

PSDE 5006

by Phillip Rowe

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1. Introduction

The purpose of this assignment is to design, simulate and test a series of analogue filter circuits. In this assignment a number of circuits will need to be designed and also simulated in order to see their outcomes. Throughout the assignment all of the circuits will get a critical analyse of their performance. Background research will also be carried out into active filters. Main types of filters will be compared and contrasted. An explanation of how filters are used in today's world will be given and also an explanation of how filters are used in two control processes.

2. Research

What is an active filter?

The active filter is an analogue electronic filter which makes the use of active components like amplifiers, resistors and capacitors. Amplifiers which are in the filter design can be used in order to improve the actual performance and also predictability of the filter which helps cut circuit costs by eliminating the need for expensive inductors.

Three main types of filters

There are 3 main types of filters. These will all be listed below and the advantages/disadvantages will be given of each individual filter.

Bessel

The Bessel filter is a linear form of filter that provides a maximally flat group delay or propagation delay across the frequency spectrum, but offers a slower transition from pass-band to stop-band than for other forms of filter of the same order. Radio electronics. (2015)

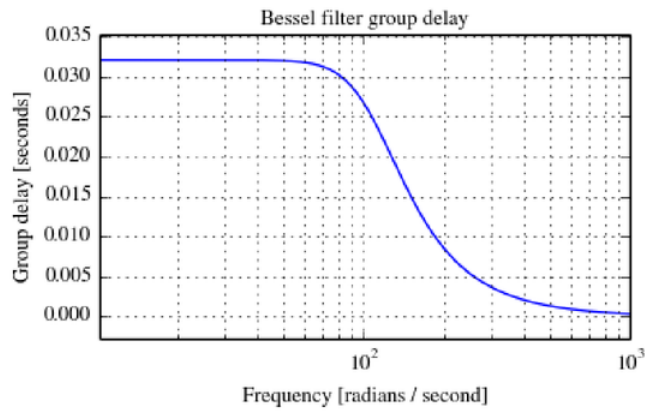
Even though the Bessel offers all of those good performance perks it isn't used as widely as the Tschebyscheff or the Butterworth filters for RF applications. It also has a maximally flat group delay which basically means that more often Bessel filter are used in audio applications like audio cross-over networks.

Some of the key features of a Bessel filter are:

- Maximally flat group delay which means that it equally exhibits a maximally linear phase response.

- The overshoot which is a direct result of the flat group which gives an output for a square wave input with zero overshoot due to the fact that the frequencies are being postponed by the same amount.
- Finally it has slow cut off which means the transition from the pass to stop band with the Bessel filter is a lot shallower and also slower than other available filters.

Below in figure 1 shows a Bessel filter group delay.



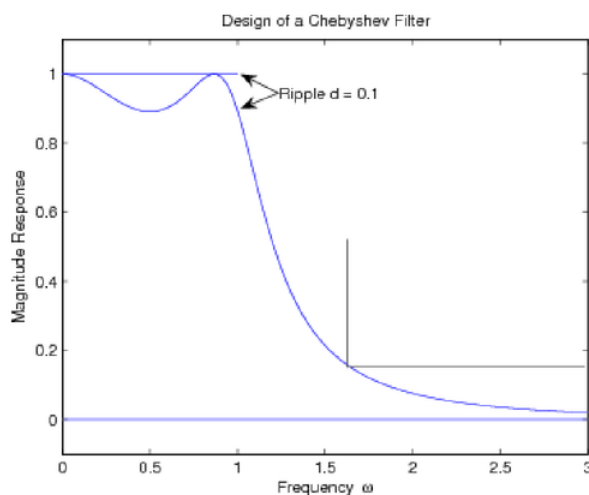
(Figure 1)

(The Scipy community. (2014).

Tschebyscheff

Tschebyscheff filters are normally used in order to separate a single band of frequencies from another. They cannot match the performance of a windowed-sinc filter but they are more than adequate for a wide variety of applications. One of the primary attributes of the tschbyscheff filter is its speed, usually more order of magnitude faster than a windowed-sinc filter. The reason for this is because they are carried out by recursion compared to convolution. When designing these filters they are based on a mathematical technique called "The z-transform".

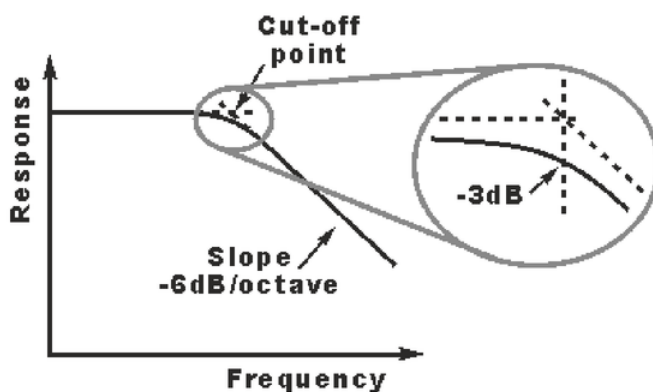
The Tschebyscheff is a filter which is commonly used in RF and a numerous amount of other applications. The Tschebyscheff provides a much steeper roll-off compared to other filters which are commonly used such as the Butterworth filter. Whilst the increased roll-off of the Tschebyscheff is a good thing it comes at a price of ripple, this exchange makes it unsuitable for a numerous amount of applications. Despite these factors the Tschebyscheff is a filter widely using in RF applications where the ripple does not cause an issue. A benefit of the steep roll-off can be that it can remove out of band spurious emissions such as intermodulation and harmonics.



(Figure 2 - Unkown. (2015).)

Butterworth

A Butterworth filter is a RF filter which is widely used in a range of radio frequency filter applications. One of the main key features of a Butterworth filter compared to the other types of filters is that it has a nominally flat response inside its pass-band and also has an adequate roll-off. Because of this the Butterworth filter is usually known as the maximally flat magnitude filter. Due to all of these factors the Butterworth filter is usually seen as a very good all round type of filter which is very suitable for a variety of applications, despite it not providing the best cut-off. Despite saying all of this the Butterworth does have one main disadvantages and that is that it achieves the pass band flatness at the expense of a wide transition band. The Butterworth also has very poor phase characteristics also. An ideal frequency response is referred to as a "brick wall". The Butterworth estimations can be found below.



(Figure 3- Ian Poole. (2014).)

Modern applications of filters

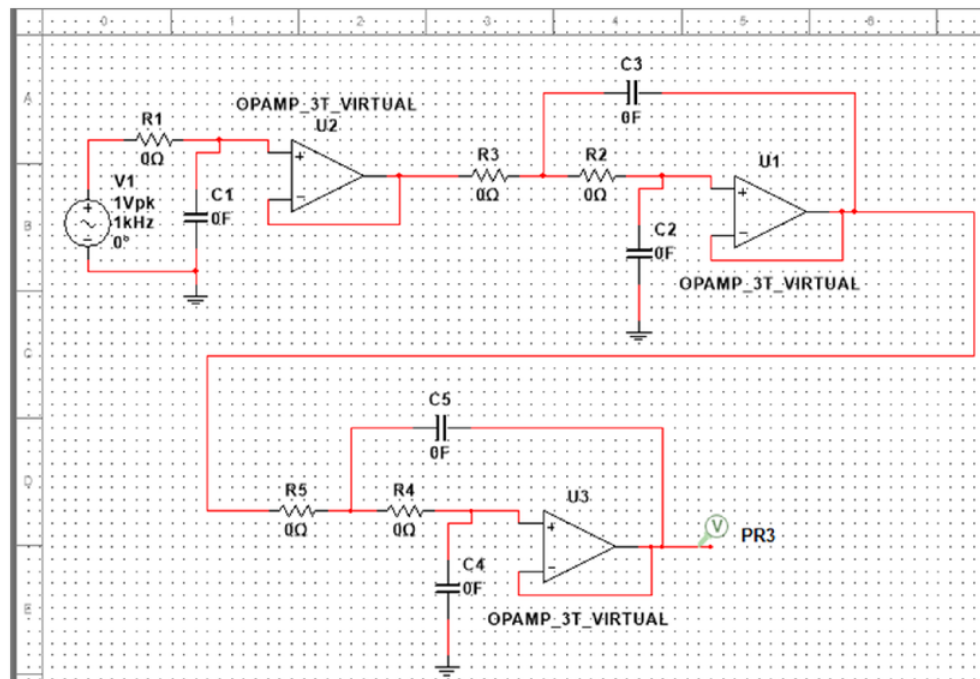
The main purpose of filters in today's electronics is to deal with processing signals, to be more specific filters are needed to remove frequency components from the main signal. Filters are also able to enhance processing signals which is a major benefit.

A vast use for filters is inside of high performance music devices where a vast amount of audio frequencies need to be amplified. In the case of the music stereo the filter would calculate the best quality and work out the best power efficiency for the system. The further stages of filters are more complex. Filter circuits can make use of equalisers which can change the amplitudes of many different frequencies. For example when the user is using the music system the settings can be changed. These filters can also be used in order to block signals so any distortions can be blocked from the music system. By doing this it can provide better performance sounds.

A second practical use of these filters would be the conditioning in power circuits of voltage waveforms. Some electronic applications may be highly sensitive to any harmonics in which could be contained in the supply voltage. For this to work properly it would need power conditioning.

3. Bessel low pass filter

The first circuit that was creased was the 5th order low pass Bessel filter. Firstly using theory the component values were calculated and then put into multisim. The circuit was creased first on multisim and then the values were added later in order to get the cut off frequency and the rate of roll off. As shown below this was the circuit used for all of the filters however the values were added last in order to perform the testing.



(Figure 4)

Now the calculations will be displayed to show where the component values came from and then the performance of the filter will be shown.

1st order

$C1 = 40 \times 10^{-11}$ - This capacitor value was chosen at random.

$F = 90 \text{ kHz}$ - This was given by the tutor to ensure everybody had different frequencies.

$R1 = a1/2\pi FC1$ $R1 = 0.6656/2\pi \times 90,000 \times 40 \times 10^{-11} = 2942.6 \Omega$

2nd stage

$A2 = 1.1402$ $B2 = 0.4128$

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$C1 = 400\text{pf}$

$C2 = 4 \times 0.4128 / 1.1042 = 5.792\text{nf}$

$R1 = 1.402 \times 5.792 + \sqrt{1.402^2 \times 5.792\text{nf}^2 - 4 \times 0.4128 \times 400\text{pf} \times 5.792\text{nf} / 4 \times 3.14 \times 90000 \times 400\text{pf} \times 5.792\text{nf}}$
 $= 1.63\text{k}\Omega$

$R2 = 1.402 \times 5.792 - \sqrt{1.402^2 \times 5.792\text{nf}^2 - 4 \times 0.4128 \times 400\text{pf} \times 5.792\text{nf} / 4 \times 3.14 \times 90000 \times 400\text{pf} \times 5.792\text{nf}}$
 $= 1.63\text{k}\Omega$

Stage 3

$A = 0.6216$ $b = 0.3245$

$C1 = 400\text{pf}$

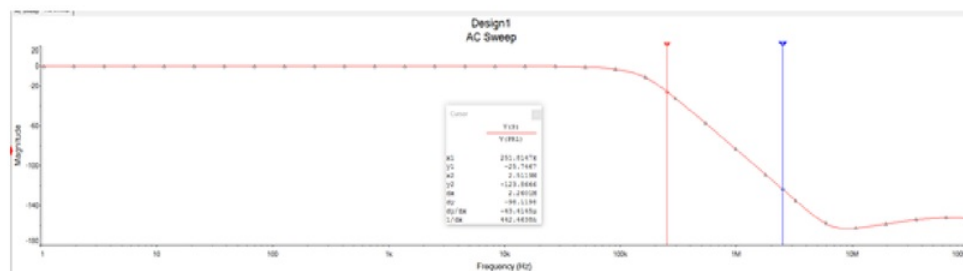
$C2 = 400\text{pf} \times (4 \times 0.3245 / 0.6216^2) = 83.52\text{nf}$

$R1 = 0.6216 \times 83.52\text{nf} + \sqrt{0.6216^2 \times 5.792\text{nf}^2 - 4 \times 0.3245 \times 400\text{pf} \times 83.52\text{nf} / 4 \times 3.14 \times 90000 \times 400\text{pf} \times 83.52\text{nf}}$
 $= 1.26\text{k}\Omega$

$R2 = 0.6216 \times 83.52\text{nf} - \sqrt{0.6216^2 \times 5.792\text{nf}^2 - 4 \times 0.3245 \times 400\text{pf} \times 83.52\text{nf} / 4 \times 3.14 \times 90000 \times 400\text{pf} \times 83.52\text{nf}}$
 $= 1.49\text{k}\Omega$

After producing these results I put them into the circuit which is shown in figure 4 and found that $C2$ did not produce the correct results as expected so this was changed to the value of 1.35nF

After editing the component value a AC sweep was run and shown in figure 5 Below is the result.

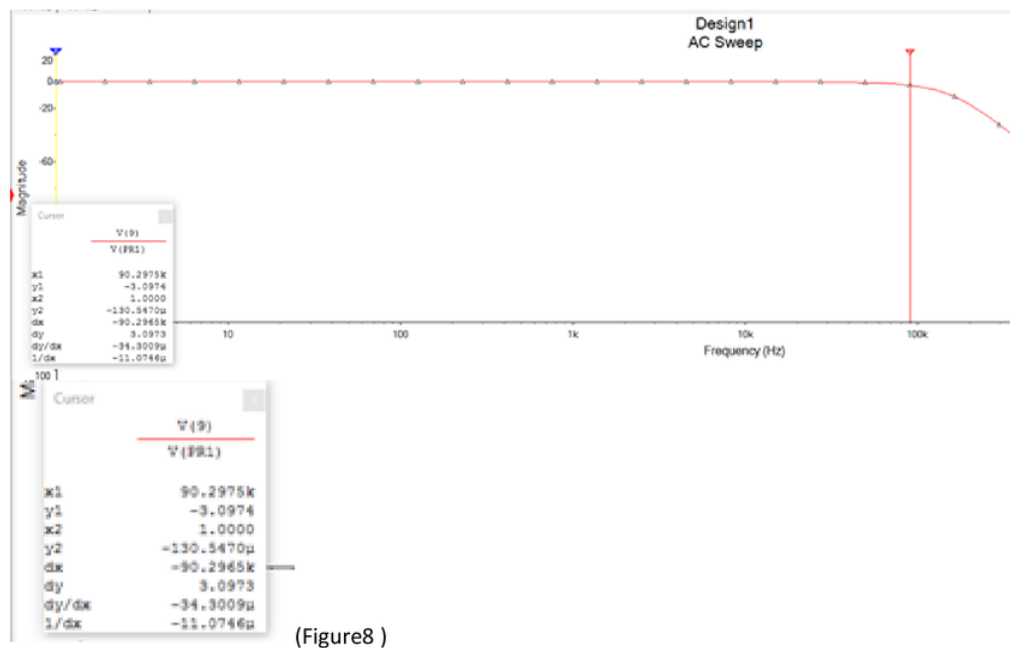


(Figure 5)

Cursor	
V(9)	
V(PR1)	
x1	251.8147k
y1	-25.7467
x2	2.5119M
y2	-123.8666
dx	2.2601M
dy	-98.1198
dy/dx	-43.4145μ
1/dx	442.4638n

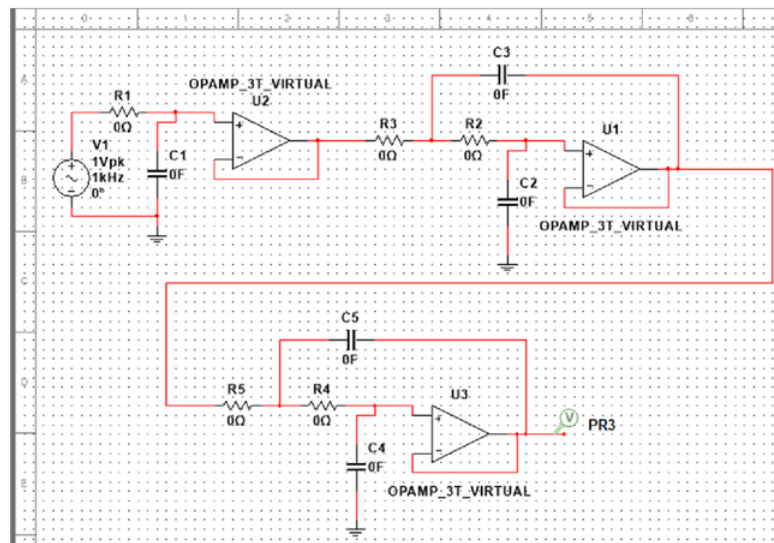
(Figure6)

As shown in figure 6 above the rate of roll off over 1 decade and this shown by the difference in dy/dx in figure 7 above. Also below in figure 8 Shows the cut off frequency of the circuit which occurs at -3DB and it should be 90Khz, as shown by figure 8 The value is indeed 90Khz.



4. Tschebyscheff

Just like the previous filter the same method will be applied apart from different coefficients will be used in order to calculate component values. Figure 9 shows the circuit which was built and then the values calculated were added to that circuit in order to simulate results.



(Figure9)

Stage 1

$$A = 5.6334 \quad C1 = 4000\text{pf}$$

$$R1 = 5.6334 / (2 \times 3.14 \times 90000 \times 4000\text{pf}) = 2490.5\Omega$$

Stage 2

$$A = 0.7620 \quad B = 2.6530 \quad C1 = 4000\text{pf}$$

$$C2 = 4000\text{pf} (4 \times 2.6530 / 0.5806) = 7.8\text{nf}$$

$$R1 = 0.7620 \times 7.8\text{nf} + \sqrt{0.7620^2 \times 7.8\text{nf} - 4 \times 2.6530 \times 400\text{pf} \times 7.8\text{nf}} / (4 \times 3.14 \times 90000 \times 400\text{pf} \times 7.8\text{nf}) = 1.52\text{k}\Omega$$

$$R2 = 0.7620 \times 7.8\text{nf} - \sqrt{0.7620^2 \times 7.8\text{nf} - 4 \times 2.6530 \times 400\text{pf} \times 7.8\text{nf}} / (4 \times 3.14 \times 90000 \times 400\text{pf} \times 7.8\text{nf}) = 1.85\text{k}\Omega$$

Stage 3

$$A = 0.1172 \quad B = 1.0686 \quad C1 = 4000\text{pf}$$

$$C2 = 4000\text{pf} (4 \times 1.0686 / 0.1172^2) = 1.244\text{uf}$$

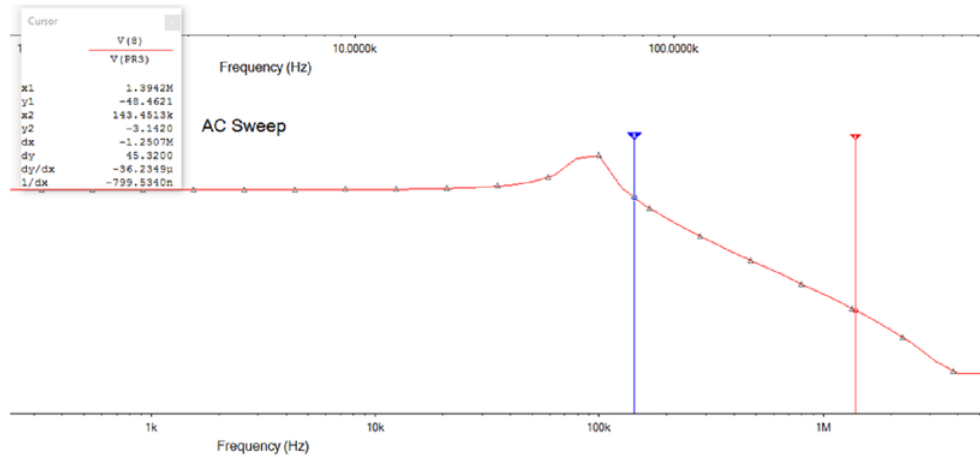
Due to this particular filter being a little more challenging to get the correct response the value of C2 was changed to 9.44nf.

$$R1 = 0.1171 \times 1.244\text{uf} + \sqrt{0.1172^2 \times 1.244\text{uf}^2 - 4 \times 1.0686 \times 4000\text{pf} \times 1.244\text{uf}} / (4 \times 3.14 \times 90000 \times 4000\text{pf} \times 1.244\text{uf}) = 1.77\text{k}\Omega$$

$$R2 = 0.1171 \times 1.244\text{uf} - \sqrt{0.1172^2 \times 1.244\text{uf}^2 - 4 \times 1.0686 \times 4000\text{pf} \times 1.244\text{uf}} / (4 \times 3.14 \times 90000 \times 4000\text{pf} \times 1.244\text{uf}) = 56\text{K}\Omega$$

Once again due to the Tschebyscheff being a challenging filter to build the results from the AC sweep analysis were not as good as the other filters.

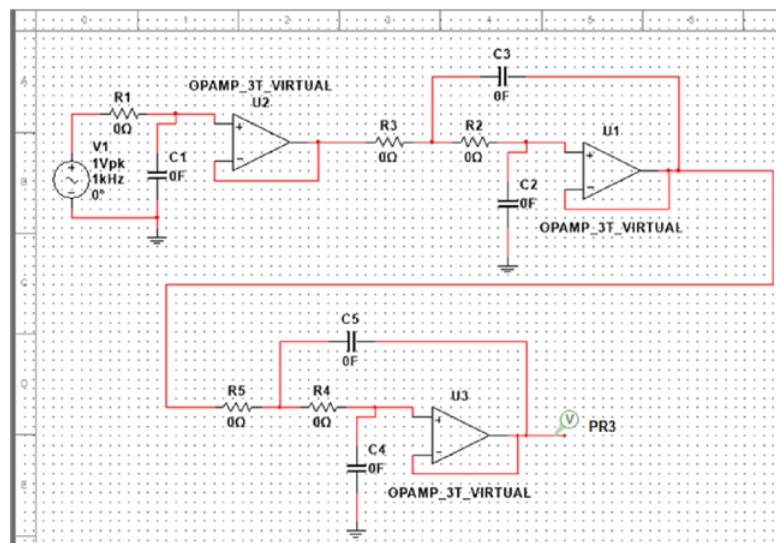
As shown below in figure 10 is the rate of roll off over 1 decade which as seen in the figure does not look how it should there is a spike instead of a smooth decay. This is down to the results which were calculated however the tschebyscheff is a much harder filter to design and it is harder to get the correct response out of it. Since the rate of roll off was not correct the values for the cut off point were not correct also.



(Figure10)

5. Butterworth low pass filter

This is the final low pass filter that was built. The circuit diagram for this is shown below in figure11. And the component values were calculated as followed.



(Figure11)

Stage 1

$$A=1 \quad C1 = 400\text{pf}$$

$$R1 = 1/2 \times 3.14 \times 90000 \times 400\text{pf} = 4420\Omega$$

Stage 2

$$A=1.6180 \text{ B}=1 \text{ C1}= 400\text{pf}$$

$$C2= 400\text{pf}(4 \times 1/1.6180^2)=98\text{nf}$$

$$R1=1.6180 \times 98\text{nf} + \sqrt{1.6180^2 \times 98\text{nf} - 4 \times 1 \times 400\text{pf} \times 98\text{nf}} / 4 \times 3.14 \times 90000 \times 400\text{pf} \times 98\text{nf} = 1.37\text{k} \Omega$$

$$R1=1.6180 \times 98\text{nf} - \sqrt{1.6180^2 \times 98\text{nf} - 4 \times 1 \times 400\text{pf} \times 98\text{nf}} / 4 \times 3.14 \times 90000 \times 400\text{pf} \times 98\text{nf} = 5.79\text{k} \Omega$$

Stage 3

$$A=0.6180 \text{ B}=1 \text{ C1}= 400\text{pf}$$

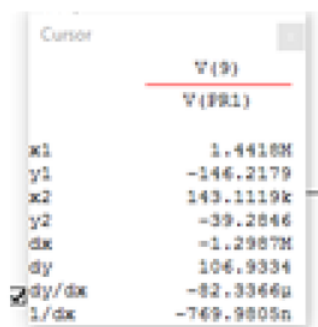
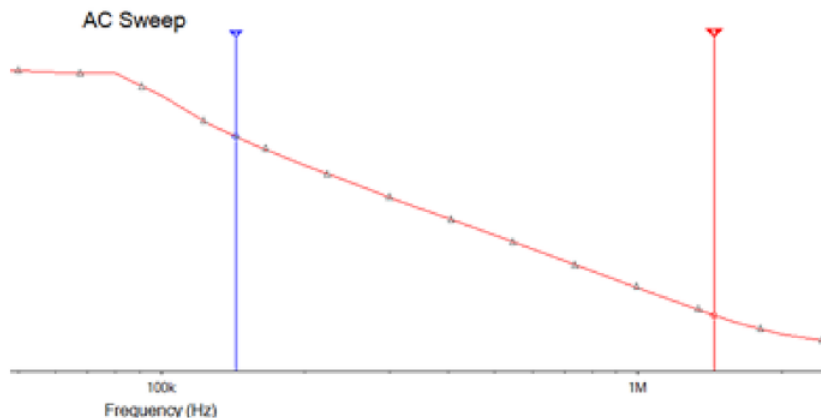
$$C2= 400\text{pf} (4 \times 1/0.6180)= 2.5\text{nf}$$

$$R1=0.6180 \times 2.5\text{nf} + \sqrt{0.6180^2 \times 2.5\text{nf} - 4 \times 1 \times 400\text{pf} \times 2.5\text{nf}} / 4 \times 3.14 \times 90000 \times 400\text{pf} \times 2.5\text{nf} = 4.62\text{kk} \Omega$$

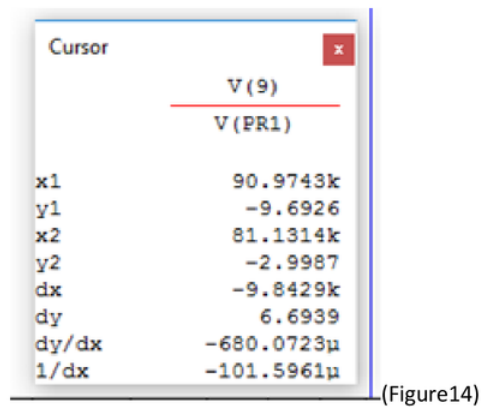
$$R2=0.6180 \times 2.5\text{nf} - \sqrt{0.6180^2 \times 2.5\text{nf} - 4 \times 1 \times 400\text{pf} \times 2.5\text{nf}} / 4 \times 3.14 \times 90000 \times 400\text{pf} \times 2.5\text{nf} = 7.53\text{kk} \Omega$$

Now that all these values have been calculated the circuit was completed and the AC sweep was simulated. Below in figure 12 is the rate of roll off of the simulated circuit. The rate of roll off results is shown in figure13 and they all look correct as the filter is working as a 5th order filter should. Also in figure 14 is the results for the cut off point was shown at -3db and occurred at 82Khz which is slightly out considering the expected result is 90Khz. To bring this value closer some component values could be altered.

(Figure12)



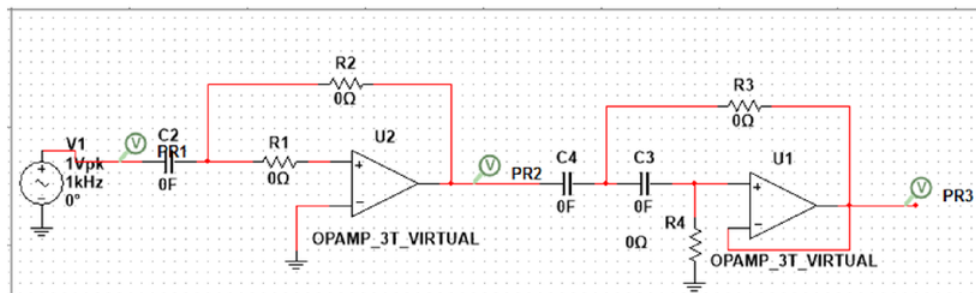
(Figure 13)



Looking back at all the results in this testing phase the Bessel filter gave the best results however the other two filters did work just not as well as the Bessel, this could be down to human calculation error and also that initial guessing of a capacitor value could lead to circuits not working to their full potential.

3rd order high pass filter

This filter is made up of a 1st stage and a second stage. The circuit in figure 15 is what was used in order to simulate an AC sweep and the calculated values that follow were place into the circuit.



(Figure15)

Stage 1

$$C1 = 400\text{pf} \quad F = 90\text{khz}$$

$$R1 = 1/2 \times 3.14 \times 90000 \times 400\text{pf} = 4420 \, \Omega$$

$$R2 = \text{The same as } R1 = 4420 \, \Omega$$

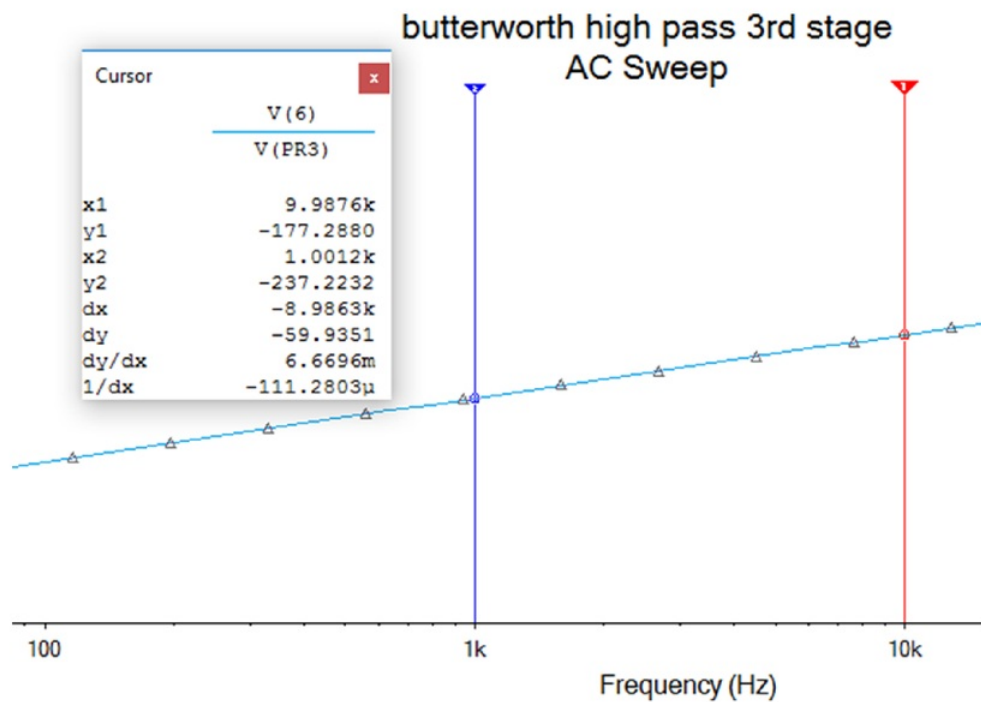
Stage 2

$$C1 = 400\text{pf} \quad A=1 \quad B=1$$

$$R1 = 1/3 \times 3.14 \times 90000 \times 400\text{pf} \times 1 = 8841 \, \Omega$$

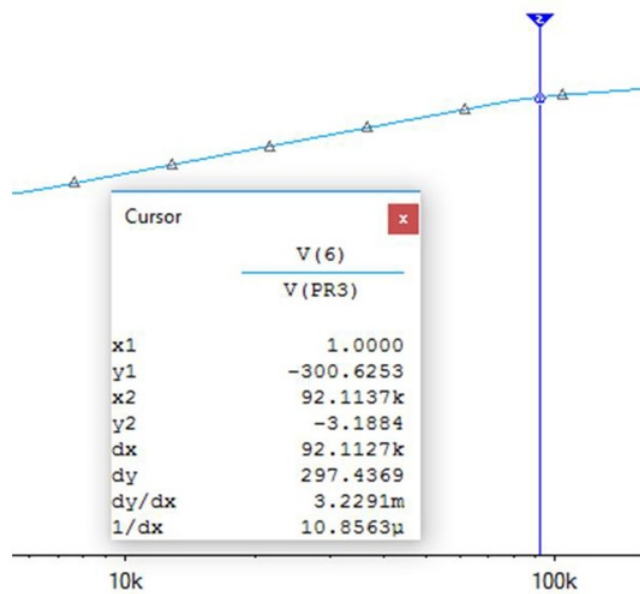
$$R2 = 1/4 \times 3.14 \times 90000 \times 400\text{pf} \times 1 = 2210 \, \Omega$$

In figure 16 Shows the rate of roll off for this 3rd stage high pass filter. The rate of roll off is expected to be 20DB per order per decade so for this filter it should result as 60db per decade.



(Figure16)

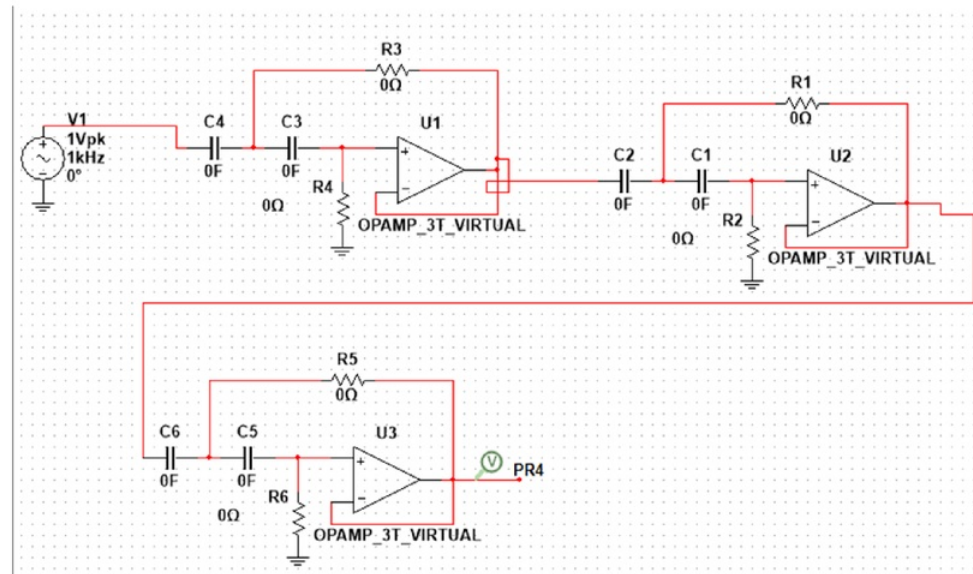
As shown above in figure 16 The simulated AC sweep gave the expected result. Also below in figure 17 Shows the cut off frequency at -3db and it should occur at 90Khz and as shown in the figure it does.



(Figure17)

6th order high pass filter

This filter is made up of 3 stage 2 filters. As shown in figure 18 below is the circuit for this filter. The calculated values were added later in order to simulate the AC sweep.



(Figure18)

Stage 1

A=1.9319 B=1 C= 400pf F=90khz

$$R1 = 1/3.14 \times 90000 \times 400 \text{pf} \times 1.9319 = 4576 \, \Omega$$

$$R2 = 1.9319/4 \times 3.14 \times 90000 \times 400 \text{pf} \times 1 = 4270 \, \Omega$$

Stage 2

A=1.4142 B=1 c=400pf

$$R1 = 1/3.14 \times 90000 \times 400 \text{pf} \times 1.4142 = 6252 \, \Omega$$

$$R2 = 1.4142/4 \times 3.14 \times 90000 \times 400 \text{pf} \times 1 = 3126 \, \Omega$$

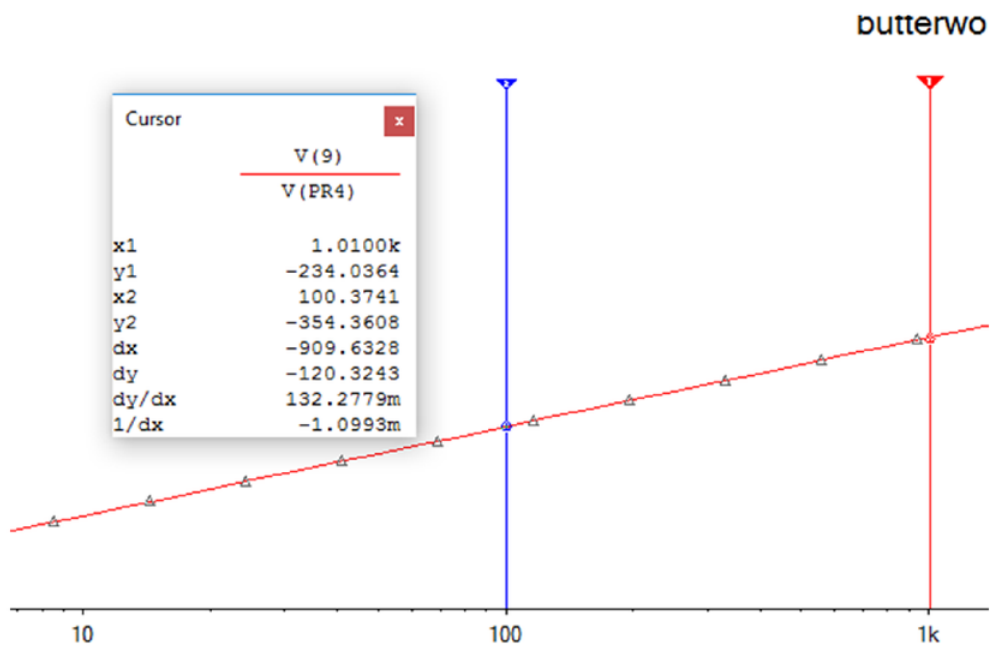
Stage 3

A=0.5176 B=1 C=400pf

$$R1 = 1/3.14 \times 90000 \times 400 \text{pf} \times 0.5176 = 17082 \, \Omega$$

$$R2 = 0.5176/4 \times 3.14 \times 90000 \times 400 \text{pf} \times 1 = 1144 \, \Omega$$

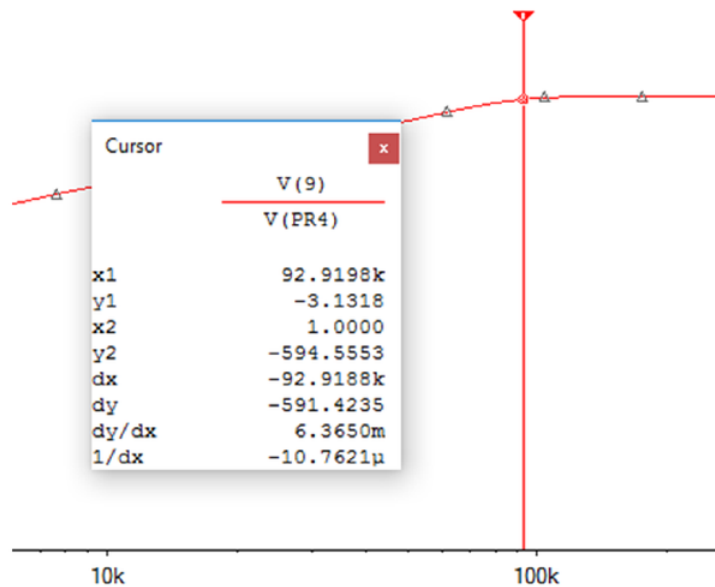
These calculated values were put into the circuit and then an AC sweep was run. Shown in figure 19 is the rate of roll off for this filter. The expected figure should be double the value of the 3rd order as the value should be 20DB per order per decade. So since this is a 6th order filter the expected result is 120DB and as shown in figure 19 that is what the simulated value is.



(Figure19)

As shown in the figure below is the cut off frequency at -3DB this should occur at 90Khz and as shown in the figure it does.

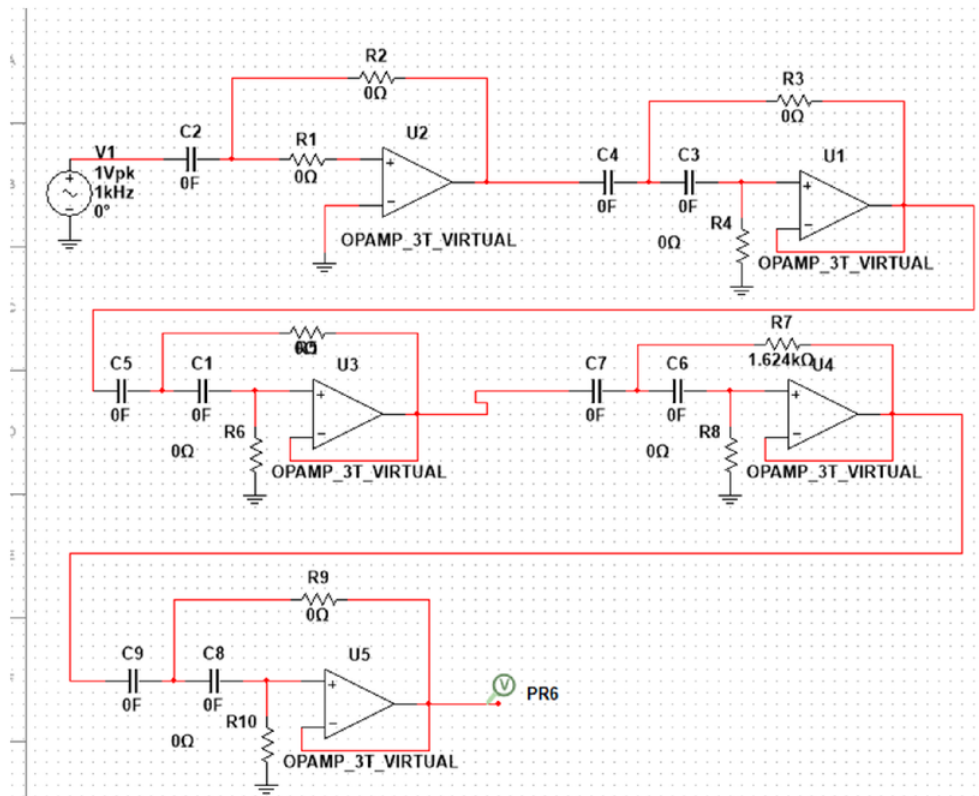
stage



(Figure20)

9th order high pass filter

This filter is made up of 1 first stage and 4 second stage filters. As shown below in figure 21 is the circuit which was used in order to run an AC sweep. The calculated values were added into that circuit and the results were collected.



(Figure21)

Stage 1

A=1 C=400pf

$R1 = 1/2 \times 3.14 \times 90000 \times 1 \times 400 \text{pf} = 4420 \Omega$

R2 is the same as R1 in this case so $R2 = 4420 \Omega$

Stage 2

A=1.8794 B=1 C=400pf

$R1 = 1/3.14 \times 90000 \times 400 \text{pf} \times 1.8794 = 4704 \Omega$

$R2 = 1.8/4 \times 3.14 \times 90000 \times 400 \text{pf} \times 1 = 3978 \Omega$

Stage 3

A=1.532 B=1 C=400pf

$R1 = 1/3.14 \times 90000 \times 400 \text{pf} \times 1.532 = 5771 \Omega$

$R2 = 1.532/4 \times 3.14 \times 90000 \times 400 \text{pf} \times 1 = 2210 \Omega$

Stage 4

A=1 B=1 C=400pf

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$$R1 = 1/3.14 \times 90000 \times 400 \text{ pF} \times 1 = 8841 \, \Omega$$

$$R2 = 1/4 \times 3.14 \times 90000 \times 400 \text{ pF} \times 1 = 2210 \, \Omega$$

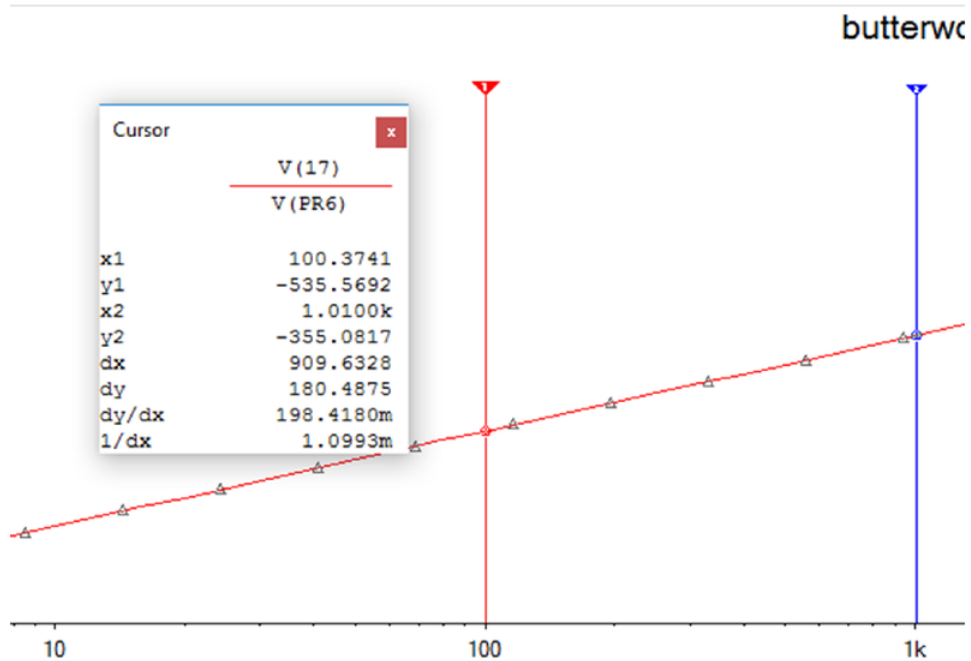
Stage 5

$$A=0.34 \quad B=1 \quad C=400 \text{ pF}$$

$$R1 = 1/3.14 \times 90000 \times 400 \text{ pF} \times 0.39 = 26005 \, \Omega$$

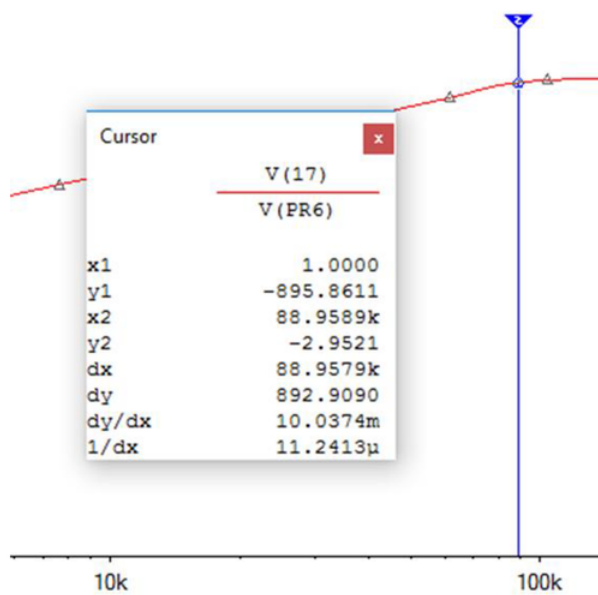
$$R2 = 0.34/4 \times 3.14 \times 90000 \times 400 \text{ pF} \times 1 = 751 \, \Omega$$

The calculated values above were entered into the circuit and then the AC sweep was run and as shown in figure 22 Below this shows the rate of roll off with which be 180DB and as shown in the figure it is 180DB which is 20DB per decade per order.



(Figure22)

Also shown below is the cut off frequency at -3DB which should be at 90Khz and as shown in figure 23 It is.



(Figure 23)

Analysis and conclusion

Looking back at all the filter results for the Bessel, tschebyscheff and the buttworth the Bessel had to best results from the tests that were carried out. The discrepancies in results could be down to calculation error or the actual filter coefficients giving results which aren't the best suited for the simulation carried out. Another reason for possible errors is due to the fact that the capacitor value is always guess so then some values may not work or give the desired component values. The calculations were all completed by following formulas however some errors could have been made due to human error in rounding etc which could of cause results to vary slightly.

Comparing the 3rd, 6th and 9th order filter there is a clear correlation between the coefficients and the resistor values. As the coefficients decrease the resistor value rises dramatically for R1 and drops for R2. From the simulations it was also clearly seen that the response of the filter gets better as the stages go along which is what is expected. What can aslo be seen from the testing of the high pass filters is that as the filter order is increased so is the rate of roll off as it increases 20DB per order per decade this is a perk of the higher order filters.

Comparing the theory results to the simulated results is very varied some filters worked correctly and exactly as they should however others weren't as well performance matched. Again this could be due to calculation error however the tschebyscheffs coefficients do give readings which are hard to use.

To conclude as the filter order increases so does the responsiveness of the filter. If the testing phase of this assignment was to be done again then more indepth research would be done into how to get the correct response from every filter, also during the calculation phase the rounding would be done more accurately to ensure the best results possible for the simulation.

Harvard referencing

Radio electronics. (2015). Bessel RF Filter Basics. Available: <http://www.radio-electronics.com/info/rf-technology-design/rf-filters/bessel-rf-filter-basics.php>. Last accessed 5th December 2017.

The Scipy community. (2014). scipy.signal.bessel. Available: <https://docs.scipy.org/doc/scipy-0.14.0/reference/generated/scipy.signal.bessel.html>. Last accessed 5th December 2017.

Unkown. (2015). Chebyshev filter properties. Available: <https://archive.cnx.org/contents/0eaa1728-2824-4aed-b7b2-75981117e57a@2/chebyshev-filter-properties>. Last accessed 20/12/2017.

Ian Poole. (2014). Chebyshev RF Filter Basics. Available: <http://www.radio-electronics.com/info/rf-technology-design/rf-filters/chebyshev-rf-filter-basics.php>. Last accessed 20/12/2017.

Analog. (2014). Chebyshev filters. Available: http://www.analog.com/media/en/technical-documentation/dsp-book/dsp_book_Ch20.pdf. Last accessed 20/12/2017.

Wayne Storr. (2016). Butterworth filter design. Available: http://www.electronics-tutorials.ws/filter/filter_8.html. Last accessed 21/12/2017.

FINAL GRADE

GENERAL COMMENTS

Instructor

70/100

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GRADING FORM: CSG-RUBIC

PHILLIP ROWE**70****RESEARCH-INFORMED LITERATURE**

There was 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. Your reference list was of an appropriate length for this assignment.

7**KNOWLEDGE AND UNDERSTANDING**

The knowledge and understanding of the subject demonstrated by this assignment was generally very good. There were very few gaps in your knowledge of the basic principles and your understanding of the higher level concepts was very good. Your research and explanation was particularly good and extended your knowledge well beyond that contained in the course notes.

22**ANALYSIS**

Your explanation of the design process was good, however the conclusions lacked some detail. You

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could have evaluated the use of the various components, specified whether the solution met the specification and suggested ways to improve the solution. You have however demonstrated good analytical skills and your approach to the task was logical. Further work – in your conclusion, you should relate the results to the original specification and to accepted theory.

PRACTICAL APPLICATION AND DEP.



Your application of practical skills for this task was generally good. You used the resources available in MultiSim appropriately when designing the circuit and you used appropriate options for testing and evaluating the circuit performance. You managed to design a basic circuit that functioned within the specification and achieved this by only asking for assistance when appropriate. Your results were good and allowed for a reasonable conclusion to be attempted.

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SKILLS FOR PROFESSIONAL PRAC.



In this assignment you have demonstrated skills in working individually and also collaboratively. Your written report was of an appropriate length, you could however be more efficient with your word count. The report was well presented, with good diagrams in appropriate places, good sentence/paragraph structure and clear calculations.

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