Python Heterodyne Measurement Automation

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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

Program Overview

Program Process

- 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
- After the loop, sorts plots by beat frequency and adds a calibrated RF power vs. beat frequency plot
- Prompts the user the save the data to a .txt file

Required 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

Equipment Used

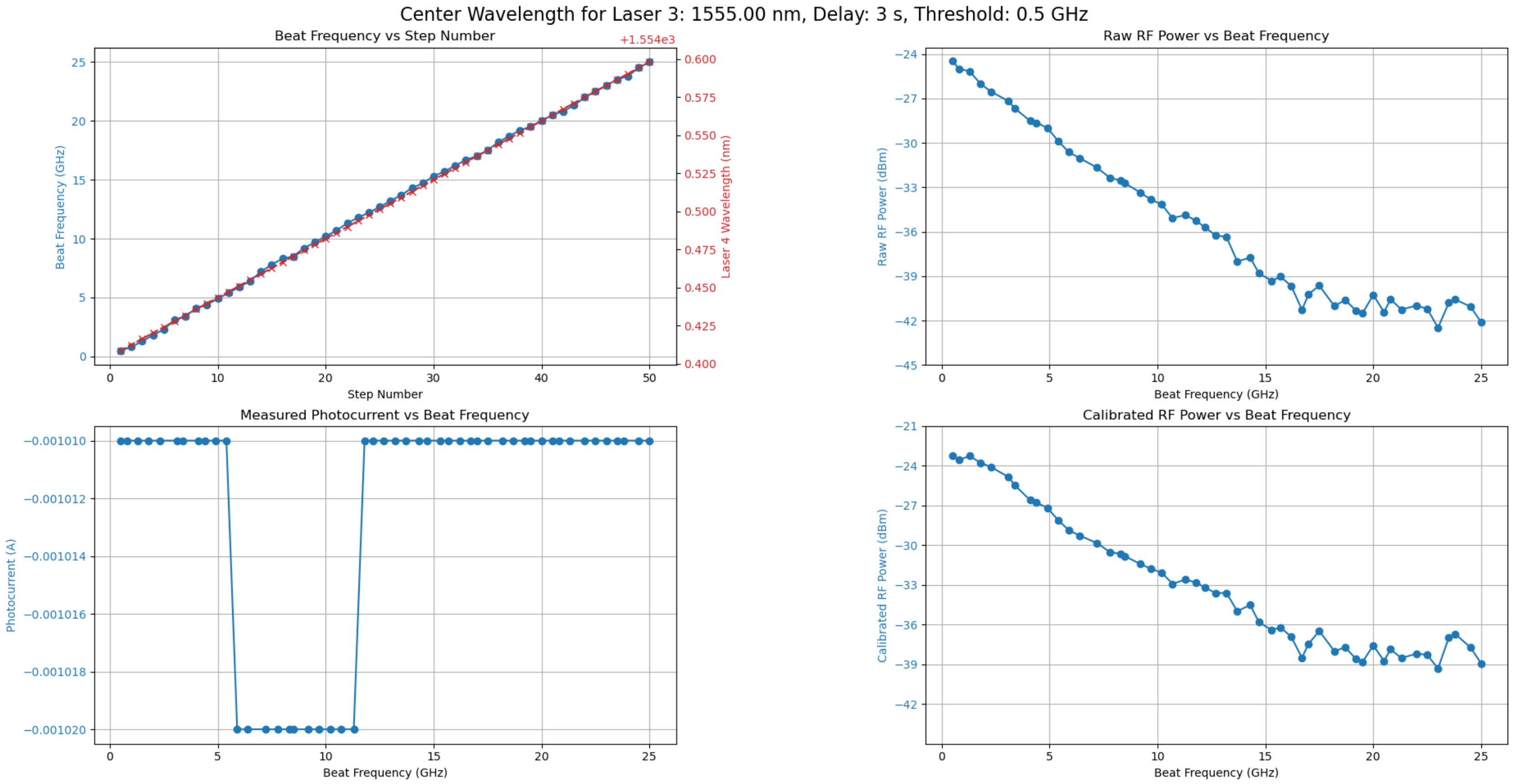
- Anritsu ECL Lasers 3 and 4
- HP ESA 8565E
    - Newport Commercial PD
- HP Wavelength Meter 86120C
- KEOPSYS Optical Amplifier
- Agilent Attenuator 81577A (VOA)
- Keithley Source meter 2400-C (High Power 3)
- Rohde & Shwarz Power Meter NRP-Z58

User Inputs in Program

- Starting wavelength for laser 3 and laser 4
- Start and end beat frequency
- Threshold that is acceptable within start frequency to begin
- Number of steps
- Delay time (s) between updating lasers and taking new measurements
- Output data to .txt file (yes/no)
    - File name
    - Device number
    - Trial comments

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

Prior to Running the Program

File Pathing and GPIB Addresses

- To correctly calculate the Calibrated RF power, the file paths must be correctly updated
- For RF probe loss, the program automatically reads in data from an s2p file
- For RF link loss, the program reads in an excel file
  - The excel file must contain no headers, column 1 must be frequencies and column 2 must be link loss in dB
- All GPIB addresses must be correctly labeled for the instruments – these should never change but it could be safe to check
  - Output from "Connected Devices" or NI Max connected devices to view GPIB addresses

```
##################################################################################################################
####                                 FILE PATHS AND GPIB ADDRESS THAT NEED TO BE MANUALLY UPDATED BY THE USER
##################################################################################################################

filepath = 'C:/Users/Tommy/Downloads/1_2_1mm_cable_BW_20240306_ft4xx.s2p' # s2p file path for RF probe loss
excel_filepath = 'C:/Users/Tommy/Downloads/probe_loss.xlsx' # Excel file path for RF link loss

# Initialize the VISA resource manager
rm = pyvisa.ResourceManager()

# List all connected VISA devices (Optional: To verify connections)
print("Connected devices:", rm.list_resources())

# Create a VISA adapter for the ECL laser and wavelength meter
# *** The GPIB should always be the same, so these should not need to be changed ***

ecl_adapter = rm.open_resource('GPIB0::10::INSTR')  # Update with your actual GPIB address
wavelength_meter = rm.open_resource('GPIB0::20::INSTR')  # Update with your actual GPIB address
spectrum_analyzer = rm.open_resource('GPIB0::18::INSTR')  # Update with your actual GPIB address
keithley = rm.open_resource('GPIB0::24::INSTR')  # Update with your actual GPIB address
RS_power_sensor = rm.open_resource('RSNRP::0x00a8::100940::INSTR') # Update with your actual VISA address for the RS NRP-Z58 sensor
voa = rm.open_resource('GPIB0::26::INSTR')  # Update with your actual GPIB address
```

Python Library, Driver, Software Installation

- pip install pymeasure pyvisa matplotlib scikit-rf numpy pandas openpyxl scipy (enter this command into python terminal)
- NRP Toolkit
- VISA Library Passport for NRP (To connect with R&S NRP-Z58 power meter)
- NI Max (To view what devices are connected to GPIB addresses)
- R&S Power Viewer (To zero the power meter prior to turning on other equipment)

* Installation links can be found in the "requirements" file in the github repository

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Using the Program

Steps of Use

1. Ensure setup is correct (cables, Bias-T, chip, etc)
2. Turn on all equipment, zero R&S Power Meter
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. Run the program and enter user inputs into terminal
    1. While the program is running, it can be cancelled at any time using (ctrl + c) on the keyboard; no data saved
    2. To exit loop early, select terminal and type any keystroke on keyboard, loop will exit and data will be saved
    3. At conclusion of the program, the plots will stay open and can be saved or closed
    4. Once the plots figure has been closed, the user will be prompted as to output the data or not

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

Access Code and Related Files

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

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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
  - Laser 4 has an actual wavelength of ~ 1nm below that of laser 3, advised to set laser 3 wavelength 1-2nm below laser 4 for initial trials to avoid accidentally overstepping the calibration loop
- User-input delay between updating lasers and remeasuring of over 2 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>

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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

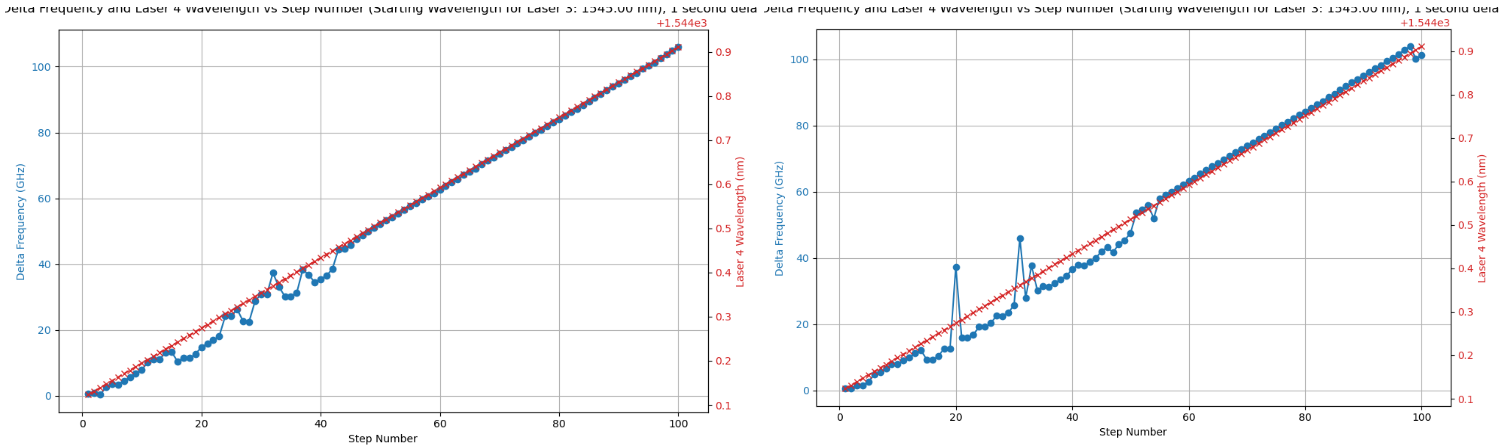
- Center wavelength 1555nm: Inconsistency for all delay periods, longer delay may have less consistency but were still inconsistent. Common issues when laser 4 is set between 1554.9-1555.2 nm

Conclusion

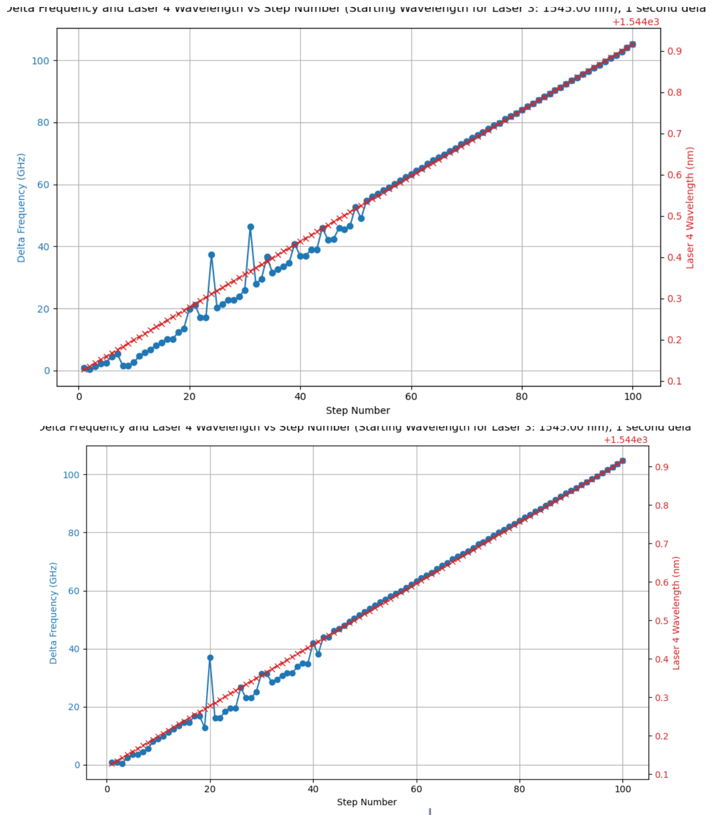
- Of the three tested center wavelengths, 1555nm appears to be the most consistent. Results may differ significantly between periods where the instruments have been turned off. Consecutive measurements may also be inconsistent with little delay between them. The measurements seem to be more accurate 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

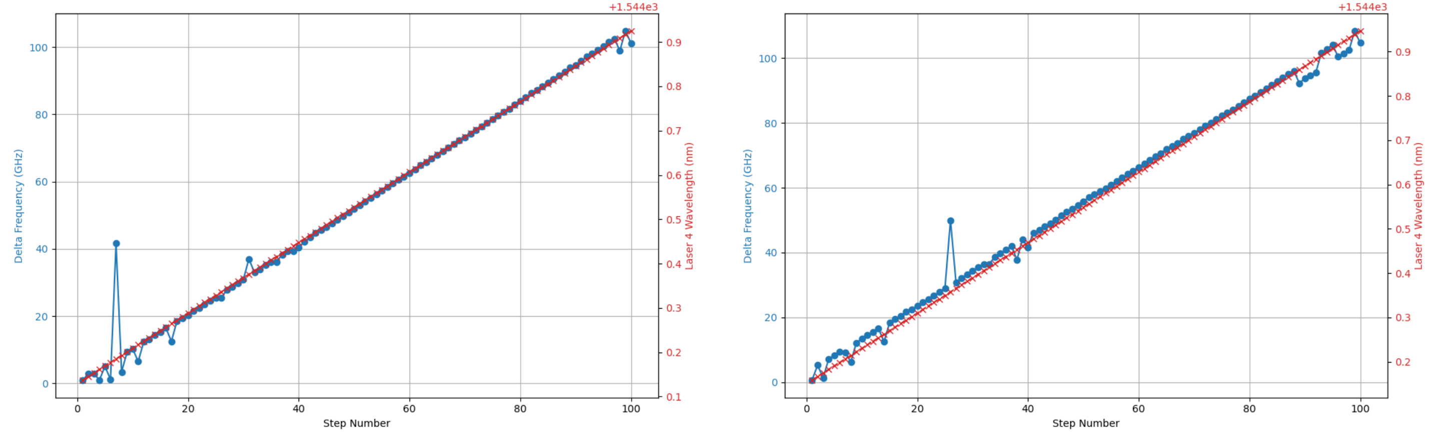
1s Delay



1.5s Delay



2s Delay



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

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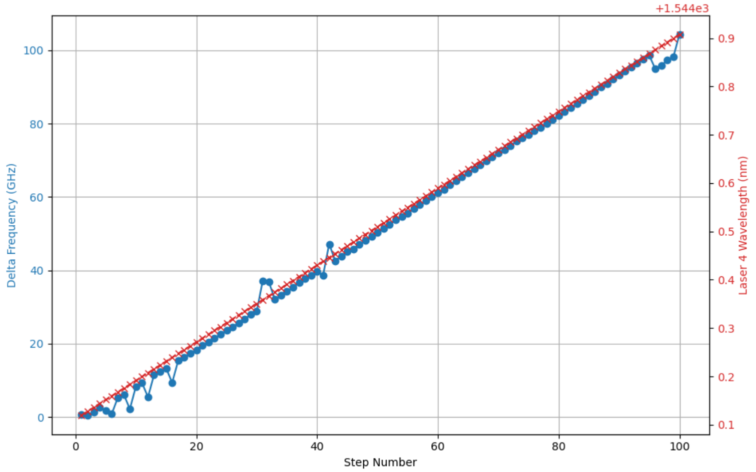
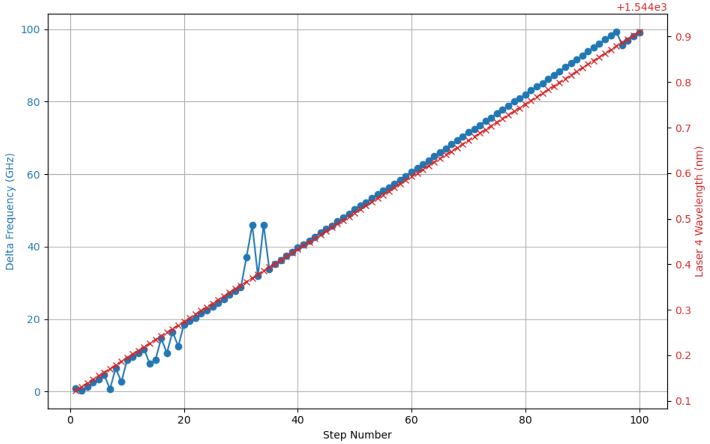
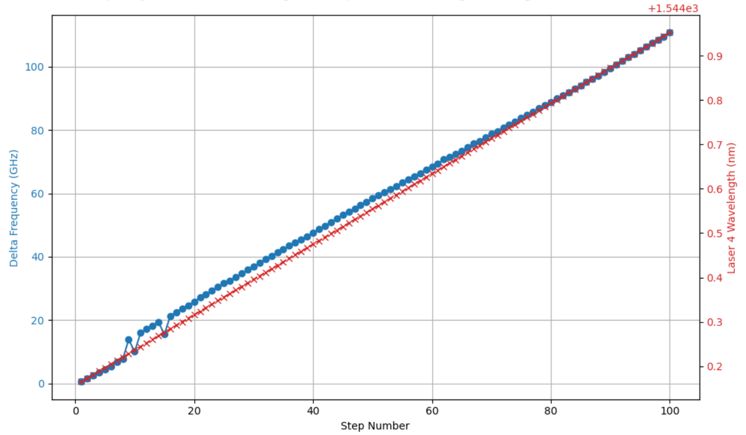
Beat Frequency vs. Step Graphing – 1545 nm

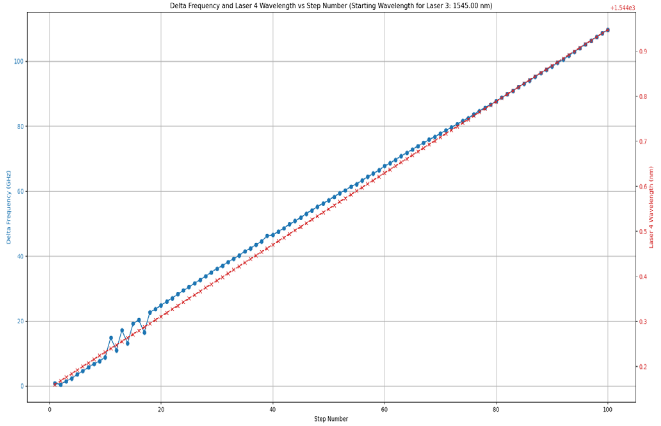
3s Delay





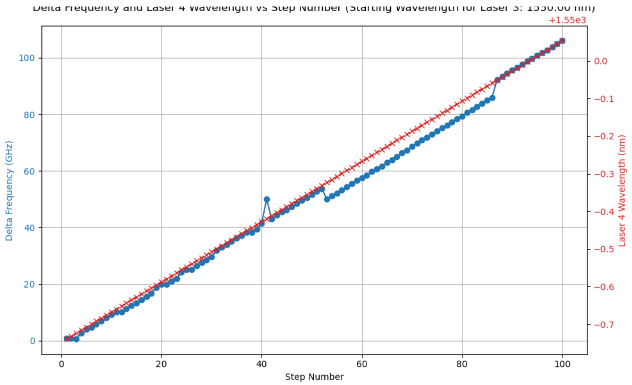
4s Delay

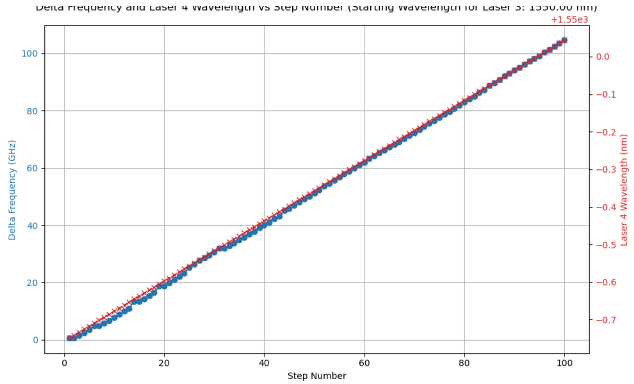




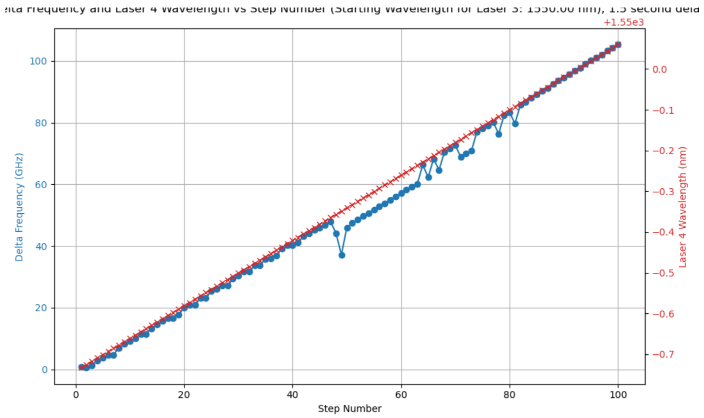
Beat Frequency vs. Step Graphing – 1550 nm

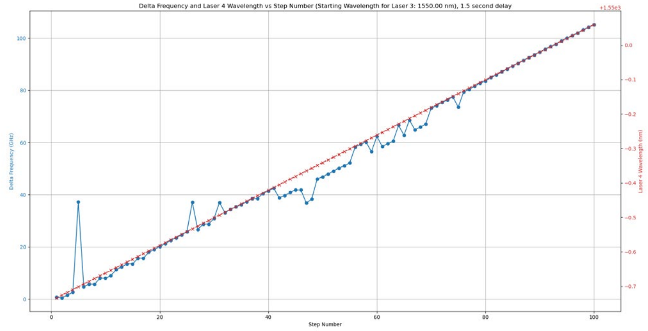
1s Delay



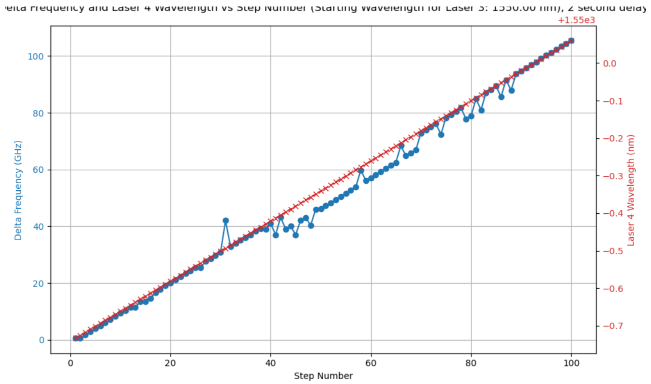


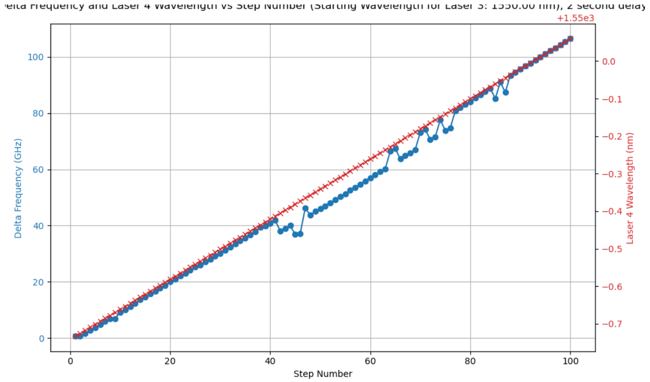
1.5s Delay





2s Delay





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

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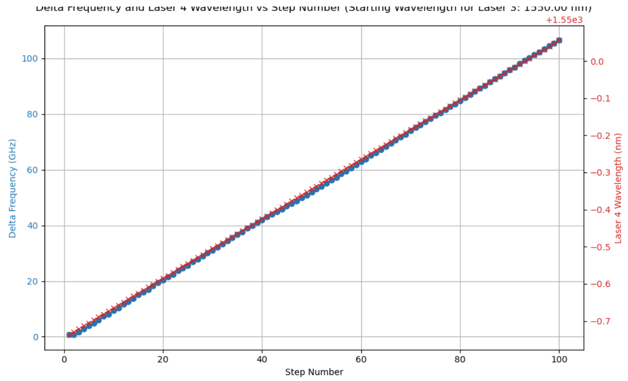
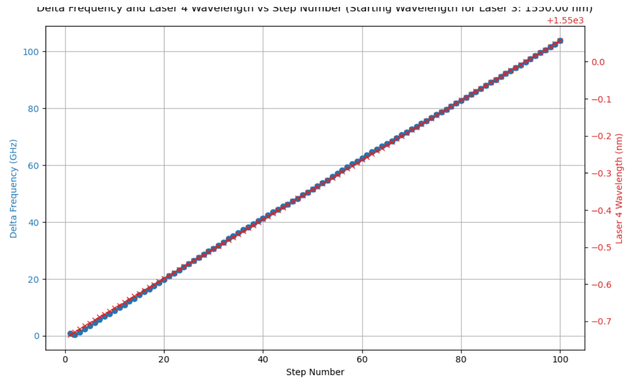
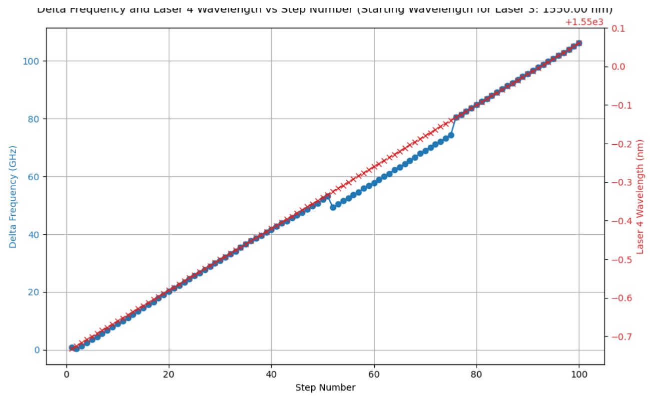
Beat Frequency vs. Step Graphing – 1550 nm

3s Delay

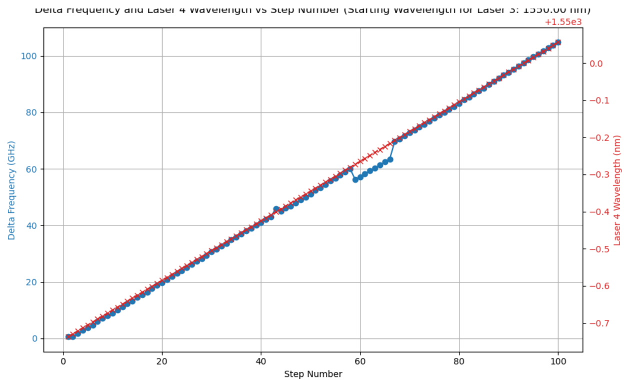


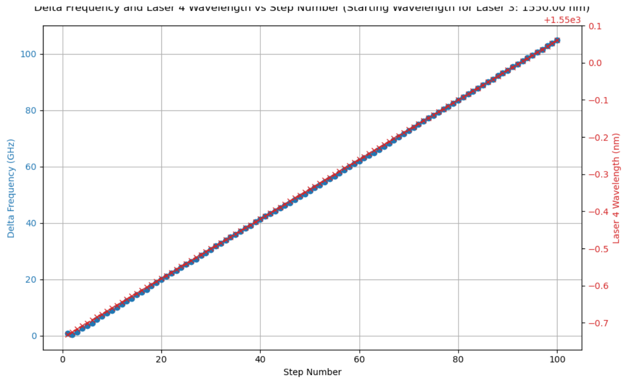


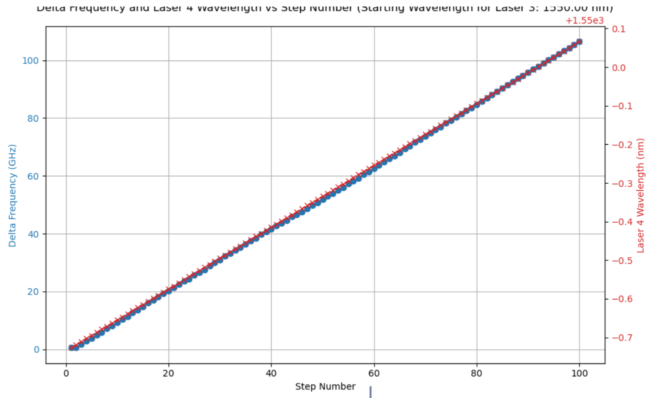
4s Delay



5s Delay







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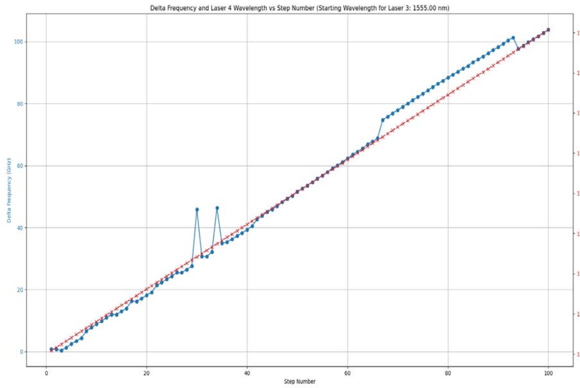
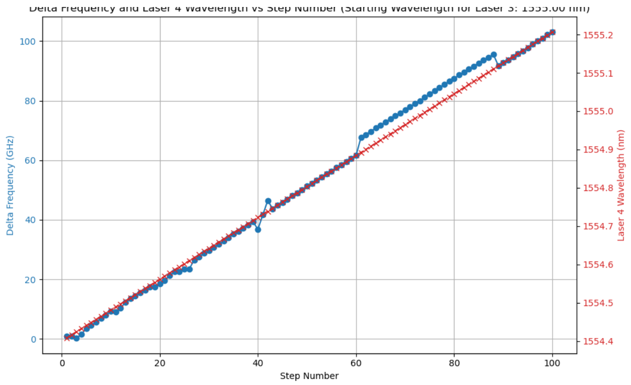
Issues common when laser 4 is set between 1549.5-1549.9 nm

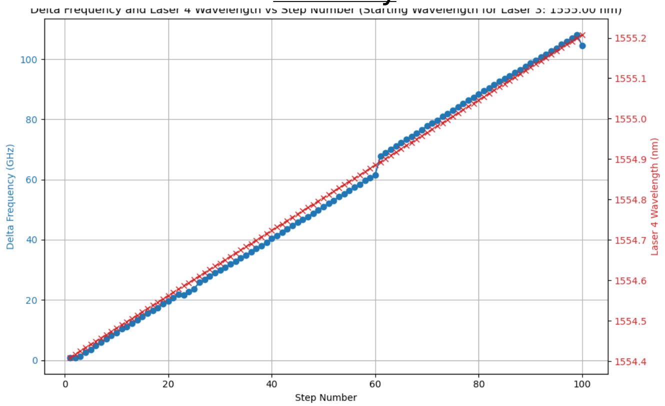
Beat Frequency vs. Step Graphing – 1555 nm

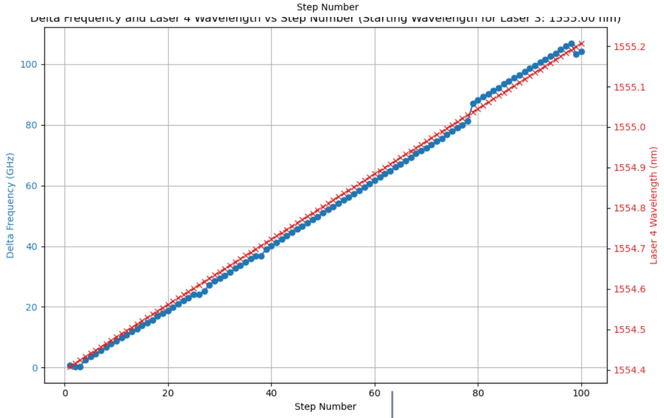
1s Delay



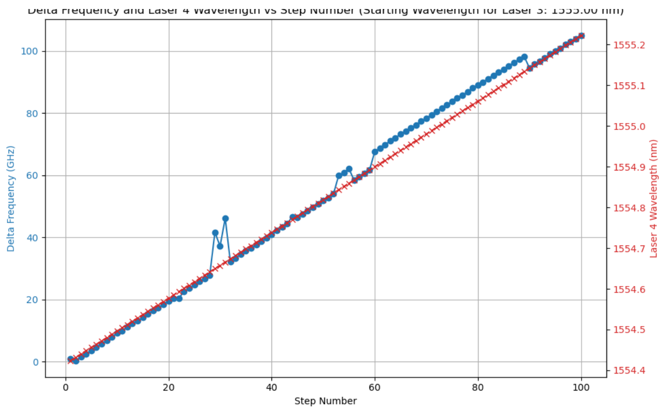


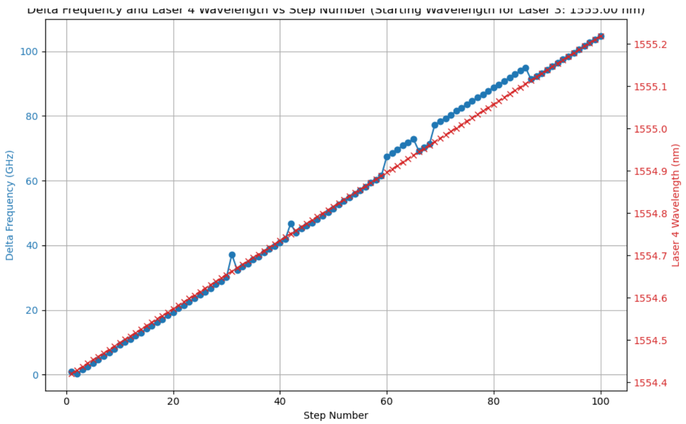
2s Delay





3s Delay





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

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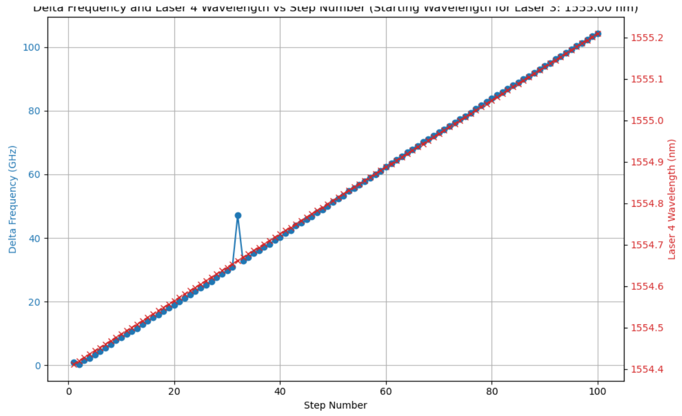
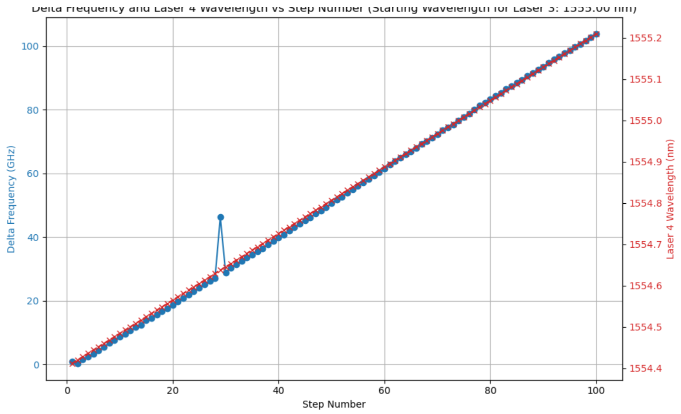
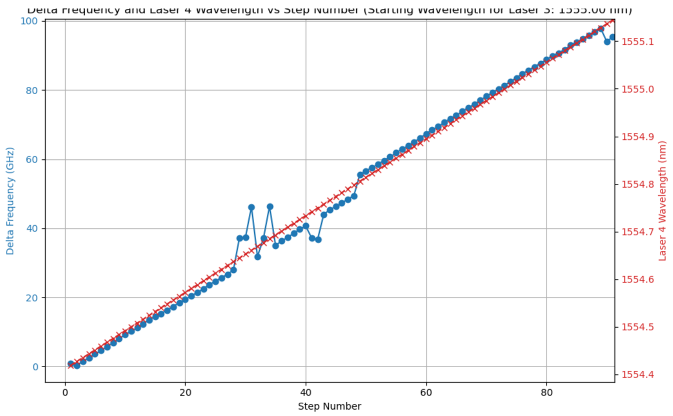
Beat Frequency vs. Step Graphing – 1555 nm

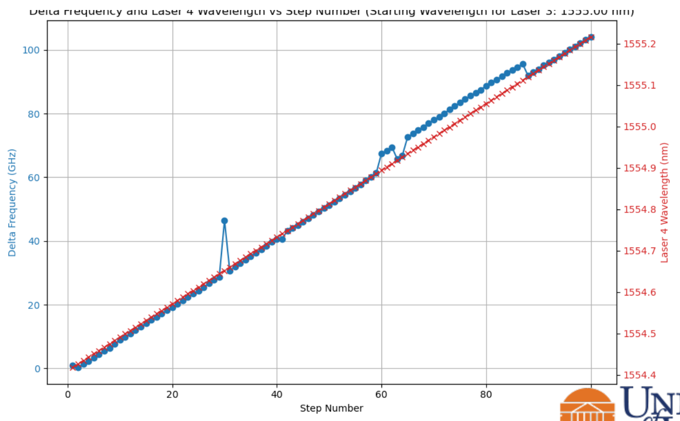
4s Delay





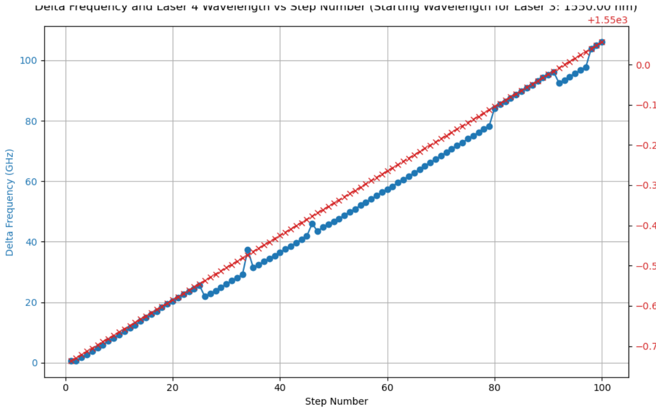
5s Delay

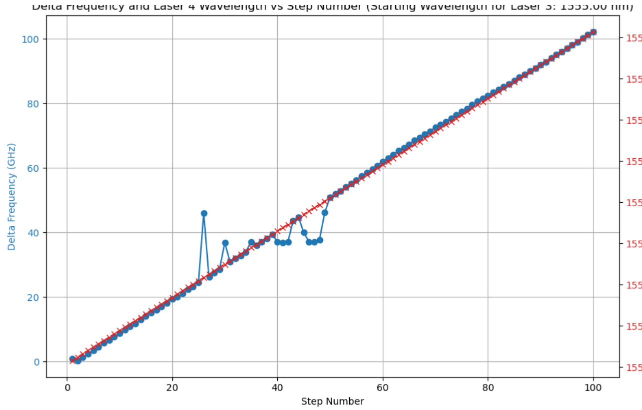


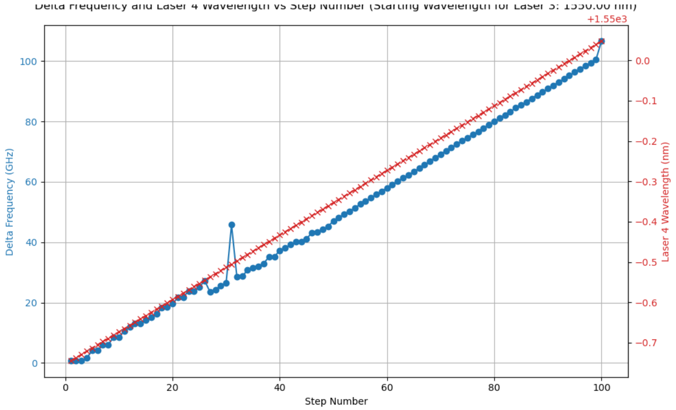


Single Point ESA vs. Averaged

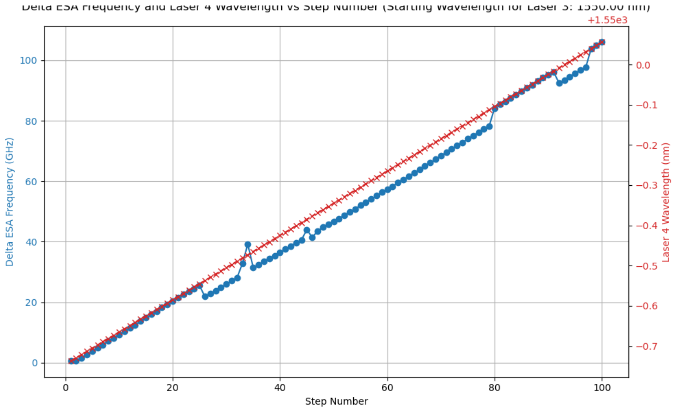
Single Point ESA Measurement

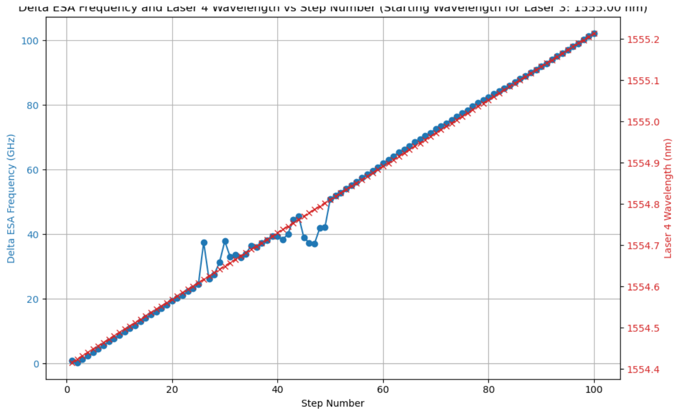


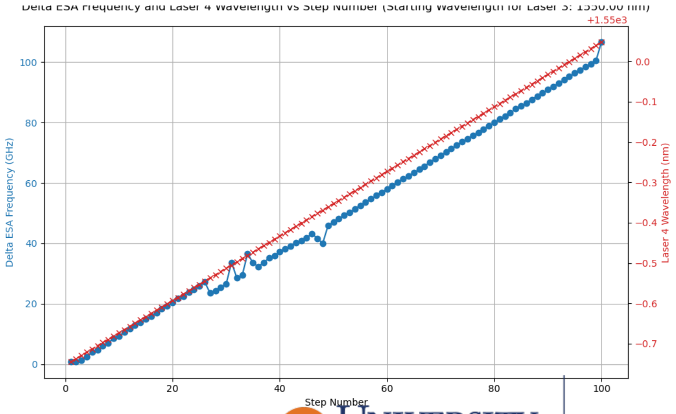




Averaged ESA Measurement

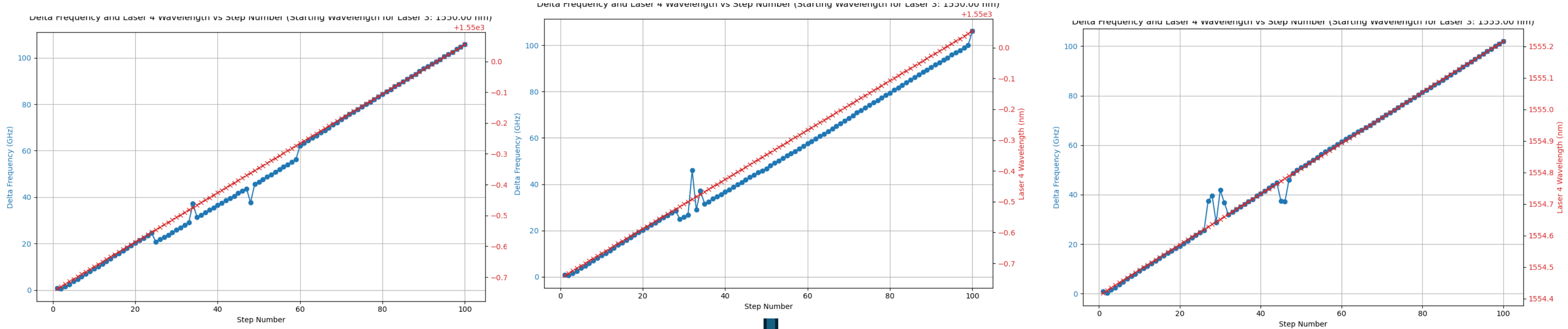




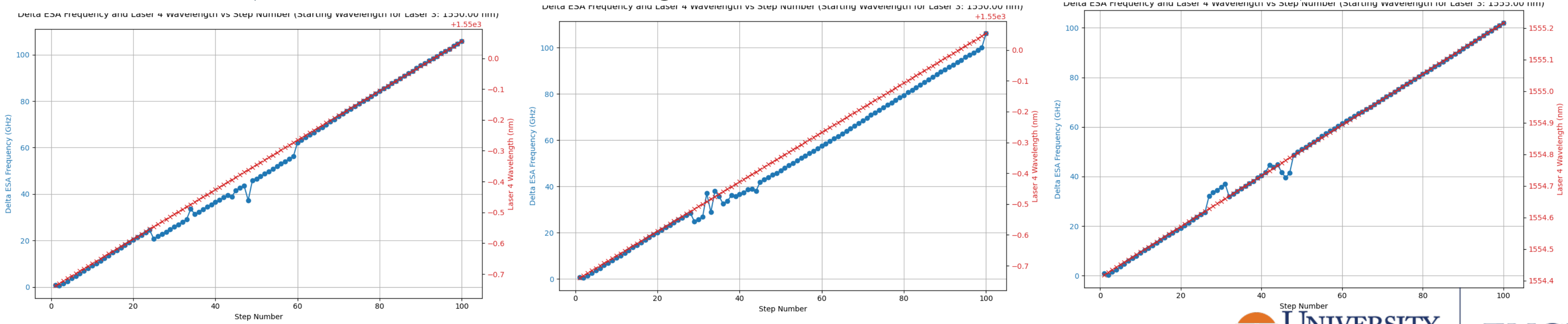


Single Point ESA vs. Averaged

Single Point ESA Measurement



Averaged ESA Measurement



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.