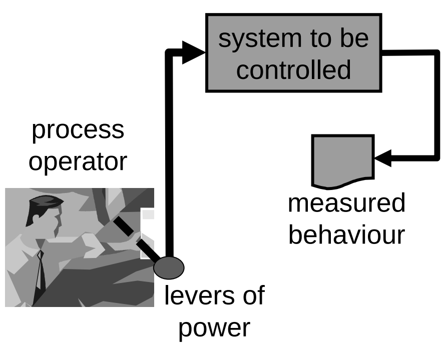
WHAT IS CONTROL ?

Control is the process of altering, manually or automatically, the performance of a system to a desired one

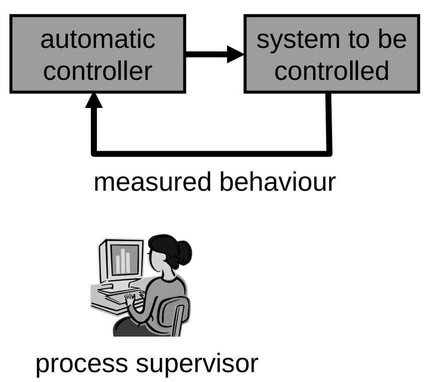
WHY CONTROL ?

Because systems by themselves usually do **not** behave the way we would like them to

Manual Control



Automatic Control



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MAIN AIMS OF CONTROL SYSTEMS

- ***Regulation –*** regulate the output from some process to remain constant to a required value despite disturbances and/or noise
- ***Tracking or Servo system*** – make the process output follow a particular changing form
- ***Sequential Control*** – make events occur in a particular sequence, either time driven or event driven

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THE THREE ELLEMENTS FOR SUCCESSFUL CONTROL DESIGN

- a definition of desired behaviour
- an ability to generate and apply actions
- a means to select actions or to make modifications that when applied to the system will result in the desired behaviour being obtained

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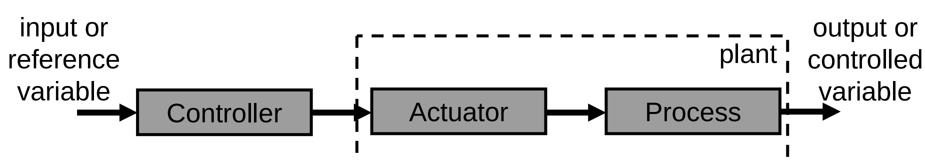
OPEN- versus CLOSED-LOOP CONTROL

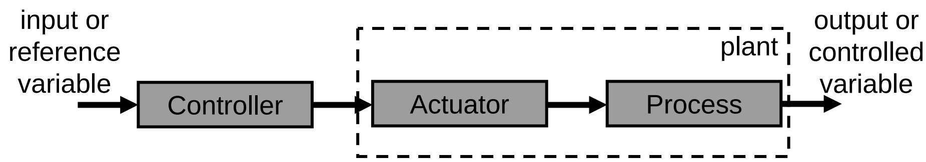
- ***Open-Loop Control*** – the controller does ***not*** use a measure of the system output to be controlled in computing the control action to take
- ***Closed-Loop Control*** – the controlled output ***is*** measured and fed back for use in the computation of the control action

OPEN-LOOP CONTROL



- ***Process*** – of which a variable (output) is being controlled
- ***Controller*** – determines the action to be taken as a result of the system input
- ***Actuator*** – gives an output of some action designed to change the controlled variable

OPEN-LOOP CONTROL: Some Comments



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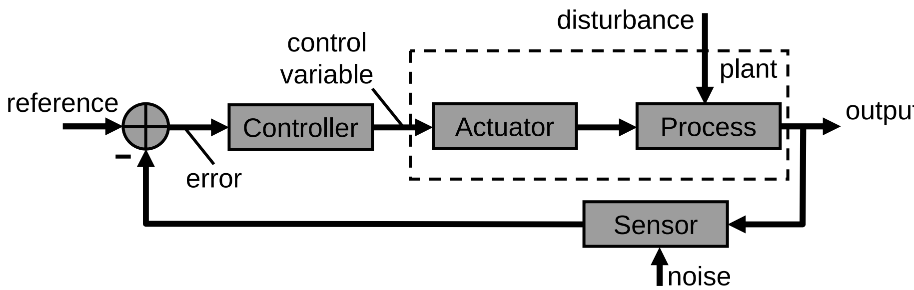
CLOSED-LOOP or FEEDBACK CONTROL

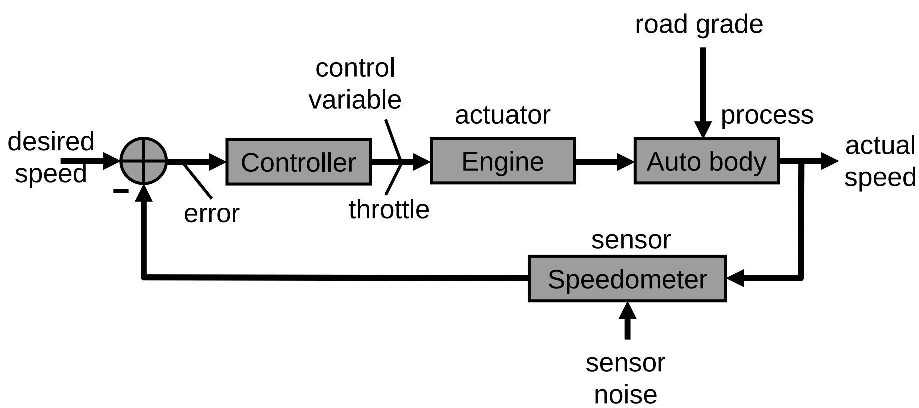


<u>Main futures: *Feedback* and *Comparison*</u>

- ***Sensor*** – measures the system output and feeds it back
- ***Comparator*** – computes the difference between the reference signal and the sensor output to give the controller a measure of the system error

CLOSED-LOOP or FEEDBACK CONTROL

Example: Automobile Cruise Control

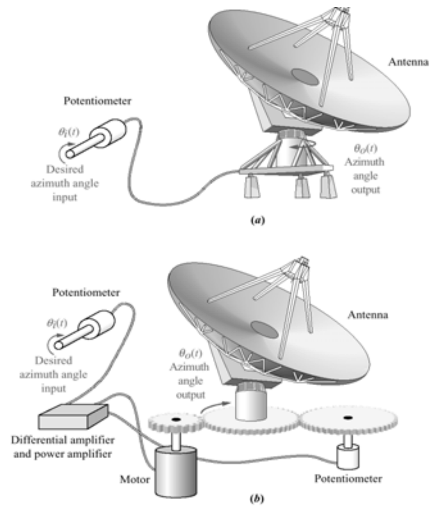


THE EFFECTS OF FEEDBACK

- Reduce the error between the actual and the desired value
- Change the stability of the system
- Change the overall system gain
- Change the sensitivity of the system gain
- Change the bandwidth of the system
- Reduce the effect of external disturbances and noise
- Reduce the effect of variations of system parameters

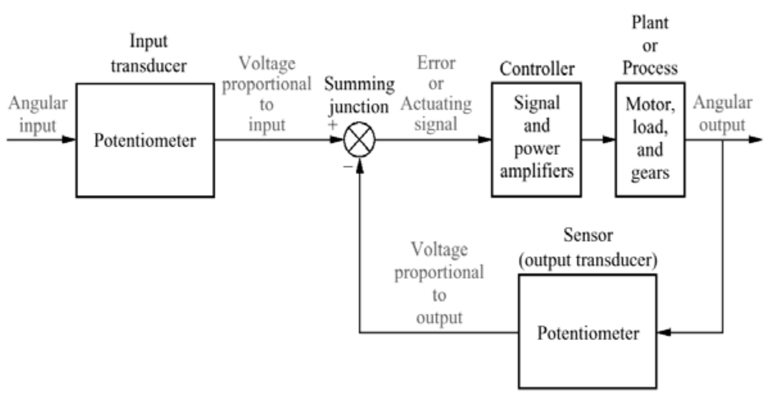
THE DESIGN PROCESS

- Transform Requirements into a Physical System



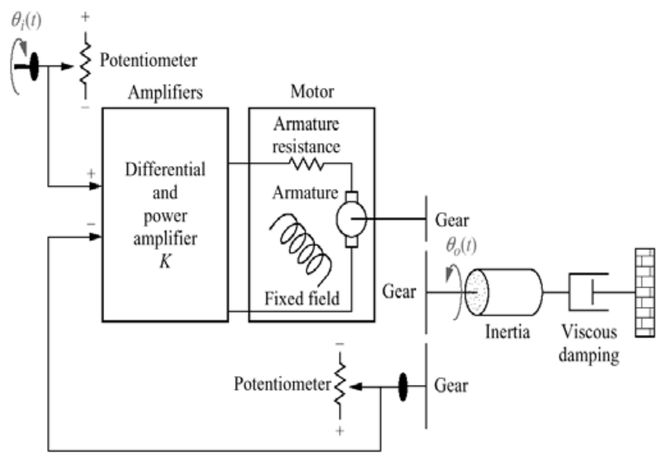
THE DESIGN PROCESS

- Draw a Functional Block Diagram



THE DESIGN PROCESS

- **Create a Schematic**



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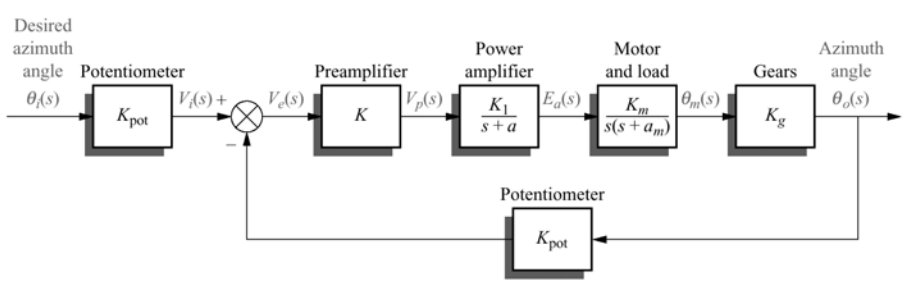
THE DESIGN PROCESS

- **Develop a Mathematical Model** (Block Diagram)



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THE DESIGN PROCESS

- **Reduce the Block Diagram**
- **Analyse and Design**

MATHEMATICAL MODELING

WHAT IS A MODEL ?

The term ***model***, as it is used and understood by control engineers, primarily means a set of differential equations that describe the dynamic behaviour of a system

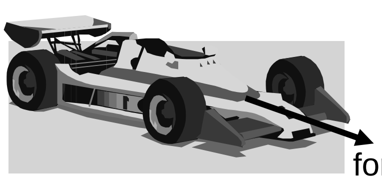
MATHEMATICAL MODELING

HOW IS A MODEL OBTAINED?

- Using principles of underlying physics
- Testing a prototype, measuring the response to specific inputs, and using the data to construct an analytical model

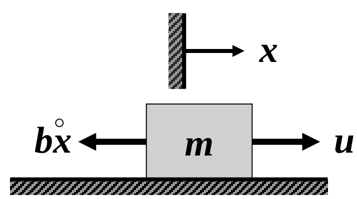
MATHEMATICAL MODELING

Example: A Simple System; Cruise Control Model



force u

physical system



free body diagram

Equations of motion:

$$u - b\dot{x} = m\ddot{x} \Rightarrow \ddot{x} + \frac{b}{m}\dot{x} = \frac{u}{m}$$

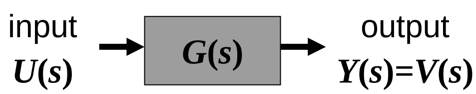
or $(v = \dot{x})$

$$\dot{v} + \frac{b}{m}v = \frac{u}{m}$$

Example: A Simple System; Cruise Control Model

Apply Laplace transform to $\dot{v} + \frac{b}{m} v = \frac{u}{m}$ with zero initial conditions

$$V(s) = \underbrace{\frac{1/m}{s + b/m}}_{\text{Transfer Function}} U(s) = \underbrace{G(s)}_{\text{Transfer Function}} U(s), \quad s \in \mathbb{C}$$



$Y(s)=G(s)U(s)$ **INPUT/OUTPUT DESCRIPTION**

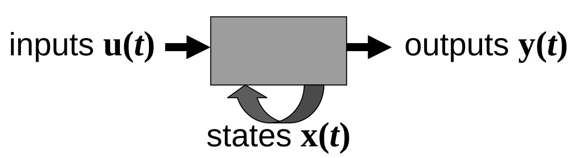
FREQUENCY DOMAIN – ($s=j\omega$) **FREQUENCY RESPONSE**

Example: A Simple System; Cruise Control Model

Introduce two variables (*states*) $x_1 = x, \ x_2 = \dot{x}$

Then
$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & -b/m \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ -1/m \end{bmatrix} u$$

$$y = v = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$



$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u}$$
$$\mathbf{y} = \mathbf{C}\mathbf{x} + \mathbf{D}\mathbf{u}$$

STATE – SPACE or INTERNAL DESCRIPTION

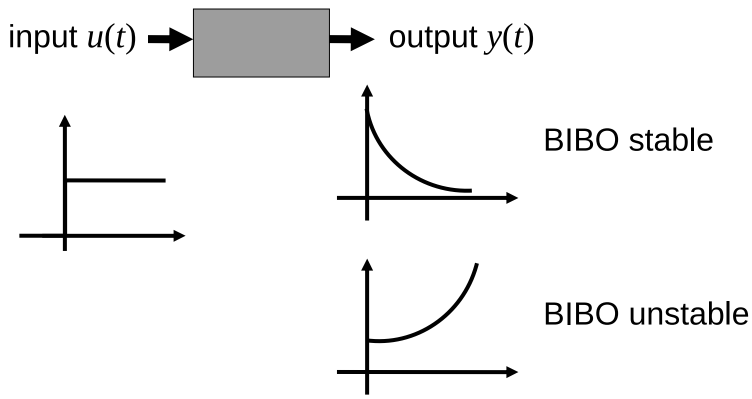
BASIC PERFORMANCE CRITERIA

- **Stability**
- **Time response shape**
- **Frequency response shape**

BASIC PERFORMANCE CRITERIA
Input/Output Stability

- ***Bounded-Input Bounded-Output* (BIBO) Stability**

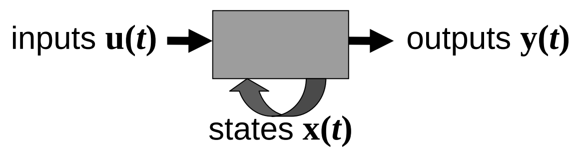
For every bounded input the output of the system is bounded as well

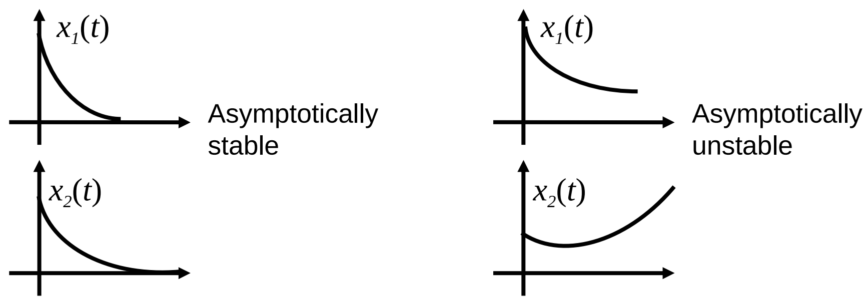


BASIC PERFORMANCE CRITERIA
Internal Stability

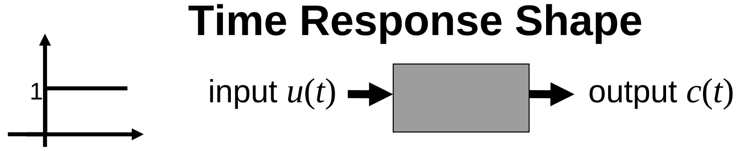
➢ ***Asymptotic* Stability**

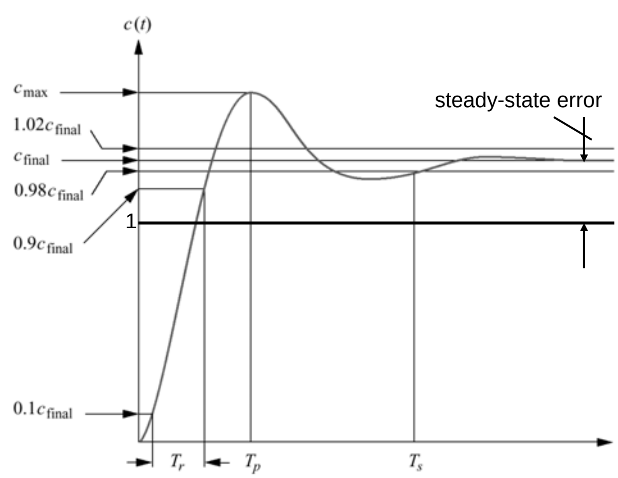
All states tend to zero as time tends to infinity for **every** initial condition





BASIC PERFORMANCE CRITERIA
Time Response Shape





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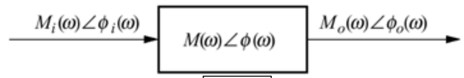
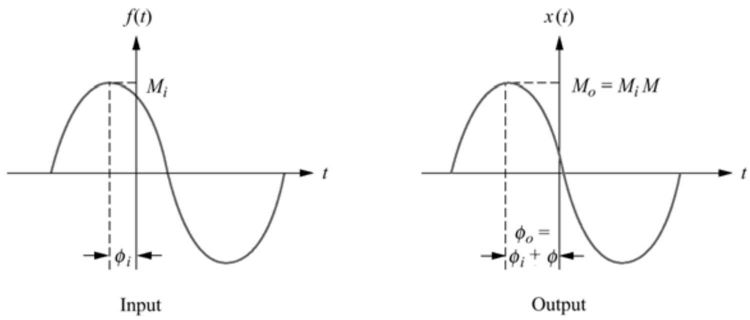
BASIC PERFORMANCE CRITERIA
Frequency Response Shape

WHAT IS FREQUENCY RESPONSE?



$$G(j\omega) = M(\omega)\angle\phi(\omega)$$



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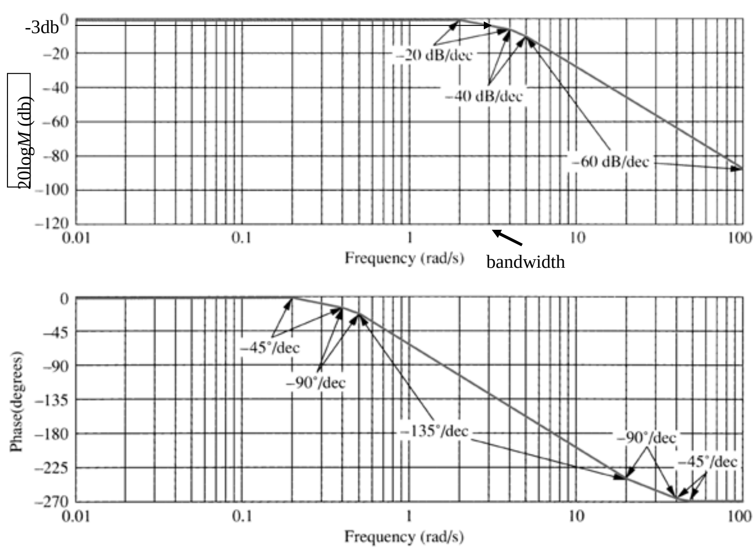
BASIC PERFORMANCE CRITERIA
Frequency Response Shape



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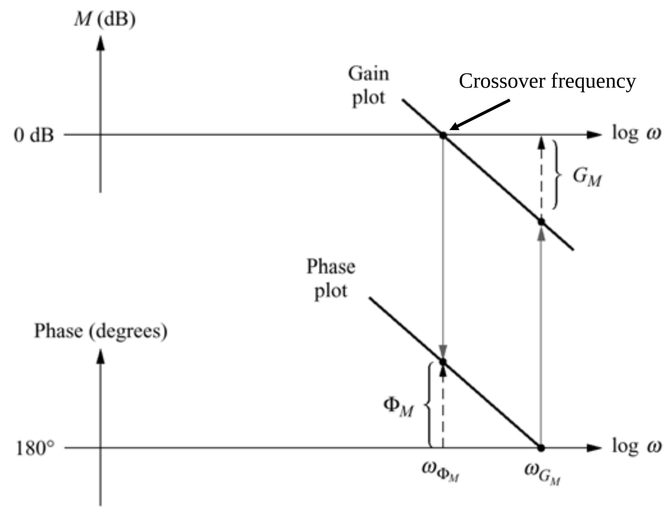
BASIC PERFORMANCE CRITERIA
Frequency Response Shape



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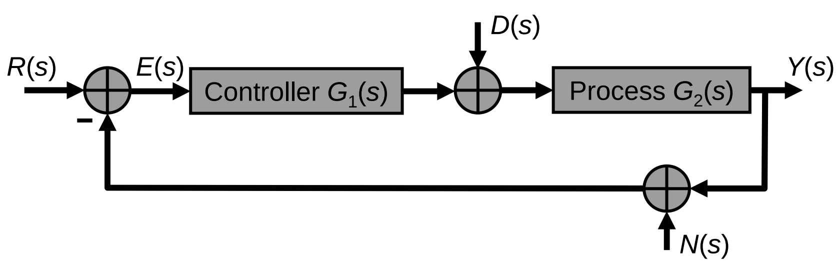
THE CONTROL DESIGN TRADE – OFF



$$Y = Y_r + Y_d + Y_n = \frac{G_1G_2}{1+G_1G_2}R + \frac{G_2}{1+G_1G_2}D - \frac{G_1G_2}{1+G_1G_2}N$$

$$\textit{If } G_1 >>> \;\Rightarrow\; \{Y_r \simeq R,\; Y_d \simeq 0 \text{ and } Y_n \simeq -N\} \;\Rightarrow\; Y \simeq R - N$$

$$\textit{If } G_1 <<< \;\Rightarrow\; \{Y_r \simeq 0,\; Y_d \simeq G_2D \text{ and } Y_n \simeq 0\} \;\Rightarrow\; Y \simeq G_2D$$

THE CONTROL DESIGN TRADE – OFF

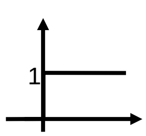
$$If\ \ G_1 >>> \ \Rightarrow \ \{Y_r \simeq R,\ Y_d \simeq 0 \text{ and } Y_n \simeq -N\} \ \Rightarrow \ Y \simeq R - N$$
$$If\ \ G_1 <<< \ \Rightarrow \ \{Y_r \simeq 0,\ Y_d \simeq G_2 D \text{ and } Y_n \simeq 0\} \ \Rightarrow \ Y \simeq G_2 D$$

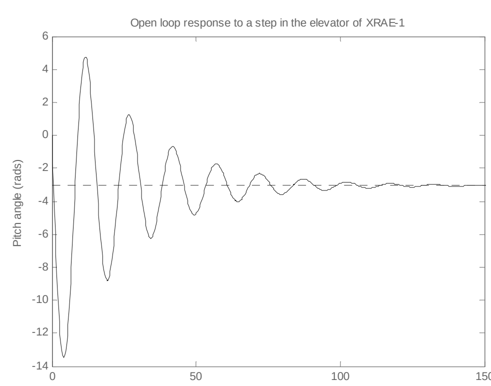
- Make the controller gain G_1 **large** at “low” frequencies so that the closed – loop system follows its reference input and rejects the external disturbances
- Make the controller gain G_1 **small** at “high” frequencies so that the closed – loop system rejects the measurement noise
- Ensure reasonable gain and phase margins at crossover frequency for stability purposes

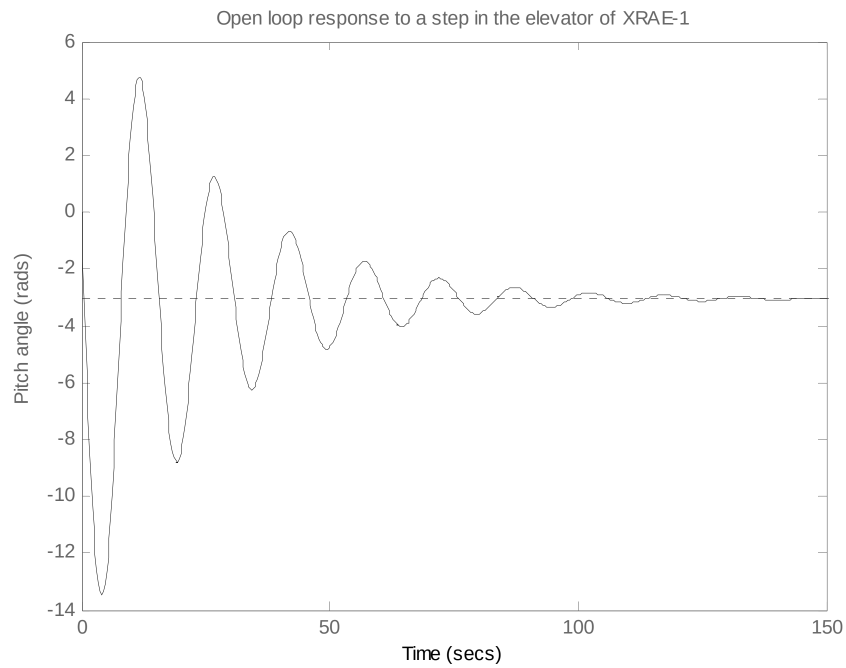
Example: “Primitive” Pitch Control of the RPV XRAE-1

Open Loop XRAE-1 (Flight Controller **Off**)

elevator → XRAE-1 → pitch angle

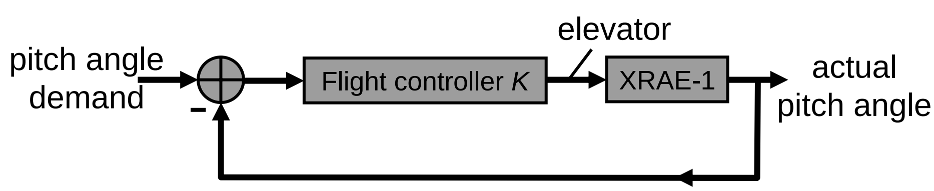


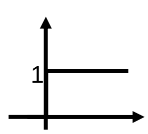


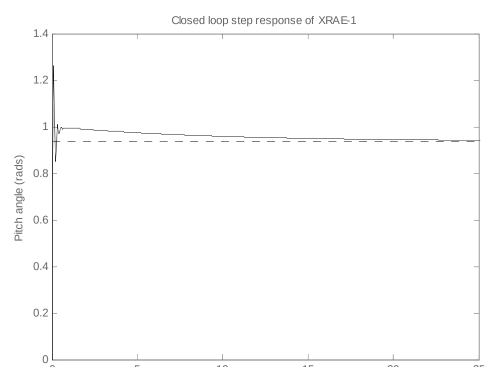


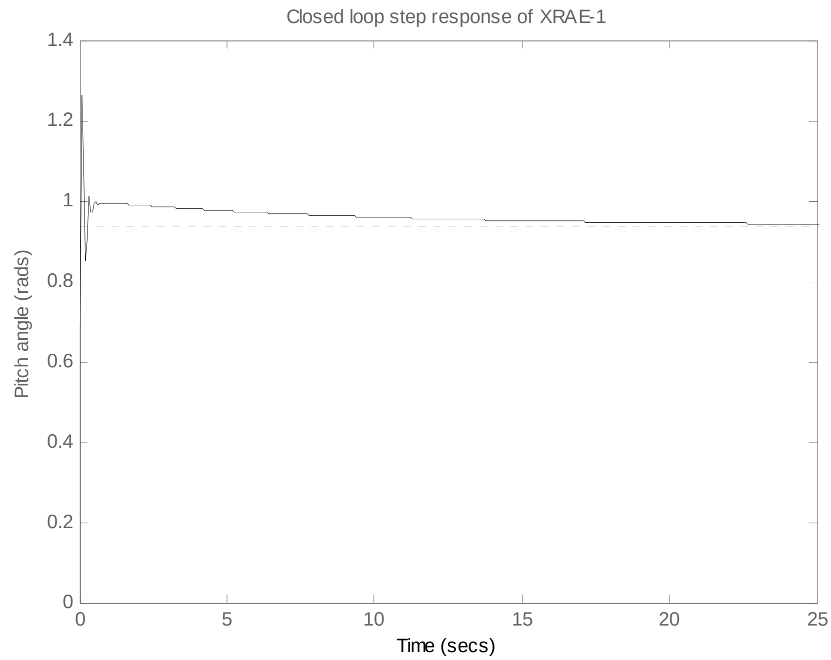
Example: “Primitive” Pitch Control of the RPV XRAE-1

Closed Loop XRAE-1 (Flight Controller **On**)









PID: A Commonly Used Controller