

# 2223685

*by* Drew GroveHenderson

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## Table of Contents

|                                                                                         |    |
|-----------------------------------------------------------------------------------------|----|
| Introduction .....                                                                      | 9  |
| Task 1. Transient Analysis of a First Order RL Electrical Circuit.....                  | 10 |
| 1.1 .....                                                                               | 10 |
| 1.2 .....                                                                               | 10 |
| 1.3 .....                                                                               | 10 |
| 1.4 .....                                                                               | 11 |
| 1.5 .....                                                                               | 11 |
| Task 2. Transient Analysis of a First Order RC Electrical Circuit .....                 | 12 |
| 2.1 .....                                                                               | 12 |
| 2.2 .....                                                                               | 12 |
| 2.3 .....                                                                               | 12 |
| 2.4 .....                                                                               | 13 |
| 2.5 .....                                                                               | 13 |
| Task 3. Frequency Performance Analysis of a First Order RL Electrical Circuit.....      | 14 |
| 3.1 .....                                                                               | 14 |
| 3.2 .....                                                                               | 14 |
| 3.3 .....                                                                               | 14 |
| 3.4 .....                                                                               | 15 |
| Task 4. Frequency Performance Analysis of a First Order RC Electrical Circuit.....      | 16 |
| 4.1 .....                                                                               | 16 |
| 4.2 .....                                                                               | 16 |
| 4.3 .....                                                                               | 16 |
| 4.4 .....                                                                               | 17 |
| Task 5. Transient Performance Analysis of a Second Order Series Electrical Circuit..... | 18 |
| 5.1 .....                                                                               | 18 |
| 5.2 .....                                                                               | 18 |
| 5.3 .....                                                                               | 18 |
| 5.4 .....                                                                               | 19 |

|                                                                                            |    |
|--------------------------------------------------------------------------------------------|----|
| 5.5 .....                                                                                  | 20 |
| 5.6 .....                                                                                  | 20 |
| 5.7 .....                                                                                  | 22 |
| Task 6. Transient Performance Analysis of a Second Order Parallel Electrical Circuit. .... | 23 |
| 6.1 .....                                                                                  | 23 |
| 6.2 .....                                                                                  | 23 |
| 6.3 .....                                                                                  | 23 |
| 6.4 .....                                                                                  | 24 |
| 6.5 .....                                                                                  | 25 |
| 6.6 .....                                                                                  | 25 |
| 6.7 .....                                                                                  | 27 |
| Task 7. Frequency Performance Analysis of a Second Order Series Electrical Circuit. ....   | 28 |
| 7.1 .....                                                                                  | 28 |
| 7.2 .....                                                                                  | 29 |
| 7.3 .....                                                                                  | 30 |
| 7.4 .....                                                                                  | 30 |
| 7.5 .....                                                                                  | 31 |
| Task 8. Frequency Performance Analysis of a Second Order Parallel Electrical Circuit. .... | 32 |
| 8.1 .....                                                                                  | 32 |
| 8.2 .....                                                                                  | 34 |
| 8.3 .....                                                                                  | 34 |
| 8.4 .....                                                                                  | 35 |
| 8.5 .....                                                                                  | 37 |
| Task 9. Frequency Performance Analysis of a First Order Electronic System. ....            | 38 |
| 9.1 .....                                                                                  | 38 |
| 9.2 .....                                                                                  | 39 |
| 9.3 .....                                                                                  | 39 |
| Task 10. Frequency Performance Analysis of a First Order Electronic System. ....           | 40 |
| 10.1 .....                                                                                 | 40 |

|                                                                                  |    |
|----------------------------------------------------------------------------------|----|
| 10.2 .....                                                                       | 40 |
| 10.3 .....                                                                       | 41 |
| Task 11. Frequency Performance Analysis of a Sallen & Key 2nd Order Filter. .... | 42 |
| 11.1 .....                                                                       | 42 |
| 11.2 .....                                                                       | 42 |
| 11.3 .....                                                                       | 43 |
| Task 12. First Order Control System Analysis .....                               | 44 |
| 12.1 .....                                                                       | 44 |
| 12.2 .....                                                                       | 45 |
| 12.3 .....                                                                       | 45 |
| 12.4 .....                                                                       | 46 |
| 12.5 .....                                                                       | 48 |
| 12.6 .....                                                                       | 48 |
| Task 13. DC Motor Model Analysis .....                                           | 49 |
| 13.1 .....                                                                       | 49 |
| 13.2 .....                                                                       | 49 |
| 13.3 .....                                                                       | 50 |
| 13.4 .....                                                                       | 52 |
| 13.5 .....                                                                       | 53 |
| 13.6 .....                                                                       | 54 |
| 13.7 .....                                                                       | 54 |
| 13.8 .....                                                                       | 54 |
| Task 14. Proportional Speed Control System.....                                  | 55 |
| 14.1 .....                                                                       | 55 |
| 14.2 .....                                                                       | 55 |
| 14.3 .....                                                                       | 58 |
| 14.4 .....                                                                       | 58 |
| 14.5 .....                                                                       | 58 |
| Task 15. Proportional-Integral Speed Control System.....                         | 59 |

|                                                                      |    |
|----------------------------------------------------------------------|----|
| 15.1 .....                                                           | 59 |
| 15.2 .....                                                           | 60 |
| 15.3 .....                                                           | 62 |
| Task 16. Proportional-Integral-Derivative Speed Control System ..... | 63 |
| 16.1 .....                                                           | 63 |
| 16.2 .....                                                           | 64 |
| 16.3 .....                                                           | 66 |
| Task 17. Controller Comparisons .....                                | 67 |
| 17.1 .....                                                           | 67 |
| 17.2 .....                                                           | 68 |
| Task 18. Overall Conclusions and Recommendations. ....               | 70 |
| 19. Appendix .....                                                   | 72 |
| Figure 1 - RL Circuit .....                                          | 10 |
| Figure 2 - Laplace transform RL Circuit.....                         | 10 |
| Figure 3 - Task 1 Matlab code.....                                   | 10 |
| Figure 4 - RL Circuit Step Response.....                             | 11 |
| Figure 5 -- Task 1 Error Table.....                                  | 11 |
| Figure 6 - RC Circuit. ....                                          | 12 |
| Figure 7 - Laplace transform RC Circuit. ....                        | 12 |
| Figure 8 - Task 2 Matlab code.....                                   | 12 |
| Figure 9 - RC Circuit Step Response. ....                            | 13 |
| Figure 10 - Task 2 Error Table. ....                                 | 13 |
| Figure 11 - Task 3 Matlab code.....                                  | 14 |
| Figure 12 - RL Circuit Bode Diagram. ....                            | 14 |
| Figure 13 - Task 3 Error Table .....                                 | 14 |
| Figure 14 - Task 4 Matlab code.....                                  | 16 |
| Figure 15 - RC Circuit Bode Diagram.....                             | 16 |
| Figure 16 - Task 5 Error Table. ....                                 | 16 |
| Figure 17 - Task 5 Multi-sim Circuit. ....                           | 18 |
| Figure 18 – Task 5 Under damping Matlab code.....                    | 19 |
| Figure 19 – Task 5 Over damping Matlab code.....                     | 19 |
| Figure 20 – Task 5 Critical damping Matlab code.....                 | 19 |

|                                                        |    |
|--------------------------------------------------------|----|
| Figure 21 -Task 5 No damping Matlab code.....          | 19 |
| Figure 22 - Task 5 Error Table. ....                   | 20 |
| Figure 23 - Task 5 Under damping Step Response.....    | 20 |
| Figure 24 - Task 5 Over damping Step Response.....     | 21 |
| Figure 25 - Task 5 Critical damping Step Response..... | 21 |
| Figure 26 - Task 5 No damping Step Response.....       | 22 |
| Figure 27 - Task 6 Multi-sim Circuit.....              | 23 |
| Figure 28 - Task 6 Over damping Matlab code.....       | 24 |
| Figure 29 - Task 6 Under damping Matlab code.....      | 24 |
| Figure 30 - Task 6 Critical damping Matlab code. ....  | 25 |
| Figure 31 - Task 6 No damping Matlab code.....         | 25 |
| Figure 32 - Task 6 Error Table. ....                   | 25 |
| Figure 33 - Task 6 Over damping Step Response.....     | 25 |
| Figure 34 - Task 6 Under damping Step Response.....    | 26 |
| Figure 35 - Task 6 Critical damping Step Response..... | 26 |
| Figure 36 - Task 6 No damping Step Response.....       | 27 |
| Figure 37 - Task 7 Matlab code.....                    | 29 |
| Figure 38 - Task 7 Error Table. ....                   | 30 |
| Figure 39 - Task 7 Bode Diagram. ....                  | 30 |
| Figure 40 - Task 7 - Root locus seperation.....        | 31 |
| Figure 41 - Task 8 Over damping Matlab code.....       | 34 |
| Figure 42 - Task 8 Under damping Matlab code.....      | 34 |
| Figure 43 - Task Critical damping Matlab code. ....    | 34 |
| Figure 44 - Task 8 No damping Matlab code.....         | 34 |
| Figure 45 - Task 8 $\omega_0$ Values. ....             | 34 |
| Figure 46 - Task 8 $\omega_{c1}$ Values.....           | 34 |
| Figure 47 - Task 8 $\omega_{c2}$ Values.....           | 35 |
| Figure 48 - Task 8 Beta Values.....                    | 35 |
| Figure 49 - Task 8 Over damping Bode Diagram. ....     | 35 |
| Figure 50 - Task 8 Under damping Bode Diagram. ....    | 36 |
| Figure 51 - Task 8 Critical damping Bode Diagram. .... | 36 |
| Figure 52 - Task 8 No damping Bode Diagram. ....       | 37 |
| Figure 53 - Task 9 Multi-sim Circuit.....              | 38 |
| Figure 54 - Task 9 Matlab code.....                    | 39 |
| Figure 55 - Task 9 Bode Diagram. ....                  | 39 |
| Figure 56 - Task 9 Error Table. ....                   | 39 |
| Figure 57 - Task 10 Multi-sim Circuit.....             | 40 |

|                                                                          |    |
|--------------------------------------------------------------------------|----|
| Figure 58 - Task 10 Matlab code.....                                     | 40 |
| Figure 59 - Task 10 Bode Diagram. ....                                   | 41 |
| Figure 60 - Task 10 Error Table. ....                                    | 41 |
| Figure 61 - Task 11 Multi-sim Circuit.....                               | 42 |
| Figure 62 - Task 11 Matlab code.....                                     | 42 |
| Figure 63 - Task 11 Bode Diagram. ....                                   | 43 |
| Figure 64 - Task 11 Error Table. ....                                    | 43 |
| Figure 65 - Task 12 Matlab code.....                                     | 44 |
| Figure 66 - Task 12 Pole-Zero Map.....                                   | 44 |
| Figure 67 - Task 12 Open Loop Response.....                              | 45 |
| Figure 68 - Task 12 Closed Loop Response. ....                           | 45 |
| Figure 69 - Task 12 Matlab code.....                                     | 46 |
| Figure 70 - Task 12 Root Locus. ....                                     | 46 |
| Figure 71 - Task 12 Response with a k of 0.02. ....                      | 46 |
| Figure 72 - Task 12 Response with a k of 1. ....                         | 47 |
| Figure 73 - Task 12 Response with a k of 3. ....                         | 47 |
| Figure 74 - Task 12 Root Locus of various gains. ....                    | 48 |
| Figure 75 - Task 12 Error Table. ....                                    | 48 |
| Figure 76 - DC Motor Model.....                                          | 49 |
| Figure 77 - DC Motor Circuit. ....                                       | 49 |
| Figure 78 - Task 13 Matlab code first pole. ....                         | 50 |
| Figure 79 - Task 13 Pole-Zero Map first pole. ....                       | 51 |
| Figure 80 - Task 13 Matlab code second pole.....                         | 51 |
| Figure 81 - Task 13 Pole-Zero Map second pole.....                       | 52 |
| Figure 82 - Task 13 Simulink model.....                                  | 52 |
| Figure 83 - Task 13 Open loop response with no load just friction.....   | 53 |
| Figure 84 - Task 13 Closed loop response with TSTALL added.....          | 53 |
| Figure 85 - Task 13 Closed loop response with a disturbance of 0.03..... | 54 |
| Figure 86 - Task 13 Error Table. ....                                    | 54 |
| Figure 87 - Task 14 Subsystem. ....                                      | 55 |
| Figure 88 - Auto tune feature for optimum value. ....                    | 55 |
| Figure 89 - Second Kp Value. ....                                        | 56 |
| Figure 90 - Second Kp Parameters. ....                                   | 56 |
| Figure 91 - Third Kp Value. ....                                         | 57 |
| Figure 92 - Third Kp Parameters.....                                     | 57 |
| Figure 93 - Task 14 Model Simulation.....                                | 58 |
| Figure 94 - Kp Value Table Measurements.....                             | 58 |

|                                                                  |    |
|------------------------------------------------------------------|----|
| Figure 95 – Auto tune feature with optimum value. ....           | 59 |
| Figure 96 - Auto tuned value. ....                               | 59 |
| Figure 97 - Second PI controller showing Ki value. ....          | 60 |
| Figure 98 - Second PI controller's parameters. ....              | 60 |
| Figure 99 - Third PI controller's parameters. ....               | 61 |
| Figure 100 – Third PI controller showing Ki Value. ....          | 61 |
| Figure 101 - Response of varying Ki. ....                        | 62 |
| Figure 102 – Ki Value Table Measurements. ....                   | 62 |
| Figure 103 - First controller with Kp & Ki values the same. .... | 63 |
| Figure 104 - First controller parameters. ....                   | 63 |
| Figure 105 - Second controller parameters. ....                  | 64 |
| Figure 106 - Second controller with a varied Kd of 0.08. ....    | 64 |
| Figure 107 - Third controller parameters. ....                   | 65 |
| Figure 108 - Third controller with a varied Kd of 0.5. ....      | 65 |
| Figure 109 - Response of the varying Kd. ....                    | 66 |
| Figure 110 - Kd Value Table Measurements. ....                   | 66 |
| Figure 111 - First controller with just a Kp value. ....         | 67 |
| Figure 112 - Second controller with a Kp and a Ki value. ....    | 67 |
| Figure 113 - Third controller with Kp, Ki and Kd value. ....     | 68 |
| Figure 114 - Response of all three types of controller. ....     | 69 |
| Figure 115 - PID K Value Measurements. ....                      | 69 |

## Introduction

In this report there is the creation of electrical, electronic circuits and control systems. The modelling and simulations produce results which must be compared to the results of using advance mathematics techniques. The methods of analysis differ throughout the report depending on the configuration of the circuit.  2 The report gives an understanding of how to predict the performance of each circuit. La Place is used to input the values into the software to produce simulations which are analysed with the predicted calculations, which shows systematic understanding of these circuits.



## Task 1. Transient Analysis of a First Order RL Electrical Circuit

### 1.1

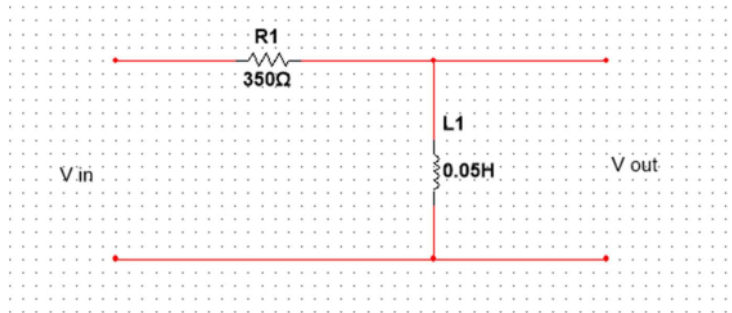


Figure 1 - RL Circuit.

Resistor = 350Ω

Inductor = 0.05H

$$\text{Time constant } \tau = \frac{L}{R} = \frac{0.05}{350} = 0.000143 \text{ sec}$$

### 1.2

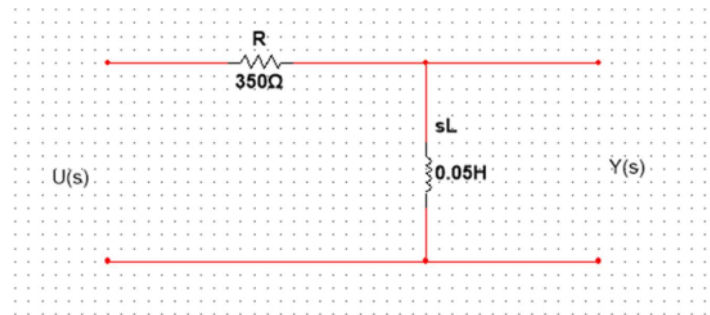


Figure 2 - Laplace transform RL Circuit.

$$H = \frac{sL}{R + sL} = \frac{s0.05}{350 + s0.05}$$

### 1.3

#### Command Window

```
>> s = tf('s');  
>> system = 0.05*s/(0.05*s + 350);  
>> step(system);  
>> grid on
```

Figure 3 - Task 1 Matlab code.

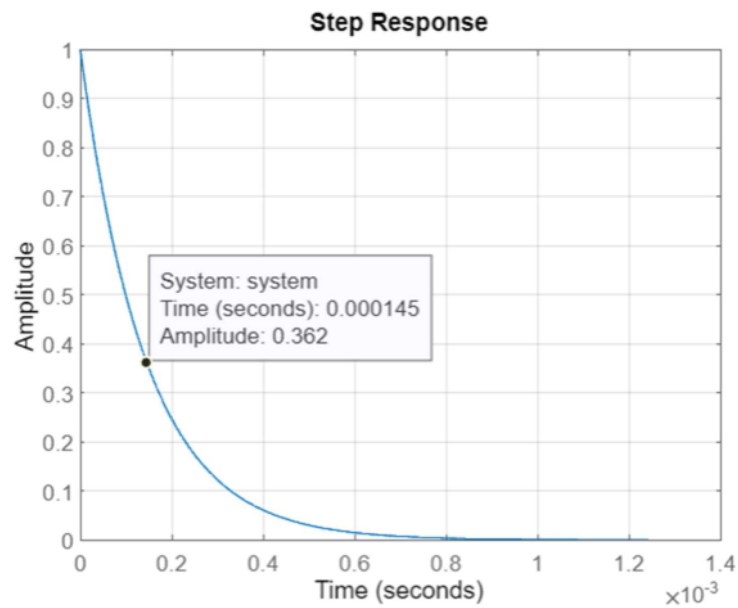


Figure 4 - RL Circuit Step Response

#### 1.4

| Calculated | Simulated | Error    |
|------------|-----------|----------|
| 0.000143   | 0.000145  | 0.000002 |

Figure 5 -- Task 1 Error Table.

#### 1.5

This type of response is an exponential decay, the solution is a 1<sup>st</sup> order  $e^{-t} = 0.368$



Matlab response proves the analysis is correct however the rounding up on both methods has caused an error.

## Task 2. Transient Analysis of a First Order RC Electrical Circuit

### 2.1

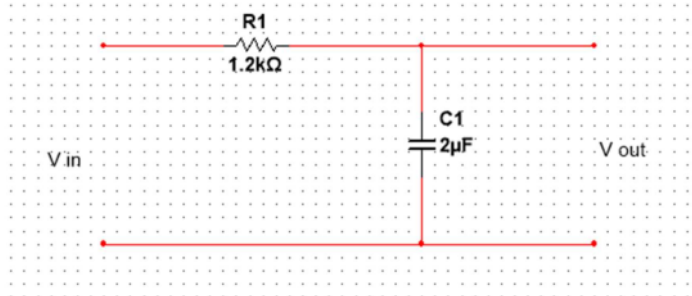


Figure 6 - RC Circuit.

Resistor =  $1.2\text{k}\Omega$

Capacitor =  $2\mu\text{F}$

Time constant  $\tau = R * C = 1200 * (2 * 10^{-6}) = 0.0024 \text{ sec}$

### 2.2

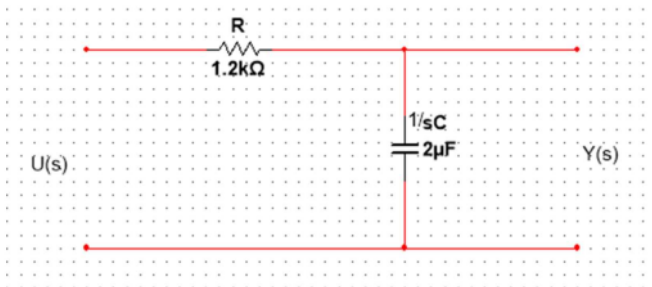


Figure 7 - Laplace transform RC Circuit.

$$H(s) = \frac{1}{\tau s + 1} = \frac{1}{0.0024s + 1}$$

### 2.3

```
>> s = tf('s');  
>> system = 1/(0.0024*s + 1);  
>> step(system);  
>> grid on
```

Figure 8 - Task 2 Matlab code.

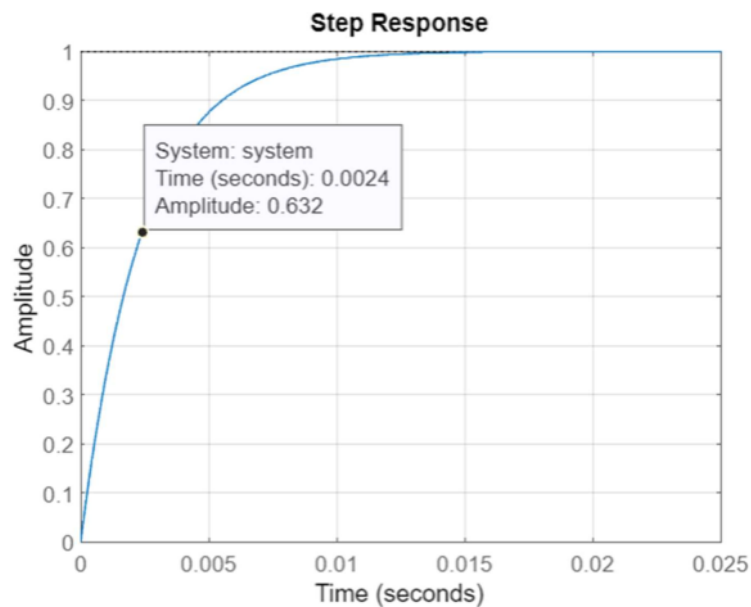


Figure 9 - RC Circuit Step Response.

## 2.4

| Calculated | Simulated | Error |
|------------|-----------|-------|
| 0.0024     | 0.0024    | 0     |

Figure 10 - Task 2 Error Table.

## 2.5

This type of response is an exponential rise, the solution is a 1<sup>st</sup> order ODE is  $e^{-1} = 0.368 - 1 = 0.632$ .  6

Matlab response proves the analysis is correct I have been able to drop the cursor on the graph accurately so both simulated and calculated were exactly the same.  7

### Task 3. Frequency Performance Analysis of a First Order RL Electrical Circuit

#### 3.1

$$\omega_c = \frac{R}{L} = \frac{350}{0.05} = 7000$$

8

$$H(s) = \frac{s}{s + \omega_c} = \frac{s}{s + 7000}$$

#### 3.2

##### Command Window

```
>> s = tf('s');
>> system = (s/(s+7000));
>> bode(system);
>> grid on
```

Figure 11 - Task 3 Matlab code.

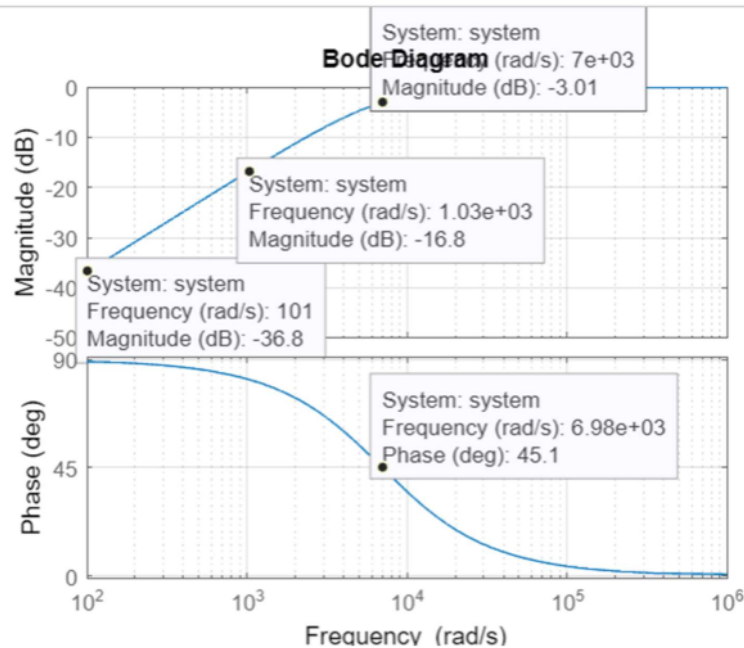


Figure 12 - RL Circuit Bode Diagram.

#### 3.3

|             | Calculated | Measured  | Error |
|-------------|------------|-----------|-------|
| $\omega_c$  | 7000       | 7,030     | 30    |
| $\emptyset$ | 45°        | 45.1°     | 0.1°  |
| roll -on    | - 20dB/dec | -20dB/dec | 0     |

Figure 13 - Error Table

9

### 3.4

This circuit creates a high pass filter, it is difficult to land the cursor on the Matlab graphs, so the calculated and measured results are slightly different. The first graph shows that under steady state conditions that a high pass filter is created, this is shown by the wave increasing to a point then plateauing.



## Task 4. Frequency Performance Analysis of a First Order RC Electrical Circuit.

### 4.1

$$H(s) = \frac{\omega c}{s + \omega c} = \frac{416.6}{s + 416.6}$$

$$\omega c = \frac{1}{RC} = \frac{1}{1200 \times (2 \times 10^{-6})} = 416.6$$

### 4.2

#### Command Window

```
>> s = tf('s');
>> system = (416.6/(s+416.66));
>> bode(system);
>> grid on
```

Figure 14 - Task 4 Matlab code.

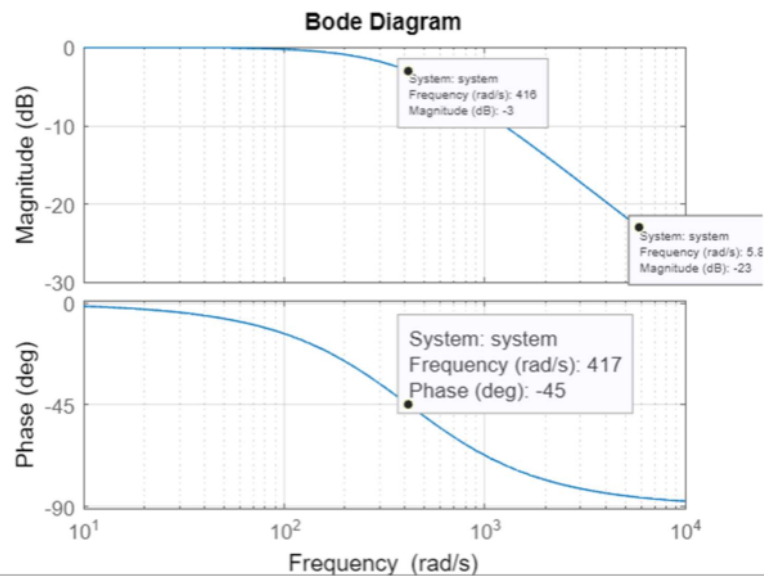


Figure 15 - RC Circuit Bode Diagram.

### 4.3

|             | Calculated | Measured  | Error |
|-------------|------------|-----------|-------|
| $\omega c$  | 416.66     | 416       | 0.66  |
| $\emptyset$ | -45°       | -45°      | 0.0°  |
| roll -on    | - 20dB/dec | -20dB/dec | 0     |

Figure 16 - Task 5 Error Table.

#### 4.4

This circuit creates a low pass filter, I've been able to drop the Matlab cursor exactly where I wanted so there is no error between my degrees. The graph above implies that this is a low pass filter because the wave stays at the same value to a point then drops off finally to a nothing.



## Task 5. Transient Performance Analysis of a Second Order Series Electrical Circuit.

### 5.1

The below values are what I've selected to input to the circuit.

Resistor =  $4\Omega$

Inductor =  $0.2\text{H}$

Capacitor =  $35\mu\text{F}$

### 5.2

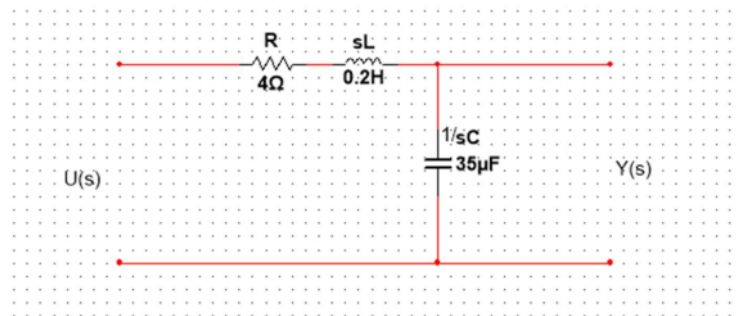


Figure 17 - Task 5 Multi-sim Circuit.

### 5.3

$$K = 1$$

$$\omega_n = \frac{1}{\sqrt{L \cdot C}} = \frac{1}{\sqrt{0.2 \cdot (35 \cdot 10^{-6})}} = 377.96 \text{ rad/s}$$

13

$$\zeta = \frac{R}{2} * \sqrt{\frac{C}{L}} = \frac{4}{2} * \sqrt{\frac{(35 * 10^{-6})}{0.2}} = 0.0264 \text{ therefore underdamped } \zeta < 1$$

$$H(s) = \frac{k\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} = \frac{377.96^2}{s^2 + (2 * 0.0264 * 377.96)s + 377.96^2} = \frac{142853.76}{s^2 + 19.96s + 142853.76}$$

$$\zeta = \frac{R}{2} * \sqrt{\frac{C}{L}} = \frac{250}{2} * \sqrt{\frac{(35 * 10^{-6})}{0.2}} = 1.65 \text{ therefore overdamped } \zeta > 1$$

$$H(s) = \frac{k\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} = \frac{377.96^2}{s^2 * (2 * 1.65 * 377.96)s + 377.96^2} = \frac{142853.76}{s^2 * 1247.268s + 142853.76}$$

Rearrange to find out the resistance required to produce critical dampening.

$$R = \frac{2 * \zeta}{\sqrt{\frac{C}{L}}} = \frac{2 * 1}{\sqrt{\frac{(35 * 10^{-6})}{0.2}}} = 151.186\Omega$$

$$\zeta = \frac{R}{2} * \sqrt{\frac{C}{L}} = \frac{151.186}{2} * \sqrt{\frac{(35 * 10^{-6})}{0.2}} = 1 \text{ therefore critical dampening } \zeta = 1$$

$$H(s) = \frac{k\omega n^2}{s^2 + 2\zeta\omega ns + \omega n^2} = \frac{377.96^2}{s^2 * (2 * 1 * 377.96)s + 377.96^2} = \frac{142853.76}{s^2 * 755.92s + 142853.76}$$

$$\zeta = \frac{R}{2} * \sqrt{\frac{C}{L}} = \frac{0.000001}{2} * \sqrt{\frac{(35 * 10^{-6})}{0.2}} = 6.6 * 10^{-9} \text{ therefore no damping } \zeta = 0$$

$$H(s) = \frac{k\omega n^2}{s^2 + 2\zeta\omega ns + \omega n^2} = \frac{377.96^2}{s^2 * (2 * (6.6 * 10^{-9}) * 377.96)s + 377.96^2}$$

$$= \frac{142853.76}{s^2 * (4.98 * 10^{-6})s + 142853.76}$$

#### 5.4

```
>> s = tf('s');
>> system = 142853.76/(s^2+19.96*s+142853.76);
>> step(system);
>> grid on
```

Figure 18 – Task 5 Under damping Matlab code.

#### Command Window

```
>> s = tf ('s');
>> system = 142853.76/(s^2+1427.268*s+142853.76);
>> step(system);
>> grid on
```

Figure 19 – Task 5 Over damping Matlab code.

```
>> s = tf('s');
>> system = 142853.76/(s^2+755.92*s+142853.76);
>> step(system);
>> grid on
```

Figure 20 – Task 5 Critical damping Matlab code

```
>> s = tf('s');
>> system = 142853.76/(s^2+(4.98*10^-6)*s+142853.76);
>> step(system);
>> grid on
```

Figure 21 -Task 5 No damping Matlab code.

## 5.5

### Error Table

| Resistor | $\zeta$ | $\zeta$     | Effect             |
|----------|---------|-------------|--------------------|
| 4        | 0.0264  | $\zeta < 1$ | underdamping       |
| 250      | 1.65    | $\zeta > 1$ | overdamping        |
| 151.186  | 1       | $\zeta = 1$ | critical dampening |
| 0.000001 | 0       | $\zeta = 0$ | no damping         |

Figure 22 - Task 5 Error Table.

## 5.6

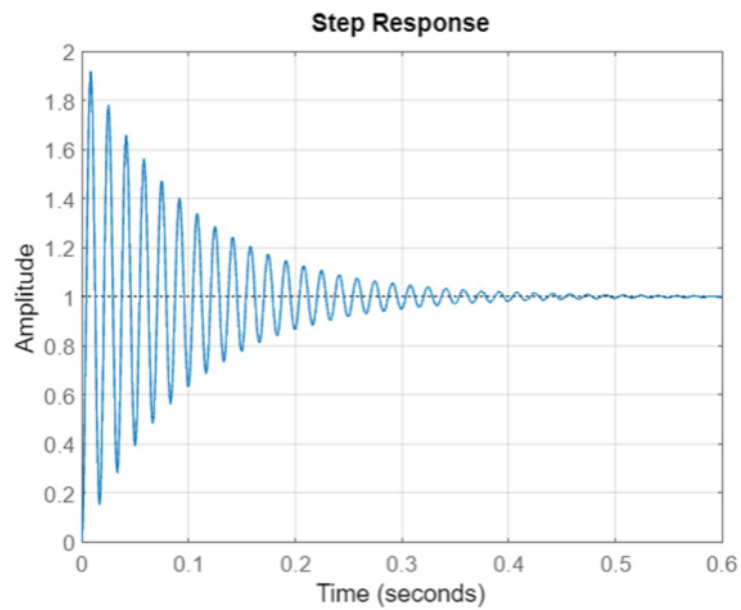


Figure 23 - Task 5 Under damping Step Response.

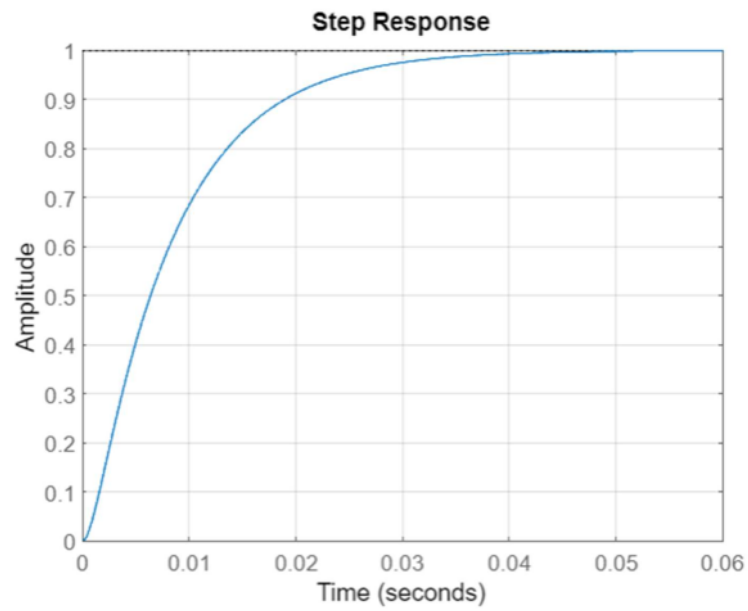


Figure 24 - Task 5 Over damping Step Response.

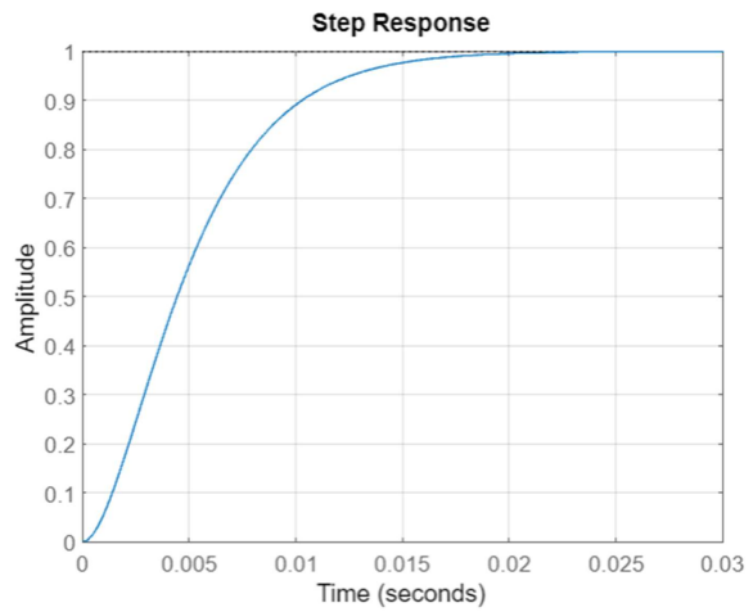


Figure 25 - Task 5 Critical damping Step Response.

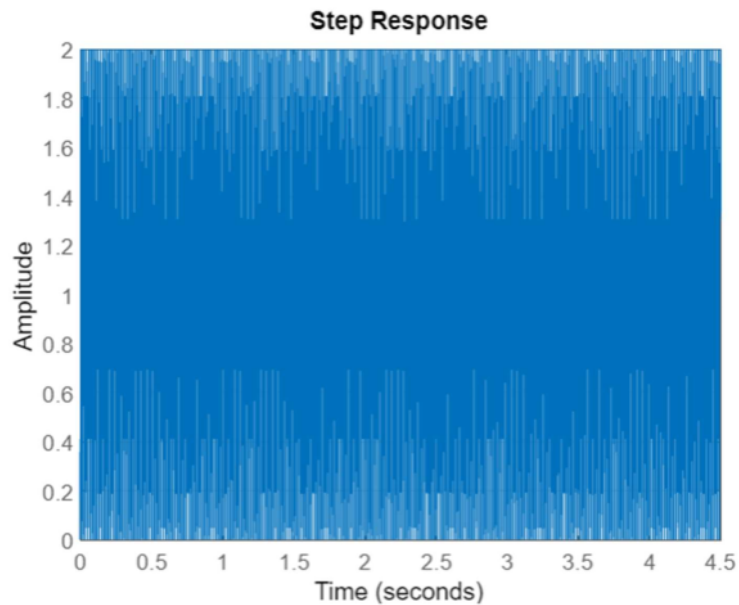


Figure 26 - Task 5 No damping Step Response.

### 5.7

When the resistor value is at its largest this calculated a damping factor, this creates an overdamped response as shown in the graphs above. Vice versa when the R value is much lower this results in an underdamping. I had to rearrange the sigma equation to find R to input it in the damping factor equation, this as shown above resulted <sup>14</sup> critically damped output. When I made the resistor value as low as possible this ensured that there was no damping <sup>15</sup> on the output creating a consistent oscillating wave.

## Task 6. Transient Performance Analysis of a Second Order Parallel Electrical Circuit.

### 6.1

The below values are what I've selected to input to the circuit.

Resistor =  $4\Omega$

Inductor =  $0.25\text{H}$

Capacitor =  $40\mu\text{F}$

### 6.2

Multi-sim circuit

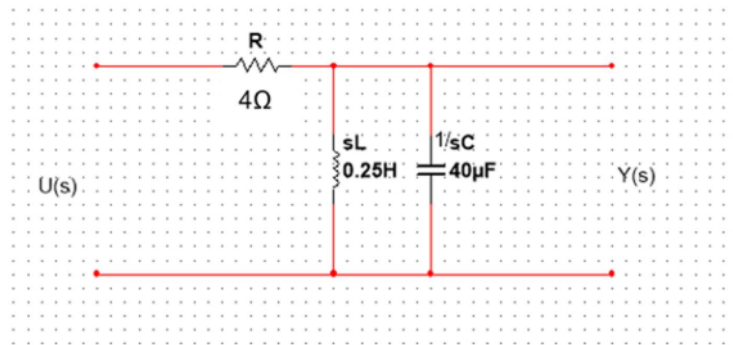


Figure 27 - Task 6 Multi-sim Circuit

### 6.3

Because of the final value theorem, the final value in the graphs should be zero.

$$\omega_n = \frac{1}{\sqrt{L * C}} = \frac{1}{\sqrt{0.25 * (40 * 10^{-6})}} = 316.28 \text{ rad/s}$$

$$\zeta = \frac{1}{2R} * \sqrt{\frac{L}{C}} = \frac{1}{2 * 4} * \sqrt{\frac{0.25}{(40 * 10^{-6})}} = 9.88 \text{ over damping } \zeta > 1$$

$$H(s) = \frac{s * \frac{1}{RC}}{s^2 + \frac{1}{RC} * s + \frac{1}{LC}} = \frac{s * \frac{1}{(4 * (40 * 10^{-6}))}}{s^2 + \frac{1}{(4 * (40 * 10^{-6}))} * s + \frac{1}{(0.25 * (40 * 10^{-6}))}}$$

$$= \frac{s * 6250}{s^2 + 6250s + 100000}$$

$$\zeta = \frac{1}{2R} * \sqrt{\frac{L}{C}} = \frac{1}{2 * 300} * \sqrt{\frac{0.25}{(40 * 10^{-6})}} = 0.13 \text{ under damping } \zeta < 1$$

$$H(s) = \frac{s * \frac{1}{RC}}{s^2 + \frac{1}{RC} * s + \frac{1}{LC}} = \frac{s * \frac{1}{(300 * (40 * 10^{-6}))}}{s^2 + \frac{1}{(300 * (40 * 10^{-6}))} * s + \frac{1}{(0.25 * (40 * 10^{-6}))}}$$

$$= \frac{s * 83.3}{s^2 + 83.3s + 100000}$$

Rearrange the zeta equation and substitute 1 in its place to find the resistor value.

$$R = \frac{\zeta}{2} \sqrt{\frac{L}{C}} = \frac{1}{2} \sqrt{\frac{0.25}{(40 * 10^{-6})}} = 39.528 \Omega$$

$$\zeta = \frac{1}{2R} * \sqrt{\frac{L}{C}} = \frac{1}{2 * 39.528} * \sqrt{\frac{0.25}{(40 * 10^{-6})}} = 1 \text{ critical damping } \zeta = 1$$

$$H(s) = \frac{s * \frac{1}{RC}}{s^2 + \frac{1}{RC} * s + \frac{1}{LC}} = \frac{s * \frac{1}{(39.528 * (40 * 10^{-6}))}}{s^2 + \frac{1}{(39.528 * (40 * 10^{-6}))} * s + \frac{1}{(0.25 * (40 * 10^{-6}))}}$$

$$= \frac{s * 632.46}{s^2 + 632.46s + 100000}$$

$$\zeta = \frac{1}{2R} * \sqrt{\frac{L}{C}} = \frac{1}{2 * 10000} * \sqrt{\frac{0.25}{(40 * 10^{-6})}} = 3952 * 10^{-6} \text{ no damping } \zeta = 0$$

$$H(s) = \frac{s * \frac{1}{RC}}{s^2 + \frac{1}{RC} * s + \frac{1}{LC}} = \frac{s * \frac{1}{((10000) * (40 * 10^{-6}))}}{s^2 + \frac{1}{((10000) * (40 * 10^{-6}))} * s + \frac{1}{(0.25 * (40 * 10^{-6}))}}$$

$$= \frac{s * 2.5}{s^2 + 2.5 * s + 100000}$$

#### 6.4

```
>> s=tf('s');
>> system=(s*6250)/((s^2)+(6250*s)+(100000));
>> step(system);
>> grid on
```

Figure 28 - Task 6 Over damping Matlab code.

```
>> s=tf('s');
>> system=(s*83.3)/((s^2)+(83.3*s)+(100000));
>> step(system);
>> grid on
```

Figure 29 - Task 6 Under damping Matlab code.

```
>> s=tf('s');
>> system=(s*632.46)/((s^2)+(632.46*s)+(100000));
>> step(system);
>> grid on
```

Figure 30 - Task 6 Critical damping Matlab code.

#### Command Window

```
>> s=tf('s');
>> system=(s*2.5)/((s^2)+(2.5*s)+(100000));
>> step(system);
>> grid on
```

Figure 31 - Task 6 No damping Matlab code.

## 6.5

| Resistor | $\zeta$ | $\zeta$     | Effect             |
|----------|---------|-------------|--------------------|
| 4        | 9.88    | $\zeta > 1$ | overdamping        |
| 300      | 0.13    | $\zeta < 1$ | underdamping       |
| 39.528   | 1       | $\zeta = 1$ | critical dampening |
| 100000   | 0       | $\zeta = 0$ | no damping         |

Figure 32 - Task 6 Error Table.

## 6.6

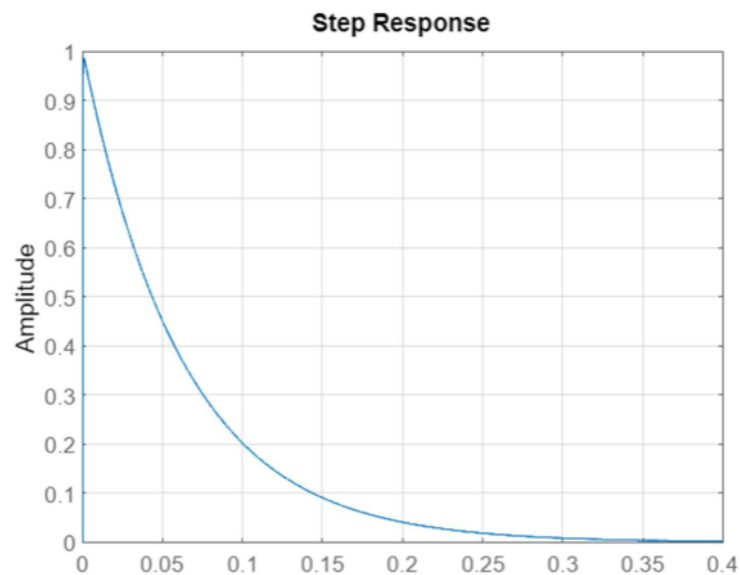


Figure 33 - Task 6 Over damping Step Response.

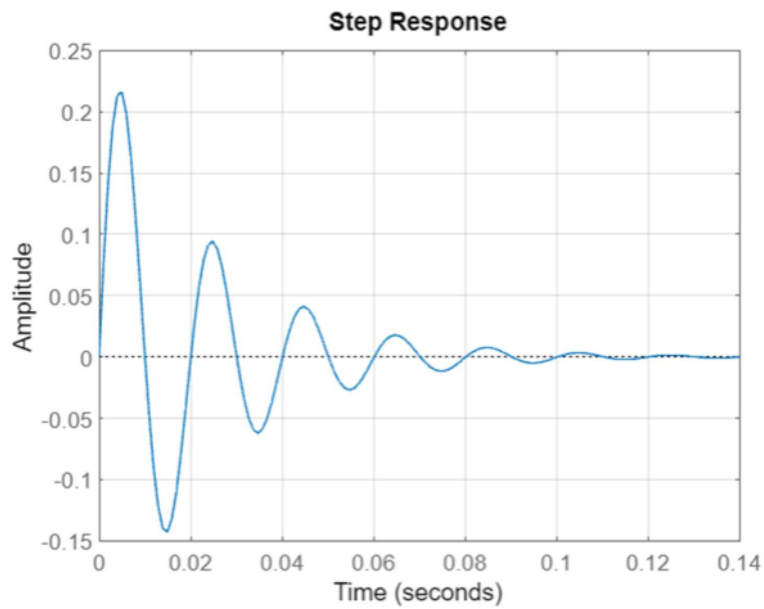


Figure 34 - Task 6 Under damping Step Response.

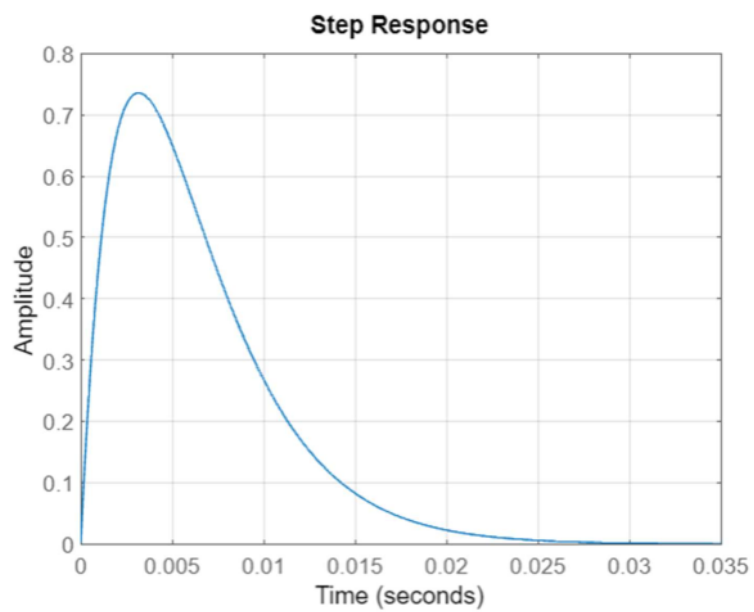


Figure 35 - Task 6 Critical damping Step Response.

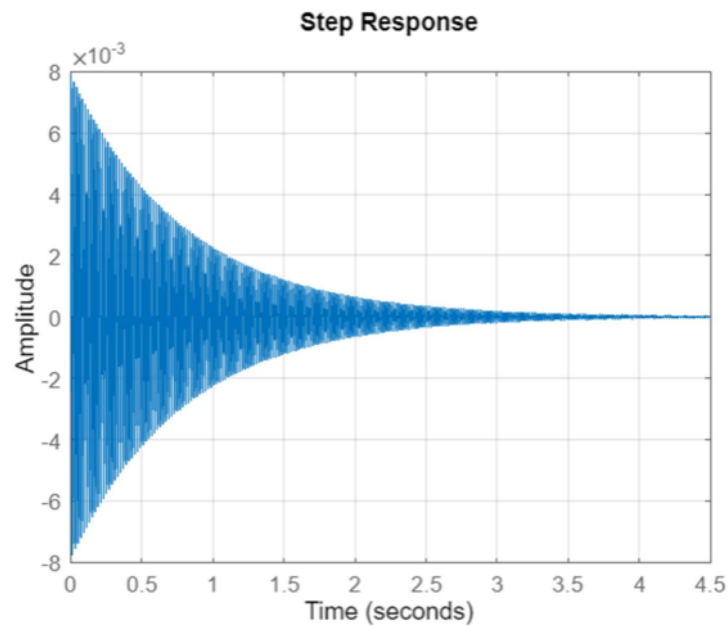


Figure 36 - Task 6 No damping Step Response.

## 6.7

The denominator (R) value is increasing the damping decreases and vice versa when in the R value decreases the damping increases. When the RLC circuit is over damped there are no oscillations, and it is slow in reaching zero. When it is under damped it is oscillatory to a for a certain time then slows down. The critical damping has no overshoot it reaches zero the fastest. As in the graph shown above the no damping leaves the wave to constantly oscillate with no sign of dampening. The table shown above suggest the relationship between the dampening factor and sigma changes the type of dampening.

## Task 7. Frequency Performance Analysis of a Second Order Series Electrical Circuit.

### 7.1

$$\omega_n = \frac{1}{\sqrt{L * C}} = \frac{1}{\sqrt{0.2 * (35 * 10^{-6})}} = 377.96 \text{ rad/s}$$

$$\zeta = \frac{R}{2} * \sqrt{\frac{C}{L}} = \frac{4}{2} * \sqrt{\frac{(35 * 10^{-6})}{0.2}} = 0.026 \text{ under damping } \zeta < 1$$

$$\omega_m = \sqrt{\frac{1}{LC}} - \frac{1}{2} \left(\frac{R}{L}\right)^2 = \sqrt{\frac{1}{(0.2 * (35 * 10^{-6}))}} - \frac{1}{2} \left(\frac{4}{0.2}\right)^2 = 377.96 - 200 = 177.96 \text{ rad/s}$$

$$H(s) = \frac{\frac{1}{LC}}{s^2 + \frac{R}{L}s + \frac{1}{LC}} = \frac{142857.14}{s^2 + \frac{4}{0.2}s + 142857.14} = \frac{142857.14}{s^2 + 20s + 142857.14}$$

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}} = \frac{1}{4} \sqrt{\frac{0.2}{(35 * 10^{-6})}} = 18.898$$

$$\zeta = \frac{R}{2} * \sqrt{\frac{C}{L}} = \frac{300}{2} * \sqrt{\frac{(35 * 10^{-6})}{0.2}} = 1.984 \text{ over damping } \zeta > 1$$



$$H(s) = \frac{\frac{1}{LC}}{s^2 + \frac{R}{L}s + \frac{1}{LC}} = \frac{142857.14}{s^2 + \frac{300}{0.2}s + 142857.14} = \frac{142857.14}{s^2 + 1500s + 142857.14}$$

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}} = \frac{1}{300} \sqrt{\frac{0.2}{(35 * 10^{-6})}} = 0.25$$

$$R = 2 \sqrt{\frac{L}{C}} = 2 \sqrt{\frac{0.2}{(35 * 10^{-6})}} = 151.186 \Omega$$

$$\zeta = \frac{R}{2} * \sqrt{\frac{C}{L}} = \frac{151.186}{2} * \sqrt{\frac{(35 * 10^{-6})}{0.2}} = 1 \text{ critical damping } \zeta = 1$$

$$H(s) = \frac{\frac{1}{LC}}{s^2 + \frac{R}{L}s + \frac{1}{LC}} = \frac{142857.14}{s^2 + \frac{151.186}{0.2}s + 142857.14} = \frac{142857.14}{s^2 + 755.93s + 142857.14}$$

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}} = \frac{1}{151.186} \sqrt{\frac{0.2}{(35 * 10^{-6})}} = 0.499$$

$$\zeta = \frac{R}{2} * \sqrt{\frac{C}{L}} = \frac{0.000001}{2} * \sqrt{\frac{(35 * 10^{-6})}{0.2}} = 6.61 * 10^{-9} \text{ no damping } \zeta = 0$$

$$H(s) = \frac{\frac{1}{LC}}{s^2 + \frac{R}{L}s + \frac{1}{LC}} = \frac{142857.14}{s^2 + \frac{0.000001}{0.2}s + 142857.14} = \frac{142857.14}{s^2 + (5 * 10^{-6})s + 142857.14}$$

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}} = \frac{1}{0.000001} \sqrt{\frac{0.2}{(35 * 10^{-6})}} = 75592894.6$$

## 7.2

```
>> s=tf('s');
system = 142857.14/(s^2 + 20*s + 142857.14);
bode(system);
grid on
hold on

s=tf('s');
system = 142857.14/(s^2 + 200*s + 142857.14);
bode(system);
s=tf('s');
system = 142857.14/(s^2 + 400*s + 142857.14);
bode(system);
s=tf('s');
system = 142857.14/(s^2 + 600*s + 142857.14);
bode(system);
s=tf('s');
system = 142857.14/(s^2 + 755.93*s + 142857.14);
bode(system);
s=tf('s');
system = 142857.14/(s^2 + 0.000005*s + 142857.14);
bode(system);
s=tf('s');
system = 142857.14/(s^2 + 1500*s + 142857.14);
bode(system);
>> grid on
```

Figure 37 - Task 7 Matlab code.

### 7.3

$$20 \log(18.898) = 25.53$$

$$20 \log(0.25) = -12.04$$

$$20 \log(0.499) = -6.03$$

$$20 \log(75592894.6) = 157.56$$

|                  | Measured db value | Calculated db value | Error |
|------------------|-------------------|---------------------|-------|
| Under damping    | 25.4              | 25.53               | 0.13  |
| Over damping     | -11.8             | -12.04              | -0.24 |
| Critical damping | -5.93             | -6.03               | 0.1   |
| No damping       | 155               | 157.56              | 2.56  |

Figure 38 - Task 7 Error Table.

### 7.4

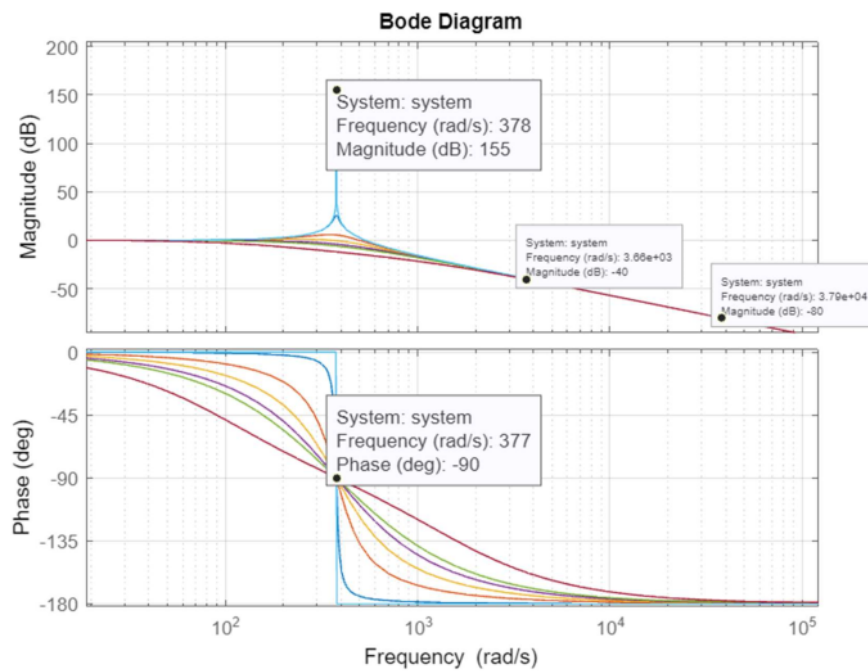


Figure 39 - Task 7 Bode Diagram.

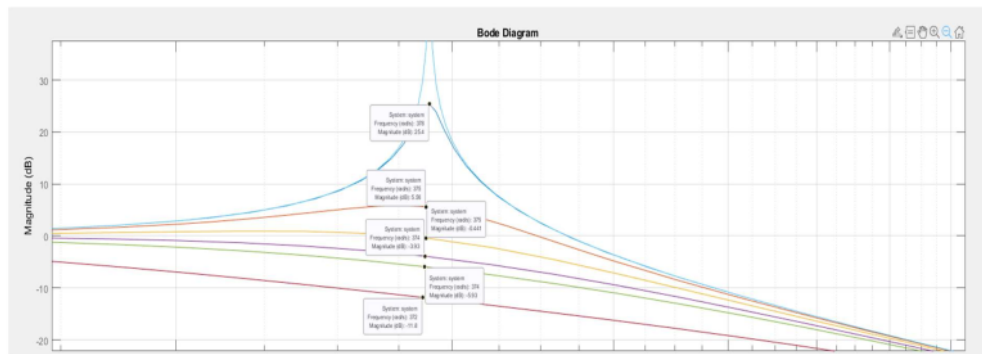


Figure 40 - Task 7 - Root locus separation.

### 7.5

The  $\omega_m$  moves towards the  $\omega_0$  as the  $R$  is varied this is shown in the graph above. I have plotted several locus points to show the deviation as the  $R$  changes. When  $R$  is changed the damping factor also changes. The results shown in the table in 7.3, suggest that there can be a considerable error when using Matlab because of the difficulty in selecting the peak of the frequencies. Even though there is an error it does show that there is some level of accuracy in the calculations and graph produced.

## Task 8. Frequency Performance Analysis of a Second Order Parallel Electrical Circuit.

### 8.1

The below values are what I've used from Task 6 to input to the circuit.

Inductor = 0.25H

Capacitor = 40uF

Over damping values (Resistor = 4Ω):

$$\beta = \frac{1}{RC} = \frac{1}{4 * (40 * 10^{-6})} = 6250$$

$$\omega_o = \frac{1}{\sqrt{LC}} = \frac{1}{0.25 * (40 * 10^{-6})} = 316.22 \text{ rad/s}$$

$$\omega_o^2 = \frac{1}{LC} = \frac{1}{\sqrt{0.25 * (40 * 10^{-6})}} = 100000 \text{ rad/s}$$

Upper

$$\omega_c^2 = \frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \left(\frac{1}{LC}\right)} = \frac{1}{2 * 4 * (40 * 10^{-6})} + \sqrt{\left(\frac{1}{2 * 4 * (40 * 10^{-6})}\right)^2 + \left(\frac{1}{0.25 * (40 * 10^{-6})}\right)} = 6265.96 \text{ rad/s}$$

Lower

$$\begin{aligned} \omega_c^1 &= -\frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \left(\frac{1}{LC}\right)} \\ &= \frac{1}{2 * 4 * (40 * 10^{-6})} + \sqrt{\left(\frac{1}{2 * 4 * (40 * 10^{-6})}\right)^2 + \left(\frac{1}{0.25 * (40 * 10^{-6})}\right)} \\ &= 15.96 \text{ rad/s} \end{aligned}$$

$$Q = \frac{\omega_o}{\beta} = \frac{316.22}{6250} = 0.0505$$

$$H(s) = \frac{s\beta}{s^2 + s\beta + \omega_o^2} = \frac{s * 6250}{s^2 + (s * 6250) + 100000}$$

Under damping values (Resistor = 300Ω):

$$\beta = \frac{1}{RC} = \frac{1}{300 * (40 * 10^{-6})} = 83.3$$

Upper

$$\omega_c^2 = \frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \left(\frac{1}{LC}\right)} = \frac{1}{2 * 300 * (40 * 10^{-6})} + \sqrt{\left(\frac{1}{2 * 300 * (40 * 10^{-6})}\right)^2 + \left(\frac{1}{0.25 * (40 * 10^{-6})}\right)} = 360.63 \text{ rad/s}$$

Lower

$$\begin{aligned} \omega_c^1 &= -\frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \left(\frac{1}{LC}\right)} \\ &= \frac{1}{2 * 300 * (40 * 10^{-6})} + \sqrt{\left(\frac{1}{2 * 300 * (40 * 10^{-6})}\right)^2 + \left(\frac{1}{0.25 * (40 * 10^{-6})}\right)} \\ &= 277.29 \text{ rad/s} \end{aligned}$$

$$Q = \frac{\omega o}{\beta} = \frac{316.22}{83.3} = 3.79$$

$$H(s) = \frac{s\beta}{s^2 + s\beta + \omega o^2} = \frac{s * 83.3}{s^2 + (s * 83.3) + 100000}$$

Critical damping values (Resistor = 39.528Ω):

$$\beta = \frac{1}{RC} = \frac{1}{39.528 * (40 * 10^{-6})} = 632.46$$

Upper

$$\omega c^2 = \frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \left(\frac{1}{LC}\right)} = \frac{1}{2 * 39.528 * (40 * 10^{-6})} + \sqrt{\left(\frac{1}{2 * 39.528 * (40 * 10^{-6})}\right)^2 + \left(\frac{1}{0.25 * (40 * 10^{-6})}\right)} = 763.45 \text{ rad/s}$$

Lower

$$\begin{aligned} \omega c^1 &= -\frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \left(\frac{1}{LC}\right)} \\ &= \frac{1}{2 * 39.528 * (40 * 10^{-6})} + \sqrt{\left(\frac{1}{2 * 39.528 * (40 * 10^{-6})}\right)^2 + \left(\frac{1}{0.25 * (40 * 10^{-6})}\right)} = 130.98 \text{ rad/s} \end{aligned}$$

$$Q = \frac{\omega o}{\beta} = \frac{316.22}{632.46} = 0.499$$

$$H(s) = \frac{s\beta}{s^2 + s\beta + \omega o^2} = \frac{s * 632.46}{s^2 + (s * 632.46) + 100000}$$

No damping values (Resistor = 10kΩ):

$$\beta = \frac{1}{RC} = \frac{1}{10000 * (40 * 10^{-6})} = 2.5$$

Upper

$$\omega c^2 = \frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \left(\frac{1}{LC}\right)} = \frac{1}{2 * 10000 * (40 * 10^{-6})} + \sqrt{\left(\frac{1}{2 * 10000 * (40 * 10^{-6})}\right)^2 + \left(\frac{1}{0.25 * (40 * 10^{-6})}\right)} = 317.48 \text{ rad/s}$$

Lower

$$\begin{aligned} \omega c^1 &= -\frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \left(\frac{1}{LC}\right)} \\ &= \frac{1}{2 * 10000 * (40 * 10^{-6})} + \sqrt{\left(\frac{1}{2 * 10000 * (40 * 10^{-6})}\right)^2 + \left(\frac{1}{0.25 * (40 * 10^{-6})}\right)} = 314.98 \text{ rad/s} \end{aligned}$$

$$Q = \frac{\omega o}{\beta} = \frac{316.22}{2.5} = 126.488$$

$$H(s) = \frac{s\beta}{s^2 + s\beta + \omega o^2} = \frac{s * 2.5}{s^2 + (s * 2.5) + 100000}$$

## 8.2

### Matlab code

```
s = tf('s');
system = (s*6250)/((s^2) + (s*6250) + 100000);
bode(system);
grid on
```

Figure 41 - Task 8 Over damping Matlab code.

```
s = tf('s');
system = (s*83.3)/((s^2) + (s*83.3) + 100000);
bode(system);
grid on
```

Figure 42 - Task 8 Under damping Matlab code.

```
s = tf('s');
system = (s*632.46)/((s^2) + (s*632.46) + 100000);
bode(system);
grid on
```

Figure 43 - Task Critical damping Matlab code.

```
s = tf('s');
system = (s*2.5)/((s^2) + (s*2.5) + 100000);
bode(system);
grid on
```

Figure 44 - Task 8 No damping Matlab code.

## 8.3

| Resistance value ( $\Omega$ ) | Measured $\omega_0$ value (rad/s) | Calculated $\omega_0$ value (rad/s) | Error |
|-------------------------------|-----------------------------------|-------------------------------------|-------|
| 4                             | 317                               | 316.22                              | 0.78  |
| 300                           | 316                               | 316.22                              | 0.22  |
| 39.528                        | 317                               | 316.22                              | 0.78  |
| 10000                         | 316                               | 316.22                              | 0.22  |

Figure 45 - Task 8  $\omega_0$  Values.

23

| Resistance value ( $\Omega$ ) | Measured $\omega_{c1}$ value (rad/s) | Calculated $\omega_{c1}$ value (rad/s) | Error |
|-------------------------------|--------------------------------------|----------------------------------------|-------|
| 4                             | 16                                   | 15.96                                  | 0.04  |
| 300                           | 277                                  | 277.29                                 | 0.29  |
| 39.528                        | 131                                  | 130.98                                 | 0.02  |
| 10000                         | 315                                  | 314.98                                 | 0.02  |

Figure 46 - Task 8  $\omega_{c1}$  Values.

| Resistance value ( $\Omega$ ) | Measured $\omega c^2$ value (rad/s) | Calculated $\omega c^2$ value (rad/s) | Error |
|-------------------------------|-------------------------------------|---------------------------------------|-------|
| 4                             | 6230                                | 6265.97                               | 35.97 |
| 300                           | 360                                 | 260.63                                | 0.63  |
| 39.528                        | 760                                 | 763.45                                | 3.45  |
| 10000                         | 317                                 | 317.48                                | 0.48  |

Figure 47 - Task 8  $\omega c^2$  Values.

| Resistance value ( $\Omega$ ) | Measured $\beta$ | Calculated $\beta$ | Error |
|-------------------------------|------------------|--------------------|-------|
| 4                             | 6214             | 6250               | 36    |
| 300                           | 83               | 83.3               | 0.3   |
| 39.528                        | 629              | 631.46             | 2.46  |
| 10000                         | 2                | 2.5                | 0.5   |

Figure 48 - Task 8 Beta Values.

#### 8.4

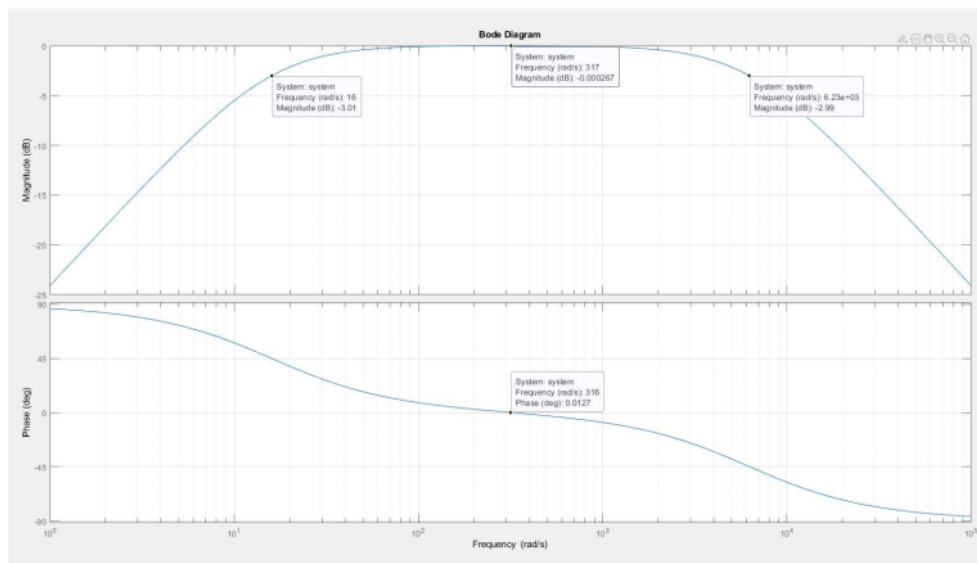


Figure 49 - Task 8 Over damping Bode Diagram.

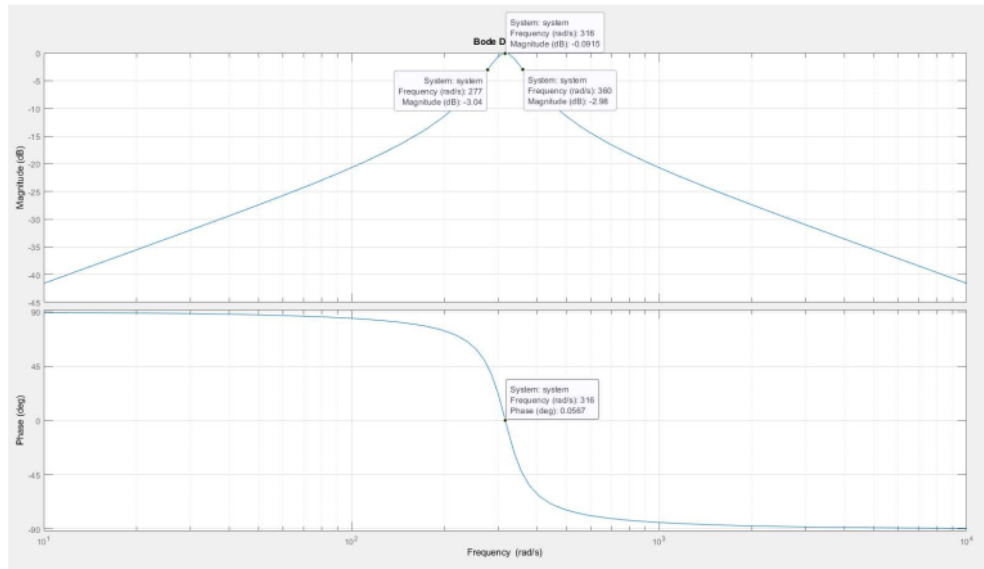


Figure 50 - Task 8 Under damping Bode Diagram.

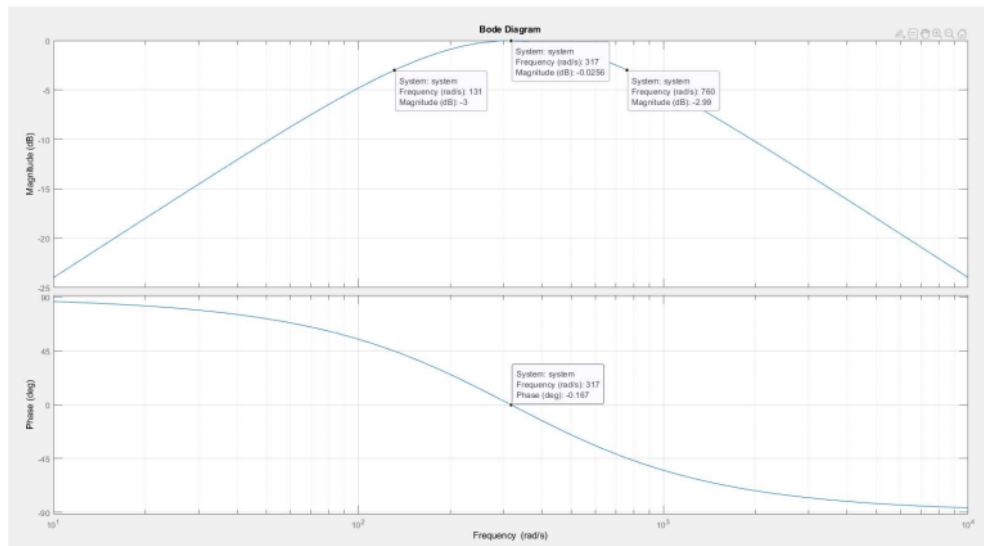


Figure 51 - Task 8 Critical damping Bode Diagram.

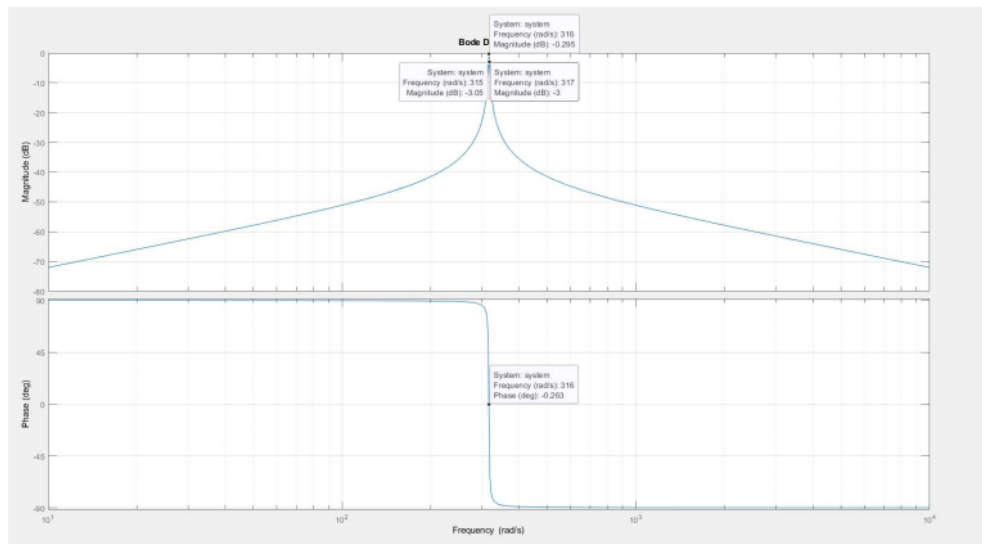


Figure 52 - Task 8 No damping Bode Diagram.

### 8.5

This circuit is a second order resonant parallel circuit, the omega zero is the resonant frequency. The upper and lower cut off can be calculated and measured by looking at the graph and checking the  $\pm 3$  dB from the maximum frequency point. It was difficult to accurately position the cursor onto the graphs so error would occur, the software itself sometimes doesn't let you position the cursor where you want. It is obvious to see that error have occurred from the Matlab rounding of numbers. However, only a couple of the errors were way ward which shows a level of accuracy had been accomplished.

## Task 9. Frequency Performance Analysis of a First Order Electronic System.

### 9.1

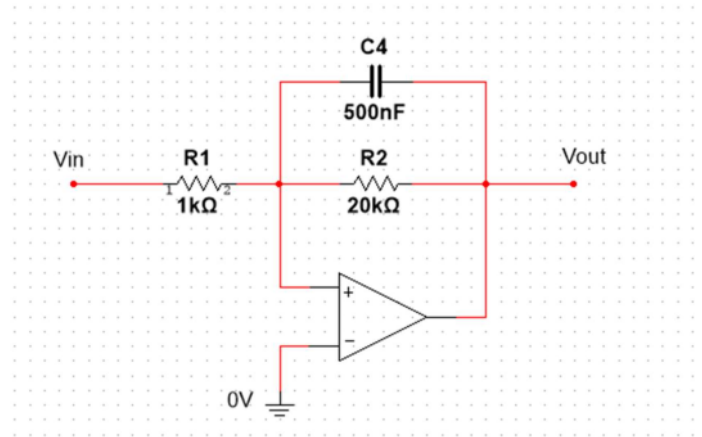


Figure 53 - Task 9 Multi-sim Circuit.

$$\omega_c = \frac{1}{CR2} = \frac{1}{(500 * 10^{-9}) * 20000} = 100 \text{ rad/s}$$

$$K = \frac{R2}{R1} = \frac{20000}{1000} = 20$$

$$20 \log(20) = 26 \text{ db}$$

$$H(s) = -K \left[ \frac{\omega_c}{s + \omega_c} \right] = -20 \left[ \frac{100}{s + 100} \right]$$

## 9.2

```

1  s=tf('s');
2  system = -20*(100/(s+100));
3  bode(system);
4  grid on
5

```

Figure 54 - Task 9 Matlab code.

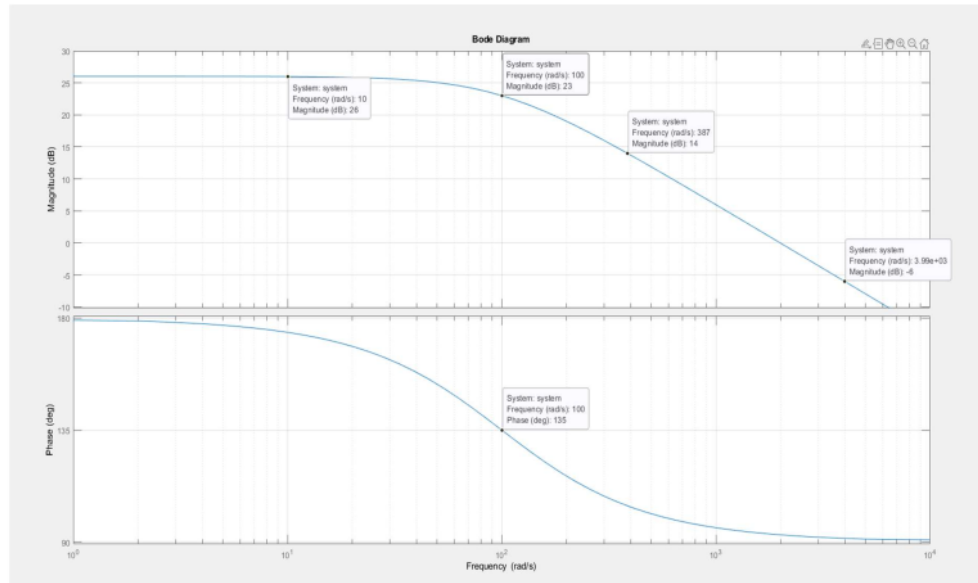


Figure 55 - Task 9 Bode Diagram.

|                      | Measured  | Calculated | Error |
|----------------------|-----------|------------|-------|
| $\omega_c$           | 100rad/s  | 100rad/s   | 0     |
| $\phi$ at $\omega_c$ | 135°      | 135°       | 0°    |
| k                    | 26db      | 26db       | 0     |
| roll off             | 20db/1dec | 20db/1dec  | 0     |

Figure 56 - Task 9 Error Table.

## 9.3

This circuit is an active low pass filter, its phase shift cut off is at 135° because of its inverting nature which is calculated by adding 180° to -45°. It is a first order differentiate due to the s, if it was s<sup>2</sup> it would be a second order. The magnitude is measured in db and the cut off is measured by finding the point which is -3 from the overall gain. As shown in my results table, there are no errors because of the points on the graphing being close to be hit. The frequency of the cut-off and the phase shift cut off should be the exact same which it is 100 rad/s.

## Task 10. Frequency Performance Analysis of a First Order Electronic System.

### 10.1

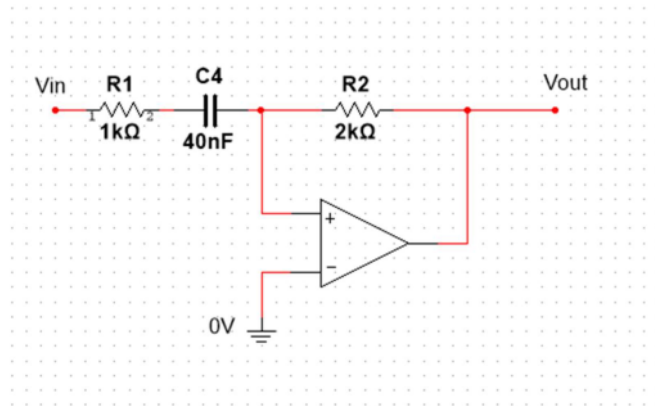


Figure 57 - Task 10 Multi-sim Circuit.

$$\omega_c = \frac{1}{CR2} = \frac{1}{(40 * 10^{-9}) * 1000} = 25000 \text{ rad/s}$$

$$K = \frac{R2}{R1} = \frac{2000}{1000} = 2$$

$$20 \log(2) = 6 \text{ db}$$

$$H(s) = -K \left[ \frac{s}{s + \omega_c} \right] = -2 \left[ \frac{s}{s + 25000} \right]$$

### 10.2

```
1  s=tf('s');
2  system = -2*(s/(s+25000));
3  bode(system);
4  grid on
```

Figure 58 - Task 10 Matlab code.

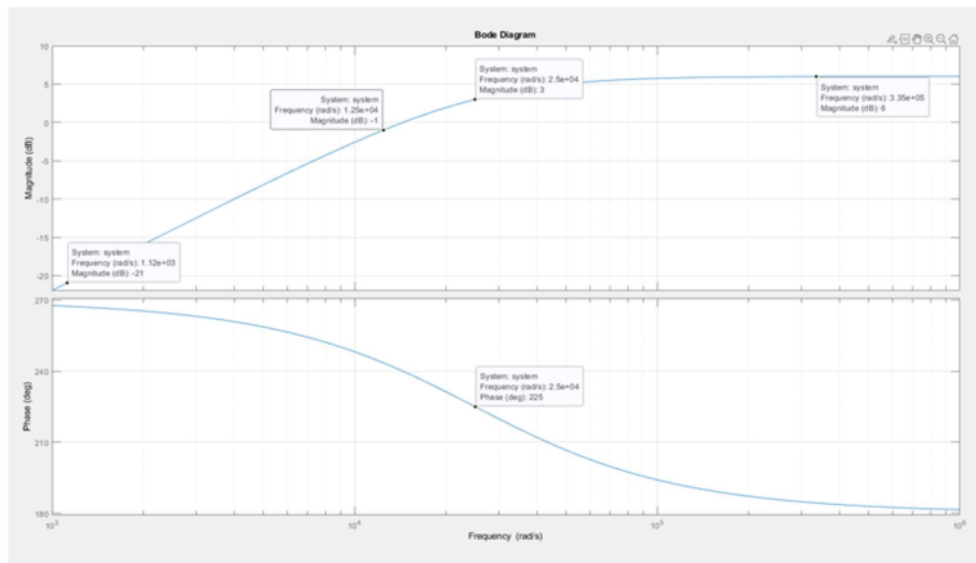


Figure 59 - Task 10 Bode Diagram.

|                      | Measured   | Calculated | Error |
|----------------------|------------|------------|-------|
| $\omega_c$           | 25000rad/s | 25000rad/s | 0     |
| $\phi$ at $\omega_c$ | 225°       | 225°       | 0°    |
| k                    | 6db        | 6db        | 0     |
| roll off             | 20db/1dec  | 20db/1dec  | 0     |

Figure 60 - Task 10 Error Table.

### 10.3

This circuit is an active high pass filter, its phase shift cut off is at 225° because of its inverting nature which is calculated by adding 180° to 45°. It is a first order differentiate due to the s, if it was s<sup>2</sup> it would be a second order. The magnitude is measured in db and the cut off is measured by finding the point which is -3 from the overall gain. As shown in my results table, there are no errors because of the points on the graphing being able to be hit. The frequency of the cut-off and the phase shift cut off should be the exact same which it is 25000 rad/s.

## Task 11. Frequency Performance Analysis of a Sallen & Key 2nd Order Filter.

### 11.1

The values used in the circuit below:

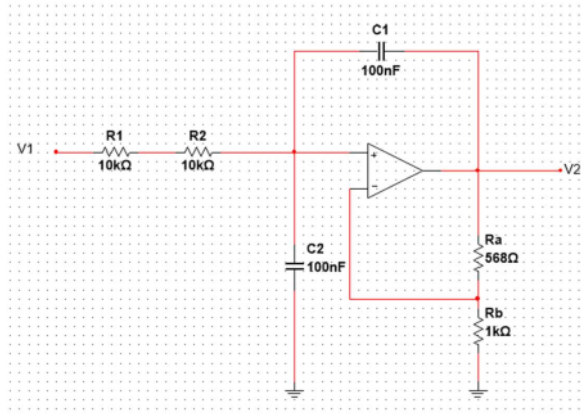


Figure 61 - Task 11 Multi-sim Circuit.

$$K = 1.568$$

$$\omega c = 1000 \text{ rad/s}$$

$$Ra = (k - 1) * Rb = (1.568 - 1) * 1000 = 568\Omega$$

$$R = \frac{1}{\omega c C} = \frac{1}{1000 * (100 * 10^{-9})} = 10000\Omega$$

$$Q = \frac{1}{3 - 1.586} = 0.707$$

$$H(s) = \frac{k\omega c^2}{s^2 + \left(\frac{\omega c}{Q}\right)s + \omega c^2} = \frac{1.586 * 1000^2}{s^2 + \left(\frac{1000}{0.707}\right)s + 1000^2}$$

### 11.2

```
1  s=tf('s');
2  system = (1.586*1000^2)/(s^2+(1000/0.707)*s+1000^2);
3  bode(system);
4  grid on
```

Figure 62 - Task 11 Matlab code.

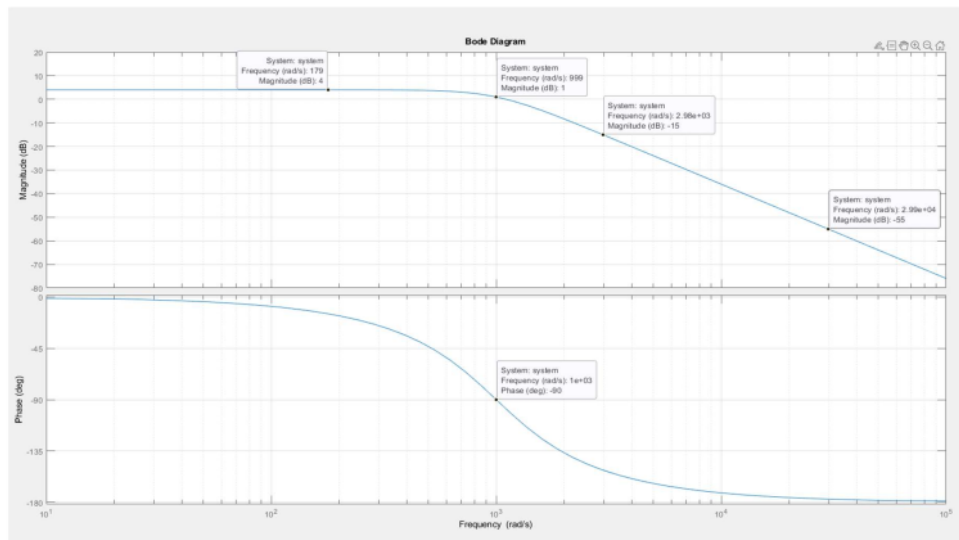


Figure 63 - Task 11 Bode Diagram.

|                      | Measured  | Calculated | Error |
|----------------------|-----------|------------|-------|
| $\omega_c$           | 999rad/s  | 1000rad/s  | 1     |
| $\phi$ at $\omega_c$ | -90°      | -90°       | 0°    |
| k                    | 4db       | 4db        | 0     |
| roll off             | 40db/1dec | 40db/1dec  | 0     |
| cut off              | 1db       | 1db        | 0     |

Figure 64 - Task 11 Error Table.

### 11.3

This is a low pass filter circuit which is a 2<sup>nd</sup> order, the gradient is much steeper than task 9, the roll off is more selective because it is a 2<sup>nd</sup> order not 1<sup>st</sup> order. There is only one error between the measured and calculated results this is due to the rounding up when calculating the  $\omega_c$ .

This is a Butterworth filter which is designed to create a flat frequency response in the passband. It is commonly known as the maximally flat magnitude filter, the higher the order the steeper gradient which is produces better the fi (Wikipedia, 2023).

## Task 12. First Order Control System Analysis

### 12.1

The open loop performance is calculated by the below code input into Matlab. The Pole-Zero map suggest that this is unstable because it's in the right-hand side of the plane where the frequency is positive.

The pole exists at  $s - 0.4 = 0$ ,

```
num = [6.5];  
den = [1, -0.4];  
[zz, pp, kk] = tf2zp(num, den);  
pzmap(pp, zz);
```

Figure 65 - Task 12 Matlab code.

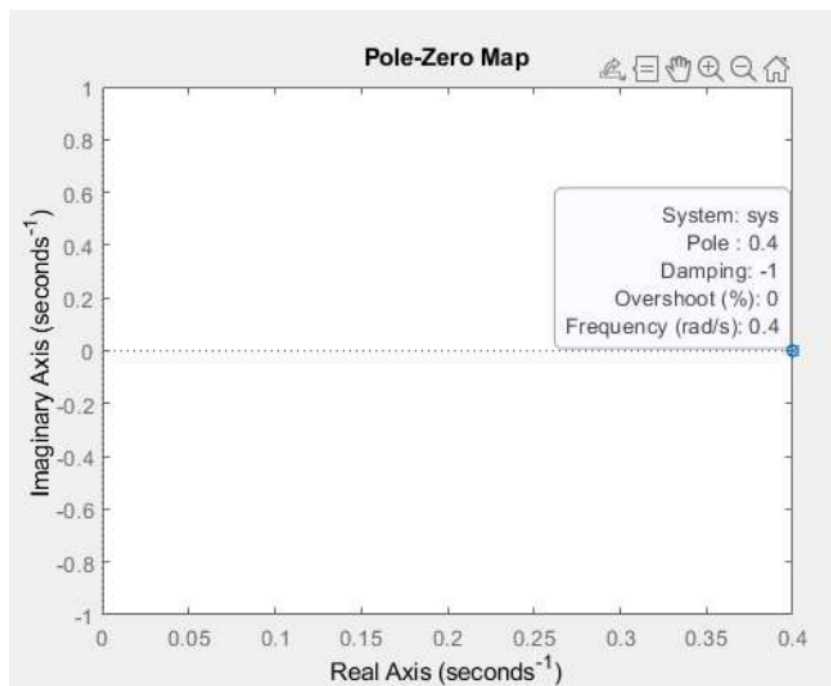


Figure 66 - Task 12 Pole-Zero Map

Simulink showing simulation which becomes unstable.

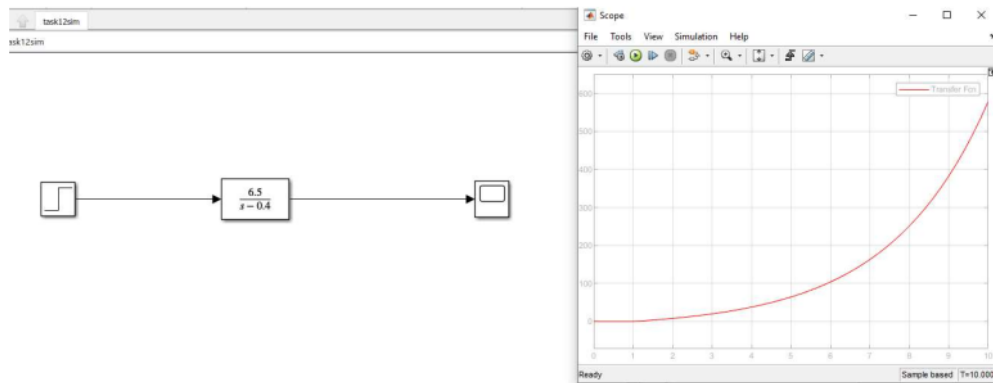


Figure 67 - Task 12 Open Loop Response.

## 12.2

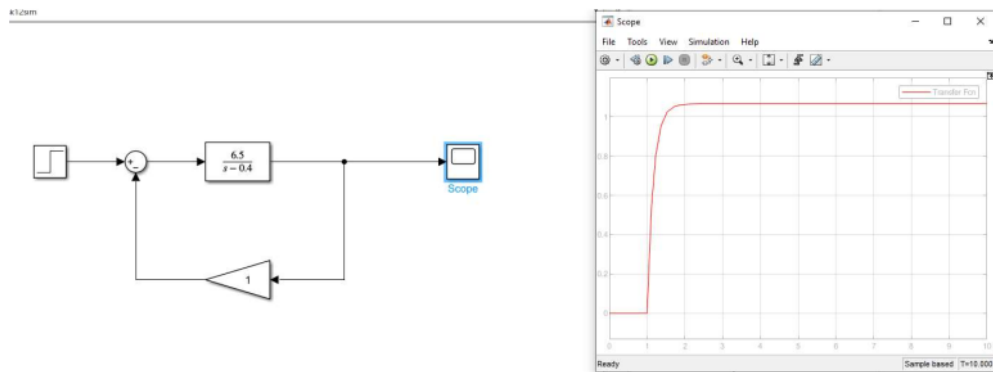


Figure 68 - Task 12 Closed Loop Response.

## 12.3

$$\frac{Y(s)}{R(s)} = \frac{G(s)}{1 + G(s)H(s)} = \frac{\frac{6.5}{(s-0.4)}}{1 + (\frac{6.5}{s-0.4} * K)}$$

Multiply by  $s - 0.4$

$$\frac{Y(s)}{R(s)} = \frac{6.5}{s - 0.4 + (6.5 * K)}$$

$$s - 0.4 + 6.5K = 0$$

$$s - (6.5K - 0.4) = 0$$

$$s = -(6.5K - 0.4)$$

$$s = -6.5K + 0.4$$

$$s = 0.4 - 6.5K$$

$$s = 0 = 0.4 - (6.5 * 0.0614)$$

```

1  clear all
2  num = [6.5];
3  den = [1, -0.4];
4  rlocus(num,den);
5  grid on
6

```

Figure 69 - Task 12 Matlab code.

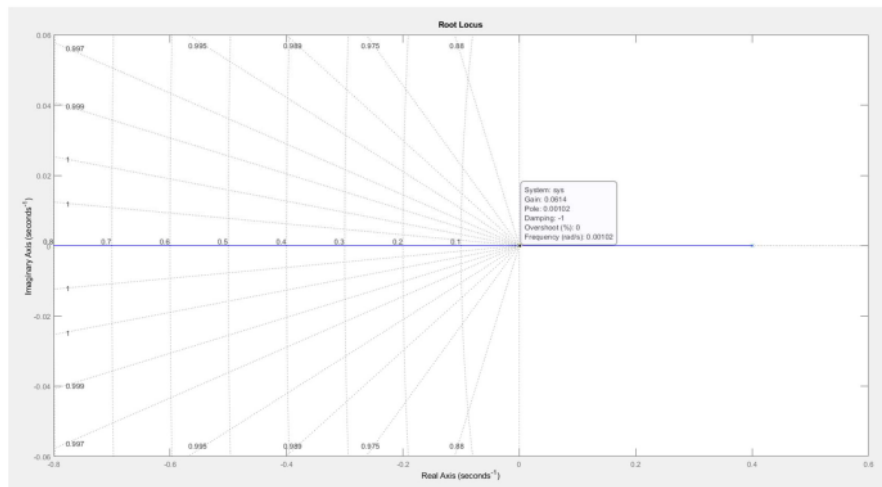


Figure 70 - Task 12 Root Locus.

As shown in the graph and the calculation that 0.0614 is the minimum amount of gain required for the pole to be on zero.

## 12.4

$$s = 0 = 0.4 - (6.5 * 0.02) = 0.27$$

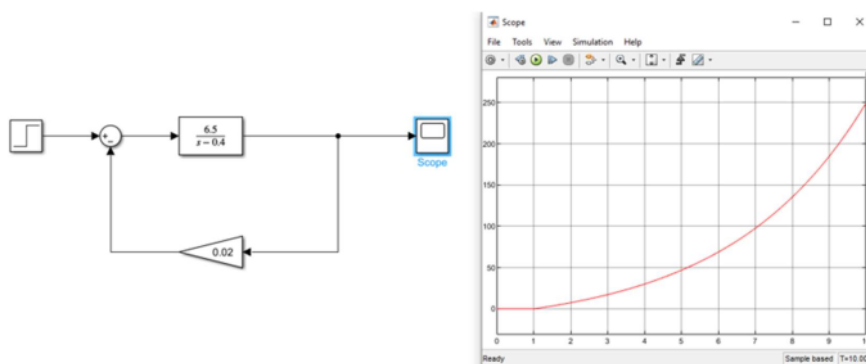


Figure 71 - Task 12 Response with a k of 0.02.

$$s = 0 = 0.4 - (6.5 * 1) = -6.1$$

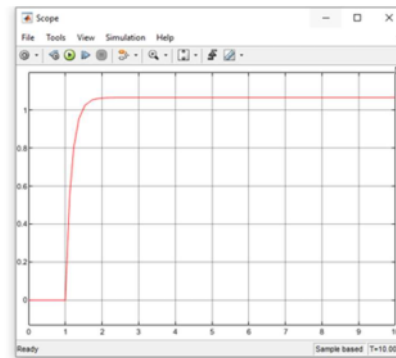
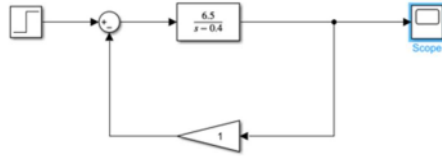


Figure 72 - Task 12 Response with a k of 1.

$$s = 0 = 0.4 - (6.5 * 3) = -19.1$$

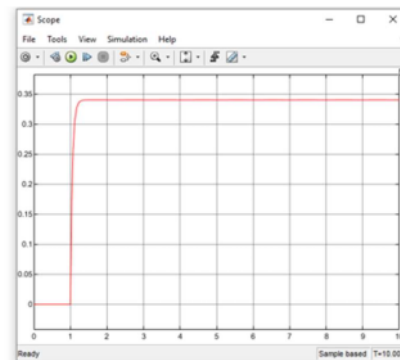
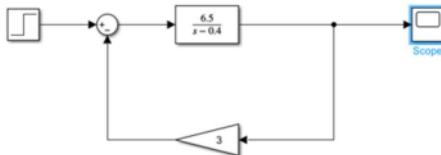


Figure 73 - Task 12 Response with a k of 3.

Below shows the root locus of one stable gain and one unstable gain using some of the values above.

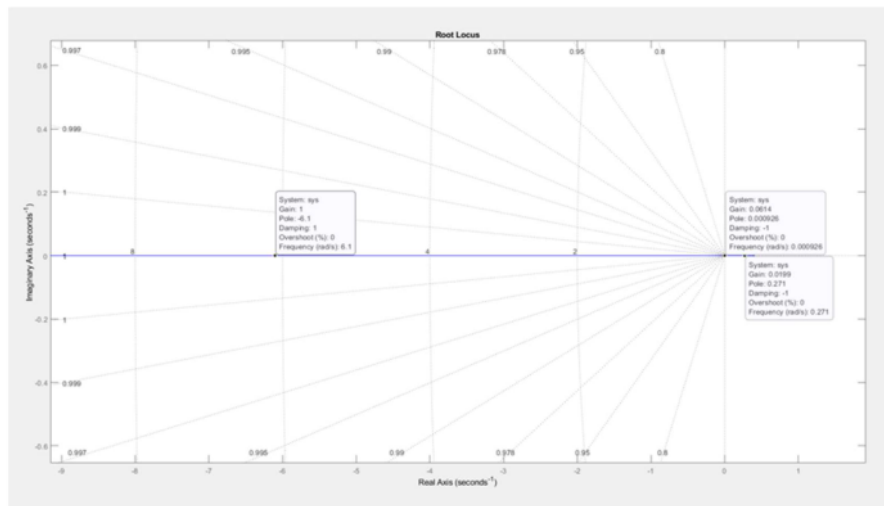


Figure 74 - Task 12 Root Locus of various gains.

## 12.5

Table of values

| K Value | Pole  | Measured Stability | Calculated Stability |
|---------|-------|--------------------|----------------------|
| 0.2     | 0.27  | Unstable           | Unstable             |
| 1       | -6.1  | Stable             | Stable               |
| 3       | -19.1 | Stable             | Stable               |

Figure 75 - Task 12 Error Table.



## 12.6

From my findings, it is obvious to see that if the gain is large enough it produces a stable system. The negative feedback is used because positive feedback can make the system unstable. The root locus graph shows for the system to be stable the pole must be in the left-hand plane. If the pole is at zero the system is neither stable or unstable and shown from my calculation and graph measurements, 0.0614 would create this.

## Task 13. DC Motor Model Analysis

### 13.1

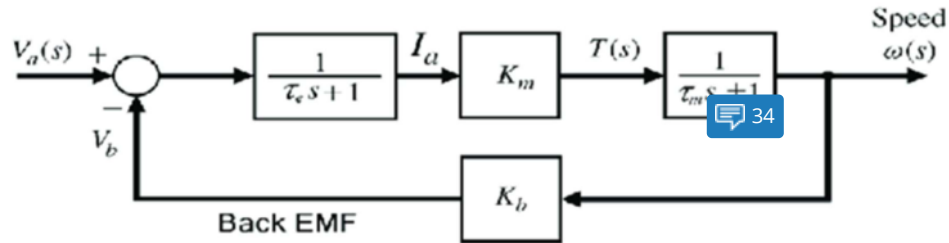


Figure 76 - DC Motor Model.

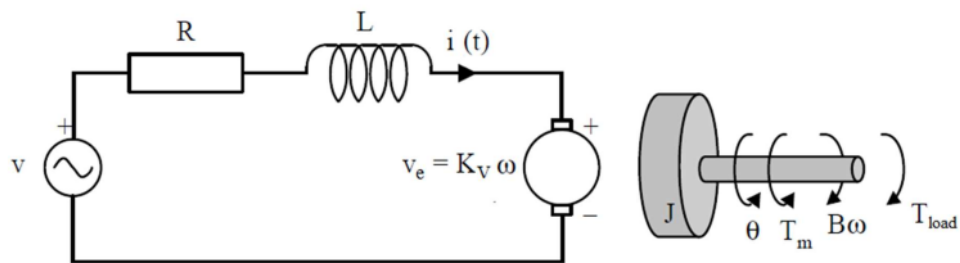


Figure 77 - DC Motor Circuit.

$$G(s) = \frac{k\omega n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

### 13.2

As shown before, we deduced the damping factor, natural frequency, stall torque and the theoretical frictionless no-load-speed.

$$\omega_n = \sqrt{\frac{R_a b}{L_a J} + \frac{K_T K_e}{L_a J}} = \sqrt{\frac{1.5 * (4.6 * 10^{-6})}{0.165 * 0.0042} + \frac{0.063 * 0.063}{0.165 * 0.0042}} = 2.395$$

$$\zeta = \frac{\left(\frac{b}{J} + \frac{R_a}{L_a}\right)}{2\omega_n} = \frac{\left(\frac{4.6 * 10^{-6}}{0.0042} + \frac{1.5}{0.165}\right)}{2 * 2.395} = 0.0115$$

$$T_{STALL} = \frac{K_m V_a}{R_a} = \frac{0.063 * 15}{1.5} = 0.63 \text{ Nm}$$

$$(Without\ friction)\Omega_{NL} = \frac{V_a}{K_m} = \frac{15}{0.063} = 238.095\ rad/s$$

$$(With\ friction)\Omega = \frac{K_T V_a}{bR_a + K_T K_e} = \frac{0.063 * 15}{(4.6 * 10^{-6}) * 1.5 + 0.063 * 0.063} = 237.6820$$

### 13.3

$$a = 1$$

$$b = 2\zeta\omega_n = \left( \frac{b}{J} + \frac{R_a}{L_a} \right) = \left( \frac{4.6 * 10^{-6}}{0.0042} + \frac{1.5}{0.165} \right) = 9.092$$

$$c = \omega_n^2 = \left( \frac{R_a}{L_a} + \frac{K_T K_e}{L_a J} \right) = \frac{1.5 * (4.6 * 10^{-6})}{0.165 * 0.0042} + \frac{0.063 * 0.063}{0.165 * 0.0042} = 5.737$$

Poles:

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{-9.092 \pm \sqrt{9.092^2 - 4 * 1 * 5.737}}{2 * 1} = -0.6822\ or\ -8.4098$$

```
num = [1];
den = [1, 0.6822];
[zz,pp,kk] = tf2zp(num,den);
pzmap(pp,zz);
```

Figure 78 - Task 13 Matlab code first pole.

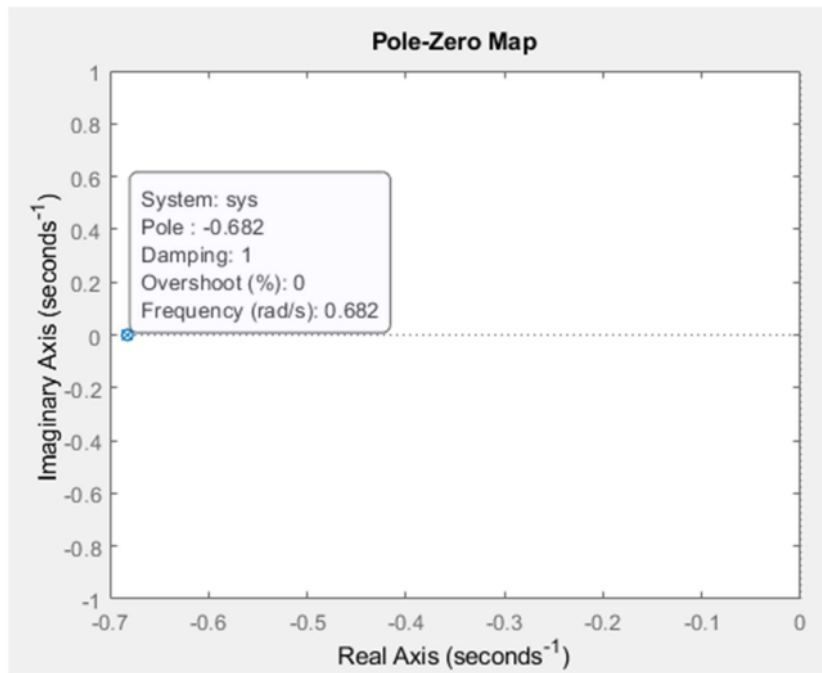


Figure 79 - Task 13 Pole-Zero Map first pole.

```
num = [1];
den = [1, 8.4098];
[zz,pp,kk] = tf2zp(num,den);
pzmap(pp,zz);
```

Figure 80 - Task 13 Matlab code second pole.

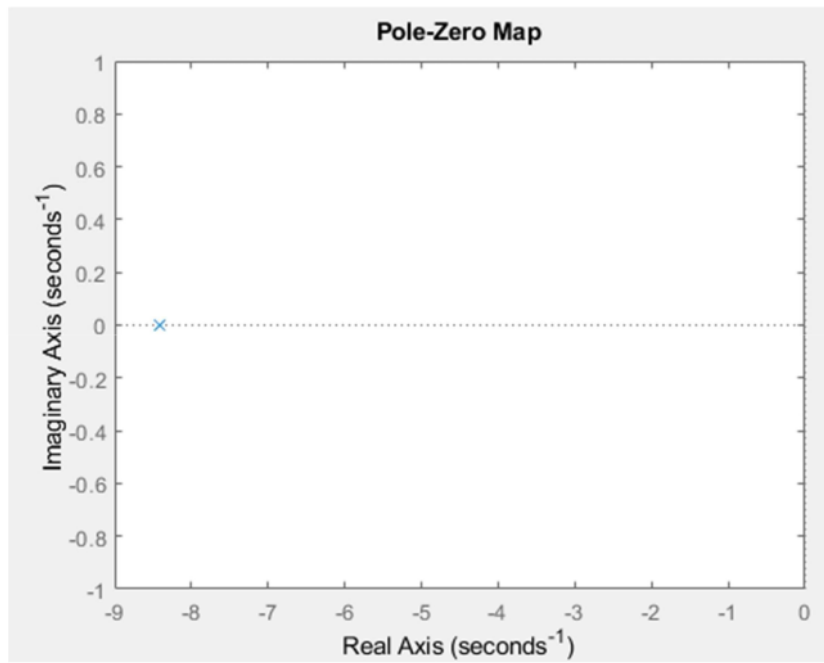


Figure 81 - Task 13 Pole-Zero Map second pole.

### 13.4

Simulink model of closed loop.

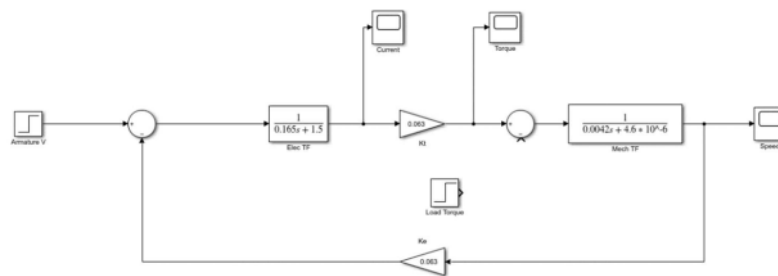


Figure 82 - Task 13 Simulink model.

### 13.5

Here is the highest speed of the motor with friction being simulated, this is over a 30 second duration with an armature voltage of 15Vdc with a step input. By setting the disturbance to zero this made certain there was no load.

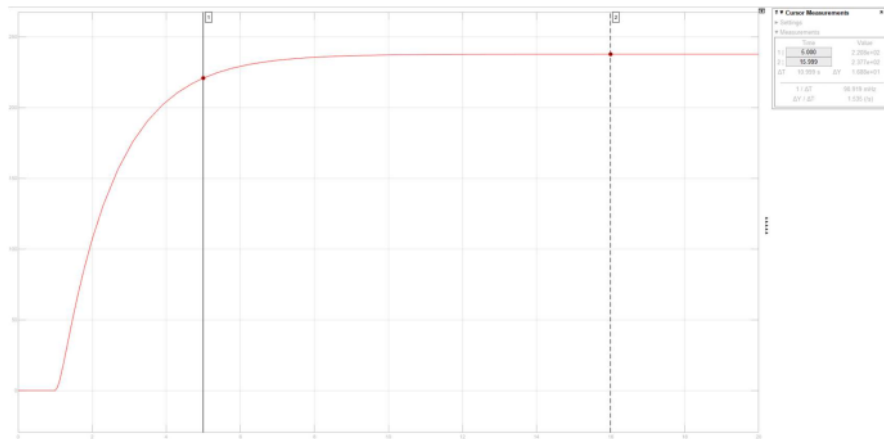


Figure 83 - Task 13 Open loop response with no load just friction.

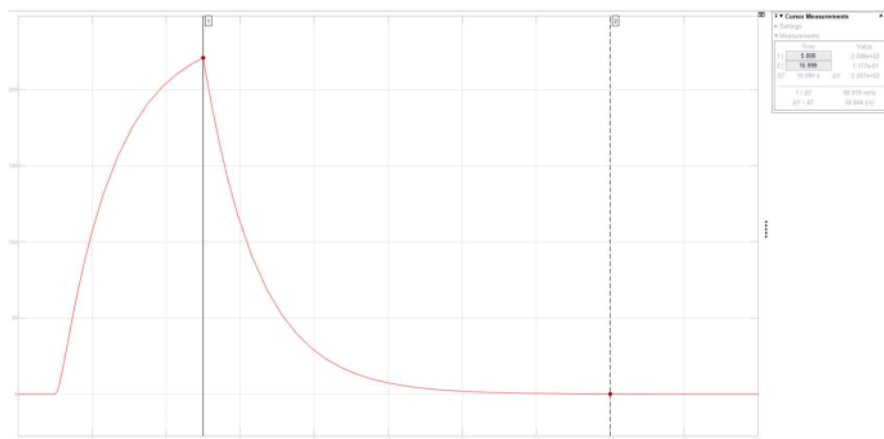


Figure 84 - Task 13 Closed loop response with TSTALL added.

### 13.6

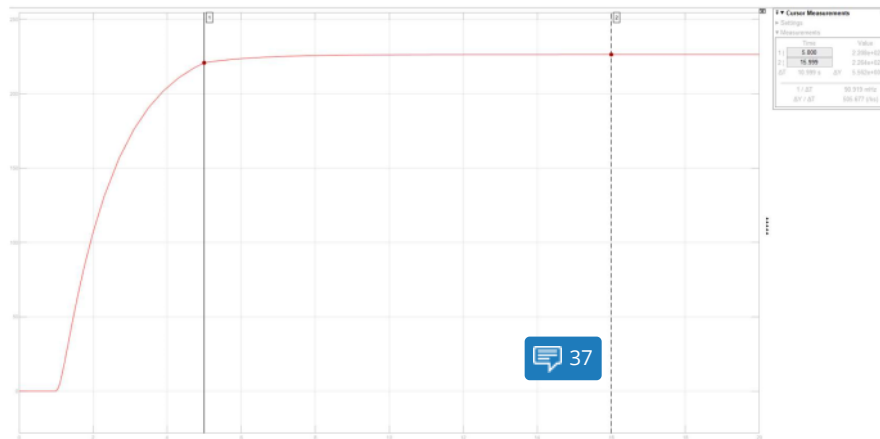


Figure 85 - Task 13 Closed loop response with a disturbance of 0.03.

$$\Omega_L = \frac{V_a - \frac{R_a T_L}{K_T}}{\frac{R_a b}{K_T} + K_e} = \frac{15 - \frac{1.5 * 0.03}{0.063}}{\frac{1.5 * (4.6 * 10^{-6})}{0.063} + 0.063} = 226.3638 \text{ rad/s}$$

### 13.7

|                       | Calculated | Simulated | Error  |
|-----------------------|------------|-----------|--------|
| No Load Speed (rad/s) | 237.682    | 237.7     | 0.018  |
| Loaded Speed (rad/s)  | 226.3638   | 226.4     | 0.0362 |

Figure 86 - Task 13 Error Table.

### 13.8

The error between the calculated and simulated result are minimal as shown above. As you can see that when a load is applied the speed is reduced. The calculated TSTALL is the minimum amount of torque required for the motor to stall.

## Task 14. Proportional Speed Control System

### 14.1

The motor model converted into a subsystem with a step speed setpoint of 140 rad/s as shown in *Figure 87*.

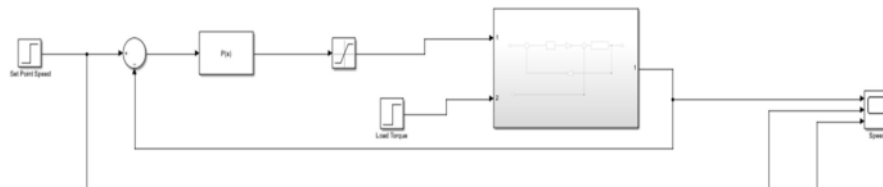


*Figure 87 - Task 14 Subsystem.*

In *Figure 88*, I have run the auto tune feature to find out the optimum value for the constant  $K_p$ .

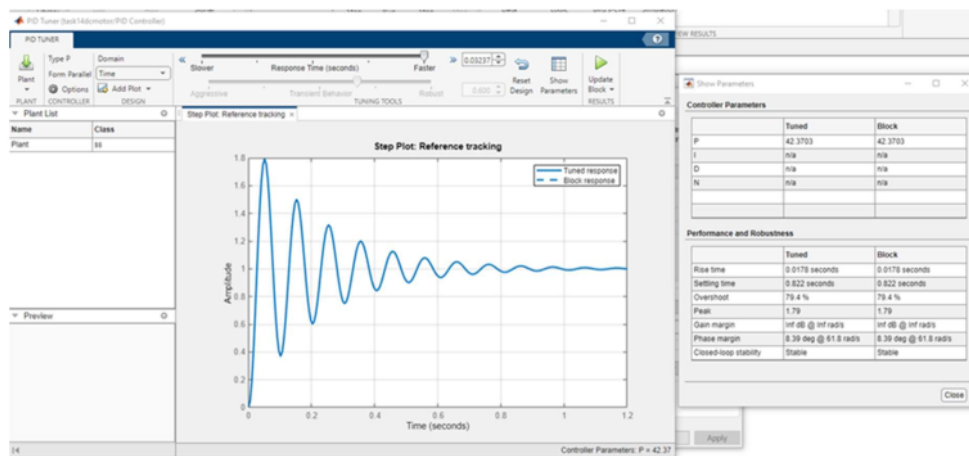


*Figure 88 - Auto tune feature for optimum value.*

### 14.2

I have then incorporated the system two more times and fed the speed output signals into the scope. The two new values have been adjusted and now they are both below the auto tuned value which I earlier created.

Block Parameters: PID Controller1

PID 1dof (mask) (link)

This block implements continuous- and discrete-time PID control algorithms and includes advanced features such as anti-windup, external reset, and signal tracking. You can tune the PID gains automatically using the 'Tune...' button (requires Simulink Control Design).

Controller: P Form: Parallel

Time domain:

☒ Continuous-time

☐ Discrete-time

Discrete-time settings

Sample time (-1 for inherited): -1

Compensator formula

P

Main Initialization Output Saturation Data Types State Attributes

Controller parameters

Source: internal

Proportional (P): 0.713417432363593

Automated tuning

Select tuning method: Transfer Function Based (PID Tuner App) Tune...

☒ Enable zero-crossing detection

OK Cancel Help Apply

Figure 89 - Second Kp Value.

Show Parameters

Controller Parameters

|   | Tuned   | Block   |
|---|---------|---------|
| P | 0.71342 | 0.71342 |
| I | n/a     | n/a     |
| D | n/a     | n/a     |
| N | n/a     | n/a     |

Performance and Robustness

|                       | Tuned               | Block               |
|-----------------------|---------------------|---------------------|
| Rise time             | 0.205 seconds       | 0.205 seconds       |
| Settling time         | 0.691 seconds       | 0.691 seconds       |
| Overshoot             | 13.2 %              | 13.2 %              |
| Peak                  | 1.04                | 1.04                |
| Gain margin           | inf dB @ inf rad/s  | inf dB @ inf rad/s  |
| Phase margin          | 60 deg @ 6.18 rad/s | 60 deg @ 6.18 rad/s |
| Closed-loop stability | Stable              | Stable              |

Close

Figure 90 - Second Kp Parameters.

Block Parameters: PID Controller2

PID 1dof (mask) (link)

This block implements continuous- and discrete-time PID control algorithms and includes advanced features such as anti-windup, external reset, and signal tracking. You can tune the PID gains automatically using the 'Tune...' button (requires Simulink Control Design).

Controller: P Form: Parallel

Time domain:

☒ Continuous-time

☐ Discrete-time

Discrete-time settings

Sample time (-1 for inherited): -1

Compensator formula

P

Main Initialization Output Saturation Data Types State Attributes

Controller parameters

Source: Internal

Proportional (P): 0.0853691394403448

Automated tuning

Select tuning method: Transfer Function Based (PID Tuner App) Tune...

☒ Enable zero-crossing detection

OK Cancel Help Apply

Figure 91 - Third Kp Value.

Show Parameters

Controller Parameters

|   | Tuned    | Block    |
|---|----------|----------|
| P | 0.085369 | 0.085369 |
| I | n/a      | n/a      |
| D | n/a      | n/a      |
| N | n/a      | n/a      |

Performance and Robustness

|                       | Tuned                 | Block                 |
|-----------------------|-----------------------|-----------------------|
| Rise time             | 1.24 seconds          | 1.24 seconds          |
| Settling time         | 2.25 seconds          | 2.25 seconds          |
| Overshoot             | 0 %                   | 0 %                   |
| Peak                  | 0.575                 | 0.575                 |
| Gain margin           | Inf dB @ Inf rad/s    | Inf dB @ Inf rad/s    |
| Phase margin          | 134 deg @ 0.618 rad/s | 134 deg @ 0.618 rad/s |
| Closed-loop stability | Stable                | Stable                |

Close

Figure 92 - Third Kp Parameters.

In Figure 93, is the model being simulated, with all the results collated into Figure 94, such as the steady state error, rise time, and overshoot of all three responses.

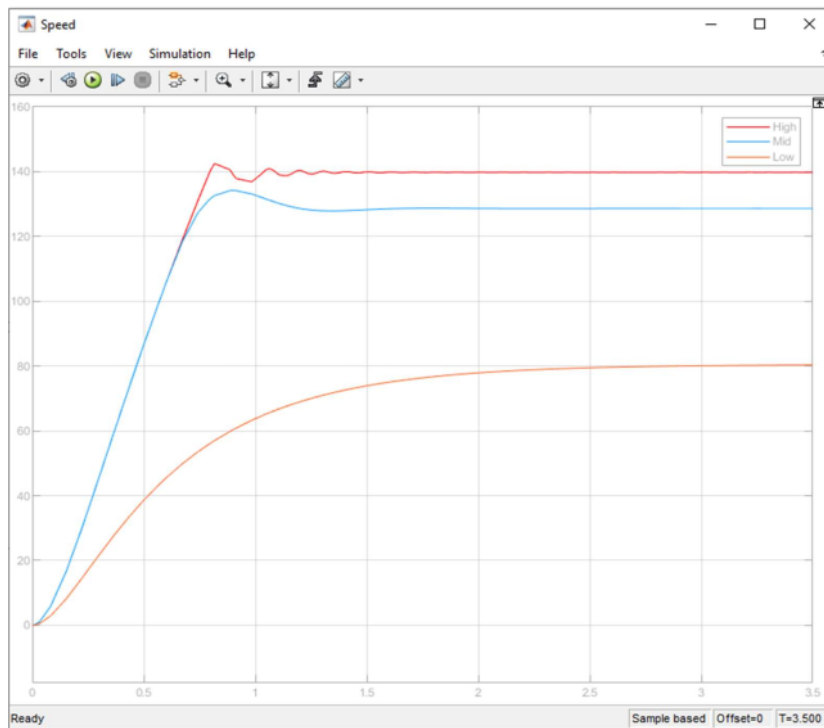


Figure 93 - Task 14 Model Simulation.

### 14.3

When increasing the  $K_p$  the overshoot increases, and its rise time reduces so it becomes much faster. When the  $K_p$  is decreased the overshoot also decreases meanwhile the steady state error rises drastically and the rise time can enter being over one second.

### 14.4

| Kp Value | Steady State Error | Rise Time (s) | Overshoot | Settling Time (s) |
|----------|--------------------|---------------|-----------|-------------------|
| 42.3703  | 0                  | 0.0178        | 79.38%    | 0.822             |
| 0.71342  | 12.05              | 0.205         | 13.26%    | 0.691             |
| 0.085369 | 60                 | 1.24          | 0%        | 2.25              |

Figure 94 - Kp Value Table Measurements.

### 14.5

When the steady error is minimal the overshoot is high, this is correlated to the rise time. If the rise time is small for example under 0.02 this means the  $K_p$  value will be large, and the steady state error will be near to nothing. The results shown provide evidence to these statements, there is an example of a 'High', 'Mid' and 'Low'  $K_p$  values to show a distinct difference in the measured value.

## Task 15. Proportional-Integral Speed Control System.

### 15.1

Below is the first controller set to PI and has been auto tuned, I then progressed to complete this on the other controllers ensuring the Kp is the same value in all three systems.

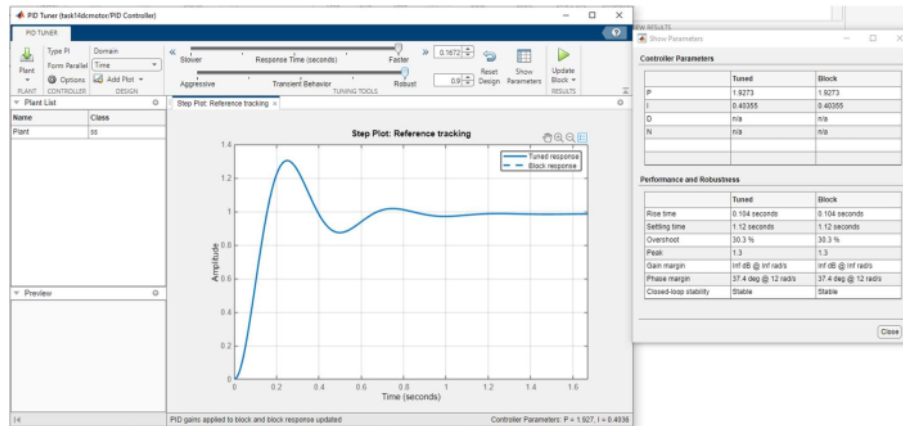


Figure 95 – Auto tune feature with optimum value.

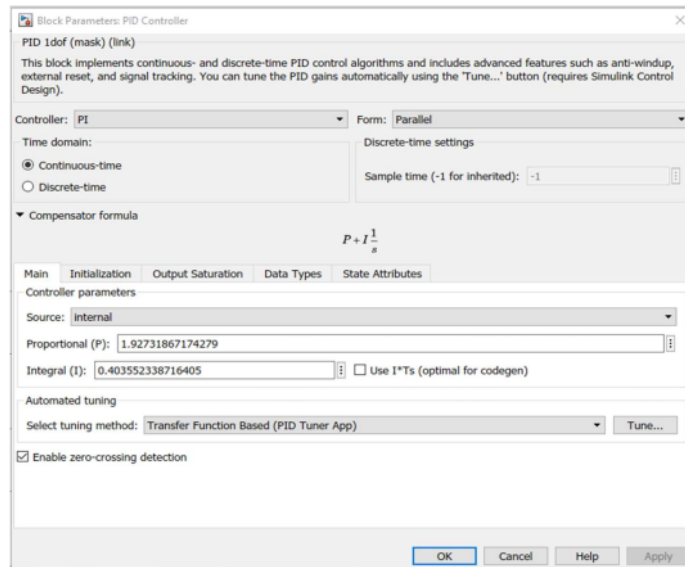


Figure 96 - Auto tuned value.

## 15.2

I have changed the values of the Ki on the other two controllers to 0.1 and 1, as shown in the Figures below.

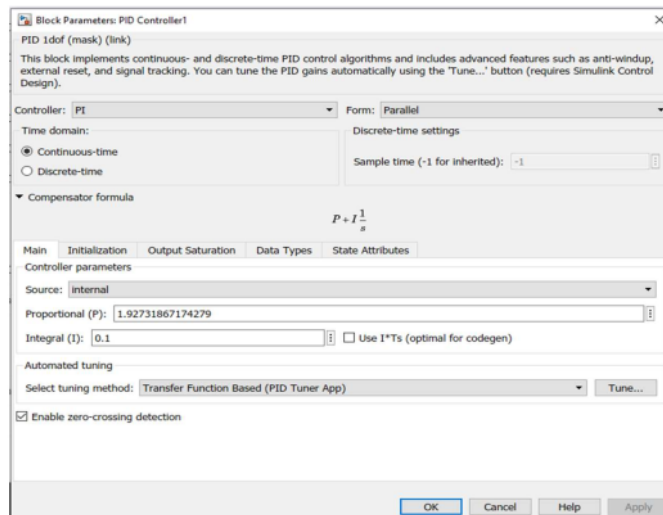


Figure 97 - Second PI controller showing Ki value.

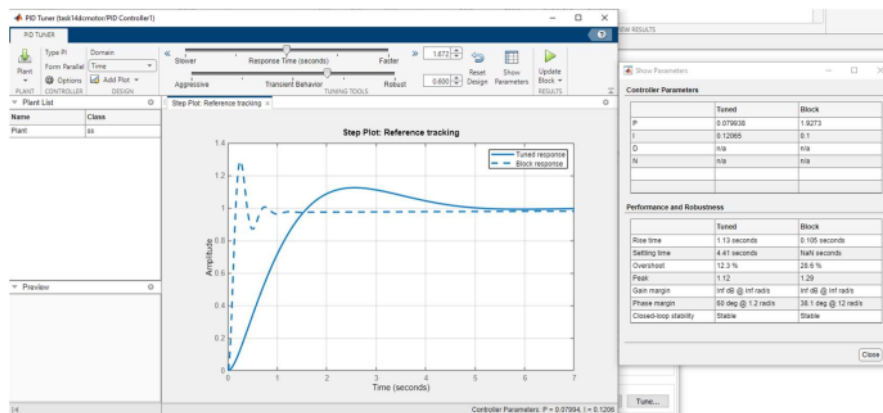


Figure 98 - Second PI controller's parameters.

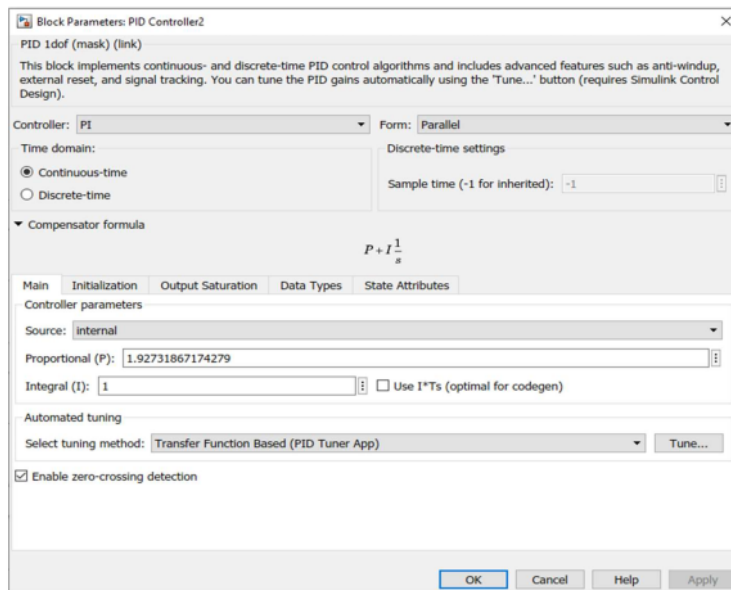


Figure 100 – Third PI controller showing Ki Value.

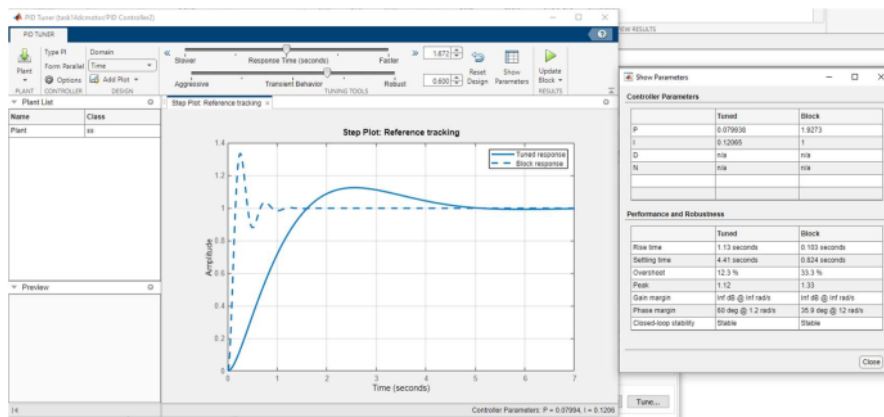


Figure 99 - Third PI controller's parameters.

### 15.3

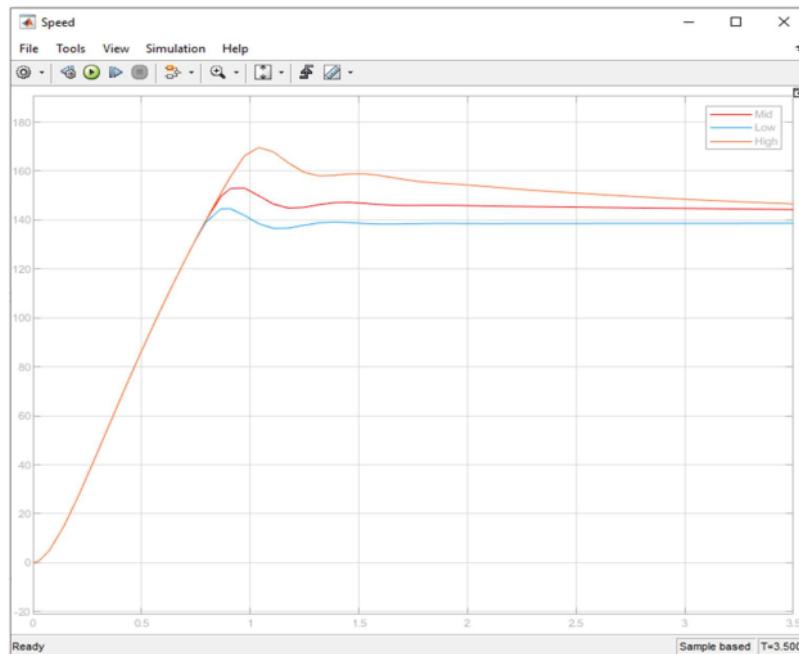


Figure 101 - Response of varying  $K_i$ .

| Ki Value | Steady State Error | Rise Time (s) | Overshoot | Settling Time (s) |
|----------|--------------------|---------------|-----------|-------------------|
| 0.40335  | 0                  | 0.104         | 30.30%    | 1.12              |
| 0.1      | 6                  | 0.105         | 28.60%    | NaN               |
| 1        | 2                  | 0.103         | 33.30%    | 0.824             |

Figure 102 –  $K_i$  Value Table Measurements.

When the lower  $K_i$  value was selected even though it is only 0.3 difference compared to the second value selected its steady state error was three times the difference. As shown in the results table the lower the  $K_i$  value the quicker the settling time with 0.1 resulting in nanoseconds. Interesting the larger  $K_i$  Value doesn't have a larger settling time than the tuned value. Each value has a similar oscillation response, they are just varying in rise times and overshoot percentage slightly. Introducing the integral control when tuned has reduced the overshoot by over half compared to just having tuned proportional control response.

## Task 16. Proportional-Integral-Derivative Speed Control System

### 16.1

Here all three controllers have the same autotuned value of Kp and Ki.

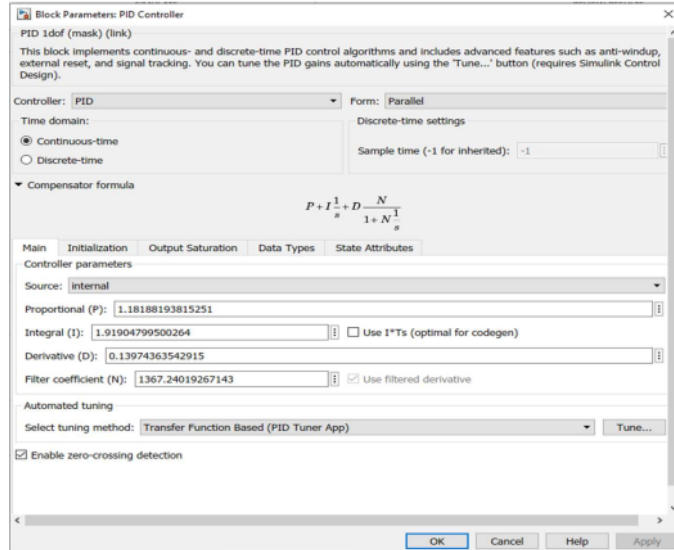


Figure 103 - First controller with Kp & Ki values the same.

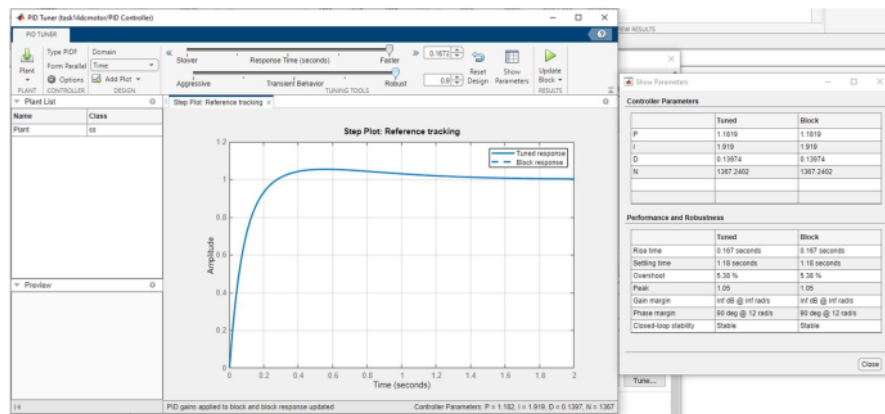


Figure 104 - First controller parameters.

## 16.2

As shown the effect of varying the Kd can be much more harsh increase.

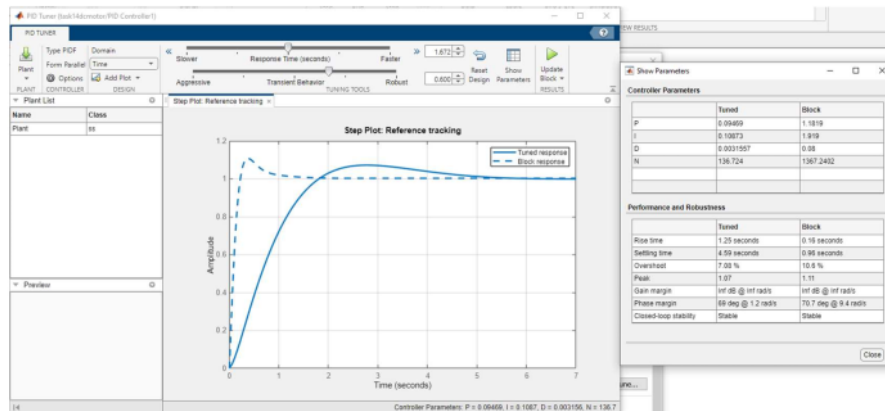


Figure 105 - Second controller parameters.

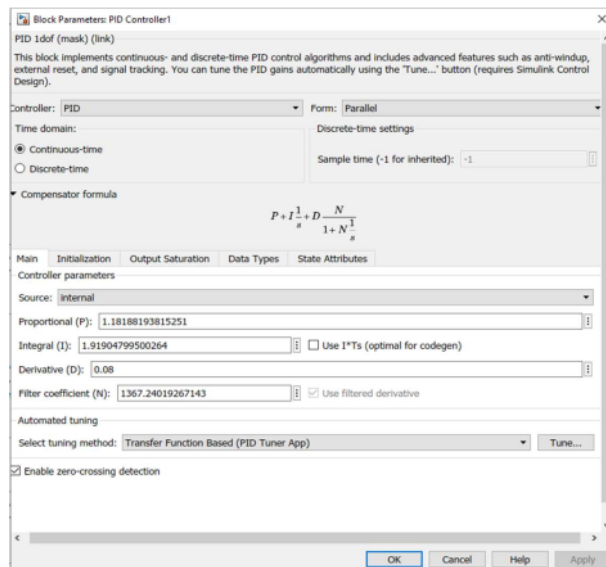


Figure 106 - Second controller with a varied Kd of 0.08.

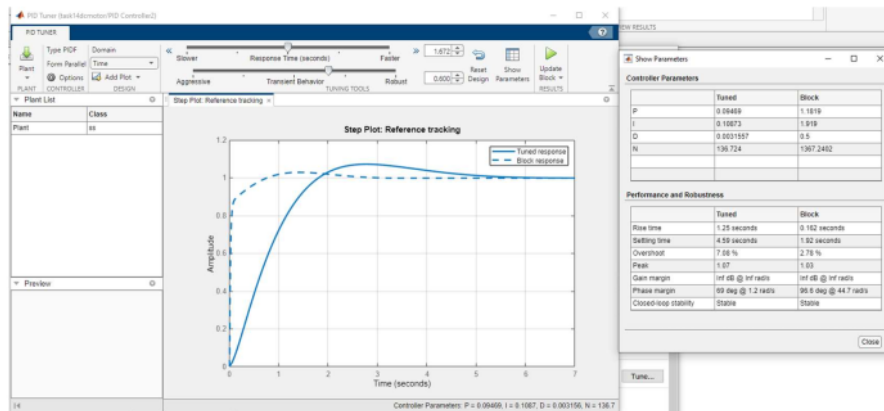


Figure 107 - Third controller parameters.

The figure shows the 'Block Parameters: PID Controller2' dialog box. The 'Controller' is set to 'PID' and the 'Form' is 'Parallel'. The 'Time domain' is set to 'Continuous-time'. The 'Compensator formula' is displayed as:

$$P + I \frac{1}{s} + D \frac{N}{1 + N \frac{1}{s}}$$

The 'Main' tab is selected, showing the following parameters:

- Source: internal
- Proportional (P): 1.18188193815251
- Integral (I): 1.91904799500264
- Derivative (D): 0.5
- Filter coefficient (N): 1367.24019267143

The 'Automated tuning' section shows the 'Select tuning method' set to 'Transfer Function Based (PID Tuner App)' with a 'Tune...' button. The 'Enable zero-crossing detection' checkbox is checked. The dialog box has 'OK', 'Cancel', 'Help', and 'Apply' buttons at the bottom.

Figure 108 - Third controller with a varied Kd of 0.5.

### 16.3

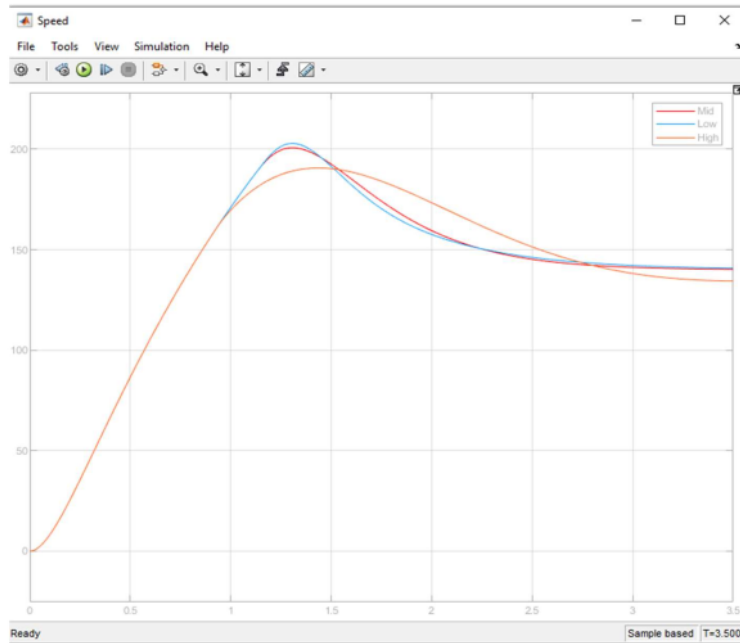


Figure 109 - Response of the varying Kd.

| Kd Value | Steady State Error | Rise Time (s) | Overshoot | Settling Time (s) |
|----------|--------------------|---------------|-----------|-------------------|
| 0.13974  | 0                  | 0.167         | 5.38%     | 1.18              |
| 0.08     | 0.5                | 0.16          | 10.60%    | 0.96              |
| 0.5      | 6                  | 0.162         | 2.78%     | 1.92              |

Figure 110 - Kd Value Table Measurements.

As shown by the results the Kd Value has a clear effect on the overshoot and settling time. The two selected values of Kd work in an opposite direction to each other, if the overshoot has increased its settling time has decreased and vice versa. The tuned Kd Value has the slowest rise time; however, the selected values are only slightly faster by a few milliseconds. By adding a derivative control this produces a response with minimal oscillations compared to just having a proportional and integral control.



## Task 17. Controller Comparisons

### 17.1

In the following figures are each of the controllers with each having different control parameters regarding P, PI and PID.

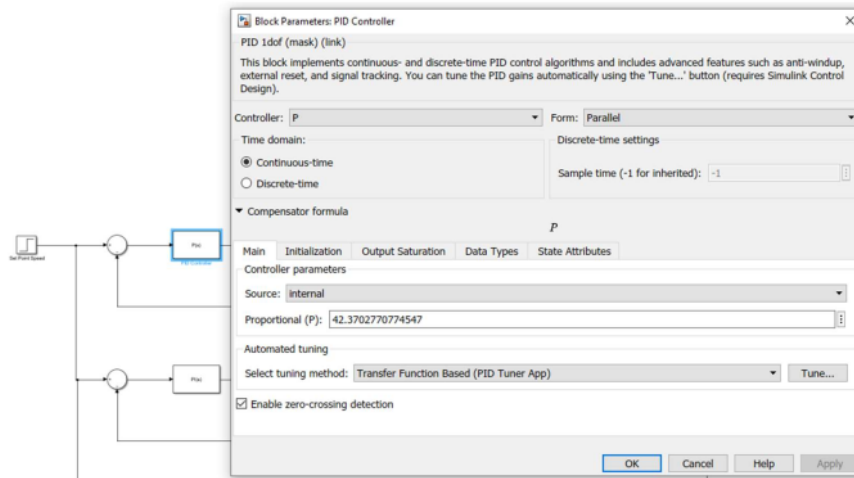


Figure 111 - First controller with just a  $K_p$  value.

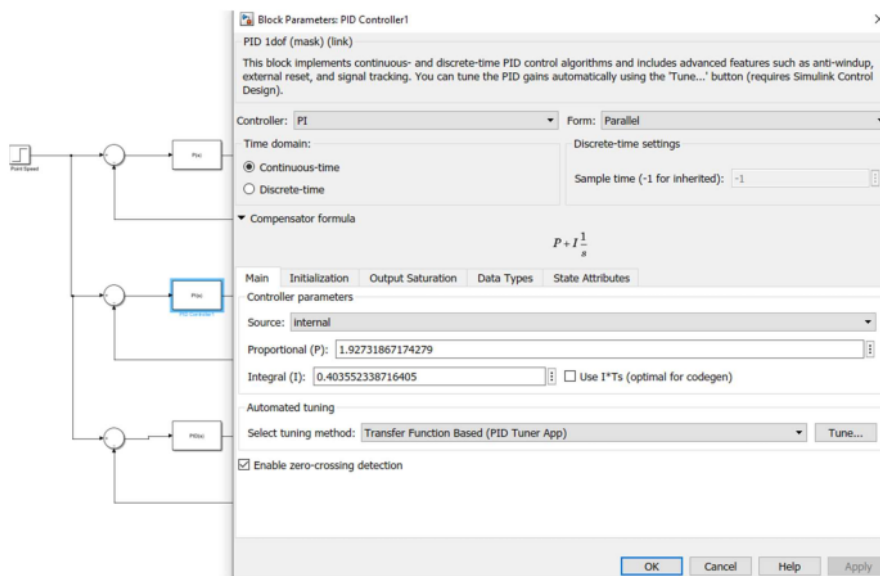


Figure 112 - Second controller with a  $K_p$  and a  $K_i$  value.

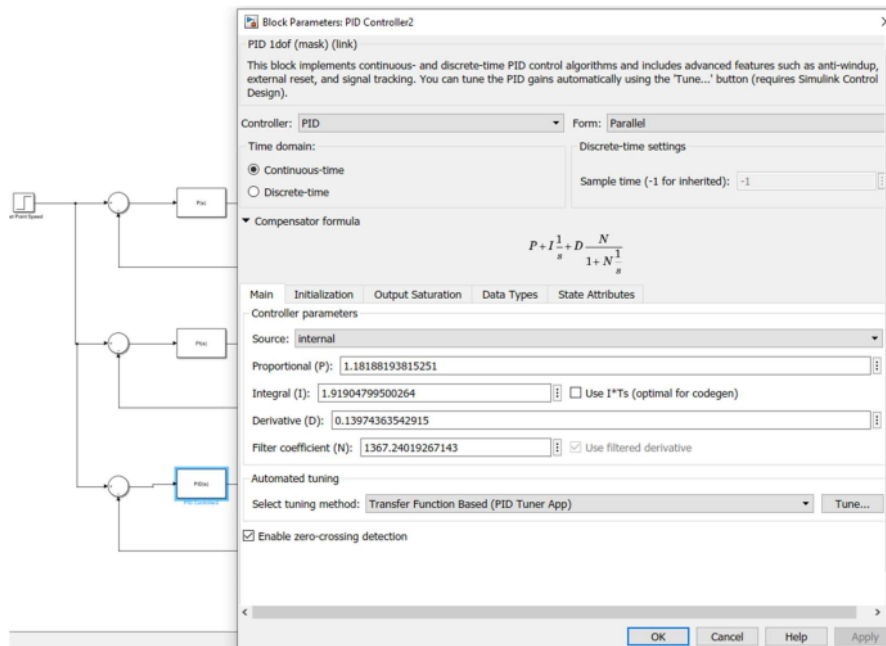


Figure 113 - Third controller with  $K_p$ ,  $K_i$  and  $K_d$  value.

## 17.2

Running the system produced Figure 110, demonstrating how the different types of controller performs.

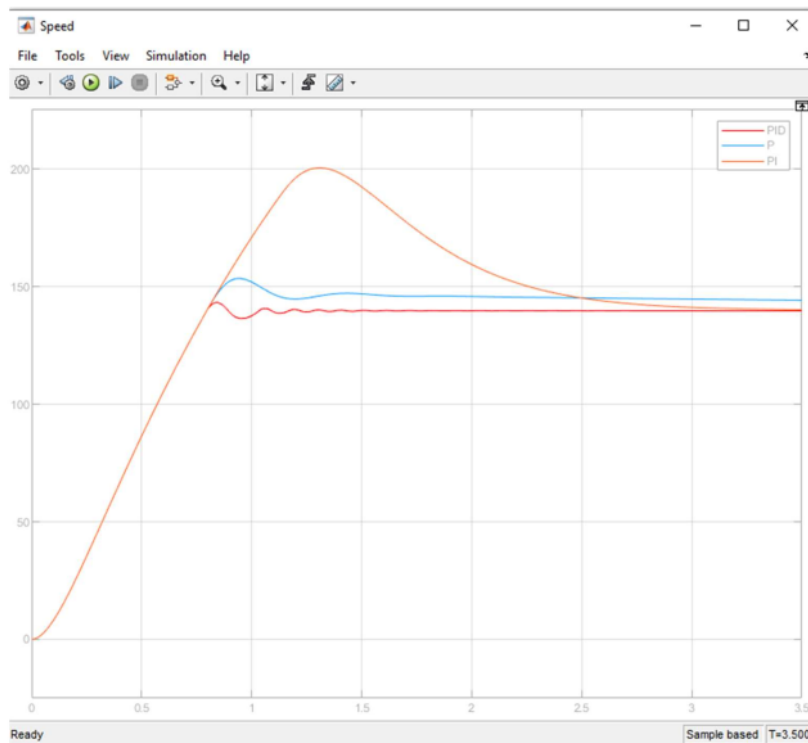


Figure 114 - Response of all three types of controller.

### 17.3

The parameters from each of the values as shown in Figures 88, 95 & 104.

|     | Kp Value | Ki Value | Kd Value | Steady State Error | Rise Time (s) | Overshoot | Settling Time (s) |
|-----|----------|----------|----------|--------------------|---------------|-----------|-------------------|
| P   | 42.3702  |          |          | 4                  | 0.0178        | 79.40%    | 0.822             |
| PI  | 1.9273   | 0.4035   |          | 0                  | 0.104         | 30.30%    | 1.12              |
| PID | 1.1818   | 1.919    | 0.1397   | 0                  | 0.167         | 5.38%     | 1.18              |

Figure 115 - PID K Value Measurements.

As shown in the table above incorporating the proportional, integral and derivative control reduces the overshoot however this slightly increases the settling time. Using only the proportional control the overshoot is over 50%, with only steady state error out of each of the different options of control. To conclude it is evident that the PID control is best due to its accurate control trying to minimise overshoot in a respectable time. The disadvantage of proportional control is that it has some sort of steady state error compared to the other two control t



## Task 18. Overall Conclusions and Recommendations.

To begin with carrying out transient analysis on circuits which is an evaluation of a circuit response over a set area in time. This was performed on RC and RL circuits to calculate the difference between the simulated version and the calculated results. The next aspect was calculating first and second order responses, these responses are allocated to different areas of the slope. These were achieved on parallel electronic circuits, again looking at the calculated results to the simulations completed on Matlab.

Carrying out the simulations of cascading filters gave an insight to understanding that increasing the order of the filter the more selective the filter becomes. In the filters section of the assignment, it became apparent that it can be difficult to select the exact points on the simulations on Matlab because of the cursor movement. This created an error in the tables created but the reasoning behind it was taken into account. Moving from first order to second order it was evident that the earlier assumption that the increase of orders filters it more. Some of the results had errors however, this was because of the rounding of the numbers in the calculation stage. Researching a type of filter gave a more grounded understanding of what was trying to be created.

At the start of the control section of the assignment open loop responses were evaluated, this was to create an understanding of stable and unstable systems and how to use evaluate a Pole-Zero Map to come to that conclusion. This carried onto closed loops, with the integration of PID control and the evaluation of P, I and D individually. This feature of the assignment thoroughly built and understood how to control a closed up using PID control and why each of them have their own importance.

The recommendations for this module would be to introduce research sections so a further understanding can be improved. This could be a small area for the three sections electrical, electronics and control. The software Matlab was a consistent issue trying to perform the simulated results. The results measurement was difficult due to the cursor selection which became worse on the MATLAB online. In the future maybe a better software can be used or to not use the MATLAB online throughout the assignment to ensure the errors were as small as possible.

To give the learners a more of a hands-on experience carrying out some of the systems circuitry physically can be advantageous. Some learners can benefit from this drastically others it may not make as much difference. Rather than keeping the analysis to first and

second order responses a few other systems could have been expanded to practice the theory that the larger the order the more filtration achieved.

## 19. Appendix

Wikipedia, 2023. *Butterworth filter*. [Online]  
Available at: [https://en.wikipedia.org/wiki/Butterworth\\_filter](https://en.wikipedia.org/wiki/Butterworth_filter)  
[Accessed 14th February 2023].

FINAL GRADE

GENERAL COMMENTS

Instructor

71 /100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5



Comment 1

avoid heading style one for subheadings which are numerical only

PAGE 6

PAGE 7

PAGE 8

PAGE 9



Comment 2

Laplace



Comment 3

good

PAGE 10



#### Comment 4

explain what this is

PAGE 11

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#### Comment 5

this needs more explanation, state the equation of the time response

PAGE 12

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PAGE 13

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#### Comment 6

WW



#### Comment 7

comment as per task 1

PAGE 14

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#### Comment 8

define the quantities you are calculating



#### Comment 9

WW

PAGE 15

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#### Comment 10

WW



#### Comment 11

descriptive and vague

PAGE 16

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PAGE 17

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#### Comment 12

comment as per task 3



### Comment 13

need to explain how you arrived at these equations in basic terms, e.g. the TF



### Comment 14

explain sigma



### Comment 15

WW



### Comment 16

state it at least



### Comment 17

again a lot of undefined terms



### Comment 18

WW



### Comment 19

needs a definition, errors exist



### Comment 20

see previous comments, you must at least give definitions for the quantities and some explanation from the circuit

PAGE 29

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PAGE 30

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### Comment 21

put measured values from response graphs first then tabulate

PAGE 31

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### Comment 22

does not mean anything without definitions

PAGE 32

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PAGE 33

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PAGE 34

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### Comment 23

again with no definitions hard to see what the relationship is

PAGE 35

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PAGE 36

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PAGE 37

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### Comment 24

symbol ?



### Comment 25

good , more of this simple theory needed throughout report

PAGE 38

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PAGE 39

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### Comment 26

good



### Comment 27

yes, why active?



### Comment 28

explain/define



### Comment 29

good



### Comment 30

WW



### Comment 31

show TF



### Comment 32

show calculated min k



### Comment 33

good work



### Comment 34

either explain the TFs or put in the form of component values



### Comment 35

where?

PAGE 50

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### Comment 36

need to show how you arrived at this

PAGE 51

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PAGE 52

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PAGE 53

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PAGE 54

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### Comment 37

load is meant to be applied at 10 sec

PAGE 55

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PAGE 56

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PAGE 57

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PAGE 58

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### Comment 38

seems too high check graph

PAGE 59

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PAGE 60

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PAGE 61

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PAGE 62

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PAGE 63

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PAGE 64

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PAGE 65

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Comment 39

good work



Comment 40

good work

GRADING FORM: NEW CSG-RUBRIC

DREW GROVEHENDERSON

71

1. ENGAGEMENT WITH LITERATURE



NA

0

2. KNOWLEDGE AND UNDERSTANDING



Reasonably accurate and detailed knowledge has been shown, see comments regarding some

20

poorly defined areas in the first two topics, control has a better demonstration of knowledge via expanded explanations and commentary on each process. 20/30

### 3. COGNITIVE AND INTELLECTUAL



Some critical analysis of concepts and principles, though descriptive in parts, see comments. Conclusion is good. 20/30

**20**

### 4. PRACTICAL APPLICATION



Advanced application of Matlab methods and simulation, clear data and results, mostly well laid out and explained. 24/30

**24**

### 5. TRANSFERABLE SKILLS



Communication is effective and confident, topics are introduced and the analysis and conclusions are sufficiently detailed. 7/10

**7**