

Aled Edgell Assignment 1

by Aled Edgell

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Assignment 1

Aled Edgell

Electrical Principles,
Method And
Simulation
PSDE 5009

23/01/2018

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Word count: 3277

1.Introduction

During this assignment several circuits will be tested, including high and low pass filter in both first order and second order. This will allow a good comparison between the different orders and the benefits of higher order filters.

The circuits specified will have components chosen that will suit the intended circuit, from there calculations will take place to find the suitable values that will need to be implemented into the Matlab simulation software. Using this software both step input simulations and bode simulations will be run depending on the circuit which will allow measurements to be carried out and compared to the calculated values, if the values differ from that of the calculated values calculations will be redone to find the error and create a functional circuit.

By the end of this assignment the aim is to show how the calculations for the circuits are carried out using the Laplace transform to find the transfer function which will be used in the Matlab software, The method that the values found from calculating the components of the circuit are inserted into Matlab to create the desired Graphs for the measurements to take place, and how the different testing methods will take place.

2. Analysis of First Order Electronic Circuits

During this task 2 circuit will be created using suitable components and equations will be calculated using theory based calculations. The first circuit that will be looked at is a first order RL Circuit (Figure 1)

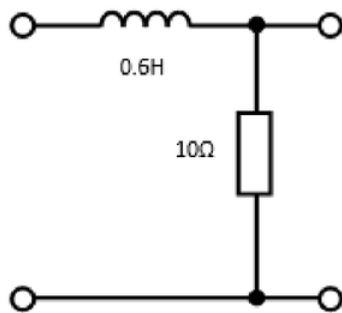


Figure 1: First Order RL Circuit used in theory calculations.

Using the Laplace model, the transfer function can be found as shown below.

$$Y(S) = \frac{R}{R+SL} \times U(S)$$

$$Y(S) = \frac{R}{R+SL} \times \frac{1}{S}$$

$$Y(S) = \frac{R}{S(SL+R)}$$

To proceed the top and bottom must be divided by L.

$$Y(s) = \frac{\frac{R}{L}}{S(\frac{SL}{L} + \frac{R}{L})} = \frac{\frac{R}{L}}{S(S + \frac{R}{L})}$$

$$\text{Let 'a'} = \frac{R}{L}$$

$$Y(s) = \frac{a}{S(S+a)}$$

$$Y(t) = \mathcal{L}^{-1}\{Y(s)\}$$

$$Y(t) = \mathcal{L}^{-1}\left\{\frac{s}{s(s+a)}\right\}$$

$$Y(t) = 1 - e^{-at}$$

$$Y(t) = 1 - e^{-\frac{R}{L}t} \quad \therefore H(s) = \frac{\tau s}{\tau s + 1}$$

Now that the transfer function has been calculated the time constant and the cut-off frequency must be found. The calculations for both are shown below.

$$\tau = \frac{L}{R} = \frac{0.6}{10} = 0.06 \text{ Seconds}$$

$$5\tau = 5 \times 0.06 = 0.3 \text{ Seconds}$$

$$\text{Cut-off frequency} = \frac{R}{L} = \frac{10}{0.6} = 16.67 \text{ rad/s}$$

Now that the calculations have been carried out they can be used in the Matlab software where the simulations will take place for the analysis. Below is the information that was used for the simulation (Figure 2).

```

2 - num = [1];
3 - den = [6e-2 1];
4 - step(num,den);
5 - xlabel('Time,Secs');
6 - ylabel('Output voltage, Volts');
7 - grid

```

Figure 2: First Order RL Circuit Matlab Step values.

According to mathematical theory when the circuit is at its time constant it should be at an amplitude of 0.632. which is 63.2% of its final value. When reaching its 5 times constant is should be almost exactly at its max value as this is the time it takes to reach it. Using the Matlab software we can use cursors to accurately measure these theories, below is a screenshot of the circuit created (Figure 3).

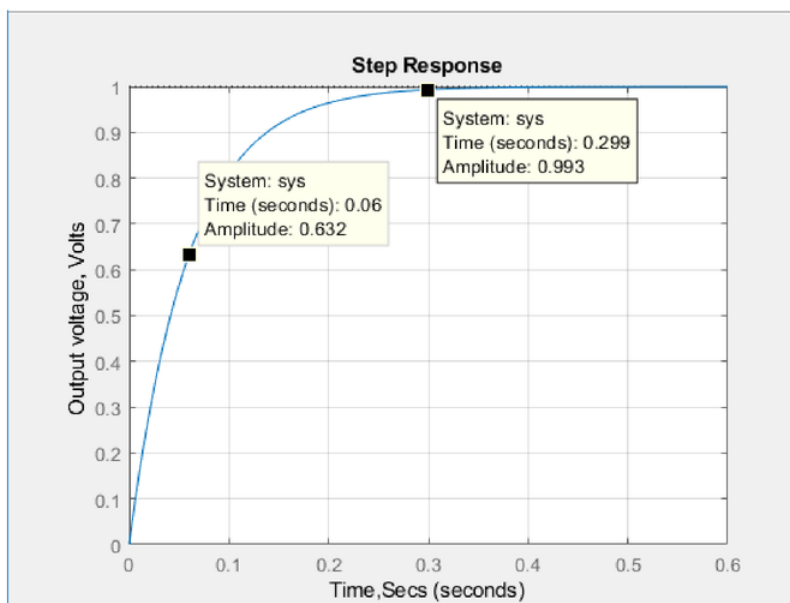


Figure 3: First Order RL Circuit Matlab Step results.

As can be seen from the results the time constant and the 5 times constant were showing the same as the calculated values, The final simulation for this circuit requires to switch from a step input to a bode input, this will allow the measuring of the cut-off frequency which should be 16.67 rad/s at -3Db. The change to the Matlab equation to achieve this can be seen in figure 4 and the results can be seen in figure 5.

```

2 - num = [1];
3 - den = [6e-2 1];
4 - bode(num,den);
5 - xlabel('Time,Secs');
6 - ylabel;
7 - grid

```

Figure 4: First Order RL Circuit Matlab Bode values.

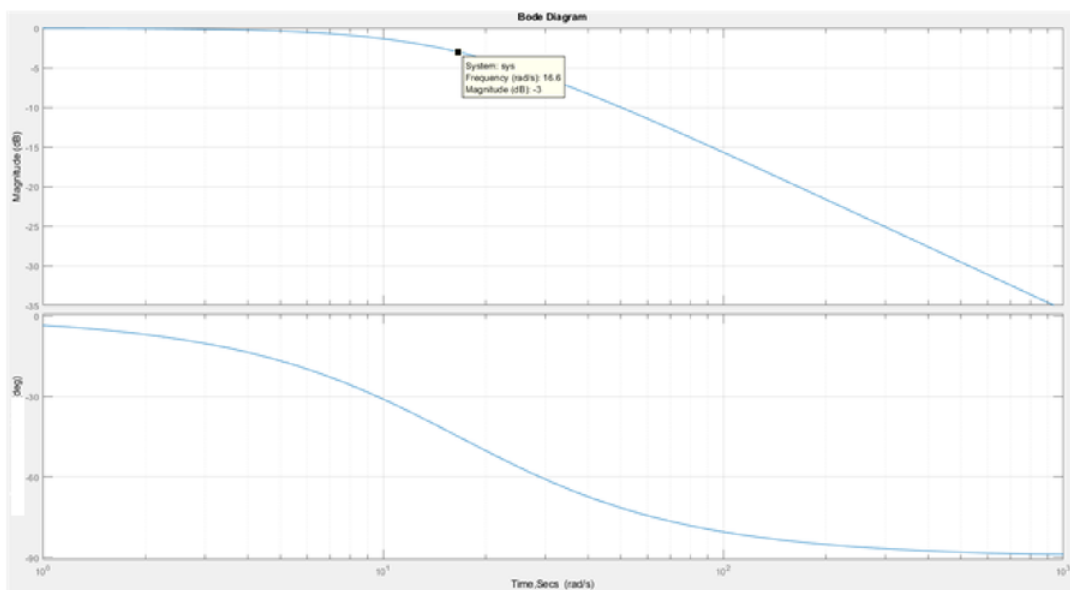


Figure 5: First Order RL Circuit Matlab Bode values.

As can be seen from the cursor placed on the simulation the frequency cut-off is the same value as was calculated. Now that the first circuit has been fully simulated the transfer function will be calculated for the second circuit which is an RC circuit (Figure 6), again using the Laplace model.

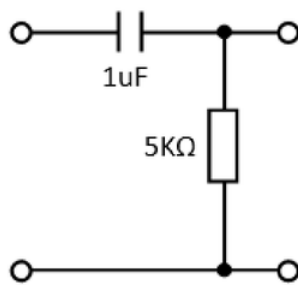


Figure 6: First Order RC Circuit.

To calculate the transfer function the following equations will be used.

$$Y(s) = \frac{R}{\frac{1}{s}C + R} \times U(s)$$

$$Y(s) = \frac{SCR}{1 + SCR} \times U(s)$$

$$Y(s) = \frac{RCS}{RCS + 1} \times \frac{1}{s}$$

Divide the top and bottom by RC

$$Y(s) = \frac{\frac{RC}{RC}}{\frac{RCS}{RC} + \frac{1}{RC}} = \frac{1}{s + RC}$$

$$\text{Let } a = \frac{1}{RC} \quad \therefore y(s) = \frac{1}{s+a}$$

$$Y(t) = \mathcal{L}^{-1}\{Y(s)\}$$

$$Y(t) = \mathcal{L}^{-1}\left\{\frac{1}{s+a}\right\}$$

$$Y(t) = e^{-at}$$

$$Y(t) = e^{-\frac{t}{RC}} \quad \therefore H(s) = \frac{RC}{RC + 1}$$

The time constant, the five times constant and the cut-off frequency for this circuit can be calculated using the following equations:

$$\tau = R \times C = 5000 \times 1 \times 10^{-6} = 0.005 \text{ Seconds}$$

$$5\tau = 5 \times 0.005 = 0.025 \text{ Seconds}$$

$$\text{Cut-off frequency} = \frac{1}{R \times C} = \frac{1}{5000 \times 1 \times 10^{-6}} = 200 \text{ rad/s}$$

Using the same method as before a step response of 1v will be simulated as shown below (Figure 7).

```

2 - num = [5e-3 0];
3 - den = [5e-3 1];
4 - step(num,den);
5 - xlabel('Time,Secs');
6 - ylabel('Output voltage, Volts');
7 - grid

```

Figure 7: First Order RC
Circuit Matlab Step
values.

Similar to the first circuit the amplitude at the time constant can be found. However, instead of it being at 0.632, it will be inversed as this is a high pass filter, so it would be $1 - 0.632 = 0.368$.

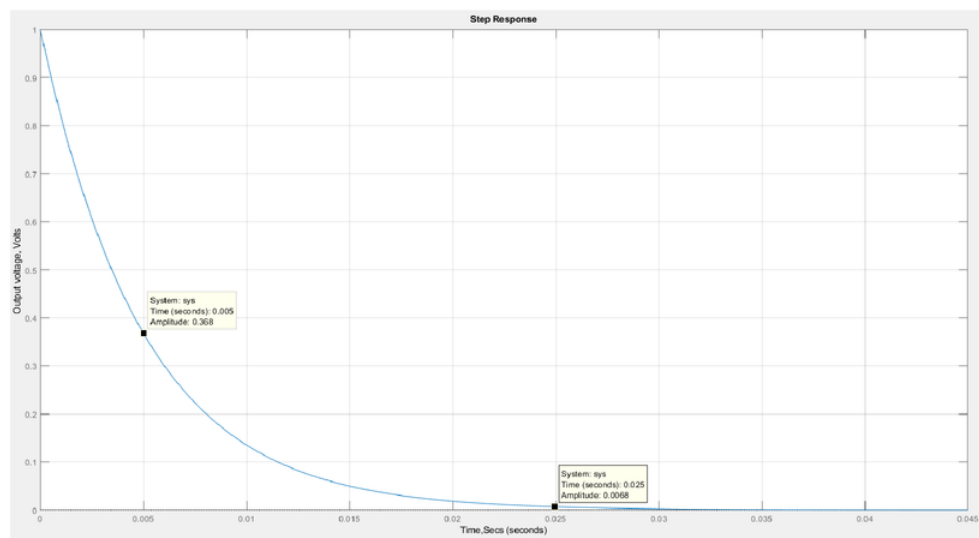


Figure 8: First Order RC
Circuit Matlab Step
Results.

As can be seen from the results shown above (Figure 8) the time constant and the 5 times constant are the same as those that were calculated. This proves that this circuit is functioning as intended, as long as the cut off frequency is accurate. Which again will be simulated using the bode function which can be seen below (Figure 9).

```

2 - num = [5e-3 0];
3 - den = [5e-3 1];
4 - bode(num,den);
5 - xlabel('Time,Secs');
6 - ylabel('Output voltage, Volts');
7 - grid

```

Figure 9: First Order RC
Circuit Matlab Bode
values.

As can be seen below unlick the first circuit which was a low pass filter which allowed the lower end of the frequency range to pass the high pass filter is shows that below the cut-off frequency is the lower end of the frequency which will be ignored by the filter (Figure 10).

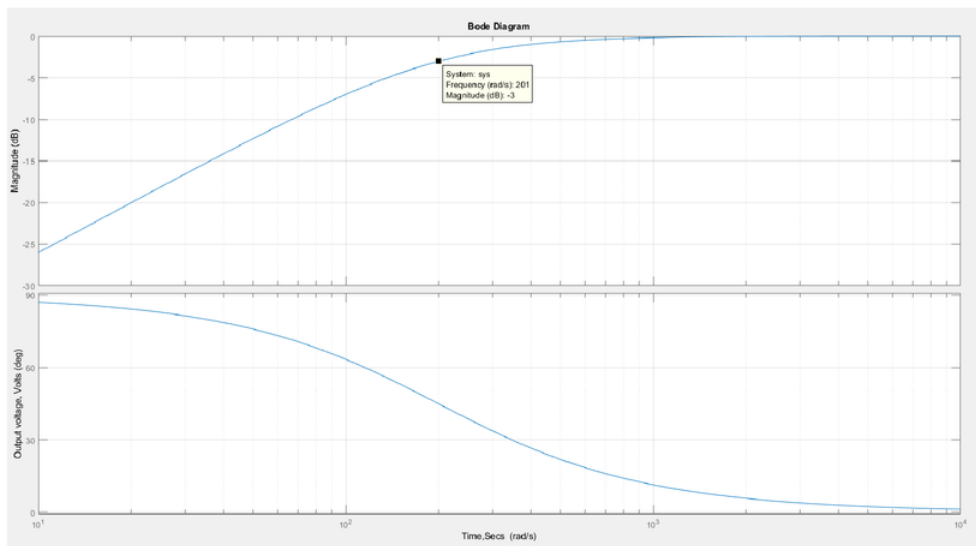


Figure 10: First Order RC
Circuit Matlab Bode
Results.

Comparing both the circuit to the Matlab simulation they both had the same values as was calculated using the equations above. This shows that in both theoretical and simulation the circuits are functioning as were designed.

3. Analysis of Second Order Electronic Circuits

During this task 2 second order circuits will be analysed, one will be a low pass filter the other a parallel resonant filter. The first one that will be carried out will be the low pass filter (Figure 11). The first step to do this will be to calculate the transfer function using the Laplace model as seen in the equations below.

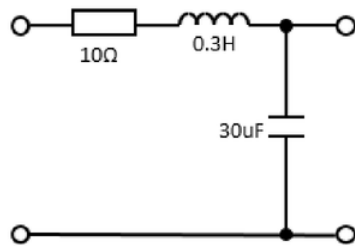


Figure 11: Second order low pass filter circuit.

$$Y(S) = \frac{\frac{1}{sC}}{R + sL + \frac{1}{sC}} \times U(S)$$

Multiply top and bottom by $\frac{s}{L}$

$$\therefore \frac{Y(s)}{X(s)} = \frac{\frac{1}{sC} \times \frac{s}{L}}{R \times \frac{s}{L} + sL \times \frac{s}{L} + \frac{1}{sC} \times \frac{s}{L}}$$

$$\therefore H(s) = \frac{\frac{1}{LC}}{s^2 + \frac{R}{L}s + \frac{1}{C}}$$

$$\frac{1}{LC} = \frac{1}{0.3 \times 30 \times 10^{-6}} = 111111.1$$

$$\frac{R}{L} = \frac{10}{0.3} = 33.3$$

$$\omega_o = \frac{1}{\sqrt{LC}} = 333.3 \text{ rad/s}$$

Using the results from above the following values can be used in Matlab to simulate the circuit (Figure 12).

$$H(s) = \frac{111111.1}{s^2 + 33.3s + 111111.1}$$

```

2 - num = [0 0 111111.1];
3 - den = [1 33.3 111111.1];
4 - bode(num,den);
5 - xlabel('Time,Secs');
6 - ylabel('Output voltage, Volts');
7 - grid

```

Figure 12: Second order low pass filter circuit Bode under damping values.

Below is the result from the simulation (Figure 13).

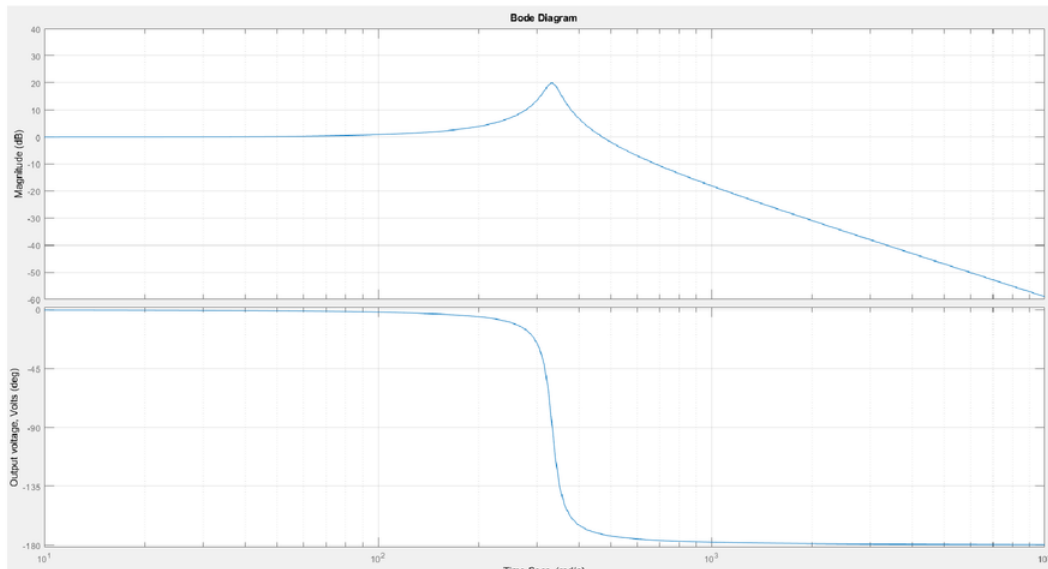


Figure 13: Second order low pass filter circuit Bode under damping results.

As can be seen from the simulation the circuit is under damped. This is due to the resistors value being too low as a result the roll-off value is very small, the correct resistance for the circuit to be critically damped can be seen below.

$$\text{for } \zeta = 1 \quad R = 2 \sqrt{\frac{L}{C}} = 200\Omega$$

Which gives an $\frac{R}{L}$ value of 666.67

To achieve critically damped this value will replace the previous value inserted into Matlab (Figure 14).

```

2 - num = [111111.11];
3 - den = [1 666.67 111111.11];
4 - bode(num,den);
5 - xlabel('Time,Secs');
6 - ylabel('Output voltage, Volts');
7 - grid

```

Figure 14: Second order low pass filter circuit Bode critical damping values.

As can be seen the value has been changed and the new simulation (Figure 15) shows that the circuit is now critically damped, and is functioning correctly as a low pass filter.

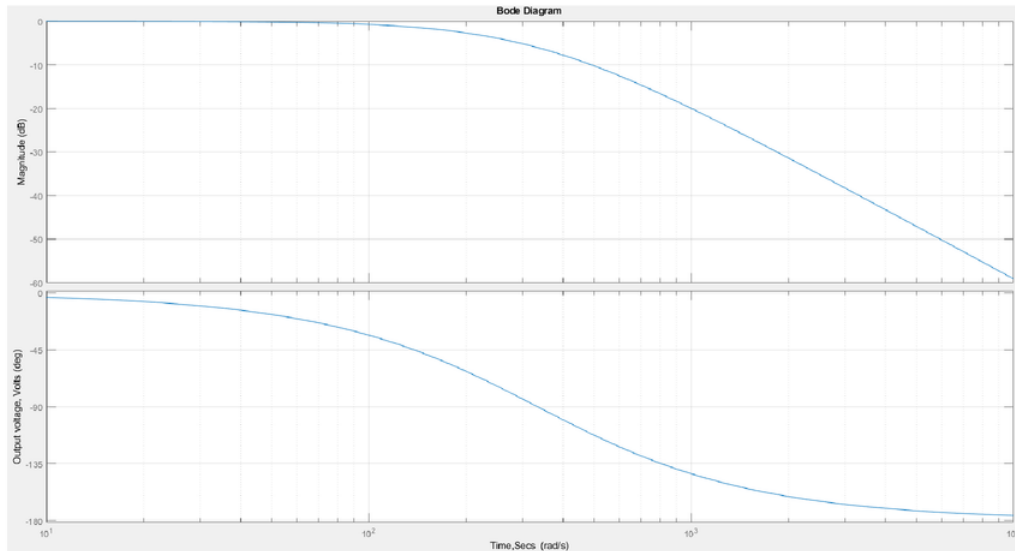


Figure 15: Second order low pass filter circuit Bode critical damping results.

If the circuit requires over damping a smiler method is used, however since the critical damped value has already been calculated to achieve overdamping a value higher than that could be used for example 250Ω which will give an $\frac{R}{L}$ value of 833.33, using this circuit in Matlab will show the difference (Figure 16).

```

2 - num = [111111.11];
3 - den = [1 833.33 111111.11];
4 - bode(num,den);
5 - xlabel('Time,Secs');
6 - ylabel('Output voltage, Volts');
7 - grid

```

Figure 16: Second order low pass filter circuit Bode over damping values.

As can be seen below the circuit now has a higher roll-off (Figure 17).

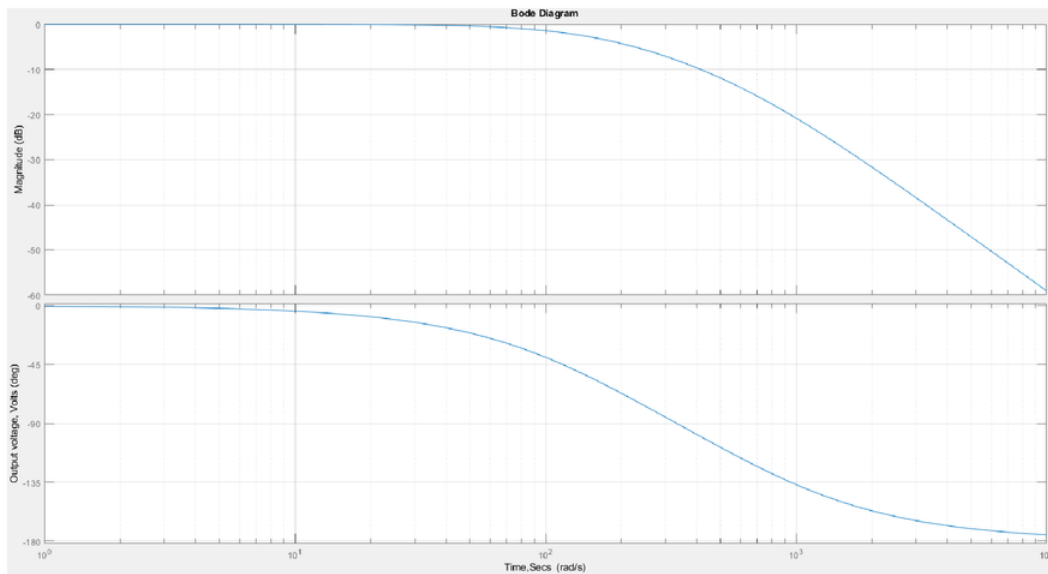


Figure 17: Second order low pass filter circuit
Bode over damping results.

Although the resistance was only change by 50Ω the roll- off has increased, however if it was increased by a larger resistance then it would start to become unstable as ripples will begin to appear.

The cut off frequency for the circuit can be calculated with the following equation, which will be using the original circuits values.

$$\sqrt{\frac{1}{L \times C} - \frac{1}{2} \left(\frac{R}{L}\right)^2}$$

Which gives a value of 332.5 Below is the results from the original circuit with a cursor in place to measure the cut-off frequency (Figure 18).

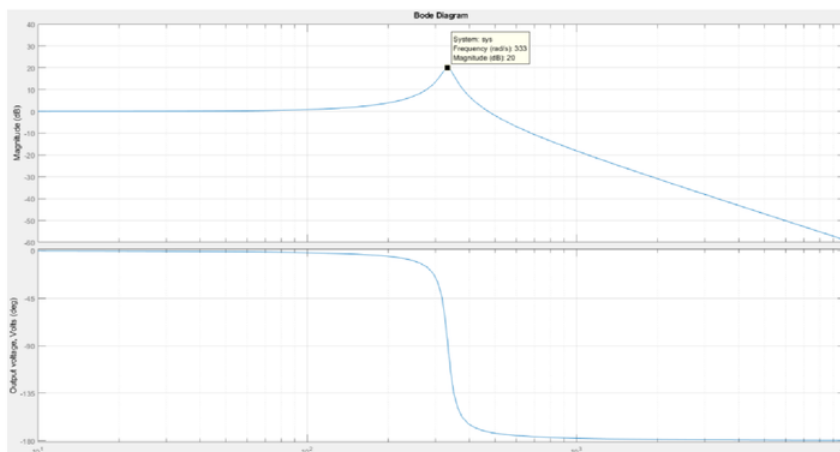


Figure 18: Second order low pass filter circuit Bode under damping cut-off.

In the next part of this task the resistance for the circuit will be changed multiple times and the graphs will be held so that the overlap (Figure 19).

```

2 - num = [111111.11];
3 - den = [1 33.3 111111.11];
4 - bode(num,den);
5 - xlabel('Time,Secs');
6 - ylabel('Output voltage, Volts');
7 - grid
8 - hold on
9 - num = [111111.11];
10 - den = [1 100 111111.11];
11 - bode(num,den);
12 - xlabel('Time,Secs');
13 - ylabel('Output voltage, Volts');
14 - grid
15 - hold on
16 - num = [111111.11];
17 - den = [1 150 111111.11];
18 - bode(num,den);
19 - xlabel('Time,Secs');
20 - ylabel('Output voltage, Volts');
21 - grid
22 - hold on
23 - num = [111111.11];
24 - den = [1 200 111111.11];
25 - bode(num,den);
26 - xlabel('Time,Secs');
27 - ylabel('Output voltage, Volts');
28 - grid
29 - hold on

```

Figure 19: Second order low pass filter
Matlab multiple resistor values.

Using the cursors the difference between ω_o and ω_m can be seen (Figure 20)

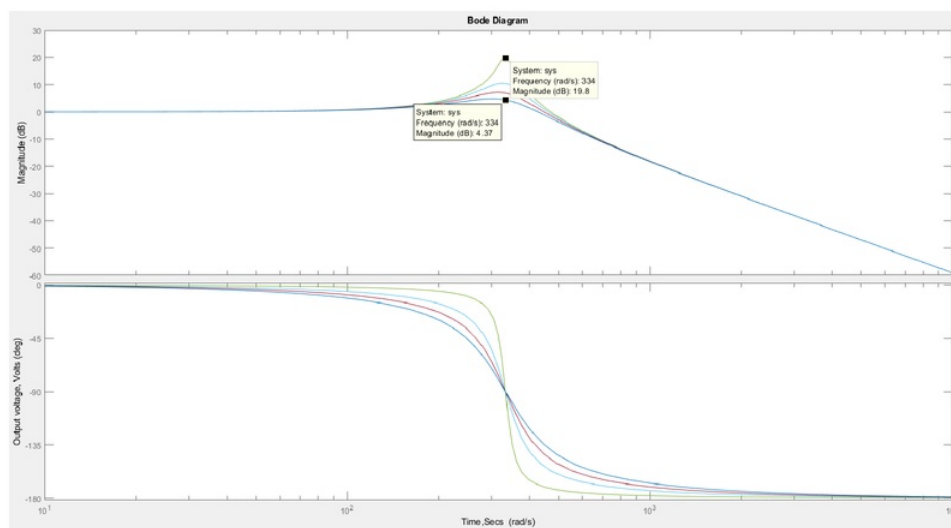


Figure 20: Second order low pass filter
Matlab multiple resistor results.

As can be seen the more the resistance is increased the closer ω_0 gets to ω_m as the peak increases. For the second circuit the parallel resonant circuit (Figure 21). The first calculation that will need to be carried out is to find the transfer function which is shown below:

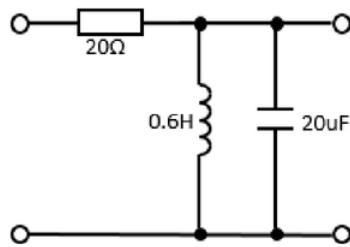


Figure 21: Second order parallel resonant filter circuit.

$$Y(s) = \frac{Z_p(s)}{R + Z_p(s)} \times X(s)$$

$Z_p(s)$ is the parallel impedance of SL and $1/SC$

$$Z_p(s) = \frac{SL \times \frac{1}{SC}}{SL + \frac{1}{SC}} = \frac{SL}{(S^2 LC + 1)}$$

$$Y(s) = \frac{\frac{SL}{(S^2 LC + 1)}}{R + \frac{SL}{(S^2 LC + 1)}}$$

$$\frac{Y(s)}{X(s)} = \frac{SL}{R(S^2 LC + 1) + SL}$$

Divide top and bottom by RLC

$$H(s) = \frac{S \times \frac{1}{RC}}{S^2 + \frac{1}{RC}S + \frac{1}{LC}}$$

$$\frac{1}{RC} = \frac{1}{20 \times 20 \times 10^{-6}} = 2500$$

$$\frac{1}{LC} = \frac{1}{0.6 \times 20 \times 10^{-6}} = 83333.34$$

$$\therefore H(s) = \frac{83333.34}{S^2 + 2500 + 83333.34}$$

Using these values the Matlab simulation can be run as shown below (Figure 22).

```
2 - num = [0 1 2500];  
3 - den = [1 2500 83333.34];  
4 - bode(num,den);  
5 - xlabel('Time,Secs');  
6 - ylabel('Output voltage, Volts');  
7 - grid
```

Figure 22: Second order parallel resonant filter circuit Matlab bode Values

As shown below this is again an under damped circuit (Figure 2n) as the resistors value is to low.

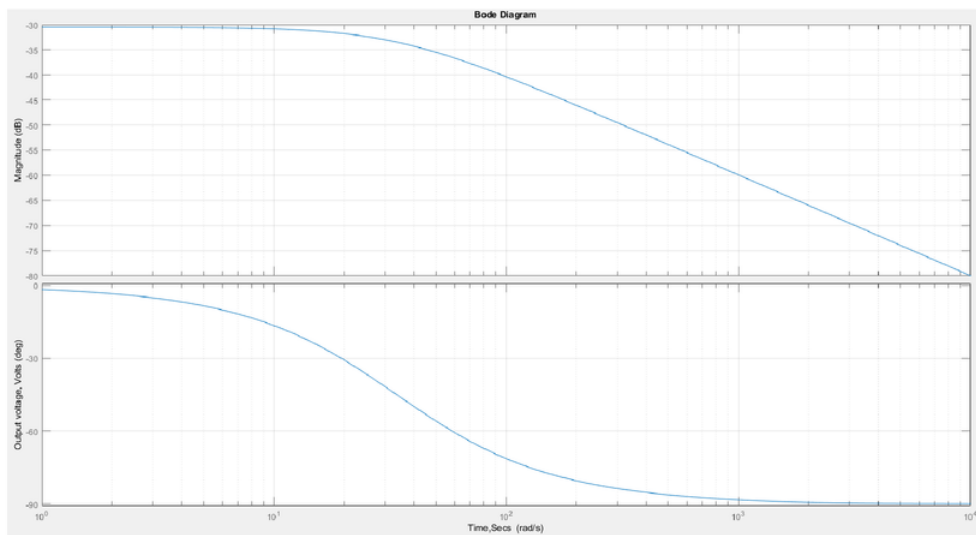


Figure 23: Second order parallel resonant filter circuit Matlab bode Values

4. Analysis of First Order Electronic Systems

For this task 2 first order electronic systems will be analysed the first will be a high pass system (Figure 24) and the second will be the Low pass filter (Figure 28).

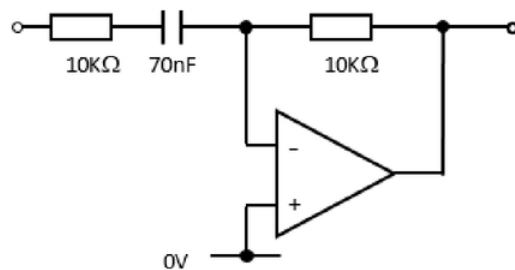


Figure 24: high pass electronic system circuit.

To find the transfer function first the Impedance must be calculated, this is shown below.

$$Z1(s) = \frac{1}{SC} + R1 = \frac{1 + SCR1}{SC}$$

$$Z2(s) = R2$$

$$H(s) = \frac{-Z2(s)}{Z1(s)}$$

$$H(s) = \frac{-R2}{(1 + SCR1)/SC}$$

$$H(s) = \frac{-R2 \times SC}{(1 + SCR1)}$$

$$-\frac{R2}{R1} = \left\{ \frac{SCR1}{(1 + SCR1)} \right\}$$

$$\text{Or } H(s) = -\frac{R2}{R1} \left\{ \frac{s}{s + \frac{1}{CR1}} \right\}$$

$$K = \frac{R2}{R1} = \frac{10K}{10K} = 1$$

$$WC = \frac{1}{CR1} = \frac{1}{10K \times 70n} = 1429$$

$$H(s) = -1 \left\{ \frac{s}{s + 1429} \right\}$$

To find the cut-off frequency $20\log(1) = 0\text{dB} - 3\text{dB}$

Cut-off frequency = -3Db

To evaluate the circuit the values just calculated will be entered into Matlab to carry out a frequency response (Figure 25).

```

2 - num = [-1 0];
3 - den = [1 1429];
4 - bode(num,den);
5 - xlabel('Time,Secs');
6 - ylabel('Output voltage, Volts');
7 - grid

```

Figure 25: high pass electronic system Matlab bode values.

Using the cursers (Figure 26) the cut-off frequency can be measured as stated earlier the cut-off frequency should be 1429 at -3dB.

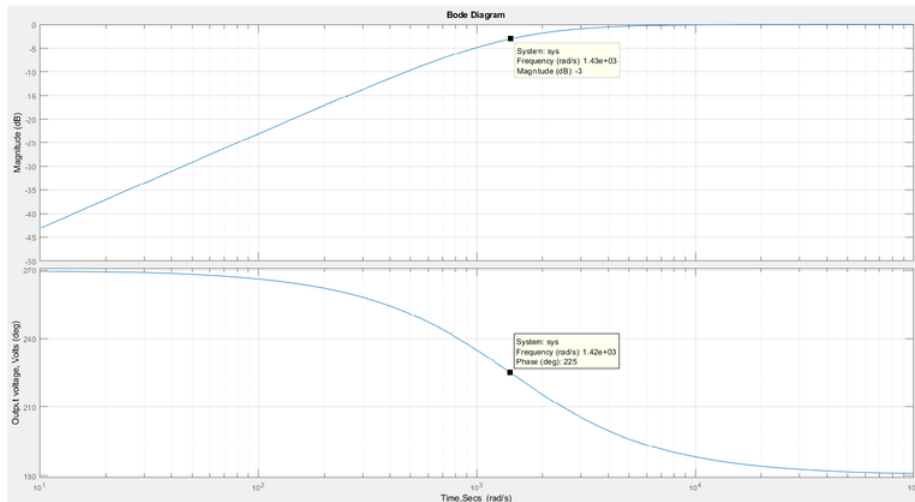


Figure 26: high pass electronic system Matlab bode results.

Using the image below (Figure 27) The drop per decade can be found. Lines have been drawn from each decade up until they reach the graph then across to the change in dB. As can be seen the difference between the 2 values is 17.5dB this shows that the roll-off for this circuit is 17.5dB per decade.

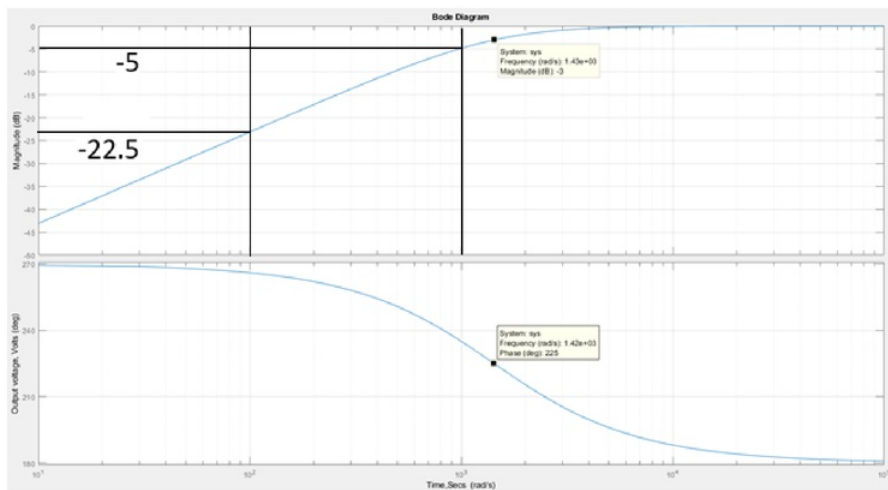


Figure 27: high pass electronic system
Matlab roll-off values.

On the Second circuit (Figure 28) the capacitance chosen is 500nF using the calculations below the values for the simulation on Matlab will be found.

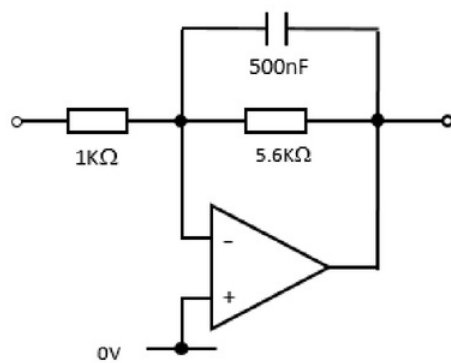


Figure 28: Low pass electronic system circuit.

$$Z(s) = R1$$

$$Z2(s) = \frac{R2}{1 + sCR2}$$

$$Z2(s) = \frac{R2 \times \frac{1}{s}}{R2 + \frac{1}{s}}$$

$$Z2(s) = \frac{R2}{(1 + sCR2)}$$

$$H(s) = \frac{-R2}{(1 + sCR2)} \times \frac{1}{R1}$$

$$H(s) = \frac{-R2}{R1} \left\{ \frac{\frac{1}{CR2}}{s + \frac{1}{CR2}} \right\}$$

Let $K = \text{Gain} = 5.6$

Cut-off frequency = 357.14

$$H(s) = -5.6 \left\{ \frac{357.14}{s + 357.14} \right\}$$

In dB $K = 20\log(5.6) = 14.96\text{dB}$

Therefore, cut-off frequency takes place at 11.96dB

Using the Information gathered a Matlab simulation was created (Figure 29)

```

1 %Second Order RLC - example 2
2 num = [-5.6 | 357.14];
3 den = [1 357.14];
4 bode(num,den);
5 xlabel('Time,Secs');
6 ylabel('Output voltage, Volts');
7 grid

```

Figure 29: low pass electronic system
Matlab bode values.

Again using the cursors, the cut-off frequency can be found (Figure 30)

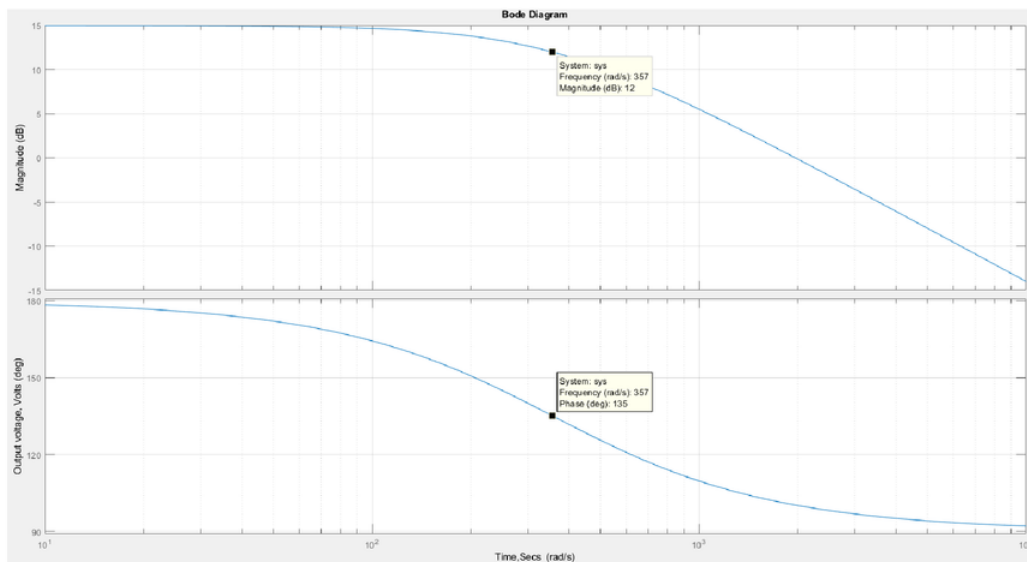


Figure 30: low pass electronic system
Matlab bode results.

As can be seen in the image above the cut-off frequency calculated is being measured at -3dB this shows that the calculated circuit and the simulated circuit are the same. However, to calculate the roll-off the same method must be used again which will provide a 6dB per decade roll-off.

5. Analysis of Second Order Electronic Systems

In this task 2 sallen & key filters will be analysed. The first will be a low pass filter (Figure 31) which can be seen below.

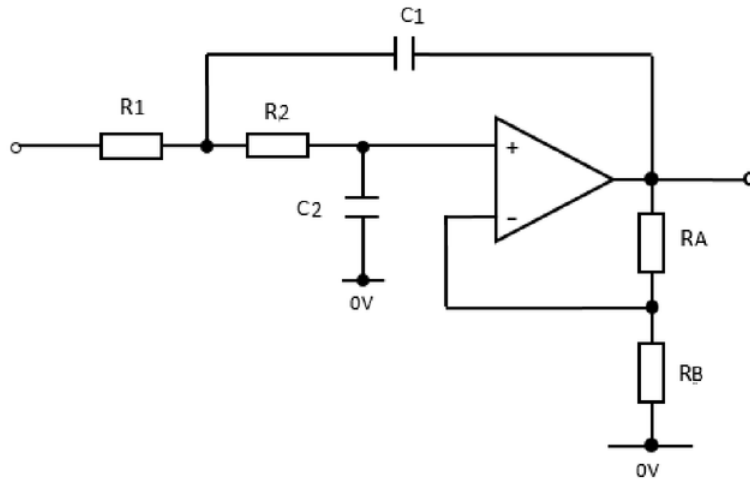


Figure 31: Second order sallen & key Low pass filter circuit.

For this circuit a Butterworth filter will be used which means $K = 1.586$ and a WC value of 800rad/s and a value of 200nF for C .

$$R1 = \frac{1}{WC \times C} = 6.25K\Omega$$

$$R2 = R1 = 6.25K\Omega$$

Therefore if $R_B = 2K\Omega$

$$R_A = (K-1) \times 2000 = 1172\Omega$$

$$Q = \frac{1}{3-K} = 0.707$$

$$\frac{WC}{Q} = 1131.54$$

$$H(s) = \frac{KWC^2}{s^2 + \left(\frac{WC}{Q}\right)^2 + WC^2} = \frac{1015040}{s^2 + 1131.54 + 640000}$$

Using these values, a Matlab simulation can be made, as shown below (Figure 32). The cut-off frequency for this circuit is calculated at 1dB .

```

2 - num = [1015040];
3 - den = [1 1131.54 640000];
4 - bode(num,den);
5 - xlabel('Time,Secs');
6 - ylabel('Output voltage, Volts');
7 - grid on

```

Figure 32: Second order
sallen & key Low pass filter
bode values.

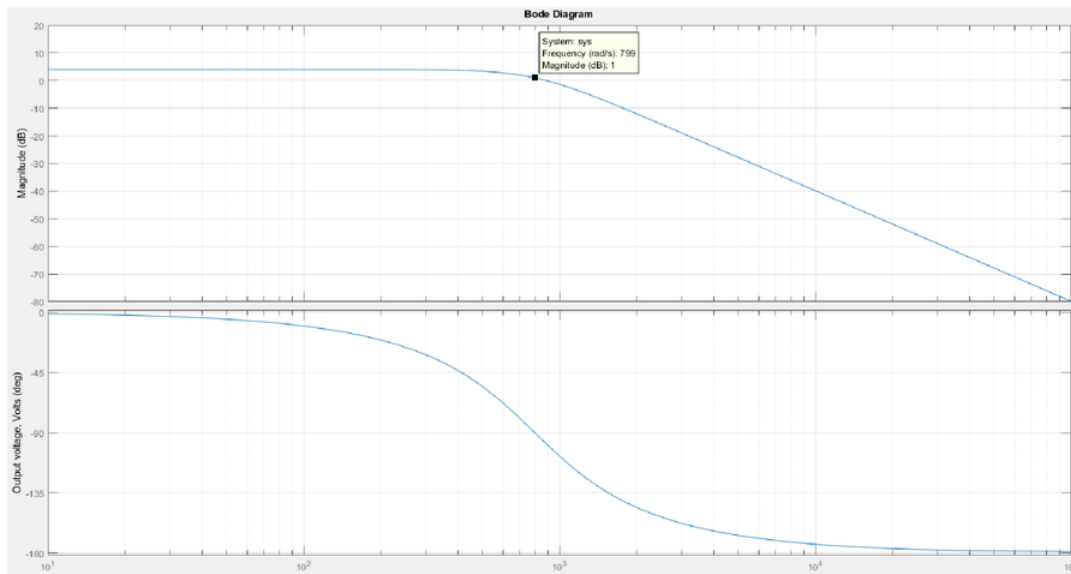


Figure 33: Second order sallen & key
Low pass filter bode results.

Above is the result from the Matlab simulation (Figure 33), as in previous circuits a cursor is used to measure the cut-off frequency, as can be seen the frequency is reading 799rad/s at 1dB which is almost exactly what the calculations were intending for.

For the second circuit a High pass sallen & key filters will be analysed (Figure 34)

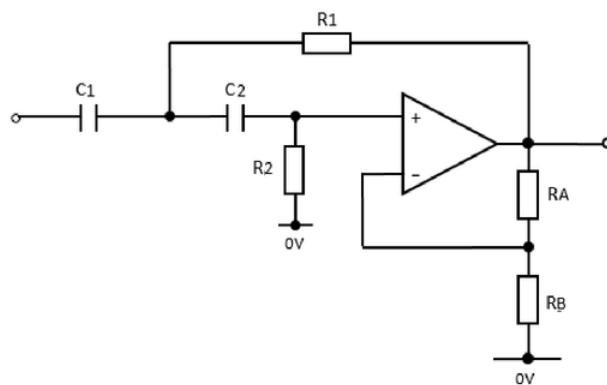


Figure 34: Second order
sallen & key High pass
filter circuit.

For this circuit a Butterworth filter will be used which means $K = 1.586$ and a ω_c value of 800rad/s

Using the same values as the first circuit.

$$H(s) = \frac{K S^2}{S^2 + \left(\frac{WC}{Q}\right)s + WC^2} = \frac{1.586 S^2}{S^2 + 1131.54 + 640000}$$

This will allow the comparison of both the circuits in Matlab. However, first the values for the High pass sallen & key filter must be added, as shown below (Figure 35).

```
2 - num = [1.586 0 ];
3 - den = [1 1131.54 640000];
4 - bode(num,den);
5 - xlabel('Time,Secs');
6 - ylabel('Output voltage, Volts');
7 - grid on
```

Figure 35: Second order sallen & key High pass filter bode values.

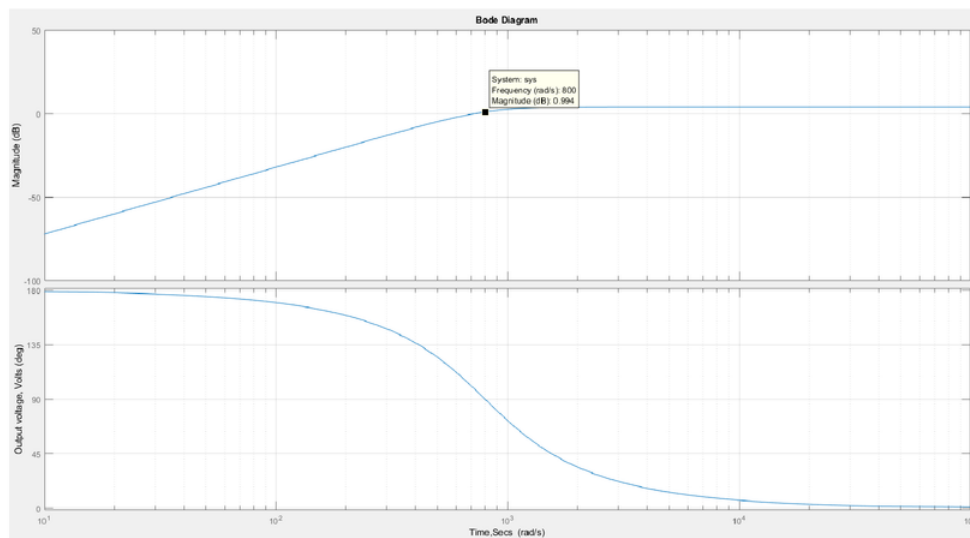


Figure 36: Second order sallen & key Low pass filter bode results.

Again, as can be seen in the results above (Figure 36) The value of the cut-off frequency is almost exactly as calculated. To finish comparing the circuits they have been combined together so they overlap together. This can be seen below (Figure 37)

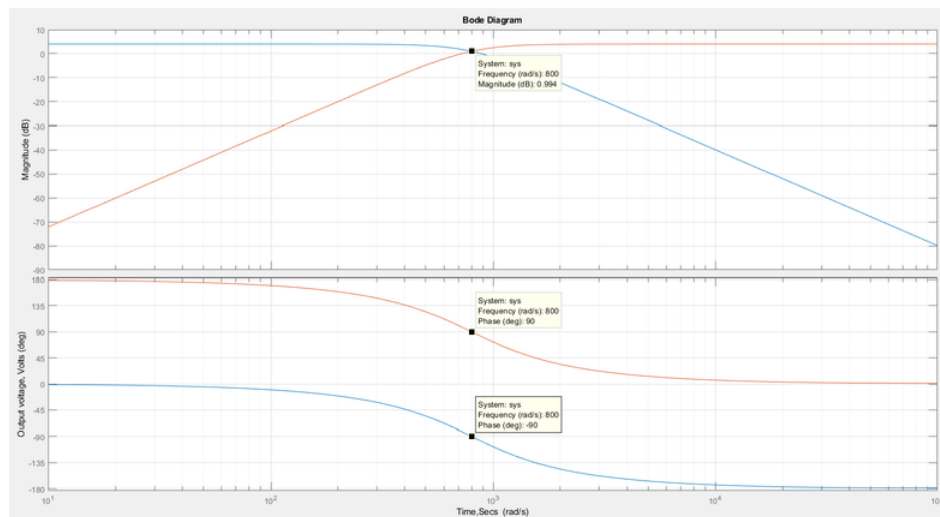


Figure 37: Second order sallen & key
Low pass filter and High pass filter
comparison.

As can be seen from the graph both the circuits overlap at the cut-off frequency. However, it can be seen that the Low pass filter has a slightly higher roll-off than the high pass filter. The difference between the two is minor however, If a circuit is required to have a better roll-off the desired roll-off can be achieved by recalculating the values and finetuning the circuit.

6. Conclusion

As a conclusion by looking at the different circuits that have been calculated and tested using the Matlab simulation software. The difference between the circuits is clear. The main difference being the roll-off. As could be seen from the circuits the higher the order the better the roll-off was. This is because of the extra components and steps to the filter which are incorporated into it to make sure it has a sharp steady roll-off with little to no ripple. The ideal filter would have a 90° drop after it hits its cut-off frequency. However, when the number of orders increases in a circuit the number of components needed increases which leads to an increase in price and in the complexity of the equations. As was seen, the calculations required for the first order circuits were fewer and less rigorous than the second order filters, however the number of orders could increase much higher however it is the complexity and costs that is required to make a high order filter that leaves a demand for lower order filters.

In the 5th part of the assignment the low pass and high pass filters were overlapped to show that the cut-off frequency was the same for both. However, this is similar to how a band pass filter works which requires the high and low pass filters to have different cut-off frequencies, however this means the low end and the high end of the frequency will be allowed to pass but the middle section will be blocked.

To improve on the circuits that were created, especially for the second order filters the results from the first test could have been reused to calculate a better roll-off which would make the circuit more efficient and effective in practical use, and provide a better understanding of the filter.

Aled Edgell Assignment 1

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

61 / 100

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QM

Sp.
Spelling error

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GRADING FORM: CSG-RUBIC

ALED EDGELL

61

RESEARCH-INFORMED LITERATURE



N/A

KNOWLEDGE AND UNDERSTANDING



Sections 2, 3: Explanations for Electric Circuits –
Generally well explained. Further marks were
available for greater accurate in task 2 . (7/10)
Sections 4, 5: Explanations for Electronic Systems
– Good explanations given with good use of
equation editor and clear diagrams (8/10)

15

ANALYSIS



Sections 2, 3: Analysis, Modelling and Testing of
Electric Circuits - Generally very good. Further

27

marks were available for the step responses of task 2 and greater accuracy as there are some errors in task 2(b) when entering the numerator into Matlab which produced the wrong response. (11/20)

Sections 4, 5: Analysis, Modelling and Testing of Electronic Systems - Some good analysis given but not all graphic results have been analysed and there are some errors which have not been spotted. You have also misunderstood the last question which required a comparison between 1st and 2nd order filters. (10/20) Section 6: Conclusions and recommendations – Good conclusions offered and one recommendation. However, one of your conclusions is based on a misunderstanding of the question. (6/10)

PRACTICAL APPLICATION AND DEP.



Sections 2,3,4,5: Use of Matlab – Generally good but there are some errors in converting the numerator of some transfer functions into Matlab code which produced the wrong results. (6/10)

Sections 2,3,4,5: Accuracy and Presentation Quality of Results – Generally good but some of your original screens were too large so that when you used the screen dump facility, you had to reduce the size to fit on your page which meant that text size for the results is too small to read and some of poor quality..(5/10)

11

SKILLS FOR PROFESSIONAL PRAC.



Section 1: Introduction: Very good (4/5) All sections: Overall Report Quality - Good, clear diagrams, well structured. (4/5)

8