

assignment 1

by Trystan Daniels

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TRYSTAN DANIELS

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1. INTRODUCTION

Throughout this assignment 2 types of electrical circuits and 2 types of electrical will be analysed and simulated using theory prediction and matlab. The two types of electrical circuit are first order and second order circuits, in this section I will be looking at a low pass filter, high pass filter in first order. Then a low pass filter and a parallel resonant filter in the second order circuit. The two types of electrical systems are first order and second order systems. Here a high pass and low pass first order filters will be analysed. For the second order systems a sallen & key low pass filter and a sallen & key high pass filter will be analysed.

Suitable component values will be chosen for each circuit, the laplace model will then be formed deriving the transfer function. Using the chosen component values the transient performance will be predicted using theory then simulated using Matlab. Also the frequency response will be predicted then simulated again using Matlab. Taking both predicted and simulated results and comparing together.

For the two types of electrical systems values for capacitor 1 and 2 will be chosen then the frequency response will be produced using matlab comparing the results to predicted theory results.

2. ANALYSIS OF FIRST ORDER ELECTRIC CIRCUITS

Task 1 a)

Low pass filter

See Figure 1 for laplace model of the low pass filter circuit.

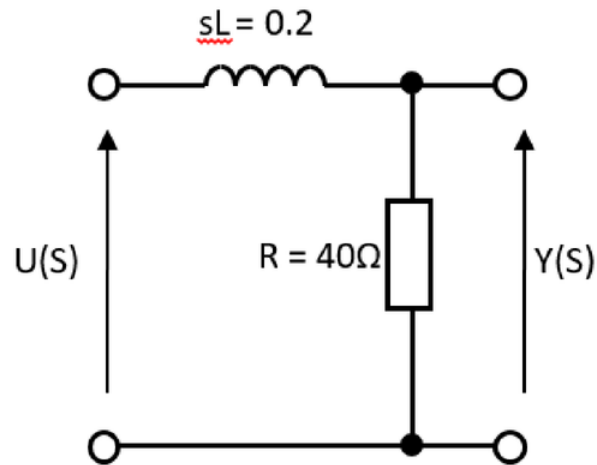


Figure 1

Deriving the transfer function:

$$Y(s) = \frac{R}{R + sL} X U(s)$$

$$Y(s) = \frac{R}{R + sL} X \frac{1}{s} \text{ (step input)}$$

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

Divide top and bottom by L

$$Y(s) = \frac{\frac{R}{L}}{s \left(s + \frac{R}{L} \right)}$$

Let $a = R/L$

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

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

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

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

$$y(t) = 1 - e^{-\frac{R}{L} t}$$

$$y(t) = 1 - e^{-\frac{t}{\tau}}$$

$$\text{Let } \tau = \frac{L}{R} = \frac{0.2}{40} = 0.005 \text{ seconds}$$

Transfer function

$$\frac{Y(s)}{U(s)} = \frac{R}{R + sL}$$

Divide top and bottom by R

$$= \frac{1}{\tau s + 1}$$

Insert circuit values

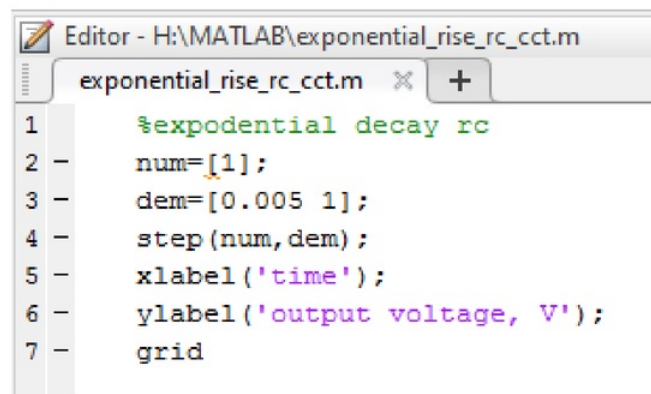
$$= \frac{1}{0.005 + 1}$$

Cut off frequency

$$\omega_c = \frac{R}{L} = \frac{40}{0.2} = 200 \text{ rad/s}$$

Matlab simulation

Step transient response:



```

1 %exponential decay rc
2 num=[1];
3 dem=[0.005 1];
4 step(num,dem);
5 xlabel('time');
6 ylabel('output voltage, V');
7 grid

```

Figure 2

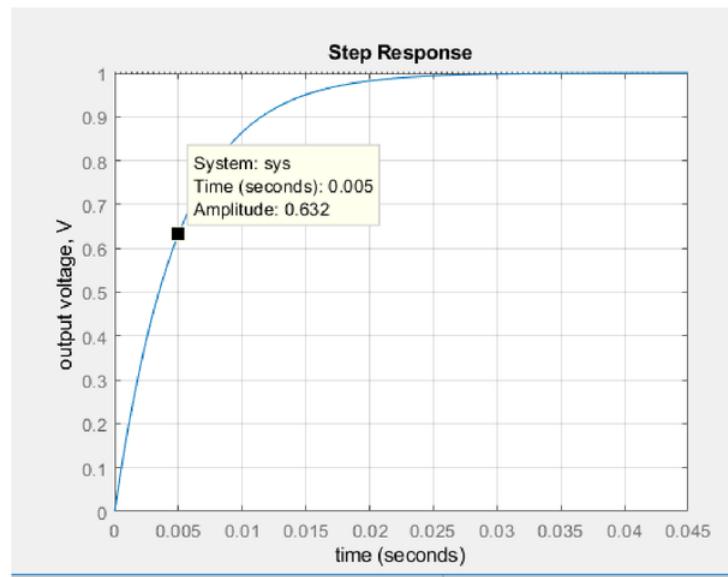


Figure 3

Above in figure 3 is the step response for the circuit in matlab. From the graph you can see at 0.632 the time matches the calculated time constant of 0.005s. By 5 times the time constant (0.025s) the circuit has reach steady state.

Frequency response:

```
%low pass
num=[200];
dem=[1 200];
bode(num,dem);
grid
```

Figure 4

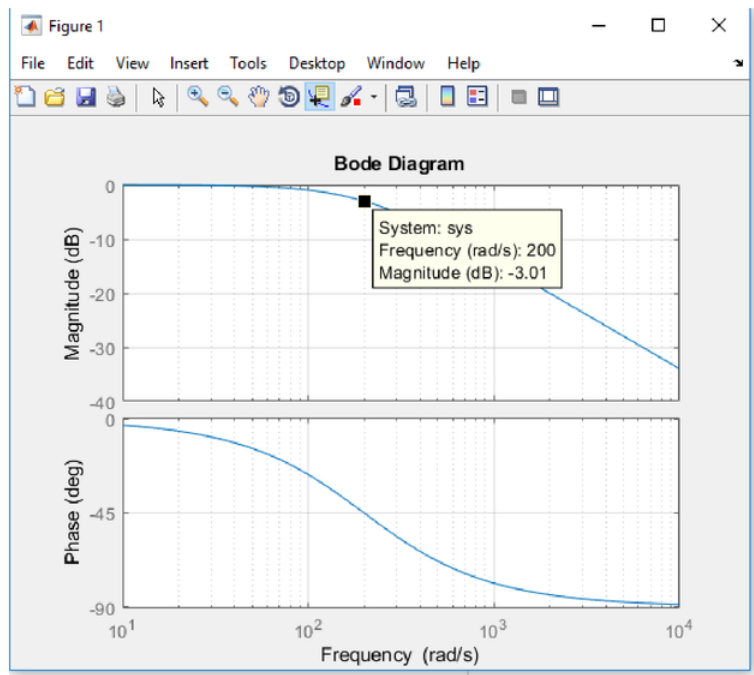


Figure 5

Above in figure 5 is the graph showing the -3dB point at the circuit which shows the cut off frequency. The simulated cut off frequency matches the calculated cut off frequency being 200rad/s.

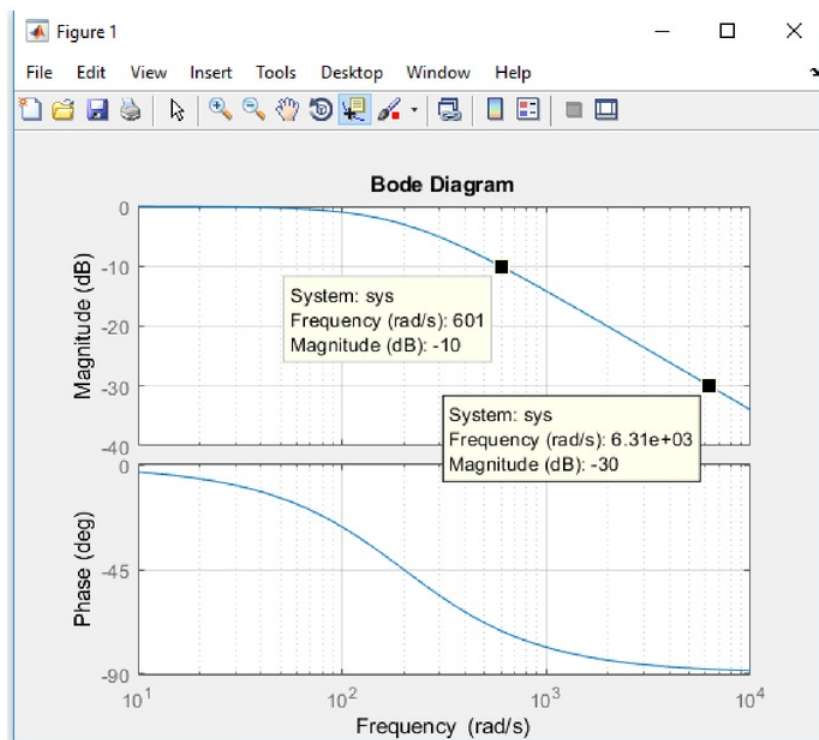


Figure 6

Figure 6 above show that the circuit drops by 20dB's per decade as a first order circuit should.

Task 1 b)

High pass filter

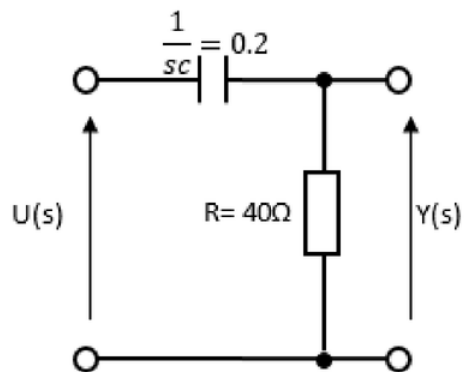


Figure 7

Figure 7 above shows the laplace model of the first order high pass filter.

Deriving the transfer function:

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

Multiply top and bottom by sC

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

For a step input $u(s) = \frac{1}{s}$

Therefore:

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

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

Divide top and bottom by RC :

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

Let $a = \frac{1}{RC}$

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

From the table of transforms:

$$\mathcal{L}^{-1}\{YCS\} = \mathcal{L}^{-1}\left\{\frac{1}{s + a}\right\}$$

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

$$Y(t) = e^{-t/RC}$$

(exponential decay where $RC = \tau$ (time constant))

Transfer function:

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

Therefore:

$$H(s) = \frac{\tau s}{\tau s + 1} \text{ where } \tau s = RC = 8$$

Cut off frequency:

$$WC = \frac{1}{RC} = \frac{1}{(40 \times 0.2)} = 0.125$$

Time constant = $RC = 8s$

Matlab simulation

Step input transient response:

Figure 8 below shows the values for the step response graph entered into matlab.

```
%High pass filter - step response
num=[1];
dem=[8 1];
step(num,dem);
xlabel('time');
ylabel('output voltage, V');
grid
```

Figure 8

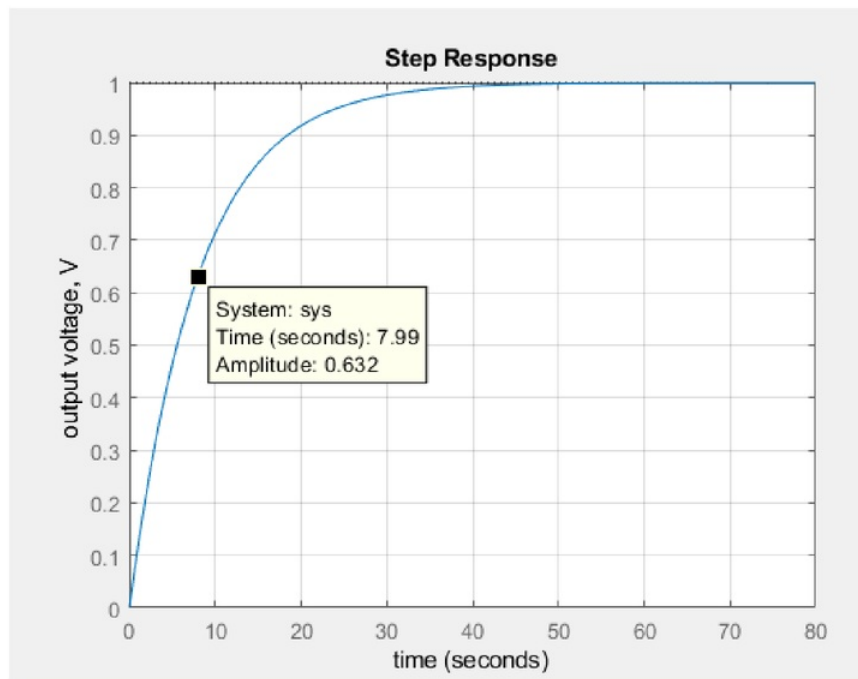


Figure 9

In the above figure 9 is the step response of the high pass filter.

Frequency response:

```
high_pass_taskB.m  ✕  +  
%low pass  
- num=[1 0];  
- dem=[1 0.125];  
- bode(num,dem);  
- grid
```

Figure 10

Figure 10 shows the values entered into matlab.

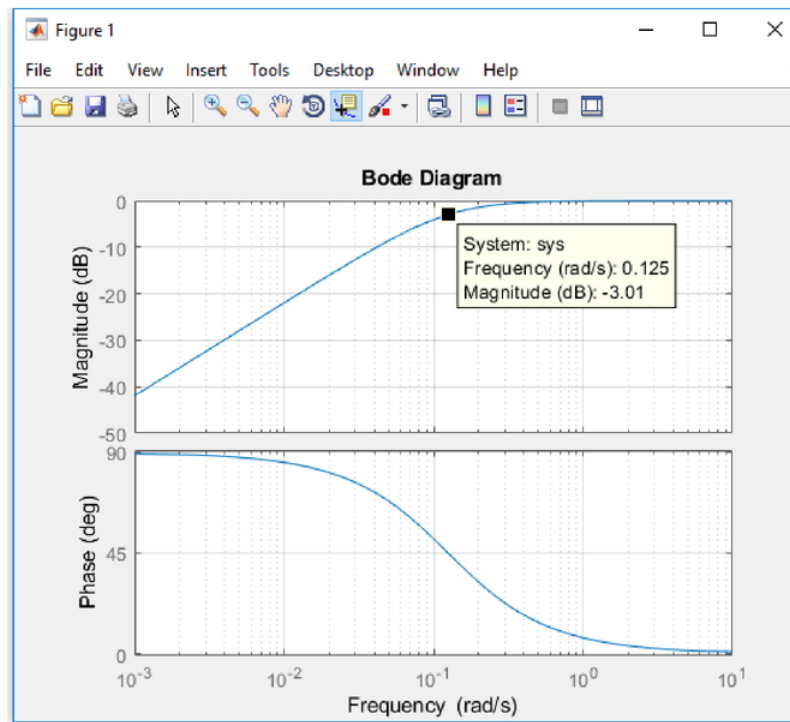


Figure 11

Figure 11 shows the cut off frequency being 0.125rad/s at the -3db value, this matches the theory calculated above.

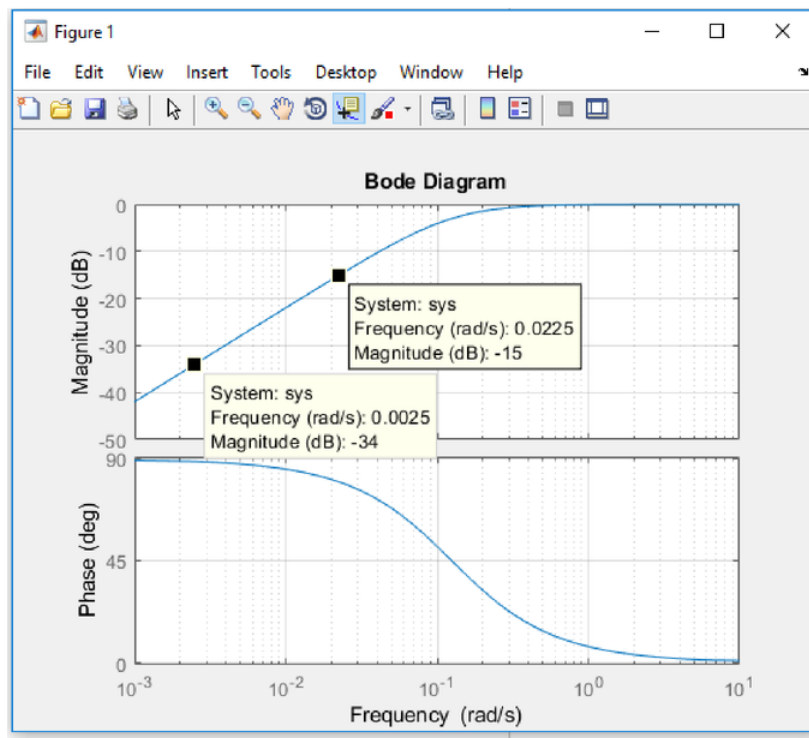


Figure 12

Figure 12 above shows the 20dB drop per decade in this circuit as it's a first order circuit.

3. ANALYSIS OF SECOND ORDER ELECTRIC CIRCUITS

Task 2A)

Second order low pass filter

Laplace Model (SEE FIGURE 13):

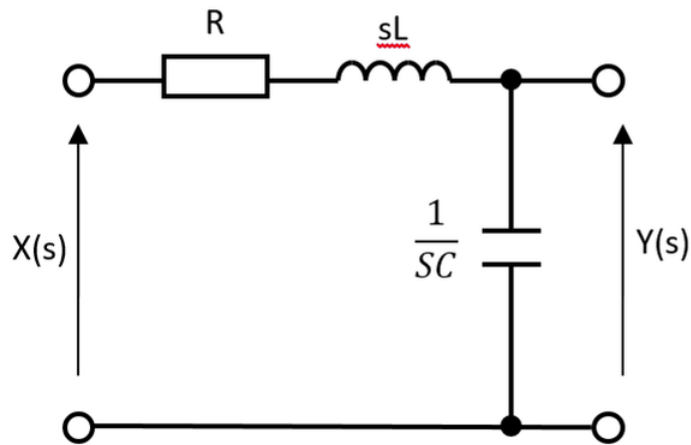


Figure 13

Deriving transfer function:

Using potential divider rule –
$$Y(s) = \frac{1/sC}{R + sL + 1/sC} X(s)$$

Multiplying top and bottom by S/L –

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

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

The above is a second order transfer function as for the S^2 .

Natural frequency equation: $\omega_n = \frac{1}{\sqrt{LC}}$

Damping factor equation: $\zeta = \left(\frac{R}{2}\right)\left(\sqrt{\frac{C}{L}}\right)$

For frequency analysis $S = j\omega$

$$H(j\omega) = \frac{1/LC}{(j\omega)^2 + (R/L)(j\omega) + 1/LC}$$

$$H(j\omega) = \frac{1/LC}{(-\omega)^2 + (j)(R/L)(\omega) + 1/LC}$$

$$H(j\omega) = \frac{1/LC}{(1/LC - \omega^2) + (j)(R/L)(\omega)}$$

Made easier to analyse by multiplying top and bottom by LC

$$H(j\omega) = \frac{1}{(1 - \omega^2 LC) + (j)(\omega)(R)(C)}$$

$$\| H(j\omega) \| = \frac{1}{\sqrt{(1 - \omega^2 LC)^2 + \omega^2 R^2 C^2}}$$

To find the maximum value of $\| H(j\omega) \|$ in this case, differentiate needs to be set to zero.

Therefore:

$$\| H(j\omega) \|_{max} = \frac{1}{\sqrt{\frac{R^2 C}{L} \left(1 - \frac{R^2 C}{4L}\right)}}$$

$$\text{At a frequency } \omega_m = \sqrt{\frac{1}{LC} - \frac{1}{2} \left(\frac{R}{L}\right)^2}$$

The circuit has a maximum value of >1 due to magnification.

$$\text{Where } Q = \frac{1}{R} \sqrt{\frac{L}{C}}$$

The resonant frequency occurs when $1 - \omega_o^2 LC = 0$

$$\text{Therefore: } \omega_o = \frac{1}{\sqrt{LC}}$$

$$R = 10\Omega \quad L = 0.1H \quad C = 52\mu F \quad R/L = 100 \quad 1/LC = 192\,307.7$$

$$\omega_m = \sqrt{\frac{1}{(0.1)(52 \times 10^{-6})} - \frac{1}{2} \left(\frac{10}{0.1}\right)^2} = 432.8 \text{ rad/s}$$

$$\omega_o = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{(0.1)(52 \times 10^{-6})}} = 438.5 \text{ rad/s}$$

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}} = \frac{1}{10} \sqrt{\frac{0.1}{52 \times 10^{-6}}} = 4.39$$

To find R value for critically damped circuit the equation below was used:

$$R^2 = 4X \frac{L}{C}$$

$$R^2 = 4X \frac{0.1}{52 \times 10^{-6}}$$

$$R^2 = 7692.3$$

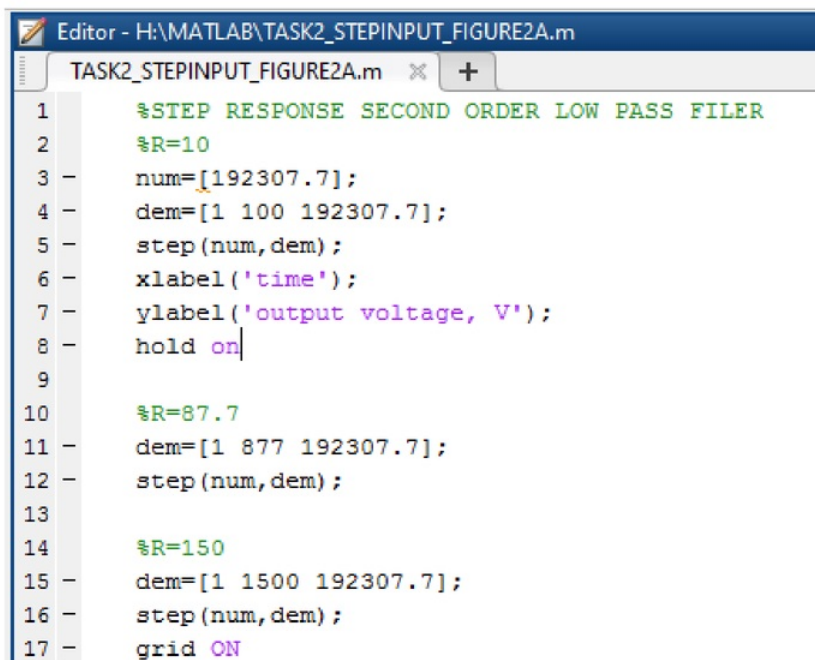
$$R = \sqrt{7692.3}$$

$$R = 87.7\Omega$$

Matlab simulation

Step Response:

Figure 14 and 15 below show the step input for this low pass second order filter. On the graph are 3 plots here the resistance is varied to show underdamped, over damped and critical damping. 10Ω being underdamped/no damping, 87.7Ω being critically damping where the circuit is at its best and 150Ω being overdamped.



```

Editor - H:\MATLAB\TASK2_STEPINPUT_FIGURE2A.m
TASK2_STEPINPUT_FIGURE2A.m  X  +
1  %STEP RESPONSE SECOND ORDER LOW PASS FILER
2  %R=10
3  num=[192307.7];
4  dem=[1 100 192307.7];
5  step(num,dem);
6  xlabel('time');
7  ylabel('output voltage, V');
8  hold on
9
10 %R=87.7
11 dem=[1 877 192307.7];
12 step(num,dem);
13
14 %R=150
15 dem=[1 1500 192307.7];
16 step(num,dem);
17 grid ON
  
```

Figure 14

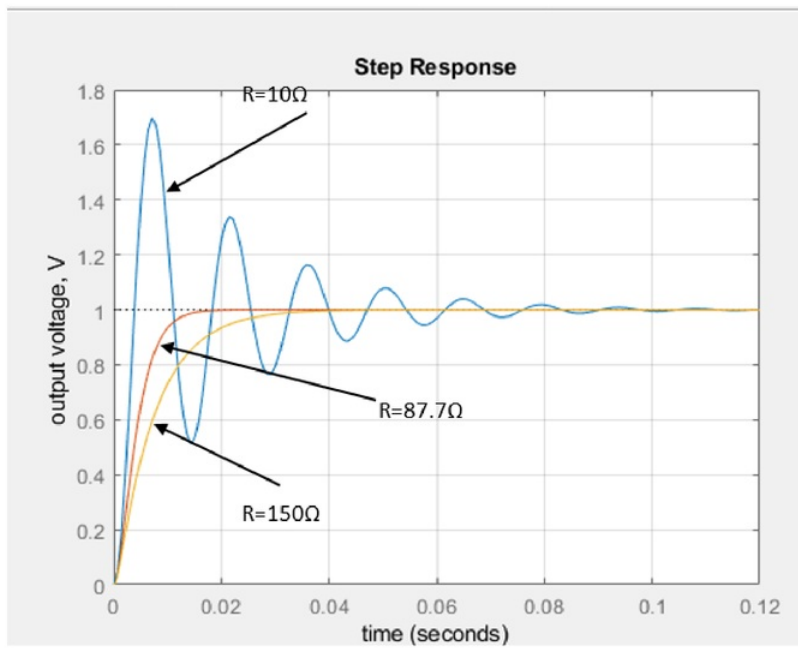


Figure 15

Above in figure 15 is the step response graph for the RLC second order low pass filter. The 10Ω blue line shows that the circuit is underdamped. The calculated critical damping value of 87.7Ω is the orange line, where you can see no distortion in the step response. The 150Ω yellow line shows a overdamped circuit.

```

Editor - H:\MATLAB\TASK2_FREQUENCY_FIGURE2A.m
TASK2_FREQUENCY_FIGURE2A.m  X  +
1  %FREQUENCY RESPONSE LOW PASS SENCOND ORDER FILTER
2  %UNDERDAMPED R=10
3  num=[192307.7];
4  dem=[1 100 192307.7];
5  bode(num,dem);
6  hold on
7
8  %UNDERDAMPED R=1
9  dem=[1 10 192307.7];
10 bode(num,dem);
11
12 %CRITICALLY DAMPED R=87.7
13 dem=[1 877 192307.7];
14 bode(num,dem);
15
16 %OVERDAMPED R=150
17 dem=[1 1500 192307.7];
18 bode(num,dem);
19 grid on

```

Figure 16

Figure 16 shows the values entered into matlab to produce a bode diagram, using differnet damping values. Below in figure 17 is the bode diagram, this shows the 87.7Ω circuit being the critically damped circuit as for its smooth curve.

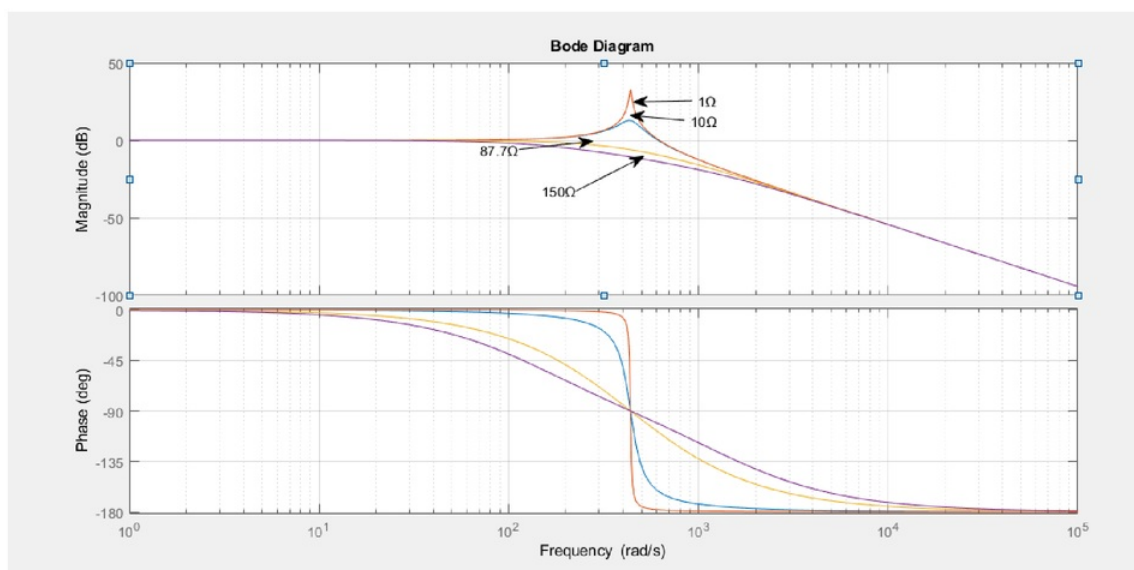


Figure 17

Task 2B)

Second order parallel resonant filter

Laplace model:

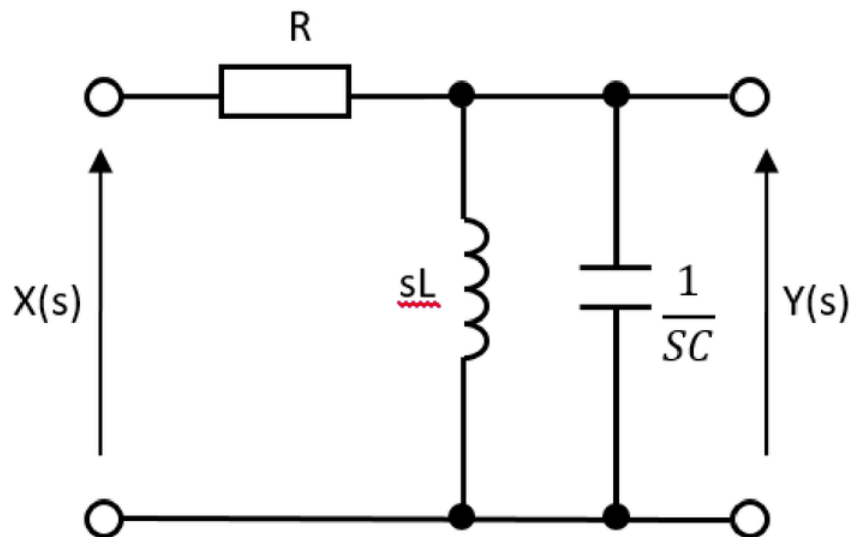


Figure 18

Figure 16 show the laplace model of a second order parallel resonant filter.

Deriving the transfer function:

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

$Z_p(s)$ is the parallel impedance of sL and $1/sC$.

$$Z_p(s) = \frac{sL \times 1/sC}{(sL) \times (1/sC)}$$

$$= \frac{sL}{S^2LC + 1}$$

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

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

Divide top and bottom by RLC

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

The S^2 means that this is a second order transfer function.

The above equation can be compared with the standard second order equation.

Standard equation:

$$S^2 + 2\zeta\omega_n s + \omega_n^2$$

ω_n = natural frequency of oscillation

From the above:

$$\omega_n^2 = \frac{1}{LC} \quad \omega_n = \frac{1}{\sqrt{LC}} \quad 2\zeta\omega_n = \frac{1}{RC}$$

$$\zeta = \frac{1}{2\omega_n RC} = \frac{\sqrt{LC}}{2RC} = \frac{1}{2R} \sqrt{\frac{L}{C}}$$

NOTE:

$\zeta < 1$ = Underdamped

$\zeta > 1$ = Overdamped

$\zeta = 1$ = critically damped

$\zeta = 0$ = no damping

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

Where,

$$R = 10\Omega \quad L = 0.1H \quad C = 52\mu F$$

$$\text{Natural frequency} = \omega_n^2 = \frac{1}{LC} \quad \omega_n = \frac{1}{\sqrt{LC}} \quad \omega_n = \frac{1}{\sqrt{(0.1)(52 \times 10^{-6})}} = 438.5 \text{ rad/s}$$

$$\frac{1}{LC} = \frac{1}{(0.1)(52 \times 10^{-6})} = 192307.7$$

$$\text{Damping} = \frac{1}{2R} \sqrt{\frac{L}{C}} = \frac{1}{2(10)} \sqrt{\frac{0.1}{52 \times 10^{-6}}} = 2.19 (\text{overdamped})$$

$$\frac{1}{RC} = 1923$$

$$\text{Critical damping: } R = \sqrt{\frac{L}{C}} = \sqrt{\frac{0.1}{52 \times 10^{-6}}} = 21.926\Omega$$

$$\frac{1}{RC} = 877.07$$

$$H(s) = \frac{s \times 1/RC}{s^2 + 1/RC \times s + 1/LC} = \frac{s \times 1923}{s^2 + 1923s + 192307.7}$$

```

Editor: F:\MATLAB\TASK2_STEPINPUT_FIGURE2b.m
TASK2_STEPINPUT_FIGURE2b.m  X  +
1  %STEP RESPONSE SECOND ORDER PARALLEL RESONANT FILTER
2  %OVERDAMPED R=10
3  num=[1923];
4  den=[1 1923 192307.7];
5  step(num,den);
6  xlabel('time');
7  ylabel('output voltage, V');
8  hold on
9
10 %CRITICAL DAMPING R=21.926
11 den=[1 877.07 192307.7];
12 step(num,den);
13
14
15 %UNDERDAMPING R=50
16 den=[1 384.6 192307.7];
17 step(num,den);
18 grid ON

```

Figure 19

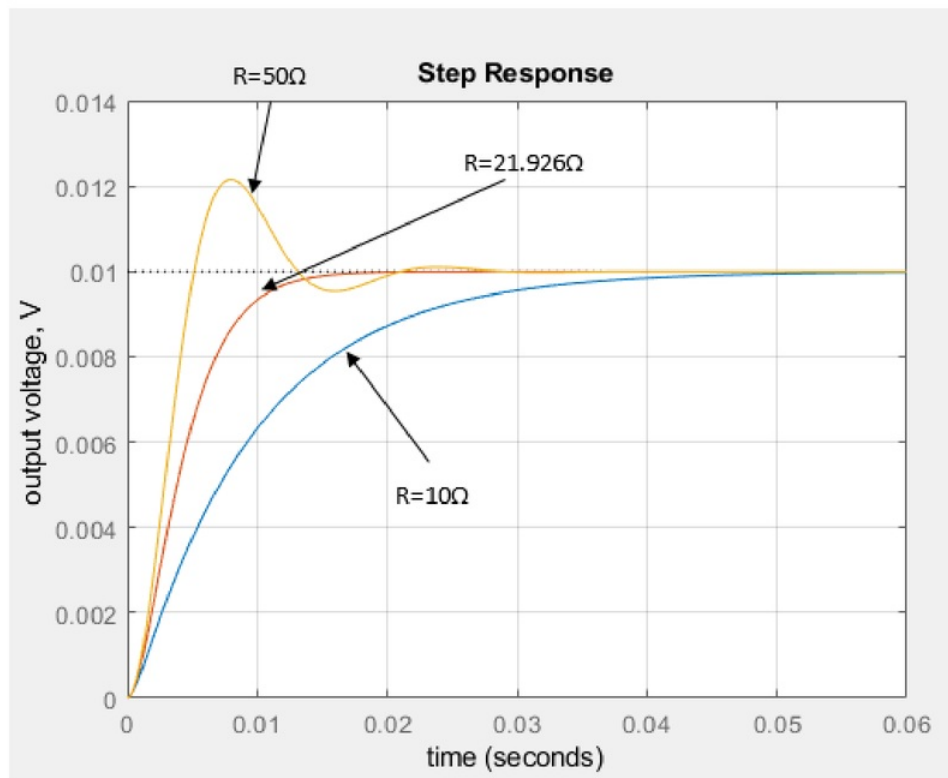
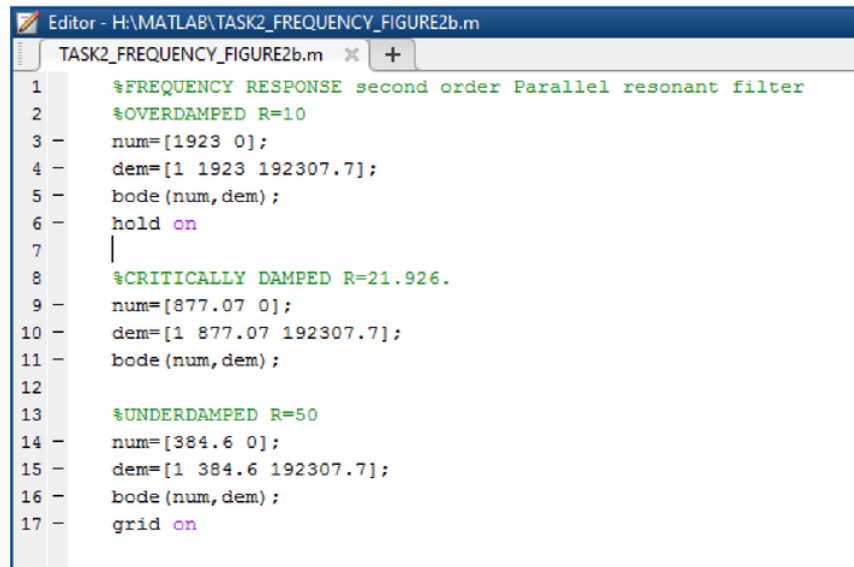


Figure 20

Above in figure 19 and 20 is the step response for the parallel resonant filter. The response backs the theory of the 21.92 ohm being the critically damped circuit as for its smooth step response. Also from the step response the underdamped 50ohms circuit is proven as for its hardly no damping through the step response but eventually smoothing off. The 10ohms circuit proves that the theory is right in saying that its overdamped as for its curved step response. This also proves the theory to damp a resonant parallel filter decrease the resistance. Whereas the opposite works to increase damping in a second order low pass filter, therefor you must increase the resistance to increase the damping.



```

1  %FREQUENCY RESPONSE second order Parallel resonant filter
2  %OVERDAMPED R=10
3  num=[1923 0];
4  dem=[1 1923 192307.7];
5  bode(num,dem);
6  hold on
7  |
8  %CRITICALLY DAMPED R=21.926.
9  num=[877.07 0];
10 dem=[1 877.07 192307.7];
11 bode(num,dem);
12
13 %UNDERDAMPED R=50
14 num=[384.6 0];
15 dem=[1 384.6 192307.7];
16 bode(num,dem);
17 grid on

```

Figure 21

Figure 21 and 22 show the bode diagram for the parallel resonant filter. This diagram consists of 3 different circuits, where the damping factor is varied changing the resistance value. From figure 22 the underdamped 50ohm circuit is very sharp which shows that its under damped, whereas the critically damped 21.926 ohm circuit has a smooth line. The overdamped circuit can be seen as it's a curved line. Figure 22 backs the theory of as you decrease the resistance the damping increases for this parallel resonant circuit.

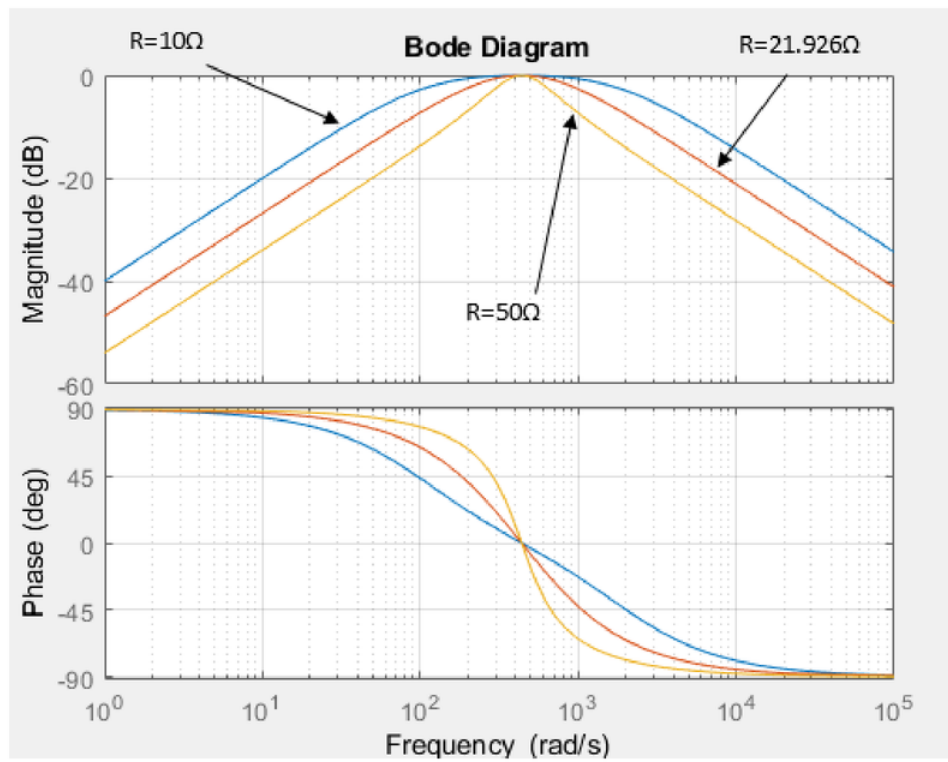


Figure 22

4. ANALYSIS OF FIRST ORDER ELECTRONIC SYSTEMS

High pass filter system task 3A

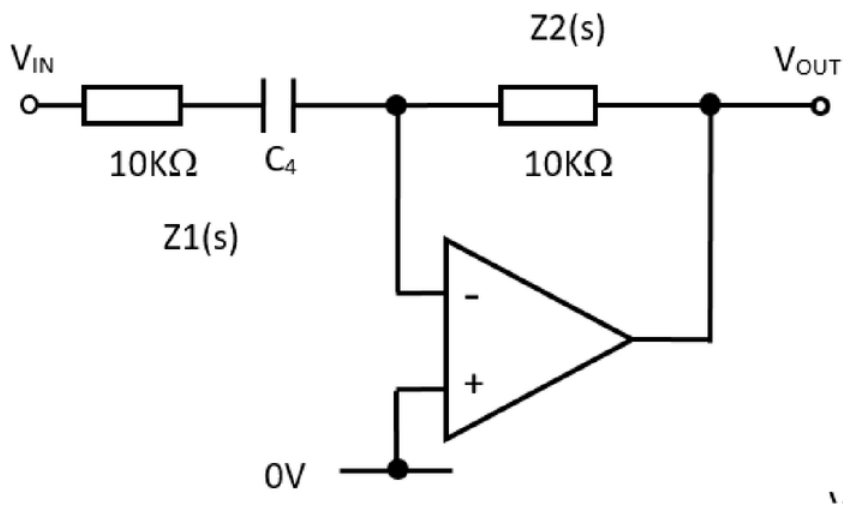


Figure 23

$$H(s) = -K \left(\frac{s}{s + WC} \right)$$

$$\text{Gain: } k = \frac{R2}{R1}$$

$$WC = 1/CR$$

Similar to the previous high pass filter with a negative gain. For a high pass filter at WC phase angle = 45° . However due to the phase shift of 180° $wc = 45 + 180 = 225^\circ$.

Where,

$$C = 50\text{nF} \quad R = 10\text{k}\Omega$$

$$K = \frac{10\text{k}}{10\text{k}} = 1$$

$$WC = \frac{1}{50 \times 10^{-9} \times 10,000} = 2000\text{rad/s}$$

$$H(s) = -1 \left(\frac{s}{s + 2000} \right)$$

In matlab

Num = [-1 0];

Den = [1 2000];

Bode (num,den);

Grid

In dB's 1 is:

$$20\log(1) = 0$$

Therefore cut-off = magnitude = -3dB.

```
TASK3_FREQUENCY_FIGURE3a.m  x  +  
  
%task 3 - High pass filter  
- num=[-1 0];  
- den=[1 2000];  
- bode(num,den);  
- grid
```

Figure 24

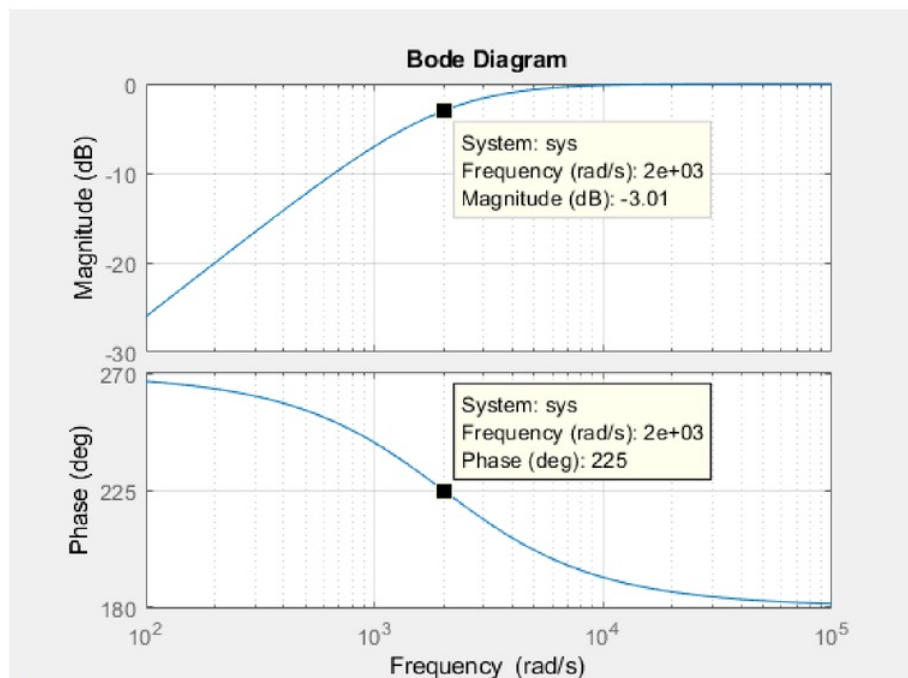


Figure 25

Figure 23 and 24 show the bode diagram for high pass filter system. The frequency at the cut off of -3dB is 2000 rad/s as calculated. Also the diagram shows the phase shift has occurred as predicted and is 225 degrees at 2000raad/s.

Low pass filter system task 3B

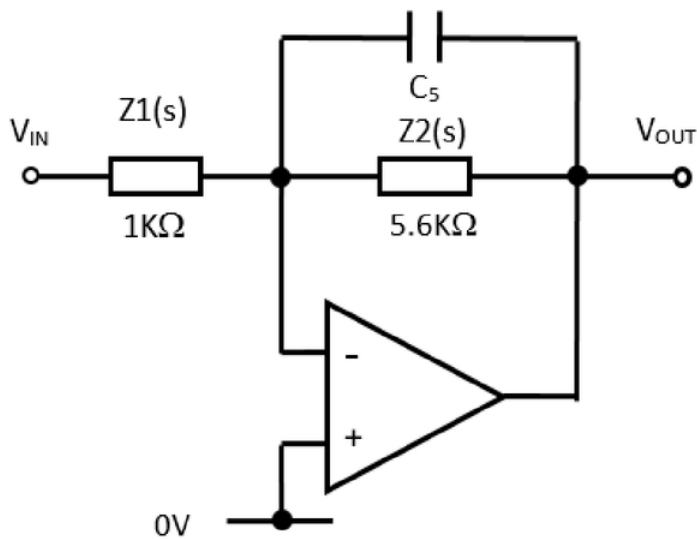


Figure 26

$$H(s) = -K \left(\frac{S}{S + WC} \right)$$

Gain: $k = \frac{R2}{R1}$

$WC = \frac{1}{CR}$

The negative sign shows that its an inverting amplifier which gives a 180° phase shift. Which changes the cut off angle to $-45 + 180 = 135^\circ$

Where,

$R1 = 1k\Omega \quad R2 = 5.6k\Omega \quad C = 500nF$

$WC = \frac{1}{CR} = \frac{1}{500 \times 10^{-9} \times 5600} = 357.14$

Gain: $k = \frac{R2}{R1} = \frac{5.6k}{1k} = 5.6 \text{ gain}$

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

In matlab:

Num = [-5.6 x 357.14]

Den = [1 357.14]

Bode = (Num,Den)

Grid

In dB's 5=

$20\log(5) = 14.96$

Cut off at = 11.96

```
TASK3_FREQUENCY_FIGURE3b.m x +
%task 3 - Low pass filter
num=[-5.6*357.14];
den=[1 357.14];
bode(num,den);
grid
```

Figure 27

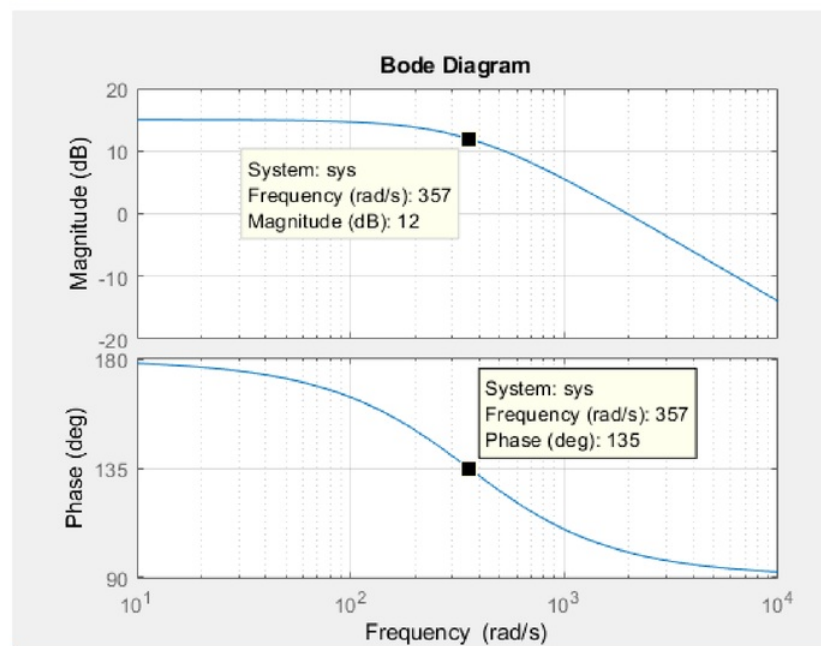


Figure 28

Figure 27 and 28 consists of the bode diagram for the low pass filter system. From the diagram at 12dB's the frequency is a 357rad/s, this corresponds to the predicted value in theory. Another theory backing factor is the phase angle at cut off frequency. As there is a negative gain there is a phase shift of 180degrees which results in the cut off frequency phase angle being 135degrees as predicted.

5. ANALYSIS OF SECOND ORDER ELECTRONIC SYSTEMS

Sallen & Key Low Pass Filter

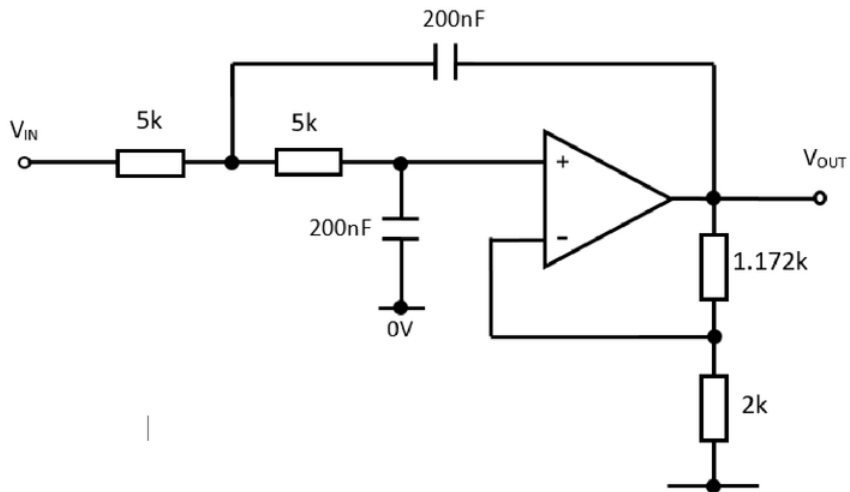


Figure 29

$$\omega_c = 1000$$

$$\text{Let } C = 200\text{nF}$$

$$R = \frac{1}{1000 \times 200 \times 10^{-9}} = 5\text{k}\Omega$$

$$\text{Butterworth } k = 1.586$$

$$\text{If } R_b = 2\text{k}\Omega, R_a = (k - 1) \times R_b$$

$$= (1.586 - 1) \times 2$$

$$= 1.172\text{k}\Omega$$

$$\text{In dB's } 1.586 = 4\text{dB}$$

$$WC = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

$$WC = \frac{1}{\sqrt{(5000)(5000)(200 \times 10^{-9})(200 \times 10^{-9})}}$$

$$WC = 1000$$

$$\frac{WC}{Q} = \frac{3 - K}{RC}$$

$$= \frac{3 - 1.586}{(5000 \times 200 \times 10^{-9})}$$

$$1414$$

$$H(s) = \frac{1.586 \times 1000^2}{s^2 + 1414s + 1000^2}$$

$$H(s) = \frac{1586000}{s^2 + 1414s + 1000000}$$

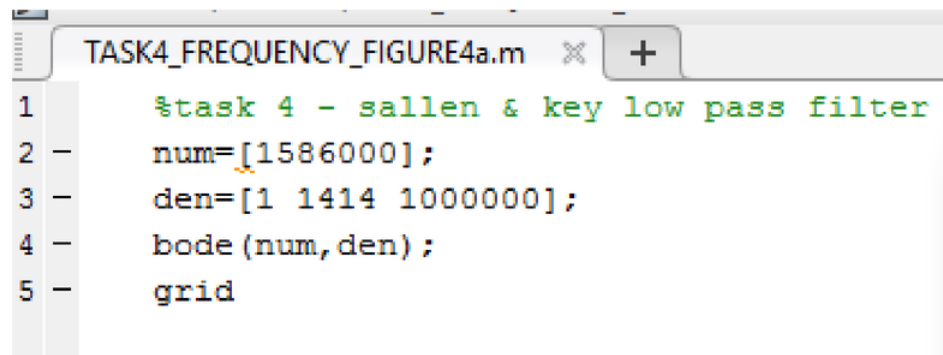
In matlab:

NUM [1586 000];

DEN [1 1414 1000 000];

Bode (NUM,DEN);

grid.



```

1      %task 4 - sallen & key low pass filter
2      num=[1586000];
3      den=[1 1414 1000000];
4      bode(num,den);
5      grid

```

Figure 30

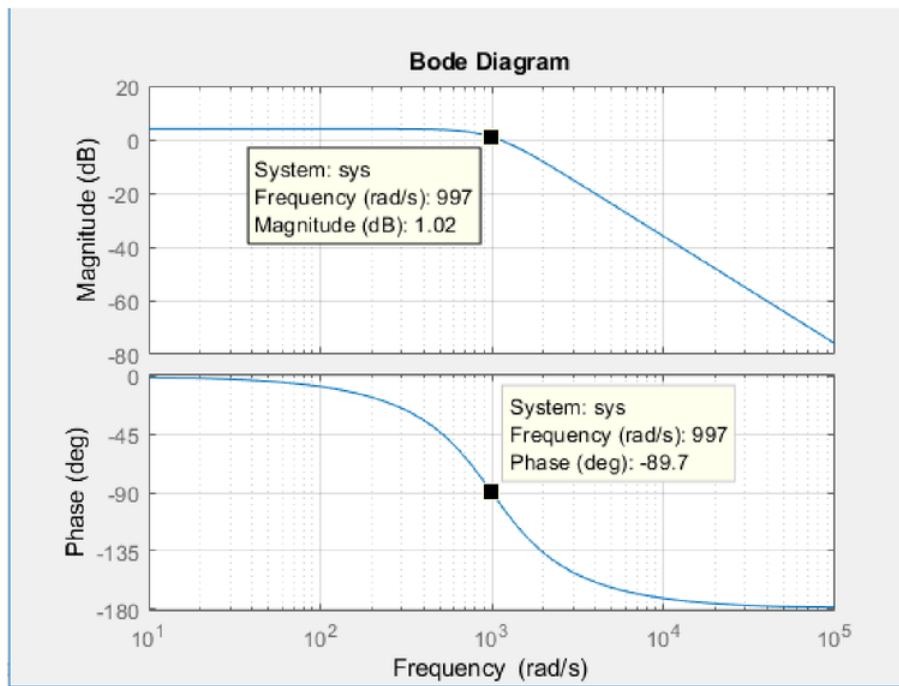


Figure 31

Figure 30 and 31 shows the bode diagram for a sallén and key low pass filter. From the theory the predicted cut off frequency is 1000 rad/s which corresponds to the bode diagram above in figure 31.

This is a second order system therefore it drops by 40 dB 's per decade as can be seen using figure 31.

Sallen & Key High Pass Filter

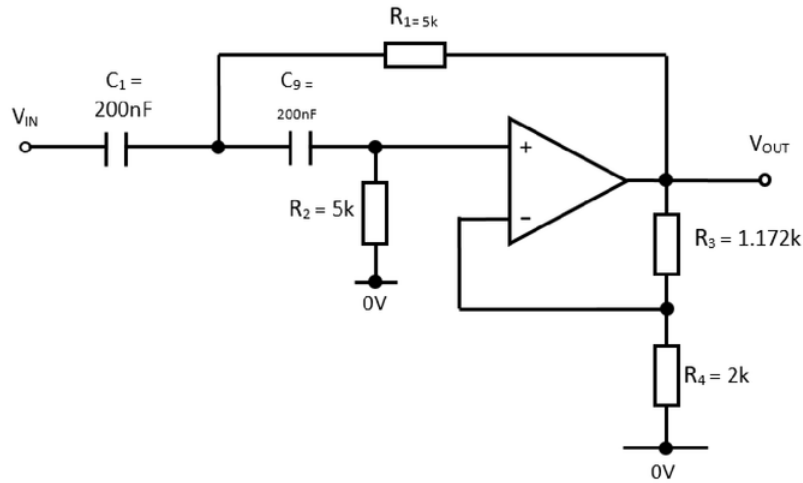


Figure 32

Using the same values as the low pass.

Where,

$R = 5k$

$C = 200nF$

$WC = 1000$

$K = 1.586$

$WC/Q = 1414$

$$H(s) = \frac{1.586 S^2}{S^2 + 1414 S + 1000\,000}$$

In matlab:

```
Num [1.586 0 0];
```

```
Den [1 1414 1000 000];
```

```
Bode (Num,Den);
```

```
Grid.
```

```
TASK4_FREQUENCY_FIGURE4b.m x +
1 %task 4 - sallan & key High pass filter
2 - num=[1.586 0 0];
3 - den=[1 1414 1000000];
4 - bode(num,den);
5 - grid
```

Figure 33

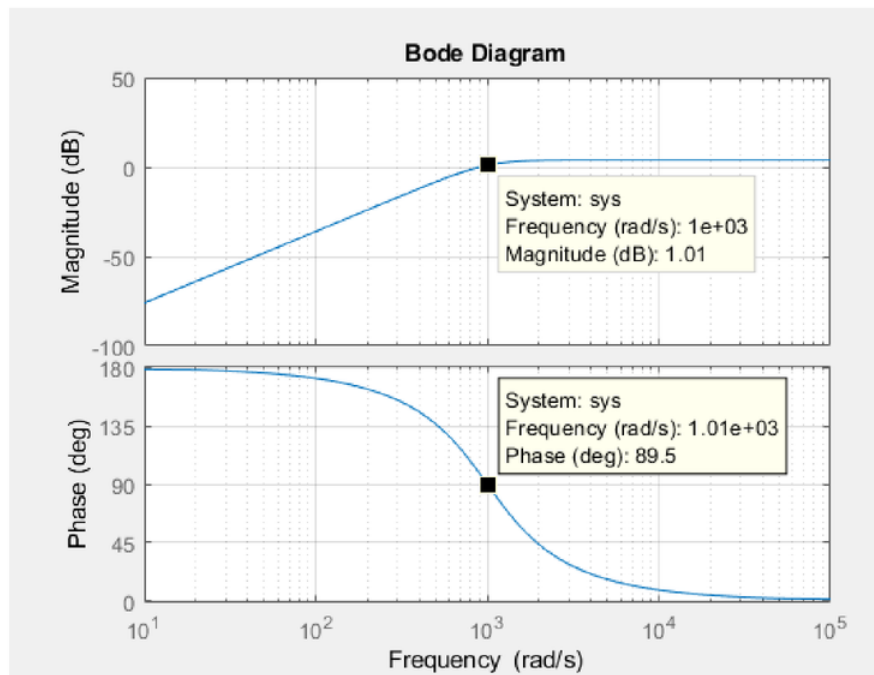


Figure 34

Figure 33 and 34 consists of the sallan and key high pass filter bode diagram. The cut off frequency is the same as the low pass filter at 100rad/s as can be also seen in the calculations. Where the phase angle is negative 89.5 in this high pass filter where it was positive for the low pass filter. This circuit will also drop by 40dB/s per decade as it's a second order system.

6. CONCLUSION AND RECOMMENDATIONS

In conclusion throughout all tasks the predicted theory and calculation do match the results using the matlab software.

And improvement would to have further damping factors and circuits to prove the theory further using the step diagrams and bode diagrams. No further recommendations can be seen at the time as all tasks and theory was proven using matlab.

assignment 1

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

58/100

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GRADING FORM: CSG-RUBIC

TRYSTAN DANIELS

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RESEARCH-INFORMED LITERATURE



N/A

KNOWLEDGE AND UNDERSTANDING



Sections 2, 3: Explanations for Electric Circuits –
Good explanations with clear diagrams. Further

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marks were available for greater accuracy in some of your equations. (6/10) Sections 4, 5: Explanations for Electronic Systems – Generally good with diagrams and some equations although further explanations could have been given for task 4. (6/10)

ANALYSIS



Sections 2, 3: Analysis, Modelling and Testing of Electric Circuits - Good evidence of analysis. However, not all aspects have been considered and measured and further analysis was possible. (12/20) Sections 4, 5: Analysis, Modelling and Testing of Electronic Systems - Good but roll-off could have been measured and comparisons made between the types of filter by their order. (13/20) Section 6: Conclusions and recommendations – Briefly stated but you could have summarized what you had learnt . (3/10)

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PRACTICAL APPLICATION AND DEP.



Sections 2,3,4,5: Use of Matlab – Good. Further marks were available for greater accuracy. (6/10) Sections 2,3,4,5: Accuracy and Presentation Quality of Results – Mostly good, well presented and accurate but there are some errors not noticed. (6/10)

12

SKILLS FOR PROFESSIONAL PRAC.



Section 1: Introduction: Briefly stated (3/5) All sections: Overall Report Quality - Good, well structured (3/5)

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