Lead Tuning

10 - Step Process

*** with Position-Control Example ***

Step–by–step recipe for success

Each step demonstrated by example

- Current Driver Circuit (1^{st} order system)
- Motor & Load (2^{nd} order system)
- Digital Tachometer with discretization error
- Typical u-controller with average clock speed

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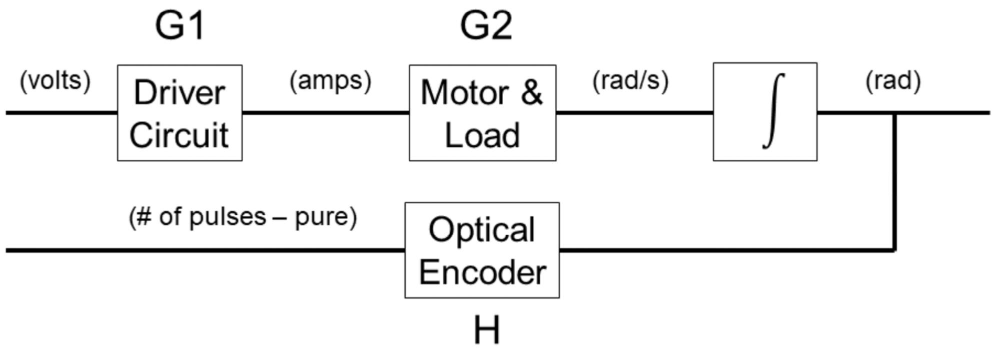
Step 1: System ID & Linearize

$$\frac{K_{mech}}{Ms^2 + Bs + K} \qquad \frac{K_{elec}}{Cs^2 + {}^{s}/_{R} + {}^{1}/_{L}}$$



Break system into sub-systems

ID all signals

Develop model of each sub-system

- Most elec / mech systems can be APPROXIMATED as 2nd order system + gain
- Calculate Xfer Functions "G1, G2, …" from Data Sheets (**DS**) & known values

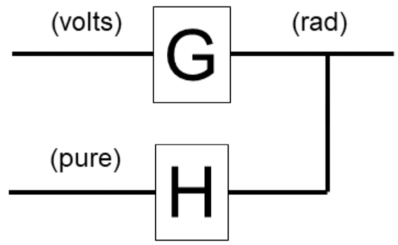
If no data sheet, record step response at reasonable OPERATING POINT and APPROXIMATE:

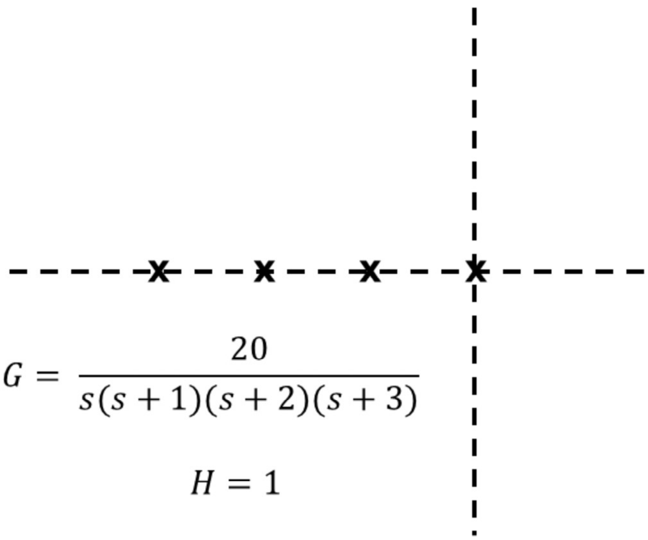
- 0-order linear approximation
- 1st or 2nd order approximation
- Additional (3rd) poles if shape "unusual"

<u>Hint</u>

- Linear sub-system modeled by constant (gain)
- DELAY modeled by POLE
- Neglect non-linearities (discontinuities, noise, etc.)

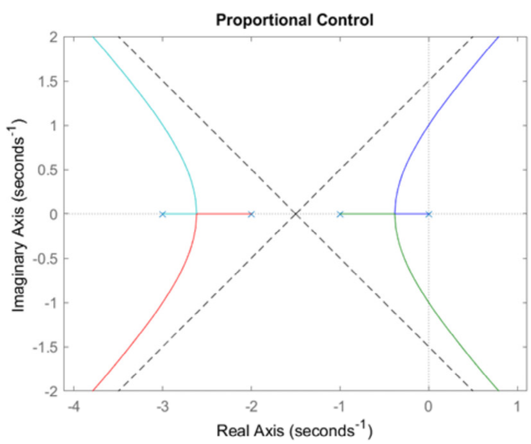
Step 2: System P&Z





$$G = \frac{20}{s(s+1)(s+2)(s+3)}$$

$$H = 1$$

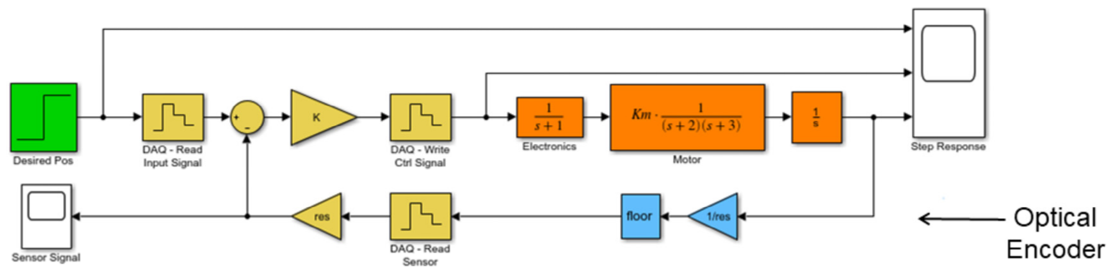


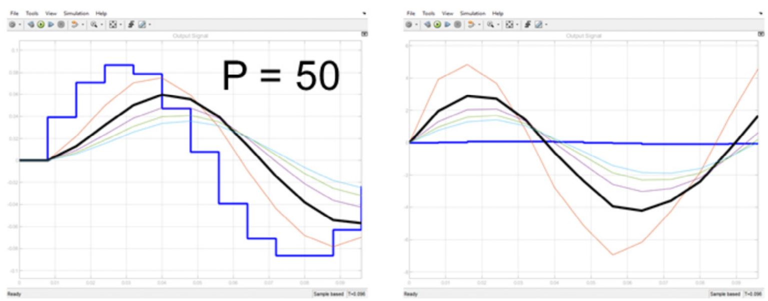
Combine & compute Loop Gain (GH)

- Identify Poles & Zeros

Plot Root-Locus

Step 3: Model System & Design Filter

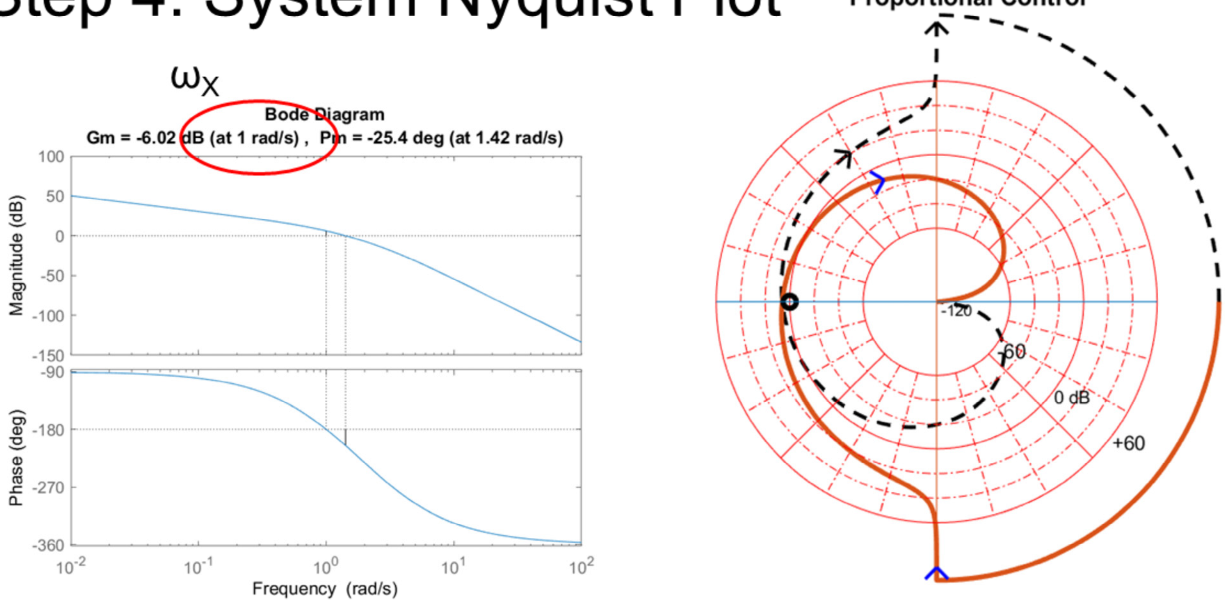




Design Filter

- Generate sensor noise model
- Optimize P (filter pole location)

Step 4: System Nyquist Plot



Generate Bode & Nyquist plot

- "margin" function shows Gm, Pm & X-over frequencies

Stable System:

- Positive margins
- Gm X-Over Freq > Pm X-Over Freq

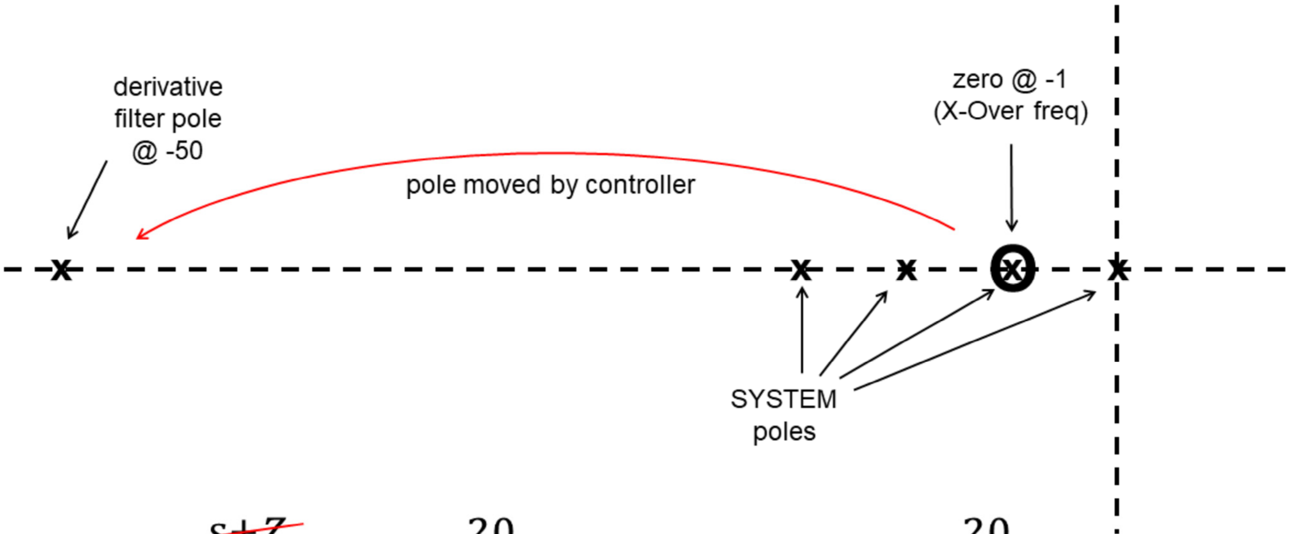
Unstable System:

- Negative margins
- Gm X-Over Freq < Pm X-Over Freq

Choose SMALLER X-Over Freq

- Sytem is unstable
- wx = Gm X-Over Freq = 1 rad/s

Step 5: Controller P&Z



$$KG = K\frac{\cancel{s+Z}}{s+P}\,\frac{20}{s\cancel{(s+1)}(s+2)(s+3)} = K\frac{20}{s(s+P)(s+2)(s+3)}$$

Add controller Poles & Zeros to Root-Locus

<u>Controller Pole & Zero</u>

- 1 Pole @ P (filter pole)
- 1 zeros at X-Over frequency wx

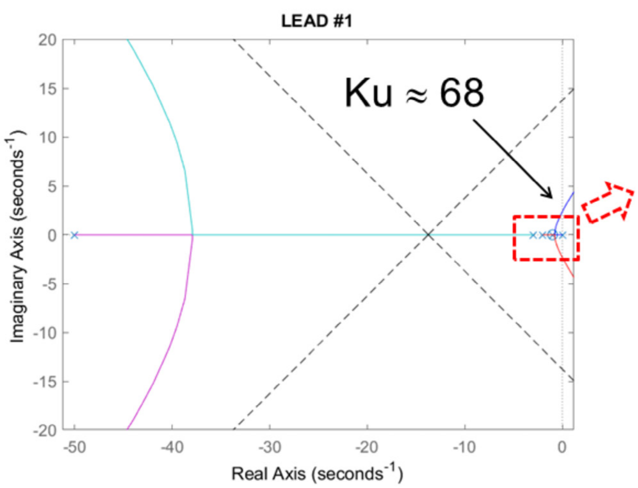
<u>Lead Controller</u>

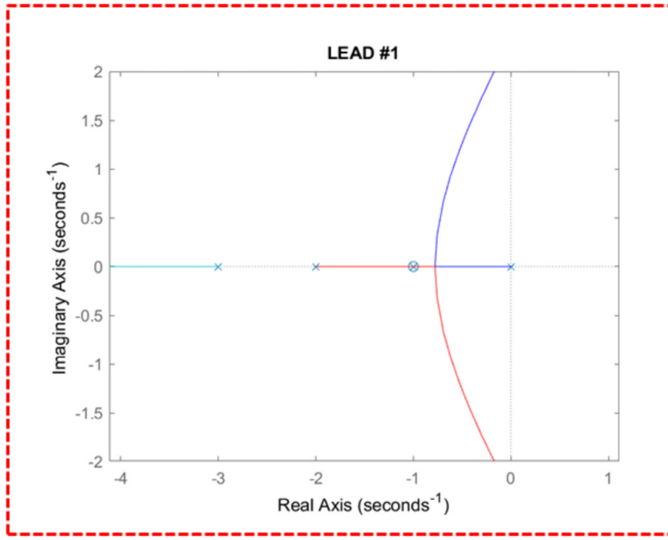
- Cancel pole @ -1 with zero @ -1
- Add pole @ -50
- Effectively MOVED pole @ -1 → -50

<u>Note</u>

The zero will not always cancel a pole. In this example, the two happen to coincide, but the effect will be similar when they do not.

Controller Root Locus



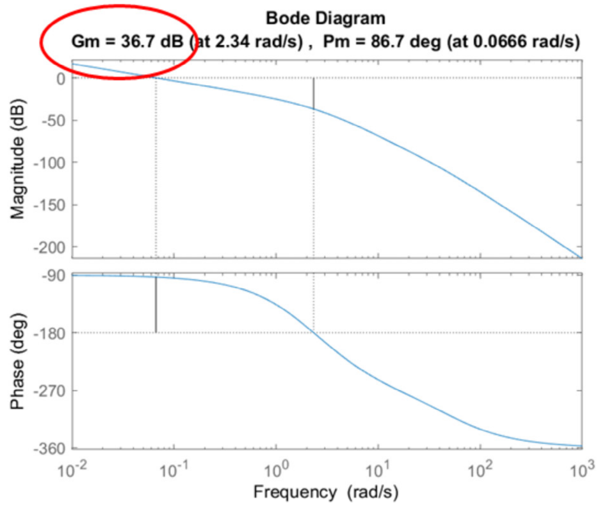


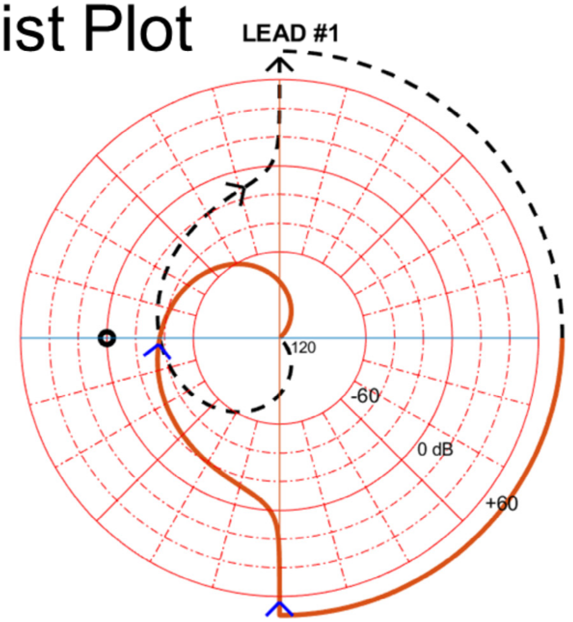
Zoom in on Dominant Poles

- Filter pole is Non-Dominant (typical)
- Moves further to left as Gain increases

Step 6: Controller Nyquist Plot

K_U (in dB)





$$K_U = 10^{Gm/20} = 10^{36.7/20} = 68$$

Generate Bode & Nyquist plots

- Unity gain (K=1)
- Find Ku = Gain Margin
- Convert from dB to pure units

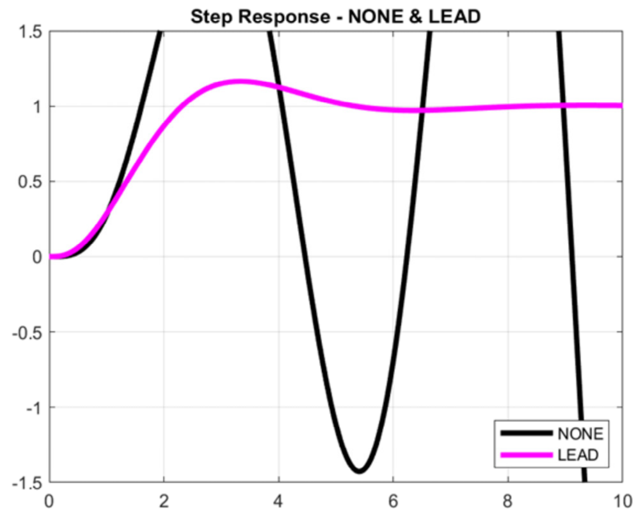
Step 7: Tune PD Gains

$$K = K_U \times 20\% = 13.6$$

$$K_P = \frac{KZ}{P}$$

$$K_D = K_P \frac{P - Z}{PZ}$$

K_{pd} = [0.27 0.27]



Select reasonable K value

- K = Ku * 10% → 50%

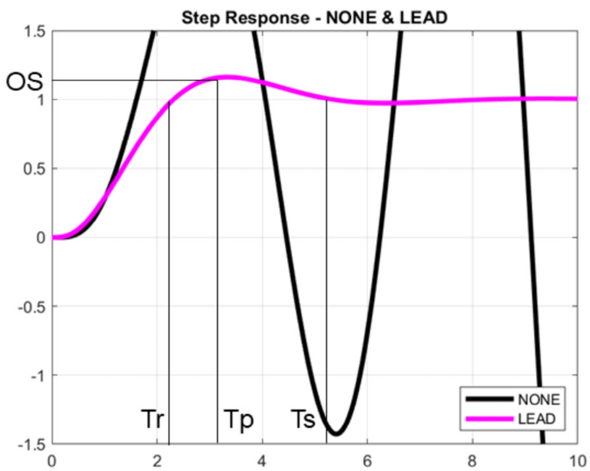
Plot step response

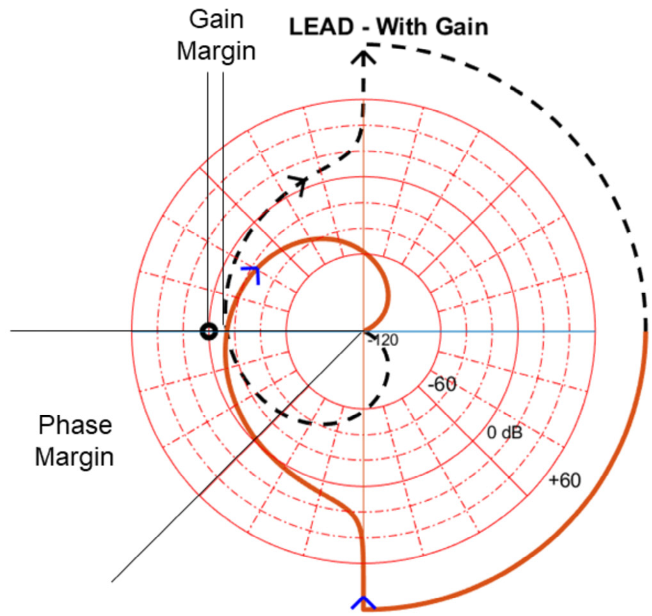
- Compute Gains Kpd = [Kp   Kd]
- Apply gains and filter to PD controller

Adjust design parameters & repeat

- Z = wx * 50% → 150%
- K = Ku * 5% → 80%

Step 8: Evaluate



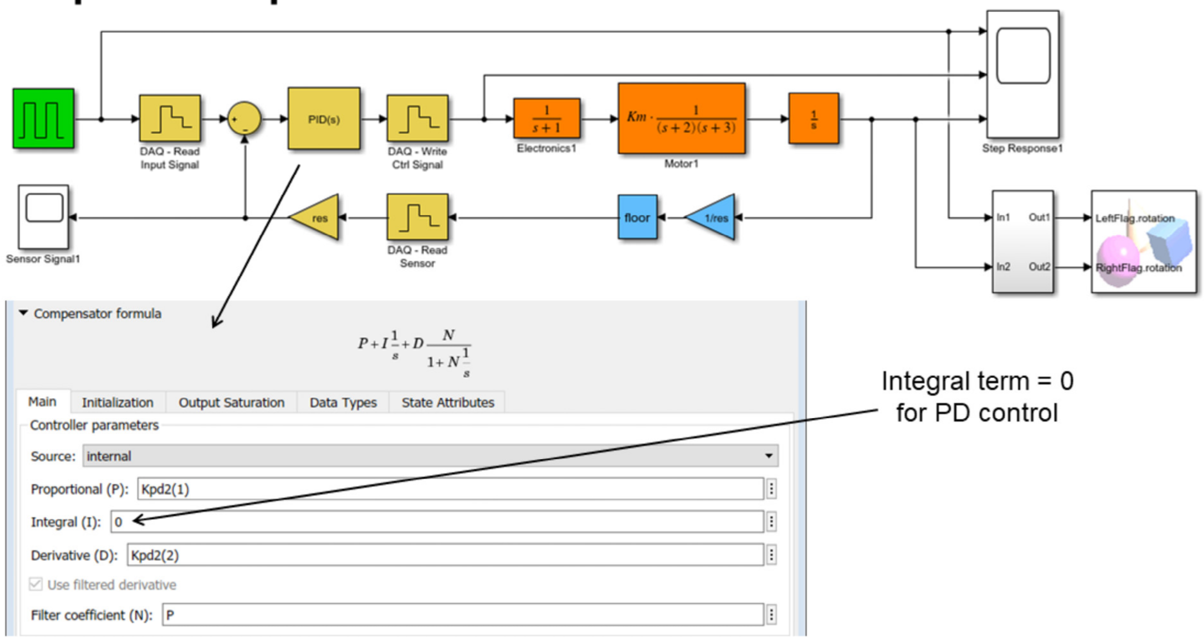


Measure

- Rise Time (Tr)
- Peat Time (Tp)
- Settle Time (Ts)
- Over-Shoot or % Over-Shoot (OS)
- Gain Margin
- Phase Margin

If RCGs not satisfied, Re-Tune

Step 9: Implement



Implement in Simulink

- Implement filters using Matlab code, not X-fer function block
- Compare results
- Any difference = Software Bug

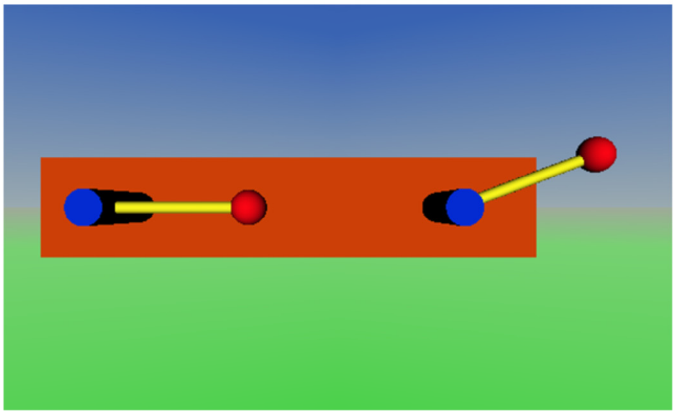
Port to Micro-Controller

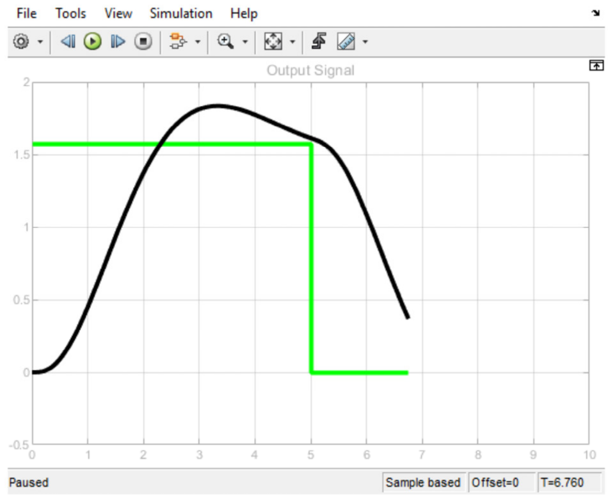
- Implement filter in Micro-Controller
- Set PD gains in Micro-Controller
- Generate & measure step response (on test bench)
- Compare to simulated results (from Step 8)

<u>If Simulation does not match Experiment</u>

- Identify software bugs
- Identify modeling errors
- Go to Step 1

Step 10: Fine-Tune





Fine-tune individual PD gains

- Account for non-linearities
- Attempt to restore theoretical response (Step 9)