Fall 2022 (111-1)

控制系統
Control Systems

Unit 1A
Introduction - Course Information

Feng-Li Lian

NTU-EE

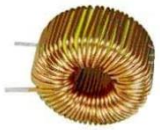
Sep 2022 – Dec 2022

電機系課程關聯圖

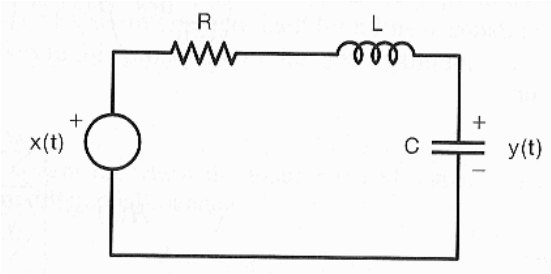
	科學類			系統類			
四下 | 三上	半導體實驗		光電實驗	電機機械實驗	網路與多媒體實驗	數位電路實驗	系訂選修18學分
	電磁波實驗		生醫工程實驗	**自動控制實驗**	通信專題實驗	嵌入式系統實驗	
	固態電子學	近代物理	光電導論	電力工程導論	資料結構與程式設計	積體電路設計	
	微波系統導論		生醫工程概論	**控制系統**	通信原理	電子設計自動化導論	
三上	電子電路實驗(三)	電磁學(二)	電子學(三)		專題演講		
二下	電子電路實驗(二)	電磁學(一)	電子學(二)	**信號與系統**	**機率與統計**	複變/ 離散數學	
二上	電子電路實驗(一)		電子學(一)	**電路學**	交換電路與邏輯設計	**微分方程**	
一下	普通物理學甲及實驗(下)				計算機概論	**線性代數**	**微積分甲(下)**
一上	普通物理學甲及實驗(上)		普通化學丙及實驗/	生物科學通論	**計算機程式**		**微積分甲(上)**

- Technology






- Engineering

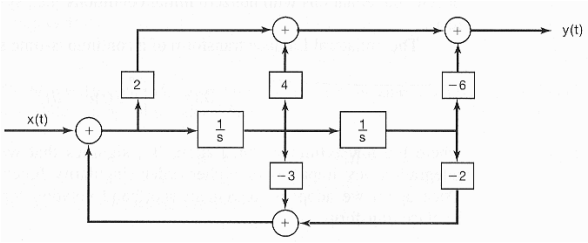


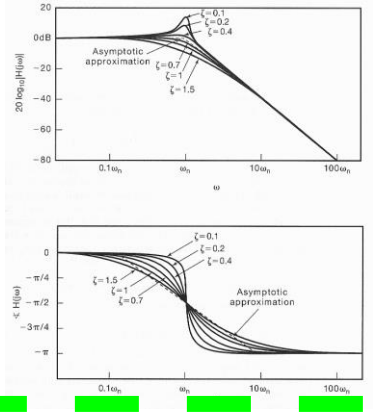
- Mathematics

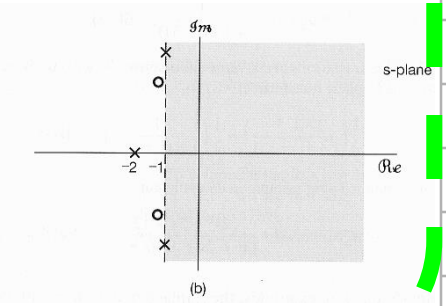
$$LC\,\frac{d^2y(t)}{dt^2} + RC\,\frac{dy(t)}{dt} + y(t) = x(t)$$

$$\frac{1}{LC\,s^2 + RC\,s + 1} = \frac{Y(s)}{X(s)} = T(s)$$

- Graph







Flowchart of Signals and Systems

Introduction (Chap 1)

LTI & Convolution (Chap 2)

Bounded/Convergent

Periodic

FS (Chap 3)

CT

DT

Aperiodic

FT

CT (Chap 4)

DT (Chap 5)

Unbounded/Non-convergent

LT CT (Chap 9)

zT DT (Chap 10)

Time-Frequency (Chap 6)

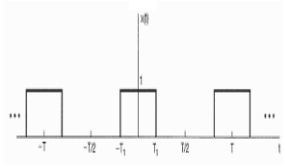
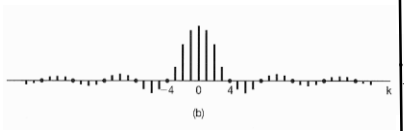
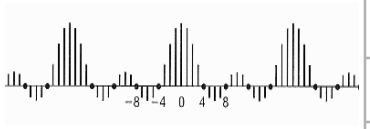
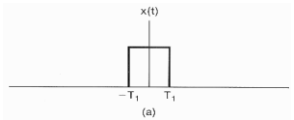
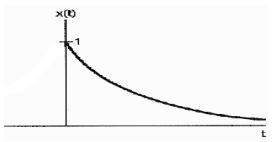
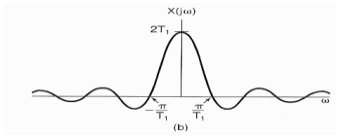
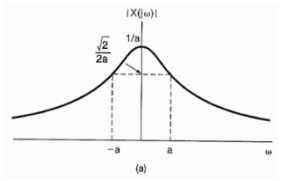
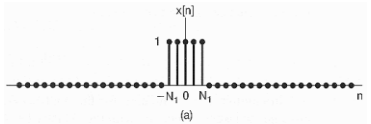
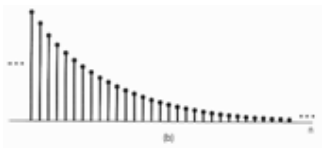
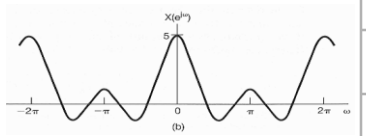
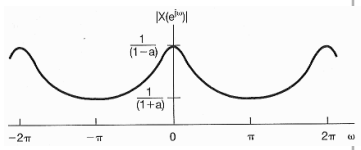
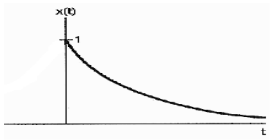
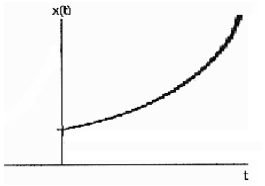
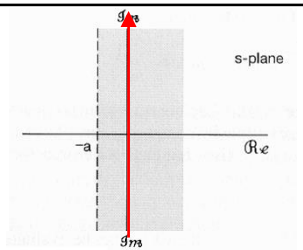
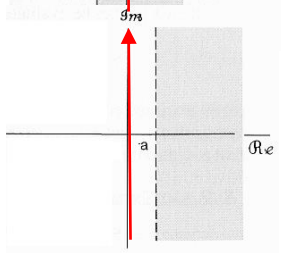
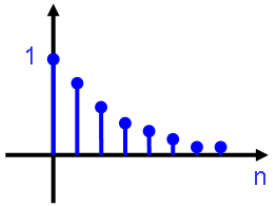
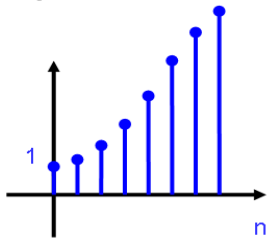
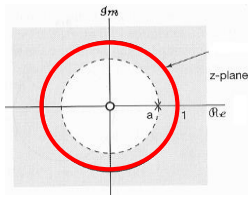
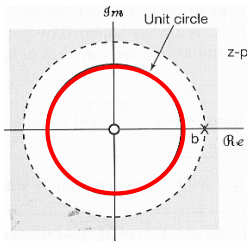
CT-DT (Chap 7)

Communication (Chap 8)

Control (Chap 11)

Digital Signal Processing (dsp-8)

Fourier Series, Fourier Transform, Laplace Transform, z-Transform

	CT		DT	
	time	frequency	time	frequency
FS				
FT	 	 	 	 
LT/zT	 	 	 	 

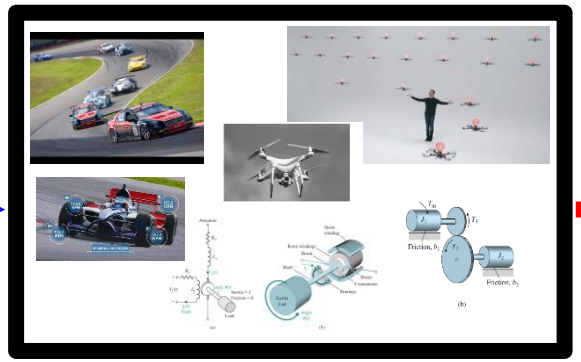
Plant (P)

Signals & Systems

Ref (r)

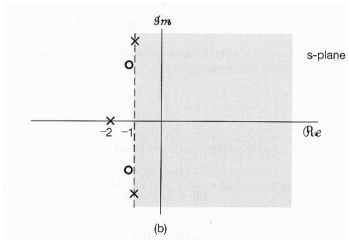
Input (u)

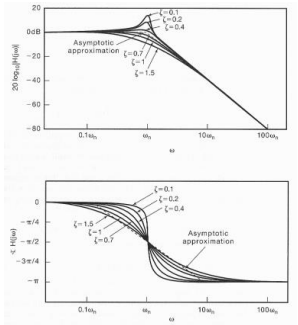
Output (y)



$$\frac{d^2y(t)}{dt^2} + 2\frac{dy(t)}{dt} - 3\,y(t) = 5\,u(t)$$

$$P(s) = \frac{Y(s)}{U(s)} = \frac{5}{s^2 + 2s - 3}$$





Control Systems

1. Model
2. Response
3. Analysis
4. Feedback
5. Control

Controller

$$\frac{d^2y(t)}{dt^2} + 4\frac{dy(t)}{dt} + 3\,y(t) = 3\,r(t)$$

$$G(s) = \frac{Y(s)}{R(s)} = \frac{3}{s^2 + 4s + 3}$$

Outline of Textbook & Lectures

- 1: Overview and Introduction
- 2: Dynamic Models
- 3: Dynamic Response
- 4: Feedback Analysis
- 5: Analysis & Design: Root Locus
- 6: Analysis & Design: Bode Plot
- 7: State-Space Design
- 8: Digital Control
- 9: Nonlinear Systems
- 10: Case Study

- 物理定律, 工程問題
- 函數, 方程式, 多項式
- 系統特性,公式
- 多項式根的特性
- 頻率響應的特性

- 線性代數, 微分方程
- 離散時間, 數位信號
- 非線性函數, 特徵

- 統整分析與設計

Outline of Textbook & Lectures

- 1: Overview and Introduction
- 2: Dynamic Models
- 3: Dynamic Response
- 4: Feedback Analysis
- 5: Analysis & Design: Root Locus
- 6: Analysis & Design: Bode Plot
- 7: State-Space Design
- 8: Digital Control
- 9: Nonlinear Systems
- 10: Case Study

- 建模 **Modeling**
- 分析 **Analysis**
- 設計 **Design**
- 統整分析與設計

Outline of Textbook & Lectures

- 1: An Overview and Brief History of Feedback Control
- 2: Dynamic Models
- 3: Dynamic Response
- 4: A First Analysis of Feedback
- 5: The Root-Locus Design Method
- 6: The Frequency-Response Design Method
- 7: State-Space Design
- 8: Digital Control
- 9: Nonlinear Systems
- 10: Control System Design:

  Principles and Case Studies

- 信號與系統

- 線性系統
- 數位控制
- 非線性系統

Lectures and Exams

- U1A, U1B (Introduction)
- U2A, U2B, … (Dynamic Models)

- Midterm Exam
  - U3A, U3B, … **(Dynamic Response)**
  - U4A, U4B, … **(Feedback Analysis)**

- Final Exam
  - U5A, U5B, … **(Root-Locus Design)**
  - U6A, U6B, … **(Frequency-Response Design)**

- Case Study& Projects
  - U7A, U7B, … **(Case Study)**

Grading

- 作業 (20%)： 10次 (20-30%)
- 考試 (30%+30%)： 2次 (40-50%)
- 專題 (20%)： 1次 (20%)
  - » 兩人一組，自選主題
  - » 完成(A)建模，(B)分析與(C)設計三階段任務
  - » 拍攝一段 5min 報告影片，分享到影音平台 (e.g., YT, FB)
  - » 共同參與互相評分：A, B, C
- 互動學習迴授 (20%, Optional)： (20%)
  - » 分享課程進行過程
  - » 討論分析研究進階課題

Grading

- A+：所有目標皆達成且超越期望
- A ： 所有目標皆達成
- A-： 所有目標皆達成，但需一些精進
- B+： 達成部分目標，且品質佳
- B ： 達成部分目標，但品質普通
- B-： 達成部分目標，但有些缺失
- C+： 達成最低目標
- C ： 達成最低目標，但有些缺失
- C-： 達成最低目標但有重大缺失
- F ： 未達成最低目標
- X： 因故不核予成績

- 作業：18-20
- 考試：54-60
- 專題：18-20
- 總分：90-99 → (A)
  100+ → (A+)

- 作戰組：
  - 電機三，電機四
- 強化組：
  - 電機二
- 獨立組：
  - 其他

Syllabus

Lecture Information:

- Time: Fridays 9:10am-12noon
- Room: EE2-229 or MS-Teams
- Office Hours: by e-mail appointment
- Website: **NTU-Cool** or http://homepage.ntu.edu.tw/~fengli/Teaching/ControlSystems/

Instructor:

- 連豊力 (Feng-Li Lian)
- Office: MD-717
- Email: fengli@ntu.edu.tw
- Phone: 02-3366-3606

Textbook & References:

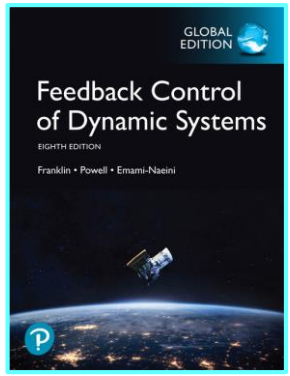
- Feedback Control of Dynamic Systems
- Modern Control Systems
- Control Tutorials for MATLAB and Simulink

Grading:

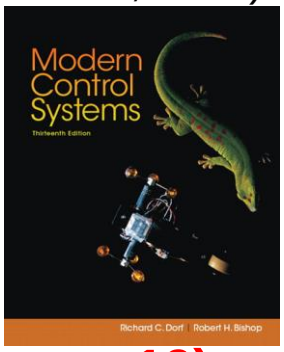
Exam x 2:	60%
HW x N :	20%
Project x 1:	20%
Optional:	20%

References

- **Feedback Control of Dynamic Systems (Franklin19)**
  - by Gene F. Franklin, J David Powell, Abbas Emami-Naeini, (8th Ed., 2019)
  - 出版社： Pearson 代理商： 滄海書局

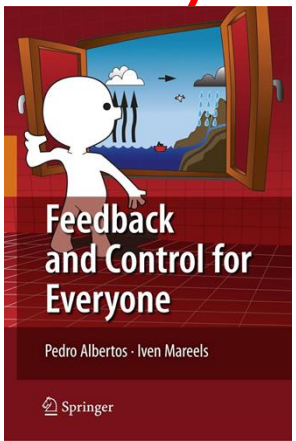


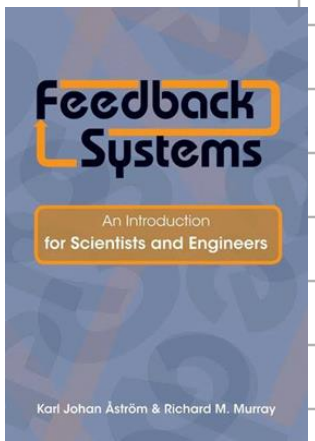
- **Modern Control Systems (Dorf17)**
  - by Richard C. Dorf, Robert H. Bishop, (13th Ed., 2017)
  - 出版社： Pearson 代理商： 巨擘書局



- **Control Tutorials for MATLAB and Simulink (Messner19)**
  - by Bill Messner and Dawn Tilbury, (1996, 1997, 2011, 2017, 2019)
  - 資料： Website: Control Tutorials

- **Feedback Systems:**
  An Introduction for Scientists and Engineers (Astrom19)
  - by Karl J. Astrom and Richard M. Murray, (2nd Ed., 2019)
  - 出版社： fbsbook.org





- **Feedback and Control for Everyone (Albertos10)**
  - by Pedro Albertos, Iven Mareels, (13th Ed., 2010)
  - 出版社： Springer

Unit 1
Introduction

Unit 1 - Introduction

- U1A Introduction to Course
  -
- U1B Introduction to Feedback and Control
  -
- U1C Overview and History
  -
- U1D Examples
  -
- U1E Examples
  -
- U1F Examples
  -

Unit 2
Dynamic Models

- For the plant to be analyzed and controlled
  - Dynamic Models
  - Mathematical Models
- Methodology
  - Based on Physics and By Differential Equations
  - From Experimental Data (System Identification)
- Key Ingredients:
  - Physics, Chemistry, Biology, Sociology, Economics, etc.
  - Differential Equations (Equations of Motion, Dynamic Equations)
  - Laplace Transforms, Fourier Transforms
  - Transfer Function (From Input to Output)

- Mechanical Systems
  - U2A: Translational Motion
  - U2B: Rotational Motion
  - U2C: Combined Rotation and Translation
  - U2D: Distributed Parameter Systems
- Electrical Circuits
  - U2E: Kirchhoff's Current Law (KCL)
  - U2E: Kirchhoff's Voltage Law (KVL)
  - U2E: Operational Amplifier
- Electromechanical Systems
  - U2F: Loudspeakers
  - U2F: Motors
  - U2F: Gears
- Heat and Fluid-Flow Models
  - U2G: Heat Flow
  - U2G: Incompressible Fluid Flow

Unit 3
Dynamic Response

Unit 3 - Dynamic Response

- U3A Review of Laplace Transforms
  - Laplace Transforms: From Differential Eqns to Algebraic Eqns
  - Transfer Functions, Frequency Response, Poles and Zeros
  - Step, Ramp, Impulse Functions
  - Laplace Transforms and Inverse LT, The Final Value Theorem
  - Using Laplace Transforms to Solve Differential Equations
- U3B System Modeling Diagrams: Model Visualization
- U3C Effect of Pole Locations
- U3D Time-Domain Specifications
  - Rise Time
  - Overshoot and Peak Time
  - Settling Time
- U3E Effects of Zeros and Additional Poles
- U3F Stability
  - Bounded Input–Bounded Output Stability
  - Stability of LTI Systems
  - Routh’s Stability Criterion

Unit 4
Feedback Analysis

Unit 4 - Feedback Analysis

- U4A The Basic Equations of Control
  - Open-Loop and Closed-Loop Systems
  - Stability, Tracking, Regulation, Sensitivity
- U4B Control of Steady-State Error to Polynomial Inputs: System Type
  - Control of Steady-State Error to Polynomial Inputs
  - System Type for Tracking
  - System Type for Regulation and Disturbance Rejection
- U4C PID Control
  - PID Control (Proportional, Integral, Derivative)
  - P, I, D, PI, PD, PID
  - Examples
- U4D Ziegler–Nichols Tuning
  - Ziegler–Nichols Tuning of the PID Controller,
  - Examples
- U4E Feedforward Control by Plant Model Inversion
  - Feedforward Control by Plant Model Inversion
  - Examples

Unit 5
Root Locus

Unit 5 Root Locus

- U5A Root Locus of a Basic Feedback System
  - Root-Locus Method of Evans
- U5B Guidelines for Determining a Root Locus
  - Formal Definition of Root Locus
  - Rules for Determining a Positive (180◦) Root Locus
  - Selecting the Parameter Value
- U5C Selected Illustrative Root Loci
  - PD, Lead Compensator
  - Collocated vs Non-Collocated Flexibility, Complex Multiple Roots
- U5D Design Using Dynamic Compensation
  - Lead Compensation, Lag Compensation, Notch Compensation
- U5E Design Examples Using the Root Locus
  - Autopilot Design in the Smaller Airplane - Piper Dakota
- U5F Extensions of the Root-Locus Method
  - Rules for Plotting a Negative (0◦) Root Locus
  - Consideration of Two Parameters

Unit 6
Bode Plot

Unit 6 Bode Plot

- U6A Frequency Response
  - System Response and Frequency Response
- U6B Bode Plot Techniques
  - Bode Form of the Transfer Function
- U6C Nonminimun-Phase & Steady-State Errors
- U6D Neutral Stability
- U6E Nyquist Stability Criterion
- U6F Stability Margins
- U6G Bode's Gain–Phase Relationship
- U6H Closed-Loop Frequency Response
- U6I PD Compensation and Lead Compensation
- U6J PI Compensation and Lag Compensation
- U6K PID Compensation
- U6L Compensation Characteristics & Design Considerations

Unit 7
Case Study

Unit 7 Case Study

- From Chapter 10
  - Outline of Control Systems Design
  - Satellite's Attitude Control
  - Lateral and Longitudinal Control of a Boeing
  - Fuel–Air Ratio in an Automotive Engine
  - Read Write Head Assembly of a Hard Disk
  - RTP Systems in Semiconductor Wafer Manufacturing
  - Chemotaxis, or How E. Coli Swims Away from Trouble
  - Quadrotor Drone

- From Control Tutorials Website
  - Cruise Control
  - Motor Speed
  - Motor Position
  - Suspension
  - Inverted Pendulum
  - Aircraft Pitch
  - Ball & Beam

Unit 8
Final Project

Unit 8 Project

- 主題與工作：
  - 兩人一組，自選主題
  - 可以從下面資料之中，挑選一個主題：
    - 課本第十章
    - Control Tutorial 網站
    - 自行挑選有興趣的主題
  - 主要工作：
    - 研讀上述資料
    - 整理關於 Model, Analysis, Design 的資料：
      - > Models: Differential Equations, Transfer Function
      - > Analysis: Timing Properties, Frequency Properties, Pole/Zero, etc.
      - > Design: By Root Locus, By Bode Plot, etc.

- 繳交報告：
  - 一份 pptx 報告 與 一段影片
  - 報告使用 pptx 編輯，整理Model, Analysis, Design 的資料
  - 文字與方程式符號等資料，需要重新編輯，不可以直接貼圖的方式
  - 所有數據圖，需要用 Matlab 重新產生，不可以直接從資料中複製過來
  - 拍攝一段 5-10min報告影片，上傳到NTU-Cool
  - 共同參與互相評分： A, B, C or 9, 6, 3

Unit 8 Project

A or 9：

- 針對所挑選的主題，完成：**Model, Analysis, Design** 等三部分的工作
  - **Models:** Differential Equations, Transfer Function
  - **Analysis:** Timing Properties, Frequency Properties, Pole/Zero, etc.
  - **Design:** By Root Locus, By Bode Plot, etc.
- 編輯專題報告，文字，方程式，數據圖等，

  都是從新編輯或自行撰寫程式執行的結果，

  並不是從參考資料上，直接複製貼上的圖片資料。

B or 6：

- 針對所挑選的主題，完成：**Model, Analysis, Design** 等三部分的工作
- 但是，專題報告上的文字，方程式，數據圖等大部分內容，

  都是從其他資料直接複製貼上而來的，

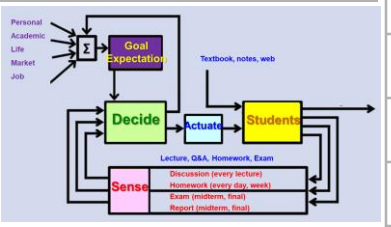
  看不出來，是否已經瞭解該問題的核心內容以及會使用與控制系統有關的分析工具！

C or 3：

- 各方面（主題，分析過程，論述）都很缺乏！

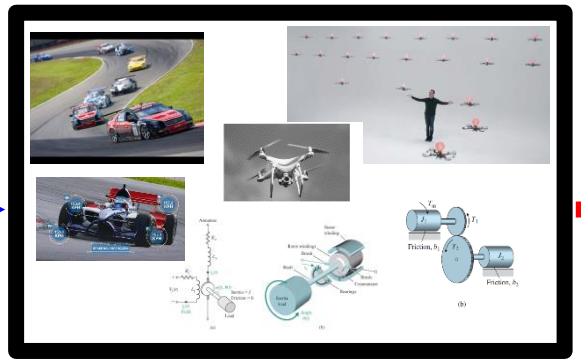
Appendix

Plant, Input, Output, Action, Goal



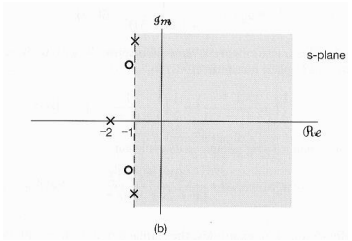
Plant (P)

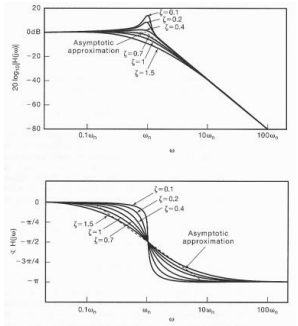
Ref (r) → Input (u) → Output (y)



$$\frac{d^2y(t)}{dt^2} + 2\frac{dy(t)}{dt} - 3\,y(t) = 5\,u(t)$$

$$P(s) = \frac{Y(s)}{U(s)} = \frac{5}{s^2 + 2s - 3}$$





Controller

$$\frac{d^2y(t)}{dt^2} + 4\frac{dy(t)}{dt} + 3\,y(t) = 3\,r(t)$$

$$G(s) = \frac{Y(s)}{R(s)} = \frac{3}{s^2 + 4s + 3}$$

1. Model
2. Response
3. Analysis
4. Feedback
5. Control