

# 1809800

*by* Iwan CostelloDowns

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## Table of Contents

|                                                                        |    |
|------------------------------------------------------------------------|----|
| 1. Executive Summary .....                                             | 4  |
| 2. Transient Response of a Second Order System.....                    | 5  |
| <i>Fig.1 – Simple Control System</i> .....                             | 5  |
| <i>Fig.2 – Simple Control System Step Response</i> .....               | 5  |
| 3. Control System Modelling.....                                       | 6  |
| <i>Fig.3 – Argand Diagram</i> .....                                    | 7  |
| <i>Fig.4 – Step Response Control System Modelling</i> .....            | 8  |
| <i>Fig.5 – Root Locus Control System Modelling</i> .....               | 9  |
| <i>Fig.6 – Critical Damping Control System Modelling</i> .....         | 10 |
| <i>Fig.7 – Critical Stability Control System Modelling</i> .....       | 11 |
| 4. Block Diagram Reduction Method .....                                | 13 |
| <i>Fig.8 – Block Diagram</i> .....                                     | 13 |
| <i>Fig.9 – Block Diagram Simulink Model</i> .....                      | 16 |
| <i>Fig.10 – Transfer Function Response Graph</i> .....                 | 16 |
| <i>Fig.11 – Block Diagram Poles and Zeroes</i> .....                   | 17 |
| <i>Fig.12 – Block Diagram Step Response</i> .....                      | 18 |
| 5. Frequency Response Method .....                                     | 19 |
| <i>Fig.13 – Frequency Response Phase and Magnitude Responses</i> ..... | 20 |
| 6. Digital Control Systems.....                                        | 21 |
| <i>Fig.14 – Digital Control System</i> .....                           | 21 |
| <i>Fig.15 – Digital Control System Simulation</i> .....                | 24 |
| 7. Conclusion and Overall Recommendations .....                        | 25 |
| 8. Appendix .....                                                      | 26 |

# 1. Executive Summary

## *A good summary*

This assignment observes the relative usefulness of control system modelling and analysis via theoretical understanding and computational analysis. The first task involved simple control system in which behavioural characteristics of the response were calculated and compared to simulated MATLAB results, this task was deemed a definite success as the results are reliable and accurate across both methods. The second task involved a more in-depth modelling of a control system and plotting the actual argand diagram in response to calculated poles and zeroes, again the validity of the results was confirmed via the simulation. The third task looked at a block diagram control system and using the block diagram reduction method to find the transfer function, the results of this task were similarly accurate and confirmed to be correct via simulation. A frequency response analysis was covered in task four and the process of setting up a bode plot was observed. The final task involved finding a sampling time of a digital control system was calculated and then simulated and graphed which proved useful in determining how to model a digital control system and using Simulink. Finally an overall conclusion of the assignment was made in which the relative success of calculation and stimulatory methods of control system modelling within this assignment, further aspects fo analysis were discussed and recommendations on further discussion were offered.

## 2. Transient Response of a Second Order System

Using the simple control system as seen in Fig.1 values for K and a where chosen. Using these values, the system can be reduced to a single transfer function as seen in Appendix 1.

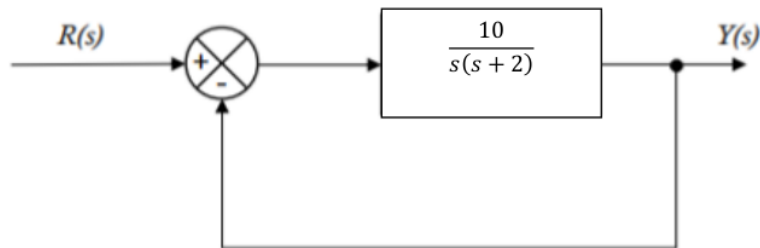


*Fig.1 – Simple Control System*

Using the chosen values of K and a as 10 and 2 respectively, calculations were carried out in appendix 1 to predict the system reaction to a step response. To ensure that the calculation is correct a simulation of the system was run on MATLAB as seen in Fig.1. Drawing data from both methods a table was collated to ensure validity of results.

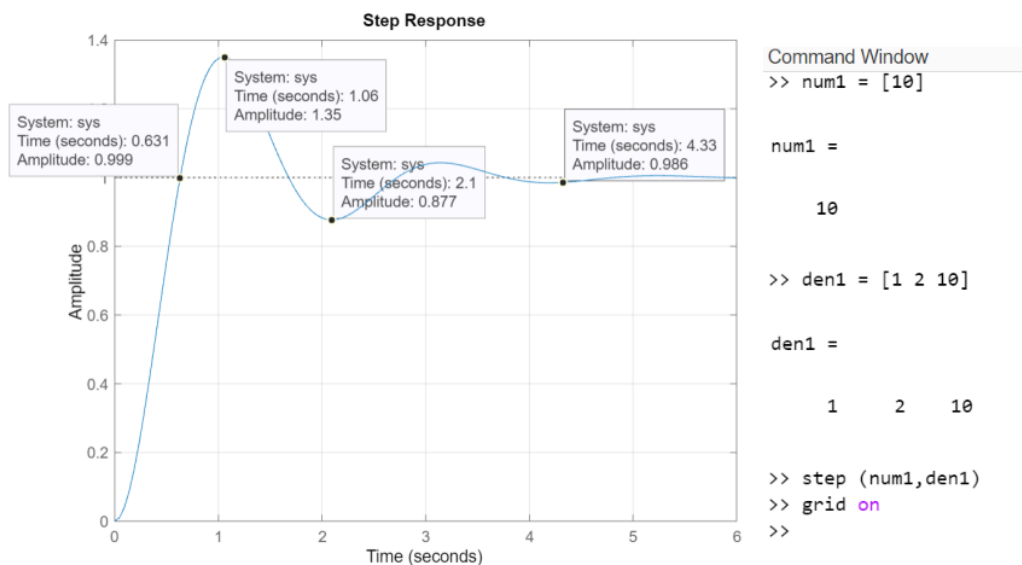


*Fig.2 – Simple Control System Step Response*

| <u>Calculated Values</u>    |                | <u>Simulated Values</u>     |               |
|-----------------------------|----------------|-----------------------------|---------------|
| <u>Parameter</u>            | <u>Value</u>   | <u>Parameter</u>            | <u>Value</u>  |
| <i>Rise Time</i>            | 0.5988 seconds | <i>Rise Time</i>            | 0.631 seconds |
| <i>Peak Time</i>            | 1.04 seconds   | <i>Peak Time</i>            | 1.06 seconds  |
| <i>Percentage Overshoot</i> | 33.2%          | <i>Percentage Overshoot</i> | 35%           |
| <i>Settling Time</i>        | 4 seconds      | <i>Settling Time</i>        | 4.33 seconds  |
| <i>Damped Frequency</i>     | 2.99rad/s      | <i>Damped Frequency</i>     | 2.99rad/s     |

From the table it can be observed that the rise times are somewhat different but by only a few milliseconds, despite this difference they are similar enough to claim validity. The peak times are almost identical as is the settling time where the curve settles to within 2% of its final value at the 4 second period. Because of the similarity it can therefore be said that they are correct. The percentage overshoot likewise is quite similar with a 2% difference, despite this they are similar enough to state they are repeatable and reliable results. Furthermore the number of oscillations calculated to be 1.911 which is corroborated on the graph as that is roughly the same oscillations before falling into 2%. Using the simulated data the damped frequency can be checked:

$$\pi \left( \frac{1}{2.1} \times 2 \right) = 2.99 \text{ rad/s}$$

Both the calculated and simulated variants are identical and can therefore be confirmed to be accurate.

### 3. Control System Modelling

An open loop control system can be represented with the following equation:

$$\frac{d^2y}{dt^2} + a \frac{dy}{dt} + by = \frac{d^2x}{dt^2} - p \frac{dx}{dt} + qx$$

Where 'x' is the input and 'y' is the output; both being functions of time. Appendix 2 show the calculations needed to translate the equation into the frequency domain to produce the loop transfer function of the system. The values for a, b, p, and q, are:

$$\frac{d^2y}{dt^2} + 1 \frac{dy}{dt} + 4y = \frac{d^2x}{dt^2} - 1 \frac{dx}{dt} + 4x$$

Using the calculation the poles and zeroes can be found, plotting these results can be seen in Fig.3.

From this graph certain characteristics of the system can be extrapolated. As the poles lay on the left-hand side it can be stated as they are on the real axis means this system will be stable. The poles being in the in the right-hand side means the system will be overdamped.

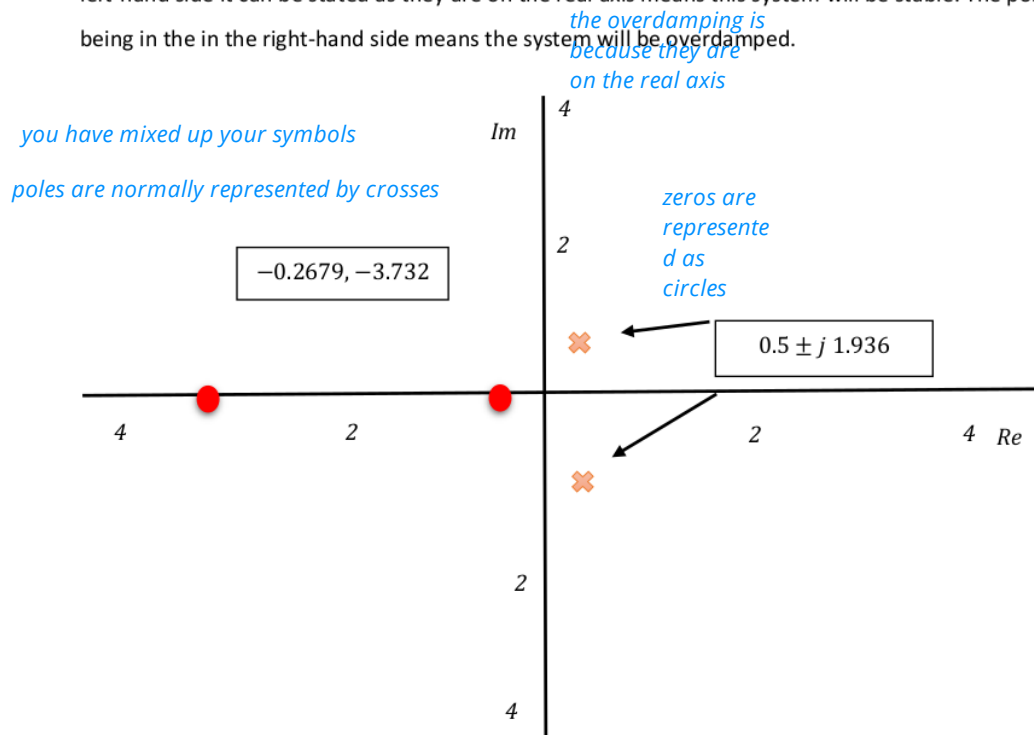


Fig.3 – Argand Diagram

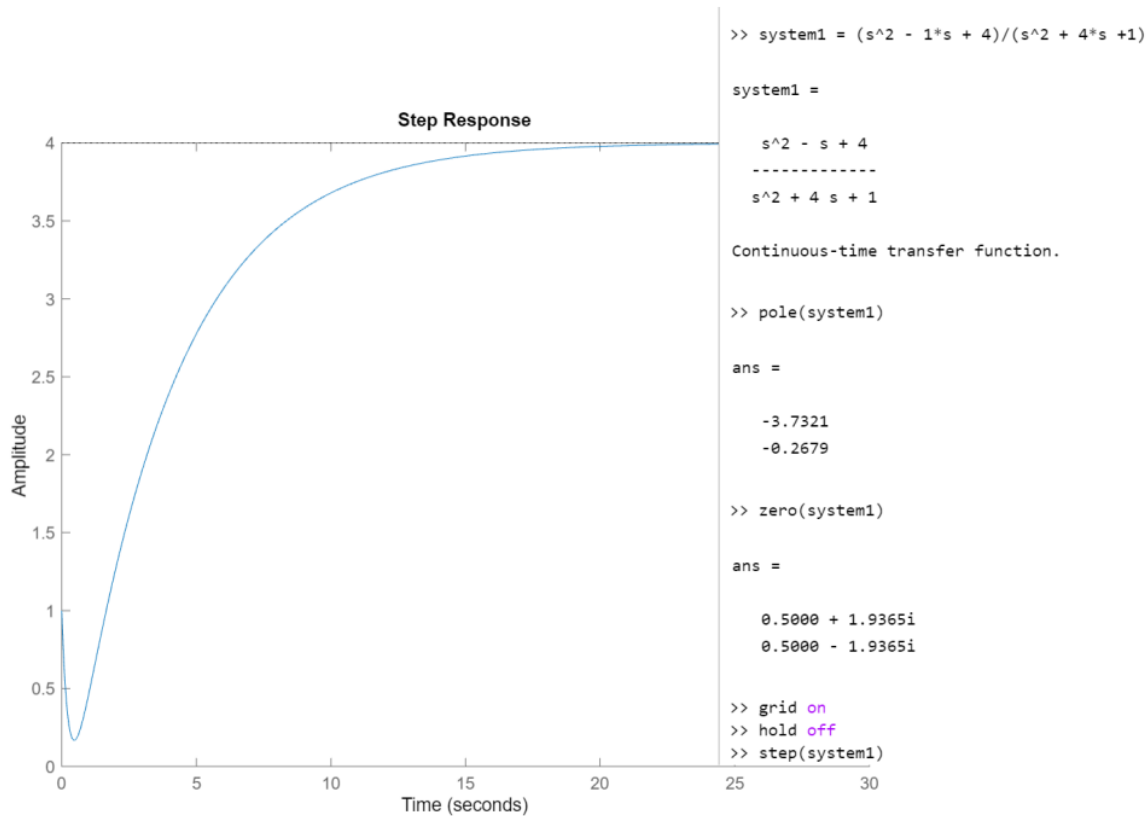


**Fig.4 – Step Response Control System Modelling**

Fig.4 shows the step response to the control system with the corresponding MATLAB code. The curve can be seen to behave in an overdamped state with a drop at the start and a quick levelling off into steady state without oscillation, it also confirms the poles and zero values with individual functions based on the transfer function, proving the calculation to be correct. Further analysis was carried out using the root locus analysis of the transfer function as can be seen in Fig.5. Using this simulation the poles and zeros confirmed by the program have been plotted and can be seen to be in the theorised configuration from the argand diagram.

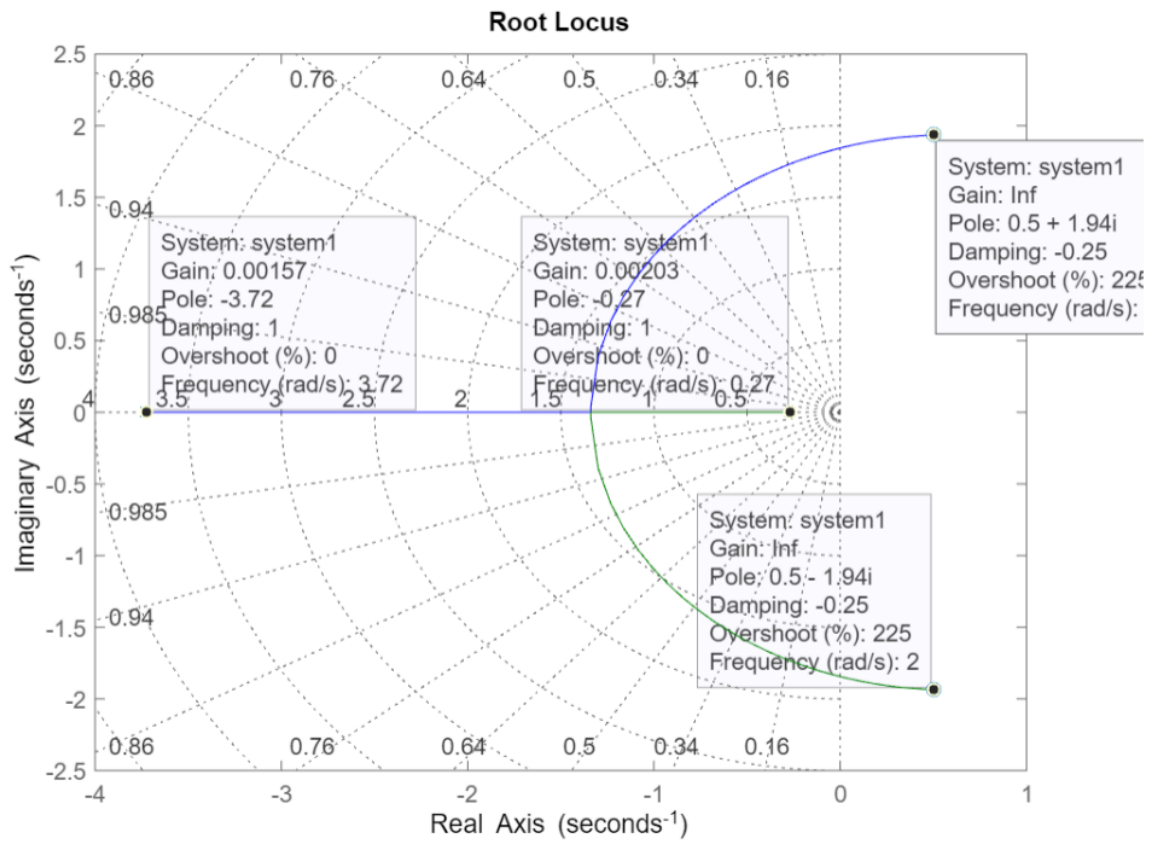


*Fig.5 – Root Locus Control System Modelling*

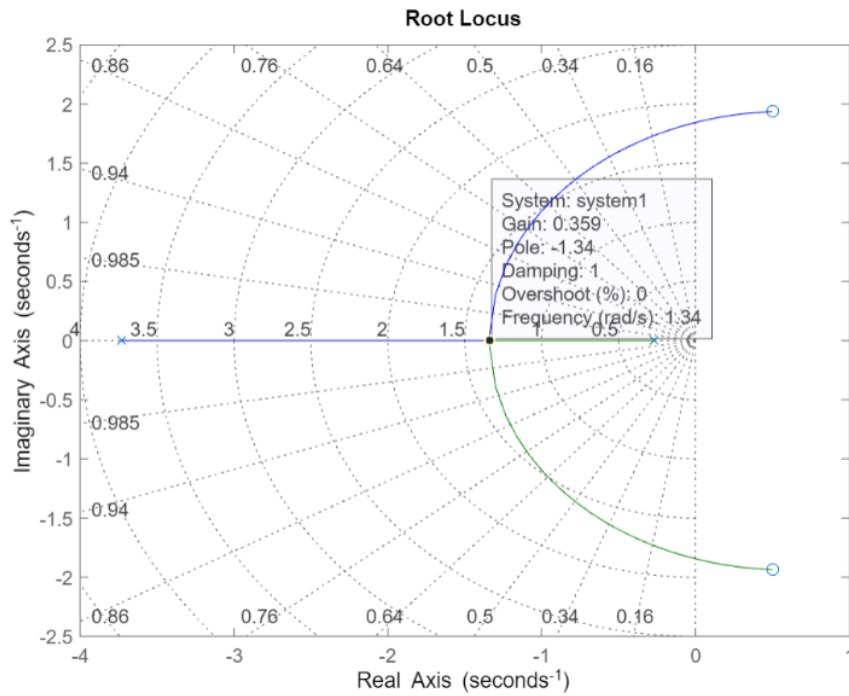


**Fig.6 – Critical Damping Control System Modelling**

The simulation root locus diagram can also allow further analysis of the controls system, such values as critical damping, critical stability as well as instability. Fig.6 shows the root locus response of the controls system with a marker at the point of critical damping.

Subbing in the value of the gain as K will give us calculated corroboration.

$$T(s) = s^2 + \frac{(4 - 1(0.359))}{(1 + (0.359))}s + \frac{(1 + 4(0.359))}{(1 + (0.359))}$$

$$T(s) = s^2 + 2.679s + 1.792$$

This is compared to the general transfer function of the denominator ' $s^2 + 2\zeta\omega_n s + \omega_n^2$ ':

$$\omega_n^2 = 1.792, \text{ therefore, } \omega_n = \sqrt{1.792} = 1.3388$$

And:

$$2\zeta\omega_n s = 2.679, \text{ therefore, } \zeta = \frac{2.679}{2\sqrt{1.792}} = 1.00063$$

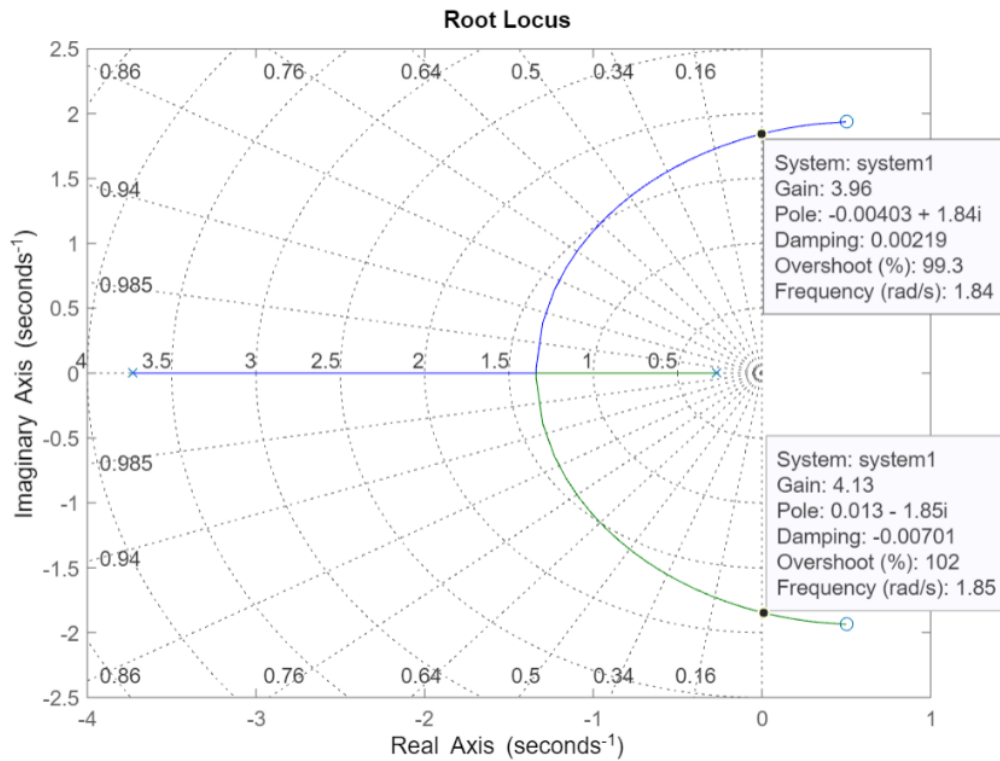


**Fig.7 – Critical Stability Control System Modelling**

Using the simulation the point of critical stability can be found and is displayed in Fig.7 on the root locus diagram. The gain is approximately 4 on the axis. Furthermore the critical instability can also be calculated and proved. To add negative feedback a new transfer function has to be derived for the closed loop system.

$$T(s) = \frac{G(s)}{1 + G(s) + H(s)} = \frac{\frac{s^2 - 1s + 4}{s^2 + 4s + 1}}{1 + K \times \left(\frac{s^2 - 1s + 4}{s^2 + 4s + 1}\right)}$$

$$T(s) = \frac{s^2 - 1s + 4}{(s^2 + 4s + 1) + K \times (s^2 - 1s + 4)} = \frac{s^2 - 4s + 3}{s^2 + 4s + 1 + Ks^2 - 1Ks + 4K}$$

$$T(s) = \frac{s^2 - 1s + 4}{(1 + K)s^2 + (4 - 1K)s + (1 + 4K)}$$

By factoring by  $(1 + K)$ ;

$$T(s) = \frac{1}{(1 + k)} \frac{s^2 - 1s + 4}{s^2 + \frac{(4 - 1K)}{(1 + k)}s + \frac{(1 + 4K)}{(1 + k)}}$$

Using the following equation the value of k can be proved mathematically in relation to the results of the simulation of the root locus the accuracy of the results can be validated. Using denominator as the transfer function.

$$T(s) = s^2 + \frac{(34 - 1k)}{(1 + k)}s + \frac{(1 + 4k)}{(1 + k)}$$

$$s^2 + \frac{(4 - 1k)}{(1 + k)}s + \frac{(1 + 4k)}{(1 + k)} = 0$$

Simplifying to;

$$\frac{(4 - 1k)}{(1 + k)}s = 0$$

Finally:

$$4 - 1k = 0, \text{ therefore, } K = 4$$

This is in line with the simulation, adding to the reputability of the results.

## 4. Block Diagram Reduction Method

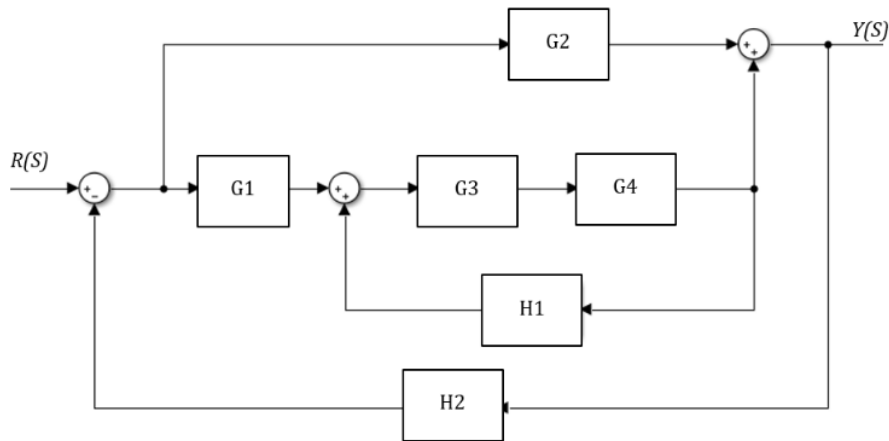


*Fig.8 – Block Diagram*

Fig.8 shows a block diagram with six individual transfer blocks with the 's' component removed for simplicity sake. Using the block diagram reduction method, the diagram will be reduced to a single transfer function finding an expression for T in terms of  $G_1$ ,  $G_2$ ,  $G_3$ ,  $G_4$ ,  $H_1$  and  $H_2$ . Once the transfer function is found selected values for 'a', 'b', 'c', and 'd' will be chosen and a final derivative of T will be found in terms of the complex frequency variable 's'.

Below are the transfer blocks for each part of the system that will be reduced as well as where the chosen values will go.

$$G_1 = a$$

$$G_2 = b$$

$$G_3 = c/(s + 1)$$

$$G_4 = 1/s$$

$$H_1 = 1/(s + 1)$$

$$H_2 = d$$

To simplify:

$$G_5 = G_3 G_4$$

$$G_6 = \frac{G_5}{1 - G_5 H_1}$$

$$G_7 = G_6 G_1 + G_2$$

H1 is positive feedback and H2 is negative feedback:

$$T = \frac{G_7}{1 + G_7 H_2}$$

$$T = \frac{G_6 G_1 + G_2}{1 + (G_6 G_1 + G_2) H_2}$$

$$T = \frac{G_6 G_1 + G_2}{1 + H_2 G_6 G_1 + H_2 G_2}$$

$$T = \frac{\left(\frac{G_5}{1 - G_5 H_1}\right) G_1 + G_2}{1 + H_2 \left(\frac{G_5}{1 - G_5 H_1}\right) G_1 + H_2 G_2}$$

Multiplying  $1 - G_5 H_1$  into numerator:

$$T = \frac{G_5 G_1 + G_2 (1 - G_5 H_1)}{(1 - G_5 H_1) + H_2 G_5 G_1 + H_2 G_2 (1 - G_5 H_1)}$$

$$T = \frac{G_5 G_1 + G_2 - G_2 G_5 H_1}{1 - G_5 H_1 + H_2 G_5 G_1 + H_2 G_2 - H_2 G_2 G_5 H_1}$$

$$T = \frac{(G_3 G_4) G_1 + G_2 - G_2 (G_3 G_4) H_1}{1 - (G_3 G_4) H_1 + H_2 (G_3 G_4) G_1 + H_2 G_2 - H_2 G_2 (G_3 G_4) H_1}$$

$$T = \frac{G_3 G_4 G_1 + G_2 - G_2 G_3 G_4 H_1}{1 - G_3 G_4 H_1 + H_2 G_3 G_4 G_1 + H_2 G_2 - H_2 G_2 G_3 G_4 H_1}$$

Using this formula the transfer function can be found.

Entering chosen Values into equation:

$$G1 = 5$$

$$G2 = 2$$

$$G3 = 2/s + 1$$

$$G4 = 1/s$$

$$H1 = 1/s + 1$$

$$H2 = 2$$

$$T = \frac{(\frac{2}{s+1} \times \frac{1}{s} \times 5) + (2)(-2 \times \frac{2}{s+1} \times \frac{1}{s} \times \frac{1}{s+1})}{1 - (\frac{2}{s+1} \times \frac{1}{s} \times \frac{1}{s+1}) + (2 \times \frac{2}{s+1} \times \frac{1}{s} \times 5) + (2 \times 2) - (2 \times 2 \times \frac{2}{s+1} \times \frac{1}{s} \times \frac{1}{s+1})}$$

$$T = \frac{\frac{10}{s(s+1)} + 2 - \frac{4}{s(s+1)^2}}{1 - \left(\frac{2}{s(s+1)^2}\right) + \frac{20}{s(s+1)} + 4 - \frac{8}{s(s+1)^2}}$$

$$T = \frac{(10(s+1)) + 2s(s+1)^2 - 4}{s(s+1)^2 - 2 + 20(s+1) + 4s(s+1)^2 - 8}$$

$$T = \frac{2s^3 + 4s^2 + 12s + 6}{5s^3 + 10s^2 + 25s + 10}$$

Using this new transfer function and the values chosen a Simulink model can be created as seen below in Fig.9.

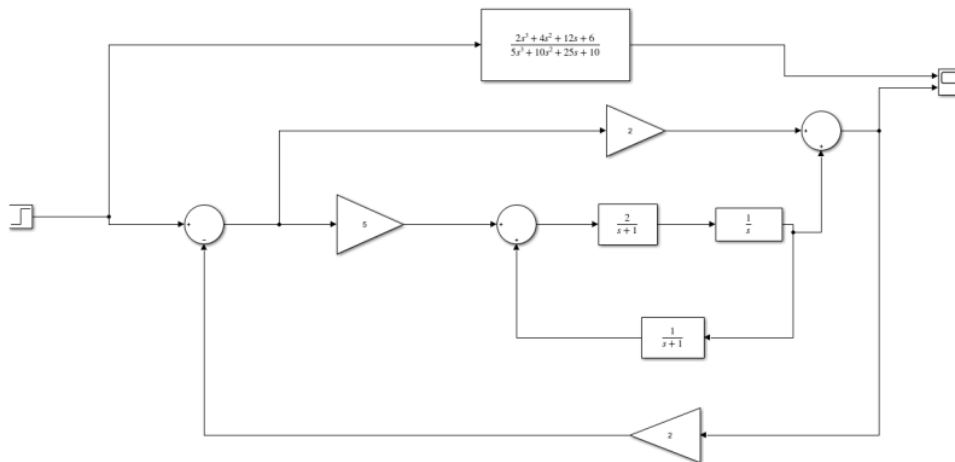


**Fig.9 – Block Diagram Simulink Model**

Using the Simulink probe and adding a step input, when run the model of the block diagram in parallel with the calculated transfer function gives the following response in Fig.10. This proves the reduction method is correct as both responses are identical.

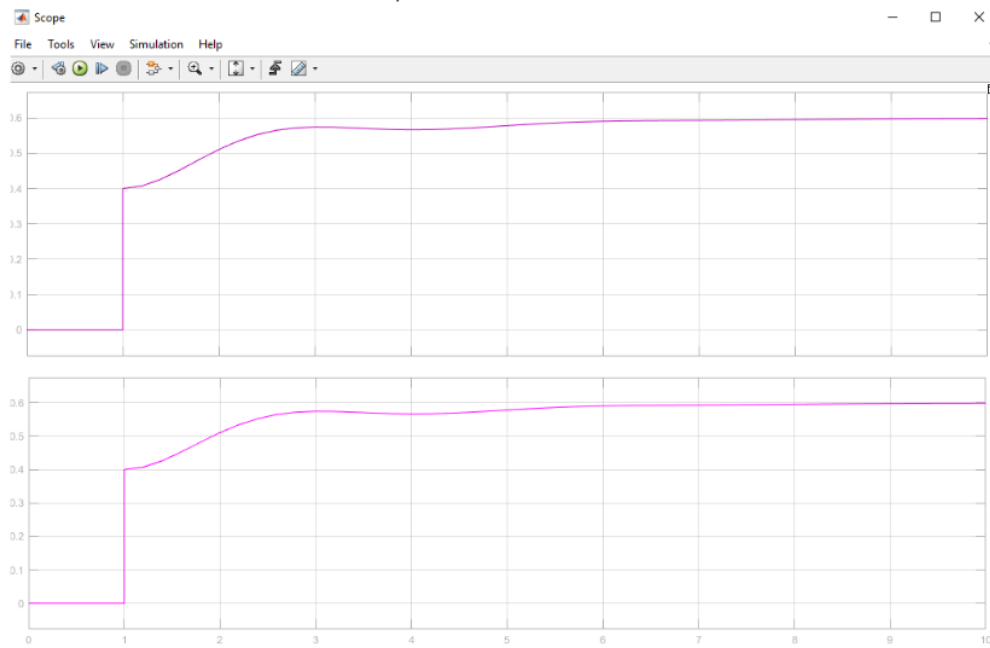


**Fig.10 – Transfer Function Response Graph**

Furthermore, MATLAB allows us to find the poles and zeroes of the system as seen earlier.

```
>> s = tf('s');  
>> system1 = (2*s^3 + 4*s^2 + 12*s + 6)/(5*s^3 + 10*s^2 + 25*s + 10)
```

```
system1 =
```

$$\frac{2 s^3 + 4 s^2 + 12 s + 6}{5 s^3 + 10 s^2 + 25 s + 10}$$

Continuous-time transfer function.

```
>> pole (system1)
```

```
ans =
```

```
-0.7666 + 1.9227i  
-0.7666 - 1.9227i  
-0.4668 + 0.0000i
```

```
>> zero (system1)
```

```
ans =
```

```
-0.7102 + 2.1616i  
-0.7102 - 2.1616i  
-0.5795 + 0.0000i
```

*Fig.11 – Block Diagram Poles and Zeroes*

Running step response as seen in Fig.12 it can be observed the system is slightly underdamped.

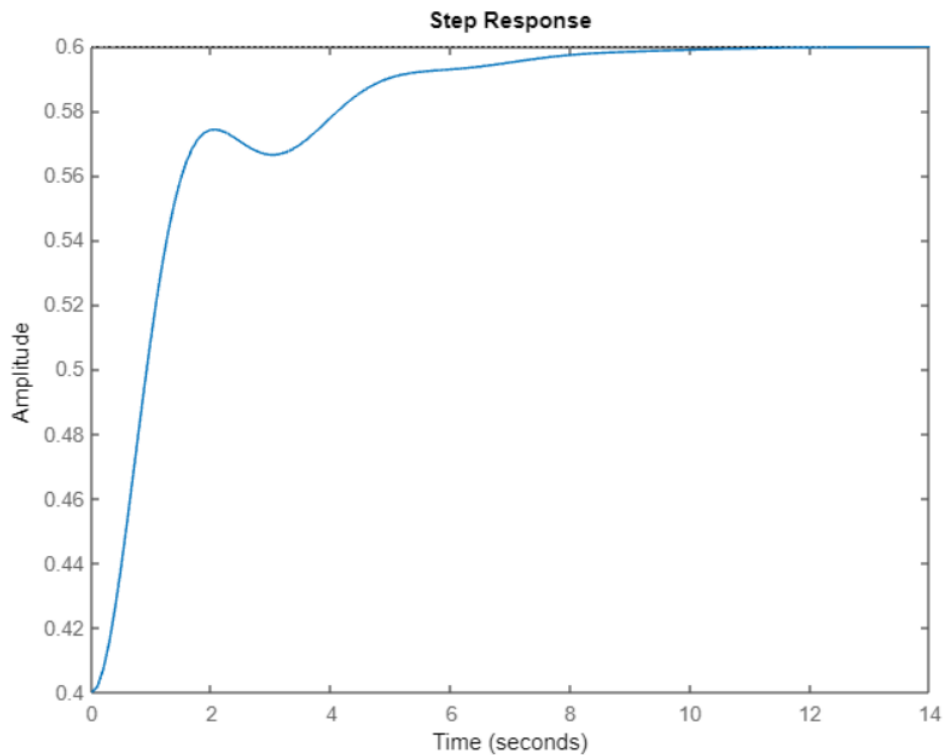


*Fig.12 – Block Diagram Step Response*

This task proves that the block diagram method is a viable source for analysing control systems and deriving the transfer function to enable critical analysis. Once again MATLAB has provided a useful barometer for not only analysing control systems but validating results.

## 5. Frequency Response Method

Within this task the frequency response method for control analysis will be undertaken

This task will focus on a control system that has the following transfer function:

$$G(S) = \frac{k(s + p)}{(s + q)(s + r)}$$

Selecting values for p, q and r and inserting into transfer function.

$$p = 4$$

$$q = 10$$

$$r = 200$$

$$G(s) = \frac{K(s + 4)}{(s + 10)(s + 200)}$$

Assuming that the overall gain is 1.

$$K = \frac{k \times p}{q \times r}$$

$$1 = \frac{k \times 4}{10 \times 200}$$

Therefore:

$$4 \times k = 2000$$

$$\frac{2000}{4} = k$$

$$k = 500$$

New Transfer function:

$$G(s) = \frac{500(s + 4)}{(s + 10)(s + 200)} = \frac{500s + 2000}{s^2 + 210s + 2000}$$

Entering this transfer function into MATLAB and plotting the bode response give the following responses.

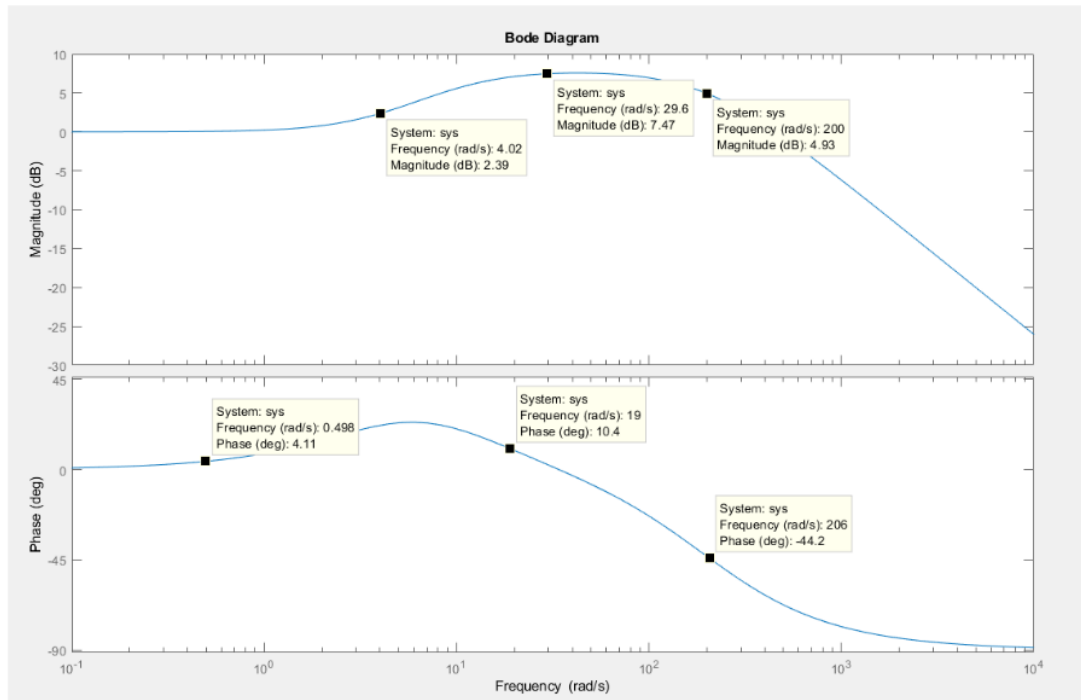


*Fig.13 – Frequency Response Phase and Magnitude Responses*

From this experiment we can conclude that that bode diagrams are useful for analysing control system responses in the frequency domain in terms of their phase and magnitude.

*Little analysis and no calculation of phase margin*

## 6. Digital Control Systems

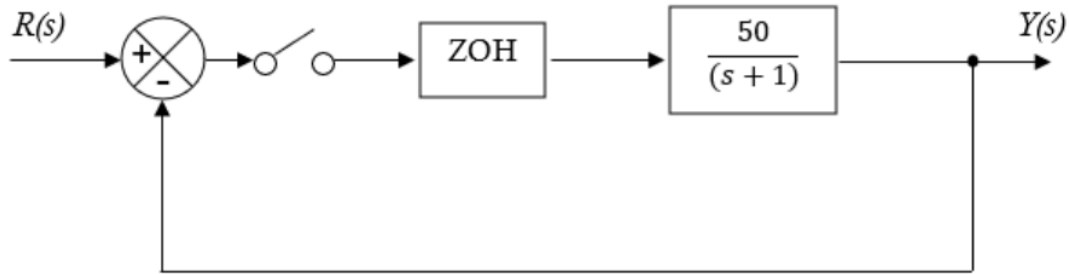


*Fig.14 – Digital Control System*

Fig.14 shows a digital control system in block form, using calculations the minimum sampling frequency can be found for stability within the z-plane. In line with the ethos of this assignment the calculated results will be compared to simulated values to ensure repeatability and accuracy.

ZOH Laplace transform:

$$ZOH = \frac{1 - e^{-sT}}{s}$$

For an open loop transfer function:

$$G(s) = \frac{1 - e^{-sT}}{s} \times \frac{50}{(s + 1)}$$

To produce Z transforms given that  $z = e^{sT}$

$$G(z) = z\{G(s)\}$$

$$G(z) = (1 - z^{-1})50z\left\{\frac{1}{s(s + 1)}\right\}$$

Then with partial fractions method:

$$\frac{1}{s(s + 1)} = \frac{A}{s} + \frac{B}{s + 1}$$

Combining A and B fractions

$$\frac{1}{s(s + 1)} = \frac{A(s + 1) + Bs}{s(s + 1)}$$

$$1 = A(s + 1) + Bs$$

When  $s = 0$

$$A = 1$$

When  $s = -1$

$$B = -1$$

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

$$\begin{aligned} z \left\{ \frac{1}{s(s+1)} \right\} &= z \left\{ \frac{1}{s} - \frac{1}{s+1} \right\} \\ &= 1z \left\{ \frac{1}{s} - \frac{1}{s+1} \right\} \end{aligned}$$

Using the z transfer table:

$$= \left\{ \frac{z}{z-1} - \frac{z}{z-e^{-T}} \right\}$$

$$G(z) = (1 - z^{-1})50 \times 1z \left\{ \frac{z - e^{-T} - z + 1}{(z-1)(z-e^{-T})} \right\}$$

$$G(z) = \left( \frac{z-1}{z} \right) 50 \times 1z \left\{ \frac{1 - e^{-T}}{(z-1)(z-e^{-T})} \right\}$$

$$G(z) = \frac{50(1 - e^{-T})}{z - e^{-T}}$$

$$T(z) = \frac{G(z)}{1 + G(z)}$$

$$T(z) = \frac{\left( \frac{50(1 - e^{-T})}{z - e^{-T}} \right)}{1 + \frac{50(1 - e^{-T})}{z - e^{-T}}}$$

$$\frac{50(1 - e^{-T})}{z - e^{-T} + 50(1 - e^{-T})}$$

$$\frac{50(1 - e^{-T})}{z + 50 - 51e^{-T}}$$

To find the pole:

$$z + 50 - 51e^{-T} = 0 \quad \text{therefore,} \quad z = 51e^{-T} - 50$$

$$-1 < z < 1$$

Z=1:

$$1 = 51e^{-T} - 50$$

$$51 = 51e^{-T}$$

$$e^{-T} = \frac{51}{51} = 1$$

Logs to the base e:

$$-T = \ln(1)$$

$$T = \frac{0}{-1}$$

$$T = 0 \text{ seconds}$$

Z=-1:

$$-1 = 51e^{-T} - 50$$

$$49 = 51e^{-T}$$

$$e^{-T} = \frac{49}{51} = 0.9607$$

Natural log:

$$-T = -0.04$$

$$T = 0.04 \text{ seconds}$$

$$\text{Maximum sampling period} = 40 \text{ milliseconds}$$

$$\text{Minimum sampling period} = \frac{1}{0.04} = 25\text{Hz}$$

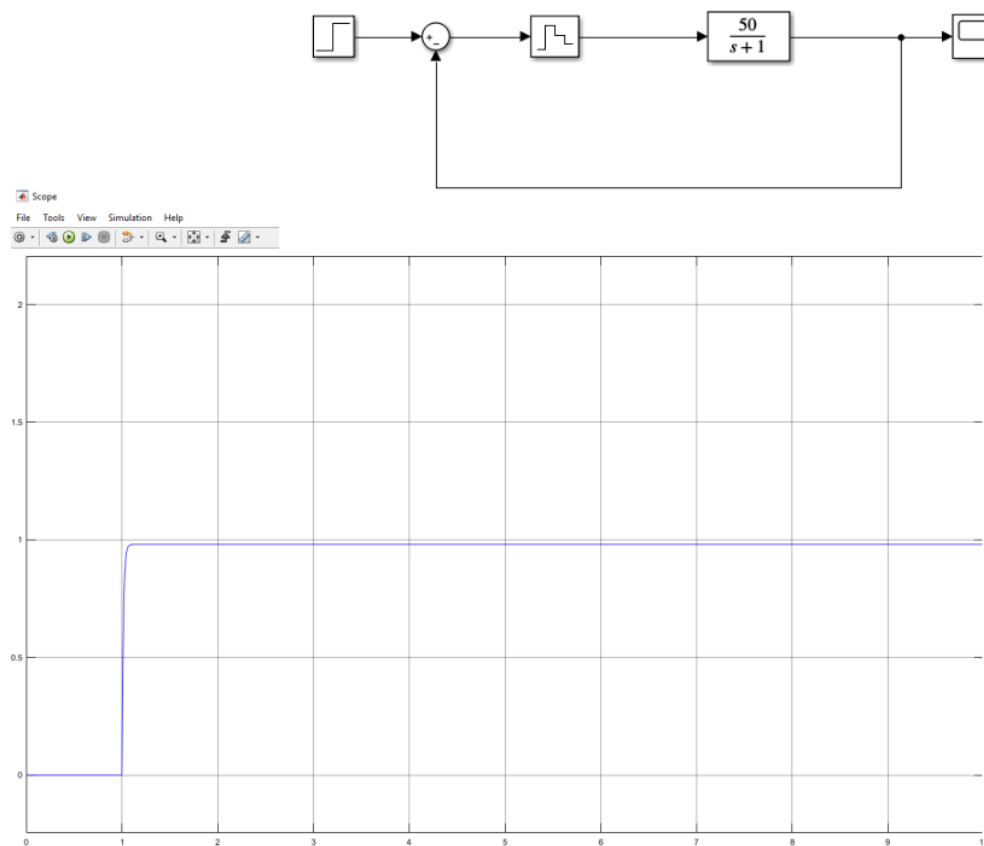


*Fig.15 – Digital Control System Simulation*

We can see that from entering the calculated values for the sampling period that when the step input for the block diagram is run the response from the probe shows us that the system is critically stable and possesses no oscillation. This ensures our calculated results are correct and repeatable.

*Little analysis, you could have shown the response below and at the critical sampling frequency*

## 7. Conclusion and Overall Recommendations

This assignment overall was an insightful demonstration into the application of control systems and how to effectively derive their transfer functions and make sound assessments on their behaviour. Furthermore the assignment allowed a critical analysis of how stimulatory software enables engineers to effectively predict a systems behaviour and even proof check their calculated results. As was observed during the report the MATLAB results often aligned with the calculated response values which not only means that the simulations were accurate but that the various methods to ascertain transfer functions are suitable for engineers to use. Further recommendations to the aspects of the report are that further analysis could have been done on the frequency response task, as that section lacks detail and could further be explained. A possible improvement to amend into the assignment would be a practical analysis and implementation of theoretical and simulated values onto a physical control rig to observe and compare calculated and practical methods of evaluation in a real engineering environment.

*Mainly descriptive, shows little of what you have learned.*

## 8. Appendix

### Appendix 1 – Transient Response of a Second Order System Calculations.

Reducing to a single transfer function by multiplying both the numerator and denominator by  $s(s+4)$ :

$$T(s) = \frac{\frac{10}{s(s+2)}}{1 + \frac{10}{s(s+2)} \times 1} = \frac{10}{s(s+2) + 10} = \frac{10}{s^2 + 2s + 10}$$

Using the standard transfer function for second order circuits, the natural frequency can be solved:

$$\frac{10}{s^2 + 2s + 10} \text{ compares to } \frac{K\omega_n^2}{s^2 + 2\Sigma\omega_n s + \omega_n^2}$$

From this,

$$\omega_n^2 = 10 \quad \text{therefore,} \quad \omega_n = \sqrt{10} = 3.16 \text{ rad/s}$$

$$K\omega_n^2 = 10 \text{ and } \omega_n^2 = 10 \quad \text{therefore } K = 1$$

From the comparison of the transfer functions above, the damping factor is:

$$2\Sigma\omega_n = 2$$

$$\Sigma = \frac{2}{2\omega_n} = \frac{2}{2 \times 3.16} = 0.316$$

Which is underdamped

To work out the damped frequency:

$$\omega = \omega_n \sqrt{1 - \Sigma^2}$$

$$\omega = 3.16 \sqrt{1 - 0.316^2} = 2.998 \text{ rad/s}$$

Rise time:

$$t_r = \frac{\pi}{2 \times 3.16 \sqrt{1 - 0.316^2}} = 0.523$$

Or

$$t_r = \frac{\pi - \tan^{-1}\left(\frac{\sqrt{1-0.316^2}}{0.316}\right)}{3.16} = 0.5988$$

Peak time:

$$t_p = \frac{\pi}{3.16\sqrt{1-0.316^2}} = 1.04 \text{ seconds}$$

Percentage overshoot:

$$\text{Percentage overshoot} = 100 e^{-\left(\frac{-0.316\pi}{\sqrt{1-0.316^2}}\right)} = 33.2\%$$

Settling time within 2%:

$$t_s(2\%) = \frac{4}{0.316 \times 3.16} = 4 \text{ seconds}$$

To work out the number of oscillations during the settling time:

$$n = \frac{2}{\pi} \sqrt{\frac{1}{\Sigma^2}} - 1 = \frac{2}{\pi} \sqrt{\frac{1}{0.316^2}} - 1 = 1.911$$

Appendix 2 – Control System Modelling Calculations.

Chosen Values:

$$\frac{d^2y}{dt^2} + 1 \frac{dy}{dt} + 4y = \frac{d^2x}{dt^2} - 1 \frac{dx}{dt} + 4x$$

dy Laplace Transform:

$$\mathcal{L} \left\{ \frac{d^2y}{dt^2} + a \frac{dy}{dt} + by \right\} = s^2 Y(s) + as Y(s) + bY(s), \text{ where } Y(0) = 0$$

dx Laplace Transform:

$$\mathcal{L} \left\{ \frac{d^2x}{dt^2} - p \frac{dx}{dt} + qx \right\} = s^2 X(s) - ps X(s) + qX(s), \text{ where } X(0) = 0$$

With the chosen values entered these equations become:

$$\mathcal{L} \left\{ \frac{d^2y}{dt^2} + 4 \frac{dy}{dt} + 1y \right\} = s^2 Y(s) + 4s Y(s) + Y(s), \text{ where } Y(0) = 0$$

And:

$$\mathcal{L} \left\{ \frac{d^2x}{dt^2} - 1 \frac{dx}{dt} + 4x \right\} = s^2 X(s) - 1s X(s) + 4X(s), \text{ where } X(0) = 0$$

The equation becomes:

$$s^2 Y(s) + 4s Y(s) + Y(s) = s^2 X(s) - 1s X(s) + 4X(s)$$

This is factorised to become:

$$Y(s)[s^2 + 4s + 1] = X(s)[s^2 - 1s + 4]$$

$$\frac{Y(s)}{X(s)} = \frac{s^2 - 1s + 4}{s^2 + 4s + 1}$$

$$G(s) = \frac{s^2 - 1s + 4}{s^2 + 4s + 1}$$

The systems poles are found:

$$s = \frac{-b \pm \sqrt{(b)^2 - 4(ac)}}{2(a)} = \frac{-4 \pm \sqrt{(4)^2 - 4(1 \times 1)}}{2(1)} = -0.2679, -3.732$$

The systems Zeros are found:

$$s = \frac{-b \pm \sqrt{(b)^2 - 4(ac)}}{2(a)} = \frac{-(-1) \pm \sqrt{(-1)^2 - 4(1 \times 4)}}{2(4)} = 0.5 \pm j 1.936$$

1809800

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GRADEMARK REPORT

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FINAL GRADE

GENERAL COMMENTS

Instructor

59/100

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PAGE 1

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PAGE 2

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PAGE 3

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PAGE 4

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**Text Comment.** A good summary

PAGE 5

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PAGE 6

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PAGE 7

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**Text Comment.** the overdamping is because they are on the real axis

**Text Comment.** you have mixed up your symbols

**Text Comment.** poles are normally represented by crosses

**Text Comment.** zeros are represented as circles

PAGE 8

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PAGE 9

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PAGE 10

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PAGE 11

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PAGE 12

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PAGE 13

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PAGE 14

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PAGE 15

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PAGE 16

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PAGE 17

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PAGE 18

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PAGE 19

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PAGE 20

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**Text Comment.** Little analysis and no calculation of phase margin

PAGE 21

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PAGE 22

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PAGE 23

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PAGE 24

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**Text Comment.** Little analysis, you could have shown the response below and at the critical sampling frequency

PAGE 25

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**Text Comment.** Mainly descriptive, shows little of what you have learned.

PAGE 26

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PAGE 27

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PAGE 28

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PAGE 29

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GRADING FORM: NEW CSG-RUBRIC

IWAN COSTELLODOWNS

## 1. ENGAGEMENT WITH LITERATURE



N/A

## 2. KNOWLEDGE AND UNDERSTANDING



Knowledge is reasonably extensive. Exhibits very competent critical understanding of the well-established concepts and principles of the subject and the main methods of enquiry. Breadth and depth of knowledge. (13/20)

13

## 3. COGNITIVE AND INTELLECTUAL



Some critical evaluation and analysis of concepts and principles, though descriptive in parts. An emerging awareness the limits of their knowledge and ability to use evidence to support the argument though with some tendency to assert/state opinion rather than argue on the basis of reason and evidence. Mostly valid arguments and logical judgements. (15/30)

15

## 4. PRACTICAL APPLICATION



A very good application of a range of established methods, materials, tools and/or techniques. Very good consideration of the context of the application, with perceptive insights. Consistent, accurate and logical application of theory to practice, making appropriate links between the two. Can identify problems and propose appropriate solutions outside the context in which they were first studied. Evidence of some creativity. (19/30)

19

## 5. TRANSFERABLE SKILLS



Can communicate well, confidently and consistently in a suitable medium for the audience. Work is coherent, fluent, well-structured and organised. Can work very well autonomously and/or as part of a team, with very good contribution to group activities. Demonstrates very good skills for employment requiring the exercise of personal responsibility and decision-making, with just occasional minor weakness. (12/20)

12