DESIGN PROJECT:

DESIGN OF DIGITAL CONTROLLER FOR THE MODIFIED ACC BENCHMARK PROBLEM

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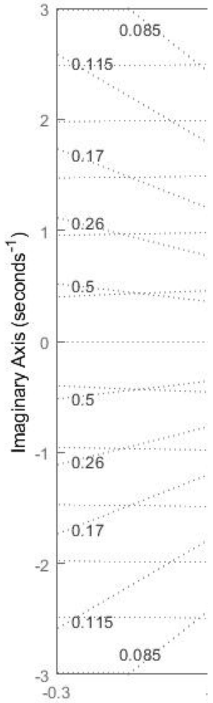
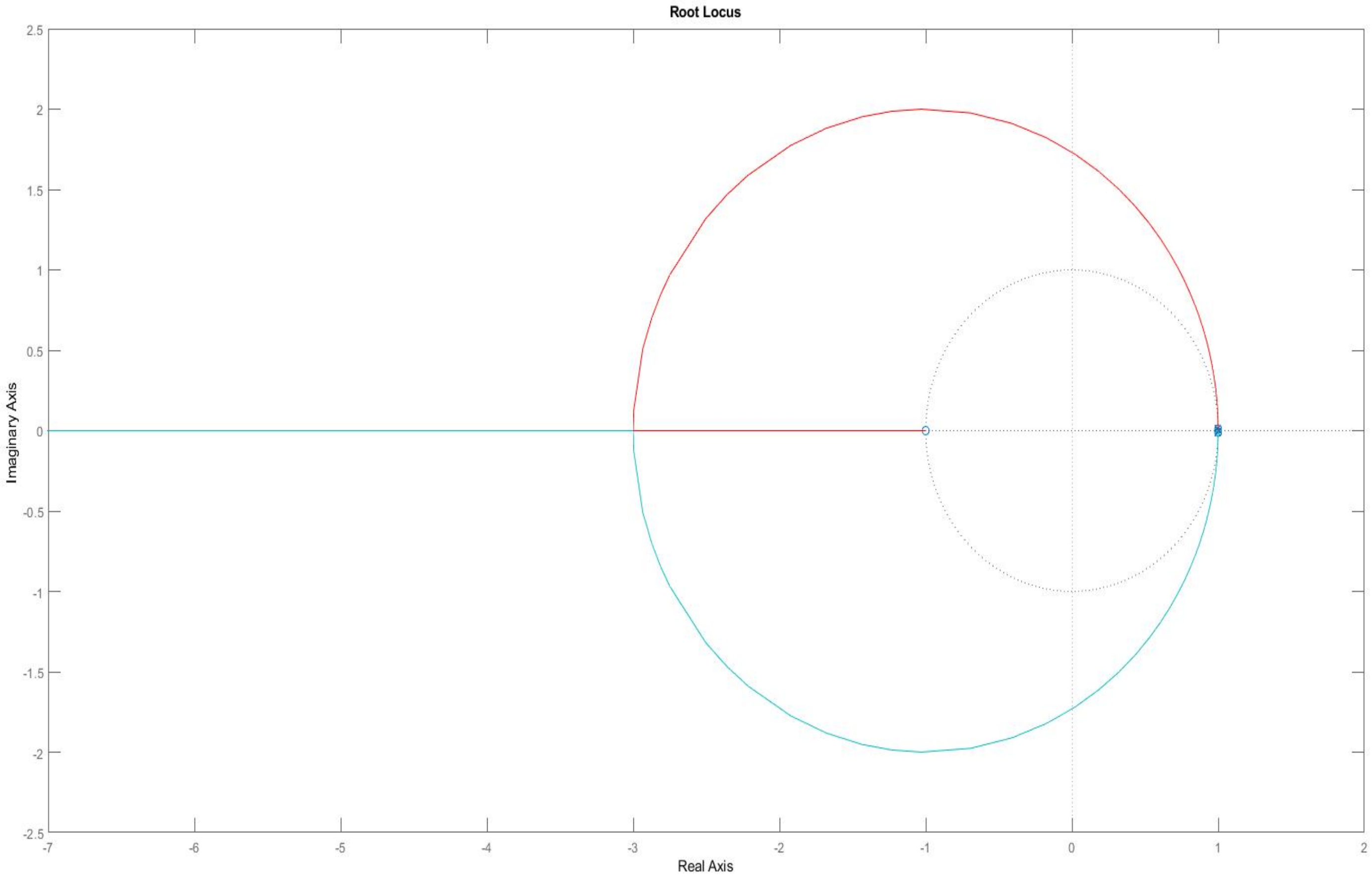
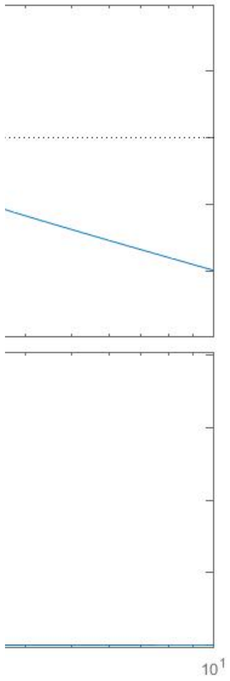
PLANT DESCRIPTION

Collocated Transfer Function

$$G_c = \frac{1}{s^2} \cdot \frac{s^2 + 0.004s + 1}{s^2 + 0.008s + 2} \xrightarrow[T_s = 0.01s]{\text{Zero Order Hold}} G_{c,d} = \frac{5z^{-1} - 4 \cdot 999z^{-2} - 4 \cdot 999z^{-3} + 5z^{-4}}{1 - 4z^{-1} + 5 \cdot 999z^{-2} - 4z^{-3} + z^{-4}} \times 10^{-5}$$



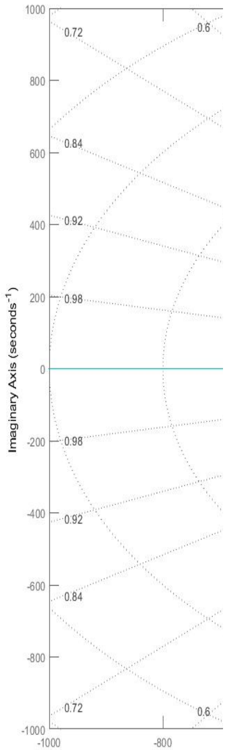


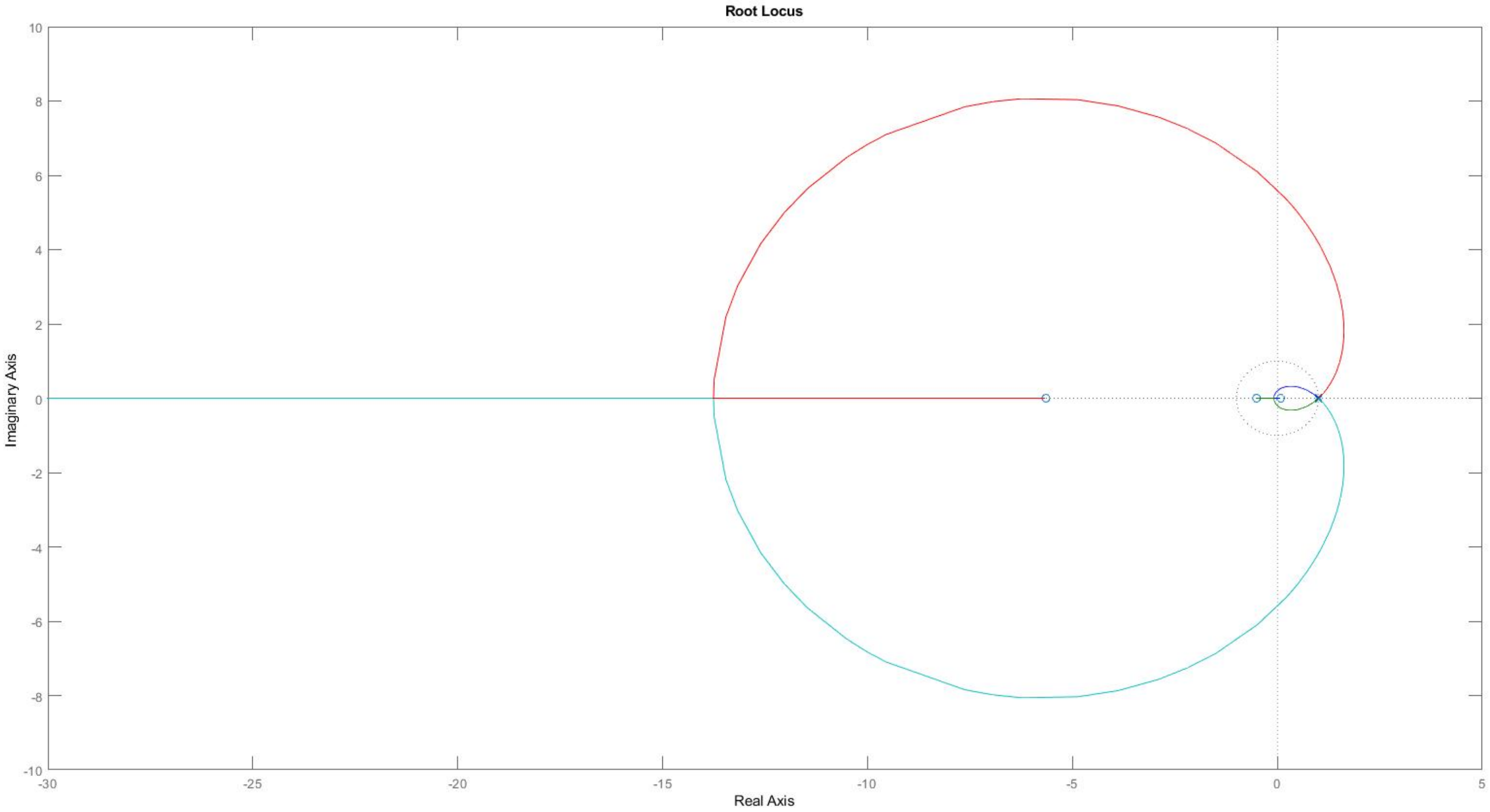


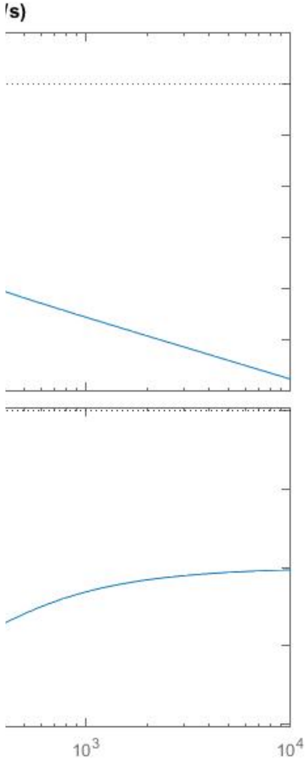
PLANT DESCRIPTION

Non-Collocated Transfer Function

$$G_{nc} = \frac{1}{s^2} \cdot \frac{0.004s + 1}{s^2 + 0.008s + 2} \xrightarrow[T_s\,=\,0.01s]{\text{Zero Order Hold}} G_{\text{nc},d} = \frac{1.083z^{-1} + 6.583z^{-2} + 2.583z^{-3} + 0.25z^{-4}}{1 - 4z^{-1} + 5 \cdot 999z^{-2} - 4z^{-3} + z^{-4}} \times 10^{-9}$$







CHALLENGES

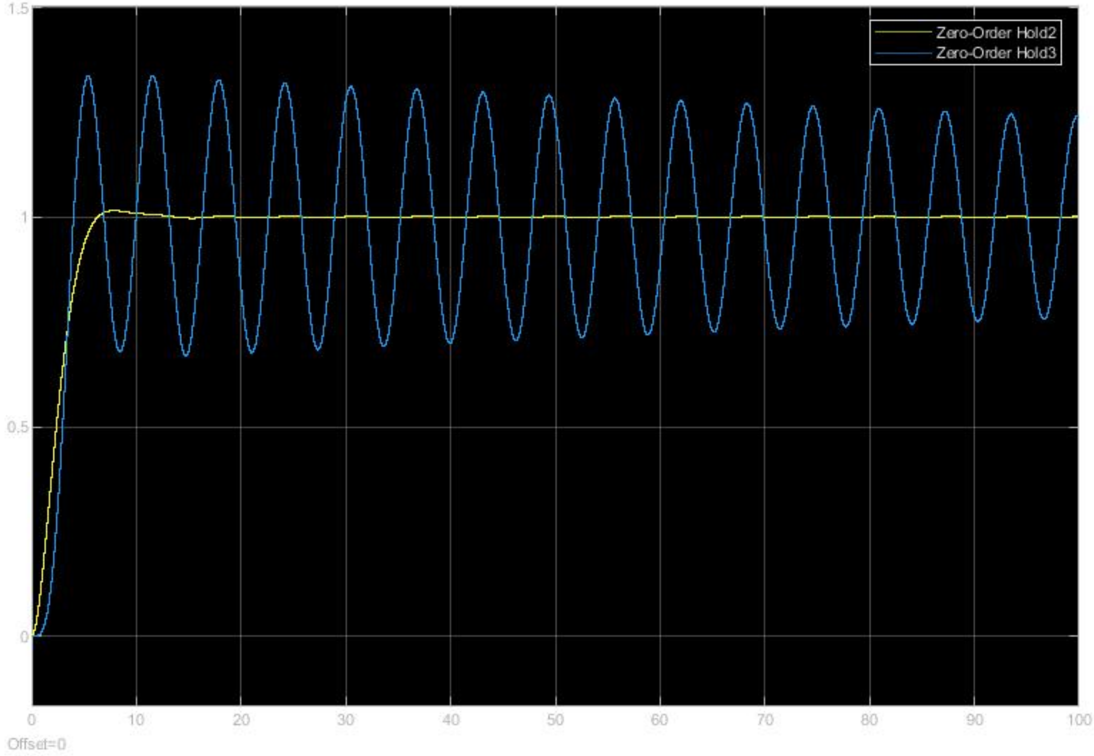
- Impulse disturbance exist on the non-collocated part of the system.
- Both the system have their poles and zeros very close to imaginary axis.
- Both plant margins are far from stable having negative high gain and phase margins.

DESIGN APPROACH

- Stabilizing the collocated and the non-collocated system using Proportional Gain with Velocity Feedback from the collocated response
- Still integrals tend to disturb the non-collocated system and make it more unstable, integral controller is not used.
- Using basic of design of PID Controllers, we tend to get the values for Kp and Kv.
- Hence iterating and simulating for obtained values from calculation as well as computing the nearby values, the best obtained results are from the values

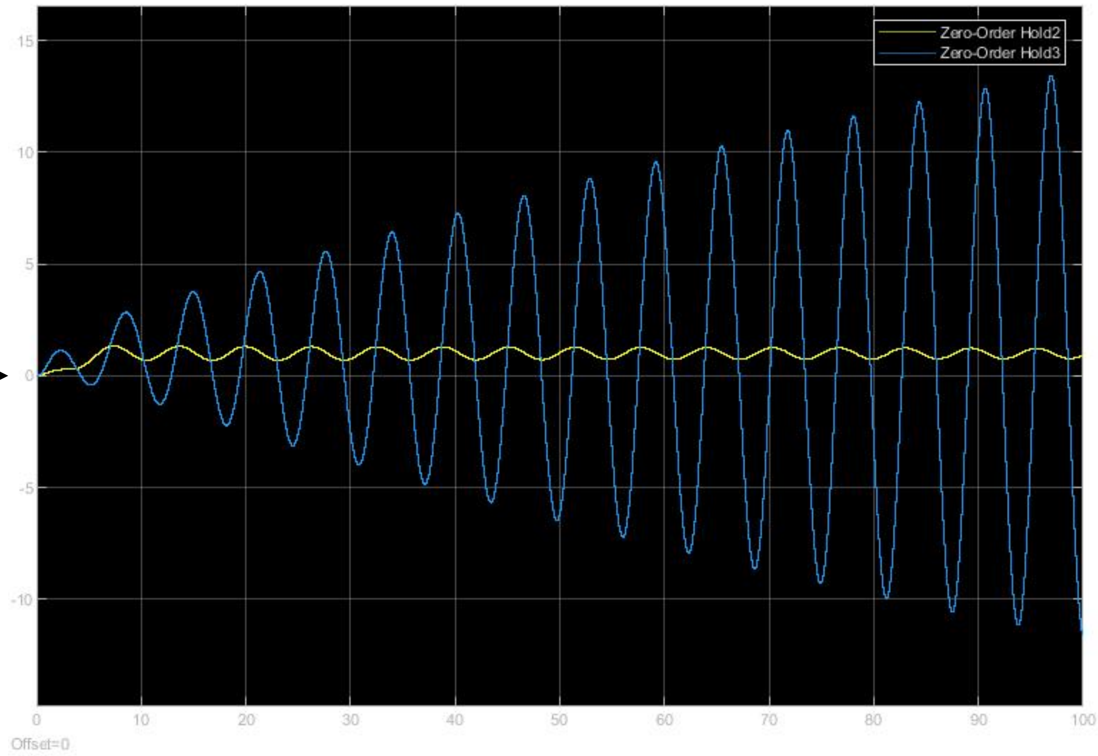
$$For\ k = 1$$
$$Kp = 0.4\ ; Kv = 1$$

Step Responses

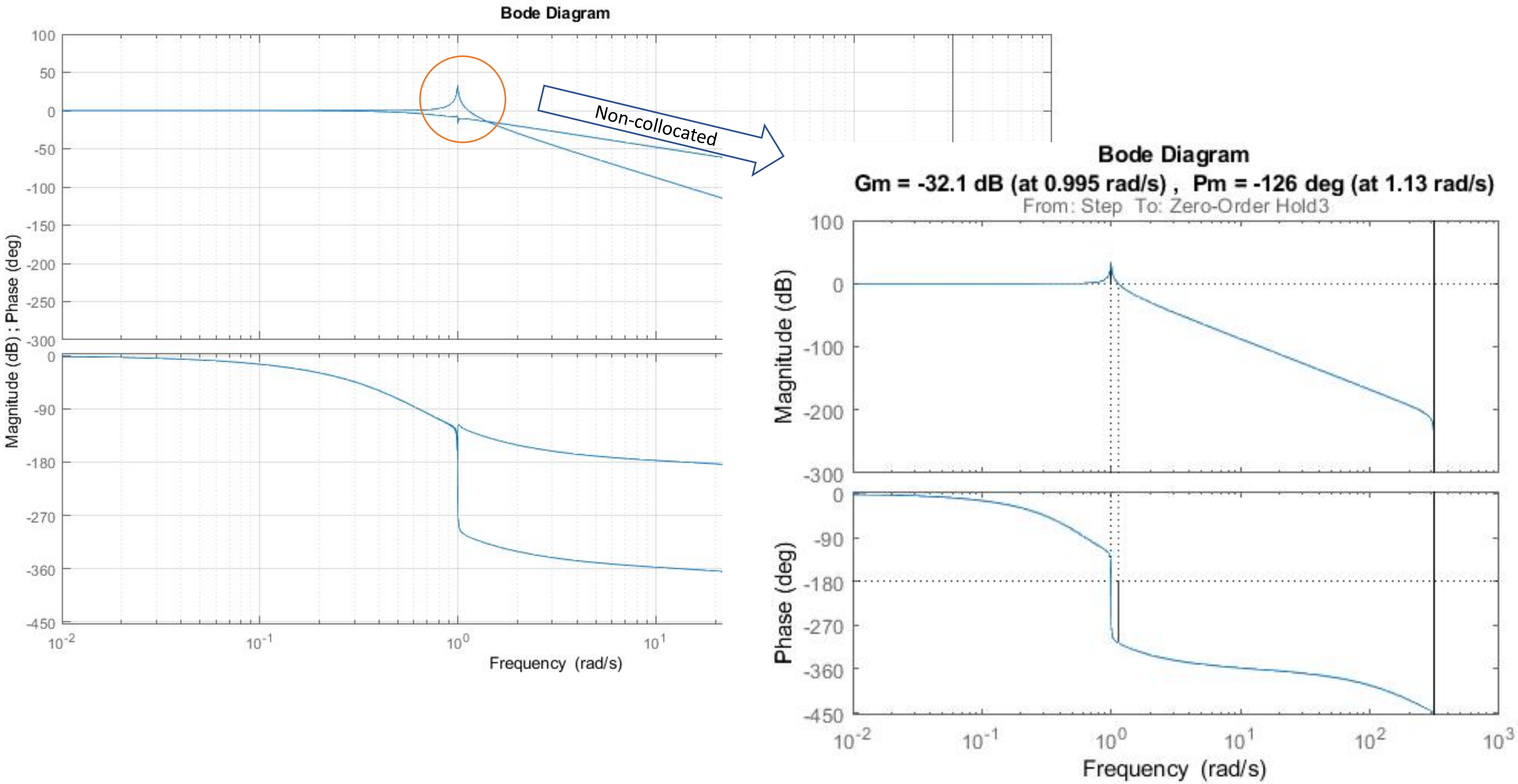


without impulse distubance

disturbance



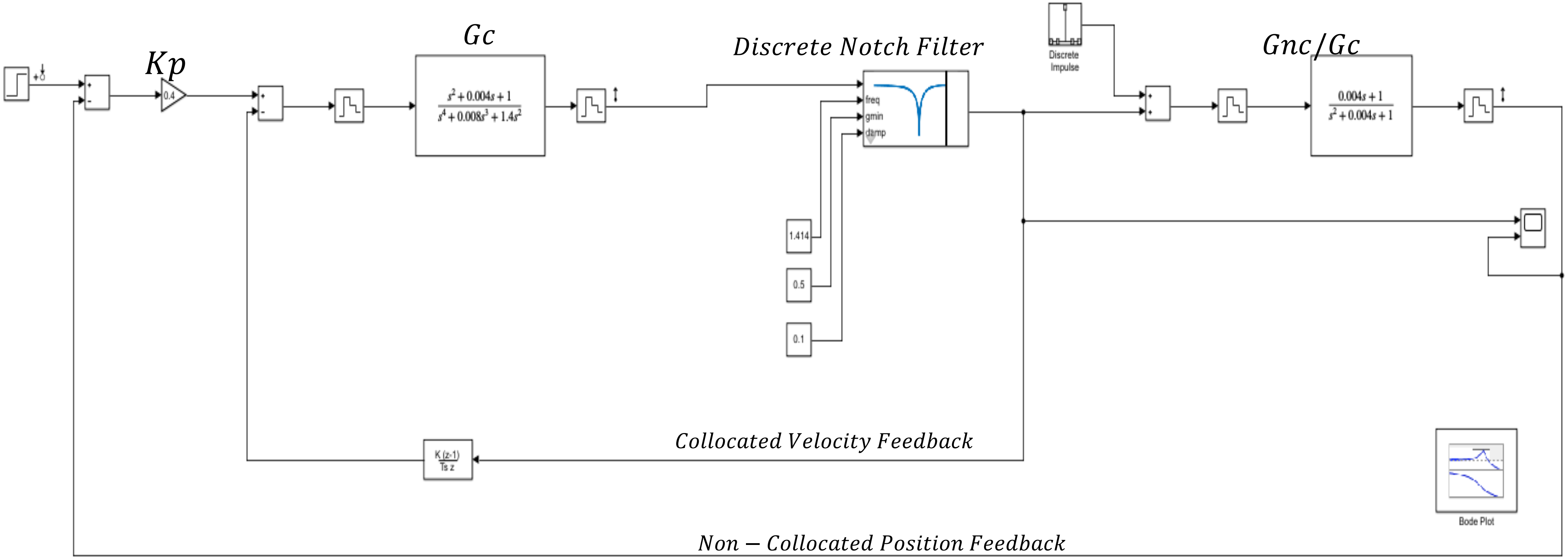
with impulse disturbance



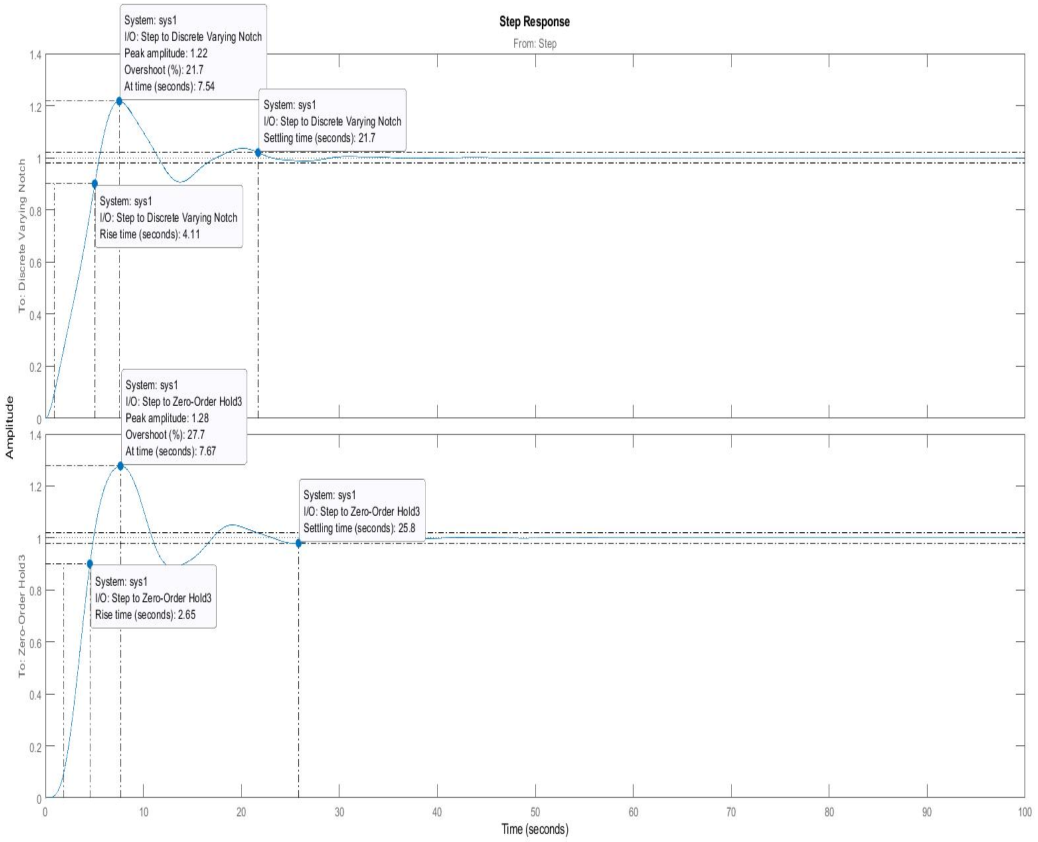
Complex Pole Pair Frequency which makes non − collocated unstable!!

SIMULATION BLOCK DIAGRAM

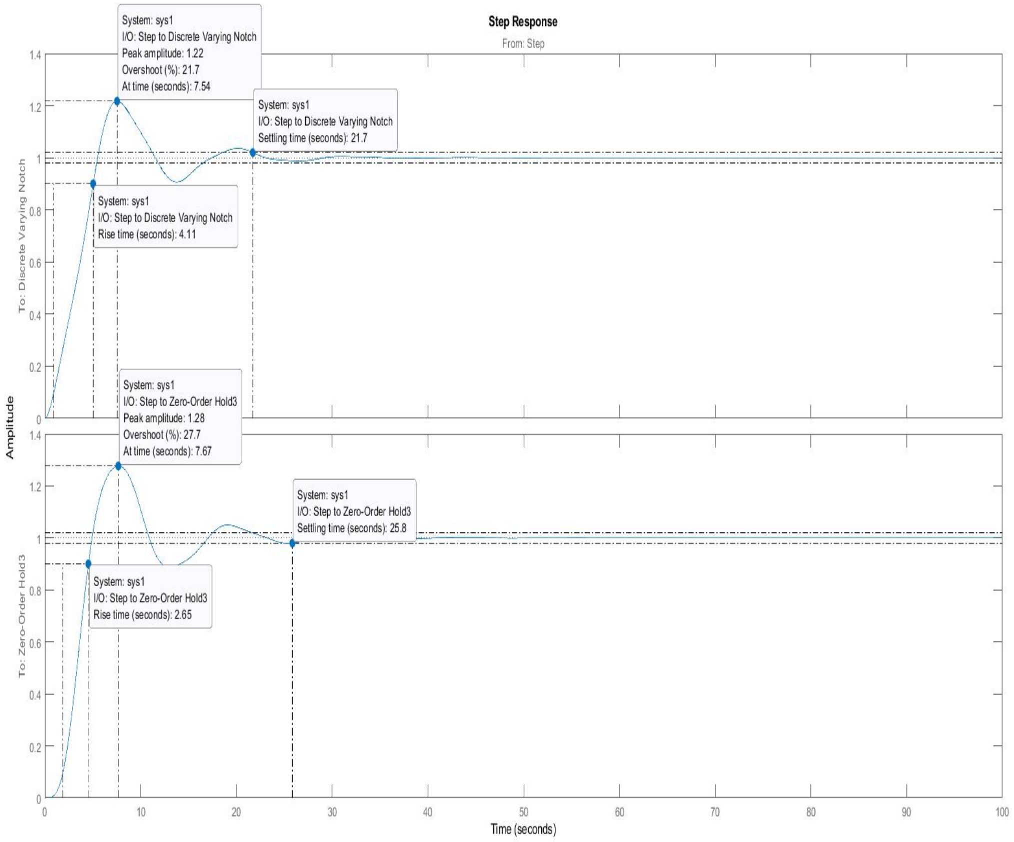
$PV\ Control + Notch\ Filter\ Block\ Diagram$



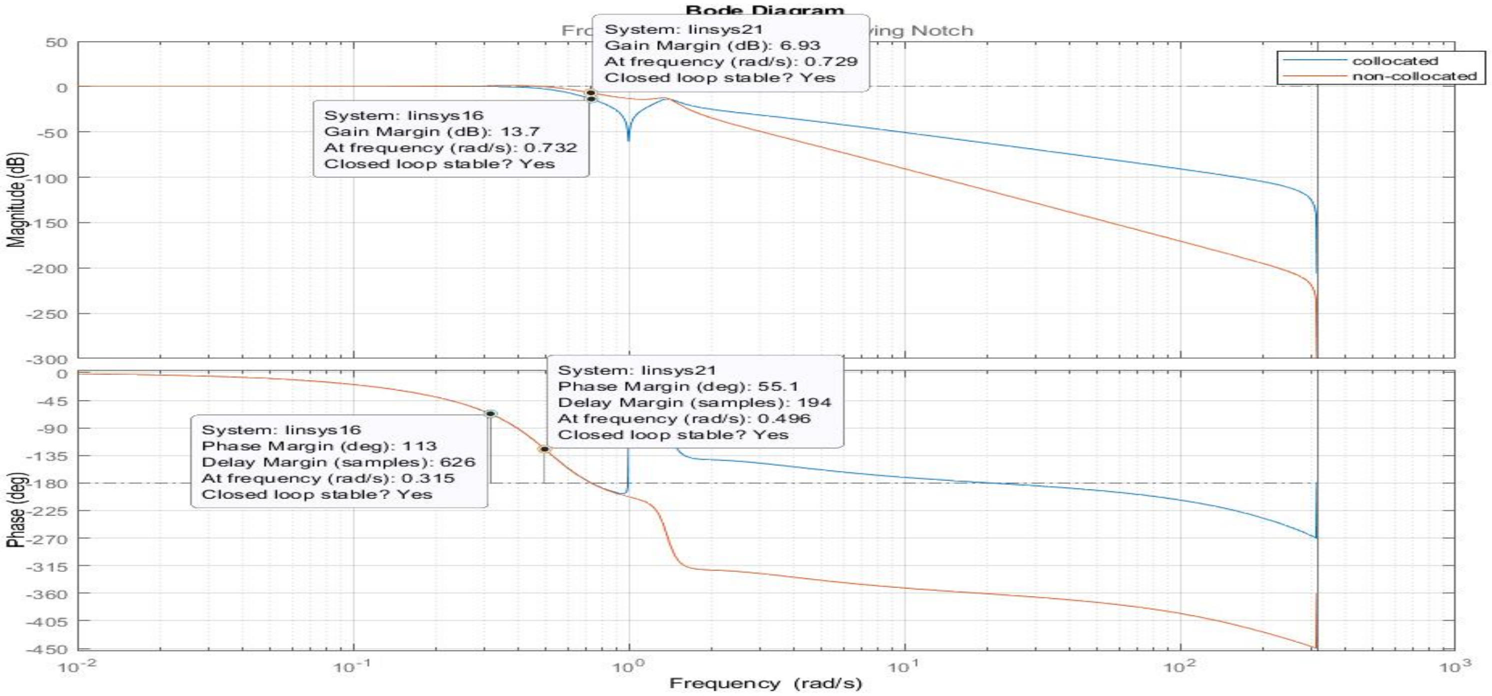
STEP RESPONSES



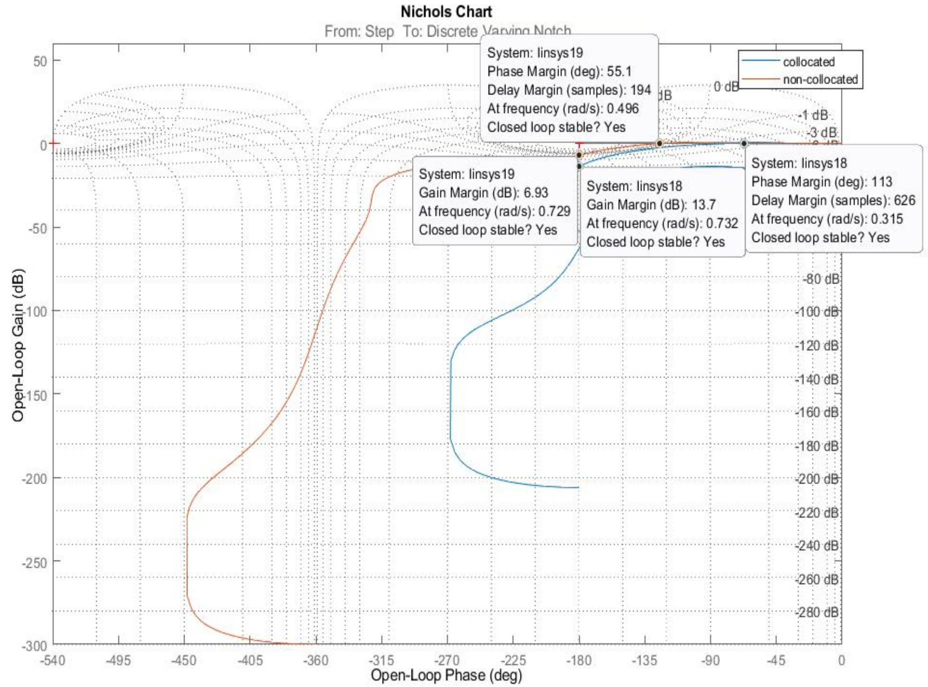
with impulse disturbance



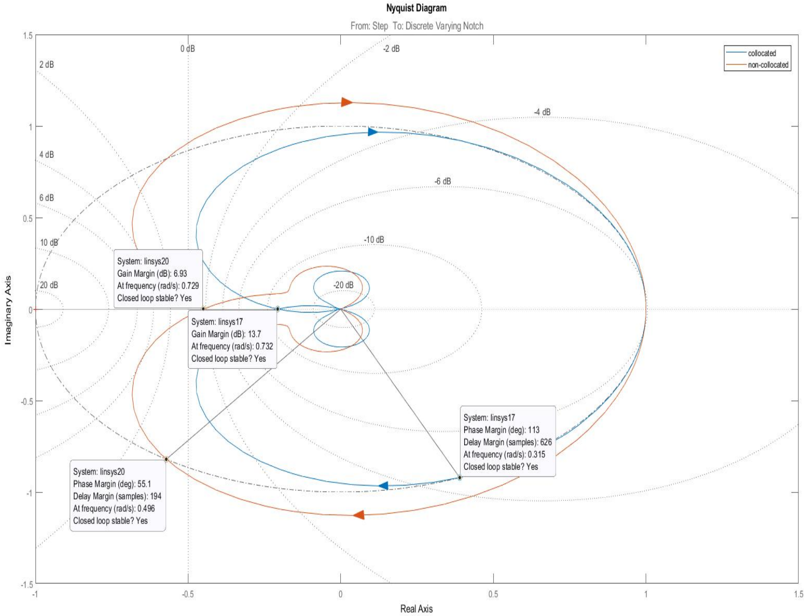
with white noise disturbance



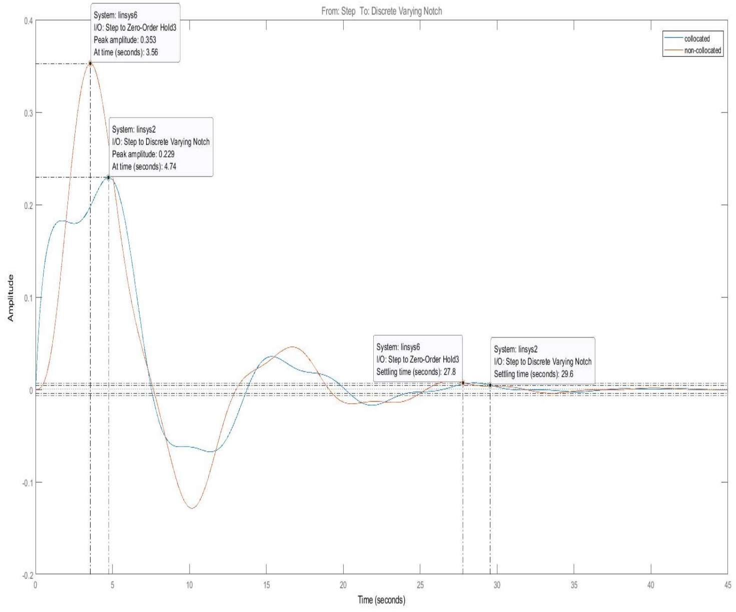
Bode Diagram
System: linsys21
Gain Margin (dB): 6.93
At frequency (rad/s): 0.729
Closed loop stable? Yes
collocated
non-collocated
System: linsys16
Gain Margin (dB): 13.7
At frequency (rad/s): 0.732
Closed loop stable? Yes
Magnitude (dB)
System: linsys21
Phase Margin (deg): 55.1
Delay Margin (samples): 194
At frequency (rad/s): 0.496
Closed loop stable? Yes
System: linsys16
Phase Margin (deg): 113
Delay Margin (samples): 626
At frequency (rad/s): 0.315
Closed loop stable? Yes
Phase (deg)
Frequency (rad/s)



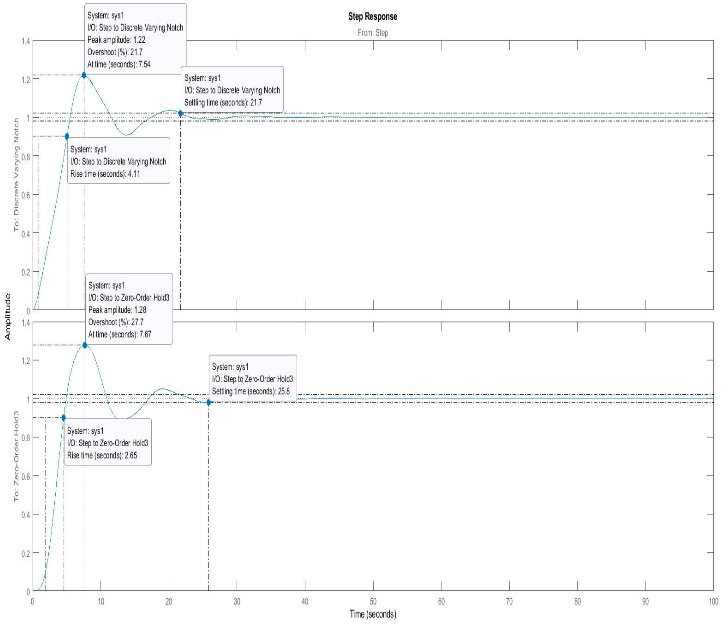
Nichols Chart
From: Step To: Discrete Varying Notch
System: linsys19
Phase Margin (deg): 55.1
Delay Margin (samples): 194
At frequency (rad/s): 0.496
Closed loop stable? Yes
collocated
non-collocated
System: linsys19
Gain Margin (dB): 6.93
At frequency (rad/s): 0.729
Closed loop stable? Yes
System: linsys18
Gain Margin (dB): 13.7
At frequency (rad/s): 0.732
Closed loop stable? Yes
System: linsys18
Phase Margin (deg): 113
Delay Margin (samples): 626
At frequency (rad/s): 0.315
Closed loop stable? Yes
Open-Loop Gain (dB)
Open-Loop Phase (deg)



Nyquist Diagram
From: Step To: Discrete Varying Notch
collocated
non-collocated
System: linsys20
Gain Margin (dB): 6.93
At frequency (rad/s): 0.729
Closed loop stable? Yes
System: linsys17
Gain Margin (dB): 13.7
At frequency (rad/s): 0.732
Closed loop stable? Yes
System: linsys17
Phase Margin (deg): 113
Delay Margin (samples): 626
At frequency (rad/s): 0.315
Closed loop stable? Yes
System: linsys20
Phase Margin (deg): 55.1
Delay Margin (samples): 194
At frequency (rad/s): 0.496
Closed loop stable? Yes
Imaginary Axis
Real Axis



From: Step To: Discrete Varying Notch
System: linsys6
I/O: Step to Zero-Order Hold3
Peak amplitude: 0.353
At time (seconds): 3.56
System: linsys2
I/O: Step to Discrete Varying Notch
Peak amplitude: 0.229
At time (seconds): 4.74
collocated
non-collocated
System: linsys6
I/O: Step to Zero-Order Hold3
Settling time (seconds): 27.8
System: linsys2
I/O: Step to Discrete Varying Notch
Settling time (seconds): 29.6
Amplitude
Time (seconds)



Step Response
From: Step
System: sys1
I/O: Step to Discrete Varying Notch
Peak amplitude: 1.22
Overshoot (%): 21.7
At time (seconds): 7.54
System: sys1
I/O: Step to Discrete Varying Notch
Settling time (seconds): 21.7
System: sys1
I/O: Step to Discrete Varying Notch
Rise time (seconds): 4.11
To: Discrete Varying Notch
System: sys1
I/O: Step to Zero-Order Hold3
Peak amplitude: 1.28
Overshoot (%): 27.7
At time (seconds): 7.67
System: sys1
I/O: Step to Zero-Order Hold3
Settling time (seconds): 25.8
System: sys1
I/O: Step to Zero-Order Hold3
Rise time (seconds): 2.65
To: Zero-Order Hold3
Amplitude
Time (seconds)

REQUIRED VS OBTAINED SPECIFICATION

Required

- Gain Margins ≥ 6 dB
- Phase Margin ≥ 30^0
- Mass #2 Settling time < 40s with impulse disturbance ‘d’

Obtained

- GM   Collocated =13.7 dB

  Non-Collocated= 6.93 dB
- PM   Collocated =113^0

  Non-Collocated= 55^0
- Mass #2 Settling time= 25.8 sec

SAMPLE DATA EFFECTS AND COMPENSATION

- The sampling data is set to $T_s=0.01s$ which satisfies Nyquist-Shannon theorem and also $T_s < P.M/\omega_c$(cross-over frequency) and it is well greater not to generate quantization errors.
- Since integral control is not used, hence the compensation for $z=1$ is not required.
- Velocity feedback consists of a derivative term and the derivative action is developed using Backwards Difference Method rather than Trapezoidal as it develops a pole $z=-1$ which makes the digital system unstable.