

Circuit Design and Analysis Ass1

by Tomas James Roch

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Electronic Circuit Analysis

Assignment 1

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Abstract

In this report, a multiple feedback topology filter was designed to remove high and low frequency noise from a sinusoidal signal. Proteus simulation software was used to simulate the design to prove the design reduced noise by at least 30dB.

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Introduction

Using Proteus simulation software, a sinusoidal 0.2Vrms 39KHz signal was corrupted with high and low frequency noise of 110KHz and 14KHz. A multiple feedback topology bandpass filter design was tested and modified until a reduction of at least 30dB was achieved for both high and low frequency.

Active filters

The purpose of a filter is to remove any unwanted frequencies from a signal so that only waveforms that match a certain frequency criterion remain. Purely passive filters can be constructed using capacitors, resistors and inductors however large coils are required for filtering low frequencies.

Active filters use passive components together with op amps and are commonly used as they can be adjusted simply using resistors, can be used to amplify signals, and act as buffers between the input signal and the output.

Using a single resistor and capacitor with an op amp will create a first order filter, by where the attenuation into the stop band of the filter will be 20dB per decade. Adding a second network will create a sharper response of 40dB per decade. Further op amp circuits can be cascaded with the first for further increase the rate of roll off for a sharper response [1].

Increasing the order of the filter has its disadvantages, primarily the inaccuracies caused by more components. Resistors and capacitors have a certain tolerance which can affect the cut off frequency of the filter. More components also means higher cost, greater size and a more dramatic effect from component aging. It also becomes harder to balance the input currents to the op amps, which can cause an offset in the output. Reducing the size of the resistors in the network can minimise this by increasing the current, however this will affect the power dissipation.

Filter topology

Different filter topologies can be used for different situations

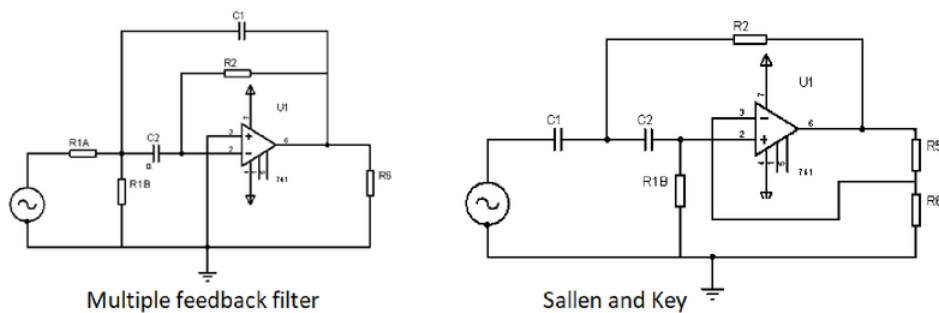


Figure 1

Figure 1 shows the physical differences between the Sallen and Key and the multiple feedback topologies for a band pass filter. Both work off similar principles where by the two capacitors in each circuit will have a high impedance to low frequencies, one blocking the input and the other increasing the gain of the circuit through the op amps feedback, thus creating both a high and low cut off frequency (thus band pass filter). The overall gain of the multiple feedback is set by the potential divider created by R1A and R1B, whereas the gain of the Sallen and Key circuit is set by a potential divider in the output created by R5 and R6.

The signal is fed into the inverting input of the multiple feedback filter, meaning that the output is inverted. A 180 degree phase shift will be observed.

An advantage of the multiple feedback amplifier, demonstrated in this report, over the Sallen and Key filter is that it is less effected by inaccuracies of the components used. For higher Q values or higher gains, Chevychev filter response is more easily obtained with a peak in the passband section.

Filter orders and responses

The Q value (or quality value) of a band pass filter describes the ratio between the width of the pass band with respect to the gain at the centre frequency. A higher value creates a higher 'peak' in the filter. The Q value is set by increasing all the resistor values by a certain ratio with respect to the capacitor values and will affect the gradient of the initial cut off of the filter.

Using a first order filter as an example, a Chebyshev response will have a much sharper cut off than the Bessel filter, before each finally reaching a roll off of 20dB per decade. The disadvantage of this aggressive cut off is that it causes a rippling effect in the pass band (shown in figure 2) which causes a poor response in the time domain [2].

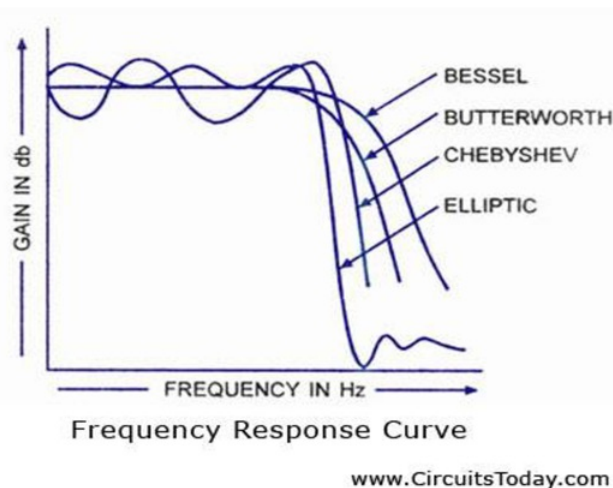


Figure 2 – Filter frequency responses [3]

Figure 2 shows typical responses of a filter based on the Q value (in this instance for a low pass filter) set by the resistor and capacitor network. Bessel, Butterworth and Chebyshev are the more common responses. All have a similar attenuation in the stop band of the filter, however the filter response describes the initial roll off.

Cascading several different filters together to generate a higher order filter has the added advantage that different filter responses can be combined to get the best of both. Cascading a Bessel filter with a Chebyshev filter would result in a sharper roll off than that of the Bessel filter, but without the initial peak seen in the Chebyshev filter.

Design 1

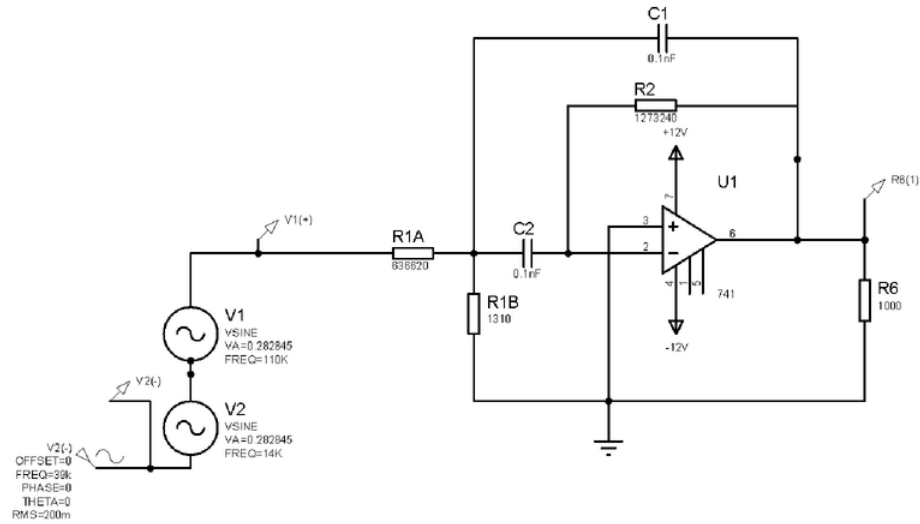


Figure 3 - Design 1 schematic

For this design, the values of both C1 and C2 were kept the same and the resistors in the circuit altered to give the required cut off frequency. Altering these values would mean different resistors would be required. The capacitor values were selected to allow suitable typical resistor values to be used.

The formulae used to calculate the resistor network values were as follows –

$$k = 2\pi f_o C$$

Where-

k is the ratio used to determine the size of all the resistors with respect to the capacitor sizes.

f_o is the centre frequency of the band pass filter (in this case 39KHz was used to allow for maximum gain at the signal frequency).

C is the capacitor value

$$Q = \frac{f_o}{\text{Bandwidth}}$$

This value demonstrates the rate at which the amplitude of the signal is reduced with respect to frequency. A higher value represents a sharper cut off, with the bandwidth determined by the point at which the signal is reduced by 3dBs. Research suggested that a Q value of around 15 to 20 was possible and so a value of 15.6 was selected [4].

$$R1A = \frac{Q}{Hk}$$

$$R1B = \frac{Q}{(2Q^2 - H)k}$$

$$R2 = \frac{2Q}{k}$$

H is desired gain at the centre frequency which in this design was kept at 1.

R6 was given a value of 1000ohms to provide a load for the circuit.

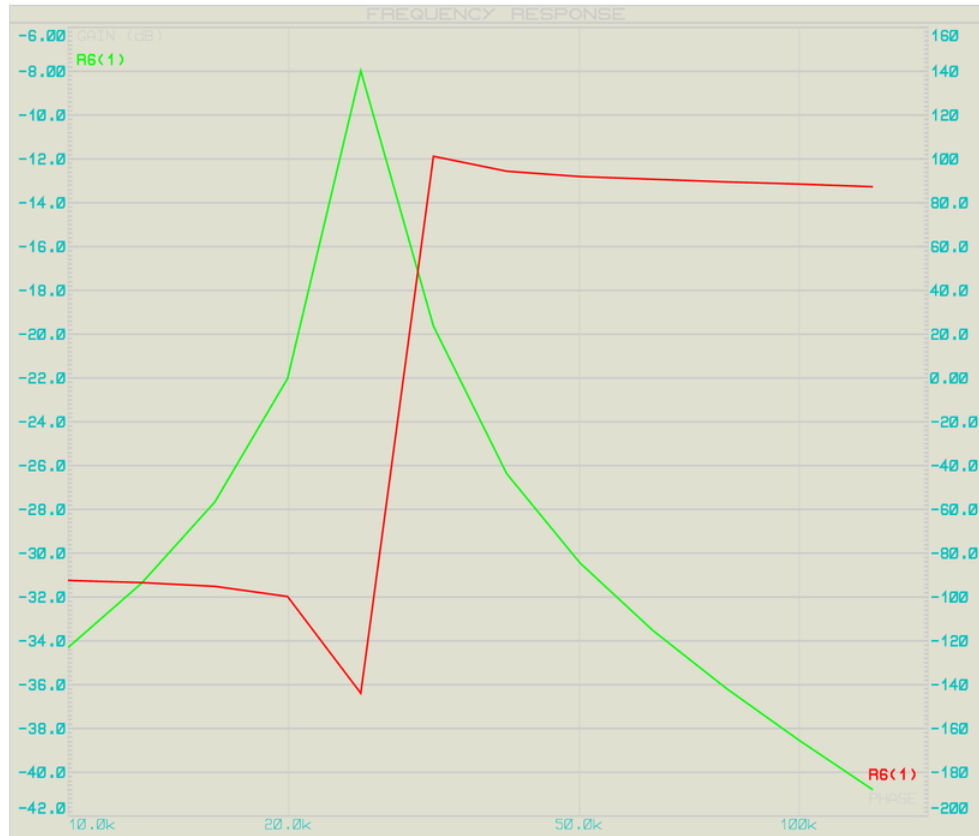


Figure 4 – Design 1 phase and gain

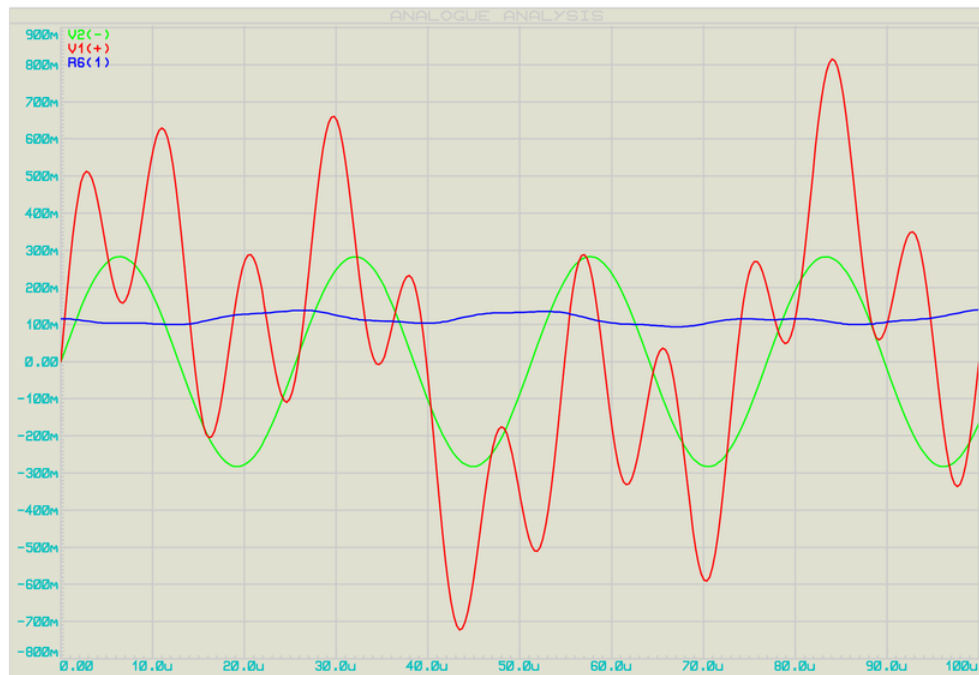


Figure 5 – Design 1 frequency response

It can be seen from figure 2 and 3 that the response of the first design is very poor. A high Q value has resulted in a significant reduction in gain at the centre frequency, greatly reducing the output signal (blue trend on figure 3) with the high and low filter networks interfering with one another. It is evident that the specified pass band is too narrow to allow a gain of one at the centre frequency, and to reach a reduction of 30dB by the noise frequencies using a first order filter. The initial design will be altered to get the best possible result, and will then be cascaded with other filters to increase the roll off rate.

Design 2

For the second design, gain was added to the original design. A reduction of 8dB was observed and so a gain of 2.511 (using the formula $\frac{1}{10^{20}}$) was incorporated into the resistor network by altering the value of H.

R1A and R1B form a potential divider on the input to the circuit thus allowing the gain to be varied.

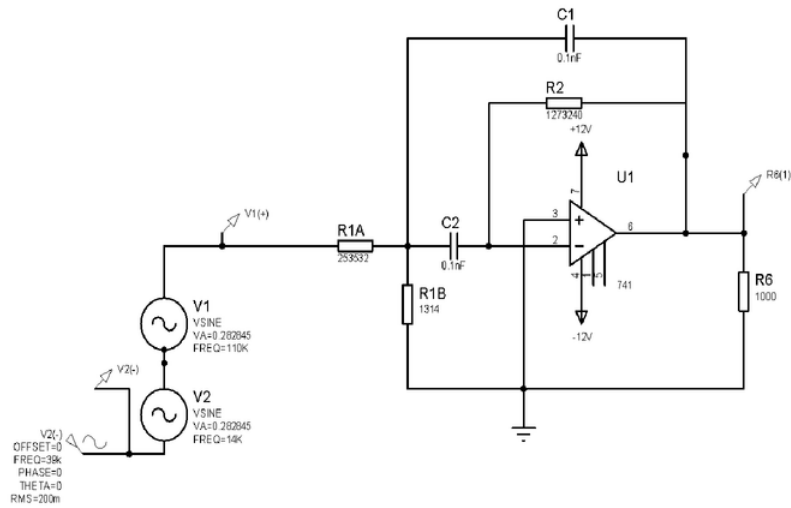


Figure 6 – Design 2 schematic

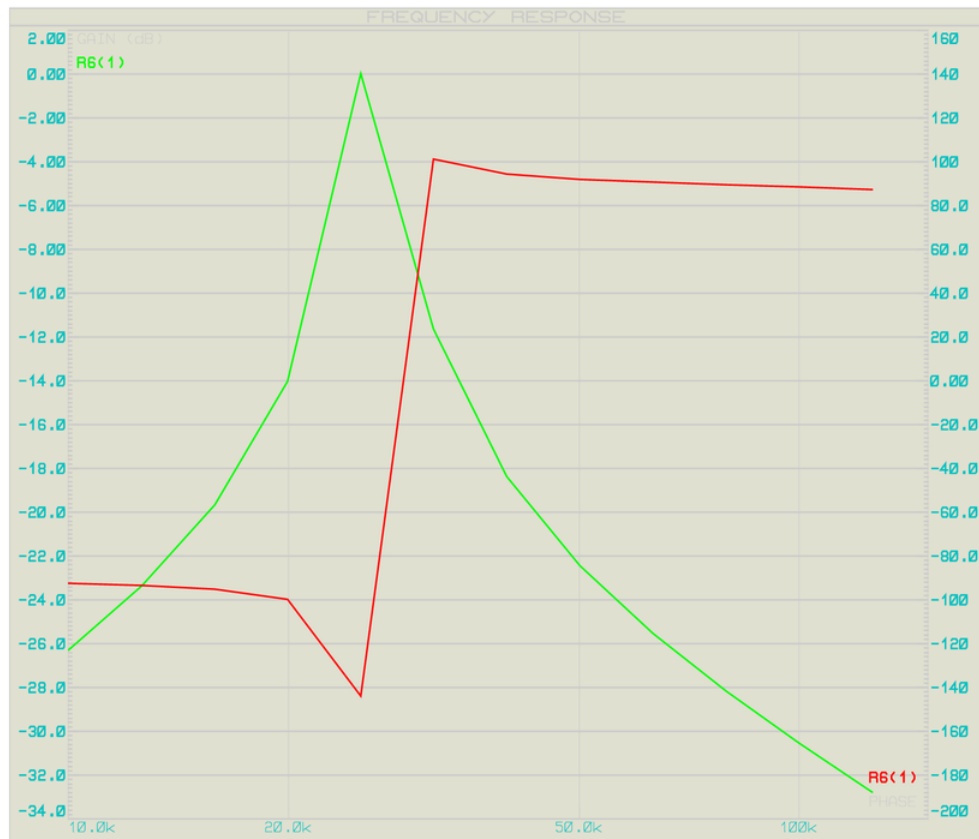


Figure 7 – Design 2 phase and gain

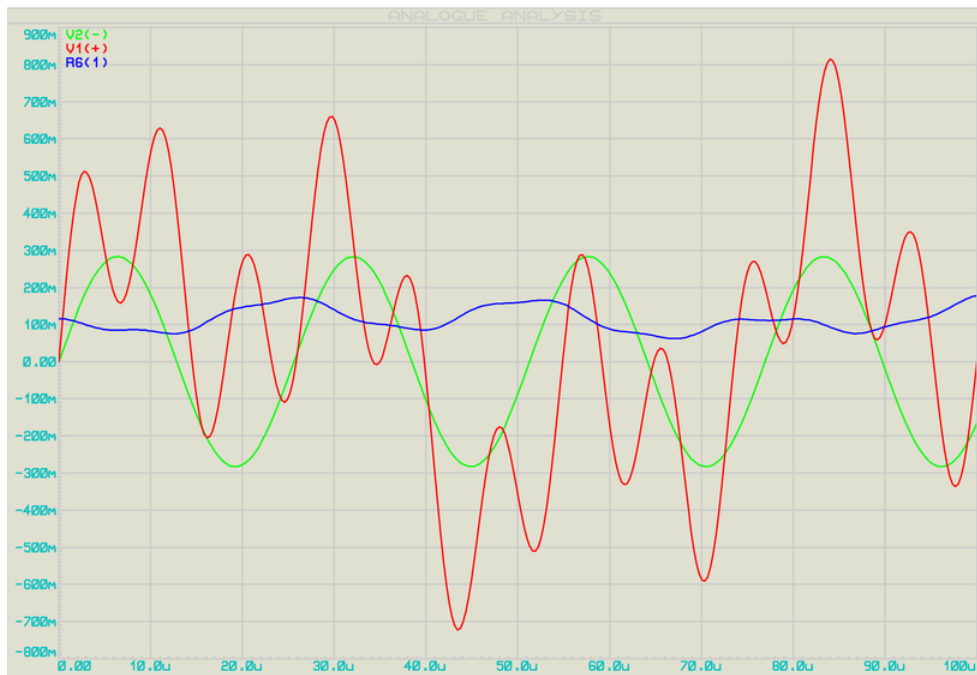
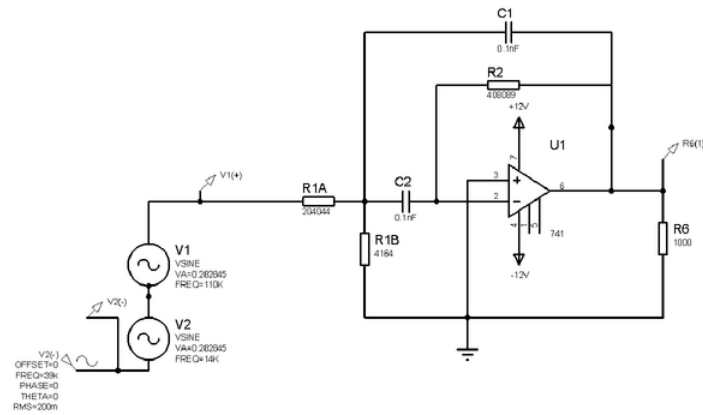


Figure 8 – Design 2 frequency response

Figure 5 demonstrates that the gain of the centre frequency of the filter has now been returned to 1. However the Q value is too high and the centre frequency is not where it should be, confirming that the low pass network is interfering the high pass. This can be seen in figure 6, where the blue output trend is greatly reduced in comparison to the green input trend and still contains some of the noise.

Design 3

Figure 9 – Design 3 schematic



For the third design, the Q value was reduced to 5, to maintain amplitude at the centre frequency. The H value was returned to 1.



Figure 10 – Design 3 phase and gain

Figure 5 shows that although the amplitude at the centre frequency has been improved there is still some reduction. It can also be seen that the reduction in noise at 14KHz and 110KHz is no longer enough to meet the specification.

Design 4

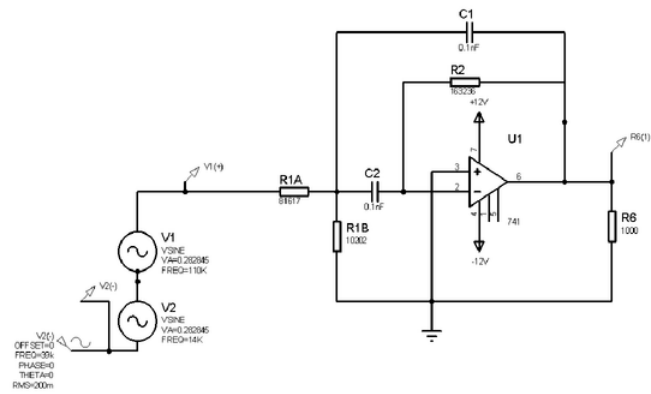


Figure 11 – Design 4 schematic

The Q value of the filter was further reduced to 2 to achieve the desired centre frequency.

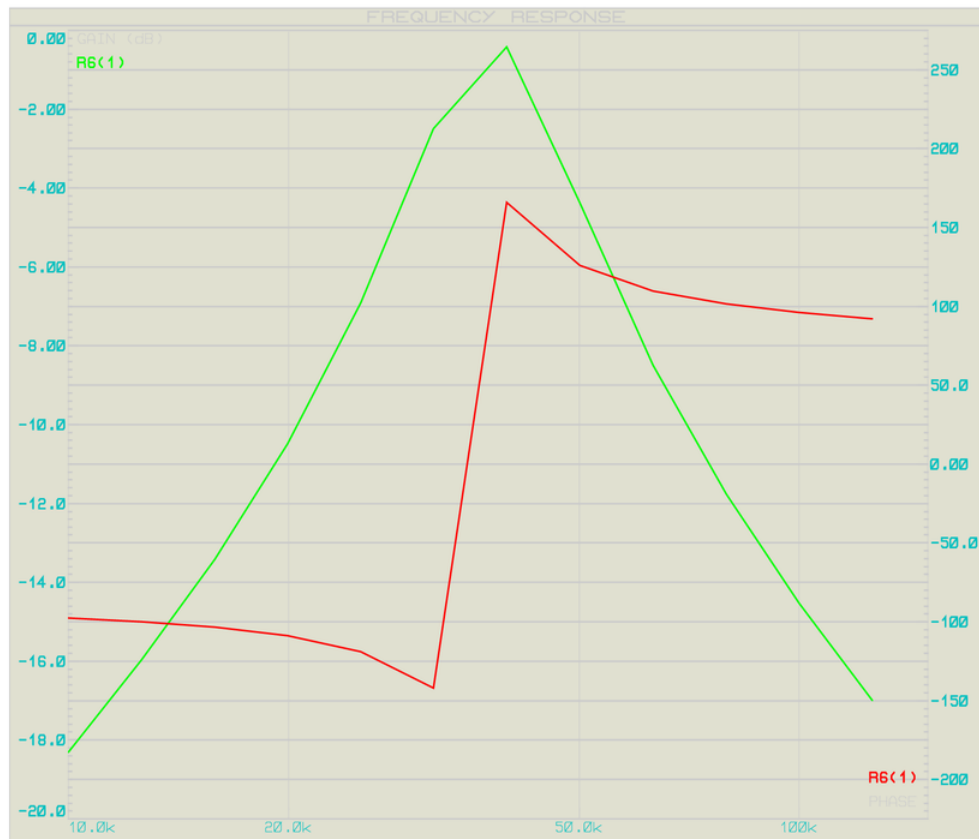


Figure 12 – Design 4 phase and gain

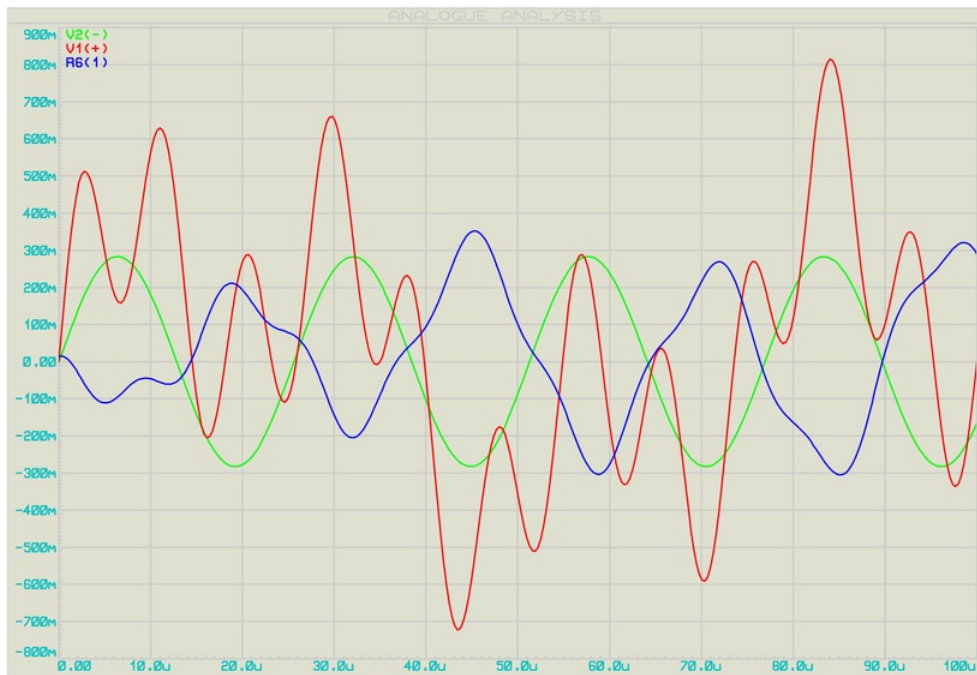


Figure 13 – Design 4 frequency response

Figure 10 demonstrates that the centre frequency of the filter is now at the correct point although there is still some reduction in amplitude. Figure 11 confirms that there is still a substantial amount of noise left in the output signal causing some distortion.

Design 5

It is evident from the previous design that the filter has been improved as far as it can be using a first order topology with a single op amp.

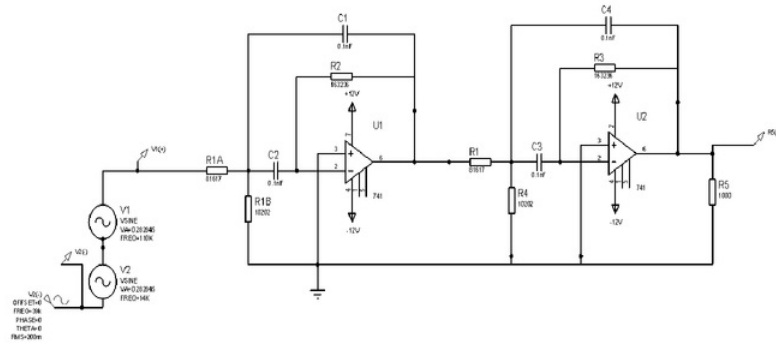


Figure 14 – Design 5 schematic



Figure 15 – Design 5 phase and gain

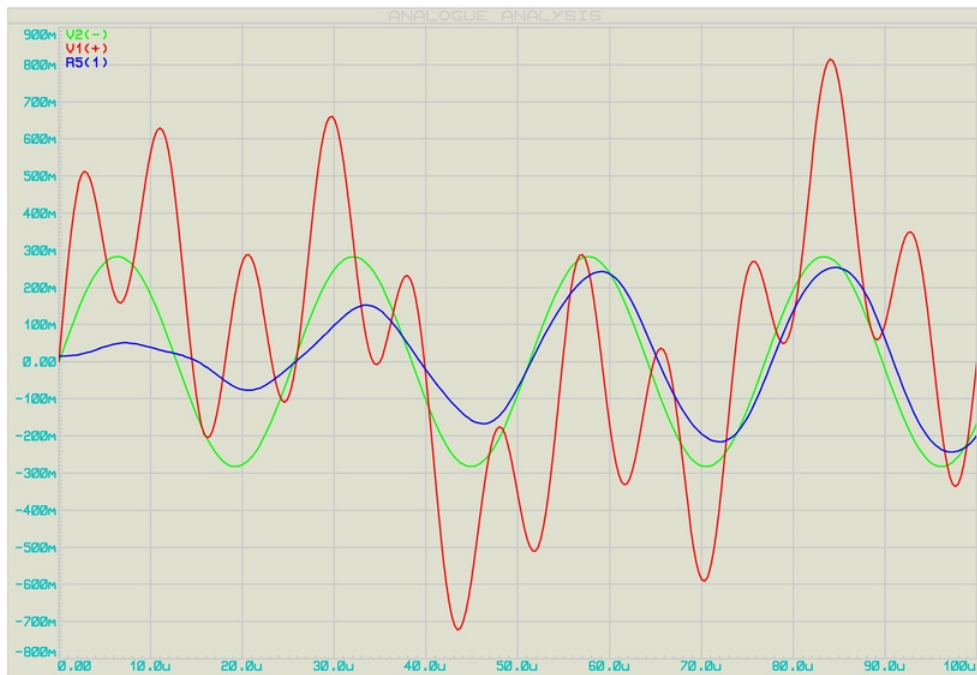


Figure 16 – Design 5 frequency response

Figure 13 and 14 shows that the filter has greatly improved. There is some reduction in amplitude of the signal but the noise has been greatly reduced and the output of the filter largely resembles the input.

Note that the phase shift caused by the two op amps have cancelled, and the signals are now very nearly in phase with one another.

Design 6

For the next design, a third op amp was added and the gain of the final stage increased slightly (increasing the value of k).

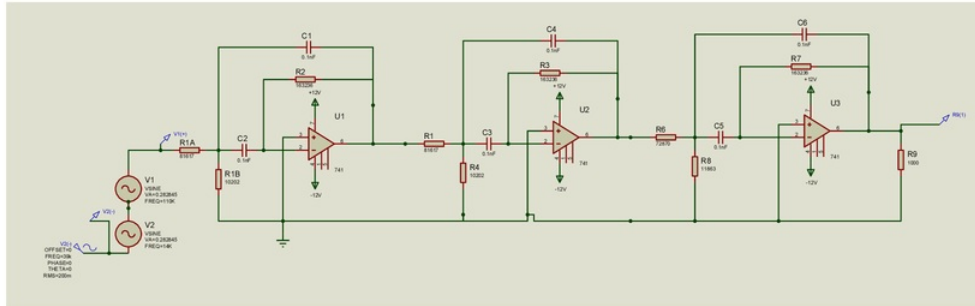


Figure 17 – Design 6 schematic



Figure 18 - Design 6 phase and gain

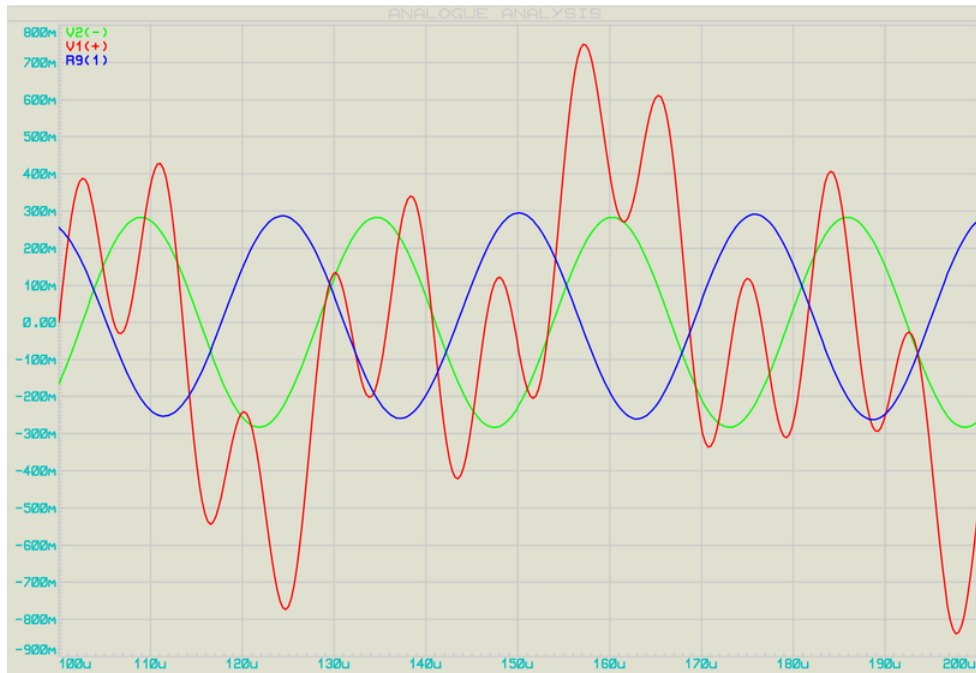


Figure 19 – Design 6 frequency response

Design 6 had no reduction in amplitude at the signal frequency and no noise is visible in the output of the filter, although there is a significant phase shift with respect to the input.

Figure 17 shows that there is a DC component included in the output signal possibly caused by offset currents into the op amp. The gain and bandpass of the circuit is controlled by the feedback network around the op amp, where the input voltages to the op amp are altered by the output. If the resistors are not balanced correctly, equal voltages at both inputs will result in different currents, which will generate a small DC offset in the output.

Design 7

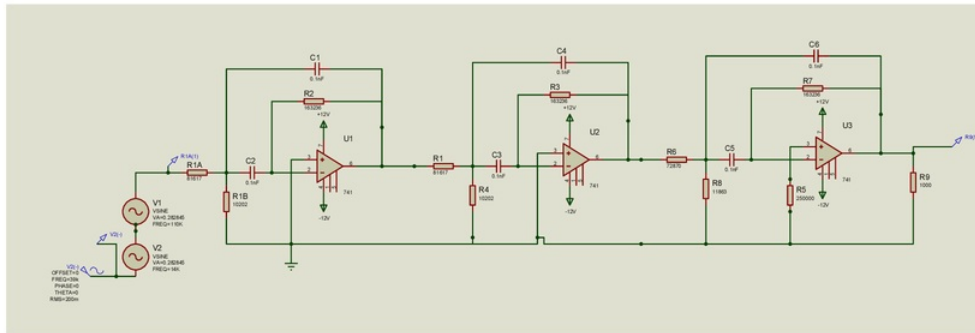


Figure 20 – Design 7 Schematic

For the final design a 250Kohm resistor was added to the non-inverting input of the final stage, which as shown in figure 21 and 22, has reduced the DC offset however has resulted in a small reduction in gain.

Standard resistor values will now be added and the circuit re tested.

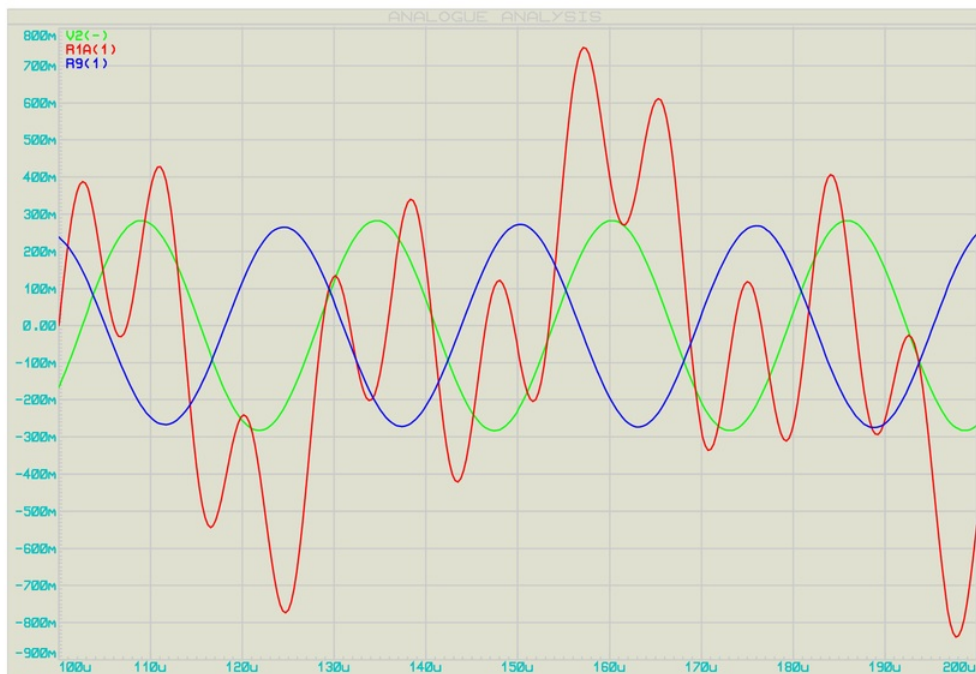


Figure 21 – Design 7 frequency response



Figure 22 – Design phase and gain

Final Design

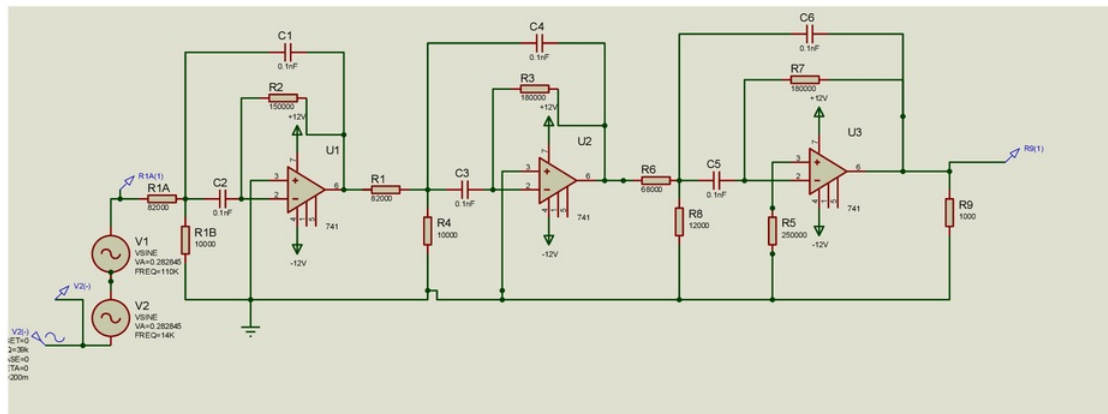


Figure 23 –Final Design schematic

Figure 23 shows the final design using standard resistor and capacitor values. These required rounding either up or down to ensure that the cut of frequencies and gain of the overall circuit was not lost. The frequency response, phase shift and gain are shown in figures 24 and 25.

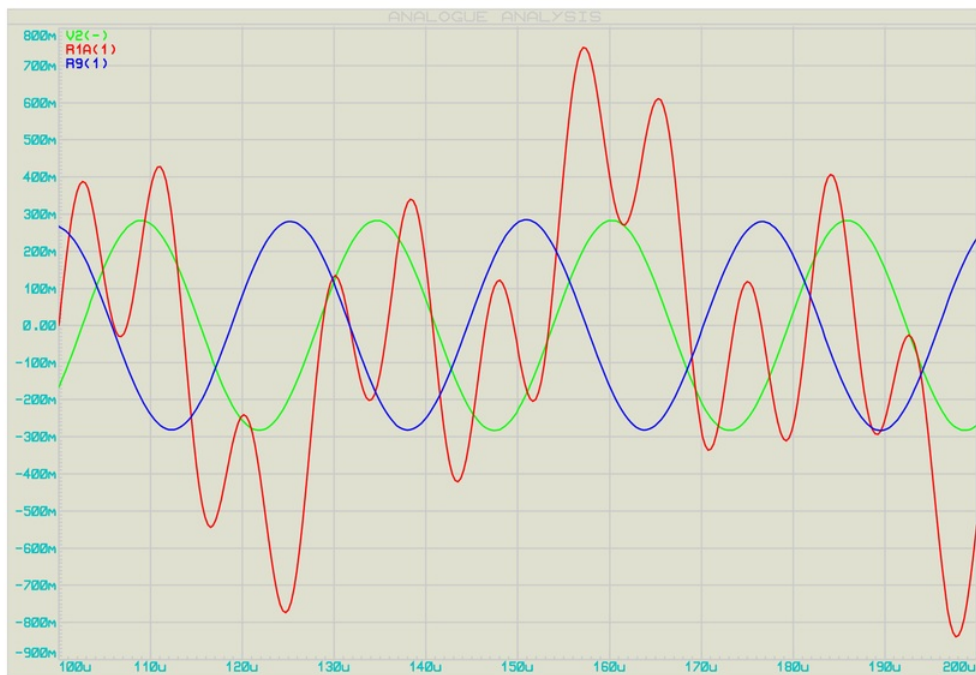


Figure 24 – Final design frequency response



Figure 25 – Final design gain and phase

Conclusion

A third order filter was required to ensure a steep enough roll off to reach a reduction of 30dB by the high and low noise frequencies. To further improve the design, adding a fourth stage to the filter would result in an output with a phase closer to that of the input, with an improved rate of roll off.

For this particular design, a common was used as it could easily cope with the relatively low frequencies detailed in the specification. The gain of the 741 is around 1000 for a 1KHz input and does not reach unity gain until around 1MHz. For a higher frequency filter, a different op amp may be required.

References

- [1] J. Bird, Electrical and Electronic Principles and Technology, Oxford: Reed Educations and Professional Publishing Ltd, 2000.
- [2] J.O.Bird, Electrical and Electronic Engineering Princlples, Essex: Longman Scientific and Technical, 1987.
- [3] "todays circuits," [Online]. Available: <http://todayscircuits.blogspot.com/2011/06/active-filter-types.html#.Wmei6kx2tPY>. [Accessed 12 Jan 2018].
- [4] [Online]. Available: http://www.ecircuitcenter.com/Circuits/MFB_bandpass/MFB_bandpass.htm. [Accessed 22 Dec 2017].

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GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

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Comment 1

A common what?

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RESEARCH-INFORMED LITERATURE



Inclusion of a range of research-informed literature. Very good use of referencing conventions, consistently applied. More references would have improved your mark in this area.

6.5

KNOWLEDGE AND UNDERSTANDING



Highly detailed knowledge and understanding of the main theories/concepts, and a critical awareness of the ambiguities and limitations of knowledge.

20.25

ANALYSIS

Thoroughly logical work, supported by evaluated



evidence. High quality analysis, developed independently or through effective collaboration. Ability to investigate contradictory information and identify reasons for contradictions. Strong, persuasive, conclusions, justifiable recommendations.

21.6

PRACTICAL APPLICATION AND DEP.



An advanced application of a range of methods, and techniques. Creativity evident throughout.

18.25

SKILLS FOR PROFESSIONAL PRAC.



Can communicate professionally and, confidently in a suitable format. Work is coherent, very fluent and is presented professionally.

7.4