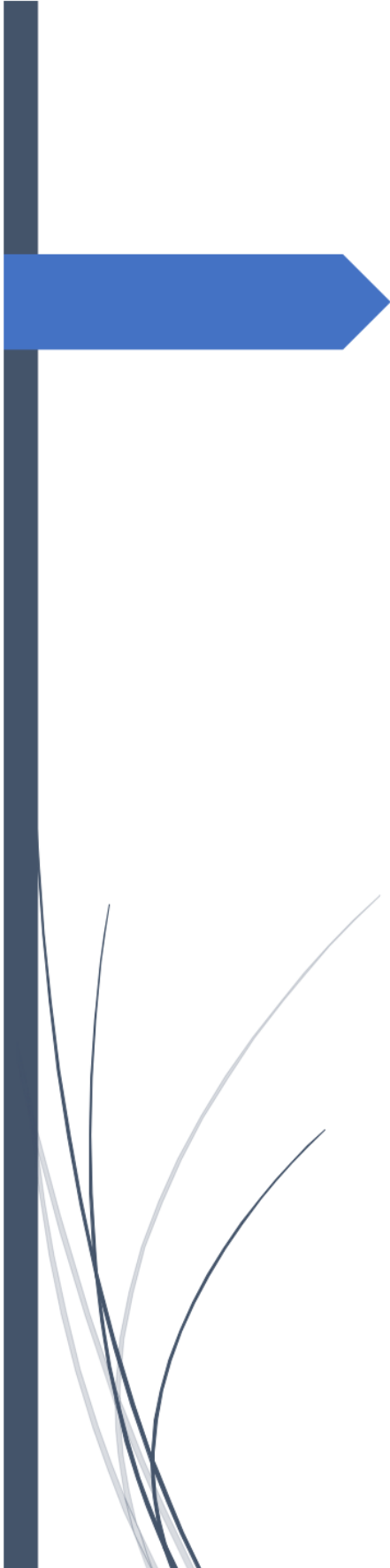


Assignment 2

by Gareth Wilkins

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1. Introduction, aims and objectives

This assignment relates to active filters with specific interest in the Bessel, Tschebyeschef and Butterworth classifications. Research will be carried out on these design methods. Fifth order low pass filters using the Bessel, Tschebyeschef and butterworth design method will be calculated and tested. Third order, sixth order and ninth order Butterworth high pass filters will be calculated and tested. A conclusion will be produced to detail the results and compared with the research performed.

2. Research into active filter design

2.1 Filters

Filters are frequency selective circuits as they filter out certain input signals based on their frequency. No practical filter can perfectly filter out selected frequencies, but they attenuate these, meaning they weaken or lessen the effect. Passive filters performance is dictated by the passive elements being the resistors, inductors and capacitors. The addition of a load to a passive filter effects the cut off frequency and pass band magnitude. The passive filter is used at higher frequency greater than 1Mhz. Passive circuit designs are shown in figure 1. (Riedel, 2015)

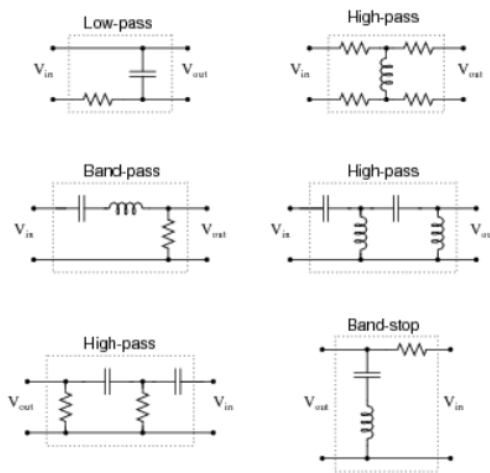


Figure 1: Passive filter circuits (All About Circuits, 2020)

Filters come in four main types being Low Pass, High Pass, Band Pass and Band reject.

The passband is the frequency that passes from the input to the output. Input Frequencies that fall outside the passband are attenuated by the circuit and fall into the band stop where the input frequency are not passed onto the output. (Riedel, 2015) The ideal frequency response of the particular filters is shown in figure 2.

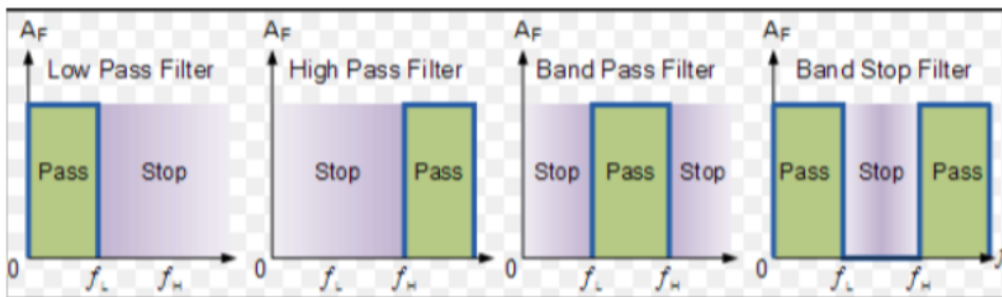


Figure 2: Ideal filter frequency response (Electronics Tutorial, 2020)

2.2 Active filters

Active filters remove the need of large inductors and replace them with op amps. Active filters provide a control over amplification which is not available with passive filters. The loading effect is avoided with the active filter as op amps act as impedance converters which separate each filter stage. (All About Electronics, 2020)

The order of an active filter affects the roll off. For a first order low pass filter a roll off of 20dB per decade is expected.

Various filter designs are available, but most applications utilise the Butterworth, Tschebyschef and Bussel classification.

Butterworth

Optimum passband flatness is delivered by the Butterworth filter. Increasing the order of the filter provides a greater roll off. A bode plot diagram comparing the order and pass band flatness is shown in figure 3. The amplitude is practically flat up to cut off frequency. This filter is used in audio systems due to its pass band flatness. (Elprocus, 2020)

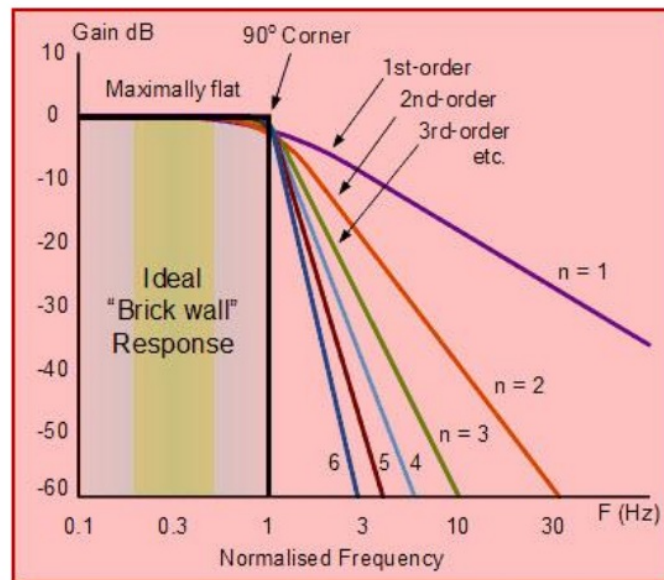


Figure 3: Effect of increasing filter order (Elprocus, 2020)

Tschebyschef

Greater gain roll off is observed with the Tschebyschef. With this though ripples are produced in the passband. Higher passband ripples yields a higher roll off filter. Filters with an even order produce ripples exceeding the 0dB point. With filters with an odd order number producing a ripple below the 0dB point. With the induced ripple this filter design is not appropriate to audio systems but can be used in systems that only have one frequency in the pass band. (Texas Instruments, 2002)

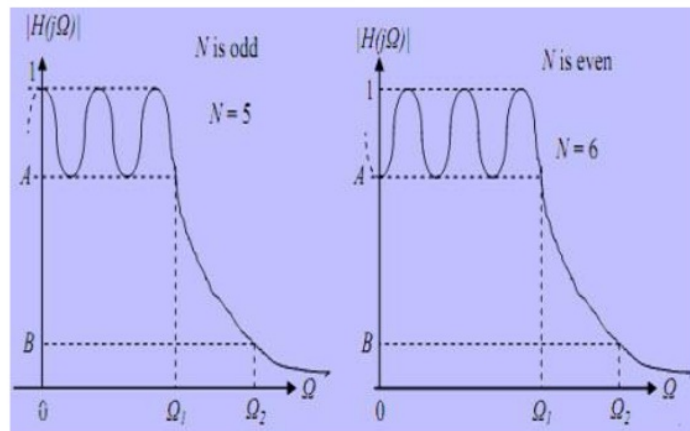


Figure 4: Tschebyschef frequency response

Bessel

A constant group delay in the filter passband is optimized with this filter. The Bessel does not produce passband as flat as the Butterworth nor does it produce a stop band as sharp as the Tscheychef. (Texas Instruments, 2002)

A comparison graph of the filter classifications is shown in figure 5.

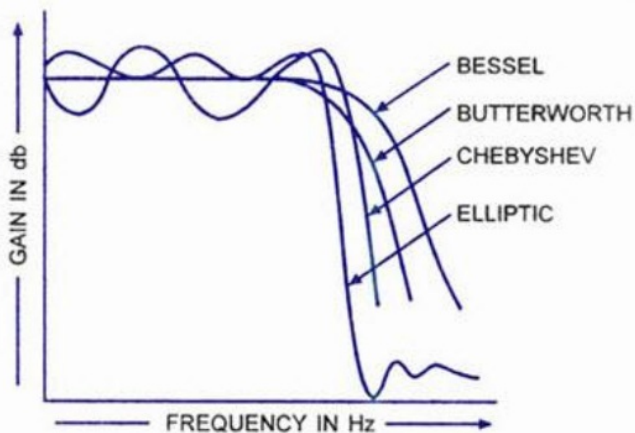


Figure 5: Comparison of active filter classification (Elprocus, 2020)

Low pass filter design

The cascading of filters involves the combining of first and second order filter stages. Even order number filters comprise second order stages only. Odd order number filters incorporate a first order stage at the start.

Cascade filter stage design to obtain filter order is shown in figure 6.

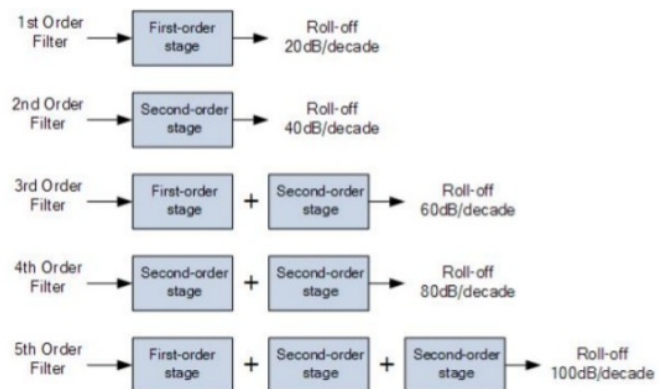


Figure 6: Effect of increasing filter order (Electronics Tutorial, 2020)

First order low pass filter is shown in figure 7.

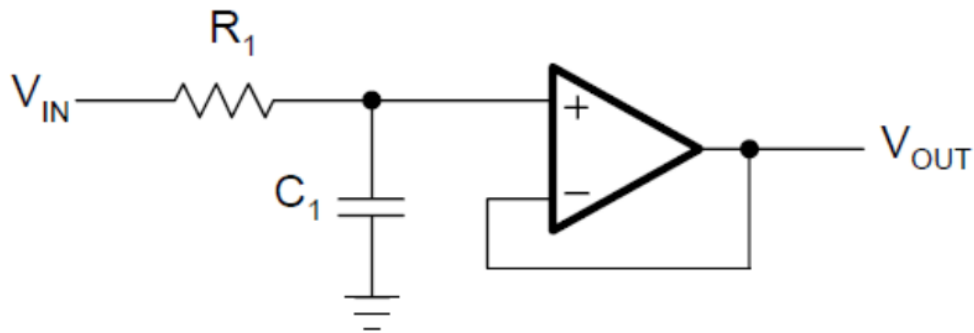


Figure 7: First order non inverting amplifier

First order calculations

A value of C_1 will be chosen and calculations will be performed to obtain the desired result. The value of R_1 is calculated by the following equation. (Texas Instruments, 2002)

$$R_1 = \frac{a_1}{2\pi f_c C_1}$$

A coefficient table is available to design of the filter stages for the different types of design. The value of A_1 and B_1 can change for each stage. (Texas Instruments, 2002) The coefficient tables are shown in appendix reference 1-3.

Second order low pass filter

A Sallen-Key second order filter is shown in figure 8.

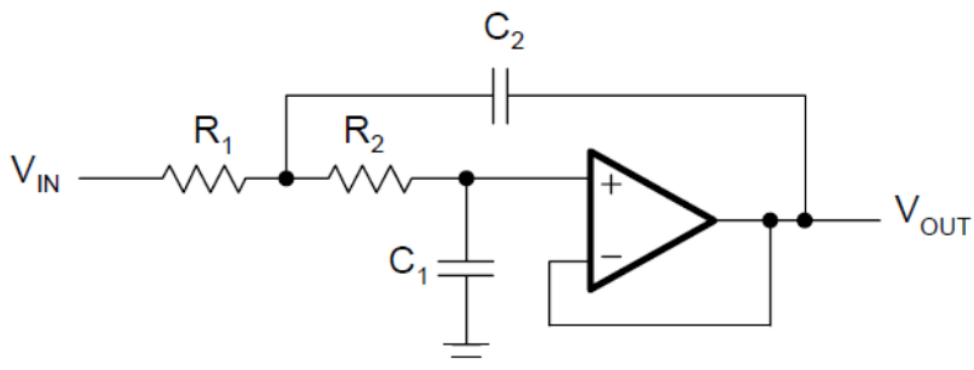


Figure 8: Sallen-key second order filter(Intechopen, 2012)

The value of C1 remains the same and C2 is calculated with the following equation

$$C_2 \geq \frac{C_1 \times 4b}{a^2}$$

With the value of C2, R1 and R2 can be calculated using the following equation

$$R = \frac{a_i C_2 \pm \sqrt{a_i^2 C_2^2 - 4b_i C_1 C_2}}{4\pi f_c C_1 C_2}$$

To simplify the design, positive numbers in the square root are desired to eliminate the use of complex numbers.

Higher order low pass filter

To acquire the desired filter characteristic higher order low pass filters can be used. Filter stages are connected in series resulting in individual frequency responses combined producing an optimal frequency response to the filter. (Texas Instruments, 2002)

High pass filter design

The circuit design remains the same but the capacitor and resistor locations are swapped to create an active high pass filter.

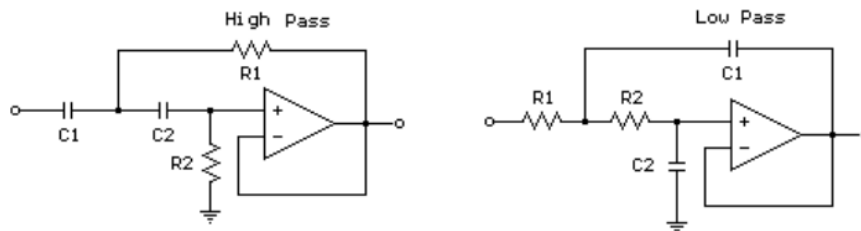


Figure 9: Converting low pass filter to high pass filter (Next, 2020)

First order high pass filter

Like the low pass filter the value of C1 will be chosen and the following calculation will be performed. The coefficient table will be used to obtain the appropriate coefficient value for the order and stage.

$$R_1 = \frac{1}{2\pi f_c a_1 c_1}$$

Second order high pass filter

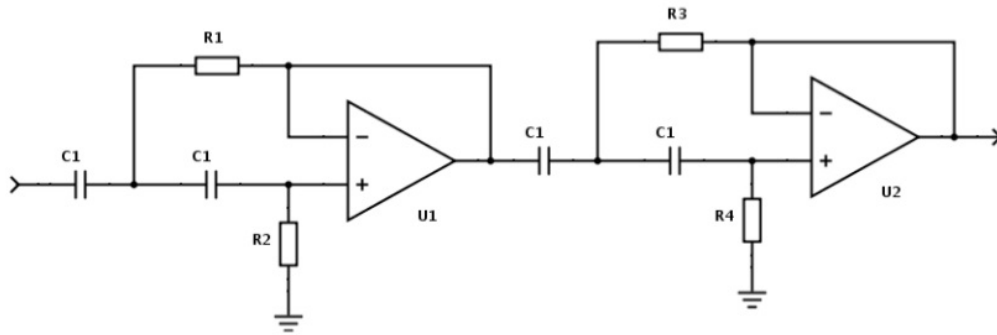


Figure 10: Second order active high pass filter

The same capacitor values are used for each capacitor and the following equations are done to calculate the resistance values for R1 and R2.

$$R_1 = \frac{1}{\pi f_c \times C \times a_2}$$

$$R_2 = \frac{a_2}{4\pi f_c \times C \times b_2}$$

Like the low pass filter the high pass filter order is achieved by connecting stages and roll off is increased as the order number increases.

Active filters are used in audio speaker systems. The low pass filter reduces the transmission of high frequencies to the subwoofer which removes the hissing noise which would be present without the filter. (Elprocus, 2020)



Figure 11: Audio subwoofer (Amazon, 2020)

3. Design method, choices and calculations

The set frequency for the circuits is 190KHz. The coefficient values were chosen from the Bessel coefficient table appendix reference 1

3.1 Bessel – Fifth Order low pass filter

A value of 0.2nF was chosen for C1

1st stage

C1= 0.2nF

A1=0.6656

B1=0

$$R_1 = \frac{a_1}{2\pi f_c C_1}$$

$$R_1 = \frac{0.6656}{2\pi \times 190K \times 0.2nF}$$

$$R_1 = 2787\Omega$$

2nd Stage

A1=1.402

B1=0.4128

C2=0.2nF

$$C_2 \geq \frac{C_1 \times 4b}{a^2}$$

$$C_2 \geq \frac{0.2nF \times 4(0.4128)}{1.1402^2}$$

$$= 254.019pF$$

Making C2 = 260pF

Calculating resistor value

$$R = \frac{a_i C_2 \pm \sqrt{a_i^2 C_2^2 - 4b_i C_1 C_2}}{4\pi f_c C_1 C_2}$$

$$R1 = \frac{1.402 \times 260\text{pF} + \sqrt{1.402^2 \times 0.2\text{nF} - 4(0.4128)(0.2\text{nF})(260\text{pF})}}{4\pi \times 190\text{K} \times 0.2\text{nF} \times 260\text{pF}}$$

$$= 2.03\text{K}$$

$$R2 = \frac{1.402 \times 260\text{pF} - \sqrt{1.402^2 \times 0.2\text{nF} - 4(0.4128)(0.2\text{nF})(260\text{pF})}}{4\pi \times 190\text{K} \times 0.2\text{nF} \times 260\text{pF}}$$

$$= 2.75\text{K}$$

3rd Stage

$$A1 = 0.6216$$

$$B1 = 0.3245$$

$$C2 = 0.2\text{nF}$$

$$C_2 \geq \frac{C_1 \times 4b}{a^2}$$

$$C_2 \geq \frac{0.2\text{nF} \times 4(0.3245)}{0.6216^2}$$

$$= 671.860\text{pF}$$

Making C2 = 680pF

Calculating resistor values

$$R = \frac{a_i C_2 \pm \sqrt{a_i^2 C_2^2 - 4b_i C_1 C_2}}{4\pi f_c C_1 C_2}$$

$$R1 = \frac{0.6216 \times 680\text{pF} + \sqrt{0.6216^2 \times 680\text{pF}^2 - 4(0.3245)(0.2\text{nF})(680\text{pF})}}{4\pi \times 190\text{k} \times 680\text{pF}}$$

$$= 1.16\text{K}\Omega$$

$$R2 = \frac{0.6216 \times 680\text{pF} - \sqrt{0.6216^2 \times 680\text{pF}^2 - 4(0.3245)(0.2\text{nF})(680\text{pF})}}{4\pi \times 190\text{k} \times 680\text{pF}}$$

$$= 1.44\text{K}\Omega$$

3.2 Tschebyscheff (-3dB) – Fifth order low pass filter

A value of 0.2nF was chosen for C1. The coefficient values were obtained from the Tschebyscheff coefficient table appendix reference 2.

Stage 1

$$C1 = 0.2\text{nF}$$

$$A1 = 5.6334$$

$$B1 = 0$$

$$R_1 = \frac{a_1}{2\pi f_c C_1}$$

$$R_1 = \frac{5.6334}{2\pi \times 190\text{k} \times 0.2\text{nF}}$$

$$23594.30148\Omega$$

Stage 2

$$A1 = 0.7620$$

$$B1 = 2.6530$$

$$C_2 \geq \frac{C_1 \times 4b}{a^2}$$

$$C_2 \geq \frac{0.2\text{nF} \times 4(2.6530)}{0.7620^2}$$

$$= 3.655\text{nF}$$

Taking C2 as 3.7nF

$$R = \frac{a_i C_2 \pm \sqrt{a_i^2 C_2^2 - 4b_i C_1 C_2}}{4\pi f_c C_1 C_2}$$

$$R1 = \frac{0.7620 \times 3.7\text{nF} + \sqrt{(1.0650 \times 3.7\text{nF})^2 - 4(2.6530)(0.2\text{nF})(3.7\text{nF})}}{4\pi \times 190\text{K} \times 0.2\text{nF} \times 3.7\text{nF}}$$

$$= 1.42\text{k}\Omega$$

$$R2 = \frac{0.7620 \times 3.7\text{nF} - \sqrt{(1.0650 \times 3.7\text{nF})^2 - 4(2.6530)(0.2\text{nF})(3.7\text{nF})}}{4\pi \times 190\text{K} \times 0.2\text{nF} \times 3.7\text{nF}}$$

$$1.77\text{k}\Omega$$

Stage 3

$$A1 = 0.1172$$

$$B1 = 1.0686$$

$$C_2 \geq \frac{C_1 \times 4b}{a^2}$$

$$C_2 \geq \frac{0.2\text{nF} \times 4(1.0686)}{0.1172^2}$$

$$= 62.237\text{nF}$$

Taking C2 as 63nF

$$R = \frac{a_i C_2 \pm \sqrt{a_i^2 C_2^2 - 4b_i C_1 C_2}}{4\pi f_c C_1 C_2}$$

$$R1 = \frac{0.1172 \times 63\text{nF} + \sqrt{(0.1172 \times 63\text{nF})^2 - 4(1.0686)(0.2\text{nF})(63\text{nF})}}{4\pi \times 190\text{K} \times 0.2\text{nF} \times 63\text{nF}}$$

$$= 218 \Omega$$

$$R2 = \frac{0.1172 \times 63\text{nF} - \sqrt{(0.1172 \times 63\text{nF})^2 - 4(1.0686)(0.2\text{nF})(63\text{nF})}}{4\pi \times 190\text{K} \times 0.2\text{nF} \times 63\text{nF}}$$

$$= 272 \Omega$$

3.3 Butterworth – Fifth order low pass filter

A value of 0.2nF was chosen for C1. The coefficient values were selected from the Butterworth coefficient table appendix reference 3.

First stage

$$C1 = 0.2nF$$

$$A1 = 1$$

$$B1 = 0$$

$$R_1 = \frac{a_1}{2\pi f_c C_1}$$

$$R_1 = \frac{1}{2\pi \times 190k \times 0.2n}$$

$$1675.318\Omega$$

Second stage

$$A1 = 1.6180$$

$$B1 = 1$$

$$C_2 \geq \frac{C_1 \times 4b}{a^2}$$

$$C_2 \geq \frac{0.2nF \times 4(1)}{1.6180^2}$$

$$= 305nF$$

Taking C2 as 350nF

$$R = \frac{a_i C_2 \pm \sqrt{a_i^2 C_2^2 - 4b_i C_1 C_2}}{4\pi f_c C_1 C_2}$$

$$R1 = \frac{1.6180 \times 350nF + \sqrt{1.6180 \times 350nF - 4(1)(0.2nF)(350nF)}}{4\pi \times 190k \times 0.2nF \times 350nF}$$

$$= 2.18k\Omega$$

$$R_2 = \frac{1.6180 \times 350\text{nF} + \sqrt{1.6180 \times 350\text{nF} - 4(1)(0.2\text{nF})(350\text{nF})}}{4\pi \times 190\text{k} \times 0.2\text{nF} \times 350\text{nF}}$$

$$= 4.6\text{k}\Omega$$

Third stage

$$C_1 = 0.2\text{nF}$$

$$A_1 = 0.6180$$

$$B_1 = 1$$

Making $C_1 = 0.2\text{nF}$

$$C_2 \geq \frac{0.2\text{nF} \times 4(1)}{0.6180^2}$$

$$= 2.095\text{nF}$$

Taking C_2 as 2.5nF

$$R = \frac{a_i C_2 \pm \sqrt{a_i^2 C_2^2 - 4b_i C_1 C_2}}{4\pi f_c C_1 C_2}$$

$$R_1 = \frac{0.6180 \times 2.5\text{nF} + \sqrt{0.6180 \times 2.5\text{nF} - 4(1)(0.2\text{nF})(2.5\text{nF})}}{4\pi \times 190\text{k} \times 0.2\text{nF} \times 2.5\text{nF}}$$

$$= 773\Omega$$

$$R_2 = \frac{0.6180 \times 2.5\text{nF} - \sqrt{0.6180 \times 2.5\text{nF} - 4(1)(0.2\text{nF})(2.5\text{nF})}}{4\pi \times 190\text{k} \times 0.2\text{nF} \times 2.5\text{nF}}$$

$$= 1.82\text{k}\Omega$$

3.4 Butterworth – Third order high pass filter

A value of 0.2nF was chosen for C1. The coefficient values were selected from the Butterworth coefficient table appendix reference 3.

First stage

$$C1 = 0.2nF$$

$$A1 = 1$$

$$B1 = 0$$

$$R_1 = \frac{1}{2\pi f_c a_1 c_1}$$

$$R_1 = \frac{1}{2\pi \times 190k \times 0.2nF}$$

$$= 4188\Omega$$

Second Stage

$$A1 = 1$$

$$B1 = 1$$

$$R_2 = \frac{1}{\pi f_c \times C \times a_2}$$

$$R_2 = \frac{1}{\pi \times 190k \times 0.2nF \times 1}$$

$$= 8376.576\Omega$$

$$R_3 = \frac{a_1}{4\pi f_c \times C \times b_2}$$

$$R_3 = \frac{1}{4\pi \times 190k \times 0.2nF \times 1}$$

$$= 2094.144\Omega$$

3.5 Butterworth – Sixth order High Pass Filter

A value of 0.2nF was chosen for C1. The coefficient values were chosen from the Butterworth coefficient table appendix reference 3.

First stage

$$C1 = 0.2nF$$

$$A1 = 1.9319$$

$$B1 = 1$$

$$R_1 = \frac{1}{2\pi f_c a_1 c_1}$$

$$R_1 = \frac{1}{2\pi \times 190k \times 1.9319 \times 0.2nF}$$

$$= 4335.926\Omega$$

$$R_2 = \frac{a_1}{4\pi f_c a_1 c_1}$$

$$R_2 = \frac{1.9319}{4\pi \times 190k \times 0.2nF \times 1}$$

$$= 4045.677\Omega$$

Second stage

$$A1 = 1.4142$$

$$B1 = 1$$

$$R_3 = \frac{1}{2\pi f_c a_1 c_1}$$

$$R_3 = \frac{1}{2\pi \times 190k \times 1.4142 \times 0.2nF}$$

$$= 5923.190\Omega$$

$$R_4 = \frac{a_1}{4\pi f_c a_1 c_1}$$

$$R_4 = \frac{1.4142}{4\pi \times 190k \times 1.4142 \times 0.2nF}$$

$$= 2961.538\Omega$$

Third stage

$$A_1 = 0.5176$$

$$B_1 = 1$$

$$R_5 = \frac{1}{\pi f_c \times C \times a_3}$$

$$R_5 = \frac{1}{\pi \times 190k \times 0.2nF \times 0.5176}$$

$$= 16183.493\Omega$$

$$R_6 = \frac{a_3}{4\pi f_c \times C \times b_3}$$

$$R_6 = \frac{0.5176}{4\pi \times 190k \times 0.2nF \times 1}$$

$$= 1083.929\Omega$$

3.6 Butterworth - Ninth order high pass filter

The value of 0.2nF was chosen for C1. The coefficient values were obtained from the Butterworth coefficient table appendix reference 3.

Stage 1

$$C1 = 0.2nF$$

$$A1 = 1$$

$$B1 = 0$$

$$R_1 = \frac{1}{2\pi f_c a_1 c_1}$$

$$R_1 = \frac{1}{2\pi \times 190k \times 1 \times 0.2nF}$$

$$= 4188.288\Omega$$

Stage 2

$$A1 = 1.8794$$

$$B1 = 1$$

$$R_2 = \frac{1}{\pi f_c a_1 c_1}$$

$$R_2 = \frac{1}{\pi \times 190k \times 1.8794 \times 0.2nF}$$

$$= 4457.048\Omega$$

$$R_3 = \frac{a_1}{4\pi f_c \times C \times b_3}$$

$$R_3 = \frac{1.8794}{4\pi \times 190k \times 0.2uF \times 1}$$

$$= 3935.734\Omega$$

Third stage

$$A1 = 1.5321$$

$$B1 = 1$$

$$R_4 = \frac{1}{\pi f_c c_1 a_1}$$

$$R_4 = \frac{1}{\pi \times 190k \times 0.2nF \times 1.5321}$$

$$= 5467.382\Omega$$

$$R_5 = \frac{a_2}{4\pi f_c \times C \times b_2}$$

$$R_5 = \frac{1.5321}{4\pi \times 190k \times 0.2nF \times 1}$$

$$= 3208.438\Omega$$

Fourth stage

$$A1 = 1$$

$$B1 = 1$$

$$R_6 = \frac{1}{\pi f_c \times C \times a_3}$$

$$R_6 = \frac{1}{\pi \times 190k \times 0.2nF \times 1}$$

$$= 8376.576\Omega$$

$$R_7 = \frac{a_3}{4\pi f_c \times C \times b_3}$$

$$R_7 = \frac{1}{4\pi \times 190k \times 0.2nF \times 1}$$

$$= 2094.144\Omega$$

Fifth stage

$$A1 = 0.3473$$

$$B1 = 1$$

$$R_8 = \frac{1}{\pi f_c \times C \times a_3}$$

$$R_8 = \frac{1}{\pi \times 190k \times 0.2nF \times 0.3473}$$

$$= 24119.136\Omega$$

$$R_9 = \frac{a_3}{4\pi f_c \times C \times b_3}$$

$$R_9 = \frac{0.3473}{4\pi \times 190k \times 0.2nF \times 1}$$

$$= 727.296\Omega$$

4. Testing and improving the design

4.1 Bessel

The Bessel 5th order low pass filter was constructed in MultiSim and is shown in figure 12.

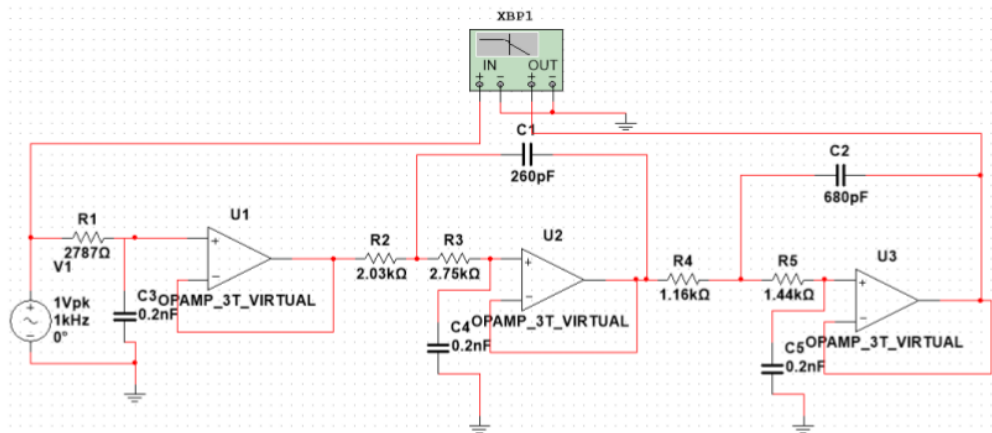


Figure 12: Bessel fifth order low pass filter circuit

The Bode plot instrument was used to measure the frequency response which is shown in figure 13.

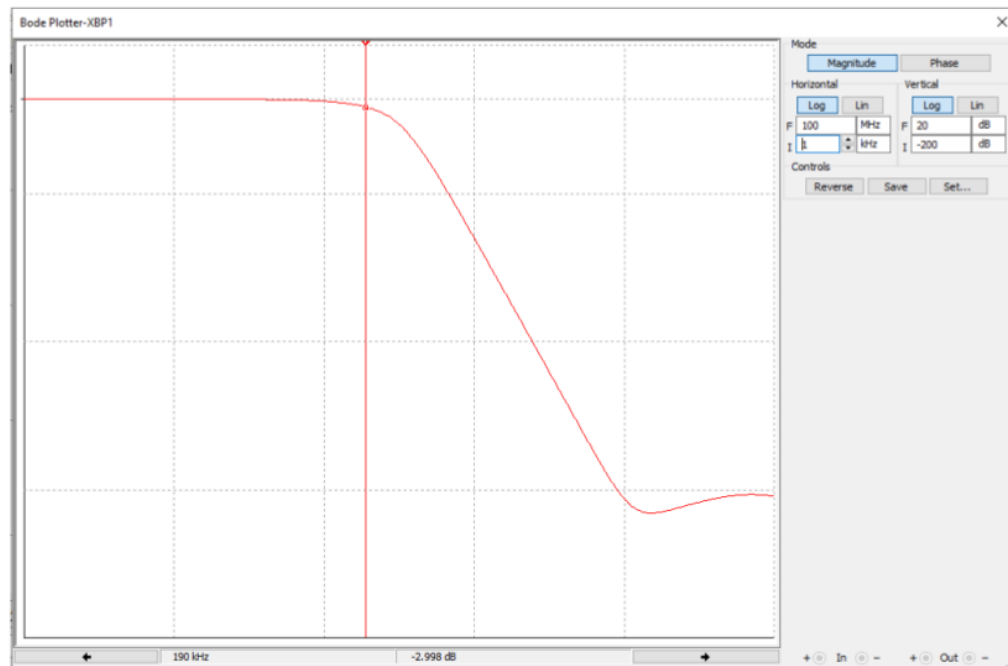


Figure 13: Bode plot of Bessel fifth order low pass filter

In figures 14 and figure 15 the roll off is measured to obtain a roll off value of 97.099dB per decade.

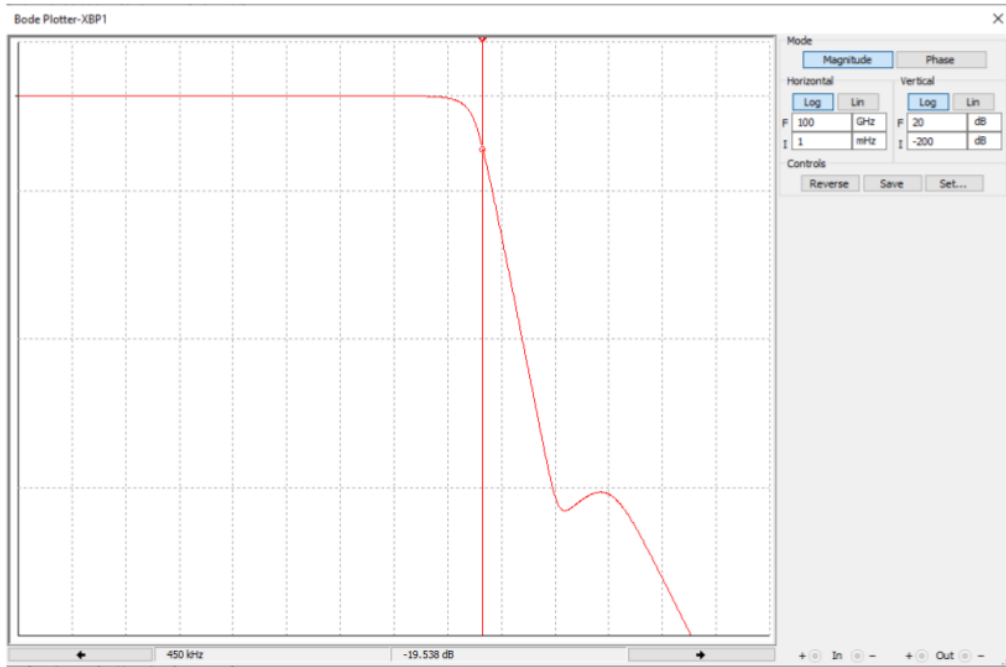


Figure 15: Bessel fifth order low pass filter roll off measurement

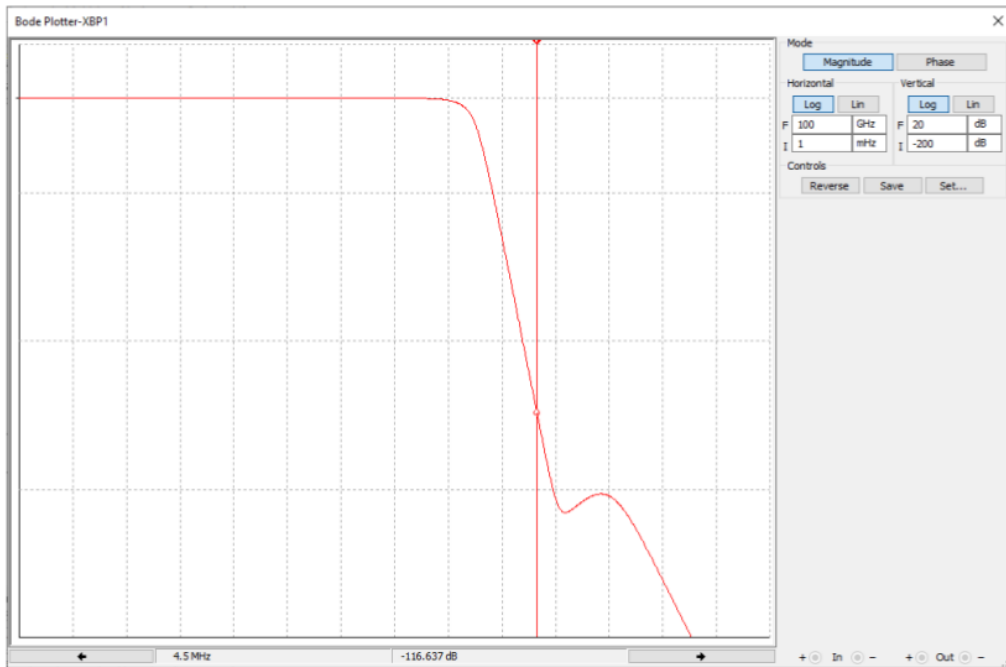


Figure 14: Bessel fifth order low pass filter roll off measurement

Table 1 shows the results of the Bessel fifth order low pass filter results.

Table 1: Fifth order Bessel low pass filter results

Parameter	Simulated
dB value @ 190K	-2.98
Roll off	97.099
Passband	Flat

4.2 Tschebyscheff

The Tschebyscheff fifth order filter was constructed on Multisim and is shown in figure 16.

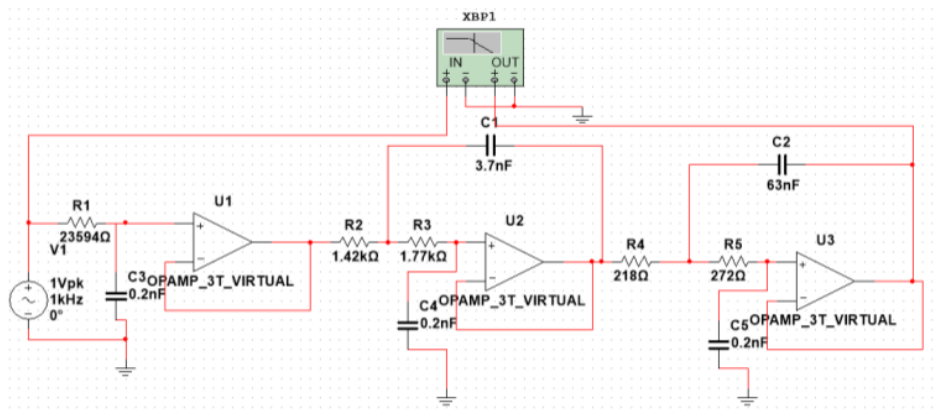


Figure 16: Tschebyscheff fifth order low pass filter circuit

The Bode plot instrument was used to measure the frequency response. This is shown in figure 17.

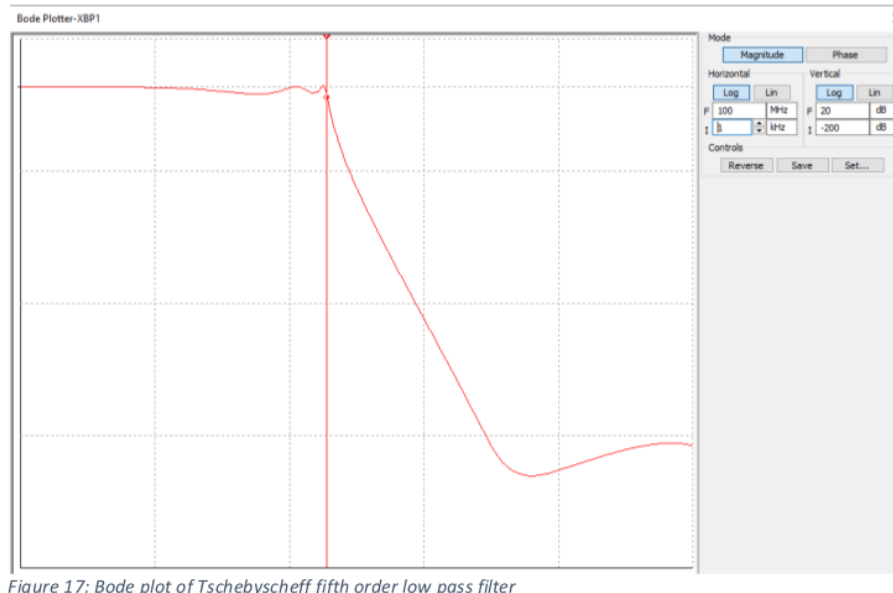


Figure 17: Bode plot of Tschebyscheff fifth order low pass filter

The frequency response shows that the Tschhebyscheff filter contains ripples in the passband below the 0dB point before reaching cut off frequency. The filter roll off is measured in figures 18 and figure 19.

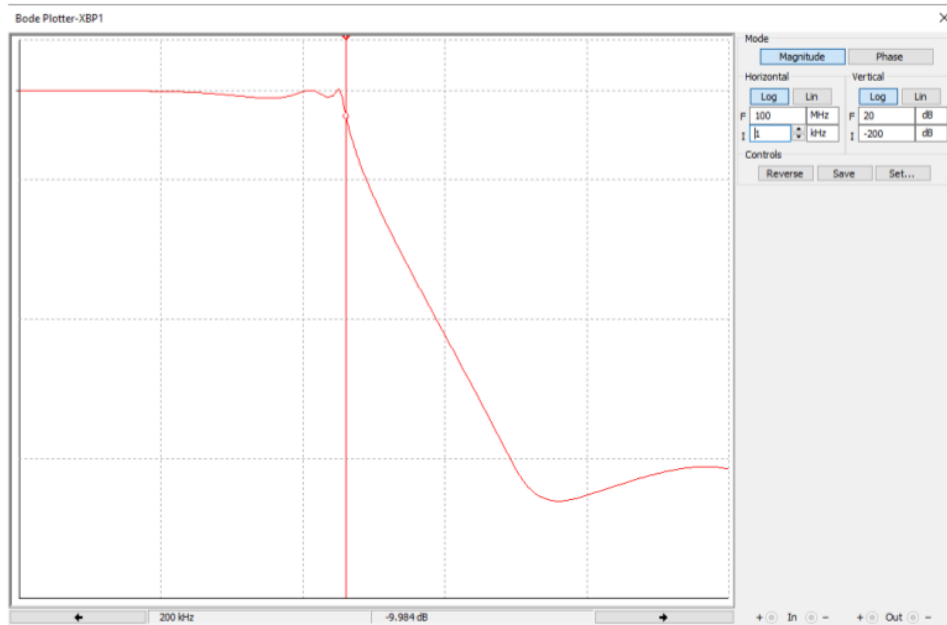


Figure 18: Tschhebyscheff fifth order low pass filter roll off measurement

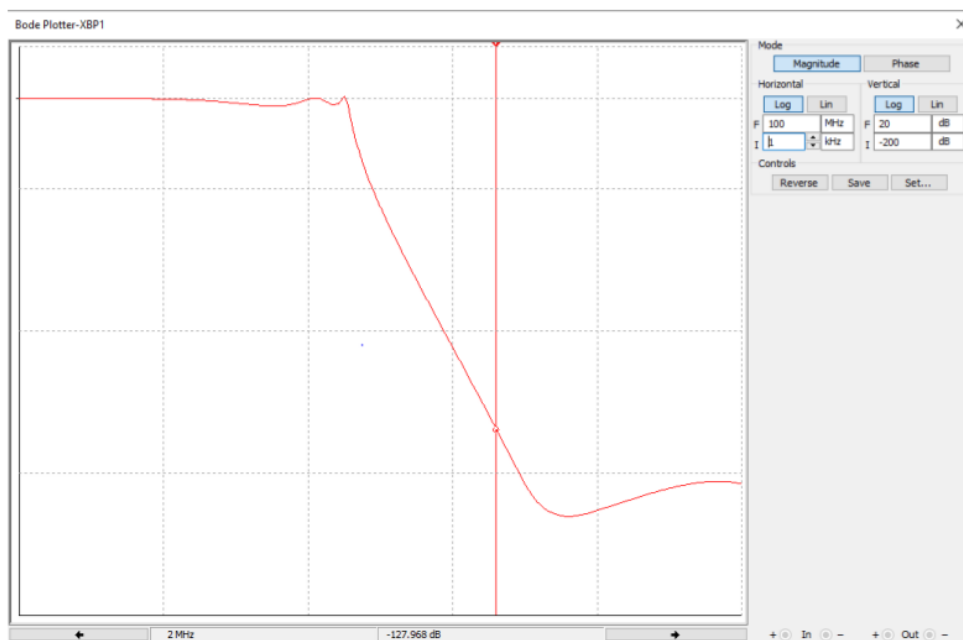


Figure 19: Tschhebyscheff fifth order low pass filter roll off measurement

Table 2 shows the results of the Tschebyscheff fifth order low pass filter.

Table 2: Tschebyscheff fifth order low pass filter results

Parameter	Simulated
dB value @ 190K	-4.073
Roll off dB/decade	117.984
Passband	Ripple

The Tschebyscheff filter produces ripples in the pass band below the 0dB point which was expected as this was found in research. Better roll off is achieved with 117.984/decade which was expected.

4.3 Butterworth

The 5th order Butterworth filter was constructed in Multisim and is shown in figure 20.

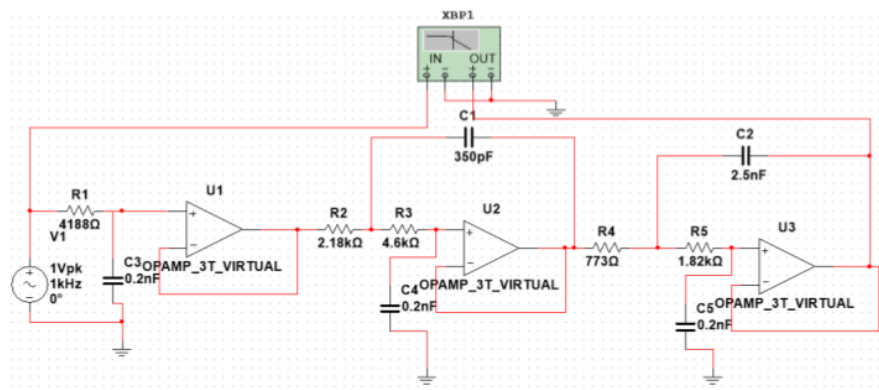


Figure 20: Tschebyscheff fifth order low pass filter circuit

The Bode plot instrument was used to analyse frequency response and is shown in figure 21.

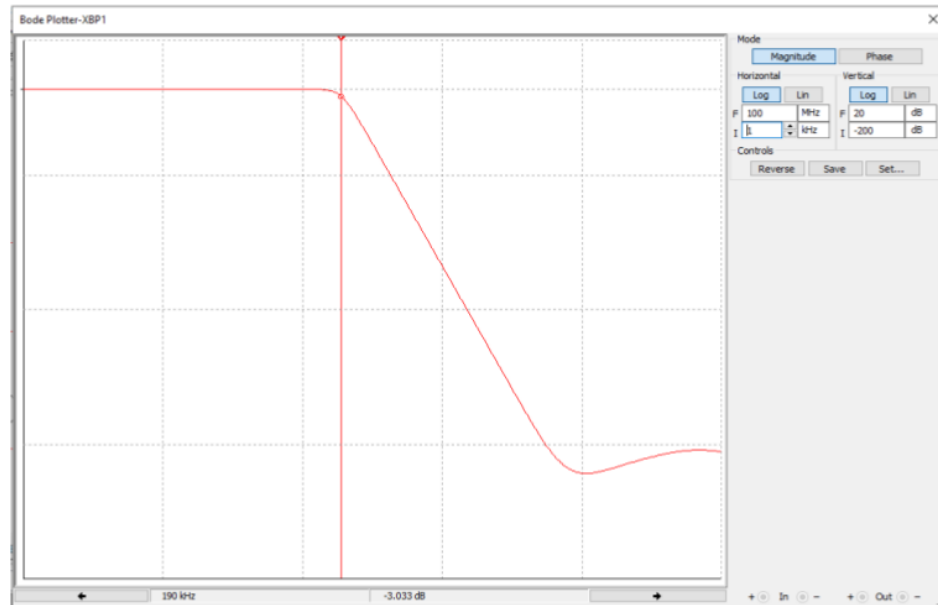


Figure 21: Bode plot of Butterworth fifth order low pass filter

The filter roll off is measured in figure 22 and figure 23.

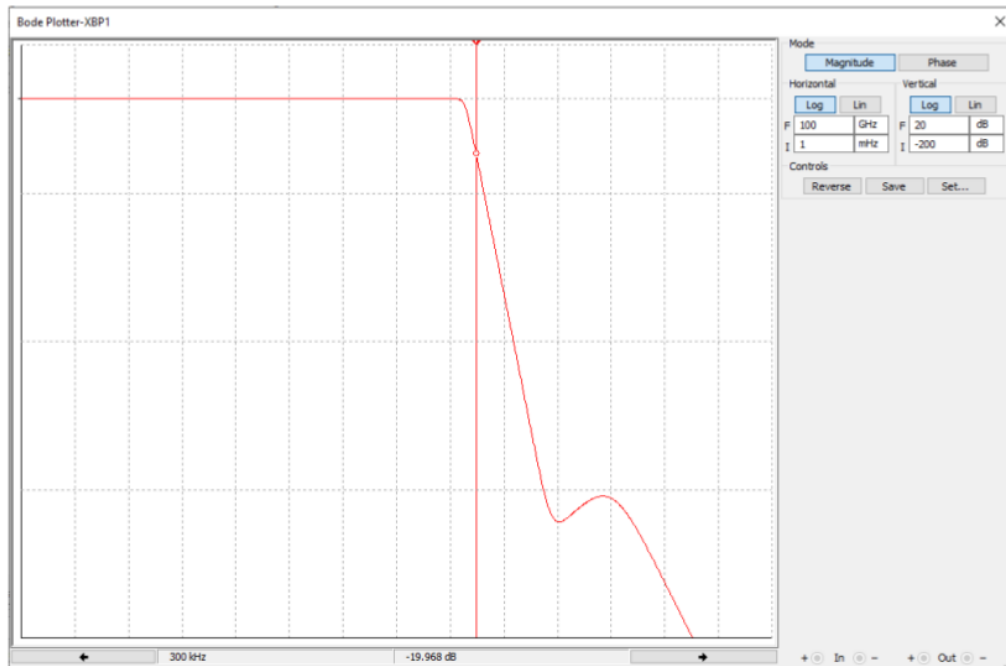


Figure 22: Butterworth fifth order low pass filter roll off measurement

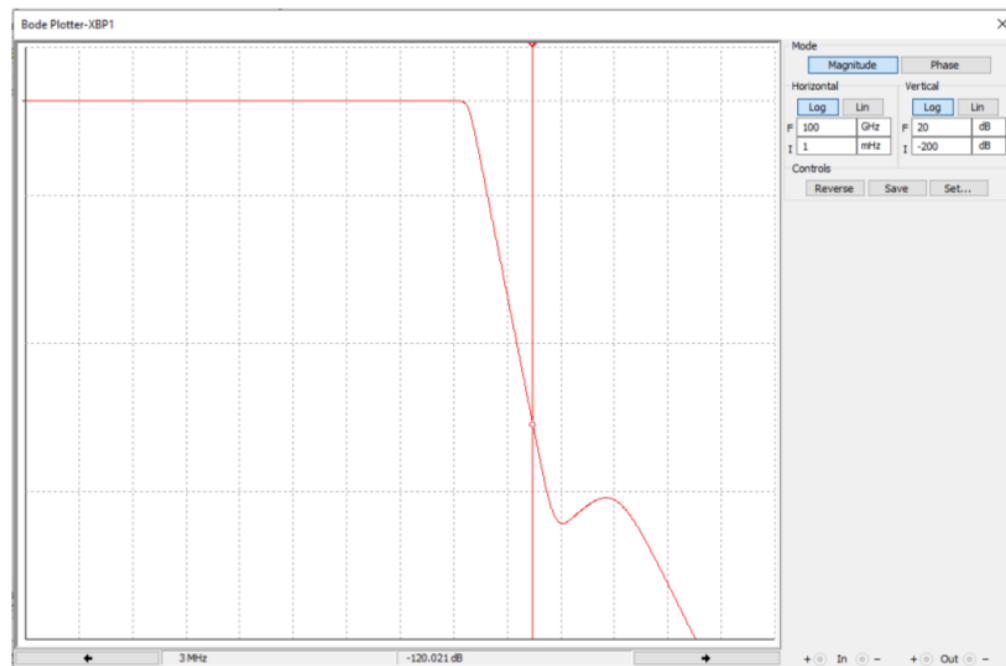


Figure 23: Butterworth fifth order low pass filter roll off measurement

In table 3 the result for the fifth order low pass Butterworth filter is shown.

Table 3: Fifth order low pass Butterworth results

Parameter	Simulated
dB value @ 190K	-3.033
Roll off dB/decade	100.053
Passband	Flat

Comparison table of filter classification

Table 4: Comparison of the tested low pass filter classifications.

Parameter	Bessel	Tschebyscheff	Butterworth
dB value @ 190K	-2.98	4.073	3.033
Roll off dB/decade	97.099	117.984	100.053
Passband	Flat	Ripple	Flat

The Bessel filter produced the flattest transition from the pass band to the stop band. The Tschebyscheff contained ripples in the passband before a sharp transition to the stop band. The Tschebyscheff has the greatest roll off with a value of 117.984 dB per decade. The Butterworth filter contains no ripples in the pass band.

4.4 High pass 3rd order Butterworth Filter

The Butterworth 3rd order high pass filter was constructed on Multisim and is shown in figure 24.

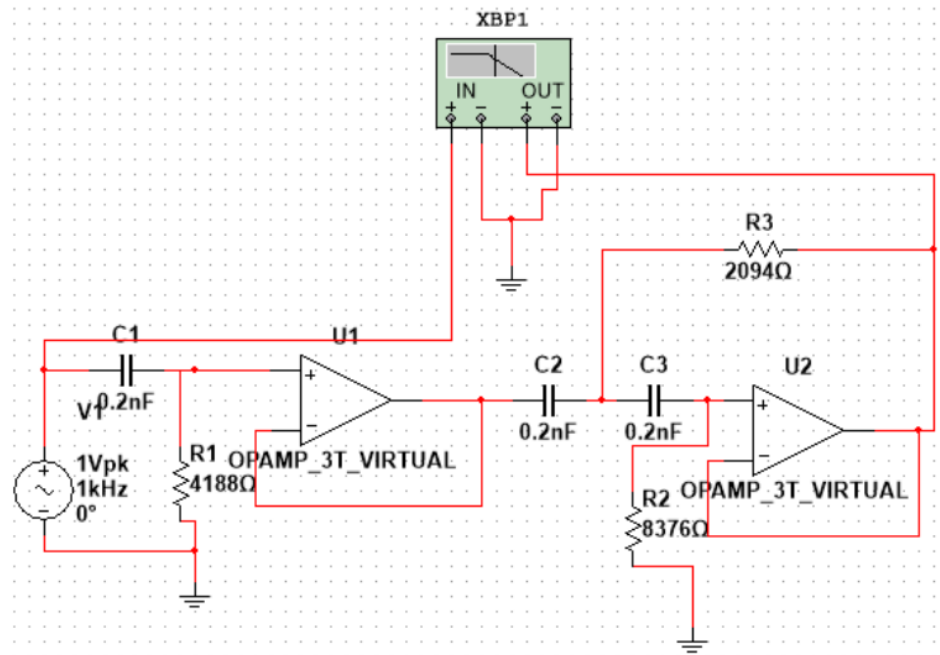


Figure 24: Butterworth 3rd order high pass filter

The Bode plot instrument was utilised to produce a frequency response which is shown in figure 25.

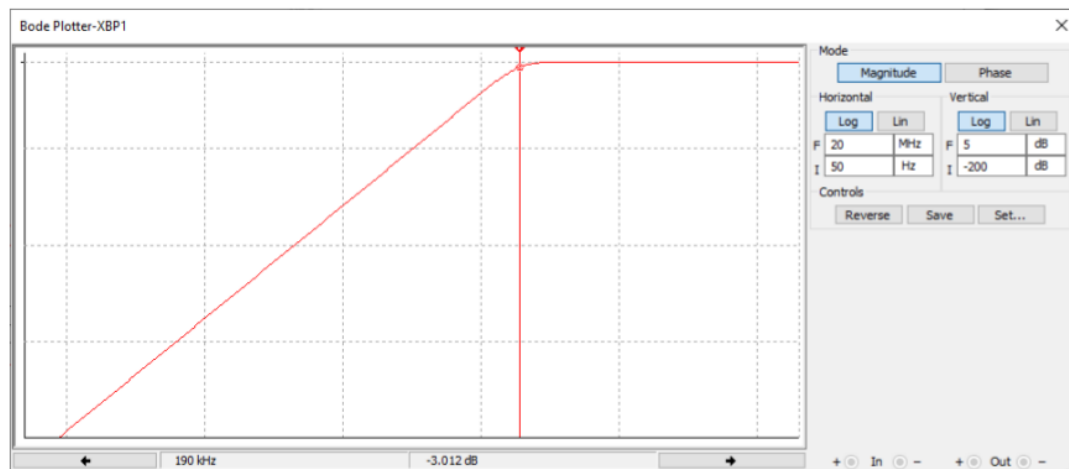


Figure 25: Bode plot of Butterworth third order high pass filter

The roll off is measured in figures 26 and figure 27.

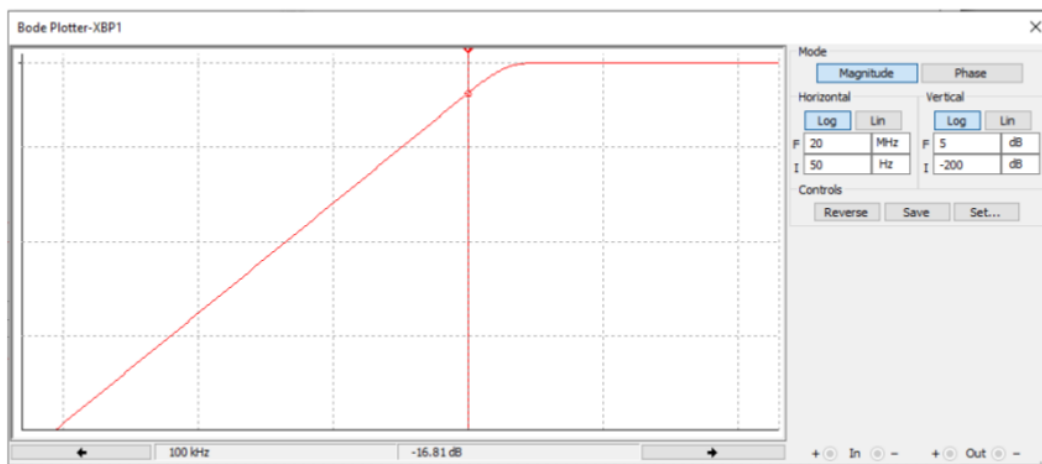


Figure 26: Butterworth third order high pass filter roll off measurement

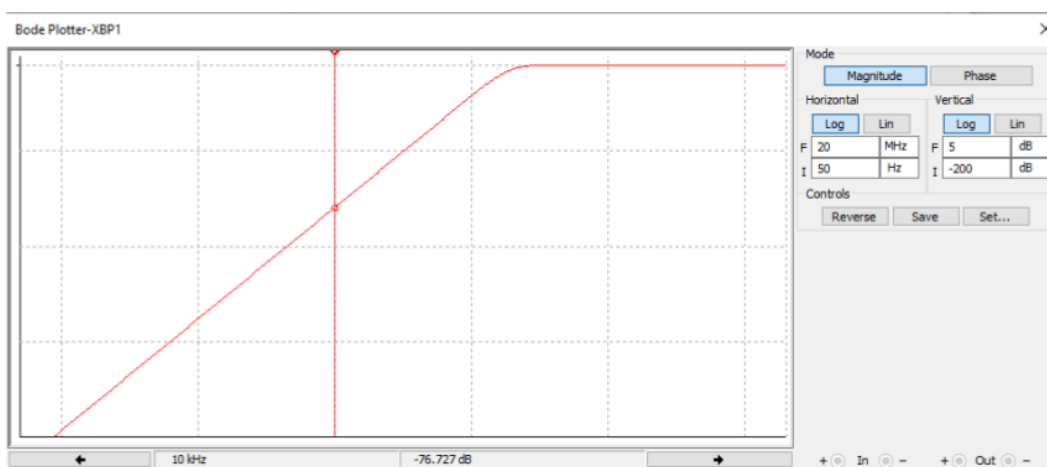


Figure 27: Butterworth third order high pass filter roll off measurement

In table 5 the Butterworth fifth order filter results are shown.

Table 5: Third order Butterworth high pass filter results

Parameter	Simulated
dB value @ 190K	-3.012
Roll off dB/decade	59.917

4.5 High pass 6th order Butterworth Filter

The Butterworth 6th order high pass filter was constructed on MultiSim and is shown in figure 28.

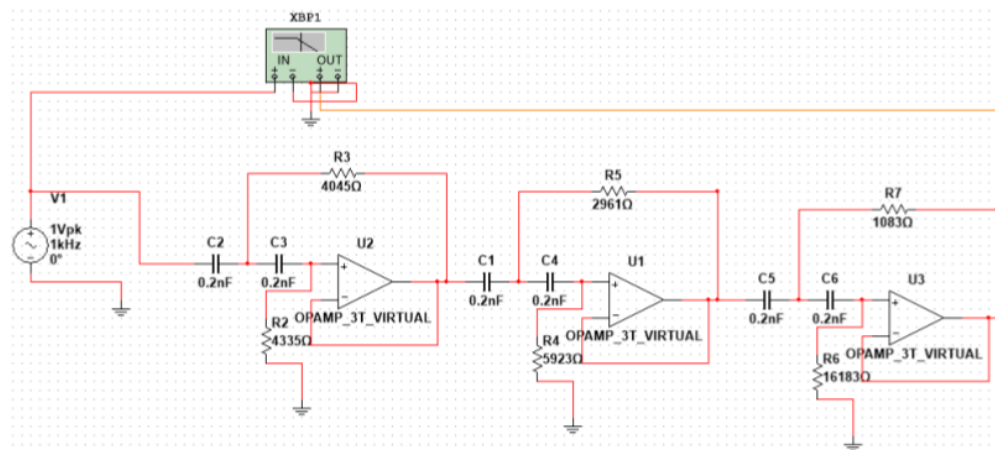


Figure 28: Butterworth sixth order high pass filter circuit

The Bodeplot instrument produced a frequency response for the circuit which is shown in figure 29.

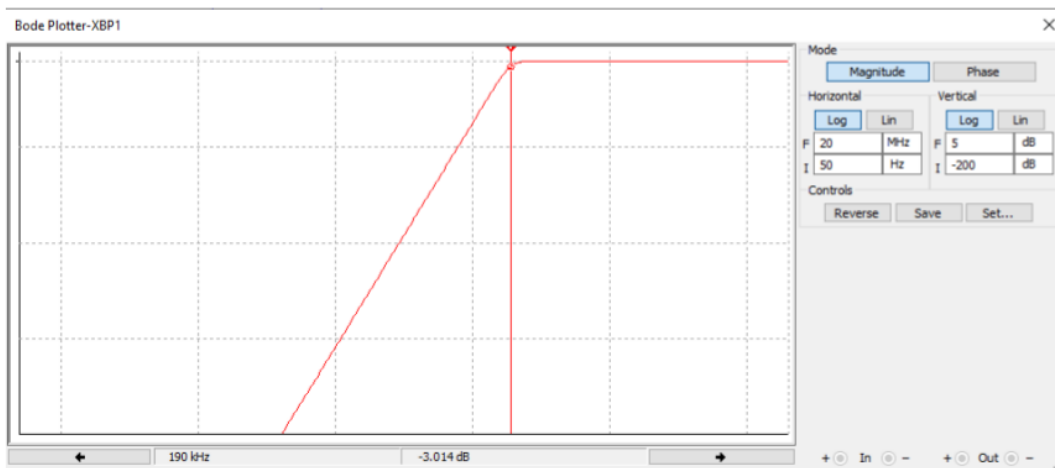


Figure 29: Bode plot of Butterworth sixth order high pass filter

The roll off measurements are shown in figures 30 and figure 31.

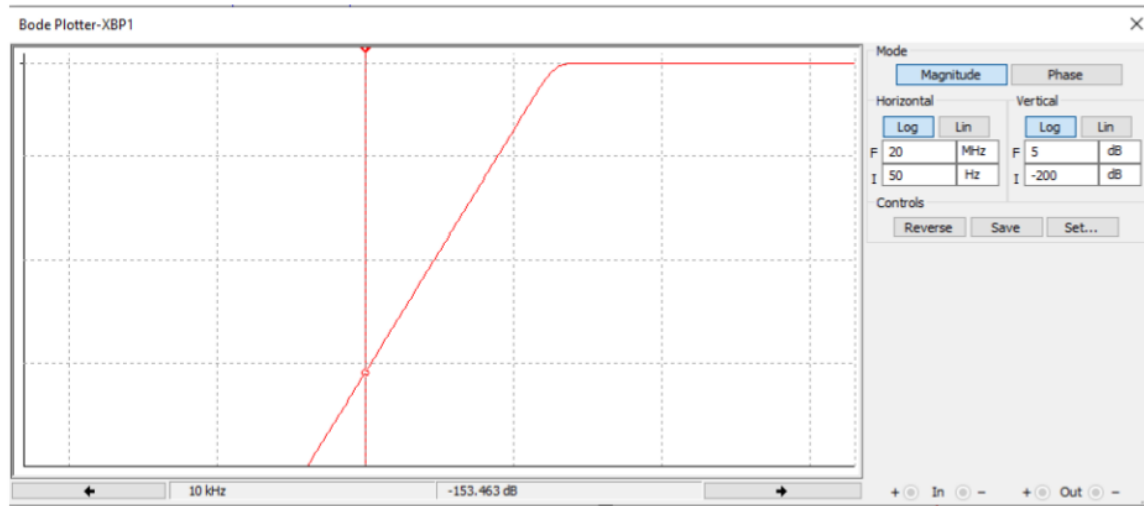


Figure 30: Butterworth sixth order high pass filter roll off measurement

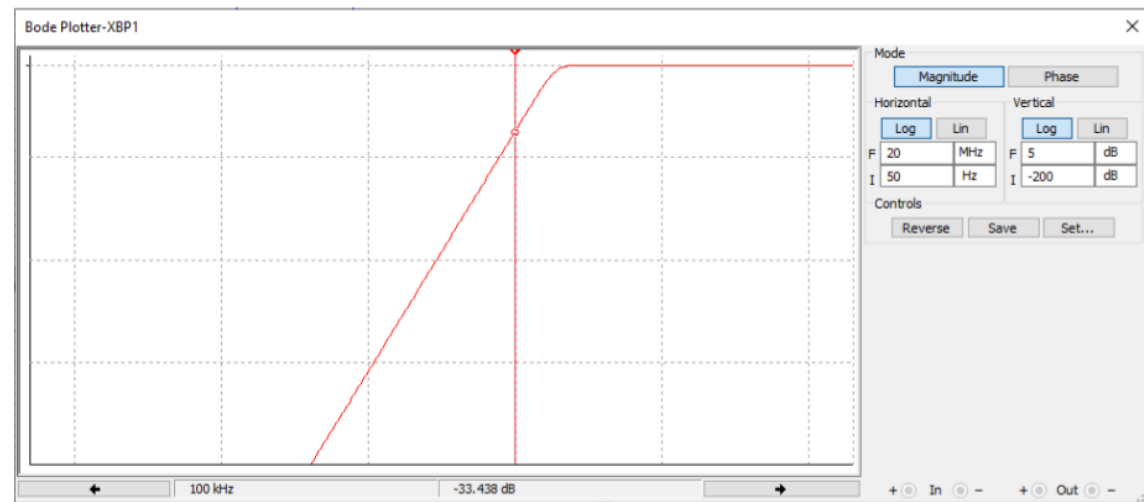


Figure 31: Butterworth sixth order high pass filter roll off measurement

Table 6: Butterworth sixth order high pass filter results

Parameter	Simulated
dB value @ 190K	3.014
Roll off dB/decade	120.025

4.5 High pass 9th order Butterworth Filter

The Butterworth 9th order high pass filter was constructed on MultiSim and is shown in figure 32.

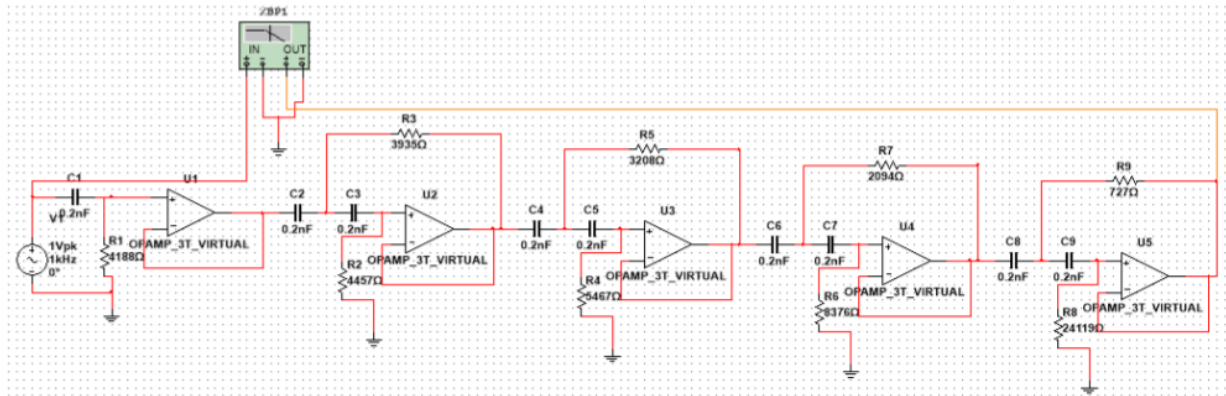


Figure 32: Butterworth ninth order high pass filter circuit

The frequency response of the filter is shown in figure 33.

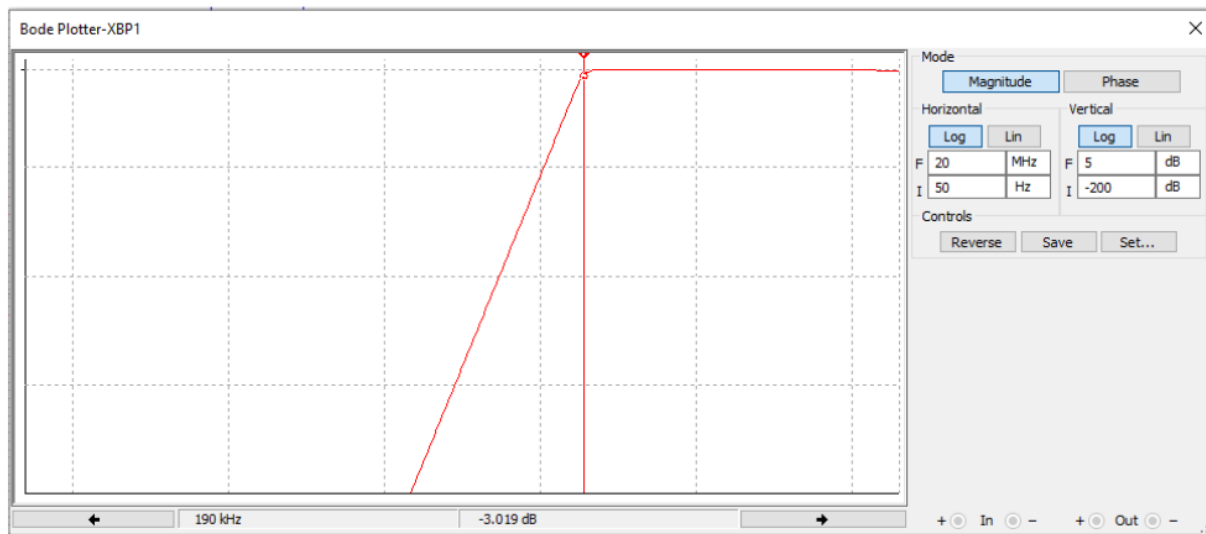


Figure 33: Bode plot of Butterworth ninth order high pass filter

The roll of measurements are shown in figures 34 and figure 35.

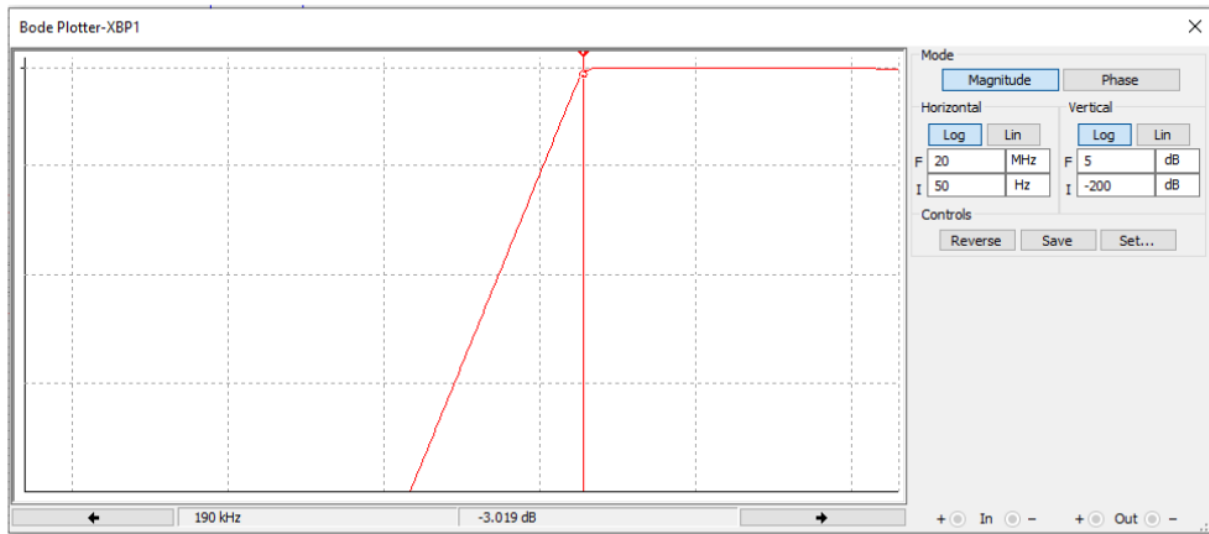


Figure 34: Butterworth ninth order high pass filter roll off measurement

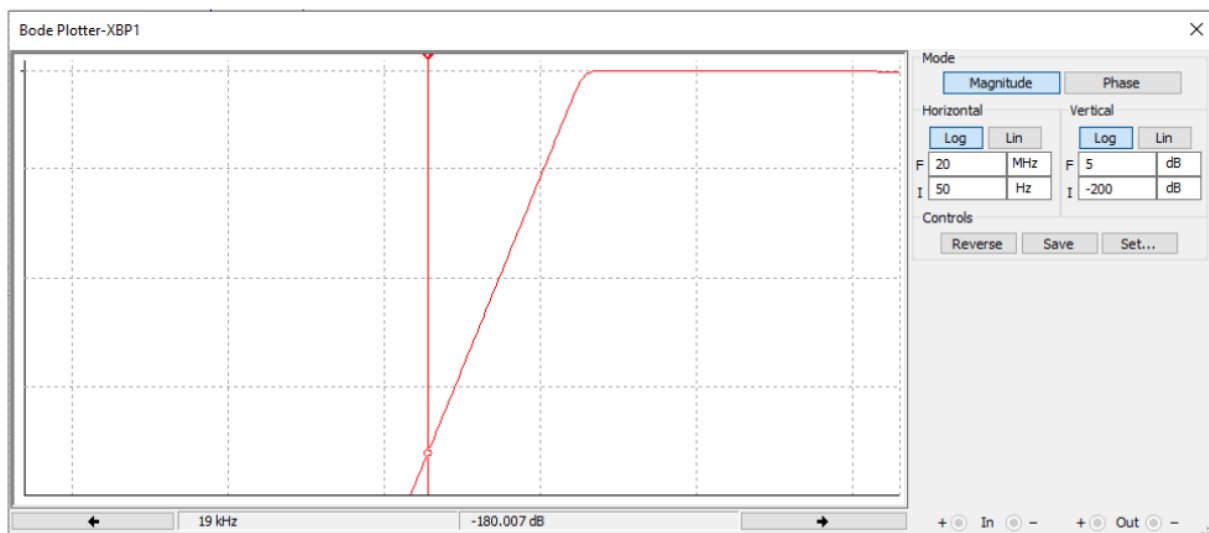


Figure 35: Butterworth ninth order high pass filter roll off measurement

Table 7 shows the ninth order Butterworth filter results

Table 7: Ninth order Butterworth high pass filter results

Parameter	Simulated
dB value @ 190K	-3.019
Roll off dB/decade	176.988

Table 8: Comparison table of Butterworth filter with increasing order number

	3 rd order	6 th order	9 th order
Roll off dB per decade	59.917	120.025	176.988

Table 8 shows the effect of increasing the filter order. Each order increases the roll off approximately 20dB per decade. This supports the research that was carried out in section one of the report.

5. Conclusion

Research was carried out on filter circuits. Passive and active filters were compared showing active filters are suited to applications with a frequency between 1Hz to 1Mhz. Active filters have the benefit of amplification control and load effect is avoided as op amps act as impedance converters. Filter classifications being Bessel, Tschebyscheff and Butterworth were compared, and their characteristics were detailed. Active filters are used in applications such as audio systems to filter out unwanted frequencies.

Further research was carried out into active low and high pass filter design. By increasing the order of the filter the roll off increases. The coefficient values for different filter classification and order is required to calculate and produce the desired filter response. This research aided the construction and testing of the circuits.

The Bessel, Tschebyschef and Butterworth filters were tested. The results showed that Tschebyschef produced the best roll off with a value of 117.984 dB per decade but ripples were produced in the passband. This was to be expected as the research showed that the Tschebyschef produces the best roll off with the disadvantage of ripples in the passband. As the filter order was an odd number the oscillations occurred below 0dB which was expected from the research.

The Butterworth high pass filter was constructed and tested to measure the effect of increasing the order number. It was shown that by increasing the order the roll off would increase meaning the filter has become more selective. This corroborates the research findings.

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7. Annex for diagrams, data sheets, results tables etc.

Table 16–4. Bessel Coefficients

n	i	a_i	b_i	k_i = f_{ci} / f_c	Q_i
1	1	1.0000	0.0000	1.000	—
2	1	1.3617	0.6180	1.000	0.58
3	1	0.7560	0.0000	1.323	—
	2	0.9996	0.4772	1.414	0.69
4	1	1.3397	0.4889	0.978	0.52
	2	0.7743	0.3890	1.797	0.81
5	1	0.6656	0.0000	1.502	—
	2	1.1402	0.4128	1.184	0.56
	3	0.6216	0.3245	2.138	0.92
6	1	1.2217	0.3887	1.063	0.51
	2	0.9686	0.3505	1.431	0.61
	3	0.5131	0.2756	2.447	1.02
7	1	0.5937	0.0000	1.648	—
	2	1.0944	0.3395	1.207	0.53
	3	0.8304	0.3011	1.695	0.66
	4	0.4332	0.2381	2.731	1.13
8	1	1.1112	0.3162	1.164	0.51
	2	0.9754	0.2979	1.381	0.56
	3	0.7202	0.2621	1.963	0.71
	4	0.3728	0.2087	2.992	1.23
9	1	0.5386	0.0000	1.857	—
	2	1.0244	0.2834	1.277	0.52
	3	0.8710	0.2636	1.574	0.59
	4	0.6320	0.2311	2.226	0.76
	5	0.3257	0.1854	3.237	1.32
10	1	1.0215	0.2650	1.264	0.50
	2	0.9393	0.2549	1.412	0.54
	3	0.7815	0.2351	1.780	0.62
	4	0.5604	0.2059	2.479	0.81
	5	0.2883	0.1665	3.466	1.42

Figure 36: Appendix reference 1: Bessel Coefficients table

Table 16–9. Tschhebyscheff Coefficients for 3-dB Passband Ripple

n	i	a _i	b _i	k _i = f _{Ci} / f _C	Q _i
1	1	1.0000	0.0000	1.000	—
2	1	1.0650	1.9305	1.000	1.30
3	1	3.3496	0.0000	0.299	—
	2	0.3559	1.1923	1.396	3.07
4	1	2.1853	5.5339	0.557	1.08
	2	0.1964	1.2009	1.410	5.58
5	1	5.6334	0.0000	0.178	—
	2	0.7620	2.6530	0.917	2.14
	3	0.1172	1.0686	1.500	8.82
6	1	3.2721	11.677 3	0.379	1.04
	2	0.4077	1.9873	1.086	3.46
	3	0.0815	1.0861	1.489	12.78
7	1	7.9064	0.0000	0.126	—
	2	1.1159	4.8963	0.670	1.98
	3	0.2515	1.5944	1.222	5.02
	4	0.0582	1.0348	1.527	17.46
8	1	4.3583	20.294 8	0.286	1.03
	2	0.5791	3.1808	0.855	3.08
	3	0.1765	1.4507	1.285	6.83
	4	0.0448	1.0478	1.517	22.87
9	1	10.175 9	0.0000	0.098	—
	2	1.4585	7.8971	0.526	1.93
	3	0.3561	2.3651	1.001	4.32
	4	0.1294	1.3165	1.351	8.87
	5	0.0348	1.0210	1.537	29.00
10	1	5.4449	31.378 8	0.230	1.03
	2	0.7414	4.7363	0.699	2.94
	3	0.2479	1.9952	1.094	5.70
	4	0.1008	1.2638	1.380	11.15
	5	0.0283	1.0304	1.530	35.85

Figure 37: Appendix reference 2: Tschhebyscheff Coefficient for 3-dB Passband ripple table

Table 16–5. Butterworth Coefficients

n	i	a _i	b _i	k _i = f _{Ci} / f _C	Q _i
1	1	1.0000	0.0000	1.000	—
2	1	1.4142	1.0000	1.000	0.71
3	1	1.0000	0.0000	1.000	—
	2	1.0000	1.0000	1.272	1.00
4	1	1.8478	1.0000	0.719	0.54
	2	0.7654	1.0000	1.390	1.31
5	1	1.0000	0.0000	1.000	—
	2	1.6180	1.0000	0.859	0.62
	3	0.6180	1.0000	1.448	1.62
6	1	1.9319	1.0000	0.676	0.52
	2	1.4142	1.0000	1.000	0.71
	3	0.5176	1.0000	1.479	1.93
7	1	1.0000	0.0000	1.000	—
	2	1.8019	1.0000	0.745	0.55
	3	1.2470	1.0000	1.117	0.80
	4	0.4450	1.0000	1.499	2.25
8	1	1.9616	1.0000	0.661	0.51
	2	1.6629	1.0000	0.829	0.60
	3	1.1111	1.0000	1.206	0.90
	4	0.3902	1.0000	1.512	2.56
9	1	1.0000	0.0000	1.000	—
	2	1.8794	1.0000	0.703	0.53
	3	1.5321	1.0000	0.917	0.65
	4	1.0000	1.0000	1.272	1.00
	5	0.3473	1.0000	1.521	2.88
10	1	1.9754	1.0000	0.655	0.51
	2	1.7820	1.0000	0.756	0.56
	3	1.4142	1.0000	1.000	0.71
	4	0.9080	1.0000	1.322	1.10
	5	0.3129	1.0000	1.527	3.20

Figure 38: Appendix reference 3: Butterworth coefficient table

Assignment 2

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

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GARETH WILKINS**0****RESEARCH-INFORMED LITERATURE**

There was very good evidence of further reading and research from credible and reliable sources. Your interpretation and understanding of the additional research was good and demonstrated a very good underlying appreciation of the subject. Your references were appropriate to the task and applied with few errors or inconsistencies. Your reference list was of an appropriate length for this assignment.

7/10**KNOWLEDGE AND UNDERSTANDING**

The knowledge and understanding of the subject demonstrated by this assignment was generally very good. There were few gaps in your knowledge of the basic principles and your understanding of the higher level concepts was demonstrated to a high degree. You have demonstrated a competent critical understanding of the main concepts and expanded your knowledge beyond that contained in the course notes.

21/3-**ANALYSIS**



Your analysis of the task was generally very good, both in class and as shown in this assignment. You have demonstrated sound critical analysis skills and your approach to the task was logical. You carried out a detailed evaluation of the results and included a good conclusion relating the practical results to researched theory. The conclusions demonstrated very good cognitive skills and the ability to interpret quantitative and qualitative data without error.

15/20

PRACTICAL APPLICATION AND DEP.



Your application of practical skills for this task was generally very good. You used the resources appropriately when designing the circuit and you used appropriate options for testing and evaluating the circuit performance. You managed to design an effective circuit that functioned within the specification and achieved this by only asking for assistance when appropriate thus demonstrating some advanced problem solving skills. Your results were comprehensive and allowed for a detailed conclusion to be attempted.

21/30

SKILLS FOR PROFESSIONAL PRAC.



In this assignment you have demonstrated skills in working individually and also collaboratively. Your written report was written in a professional and confident style, however you still need to be more efficient with your word count. The report was very well presented, with excellent diagrams in appropriate places, good sentence/paragraph

8/10

structure and clear calculations.