

# 1909750

*by* Ethan Joel

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

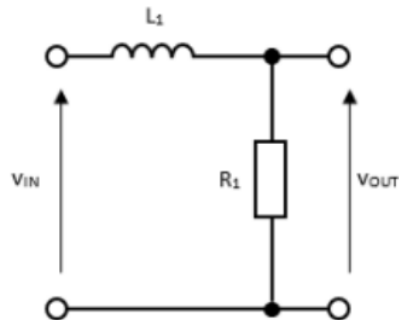


Figure 1 - RL Circuit

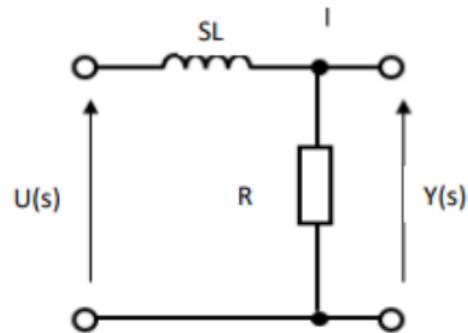


Figure 2 - Laplace Model

For the chosen circuit, the component values chosen are as follows;

- $R = 5\Omega$
- $L = 0.7H$

The time constant for this circuit can be calculated by inserting the component values into the following formula;

$$T = \frac{L}{R} = \frac{0.7}{5} = 0.14s$$

Below is the transfer function for the above circuit;

$$H(s) = \frac{1}{Ts + 1} = \frac{1}{0.14s + 1}$$

From this circuit, an exponential rise is expected in the form  $= 1 - e^{-\frac{t}{0.14}}$ .

You have worked this out correctly, well!

MATLAB Code;

```
>> num = [1];  
>> den = [0.14 1];  
>> step(num,den)  
grid  
fx >> |
```

Figure 3 - MATLAB Code

MATLAB Results

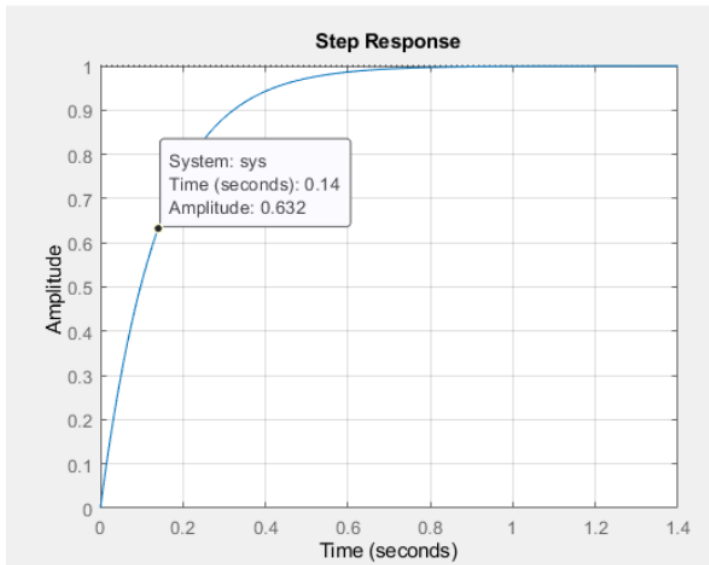


Figure 4 - MATLAB Graph

|                               |       |
|-------------------------------|-------|
| Calculated Time Constant      | 0.14s |
| Actual Time Constant (MATLAB) | 0.14s |

As you can see from the simulated graph from MATLAB, at 0.632(1 Time constant), we have a value of 0.14s. Which is exactly the same as the calculated value.

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

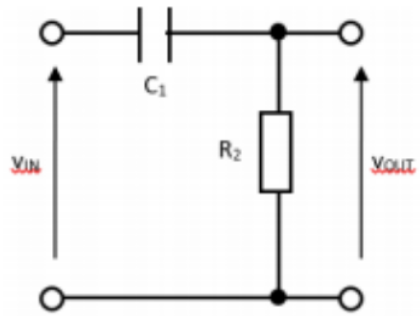


Figure 5 - RC Circuit

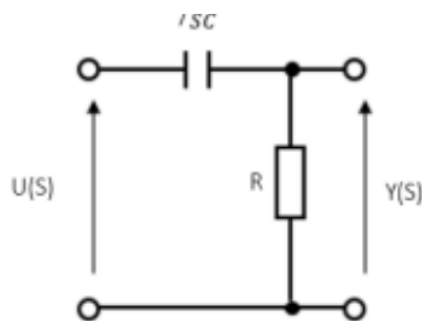


Figure 6 - Laplace Model

For the chosen circuit, the component values chosen are as follows;

- $R = 2.5k\Omega$
- $C = 3\mu F$

The time constant can be calculated by the following formula;

$$T = R \times C = 2500 \times 3 \times 10^{-6} = 7.5ms$$

The transfer function for this circuit is as follows;

$$H(s) = \frac{ts}{ts + 1} = \frac{7.5ms}{s + 1}$$

From this type of circuit and transfer function, the expected outcome of this circuit is an exponential decay in the form of  $y(t) = e^{-\frac{t}{7.5 \times 10^{-3}}}$

Next, the transfer function will be inputted into MATLAB with a step input to display a graph for the transient response. The time constant is expected to be 7.5ms at an amplitude of 0.368  $\frac{1}{2}$

MATLAB Code

```
>> num = [7.5e-3 0];
>> den = [7.5e-3 1];
>> step(num,den);
>> grid
fx >> |
```

Figure 7 - MATLAB Code

MATLAB Results

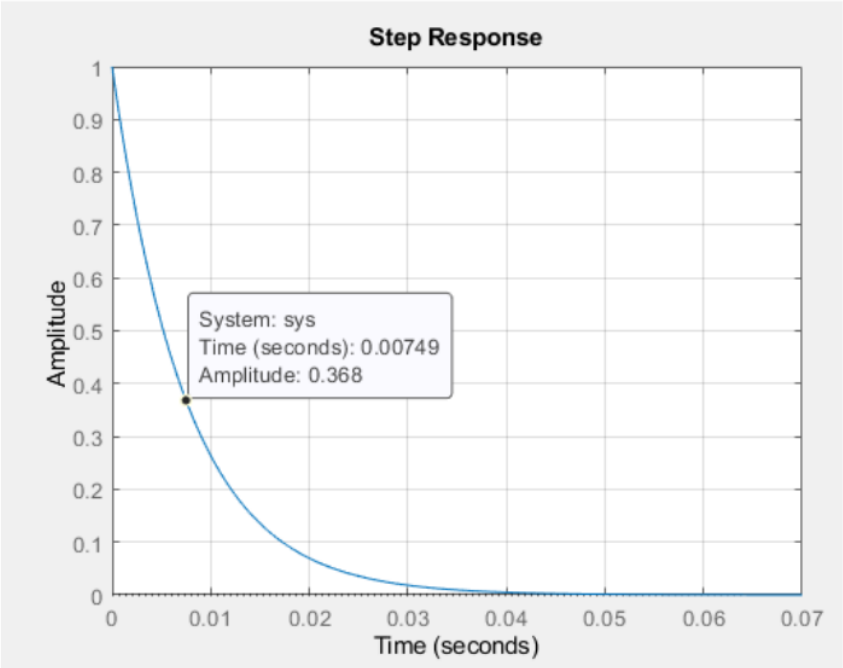


Figure 8 - MATLAB Graph

|                               |        |
|-------------------------------|--------|
| Calculated Time Constant      | 7.5ms  |
| Actual Time Constant (MATLAB) | 7.49ms |

As seen from the table of results below, the results are only 0.01ms off which is hardly anything.



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

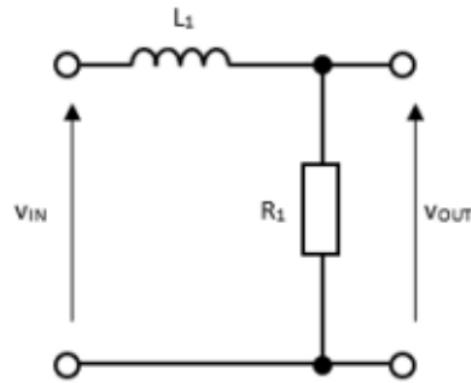


Figure 9 - RL Circuit

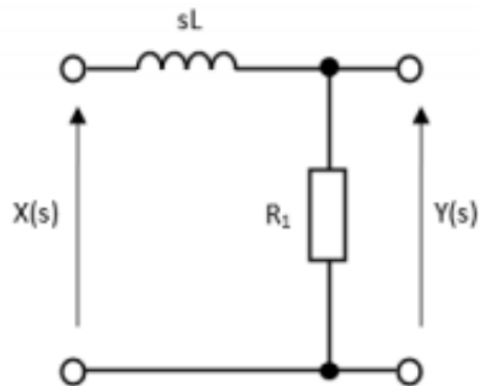


Figure 10 - Laplace Model

For the chosen circuit, the component values chosen are as follows;

- $R = 5\Omega$
- $L = 0.7H$

To find the transfer function of this circuit, the potential divider rule must be used as follows;

$$Y(s) = \frac{R}{sL + R} X(s) \qquad Y(s) = \frac{5}{s0.7 + 5} X(s)$$

$$\frac{Y(s)}{X(s)} = \frac{R/L}{S + R/L} \qquad \frac{Y(s)}{X(s)} = \frac{5/0.7}{S + 5/0.7}$$

After this, the formula above can be compared with the transfer function of a low pass filter;

$$H(s) = \frac{\omega c}{s + \omega c} = \frac{7.143}{s + 7.143}$$

$\omega c$  is known as the cut off frequency and is calculated by  $L/R$ . Therefore, it gives us a value of 7.143rad/s

With regards to Phase shift, this can be calculated by the following formula;

$$\theta(j\omega) = -\tan^{-1}\left(\frac{\omega L}{R}\right) \quad \omega = \omega c = \frac{1}{T}$$

$$\theta(j\omega) = -\tan^{-1}(1) = -45^\circ$$

Once the phase shift and cut off frequency had been calculated, the next stage involved performing a bode plot on MATLAB to see the frequency response of the circuit.

MATLAB Code

```
>> num = [7.143];
>> den = [1 7.143];
>> bode(num,den);
grid
fx >> |
```

Figure 11 - MATLAB Code

MATLAB Results

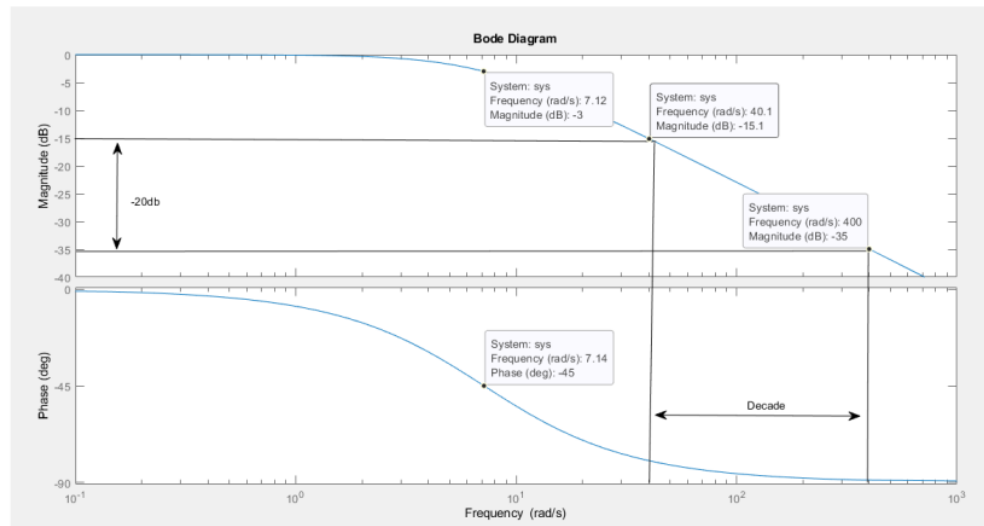


Figure 12 - MATLAB Graph

You have worked this out correctly, well

|                                 |      |        |
|---------------------------------|------|--------|
| Magnitude Difference per decade | 20db | 20.1db |
| Phase Shift                     | -45  | -45    |

As you can see from the table of results, the comparison between both the calculated values and the simulated values are almost the same. The ever so slight differences are likely down to human error when placing the cursors on the MATLAB graph. The fact the results are nearly exact proves the calculations were indeed correct.



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

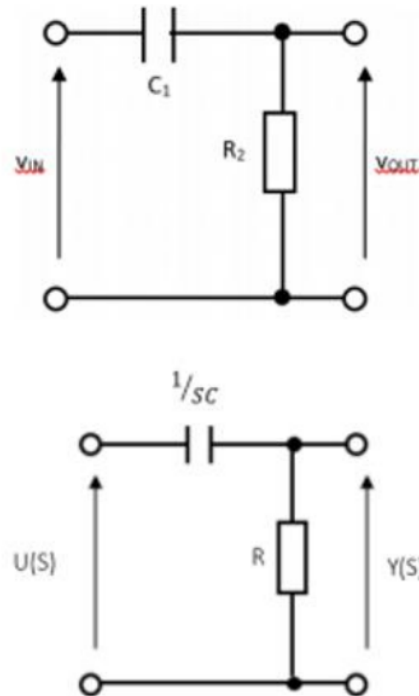


Figure 13 - Laplace Model

For the chosen circuit, the component values chosen are as follows;

- $R = 2.5k\Omega$
- $C = 3\mu F$

The time constant can be calculated by the following formula;

$$T = R \times C = 2500 \times 3 \times 10^{-6} = 7.5ms$$

The cut off frequency can be calculated by the following formula;

$$\omega C = \frac{1}{T} = \frac{1}{0.0075s} = 133.33rad/s$$

The transfer function is as follows;

$$H(s) = \frac{s}{s + \omega C} = \frac{s}{s + 133.33}$$

Phase shift

$$\theta(j\omega) = \tan^{-1}\left(\frac{1}{\omega RC}\right)$$

$$90^\circ - (\tan^{-1}(\omega RC)) = 90^\circ - 45^\circ = 45^\circ$$

Once the phase shift and cut off frequency had been calculated, the next stage involved performing a bode plot on MATLAB to see the frequency response of the circuit.

MATLAB Code

```
>> num = [1 0];  
>> den = [1 133.33];  
>> bode(num,den);  
grid  
fx >> |
```

Figure 14 - MATLAB Code

MATLAB Results

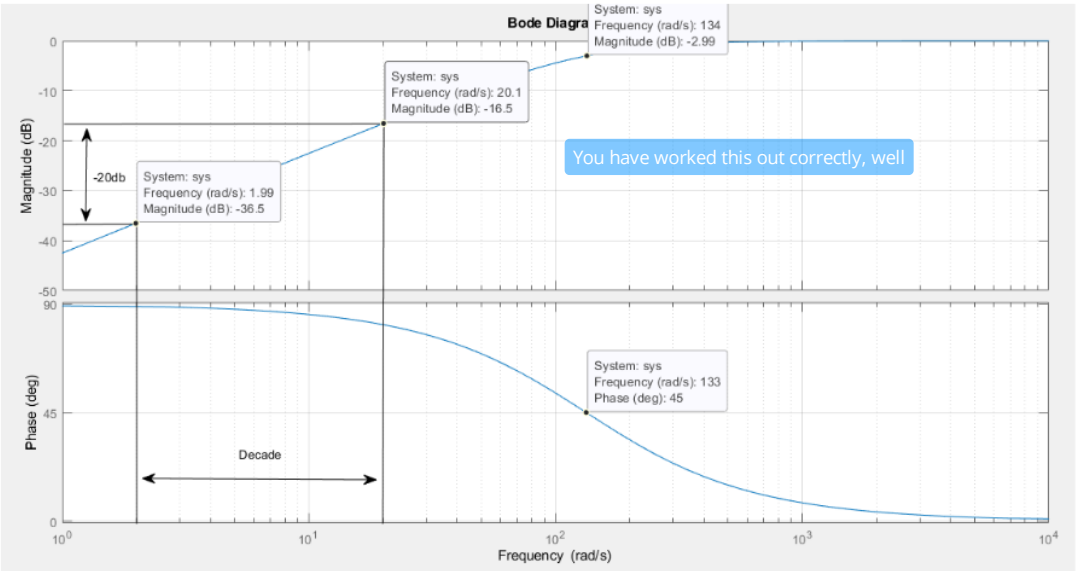


Figure 15 - MATLAB Graph

|                                 | Calculated Result (rad/s) | Simulated Result |
|---------------------------------|---------------------------|------------------|
| Cut-off Frequency at -3db       | 133.33                    | 134              |
| Magnitude Difference per decade | -20db                     | -20db            |
| Phase Shift                     | 45°                       | 45°              |

As you can see from the table of results, the comparison between both the calculated values and the simulated values are almost the same. The ever so slight differences are likely down to human error when placing the cursors on the MATLAB graph. The fact the results are nearly exact proves the calculations were indeed correct.



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

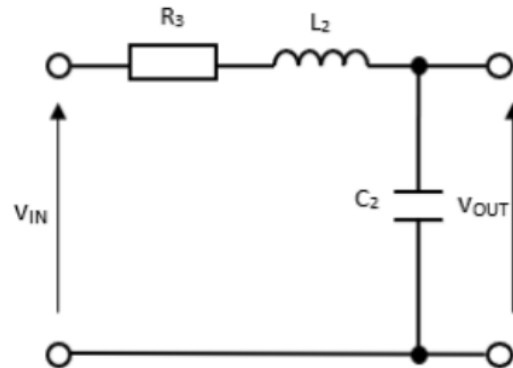


Figure 16 - Series Circuit

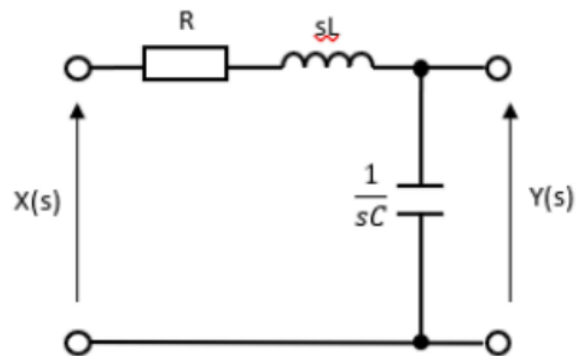


Figure 17 - Laplace Model

For the circuit above, the component values chosen are;

- $R = 25\Omega$
- $L = 0.2\text{H}$
- $C = 50\mu\text{F}$

For this circuit, the following equations are needed;

The time constant for this circuit is calculated as follows;

$$T = \frac{R}{L} = \frac{25}{0.2} = 125\text{s}$$

Incorrect

The natural frequency is calculated by;

$$\omega_n^2 = \frac{1}{LC} = \frac{1}{0.2 \times (50 \times 10^{-6})} = 100,000$$

$$\omega_n = \sqrt{100000} = 316.228\text{rad/s}$$

The transfer function for this circuit is as follows;

$$H(s) = \frac{K\omega n n^2}{s^2 + 2\zeta\omega n s + \omega n^2}$$

**K** represents the gain

**$\omega n$**  represents the natural frequency of oscillation

**$\zeta$**  represents the damping factor

As shown in the transfer function for this circuit, the ' $s^2$ ' term represents a second order function.

$$H(s) = \frac{100,000}{s^2 + 125s + 100,000}$$

When  $K = 1$

$2\zeta\omega n = R/L = 125$  therefore;

$\zeta = 125 \times 316.228$

$$\zeta = \frac{125}{2 \times 316.228} = 0.1976422$$

The value of  $\zeta$  determines the damping factor of the circuit and is explained in the key below

**$\zeta < 1$  = Underdamped**

**$\zeta > 1$  = Overdamped**

**$\zeta = 1$  = Critically damped**

**$\zeta = 0$  = No damping**

**Underdamped**

**MATLAB Code**

```
>> %underdamped
>> num = [100000];
>> den = [1 125 100000];
>> step(num,den);
grid
fx >> |
```

Figure 18 - MATLAB Code

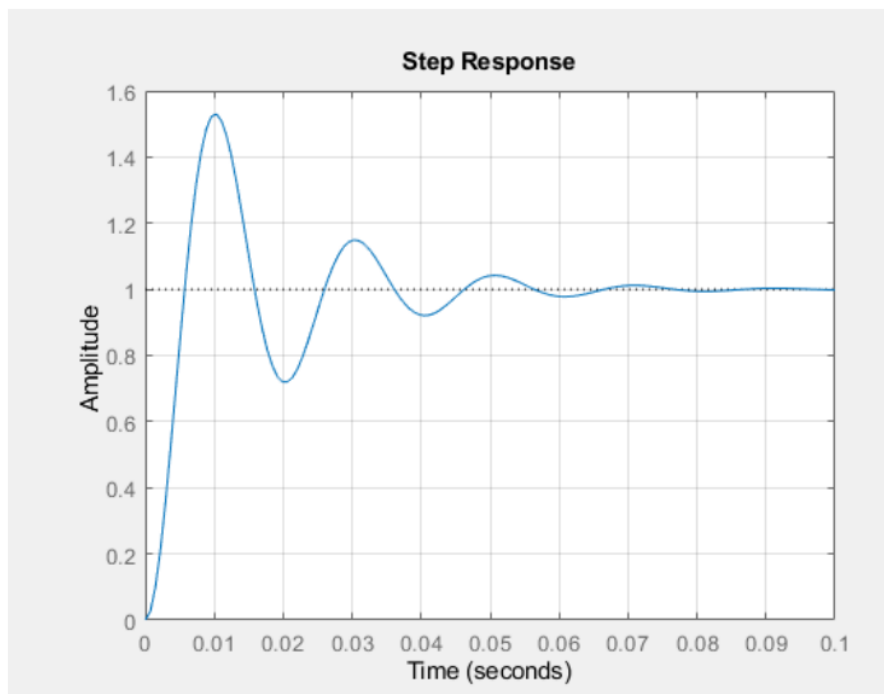


Figure 19 - MATLAB Graph

| Underdamped                                                                                                                                                                                                              |                           |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| Expected                                                                                                                                                                                                                 | Actual (Simulated Result) |
| Underdamped                                                                                                                                                                                                              | Underdamped               |
| Due to the value of Z being under 1 at 0.1976422, it's expected that the results are underdamped. This is shown clearly in Figure 5.2 where there is an initial overshoot before gradually settling at an amplitude of 1 |                           |

### Overdamped

To ensure a circuit is 'Overdamped', the damping factor must be a value greater than 1. To ensure this, the value of the resistor in the circuit will be changed.

$$\frac{R}{L} = \frac{250}{0.2} = 1250\Omega$$

$$\zeta = \frac{250}{2 \times 316.228} = 1.976422$$

#### MATLAB Code

```
>> %overdamped
>> num = [100000];
>> den = [1 1250 100000];
>> step(num,den);
fx >> |
```

Figure 20 - MATLAB Code

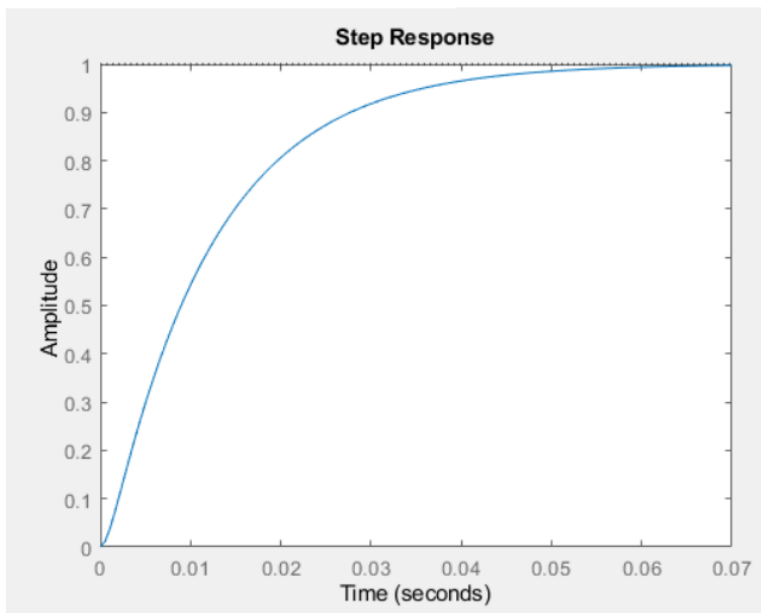


Figure 21 - MATLAB Graph

| Overdamped                                                                                                                                                                                                  |                           |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| Expected                                                                                                                                                                                                    | Actual (Simulated Result) |
| Overdamped                                                                                                                                                                                                  | Overdamped                |
| Due to the value of Z being over 1 at 1.976422, it's expected that the results are overdamped. This is shown clearly in Figure 5.4 where the response can be seen gradually increasing before levelling out |                           |

#### Critically Damped

To ensure a circuit is Critically damped, the damping factor must be equal to 1. Therefore again, to ensure this the resistor value in the circuit was changed as shown below.;

$$\frac{R}{L} = \frac{130}{0.2} = 650\Omega$$

$$\zeta = \frac{650}{2 \times 316.228} = 1.02773$$

#### MATLAB Code

```
>> %critically damped
>> num = [100000];
>> den = [1 650 100000];
>> step(num,den);
fx >> |
```

Figure 22 - MATAB Code

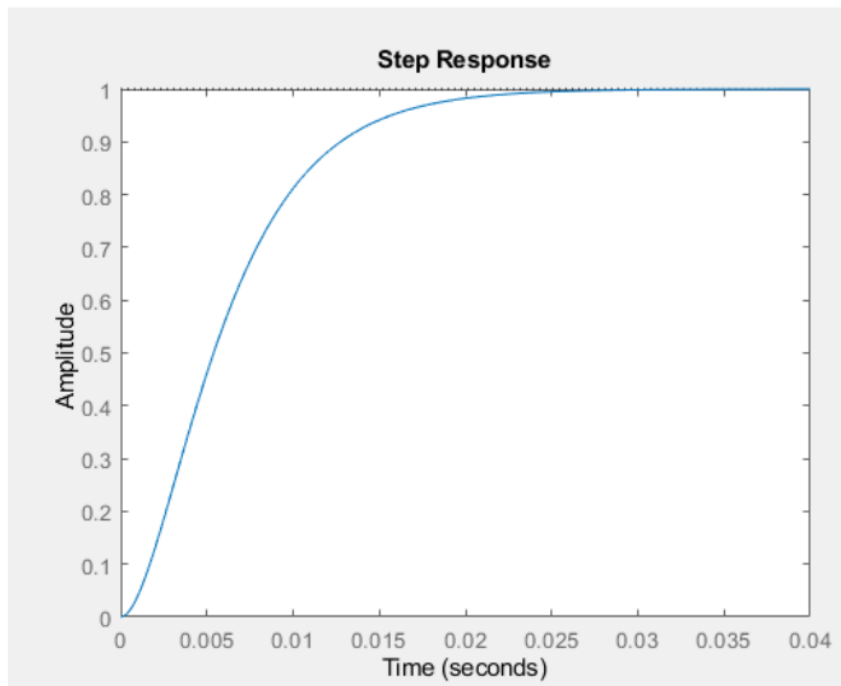


Figure 23 - MATLAB Graph

| Critically Damped                                                                                                                                                                                                                                                                   |                           |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| Expected                                                                                                                                                                                                                                                                            | Actual (Simulated Result) |
| Critically Damped                                                                                                                                                                                                                                                                   | Critically Damped         |
| Due to the value of Z being near enough exactly 1 at 1.02773 it's expected that the results are critically damped. This is shown clearly in Figure 5.6 where the response can be seen increasing rapidly before steadily slowing down until the response reaches an amplitude of 1. |                           |

#### No damping circuit

To ensure that a circuit has no damping, the damping factor must have a value equal to zero. Again for this to occur, the resistor value in the circuit must be altered which is shown below;

$$\frac{R}{L} = \frac{0}{0.2} = 0\Omega$$

$$\zeta = \frac{0}{2 \times 316.228} = 0$$

MATLAB Code

```
>> %No Damping
>> num = [100000];
>> den = [1 0 100000];
>> step(num,den);
fx >>
```

Figure 24 - MATLAB Code

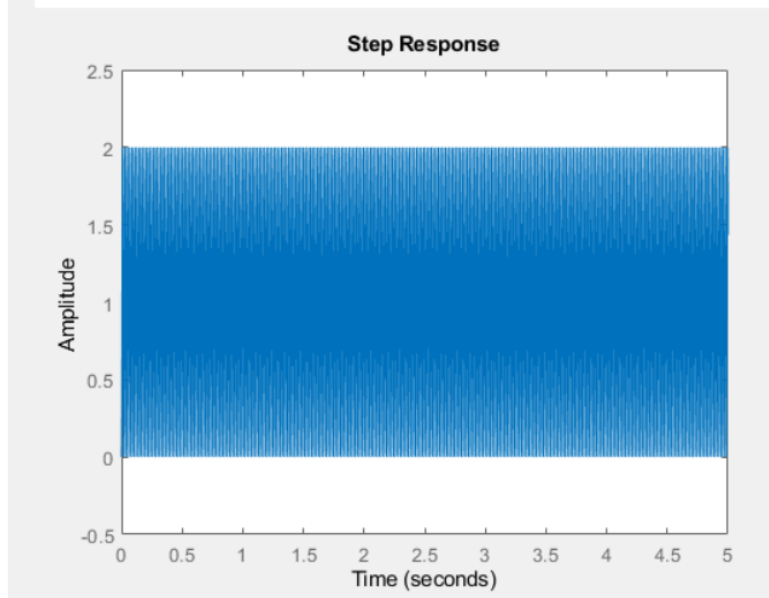


Figure 25 - MATLAB Graph

| No Damping                                                                                                                                                            |                           |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| Expected                                                                                                                                                              | Actual (Simulated Result) |
| No Damping                                                                                                                                                            | No damping                |
| Due to the value of Z being exactly 0, it's expected that the circuit has no damping. This is clearly shown in Figure 5.8 where the waveform is constantly vibrating. |                           |

**Table of Results**

| <u>Expected Circuit Response</u> | <u>Simulated Circuit Response</u> | <u>Resistor Value (<math>\Omega</math>)</u> |
|----------------------------------|-----------------------------------|---------------------------------------------|
| Underdamped                      | Underdamped                       | 125                                         |
| Overdamped                       | Overdamped                        | 1250                                        |
| Critically Damped                | Critically Damped                 | 650                                         |
| No Damping                       | No Damping                        | 0                                           |

The table of results above display each of the circuit responses. It's evident to see that by altering the value of the resistor, the value of  $\zeta$  (Damping Factor) changes. This shows that altering the damping factor to different values changes the response of the circuit.

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

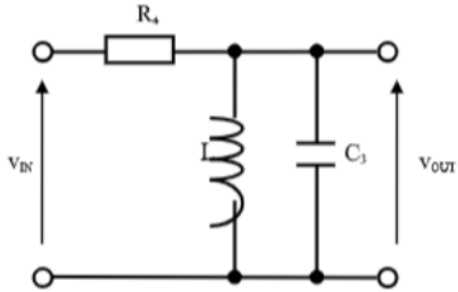


Figure 27 - RLC Circuit

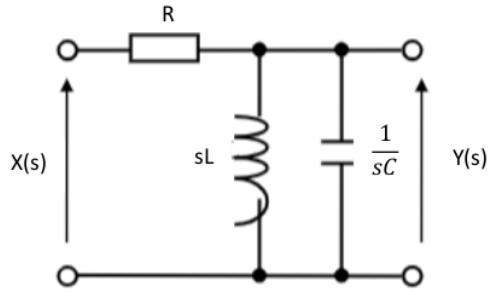


Figure 26 - Laplace Model

For the circuit above, the component values chosen are;

- $R = 25\Omega$
- $L = 0.5H$
- $C = 50\mu F$

Natural Frequency is calculated as follows;

$$\omega_n = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{0.5 \times 50 \times 10^{-6}}} = 200$$

Therefore  $\omega_n^2$ ;

$$200^2 = 40,000 \text{ rad/s}$$

$$2\zeta\omega_n = \frac{1}{RC} = \frac{1}{25 \times 50 \times 10^{-6}} = 800$$

The transfer for this circuit is as follows;

$$H(s) = \frac{s \times \frac{1}{RC}}{s^2 + 2\zeta\omega_n s + \omega_n^2} = \frac{s \times 800}{s^2 + 800 + 40000}$$

Finally, the formula for the Damping factor for this circuit is as follows;

$$\zeta = \frac{1}{2R} \sqrt{\frac{L}{C}} = \frac{1}{2 \times 25} \sqrt{\frac{0.5}{(50 \times 10^{-6})}} = 2$$

Similarly, to Task 5, if the Damping factor is  $> 1$ , the circuit should be Overdamped.

**Overdamping**

**MATLAB Code**

```
>> %Overdamped
>> num = [800 0];
>> den = [1 800 40000];
>> step(num,den);
```

Figure 28 - MATLAB Code

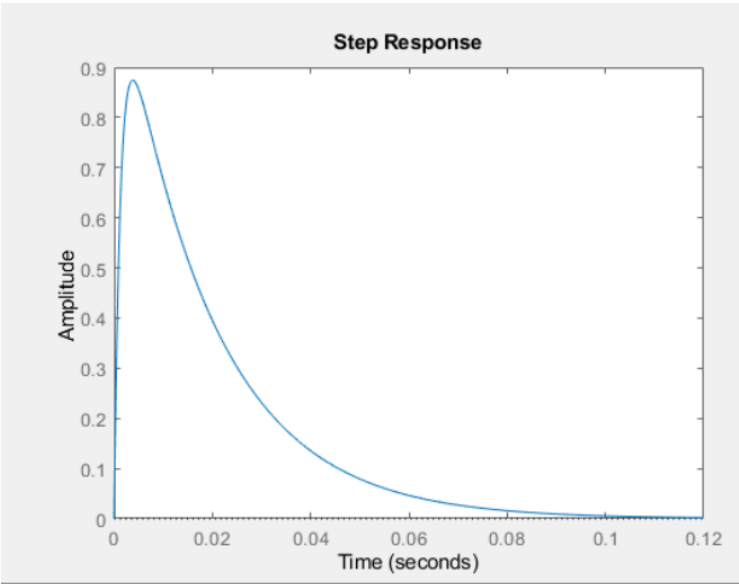


Figure 29 - MATLAB Graph

| Overdamped                                                                                                                                                                                                                                                 |                           |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| Expected                                                                                                                                                                                                                                                   | Actual (Simulated Result) |
| Overdamped                                                                                                                                                                                                                                                 | Overdamped                |
| Due to the value of Z being exactly 2, it's expected that the circuit is overdamped. This is clearly shown in Figure 6.1 where the waveform rapidly increases to an amplitude of 0.9 before rapidly decreasing to an eventual steady state amplitude of 0. |                           |

### Underdamping

To achieve an Underdamped circuit, the damping factor must be less than 1. To alter this value, the resistor value in the circuit needs to be changed. This is shown below;

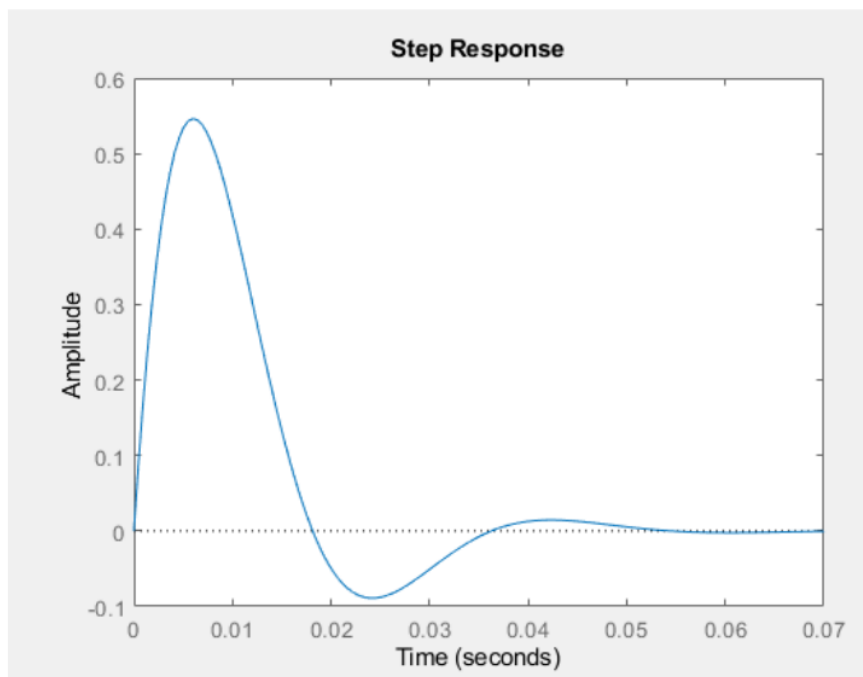
$$2\zeta\omega n = \frac{1}{RC} = \frac{1}{100 \times 50 \times 10^{-6}} = 200$$

$$\zeta = \frac{1}{2R} \sqrt{\frac{L}{C}} = \frac{1}{2 \times 100} \sqrt{\frac{0.5}{(50 \times 10^{-6})}} = 0.5$$

MATLAB Code

```
>> %underdamped  
>> num = [200 0];  
>> den = [1 200 40000];  
>> step(num,den);  
fx >>
```

Figure 30 - MATLAB Code



31 - MATLAB Graph

| Underdamped                                                                                                                                                                                                                                                                                                |                           |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| Expected                                                                                                                                                                                                                                                                                                   | Actual (Simulated Result) |
| Underdamped                                                                                                                                                                                                                                                                                                | Underdamped               |
| Due to the value of Z being exactly 0.5, it's expected that the circuit is underdamped. This is clearly shown in Figure 6.4 where the waveform rapidly increases to an amplitude of just over <u>0.6</u> before decreasing below an amplitude of 0. Finally, it slowly increases back up and settles at 0. |                           |

### Critically Damped

To achieve a Critically damped circuit, the damping factor must be equal to 1. Again to achieve this, the resistor value was altered and shown below;

$$2\zeta\omega n = \frac{1}{RC} = \frac{1}{50 \times 50 \times 10^{-6}} = 400$$

$$\zeta = \frac{1}{2R} \sqrt{\frac{L}{C}} = \frac{1}{2 \times 50} \sqrt{\frac{0.5}{(50 \times 10^{-6})}} = 1$$

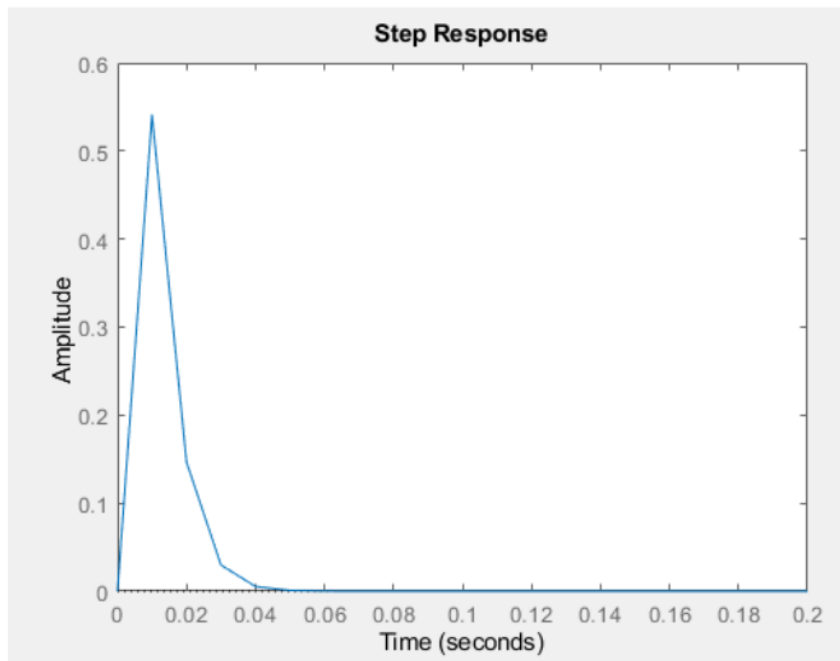


Figure 32 - MATLAB Graph

| Critically Damped                                                                                                                                                                                                                                                                                               |                           |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| Expected                                                                                                                                                                                                                                                                                                        | Actual (Simulated Result) |
| Critically Damped                                                                                                                                                                                                                                                                                               | Critically Damped         |
| Due to the value of Z being exactly 1, it's expected that the circuit is critically damped. This is clearly shown in Figure 6.6 where the waveform rapidly increases to an amplitude of just over 0.5 before rapidly decreasing below an amplitude of 0. Finally, it slowly increases back up and settles at 0. |                           |

### No Damping

To achieve a non-damping circuit, the damping factor must be equal to 0. For this the resistor value is changed to 0Ω.

$$2\zeta\omega n = \frac{1}{RC} = \frac{1}{0 \times 50 \times 10^{-6}} = 0.$$

$$\zeta = \frac{1}{2R} \sqrt{\frac{L}{C}} = \frac{1}{2 \times 50} \sqrt{\frac{0.5}{(50 \times 10^{-6})}} = 0$$

MATLAB Code

```
>> %No Damping
>> num = [0 0];
>> den = [1 0 40000];
>> step(num,den);
```

Figure 34 - MATLAB Code

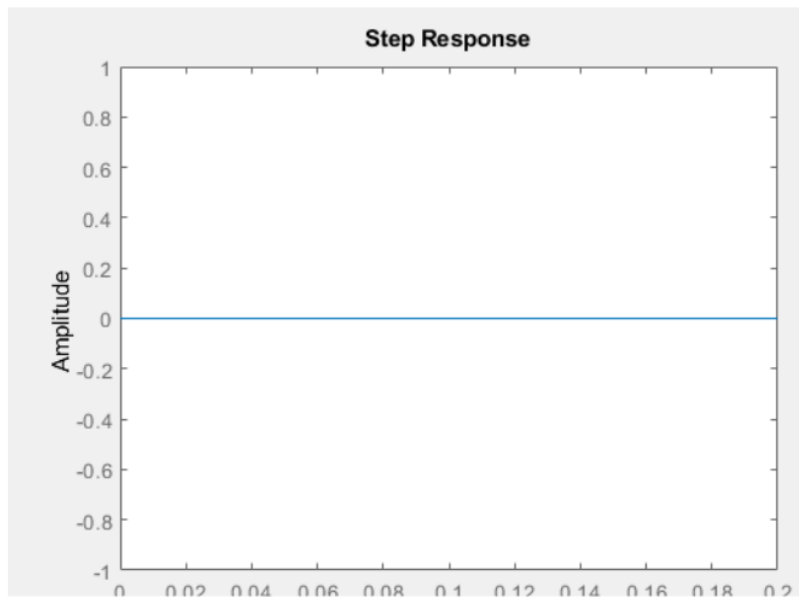


Figure 33 - MATLAB Graph

| <u>No Damping</u>                                                                                                                                                                     |                                  |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|
| <u>Expected</u>                                                                                                                                                                       | <u>Actual (Simulated Result)</u> |
| <u>No Damping</u>                                                                                                                                                                     | <u>No Damping</u>                |
| Due to the value of $Z$ being exactly 0, it's expected that the circuit has no damping. This is clearly shown in Figure 6.8 where the waveform is simply static at an amplitude of 0. |                                  |

10

#### Table of Results

| <u>Expected Circuit Response</u> | <u>Simulated Circuit Response</u> | <u>Resistor Value (<math>\Omega</math>)</u> |
|----------------------------------|-----------------------------------|---------------------------------------------|
| Underdamped                      | Underdamped                       | 100                                         |
| Overdamped                       | Overdamped                        | 25                                          |
| Critically Damped                | Critically Damped                 | 50                                          |
| No Damping                       | No Damping                        | 0                                           |

The table of results above display each of the circuit responses. It's evident to see that by altering the value of the resistor, the value of  $\zeta$  (Damping Factor) changes. This shows that altering the damping factor to different values changes the response of the circuit.

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

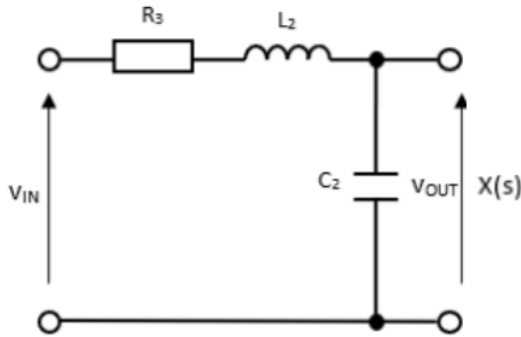


Figure 36 - RLC Circuit

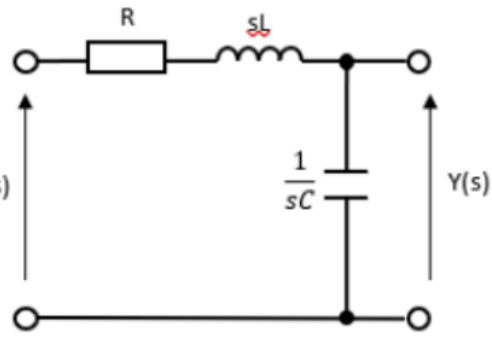


Figure 35 - Laplace Model

For the circuit above, the component values are the same as Task 5 being;

- $R = 25\Omega$
- $L = 0.2\text{H}$
- $C = 50\mu\text{F}$

Firstly, the Transfer function of this circuit is shown below;

$$H(s) = \frac{\frac{1}{LC}}{s^2 + \frac{R}{L}s + \frac{1}{LC}} = \frac{100,000}{s^2 + 125s + 100,000}$$

The next two formulas have been calculated for formulas later in the question.

$$\frac{1}{LC} = \frac{1}{0.2 \times 50 \times 10^{-6}} = 100,000$$

$$\frac{R}{L} = \frac{25}{0.2} = 125$$

The natural frequency is calculated as shown below;

$$\omega_n = \sqrt{100,000} = 316.22 \text{ rad/s}$$

Next, the Maximum frequency ' $\omega_m$ ' needs to be calculated;

$$\omega_m = \sqrt{\frac{1}{LC} - \frac{1}{2} \left(\frac{R}{L}\right)^2} = \sqrt{\frac{1}{0.2 \times 50 \times 10^{-6}} - \frac{1}{2} \left(\frac{25}{0.2}\right)^2} = 303.62$$

Also, the resonant frequency needs to be calculated as follows;

$$\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{0.2 \times 50 \times 10^{-6}}} = 316.23$$

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}} = \frac{1}{25} \sqrt{\frac{0.2}{50 \times 10^{-6}}} = 2.5$$

$$\zeta = \frac{R}{2} \sqrt{\frac{C}{L}} = \frac{25}{2} \sqrt{\frac{50 \times 10^{-6}}{0.2}} = 0.2$$

The fact the damping factor is less than 1, shows that the circuit is Underdamped.

To make the circuit critically damped, the damping factor has to be equal to 1. To achieve this, the equation needs to be re-arranged (See below);

$$R = 2 \sqrt{\frac{L}{C}} = 2 \sqrt{\frac{0.2}{50 \times 10^{-6}}} = 126.5 \Omega$$

To achieve a critically damped circuit, the resistance must be 126.5Ω. Therefore, to achieve an Overdamped circuit, any resistance higher than this value will achieve this. So, a resistance value of 250Ω has been chosen.

The final calculation needed is the phase shift. This needs to be calculated when  $\omega = \omega_0$ ;

```
>> %underdamped R=25 L=0.2 C=50uF
>> num = [100000];
>> den = [1 125 100000];
>> bode(num,den);
>> hold on
>>
>> %critically damped R=126.5
>> den = [1 632.5 100000];
>> bode(num,den);
hold on
>> %overdamped R=250
>> den = [1 1250 100000];
>> bode(num,den);
>> hold on
>> grid on
```

Figure 37 - MATLAB Code

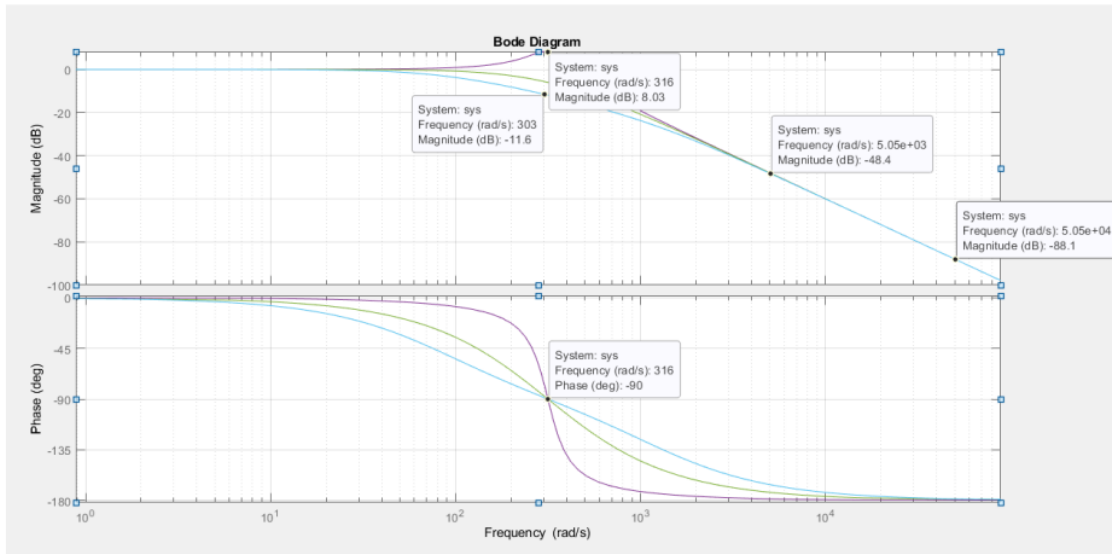


Figure 38 - MATLAB Graph

### Comparison Table

|                    | Calculated Value | Simulated Value |
|--------------------|------------------|-----------------|
| Phase Shift        | -90°             | -90°            |
| Resonant Frequency | 316.23           | 316             |
| Maximum Frequency  | 303.62           | 303             |

As shown in the table above, both the Calculated and simulated values are very similar with only the smallest of differences mainly due to rounding.

Figure 38 above shows there is a roll off of 39.7db. This is very close to the required value of 40db. The ever so slight error of 0.3db is probably down to human error when placing the cursors on the graph but the minute difference is more than acceptable.

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

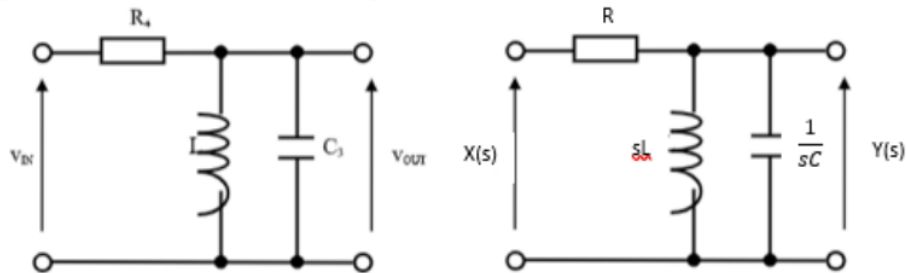


Figure 39 - Task 8

For the circuit above, the component values chosen are;

- $R = 25\Omega$
- $L = 0.5H$
- $C = 50\mu F$

The following equations are required;

$$\frac{1}{RC} = \frac{1}{25 \times 50 \times 10^{-6}} = 800$$

$$\frac{1}{LC} = \frac{1}{0.5 \times 50 \times 10^{-6}} = 40,000$$

$$\omega_o^2 = \frac{1}{LC} = 40000$$

$$\text{Therefore } \omega_o = 200$$

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

$$\text{Therefore } \beta = 800$$

$$Q = \frac{\omega_o}{\beta} = 0.25$$

$$H(s) = \frac{s \times \frac{1}{RC}}{s^2 + \frac{s}{RC} + \frac{1}{LC}} = \frac{s \times 800}{s^2 + s \times 800 + 40000}$$

$$\text{Phase shift} = \theta(j\omega_0) = -\tan^{-1}(0) = 0$$

MATLAB Code

```
>> num = [800 0];  
>> den = [1 800 40000];  
>> bode(num,den);  
>> grid on  
>>
```

Figure 40 - MATLAB Code

MATLAB Graph

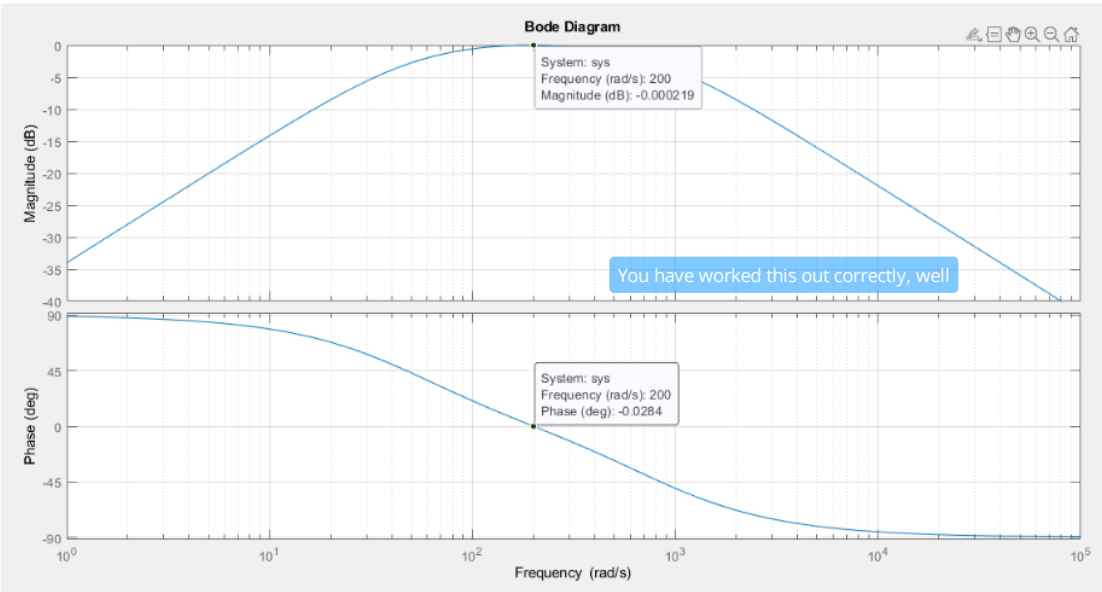


Figure 41 - MATLAB Graph

|                    | Calculated Value | Simulated Value |
|--------------------|------------------|-----------------|
| Phase shift        | 0                | 0               |
| Resonant Frequency | 200              | 200             |

As you can see from the table of results above, both the simulated values and the calculated values are exactly the same.

## 9 – Frequency Performance Analysis of a First Order Electronic system

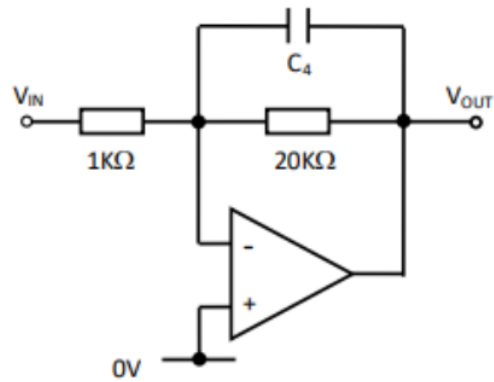


Figure 42 - Circuit Diagram

A Capacitor value of 100nF was chosen as the value for C4.

$$Z1 = 1k\Omega$$

$$Z2 = 20k\Omega$$

For all low pass filters, the following equations are used to help derive the transfer function.

$$Z1(s) = R1$$

$$Z2(s) = R2 \parallel \frac{1}{sC}$$

$$= \frac{R2 \times \frac{1}{sC}}{R2 + \frac{1}{sC}}$$

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

Now the transfer function can be derived and shown as follows;

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

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

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

The cut off Frequency is calculated by the following formula;

$$\omega c = \frac{1}{CR2}$$
$$\omega c = \frac{1}{100 \times 10^{-9} \times 20,000}$$

$$\omega c = 500 \text{ rad/s}$$

Now the transfer function and cut-off frequency have been found, the gain (K) is calculated by;

$$K = \frac{R2}{R1}$$
$$K = \frac{20,000}{1000}$$
$$K = 20$$

Next, the transfer function changes;

$$H(s) = -K \left( \frac{\omega c}{s + \omega c} \right)$$
$$H(s) = -20 \left( \frac{500}{s + 500} \right)$$

Due to the circuit containing an inverting amplifier, this means there is a phase shift at 180°. Therefore;

$$\theta = -45 + 180 = 135^\circ$$

In decibels (dB),  $20\log(20) = 26$ . Therefore, the cut off should occur at 23.

#### **MATLAB CODE**

```
>> num = [-20*500];  
>> den = [1 500];  
>> bode(num,den)  
grid on
```

Figure 43 - MATLAB Code

## MATLAB GRAPH

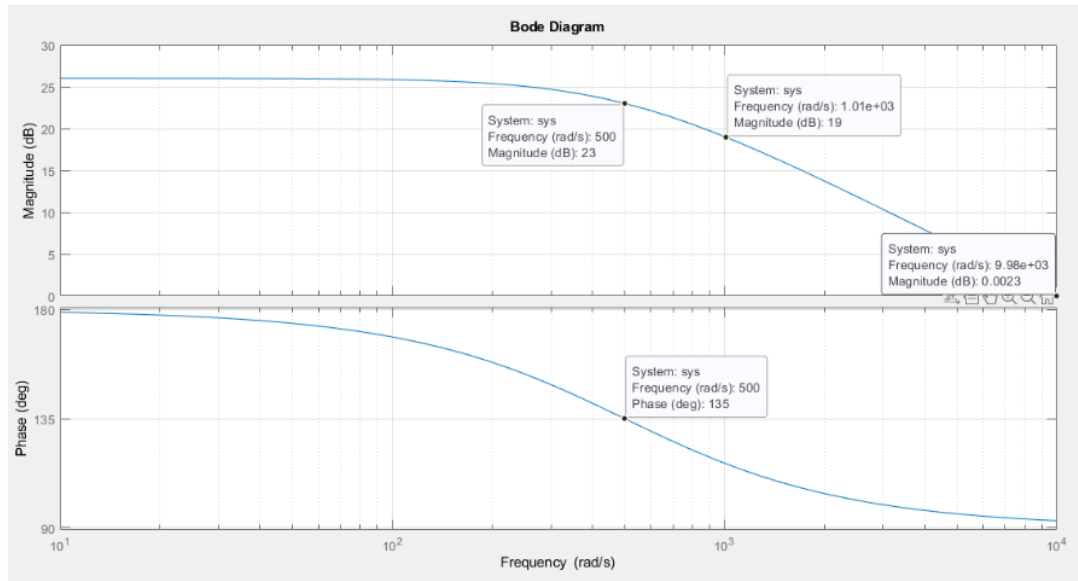


Figure 44 - MATLAB Graph

Below is a table of comparison showing the differences between the Calculated and Simulated results;

|                                 | <u>Simulated Value</u> | <u>Calculated Value</u> |
|---------------------------------|------------------------|-------------------------|
| <u>Phase Shift</u>              | 135                    | 135                     |
| <u>Cut-off Frequency at 3db</u> | 500                    | 500                     |
| <u>Roll Off</u>                 | 18.997                 | 20                      |

As shown in the comparison table, both the Phase shift and cut-off frequency were both correct as both the simulated and calculated values had the exact same value. However, the roll off had a very slight error of 1db which is likely due to human error with the exact placement of the cursors on the multisim graph. Despite this, only being 1db out verifies that the calculations were done correctly.

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## 10 – Frequency Performance Analysis of a First Order Electronic System

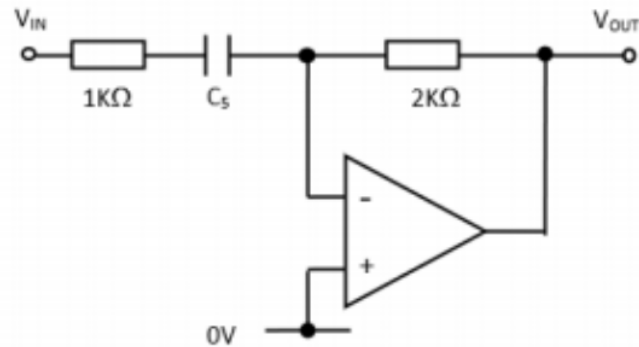


Figure 45 - Circuit Diagram

A capacitor value of 50nF was chosen for C5.

$R1 = 1k\Omega$

$R2 = 2000\Omega$

The gain for this circuit is calculated the same as the low pass filter as;

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

$$K = \frac{2000}{1000}$$

$$K = 2$$

Similarly, the cut-off frequency is calculated again the same as a low pass filter;

$$\omega_c = \frac{1}{CR1}$$

$$\omega_c = \frac{1}{50 \times 10^{-9} \times 1000}$$

$$\omega_c = 20,000 \text{ rad/s}$$

Now the transfer function can be derived;

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

$$H(s) = -2 \left( \frac{s}{s + 20,000} \right)$$

Due to the circuit containing an inverting amplifier, this means there is a phase shift at  $180^\circ$ . For a High pass filter; at  $\omega_c$ ,  $\theta = 45^\circ$

$$\text{Phase shift} = 45 + 180 = 225^\circ$$

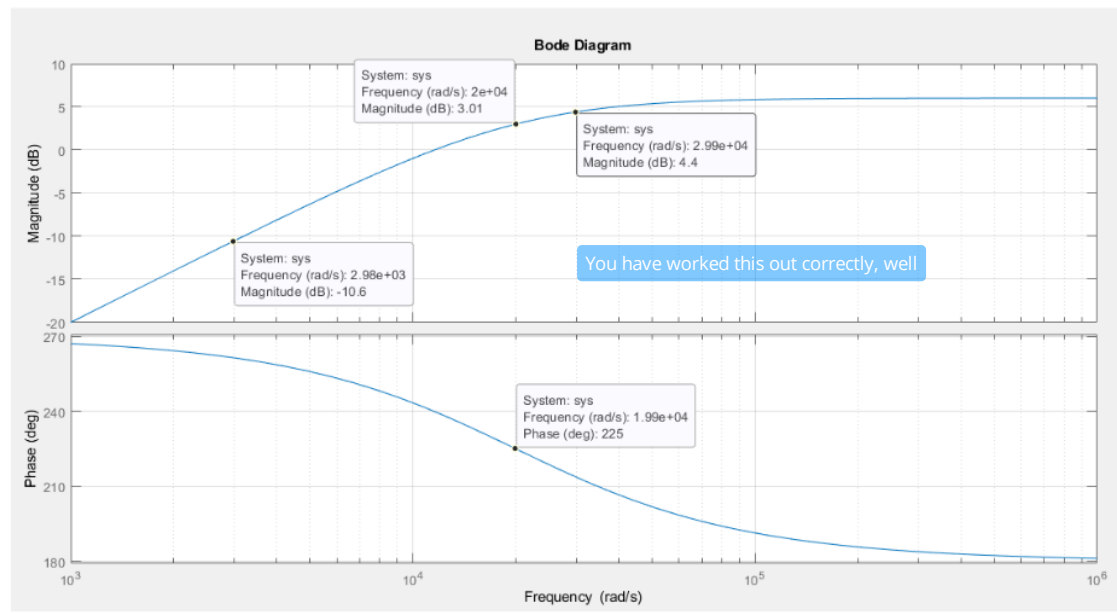
In decibels (dB),  $20\log(2) = 6.02\text{dB}$ . Therefore, the cut off should occur at 3.02dB.

### MATLAB Code

```
num = [-2 0];
den = [1 20000];
bode(num,den);
grid on
fx >> |
```

Figure 46 - MATLAB Code

### MATLAB GRAPH



Below is a table of comparison showing the differences between the Calculated and Simulated results;

|                                 | <u>Simulated Value</u> | <u>Calculated Value</u> |
|---------------------------------|------------------------|-------------------------|
| <u>Phase Shift</u>              | 225                    | 225                     |
| <u>Cut-off Frequency at 3db</u> | 20,000                 | 20,000                  |
| <u>Roll Off</u>                 | 15                     | 20                      |

Similarly to the low pass filter, both the phase shift and Cut off frequencies had the exact same value verifying that they are correct. However, the roll off had quite a difference of 5. This is down to human error within the calculations or inputting the equation into the software.



## 11 – Frequency Performance Analysis of a Fourth Order Electronic System

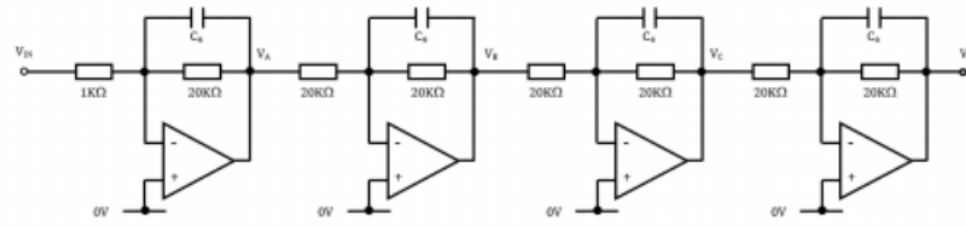


Figure 47 - Circuit Diagram

For this circuit, a capacitor value of 200nF was chosen.

Next, the gain can be calculated by the following formula;

$$K = \frac{R2}{R1} = \frac{20k}{1k} = 20$$

Therefore, once the gain has been found, the cut off frequency ( $\omega_c$ ) can be derived.

$$\omega_c = \frac{1}{CR2} = \frac{1}{200 \times 10^{-9} \times 20 \times 10^3} = 250 \text{ rads}$$

In a 4<sup>th</sup> order system, the cut-off frequency equation changes to;

$$\sqrt{4\sqrt{2} - 1} \times 250 = 108.74$$

The transfer function for this circuit is as follows.

$$H(s) = -K \left( \frac{\omega_c}{s + \omega_c} \right) = -20 \left( \frac{250}{s + 250} \right)$$

Finally, in decibels, 10 is  $20 \log(20) = 26.02 \text{ db}$  therefore the cut-off occurs at 23.02db

**See next page for images:**

```

>> wc = 250;
>> k = 20;
>> num = [-k*wc];
>> den = [1 wc];
>> bode(num,den);
grid on;
>> hold on;
>>
>> num = [k*wc^2];
>> den = [1 2*wc wc^2];
>> bode(num,den);
>> hold on;
>>
>> num = [-k*wc^3];
>> den = [1 3*wc 3*wc^2 wc^3];
>> bode(num,den);
>> hold on;
>>
>> num = [k*wc^4];
>> den = [1 4*wc 6*wc^2 4*wc^3 wc^4];
>> bode(num,den);
>> hold on;
>> |

```

Figure 48 - MATLAB Code

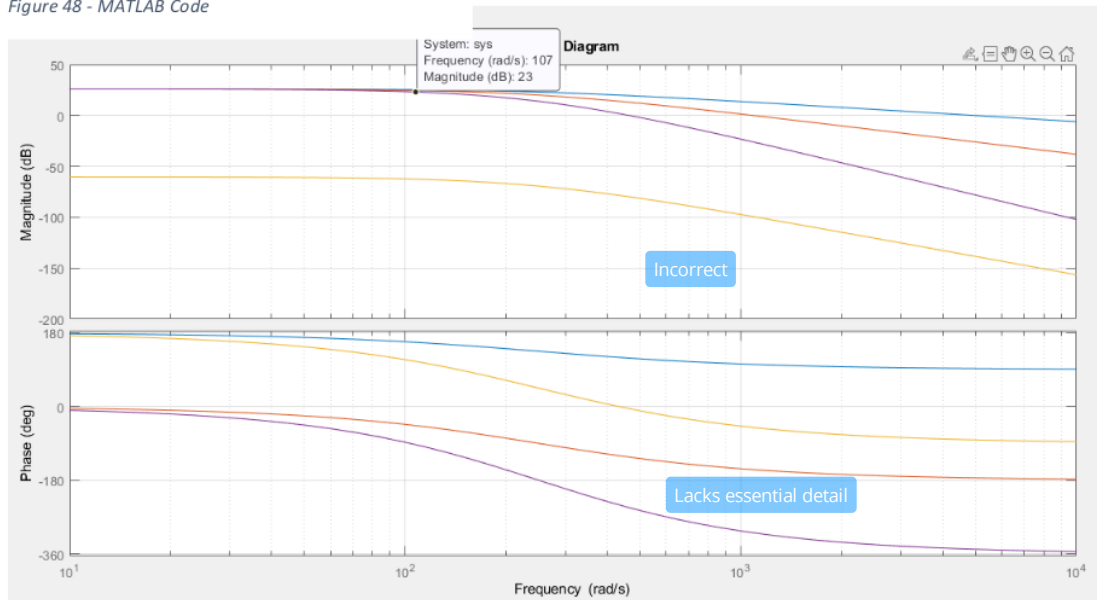


Figure 49 - MATLAB Graph

With each order circuit, it loses 3dp per order. This can be shown in figure 49 above

## 12 – First Order Control System Analysis

Figure ... below shows an open loop control system.

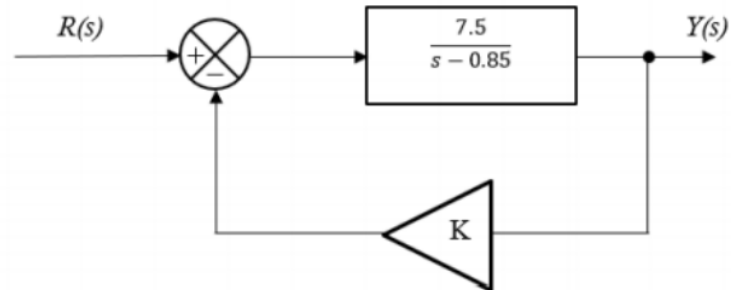


Figure 50 - Circuit Diagram

As seen from the circuit above, the transfer function is as follows.

$$H(s) = \frac{7.5}{s - 0.85}$$

From the transfer function, an argand diagram can now be drawn to show whether the system is stable or unstable.

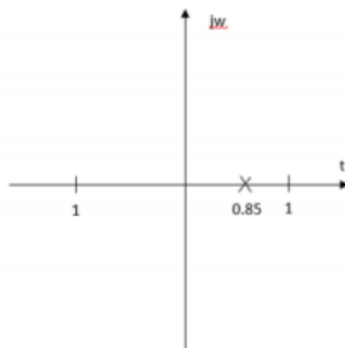


Figure 51 - Argand Diagram

Due to the pole (X) being placed in the right-hand side of the diagram. This shows that the system is Unstable. This is shown in the MATLAB simulation below;

```
>> num = [7.5];
>> den = [1 -0.85];
>> step(num,den);
grid on
>> |
```

Figure 52 - MATLAB Code

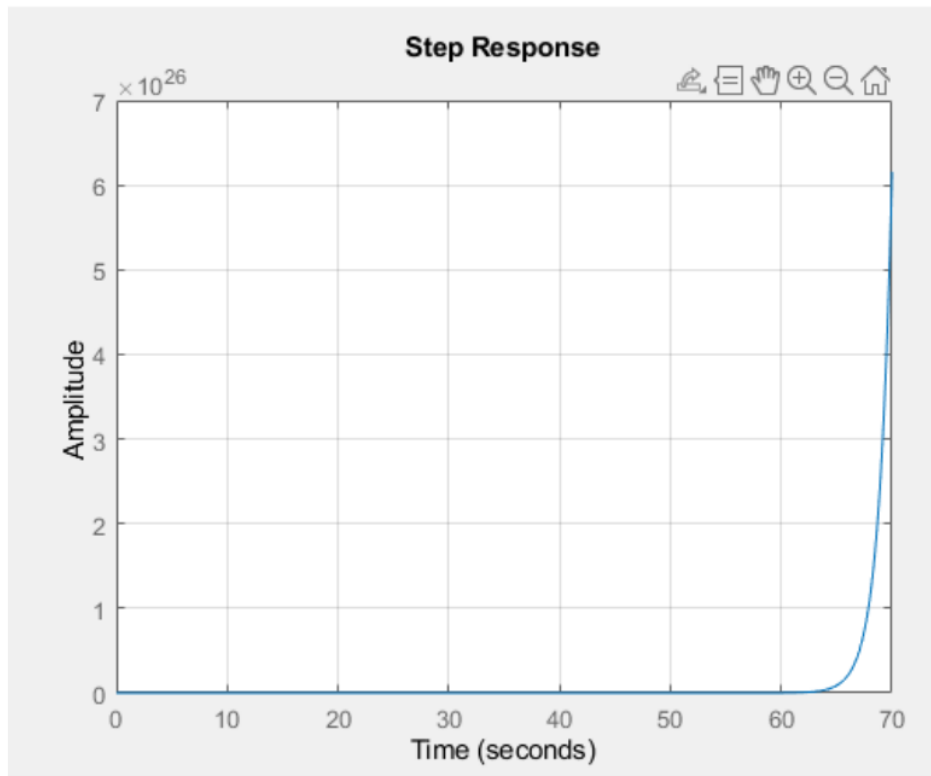


Figure 53 - MATLAB Graph

The MATLAB simulation proves that this control system is unstable.

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## 13 – DC Motor Analysis

This task contains a detailed analysis of a DC motor. Different characteristics of the motor will be calculated by using the given parameters (See below). A model will also be created using Simulink which will be used to test and compare to the calculated results.

### Motor Parameters.

Armature Resistance –  $1.5\Omega$

Armature Inductance –  $0.165\text{H}$

Rotor Inertia –  $0.00042\text{Kg m}^2$

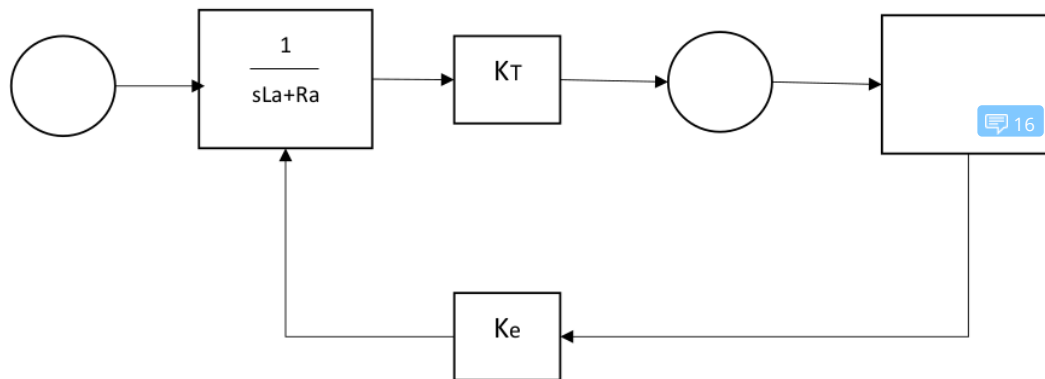
Friction Coefficient –  $4.6 \times 10^{-6} \text{ Nm/rad/s}$

Motor Voltage Constant –  $0.063 \text{ V/rad/s}$

Motor torque constant –  $0.062 \text{ Nm/A}$

Maximum Armature Voltage –  $24\text{V}$

### 13.1



Transfer Function –

$$G(s) = \frac{\frac{K_T}{L_a \times J}}{s^2 + s\left(\frac{b}{J} + \frac{R_a}{L_a}\right) + \left(\frac{R_a \times b}{L_a \times J} + \frac{K_T \times K_e}{L_a \times J}\right)}$$

Transfer Function with Values –

$$G(s) = \frac{\frac{0.062}{0.165 \times 0.00042}}{s^2 + s\left(\frac{4.6 \times 10^{-6}}{0.00042} + \frac{1.5}{0.165}\right) + \left(\frac{1.5 \times 4.6 \times 10^{-6}}{0.165 \times 0.00042} + \frac{0.062 \times 0.063}{0.165 \times 0.00042}\right)}$$

$$G(s) = \frac{894.66}{s^2 + 9.1019s + 56.54}$$

### 13.2

1) Time Constant –

$$2\zeta\omega_n = \left(\frac{b}{J} + \frac{Ra}{La}\right) = \left(\frac{4.6 \times 10^{-6}}{0.00042} + \frac{1.5}{0.165}\right) = 9.102s$$

2) Natural Frequency –

$$\omega_n = \sqrt{\left(\frac{Ra \times b}{La \times J} + \frac{K_T \times K_e}{La \times J}\right)} = \sqrt{\left(\frac{1.5 \times 4.6 \times 10^{-6}}{0.165 \times 0.00042} + \frac{0.062 \times 0.063}{0.165 \times 0.00042}\right)} = 7.514$$

3) Damping Factor –

$$\zeta = \left(\frac{2\zeta\omega_n}{2 \times \omega_n}\right) = \left(\frac{9.1019}{2 \times 7.514}\right) = 0.606 \text{ (Underdamped)}$$

4) Stall Torque –

$$\frac{K_T \times V_A}{R_A} = \frac{0.062 \times 15}{1.5} = 0.62Nm$$

5) Frictionless No-Load Speed –

$$\frac{V_a}{K_e} = \frac{15}{0.063} = 238rad/s$$

6) Current -

You have worked this out correctly, well

$$I_a = \frac{T_m}{K_T} = \frac{0.031}{0.062} = 0.5A$$

7) No Load Torque –

17

Type equation here.

### 13.3

This subtask involves plotting the poles for the motor on the Argand Diagram

$$\begin{aligned} \text{Poles 1\&2} &= \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \\ &= \frac{-9.1019 \pm \sqrt{9.1019^2 - 4 \times 1 \times 56.463}}{2 \times 1} \\ &= \frac{-9.1019 \pm \sqrt{-143.69}}{2} \end{aligned}$$

$$\begin{aligned}
 \text{Poles 1\&2} &= \frac{-9.1019 \pm j11.99}{2} \text{ or } \frac{-9.1019 - j11.99}{2} \\
 &= -4.55 + j5.995 \text{ or } -4.55 - j5.995
 \end{aligned}$$

These values are then plotted onto an argand diagram

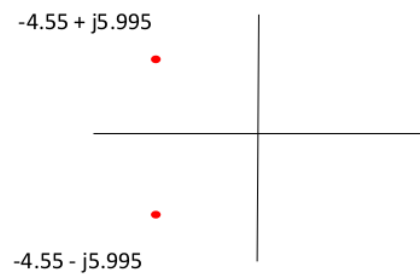


Figure 54 - Argand Diagram

The fact both the poles are in the left-hand pane show that this system is stable

13.4

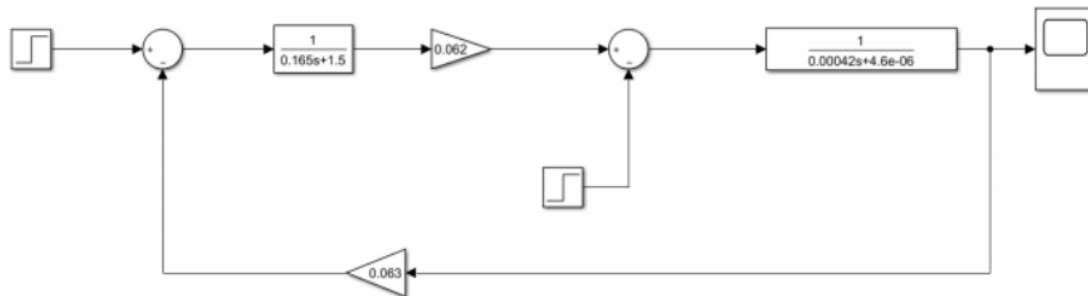


Figure 55 - Motor Circuit

### 13.5

#### Motor Speed with No Disturbance

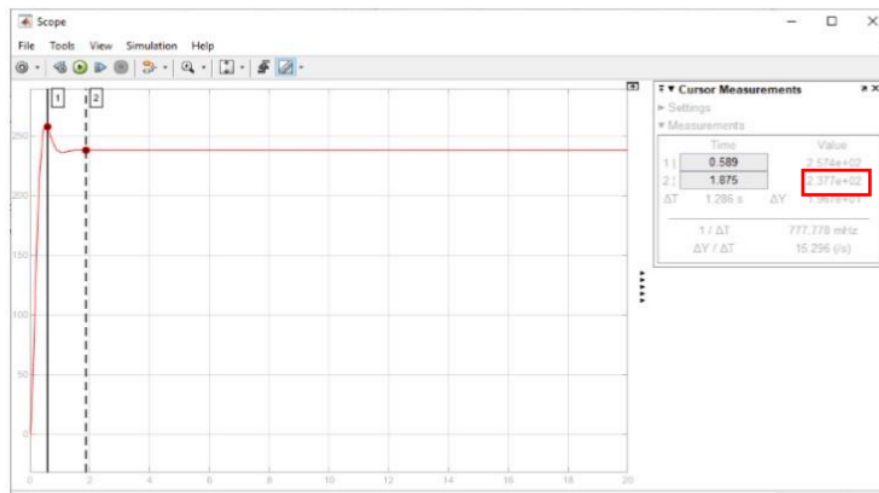


Figure 56 - Motor Speed with no disturbance

This graph shows the no load speed 237.7rad/s (Cursor 2)

#### Motor Torque with no disturbance



Figure 57 - Motor Torque with no disturbance

13.6

Motor Speed with 0.03Nm disturbance added after 10 seconds

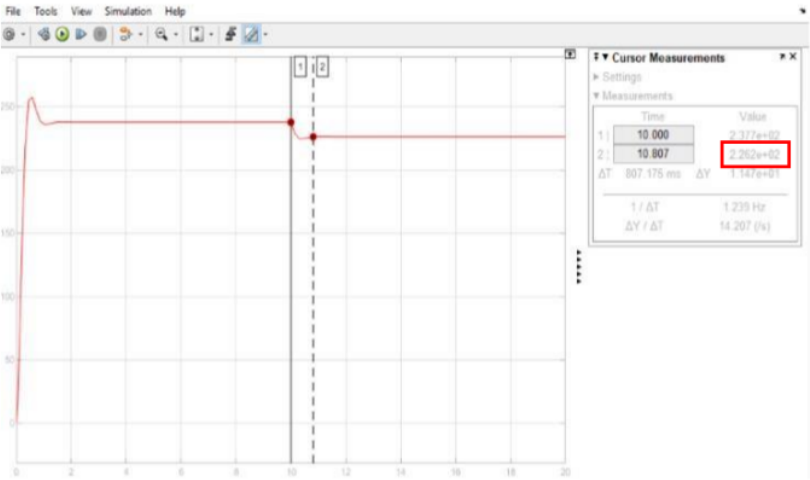


Figure 58 - Motor Speed with Disturbance added

This graph shows the motor speed with the disturbance added after 10 seconds. It shows a speed of 226.2rad/s (Cursor 2)

Motor Torque with 0.03Nm disturbance added.

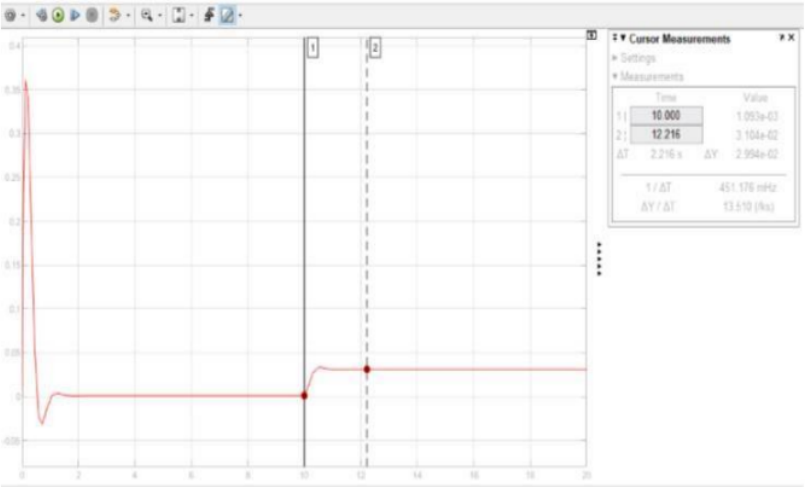


Figure 59 - Motor Torque with disturbance added

## 14 – Proportional Speed Control System

### 14.1

This task involved implementing a PID controller into the circuit. A subsystem was created with an input of 140rad/s. (See circuit below)

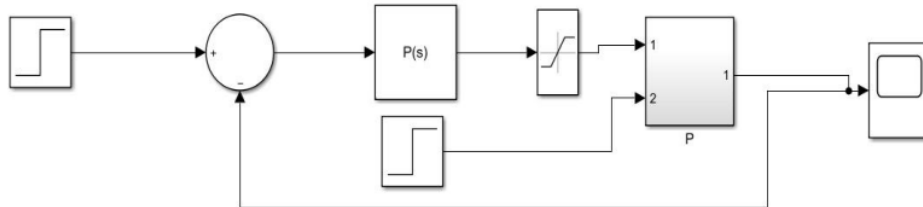


Figure 60 - Circuit Diagram

As shown above, the 'new' PID controller is connected to a single input scope which can be viewed to analyse the response. Below is an image showing the response.

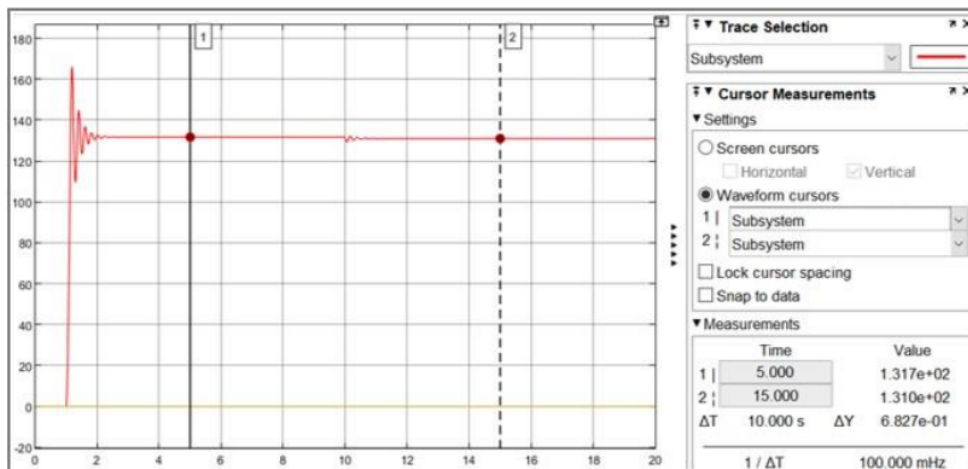


Figure 61 - Disturbance Added

Cursors 1 and 2 represent the no load speed before and after the 0.03Nm disturbance where before has a value of 1.317rad/s and after 1.310rad/s. This shows a very slight decrease of 0.07rad/s.

Next, a graph was produced to show the response when  $K_P$  is equal to 1.

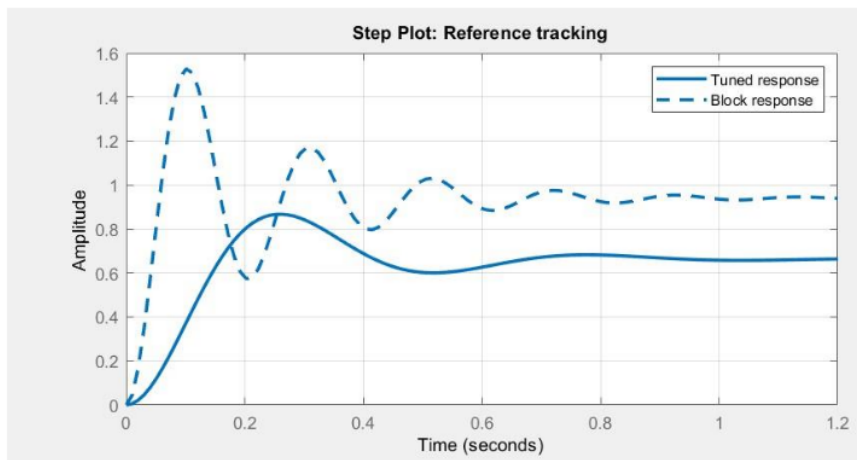


Figure 62 -  $K_P = 1$

After this, the next thing to do was to 'autotune' the controller which would give an optimum value for  $K_P$ . After autotuning, it gave an optimum  $K_p$  value of 0.12477 as shown below.

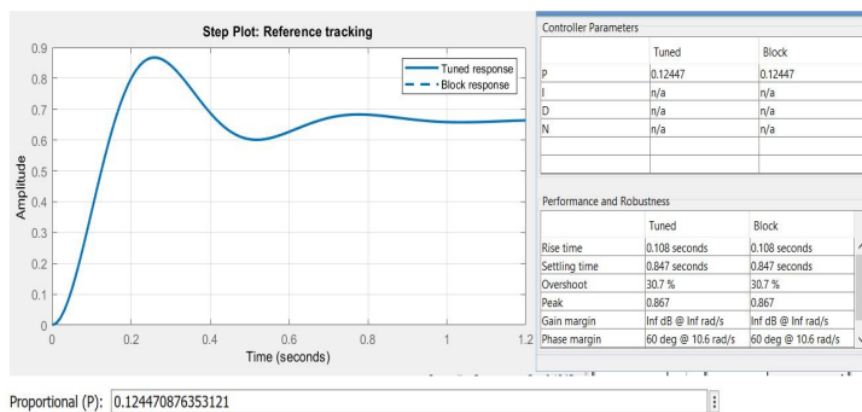


Figure 63 -  $K_P$  autotuned

## 14.2

The next stage involved changing the value of  $K_p$  to 2 random values with the inputs inputted into a 3-input scope to easily analyse the effect  $K_p$  has on the circuit's response. Other characteristics such as Overshoot, Rise time and Steady State error will be calculated and analysed.

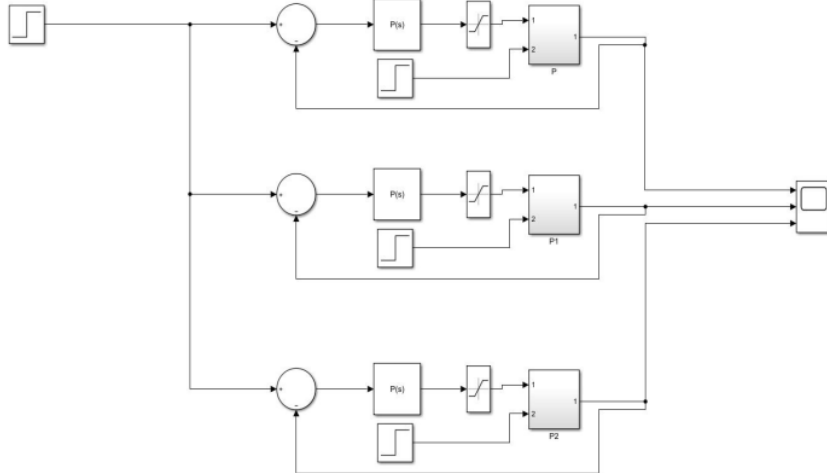


Figure 64 - Circuit Diagram

The 2 chosen values for  $K_p$  were halved (0.0622) and doubled (0.2849). The systems response can be seen in the below images.

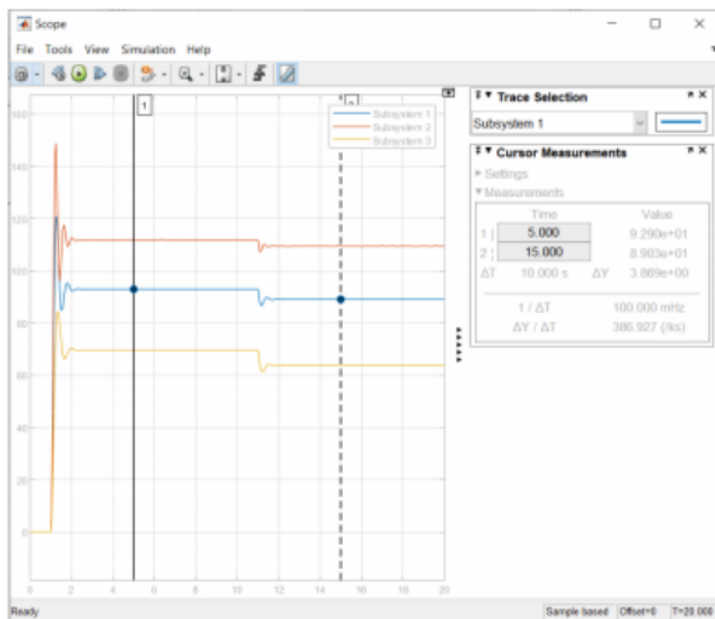


Figure 65 -  $K_p$  values

Figure 65 above, Shows the response of the first substation. The response shows at the KP value of 0.12477. As shown in the response graph, cursor 1 represents a speed of 92.9rad/s. Cursor 2 represents a value of 89.03rad/s which shows a speed decrease of around -3rad/s with the introduction of the 0.03Nm disturbance.

Below, figure 6 shows the response to sub system 2 with a KP value of 0.2849. Cursor 1 represents a speed of 111.7rad/s with cursor 2 representing a value of 109.4rad/s. This shows a speed decrease of -2.3rad/s.

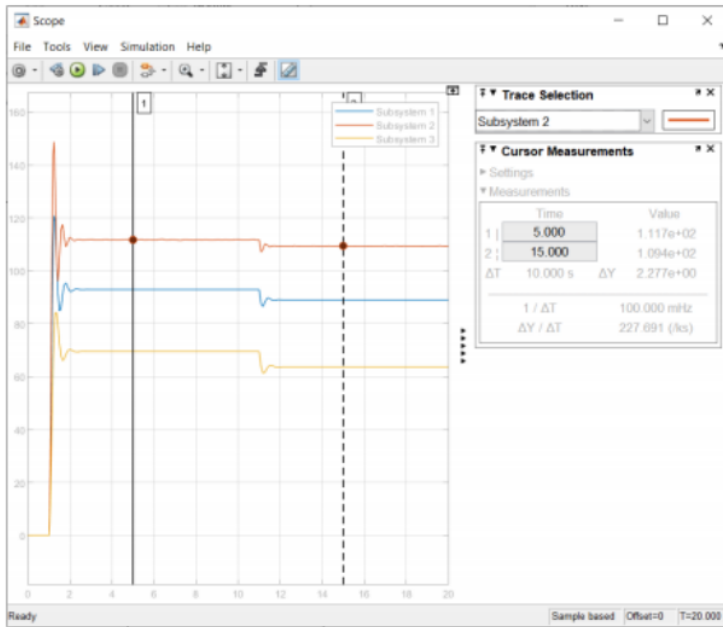


Figure 66 - KP Doubled

Finally the value of  $K_p$  was halved to get a value of 0.062. Cursor 1 shows a value of 69.51rad/s with Cursor 2 displaying 63.77. This shows that the disturbance impacted the speed difference of 5.74rad/s.

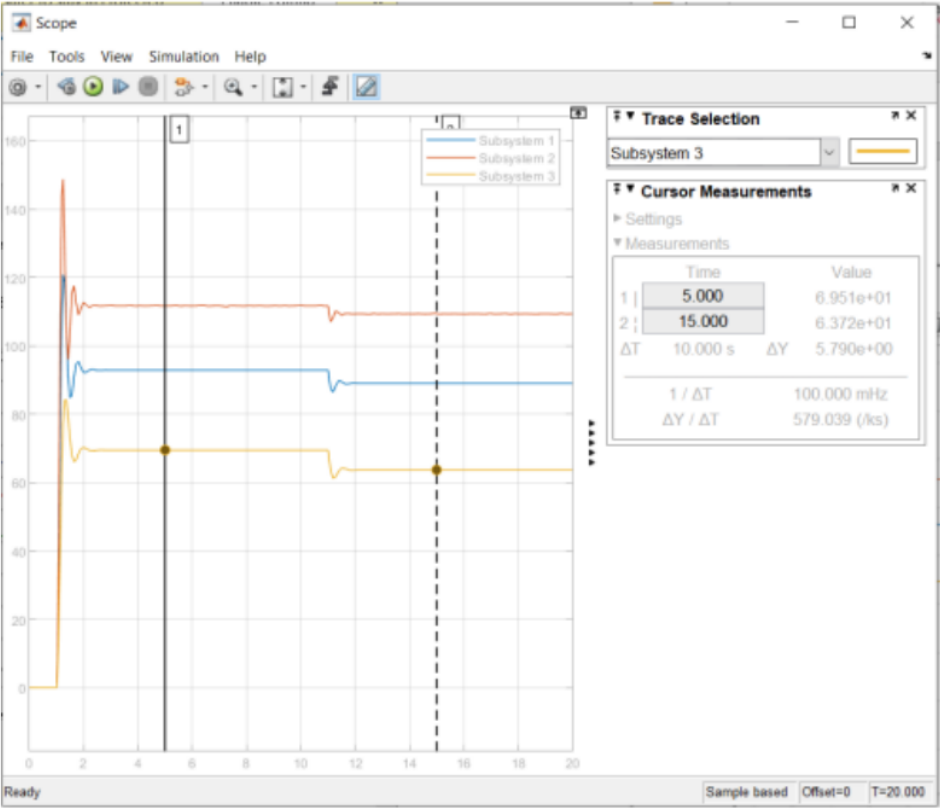


Figure 67 -  $K_p$  halved

14.3, 14.4

| P Controller           |        |        |        |
|------------------------|--------|--------|--------|
| KP Value               | 0.062  | 0.124  | 0.248  |
| Rise Time (s)          | 0.143s | 0.108s | 0.008s |
| Overshoot              | 22.4%  | 30.7%  | 41%    |
| Steady State error (s) | 47.1   | 28.6   | 70.7   |

14.5

As you can see from the comparison table above, the rise gradually decreases as the value of  $K_p$  increases. Opposing this is the overshoot, as the value of  $K_p$  increases the overshoot percentage also increases which is what we would expect.

## 15 – Proportional Integral Speed Control System

### 15.1

This task involved designing and implementing a Proportional Integral circuit. To do this, the controllers in the previous task were adapted to PI controllers instead of just P.

Figure 68 below shows the controller which was adapted to a PI controller before being autotuned.

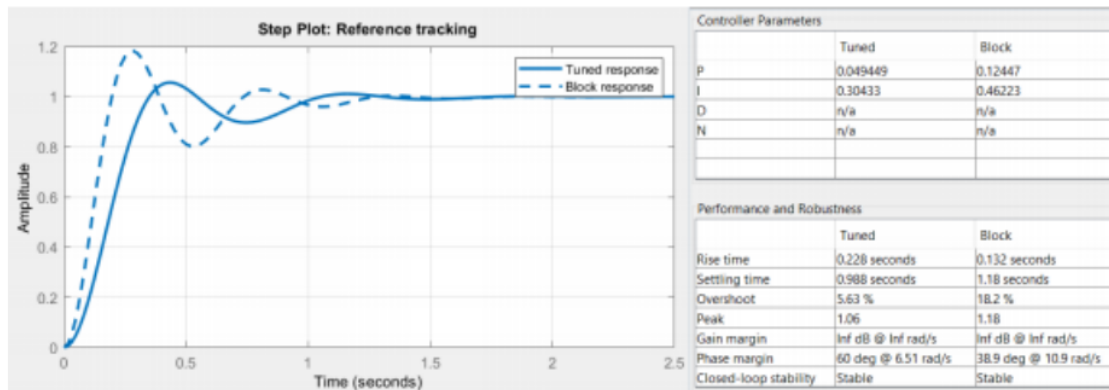


Figure 68 - PI autotuned

As shown from the images above, the values of P and I can be found as

$$P = 0.0494$$

$$I = 0.3043$$

### 15.2

Similarly, to task 14, the values of KI will be halved then doubled to be used as a comparison tool.

Firstly, the value was halved as shown in the image below.

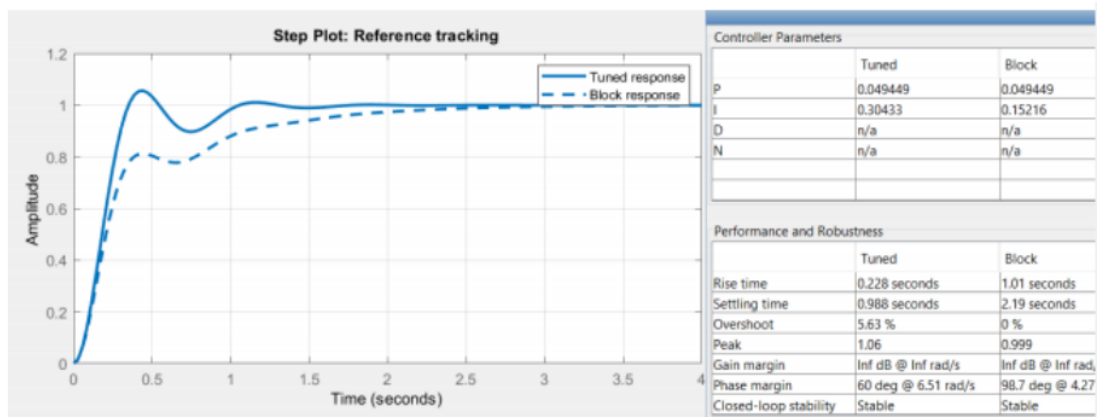


Figure 69 - KI Halved

Finally, the value of  $K_I$  was doubled. Figure 70 below shows the circuits response.

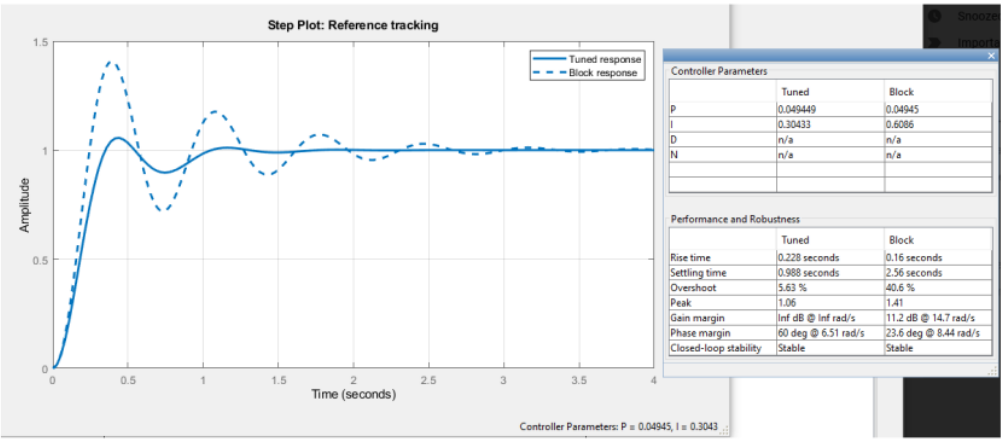


Figure 70 -  $K_I$  doubled

Once all  $K_I$  values had been inserted. A scope response (shown in figure 71 below) shows the response of the speed of the motor and how it is effected by changing the value of  $K_I$ .

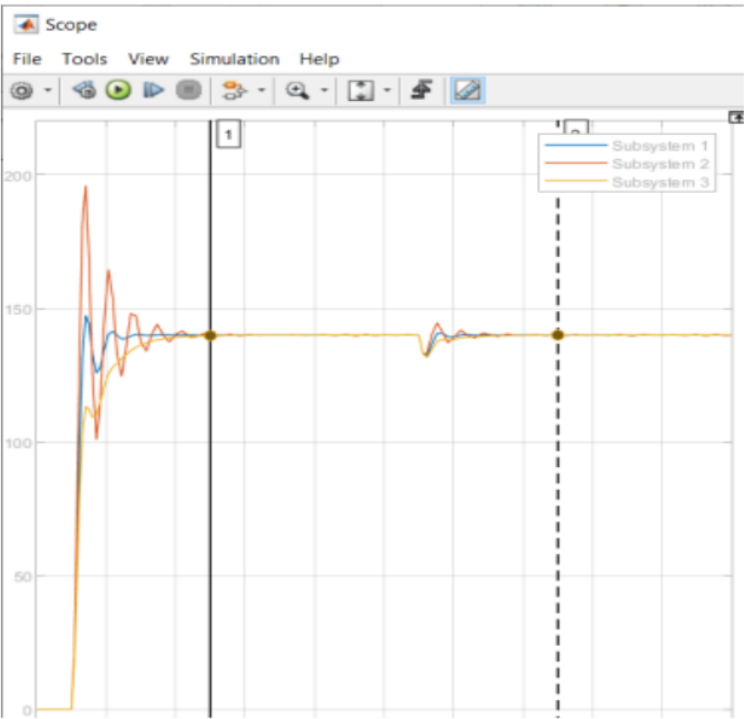


Figure 71 - three responses

As shown above, the motor speed is unaffected by the changing of the  $K_I$  value.

| <b>PI Controller</b>          |               |               |               |
|-------------------------------|---------------|---------------|---------------|
| <b>KP Value</b>               | <b>0.1521</b> | <b>0.3043</b> | <b>0.6086</b> |
| <b>Rise Time (s)</b>          | <b>1.01</b>   | <b>0.228</b>  | <b>0.16</b>   |
| <b>Overshoot</b>              | <b>2.19</b>   | <b>5.63%</b>  | <b>40%</b>    |
| <b>Settling Time (s)</b>      | <b>0</b>      | <b>0.988</b>  | <b>2.56</b>   |
| <b>Steady State error (s)</b> | <b>0.2</b>    | <b>0</b>      | <b>0</b>      |

As you can see from the table above, the value of Ki increasing has a drastic effect on the control system. Its clear to see that the overshoot percentage rises drastically up to 40% when the value is doubled. Also, the settling time increases by almost 1.5seconds from the optimum value. However, as the value does decrease also does the rise time.

## 16 – Proportional Integral Derivative Control System

This task involved designing and implementing a Proportional Integral Derivative circuit. To do this, the controllers in the previous task were adapted to PID controllers instead of just PID controller before being autotuned.

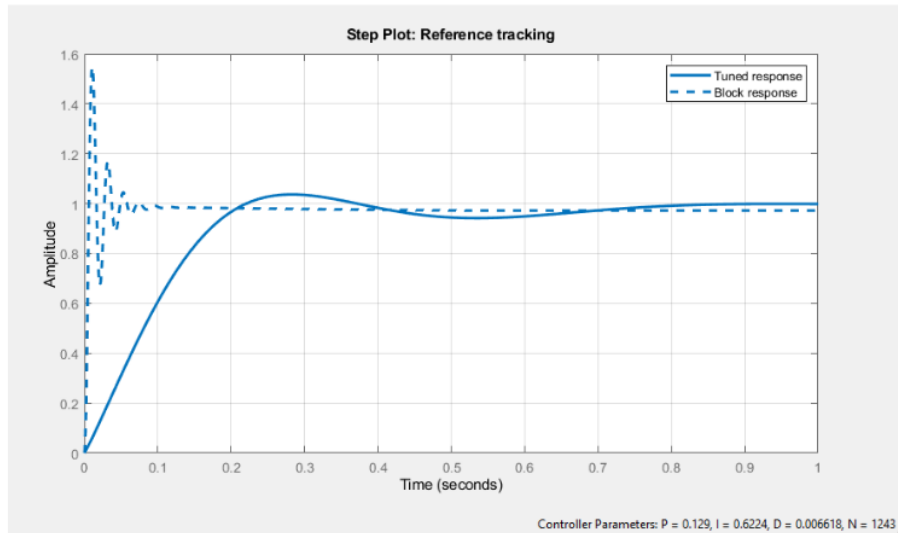


Figure 72 - PID autotuned

Once the circuit had been autotuned, the values of P I and D could be derived.

$P = 0.1920$

$I = 0.6624$

$D = 0.0066$

### 16.2

Similarly, to task 15, the values of KD will be halved then doubled to be used as a comparison tool.

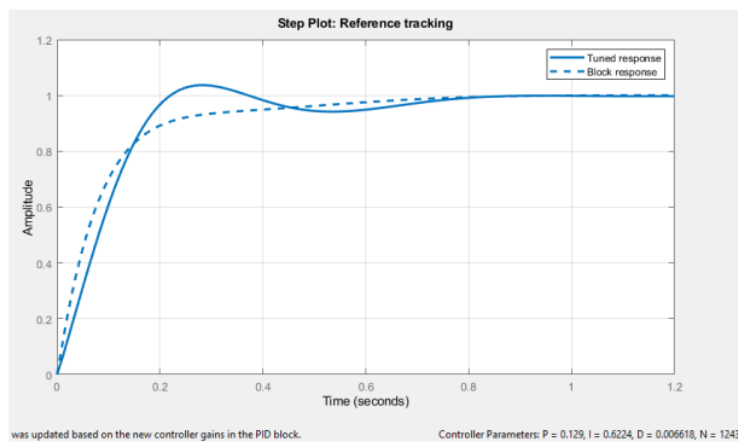


Figure 73 - PID halved

Firstly, the value was halved as shown in the image below.

The value of KD was then doubled and can be seen in figure 74... below;

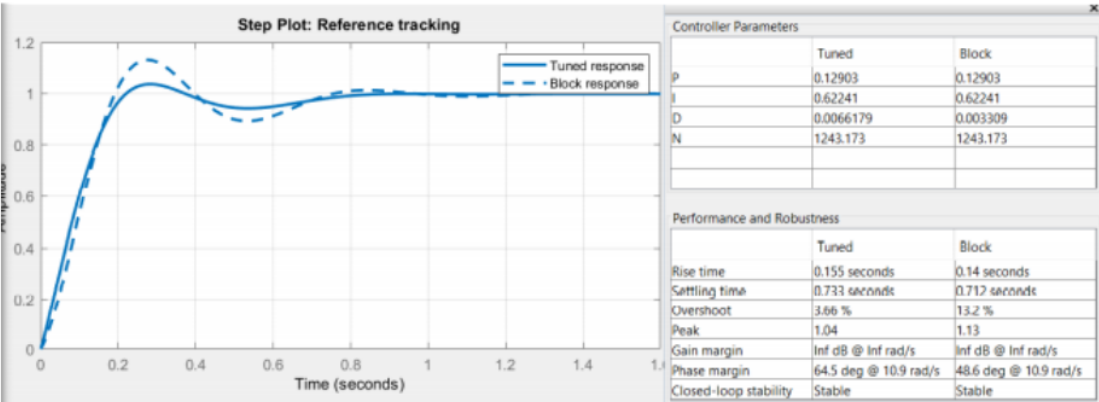


Figure 74 - PID doubled

Once all 3 values of KD have been inserted into the circuit. A scope was then placed to analyse the response from the different KD values. The response can be seen in the image below.

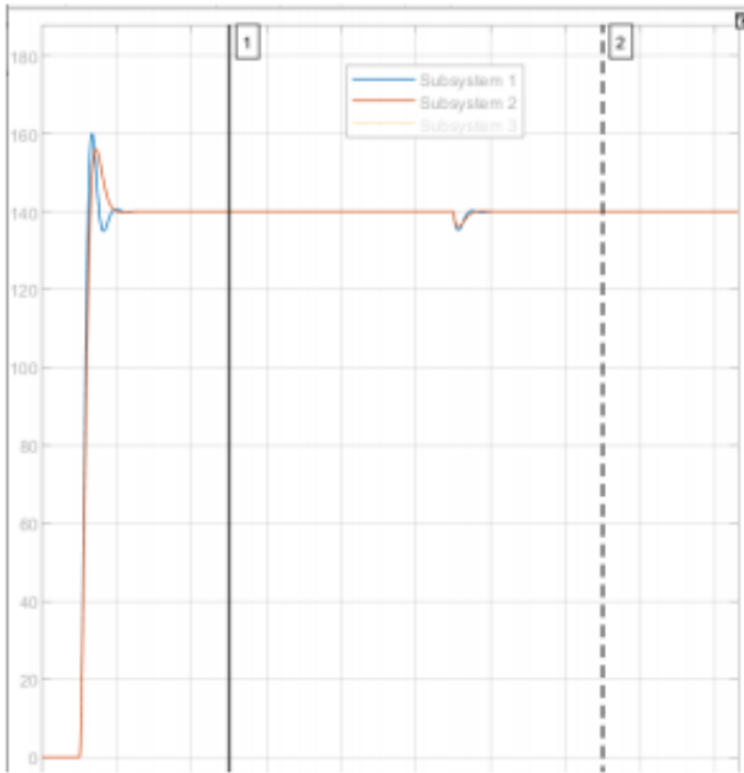


Figure 75 - Scope response

The scope shows that similarly to changing the KI values in task 15, by changing the value of KD, the motor speed also doesn't change despite the disturbance. Therefore, the only value that effects the speed of the motor is KP.

| PID Controller         |        |        |        |
|------------------------|--------|--------|--------|
| KP Value               | 0.0033 | 0.0066 | 0.0132 |
| Rise Time (s)          | 0.14s  | 0.155s | 0.201s |
| Overshoot              | 13.2%  | 3.66%  | 0.024% |
| Settling Time (s)      | 0.712s | 1.1s   | 0.638s |
| Steady State error (s) | 0rad/s | 0rad/s | 0rad/s |

## 17 – Controller Comparisons

This task includes comparing the effects of all three controllers together and the circuits response. Below is an image of the circuit created. Each controller will be autotuned individually to give the most efficient response.

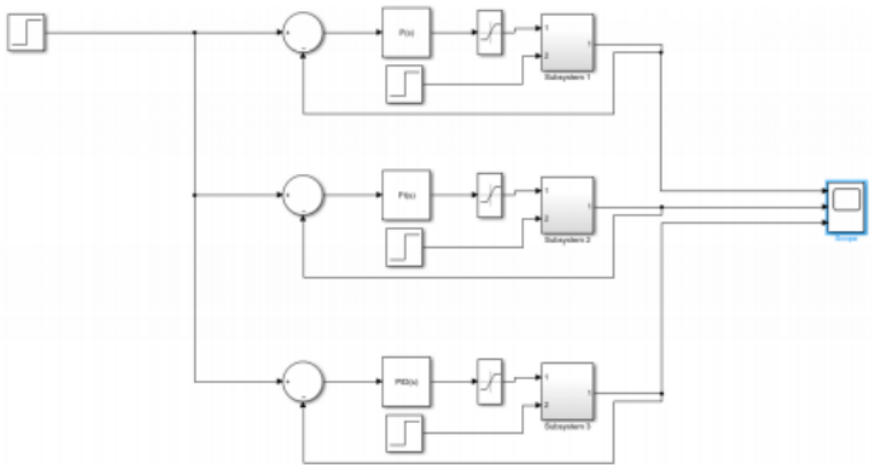


Figure 76 - Circuit Diagram

Firstly the P controller;

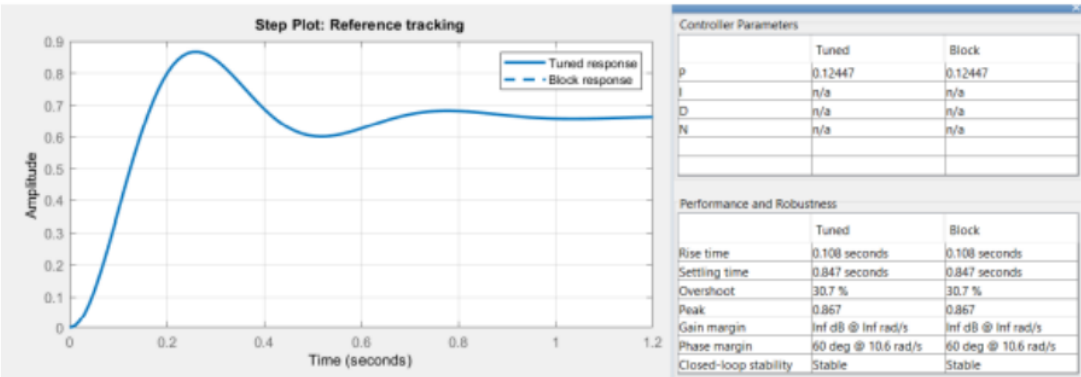


Figure 77 - P controller

Next the PI

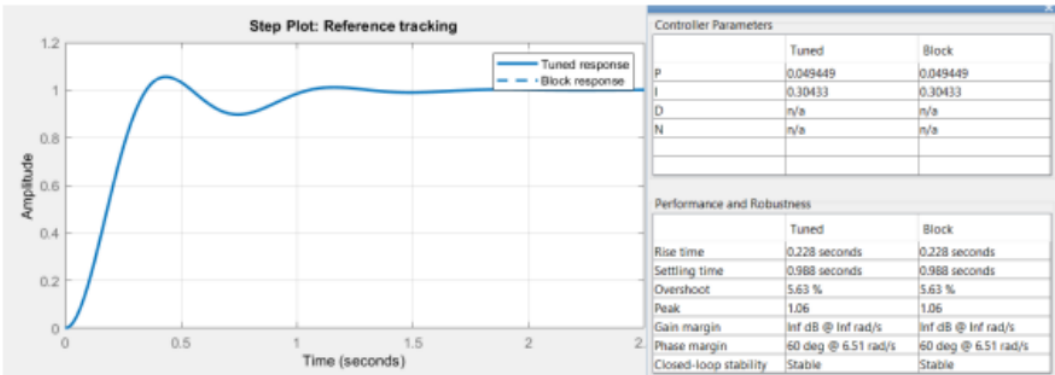


Figure 78 - PI controller

And finally the PID;

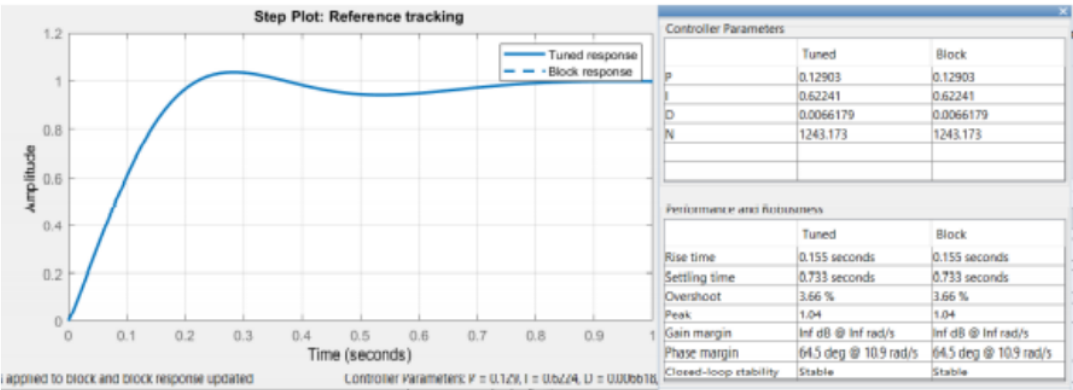


Figure 79 - PID Controller

Next, the controllers response can be analysed by the scope seen in the image below;

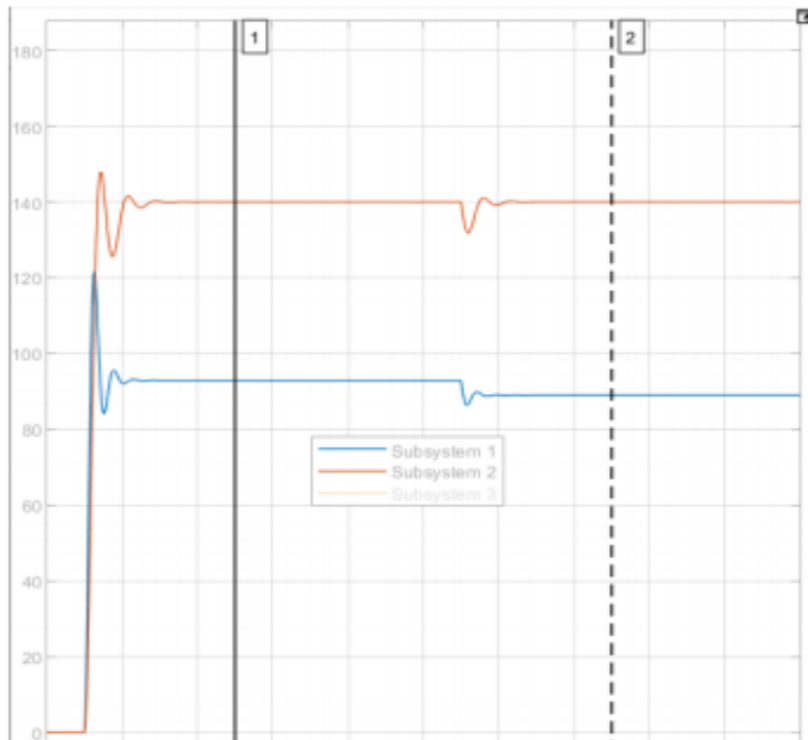


Figure 80 - Scope Response

| <b>P, Pi and PID Controller Comparison</b> |          |           |            |
|--------------------------------------------|----------|-----------|------------|
| <b>Controller Type</b>                     | <b>P</b> | <b>PI</b> | <b>PID</b> |
| <b>Rise Time (s)</b>                       | 0.105s   | 0.228s    | 0.155s     |
| <b>Overshoot</b>                           | 31.4%    | 5.63%     | 3.65%      |
| <b>Settling Time (s)</b>                   | 0.847s   | 0.988s    | 0.733s     |
| <b>Steady State error (s)</b>              | 47.1     | 0         | 0          |

As you can see from the scope and the comparison table above, its evident to see the differences that each of the three controllers has on the control system.

As previously explained in task 15 and 16, the Pi and PID controllers have barely any visual impact on the circuit. It's in fact the P controller which has the greatest impact. Its clear to see that the P controller is the only controller that has a steady state error as well as having the highest overshoot percentage.

As well as this, the P controller has an extensive overshoot of around 31% which is quite a difference of around 26% of the PI controller and 28% of the PID.

Overall, the table tells the author that when all controllers are integrated together to create the PID controller, it's the most efficient type of control for the motor and it has the least overshoot, the lowest settling time and a respectable rise time without any steady state error at all.

## 18 – Overall Conclusions and Recommendations

Throughout the assignment, the author has gained a vast knowledge of using both simulations packages; MATLAB and Simulink. The author has learnt various features and tools which will come in handy in future tasks where MATLAB and Simulink will be used.

Throughout the early stages of the assignment, knowledge was gained on different types of circuits such as RL, RC and RLC circuits and their transient response and Laplace model. Also, as well as first order circuits, second order circuits were carefully analysed and calculations were performed in order to input appropriate component values. The circuits were then placed on the simulation software 'MATLAB' where simulations were achieved, and the responses compared for a detailed review of the circuits response.

Task 13 taught the author the basic principles and fundamentals of controlling a DC motor which included various calculations to find out motor torque, speed and currents. Disturbances were also inserted to show the decrease in speed when a load is applied on the motor.

The later tasks in the assignment enhanced the authors knowledge on P, PI and PID controllers and their effects on the motors response. Various characteristics were found including rise time, overshoot percentage and steady state error which gave the author an insight of each ifof the controllers benefits and downsides. Each of the controllers have their own effect on the motor but integrating them all together in a PID controller proved to allow the motor to run the most efficient.

27

1909750

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GRADEMARK REPORT

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FINAL GRADE

GENERAL COMMENTS

Instructor

72/100

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PAGE 2

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PAGE 5

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You have worked this out correctly, well

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PAGE 6

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Comment 1

needs to be explained

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PAGE 7

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Comment 2

why? you should explain this

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PAGE 8

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Comment 3

more detailed analysis should be included

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PAGE 9

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PAGE 10

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You have worked this out correctly, well



### Comment 4

LPF circuit



You have worked this out correctly, well



### Comment 5

Analysis should be deeper, state type of circuit and relate findings to TF



### Incorrect

You have worked this out wrongly. It is not correct, check work more carefully.



### Comment 6

typo



### Comment 7

why is your results table an image?



### Comment 8

strange that all your results are images!

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### Comment 9

Fig 6.6?!

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### Comment 10

Fig 6.8? Is this pasted?

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### Comment 11

Again your analysis should be deeper, effect of R, resonance etc...

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You have worked this out correctly, well

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### Comment 12

Analysis is not just about verifying calculations, you should include the type of response and circuit , also relate to the TF and the effects of varying componenet values

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PAGE 36

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You have worked this out correctly, well



### Comment 13

see previous comment



### Incorrect

You have worked this out wrongly. It is not correct, check work more carefully.



### Lacks essential detail

Lacks detail



### Comment 14

task incomplete



### Comment 15

task incomplete



### Comment 16

model incomplete



You have worked this out correctly, well



### Comment 17

?



### Comment 18

A shame you did not tabulate results and give an analysis

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### Comment 19

P only



### Comment 20

explain

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### Comment 21

do not write results into lines of text - tabulate

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### Comment 22

unclear how/where you have worked these out



### Comment 23

wheres the theory?

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### Comment 24

see previous two comments

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### Comment 25

see previous comments



You have worked this out correctly, well



### Comment 26

conclusion should not be about what you have learned, rather what the results say



### Comment 27

include things like the importance of the TF and the predictions of responses and circuit types etc...

GRADING FORM: NEW CSG-RUBRIC

ETHAN JOEL

72

## 1. ENGAGEMENT WITH LITERATURE



NA

## 2. KNOWLEDGE AND UNDERSTANDING



Very good knowledge and understanding demonstrated. 20/30

**21**

### 3. COGNITIVE AND INTELLECTUAL



Evidence of analytical skill demonstrated, however, further observations and deductions could have been made, see comments. 18/30

**18**

### 4. PRACTICAL APPLICATION



Excellent use of software, matlab and simulink. 26/30

**25**

### 5. TRANSFERABLE SKILLS



Very good report. 8/10

**8**