

1102216

by Sean Parry

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TIME SUBMITTED	19-APR-2021 01:42PM (UTC+0100)	WORD COUNT	8145
SUBMISSION ID	149768338	CHARACTER COUNT	35048

Course: HNC Electrical and Electronic Engineering

Module: SGEE5002 Electrical Principles, Methods and Simulation

Assignment Title: Analysis, Simulation and Evaluation of Circuits and Systems

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Date Submitted: 19/04/2021

Word Count: 4867

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Task 1 - Transient Analysis of a First Order RL Electrical Circuit

1.1

$$R = 10\Omega$$

$$L = 0.5H$$

$$T = \frac{L}{R}$$



$$T = \frac{0.5}{10} = 0.05s$$

(Time constant)

1.2

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

$$U(s) = \frac{1}{s} = \text{step input}$$

$$\text{Therefore, } Y(s) = \frac{R}{sL+R} \times \frac{1}{s}$$

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

$$= \frac{\frac{R}{L}}{s^2 + s \frac{R}{L}}$$

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

$$\text{C.F.} = \frac{a}{s(s+a)} \text{ from laplace transfer table}$$

Take inverse Laplace

$$a = \frac{1}{\tau} \text{ then } Y(t) = 1 - e^{-\frac{t}{\tau}}$$

$$\text{Therefore, } a = \frac{R}{L} \text{ so } \tau = \frac{L}{R}$$

$$Y(t) = 1 - e^{-\frac{Rt}{L}}$$

$$\text{Therefore, } \frac{Y(s)}{U(s)} = \frac{1}{\frac{sL}{R} + 1} = \frac{1}{\tau s + 1}$$

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

You have worked this out correctly, well

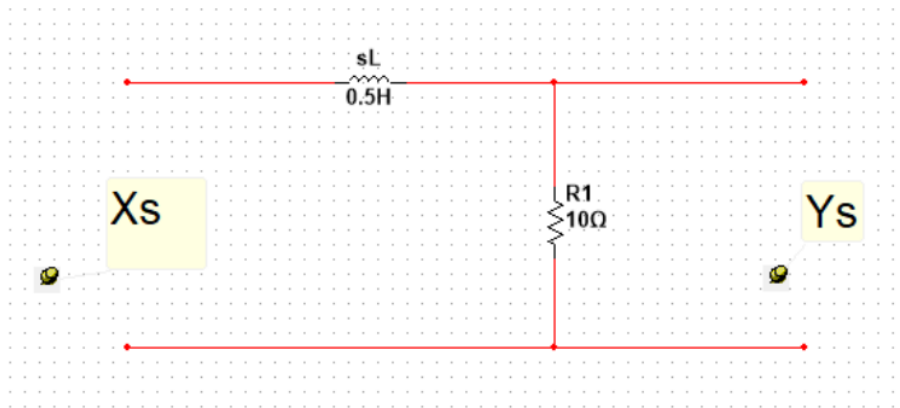
$$H(s) = \frac{1}{0.05s + 1}$$

(Transfer function)

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

(Equation for finding the transient response)

Laplace model:



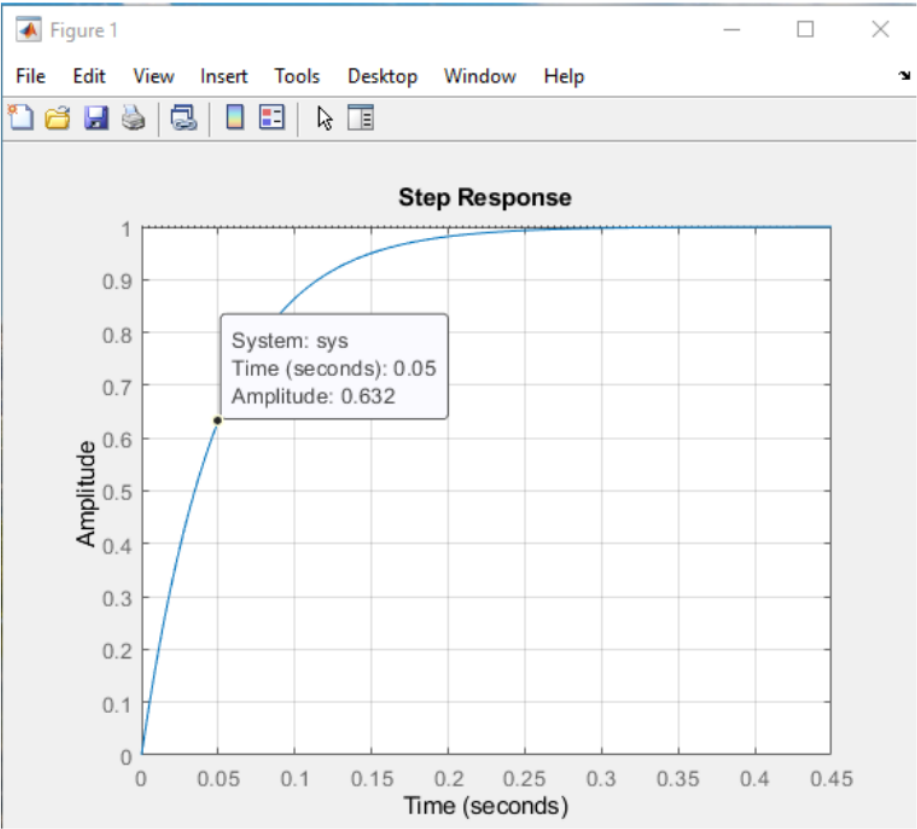
1.3

Matlab program

```
Command Window
New to MATLAB? See resources for Getting Started.

>> num = [1];
>> den = [0.05 1];
>> step(num,den);
grid
fx >>
```

Graphical Results



1.4

Theoretical and Simulation Results	
Theoretical	Simulation
$T = \frac{0.5}{10} = 0.05s$	T = 0.05s at amplitude of 0.632

It is clear that the theoretical results match that of the simulation results. The time constant was obtained at an amplitude of 0.632.



1.5

Conclusion

In order to find the transient response of a circuit, it is necessary to apply the step input with a voltage of 1V, which is the unit step input $u(t)$. Tau is measured by the inductor 'L' divided by the resistor 'R'. That provided a time constant of 0.05s. When analysing the graph, a reading was taken at the amplitude of 0.632. At the amplitude of 0.632 the graph provided a time of 0.05s, which is what was calculated. So, Let $T = \frac{L}{R}$ = time constant occurring when $y(t) = 0.632$. If one-time constant is 0.05s, five time constants will equal 0.25, (0.05x5). At 5 time constants, $y(t)$ reaches a steady state. It will level off, as can be seen in the graph.

Task 2 - Transient Analysis of a First Order RC Electrical Circuit

2.1

$$C = 10F$$

$$R = 100\Omega$$

$$T = RC$$

$$T = 100 \times 10$$

$$T = 1000$$



(Time constant)

2.2

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

$$H(s) = \frac{1000s}{1000s + 1}$$

(Transfer Function)

When using the potential divider rule:

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

$$\text{For a unit step input } U(s) = \frac{1}{s}$$

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

From the table of inverse transforms the following formula is created:

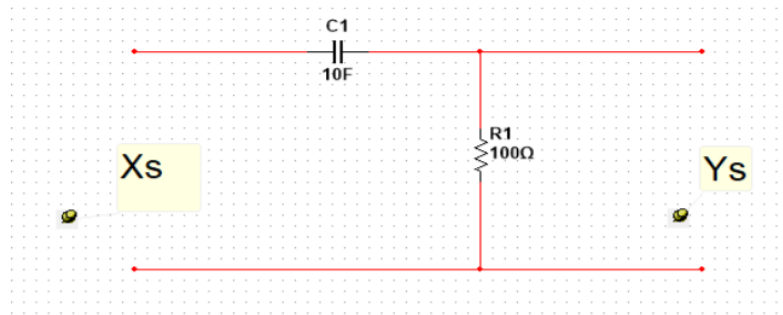
$$Y(t) = e^{\frac{-t}{\tau}}$$

This is an exponential decay where $RC = T$, the time constant at $T = \tau$, $Y(t) = 0.368$

Below is a way of finding the transient response of a circuit by applying the step input with a voltage of 1 volt, the unit step input $U(t)$

$$U(s) = \frac{1}{s} \text{ step input } Y(s) \text{ output}$$

Laplace model:

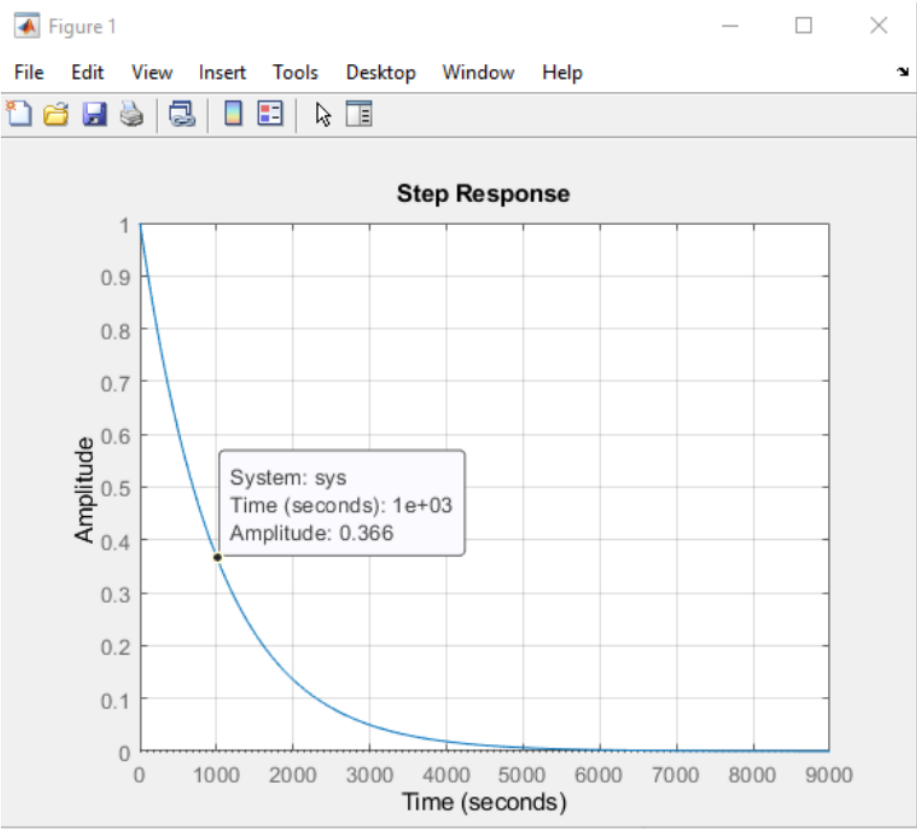


2.3

Matlab program

```
>> num = [1000 0];  
>> den = [1000 1];  
>> step (num,den);  
grid  
>>
```

Graphical Results



2.4

Theoretical and Simulation Results	
Theoretical	Simulation
$T = 100 \times 10 = 1000\text{s}$	$T = 1000\text{s}$ at amplitude of 0.366

The time constant has been calculated. The time constant was measured at an amplitude of 0.366.



2.5

Conclusion

The exponential decay is where $RC = \tau$, the time constant. In this case, $R = 100\Omega$ and $C = 10F$. Therefore, $\tau = \tau$, which is a 1000s, $(R \times C)$. $Y(t) = 0.368$. In this particular case, theoretically at an amplitude of 0.368 there should be a time of 1000s. From the simulation there is a time of 1000s at an amplitude of 0.366, which is very close to the theoretical result. After 5 time constants, $Y(t) = 0$. This is shown by the following calculation, if one-time constant is 1000s, $1000 \times 5 = 5000$ s. At 5000s there should be an amplitude of 0, which is seen in the graph. The graph levels off or reaches a steady state at 5000s.

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

3.1

In order to find the frequency response of a transfer function $H(s)$, the following equation is used: $s = j\omega$. To analyse the effect of the circuit upon the phase shift, two graphs will be needed, one for magnitude $|H(j\omega)|$ and the other, the phase $\theta(j\omega)$. This can be represented in polar form as:

$$H(j\omega) = |H(j\omega)| \angle \theta(j\omega)$$

$$Y(s) = \frac{10}{0.5s+10}$$

$$= \frac{Y(s)}{X(s)} = \frac{\frac{10}{0.5}}{s + \frac{10}{0.5}}$$

$$H(s) = \frac{20}{s+20}$$

$$\text{C.F. } H(s) = \frac{\omega_c}{s + \omega_c}$$

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

(Transfer function in terms of the cut off frequency)

This is a passive low-pass filter with inductor

(Type of frequency response)

Phase shift at the cut off frequency:

$$= -\tan^{-1}\left(\frac{1}{T_{XT}}\right)$$

$$= -\tan^{-1}(1)$$

$$= -45^\circ \text{ at } \omega_c$$

You have worked this out correctly, well

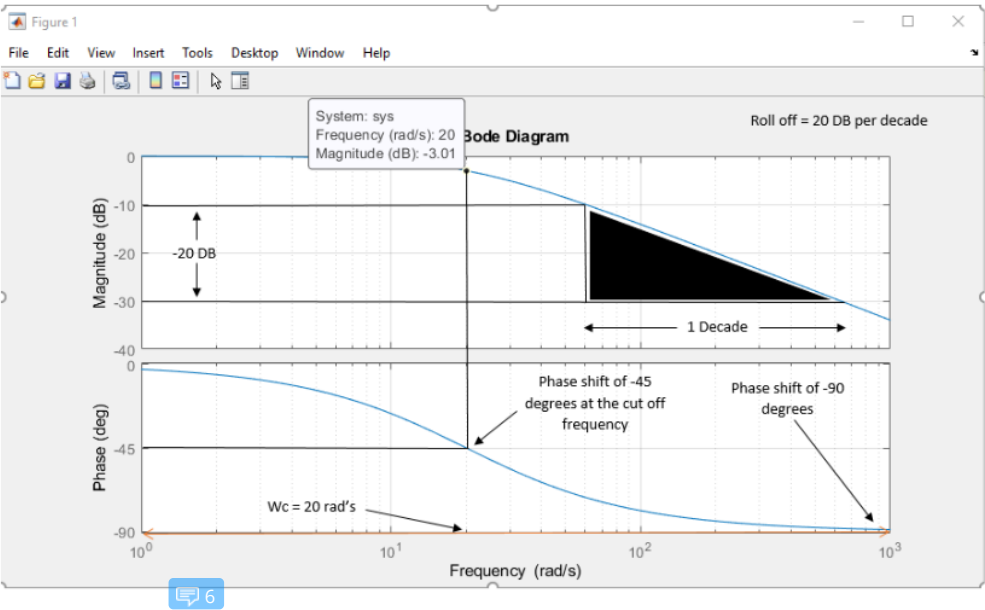
3.2

Matlab program

```
>> num = [20];
>> den = [1 20];
>> bode (num,den);
grid
>>
```

Bode diagram

Low Pass Filter



3.3

Theoretical and Simulation Results	
Theoretical	Simulation
20 rads at -3DB	20 rads at -3.01DB

3.4

Conclusion

At the cut off frequency $|H(j\omega)| \text{ dB} = -3$ at ω_c .

Phase in $\theta(j\omega)$

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

$$\omega = \infty$$

$\theta(j\omega) = -\tan^{-1}(\infty) = -90$, which we can see from the phase angle at the graph, as the graph (on the phase part) levels out at -90 degrees. Theoretically the cut off frequency at 20 rads should have occurred at -3dB exactly. From the simulation, the cut off frequency at 20 rads was achieved at -3.01dB, which is very close and accurate. Theoretically the phase angle for the low pass filter should be -45° as calculated. From the simulation, the cut off frequency reached a phase angle of -45° , which is what was desired. From taking a reading between -20 dB on the simulation, that produces 1 decade. Therefore, the roll off is 20 dB per decade. The theoretical and simulation responses are nearly exact. Discrepancies are to be expected.



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

4.1

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

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

This is the cut-off frequency = $\frac{1}{\tau}$

$$R = 100\Omega$$

$$C = 10F$$

$$T = RC = 1000 \text{ seconds}$$

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

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

$$\omega_c = \frac{1}{1000}$$

$$\omega_c = 0.001$$

(The transfer function in terms of the cut-off frequency)

High pass filter transfer function

(Type of frequency response)

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

$$\text{Phase } \theta(j\omega) = \tan^{-1}\left(\frac{\omega RC}{\omega^2 R^2 C^2}\right)$$

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

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

When $\omega=0$, $\theta(0) = 90-0$

$$= 90^\circ$$

$$\text{When } \omega=\omega_c = \frac{1}{RC}$$

$$\theta(j\omega_c) = 90 - \tan^{-1}(1)$$

$$= 90-45$$

$$= 45^\circ$$

(Phase shift at the cut off frequency)

You have worked this out correctly, well!

At $\omega = \infty$

$$\text{Theta}(\infty) = 90 - \tan^{-1}(\infty)$$

$$= 90 - 90 = 0$$

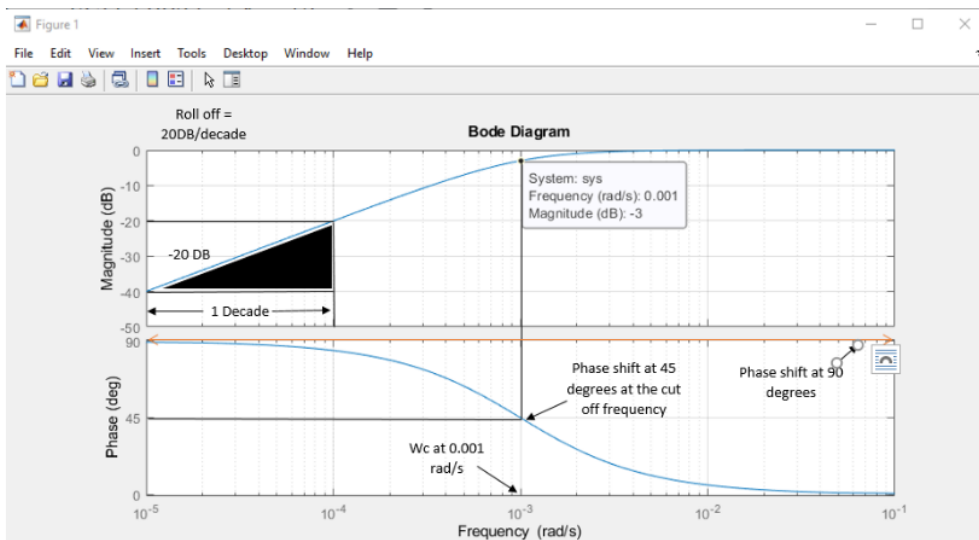
4.2

Matlab Program

```
>> num = [1 0];
>> den = [1 0.001];
>> bode (num,den);
grid
>>
```

Bode diagram

High Pass Filter



4.3

Theoretical and Simulation Results	
Theoretical	Simulation
0.001 rad's at -3dB	0.001 rad's at -3dB

4.4

Conclusion

In dB's, the following equation is used:

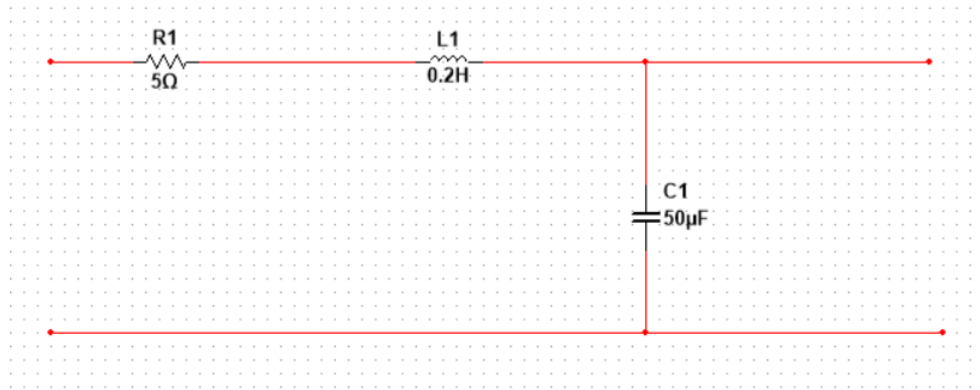
$$|H(j\omega)| \text{ dB} = 20 \log_{10} \frac{\omega RC}{\sqrt{1 + \omega^2 R^2 C^2}}$$

At cut off, $|H(j\omega)| \text{ dB} = -3\text{dB}$ at ω_c

This would be the theoretical result. ω_c , which in this case is 0.001rads should be achieved at -3dB. According to the simulation this is perfectly correct. Both the theoretical and simulation results match perfectly. The roll off is 20dB per decade, therefore between 20dB there is 1 decade indicated on the simulation graph. The phase shift at the cut off frequency was calculated at 45°, which is indicated on the simulation. If the phase shift was taken at 90°, the result is infinity. The graph levels off until the phase shift drops below 90°. The results of the phase shift and cut off frequency at -3dB match perfectly, providing perfect results.

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

Circuit Diagram:



5.1

$$R = 5\Omega$$

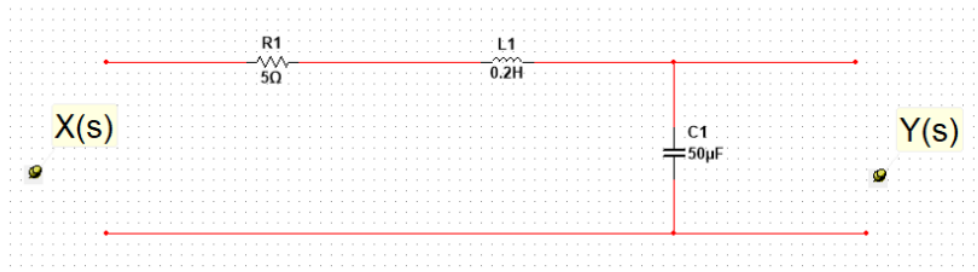
$$L = 0.2\text{H}$$

$$C = 50\mu\text{F}$$

(Components values)

5.2

Laplace model:



Transfer Function:

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

Second order transfer function

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

Transfer Function in Standard Form

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

$$H(s) = \frac{\frac{1}{0.2 \times 50\mu}}{s^2 + \frac{5}{0.2}s + \frac{1}{0.2 \times 50\mu}}$$

$$H(s) = \frac{100000}{1 + 25s + 100000s^2}$$

(Transfer Function)

5.3

$K=1$ (Gain)

$$\omega_n = \frac{1}{\sqrt{LC}}$$

$$\omega_n = \frac{1}{\sqrt{0.2 \times 50\mu}}$$

$$\omega_n = 316.2 \text{ rad/s or } 50\text{Hz}, f = \frac{\omega}{2\pi}$$

$$\zeta = \frac{R}{2} \frac{\sqrt{C}}{L}$$

$$\zeta = \frac{5}{2} \frac{\sqrt{50\mu}}{0.2}$$

$\zeta = 0.04$ (1.d.p)

Category state – Underdamped

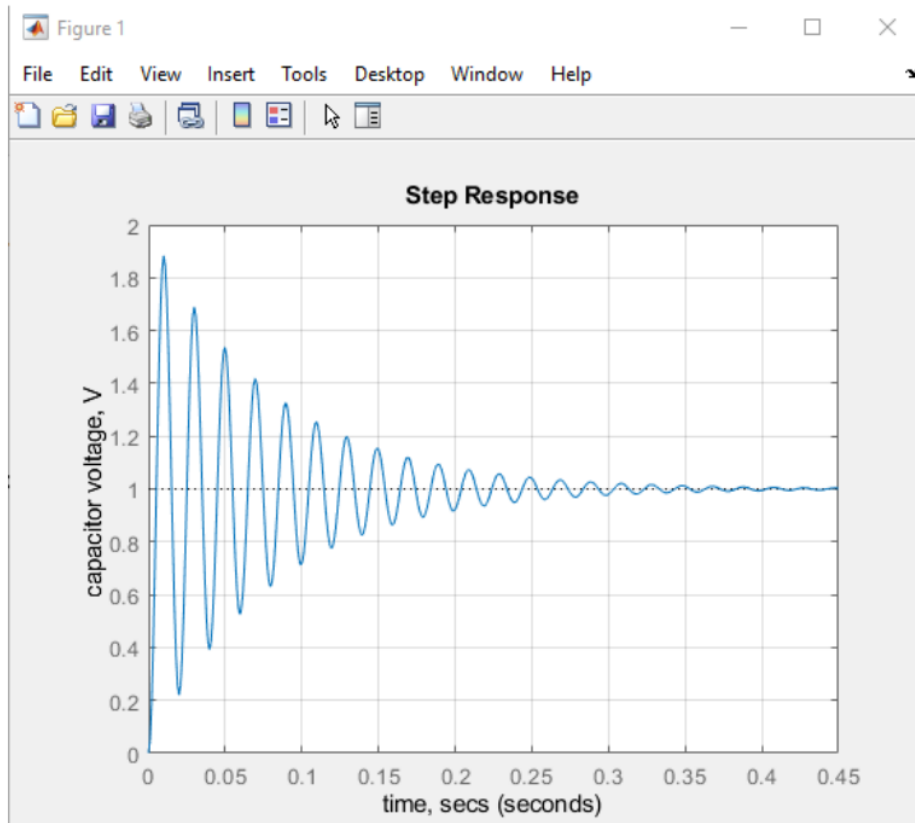
You have worked this out correctly, well

5.4

Matlab program

```
>> %RLC response to step input
>> %R=5, L=0.2, C=50u
>> %Input = 1V step
>> num = [100000];
>> den = [1 25 100000];
>> step (num,den);
grid
>> xlabel ('time, secs');
>> ylabel ('capacitor voltage, V');
>> grid
```

Response graph



5.5

Comparison between theoretical predictions and model results		
Theoretical Predictions	Model Results	Type of Damping
$\Sigma = 0.04$	$\Sigma = 0.04$ at 0.554 Amplitude	Underdamped

The theoretical prediction was a damping factor of 0.04. Since this is below zero, the model result expected was an underdamped response. The graphical model result shows the oscillation of an underdamped response. The theoretical and model results match. The damping factor of 0.04 is produced from a low resistance value of 5Ω.

5.6

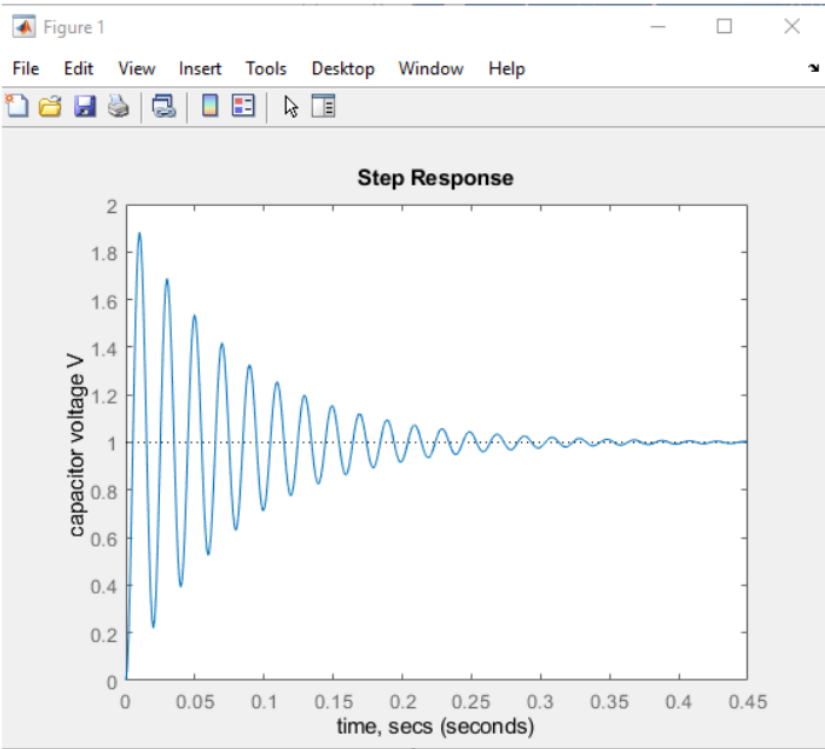
$R = 5\Omega$

$$\Sigma = \frac{R \sqrt{C}}{2 L}$$

$$\Sigma = \frac{5 \sqrt{50\mu}}{2 \cdot 0.2}$$

$\Sigma = 0.04$ (underdamped)

```
>> %R=5, Underdamped
>> num = [100000];
>> den = [1 25 100000];
>> step (num,den);
grid
>> xlabel ('time, secs');
>> ylabel ('capacitor voltage V');
>> grid
```



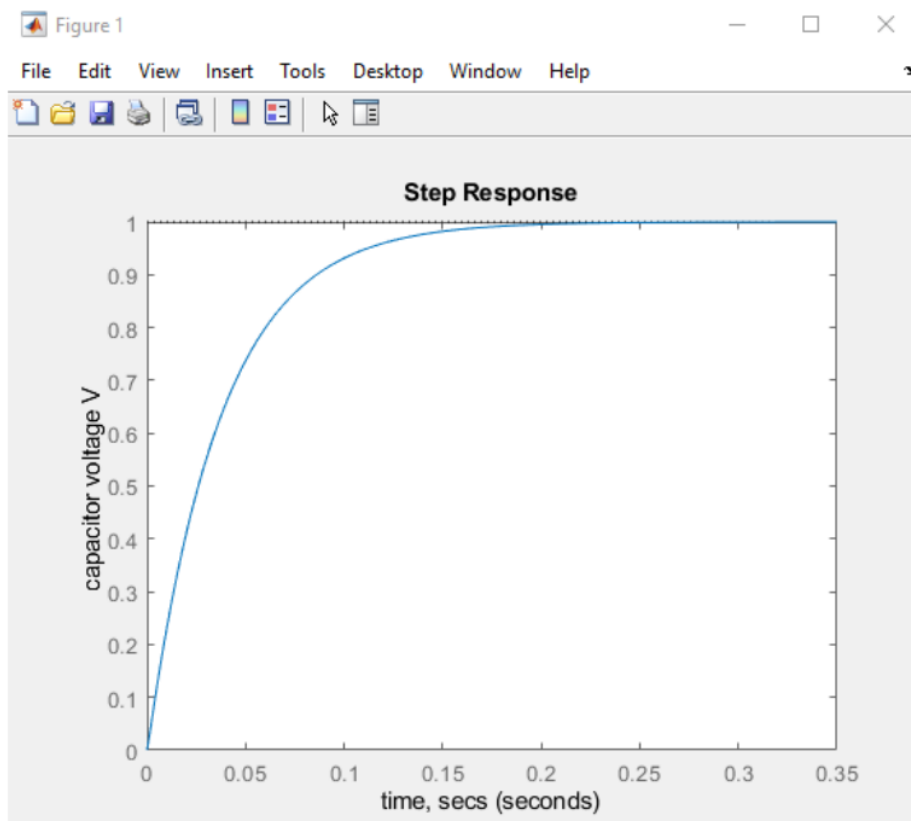
R = 750Ω

$$\Sigma = \frac{R \sqrt{C}}{2 L}$$

$$\Sigma = \frac{750 \sqrt{50\mu}}{2 \cdot 0.2}$$

Σ = 5.93 (overdamped)

```
>> %R=750, Overdamped
>> num = [1000000];
>> den = [1 3750 1000000];
>> step (num,den);
>> grid
>> xlabel ('time, secs');
>> ylabel ('capacitor voltage V');
>> grid
```



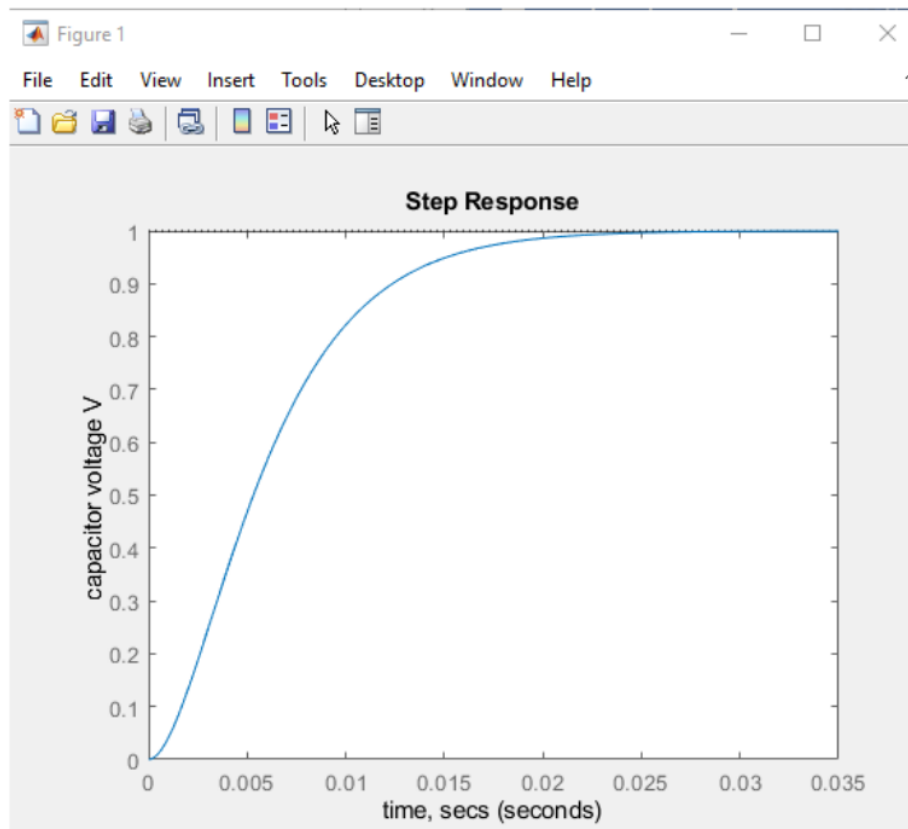
R = 127Ω

$$\Sigma = \frac{R \sqrt{C}}{2 L}$$

$$\Sigma = \frac{127 \sqrt{50\mu}}{2 \cdot 0.2}$$

Σ = 1.00 (Critically damped)

```
>> %R=127 Critically Damped
>> num = [100000];
>> den = [1 635 100000];
>> step (num,den);
grid
>> xlabel ('time, secs');
>> ylabel ('capacitor voltage V');
>> grid
```



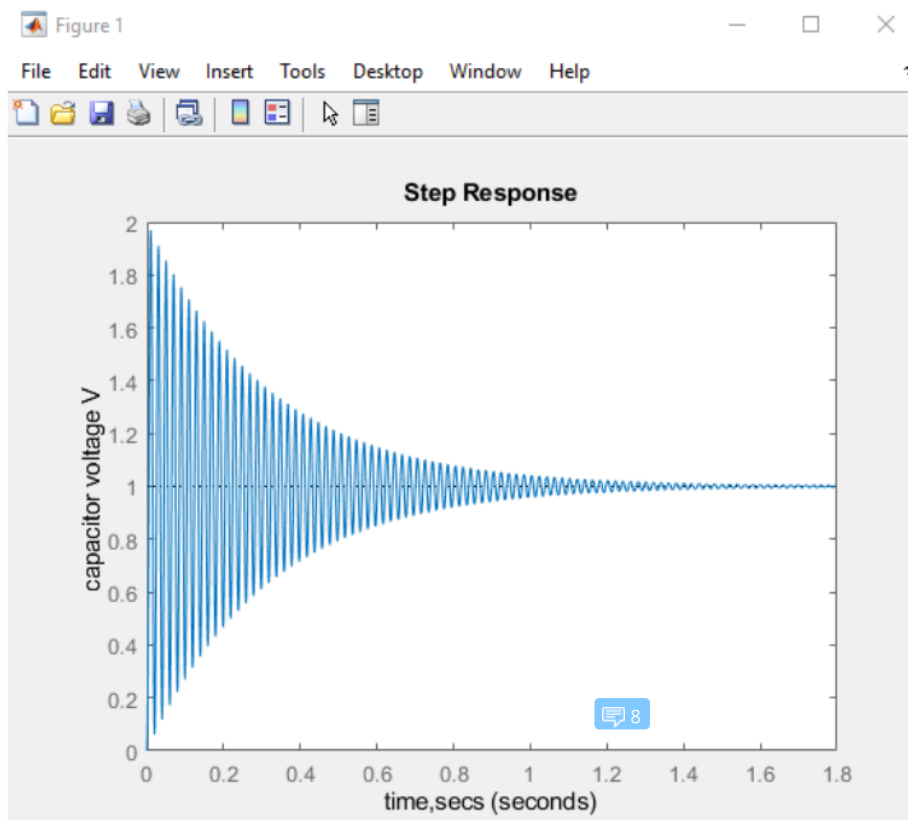
R = 1.265Ω

$$\Sigma = \frac{R\sqrt{C}}{2L}$$

$$\Sigma = \frac{1.265\sqrt{50\mu}}{2 \cdot 0.2}$$

Σ = 0.0 (no damping)

```
>> %R=1.265, No Damping
>> num = [100000];
>> den = [1 6.325 100000];
>> step (num,den);
>> grid
>> xlabel ('time,secs');
>> ylabel ('capacitor voltage V');
>> grid
```



Results		
Resistor Value	Damping Factor	Type of Damping
5Ω	0.04	Underdamped
750Ω	1.58	Overdamped
127Ω	1	Critically Damped
1.265Ω	0	No Damping

The lower the resistance the lower the damping factor and the higher the resistance the higher the damping factor.

- When the damping factor is less than 1 the response is underdamped.
- When the damping factor is greater than 1 the response is overdamped.
- When the damping factor equals 1 then the response is critically damped.
- When the damping factor equals 0 then the response is no damping, (Bolton, 2002).

The damping factor varies according to the resistance in the circuit. As the resistance varies the damping factor is in accordance with it. The damping factor rises and falls with the resistance.

Good work

5.7

Analysis

$\Sigma < 1$, underdamped

$\Sigma > 1$, overdamped

$\Sigma = 1$, critically damped

$\Sigma = 0$, no damping

The conclusion is that the damping factor varies in accordance with the resistance. Different resistance values will provide different damping factors. There are four main damping factors identified above, underdamped, overdamped, critically damped and no damped. In order to achieve one of these results with resistance has to be adjusted.

Underdamped – The condition in which damping of an oscillator causes it to return to what is known as, equilibrium with the amplitude gradually decreasing to zero. The system returns to equilibrium faster, but overshoots and crosses the equilibrium position on more than one occasion, (K.C.Agrawal, 2001).

Overdamped – This is the condition where the damping of an oscillator causes it to return to equilibrium without oscillating. Oscillator moves more slowly towards the equilibrium than what is seen in the critically damped system, (Stax, 2021).

Critically Damped – This is the condition in which the damping of an oscillator causes it to return as quickly as possible to its known equilibrium position without oscillating back and forth around this desired position. Viewed as the minimum value of damping that prevents oscillation, (Direct, 2001).

No damping – This is the condition where there is simply no damping. It rises far above and far below the equilibrium, but never reaches a steady state at the equilibrium, (W.Bolton, 2004).

Good work

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

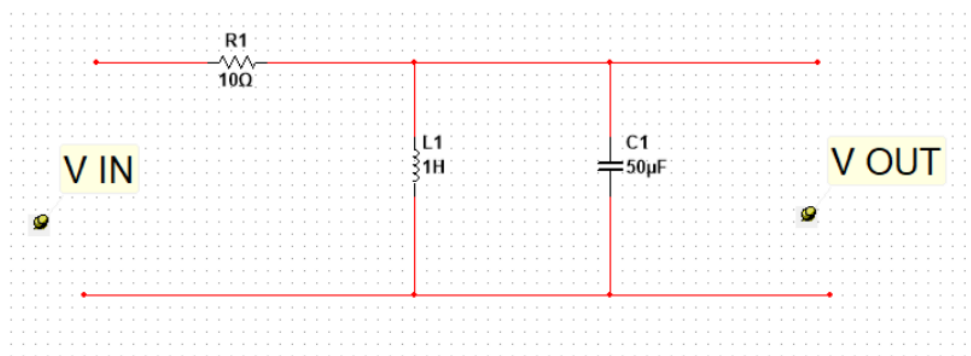
6.1

Component values:

$$R = 10\Omega$$

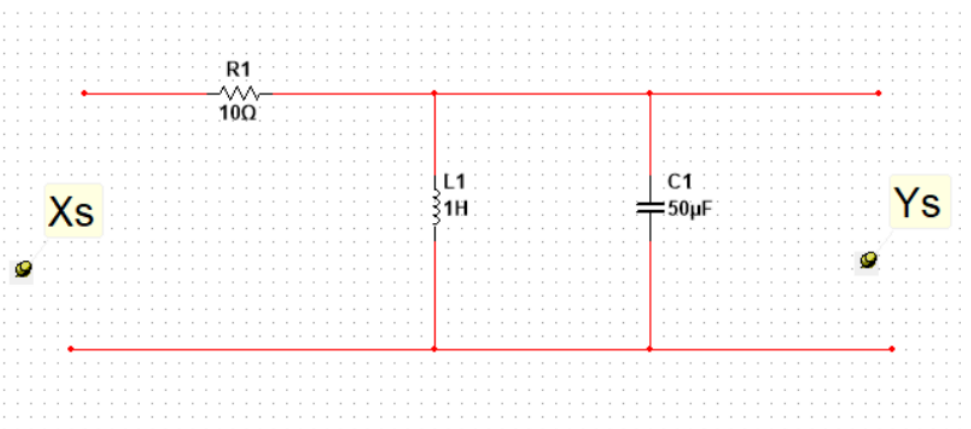
$$L = 1\text{H}$$

$$C = 50\mu\text{F}$$



6.2

The Laplace model:



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

(Second order transfer function)

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

(Transfer function in standard form)

6.3

Comparing the denominator with $s^2 + 2\Sigma\omega n s + \omega n^2$

$$\omega n^2 = \frac{1}{LC}$$

$$\omega n = \frac{1}{\sqrt{LC}}$$

$$\omega n = \frac{1}{\sqrt{1 \times 50\mu}}$$

$$\omega n = 141 \text{ rad/s or } 22\text{Hz} \left(f = \frac{\omega}{2\pi}\right) \text{ (both rounded off to 1dp)}$$

$$2\Sigma\omega n = \frac{1}{RC}$$

$$2\Sigma\omega n = \frac{1}{10 \times 50\mu}$$

$$2\Sigma\omega n = 10000$$

$$\Sigma = \frac{1}{2 \omega n RC}$$

$$= \frac{\sqrt{LC}}{2 RC}$$

$$= \frac{\sqrt{L}}{2 R \sqrt{C}}$$

$$\Sigma = \frac{1}{2R} \frac{\sqrt{L}}{C}$$

$$\Sigma = \frac{1}{2 \times 10} \frac{\sqrt{1}}{50\mu}$$

$$\Sigma = 7.1 \text{ (1.d.p)}$$

Putting values into transfer function:

$$H(s) = \frac{s \times \frac{1}{10 \times 50 \mu}}{s^2 + \frac{1}{10 \times 50 \mu} s + \frac{1}{1 \times 50 \mu}}$$

$$H(s) = \frac{2000s}{s^2 + 2000s + 20000}$$

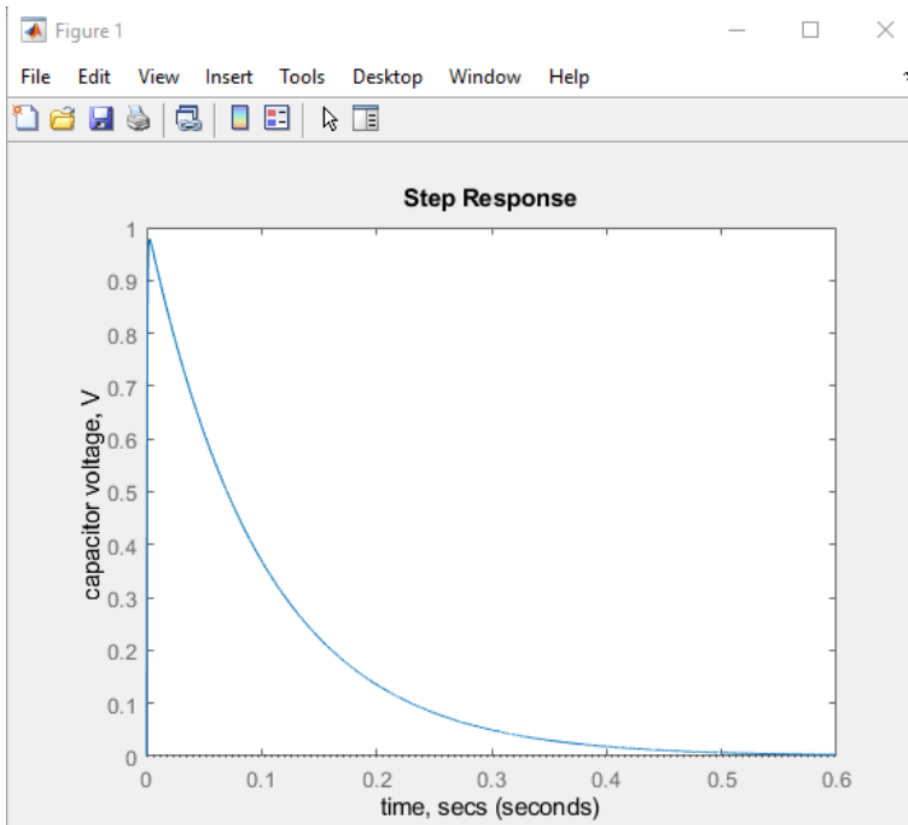
You have worked this out correctly, well

6.4

Matlab model program

```
>> num = [2000 0];  
>> den = [1 2000 20000];  
>> step(num,den);  
grid  
>> xlabel ('time, secs');  
>> ylabel ('capacitor voltage, V');  
>> grid
```

Graphical Results



The reason this graph is not oscillating is because it is massively overdamped. The value of sigma is well above 1. This is because there is a large resistor value of 10Ω . When the resistor value changes in the next section then the oscillation will be seen in the graph.

6.5

Table of results:

Comparisons between Theoretical Predictions and Model Results	
Theoretical Predictions	Model Results
$\Sigma = 7.1$ – massively overdamped	Overdamped, no oscillation.

6.6

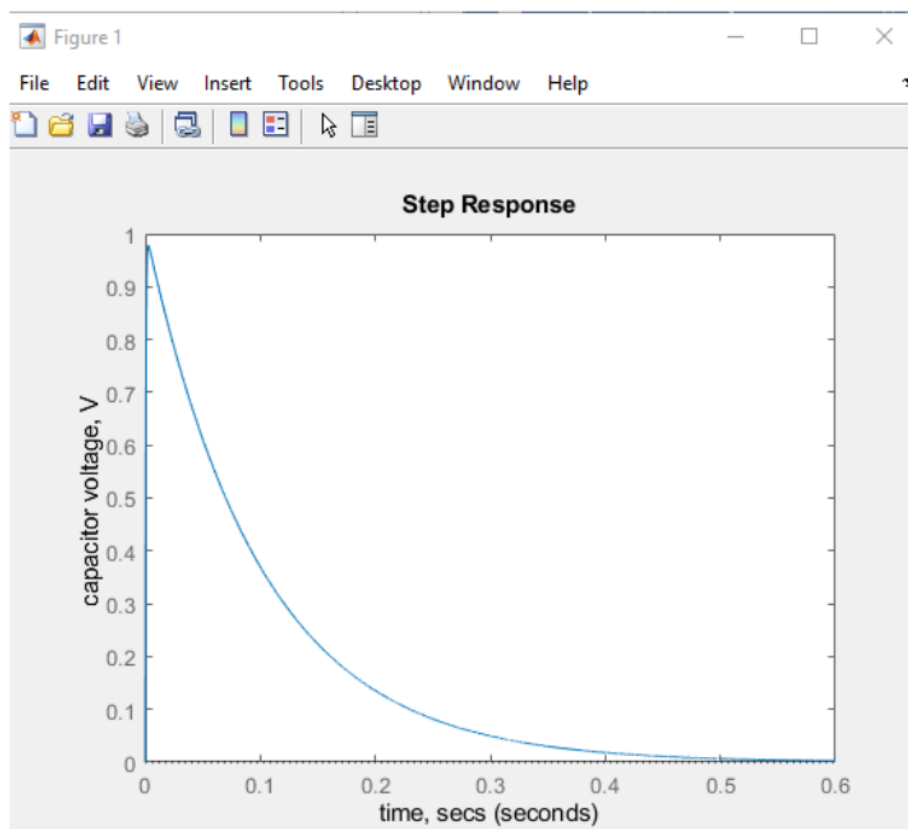
R=10

$$\Sigma = \frac{1}{2R} \frac{\sqrt{L}}{C}$$

$$\Sigma = \frac{1}{2 \times 10} \frac{\sqrt{1}}{50\mu}$$

$$\Sigma = 7.1$$

```
>> %R=5, Overdamped
>> num = [2000 0];
>> den = [1 2000 20000];
>> step (num,den);
>> grid
>> xlabel ('time, secs');
>> ylabel ('capacitor voltage, V');
>> grid
```



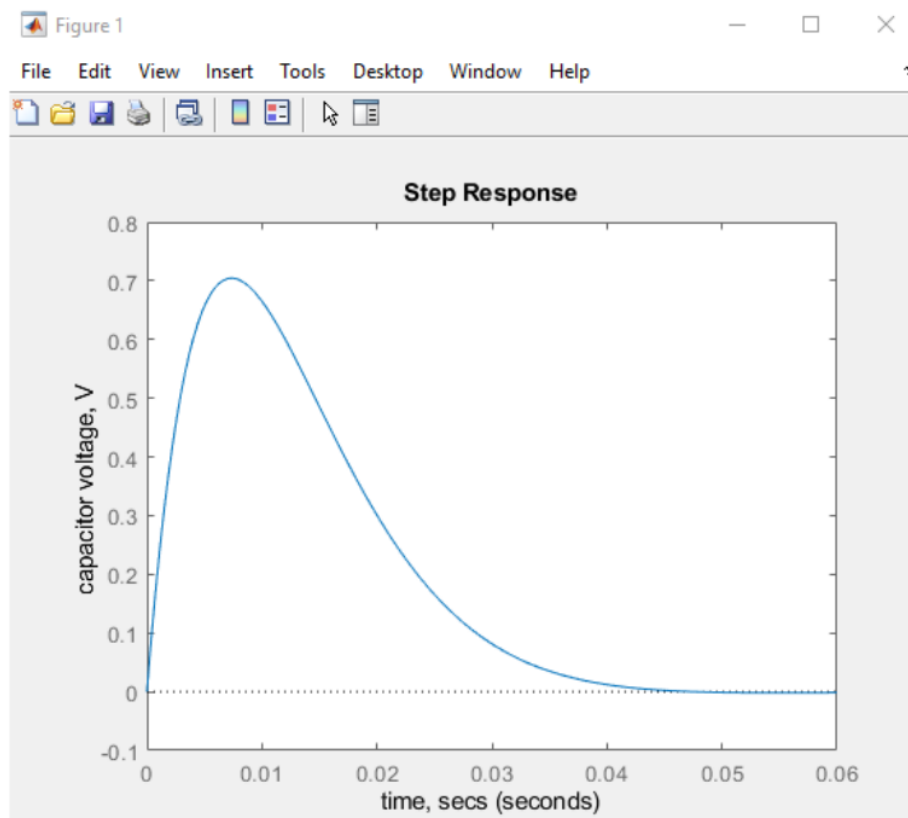
R=80

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

$$\zeta = \frac{1}{2 \times 80} \frac{\sqrt{1}}{50\mu}$$

$$\zeta = 0.88$$

```
>> %R=80, Underdamped
>> num = [250 0];
>> den = [1 250 20000];
>> step (num,den);
>> grid
>> xlabel ('time, secs');
>> ylabel ('capacitor voltage, V');
>> grid
```



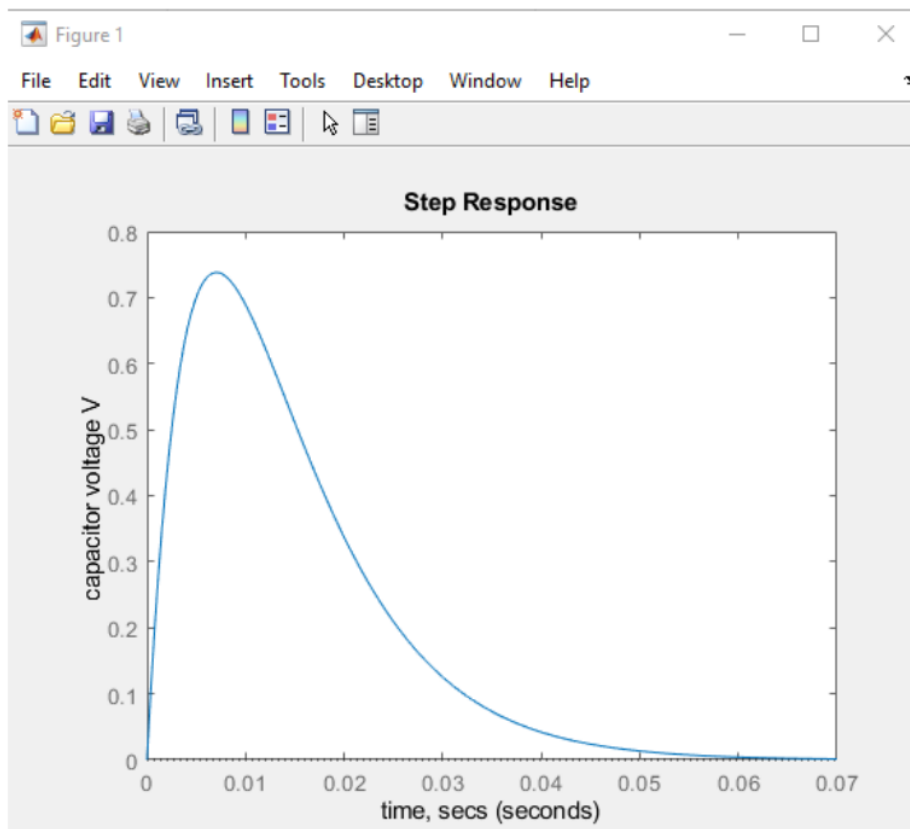
R=70

$$\Sigma = \frac{1}{2R} \frac{\sqrt{L}}{C}$$

$$\Sigma = \frac{1}{2 \times 70} \frac{\sqrt{1}}{50\mu}$$

$$\Sigma = 1.0$$

```
>> %R=70, Critically Damped
>> num = [285.7 0];
>> den = [1 285.7 20000];
>> step (num,den);
>> grid
>> xlabel ('time, secs');
>> ylabel ('capacitor voltage V');
>> grid
```



R=1000

$$\Sigma = \frac{1}{2R} \frac{\sqrt{L}}{C}$$

$$\Sigma = \frac{1}{2 \times 1000} \frac{\sqrt{1}}{50\mu}$$

$$\Sigma = 0$$

```
>> %R=1000, No Damping
>> num = [20 0];
>> den = [1 20 20000];
>> step (num,den);
>> grid
>> xlabel ('time, secs');
>> ylabel ('capacitor voltage V');
>> grid
```

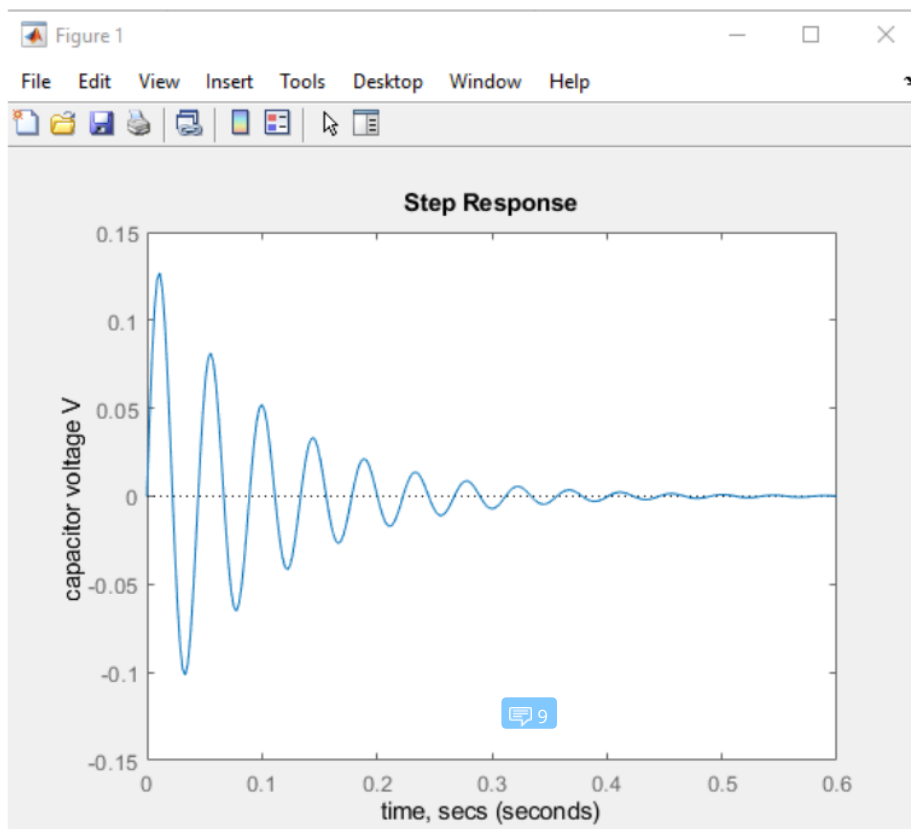


Table of Results		
Resistor Value (Ω)	Damping Factor	Response
10	7.1	Overdamped
70	1	Critically damped
80	0.88	Underdamped
1000	0	No damping

6.7

Critically damped was achieved at 70Ω , any more than that and the response was underdamped, which was seen when a resistor value of 80Ω was chosen. Any less than 70Ω was overdamped and that was seen when the resistor value was set to 10Ω . No damping was only achieved with a massive resistance value of 1000Ω . The closer to 70Ω , the closer to achieving critically damped.

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

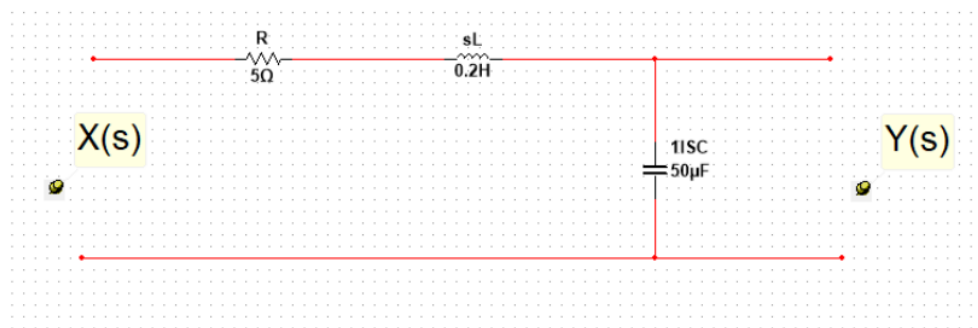
$$R = 5\Omega$$

$$L = 0.2\text{H}$$

$$C = 50\mu\text{F}$$

(Components values)

7.1



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

$$H(s) = \frac{\frac{1}{0.2 \times 50\mu}}{s^2 + \frac{5}{0.2}s + \frac{1}{0.2 \times 50\mu}}$$

$$H(s) = \frac{100000}{s^2 + 25s + 100000}$$

Transfer function

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

Standard denominator

$$\frac{1}{LC} = 100000$$

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

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

$$\omega_m = \sqrt{\frac{1}{0.2 \times 50\mu} - \frac{1}{2} \left(\frac{5}{0.2} \right)^2}$$

$$\omega_m = 315.7 \text{ rad/s}$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$\omega_0 = \sqrt{\frac{1}{0.2 \times 50 \mu}}$$

$$\omega_0 = 316.2$$

Resonant Frequency

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

$$Q = \frac{1}{5} \sqrt{\frac{0.2}{50 \mu}}$$

$$Q = 12.6$$

Quality Factor

$$20 \log (12.6) = 22.0 \text{ dB}$$

You have worked this out correctly, well

$$R = 5 \Omega$$

$$\Sigma = \frac{R}{2} \sqrt{\frac{C}{L}}$$

$$\Sigma = \frac{5}{2} \sqrt{\frac{50 \mu}{0.2}}$$

$$\Sigma = 0.04 \text{ underdamped}$$

Damping Factor

For $\Sigma=1$,

$$R = 2 \sqrt{\frac{0.2}{50 \mu}}$$

$$R = 126.49$$

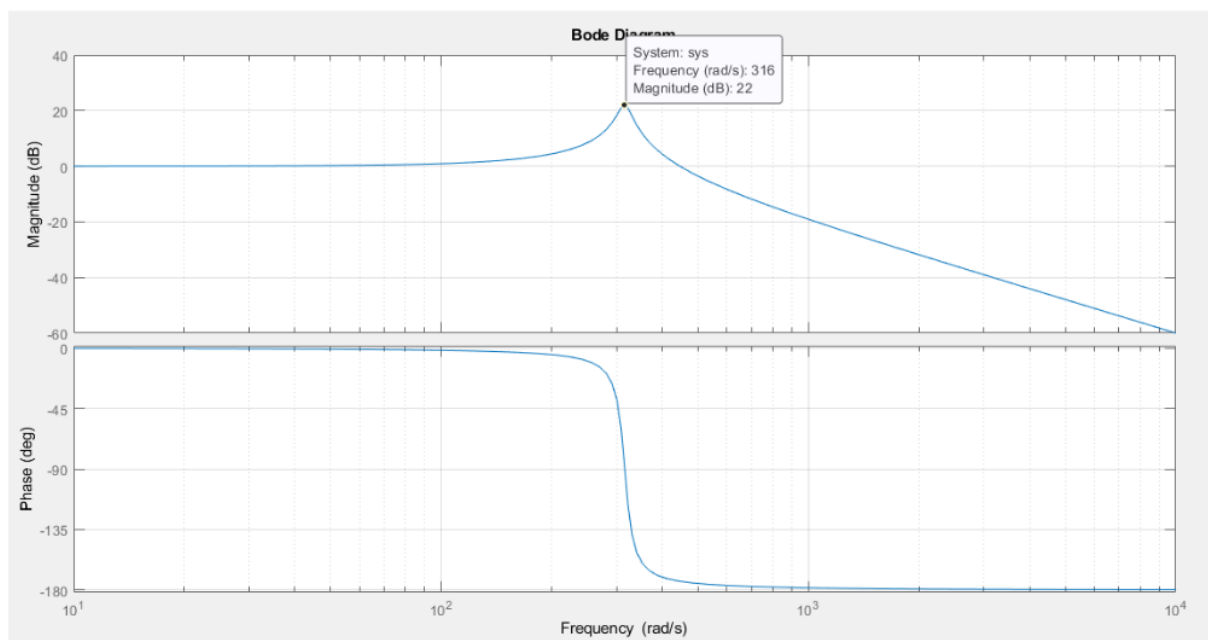
Rearranging for R to give a magnitude of 1, which is critically damped.

7.2

Matlab Programme

```
>> %R=5, L=0.2, C=50u  
>> num = [100000];  
>> den = [1 25 100000];  
>> bode (num,den);  
grid
```

Graphical Results



7.3

Comparison between theoretical predictions and model results	
Theoretical Predictions	Model Results
$\omega_o = 316.2$ and 22dB	$\omega_o = 316$ at 22dB

Theoretical predictions and model results are the same, therefore the model results are correct to that of the theoretical predictions.

7.4

$$R = 3\Omega$$

$$\Sigma = \frac{R}{2} \sqrt{\frac{C}{L}}$$

$$\Sigma = \frac{3}{2} \sqrt{\frac{50\mu}{0.2}}$$

$\Sigma = 0.02$ Underdamped

$$H(s) = [1 \ 15 \ 100000]$$

$$R = 10$$

$$\Sigma = \frac{R}{2} \sqrt{\frac{C}{L}}$$

$$\Sigma = \frac{10}{2} \sqrt{\frac{50\mu}{0.2}}$$

$\Sigma = 0.08$ Underdamped

$$H(s) = [1 \ 50 \ 100000]$$

$$R = 20$$

$$\Sigma = \frac{R}{2} \sqrt{\frac{C}{L}}$$

$$\Sigma = \frac{20}{2} \sqrt{\frac{50\mu}{0.2}}$$

$\Sigma = 0.16$ Underdamped

$$H(s) = [1 \ 100 \ 100000]$$

$$R = 126.49$$

$$\Sigma = \frac{R}{2} \sqrt{\frac{C}{L}}$$

$$\Sigma = \frac{126.49}{2} \sqrt{\frac{50\mu}{0.2}}$$

$\Sigma = 1$ Critically Damped

$$H(s) = [1 \ 632.45 \ 100000]$$

$$R = 150$$

$$\Sigma = \frac{R}{2} \sqrt{\frac{C}{L}}$$

$$\Sigma = \frac{150}{2} \sqrt{\frac{50\mu}{0.2}}$$

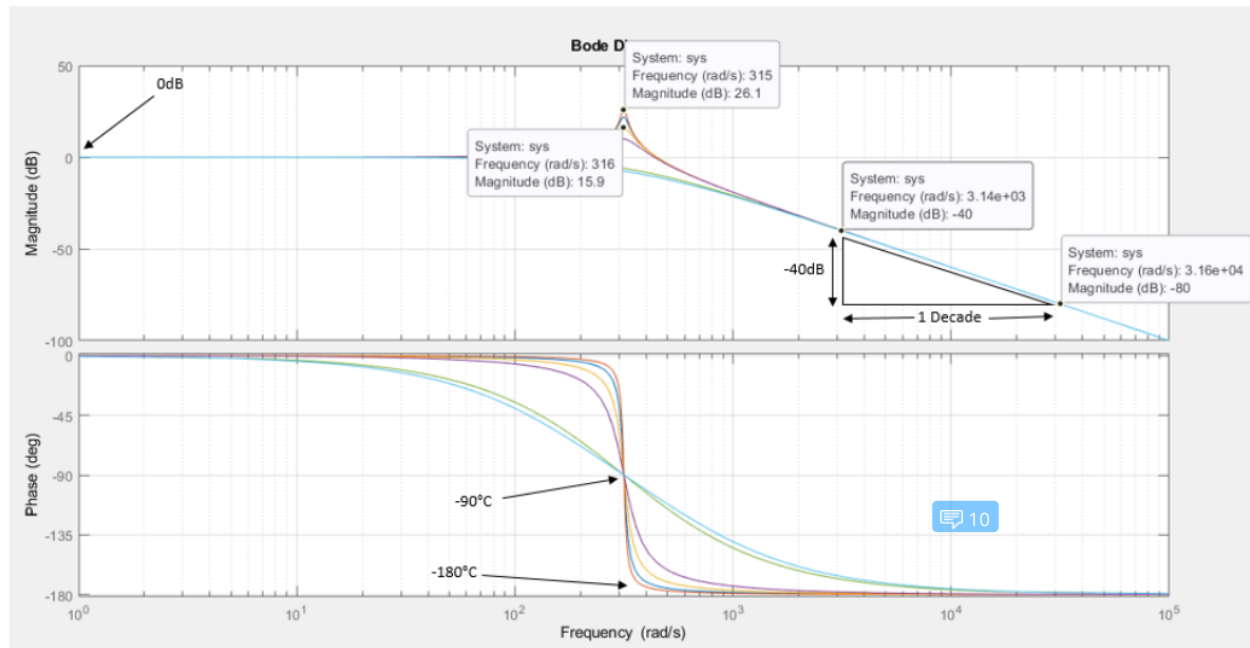
$\Sigma = 1.19$ Overdamped

$$H(s) = [1 \ 750 \ 100000]$$

Matlab Programme

```
>> %R=5, L=0.2, C=50u
>> num = [100000];
>> den = [1 25 100000];
>> bode (num,den);
hold on
>> %R=3, Underdamped
>> den = [1 15 100000];
>> bode (num,den);
>> %R=10, Underdamped
>> den = [1 50 100000];
>> bode (num,den);
>> %R=20, Underdamped
>> den = [1 100 100000];
>> bode (num,den);
>> %R=126.49, Critically Damped
>> den = [1 632.45 100000];
>> bode (num,den);
>> %R=150, Overdamped
>> den = [1 750 100000];
>> bode (num,den);
>> grid on
```

Graphical Results



7.5

Since $R=126.49\Omega$ for a magnitude of 1, then when $R>126.49\Omega$ the damping factor is overdamped and when $R<126.49\Omega$ the damping factor is underdamped.

$R = 1\Omega$ then $\omega_m = \omega_o$

When $R = 5\Omega$ then $\omega_m = 315.7 \text{ rad/s}$.

ω_m moves towards ω_o as R is varied.

Well done

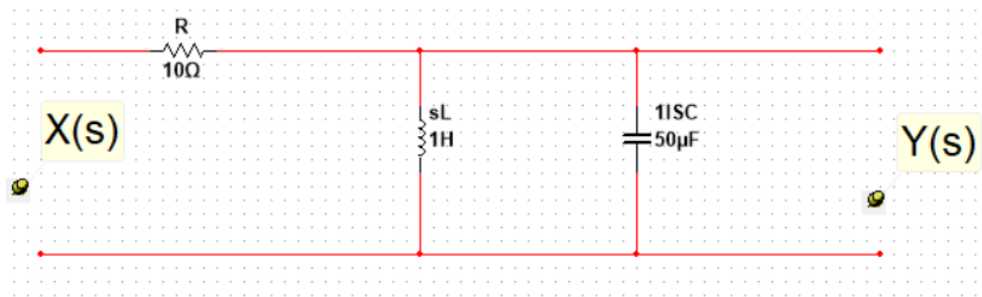
Task 8 – Frequency Performance Analysis of a Second Order Parallel Electrical Circuit

Component values:

$$R=10\Omega$$

$$L=1\text{H}$$

$$C=50\mu\text{F}$$



8.1

Transfer Function:

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

$$H(s) = \frac{s \frac{1}{10 \times 50 \mu}}{s^2 + s \frac{1}{10 \times 50 \mu} + \frac{1}{1 \times 50 \mu}}$$

$$H(s) = \frac{2000s}{s^2 + 2000s + 20000}$$

$$\omega_0^2 = 20000$$

$$\omega_0 = 141.4$$

Transfer function written in terms of ω_0 and β

$$H(s) = \frac{s \beta}{s^2 + s \beta + \omega_0^2}$$

Cut of Frequency:

$$\omega_0 = \sqrt{20000} = 141.4 \text{ rad/s}$$

The bandwidth $\beta = \omega_{c2} - \omega_{c1}$

$$\beta = \frac{1}{2RC} - - \frac{1}{2RC}$$

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

$$\beta = \frac{1}{10 \times 50 \mu}$$

$$\beta = 2000 \text{ rad/s}$$

The Q factor

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

$$Q = \frac{\frac{1}{\sqrt{LC}}}{\frac{1}{RC}}$$

$$Q = \frac{RC}{\sqrt{LC}}$$

$$Q = R \sqrt{\frac{C}{L}}$$

$$Q = 10 \sqrt{\frac{50 \mu}{1}}$$

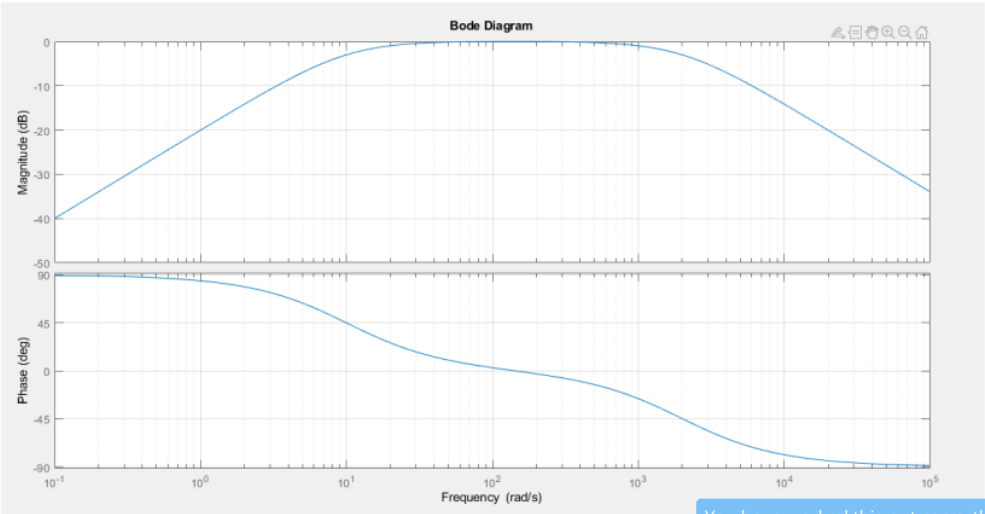
$$Q = 0.1$$

8.2

Matlab Model Program:

```
>> num = [2000 0];  
>> den = [1 2000 20000];  
>> bode (num,den);  
grid
```

Graphical Results:



The graph is very underdamped due to a low resistor value 10Ω.

8.3

Comparison between theoretical predictions and model results	
Theoretical Predictions	Model Results
$\omega_o = 141.4 \text{ rad/s at } 0\text{dB}$	$\omega_o = 141 \text{ rad/s at } 0\text{dB}$

8.4

$R=50\Omega$

$$\beta = \frac{1}{50 \times 50 \mu}$$

$\beta = 400 \text{ rad/s}$

$$H(s) = \frac{400s}{s^2 + 400s + 20000}$$

$$Q = 50 \sqrt{\frac{50 \mu}{1}}$$

$Q = 0.4$

(Underdamped)

$$R=100\Omega$$

$$\beta = \frac{1}{100 \times 50\mu}$$

$$\beta = 200 \text{ rad/s}$$

$$H(s) = \frac{200s}{s^2 + 200s + 20000}$$

$$Q = 100 \sqrt{\frac{50\mu}{1}}$$

$$Q = 0.7$$

(Underdamped)

$$R=142\Omega$$

$$\beta = \frac{1}{142 \times 50\mu}$$

$$\beta = 140.8 \text{ rad/s}$$

$$H(s) = \frac{140.8s}{s^2 + 140.8s + 20000}$$

$$Q = 142 \sqrt{\frac{50\mu}{1}}$$

$$Q = 1.0$$

(Critically damped)

$$R=150\Omega$$

$$\beta = \frac{1}{150 \times 50\mu}$$

$$\beta = 133.3 \text{ rad/s}$$

$$H(s) = \frac{133.3s}{s^2 + 133.3s + 20000}$$

$$Q = 150 \sqrt{\frac{50\mu}{1}}$$

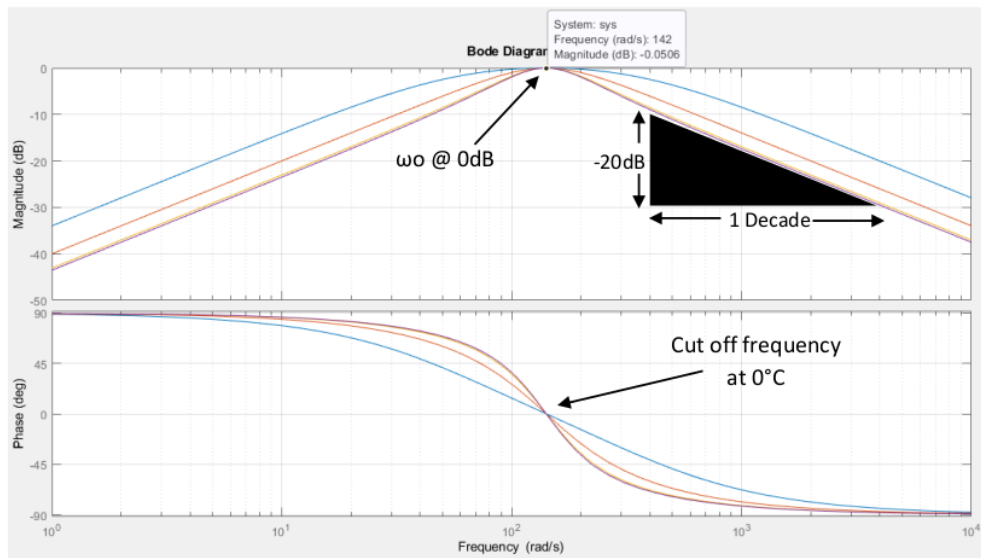
$$Q = 1.1$$

(Overdamped)

Matlab Model Program

```
>> %R=50, L=1, C=50u, (Underdamped)
>> num = [400 0];
>> den = [1 400 20000];
>> bode (num,den);
hold on
>> %R=100, L=1, C=50u, (Underdamped)
>> num = [200 0];
>> den = [1 200 20000];
>> bode (num,den);
>> %R=142, L=1, C=50u, (Critically damped)
>> num = [140.8 0];
>> den = [1 140.8 20000];
>> bode (num,den);
>> %R=150, L=1, C=50u, (Overdamped)
>> num = [133.3 0];
>> den = [1 133.3 20000];
>> bode (num,den);
>> grid on
```

Graphical Result



11

8.5

Conclusion

As the resistor value is increased up to 142Ω the quality factor reaches one, a critically damped state.

Any resistor value below 142Ω is underdamped and any resistor value above 142Ω is overdamped.

This is a very similar behavior to the series RLC circuit.

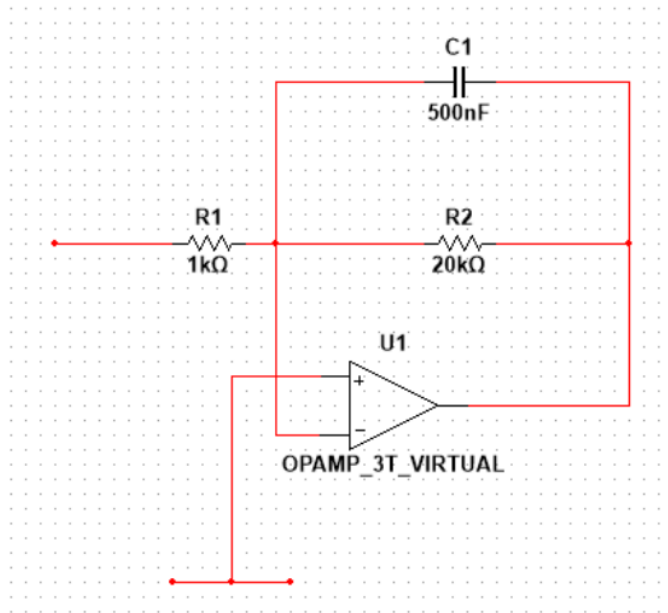
You have worked this out correctly, well

Task 9 – Frequency Performance Analysis of a First Order Electronic System

9.1

Active Low-Pass Filter

C4 = 500nF



Gain

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

$$K = \frac{20}{1}$$

$$K = 20$$

In dB's 20 is;

$$20\log_{10}(20) = 26.02\text{Db}$$

Cut off point = $26.02 - 20 = 6.02$

Cut off Frequency

$$\omega_c = \frac{1}{CR_2}$$

$$\omega_c = \frac{1}{500\pi \times 20000}$$

$$\omega_c = 100 \text{ rad/s}$$

Transfer Function

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

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

You have worked this out

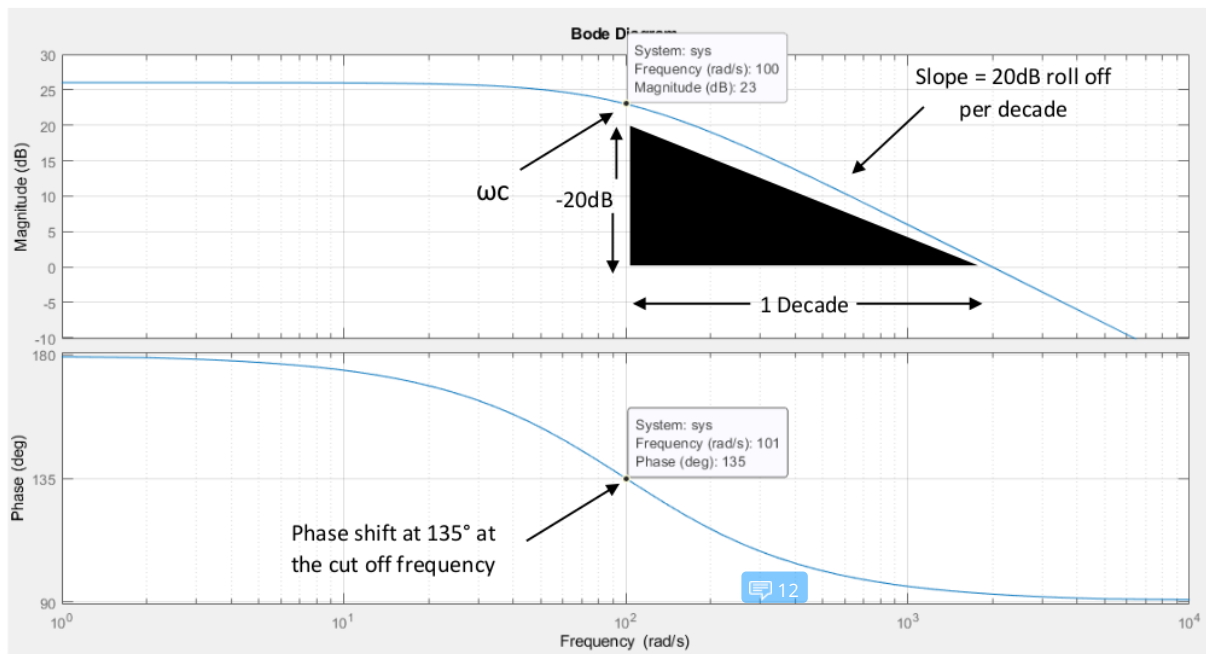
It is clear that this is an inverting amplifier which gives a phase shift of 180° . At cut off $\theta = -45 + 180 = 135^\circ$.

9.2

Matlab Model Program

```
>> num = [-2000];  
>> den = [1 100];  
>> bode (num,den);  
grid
```

Graphical Result



Theoretical Results			
Cut off Frequency	Gain	Phase Shift	Roll off/Decade
100 rad's	20	135°	20dB

Simulation Results			
Cut off Frequency	Gain	Phase Shift	Roll off/Decade
100 rad's	23 magnitude	135°	20dB

9.3

In this circuit, the sign makes it clear that it is an inverting amplifier, which provides a phase shift of 180°. At the cut off frequency is the following, $\theta = -45 + 180 = 135^\circ$. The graph clearly shows the cut off frequency at 135°. As can be seen, the theoretical results match the actual results.

Well done 

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

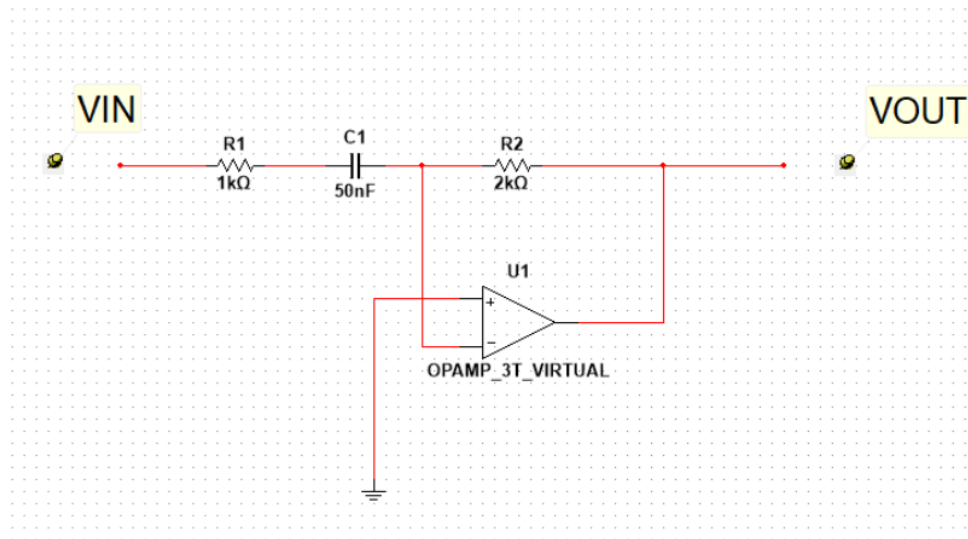
Active High-Pass Filter

10.1

$$R1 = 1k\Omega$$

$$R2 = 2k\Omega$$

$$C5 = 50nF$$



Gain

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

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

$$K = 2$$

$$\text{In dB, 2 is } 20\log(2) = 6\text{dB}$$

Therefore, cut off frequency is 3dB

Cut off Frequency

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

$$\omega_c = \frac{1}{50n \times 1000}$$

$$\omega_c = 20000 \text{ rad/s}$$

For a high pass filter, at ω_c , $\theta = 45^\circ$. Since we have a phase shift of 180° due to the '-' sign, therefore at ω_c , $\theta = 45 + 180 = 225^\circ$ at ω_c .

Transfer Function

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

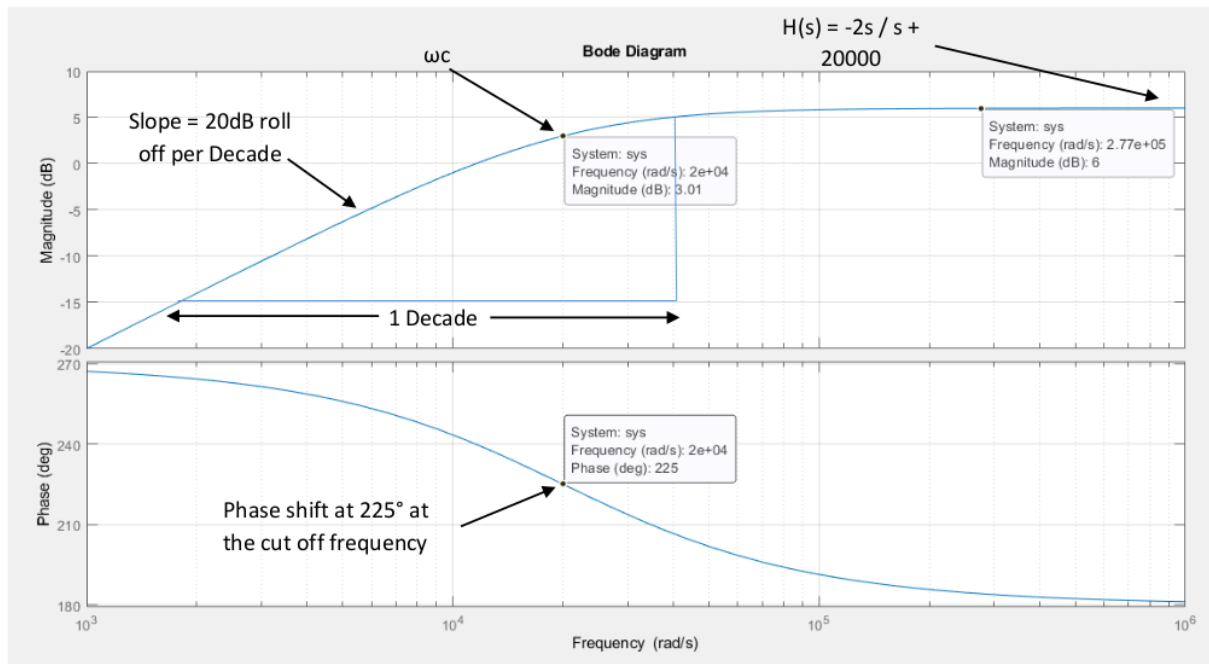
$$H(s) = -2 \left[\frac{s}{s + 20000} \right]$$

10.2

Matlab Model Program

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

Graphical Result



Theoretical Results			
Cut off Frequency	Gain	Phase Shift	Roll off/Decade
20000 rad's	2	225°	20dB

Simulation Results			
Cut off Frequency	Gain	Phase Shift	Roll off/Decade
20000 rad's	3.01 magnitude	225°	20dB

10.3

It is clear and obvious that the results are very similar to the previous version of the high pass filter with a gain of $-K$. The high pass filter, at ω_c , will result in the following, $\theta = 45^\circ$. However, the phase shift is 180° because of the minus sign. At ω_c , the result is as follows, $\theta = 45 + 180 = 225^\circ$. The graph shows the cut off frequency at 225° . The graph levels off at the transfer function of the high pass filter, where 6dB has been the result and theoretical predication.

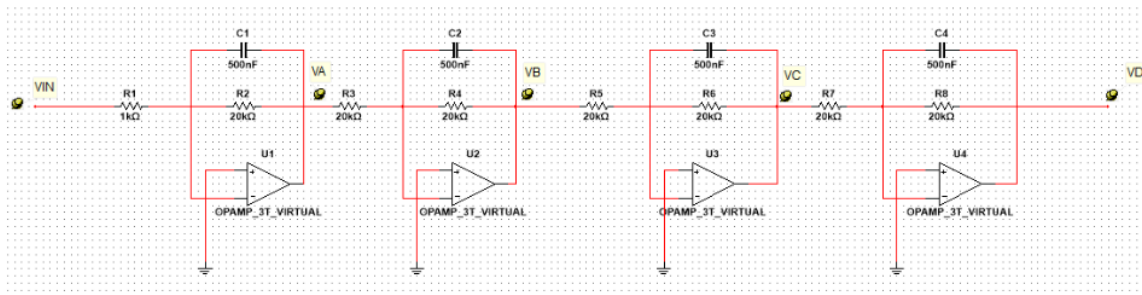
Task 11 – Frequency Performance Analysis of a Fourth Order Electronic System

11.1

$$R1 = 1K\Omega$$

$$R2-4 = 20K\Omega$$

$$C = 500nF$$



$$\omega_c = \frac{1}{R2C}$$

$$\omega_c = \frac{1}{20000 \times 500n}$$

14

$$\omega_c = 100\text{rad/s}$$

$$K = 20$$

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

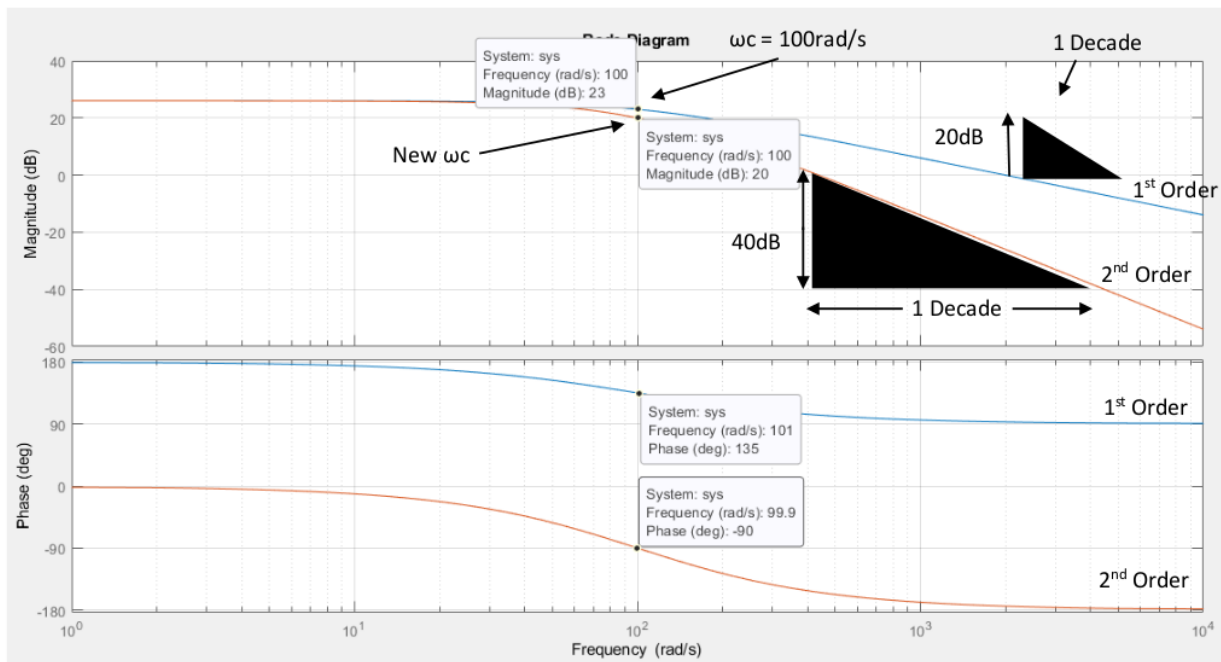
$$H(s) = \frac{20 \times 100^2}{s^2 + 2 \times 100s + 100^2}$$

$$H(s) = \frac{200000}{s^2 + 200s + 10000}$$

Matlab Model Program

```
>> num = [-2000];
>> den = [1 100];
>> bode (num,den);
>> hold on
>> num = [200000];
>> den = [1 200 10000];
>> bode (num,den);
>> grid on
```

Graphical Result – Cascaded Low Pass Filter



Note that at ω_c there is a 100 rad/s. The second order filter has reduced the gain from 23dB to 20dB, which gives a -3dB reduction. This is to be expected as each stage reduces the gain by -3dB at ω_c . Effectively, the actual overall cut off frequency has changed.

It can be shown that for a n th order filter, the cut off frequency will move to ω_{cn} , where;

$$\omega_{cn} = \sqrt{n\sqrt{2} - 1} \omega_c$$

$$\sqrt{\sqrt{2} - 1} = 0.6436$$

In this case $n=2$, therefore $\omega_{cn} = \sqrt{2\sqrt{2} - 1} \times 100 = 64.36 \text{ rad/s}$

A scaling factor of $\frac{1}{0.6436}$ can be used to move the cut off frequency back to 100 by designing both stages for $\frac{100}{0.6436} = 155.4 \text{ rad/s}$.

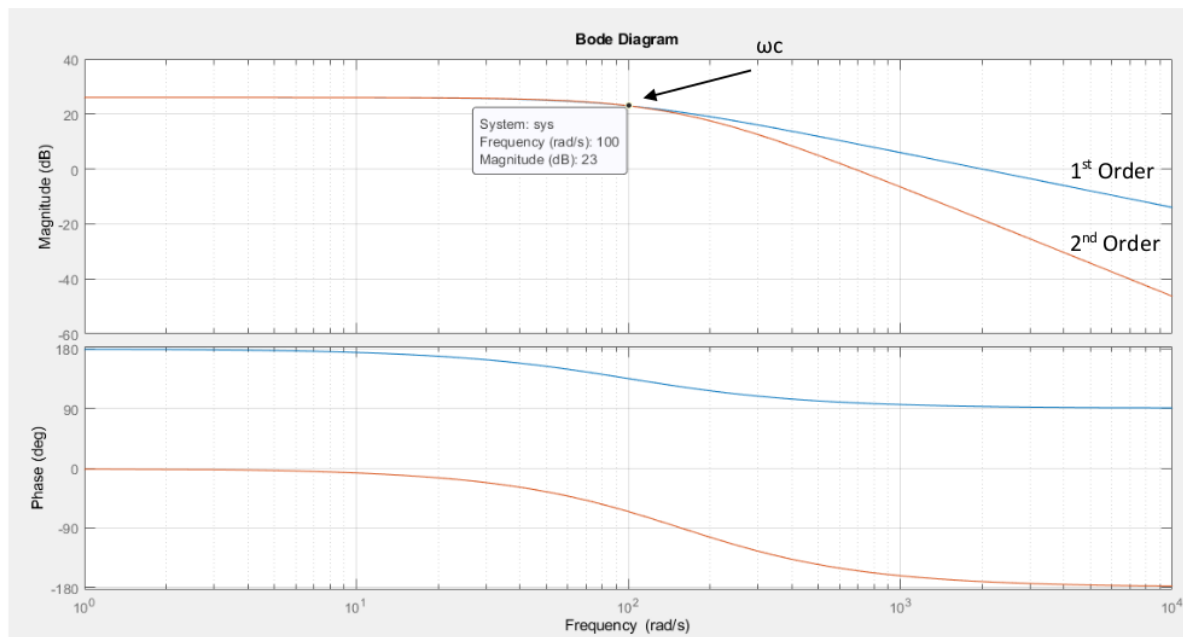
$$H(s) = \frac{20 \times 155.4^2}{s^2 + 2 \times 155.4s + 155.4^2}$$

$$H(s) = \frac{482983.2}{s^2 + 310.8s + 24149.16}$$

Matlab Model Program

```
>> num = [-2000];
>> den = [1 100];
>> bode (num,den);
hold on
>> num = [482983.2];
>> den = [1 310.8 24149.16];
>> bode (num,den);
>> grid on
```

Graphical Results



$$n = 2$$

$$\omega c^2 = 0.6436$$

$$\frac{1}{\omega c^2} = 1.554$$

$$1.554 \times 100 = 155.4 \text{ rad/s}$$

$$n = 3$$

$$\omega c^3 = 0.5098$$

$$\frac{1}{\omega c^3} = 1.962$$

$$1.962 \times 100 = 196.2 \text{ rad/s}$$

$$n = 4$$

$$\omega c^4 = 0.435$$

$$\frac{1}{\omega c^4} = 2.299$$

$$2.299 \times 100 = 229.9 \text{ rad/s}$$

$$n = 2: H(s) = \frac{3 \omega c^2}{s^2 + 2\omega c + \omega c^2}$$

$$n = 3: H(s) = \frac{-3 \omega c^3}{s^3 + 3\omega c s^2 + 3\omega c^2 s + \omega c^3}$$

$$n = 4: H(s) = \frac{3 \omega c^4}{s^4 + 4\omega c s^3 + 6\omega c^2 s^2 + 4\omega c^3 s + \omega c^4}$$

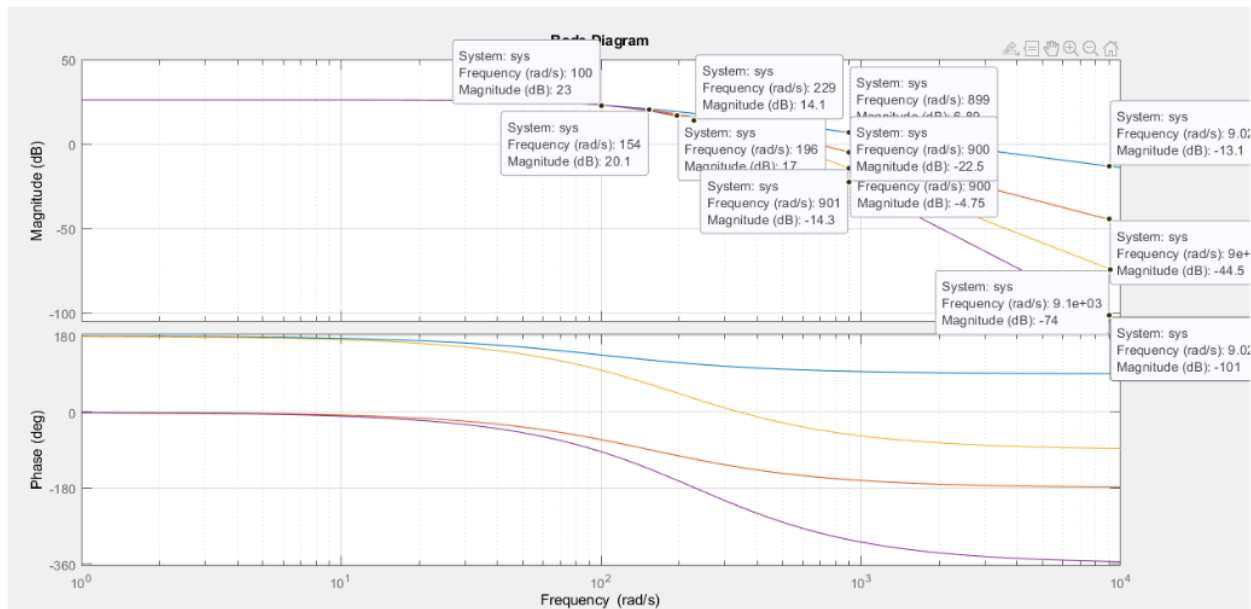
You have worked this out correctly, well

Matlab Program:

```
>> %Cascaded 4th Order Low Pass Filter Modified Design
>> %First Stage
>> wc1 = 100;
>> wc = wc1;
>> k = 20;
>> num1 = [-k*wc];
>> den1 = [1 wc];
>> bode (num1,den1);
>> grid on
>> hold on
>> %Second Stage
>> %To get the same cut off as wc, use scaling factor of 1.554
>> wc = wc1*1.554;
>> num2 = [k*wc^2];
>> den2 = [1 2*wc wc^2];
>> bode(num2,den2);
>> %Third Stage
>> %To get the same cut off as wc, use scaling factor of 1.962
>> wc = wc1 * 1.962;
>> num3 = [-k*wc^3];
>> den3 = [1 3*wc 3*wc^2 wc^3];
>> bode(num3,den3);
>> %Fourth Stage
>> %To get the same cut off as wc, use scaling factor of 2.299
>> wc = wc1*2.299;
>> num4 = [k*wc^4];
>> den4 = [1 4*wc 6*wc^2 4*wc^3 wc^4];
>> bode(num4,den4);
```



Graphical Result



11.2

The results in the graph show a gain reduction of -3db at the new cut off frequency of each nth term.

This is what was calculated in the theory.

Comparison table	
Theory	Results
1 st Order 20db decade	1 st Order 13db decade
2 nd Order 40db decade	2 nd Order 44.5db decade
3 rd Order 60db decade	3 rd Order 74db decade
4 th Order 80db decade	4 th Order 101db decade

The cut off frequency is the same to that of figure 5. In the event that it wasn't the scaling factor of $\frac{1}{0.6436}$ can be used to move the cut off frequency back to 100 by designing both stages for $\frac{100}{0.6436}$. Figure 5 and figure 7 1st order are identical with a cut off frequency of 100 rad/s and a gain of 23db. This is because the capacitor and resistor values are the same. Capacitance and resistor values for figure 5 (task 9) and figure 7 (task 11) are 500 μ F and 1K Ω .

11.3

By analyzing the theory and the results it is clear that the overall outcome is fairly accurate. The cut off frequencies for each nth term match the results, however a desired 20db decade per order was not achieved, although the results were close.

Task 12 – First Order Control System Analysis

12.1

$$\text{TF CL (Closed Loop)} = \frac{G}{1+GH}$$

16

$$\text{TF} = \frac{7.5}{s - 0.85} \cdot \frac{1}{1 + K \left(\frac{7.5}{s - 0.85} \right)}$$

$$\text{TF} = \frac{7.5}{s - 0.85 + 7.5K}$$

Equate the denominator to zero

$$s + 7.5K - 0.85 = 0$$

$$s = - (7.5K - 0.85)$$

$$s = 0.85 - 7.5K = 0$$

For a Pole,

$$7.5K = 0.85$$

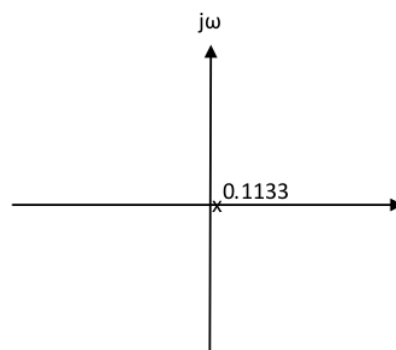
$$K = \frac{0.85}{7.5}$$

$$K = 0.1133$$

You have worked this out correctly, well

Argand Diagram:

Stability Prediction: Unstable (right hand plane). Open loop: unstable response.



12.2

$$K = 1$$

$$S - 0.85 + 7.5 = 0$$

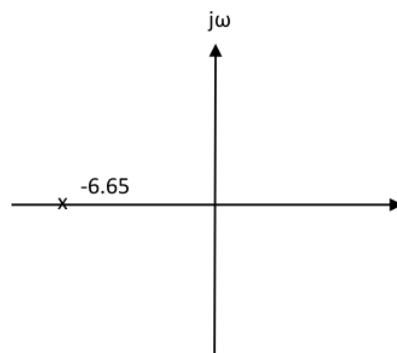
$$S + 6.65 = 0$$

$$S = -6.65 \text{ (left hand plane)}$$

Stability: Stable

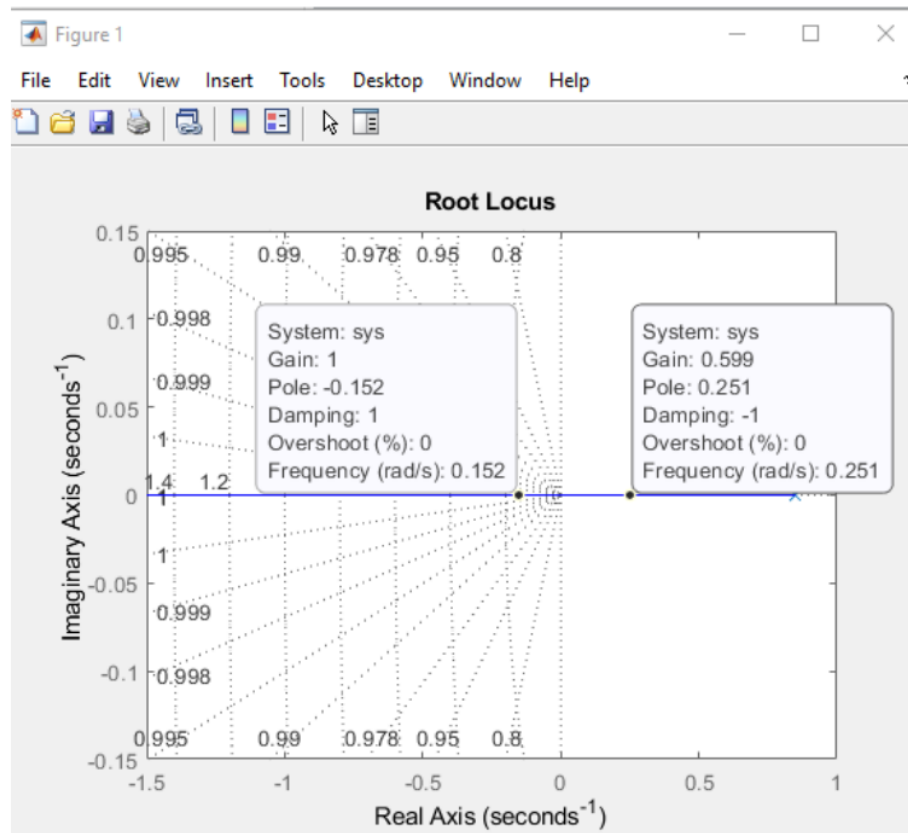
Argand Diagram:

Stability Prediction: Stable (left hand plane). Closed loop: Stable.



12.3

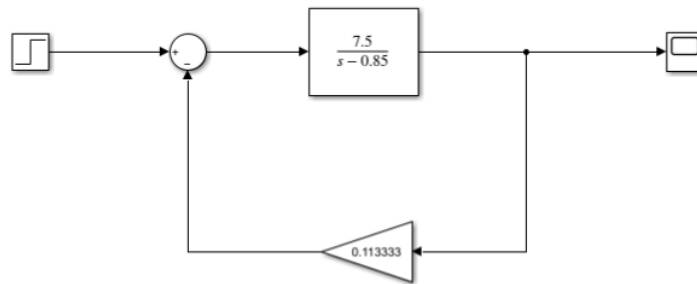
```
>> clear all
>> num = [1];
>> den = [1 -0.85];
>> rlocus(num,den);
grid
```



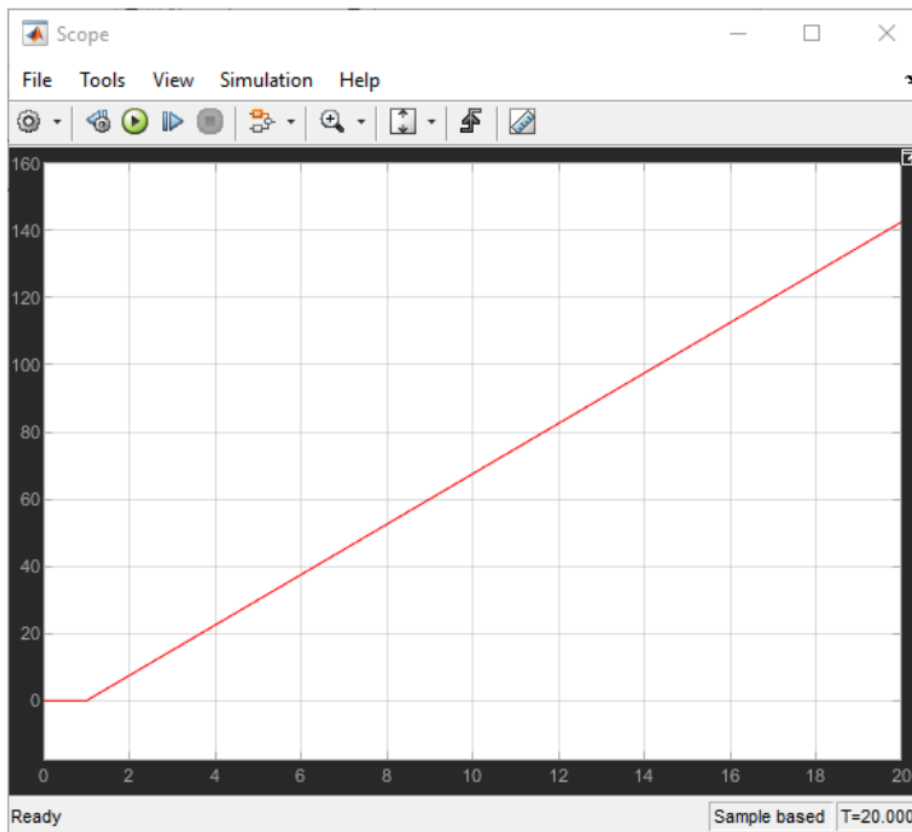
12.4

Closed loop:

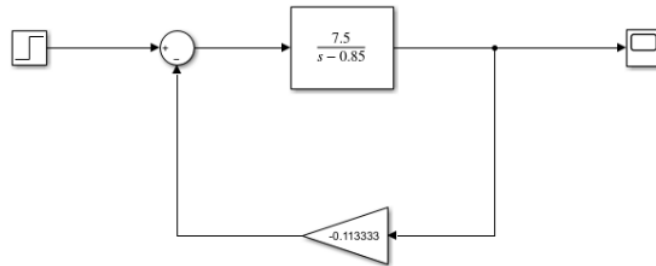
K at 0.113333



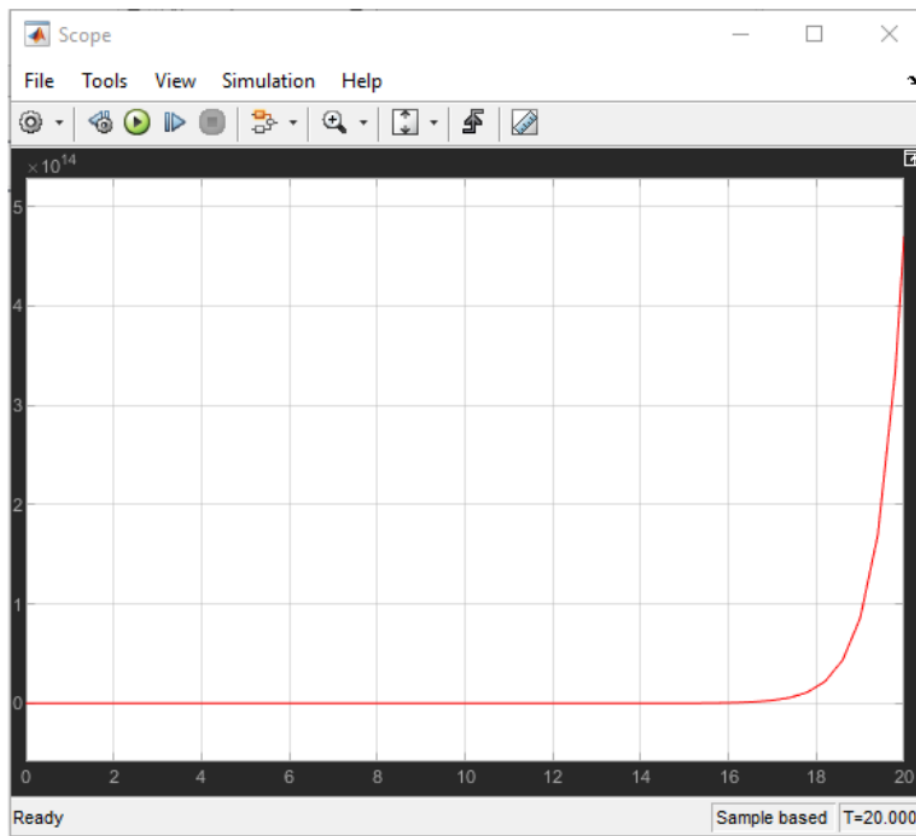
Unstable response:



K at -0.113333

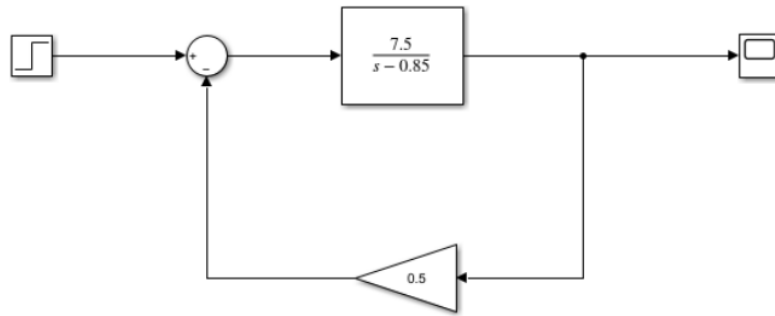


Response: unstable

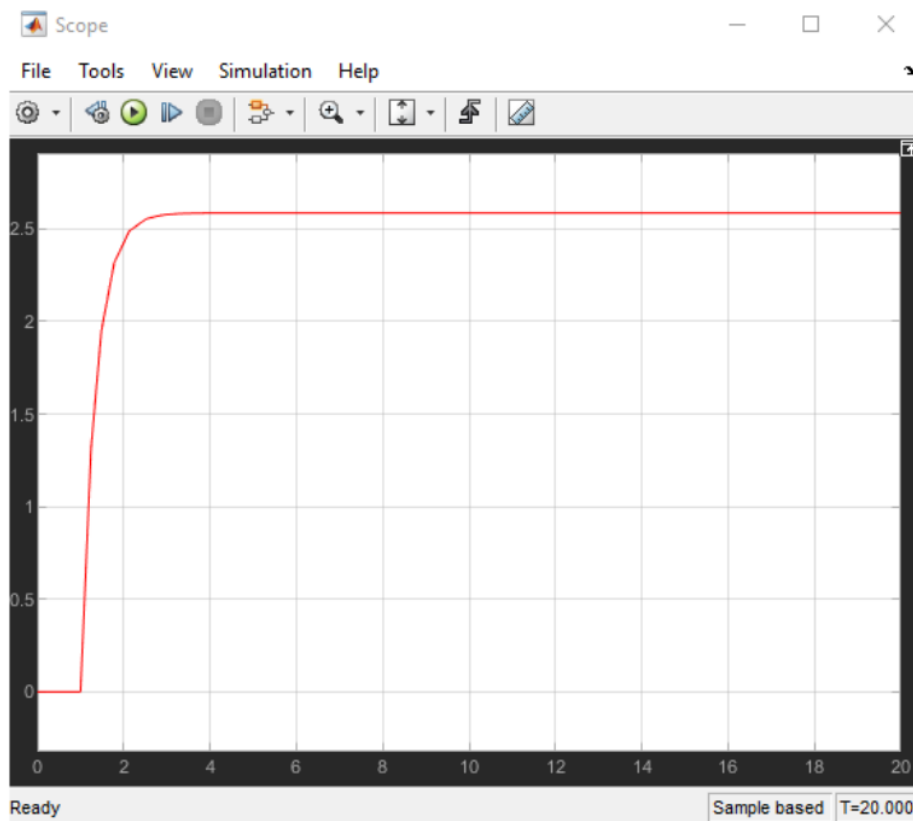


K at 0.5

Response: Stable



Response: Stable



12.5

Theoretical and Simulation Results	
Value of K	Response
0.113333	Unstable
-0.113333	Unstable
0.5	Stable

12.6

You have worked this out correctly, well

From the simulation results it is clear that any value that is equal to or below the calculated gain is unstable. Any value that is above the calculated gain of 0.113333 is stable. The value has to be above 0.1133 in order to achieve a stable response. The minimum value to obtain a stable response is then > 0.1133 .

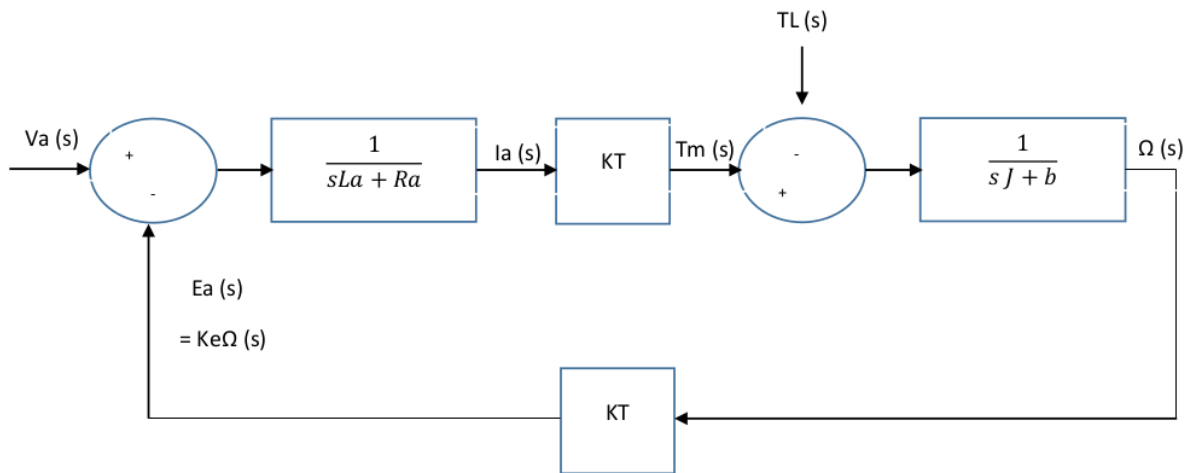
Task 13 – DC Motor Model Analysis

13.1

Transfer Function:

$$G(s) = \frac{\frac{KT}{LaJ}}{s^2 + s\left(\frac{b}{J} + \frac{Ra}{La}\right) + \frac{Rab}{LaJ} + \frac{KTKe}{LaJ}}$$

$$C.F = \frac{K\omega n^2}{s^2 + 2\sum \omega n s + \omega n^2}$$



13.2

Electrical Time Constant:

$$K_e = \text{electrical constant} = \frac{Ra}{La} = \frac{1.5}{0.165} = 9.09$$

Natural Frequency:

$$\omega_n^2 = Ra / b + K_t K_e / La$$

$$\omega_n^2 = (1.5 \times 4.6 \times 10^{-6}) / (0.165 \times 0.00042) + (0.062 \times 0.063) / (0.163 \times 0.00042)$$

$$\omega_n^2 = 57.1548$$

$$\omega_n = \sqrt{57.1548}$$

$$\omega_n = 7.56$$

Damping Factor:

$$2\zeta\omega_n = (b/J) + (Ra/La)$$

$$2\zeta\omega_n = (4.6 \times 10^{-6} / 0.00042) + (1.5 / 0.165)$$

You have worked this out correctly, well

$$2\zeta\omega_n = 9.10$$

$$\zeta = 9.10 / (2 \times 7.51)$$

$$\zeta = 0.6059$$

Stall Torque:

For some motors $K_e = K_t = T_m$

$$T_m (\text{stall}) = K_m V_a / Ra$$

$$T_m (\text{stall}) = (0.062 \times 24) / 1.5 = 0.992 \text{ Nm}$$

$$T_m (\text{stall}) = (0.062 \times 15) / 1.5 = 0.62 \text{ Nm}$$

Theoretical friction-less no – load speed:

$$\Omega_{NL} = V_a / K_m = 24 / 0.063 = 380.95 \text{ rad/s}$$

$$\Omega_{NL} = V_a / K_m = 15 / 0.063 = 238.09 \text{ rad/s}$$

Loaded Speed: with a disturbance of 0.03Nm

$$\Omega L = Va - \frac{RaTL}{KT}$$

$$\frac{Ra}{KT} \times b + Ke$$

$$\Omega L = 15 - \frac{1.5 \times 0.03}{0.062}$$

$$\frac{1.5}{0.062} \times 4.6 \times 10^{-6} + 0.063$$

$$\Omega L = 226.12$$

13.3

$$a = 1$$

$$b = 2\sum \omega n, = 9.10$$

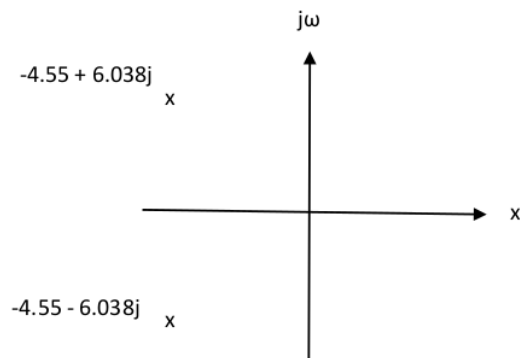
$$c = \omega n^2, = 57.1548$$

$$\text{Using quadratic formula} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$X1 = -4.55 + 6.038j$$

$$X2 = -4.55 - 6.038j$$

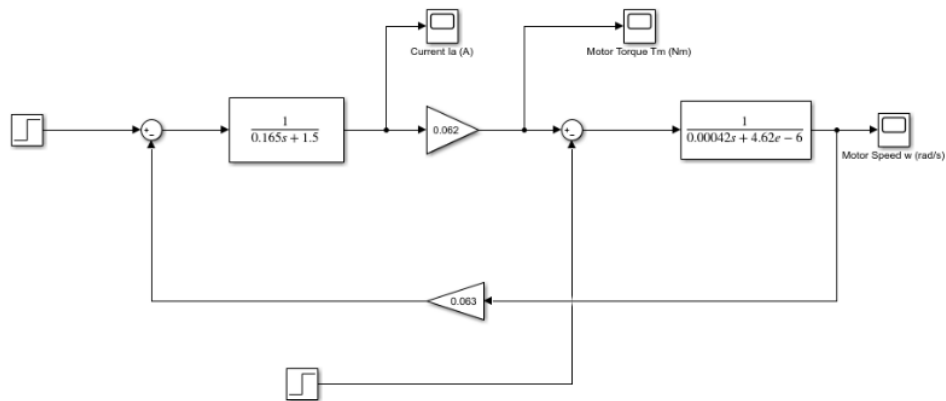
Argand Diagram



You have worked this out correctly, well

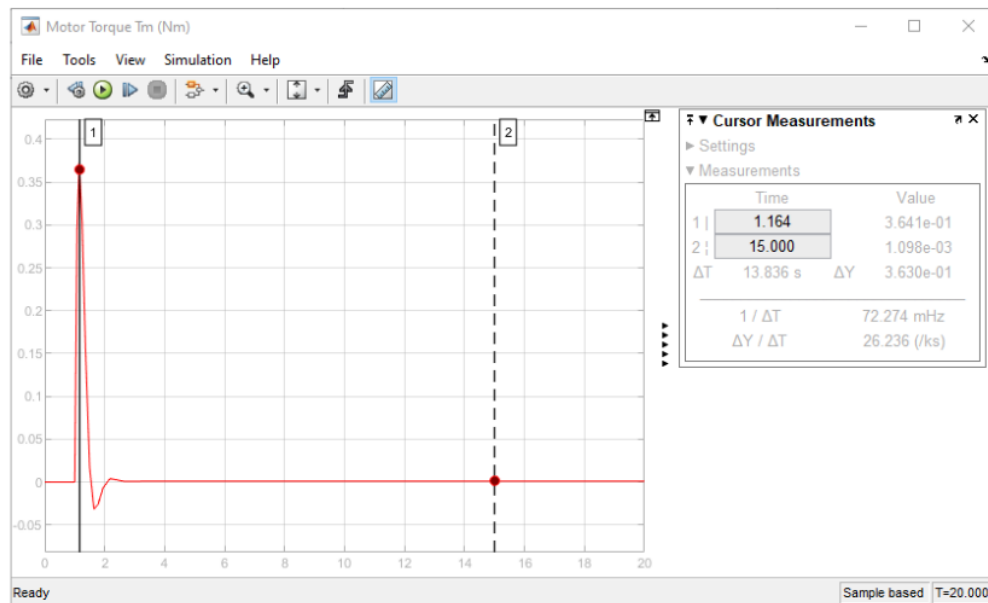
Left hand pole is stable stability

13.4



13.5

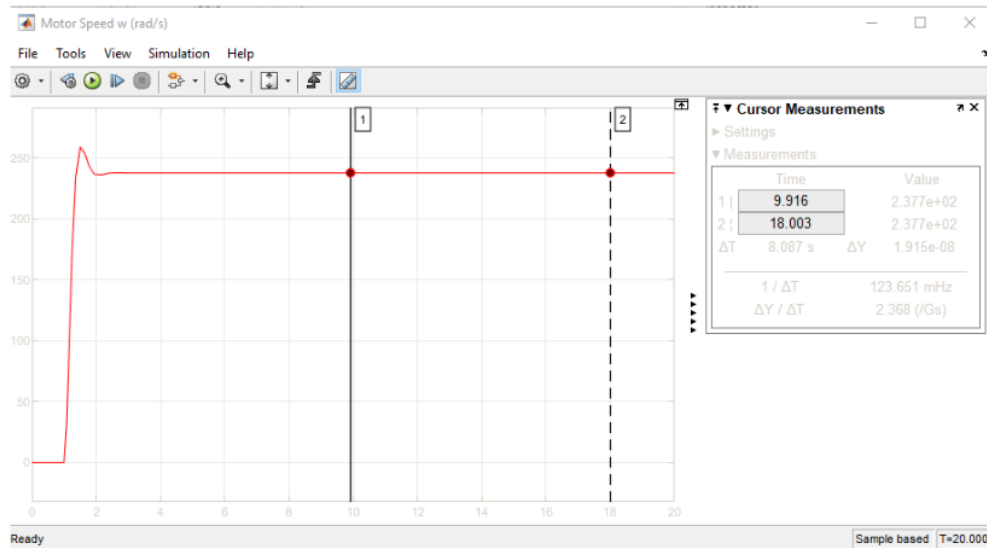
Torque Response: With zero disturbance



At 1s there is a torque of 0.36Nm and between 2 and 20 seconds there is no torque. The reason for the spike at 1 second is because of the inrush currents at start up. There is a no load speed of 1098 rad's. The settling time begins at 2 seconds.

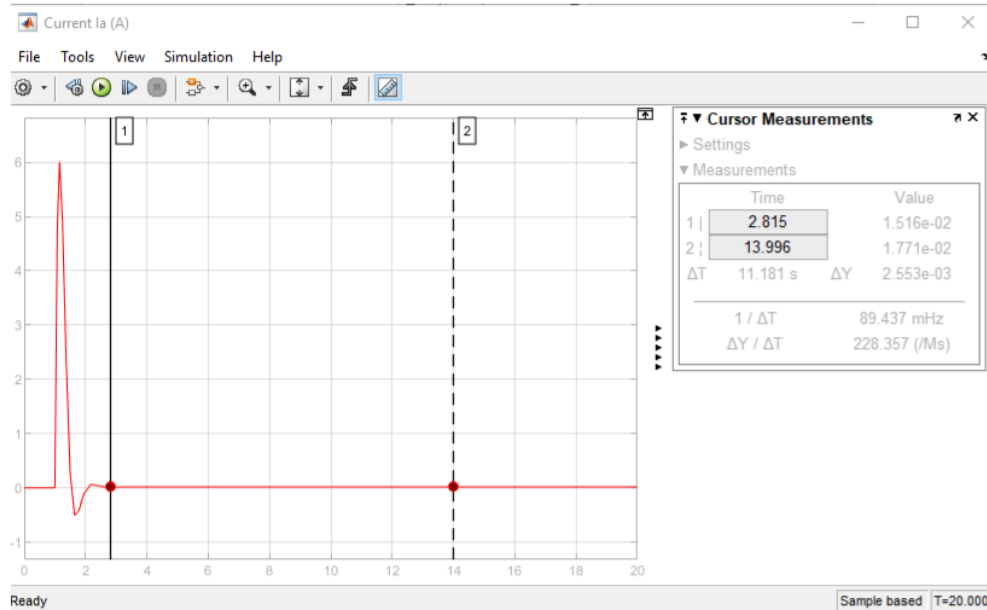
Well done

Speed Response: With zero disturbance



With no disturbance there is a slight peak, but then after 2 seconds a no load speed of 237.7 rads. Between 2 and 20 seconds is the settling time of 237.7 rads with no load.

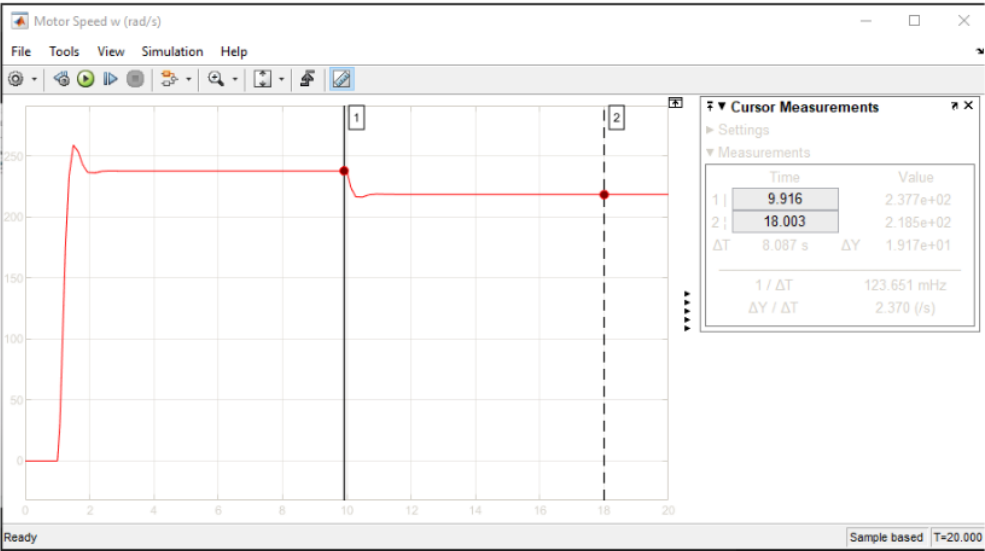
Current with no disturbance:



With no disturbance and no load, between 2 and 20 seconds there is no current. There is a no load speed of 177 rad's. The settling time begins at 2 seconds.

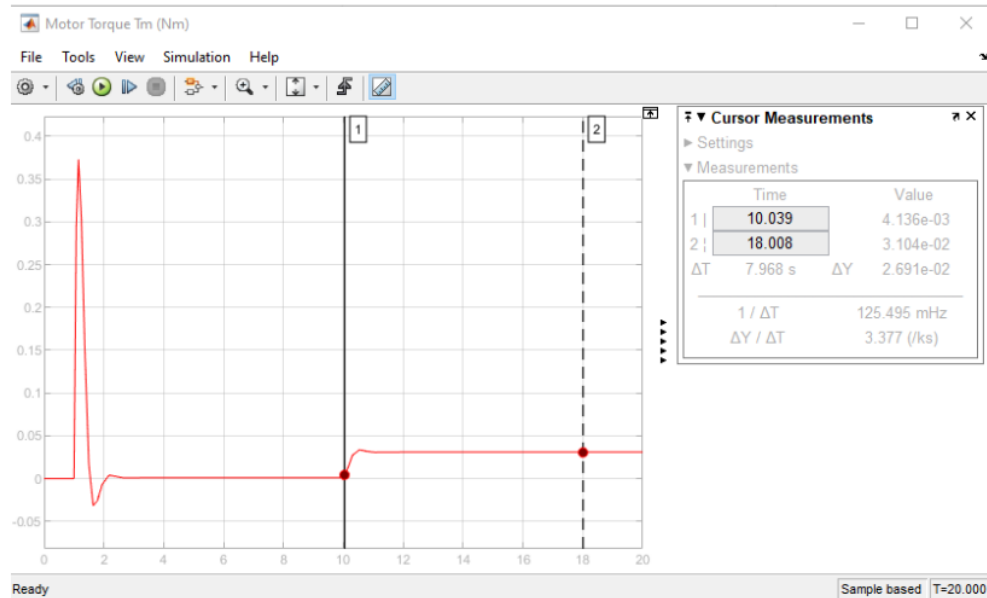
13.6

Motor speed with a disturbance of 0.03Nm



Between 2 and 10 seconds is the settling speed at 237.7 rads. After 10 seconds the load was applied and the speed dropped. The speed settled with a load at 218.5 rad's. For the current, $\frac{15}{218} = 0.14$.

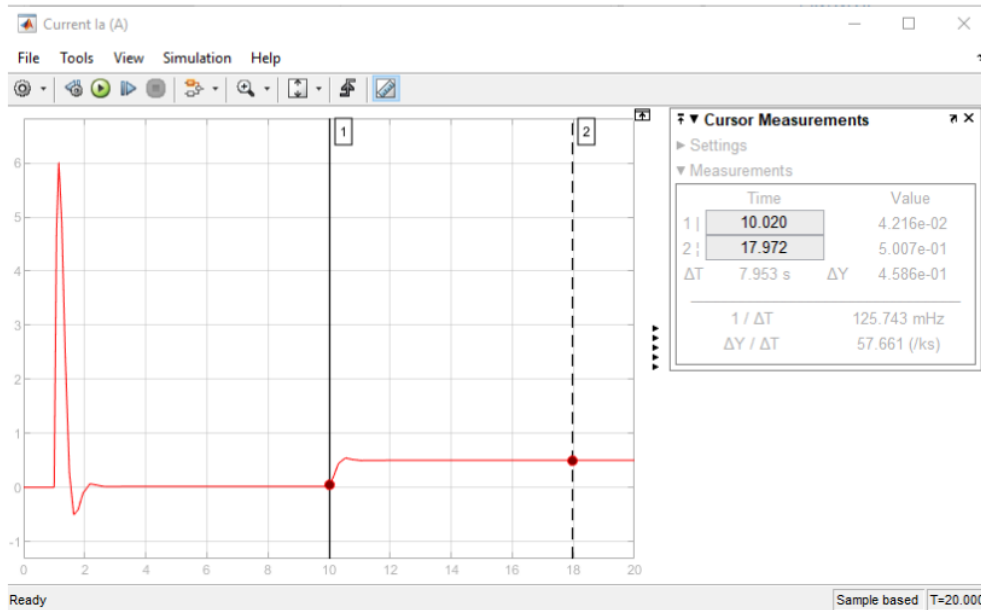
Motor torque with a disturbance of 0.3Nm



Between 2 and 10 seconds there is no load. After 10 seconds a disturbance of 0.03Nm was applied. Therefore, between 10 and 20 seconds there is a steady torque of 0.03Nm. The torque increased after 10 seconds as a result of the disturbance. The speed with the load applied is 310 rad/s. The current with the load applied is $\frac{15}{310} = 0.04A$.

You have worked this out correctly, well

Current



Between 2 and 10 seconds the current settles under no load at 0.04A. When the disturbance of 0.03Nm was applied the current increased after 10 seconds to 0.5A. The spike at 1 second is due to the inrush current at start up.

13.7

Comparison Table			
	Theoretical Results	Simulated results with no disturbances	Simulated results with a 0.03Nm disturbance
Torque	0.62Nm	0Nm	0.03Nm
No Load Speed	238.09 rad/s	237.7 rad/s	N/A
Load Speed	226.12 rad/s	N/A	218.5 rad/s
Current	0A	0A	0.04A

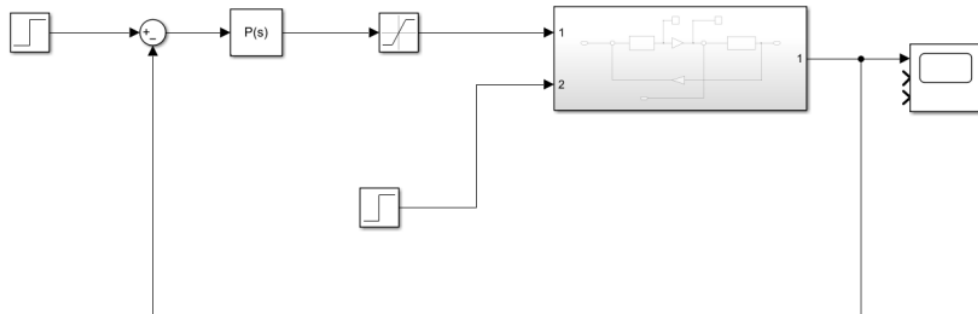
13.8

To conclude, the theoretical no load speed and simulated no load speed are about 1 rad out. They are not exactly the same and this is because friction has not been accounted for. The theoretical load speed and simulated load speed are about 8 rads out and this is down to friction. With a small disturbance of 0.3Nm applied, a decrease in speed and a slight increase in current was expected. The spikes at 1 second on all graphs is because of the startup currents and loads. There will be a dramatic increase in load and current upon startup of the motor.

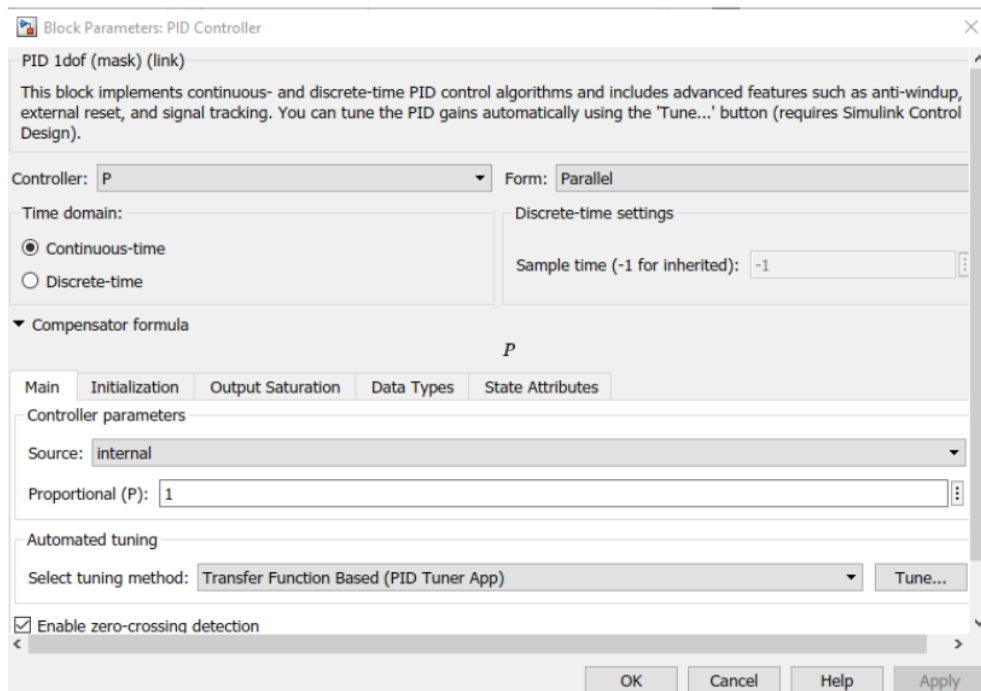
18

Task 14 – Proportional Speed Control System

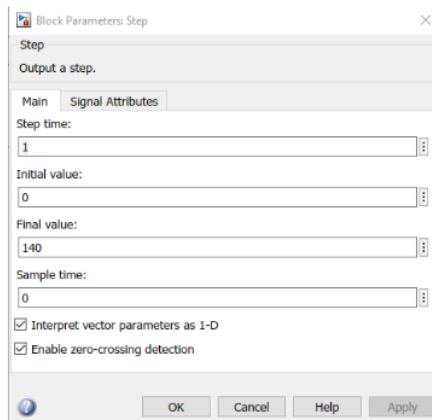
14.1



$K_P = 1$



Step speed set point of 140 rad's.



Block Parameters: Step

Step

Output a step.

Main Signal Attributes

Step time: 1

Initial value: 0

Final value: 140

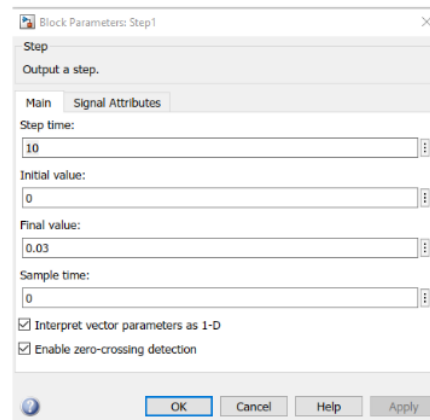
Sample time: 0

☒ Interpret vector parameters as 1-D

☒ Enable zero-crossing detection

OK Cancel Help Apply

Disturbance of 0.03Nm after 10s.



Block Parameters: Step1

Step

Output a step.

Main Signal Attributes

Step time: 10

Initial value: 0

Final value: 0.03

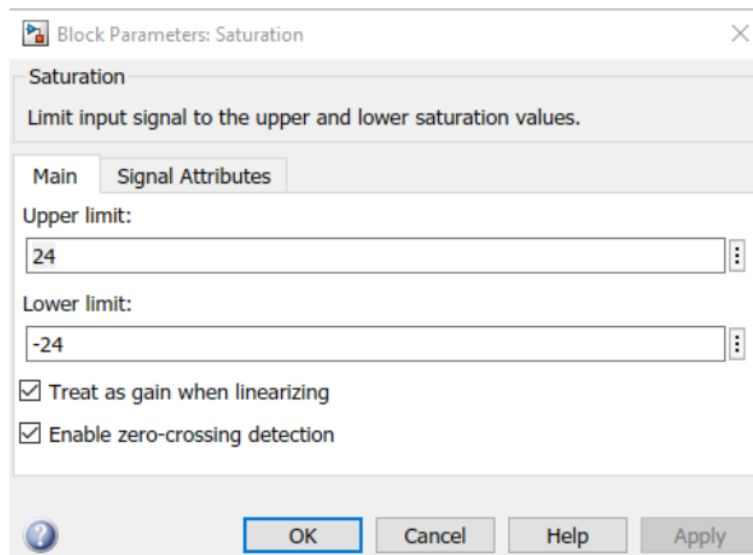
Sample time: 0

☒ Interpret vector parameters as 1-D

☒ Enable zero-crossing detection

OK Cancel Help Apply

Armature voltage is set to a maximum voltage of 24v.



Block Parameters: Saturation

Saturation

Limit input signal to the upper and lower saturation values.

Main Signal Attributes

Upper limit: 24

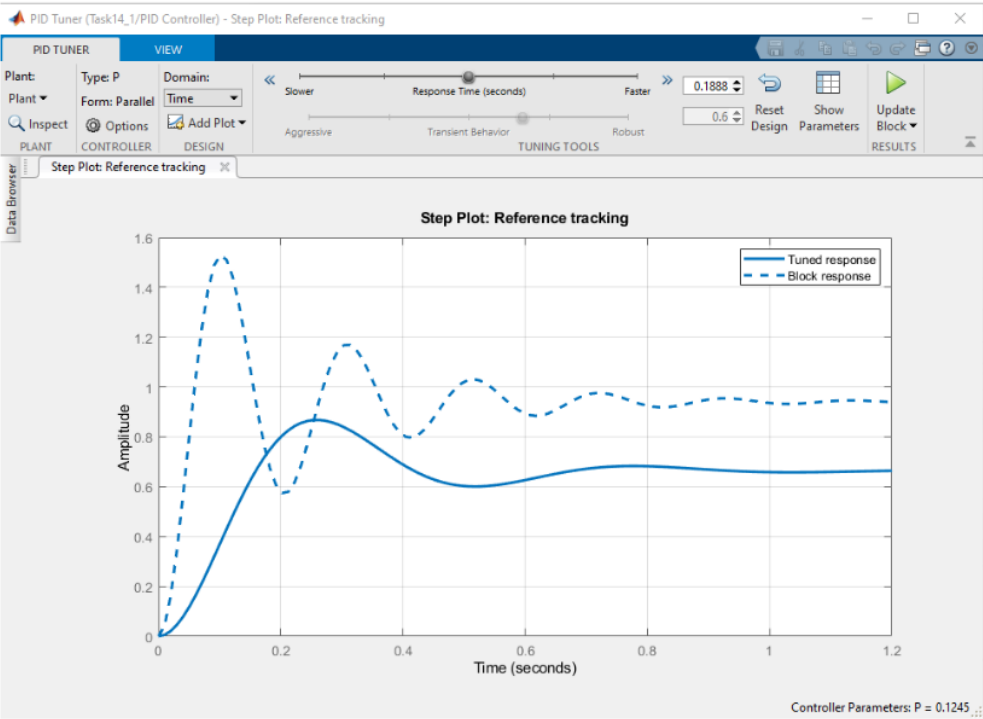
Lower limit: -24

☒ Treat as gain when linearizing

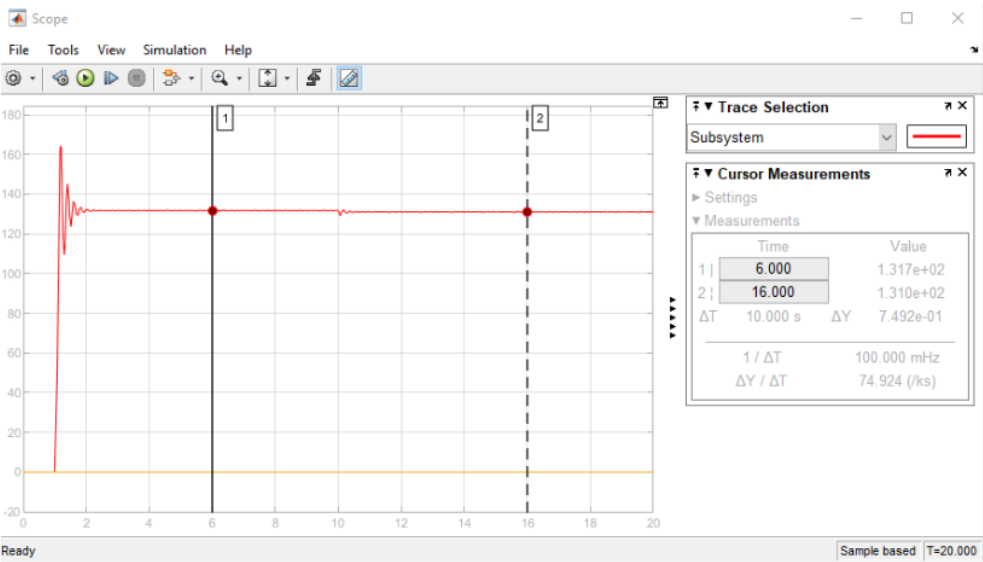
☒ Enable zero-crossing detection

OK Cancel Help Apply

Auto Tune:



Graphical Result:



Changing the KP to 0.192

Block Parameters: PID Controller

PID 1dof (mask) (link)

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

Controller: P

Form: Parallel

Time domain:
☒ Continuous-time
☐ Discrete-time

Discrete-time settings
Sample time (-1 for inherited): -1

▼ Compensator formula

P

Main

Initialization

Output Saturation

Data Types

State Attributes

Controller parameters

Source: internal

Proportional (P): 0.192

Automated tuning

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

Tune...

☒ Enable zero-crossing detection

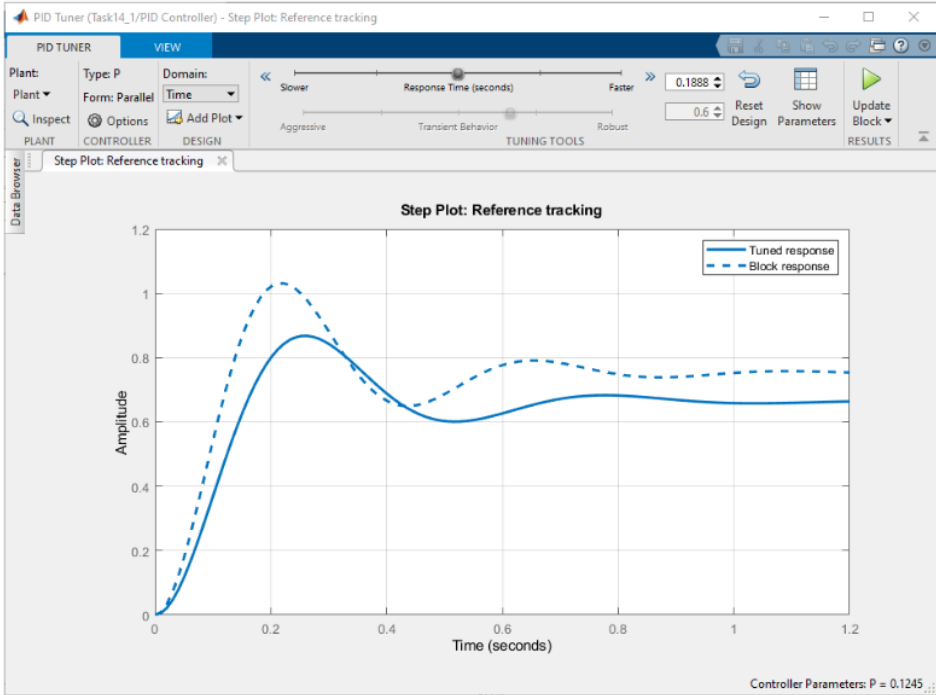
OK

Cancel

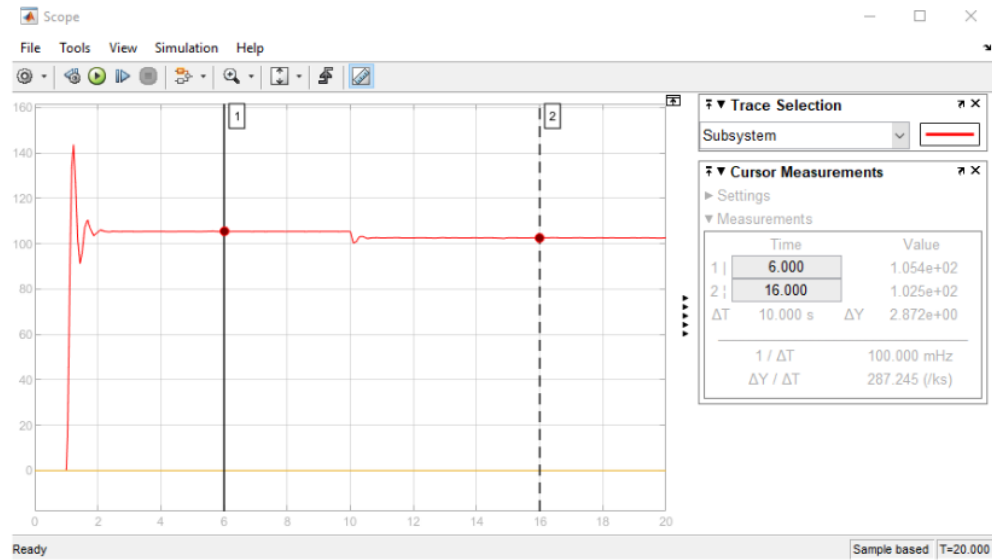
Help

Apply

Auto tune:



Graph response:



$K_p = 0.192$

SSE = $140 - 105 = 35$ rad's. With load, SSE = $140 - 102 = 38$ rad's.

$K_p = 1.2$

Block Parameters: PID Controller

PID 1dof (mask) (link)

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

Controller: **P** Form: **Parallel**

Time domain:
☒ Continuous-time
☐ Discrete-time

Discrete-time settings
Sample time (-1 for inherited): **-1**

▼ Compensator formula

P

Main Initialization Output Saturation Data Types State Attributes

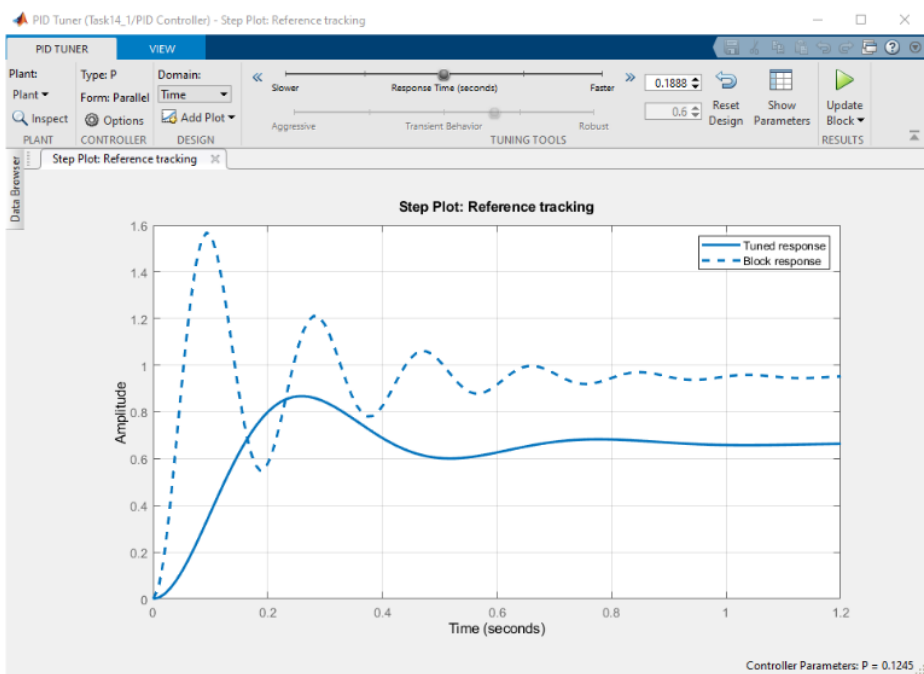
Controller parameters
Source: **internal**
Proportional (P): **1.2**

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

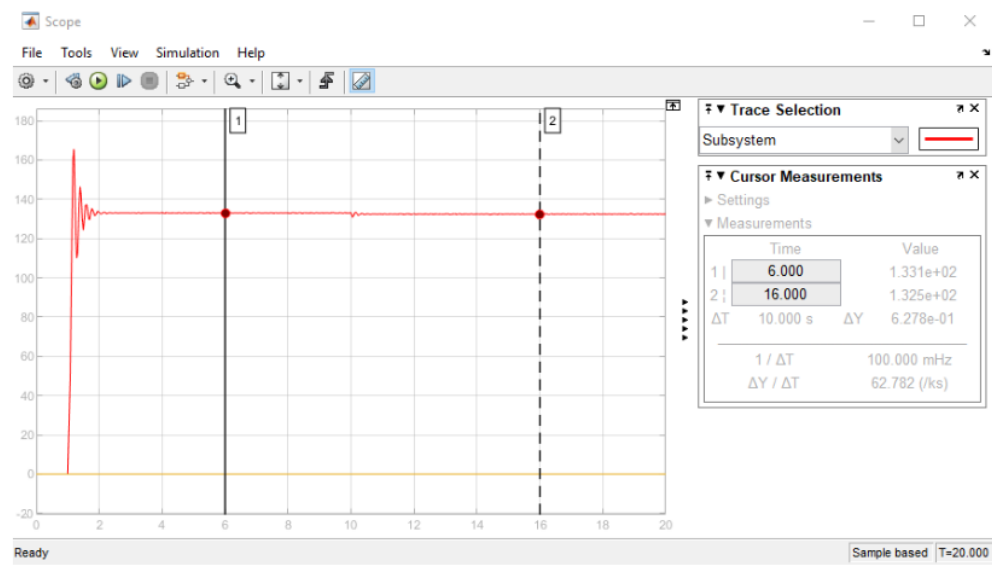
☒ Enable zero-crossing detection

OK Cancel Help Apply

Auto tune:



Graphical Result:

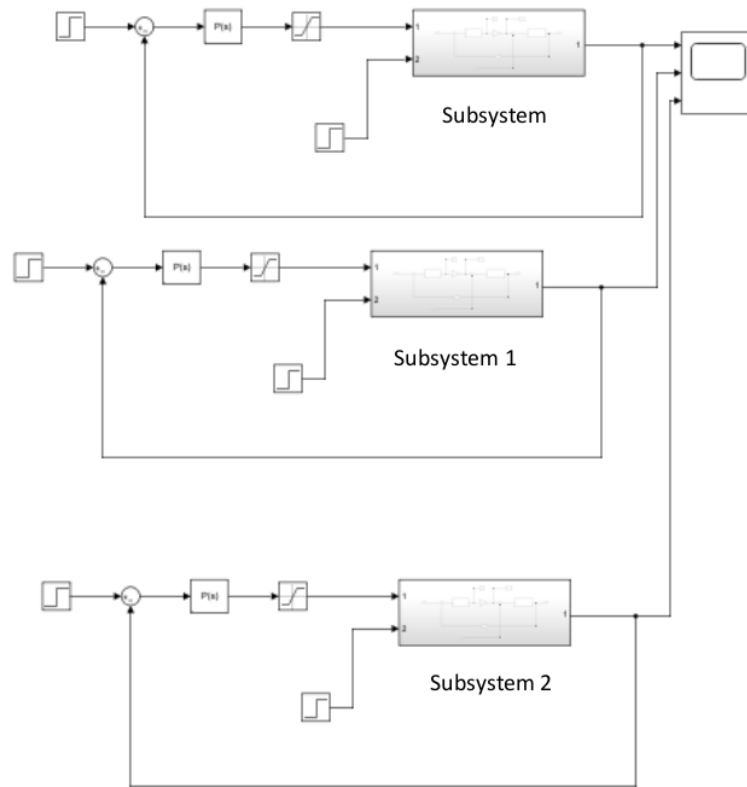


$K_p = 1.2$

SSE $140 - 133 = 7$ rad's. With load SSE = $140 - 132 = 8$ rad's.

It is clear that as the K_p or gain value is increased the steady state error decreases.

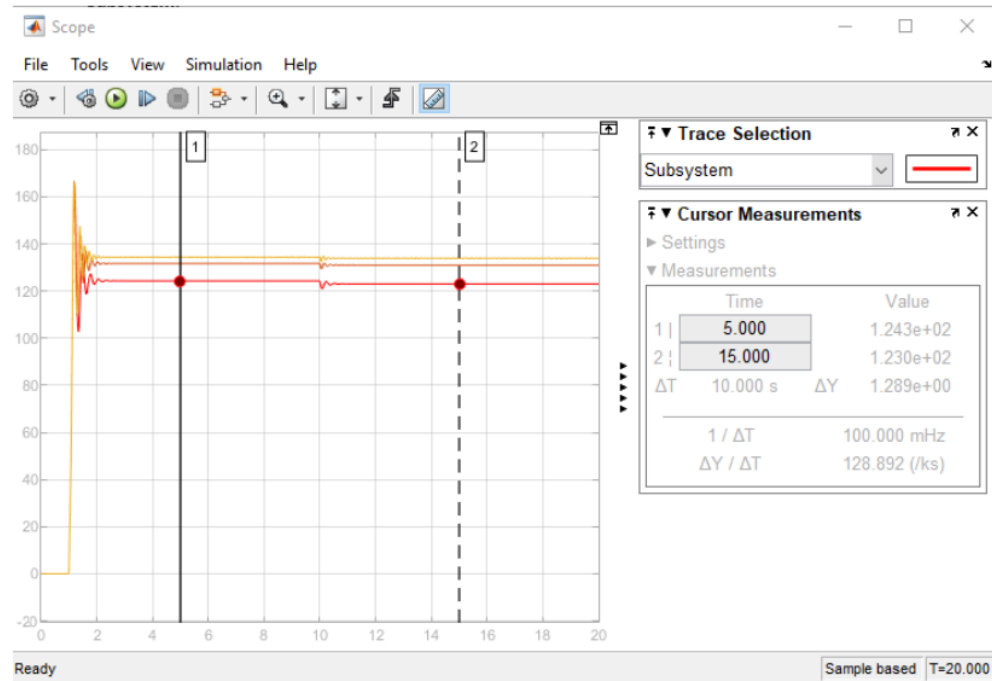
14.2



Subsystem:

$K_p = 0.5$

Steady state error:

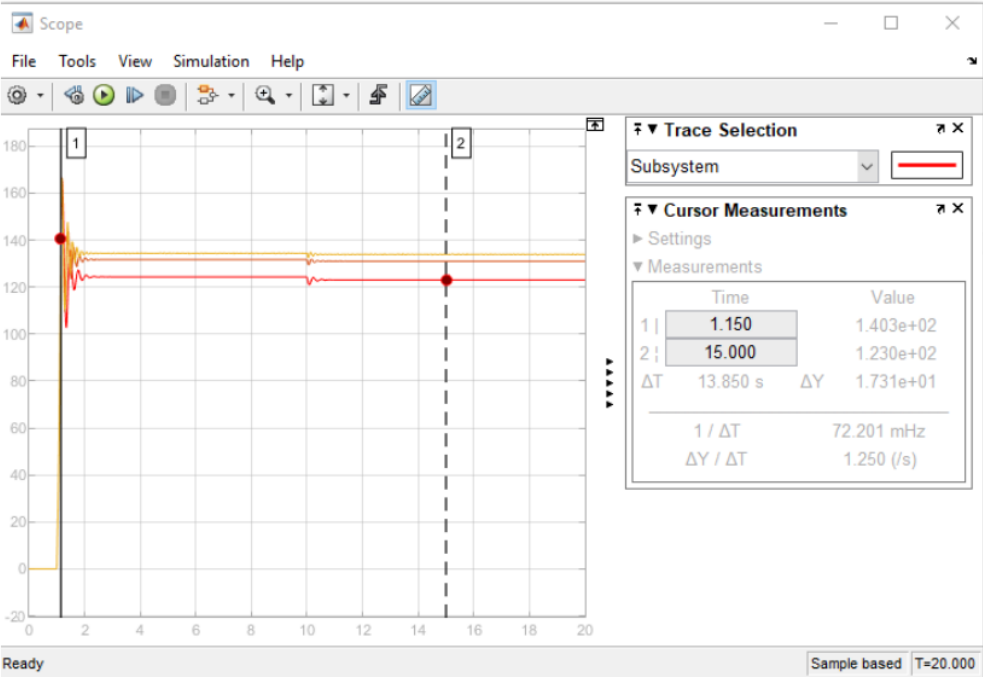


SSE: $140 - 124 \text{ rad/s} = 16 \text{ rad's}$

SSE under load: $140 - 123 \text{ rad/s} = 17 \text{ rad's}$

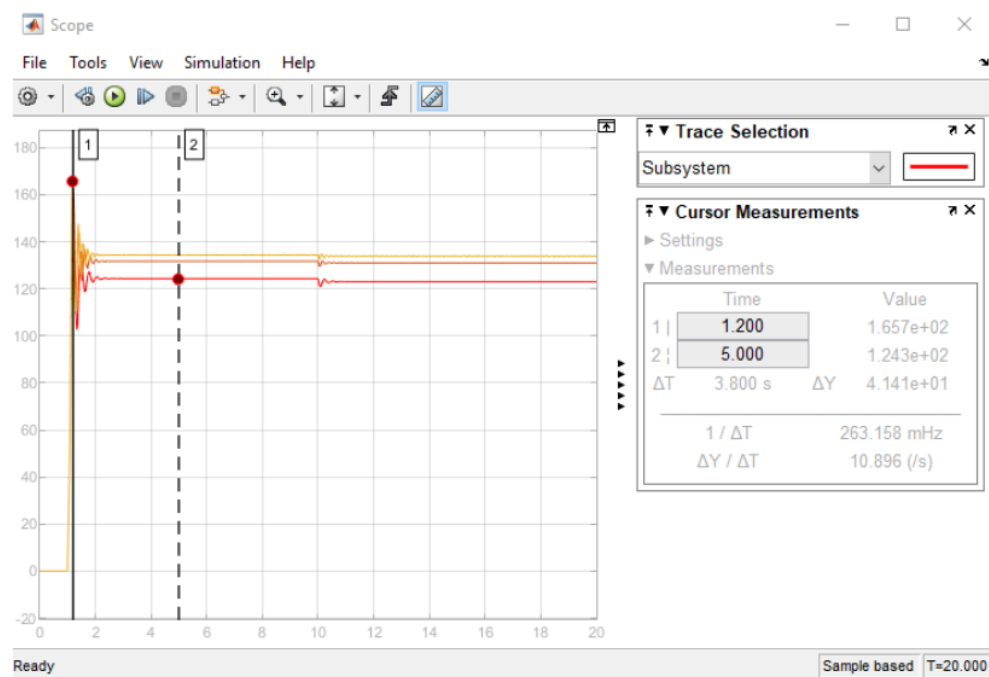
19

Rise time:



Rise time: 1.150 seconds at 140 rad/s

Overshoot:

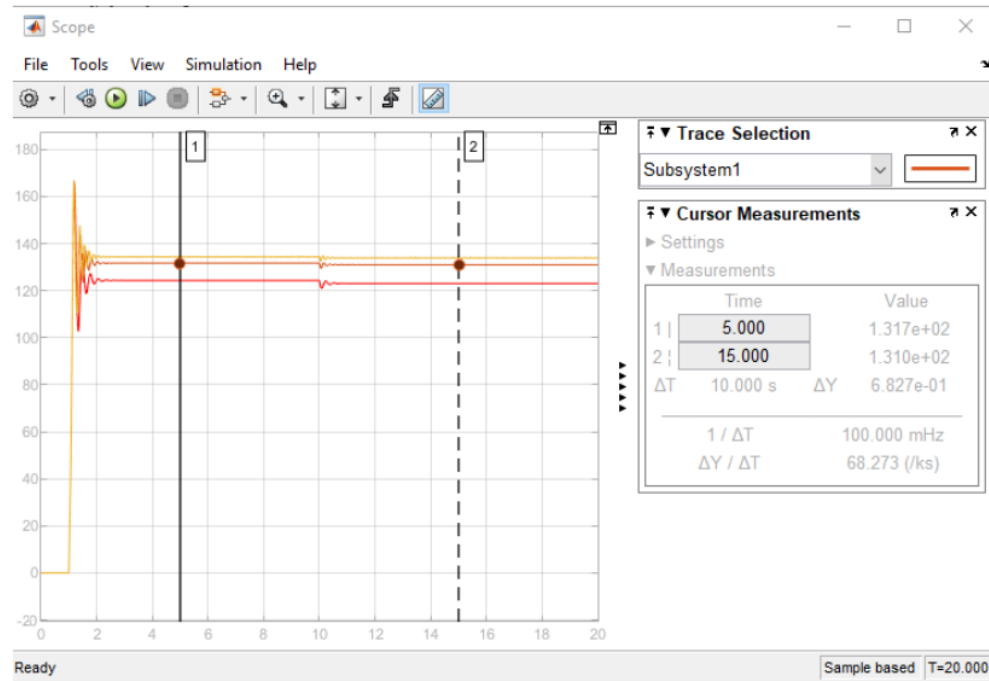


$$\text{Overshoot: } \frac{165.7 - 140}{140} \times 100 = 18\%$$

Subsystem 1:

$K_p = 1$

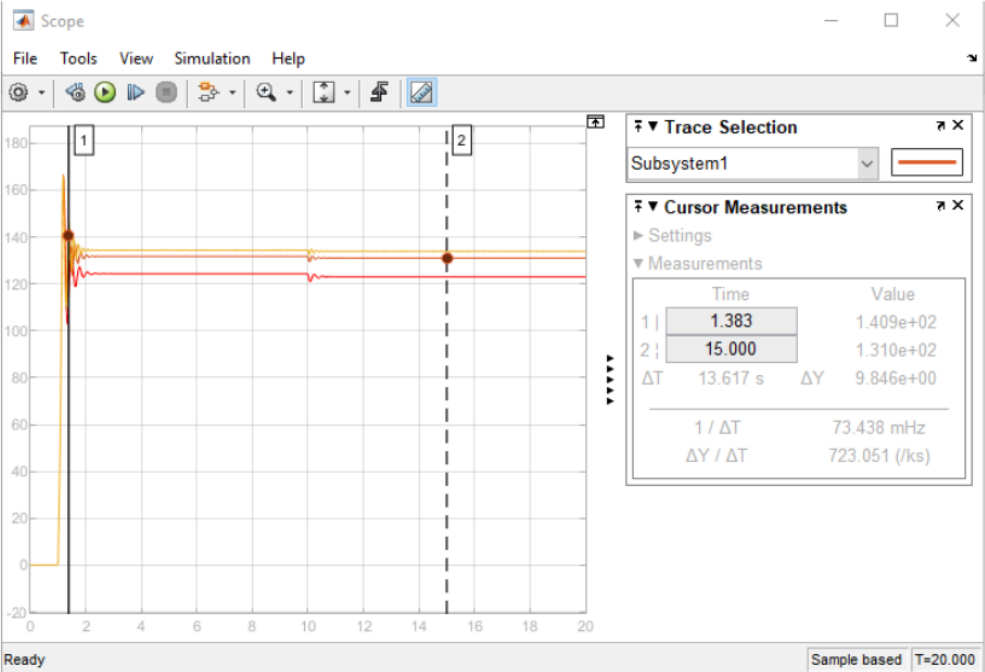
Steady state error:



SSE: $140 - 131 = 9 \text{ rad/s}$

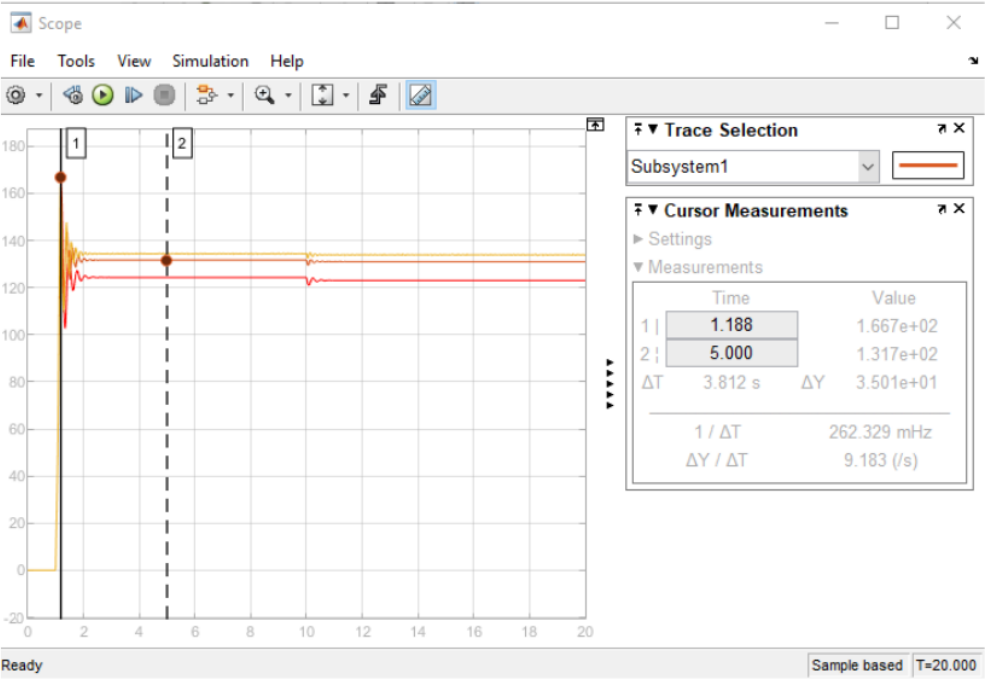
SSE under load: $140 - 131 = 9 \text{ rad/s}$

Rise time:



Rise time: 1.383 seconds at 140 rad/s.

Overshoot:

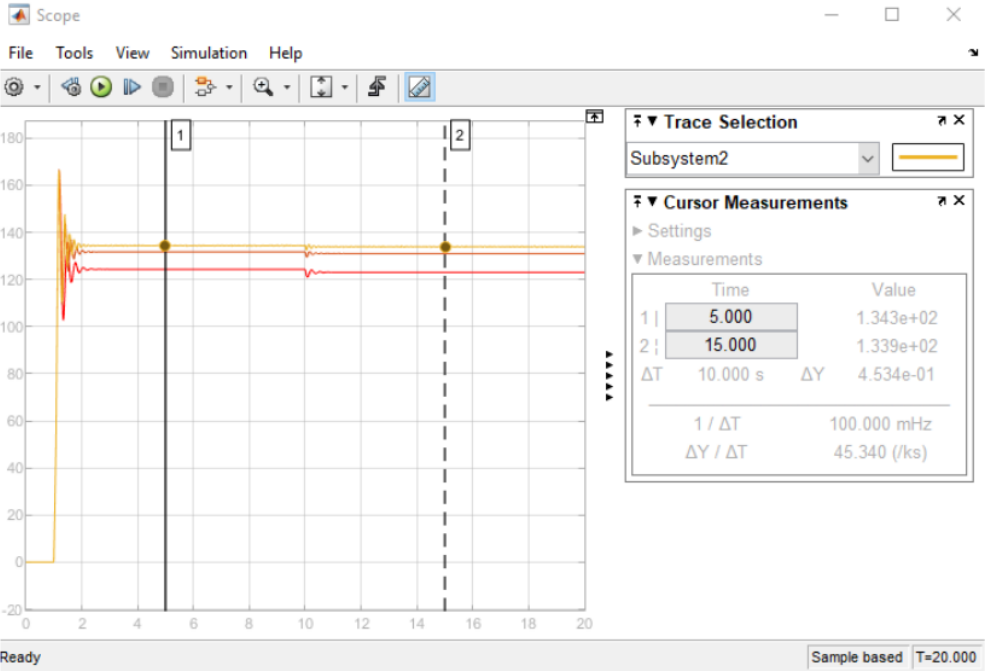


Overshoot: $\frac{166.7-140}{140} \times 100 = 19\%$

Subsystem 2:

$K_p = 1.5$

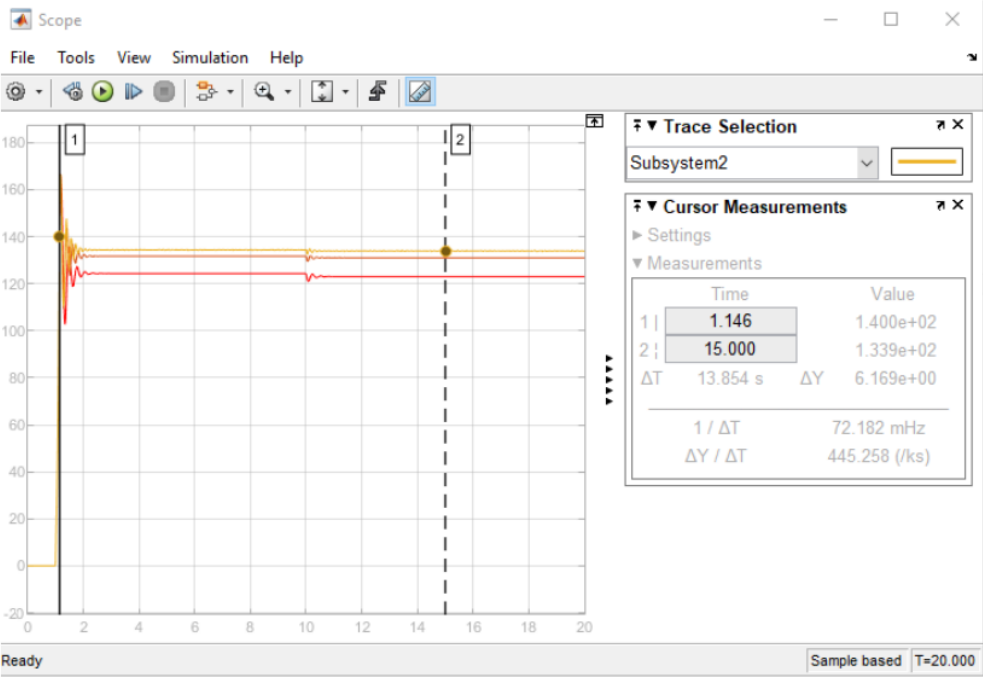
Steady state error:



SSE: $140 - 134 = 6 \text{ rad/s}$

SSE under load: $140 - 133 \text{ rad/s} = 7 \text{ rad/s}$

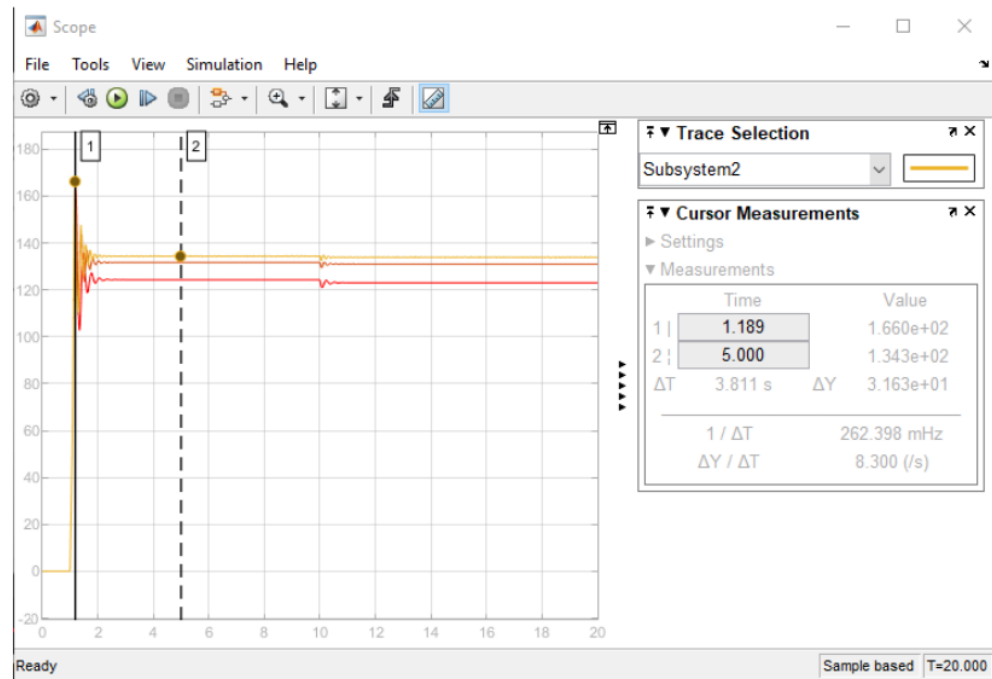
Rise time:



Rise time: 1.146 seconds at 140 rad/s.

20

Overshoot:



Overshoot: $\frac{166-140}{140} \times 100 = 18.5\%$

14.3

When increasing the value of K_p the steady state error decreased. The rise time decreased, however there was a slight rise in the time for the optimum value of the constant K_p at 1. The overshoot increased, however there was a slight decrease in subsystem 2, but not by much. By decreasing the value of K_p , there would be the opposite effect.

14.4

Table of Results for proportional control (P)					
	K_p	SSE (rad's)	SSE Under Load 0.3Nm	Rise Time (s) at 140 rad's	Overshoot
Subsystem	0.5	16	17	1.150	18%
Subsystem 1	1	9	9	1.383	19%
Subsystem 2	1.5	6	7	1.146	18.5%

21

For proportional (P) control, the rise time should decrease, there should be a small change in the settling times, the overshoot should increase and the steady state error should decrease. The simulation results are close to that, but not exactly. It is unusual that there is a slight decrease in the overshoot at 1.5 K_p and a slight increase in rise time at 1 K_p , this was not expected and does not match the theoretical results.

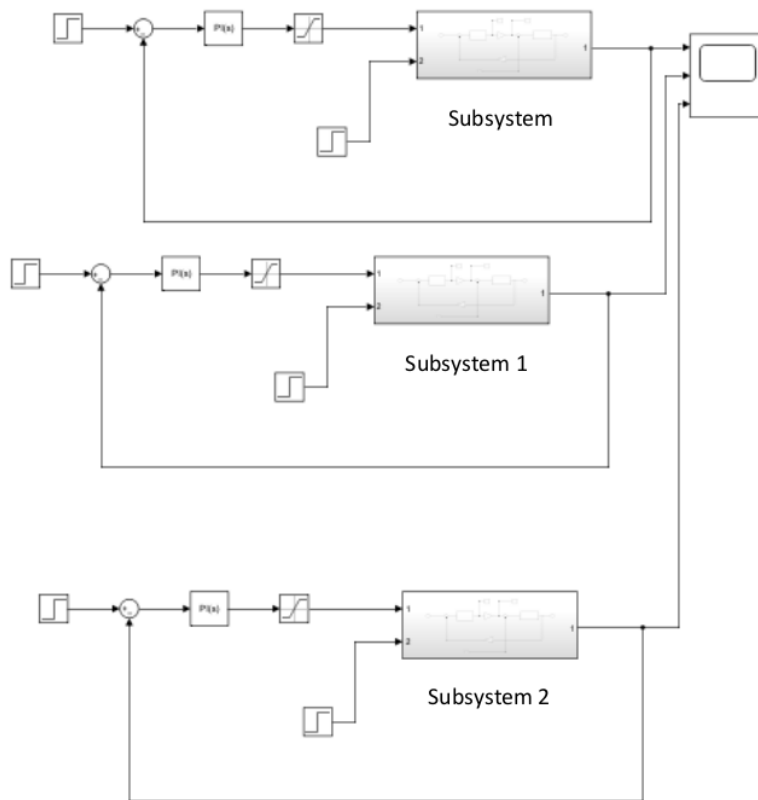
14.5

The circuits produced the results above and it is clear what effects are occurring as the K_p is increased and decreased. With P only there would have to be a high gain in order to dramatically reduce the SSE. However, it is not possible to eliminate the steady state error with proportional control only. Increasing the proportional gain decreased the steady state offset, (Bolton, 2015). In order to fine tune the circuits and eliminate the SSE, integral control will need to be added. There is not much change in the settling time due to a small disturbance of 0.03Nm.

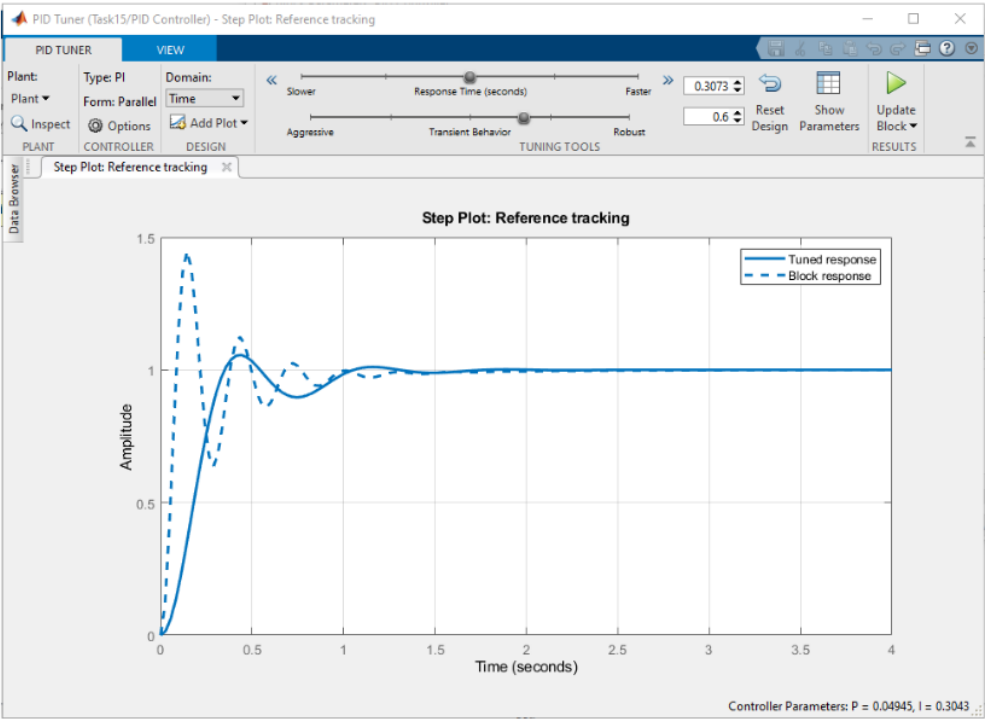
Well done

Task 15 – Proportional – Integral Speed Control System

15.1



Auto tune:



15.2

Subsystem:

Block Parameters: PID Controller

PID 1dof (mask) (link)

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

Controller:

PI

Form:

Parallel

Time domain:

☒ Continuous-time

☐ Discrete-time

Discrete-time settings

Sample time (-1 for inherited):

-1

Compensator formula

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

Main

Initialization

Output Saturation

Data Types

State Attributes

Controller parameters

Source:

internal

Proportional (P):

0.5

Integral (I):

0.2

Automated tuning

OK

Cancel

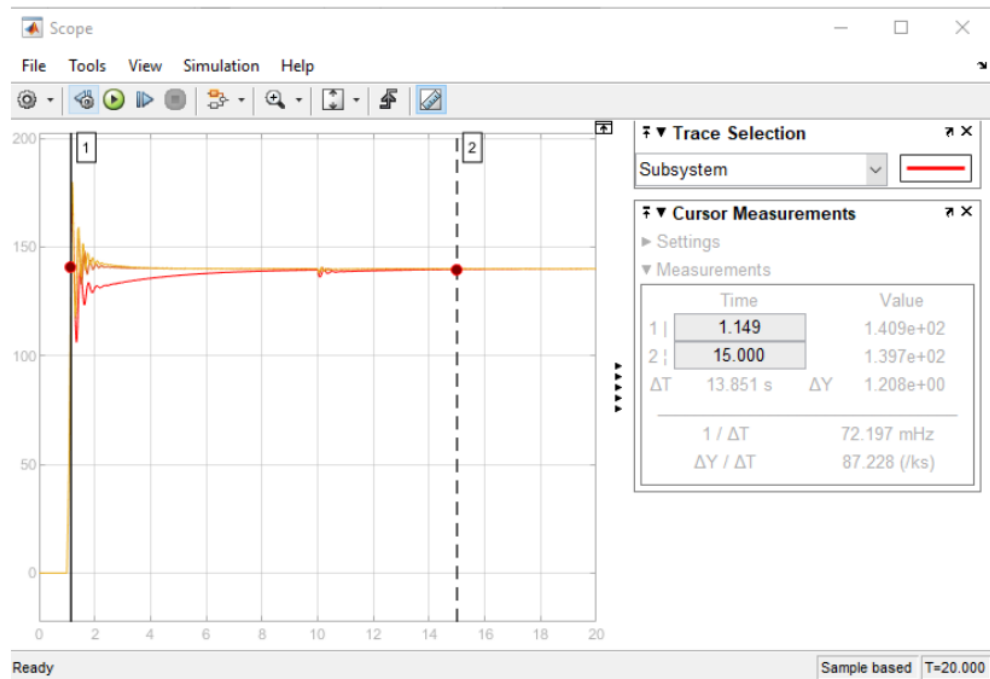
Help

Apply

$K_p = 0.5$

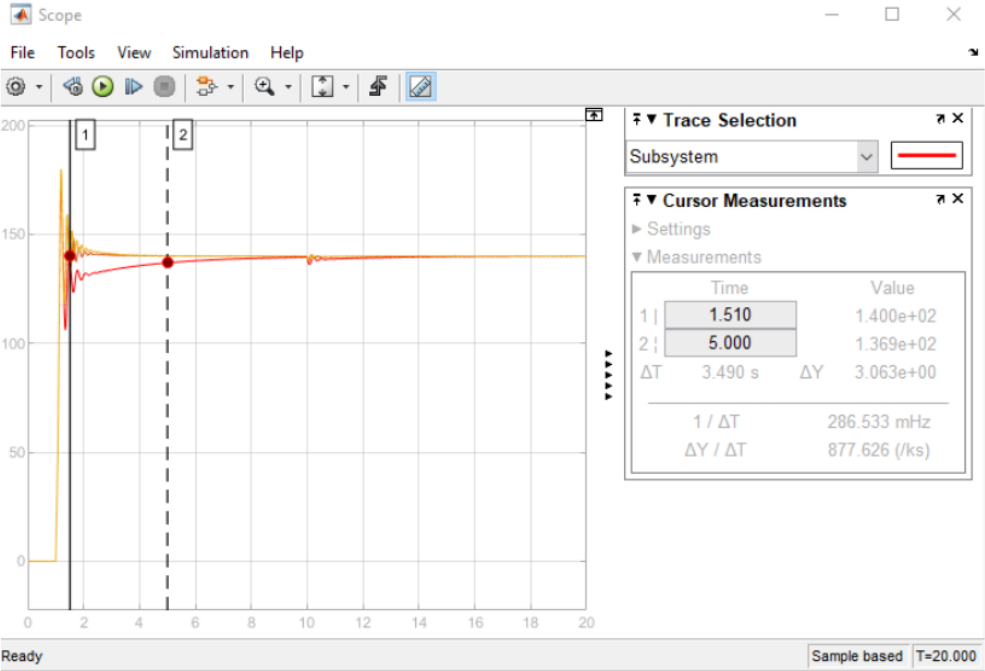
$K_i = 0.2$

Rise time:



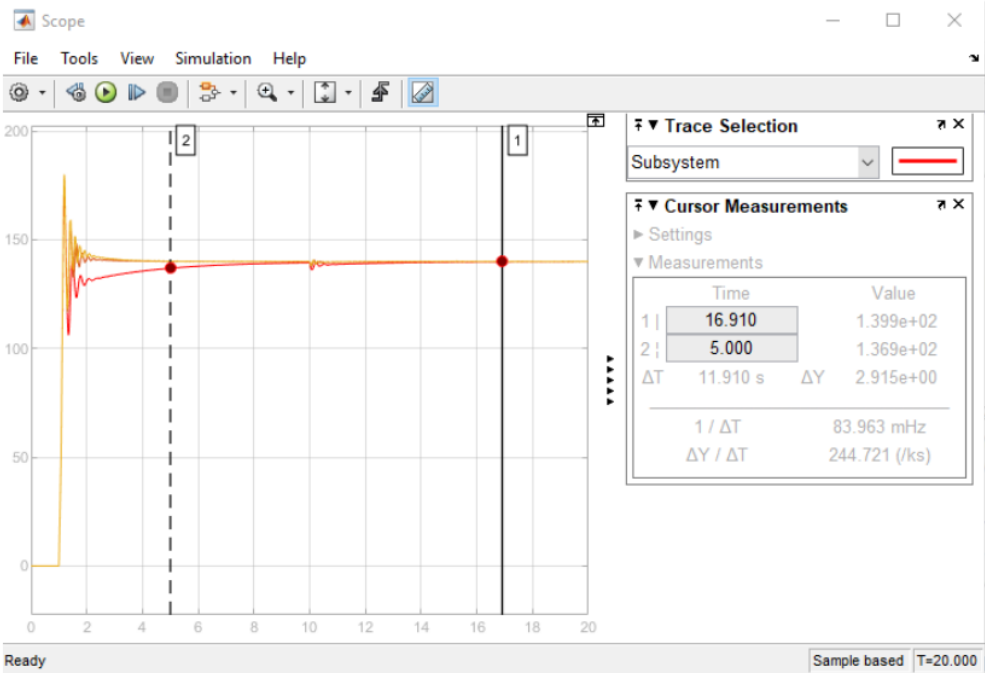
Rise time: 1.149 seconds at 140.9 rad's.

Overshoot percentage:



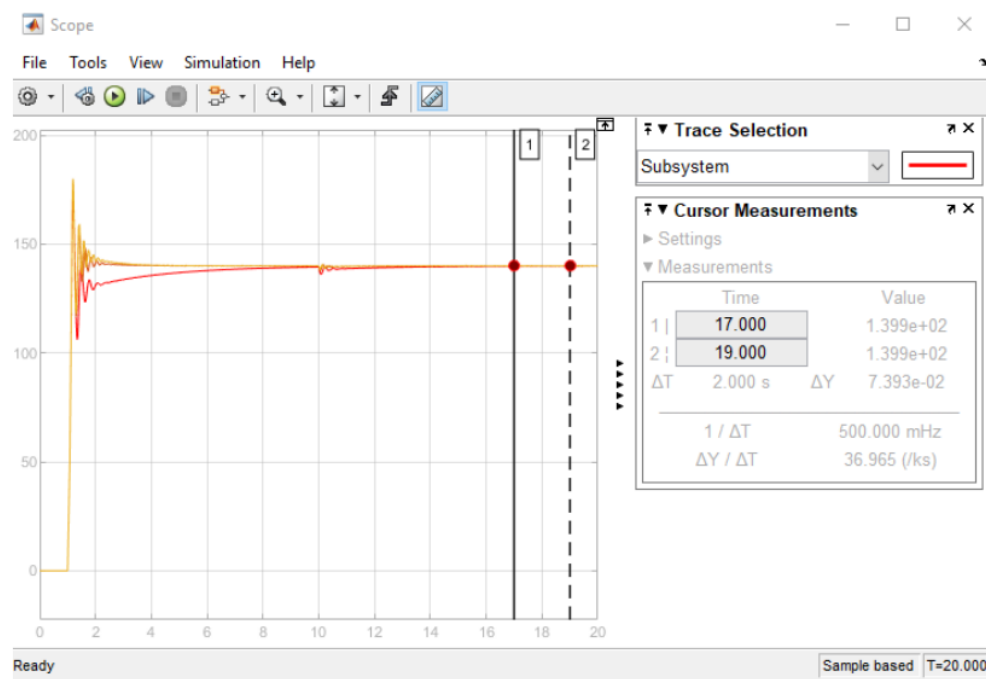
Overshoot: $\frac{140-140}{140} \times 100 = 0\%$

Settling time:



Settling time: 139.9 rad's at 16.910 seconds.

Steady state error:



Steady state error: $140 - 139.9 = 0.1 \text{ rad's}$.

Subsystem 1:

Block Parameters: PID Controller1

PID 1dof (mask) (link)

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

Controller: PI

Form: Parallel

Time domain:

Continuous-time

Discrete-time

Discrete-time settings

Sample time (-1 for inherited): -1

Compensator formula

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

Main

Initialization

Output Saturation

Data Types

State Attributes

Controller parameters

Source: internal

Proportional (P): 1

Integral (I): 1

Automated tuning

OK

Cancel

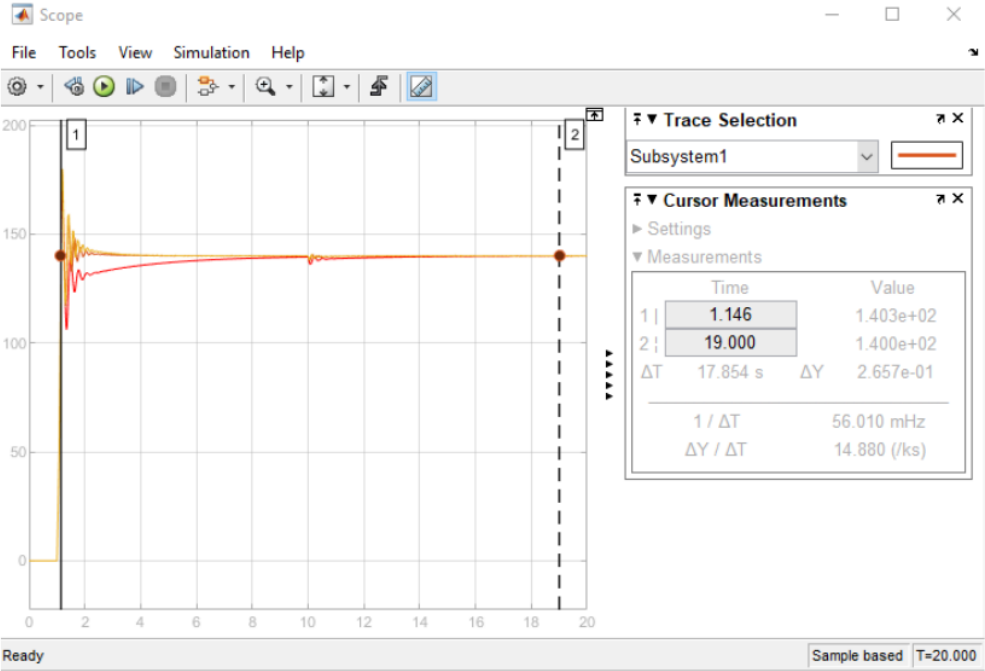
Help

Apply

Kp = 1

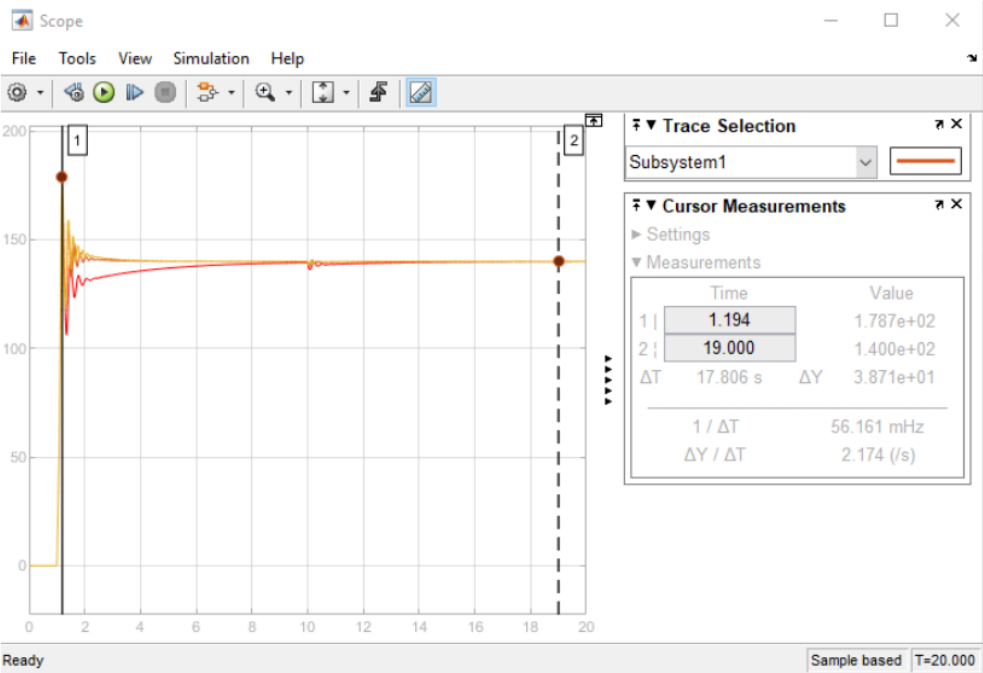
Ki = 1

Rise time:



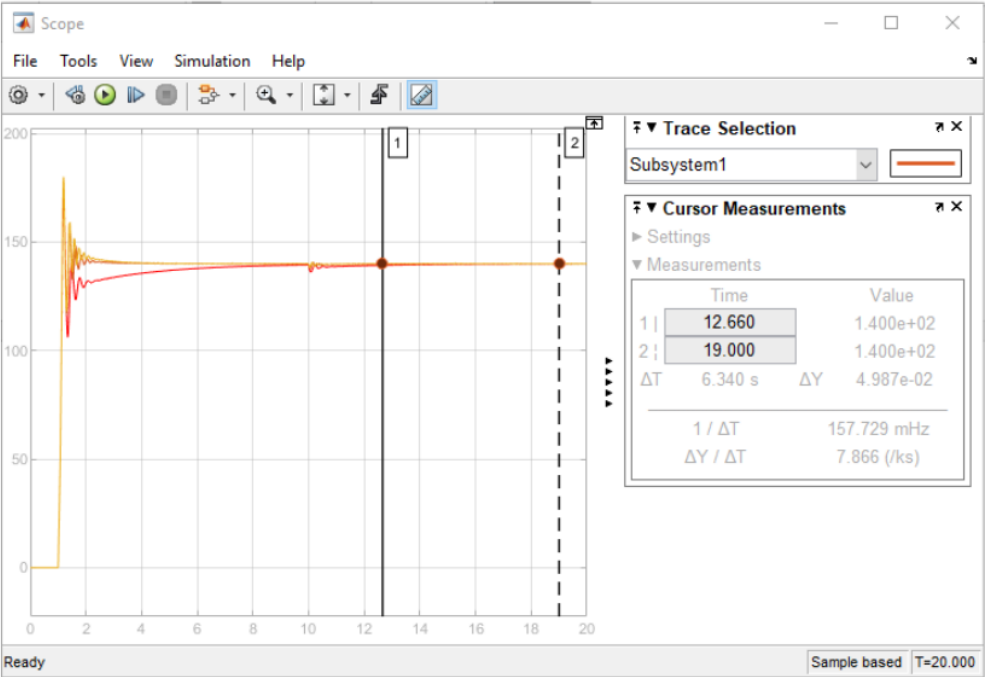
Rise time: 140.3 rad's at 1.146 seconds.

Overshoot percentage:



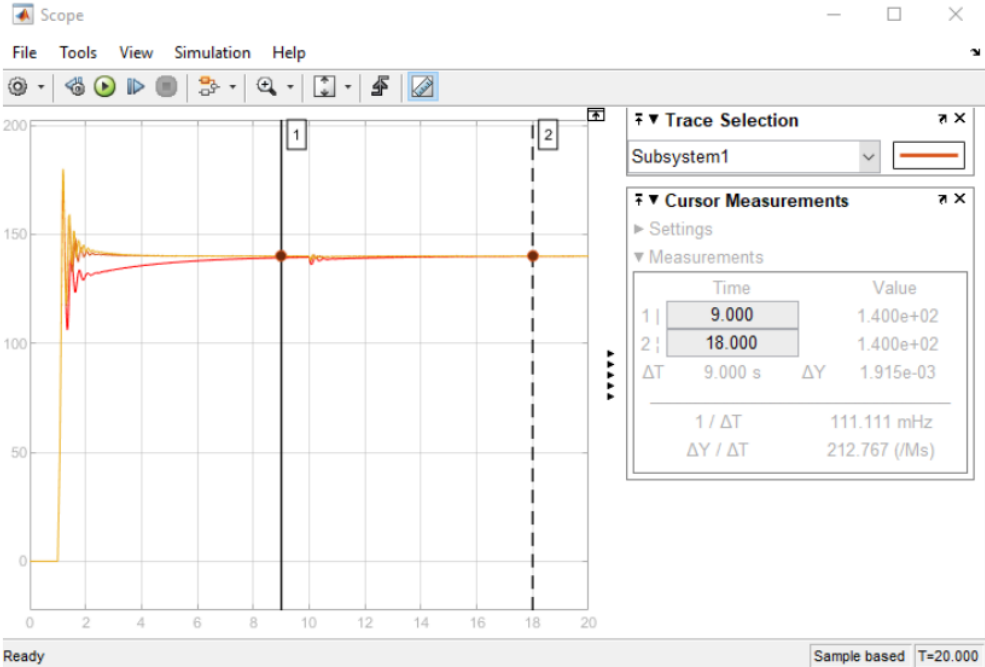
Overshoot: $\frac{178.7-140}{140} \times 100 = 27\%$

Settling time:



Settling time: 140 rad's at 12.660 seconds.

Steady state error:



Steady state error: $140 \text{ rad's} - 140 \text{ rad's} = 0 \text{ rad's}$

Subsystem 2:

Block Parameters: PID Controller2

PID 1dof (mask) (link)

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

Controller: **PI** Form: **Parallel**

Time domain:

☒ Continuous-time

☐ Discrete-time

Discrete-time settings

Sample time (-1 for inherited): **-1**

▼ Compensator formula

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

Main Initialization Output Saturation Data Types State Attributes

Controller parameters

Source: **Internal**

Proportional (P): **1.5**

Integral (I): **1.7**

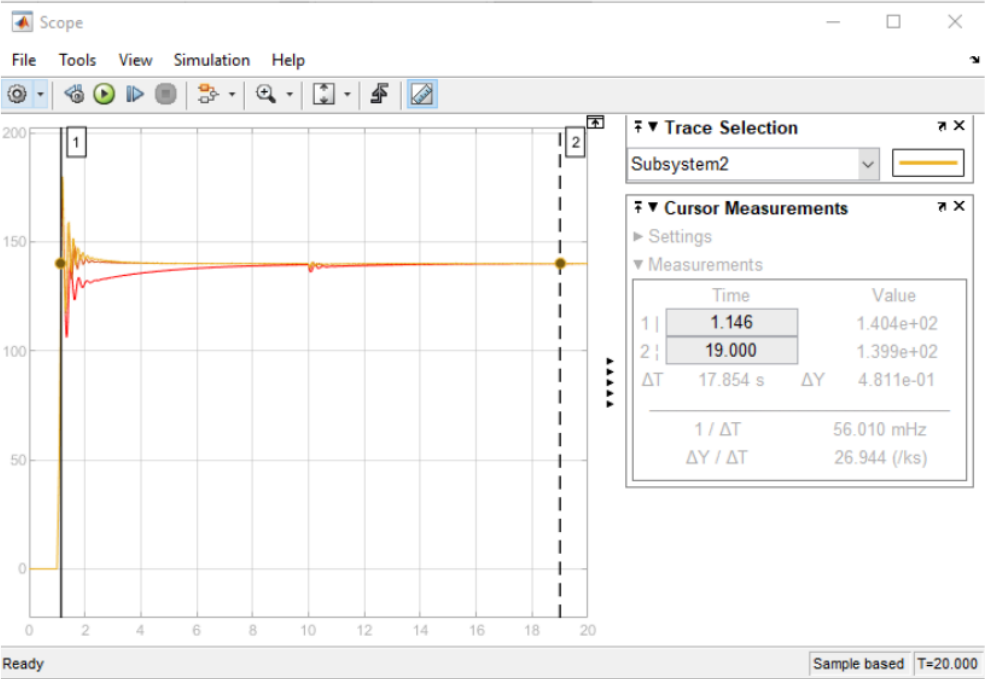
Automated tuning

OK Cancel Help Apply

Kp = 1.5

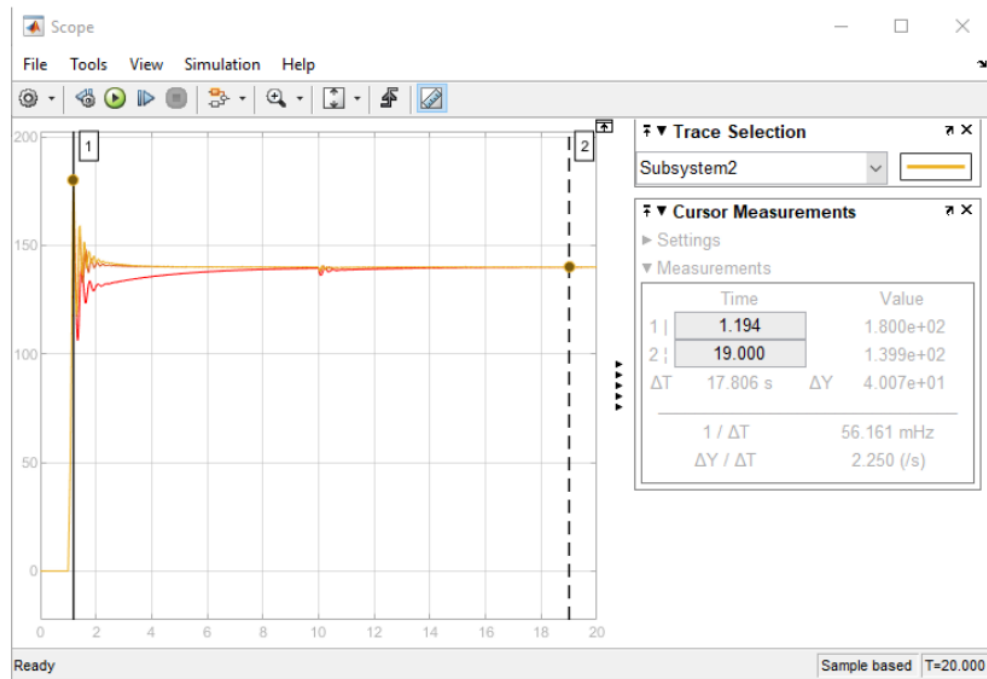
Ki = 1.7

Rise time:



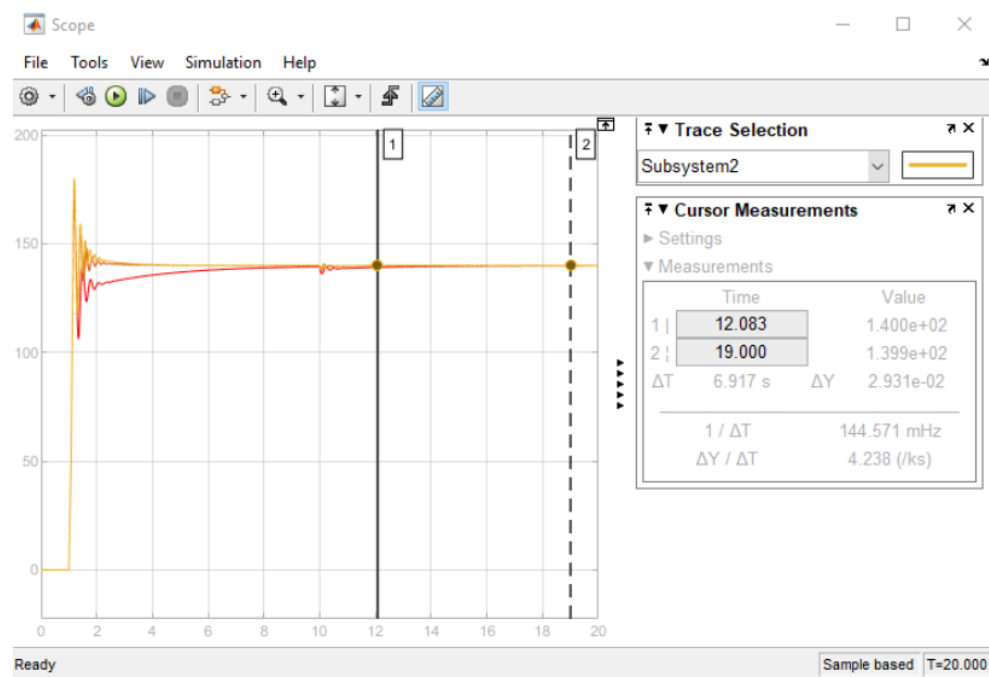
Rise time: 140.4 rad's at 1.146 seconds.

Overshoot percentage:



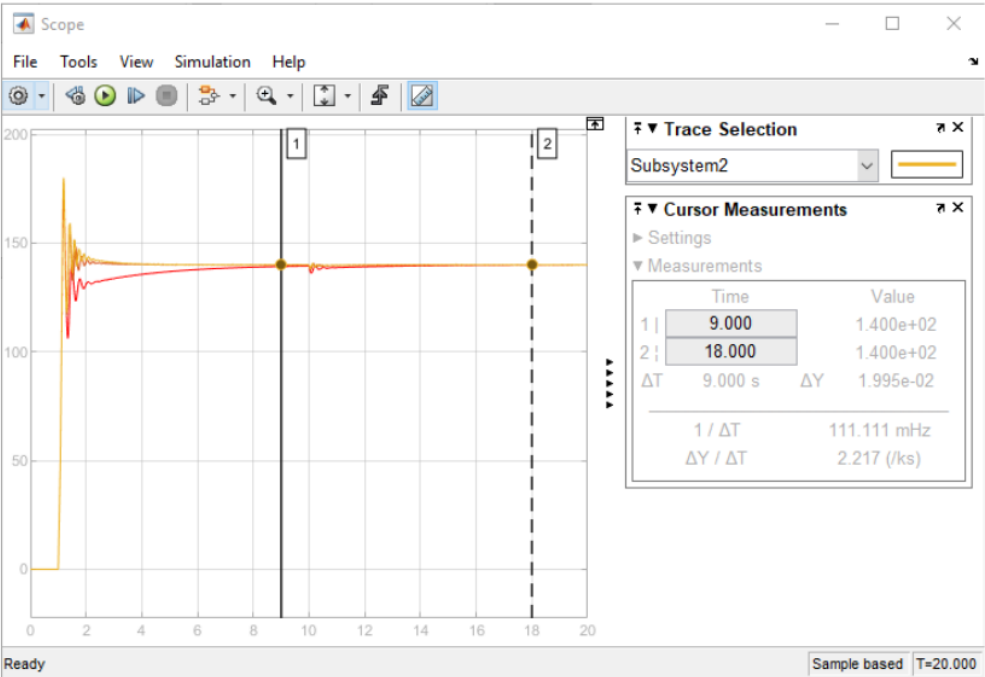
$$\text{Overshoot: } \frac{180-140}{140} \times 100 = 28.5\%$$

Settling time:



Settling time: 140 rad's at 12.083 seconds.

Steady state error:



Steady state error: $140 - 140 = 0 \text{ rad's}$.

15.3

Table of Results for Proportional - Integral control (PI)						
	Kp	Ki	Rise Time (s) at 140 rad's	Overshoot Percentage	Settling Time (s) at 140 rad's	Steady state error (rad's)
	 22					
Subsystem	0.5	0.2	1.149	0%	16.910	0.1
Subsystem 1	1	1	1.146	27%	12.660	0
Subsystem 2	1.5	1.7	1.146	28.5%	12.083	0

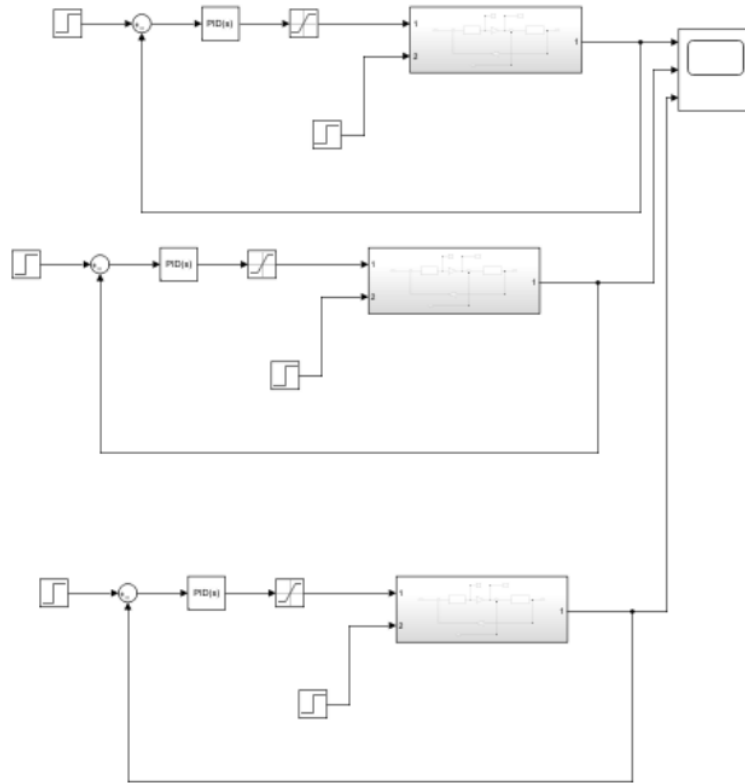
Theoretical results:

Theoretical results				
	Tr	Ts	OS	SSE
I	Decrease	Increase	Increase	Eliminate

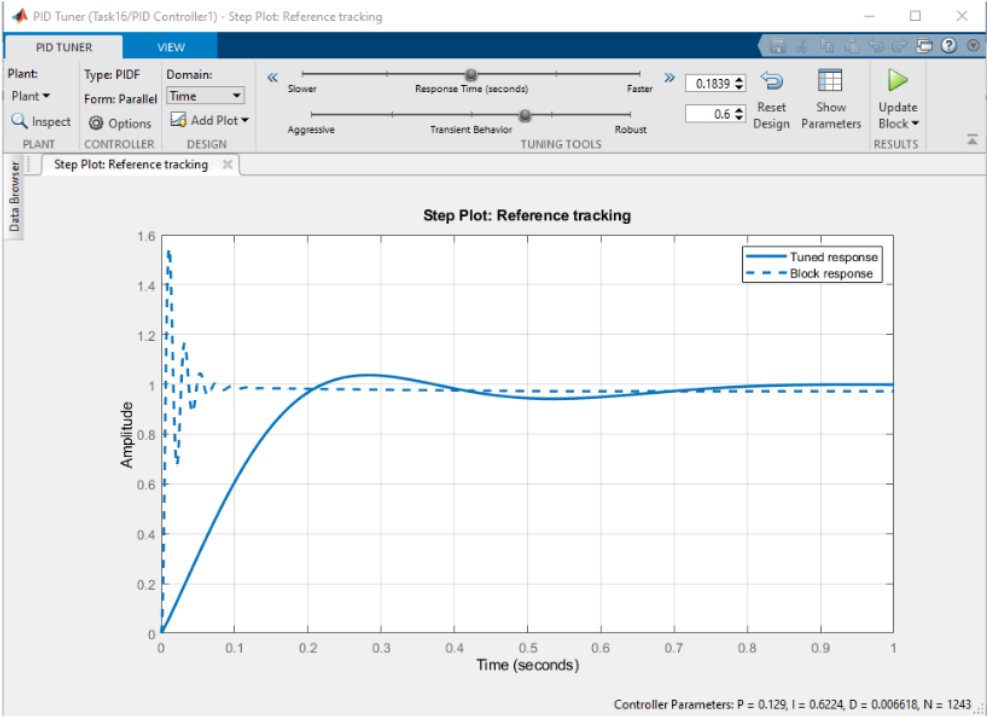
When proportional plus integral control is used, the output response to an error gives rise to a slightly higher initial deviation in the output signal compared with that which would be obtained with proportional control only, (Peter F. Stanbury, 2016). From the results it is clear that the rise time has decreased, the overshoot has increased, the settling time has decreased and the steady state error has been eliminated as the Ki value is increased. It will have the opposite effect if the Ki value was decreased. All of which bar the settling time was in accordance with the theoretical results. The integral component sums the error over time. Even a small error term will cause the integral component to increase slowly. The integral response will continually increase over time unless the error is zero, so the effect is to drive the steady state error to zero, (NI, 2020).

Task 16 – Proportional – Integral – Derivative Speed Control System

16.1

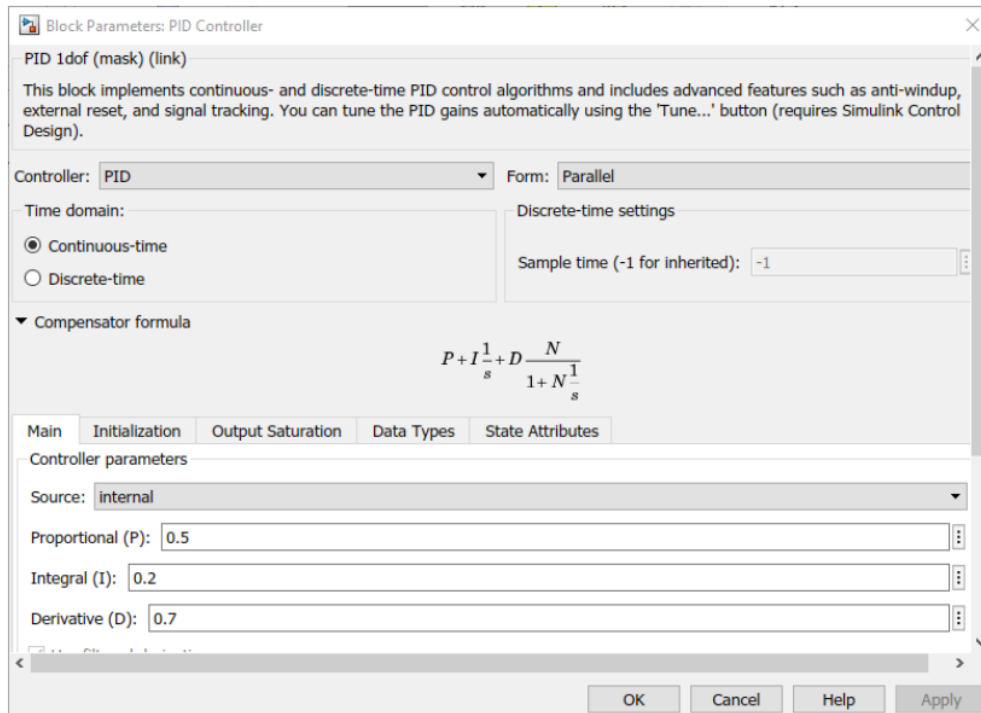


Auto Tune:



16.2

Subsystem:



Block Parameters: PID Controller

PID 1dof (mask) (link)

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

Controller: PID Form: Parallel

Time domain:

☒ Continuous-time

☐ Discrete-time

Discrete-time settings

Sample time (-1 for inherited): -1

Compensator formula

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

Main Initialization Output Saturation Data Types State Attributes

Controller parameters

Source: internal

Proportional (P): 0.5

Integral (I): 0.2

Derivative (D): 0.7

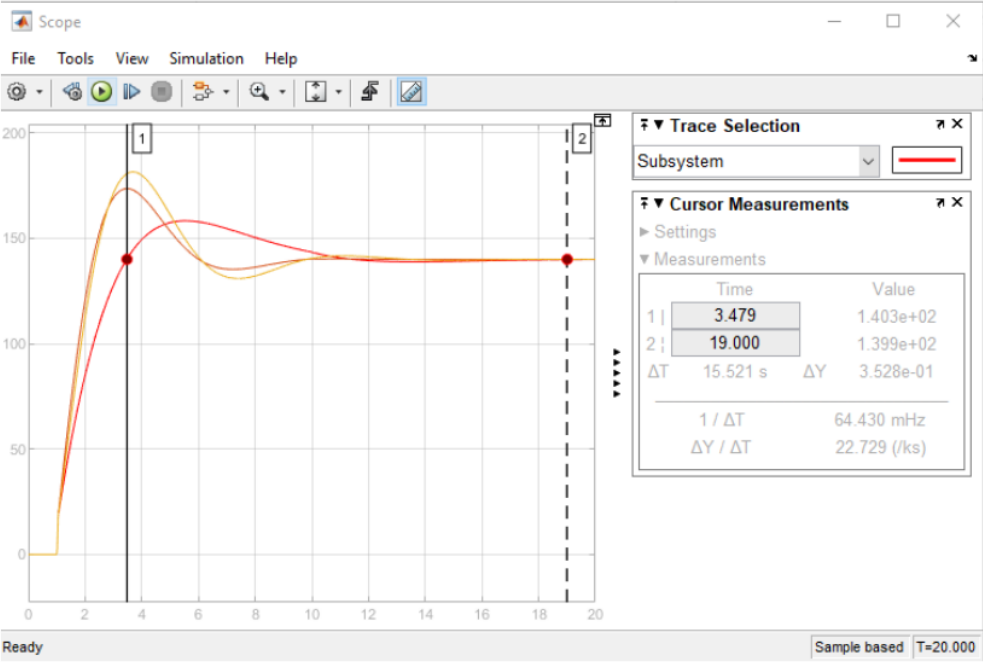
OK Cancel Help Apply

Kp = 0.5

Ki = 0.2

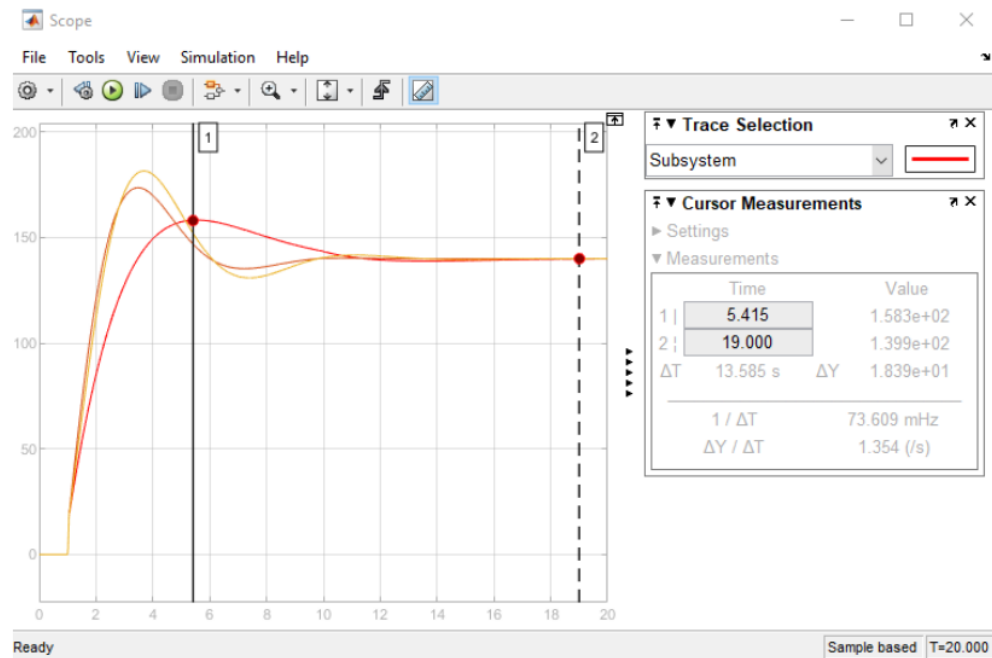
Kd = 0.7

Rise time:



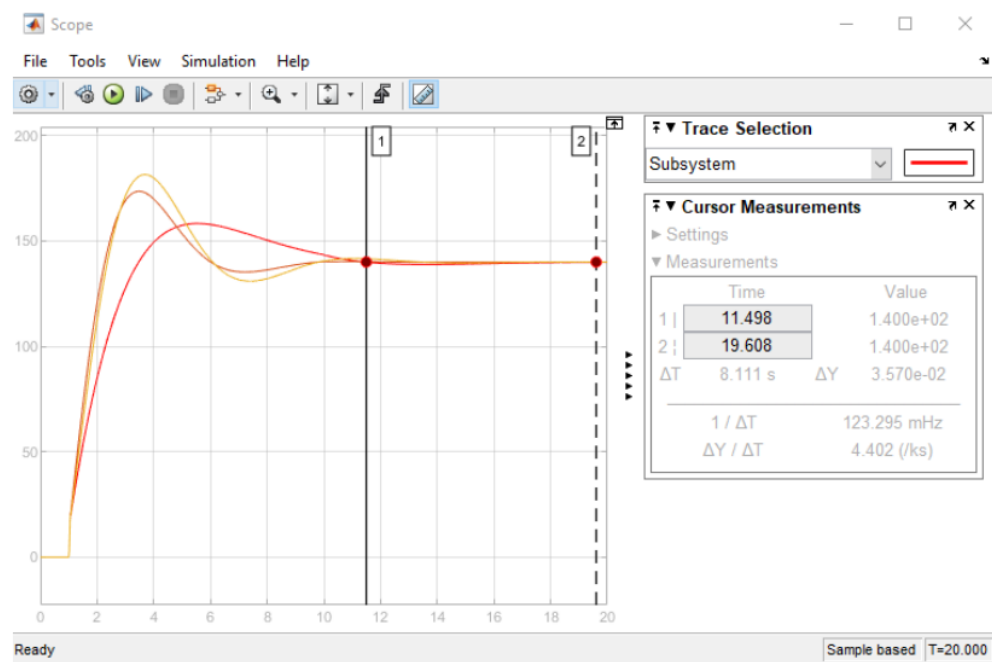
Rise time: 140 rad's at 3.479 seconds.

Overshoot percentage:



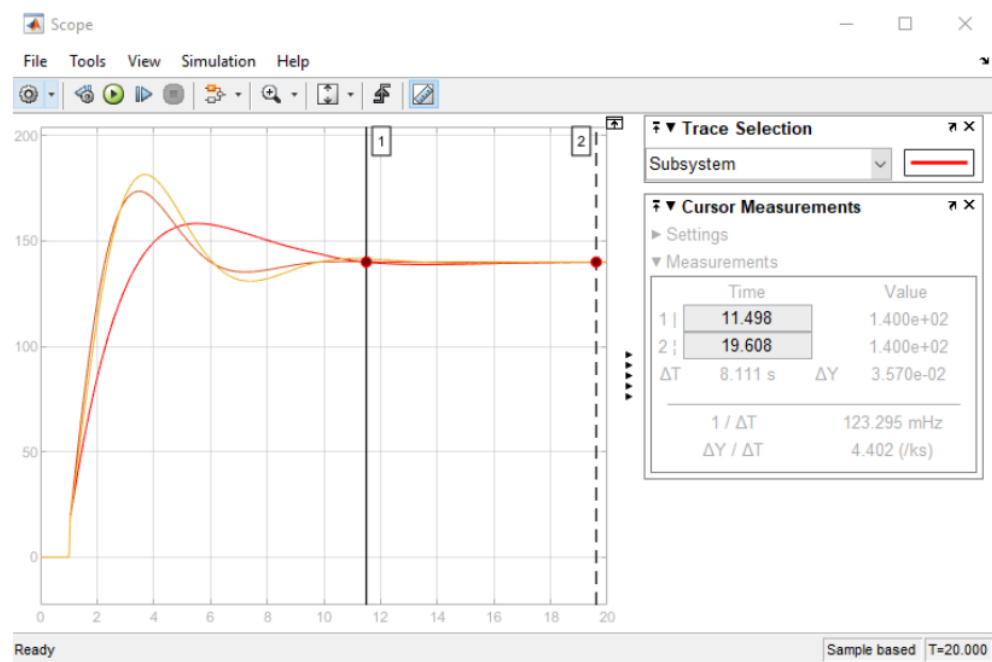
$$\text{Overshoot: } \frac{158.3 - 140}{140} \times 100 = 13\%$$

Settling time:



Settling time: 140 rad's at 11.498 seconds.

Steady state error:



Steady state error: $140 - 140 = 0 \text{ rad's}$

Subsystem 1:

Block Parameters: PID Controller1

PID 1dof (mask) (link)

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

Controller: PID Form: Parallel

Time domain:

☒ Continuous-time

☐ Discrete-time

Discrete-time settings

Sample time (-1 for inherited): -1

Compensator formula

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

Main Initialization Output Saturation Data Types State Attributes

Controller parameters

Source: internal

Proportional (P): 1

Integral (I): 1

Derivative (D): 1

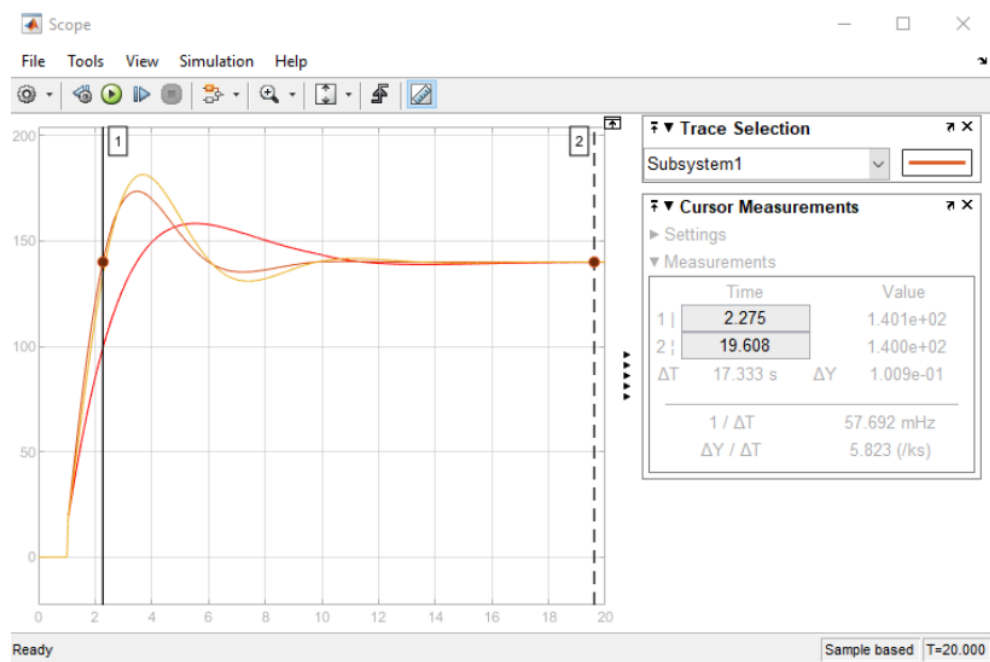
OK Cancel Help Apply

Kp = 1

Ki = 1

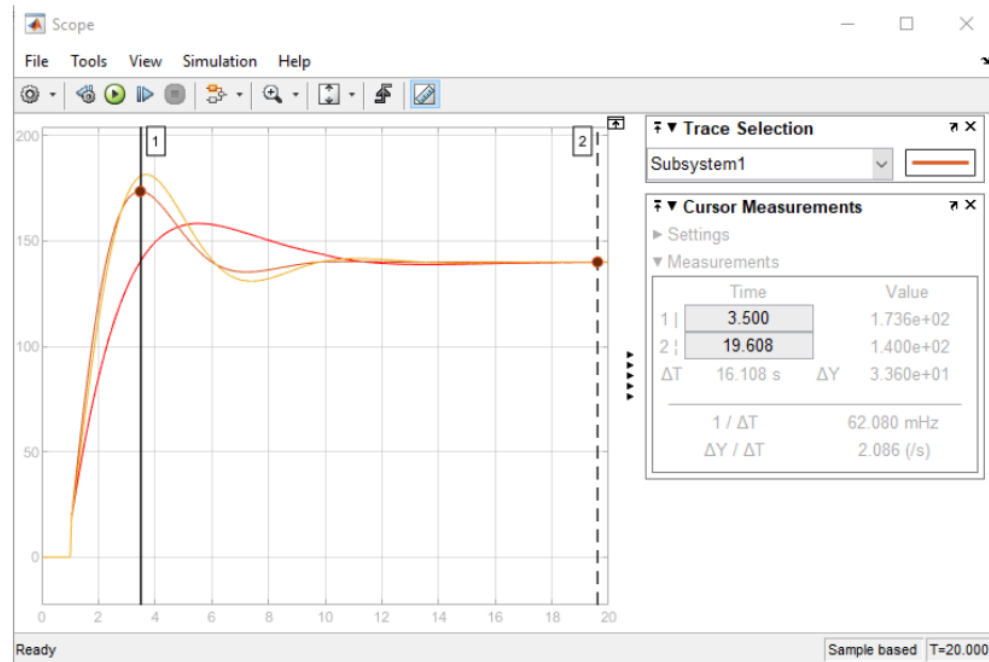
Kd = 1

Rise time:



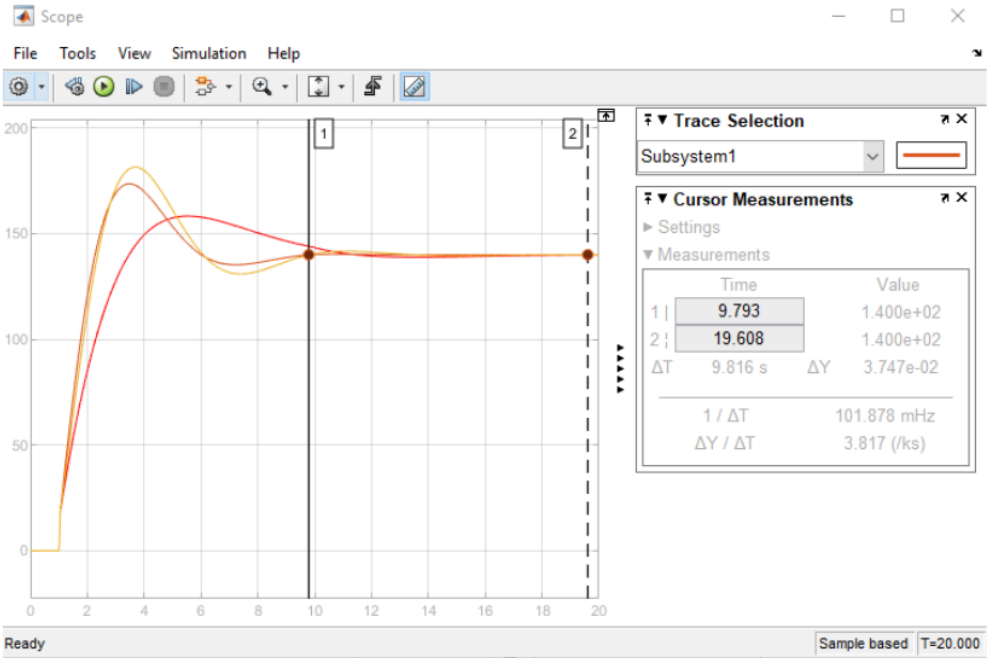
Rise time: 140.1 rad's at 2.275 seconds.

Overshoot:



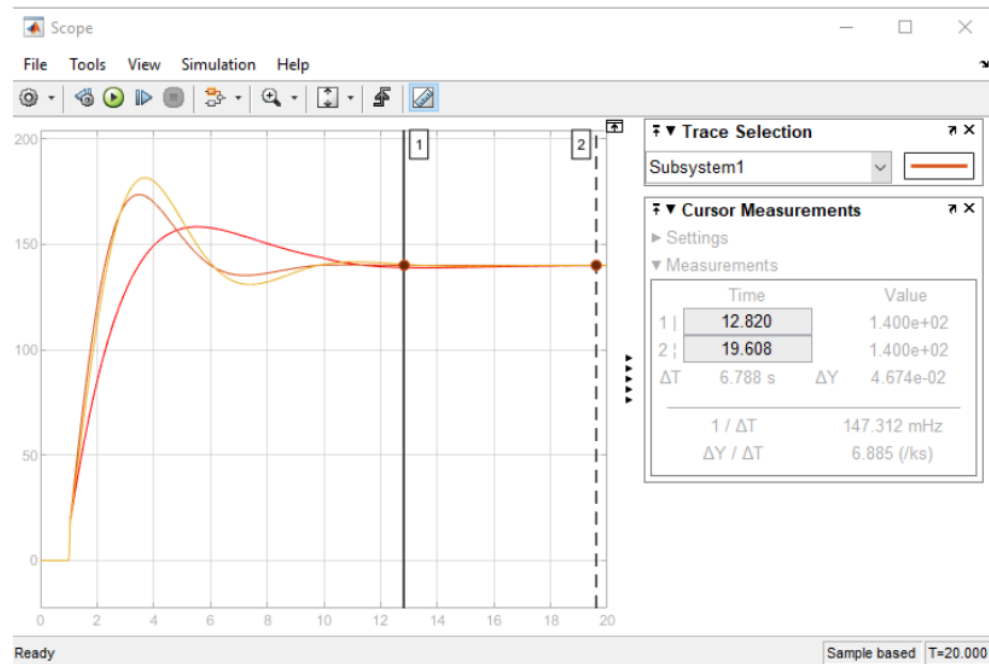
Overshoot: $\frac{173.6-140}{140} \times 100 = 24\%$

The settling time:



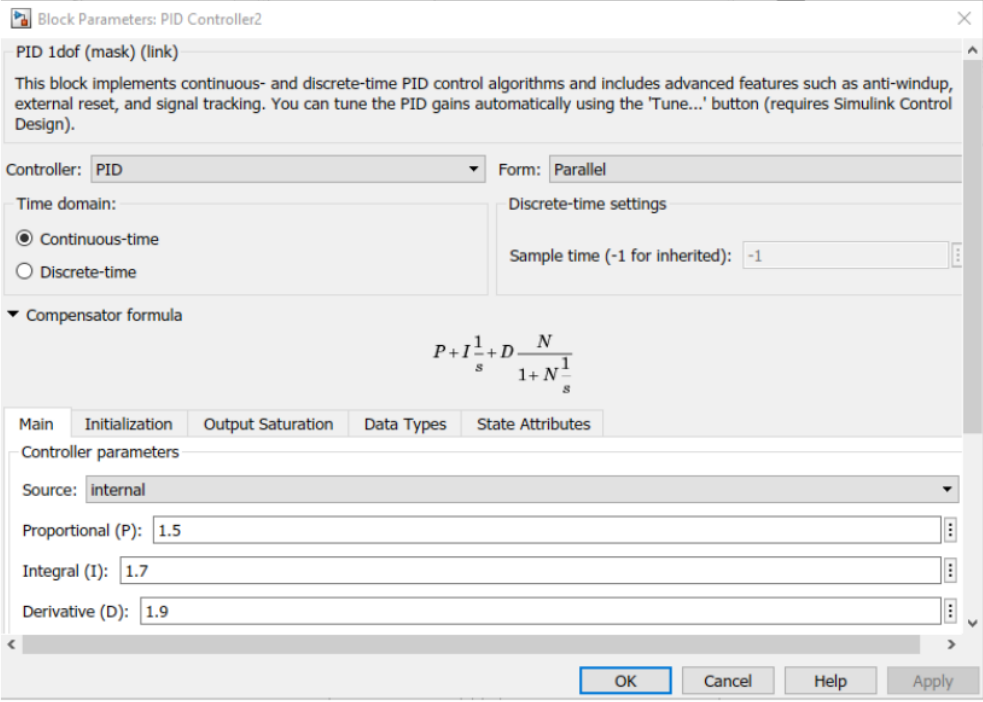
Settling time: 140 rad's at 9.793 seconds.

Steady state error:



Steady state error: $140 - 140 = 0 \text{ rad's}$.

Subsystem 2:



Block Parameters: PID Controller2

PID 1dof (mask) (link)

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

Controller: **PID** Form: **Parallel**

Time domain:

☒ Continuous-time

☐ Discrete-time

Discrete-time settings

Sample time (-1 for inherited): **-1**

Compensator formula

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

Main Initialization Output Saturation Data Types State Attributes

Controller parameters

Source: **internal**

Proportional (P): **1.5**

Integral (I): **1.7**

Derivative (D): **1.9**

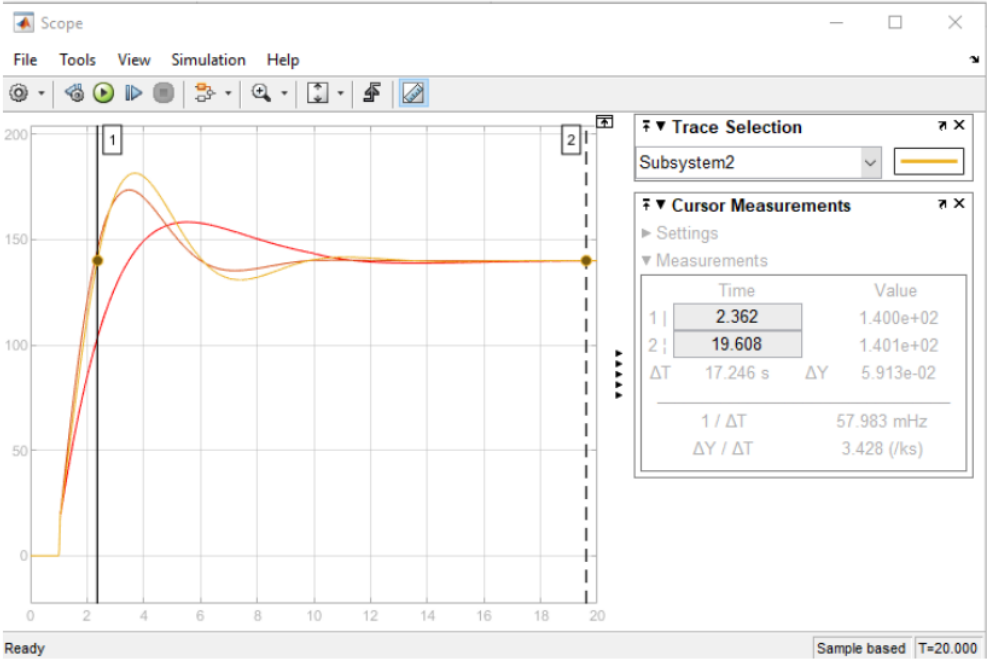
OK Cancel Help Apply

Kp = 1.5

Ki = 1.7

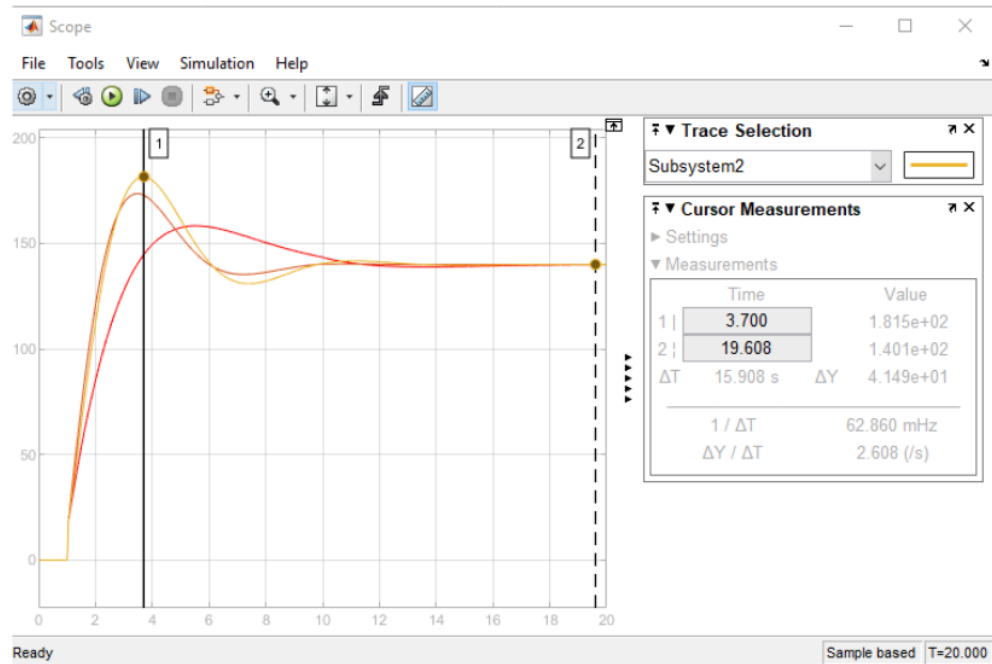
Kd = 1.9

The rise time:



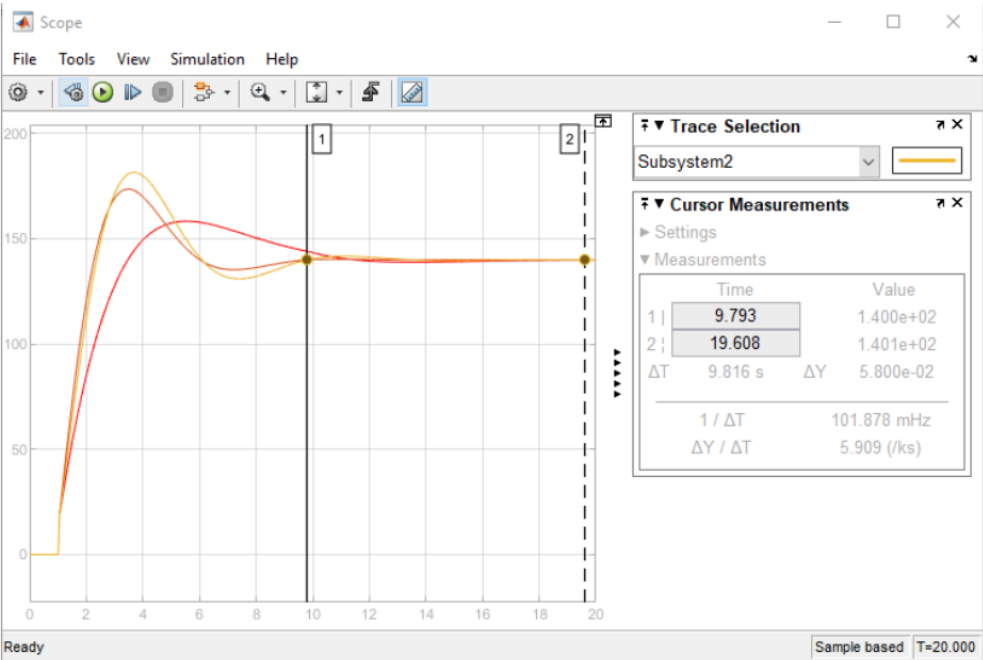
Rise time: 140 rad's at 2.362 seconds.

Overshoot percentage:



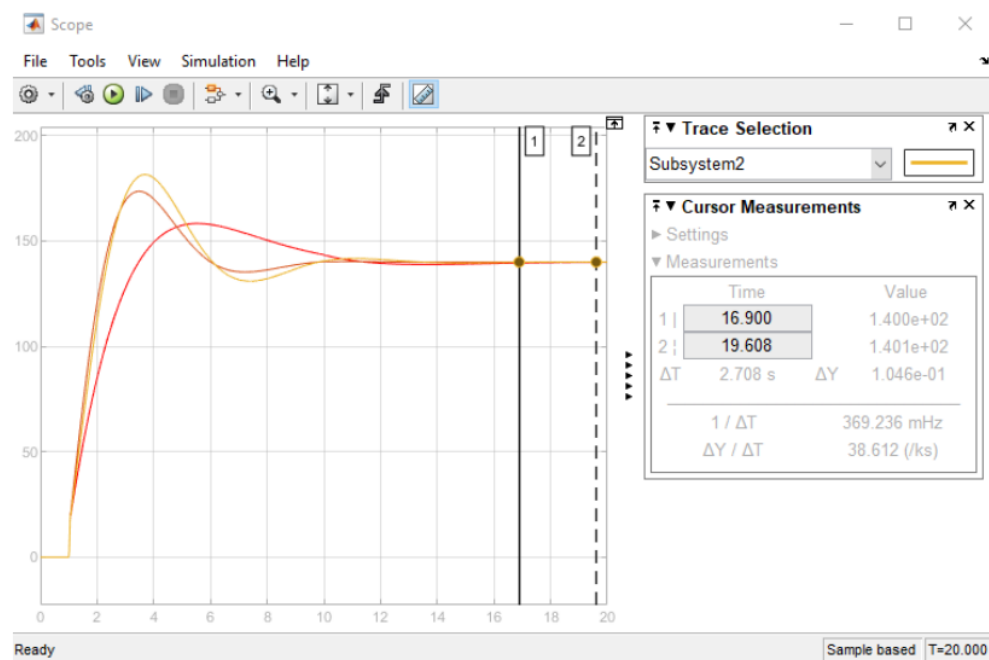
Overshoot: $\frac{181.5-140}{140} \times 100 = 29.6\%$

Settling time:



Settling time: 140 rad's at 9.793 seconds.

Steady state error:



Steady state error: $140 - 140 = 0$ rad's. From 19.608 seconds there is a steady state of 140.1 rad's, so there is a small change after the settling time.

16.3

Table of Results for Proportional - Integral – Derivative control (PID)							
	Kp	Ki	Kd	Rise Time (s) at 140 rad's	Overshoot Percentage	Settling Time (s) at 140 rad's	Steady state error (rad's)
	 23						
Subsystem	0.5	0.2	0.7	3.479	13%	11.498	0
Subsystem 1	1	1	1	2.275	24%	9.793	0
Subsystem 2	1.5	1.7	1.9	2.362	29.6%	9.793	0

Theoretical results:

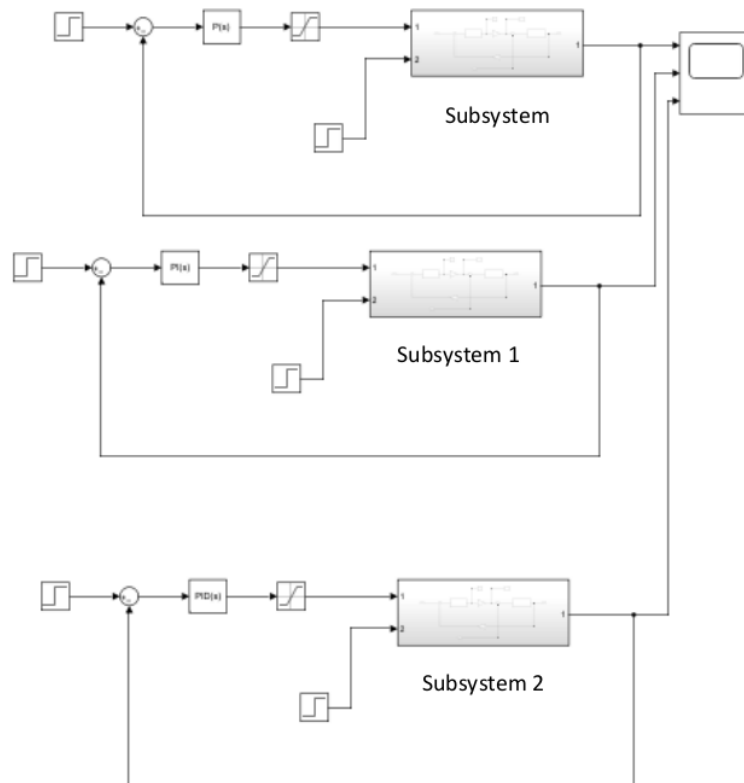
Theoretical results				
	Tr	Ts	OS	SSE
D	Small change	Decrease	Decrease	Small change

The derivative part of the PID algorithm anticipates future behavior of the error because the response of the derivative component is proportional to the rate of change of the error, (Tochukwu, 2021).

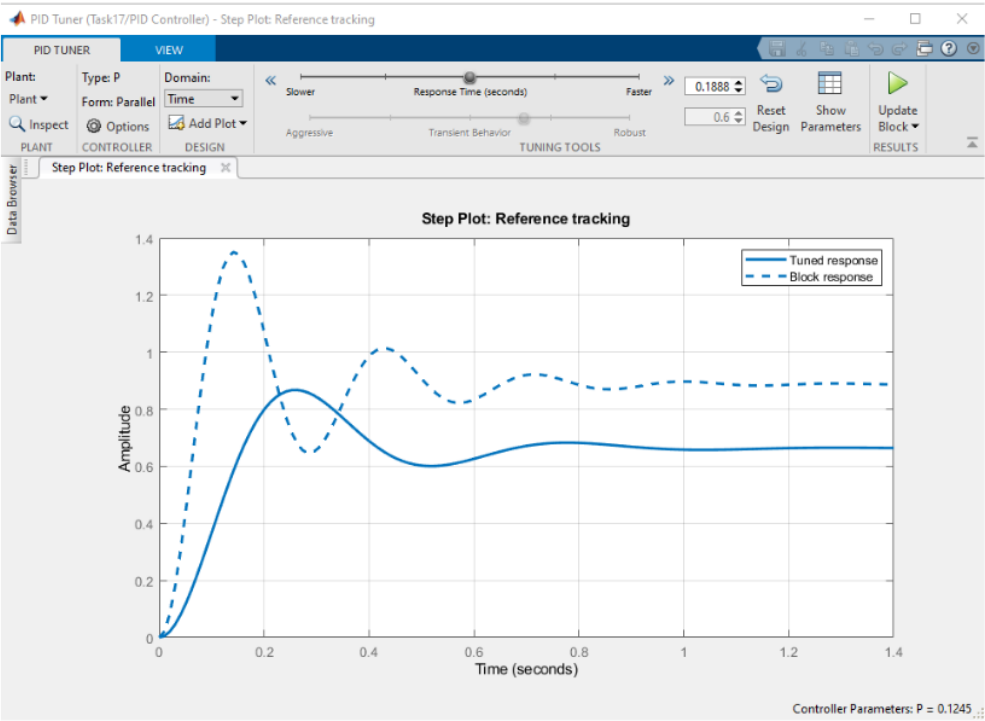
From the results it is clear that as Kd is increased there is a small change in the rise time at 140 rad's, the overshoot has increased, the settling time has decreased and there is little change in the steady state error. The steady state error has been eliminated. By decreasing Kd, it will have the opposite effect. Bar the overshoot, the rest of the results correspond and agree with the theoretical results. From theory it was expected that the overshoot should decrease, however, from the simulation results the overshoot has increased as Kd is increased.

Task 17 – Controller Comparisons

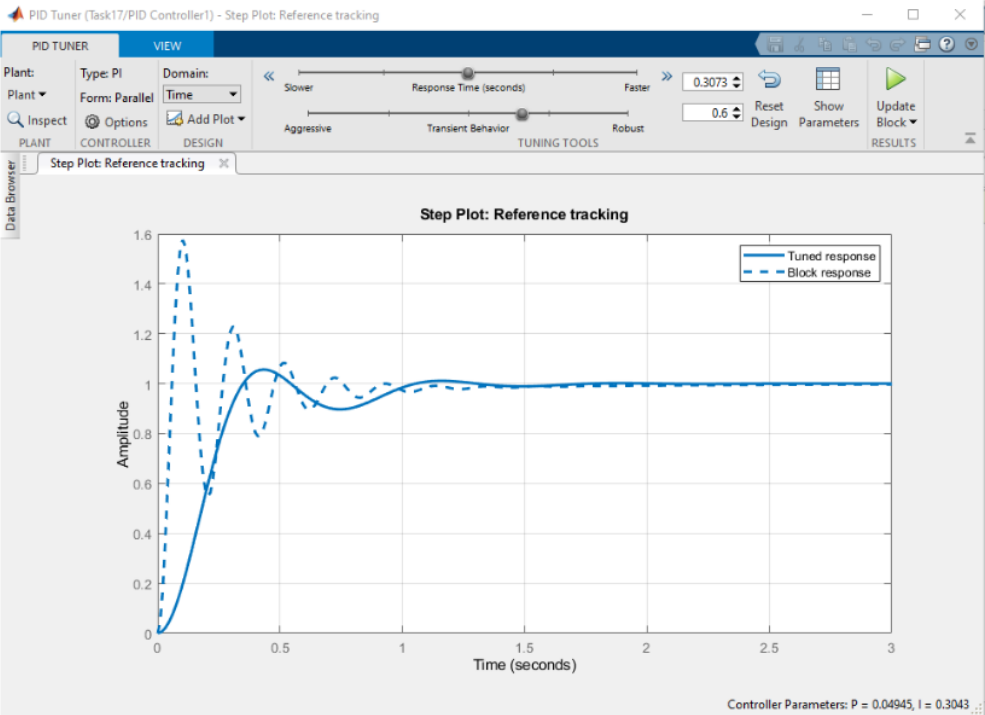
17.1



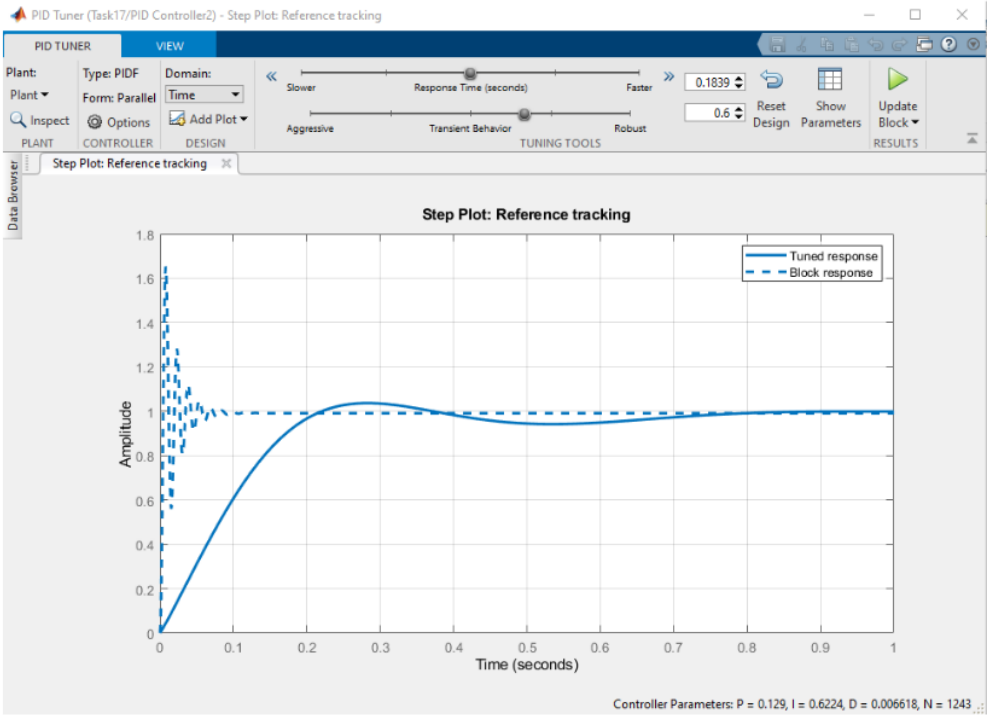
Auto tune for P:



Auto tune for PI:



Auto tune for PID:



Proportional control – Subsystem:

 Block Parameters: PID Controller

PID 1dof (mask) (link)

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

Controller: P

Form: Parallel

Time domain:
☒ Continuous-time
☐ Discrete-time

Discrete-time settings
Sample time (-1 for inherited): -1

▼ Compensator formula

$$P$$

MainInitializationOutput SaturationData TypesState Attributes

Controller parameters

Source: internal

Proportional (P): 0.5

Automated tuning

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

☒ Enable zero-crossing detection

OKCancelHelpApply

Block Parameters: PID Controller1

PID 1dof (mask) (link)

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

Controller: **PI** Form: **Parallel**

Time domain:

☒ Continuous-time

☐ Discrete-time

Discrete-time settings

Sample time (-1 for inherited): **-1**

▼ Compensator formula

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

Main Initialization Output Saturation Data Types State Attributes

Controller parameters

Source: **internal**

Proportional (P): **1**

Integral (I): **1**

Automated tuning

OK Cancel Help Apply

Proportional Integral Derivative control – Subsystem 2:

Block Parameters: PID Controller2

PID 1dof (mask) (link)

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

Controller: PID

Form: Parallel

Time domain:
☒ Continuous-time
☐ Discrete-time

Discrete-time settings
Sample time (-1 for inherited): -1

Compensator formula

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

Main

Initialization

Output Saturation

Data Types

State Attributes

Controller parameters

Source: internal

Proportional (P): 1.5

Integral (I): 1.7

Derivative (D): 1.9

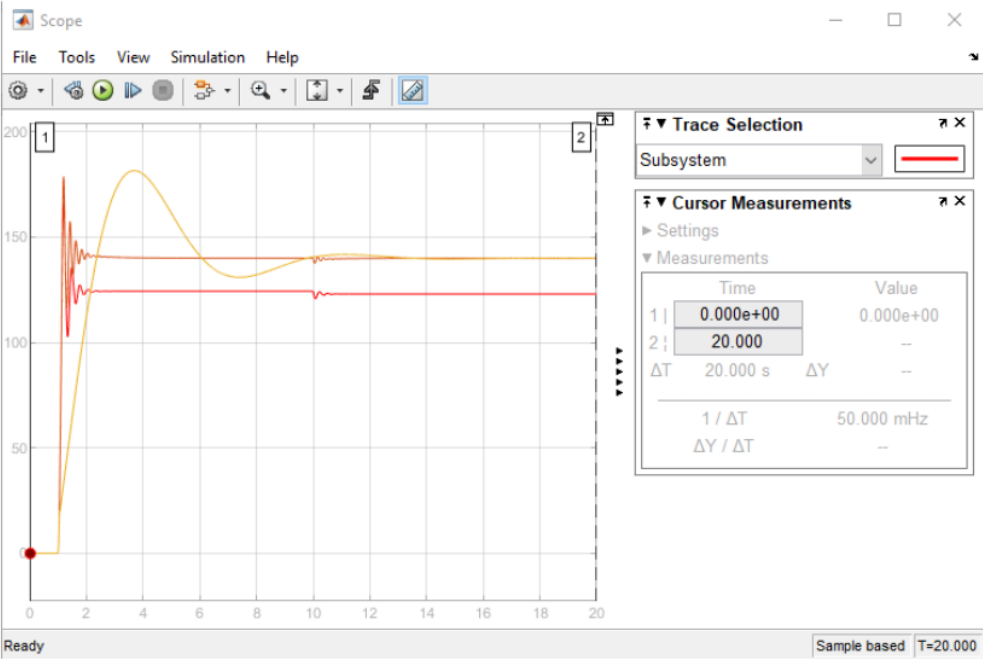
OK

Cancel

Help

Apply

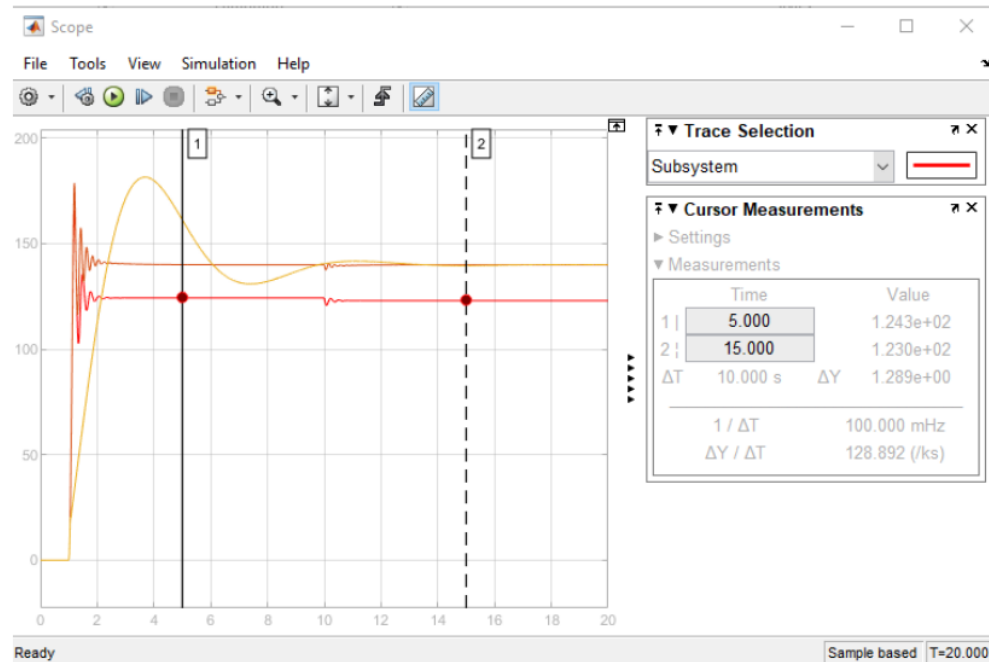
17.2



Steady state error:

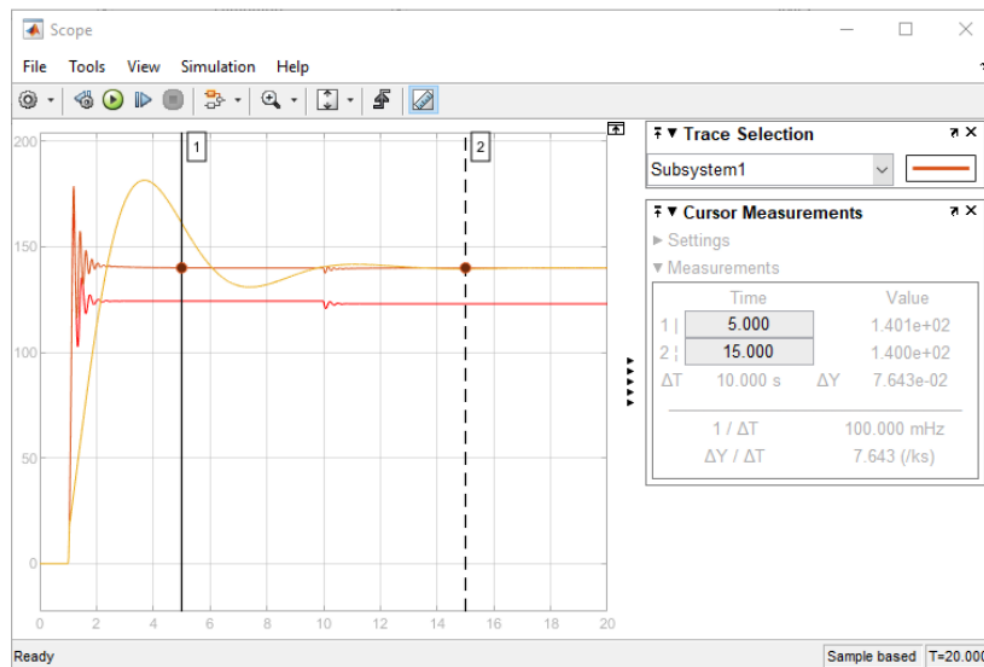
Subsystem: Proportional control only

$K_p = 0.5$



From P only it is clear from the simulation results that it has the greatest steady state error. It has a steady state error of 16 rad's and then under load a steady state error of 17 rad's. From the theory and simulation results, steady state error cannot be eliminated with P only.

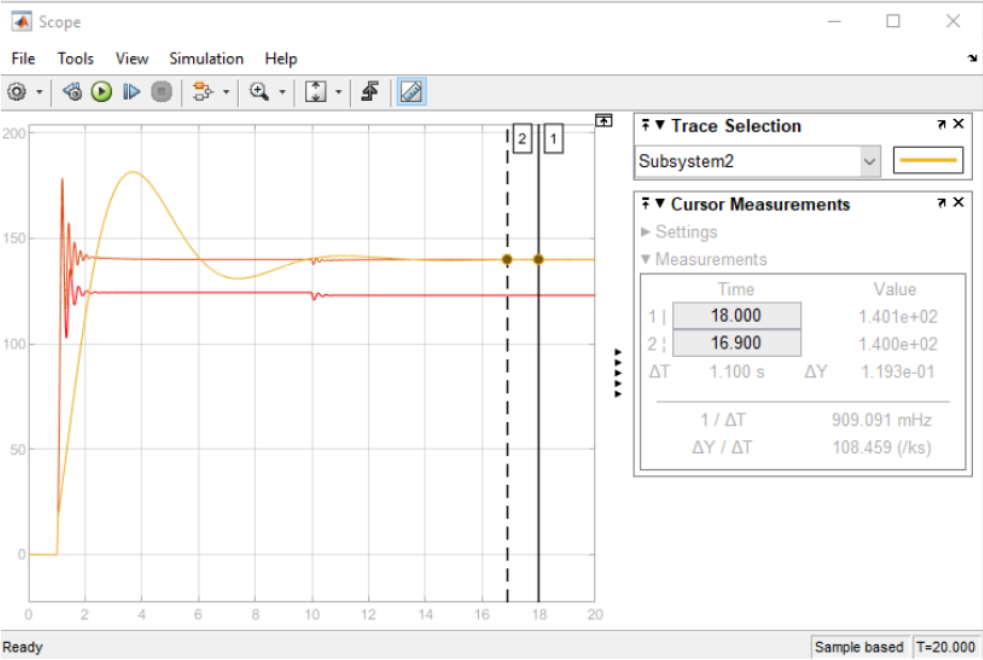
Subsystem 1: Proportional Integral control



Now that integral control has been added (I), it is clear from the results that the steady state error has been eliminated. The results settle at exactly 140 rad's, so no error.

Well done

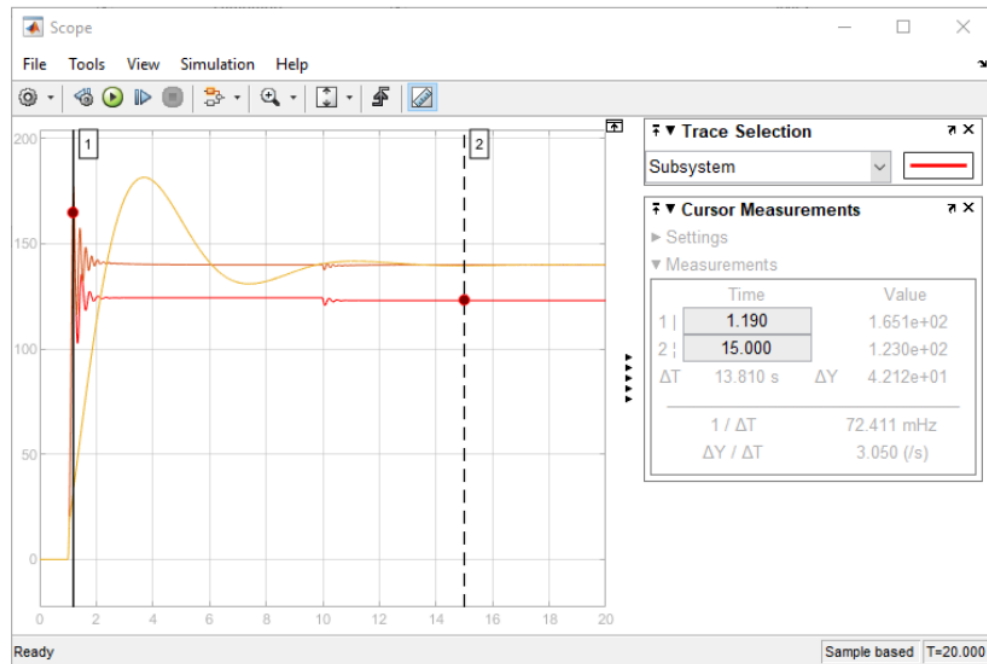
Subsystem 2: Proportional Integral Derivative control



From the PID results the steady state error has been eliminated, however, it does not achieve a steady state of 140 rad's until very late at 16.9 seconds. After the 16.9 seconds and after a 140 rad's has been achieved there is a small change in the steady state. It is clear that at 18 seconds, there is a steady state of 140.1 rad's, so 0.1 of a difference.

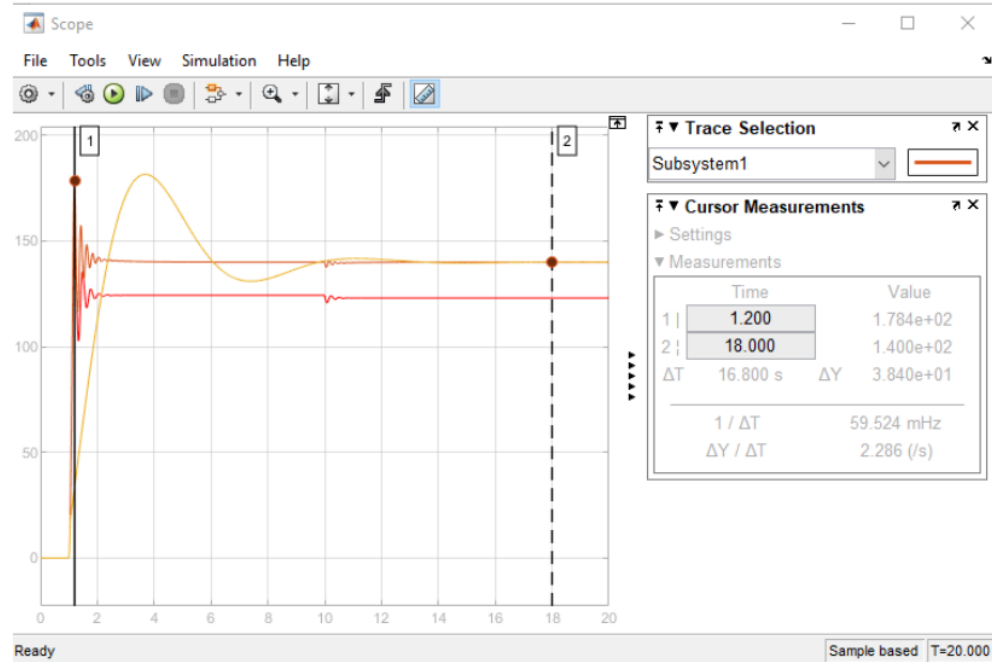
Overshoot:

Subsystem: Proportional only control



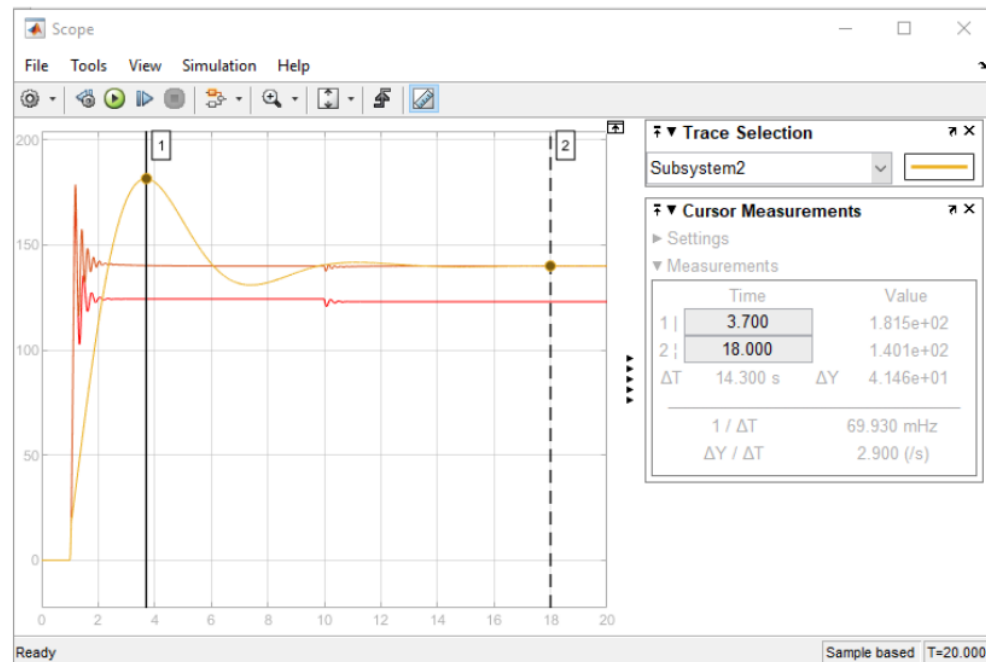
P only has an overshoot percentage of; $\frac{165.1-140}{140} \times 100 = 18\%$

Subsystem 1: Proportional Integral control



PI has an overshoot percentage of: $\frac{178.4-140}{140} \times 100 = 27\%$

Subsystem 2: Proportional Integral Derivative control



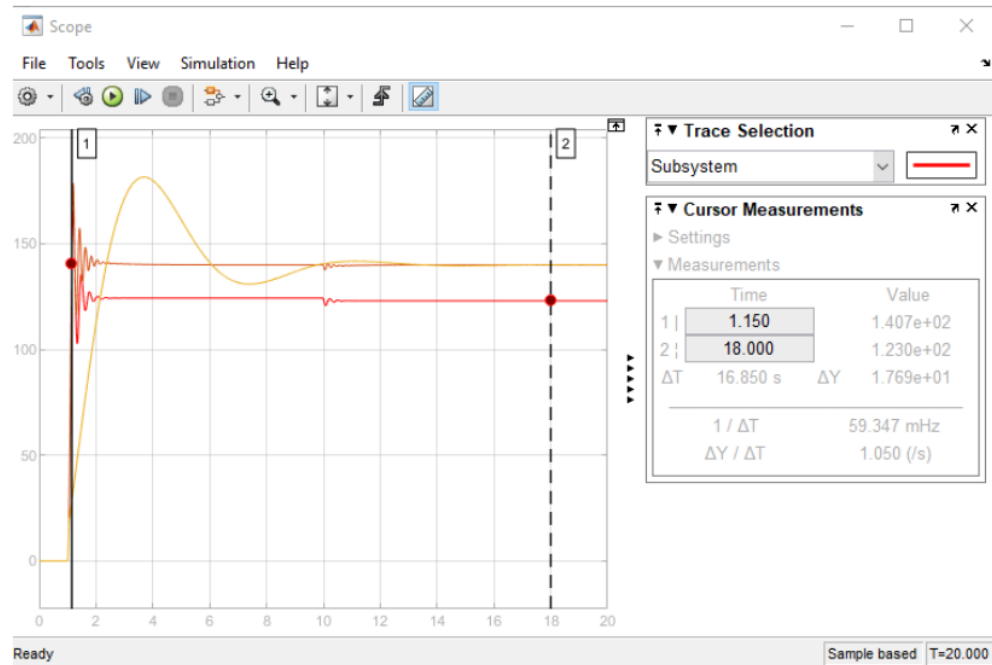
PID control has an overshoot percentage of $\frac{181.5-140}{140} \times 100 = 29\%$

It is clear from the results that the P has the lowest overshoot and PID has the greatest.

24

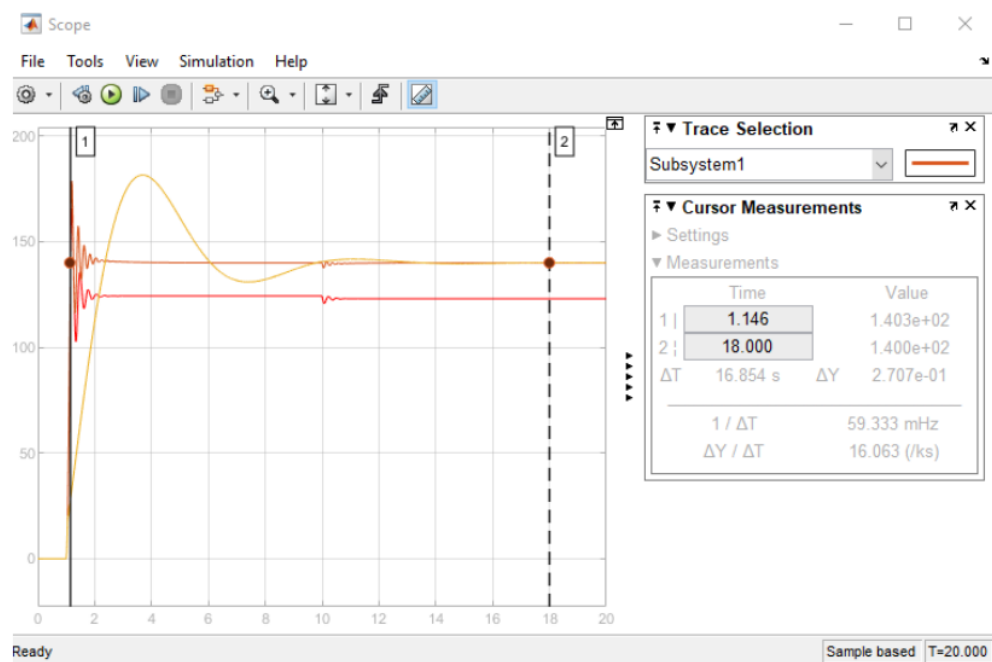
Rise time:

Subsystem: Proportional only control



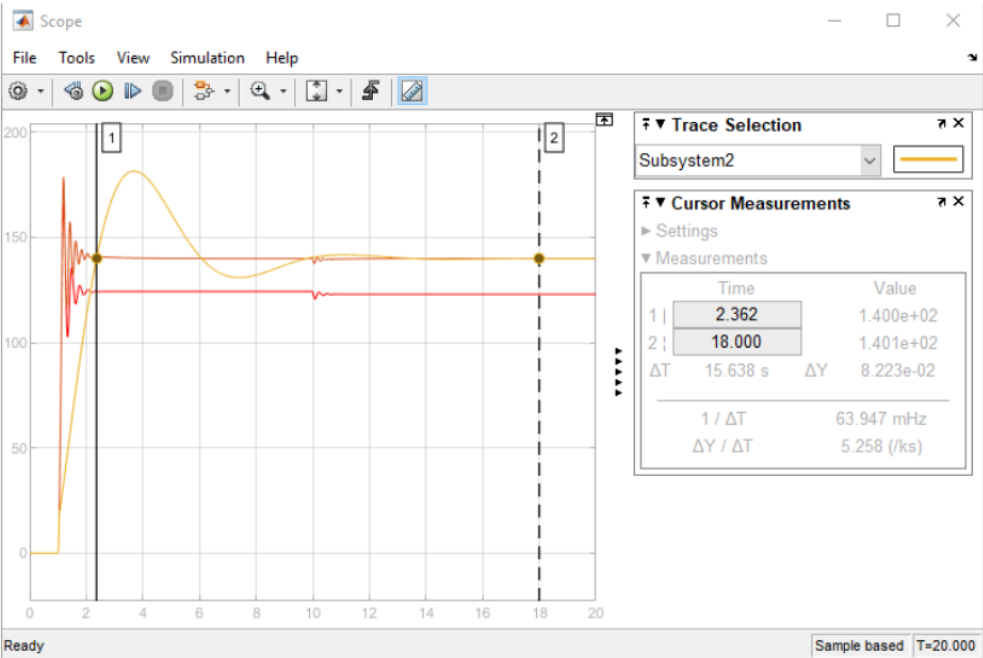
P only control has a rise time of 1.150 seconds at 140.7 rad's.

Subsystem 1: Proportional Integral control



Proportional integral control has a rise time of 1.146 seconds at 140.3 rad's.

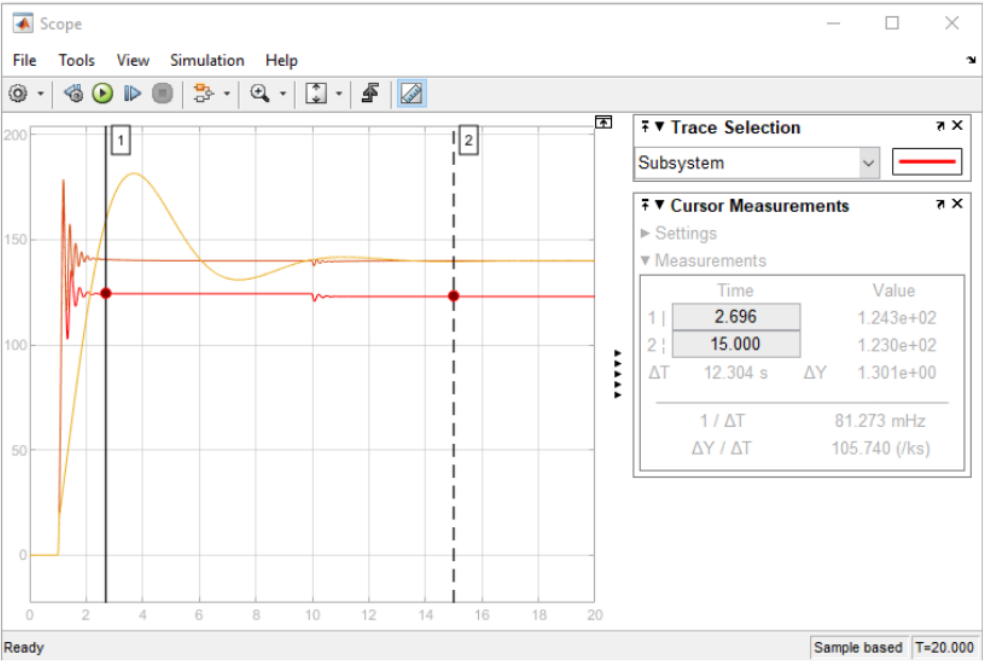
Subsystem 2: Proportional Integral Derivative control



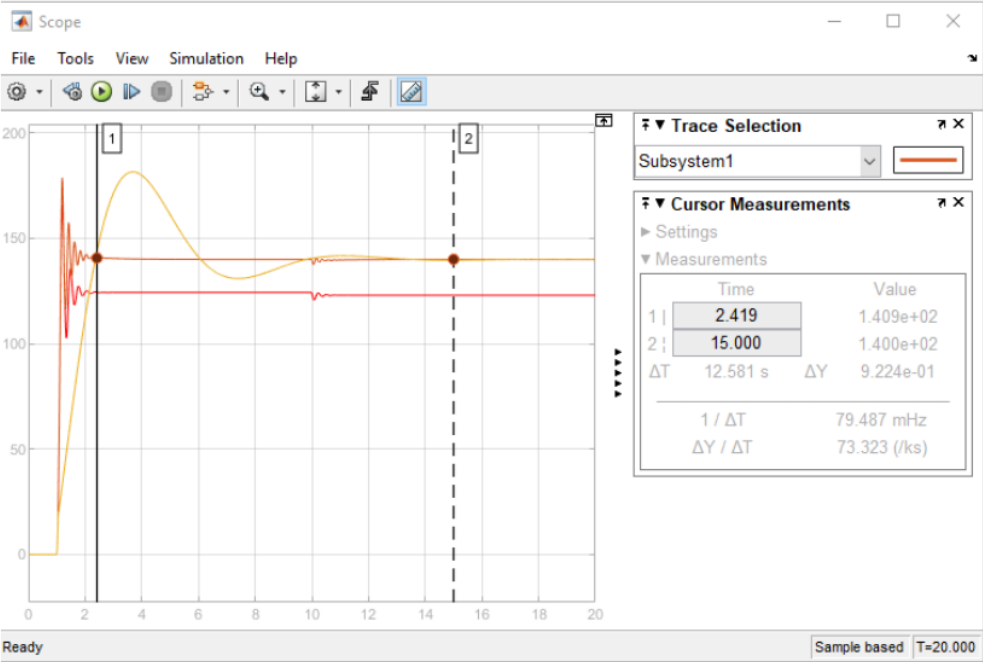
PID has a rise time of 2.362 seconds at 140 rad's.

Settling time:

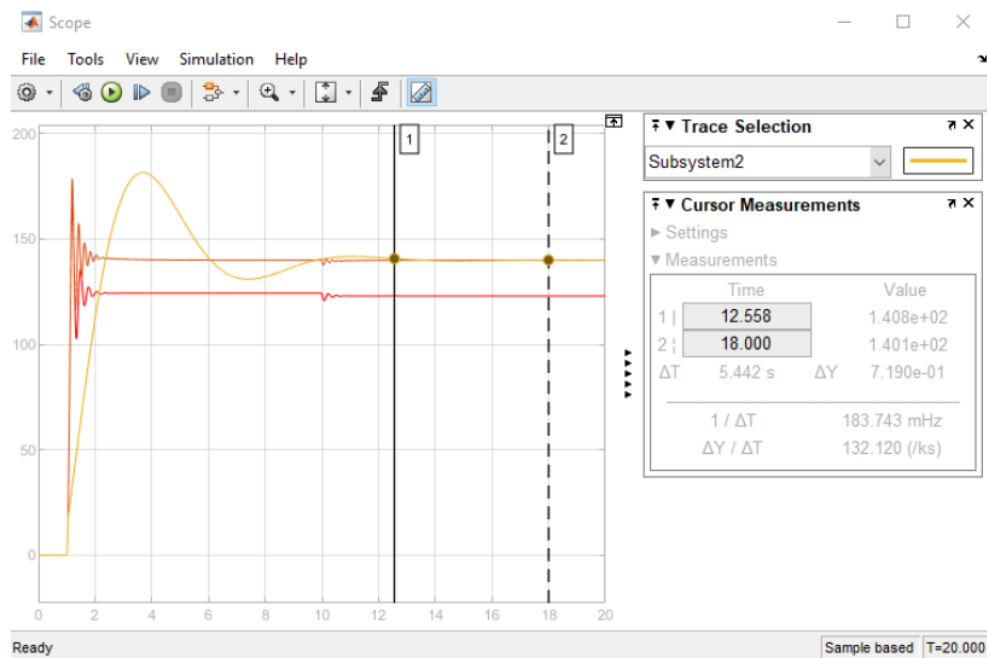
Subsystem: P control:



Subsystem 1: PI control:



Subsystem 2: PID control:



It is clear from the graphical results that P and PI control have a very early settling time, however, P only cannot settle at 140 rad/s because of the greater steady state error. PI has a very early and good settling time as the steady state error has been eliminated. PID control has a very late settling time, but does reach 140 rad/s eventually.

17.3

Results				
Control Type	SSE	OS	Rise Time	Settling Time
P	Highest	Lowest	Lowest	Early, but does not achieve 140 rad's
PI	Eliminated	Increased	Slight Decrease	Early and does achieve 140 rad's and eliminates SSE
PID	Small Change	Highest	Highest	Very late but does eliminate SSE and obtains 140 rad's

Well done

The graphical results obtained make it very clear that depending on the type of control chosen, the results behave differently. It is very difficult to fine tune a PID controller. The results obtained may not necessarily agree with the theoretical results and in order that the simulation and theoretical results might agree with each other fine tuning is needed and the K_p , K_i and K_d values will have to be altered accordingly. Much time is needed in order to alter the K_p , K_i and K_d values in order to achieve perfect results. From the results obtained here, they do provide a rough idea as to how the different controllers behave.

Task 18 – Overall Conclusions and Recommendations

In the first few tasks, an analysis of the transients for RC and RL circuits was carried out. Careful attention was given to the frequency performance for the same circuits. Proceeding from there, an analysis of the second order transients was carried out. An examination was carried out on series and parallel circuits to see how they behaved differently. Attention was given to the frequency performance of the second order transients.  25 By creating series and parallel circuits of a second order, different responses were obtained and monitored. Proceeding from there, frequency on the electronic system was scrutinized by applying op amps, which produced electronic filters instead of passive filters. For tasks 9 and 10, an analysis of active filters was carried out. For task 11, careful attention was given to fourth order electronic systems, which is another electronic filter. From the fourth order it is clear that the drop off increased at a higher order filter providing a better drop off. In task 12, an analysis went into closed loop control of a first order. Task 13 was building a motor. Task 14, 15 and 16, a three term controller on a motor system was built to see how each term of the controller reacted and behaved differently to the other two. Comparisons were produced in order to discuss the effects that the three term controllers have on a motor system.

Well done

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GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

83/100

PAGE 1

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PAGE 3



Comment 1

show circuit diagram

PAGE 4



You have worked this out correctly, well

PAGE 5



Comment 2

explain

PAGE 6



Comment 3

why? where?

PAGE 7



Comment 4

show circuit first

PAGE 8

PAGE 9



Comment 5

a bit vague

PAGE 10

PAGE 11

QM

You have worked this out correctly, well

PAGE 12



Comment 6

excellent annotation, shows good understanding

PAGE 13



Comment 7

you should state this is a LPF

PAGE 14

QM

You have worked this out correctly, well

PAGE 15

PAGE 16

PAGE 17

PAGE 18

QM

You have worked this out correctly, well

PAGE 19

PAGE 20

PAGE 21

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PAGE 23



Comment 8

this result is damped as the response converges to zero



Good work

Good work



Good work

Good work



You have worked this out correctly, well



Comment 9

there is damping here



You have worked this out correctly, well



Comment 10

excellent use of software

QM

Well done

Well done.

PAGE 41

PAGE 42

PAGE 43

QM

You have worked this out correctly, well

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Comment 11

excellent use of software

PAGE 46

QM

You have worked this out correctly, well

PAGE 47

PAGE 48

QM

You have worked this out correctly, well



Comment 12

excellent analysis tool

PAGE 49

QM

Well done

Well done

Additional Comment

Yes the results match but for a deeper analysis say what effects things like gain, TF and circuit type



Comment 13

good results



Comment 14

show TF for each stage



You have worked this out correctly, well



Comment 15

explain scaling factor



Well done

Well done



Comment 16

show the system model



You have worked this out correctly, well



Comment 17

why have you placed data points at these pole locations

PAGE 63

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QM

You have worked this out correctly, well

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PAGE 68

QM

You have worked this out correctly, well

PAGE 69

QM

You have worked this out correctly, well

PAGE 70

QM

Well done

Well done.

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QM

You have worked this out correctly, well

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Comment 18

what about the loaded speed?

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 **Comment 19**
rad/s

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 **Comment 20**
consider combining these individual measurements on one graph to condense the number of images

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 **Comment 21**
excellent results table

 **Well done**
Well done.

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Comment 22

keep this constant and just change Ki

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Comment 23

keep both K_p and K_i constant and vary K_d

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PAGE 138



Well done

Well done.



Comment 24

why is this?

QM

Well done

Well done.



Comment 25

what about the importance of the TF on predicting response?

QM

Well done

Well done

1. ENGAGEMENT WITH LITERATURE



NA

2. KNOWLEDGE AND UNDERSTANDING



Excellent knowledge and understanding demonstrated. 24/30

24

3. COGNITIVE AND INTELLECTUAL



Clear evidence of advanced analytical skills has been demonstrated throughout the report. see comments. 25/30

25

4. PRACTICAL APPLICATION



Advanced application of practical skills in both matlab and simulink software, with most impressive figures, please consider condensing the amount of graphical results by combining measurements. 24/30

24

5. TRANSFERABLE SKILLS



Excellent report 10/10

10