

Electrical principles, methods and simulation - EAP

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HNC Electrical and Electronic Engineering
SGEE5002 Electrical Principles, Methods and
Simulation

Analysis, Simulation and Evaluation of Circuits
and Systems

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Executive Summary

In this report it looks at the transient response and frequency response of a first order series circuit both an RC and RL circuit. It then looks at the transient and frequency response of a second order series circuit and what the damping  are. It then goes on to look at the frequency response of a first order low pass and high pass filter when chosen a capacitance value and the phase shift response. Finally, this report then investigates the DC model of a motor and investigates the response of adding in proportional control and looking at the effects of PID.

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Aims and Objectives

The aims and objectives of this report is to show how to apply methods of analysis, modelling and simulation in order to predict the performance of electrical, electronic and control circuits and systems.

Task 1 -Transient analysis of first order RL Electrical Circuit

The value of the resistor was chosen to be 140 ohm and then chose the value for the inductor to be 0.4H. The value for time constant is

$$\tau = \frac{0.4}{140} = 0.285\text{ms}$$

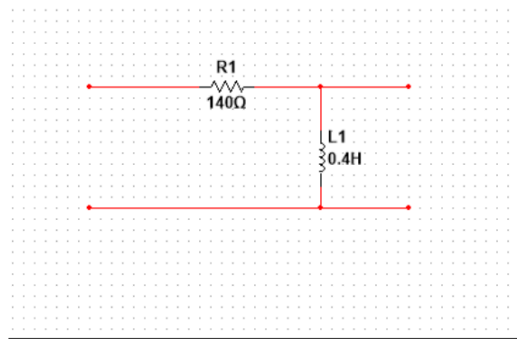


Figure 1- RL Circuit

From this circuit we can work out the output of the circuit in laplace form.

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

From this we then have to apply a step input, $U(s) = \frac{1}{s}$

Therefore, if we then multiply the equation by the step input we get:

$$Y(s) = \left(\frac{sL}{sL + R} \right) \times \left(\frac{1}{s} \right)$$

We then must rearrange the equation to make it look like one of the laplace equations in the table and so we can get the function.

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

$$= \frac{L}{sL + R}$$

If we then look at the above equation, we can see that to get s on its own and to change L to a 1 we could divide through by L.

$$= \frac{1}{s + \left(\frac{R}{L} \right)}$$

After taking the inverse of the equation from the laplace table we can see that this now matches the equation $\frac{1}{s+a}$ where a is equal to $\frac{R}{L}$.

Now that we got the laplace module we can use this to find the equation in the time domain.

$$e^{-at}$$
 4

Now we can work out the transfer function of this circuit.

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

If we then divided this equation all by R we can get the value of L into a more simpler value as we will get $\frac{L}{R}$ which as we know is the value of τ (tau).

$$= \frac{s \left(\frac{L}{R} \right)}{s \left(\frac{L}{R} \right) + 1}$$

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

So we know that τ is equal to $\frac{L}{R}$ so if I substitute the numbers in that I have chosen we will get

$$\tau = \frac{0.4}{140} = 0.285mS$$

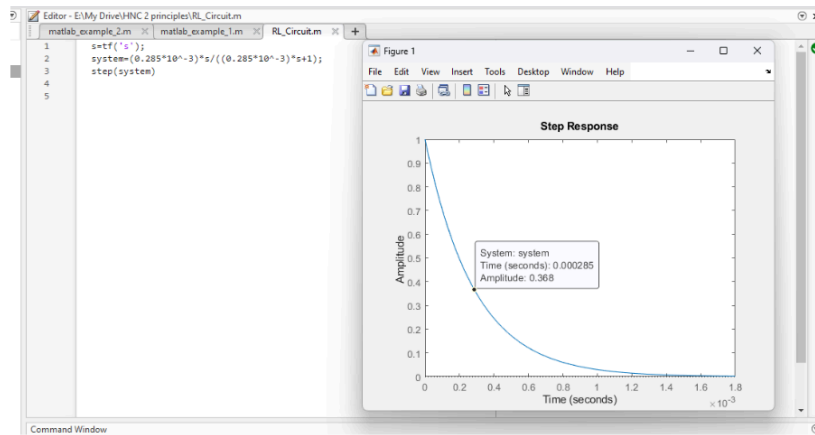


Figure 2- Transient response of an RL circuit

This was the graph produced on matlab after substituting all the number in and using the correct equation. We measured at the amplitude of 0.368 due to when looking at the laplace table and seeing the function associated with it e^{-at} . We earlier on said that a was equal to $\frac{R}{L}$ which would make the equation now $e^{-Rt/L}$ which is the same as $e^{-t/\tau}$, we know that is both t and τ are equal then it would become e^{-1} which works out to be 0.368.

6

Calculated value of τ	Measured value of τ
0.285mS	0.285mS

We used the potential divider rule to first find out what the output value would be in the laplace form, using the laplace module we would then be able to find out what the output value would be in the time domain. We could do this by adding in a step value and simply rearranging the equation around until we could find a module that suites another equation in the time domain. Once we did that, we found that the laplace module was the same as the time domain function e^{-at} . We know that with this function we would be looking at a graph that should decay exponentially. Both the values for τ came out to be the same both calculated and measured and the graph was also an exponential decay, we measured the amplitude at 0.368 due to knowing that if $t=\tau$ then $Y(s)=e^{-1}$.

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Task 2 -Transient analysis of a first order RC Electrical Circuit

The value of the resistor was chosen to be 1400 ohm and then chose the value for the capacitor to be 4uf. The value for the time constant is

$$\tau = RC = 1400 \times 4 \times 10^{-6} = 5.6mS$$

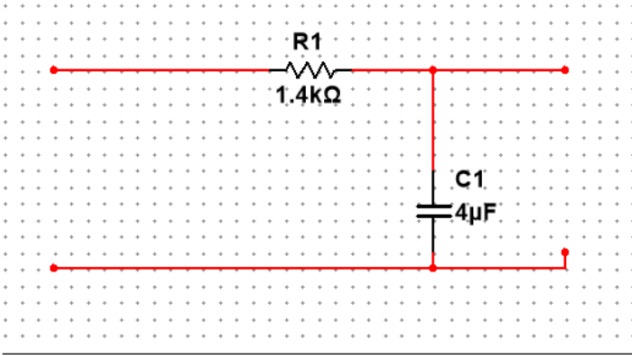


Figure 3 - RC Circuit

Using the potential divider rule we get the equation

$$Y(s) = \frac{\frac{1}{sC}}{R + \left(\frac{1}{sC}\right)} x u(s)$$



Now we need to multiply is all by sC

$$Y(s) = \frac{1}{RCs + 1} x u(s)$$

We know that $u(s)$ is equal to $\frac{1}{s}$ as it is the unit step input, this means the equation changes to

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

In order, to find the time response in the time domain we will have to rearrange and then take the inverse laplace transforms.

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

We now must divide through by RC

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

Now by taking the inverse of this equation we are now able to let $a = \frac{1}{RC}$ which would give us the transform

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

From the table of inverse transforms we can see that

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

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

We can now work out the transfer function of the circuit

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

We know that RC is equal to τ so now we can substitute that into the function

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

Knowing that τ is equal to RC we can now calculate the value of τ

$$\tau = RC = 1400 \times 4 \times 10^{-6} = 5.6 \text{ mS}$$

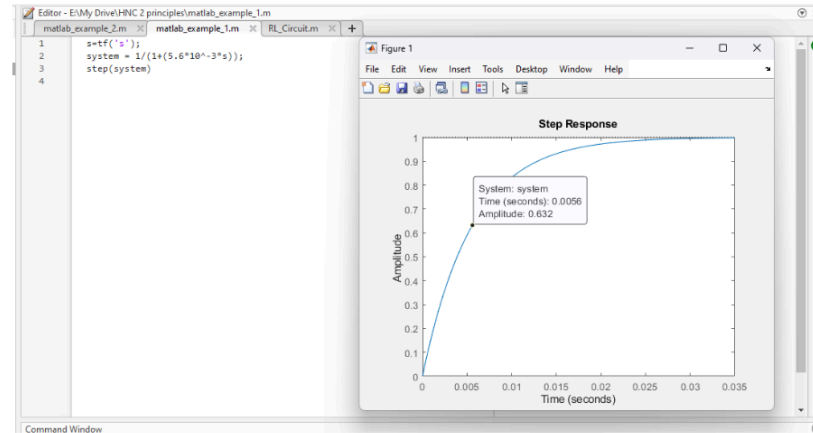


Figure 4 - Transient response of an RC circuit

This is the graph that was generated on matlab after substituting in the numbers and using the correct equation. We measured at the point of 0.632 due to the function of the graph, with it being an exponential rise the equation is $1 - e^{-t/RC}$, looking back earlier we said that τ is equal to RC so we can substitute that into the function instead $1 - e^{-t/\tau}$, if t is equal to τ then we will get $1 - e^{-1}$, this function gives you the value of 0.632 which is that point at which is measured.

Calculated value of τ	Measured value of τ
5.6mS	5.6mS

We used the potential divider rule to first find out what the output value would be in the laplace form, using the laplace module we would then be able to find out what the output value would be in the time domain. We could do this by adding in a step value and simply rearranging the equation around until we could find a module that suites another equation in the time domain. Once we did

that, we found that the laplace module was the same as the time domain function $1 - e^{-at}$. We know that with this function we would be looking at a graph that should rise exponentially. Both the values for τ came out to be the same both calculated and measured and the graph was also an exponential rise, we measured the amplitude at 0.632 due to knowing that if $t=\tau$ then $Y(t) = 1 - e^{-1}$.

Task 3 -Frequency performance analysis of a first order RL Electrical Circuit

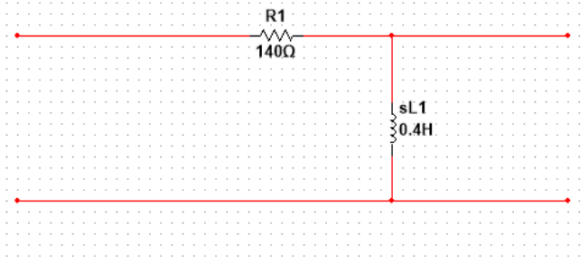


Figure 5 - RL Circuit

This is a passive High pass filter with an inductor, it is achieved by having an inductor in parallel with a resistor.

The cut-off frequency for an RL circuit can now be calculated using the formula:

$$\omega C = \frac{R}{L} = \frac{140}{0.4} = 350 \text{ rads/sec}$$

The transfer function in terms of the cut off frequency is

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

Phase angle

$$\theta = \tan^{-1}\left(\frac{\omega C}{1}\right) = 45^\circ$$

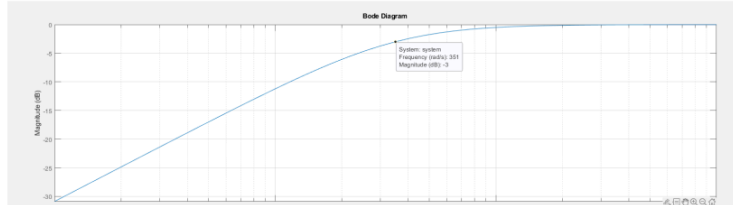


Figure 6 - Bode Plot Magnitude response marking Frequency at -3dB on RL Circuit

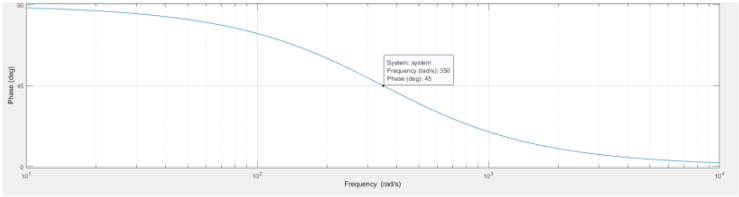


Figure 7 - Bode plot Phase response marking the angle at the frequency on RL Circuit

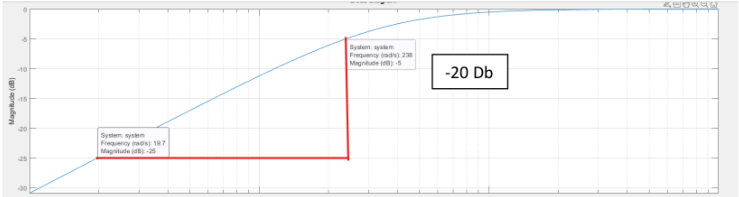


Figure 8 - Bode plot showing the 20dB drop off on RL Circuit

Parameters	Expected Value	Actual Value	Pass/Fail
ωC	350 rad/sec	350 rad/sec	pass
Phase Shift	-45°	-45°	pass
Roll off	20dB	20dB	pass

Due to the circuit's configuration, it functions as a high-pass filter, allowing only high frequencies to pass beyond the -3dB point. At the natural frequency, the phase shift is 45 degrees, and the roll-off rate is 20dB per decade. The obtained results confirm the accuracy of the calculations, as there are no discrepancies between the measured and expected values.

Task 4 -Frequency performance analysis of a First Order RC Electrical Circuit

This is a Low pass filter with a capacitor, it is achieved by having a capacitor in parallel with a resistor.

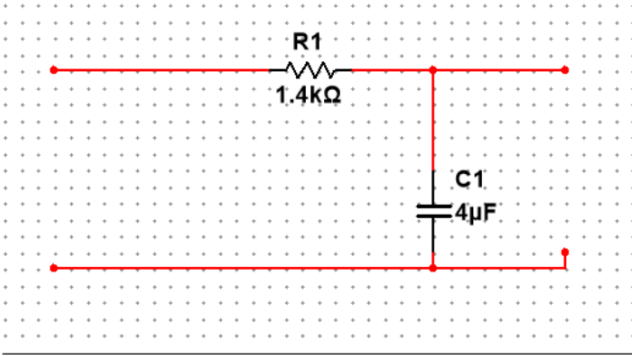


Figure 9- RC Circuit

The cut off frequency for an RC circuit can be calculated using the following formula

$$\omega C = \frac{1}{RC} = \frac{1}{1400 \times 4 \times 10^{-6}} = 178.57 \text{ rad/sec}$$

The transfer function for the RC circuit in terms of the cut off frequency is

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

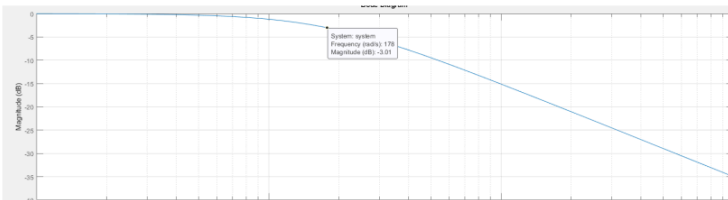


Figure 10 - Bode diagram Magnitude response marking Frequency at -3dB on RC Circuit

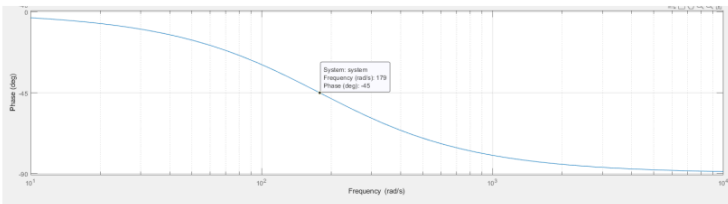


Figure 11 – Bode diagram Phase response marking the angle at the frequency on RC Circuit

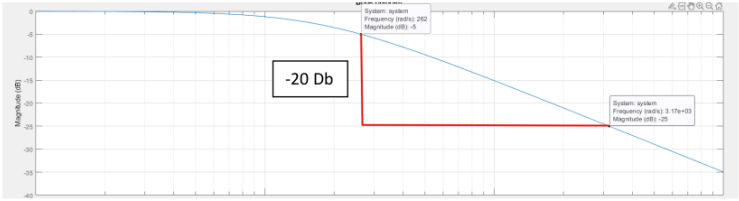


Figure 12 - Bode plot showing the 20dB drop off on RC Circuit

Parameters	Expected Value	Actual Value	Pass/Fail
ωC	178 rad/sec	178 rad/sec	pass
Phase Shift	-45°	-45°	pass
Roll off	20dB	20dB	pass

Based on the circuit's configuration, it is identified as a first-order low-pass filter, as it contains only one reactive component. This means it allows low frequencies to pass beyond the -3dB point. The circuit exhibits a phase shift of 45 degrees and a roll-off slope of -20dB per decade. The obtained results confirm the accuracy of the calculations, as there are no discrepancies between the measured and expected values.

Task 5 -Transient performance analysis of a Second Order series Electrical Circuit

The RLC circuit is analysed to examine how the resistance value influences the circuit's damping behaviour. The four types of damping—No Damping, Underdamped, Overdamped, and Critically Damped—will be illustrated. The selected component values are $L = 0.18 \text{ H}$ and $C = 62 \mu\text{F}$.

This is an image of laplace model of the circuit that is written in the laplace domain

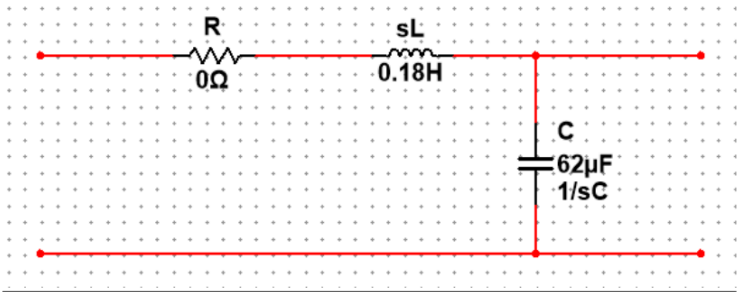


Figure 13 - Laplace model RLC circuit

1. Potential Divider Rule

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

16

2. Multiply Top and Bottom by s/L

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

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

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

K = Gain = 1

W_n = Natural Frequency = $\frac{1}{\sqrt{LC}}$

ζ = Damping Coefficient = $\frac{R}{2} \sqrt{\frac{C}{L}}$

The following equations are used to calculate the natural frequency and damping coefficient. The natural frequency remains the same for all the circuits.

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$$\text{Natural frequency} = W_n = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{0.18 \times 62 \times 10^{-6}}} = 299.34 \text{ Rads/S}$$

ζ = Damping Coefficient = $\frac{R}{2} \sqrt{\frac{C}{L}}$

Under Damped

An underdamped circuit is when the damping coefficient is less than 1 this causes the circuit to oscillate and have overshoot before reaching its steady state.

$$\text{Damping Coefficient} = \zeta = \frac{R}{2} \sqrt{\frac{C}{L}} = \frac{50}{2} \sqrt{\frac{62 \times 10^{-6}}{0.18}} = 0.46$$

$$H(s) = \frac{K W_n^2}{s^2 + 2 \zeta W_n s + W_n^2} = \frac{1 \times 299.34^2}{s^2 + (2 \times 0.46 \times 299.34) s + 299.34^2}$$

Over Damped

An overdamped circuit is when the damping coefficient is greater than 1 this causes the circuit to slowly rise to its steady state.

$$\text{Damping Coefficient} = \zeta = \frac{R}{2} \sqrt{\frac{C}{L}} = \frac{175}{2} \sqrt{\frac{62 \times 10^{-6}}{0.18}} = 1.62$$

$$H(s) = \frac{K W n^2}{s^2 + 2 \zeta W n s + W n^2} = \frac{1 \times 299.34^2}{s^2 + ((2 \times 1.62 \times 299.34) \times s) + 299.34^2}$$

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Critically Damped

A Critically damped circuit is when the damping coefficient is equal to 1 the circuit rises quickly to its steady state with no oscillation. In order to calculate the damping factor equation must be transposed to calculate the resistor value required.

$$R = \frac{2 \times \zeta}{\left(\sqrt{\frac{C}{L}}\right)} = \frac{2 \times 1}{\left(\sqrt{\frac{62 \times 10^{-6}}{0.18}}\right)} = 107.7631812$$

$$\text{Damping Coefficient} = \zeta = \frac{R}{2} \sqrt{\frac{C}{L}} = \frac{107.7631812}{2} \sqrt{\frac{62 \times 10^{-6}}{0.18}} = 1$$

No Damping

To attain a circuit with no damping the circuit must have a very low resistance, a value of 0.0000001 will be used.

$$\text{Damping Coefficient} = \zeta = \frac{R}{2} \sqrt{\frac{C}{L}} = \frac{0.0000001}{2} \sqrt{\frac{62 \times 10^{-6}}{0.18}} = 9.279607271 \times 10^{-9}$$

$$H(s) = \frac{K W n^2}{s^2 + 2 \zeta W n s + W n^2} = \frac{1 \times 299.34^2}{s^2 + ((2 \times 9.279607271 \times 10^{-9} \times 299.34) \times s) + 299.34^2}$$

Critically damped

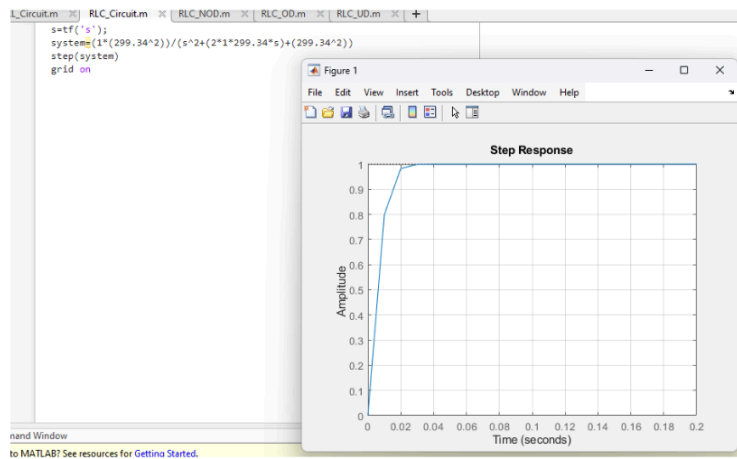


Figure 14 - Critically damped response of second order RLC circuit

Under damped

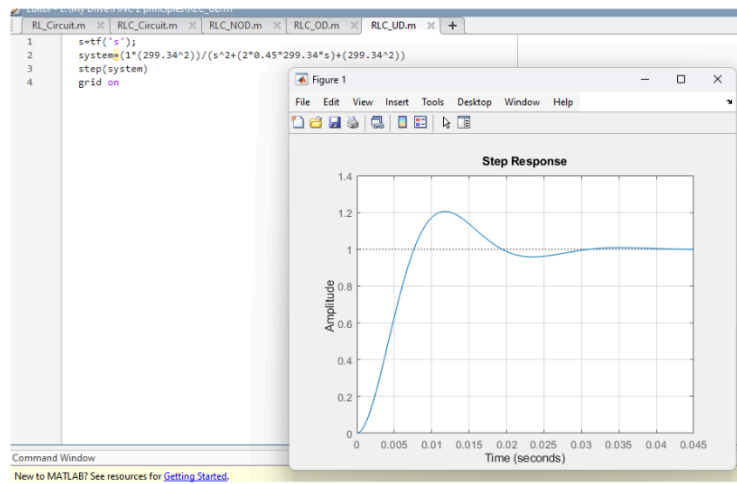


Figure 15 - Under damped response of second order RLC circuit

Over damped

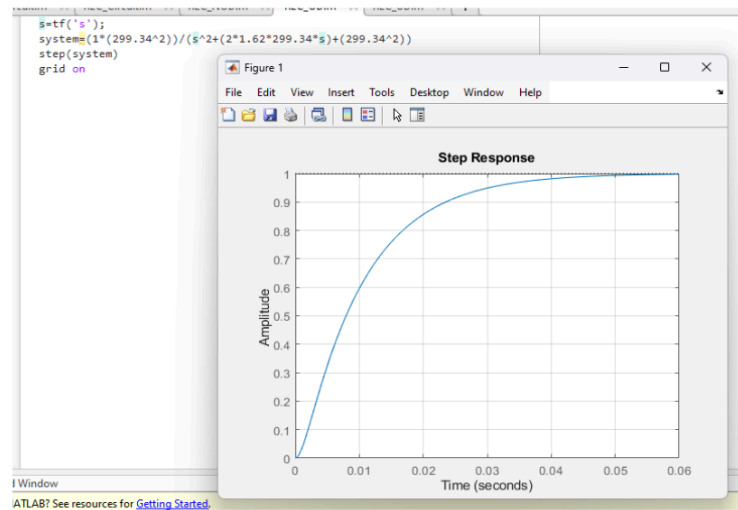


Figure 16 - Over damped response of second order RLC circuit

No Damping

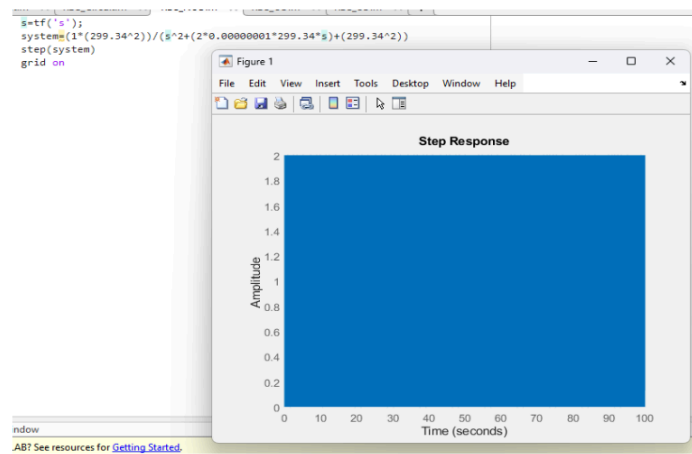


Figure 17 - No damped response of second order RLC circuit

Resistor Value (Ω)	Damping Coefficient (ζ)	Circuit Effect
50	$0.46 (\zeta < 1)$	Underdamped
175	$1.62 (\zeta > 1)$	Overdamped
107.7631812	$1 (\zeta = 1)$	Critically Damped
0.0000001	1.16	No Damping

The resistor in an RLC circuit plays a key role in determining the damping coefficient, which affects how the system responds over time. As resistance increases, the circuit dissipates more energy with each cycle, leading to a higher damping coefficient. This results in a slower, more gradual response, where the system may take longer to reach the desired value or fail to respond efficiently. On the other hand, decreasing the resistance reduces the damping, allowing the circuit to respond more quickly, but often with overshoot or oscillations that can compromise stability. This balance between speed and stability is why resistance has such a significant impact on the circuit's overall behaviour.

Task 6 – Frequency performance analysis of a Second Order Series Electrical Circuit

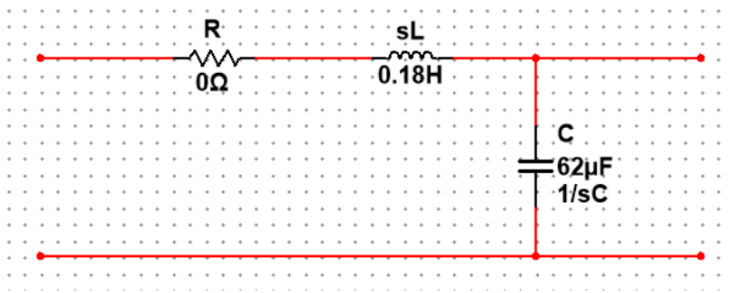


Figure 18 - Laplace model of RLC circuit

1. Potential Divider Rule

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

2. Multiply Top and Bottom by s/L

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

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

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

K = Gain = 1

Wm = Frequency for maximum amplitude = $\sqrt{\frac{1}{LC} - \frac{1}{2} \left(\frac{R}{L}\right)^2}$

Wn = Natural Frequency = $\frac{1}{\sqrt{LC}}$

ζ = Damping Coefficient = $\frac{R}{2} \sqrt{\frac{C}{L}}$

Q = Gain = $\frac{1}{R} \sqrt{\frac{L}{C}}$ (This is the quality factor which is the sharpness of the peak)

$$\text{Natural frequency} = W_n = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{0.18 \times 62 \times 10^{-6}}} = 299.34 \text{ Rads/S}$$

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

$$\frac{1}{LC} = \frac{1}{0.18 \times 62 \times 10^{-6}} = 89605.73477$$

$$\text{Matlab code} = \frac{89605}{s^2 + \text{value of } R + 89605}$$



Critically damped value of R

$$R = \frac{2 \times \zeta}{\left(\sqrt{\frac{C}{L}}\right)} = \frac{2 \times 1}{\left(\sqrt{\frac{62 \times 10^{-6}}{0.18}}\right)} = 107.7631812$$

$$\text{Damping Coefficient} = \zeta = \frac{R}{2} \sqrt{\frac{C}{L}} = \frac{107.7631812}{2} \sqrt{\frac{62 \times 10^{-6}}{0.18}} = 1$$

$$\text{Matlab code} = \frac{89605}{s^2 + 107.7631812 + 89605}$$

Damping Coefficient value for 50

$$\text{Damping Coefficient} = \zeta = \frac{R}{2} \sqrt{\frac{C}{L}} = \frac{50}{2} \sqrt{\frac{62 \times 10^{-6}}{0.18}} = 0.46$$

$$\text{Matlab code} = \frac{89605}{s^2 + 50 + 89605}$$

Damping Coefficient value for 1

$$\text{Damping Coefficient} = \zeta = \frac{R}{2} \sqrt{\frac{C}{L}} = \frac{1}{2} \sqrt{\frac{62 \times 10^{-6}}{0.18}} = 9.3 \times 10^{-3}$$

$$\text{Matlab code} = \frac{89605}{s^2 + 1 + 89605}$$

Damping Coefficient value for 5

$$\text{Damping Coefficient} = \zeta = \frac{R}{2} \sqrt{\frac{C}{L}} = \frac{5}{2} \sqrt{\frac{62 \times 10^{-6}}{0.18}} = 0.05$$

$$\text{Matlab code} = \frac{89605}{s^2 + 5 + 89605}$$

Damping Coefficient value for 10

$$\text{Damping Coefficient} = \zeta = \frac{R}{2} \sqrt{\frac{C}{L}} = \frac{10}{2} \sqrt{\frac{62 \times 10^{-6}}{0.18}} = 0.09$$

$$\text{Matlab code} = \frac{89605}{s^2 + 10 + 89605}$$

Damping Coefficient value for 250

$$\text{Damping Coefficient} = \zeta = \frac{R}{2} \sqrt{\frac{C}{L}} = \frac{250}{2} \sqrt{\frac{62 \times 10^{-6}}{0.18}} = 2.32$$

$$\text{Matlab code} = \frac{89605}{s^2 + 250 + 89605}$$

FILE	CODE	SIMULINK	ENVIRONMENT
------	------	----------	-------------

Command Window

New to MATLAB? See resources for [Getting Started](#).

```
>> s=tf('s');
system1= 89605/(s^2+50*s+89605);
bode(system1);
grid on
hold on

s=tf('s');
system2= 89605/(s^2+1*s+89605);
bode(system2);
s=tf('s');
system3= 89605/(s^2+5*s+89605);
bode(system3);
s=tf('s');
system4= 89605/(s^2+10*s+89605);
bode(system4);
s=tf('s');
system5= 89605/(s^2+107.7631812*s+89605);
bode(system5);
s=tf('s');
system6= 89605/(s^2+250*s+89605);
bode(system6);

grid on
fx >>
```

Figure 19 - Matlab code showing each resistance value changed

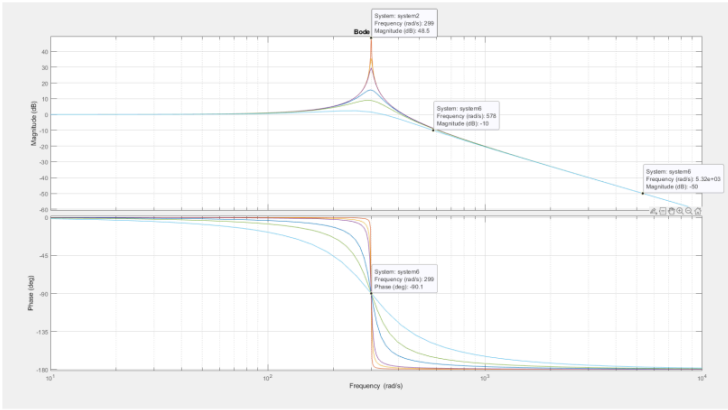


Figure 20 - Bode plot showing the magnitude and phase angle at the natural frequency value

The frequency response of a second-order RLC circuit typically exhibits key characteristics such as resonance, bandwidth, amplitude response, and phase shift. At resonance, the circuit reaches its maximum amplitude. The resonance frequency is determined by the inductance and capacitance values. The bandwidth, which is the range of frequencies where the circuit effectively responds, is influenced by the damping factor, with underdamped circuits having a narrow, sharp resonance peak and overdamped circuits showing a broader, shallower response. The phase response shifts with frequency, showing a 0° phase shift at resonance for a series RLC circuit. The damping of the circuit affects the sharpness of the resonance peak and the bandwidth, with underdamped systems showing a strong, selective peak and overdamped systems exhibiting slower, less pronounced responses. Overall, the frequency response of a second-order RLC circuit reveals a combination of resonance, phase shifts, and damping, providing insight into how the circuit reacts to different frequencies.

Task 7 -Frequency performance analysis of a First Order Electronic Systems

The Low pass filter was created on Multisim, this time looking at the effect the capacitance value effects the cut off frequency and phase shift. The component values selected are as per the brief with a selected capacitor value of $C = 470\text{nF}$.

$$\text{Gain } (K) = \frac{R2}{R1} = \frac{20000}{1000} = 20$$

$$\text{Cut off frequency } (W_c) = \frac{1}{CR2} = \frac{1}{470 \times 10^{-9} \times 20000} = 119.05 \text{ Rads/S}$$

$$\text{Transfer function } H(s) = -k \left[\frac{W_c}{s + W_c} \right] = -20 \left[\frac{119.05}{s + 119.05} \right]$$

```

Editor - E:\My Drive\HNC 2 principles\Task 7.m
Active_LPF.m Task_4.m Active_HPF.m Task_7.m +
1 s=tf('s');
2 system=-20*(119.05/(s+119.05));
3 bode(system);
4 grid on;
5

```

Figure 21 - MATLAB code for the Low pass filter

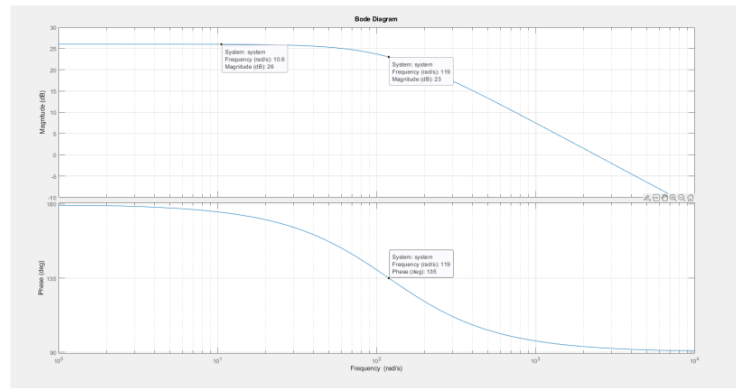


Figure 22 - Bode diagram showing the magnitude and phase angle on the frequency calculated

The consistency between the calculated and simulated results confirms that the circuit is behaving as expected based on calculated results from theory. The cutoff frequency observed in the simulation matches the predicted value, and the roll-off rate of 20 dB per decade reflects the characteristic response of a first-order filter. The DC gain of the inverting amplifier is also validated through the standard gain formula, $A_v = -R_f / R_{in}$ $A_v = -R_f / R_{in}$, where the negative sign indicates the 180-degree phase inversion inherent to inverting configurations. Additionally, due to the frequency dependent nature of the circuit particularly around the cutoff point a further phase shift of -45 degrees occurs, resulting in a total phase shift of 135 degrees. This combined phase behaviour is clearly demonstrated in the simulation's Bode plot.

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Task 8 -Frequency performance analysis of a First Order Electronic System

The high pass filter was created on Multisim, this time looking at the effect the capacitance value effects the cut off frequency and phase shift. The component values selected are as per Table 2.4, with a selected capacitor value of $C = 42\text{nF}$.

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$$\text{Gain}(K) = \frac{R_2}{R_1} = \frac{2000}{1000} = 2$$

$$\text{Cut off frequency}(W_c) = \frac{1}{CR_1} = \frac{1}{42 \times 10^{-9} \times 1000} = 23809.52 \text{ Rads/s}$$

$$\text{Transfer function } H(s) = -k \left[\frac{s}{s + W_c} \right] = -2 \left(\frac{s}{s + 23809.52} \right)$$

```

Editor - E:\My Drive\HNC 2 principles\Task_8.m
Active_LPF.m x Active_HPF.m x Task_7.m x Task_8.m x +
1      s=tf('s');
2      system=-2*(s/(s+23809.52));
3      bode(system);
4      grid on;

```

Figure 23 - MATLAB code for high pass filter

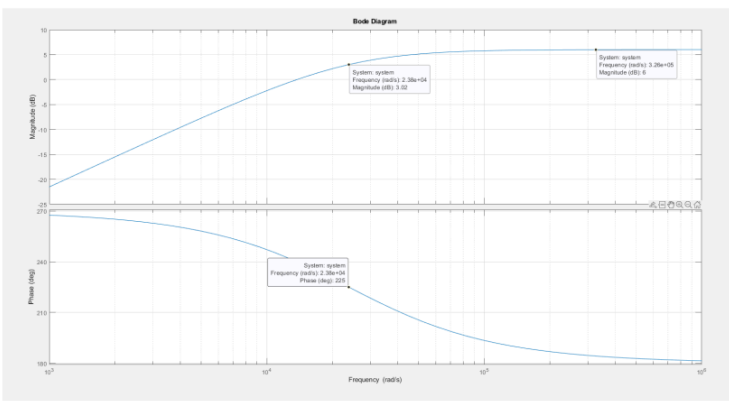


Figure 24 - Bode diagram showing magnitude and phase angle from calculated frequency

This behaviour occurs due to the combined effects of the amplifier configuration and the frequency-dependent components in the circuit. In an inverting amplifier, the signal undergoes a 180-degree phase shift because of the negative gain. Since the circuit also functions as a high-pass filter, it introduces an additional phase shift that starts near 0 degrees at low frequencies and approaches 90 degrees at high frequencies. At the cutoff frequency where the output starts to respond more significantly the phase shift is typically around 45 degrees. When this 45-degree shift from the filter is combined with the 180-degree inversion from the amplifier, the total phase shift becomes 225

degrees. This combined effect is a key characteristic of inverting high-pass filter circuits and is clearly reflected in the phase response shown in the simulation results.

Task 9 – First Order Control System Analysis

The first order control system was made on Simulink and the open loop performance was determined. This is the circuit below which when modified to determine the value of K for stability within the circuit.

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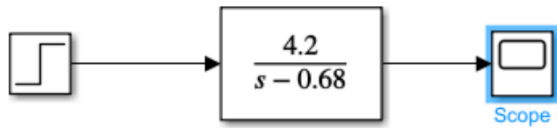


Figure 25 - Open loop control diagram

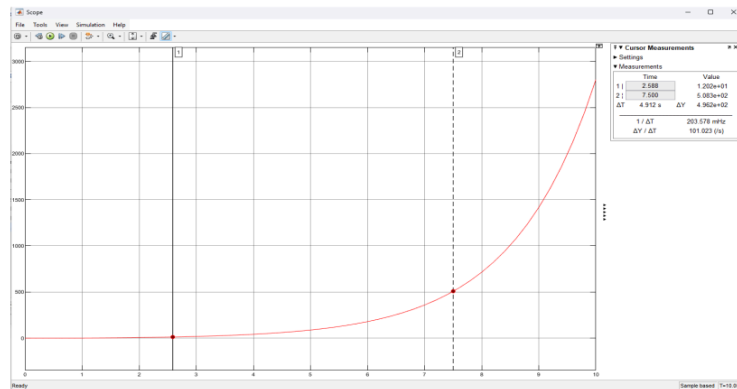


Figure 26 - Open loop response of control system

To check how stable the system is an argand map was created to see where the pole lied on the graph.

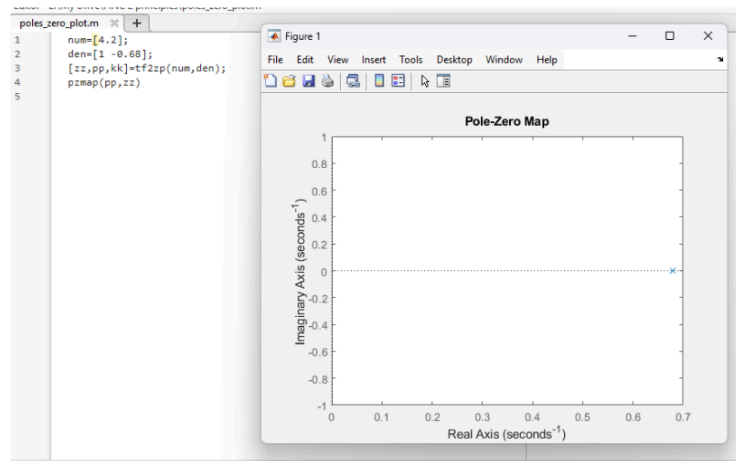


Figure 27 - Pole zero map showing where the pole lied

The pole zero map shows us that the pole is on 0.68. Thus means that the system is unstable due to it being in the positive half of the map.

To improve the stability of the system, the circuit was changed to closed loop control. This involves introducing negative feedback into the circuit. This channels a portion of the systems output back into the input to help maintain equilibrium.

The open loop system was then modified, and negative feedback was introduced, a gain of 1 was added and the system was simulated.

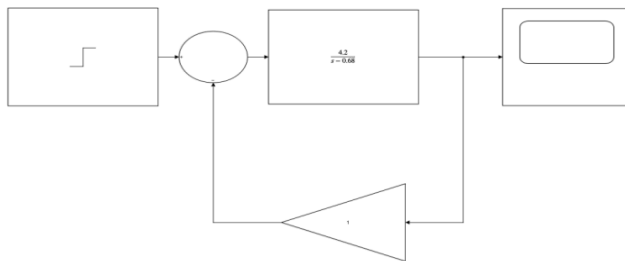


Figure 28 - Control system with feedback of 1

$$\frac{\frac{4.2}{(s - 0.68)}}{1 + \frac{4.2k}{(s - 0.68)}}$$

Multiply top and bottom by $(s - 0.68)$

$$\frac{4.2}{s - 0.68 + 4.2k}$$

$$\frac{4.2}{s + 3.52}$$

The response on the graph below shows that stability has improved within the system as there are no oscillations and can see a rise to equilibrium

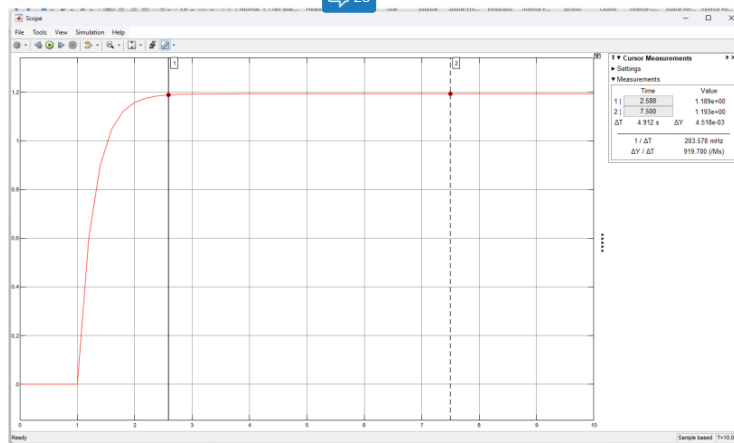


Figure 29 - Control system response with feedback of 1

An argand map was then created again to see which place the pole would lie in to see the stability on the system, as shown below the system has improved and is more stable due to the pole being positive making it lie within the negative plain.

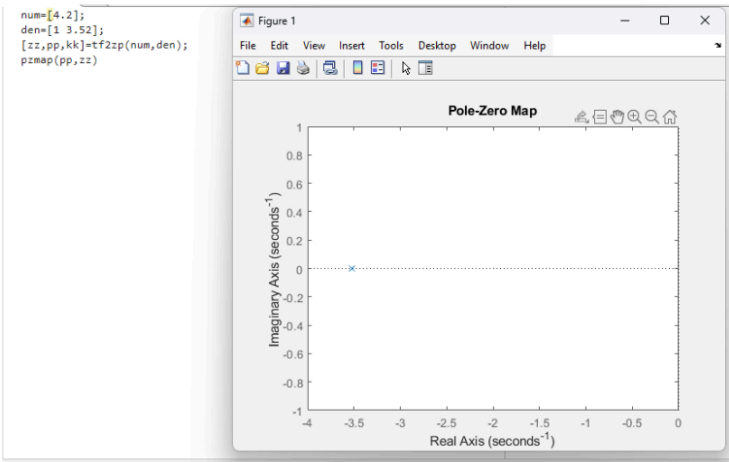


Figure 30 - Pole zero map where the pole lies after adding feedback

The system was then manipulated to find the minimum value of K to achieve a stable system

$$\frac{G(s)}{1 + G(s)H(s)}$$

$$\frac{\frac{4.2}{(s - 0.68)}}{1 + \frac{4.2}{(s - 0.68)}k} = \frac{4.2}{s - 0.68 + 4.2k}$$

$$s = 0.68 + 4.2k = 0$$

$$s = 0.68 - 4.2k$$

$$0.68 - (4.2 \times 0.16) = 8 \times 10^3$$

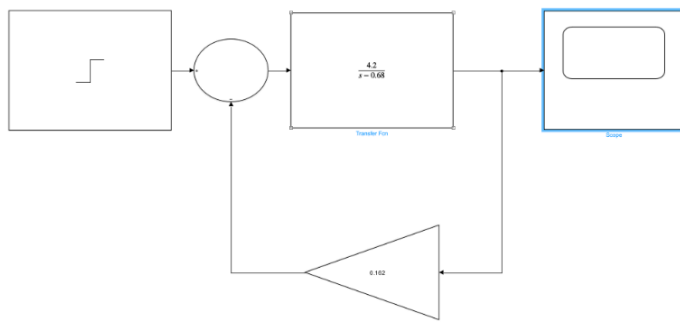


Figure 31 - Control system with feedback of 0.162 (minimum value)

The root locus was then done to show that the lowest gain value that can be entered is 0.16 to achieve a stable system.

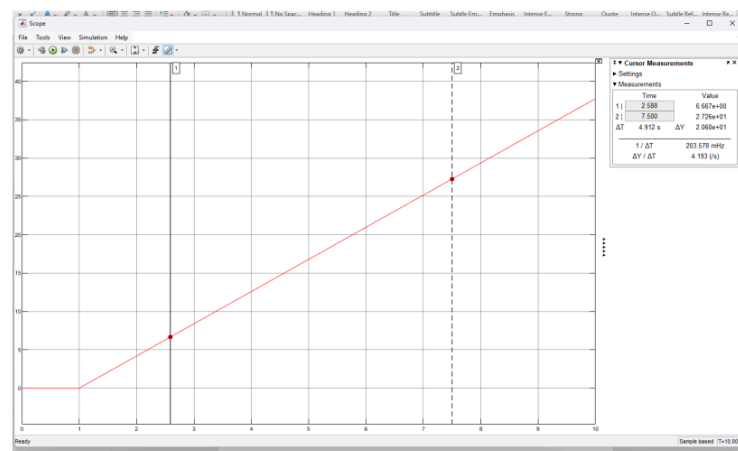


Figure 32 - Control system response with feedback of 0.162 (minimum value)

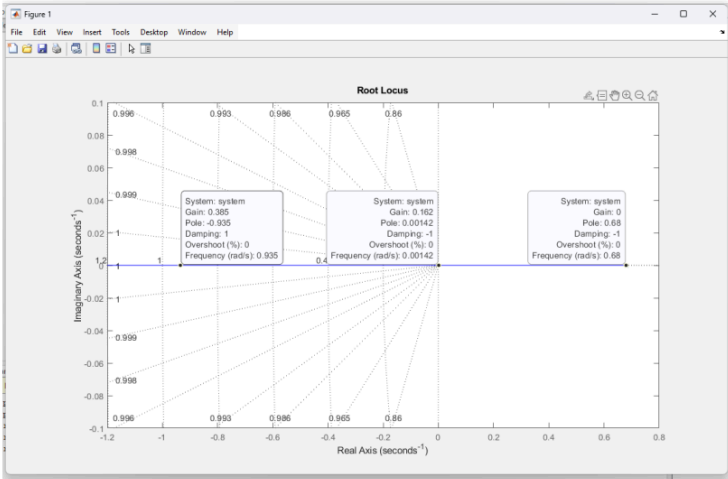


Figure 33 - Root locus showing the response of minimum value of feedback

The gain was then varied to see what the system response would be and highlight the behaviour of the system.

When $K = 10$

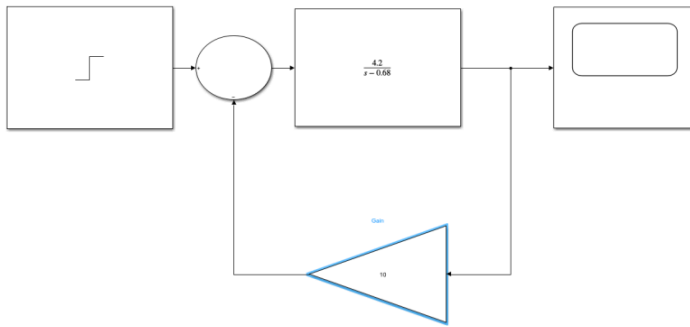


Figure 34 - Control system with feedback of 10

$$s = 0.68 - 4.2k = 0.68 - 4.2 \times (10) = -41.32$$

This would indicate a stable system as the pole is in the negative plain.

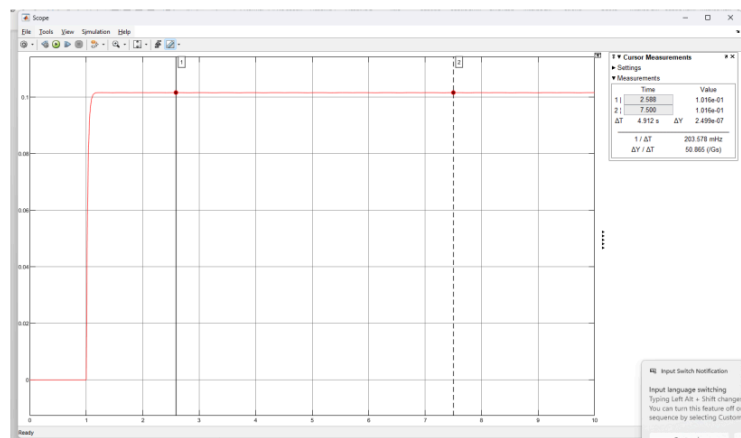


Figure 35 - Control system response with feedback of 10

When $K=0.162$

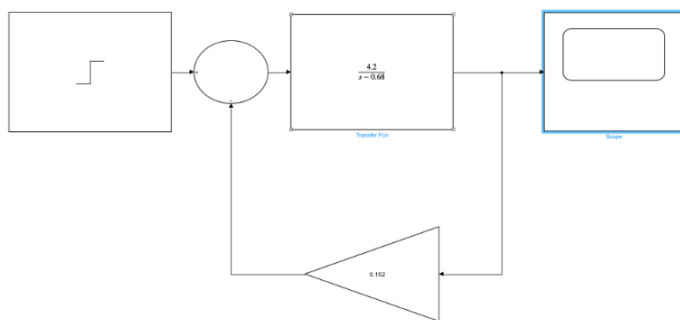


Figure 36 - Control system with feedback of 0.162 (minimum value)

$$s = 0.68 - 4.2k = 0.68 - 4.2 \times (0.162) = 0$$

This would indicate a marginally stable system as the pole is in the middle plain.

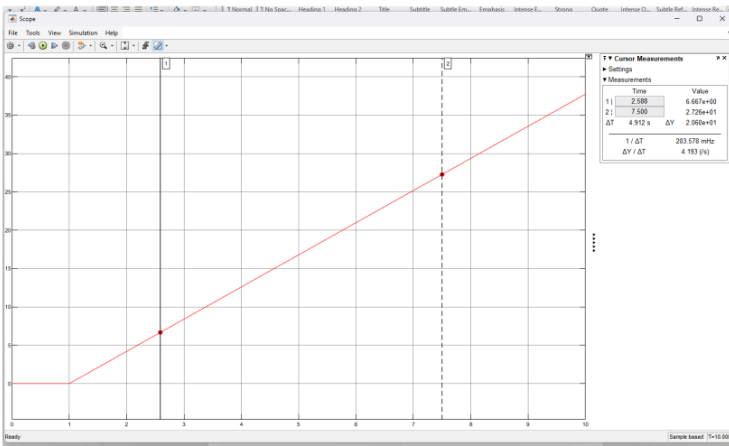


Figure 37 - Control system response with feedback of 0.162 (minimum value)

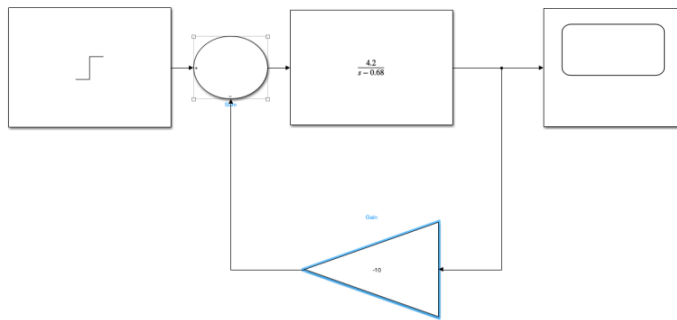


Figure 38 - Control system with feedback of -10

$$s = 0.68 - 4.2k = 0.68 - 4.2 \times (-10) = 42.68$$

This would indicate an unstable system as the pole is in the positive plain.

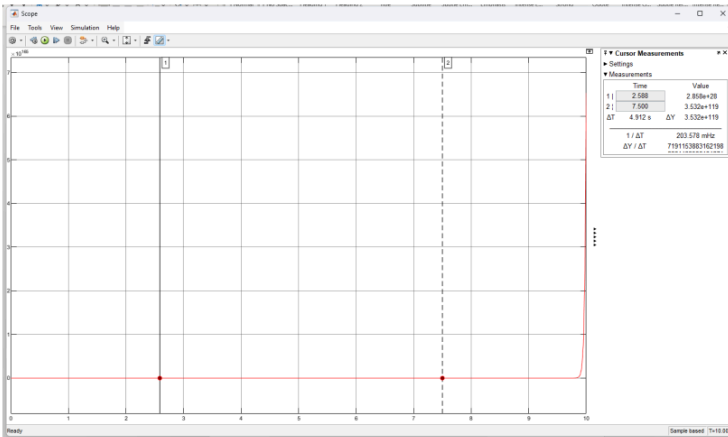


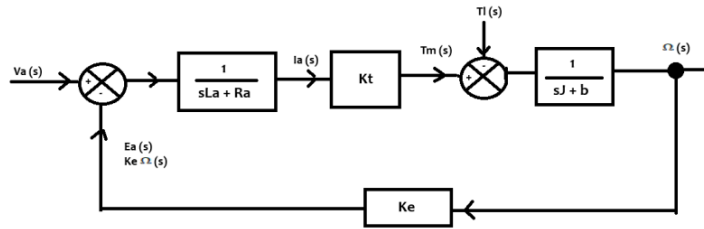
Figure 39 - Control system response with feedback of -10

K	Pole	Prediction
10	-10	Stable
0.162	0	Marginally stable
-10	10	Unstable

This behaviour can be explained by how feedback and gain influence the position of poles in a control system. In an open-loop configuration, the circuit lacks any mechanism to correct deviations in the output, which can lead to poles in the right half of the complex plane—an indication of instability. When negative feedback is applied, it feeds a portion of the output back to the input in a way that counteracts the input signal, reducing the overall system error. This action moves the poles toward the left half of the plane, indicating a stable system. The gain of the amplifier also plays a crucial role in this process. While high gain increases the sensitivity of the feedback loop, helping the circuit quickly correct errors, reducing the gain weakens the feedback's influence. This can cause the poles to shift back toward or even into the unstable region, reducing the system's ability to dampen oscillations or respond smoothly. The relationship between gain, pole placement, and system stability is a fundamental principle in control theory, and it's clearly observed in the simulated and calculated results.

Task 10 – DC Motor model analysis

The below model is mathematical version of the DC motor which includes both the electrical and mechanical transfer functions. The disturbance will be zero initially. The motor model will be built and simulated on Simulink, to build the model calculations will be required.



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Figure 40 - DC model with electrical and mechanical transfers

The full transfer function for this system is

$$G(s) = \frac{Kwn^2}{S^2 + S \zeta wn s + wn^2}$$

Natural Frequency

$$Natural\ Frequency\ (\omega n) = \sqrt{\frac{Ra\ b}{La\ J} + \frac{Kt\ Ke}{La\ J}}$$

$$Natural\ Frequency\ (\omega n) = \sqrt{\frac{1.5 \times 3.68 \times 10^{-6}}{0.2 \times 0.0035} + \frac{0.025 \times 0.025}{0.025 \times 0.0035}} = 3.01\ Rad/S$$

Damping Factor

$$\zeta = \frac{\frac{b}{J} + \frac{Ra}{La}}{2\omega n}$$

$$\zeta = \frac{\left(\frac{3.68 \times 10^{-6}}{0.00035} + \frac{1.5}{0.2}\right)}{2 \times 3.01} = 1.252$$

Stall Torque

$$Stall\ torque = \frac{Kt\ Va}{Ra} = \frac{0.025 \times 14}{1.5} = 0.233\ N/m$$

Friction less no-load speed

$$Friction\ Less\ No\ Load\ Speed\ \Omega_{NL} = \frac{Va}{Ke} = \frac{14}{0.025} = 560\ Rad/S$$

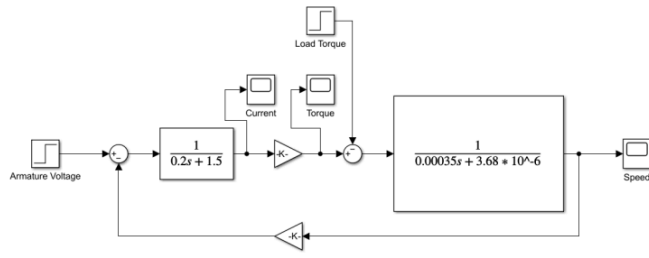


Figure 41 - MATLAB model of DC motor

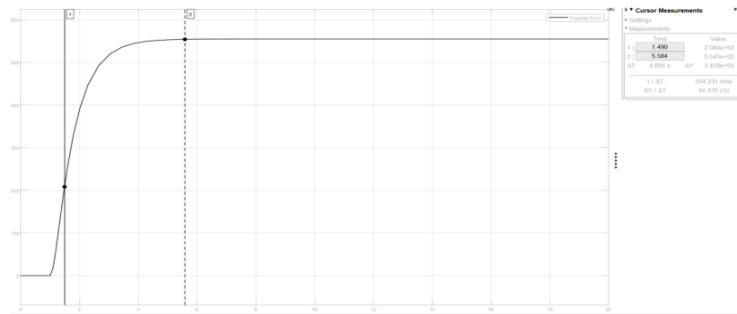


Figure 42 - Graph showing Speed after 20 seconds with no load

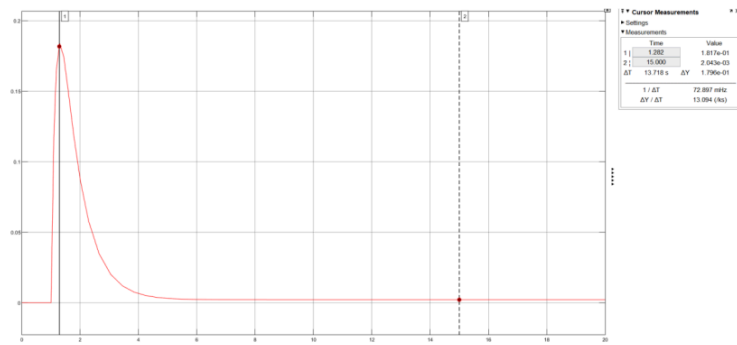


Figure 43 - Torque after 20 seconds with no load

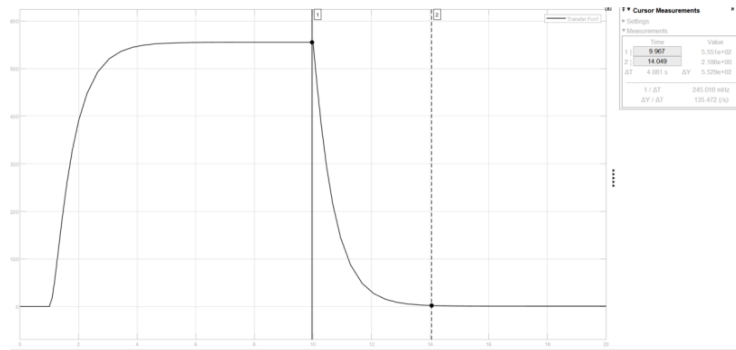


Figure 44 - Speed after 20 seconds with a load torque added after 10

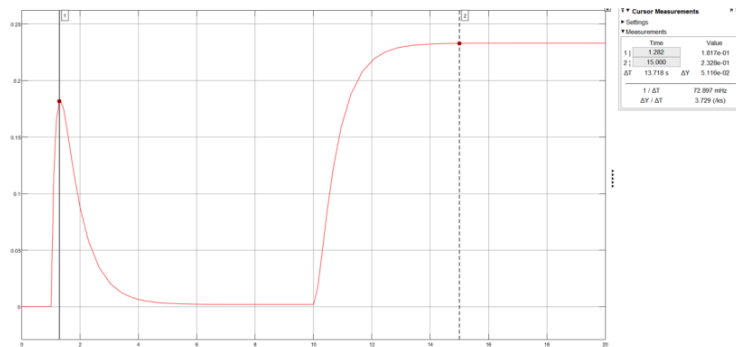


Figure 45 - Torque after 20 seconds with a load torque applied after 10 seconds

The model was again modified this time including a disturbance of 0.04Nm after 10 seconds, the speed and current were then measure and compared with the theoretical values.

$$\text{Loaded speed } \Omega L = \frac{V_a - \frac{K_e T_l}{K_t}}{\frac{R_a b}{K_t} + K_e} = \frac{14 - \left(\frac{1.5 \times 0.04}{0.025} \right)}{\left(\frac{1.5 \times 3.68 \times 10^{-6}}{0.025} \right) + 0.025} = 459.93 \text{ Rad/s}$$

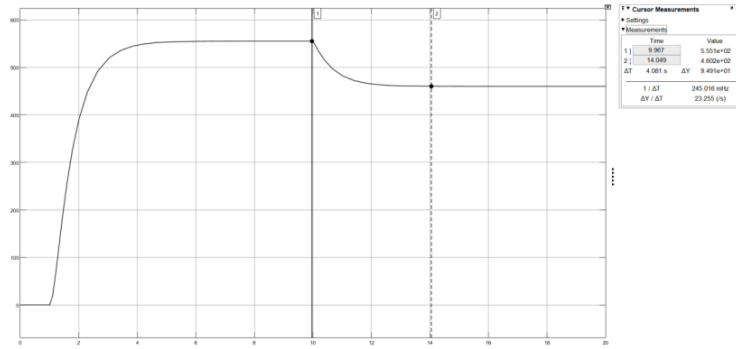


Figure 46 - Speed over 20 seconds with a loaded speed added after 10 seconds

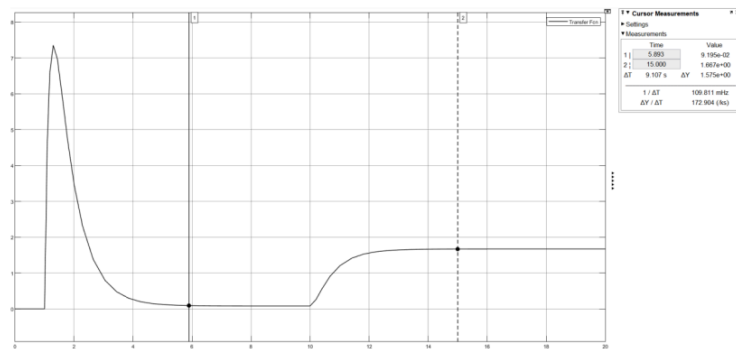


Figure 47 - Current after 20 seconds with a loaded speed added after 10 seconds

The behaviour in the simulation can be explained through the motor's response to load and torque changes. Initially, when the motor operates without a load, it accelerates to the set speed, and the current follows the expected pattern with a rise at startup, which then stabilises as the motor reaches its target speed. The introduction of stall torque after 10 seconds causes the motor to experience a sharp increase in torque, indicating the motor is under load and attempting to resist stalling. This happens because the motor tries to maintain its speed against the opposing torque, causing a rise in torque on the graph. When the stall torque is removed and a load is introduced, the motor first reaches its set speed before a slight drop occurs due to the added load. The current graph reflects this with a rise at startup, followed by stabilisation, and then an increase in current once the load is applied, as the motor works to compensate for the extra load and maintain its speed. This sequence shows how the motor adjusts to varying conditions and the relationship between speed, torque, and current.

Task 11 – Proportional speed control system

The same motor model was then used from task 10 in this one, however a proportional control (KP) was added to the circuit, the disturbance value was also decreased to 0.03Nm. The model was split into 3 circuits and fed into a scope to look at 3 different wave forms, this is done as the value of KP was varied to see what the response is.

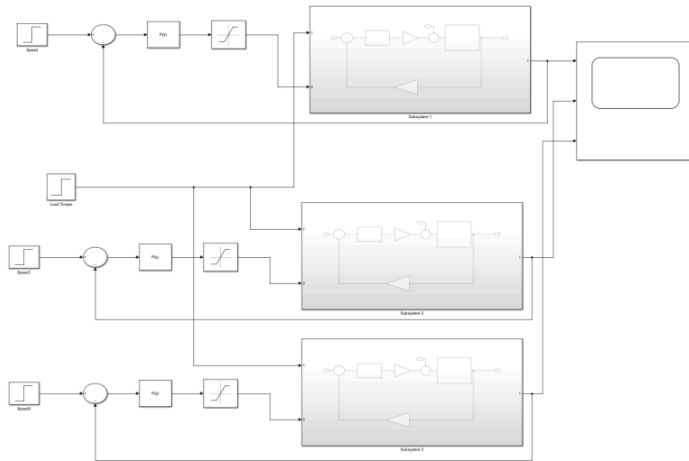


Figure 48 - Simulink model of PI controller and DC motor

One of the subcircuits was tuned to get the optimum value of KP to compare to a value below and above the optimum value.

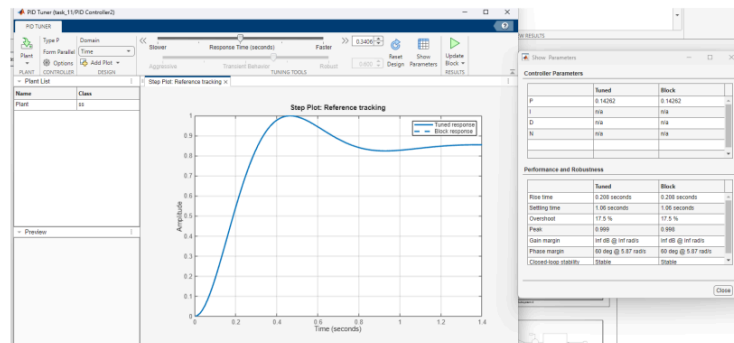


Figure 49 – P Controller tuned graph showing performance

The below figure shows how when the value of K_P is below the optimum value compared to the optimum

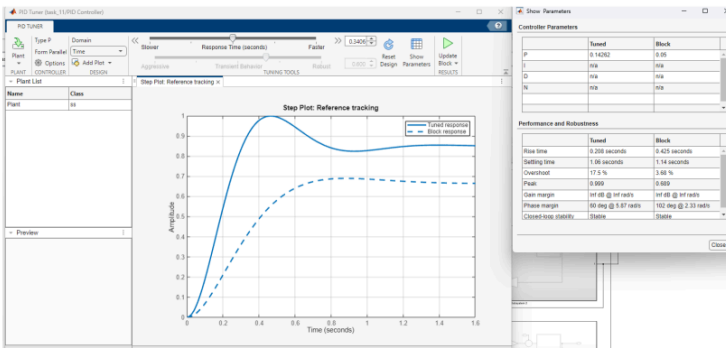


Figure 50 – P controller lower value graph showing performance against tuned value

The below figure shows how when the value of K_P is above the optimum value compared to the optimum

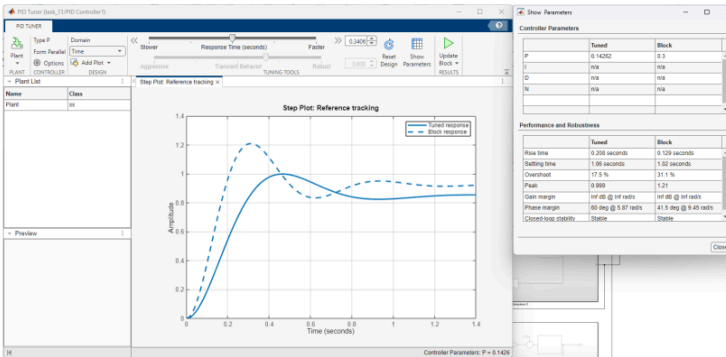


Figure 51 – P controller higher value graph showing performance against tuned value

The K_P values were measured using three input scenarios: one above the optimal value, one below, and one at the optimum. It was observed that increasing K_P led to a faster response to the error and a reduction in steady-state error. However, if K_P is set too high, it can result in greater overshoot and potential instability in the system.

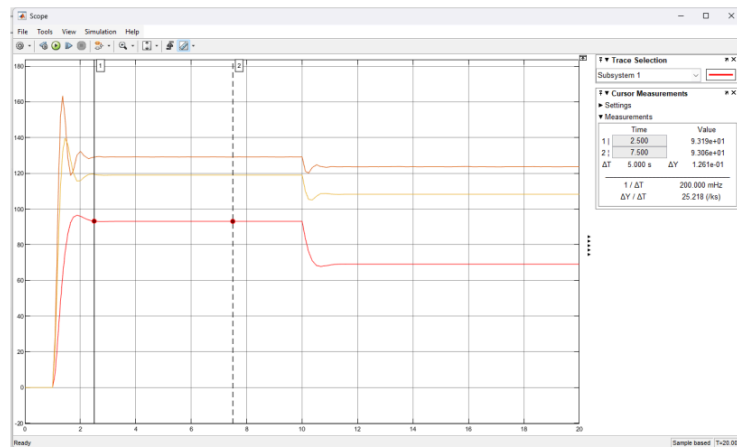


Figure 52 – P controller graph showing all subsystems against each other showing SSE, Overshoot and Rise time

Kp Value	Steady State Error	Overshoot (%)	Rise Time (s)
0.3	-15	31.5	0.129
0.14262 (Tuned)	-30	17.5	0.208
0.05	-70	3.68	0.425

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The reason for this behaviour lies in how proportional control works. Proportional control adjusts the output in proportion to the error, which helps the system respond more quickly to deviations from the desired state. Increasing K_P makes the system react faster, reducing both response time and steady-state error. However, if K_P becomes too large, the system reacts too aggressively, leading to overshooting the target and potentially causing oscillations or instability. This is because the control signal becomes too sensitive to small errors, driving the system past the desired setpoint before it can stabilize. Therefore, finding the optimal K_P value is crucial for balancing a fast response with stability.

Task 12 – Proportional- Integral speed control system

The same motor model was then used from task 11 in this one, however a proportional control (K_I) was added to the circuit. The model was split into 3 circuits and fed into a scope to look at 3 different wave forms, this is done as the value of K_I was varied to see what the response is.

One of the subcircuits was tuned to get the optimum value of K_I to compare to a value below and above the optimum value.

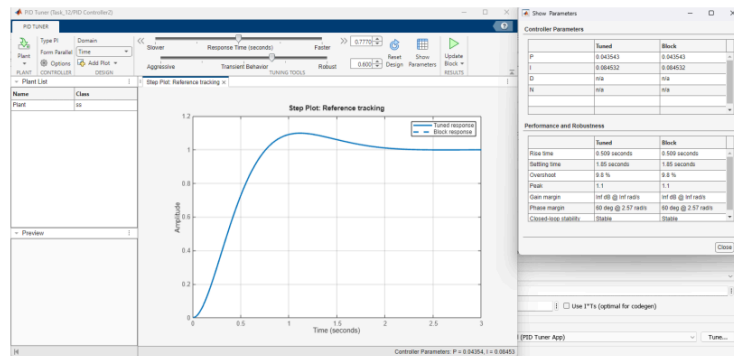


Figure 53 - PI Tuned graph showing performance

The below figure shows how when the value of KI is above the optimum value compared to the optimum

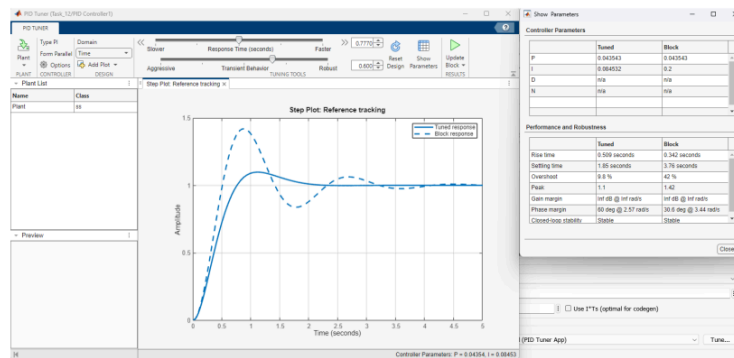


Figure 54 - PI controller higher value graph showing performance against tuned value

The below figure shows how when the value of KI is below the optimum value compared to the optimum

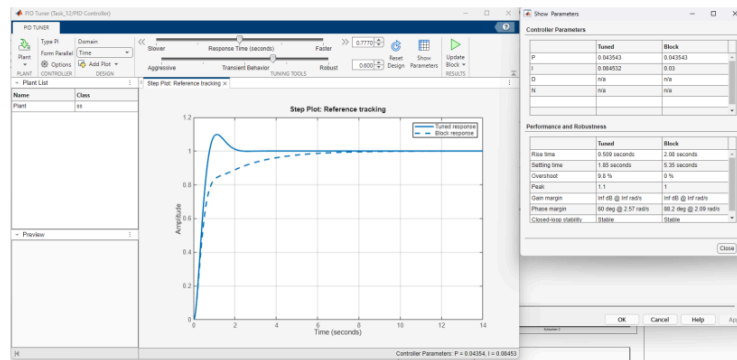


Figure 55 - PI controller lower value graph showing performance against tuned value

The KI values were measured using three input scenarios: one above the optimal value, one below, and one at the optimum. It was observed that increasing KI led to a faster response to the error and a reduction in steady-state error. However, if KI is set too high, it can result in greater overshoot and potential instability in the system.

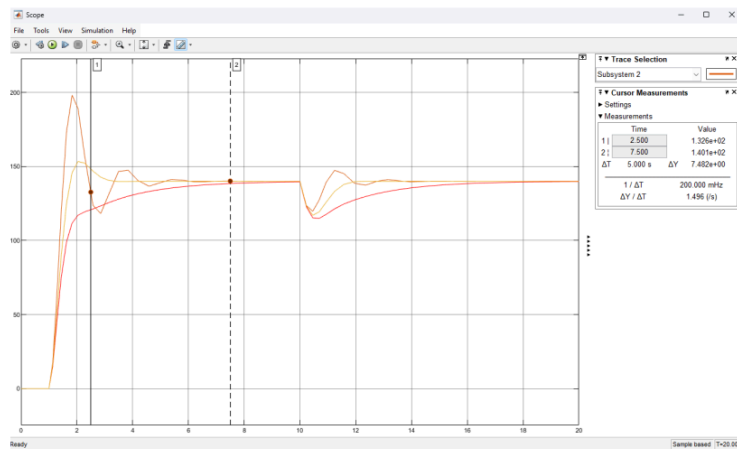


Figure 56 - PI controller graph showing all subsystems against each other showing SSE, Overshoot and Rise time

KI Value	Steady State Error	Overshoot (%)	Rise Time (s)
0.2	0	42	0.342
0.084532 (Tuned)	0	9.8	0.509
0.03	-10	0	2.08

The simulations show that introducing integral control (KI) improves the stability of the circuit, particularly in reducing steady-state error. As the value of KI increases, the system can eliminate any residual error over time by continuously adjusting the control signal based on accumulated error. This helps the system reach and maintain the desired state. However, if KI is set too high, it can cause the system to overcompensate, leading to oscillations and instability. The accumulated error can result in an overly aggressive correction, making the system slow to settle and potentially causing overshoot. Therefore, while KI is effective in reducing steady-state error, an excessively high value can destabilise the system.

Task 13 – Proportional - integral – derivative speed control system

The same motor model was then used from task 12 in this one, however a proportional control (KD) was added to the circuit. The model was split into 3 circuits and fed into a scope to [38](#) different wave forms, this is done as the value of KD was varied to see what the response is.

One of the subcircuits was tuned to get the optimum value of KD to compare to a value below and above the optimum value.

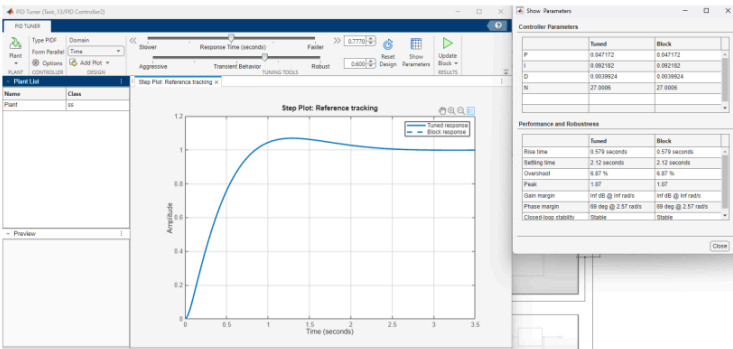


Figure 57 - PID Tuned graph showing performance

The below figure shows how when the value of KD is below the optimum value compared to the optimum

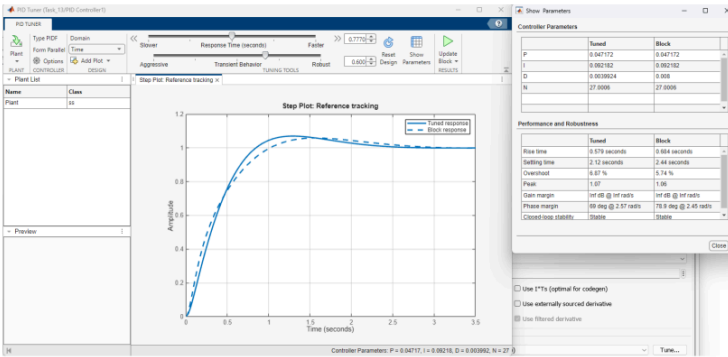


Figure 58 - PID controller higher value graph showing performance against tuned value

The below figure shows how when the value of KD is above the optimum value compared to the optimum

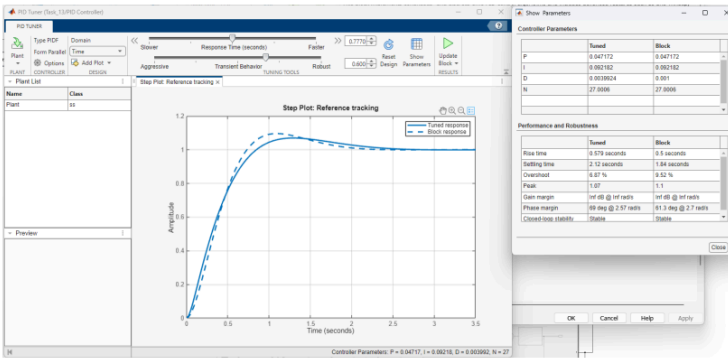


Figure 59 - PID controller lower value graph showing performance against tuned value

The KD values were measured using three input scenarios: one above the optimal value, one below, and one at the optimum. It was observed that increasing KD led to a faster response to the error and a reduction in steady-state error. However, if KD is set too high, it can result in greater overshoot and potential instability in the system.

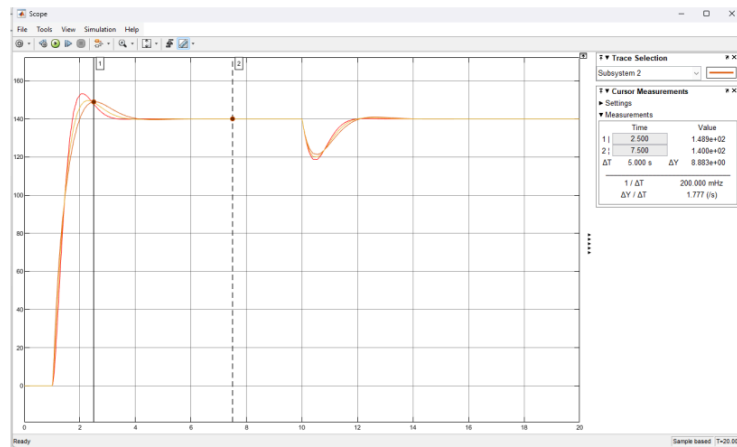


Figure 60 - PID controller graph showing all subsystems against each other showing SSE, Overshoot and Rise time

KD Value	Steady State Error	Overshoot (%)	Rise Time (s)
0.008	0	5.74	0.684
0.0039924 (Tuned)	0	6.87	0.579
0.001 (Low)	0	9.52	0.5

The simulations show that introducing derivative control (KD) enhances the stability of the circuit by improving the system's response to changes in error over time. Increasing KD helps to anticipate the future error, allowing the system to respond more quickly and smoothly, reducing overshoot and oscillations. However, if KD is set too high, it can cause the system to become too sensitive to small fluctuations in error, leading to excessive damping or even instability. This is because the derivative action might overcompensate for minor changes, making the system slow to react or causing it to oscillate as it constantly adjusts. Therefore, while KD can improve stability and response time, too large a value can negatively affect the system's performance.

Task 14 – Controller comparisons

The same model was used from task 11-13 however on this circuit there is the optimum proportional controller on each subcircuit, this is to show the response and change of adding in KP, KI And KD proportional control

The below figure shows the form waves of each subcircuit showing the response of just a KP controller then adding in a KI controller then finally adding in the KD controller.

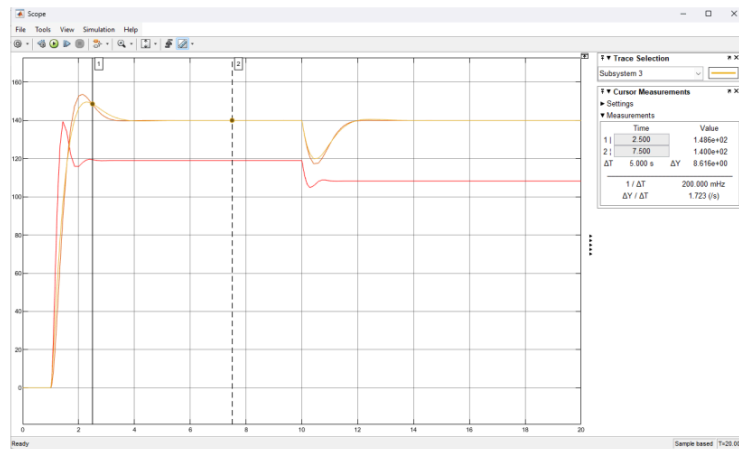


Figure 61 - Graph showing the difference between P controller, PI controller and PID controller

The three components of a PID controller—KP, KI, and KD—each influence system behaviour in different ways. The proportional gain (KP) responds to the present error, helping to reduce rise time and improve the speed of the system's response. However, while KP reduces steady-state error to some extent, setting it too high can cause excessive overshoot and potential instability. The integral gain (KI) addresses the accumulated error over time, effectively eliminating steady-state error altogether. Though useful for achieving long-term accuracy, a high KI value can slow down the response and increase overshoot due to integral windup. The derivative gain (KD) reacts to the rate of change of the error, helping to dampen oscillations and reduce overshoot, thereby improving system stability. However, a large KD can make the system overly sensitive to noise. When balanced correctly, these three elements work together to produce a stable, accurate, and responsive control system.

Task 15 – Overall conclusions and Recommendations

Electrical

In conclusion, the analysis of both the transient and frequency responses of the circuit reveal an understanding of its behaviour. The transient response, characterised by exponential decay and rise functions, was successfully modelled using the Laplace transform and verified through measured and calculated values. The circuit's behaviour, controlled by the time constant τ , showed that both decay and rise functions closely matched their theoretical response, confirming the accuracy of the calculations. Regarding frequency response, the circuit's configuration, identified as a first-order low-pass filter, exhibited the expected phase shift of 45 degrees and a roll-off rate of 20 dB per decade, with results consistent across both calculation and measurement. Additionally, the role of resistance in determining the damping coefficient was explored, demonstrating its significant impact on the stability and speed of the system's response. Increased resistance led to slower, more stable responses, while reduced resistance resulted in quicker responses but at the cost of stability.

Overall, both the transient and frequency response analyses align with theoretical predictions, providing a thorough understanding of the system's behaviour under varying conditions.

Electronic

In conclusion, the analysis of the circuit's behaviour confirms that the calculated and simulated results align, demonstrating that the circuit operates as expected according to theoretical predictions. The observed cutoff frequency and roll-off rate of 20 dB per decade validate the circuit's classification as a first-order filter, while the DC gain of the inverting amplifier is consistent with the standard gain formula, indicating the expected 180-degree phase inversion. The frequency-dependent nature of the circuit, particularly around the cutoff point, introduces an additional phase shift of -45 degrees, resulting in a total phase shift of 135 degrees. This phase behaviour is a direct result of the combined effects of the inverting amplifier and the high-pass filter components. The simulation's Bode plot clearly illustrates this behaviour, with the phase shift reflecting the interaction between the amplifier's 180-degree inversion and the filter's frequency-dependent phase shift. Overall, the circuit's performance is consistent with the expected theory, confirming its behaviour as an inverting high-pass filter.

Control

The analysis of the control system demonstrates that achieving optimal performance relies on finding the right balance among the PID components. Proportional control is vital for providing an immediate, error-dependent response, reducing both response time and steady-state error. However, if the proportional gain (KP) is too high, it can cause overreactions resulting in overshooting and oscillations.

Integral control (KI) plays an essential role in eliminating residual error over time by accumulating past errors and adjusting the control signal accordingly. While this continuous correction is beneficial for ensuring that the system reaches and maintains the required state, an excessively high KI can lead to overcompensation, causing overshoot and making the system slow to settle.

Derivative control (KD), on the other hand, improves system stability by predicting future errors based on the rate of change. This anticipation allows the system to lower oscillations and smooth out changes. Yet, like KP and KI, if KD is too high, the system may become overly responsive to minor fluctuations, leading to excessive damping or unintended oscillations.

The simulations further reveal that the motor's behaviour specifically its response to varying loads and torque changes is heavily influenced by the control mechanisms. The motor's initial acceleration, the load-induced torque changes, and the adaptation to maintain set speed all reflect the underlying principles of feedback control. As feedback loops adjust error via negative feedback, they effectively move the poles of the system into the left half of the complex plane, ensuring a stable system. However, this stability is closely tied to the gain settings of the controller, as high gain improves responsiveness while low gain reduces the effectiveness of error correction.

In conclusion, effective control depends on a well-tuned combination of proportional, integral, and derivative actions. Each component contributes uniquely to the system's speed of response and stability, and their values must be carefully balanced. An optimal tuning of these parameters not only ensures that the system reacts promptly to changes but also maintains the required performance without inducing instability.

Electrical principles, methods and simulation - EAP

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

66/100

PAGE 1

PAGE 2



Comment 1

Avoid vague statements such as looks at.

PAGE 3

PAGE 4



Comment 2

Some basic background on time constant definition would benefit the context of the work.



Comment 3

Mix of upper and lower case variables. Use the laplace model for the inductor.

PAGE 5



Comment 4

y=



Comment 5

Good work here.

PAGE 6



Comment 6

Good, but you should write the full equation in the time domain



Comment 7

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

Use correct and full equations.

PAGE 7



Comment 8

Again a mix of upper and lower case, stick to the convention. Also use the laplace model for each component.

PAGE 8



Comment 9

Good work here, there are some minor errors as mentioned in the formatting of equations.



Comment 10

WW

PAGE 9



Comment 11

This needs further explanation here. Why negative? Does not match plot?

PAGE 10



Comment 12

Pass/Fail ?



Comment 13

Natural frequency? This needs further clarification and explanation, why are these parameters as they are?



Comment 14

They are not in parallel

PAGE 11

PAGE 12



Comment 15

A good start expand this analysis.

PAGE 13



Comment 16

Mistake here, typo? Also you have not fully explained what you are doing.



Comment 17

What circuits?

PAGE 14



Comment 18

Avoid using x as the symbol for multiplication, it can be confused with the variable x

PAGE 15

PAGE 16

PAGE 17



Comment 19

You are correct and the results are clearly displayed.

PAGE 18



Comment 20

This needs checking, it does not make mathematical sense.

PAGE 19

PAGE 20

PAGE 21



Comment 21

Good work, what about the locus of w_o to w_m ?



Comment 22

Need to show the circuit first and explain your actions and calculations and reasons for choosing the circuit components.

PAGE 22



Comment 23

More verification could have been done, i.e. gain in dB and a table of results for comparison and analysis.



Comment 24

This needs explaining, why the capacitance value?

PAGE 23



Comment 25

See comments as for task 7.

PAGE 24



Comment 26

Gr

PAGE 25



Comment 27

Explain why the pole is here in terms of analysing the TF.

PAGE 26



Comment 28

WW



Comment 29

WW

PAGE 27



Comment 30

This does not make sense?

PAGE 28

PAGE 29

PAGE 30

PAGE 31

PAGE 32



Comment 31

I think you are confusing the terms here.



Comment 32

Ok , explain in terms of the root locus.



Comment 33

Terminology needs to be explained in terms of a circuit diagram,

PAGE 33



Comment 34

This model should be developed.

PAGE 34

PAGE 35



Comment 35

Results for steady state should be tabulated for comparison.

PAGE 36

PAGE 37

PAGE 38

PAGE 39



Comment 36

Good work here.

PAGE 40

PAGE 41

PAGE 42



Comment 37

Good results and analysis.



Comment 38

WW

PAGE 43

**Comment 39**

Use more meaningful legend titles.

GRADING FORM: NEW CSG-RUBRIC

EWAN ALGERPALMER**66****1. ENGAGEMENT WITH LITERATURE**

NA

0**2. KNOWLEDGE AND UNDERSTANDING**

Explanations lack depth in certain areas as marked, your derivations could be expanded and are sometimes either incorrect or missing essential steps. 20/30

20**3. COGNITIVE AND INTELLECTUAL**

Analysis is generally very good and adds to the context of each task, however there are some missing results and some terminology leaves the reader confused. 20/30

20**4. PRACTICAL APPLICATION**

Good application of practical skills for the most part with graphs correctly annotated and results tabulated, there are a few omissions as marked in the comments. 20/30

20**5. TRANSFERABLE SKILLS**



Well communicated report generally, some incorrect words used (WW) and gramatical errors (Gr) see comments. Layout and structure good.
6/10

6