The University of Texas Rio Grande Valley

College of Engineering and Computer Science

Department of Electrical & Computer Engineering

EECE 3230-1ET Electrical Engineering Lab II
Summer 2025

Lab Report #2: Filters and Transfer Functions

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Date:7/5/25

Contents

I. ABSTRACT

In this experiment, we were assigned Project H with two filters to design and build to meet certain specifications. For the first filter, we had a second-order Resonant Bandpass filter with a 360 Hz center frequency, quality factor of 12, and a 15 V/V peak gain. For the second filter we had a 5^{th} order, 1db Chebyshev low-pass filter with a 303 Hz cutoff frequency and a passband gain of 15 V/V.

Each component was derived by the use of transfer functions and included Chebyshev polynomials for the low-pass filter. After using theoretical analysis, we used PSPICE simulations to verify that the frequency response and step response plots would align with what we expected the filters to look like. We then proceeded to build each circuit using TL081 operational amplifiers, and we then measured the frequency response from 10Hz to 100 kHz. For the step responses of each filter, we used a square wave to approximate each unit step.

Our measured data revealed that the bandpass filter reached a peak at around 360 Hz with a gain that was close to 15V/V being 13.98V/V. While the Chebyshev low pass filter had a sharp roll-off with a ripple slightly higher than 1dB estimating to be around 1.36dB it was still within a reasonable margin and was likely caused by component tolerances or limitations in the op-amps themselves. Overall, the measured results validated both the design approach and the accuracy of our simulations.

II. BODY

PART A: Bandpass Filter

To begin this lab, we were first assigned a project letter which had its own set of specifications for what the filter should contain such as: the filter order, quality factor, passband gain, cutoff frequency, center frequency, and peak gain. For us, we were given project H with two separate filters to design. For the first filter (Filter #1) we had to build a 2^{nd} order resonant bandpass filter, and for the second filter (Filter #2) we had a 5^{th} order Chebyshev 1db low-pass filter (LPF). We will now begin constructing the resonant bandpass filter shown below.

To construct the Bandpass filter, the following specifications must be noted down for the given project letter filter specifications table (Table 1) which are the following:

Filter #1				
Type	Characteristic	Center (f)	Q	Peak Gain (Ao)
Bandpass	2^{nd} order Resonant	360 Hz	12	15 V/V

Table 1 - Filter Specifications for Bandpass Filter#1

Once the band-pass filter requirements are defined, the next step is to size the passive components for the second-order resonant topology. Beginning with the standard second-order band-pass transfer function, we equate its coefficients to those of the Vout/Vin expression derived from the circuit schematic.

The center (resonant) angular frequency, ω_0, is first calculated from the design target in Table 1:

$$\omega_0 = 2\pi f_0 = 2\pi \times 360 \text{ Hz} \approx 2262 \text{ rad} \cdot \text{s}^{-1}$$

With ω_0 known and all capacitors selected as 0.1 µF for ease of matching, we can solve the resulting system of coefficient equations to obtain the required resistor values R_1, R_2, and R_3. These values ensure that the implemented network meets the specified passband and quality-factor constraints while maintaining the desired gain and selectivity.

Given 2^{nd} Order Transfer Function

$$H(s) = \frac{Ao * s\left(\frac{w0}{Q}\right)}{s^2 + s\left(\frac{w0}{Q}\right) + w0^2}$$

$$H(s) = \frac{(15) \cdot s\left(\frac{2262}{12}\right)}{s^2 + s\left(\frac{2262}{12}\right) + 2262^2}$$

$$H(s) = \frac{(2828)s}{s^2 + \left(\frac{2262}{12}\right)s + 2262^2}$$

Resonant Bandpass Filter Transfer Function

$$H(s) = \frac{-s\left(\frac{1}{R1 * C1}\right)}{s^2 + (\frac{C1 + C2}{R3 * C1 * C2})s + \left(\frac{1}{(R1||R2)R3 * C1 * C2}\right)}$$

Compare Coefficients that are Highlighted

$$\frac{1}{R1 \cdot C1} = 2828$$

$$\frac{1}{R1 \cdot (0.1\mu F)} = 2828$$

$$R1 = 3536\Omega\,,\ C1 = 0.1\mu F$$

$$\frac{C1 + C2}{R3 \cdot C1 \cdot C2} = 189$$

$$\frac{(0.1\mu F + 0.1\mu F)}{R3 \cdot 0.1\mu F \cdot 0.1\mu F} = 189$$

$$R3 = 106103\Omega\,,\ C2 = 0.1\mu F$$

$$\frac{1}{(R1 \parallel R2) \cdot R3 \cdot C1 \cdot C2} = (2262)^2$$

$$\frac{1}{(3536\Omega \parallel R2) \cdot R3 \cdot C1 \cdot C2} = (2262)^2$$

$$\frac{1}{\left(\frac{3536 \cdot R2}{3536 + R2}\right) \cdot (106103\Omega) \cdot 0.1\mu F \cdot 0.1\mu F} = (2262)^2$$

$$R2 = 194.32\Omega$$

Once the theoretical values for R_1, R_2, R_3, and the capacitors were determined, practical component selection followed. Each calculated resistance was matched to the nearest available standard value resistor, and the capacitors were chosen from the same preferred series to maintain tolerance consistency. The resulting band pass filter was then assembled with a single TL081 operational amplifier. The finalized schematic is presented below.

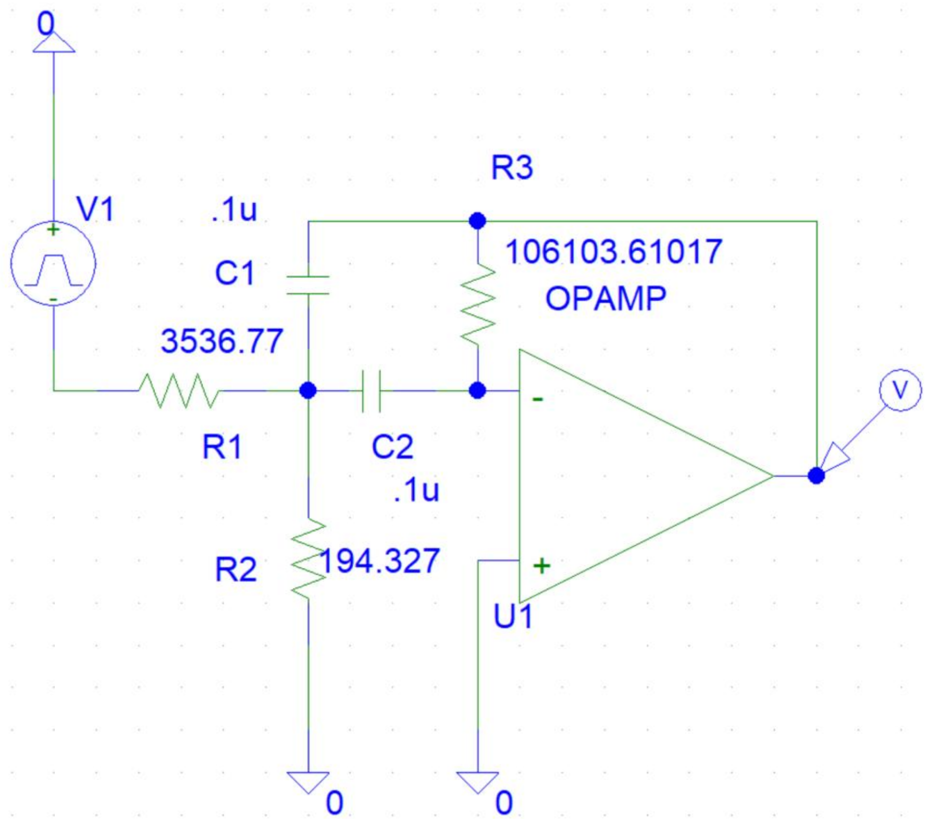
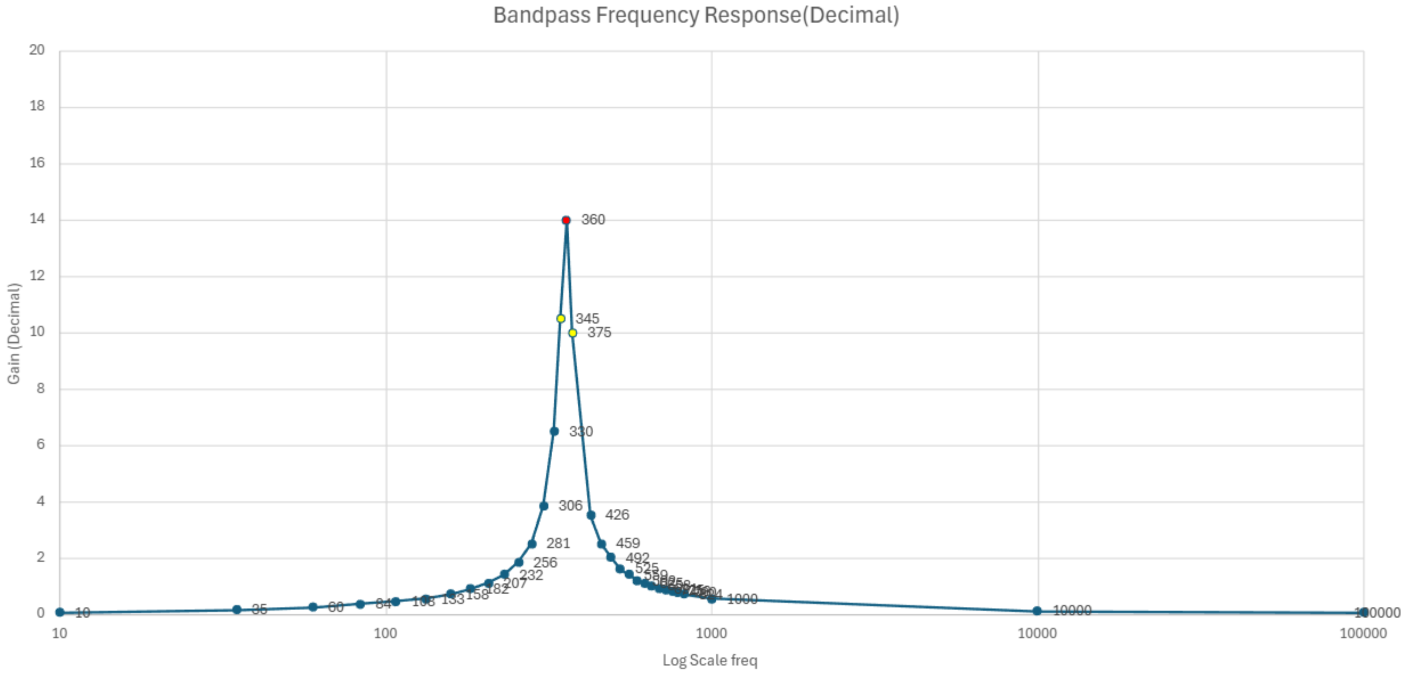


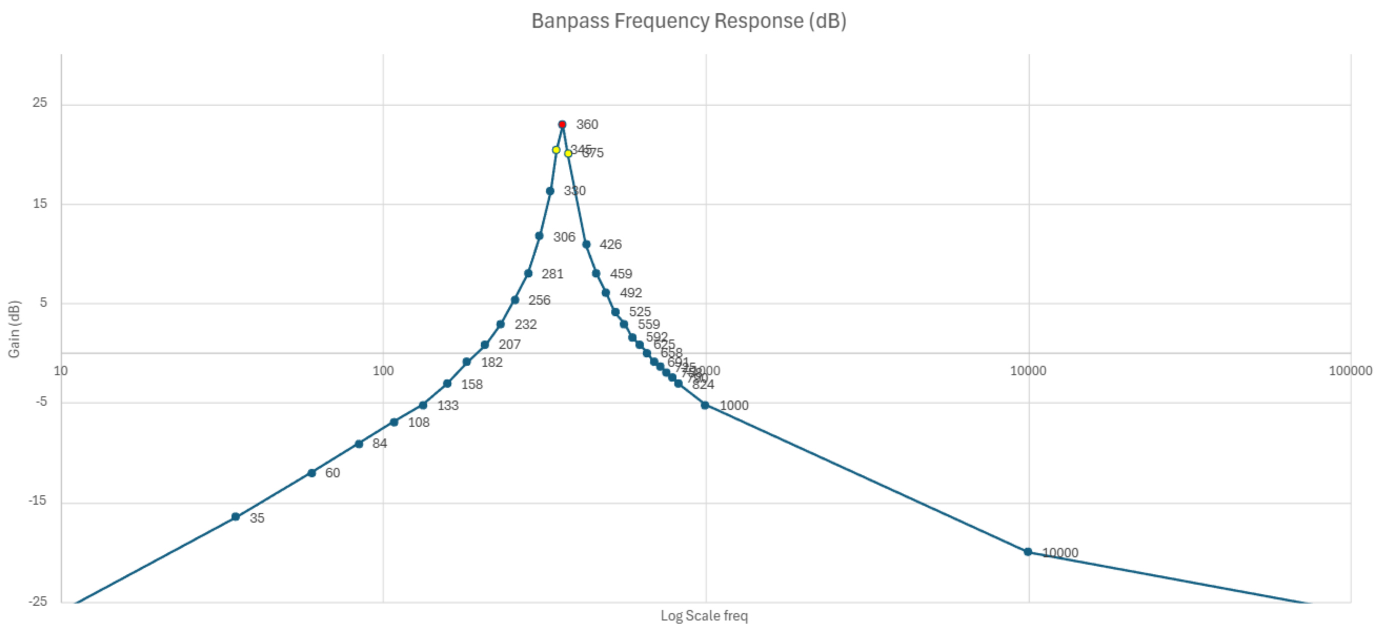
Figure 1 - Resonant Bandpass Filter Circuit Schematic

PART B: Bandpass Filter

With the resonant band-pass filter assembled, its performance must be validated against the design targets listed in Table 1. This is done by recording an experimental Bode plot. With magnitude |Vout/Vin| on the y-axis versus frequency on the x-axis using a sweep or a series of discrete test frequencies across and beyond the intended passband. From this response we extract the mid-band (peak) gain A_0, the -3 dB bandwidth, and the quality factor Q, and then compare those values to the specification. A properly tuned second-order band-pass network will display the expected bell-shaped (inverted-parabolic) magnitude curve, confirming that the circuit meets its design specifications.



Bode Plot 2 - Bandpass Filter Bode Plot (Decimal)



Bode Plot 1 - Bandpass Filter Bode Plot (Decibels)

To verify that the bandpass filter meets its design goals, we examined three quantities taken from the measured Bode magnitude response: the center (resonant) frequency fc, the -3 dB bandwidth BW, and the quality factor Q.

Center frequency

The magnitude curve peaks at 360 Hz, exactly matching the specified fc in Table 1.

Mid-band gain:

At fc the measured gain is 13.98 V/V (≈ 22.91 dB). Although the original target was 15 V/V, the 7% shortfall was accepted by the instructor.

Bandwidth and -3 dB points:

When the plot is in linear units, the -3 dB level equals $A_o/\sqrt{2}$. Hence

$A_o/\sqrt{2}$ = 13.98 V/V / $\sqrt{2}$ ≈ 9.02 V/V.

The response reaches this value at

f_L = 345 Hz (lower corner)

f_R = 375 Hz (upper corner)

Converting to angular frequency ($\omega = 2\pi f$) and subtracting gives the experimental bandwidth:

$BW_{exp} = 2\pi$ (375 Hz − 345 Hz) ≈ 188.5 rad s^{-1}.

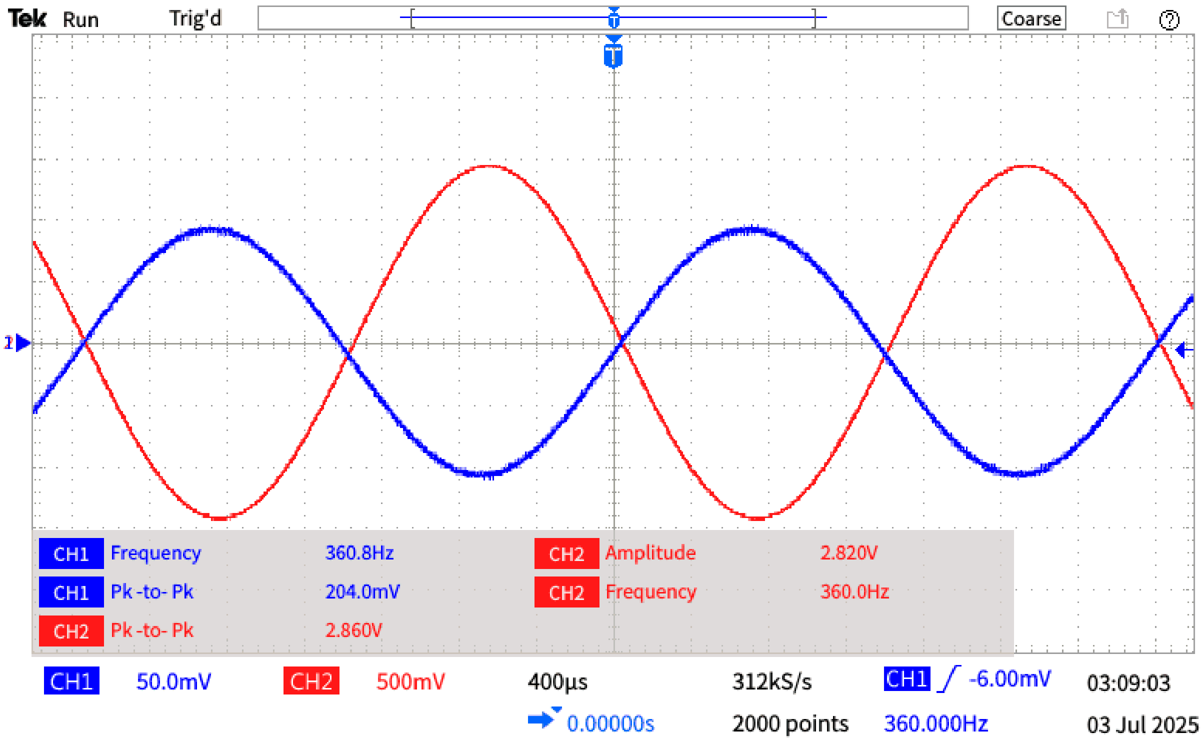
Comparison with theory:

The theoretical bandwidth is $BW_{theory} = \omega_0/Q$ = 2261.95 rad s^{-1} / 12 ≈ 188.5 rad s^{-1}, identical to the measured value.

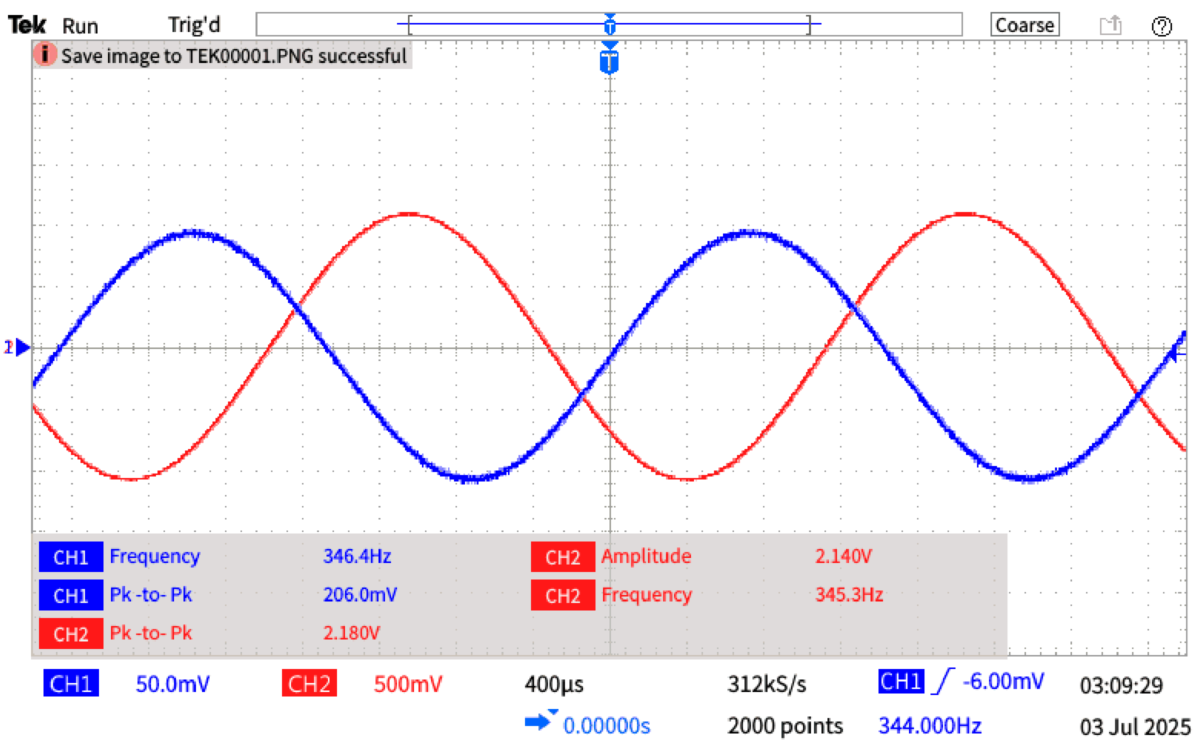
Quality factor:

Using the frequency definition, $Q = f_c/(f_R - f_L)$ = 360 Hz / (375 Hz − 345 Hz) = 12, which exactly matches the design requirement.

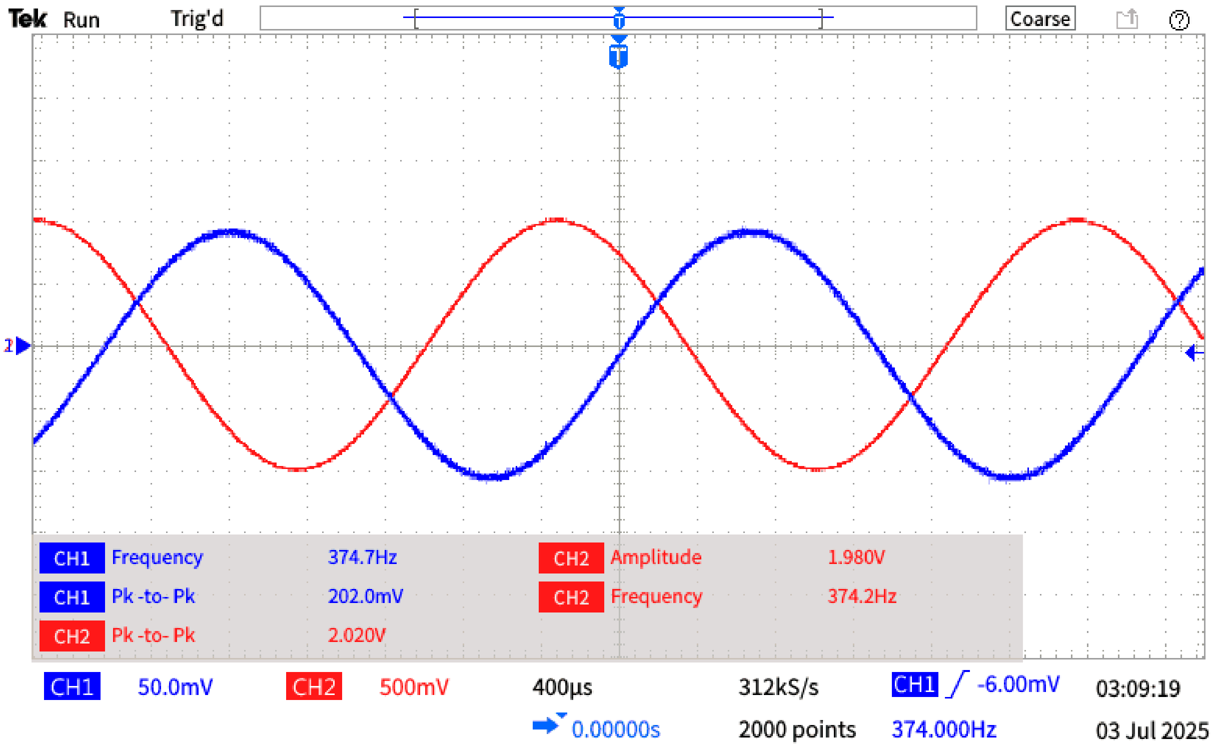
Scopeshots of fc, fL, and fR with Vin, Vout, and the -3 dB provided below.



Scope Shot 1 - fc Peak Frequency of Bandpass Filter



Scope Shot 2 - fL Left Frequency of Bandpass Filter



Scope Shot 3 - fR Right Frequency of Bandpass Filter

PART A Chebychev Low Pass Filter:

After the band-pass filter was completed, we moved on to Filter #2, the Chebyshev low-pass filter (LPF), for construction and evaluation. As with the earlier stage, the design had to meet specific performance targets. For project assignment H, the required cutoff frequency, pass-band ripple, filter order, and pass-band gain are listed in the specification table below:

Filter #2				
Type	Characteristic (Ripple)	Order (n)	Cutoff (fo)	Passband Gain (Ap)
LPF	Chebychev 1 dB	5	303 Hz	15 V/V

Table 2 - Filter Specifications for Chebychev Low Pass Filter (LPF) Filter#2

To synthesize the fifth-order Chebyshev low-pass filter, begin by listing the design targets:

Ripple (ε) = 1 dB

Filter order: $n = 5$

Cutoff frequency: $f_0 = 303$ Hz

Pass-band gain A_p: = 15 V/V

Angular cutoff frequency: $\omega_0 = 2\pi f_0 = 2\pi \times 303 \text{ Hz} \approx 1.904 \times 10^3 \text{ rad s}^{-1}$

With these parameters established, we consulted the laboratory handout for the normalized fifth-order Chebyshev denominator that corresponds to 1 dB ripple. The required polynomials are:

Chebychev Polynomials

Transfer functions based on Chebychev Polynomials result in filters with passband ripple. However, the initial rolloff near the cutoff frequency is steeper, which is useful in many applications. Like the Butterworth polynomials, there are Chebychev polynomials of different orders, depending on how sharp of a cutoff is needed. There are different sets of polynomials which allow different amounts of ripple in the passband. The polynomials for 0.5 dB ripple are:

$Q_1(s) = s + 2.863$
$Q_2(s) = s^2 + 1.425s + 1.516$
$Q_3(s) = s^3 + 1.253s^2 + 1.535s + 0.716 = (s + 0.626)(s^2 + 0.626s + 1.142)$
$Q_4(s) = s^4 + 1.197s^3 + 1.717s^2 + 1.025s + 0.379 =$
$(s^2 + 0.351s + 1.064)(s^2 + 0.845s + 0.356)$
$Q_5(s) = s^5 + 1.172s^4 + 1.937s^3 + 1.309s^2 + 0.753s + 0.179 =$
$(s + 0.362)(s^2 + 0.224s + 1.036)(s^2 + 0.586s + 0.477)$

For 1.0 dB ripple they are:

$Q_1(s) = s + 1.965$
$Q_2(s) = s^2 + 1.098s + 1.103$
$Q_3(s) = s^3 + 0.988s^2 + 1.238s + 0.491 = (s + 0.494)(s^2 + 0.494s + 0.994)$
$Q_4(s) = s^4 + 0.953s^3 + 1.454s^2 + 0.743s + 0.276 =$
$(s^2 + 0.279s + 0.987)(s^2 + 0.674s + 0.279)$
$Q_5(s) = s^5 + 0.937s^4 + 1.689s^3 + 0.974s^2 + 0.581s + 0.123 =$
$(s + 0.289)(s^2 + 0.179s + 0.988)(s^2 + 0.468s + 0.429)$
$Q_6(s) = (s^2 + 0.1244s + 0.9910)(s^2 + 0.3398s + 0.5577)(s^2 + 0.4641s + 0.1247)$

$$Q5(s) = s5 + 0.937s4 + 1.689s3 + 0.974s2 + 0.581s + 0.123$$

$$= (s + 0.289)(s2 + 0.179s + 0.988)(s2 + 0.468s + 0.429)$$

$$Q2(s) = s2 + 1.425s + 1.516$$

$$Q3(s) = (s + 0.626)(s2 + 0.626s + 1.142)$$

To complete the transfer function H(s)=K/Q5(s), the scaling constant K must be chosen so that the magnitude at s=0 equals the specified pass-band gain A_p. Solving $|H(0)|=A_p$ yields the value of K, after which the component-value synthesis can proceed.

$$K = Ap * Q(s = 0)$$

$$K = (15)(0 + 0.289)(0^2 + 0.179(0) + 0.988)(0^2 + 0.468(0) + 0.429)$$

$$K = 1.8374$$

Once the scaling factor K is determined, the normalized transfer function takes the form

$$H(s) = \frac{K}{Q(s)}$$

For low-pass design, substitute s with s/w0, where:

$$w0 = 1.904 * 10^3 \text{rad} \cdot \text{s}^{-1}$$

After this substitution, each denominator factor is algebraically scaled, so the coefficient of its highest-order term equals unity.

The next step mirrors the procedure used for the band-pass filter: match the coefficients of the normalized transfer function to the standard first and second-order low-pass templates associated with the practical circuits being implemented. Because a fifth-order Chebyshev response is required, the realization employs two cascaded second-order low-pass sections followed by one first-order section, yielding the overall fifth-order response. All capacitors are fixed at 0.1 µF, so only the resistor values need to be calculated. The detailed algebra, coefficient matching, and resulting resistor selections are presented in the following step-by-step derivation:

SIMPLIFY GENERAL TRANSFER EQUATION

$$H(s) = \frac{K}{Q(s)}$$

$$H(s) = \frac{1.8374}{(s + 0.289)(s^2 + 0.179s + 0.988)(s^2 + 0.468s + 0.429)}$$

$$H(s) = \frac{1.8374}{\left(\frac{s}{1903.81}+0.289\right)\left(\left(\frac{s}{1903.81}\right)^2+0.179\left(\frac{s}{1903.81}\right)+0.988\right)\left(\left(\frac{s}{1903.81}\right)^2+0.468\left(\frac{s}{1903.81}\right)+0.429\right)},$$

Replace s = s/w0

$$H(s) = \frac{1.8374}{\left(\frac{s}{1903.81}+0.289\right)\left(\left(\frac{s}{1903.81}\right)^2+0.179\left(\frac{s}{1903.81}\right)+0.988\right)\left(\left(\frac{s}{1903.81}\right)^2+0.468\left(\frac{s}{1903.81}\right)+0.429\right)} * \frac{s^5}{s * s^2 * s^2}$$

$$H(s) = \frac{1.8374}{\left(\frac{s}{1903.81}+0.289\right)\left(\left(\frac{s}{1903.81}\right)^2+0.179\left(\frac{s}{1903.81}\right)+0.988\right)\left(\left(\frac{s}{1903.81}\right)^2+0.468\left(\frac{s}{1903.81}\right)+0.429\right)} * \frac{\left(\frac{0.289}{1} * \frac{0.988}{1} * \frac{0429}{1}\right)}{\left(\frac{0.289}{1} * \frac{0.988}{1} * \frac{0429}{1}\right)}$$

$$H(s) = \frac{1.8374(1903.81)^5}{(s + 0.289(1903.81))(s^2 + 0.179(1903.81)s + 0.988(1903.81)^2)(s^2 + 0.468(1903.81)s + 0.429(1903.81)^2)}$$

SOLVE FOR ONE 2nd ORDER LPF RESISTANCES BY COMPARING COEFFICIENTS

$$H(s) = \frac{Ao * \left(\frac{1}{RC}\right)^2}{s^2 + \frac{3 - Ao}{RC}s + \left(\frac{1}{RC}\right)^2}$$

$$\left(\frac{1}{RC}\right)^2 = 0.988(1903.81)^2$$

$$(\left(\frac{1}{R(0.1\,uF)}\right)^2 = 0.988(1903.81)^2) = R$$

R = 5284.43 Ω

$$\frac{3 - Ao1}{RC} = 0.179(1903.81)$$

$$\frac{3 - Ao1}{(5284.43)(0.1\,uF)} = 0.179(1903.81) = 2.81992$$

$$Ao1 = 2.81992\frac{V}{V}$$

FIND R1 & R2 USING GAIN EQUATION (Ao1)

$$Ao1 = 1 + \frac{R2}{R1}$$

$$2.81992 = 1 + \frac{R2}{R1}$$

Pick R1 = 10k Ω

$$R2 = 18199.2\,\Omega$$

SOLVE FOR THE OTHER 2nd ORDER LPF RESISTANCES BY COMPARING COEFFICIENTS

$$\left(\frac{1}{RC}\right)^2 = 0.429(1903.81)^2$$

$$\left(\frac{1}{R(0.1\,uF)}\right)^2 = 0.429(1903.81)^2 = R$$

R = 8019.51

$$\frac{3 - Ao2}{RC} = 0.468(1903.81)$$

$$\frac{3 - Ao2}{(8019.51)(0.1\,uF)} = 0.468(1903.81)$$

$$Ao2 = 2.28548\frac{V}{V}$$

FIND R1 & R2 USING GAIN EQUATION (Ao2)

$$Ao2 = 1 + \frac{R2}{R1}$$

$$2.28548 = 1 + \frac{R2}{R1}$$

Pick R1 = 10k Ω

R2 = 12854.8 Ω

SOLVE FOR ONE 1st ORDER LPF RESISTANCES BY COMPARING COEFFICIENTS

$$H(s) = Ao * \frac{\frac{1}{RC}}{s + \frac{1}{RC}}$$

$$\frac{1}{RC} = 0.289(1903.81)$$

$$\frac{1}{R(0.1\,uF)} = 0.289(1903.81) = R$$

R = 18175.2 Ω

FIND R1 & R2 USING GAIN EQUATION (Ao3)

$$Ao1 * Ao2 * Ao3 = 15\frac{V}{V}$$

$$(2.81992) * (2.28548) * Ao3 = 15\frac{V}{V}$$

$$Ao3 = 2.32743\frac{V}{V}$$

$$Ao = 1 + \frac{R2}{R1}$$

$$2.32743 = 1 + \frac{R2}{R1}$$

Pick R1 = 10k Ω

R2 = 13274.3 Ω

After establishing the theoretical resistance values, each resistor was matched to the nearest available part. Where the exact value was unavailable, two resistors were placed in series to achieve the required total within tolerance. The completed filter is arranged as a cascade that begins with the first order low-pass stage, followed by the two second order stages, yielding the fifth-order Chebyshev response. Every active section uses a TL081 operational amplifier. The schematic below shows the final layout together with the rounded resistor values selected for each stage:

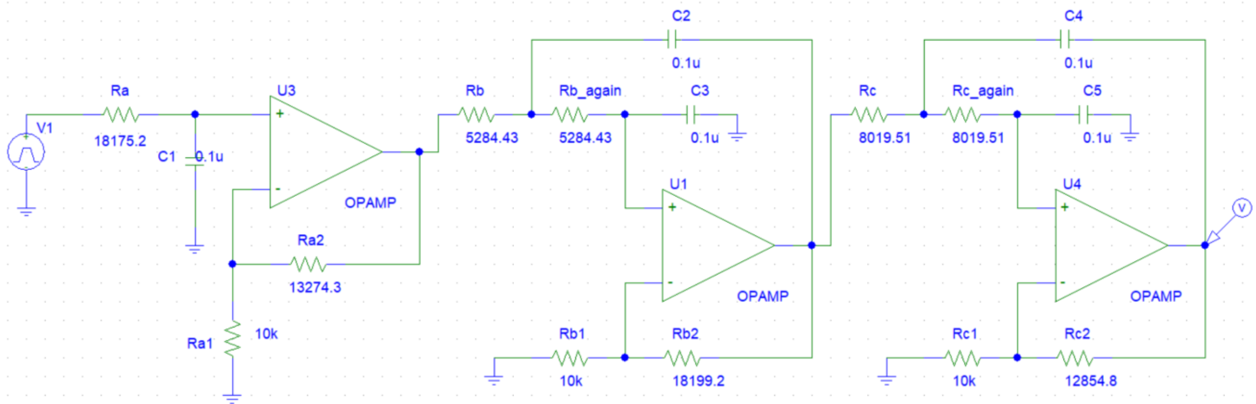
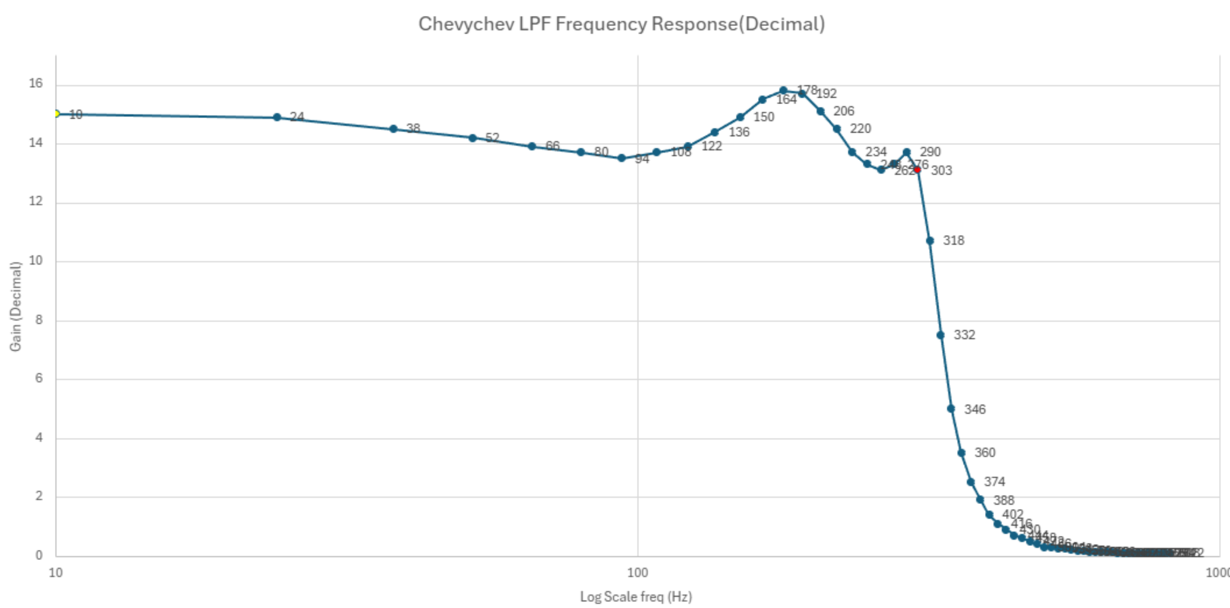


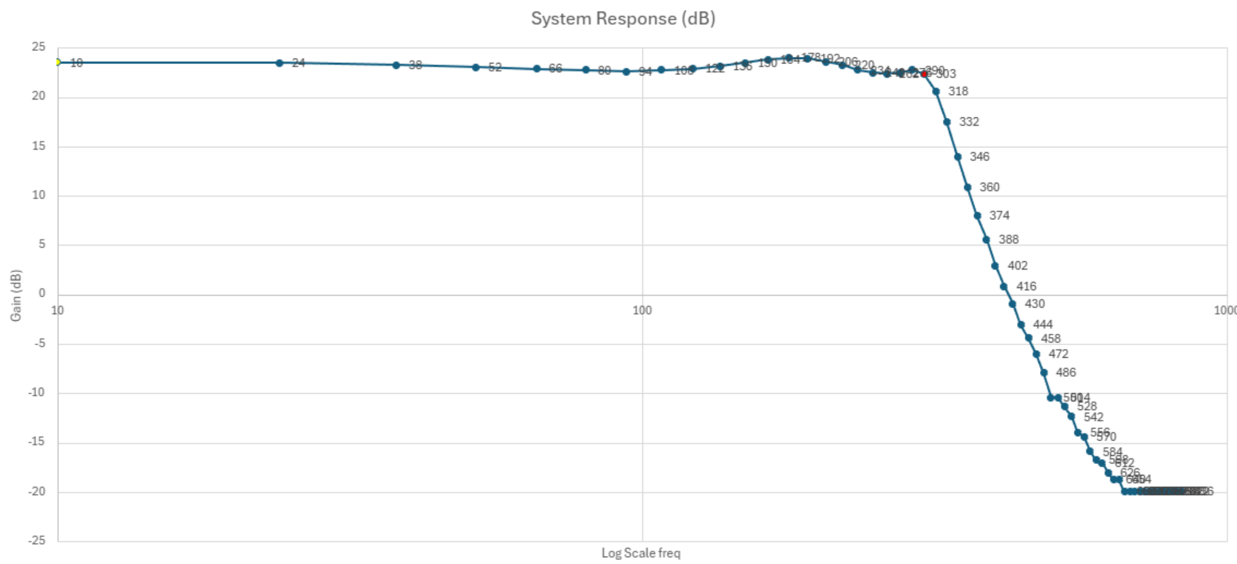
Figure 2 - Chebychev Low Pass Filter Circuit Schematic

PART B: Chebychev Low Pass Filter

Once the Chebyshev low-pass filter was assembled, its performance had to be verified. Two parameters were of primary interest: the cutoff frequency and the pass-band gain. Both were extracted from an experimental Bode-magnitude response plotted as |Vout / Vin| on the vertical axis versus frequency (Hz) on the horizontal axis. A dense set of measurement points was recorded across the spectrum to capture the characteristic shape: a nearly flat pass-band at low frequencies that exhibits a 1 dB ripple, followed by a steep roll-off beyond the cutoff. The resulting Bode plot confirms whether the observed cutoff frequency aligns with the specified 303 Hz and whether the pass-band gain approaches the design target of 15 V/V:



Bode Plot 3 – Chebychev LPF Bode Plot (Decimal)



Bode Plot 4 - Chebychev LPF Bode Plot (dB)

To confirm proper operation of the Chebyshev low-pass filter, focus on three parameters: the 1 dB pass-band ripple, the design cutoff frequency, and the specified pass-band gain. The ripple magnitude is evaluated first, using the following formula:

$$Ripple = Peak\ gain\ in\ dB - lowest\ peak\ of\ the\ ripple\ in\ dB$$

Or

$$Ripple = 20\log(peak\ gain\ decimal) - 20\log\,(lowest\ peak\ of\ ripple\ gain\ in\ decimal)$$

$$Ripple = 20\log(15.8) - 20\log(13.5) = 1.36\ dB$$

The measured response confirms that the Chebyshev low-pass stage is operating within tolerance:

Ripple assessment

The peak-to-peak variation in the pass-band, taken from the Bode plot, is 1.36 dB. Relative to the specified 1 dB ripple, the deviation is 0.36 dB, or approximately 36 percent.

Cutoff frequency

At very low frequencies the gain settles at the designed 15 V/V. Sweeping the input upward shows the gain returning to this 15 V/V plateau just before the response begins to fall, a point that occurs at 303 Hz. This measured cutoff frequency matches the design value exactly.

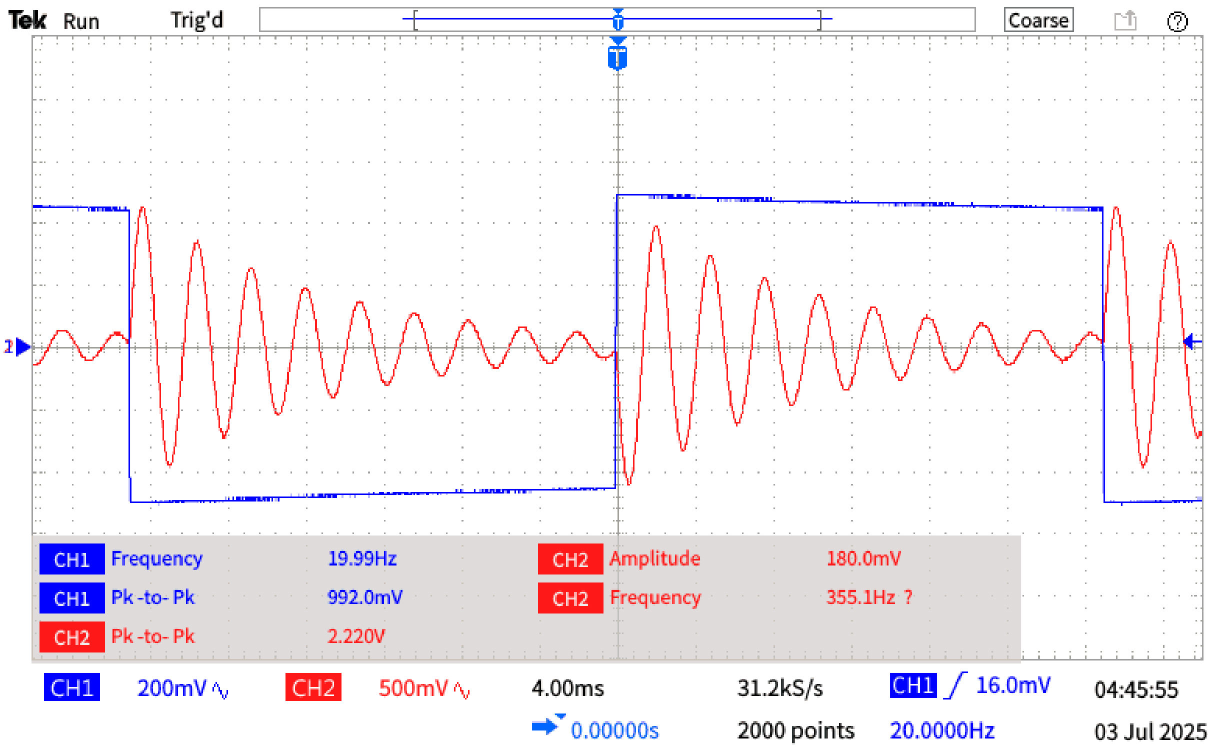
Pass-band gain

The constant low-frequency gain was recorded as 15 V/V, identical to the specification, so the error is effectively zero and was accepted by the instructor.

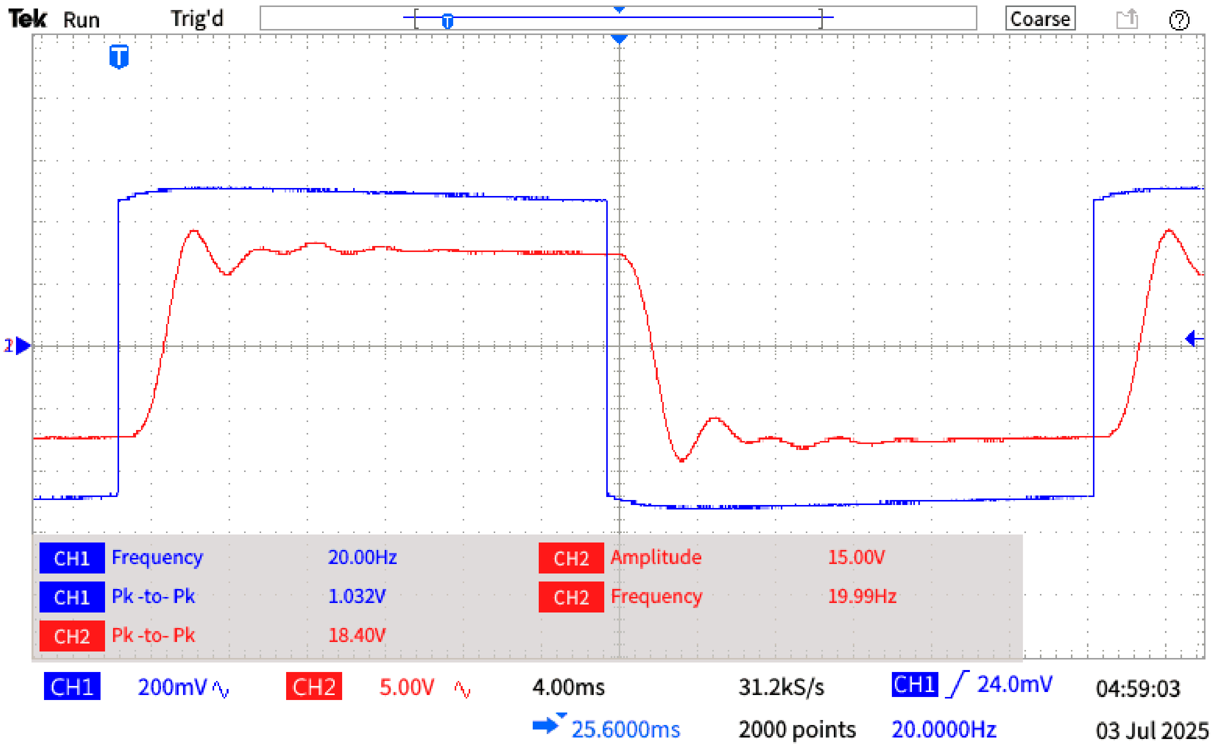
These three observations—including ripple magnitude, cutoff alignment, and pass-band gain—demonstrate that the prototype meets the project requirements.

STEP RESPONSES

Each filter's step response was captured by sending the circuit a low-frequency square wave from the function generator, effectively approximating a unit-step input. The resulting oscilloscope traces for the band-pass network and the 1 dB-ripple, fifth-order Chebyshev low-pass filter are shown below:



Scope Shot 4 - Recorded Step Response for Bandpass Filter

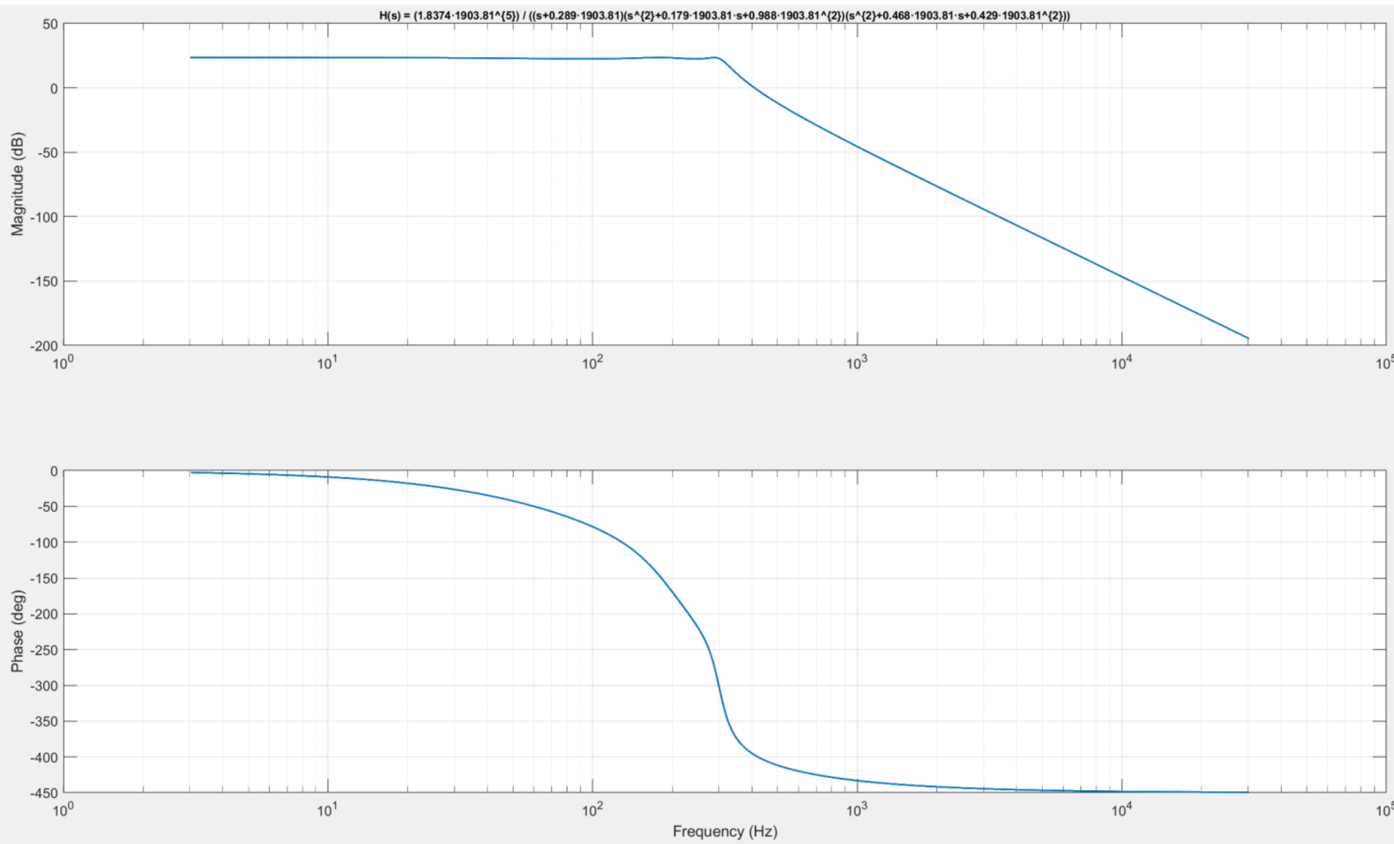


Scope Shot 5 - Recorded Step Response for Chebychev Low Pass Filter

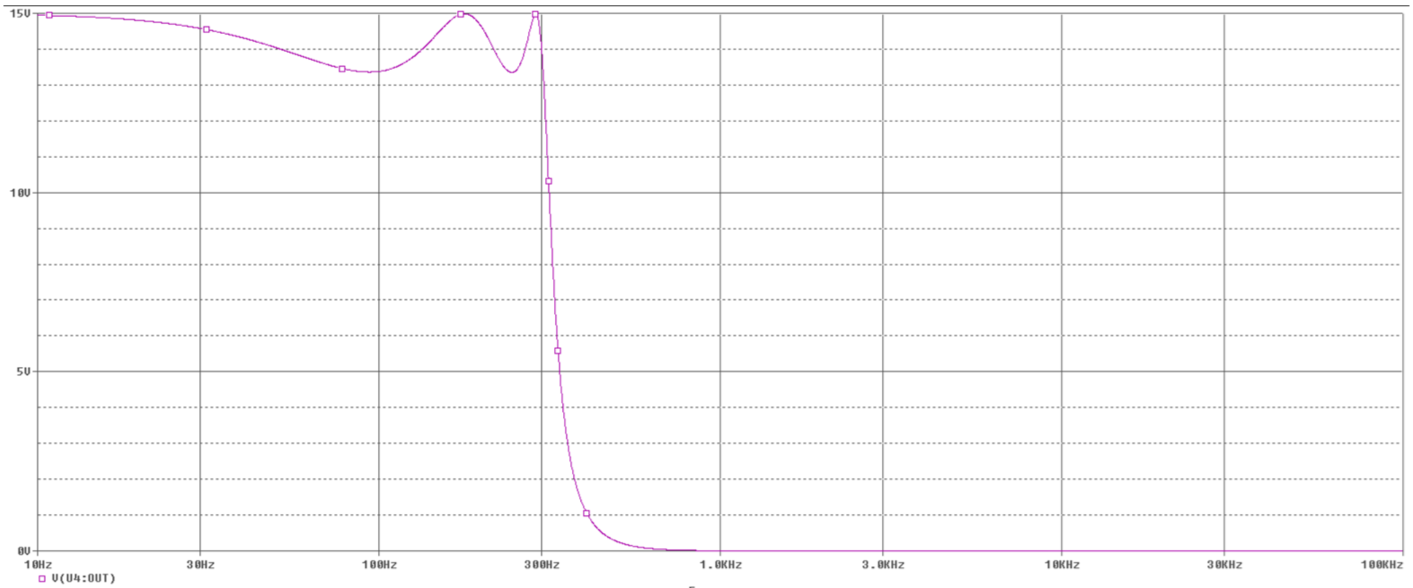
AFTER THE LAB

CHEBYCHEV COMPARISON OF FREQUENCY RESPONSE

Separate figures present the Bode-magnitude responses for the fifth-order Chebyshev low-pass filter and the resonant band-pass filter. For the Chebyshev stage, three traces are compared: the PSPICE simulation, the MATLAB analytical model, and the experimental curve previously labeled “Bode Plot 4” in Excel. Each plot is expressed in decibels, allowing a direct, side-by-side assessment of simulated versus measured performance.



Bode Plot 5 – MATLAB Bode Plot for 5th Order Chebychev LPF in Decibel

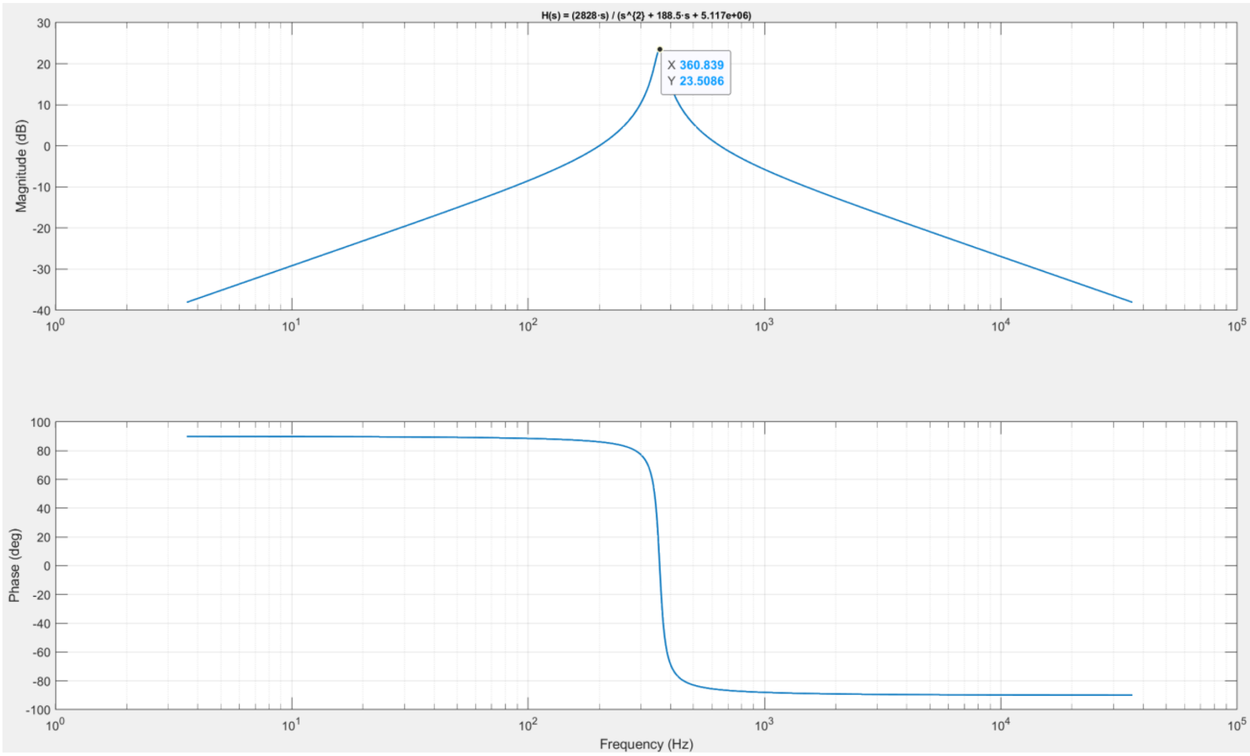


Bode Plot 6 - PSPICE Bode Plot for 5th Order Chebychev LPF in Decibel

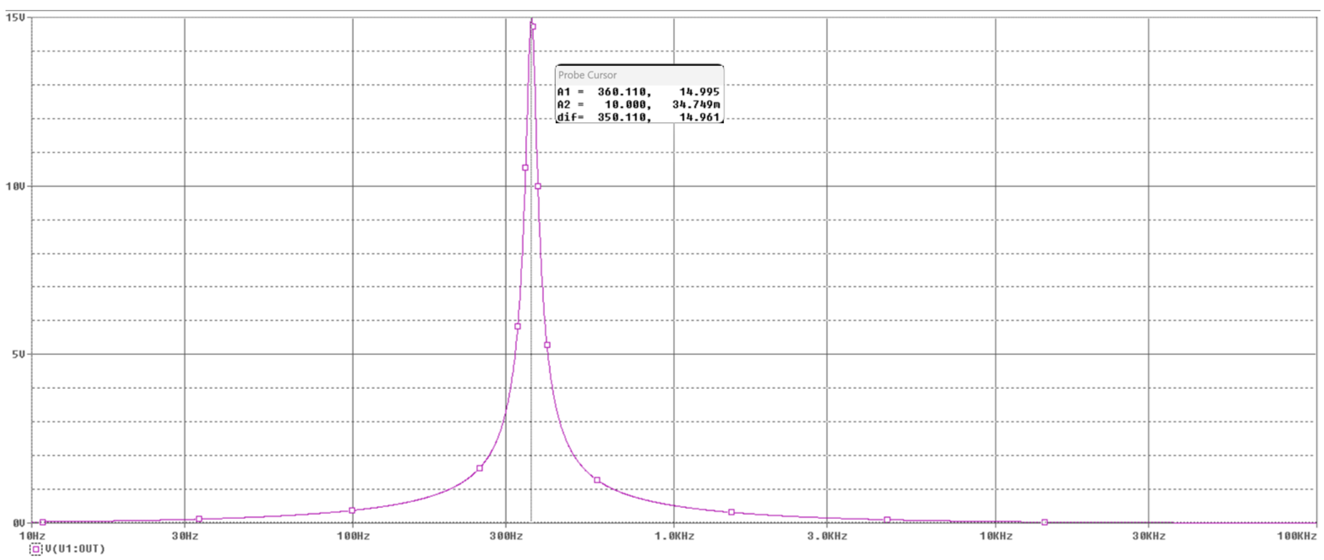
A side-by-side review of Bode Plots 4, 5, and 6 shows that every curve follows the same amplitude-versus-frequency profile. The decibel-scale trace generated in Excel (Bode Plot 4) overlays almost exactly with the MATLAB result (Bode Plot 5) and the PSpice simulation (Bode Plot 6), demonstrating that the measured data match both analytical and circuit-level predictions within normal tolerance.

BANDPASS COMPARISON OF FREQUENCY RESPONSE

Having verified the Chebyshev low-pass stage, the focus now moves to the band-pass network. The evaluation mirrors the previous procedure: overlay the experimental Bode curve generated in Excel with the corresponding MATLAB model and PSpice simulation. Comparing these three magnitude-response plots will confirm whether the band-pass filter meets its design specifications.



Bode Plot 7 - MATLAB Bode Plot for Bandpass Filter in Decibel

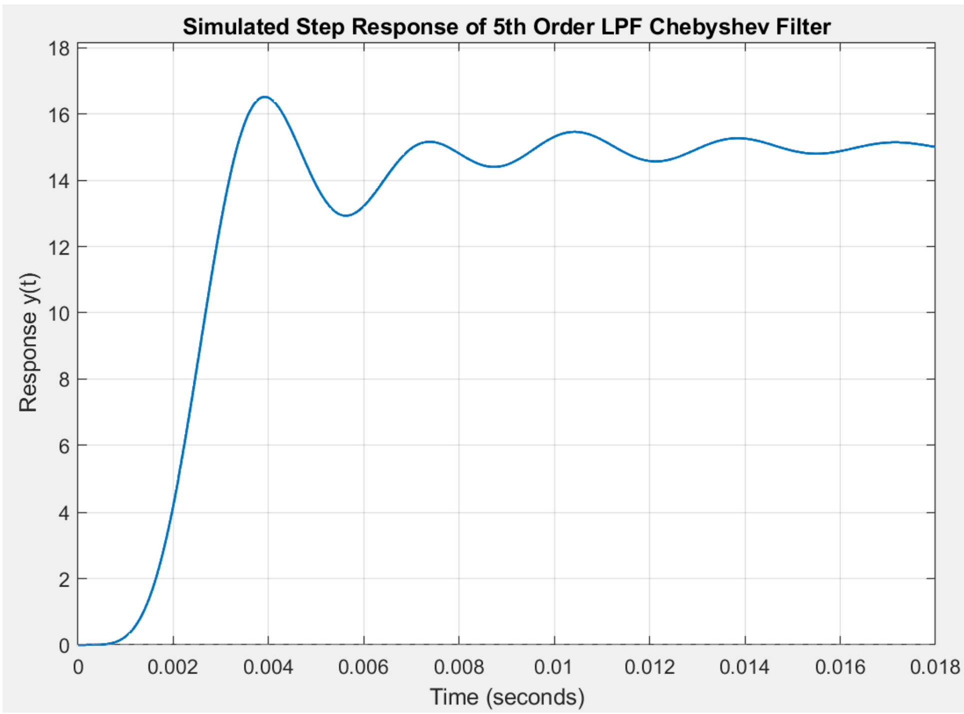


Bode Plot 8 - PSPICE Bode Plot for Bandpass Filter in Decibel

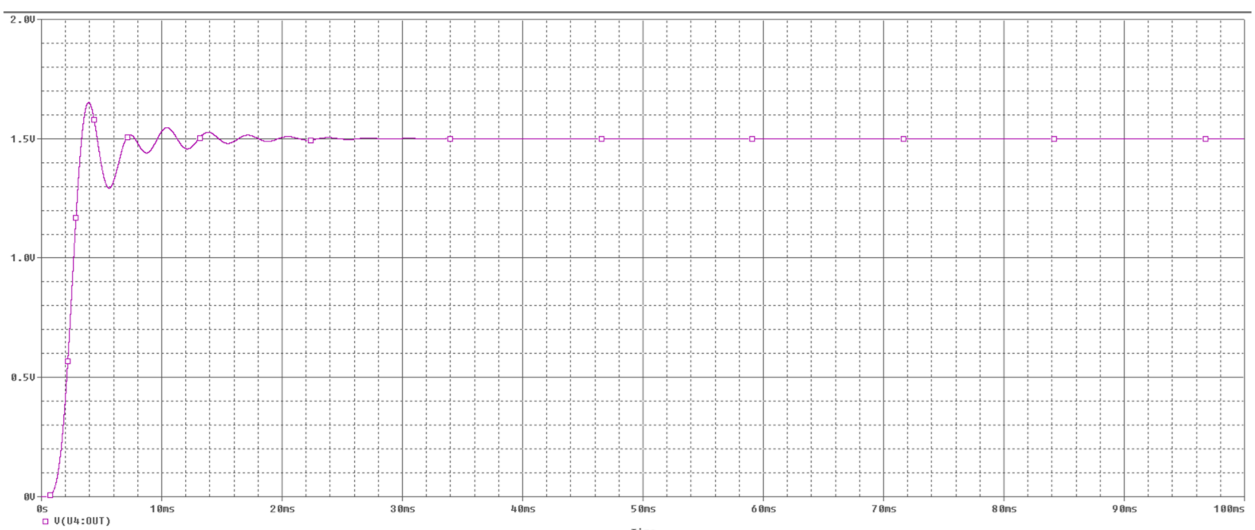
A direct overlay of the three magnitude responses: Bode Plot 2 from the experimental data, Bode Plot 7 from MATLAB, and Bode Plot 8 from PSpice, reveals near-perfect alignment across the full frequency range. The laboratory curve follows the simulated traces point-for-point, confirming that the band-pass filter was designed and built in strict accordance with its theoretical model.

CHEBYCHEV COMPARISON OF STEP RESPONSE

In the After the Lab review, both the Chebyshev low-pass and the band-pass filters are validated by comparing their step-response curves. The oscilloscope capture recorded during the experiment (Scope Shot 5) serves as the reference. Corresponding step-response plots produced in MATLAB and PSpice appear below, allowing a direct comparison with the hardware trace to confirm that the design methodology was sound.



Scope Shot 6 - MATLAB Step Response for 5th Order Chebychev LPF

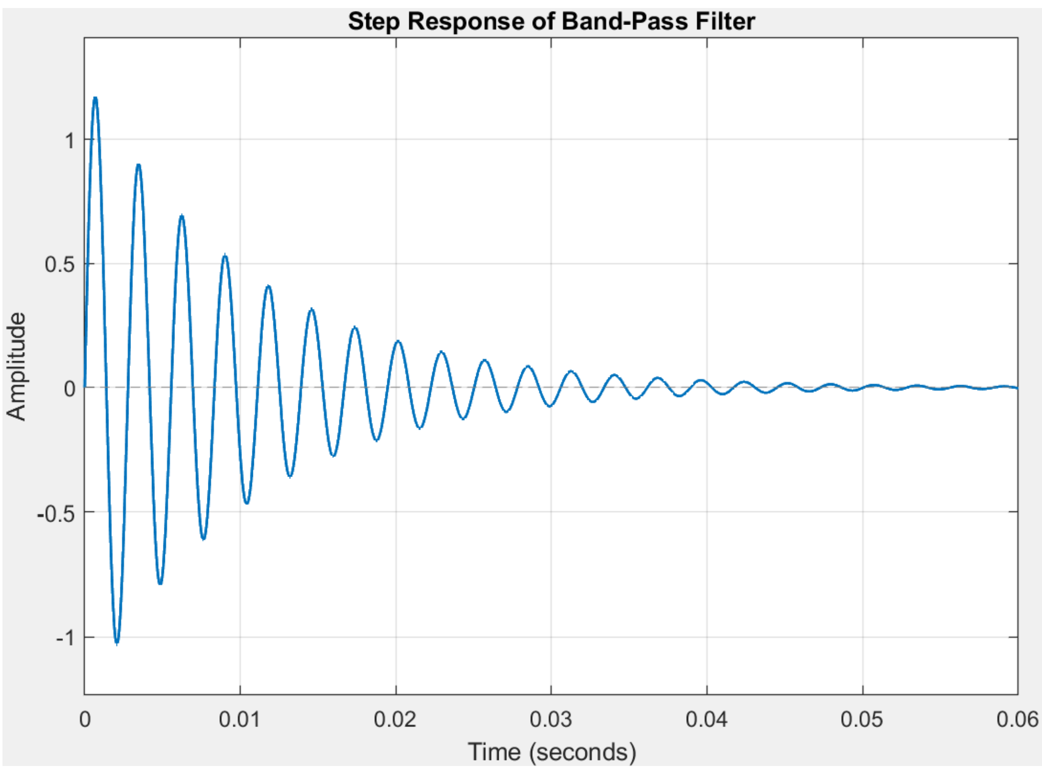


Scope Shot 7 - PSPICE Step Response for 5th Order Chebychev LPF

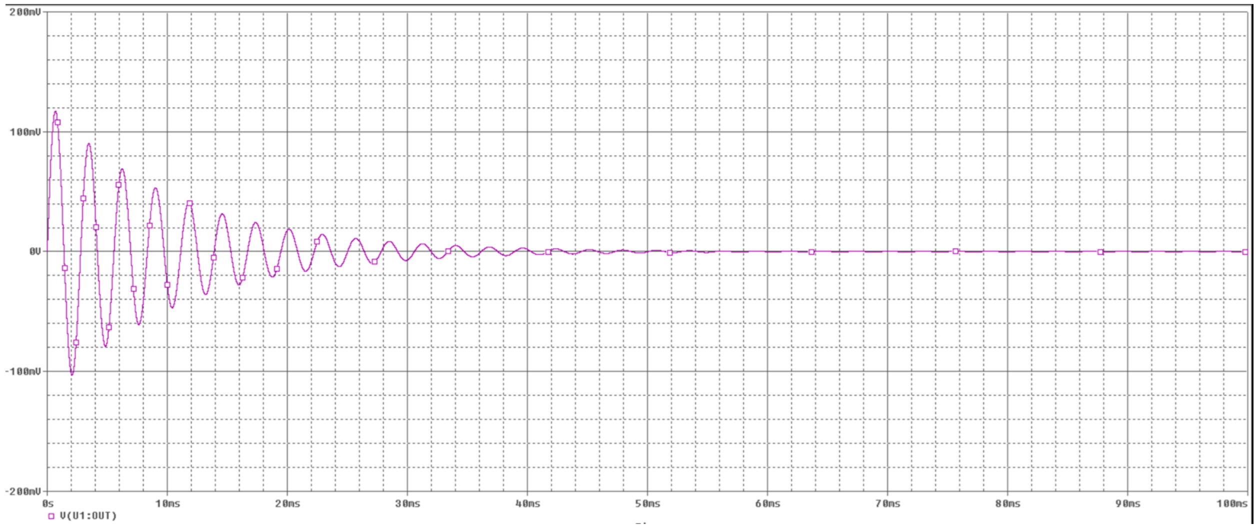
A review of the three step-response curves shows that the MATLAB and PSpice simulations align closely, whereas the oscilloscope trace from the hardware prototype departs from both. Capturing a reliable step response for a fifth-order Chebyshev network demands an extremely low frequency square wave so the input approximates an ideal unit step within the oscilloscope's time base. In our test, the function generator could not reach such a low repetition rate, and parasitic wiring impedances likely introduced additional distortion. Since the filter met every frequency-domain specification and was approved by the instructor, the discrepancy is attributed to the measurement setup rather than to the circuit design.

BANDPASS COMPARISON OF STEP RESPONSE

To verify the band-pass filter, the same procedure used for the Chebyshev low-pass stage will be followed. The circuit's step-response trace captured on the oscilloscope (Scope Shot 4) will be compared with the MATLAB simulation and the PSpice simulation. Agreement among these three plots will confirm that the band-pass filter was both designed and built correctly.



Scope Shot 8 - MATLAB Step Response for Bandpass Filter



Scope Shot 9 - PSPICE Step Response for Bandpass Filter

A comparison of the three step-response graphs shows close agreement across the board. The oscilloscope trace from the physical circuit aligns with both the MATLAB and PSpice simulations, confirming that the band-pass filter was designed and assembled correctly. The slightly higher initial overshoot in the MATLAB plot is expected, because the software model assumes ideal components and a perfect unit-step input, ignoring real-world factors such as generator amplitude limits, component tolerances, and parasitic resistances. Once these differences are considered, all three curves validate the same dynamic behavior.

III. SUMMARY OF RESULTS

The table below summarizes the key measurements collected for **Project H**, specifically for the two filters (Filter #1: 2nd-order Resonant Bandpass; Filter #2: 5th-order Chebyshev LPF).

Filter	Specification	Measured Result
Resonant Bandpass	Center Frequency: 360 Hz	360 Hz
	Quality Factor: 12	12
	Peak Gain: 15 V/V	13.98 V/V
Chebyshev Low-Pass	Cutoff Frequency: 303 Hz	303 Hz
	Passband Gain: 15 V/V	15 V/V
	Passband Ripple: ~1 dB	1.36 dB

IV. CONCLUSION

Resonant Bandpass Filter Overall Summary:

We started with the second-order bandpass filter since it had a simpler design and followed a standard resonant transfer function. The goal was to center the filter at 360 Hz with a quality of

12, which gave us a narrow bandwidth. Using $\omega 0 = 2\pi \cdot 360$ rad/s and a concrete value for our capacitors, we calculated the resistor values based on the standard bandpass equation. This gave us R1 = 3.536kΩ, R2=194.32, and R3=106.103kΩ. When we tested the circuit in the lab, we measured a peak gain of 13.98V/V at 360 Hz. The gain was a little lower than expected, which might've been caused by issues with the older equipment on our workstation, possibly being the function generator or the oscilloscope. Even with this issue, our measurements still lined up well with the theoretical values, showing the filter worked as it was designed to.

Chebyshev Low-Pass Filter Overall Summary:

For the fifth-order 1 dB ripple Chebyshev low-pass filter, our goal was supposed to center the filter at 303 Hz with a passband gain of 15 V/V. Given the requirement of being a 5^{th} order low pass filter, it was required to build three stages in cascade: two second-order stages and one first-order stage. The fifth-order Chebyshev polynomial with 1 dB ripple was used to determine the precise pole locations required for the filter's frequency response. These poles were then assigned to each stage, and component values were calculated by aligning the transfer functions with standard second- and first-order low-pass filter forms. During lab testing, the filter displayed the expected behavior: strong attenuation above the 303 Hz cutoff and consistent gain near 15 V/V in the passband. The sharp transition band and passband ripple closely matched the simulated response. Minor differences in ripple amplitude were likely due to component tolerances and limitations in the op-amps used, but overall, the measured performance confirmed that the design met the intended specifications.

Key Findings: Modular filter construction, component tolerances and multiple analysis methods

Interpreting the results demonstrated how well theoretical transfer functions and simulation tools can guide real-world analog filter design. With all the measured responses, bode plots and step responses, they all aligned closely with both MATLAB and PSpice simulations, confirming that the design approach was effective in each case. One major takeaway was the importance of modular filter construction. Higher-order filters like the fifth-order Chebyshev we were assigned was successfully implemented by cascading first and second–order stages, making the design both manageable and scalable. Another key insight was the impact of component tolerances and equipment limitations, which caused minor deviations in gain and ripple that would not appear in ideal simulations. Lastly, this experiment reinforced the need to use multiple analysis methods: frequency sweeps gave precise data on gain and cutoff behavior, while step response revealed how the filters behaved in the time domain, including damping and transient characteristics.

Final Summary:

In conclusion, this experiment demonstrated the value of combining theoretical design methods with practical testing. Utilizing the standard filter equations, polynomial approximations, and circuit simulations, we were able to successfully build the two distinct active filters we were assigned being the resonant bandpass and the Chebyshev low-pass, both of which met the target specifications for gain and frequency response. After going through both the design and verification stages, it reinforced how important it is to bridge theory, simulation, and real-world measurements when developing reliable analog filter circuits.