Active Band-Pass Filter Project

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Lab 4 Report

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1 Introduction

Electronic filters are a form of electrical circuits which behaves as a signal processing filter. Electronic filters allow wanted components of the applied signal to pass through at certain frequencies, and attenuate unwanted signal components at specific frequencies. Radio communication is an excellent example of the utilization of electronic filters.

1.1 Purpose

The purpose of this laboratory is to construct a filter from standardized filter blocks and to provide the junior analog designer an experience with second-order filter circuits as well as the Chebyshev filter response in the context of a design problem [1].

1.2 Experiment Overview

In day 1, the design calculations of a filter were presented. The design was verified through simulation. Data were obtained when performing the simulation. Then, useful parameters were measured and compared to the prelab calculated values.

In day 2, the design calculations of another filter were presented using industry standard values. The design was verified through simulation. Data were obtained when performing the simulation. Then, useful parameters were measured and compared to the parameters of the filter when using calculated design values.

2 Chebyshev Filter Design Project

2.1 Design Requirements

The filter to be designed is a fourth order Chebyshev filter. This filter is constructed by combining two second order Tow Thomas Biquad filters together.
The Chebyshev filter was designed to satisfy the following requirements:

1. Band-pass action
2. Chebyshev response
3. 3 dB passband ripple
4. Fourth-order roll-off
5. Lower cutoff frequency and upper cutoff frequency as calculated below
6. Target passband gain = +0.0 dB to −3.0 dB
7. ±8% error allowed in $f_{-3.0\,\mathrm{dB}}$
8. ±1.0 dB error allowed in passband gain
9. Supply voltages to be ±15 V
10. Op-Amps to be type **TL082** (No more than 6 Op-Amps total)
11. Output voltage swing > ±10 V

2.1.1 Overall Electronic Filter Circuit

Lower and Upper Cutoff Frequencies, ($f_{-3\,\mathrm{dB}\ lower}$, $f_{-3\,\mathrm{dB}\ lower}$):

$$X = 101078550$$

$$A = X\ mod\ 1031 = 341$$
$$B = X\ mod\ 1033 = 533$$

$$\begin{aligned} f_{-3\,\mathrm{dB}\ lower} &= \frac{A^5}{5.534*10^9} - \frac{A^4}{2.11*10^6} + \frac{A^3}{2287} - \frac{A^2}{6.1} + 20.0\,\mathrm{A} + 750 \\ &= \frac{341^5}{5.534*10^9} - \frac{341^4}{2.11*10^6} + \frac{341^3}{2287} - \frac{341^2}{6.1} + 20.0\,\mathrm{A} + 750 \end{aligned} \tag{1}$$

$$\therefore f_{-3\,\mathrm{dB}\ lower} = 338.64\,\mathrm{Hz}$$

$$\begin{aligned} \delta &= -\frac{B^2}{180,000} + \frac{B}{173} + 0.5 \\ &= -\frac{533^2}{180,000} + \frac{533}{173} + 0.5 \\ &= 2.0 \end{aligned} \tag{2}$$

$$\begin{aligned} f_{-3\,\mathrm{dB}\ upper} &= f_{-3\,\mathrm{dB}\ lower}(1+\delta) \\ &= (338.64\,\mathrm{Hz})(1+2) \end{aligned} \tag{3}$$

$$\therefore f_{-3\,\mathrm{dB}\ upper} = 1.0168\,\mathrm{kHz}$$

Bandwidth:

$$\begin{aligned} BW &= 2\pi(f_{-3\,\mathrm{dB}\ upper} - f_{-3\,\mathrm{dB}\ lower}) \\ &= 2\pi(1.0168\,\mathrm{kHz} - 338.64\,\mathrm{Hz}) \end{aligned} \tag{4}$$

$$\therefore BW = 4261\,\mathrm{rad/s}$$

Corner Frequency:

$$\begin{aligned} \omega_o &= 2\pi\sqrt{f_{-3\,\mathrm{dB}\ upper} * f_{-3\,\mathrm{dB}\ lower}} \\ &= 2\pi\sqrt{1.0168\,\mathrm{kHz} - 338.64\,\mathrm{Hz}} \end{aligned} \tag{5}$$

$$\therefore \omega_o = 3687\,\mathrm{rad/s}$$

Quality Factor:

$$\begin{aligned} Q &= \frac{\omega_o}{BW} \\ &= \frac{3687\,\mathrm{rad/s}}{4261\,\mathrm{rad/s}} \end{aligned} \tag{6}$$

$$\therefore Q = 0.8653$$

Transfer Function:

The general equation for a second order 3 dB pass-band ripple Chebychev response is as follows:

$$H_2(S) = \frac{0.7079 * 0.7079}{S^2 + 0.6449S + 0.7079} \tag{7}$$

Using the more generalized equation of the second order 3 dB pass-band riplle Chebychev response as shown below:

$$H_2(S) = \frac{a^2}{S^2 + bS + c} \tag{8}$$

By comparing Eqs. 7 and 8, the variables (a, b, and c) are determined.

$$a = 0.7079^2 \tag{9}$$

$$b = 0.6449 \tag{10}$$

$$c = \sqrt{a} = 0.7079 \tag{11}$$

In order to transform the 2^{nd} order filter equation to 4^{th} order filter equation, we replace:

$$\begin{aligned} S &\rightarrow \frac{S^2 + \omega_o^2}{BWS} \\ &= \frac{Q\left[\left(\frac{S}{\omega_o}\right)^2 + 1\right]}{\left(\frac{S}{\omega_o}\right)} \end{aligned} \tag{12}$$

$$S \rightarrow \frac{QS}{\omega_o} + \frac{Q\omega_o}{S} \tag{13}$$

By substiuting Eq. 13 into Eq. 8, the 4^{th} order filter equation is as follows:

$$H_4(S) = \frac{aBW^2S^2}{S^4 + bBW^2S^3 + (2\omega_o^2 + cBW^2)S^2 + bBW^2\omega_o^2S + \omega_o^4} \tag{14}$$

By substiuting Eqs. 9, 10, 11 into Eq. 14, we get the following transfer function for the **overall electronic filter circuit**:

$$H_4(S) = \frac{(9.0991 * 10^6)S^2}{S^4 + (2780)S^3 + (4.0042 * 10^7)S^2 + (3.7357 * 10^{10})S + (1.8480 * 10^4)} \tag{15}$$

Gain

Using Fig. 2, the total gain of the filter circuit is:

$$\therefore A_v = -0.0259\,\text{dB}$$

Using the coefficients of the 4^{th} order transfer function, two 2^{nd} order transfer functions are obatined. Splitting Eq. 15 into two second order transfer functions gives the following:

$$H_4(S) = \frac{(3016.5)S}{S^2 + (1.9437 * 10^3)S + (3.2854 * 10^7)} * \frac{(3016.5)S}{S^2 + (804.2771)S + (5.6249 * 10^6)} \tag{16}$$

Using Eq. 16, the transfer functions for the two stages are shown below:

$$H_A(S) = \frac{(3016.5)S}{S^2 + (1.9437 * 10^3)S + (3.2854 * 10^7)} \tag{17}$$

$$H_B(S) = \frac{(3016.5)S}{S^2 + (804.2771)S + (5.6249 * 10^6)} \tag{18}$$

Figure 1 shows Tow-Thomas second order filter with feedforward which is the circuit used to implement the transfer functions shown in Eqs. 17 and 18.

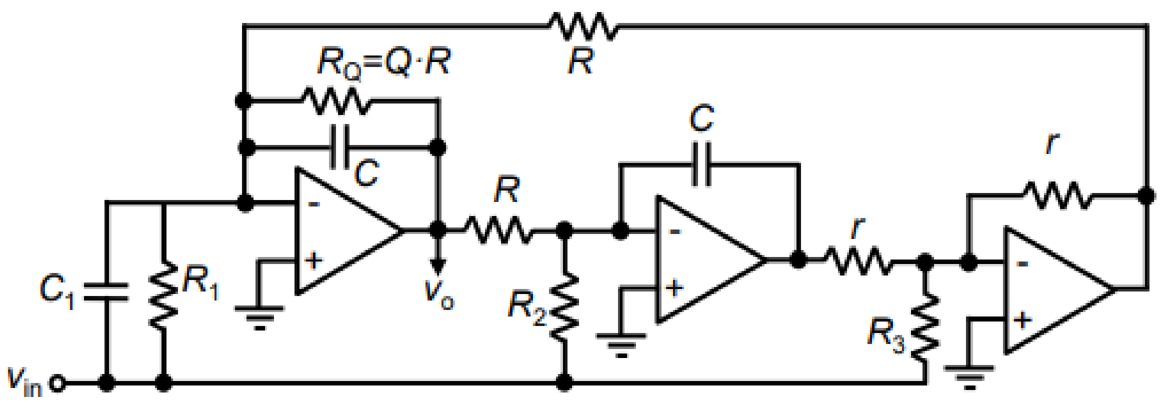

Figure 1: Tow-Thomas (with Feedforward) Second Order Filter [1]

The general form of the transfer function of the circuit shown in Figure 1 is shown below:

$$H(S) = \frac{S^2\left(\frac{C_1}{C}\right) + S\frac{1}{C}\left(\frac{1}{R_1} - \frac{r}{RR_3}\right) + \frac{1}{C^2RR_2}}{S^2 + S\frac{\omega_o}{Q} + \left(\frac{1}{RC}\right)^2} \tag{19}$$

This filter can realize different filter types. C, r can be fixed arbitrarily. Since a bandpass filter is desired, $C_1 = 0$, $R_2 = \infty$.
Therefore, Eq. 19 can be simplified and written as follows:

$$H(S) = \frac{S\frac{1}{C}\left(\frac{1}{R_1} - \frac{r}{RR_3}\right)}{S^2 + S\frac{\omega_o}{Q} + \left(\frac{1}{RC}\right)^2} \tag{20}$$

Eq. 20 has the following generalized form of a 2^{nd} order equation which is used to determine the various parameters and characteristics for Eqs. 17 and 18.

$$H(S) = \frac{aS}{S^2 + bS + c} \tag{21}$$

The theoretical response plot of the overall filter circuit is shown in Fig. 2.

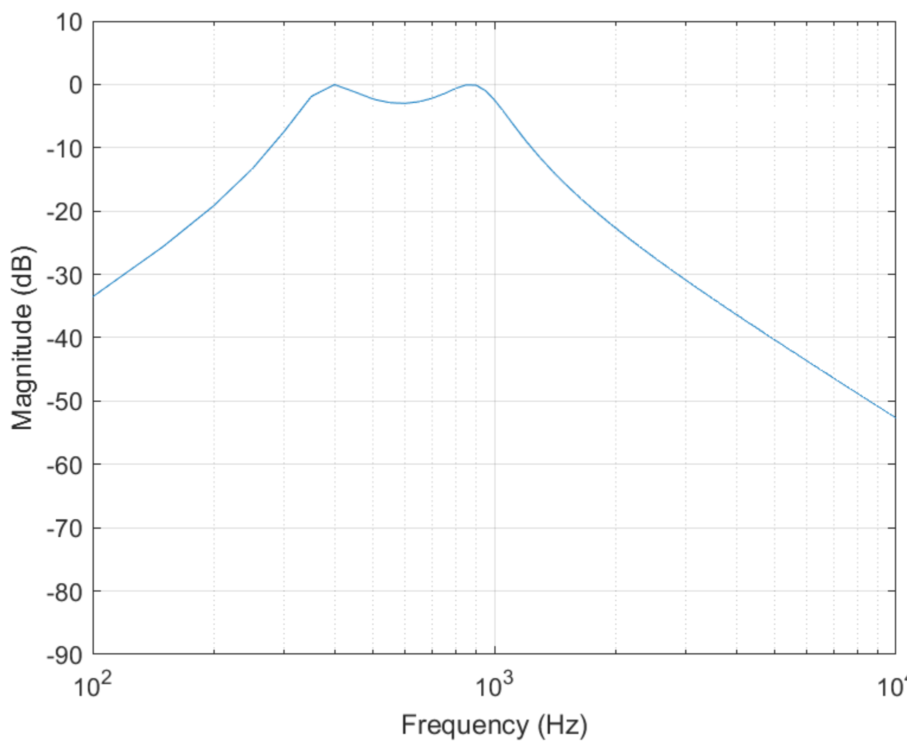

Figure 2: Theoretical Response Plot of The Overall Filter Circuit

The theoretical response plot of Eqs. 17 and 18 are shown in Fig. 3 and Fig. 4 respectively.

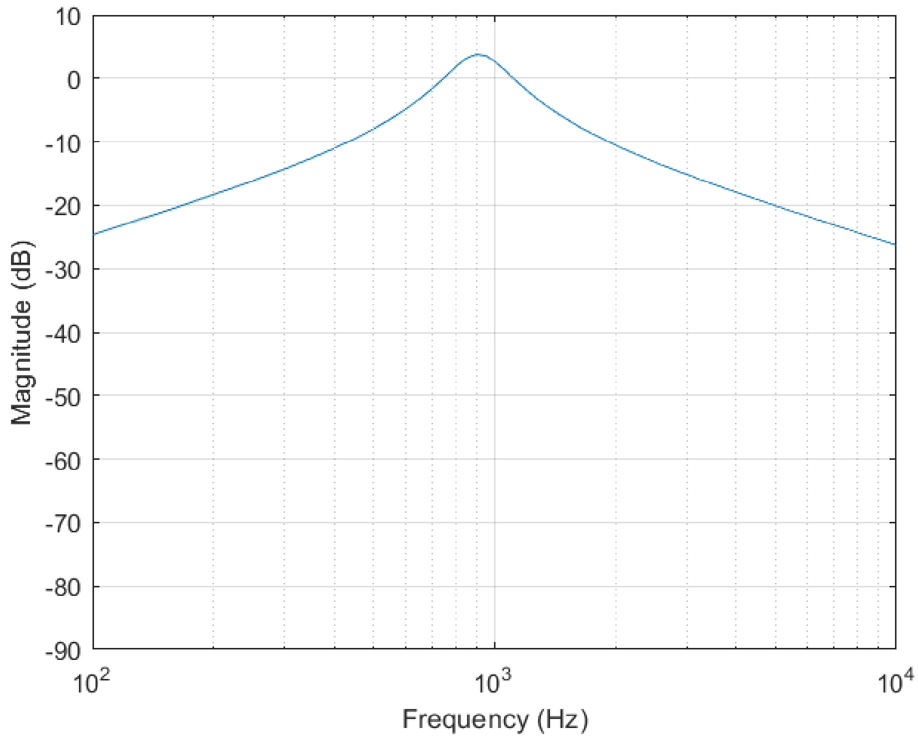

Figure 3: Theoretical Response Plot of The $H_A(S)$ Filter Circuit

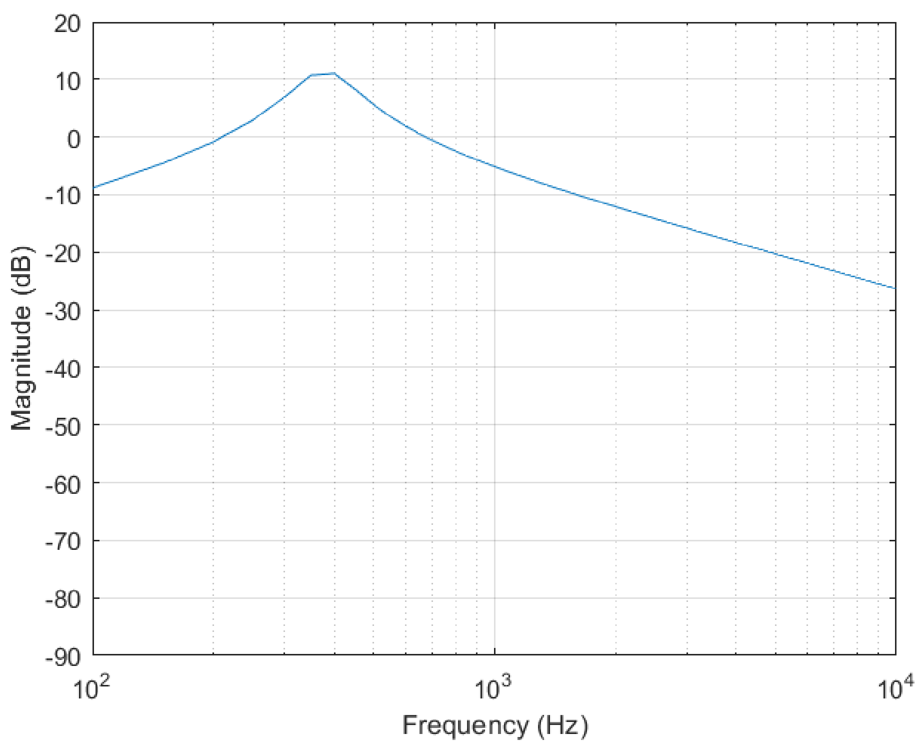

Figure 4: Theoretical Response Plot of The $H_B(S)$ Filter Circuit

2.1.2 $H_A(S)$ Parameters

By comparing Eqs. 17 and 21, the following parameters are determined.

Corner Frequency:

$$\begin{aligned}\omega_{o_A} &= \frac{1}{RC} = \sqrt{c} \\ &= \sqrt{3.2854 * 10^7}\end{aligned} \tag{22}$$

$$\therefore \omega_{o_A} \approx 5732\,\text{rad/s}$$

Bandwidth:

$$BW_A = \frac{\omega_{o_A}}{Q_A} = b \tag{23}$$

$$\therefore BW_A = 1943.7\,\text{rad/s}$$

Using Eq. 23, we get the following:

Quality Factor:

$$\begin{aligned}1943.7\,\text{rad/s} &= \frac{5732\,\text{rad/s}}{Q_A} \\ Q_A &= \frac{5732\,\text{rad/s}}{1943.7\,\text{rad/s}}\end{aligned}$$

$$\therefore Q_A = 2.9488$$

Gain:

Using Fig. 3, the gain of this stage is:

$$\therefore A_{v_A} = 3.7897\,\text{dB}$$

Capacitance Value:

C_A is assumed to be 22 nF as it as a capacitance industry standard value.

Resistance Values:

$$\begin{aligned}R_1 &= \frac{1}{\omega_{o_A} C_A} \\ &= \frac{1}{(5732\,\text{rad/s})(22\,\text{nF})}\end{aligned} \tag{24}$$

$$\therefore R_1 = 7.9302\,\text{k}\Omega$$

$$\begin{aligned}R_{q_1} &= R_1 * Q_A \\ &= (7.9302\,\text{k}\Omega)(2.9488)\end{aligned} \tag{25}$$

$$\therefore R_{q_1} = 23.385\,\text{k}\Omega$$

Assuming $r_A = R_{q_1} = 23.385\,\text{k}\Omega$, for simplicity, we get the following:

$$\begin{aligned} R_{31} &= \frac{r_A}{aR_1C_A} \\ &= \frac{23.385\,\text{k}\Omega}{(3016.5)(7.9302\,\text{k}\Omega)(22\,\text{nF})} \end{aligned} \tag{26}$$

$$\therefore R_{31} = 44.435\,\text{k}\Omega$$

2.1.3 $H_B(S)$ Parameters

By comparing Eqs. 18 and 21, the following parameters are determined.

Corner Frequency:

$$\begin{aligned} \omega_{o_B} &= \frac{1}{RC} = \sqrt{c} \\ &= \sqrt{5.6249 * 10^6} \end{aligned} \tag{27}$$

$$\therefore \omega_{o_B} \approx 2372\,\text{rad/s}$$

Bandwidth:

$$BW_B = \frac{\omega_{o_B}}{Q_B} = b \tag{28}$$

$$\therefore BW_B = 804.2771\,\text{rad/s}$$

Using Eq. 28, we get the following:

Quality Factor:

$$\begin{aligned} 804.2771\,\text{rad/s} &= \frac{2372\,\text{rad/s}}{Q_B} \\ Q_B &= \frac{2372\,\text{rad/s}}{804.2771\,\text{rad/s}} \end{aligned}$$

$$\therefore Q_B = 2.9488$$

Gain:

Using Fig. 4, the gain of this stage is:

$$\therefore A_{v_B} = 11\,\text{dB}$$

Capacitance Value:

C_B is assumed to be 33 nF as it as a capacitance industry standard value.

Resistance Values:

$$\begin{aligned} R_2 &= \frac{1}{\omega_{o_B} C_B} \\ &= \frac{1}{(2372\,\text{rad/s})(33\,\text{nF})} \end{aligned} \tag{29}$$

$$\therefore R_2 = 12.777\,\text{k}\Omega$$

$$\begin{aligned} R_{q_2} &= R_2 * Q_B \\ &= (12.777\,\text{k}\Omega)(2.9488) \end{aligned} \tag{30}$$

$$\therefore R_{q_2} = 37.677\,\text{k}\Omega$$

Assuming $r_B = R_{q_2} = 37.677\,\mathrm{k\Omega}$, for simplicity, we get the following:

$$\begin{aligned} R_{32} &= \frac{r_B}{aR_2C_B} \\ &= \frac{37.677\,\mathrm{k\Omega}}{(3016.5)(12.777\,\mathrm{k\Omega})(33\,\mathrm{nF})} \end{aligned} \tag{31}$$

$$\therefore R_{32} = 29.624\,\mathrm{k\Omega}$$

The overall filter circuit with the theoretical (calculated) components values is shown in Fig. 5.

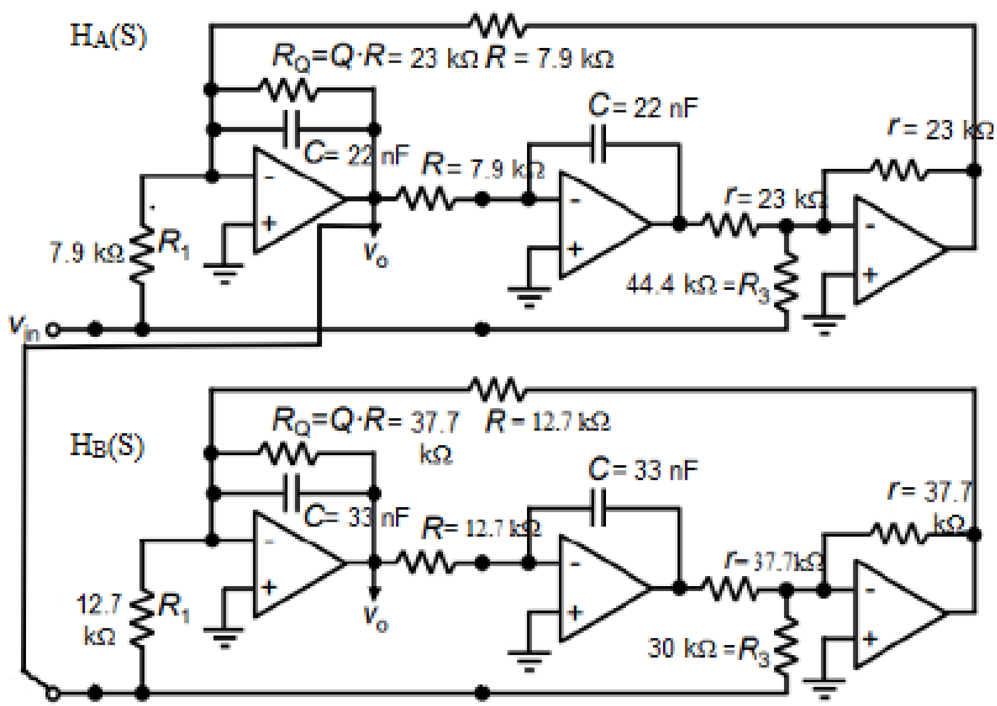

Figure 5: The Overall Filter Circuit With The Theoretical Components Values [1]

The circuit that represent each of Eqs. 17 and 18 are shown in Fig. 6 and Fig. 7 respectively.

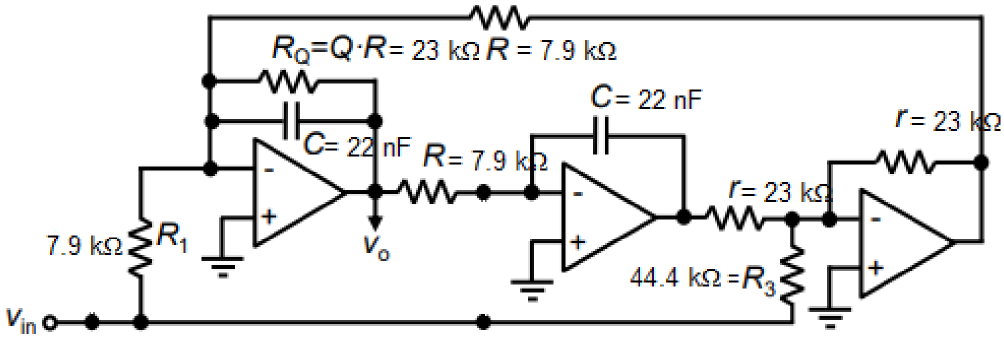

Figure 6: The $H_A(S)$ Filter Circuit With The Theoretical Components Values [1]

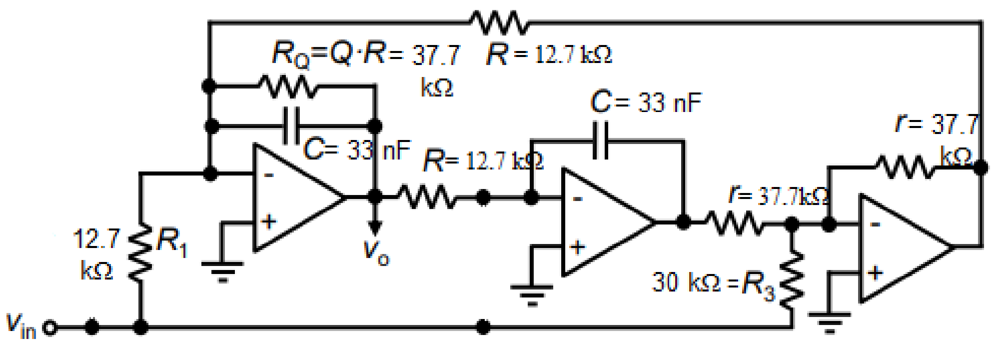

Figure 7: The $H_B(S)$ Filter Circuit With The Theoretical Components Values [1]

2.2 Simulation

2.2.1 Simulated Filter Circuit

Fig. 8 illustrates the overall filter circuit used in this part of the experiment.

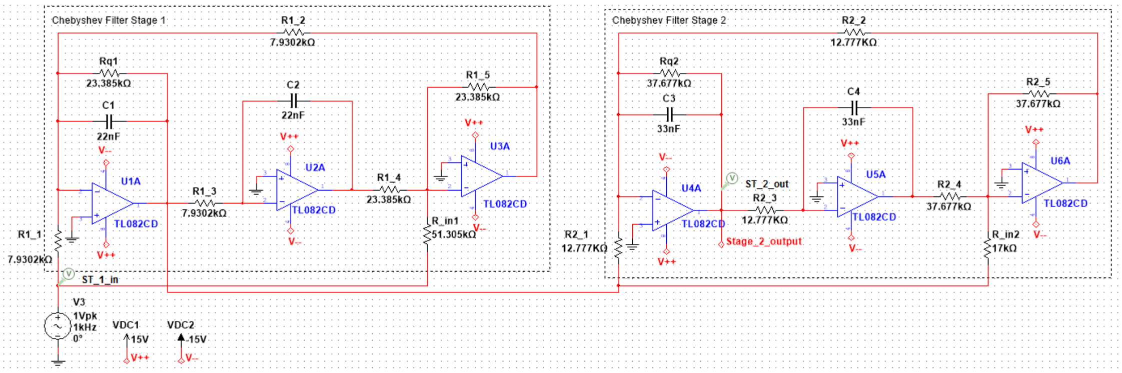

Figure 8: The Simulated Overall Filter Circuit With Theoretical Components Values

Fig. 9 illustrates the AC sweep settings of the overall filter circuit used in this part of the experiment.

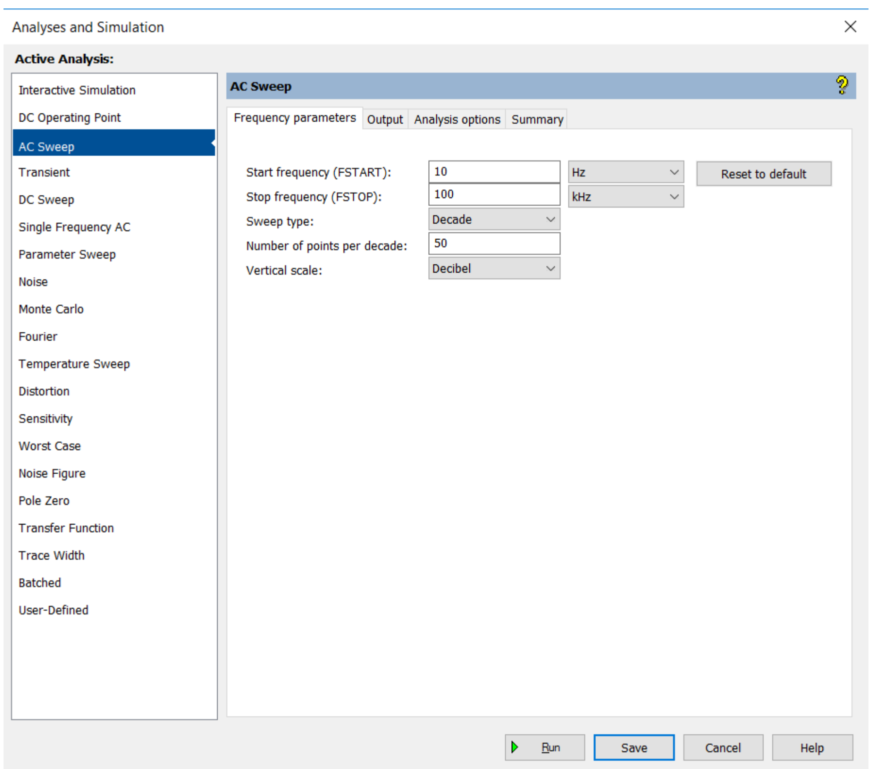

Figure 9: Overall Filter Circuit AC Sweep Simulation Settings

Fig. 10 shows the simulated response plot of the overall filter circuit.

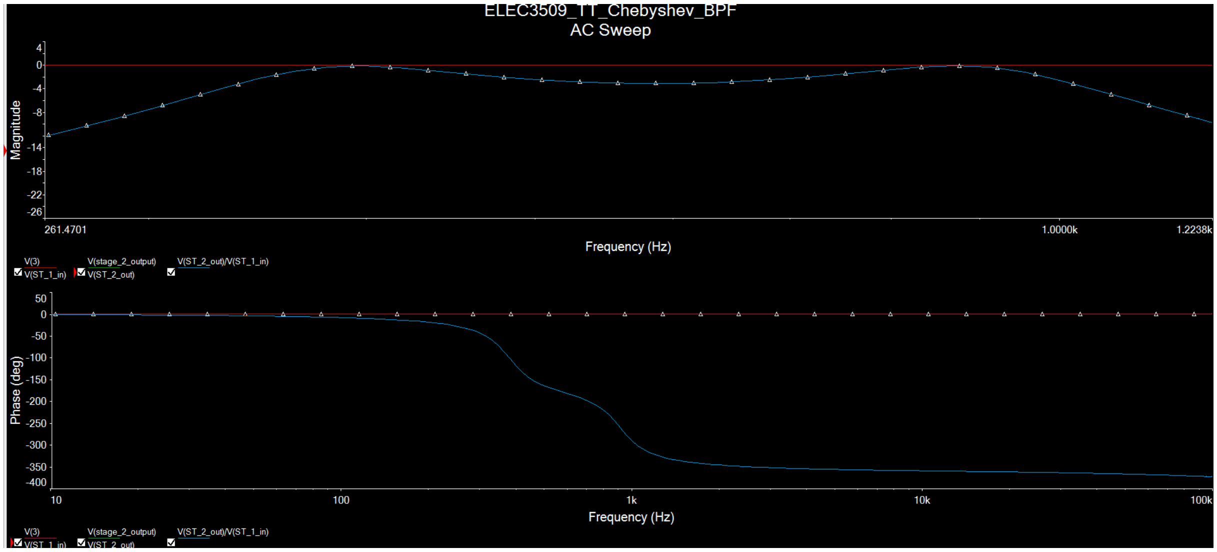

Figure 10: Overall Filter Circuit Simulated Response Plot

As shown in Fig. 8, R_{in_1} is increased and set to approximately $51\,\text{k}\Omega$ while the theoretical value is $44.4\,\text{k}\Omega$. Likewise, R_{in_2} is decreased and set to $17\,\text{k}\Omega$ while the theoretical value is approximately $30\,\text{k}\Omega$ before performing the simulation. These changes in the circuit were made to achieve the desired voltage gain of the overall filter circuit. If the theoretical values were used, the voltage gain would be around $-14\,\text{dB}$. However, the simulated plot shows the desireable gain of approximately $0\,\text{dB}$. Similarly, if the theoretical values of R_{in_1} and R_{in_2}, the frequency values would have exceeded $\pm 8\%$ error which does not satisfy the requirements of this project. Fig. 10 shows the gain in the simulated response plot which is an exact match of the theoretical response plot as shown in Fig. 2.

Note that the simulated response plot of the individual 2^{nd} order filter circuits were done while maintaining the changes done to R_{in_1} and R_{in_2} for the exact same reasons.

Note: Data were presented on the gain plot and are shown in Fig. 22.

Fig. 11 illustrates each of the individual 2^{nd} order filter circuits, $H_A(S)$ and $H_B(S)$ respectively, used in this part of the experiment.

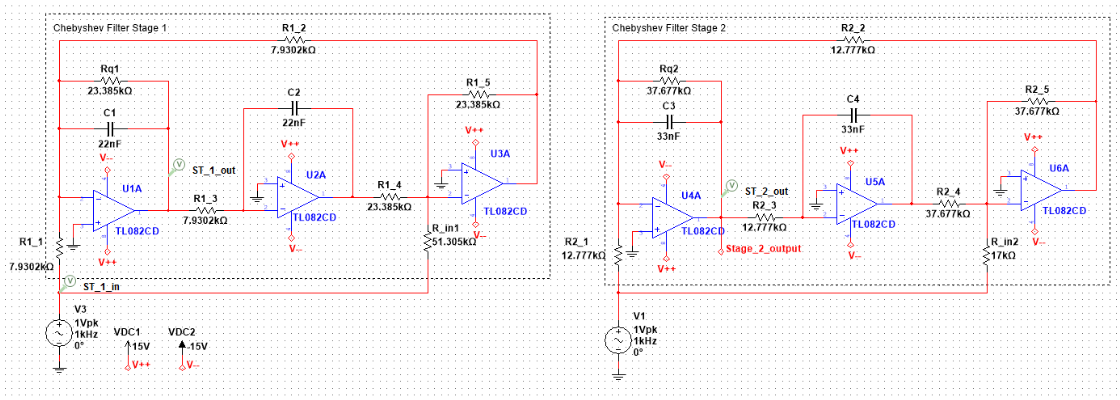

Figure 11: The Simulated Individual Filter Circuits With Theoretical Components Values

Fig. 12 illustrates the AC sweep settings of each of the individual 2^{nd} order filter circuits, $H_A(S)$ and $H_B(S)$ respectively, used in this part of the experiment.

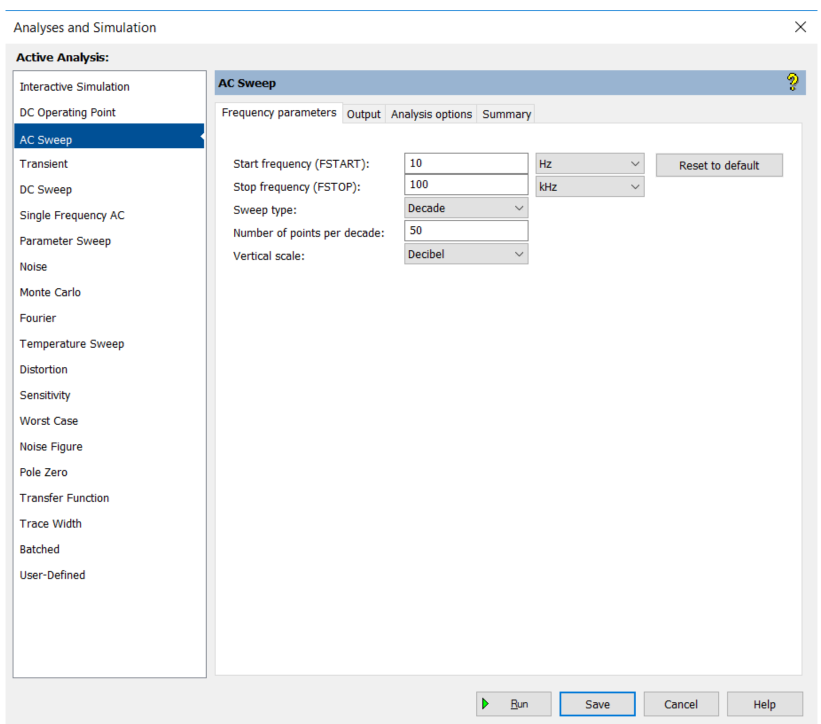

Figure 12: Overall Filter Circuit AC Sweep Simulation Settings

Fig. 13 and Fig. 14 show the simulated response plot of the individual 2^{nd} order filter circuits of $H_A(S)$ and $H_B(S)$ respectively.

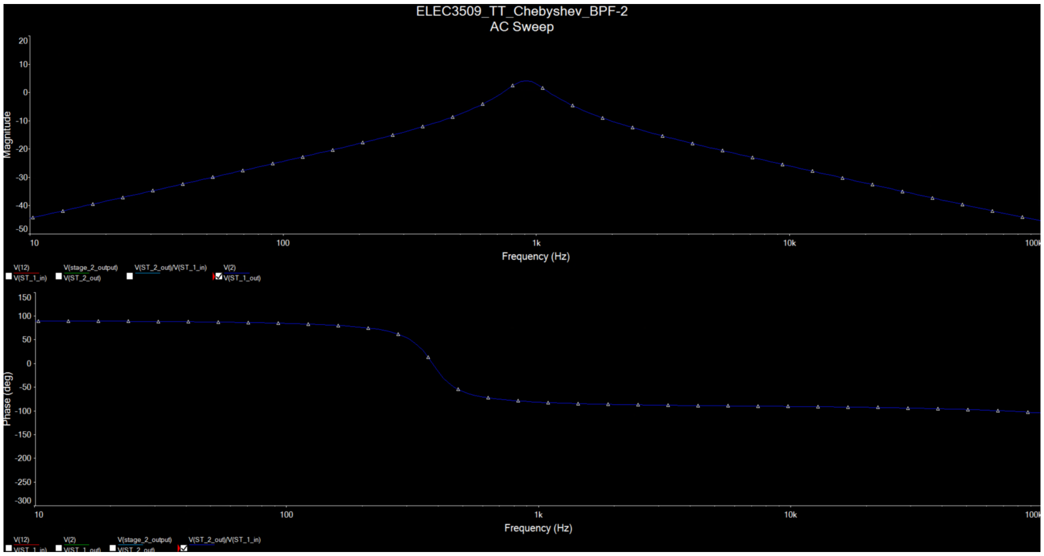

Figure 13: Simulated Response Plot of The $H_A(S)$ Filter Circuit

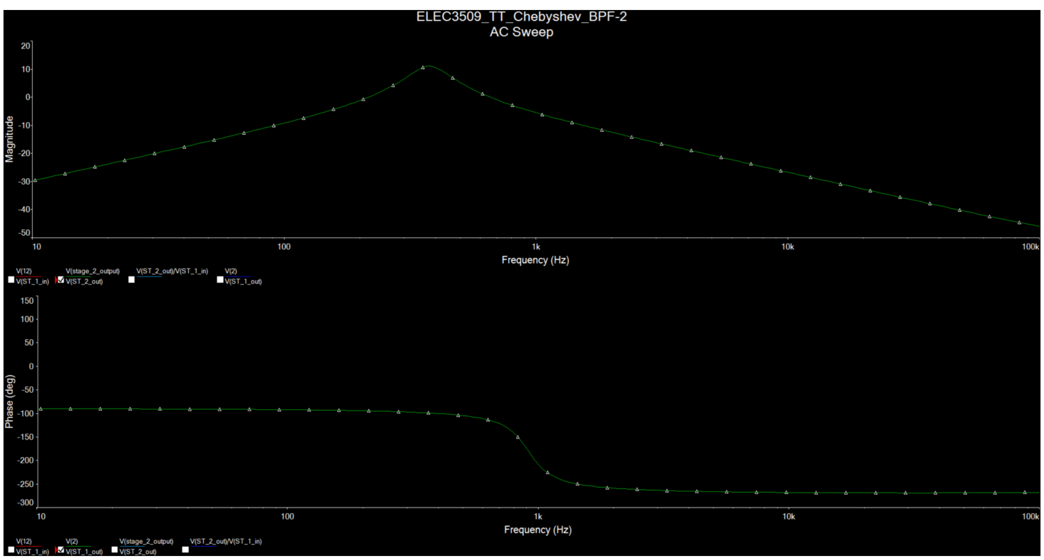

Figure 14: Simulated Response Plot of The $H_B(S)$ Filter Circuit

In comparison between Fig. 13 and Fig. 3, the gain in the simulated response plot is an exact match of the theoretical response plot for $H_A(S)$. Likewise, the comparison between Fig. 14 and Fig. 4 shows that the gain in the simulated response plot is an exact match of the theoretical response plot for $H_B(S)$.

2.2.2 Standard Simulated Filter Circuit

Fig. 15 illustrates the overall filter circuit with standard values used in this part of the experiment.

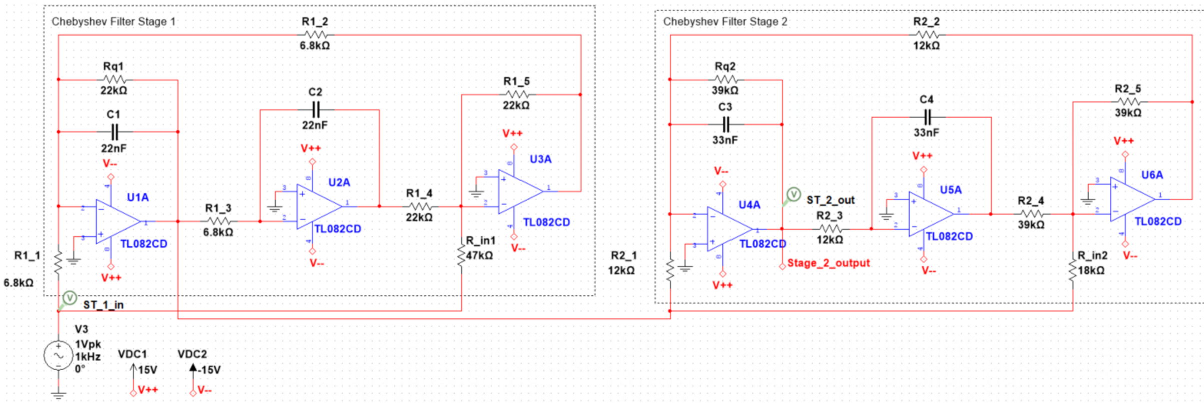

Figure 15: The Simulated Overall Filter Circuit With Standard Components Values

Fig. 16 illustrates the AC sweep settings of the overall filter circuit used in this part of the experiment.

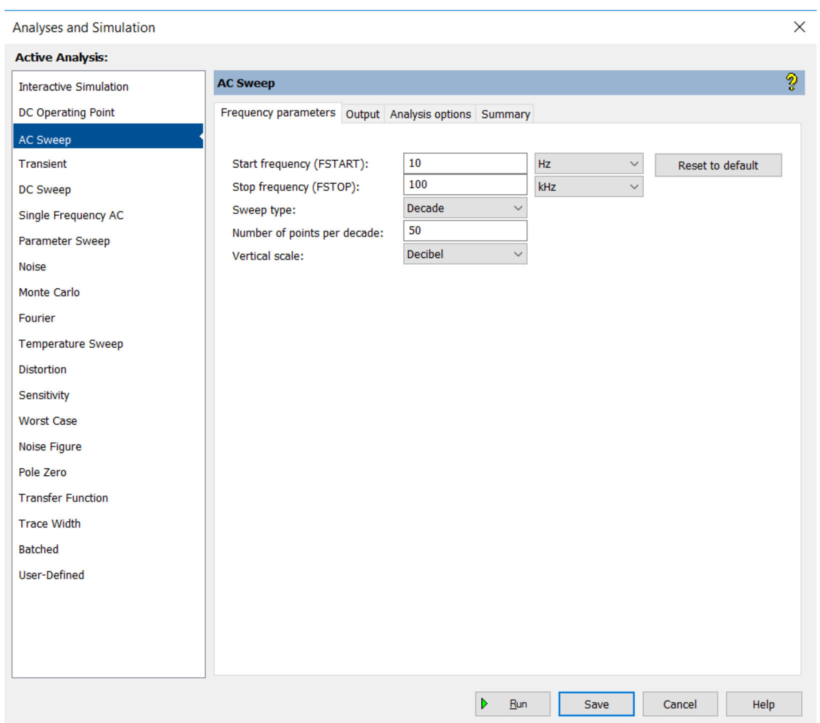

Figure 16: The Simulated Overall Filter Circuit With Standard Components Values

Fig. 17 shows the simulated response plot of the overall filter circuit using standard components values.

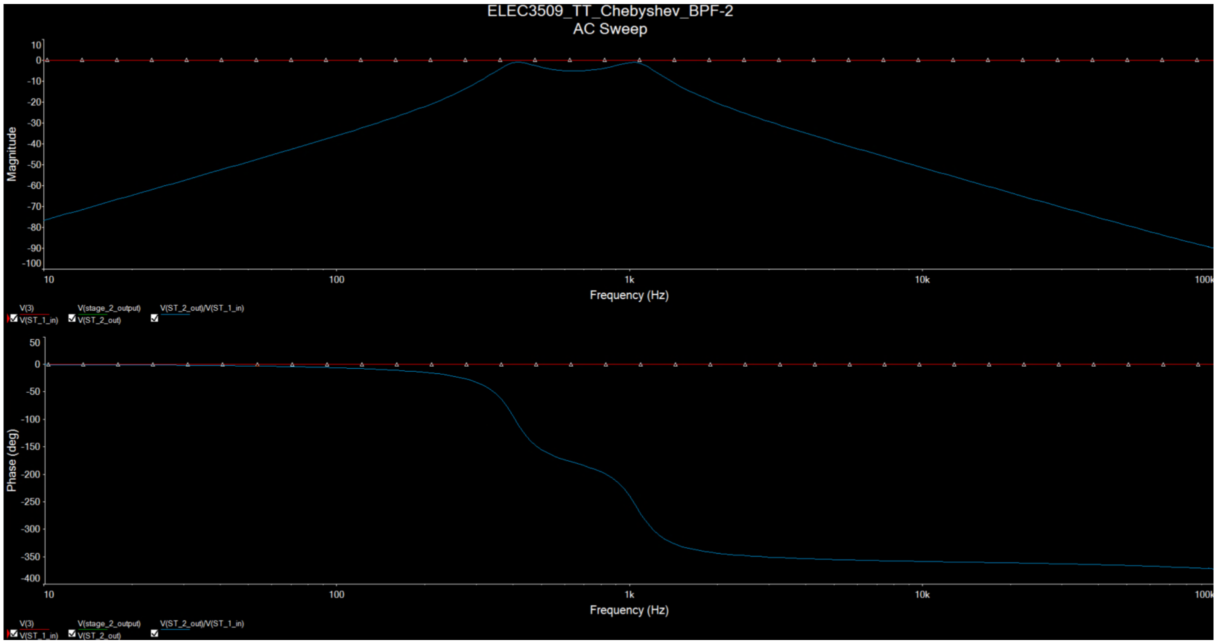

Figure 17: The Simulated Overall Filter Circuit With Standard Components Values

As shown in Fig. 17, R_{in_1} is increased and set to a standard value of $47\,\mathrm{k\Omega}$ while the theoretical value is $44.4\,\mathrm{k\Omega}$. Likewise, R_{in_2} is decreased and set to a standard value of $18\,\mathrm{k\Omega}$ while the theoretical value is approximately $30\,\mathrm{k\Omega}$ before performing the simulation. Also, R_{11}, R_{12}, and R_{13} are set to a standard value of $6.8\,\mathrm{k\Omega}$ while the theoretical value is approximately $8\,\mathrm{k\Omega}$. These changes in the circuit were made to achieve the desired voltage gain of the overall filter circuit. The closest standard values to the theoretical values were used, the voltage gain would be around $-10\,\mathrm{dB}$. However, the simulated plot shows the desireable gain of approximately $0\,\mathrm{dB}$ after performing few changes to components values. Similarly, if the theoretical values of R_{in_1}, R_{in_2}, R_{11}, R_{12}, and R_{13}, the frequency values would have exceeded $\pm 8\%$ error which does not satisfy the requirements of this project. Fig. 17 shows the gain in the simulated response plot using standard components values which is fairly a match of the theoretical and simulated response plots as shown in Fig. 10 and Fig. 2.

Note that the simulated response plot of the individual 2^{nd} order filter circuits using standard components values were done while maintaining the changes done to R_{in_1} and R_{in_2} for the exact same reasons.

Note: Data were presented on the gain plot and are shown in Fig. 23.

Fig. 18 illustrates each of the individual 2^{nd} order filter circuits using standard components values, $H_A(S)$ and $H_B(S)$ respectively, used in this part of the experiment.

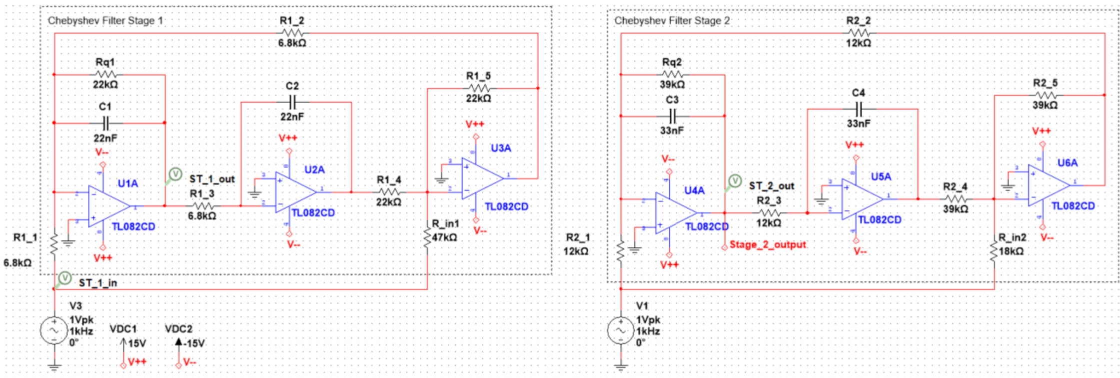

Figure 18: The Simulated Individual Filter Circuits With Standard Components Values

Fig. 19 illustrates the AC sweep settings of each of the individual 2^{nd} order filter circuits, $H_A(S)$ and $H_B(S)$ respectively, used in this part of the experiment.

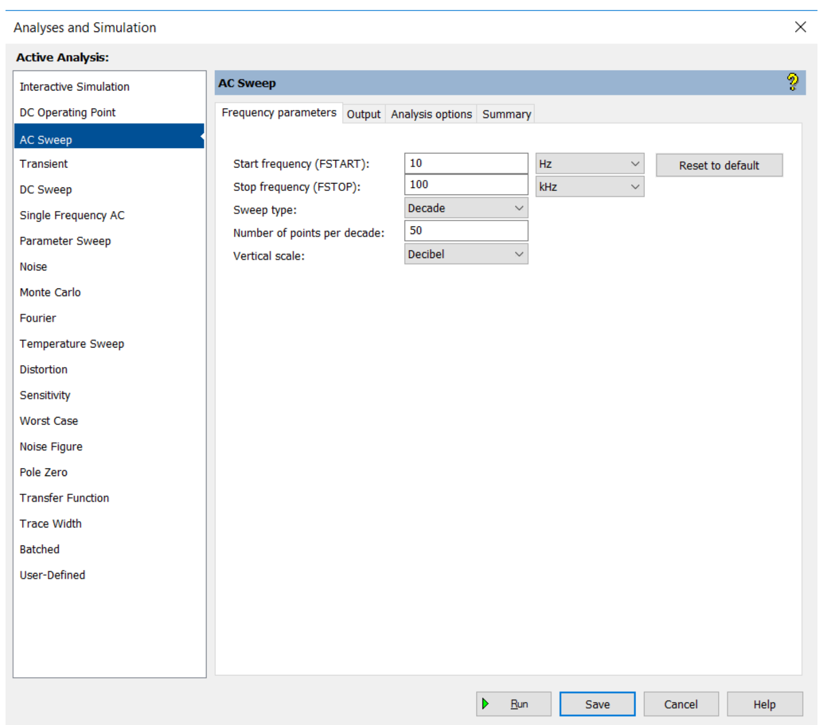

Figure 19: Individual Filter Circuits AC Sweep Simulation Settings

Fig. 20 and Fig. 21 show the simulated response plot of the individual 2^{nd} order filter circuits, using standard components values, of $H_A(S)$ and $H_B(S)$ respectively.

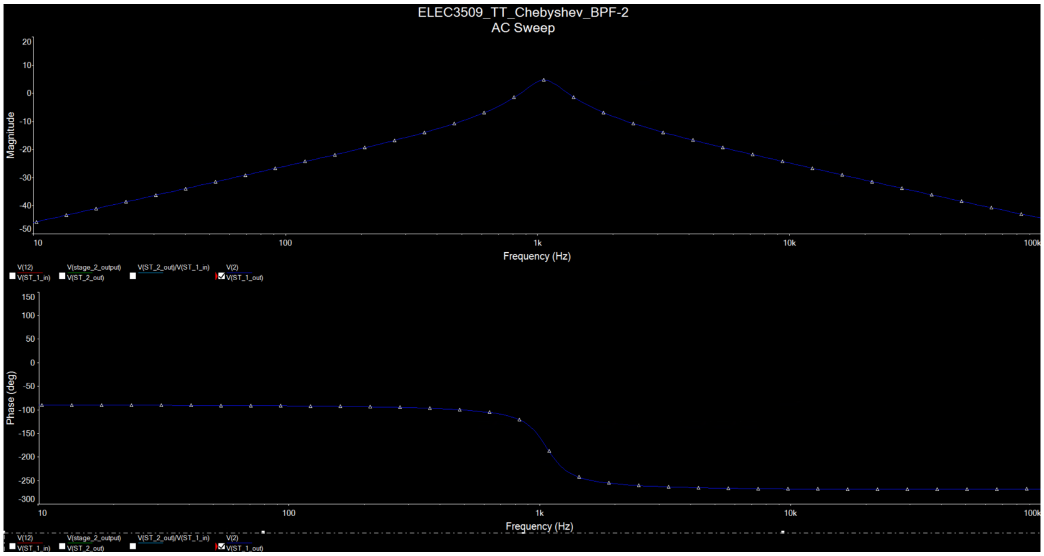

Figure 20: Simulated Response Plot, Using Standard Components Values, of The $H_A(S)$ Filter Circuit

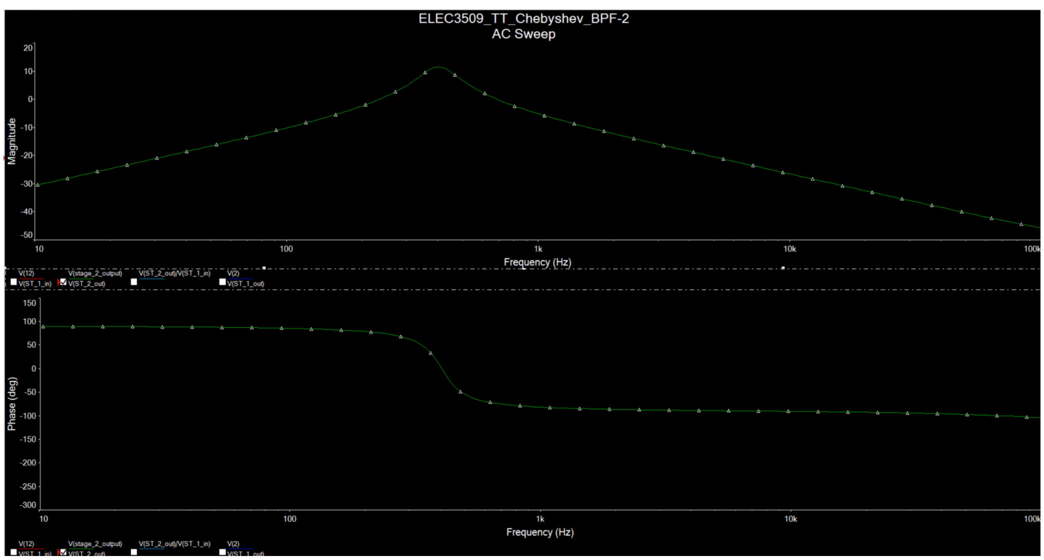

Figure 21: Simulated Response Plot, Using Standard Components Values, of The $H_B(S)$ Filter Circuit

In comparison between Fig. 20 and Fig. 13, the gain in the simulated response plot using standard components values is a fairly close match to the simulated response plot for $H_A(S)$. Likewise, the comparison between Fig. 21 and Fig. 14 shows that the gain in the simulated response plot using standard components values is afairly close match to the simulated response plot for $H_B(S)$.

3 Verification

Table 1: Summary Table for the Overall Filter Circuit

	Theoretical	Simulated	Simulated Standard Values
A_{mid}	-0.0259 dB	-0.0671 dB	-0.9671 dB
f_{lower}	338.64 Hz	339.7346 Hz	371.722 85 Hz
f_{upper}	1.0168 kHz	1.0139 kHz	1.1507 kHz
BW	4261 rad/s	4236 rad/s	4894 rad/s
Q	0.8653	0.8706	0.8396
ω_o	3687 rad/s	3688 rad/s	4109 rad/s

As shown in Table 1, the gain of the theoretical values is -0.0259 dB which is very close to the gain of the simulated values is -0.0671 dB. Also, the gain of the simulated standard values is -0.9671 dB which is very close to both theoretical and simulated gain. These results statisfy the design requirements of the Chebyshev filter project as it is within ± 1.0 dB gain error. Also, the gain results are within the trageted passband gain of $+0.0$ dB to -3.0 dB which what is desired for this project to achieve

Table 1 also shows that f_{lower} of the theoretical values is 338.64 Hz while the f_{lower} of the simulated values is 339.7346 Hz. The error percentage between the theoretical and simulated gain is 0.3%. The f_{lower} value of the simulated standard values is 371.722 85 Hz which has a 9% error percentage. These results do not satisfy the design requirements. Many attempts were done to reduce the 9% to 8% so that the f_{lower} of the simulated standard values meet the specified requirements. Due to the fact that the closest resistance and capactiance values were used, and that the calculations were student number based, the error percentage in the f_{lower} of the simulated standard values could not be further reduced while maintaining the other design requirements. An extra 1% error would not have a huge impact on the design and therefore, the number was recorded and reported.

Similarly, the same problem was encounter when measureing f_{upper}. Table 1 also shows that f_{upper} of the theoretical values is 1.0168 kHz while the f_{upper} of the simulated values is 1.0139 kHz. The error percentage between the theoretical and simulated gain is approximately 0.3% The f_{upper} value of the simulated standard values is1.1507 kHz which has a 13% error percentage. These results do not satisfy the design requirements. Many attempts were done to reduce the 13% to 8% so that the f_{upper} of the simulated standard values meet the specified requirements. Due to the fact that the closest resistance and capactiance values were used, and that the calculations were student number based, the error percentage in the f_{upper} of the simulated standard values could not be further reduced while maintaing the other design requirements.

The ripple was measured and found to be approximately 3 dB for both peaks of the gain plot for the simulated and standrad simulated values filter as shown in Fig. 24 and Fig. 25

Table 1 also shows a bandwidth of 4261 rad/s for the theoretical values while the simulated bandwidth value is 4236 rad/s. These results are almost identical and shows a very low error percentage which indicates that the simulated filter using theoretical values satifies the design requirements of this project. On the other side, the bandwidth of the simulated standard values is 4894 rad/s which is slighly larger than the theoretical and simulated values.

The quality factor, Q, of the theoretical, simulated, and standard simulated values are fairly close to each other. The Q values are 0.8653, 0.8706, and 0.8396 respectively.

Table 1 also shows that ω_o of the theoretical values is 3687 rad/s while the ω_o of the simulated values is 3688 rad/s which has a very small error percentage in comparison ω_o value of the theoretical value. The ω_o value of the simulated standard values is 4109 rad/s which slighly larger than desired.

6 Op-Amps total were used and they were all type TL082.
The supply voltages to the circuit were 15 V.
The output voltage swing is greater than ± 10 V which was verified through the simulation.

4 Discussion

Chebyshev filters can be analog or digital filters. In this lab, an analog Chebyshev filter was constructed and simulated. Chebyshev filters have a steeper roll-off tha other filters such as Butterworth filter and they have passband ripple or stopband ripple. As shown in different gain plots of the various filters built in this lab, the gain plot has a passband ripple of 3 dB as the first peak is approached and a passband ripple of 3 dB as the second peak is approached.

Due to the passband ripple shonw in the multiple gain plots, teh filter has a much smoother reponse. The filters built in this lab are 4^{th} order filters. The order of a Chebyshev filter is equal to the number of reactive components. In our case, the filter circuit has four reactive components which are the four capacitors used to construct the circuit.

For the phase of the overall filter circuit, it is seen that the phase starts droping below 0 degrees when f_{lower} is approached. The phase starts dropping and continues to drop to -360 degrees and then becomes constat at -360 degrees when f_{upper} is approached.

5 Conclusion

By the end of this laboratory, a fourth-order bandpass filter was designed and simulated based on theoretical components values. Then, another a fourth-order bandpass filter was constructed and simulated using standard components values. The purpose was to provide the junior analog designer an experience with second-order circuits as well as the Chebyshev filter response in the context of a design problem [1].

In day 1, a fourth-order bandpass filter was simulated using the theoretical values done in the prelab. The desing was simulated and verified and data were collected. The gain of the theoretical values is -0.0259 dB which is very close to the gain of the simulated values is -0.0671 dB. f_{lower} of the theoretical values is 338.64 Hz while the f_{lower} of the simulated values is 339.7346 Hz. f_{upper} of the theoretical values is 1.0168 kHz while the f_{upper} of the simulated values is 1.0139 kHz.

In day 2, a fourth-order bandpass filter was simulated using the standard compnents values. The desing was simulated and verified and data were collected. The gain of the standard simulated values is -0.9671 dB which is fairly close to the gain of the theoretical and simulated values. f_{lower} of the standard simulated values is 371.722 85 Hz while f_{upper} of the standard simulated values is 1.1507 kHz. These results did not satisfy the $\pm 8\%$ error range. However, the error percentage was close enough that a decision of recording and reporting these data was made.

All the other requirments for both the simulated and standard simulated values were meet as stated in the design project requirements.

6 References

[1] "Lab 4: Active Band-Pass Filter Project," Carleton Univeristy, Ottawa, 2017.

7 Appendix

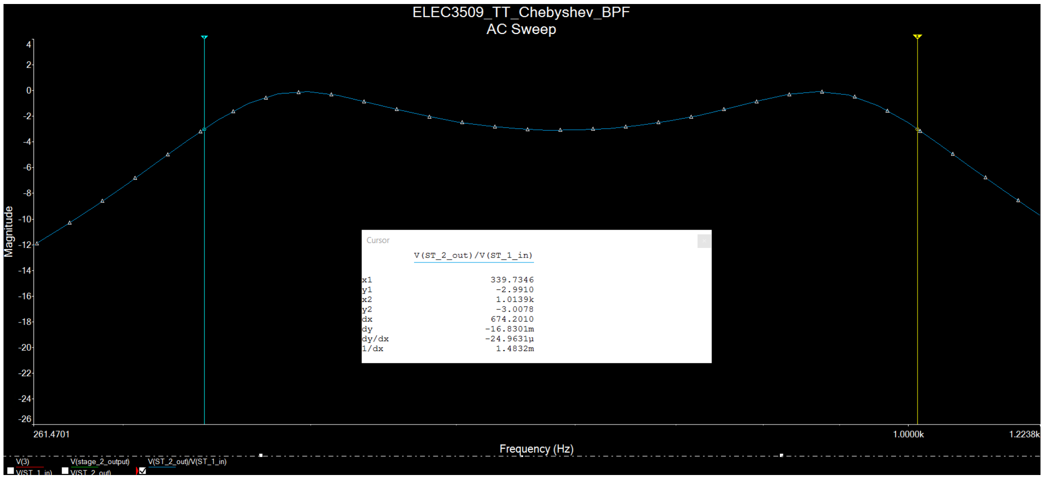

Figure 22: Simulated Response Plot of The Overall Filter Circuit

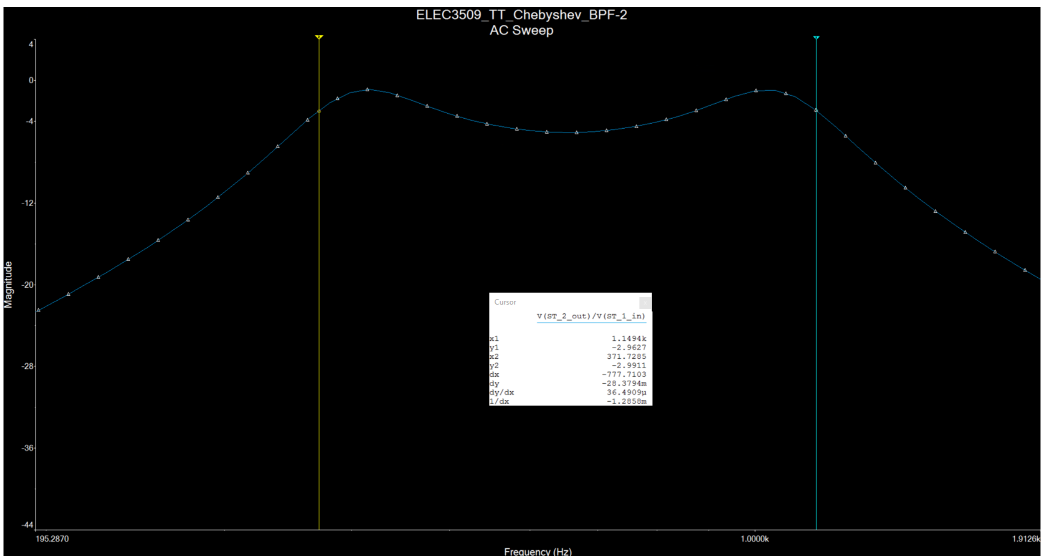

Figure 23: Standard Simulated Response Plot of The Overall Filter Circuit

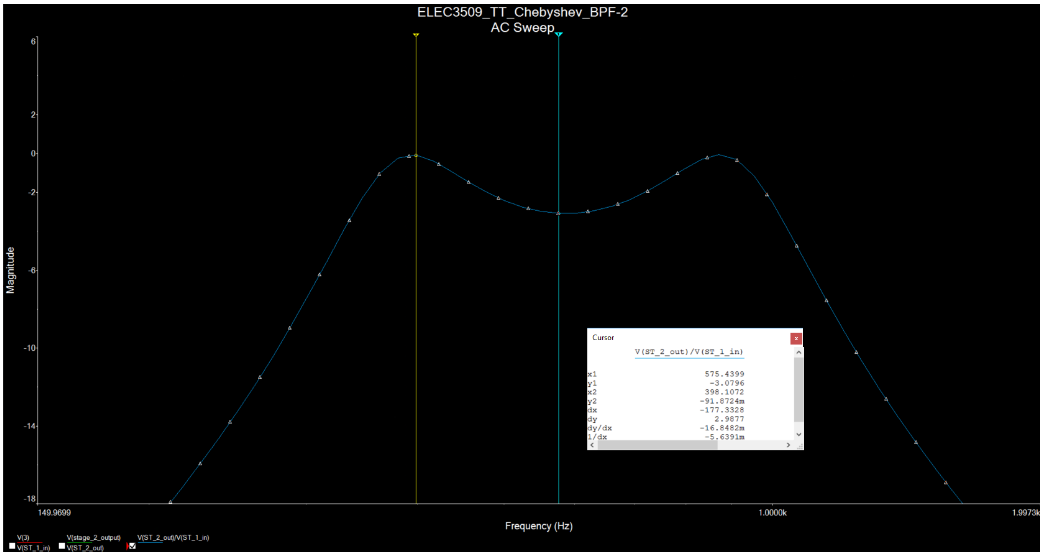

Figure 24: Simulated Ripple 1

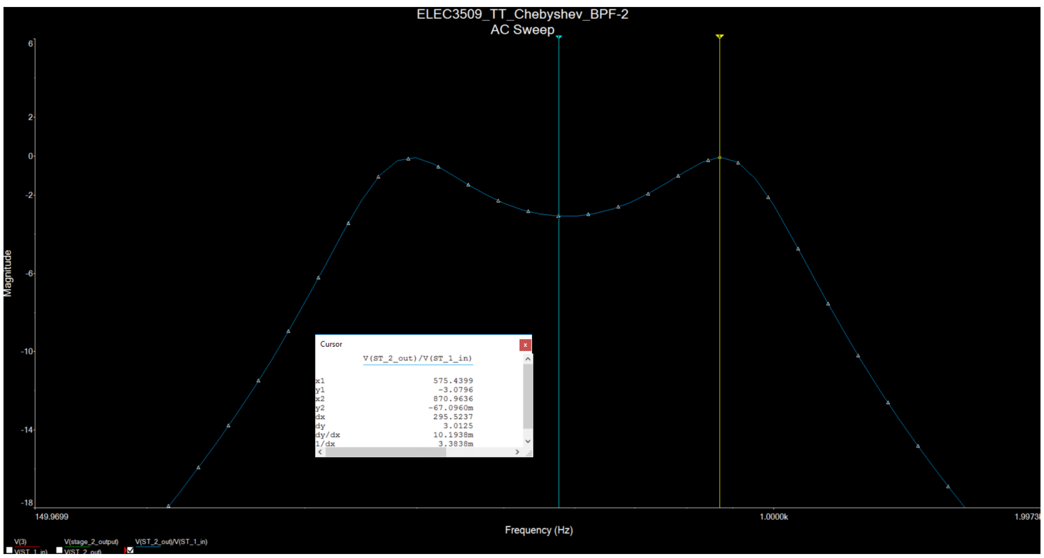

Figure 25: Standard Simulated Ripple