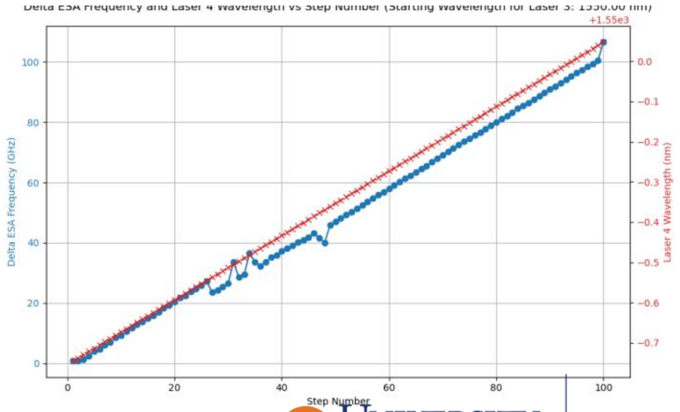




Averaged ESA Measurement







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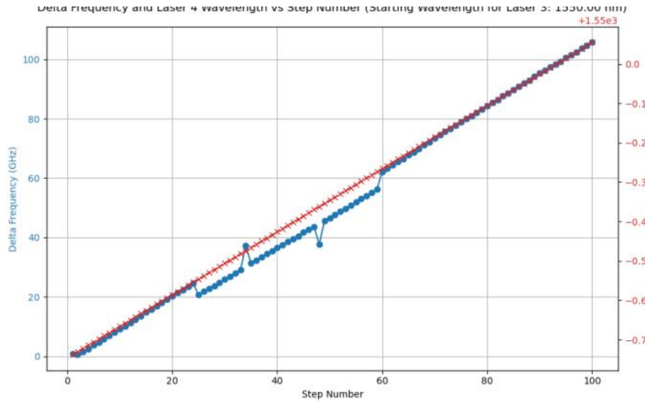
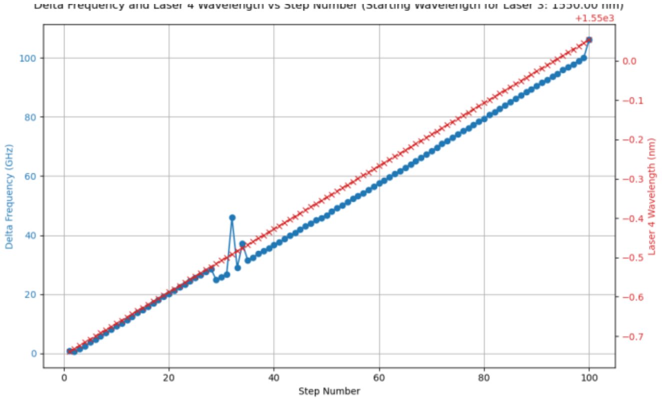
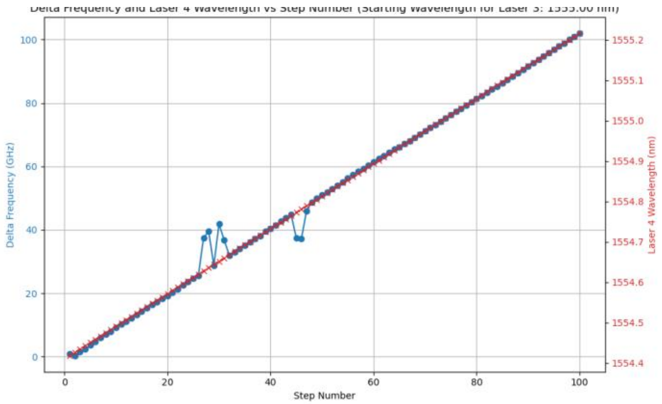
Single Point ESA vs. Averaged

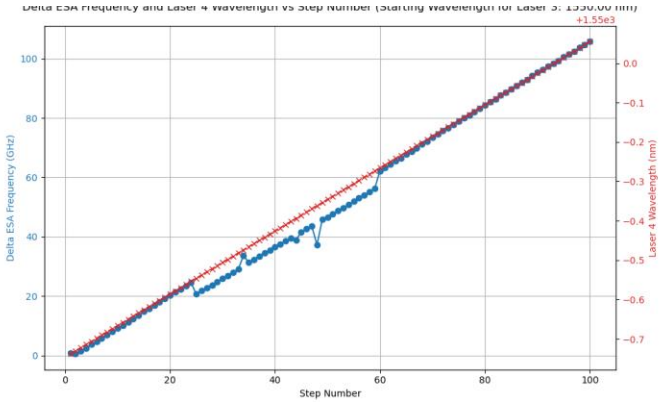
Single Point ESA Measurement

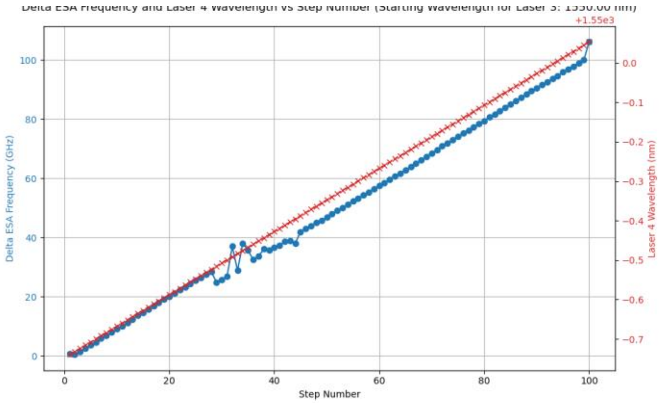


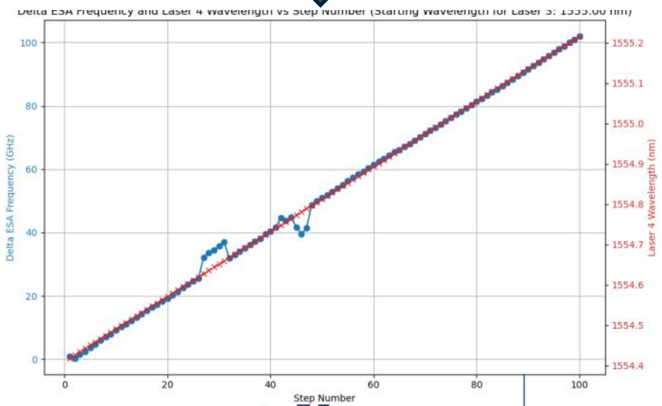




Averaged ESA Measurement







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Single Point ESA vs. Averaged

- ESA readings are automatically averaged from the instrument
- Little difference was found adding additional averaging from multiple query points for the ESA reading compared to single point reading.

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