Indian Institute of Technology Bombay

Analog Circuits Lab
EE 230

Lab 7
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23B3933

Contents

Wien Bridge Oscillator

1 Wien Bridge Oscillator

1.1 Aim of the Experiment

To design, implement and analyze the performance of a Wien Bridge Oscillator circuit. The experiment involves measuring the output waveform's magnitude and phase for the different frequencies and verifying theoretical predictions.

1.2 Circuit Design and Parameters

Circuit Description

The Wien Bridge Oscillator circuit is shown in Fig. 2. The circuit consists of:

- Resistors: $R_1 = R_2 = 10k\Omega$, $R_3 = R_4 = 10k\Omega$, $R_5 = 20k\Omega$ potentiometer (two 10kΩ pots in series).
- Capacitors: $C_1 = C_2 = 10nF$.
- Operational Amplifier: TL084 with a dual power supply of $\pm 12V$.
- Input: 10Vpp sine wave.

Theoretical Background

The oscillation frequency of the Wien Bridge Oscillator is given by:

$$f = \frac{1}{2\pi RC} \tag{1}$$

Substituting $R = 10k\Omega$ and $C = 10nF$:

$$f = \frac{1}{2\pi \times 10k\Omega \times 10nF} = 1.59kHz \tag{2}$$

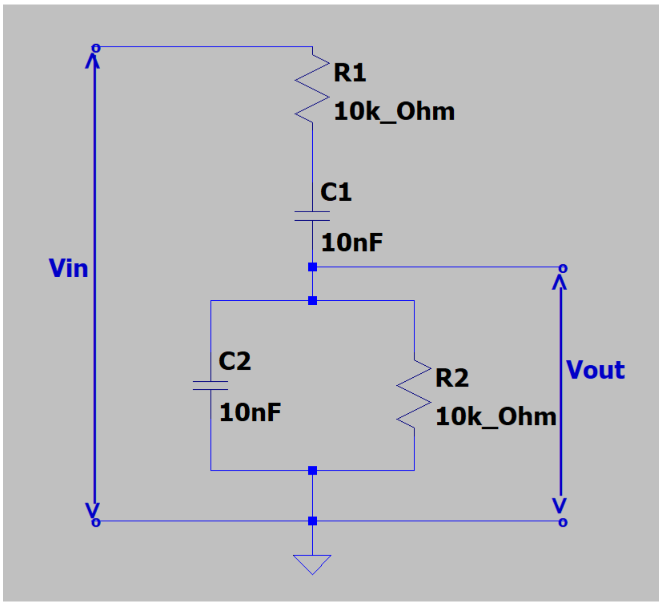

Figure 1: Wien Bridge Oscillator Equivalent Circuit

Circuit Diagram (LT Spice):

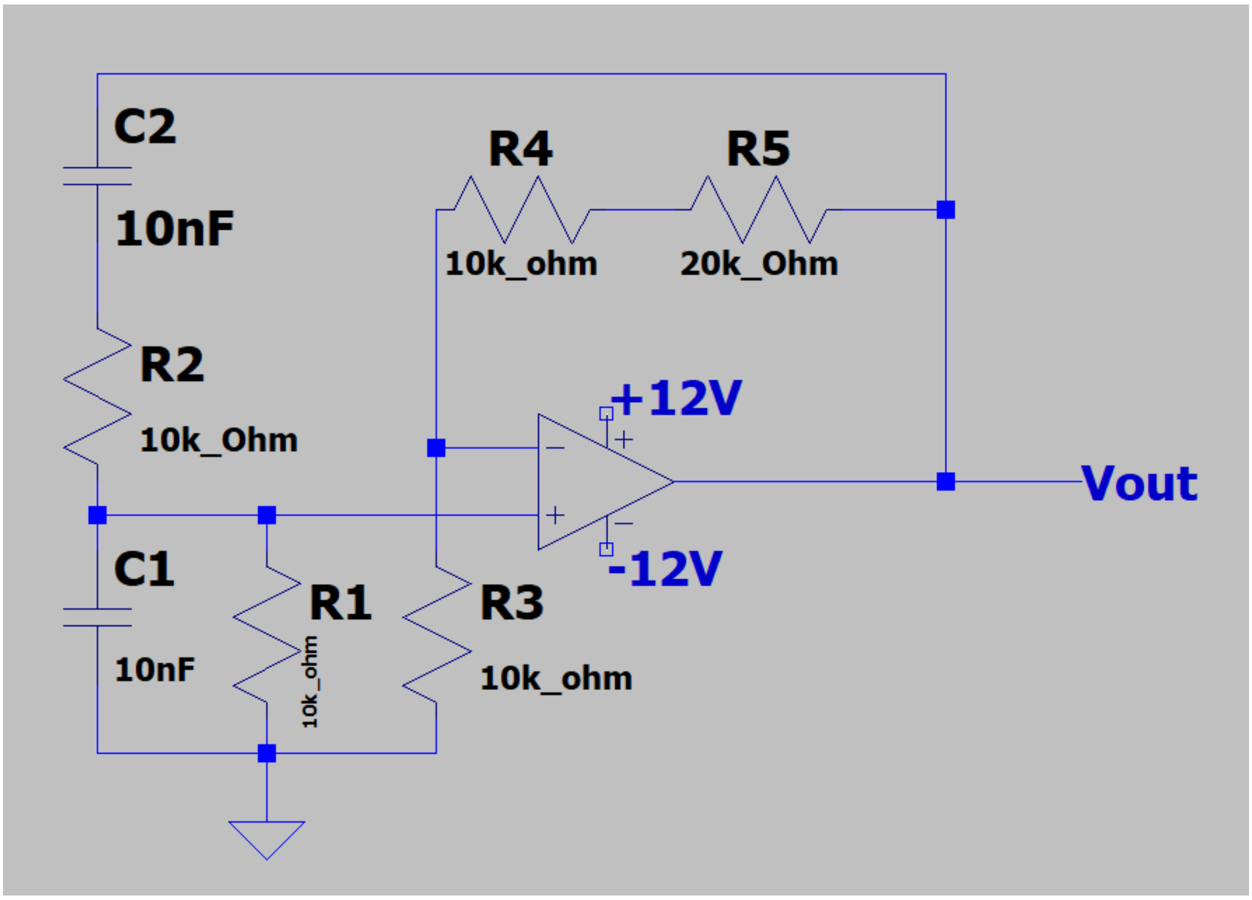

Figure 2: Wien Bridge Oscillator Circuit

1.3 Experimental Results

Table 1: Frequency Response Measurements

Frequency (Hz)	Amplitude (Vpp)	Phase Difference (degrees)
100	880 mVpp	74.66°
500	2.8 Vpp	29.16°
1k	3.18 Vpp	3.84°
1.1k	3.2 Vpp	316m°
1.103k	3.2 Vpp	0°
1.2k	3.2 Vpp	-4.5°
2k	2.96 Vpp	-18.91°
3k	2.56 Vpp	-35.76°
4k	2.16 Vpp	-48.46°
5k	1.84 Vpp	-51.36°
10k	1.04 Vpp	-70.44°
20k	600 mVpp	-61.44°
30k	400 mVpp	-78.05°

Plots from DSO while calculating amplitude at different frequencies

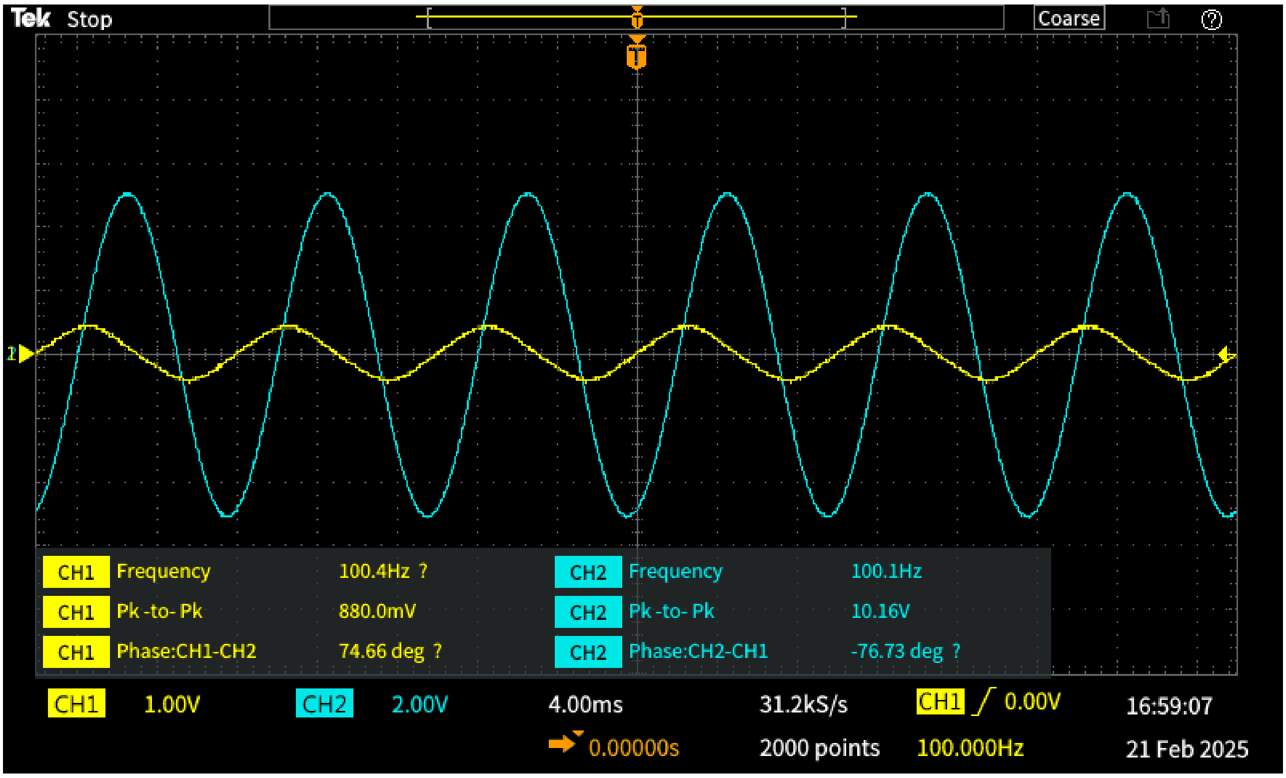

Figure 3: Plot at 100Hz frequency

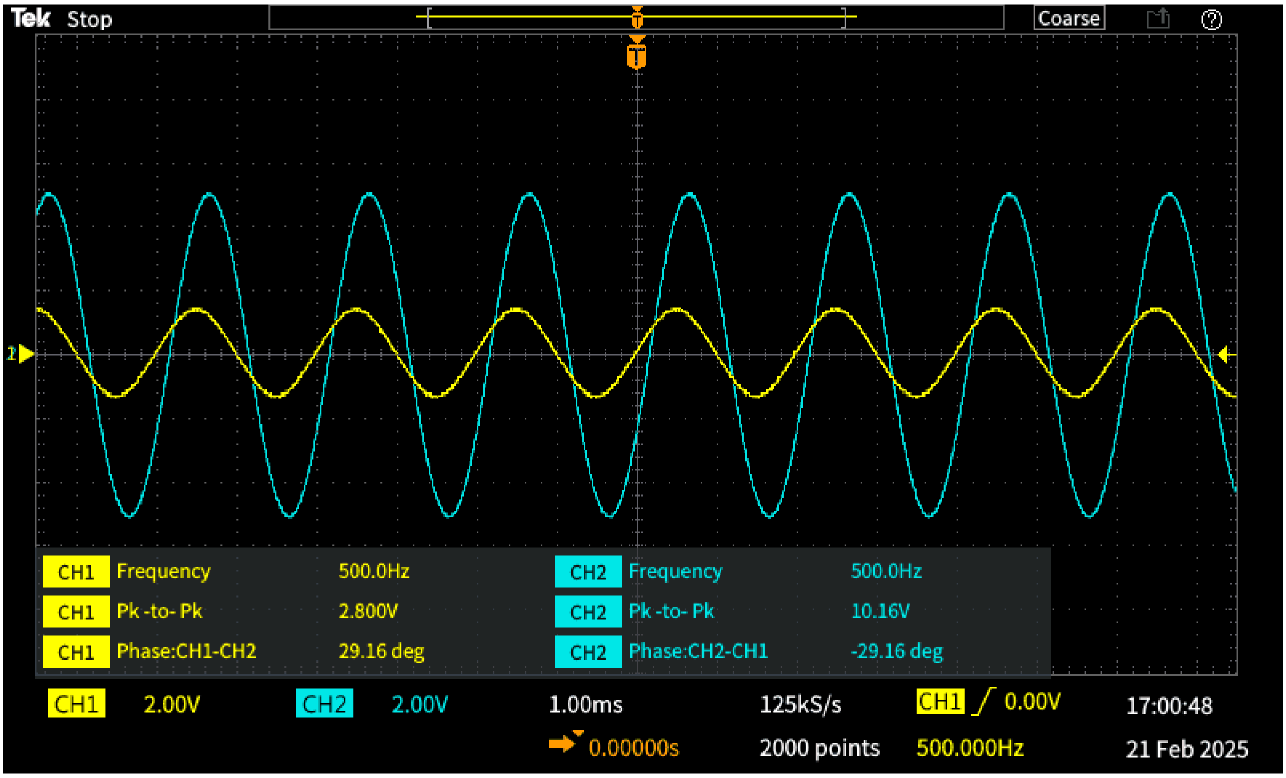

Figure 4: Plot at 500Hz frequency

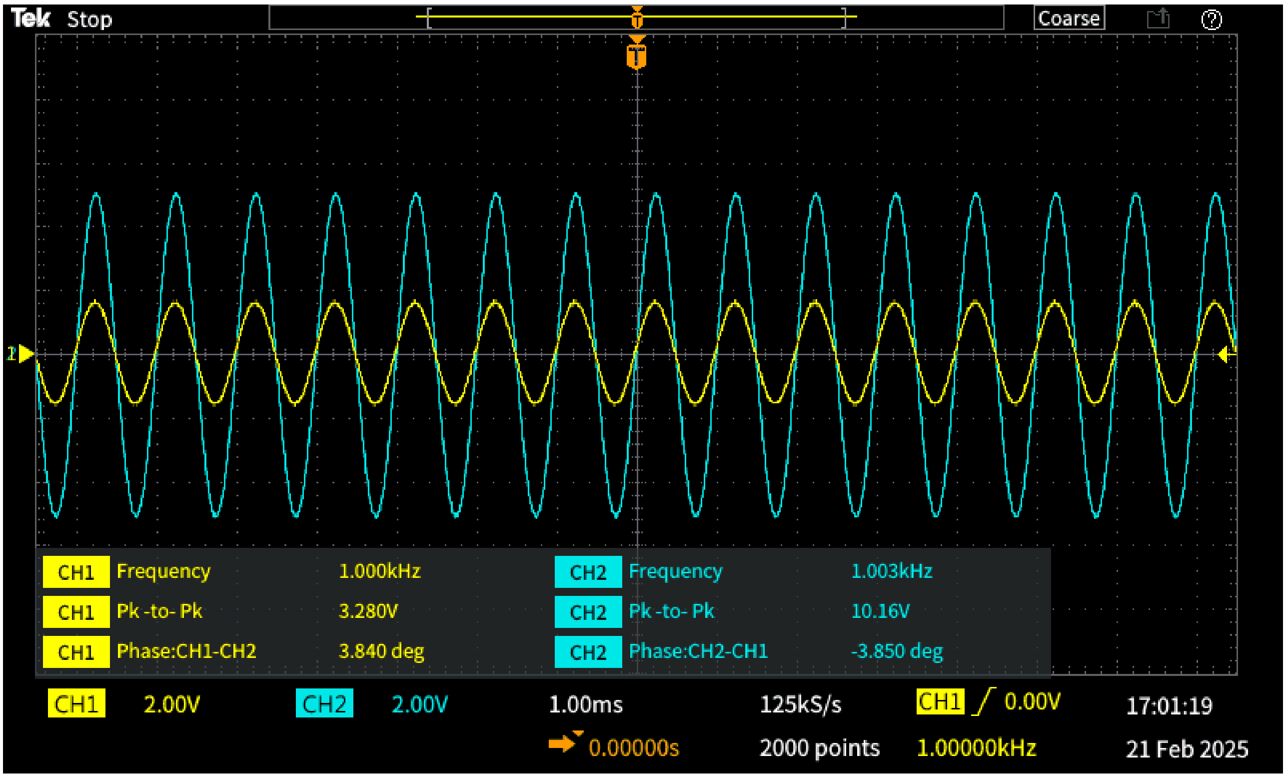

Figure 5: Plot at 1000Hz frequency

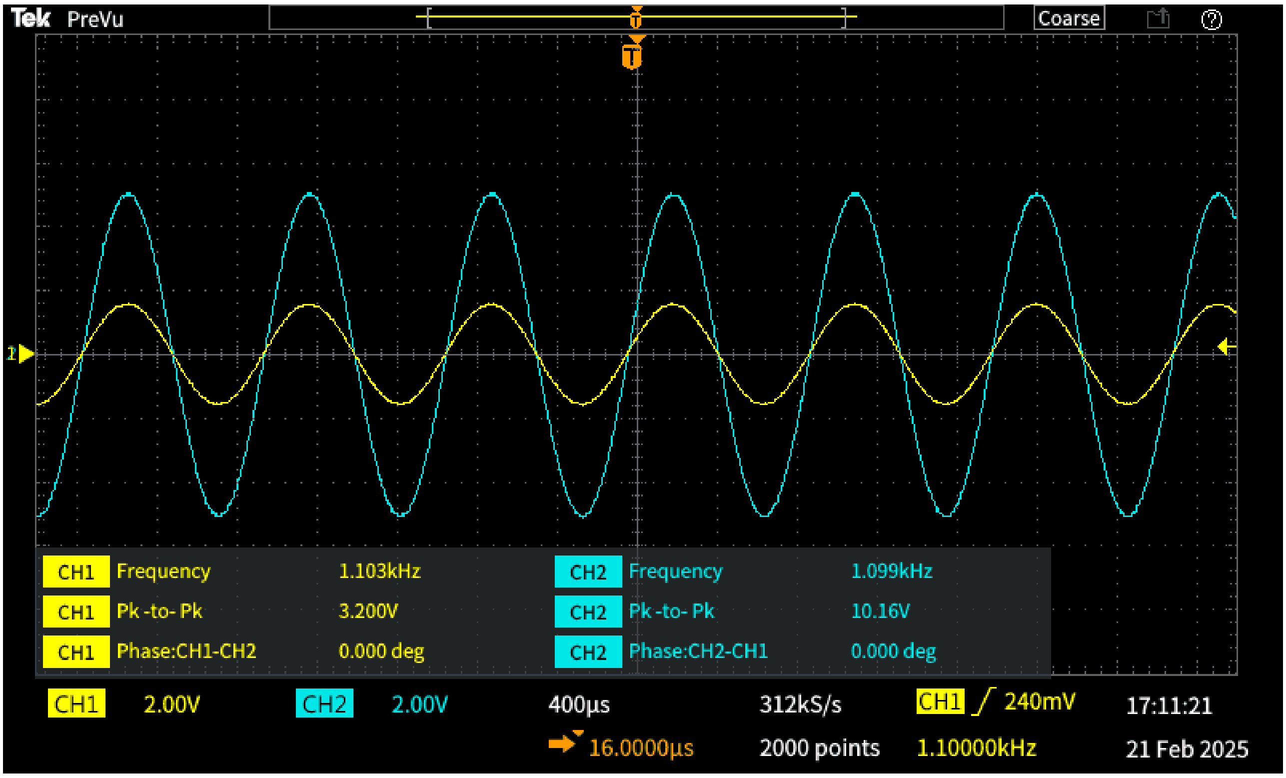

Figure 6: Plot at 1.103kHz frequency

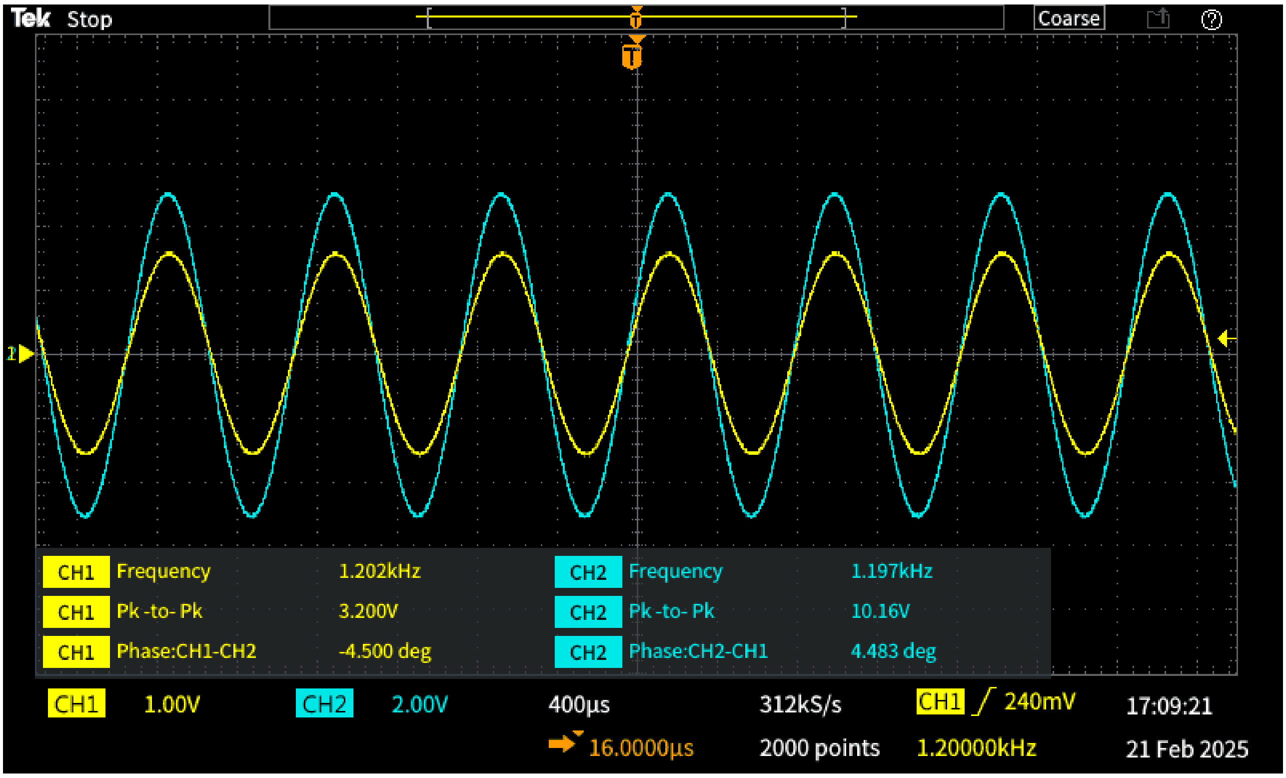

Figure 7: Plot at 1.2kHz frequency

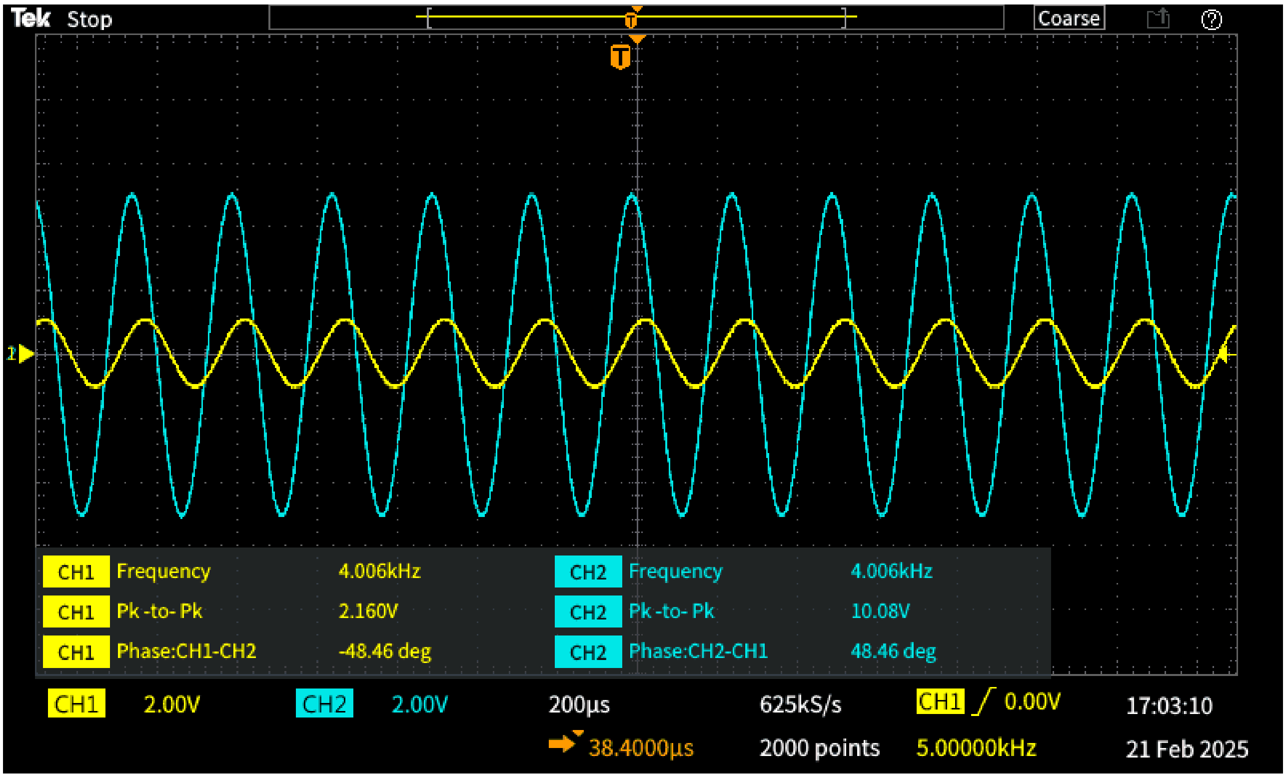

Figure 8: Plot at 4kHz frequency

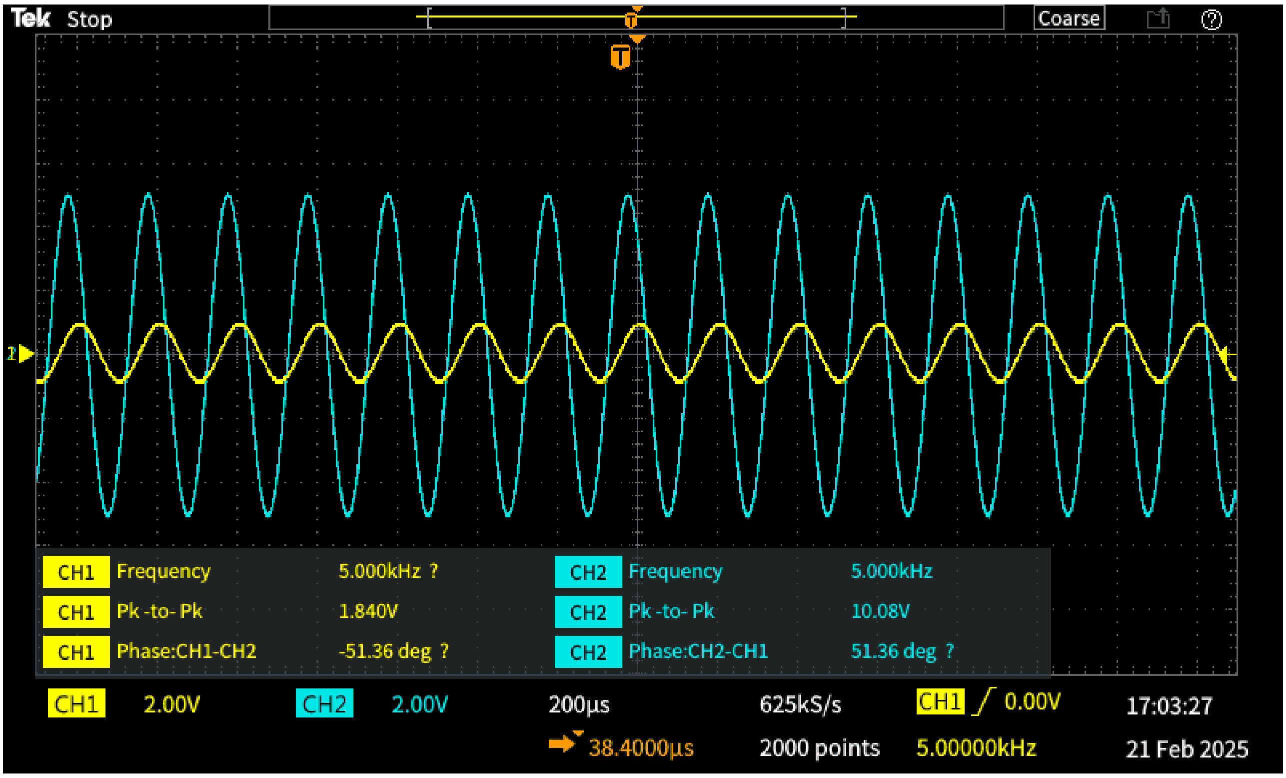

Figure 9: Plot at 5kHz frequency

Part (d): Frequency Measurement with R5 Adjustment

The potentiometer R_5 was adjusted to sustain oscillations. The measured frequency of oscillation was:

$$f_{measured} = 1.174kHz \tag{3}$$

$$Amplitude_{(peak-to-peak)} = 21Vpp \tag{4}$$

where as the theoretical value is $f = 1.59$ kHz.

Part (e): Effect of Changing R1 and R2

When $R_1 = R_2 = 5k\Omega$:

$$f_{new} = \frac{1}{2\pi \times 5k\Omega \times 10nF} = 3.18kHz \tag{5}$$

The measured value was:

$$f_{measured} = 2.4kHz \tag{6}$$

$$Amplitude_{(peak-to-peak)} = 21.2Vpp \tag{7}$$

If $R_1 \neq R_2$, the circuit does not maintain stable oscillations due to an imbalance in the feedback network.

1.4 Key Observations

1. The peak-to-peak output voltage decreases as the frequency increases beyond the designed oscillation frequency of $1.59kHz$.

2. The phase difference between input and output is $0°$ at $1.59kHz$ and increases as frequency deviates from this point.

3. With $R_1 = R_2 = 5k\Omega$, the oscillation frequency approximately doubles, confirming theoretical predictions.

4. When $R_1 \neq R_2$, stable oscillations are not achieved, validating the requirement of equal resistances for proper operation.

1.5 Conclusion and Inference

The experiment demonstrated the working principle of the Wien Bridge Oscillator. The measured oscillation frequency closely matched the theoretical value, and the circuit's stability depended on the proper selection of resistance and capacitance values. The experiment also verified the impact of component variations on oscillation frequency.

1.6 Experiment Completion Status

I have successfully completed all the sections mentioned in this Experiment

2 Sallen-Key (2-pole) Active Low-pass Filter

2.1 Butterworth Filter

2.1.1 Aim of the Experiment

To design, implement and analyze the performance of a 2nd order Butterworth Sallen-Key low-pass filter with a cutoff frequency of 1 kHz.

2.1.2 Circuit Design and Parameters

Circuit Description

The Butterworth filter circuit consists of:

- Resistor values: $R_2 = 18.4k\Omega$
- Capacitor values: $C_1 = 0.01\mu F$
- Frequency Scaling Factor: FSF = 1
- Cut-off frequency: $\mathrm{f_c}$ = 1 kHz
- Quality Factor: $Q = \frac{1}{\sqrt{2}}$

  Using the given formula:

$$f_c \times FSF = \frac{1}{2\pi RC\sqrt{mn}} \tag{8}$$

$$Q = \frac{\sqrt{mn}}{m+1} \tag{9}$$

We solve for m and n to determine R_1 and C_2.

Circuit Diagram (LT Spice):

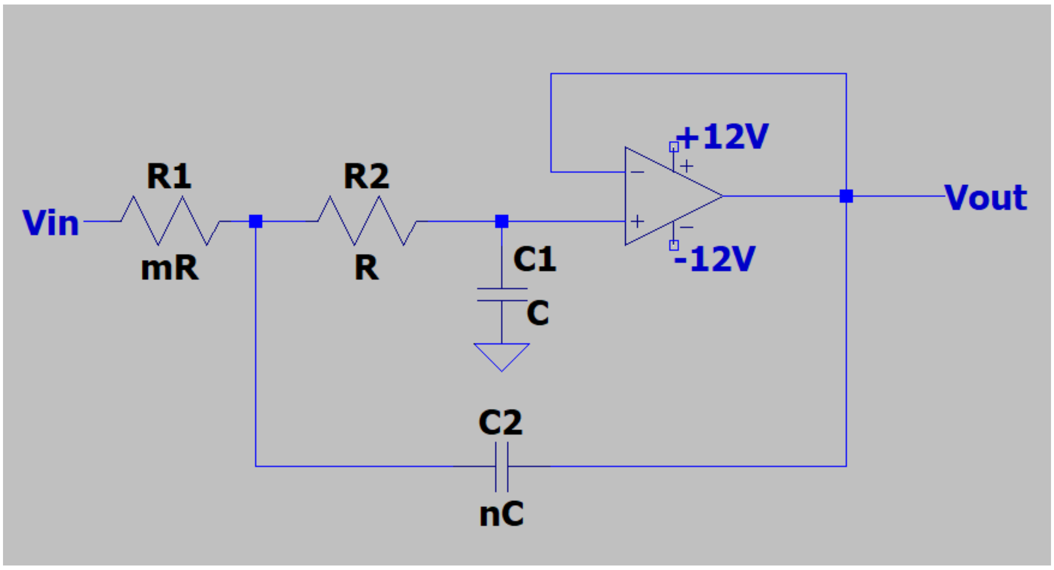

Figure 10: Sallen-Key (2-pole) active low-pass filter

2.1.3 Calculations

$$f_c \times FSF = \frac{1}{2\pi RC\sqrt{mn}} \tag{10}$$

$$=> 10^3 * 1 = \frac{1}{2\pi(18.4 * 10^3) * (0.01 * 10^{-6}) * \sqrt{mn}}$$

$$=> \sqrt{mn} = 0.8649$$

$$Q = \frac{1}{\sqrt{2}} => \frac{\sqrt{mn}}{m+1} = \frac{1}{\sqrt{2}} \tag{11}$$

$$=> m + 1 = \sqrt{2} * (0.8649)$$

$$=> m = 0.22325$$

$$=> n = 3.3506$$

R_1 = mR_2 = 4.1078kΩ, C$_2$ = nC_1 = 33.5nF

2.1.4 Experimental Results

The frequency response was calculated and plotted from 10 Hz to 10 kHz.

Table 2: Frequency Response Data for Butterworth Filter

Frequency (Hz)	Amplitude(V_{out-pp})
10	1.048 Vpp
50	1.048 Vpp
100	1.04 Vpp
150	1.016 Vpp
200	992 mVpp
250	968 mVpp
300	960 mVpp
350	928 mVpp
400	936 mVpp
450	904 mVpp
500	856 mVpp
1000	532 mVpp
1.5k	400 mVpp
2k	272 mVpp
2.5k	168 mVpp
3k	112 mVpp
3.5k	72 mVpp
4k	96 mVpp
4.5k	78 mVpp
5k	72 mVpp
7.5k	48 mVpp
10k	40 mVpp

Frequency Response of Butterworth Filter

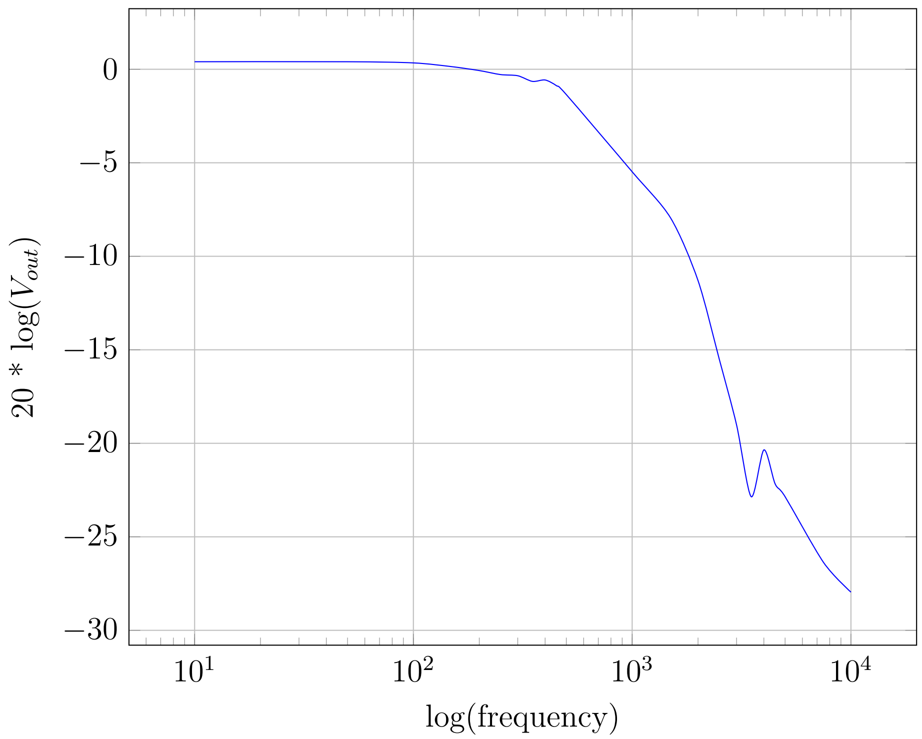

Figure 11: Frequency Response of Butterworth Filter

Plots from DSO while calculating amplitude at different frequencies

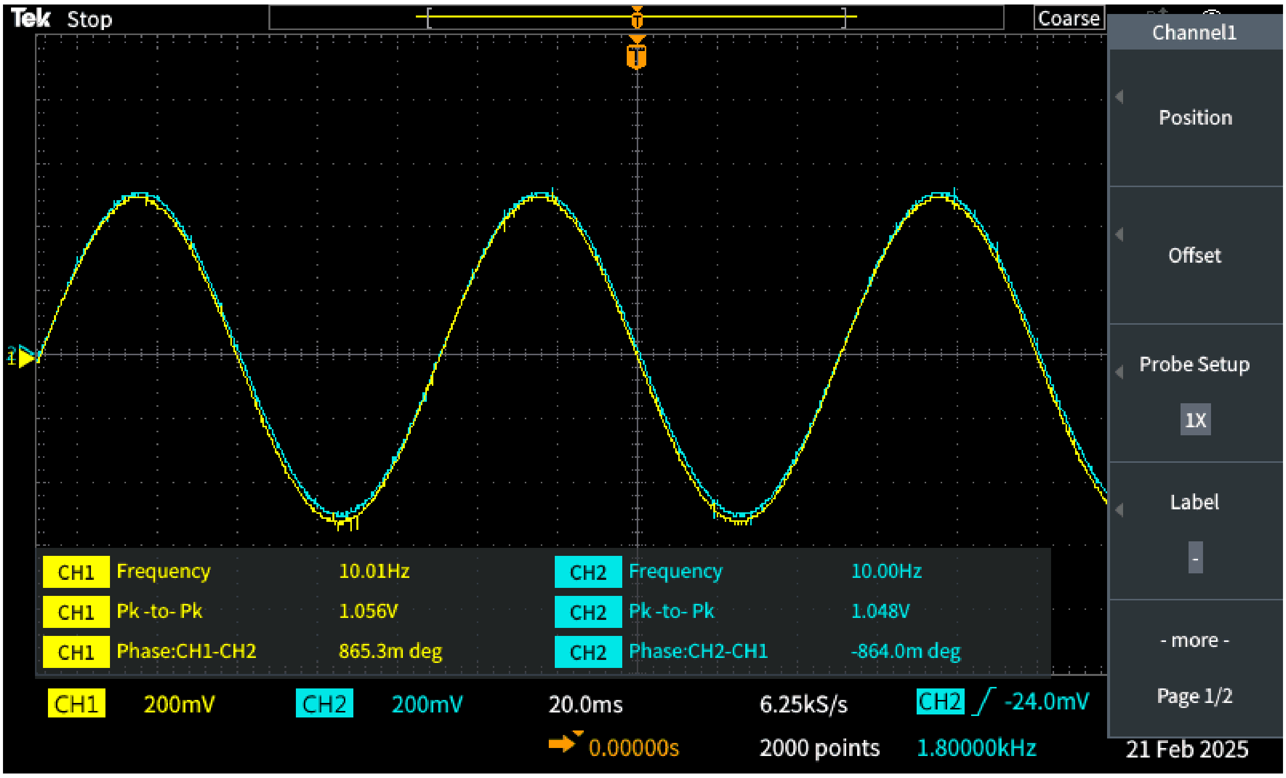

Figure 12: Plot at 10Hz frequency

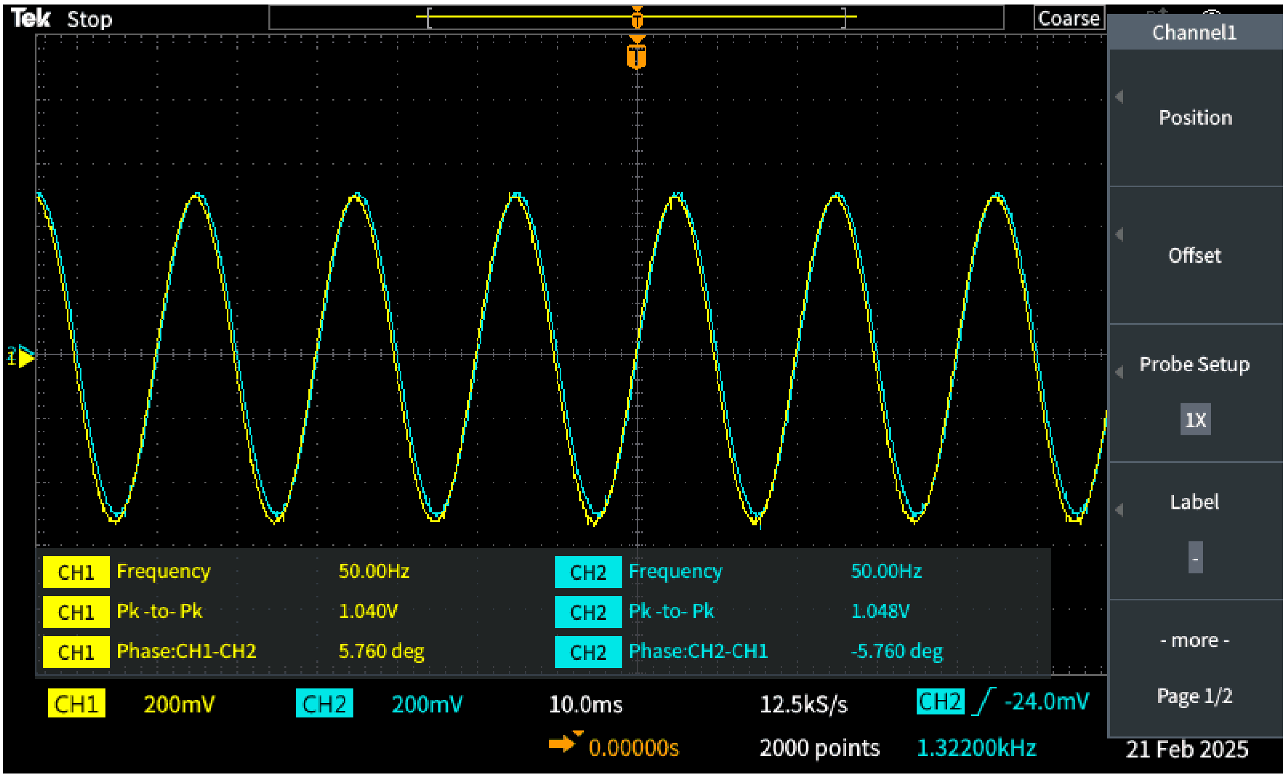

Figure 13: Plot at 50Hz frequency

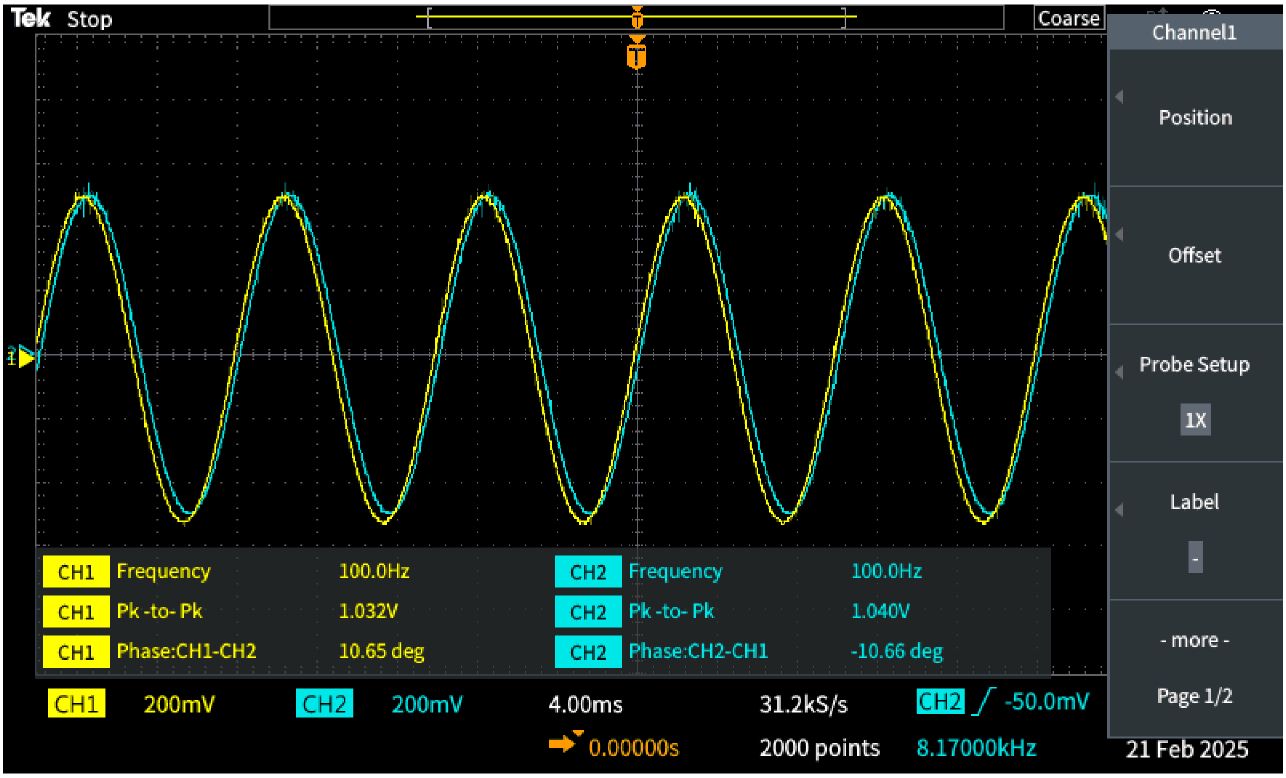

Figure 14: Plot at 100Hz frequency

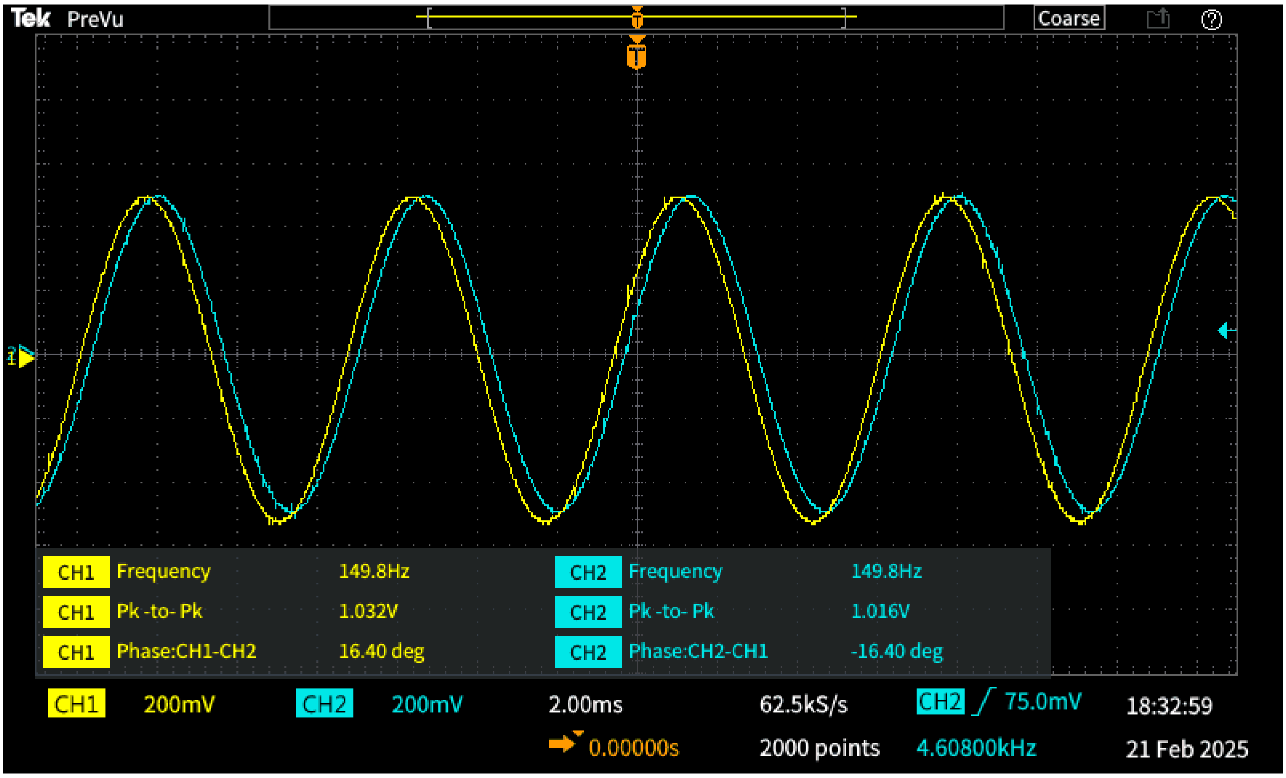

Figure 15: Plot at 150Hz frequency

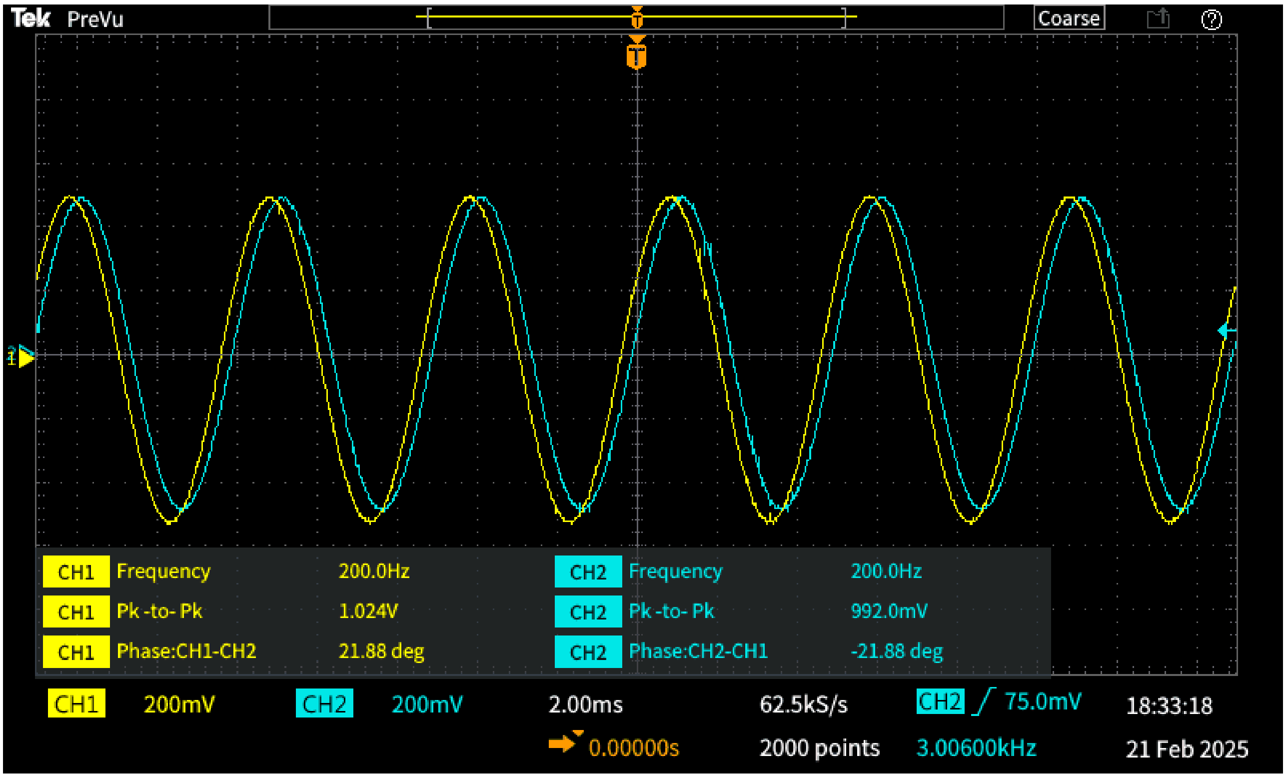

Figure 16: Plot at 200Hz frequency

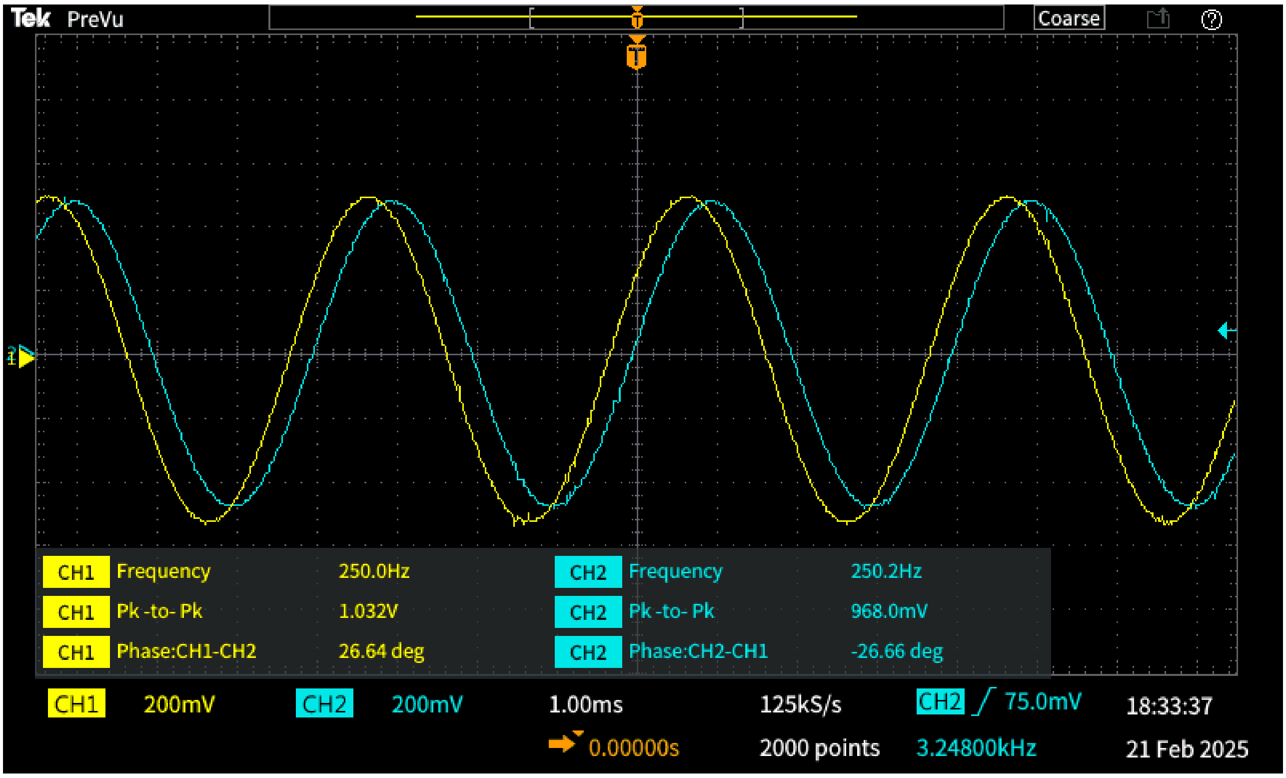

Figure 17: Plot at 250Hz frequency

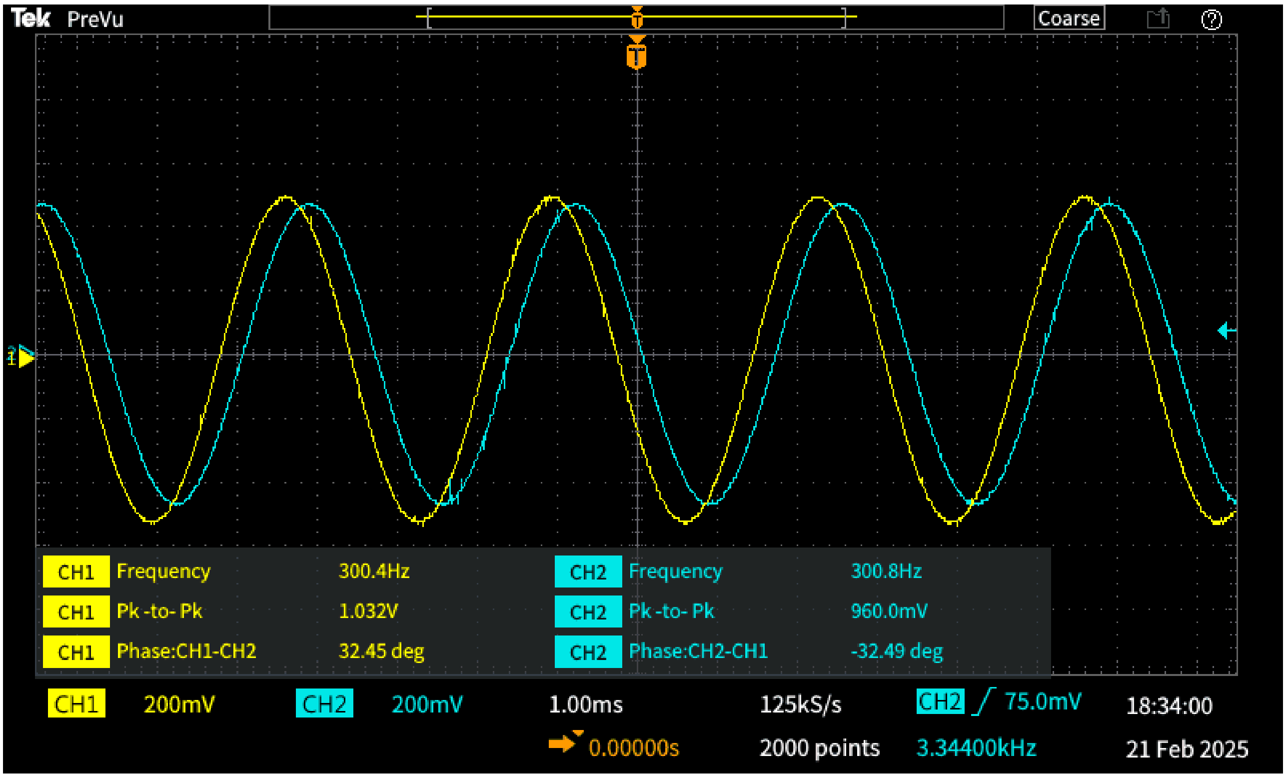

Figure 18: Plot at 300Hz frequency

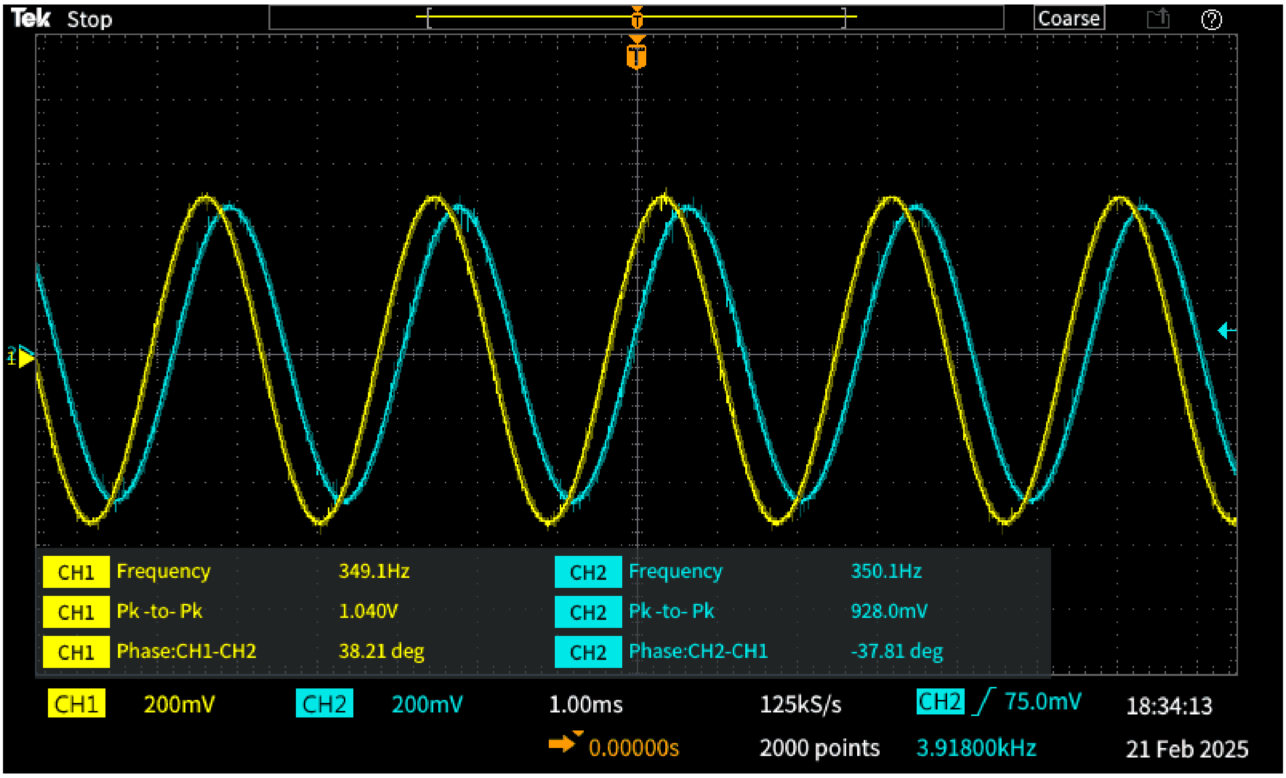

Figure 19: Plot at 350Hz frequency

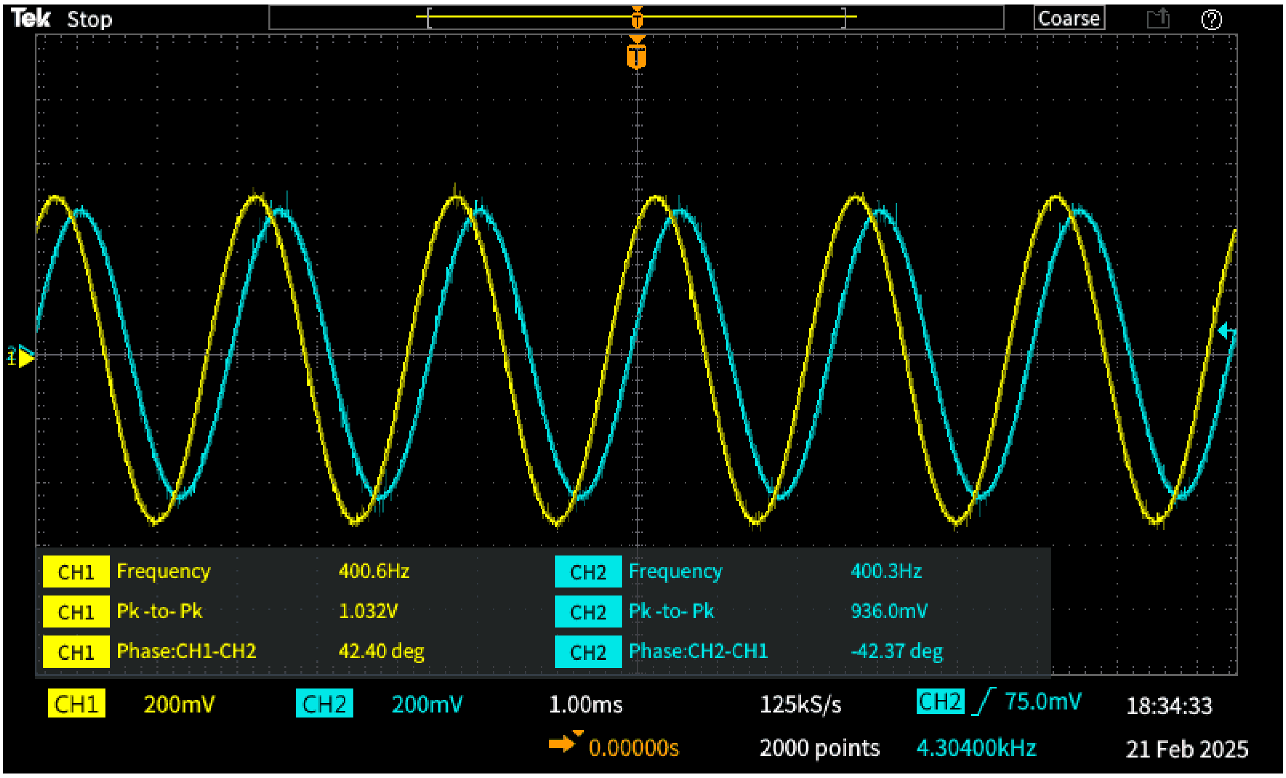

Figure 20: Plot at 400Hz frequency

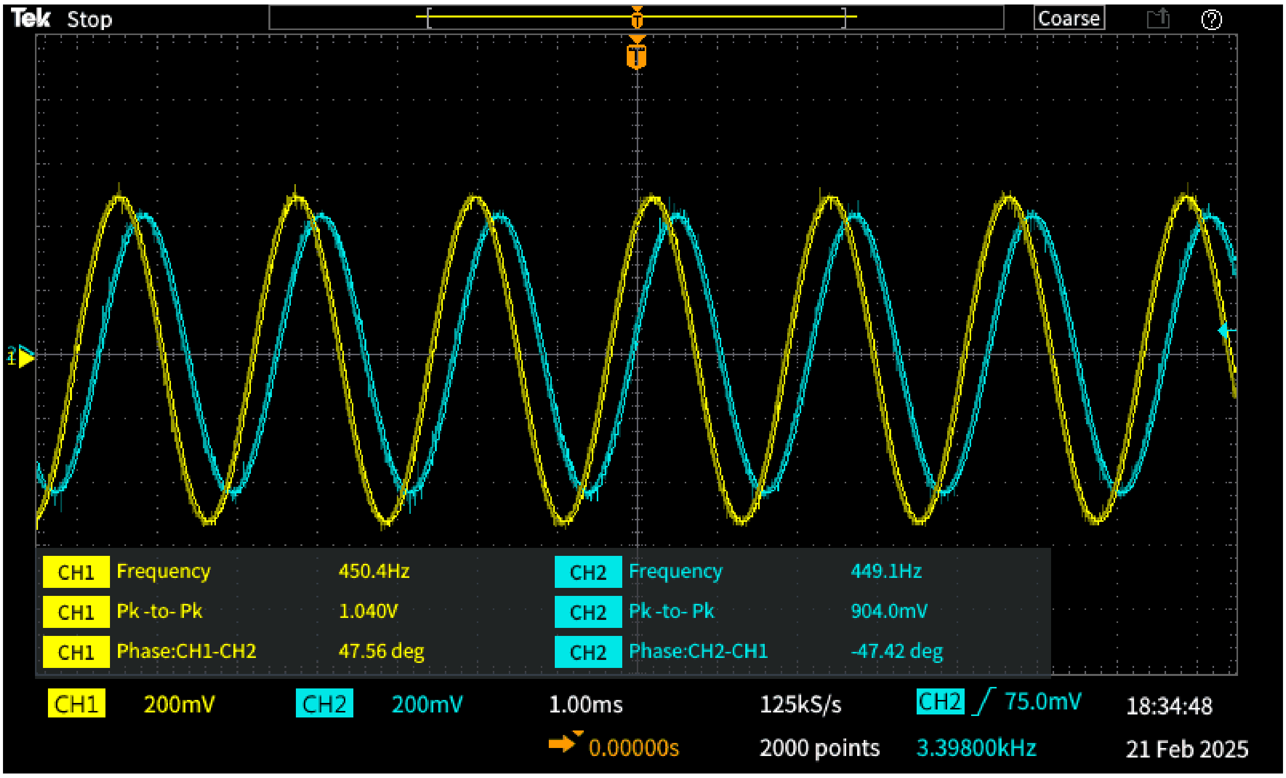

Figure 21: Plot at 450Hz frequency

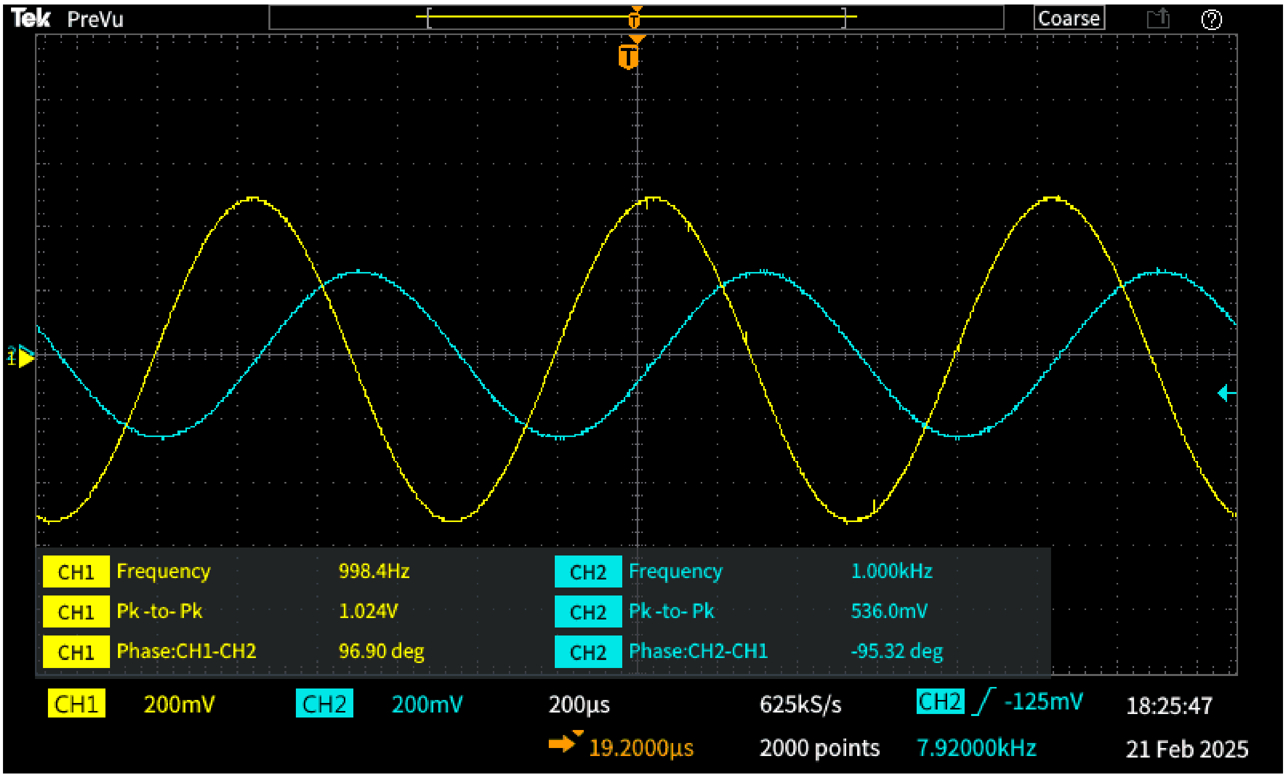

Figure 22: Plot at 1000Hz frequency

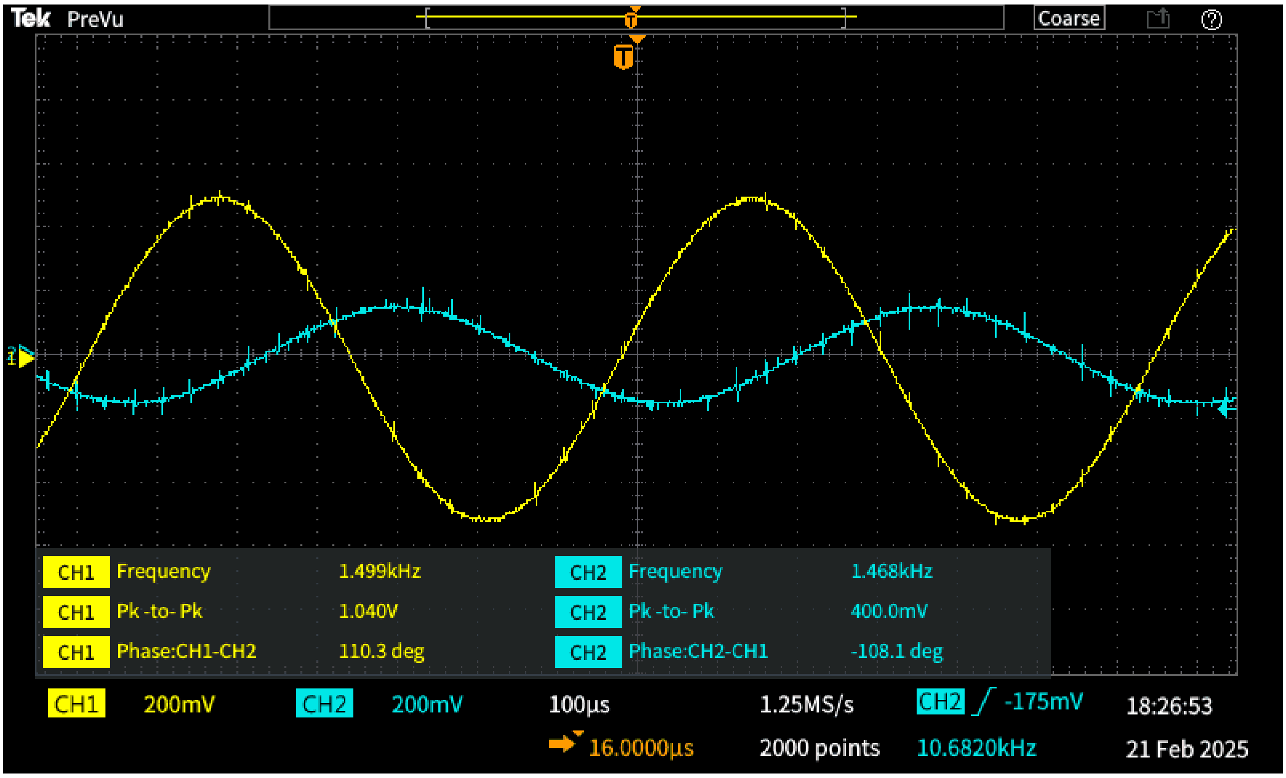

Figure 23: Plot at 1.5kHz frequency

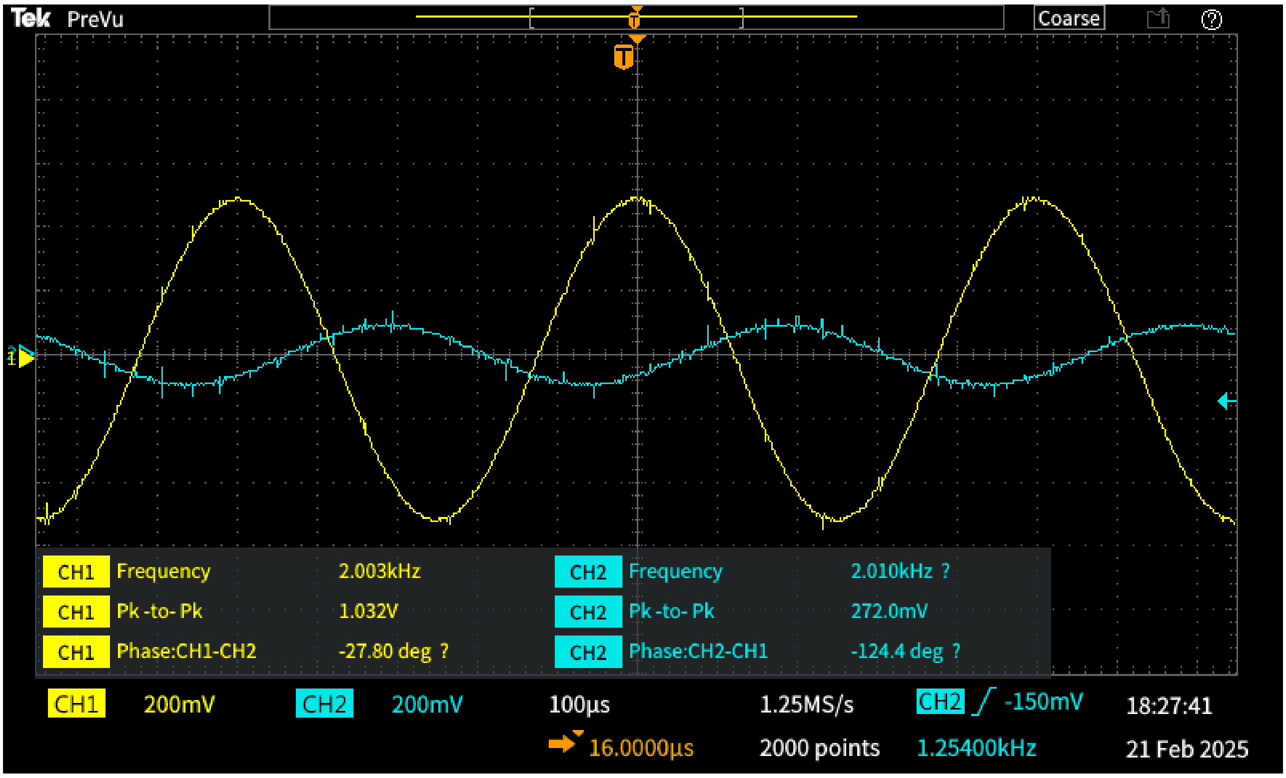

Figure 24: Plot at 2kHz frequency

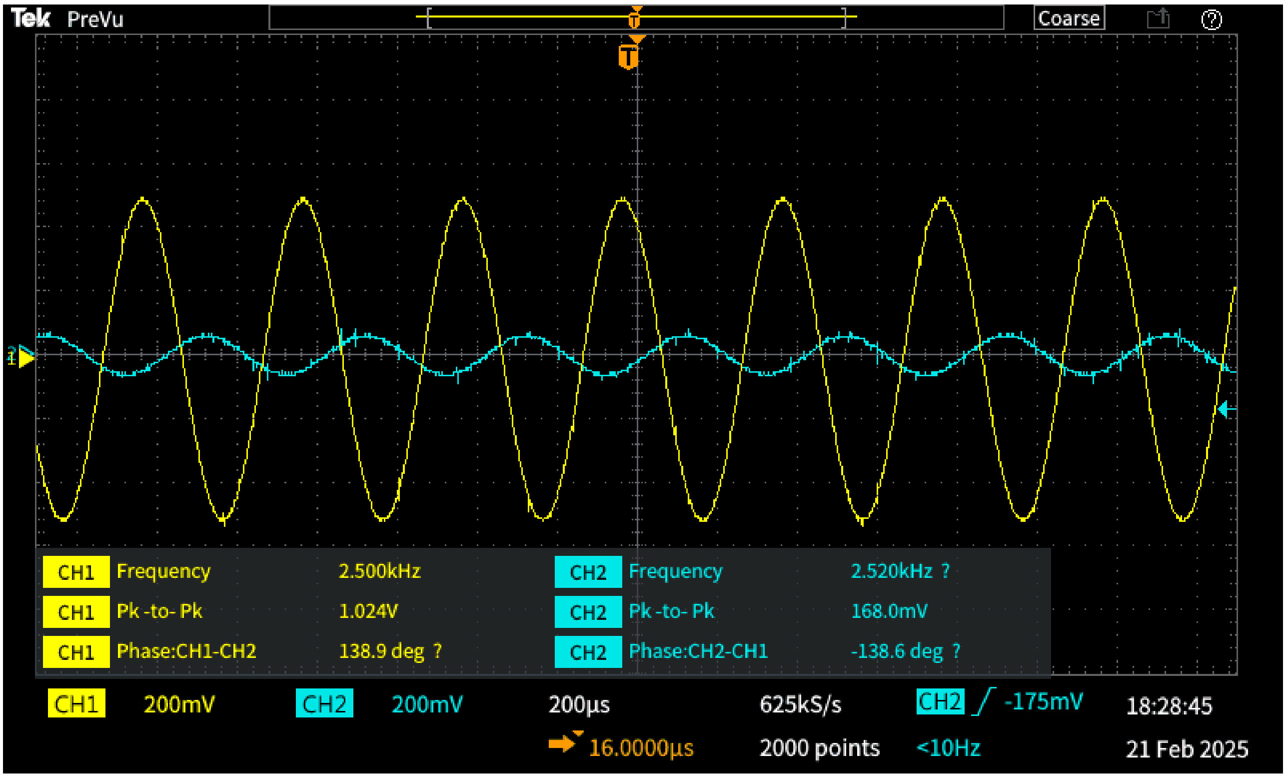

Figure 25: Plot at 2.5kHz frequency

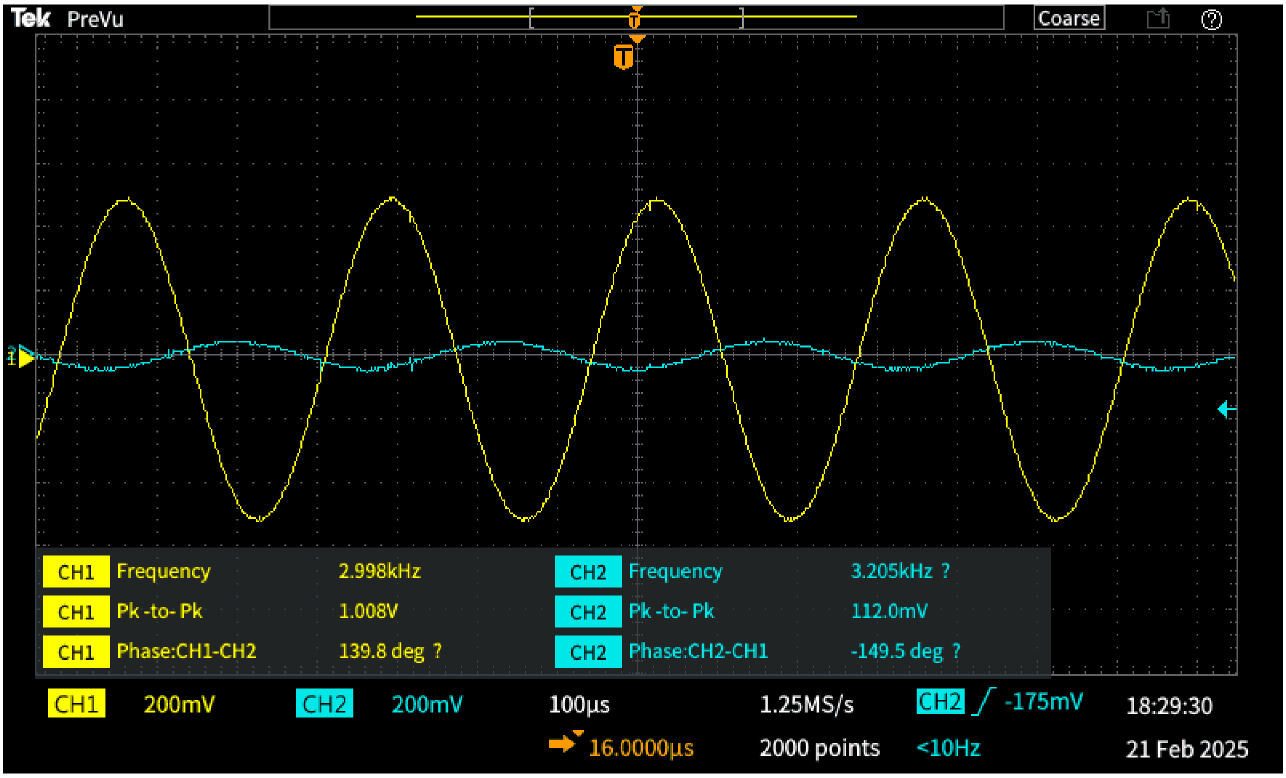

Figure 26: Plot at 3kHz frequency

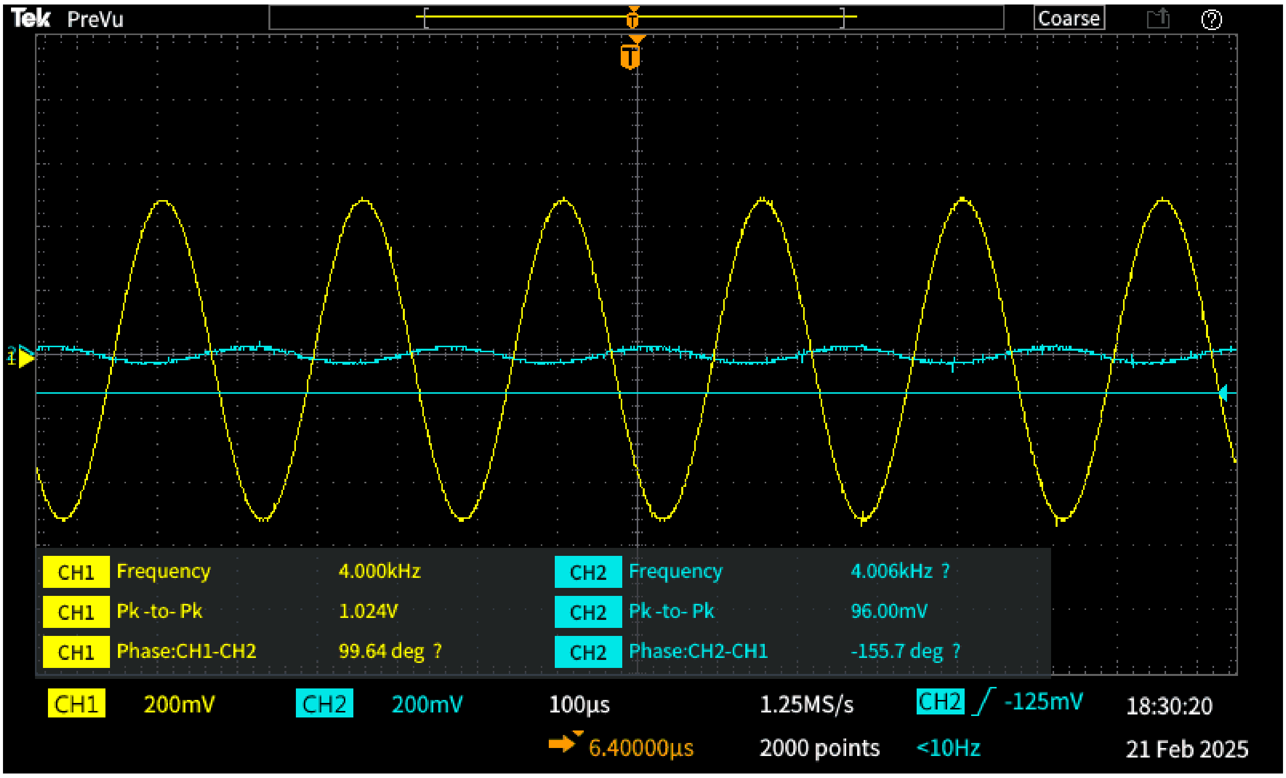

Figure 27: Plot at 4kHz frequency

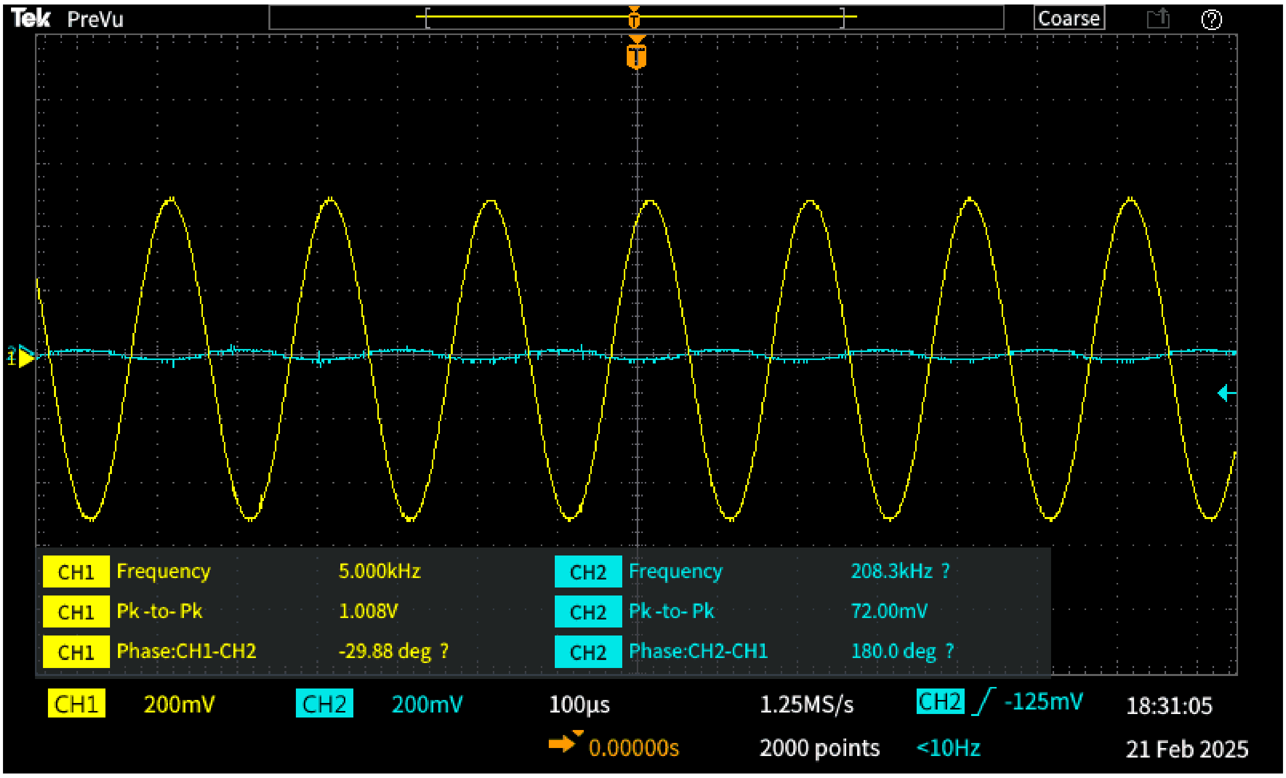

Figure 28: Plot at 5kHz frequency

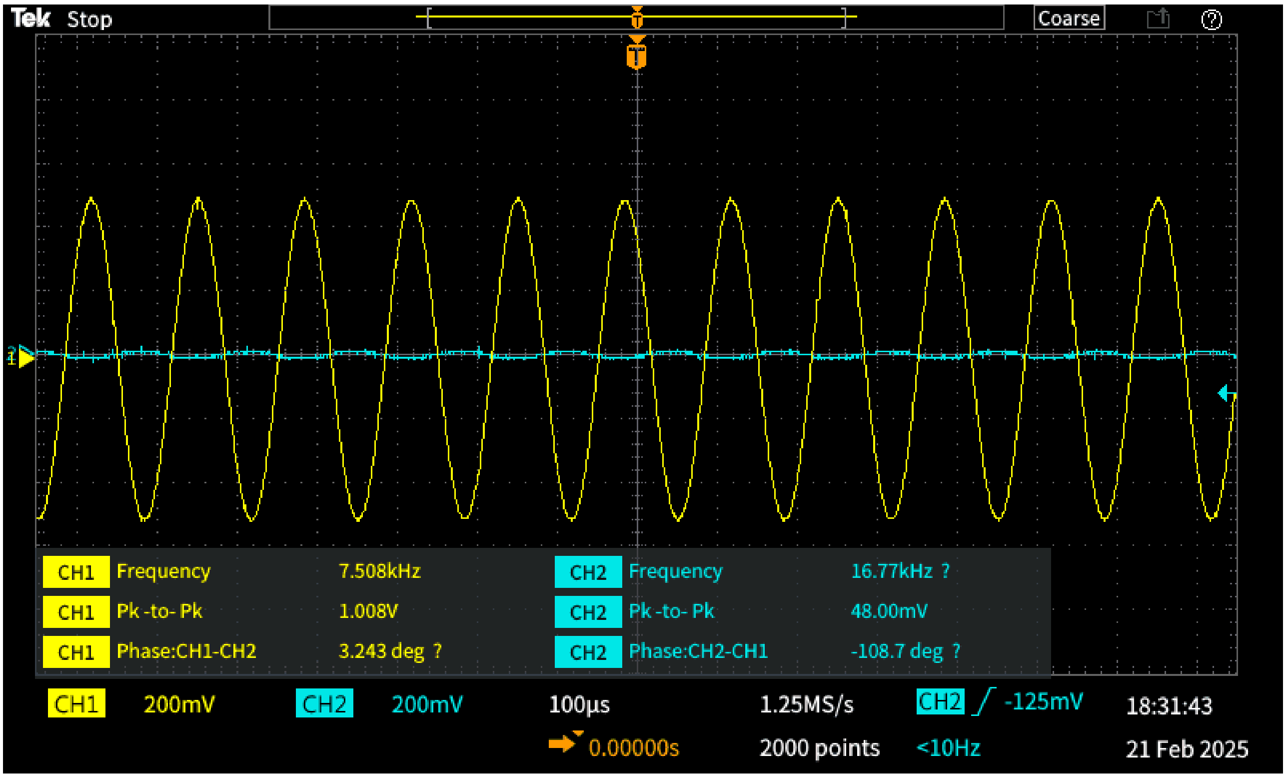

Figure 29: Plot at 7.5kHz frequency

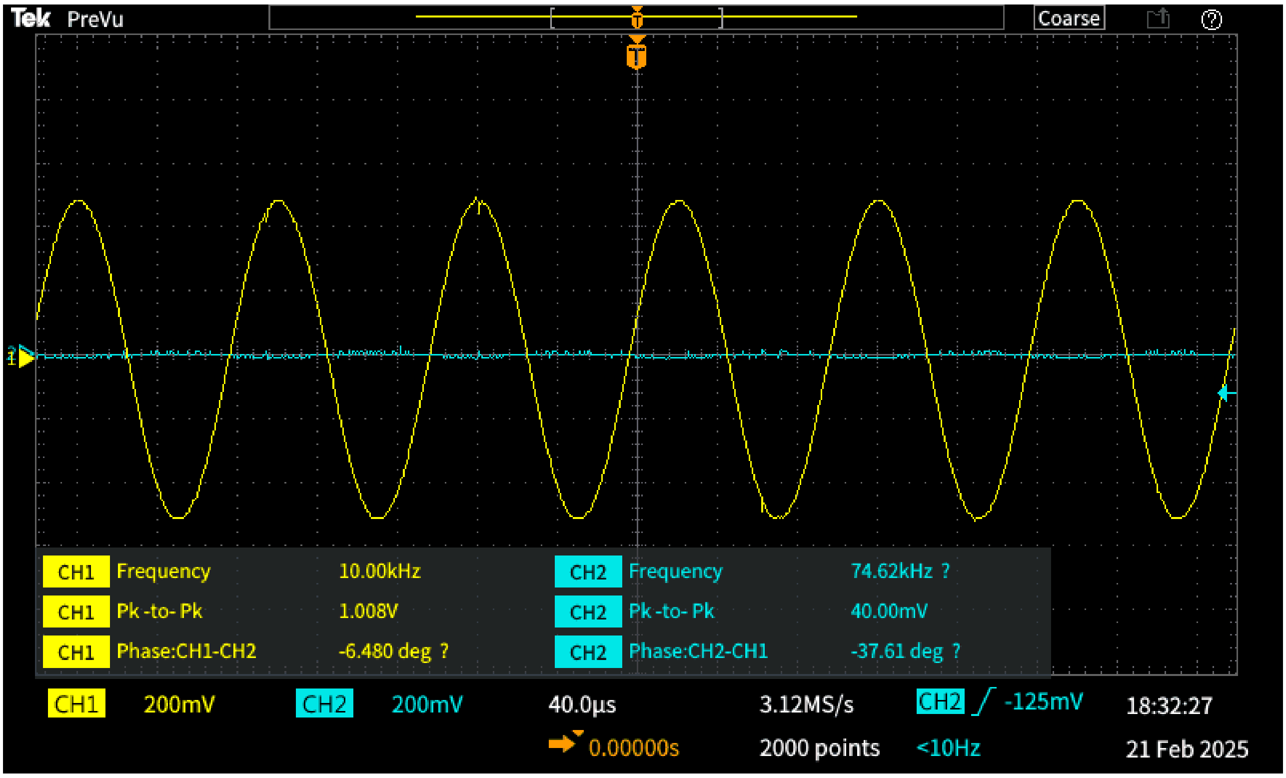

Figure 30: Plot at 10kHz frequency

2.1.5 Key Observations

- The Butterworth filter provides a smooth and maximally flat response in the passband.
- The cutoff frequency was observed to be close to the designed value of 1 kHz.
- The roll-off rate was approximately -40 dB/decade after the cutoff frequency.
- The measured gain values were consistent with theoretical predictions within an acceptable margin of error.

2.1.6 Conclusion and Inference

The Butterworth filter provided a maximally flat passband response with a gradual roll-off. It maintained a stable gain across the passband and achieved the desired cutoff frequency. The experimental results validated the theoretical design with minor deviations due to practical constraints.

2.1.7 Experiment Completion Status

I have successfully completed all the sections mentioned in this Experiment

2.2 Chebyshev Filter

2.2.1 Aim of the Experiment

To design, implement, and analyze the performance of a 2nd order Chebyshev Sallen-Key low-pass filter with a cutoff frequency of 1 kHz.

2.2.2 Circuit Design and Parameters

Circuit Description

The Chebyshev filter circuit consists of:

- Resistor values: $R_2 = 7.32k\Omega$
- Capacitor values: $C_1 = 0.01\mu F$
- Frequency Scaling Factor: FSF $= 0.8414$
- Cut-off frequency: $\mathrm{f_c} = 1$ kHz
- Quality Factor: $Q = 1.3049$

Using the given formula:

$$f_c \times FSF = \frac{1}{2\pi RC\sqrt{mn}} \tag{12}$$

$$Q = \frac{\sqrt{mn}}{m+1} \tag{13}$$

We solve for m and n to determine R_1 and C_2.

Circuit Diagram (LT Spice):

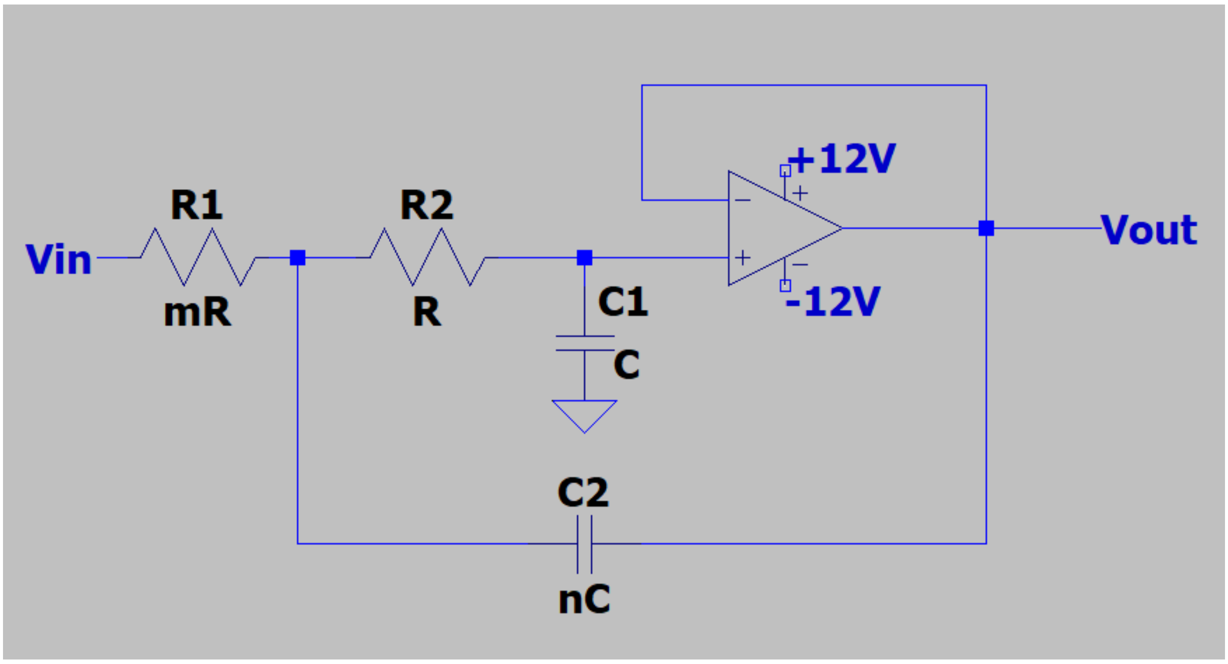

Figure 31: Sallen-Key (2-pole) active low-pass filter

2.2.3 Calculations

$$f_c \times FSF = \frac{1}{2\pi RC\sqrt{mn}} \tag{14}$$

$$=> 10^3 * 1 = \frac{1}{2\pi(7.32 * 10^3) * (0.01 * 10^{-6}) * \sqrt{mn}}$$

$$=> \sqrt{mn} = 2.584$$

$$Q = 1.3049 => \frac{\sqrt{mn}}{m+1} = 1.3049 \tag{15}$$

$$=> m + 1 = \frac{2.584}{1.3049}$$

$$=> m = 0.98022$$

$$=> n = 6.8177$$

R1 = mR2 = 7.175kΩ, $\quad C2 = nC1 = 68.177nF$

2.2.4 Experimental Results

The frequency response was calculated and plotted from 50 Hz to 10 kHz.

Table 3: Frequency Response Data for Chebyshev Filter

Frequency (Hz)	Amplitude(V_{out-pp})
50	1.016 Vpp
100	1.024 Vpp
150	1.040 Vpp
200	1.054 Vpp
250	1.088 Vpp
300	1.112 Vpp
350	1.144 Vpp
400	1.184 Vpp
450	1.216 Vpp
500	1.256 Vpp
550	1.26 Vpp
600	1.28 Vpp
700	1.2 Vpp
800	1.048 Vpp
900	864 mVpp
1000	704 mVpp
1.5k	304 mVpp
2k	160 mVpp
2.5k	120 mVpp
3k	80 mVpp
3.5k	56 mVpp
4k	48 mVpp
5k	32 mVpp
7.5k	16 mVpp
10k	8 mVpp

Frequency Response of Chebyshev Filter

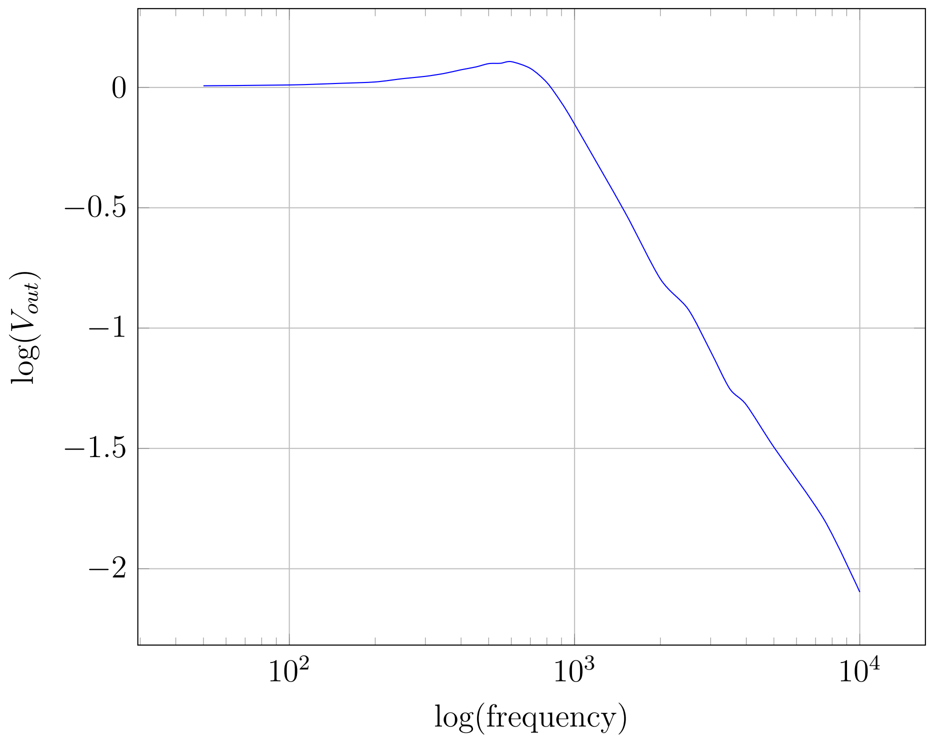

Figure 32: Frequency Response of Chebyshev Filter

2.2.5 Key Observations

- The Chebyshev filter exhibited a sharper roll-off compared to the Butterworth filter.
- The presence of passband ripples was observed due to the nature of Chebyshev filters.
- The measured cutoff frequency was slightly shifted due to FSF scaling.
- The gain fluctuated in the passband, confirming the theoretical ripple characteristics.

2.2.6 Conclusion and Inference

The Chebyshev filter provided a steeper roll-off than the Butterworth filter but introduced ripples in the passband. This trade-off between sharp frequency selectivity and passband flatness was evident in the experimental results, which closely followed theoretical expectations with minor deviations.

2.2.7 Experiment Completion Status

I have successfully completed all the sections mentioned in this Experiment

2.3 Comparison of Butterworth and Chebyshev Filters

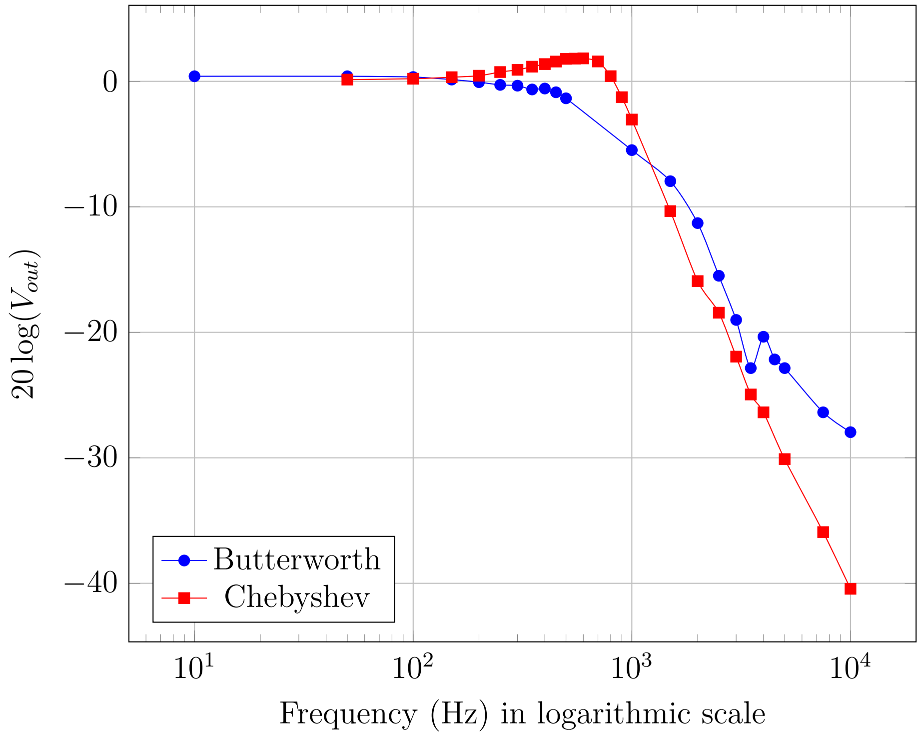

Figure 33: Comparison of Butterworth and Chebyshev Filter Frequency Responses

- The Butterworth filter provides a maximally flat response in the passband with a slower roll-off.
- The Chebyshev filter has a sharper roll-off but introduces ripples in the passband.
- The Chebyshev filter achieves better selectivity at the cost of in-band ripple.

3 Multiple-feedback Active Band-Pass Filter

3.1 Aim of the Experiment

To design and analyze a Multiple-Feedback Active Band-Pass Filter. The experiment involves calculating the center frequency and bandwidth theoretically and experimentally, then comparing the results.

3.2 Circuit Design and Parameters

Given Circuit Values

- Resistors: $R_1 = 68k\Omega$, $R_2 = 180k\Omega$, $R_3 = 2.7k\Omega$
- Capacitors: $C_1 = C_2 = 0.01\mu F$

3.3 Theoretical Calculations

3.3.1 Center Frequency (f_o)

The center frequency is given by:

$$f_o = \frac{1}{2\pi C}\sqrt{\frac{(R_1 + R_3)}{R_1 R_2 R_3}} \tag{16}$$

Substituting the given values:

$$\begin{aligned}
f_o &= \frac{1}{2\pi(0.01 \times 10^{-6})}\sqrt{\frac{(68k + 2.7k)}{(68k)(180k)(2.7k)}} \\
&= \frac{1}{6.2832 \times 0.01 \times 10^{-6}}\sqrt{\frac{70.7k}{(68k)(180k)(2.7k)}} \\
&= \frac{1}{6.2832 \times 0.01 \times 10^{-6}}\sqrt{\frac{70.7 \times 10^3}{(68 \times 10^3)(180 \times 10^3)(2.7 \times 10^3)}} \\
&= \frac{1}{6.2832 \times 0.01 \times 10^{-6}}\sqrt{\frac{70.7}{68 \times 180 \times 2.7} \times 10^{-6}} \\
&= \frac{1}{6.2832 \times 0.01 \times 10^{-6}}\sqrt{\frac{70.7}{33048} \times 10^{-6}} \\
&= \frac{1}{6.2832 \times 0.01 \times 10^{-6}}\sqrt{2.14 \times 10^{-9}} \\
&= \frac{1}{6.2832 \times 0.01 \times 10^{-6}} \times 4.6253 \times 10^{-5} \\
&= \frac{1}{6.2832} \times 4.6253 \times 10^{3} \\
&= 736.135 \text{ Hz}
\end{aligned}$$

Thus, the theoretical center frequency is approximately 736.135 Hz.

3.3.2 Quality Factor (Q)

The quality factor is given by:

$$Q = \pi f_o C R_2 \tag{17}$$

Substituting values:

$$\begin{aligned} Q &= \pi(736.135)(0.01 \times 10^{-6})(180 \times 10^{3}) \\ &= 3.1416 \times 736.135 \times 1.8 \times 10^{-3} \\ &= 4.163 \end{aligned}$$

3.3.3 Bandwidth (BW)

The bandwidth is given by:

$$BW = \frac{f_o}{Q} \tag{18}$$

Substituting the values:

$$\begin{aligned} BW &= \frac{736.135}{4.163} \\ &= 176.83 \text{ Hz} \end{aligned}$$

Thus, the theoretical bandwidth is approximately 176.83 Hz.

3.4 Circuit Diagram (LT Spice):

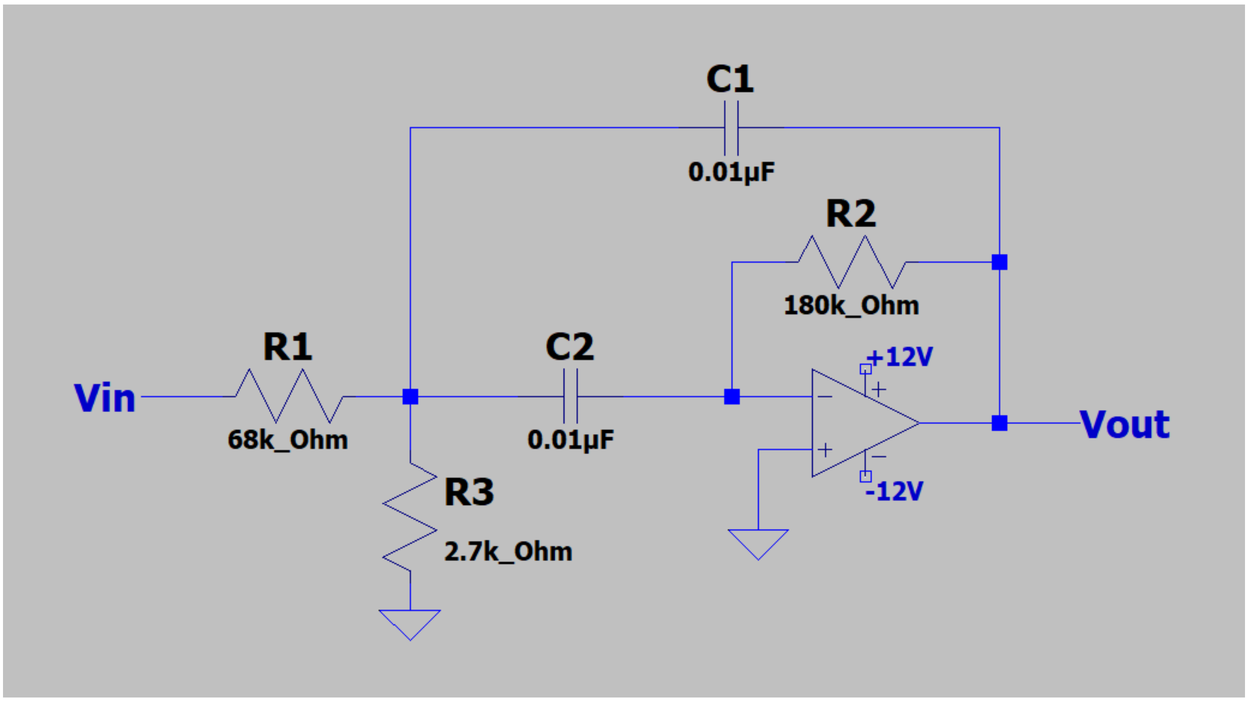

Figure 34: Multiple Feedback Active BPF

3.5 Experimental Results and Comparison

Using experimental data, the following values were observed:

Table 4: Theoretical vs Experimental Results

Parameter	Theoretical Value	Experimental Value
Center Frequency (f_o)	736.135 Hz	740 Hz
Bandwidth (BW)	176.83 Hz	180 Hz

The frequency response was calculated and plotted from 50 Hz to 10 kHz.

Table 5: Frequency Response Measurements

Frequency (Hz)	Amplitude(V_{out-pp})
50	80 mVpp
100	100 mVpp
150	152 mVpp
200	208 mVpp
250	240 mVpp
300	312 mVpp
350	400 mVpp
400	576 mVpp
450	800 mVpp
500	1.088 Vpp
600	896 mVpp
700	568 mVpp
800	400 mVpp
900	328 mVpp
1000	272 mVpp
1.5k	160 mVpp
2k	104 mVpp
2.5k	96 mVpp
3k	80 mVpp
3.5k	64 mVpp
5k	56 mVpp
7.5k	40 mVpp
10k	40 mVpp

Frequency Response of Multiple-feedback Active Band-Pass Filter

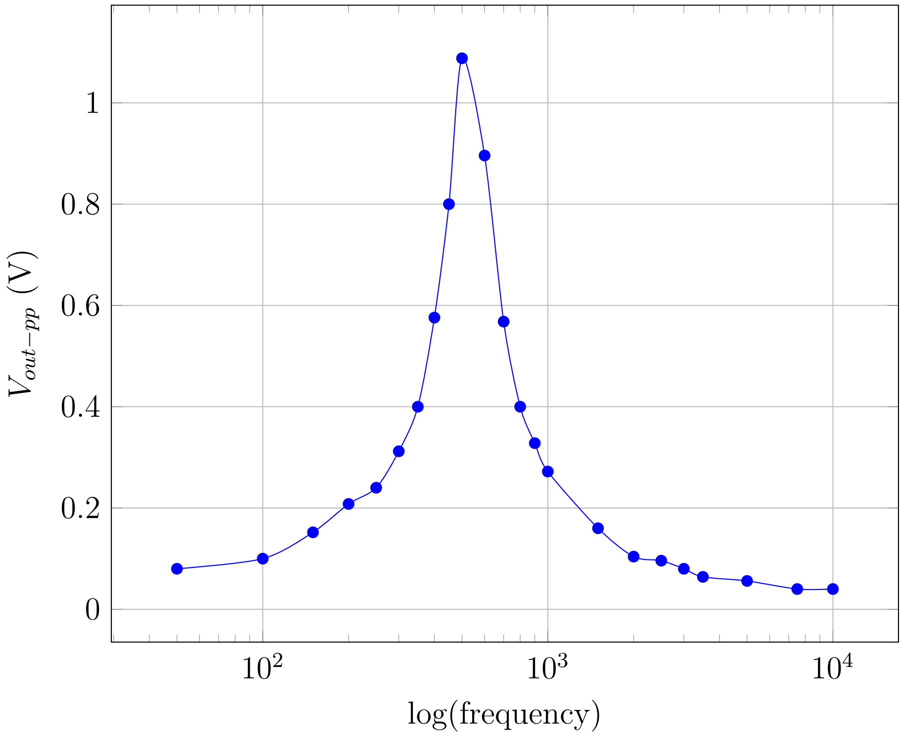

Figure 35: Frequency Response of the Multiple-feedback Active Band-Pass Filter

Plots from DSO while calculating amplitude at different frequencies

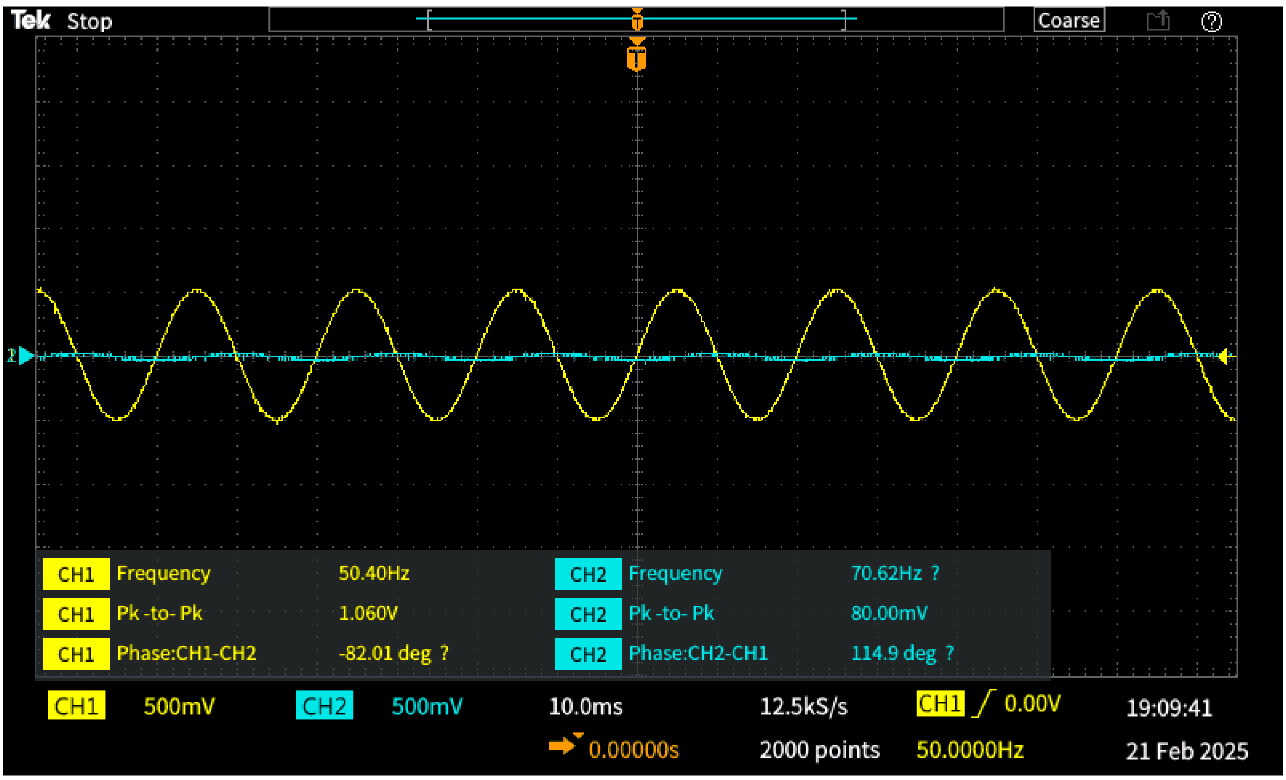

Figure 36: Plot at 50Hz frequency

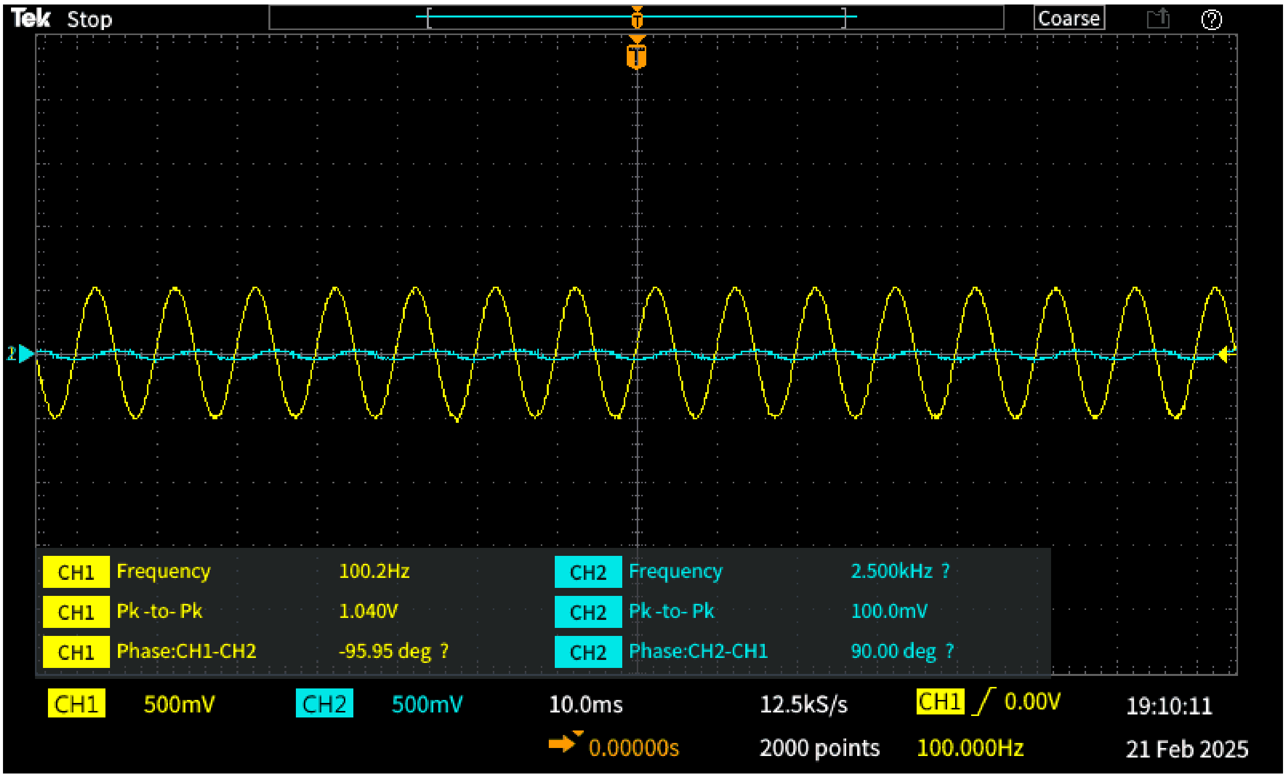

Figure 37: Plot at 100Hz frequency

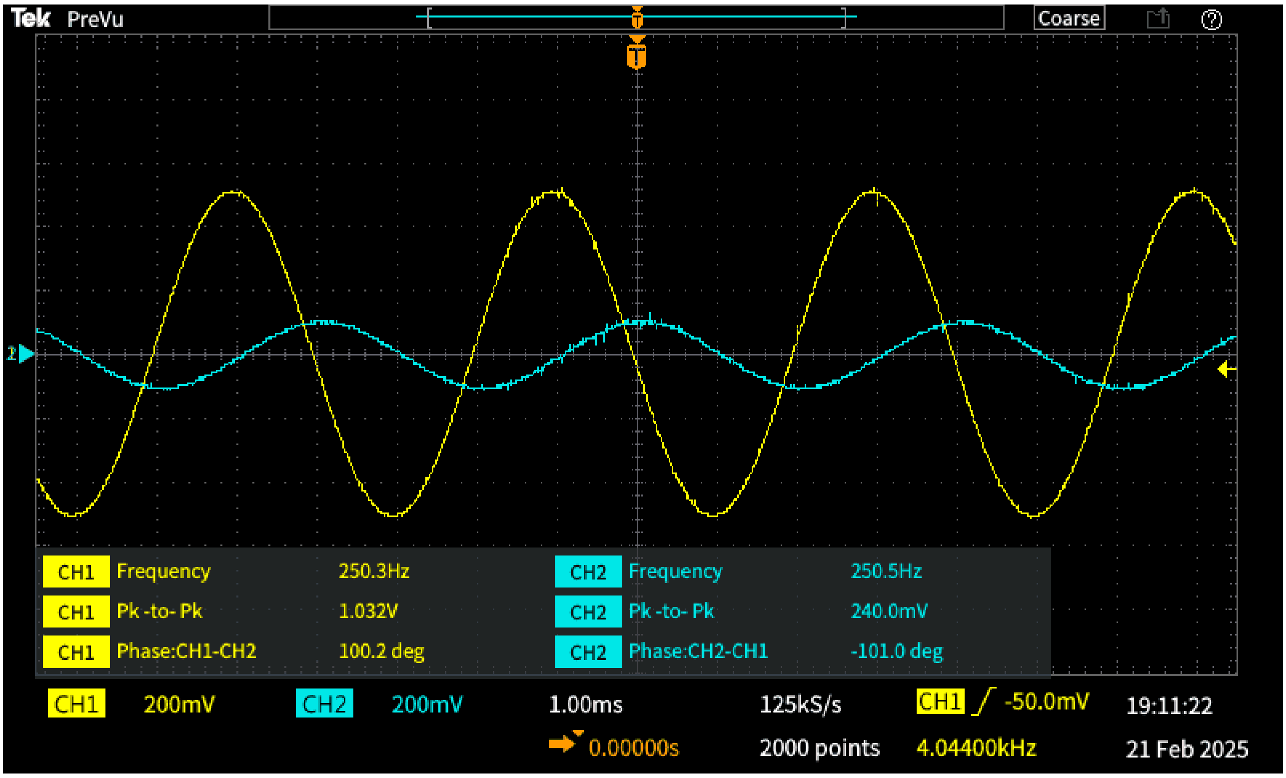

Figure 38: Plot at 250Hz frequency

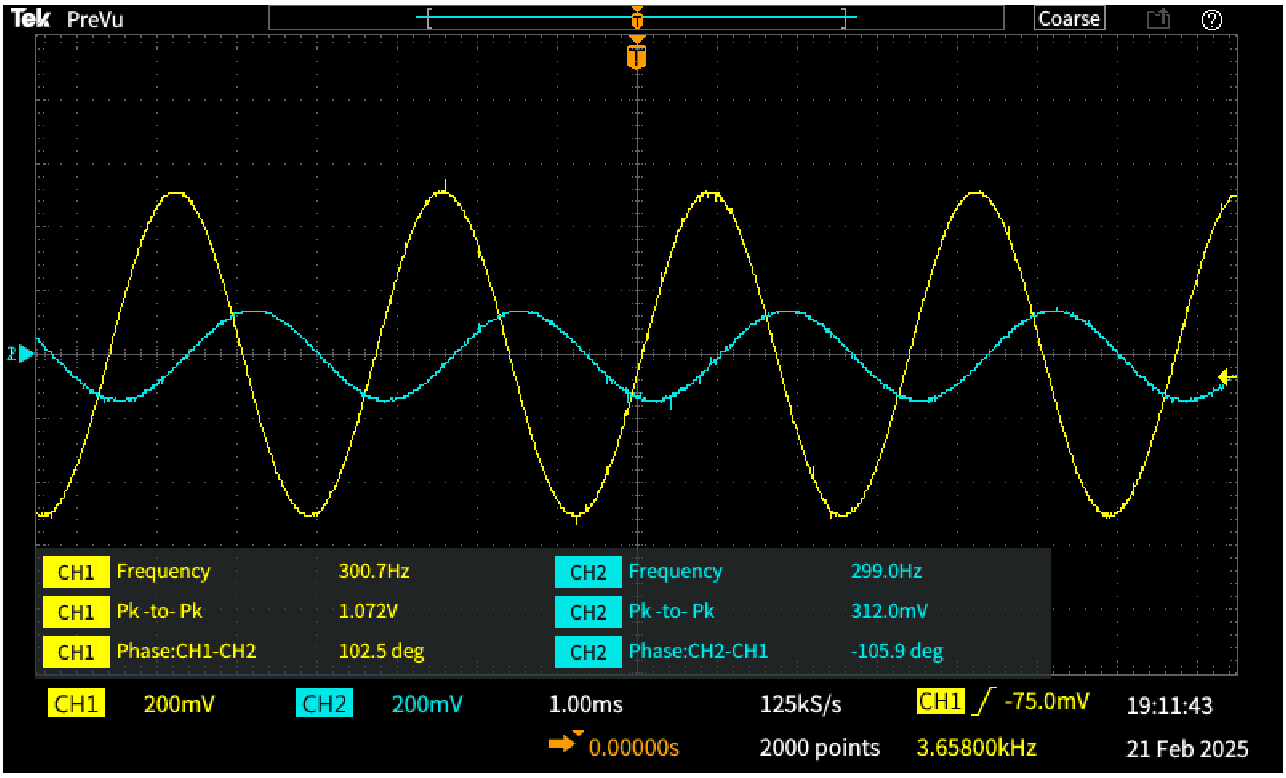

Figure 39: Plot at 300Hz frequency

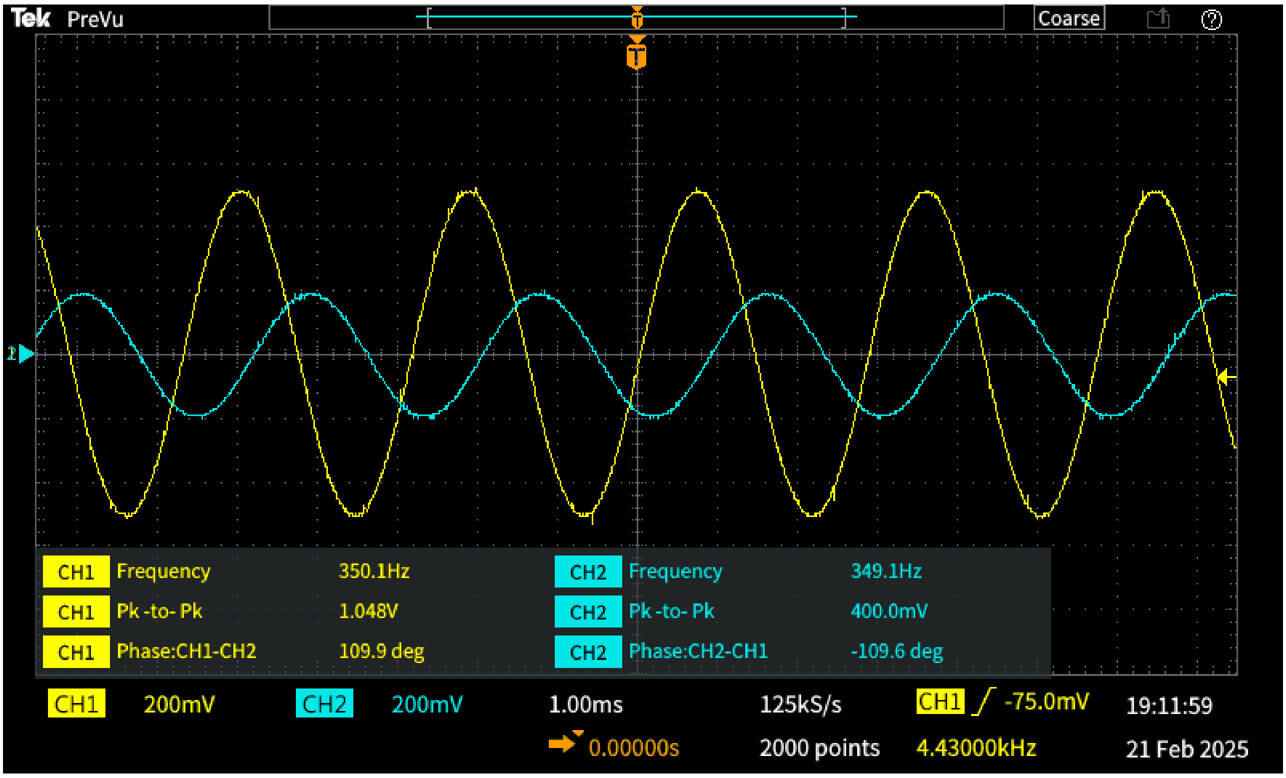

Figure 40: Plot at 350Hz frequency

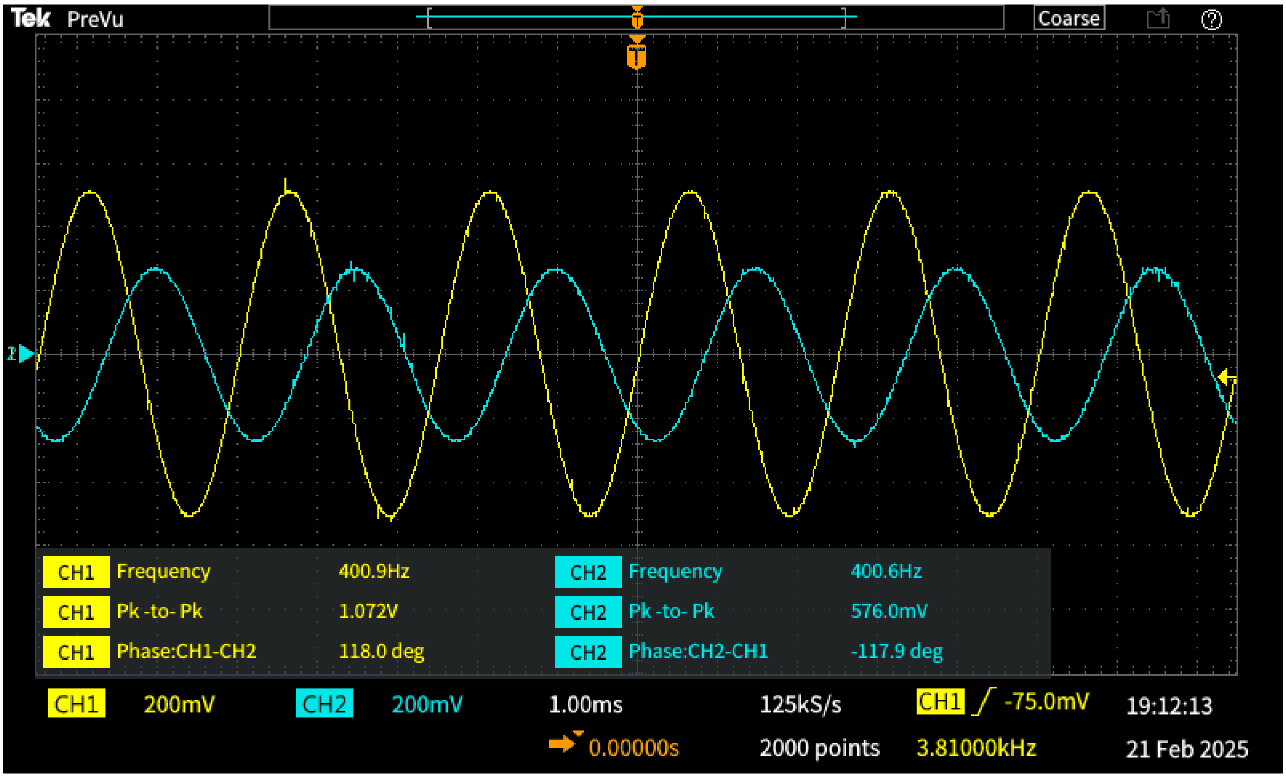

Figure 41: Plot at 400Hz frequency

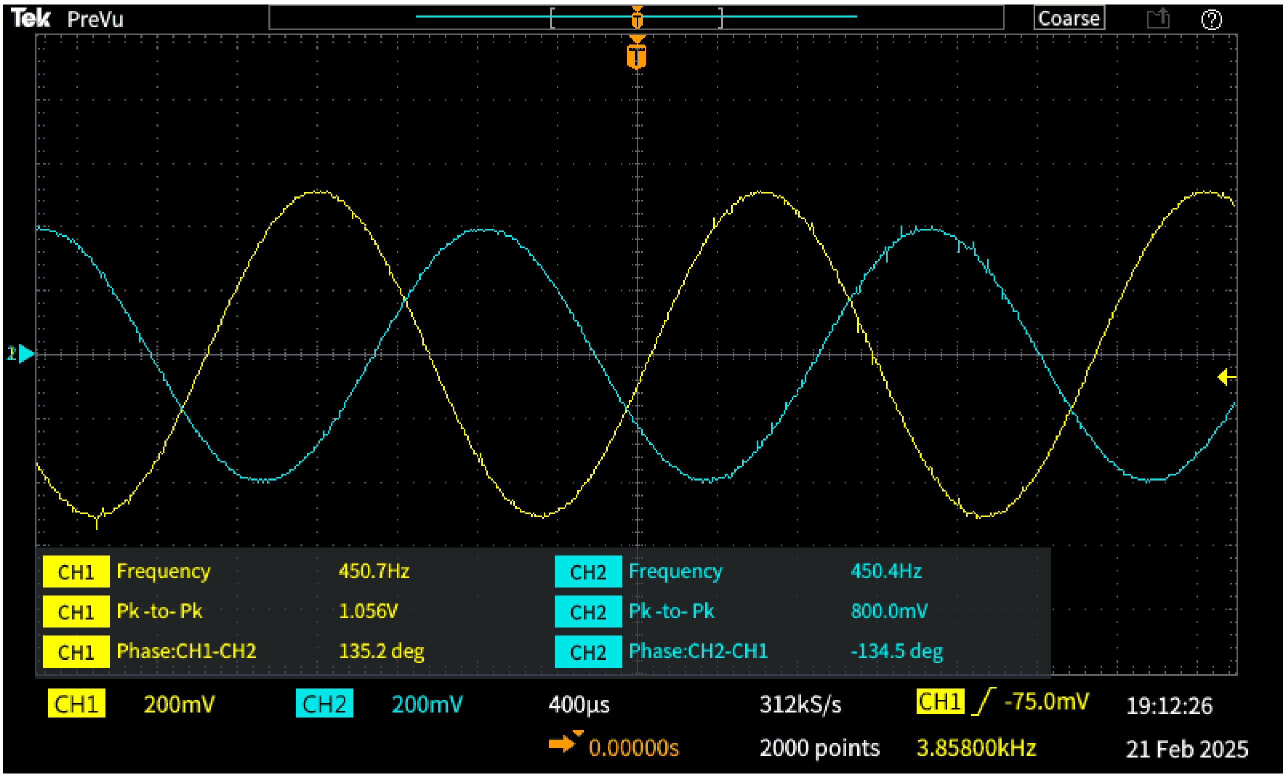

Figure 42: Plot at 450Hz frequency

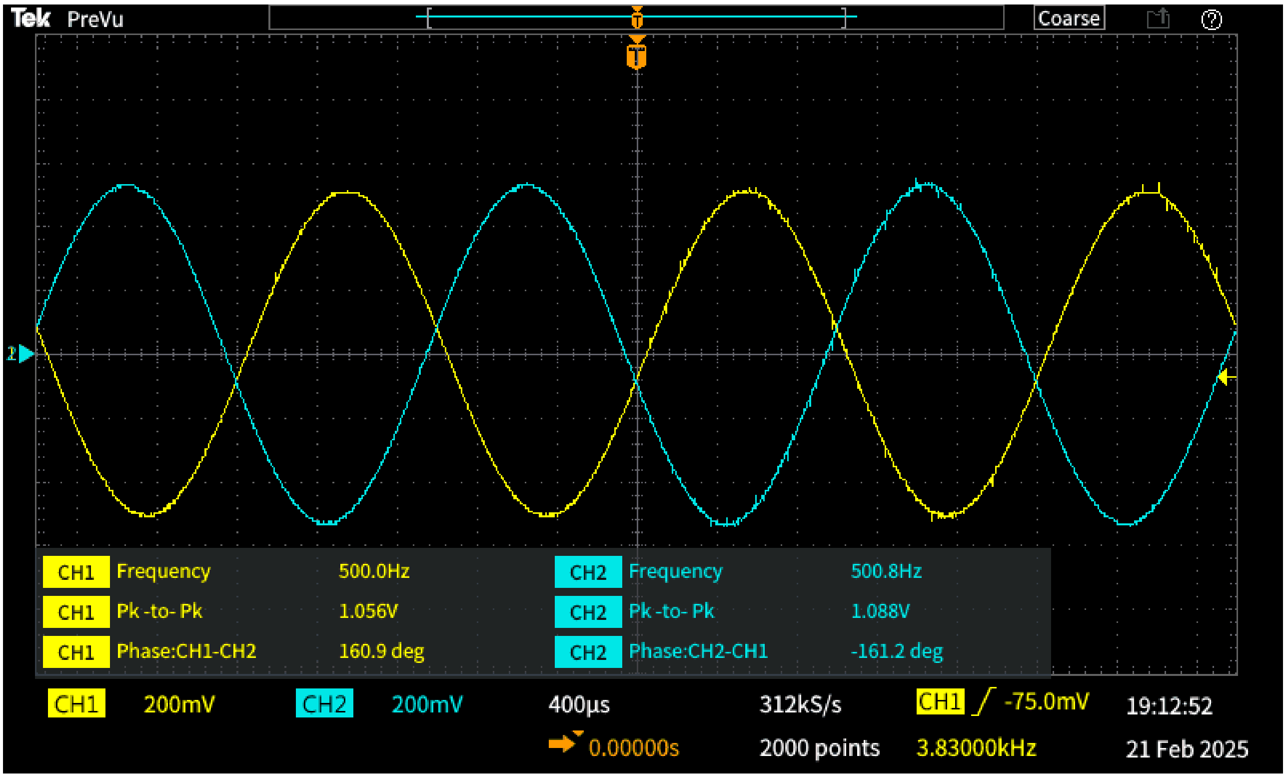

Figure 43: Plot at 500Hz frequency

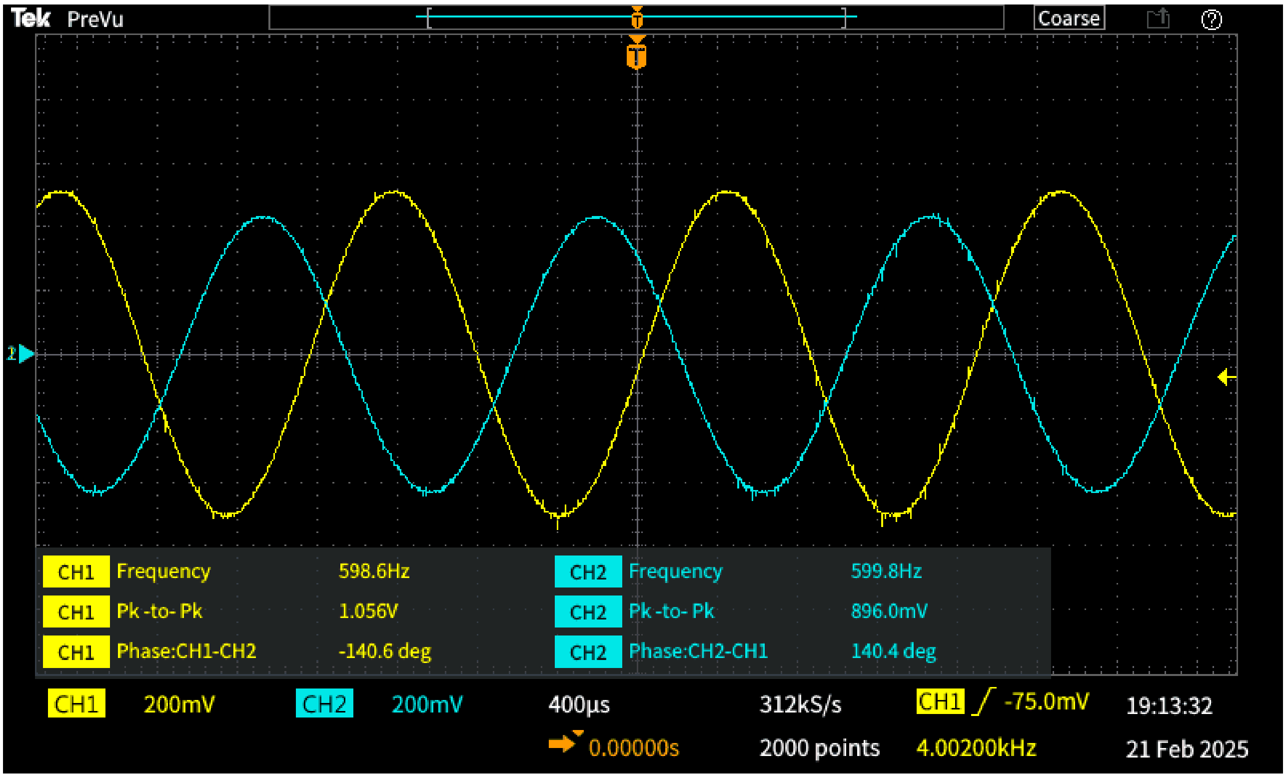

Figure 44: Plot at 600Hz frequency

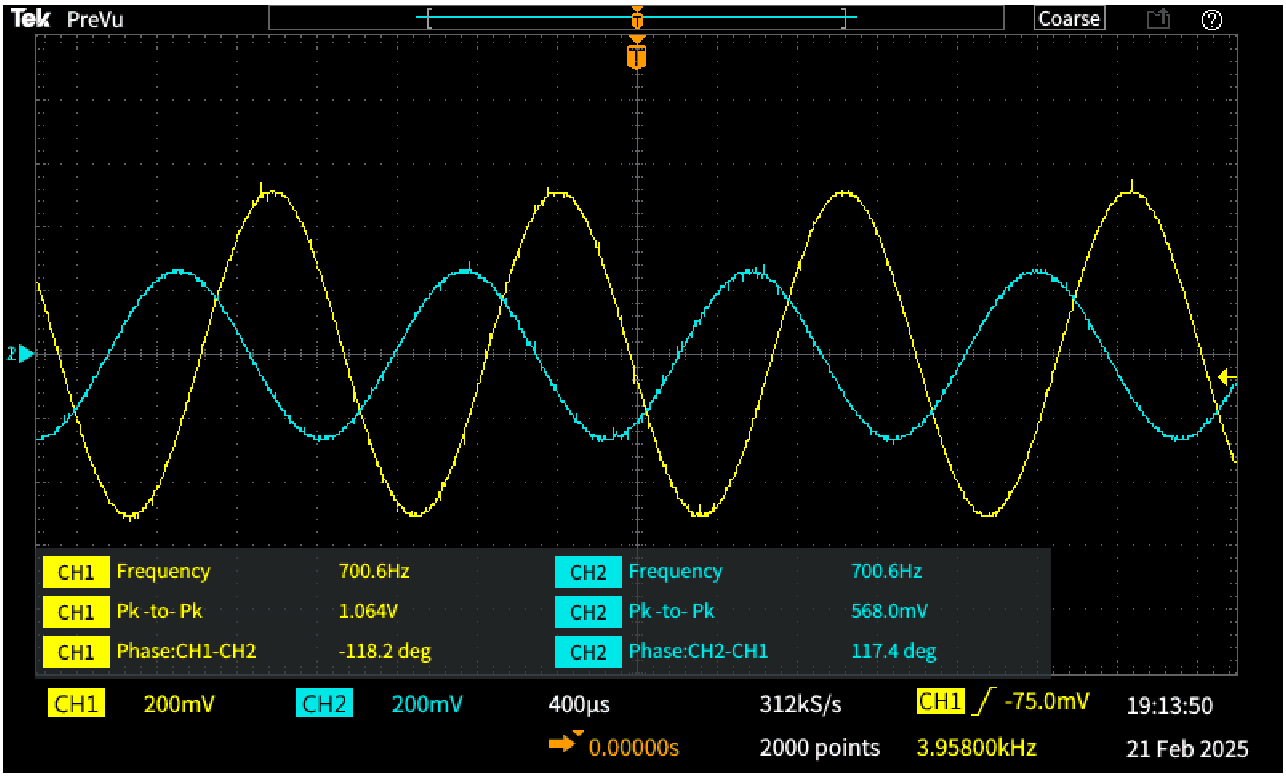

Figure 45: Plot at 700Hz frequency

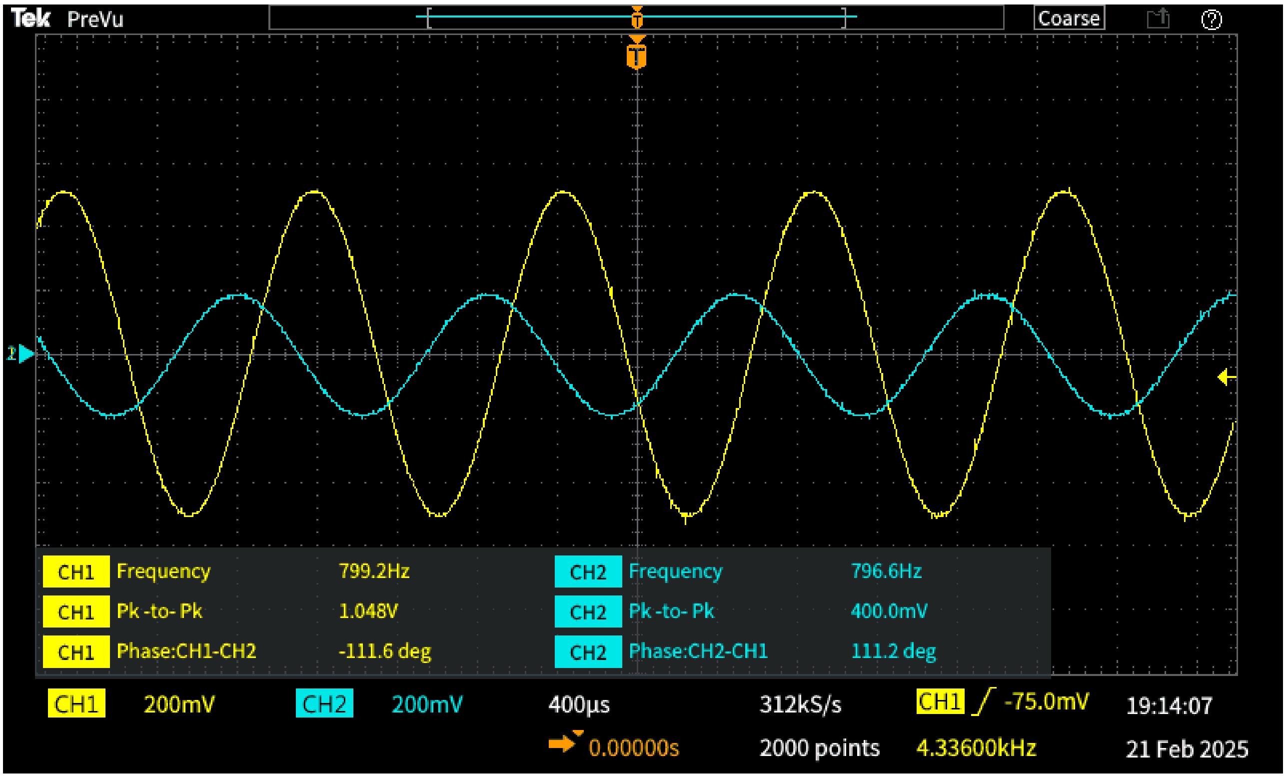

Figure 46: Plot at 800Hz frequency

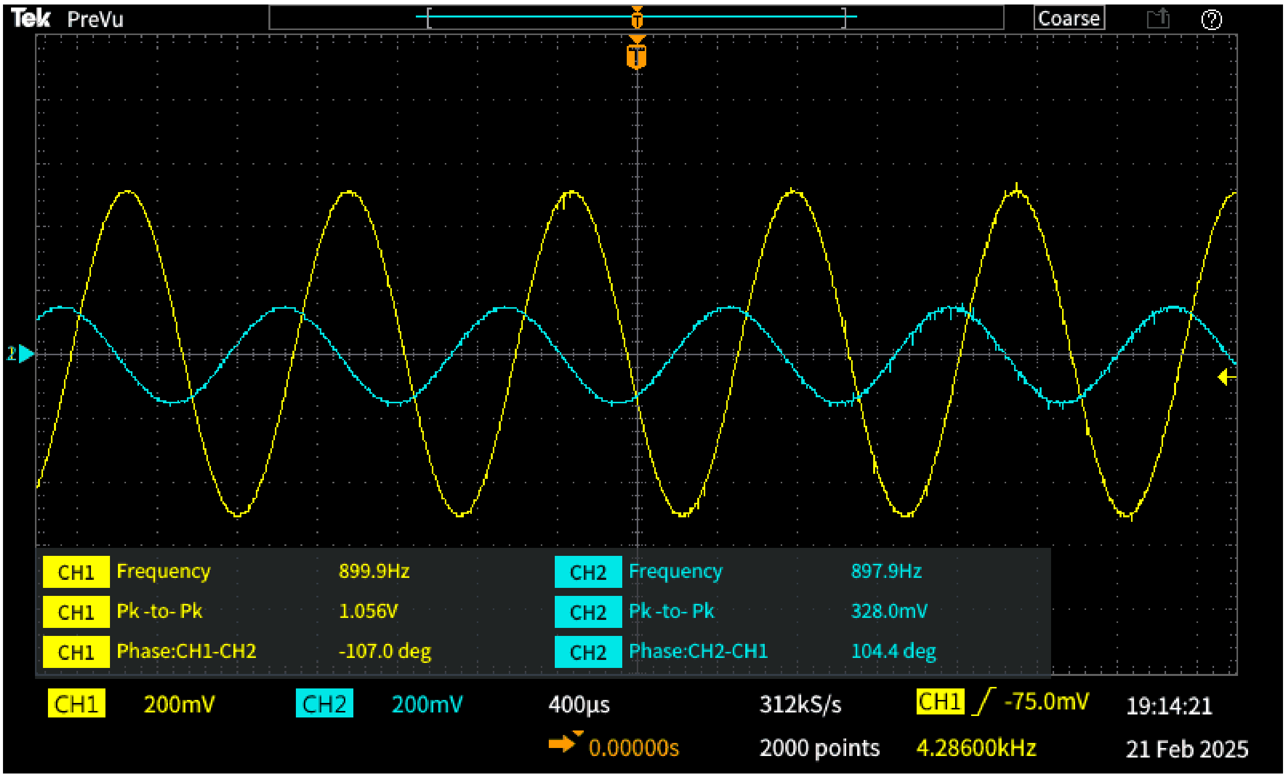

Figure 47: Plot at 900Hz frequency

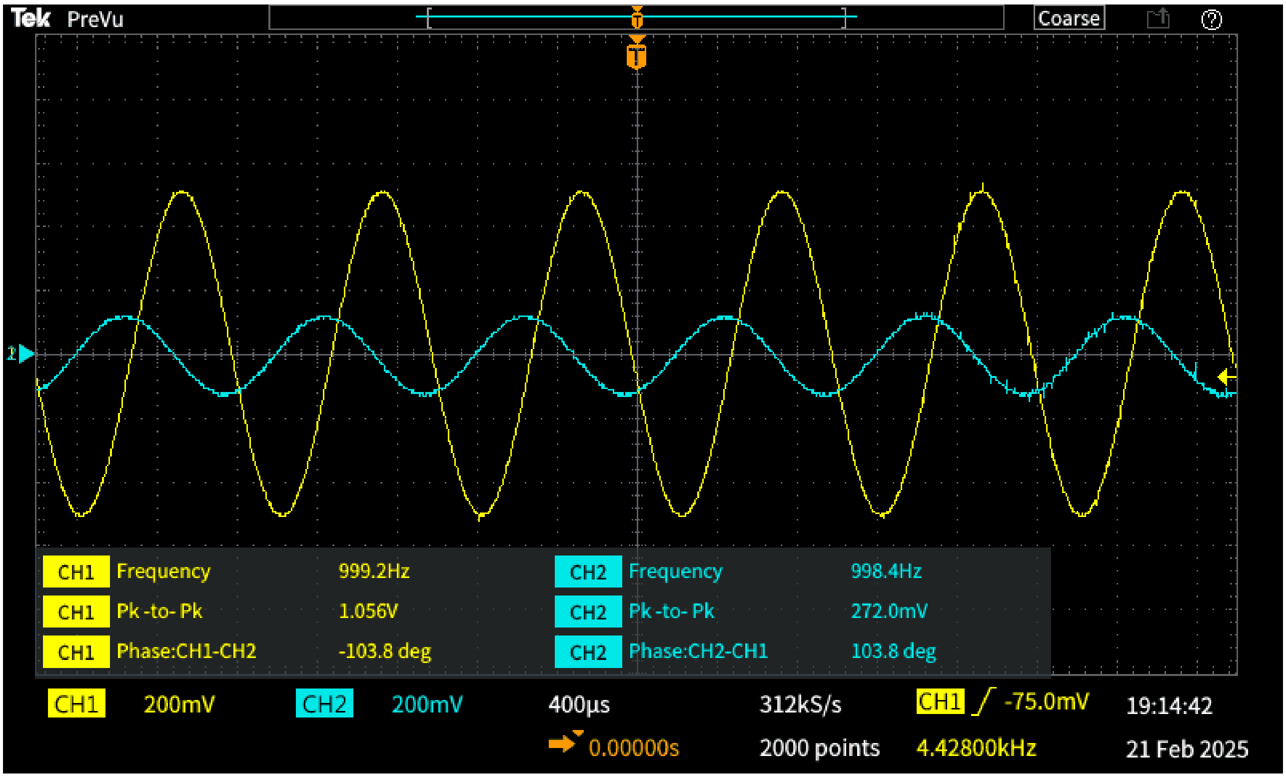

Figure 48: Plot at 1000Hz frequency

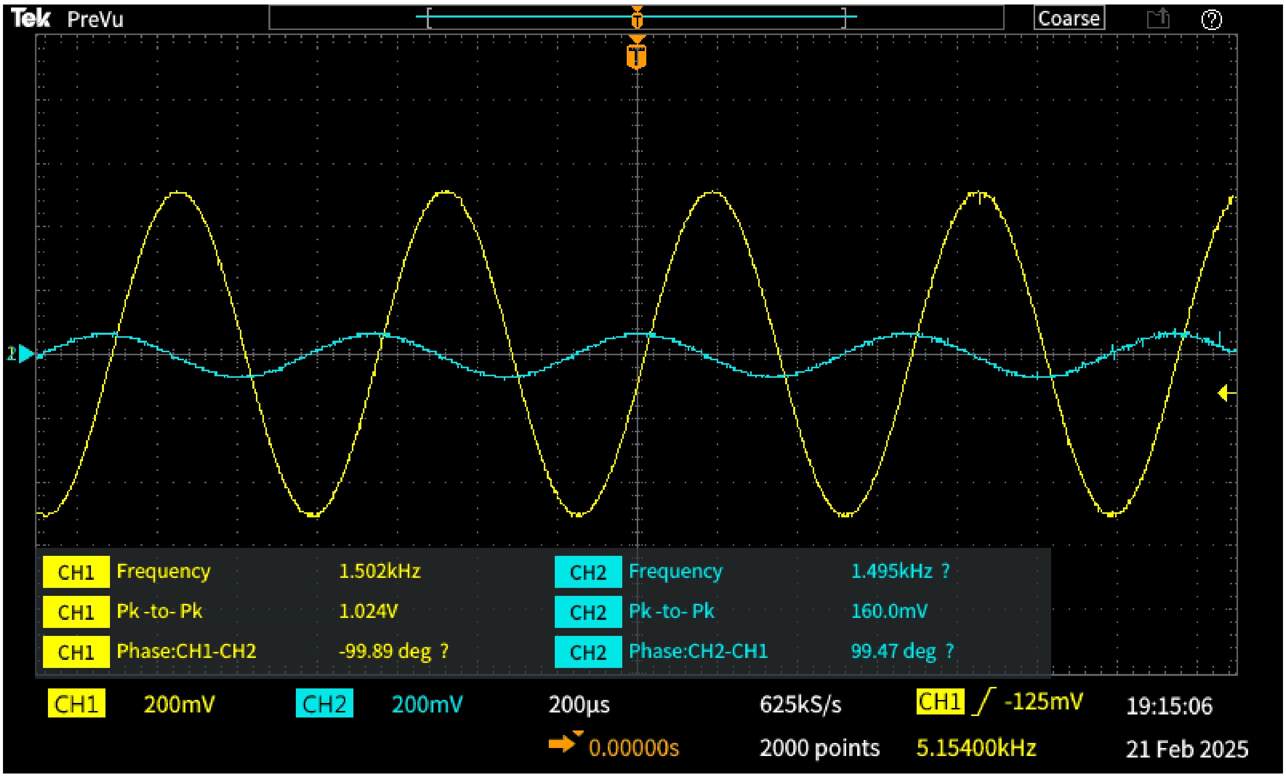

Figure 49: Plot at 1.5kHz frequency

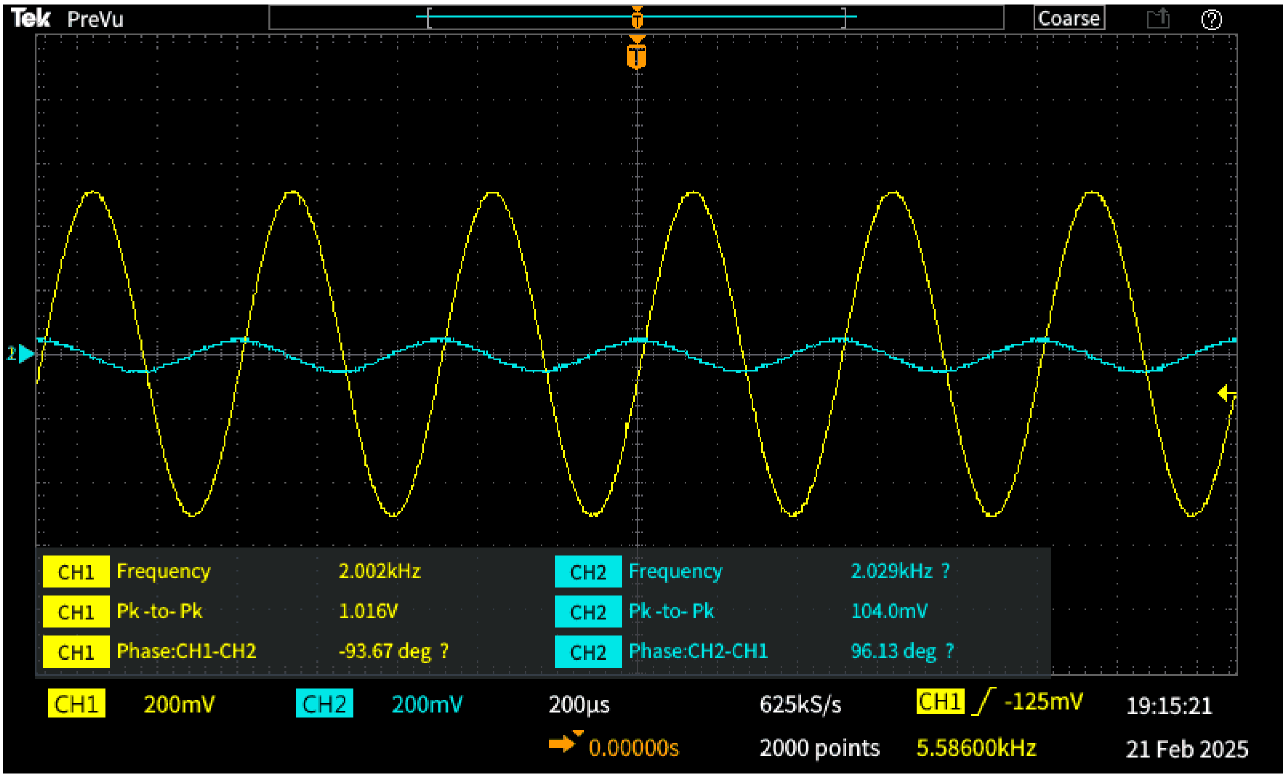

Figure 50: Plot at 2kHz frequency

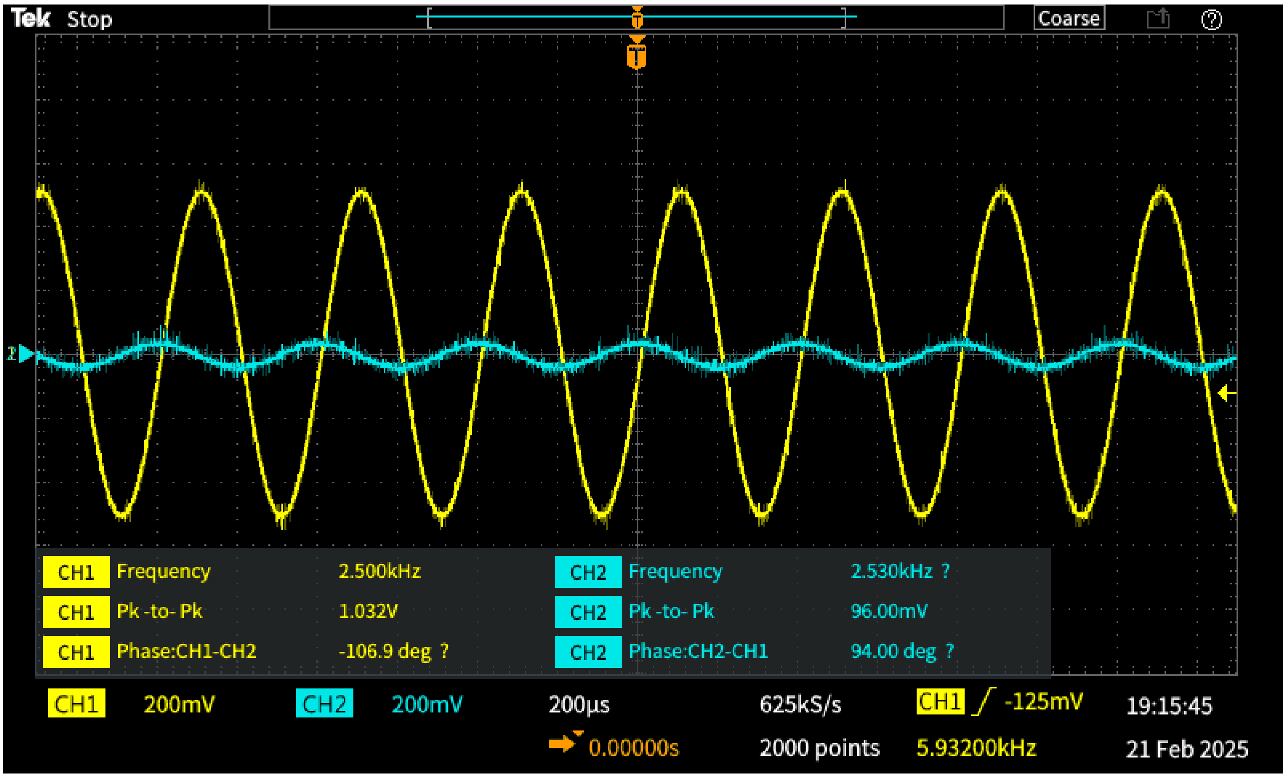

Figure 51: Plot at 2.5kHz frequency

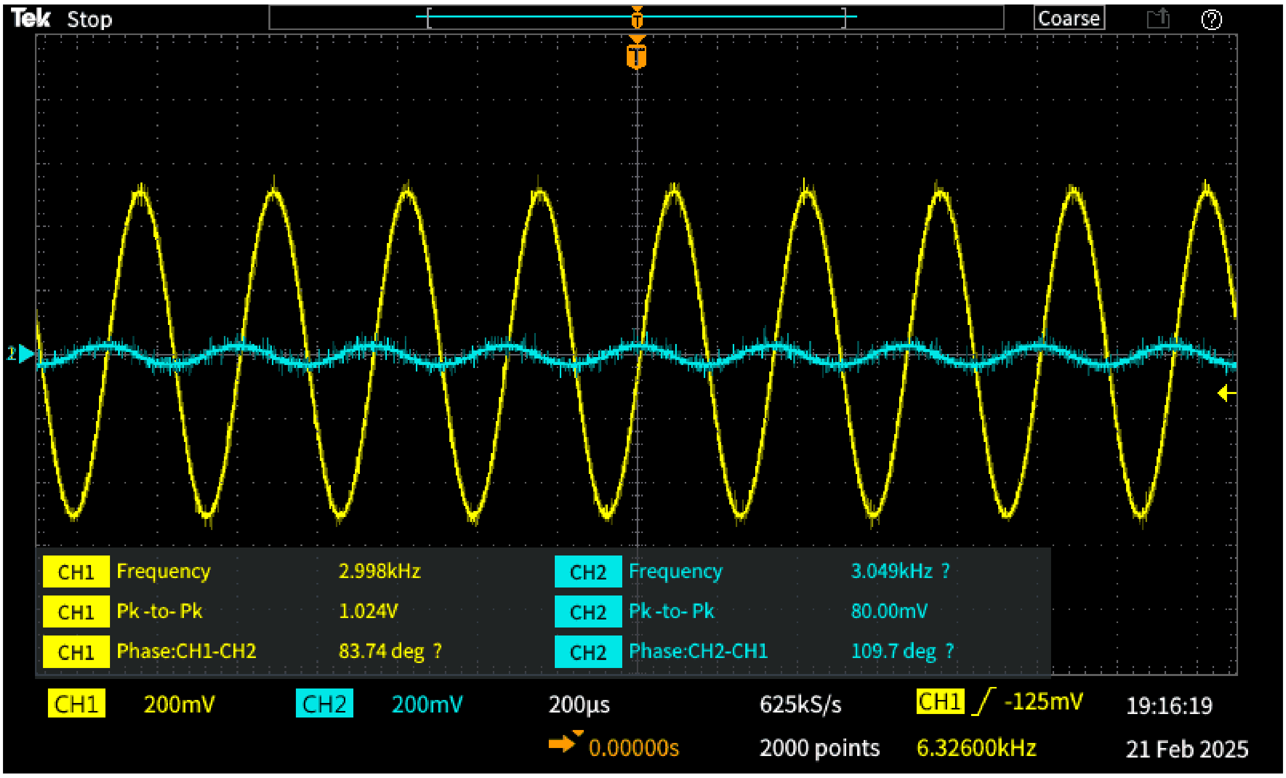

Figure 52: Plot at 3kHz frequency

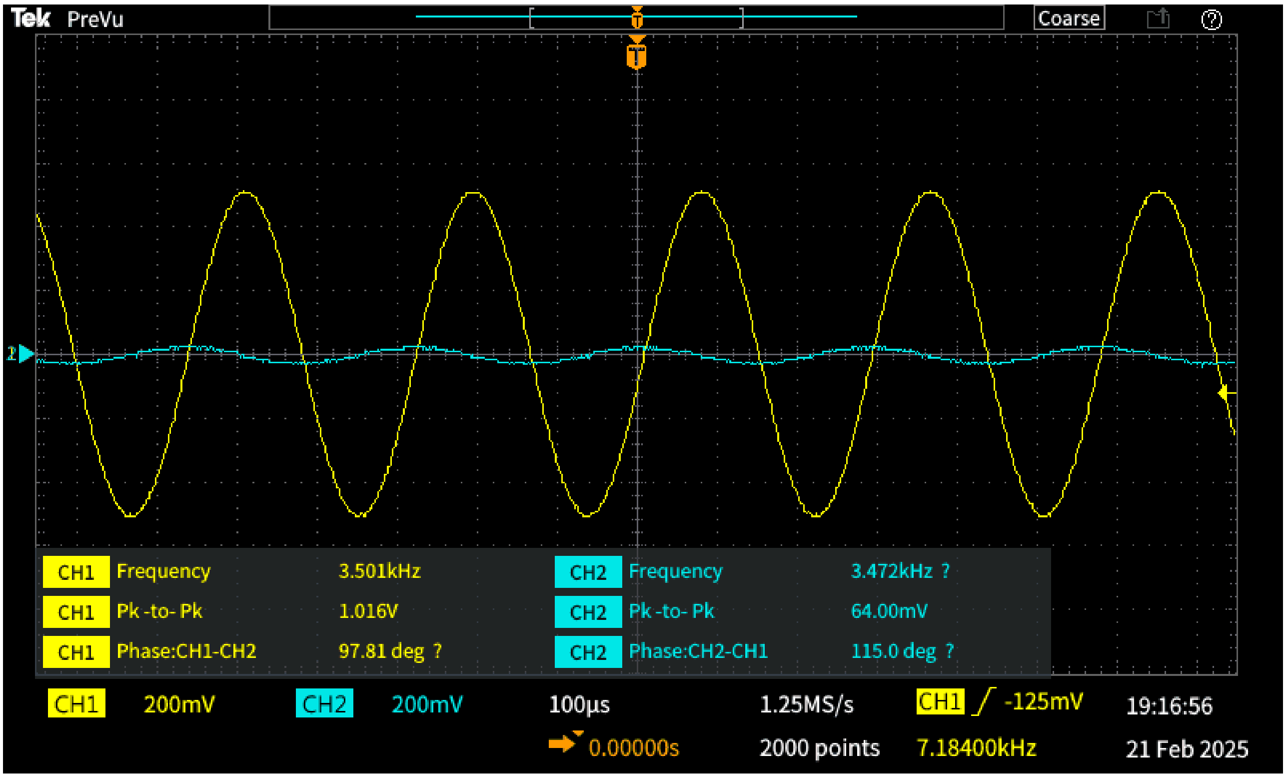

Figure 53: Plot at 3.5kHz frequency

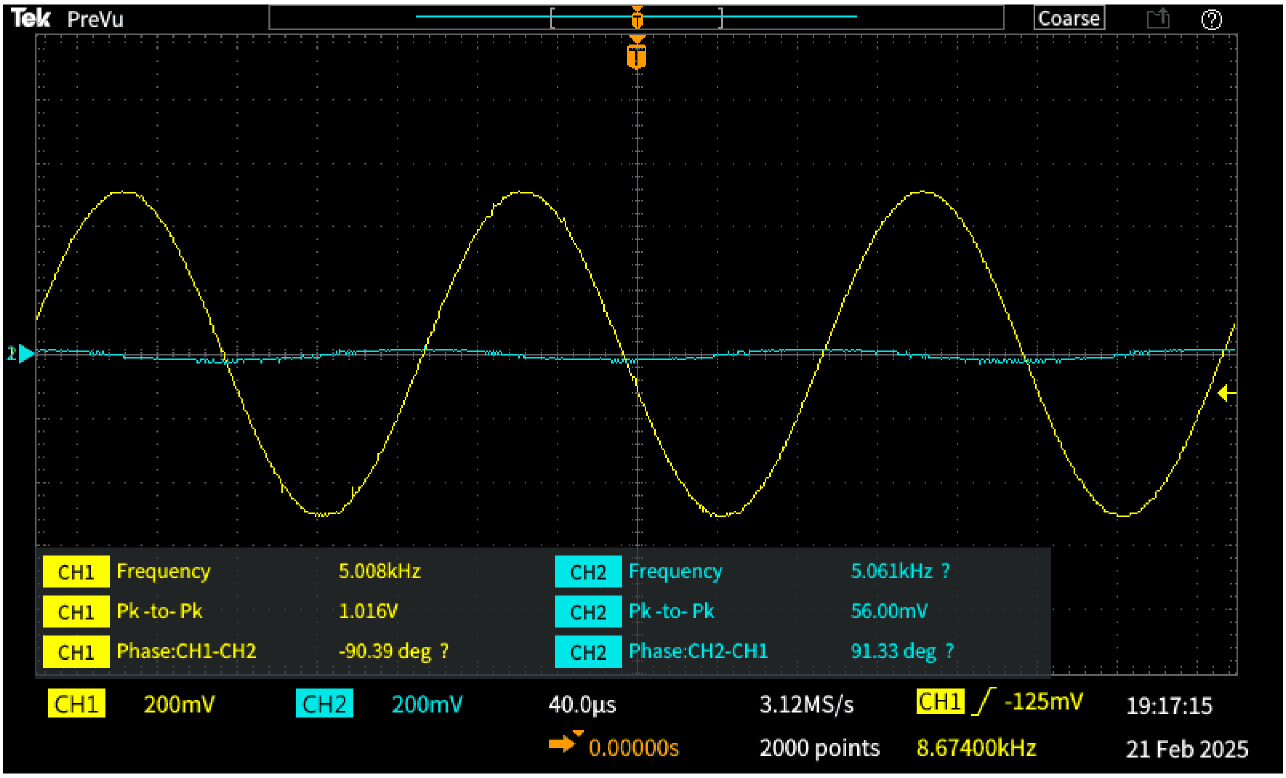

Figure 54: Plot at 5kHz frequency

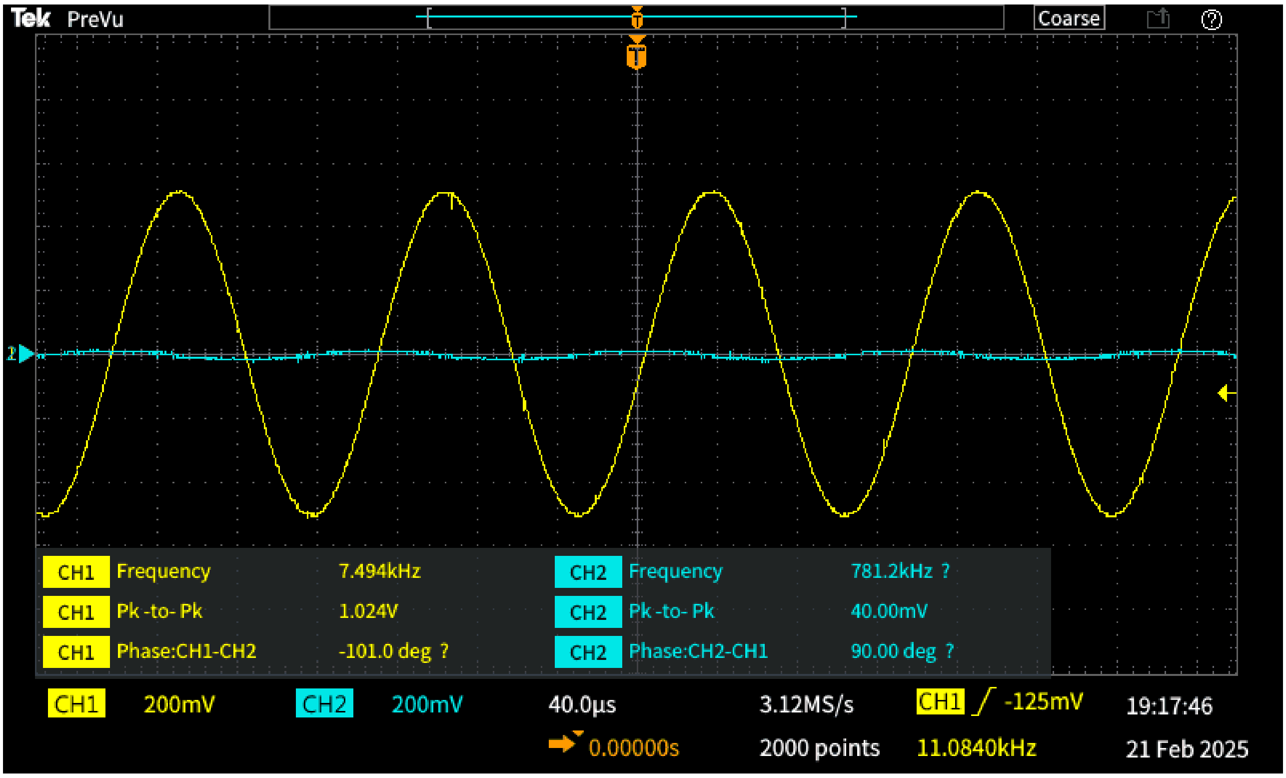

Figure 55: Plot at 7.5kHz frequency

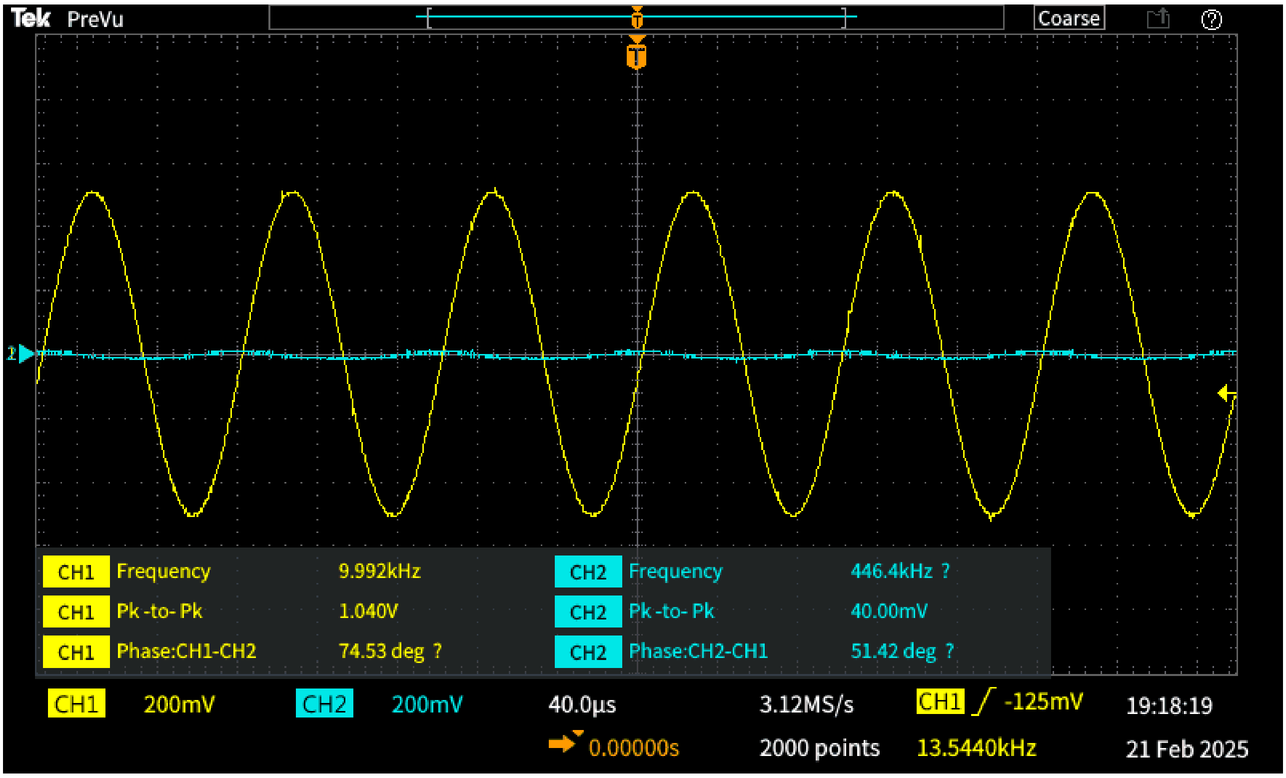

Figure 56: Plot at 10kHz frequency

3.6 Key Observations

- The bandwidth of the filter determined experimentally was observed to be around **180 Hz**, while the theoretical bandwidth was calculated as **176.83 Hz**, showing a small deviation.
- The gain decreased symmetrically on either side of the center frequency, confirming the band-pass nature of the filter.
- The response curve closely resembles the expected band-pass behavior, validating the theoretical design.

3.7 Conclusion and Inference

The theoretical and experimental values of center frequency and bandwidth are closely matching, with a minor deviation due to component tolerances and experimental uncertainties. The designed Multiple-Feedback Active Band-Pass Filter successfully achieves the desired frequency response.

3.8 Experiment Completion Status

I have successfully completed all the sections mentioned in this Experiment