

Fall 2021 (110-1)

控制系統
Control Systems

Unit 7C
Control System Design:
Engine, Hard Disk, Wafer, E-coli

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NTU-EE

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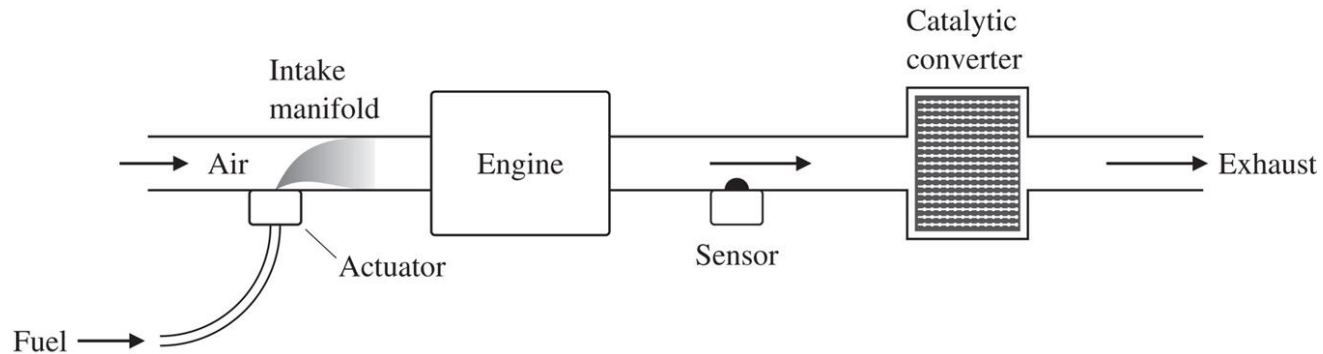
▪ Examples of Control Systems Design

- Outline of Control Systems Design
- Satellite's Attitude Control
- Fuel–Air Ratio in an Automotive Engine
- Read Write Head of a Hard Disk
- RTP Systems in Wafer Manufacturing
- Chemotaxis Swims Away from Trouble

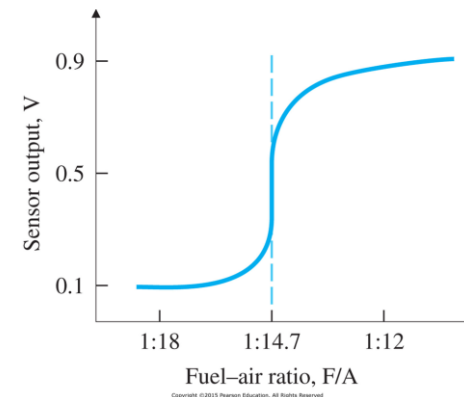
Control Tutorials Website

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

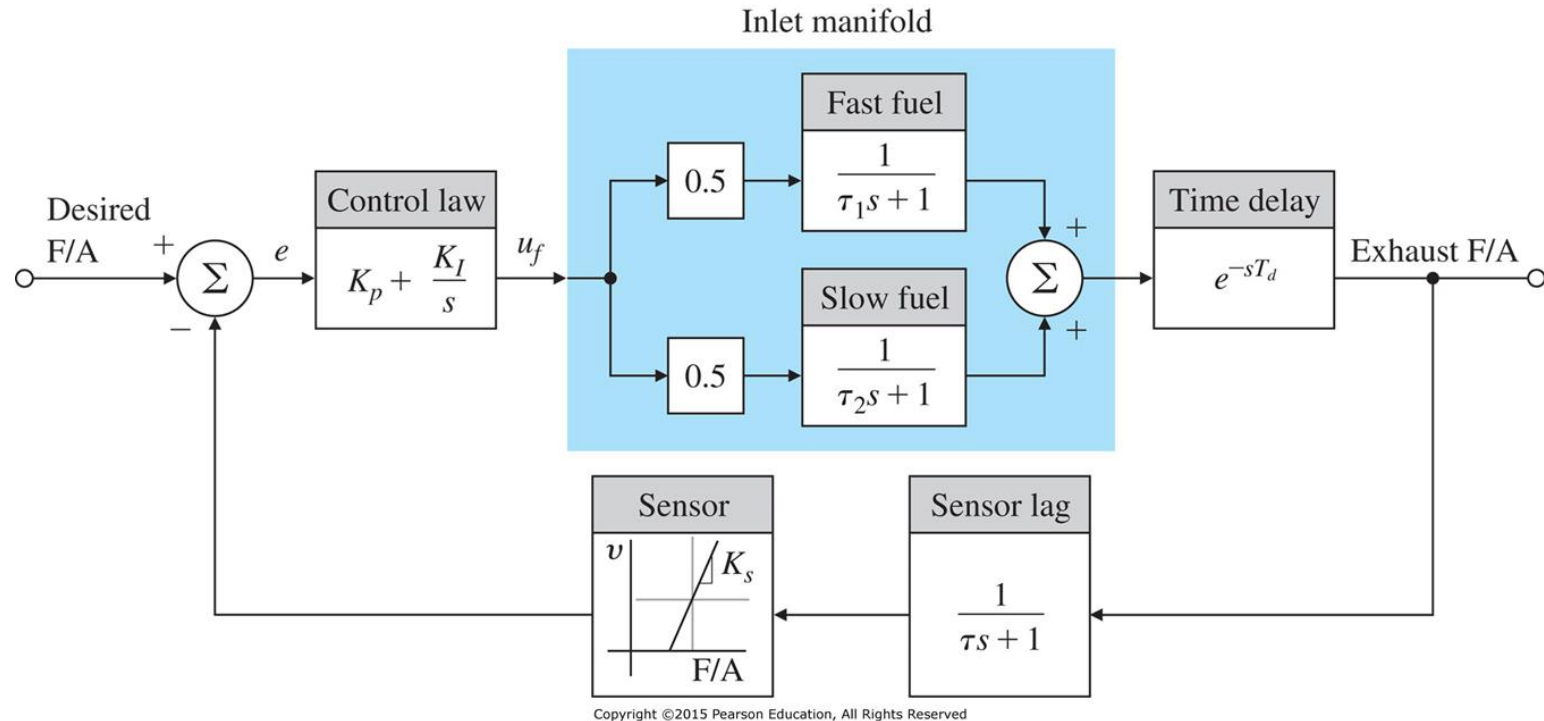
- The ratio of gasoline-mass flow to air-mass flow, (fuel-to-air ratio (F/A)), remained in 1:15



- (STEP 1) Understand the process and its performance specifications
 - A feedback control system is required to maintain the F/A within 1% of the desired level
- (STEP 2) Select sensors
 - exhaust sensor



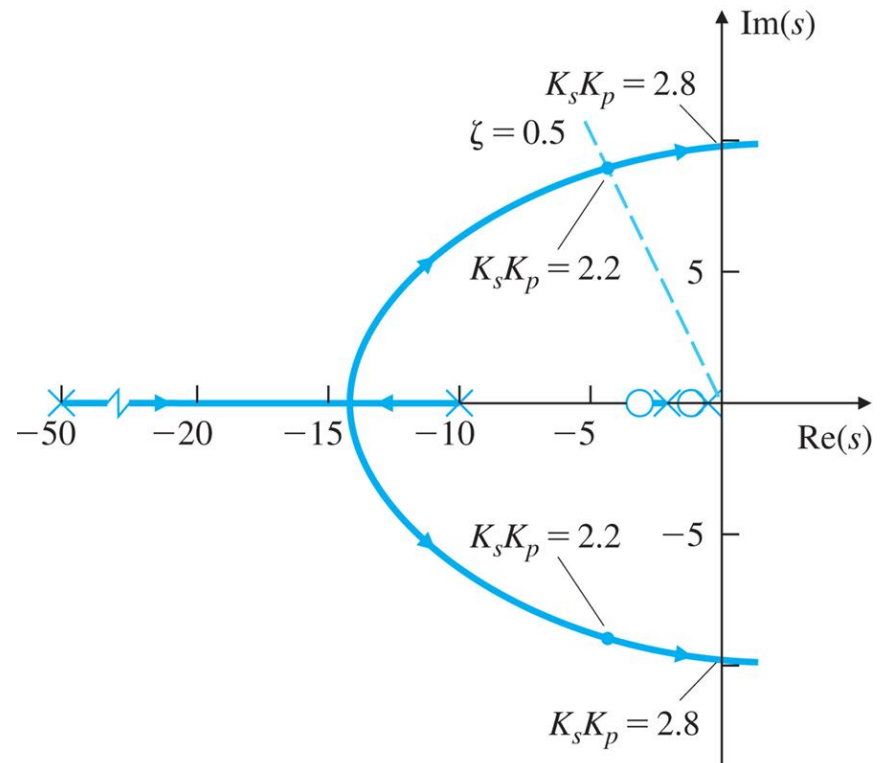
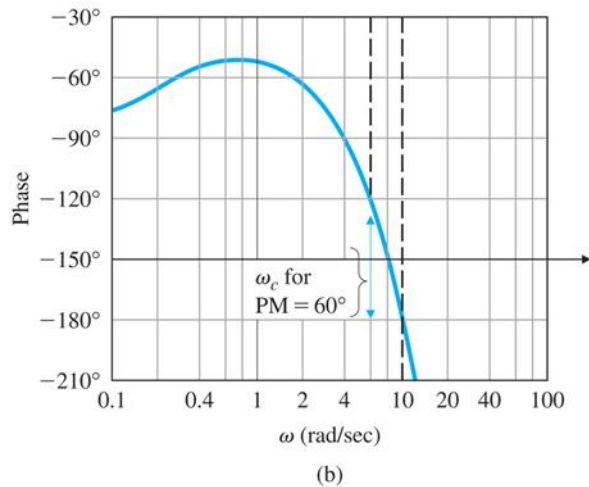
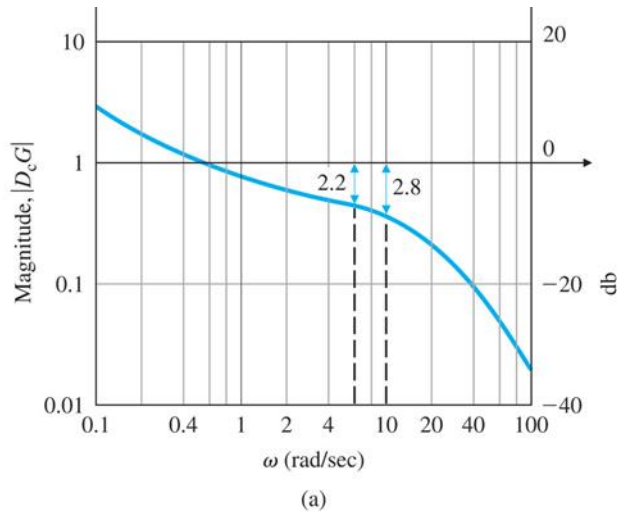
- (STEP 4) Make a linear model



$$D_c(s) = K_p + \frac{K_I}{s} = \frac{K_p}{s}(s + z), \quad z = \frac{K_I}{K_p}$$

■ (STEP 5) Try a lead-lag or P/D controller

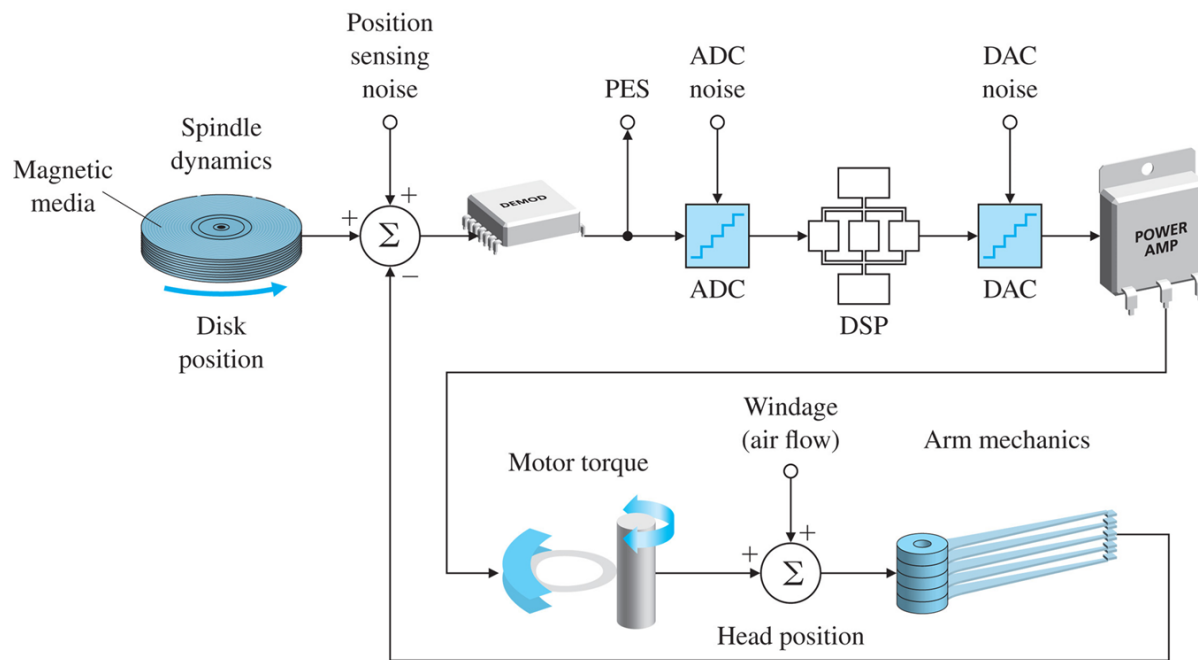
- $K_s K_p = 1.0$, $z = 0.3$



Motion control:

To seek motion to move the head from track to track

To maintain the heads over the center of the selected track



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- (STEP 1) Understand the process and its performance specifications
 - A feedback control system is required to maintain the F/A within 1% of the desired level

- (STEP 2) Select sensors
 - Track position

- (STEP 3) Select actuators
 - Motor

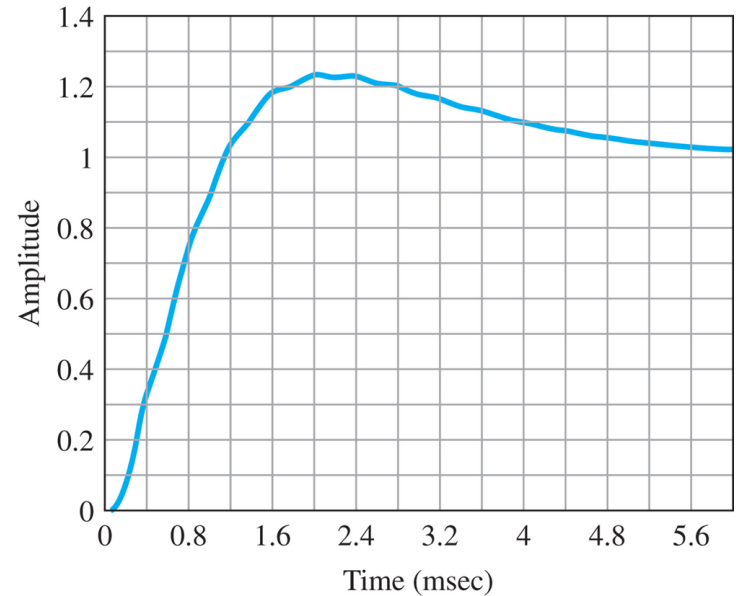
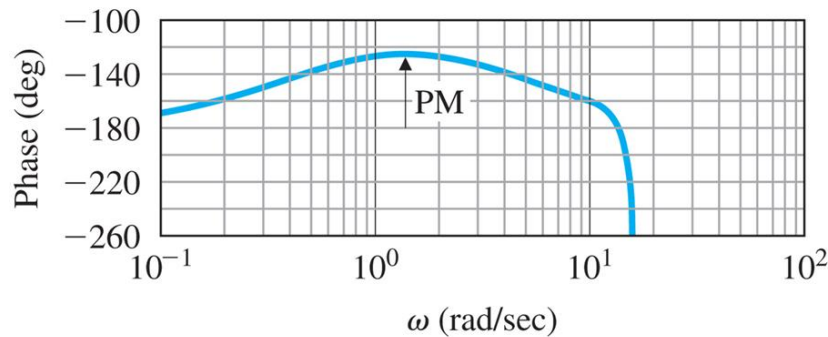
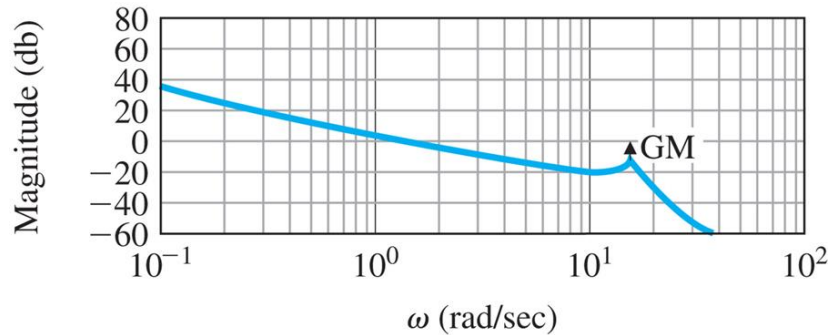
- (STEP 4) Make a linear model

$$G(s) = \frac{1}{s^2} \frac{(2\zeta s/\omega_1 + 1)}{(\frac{s^2}{\omega_1} + 2\zeta \frac{s}{\omega_1} + 1)}$$

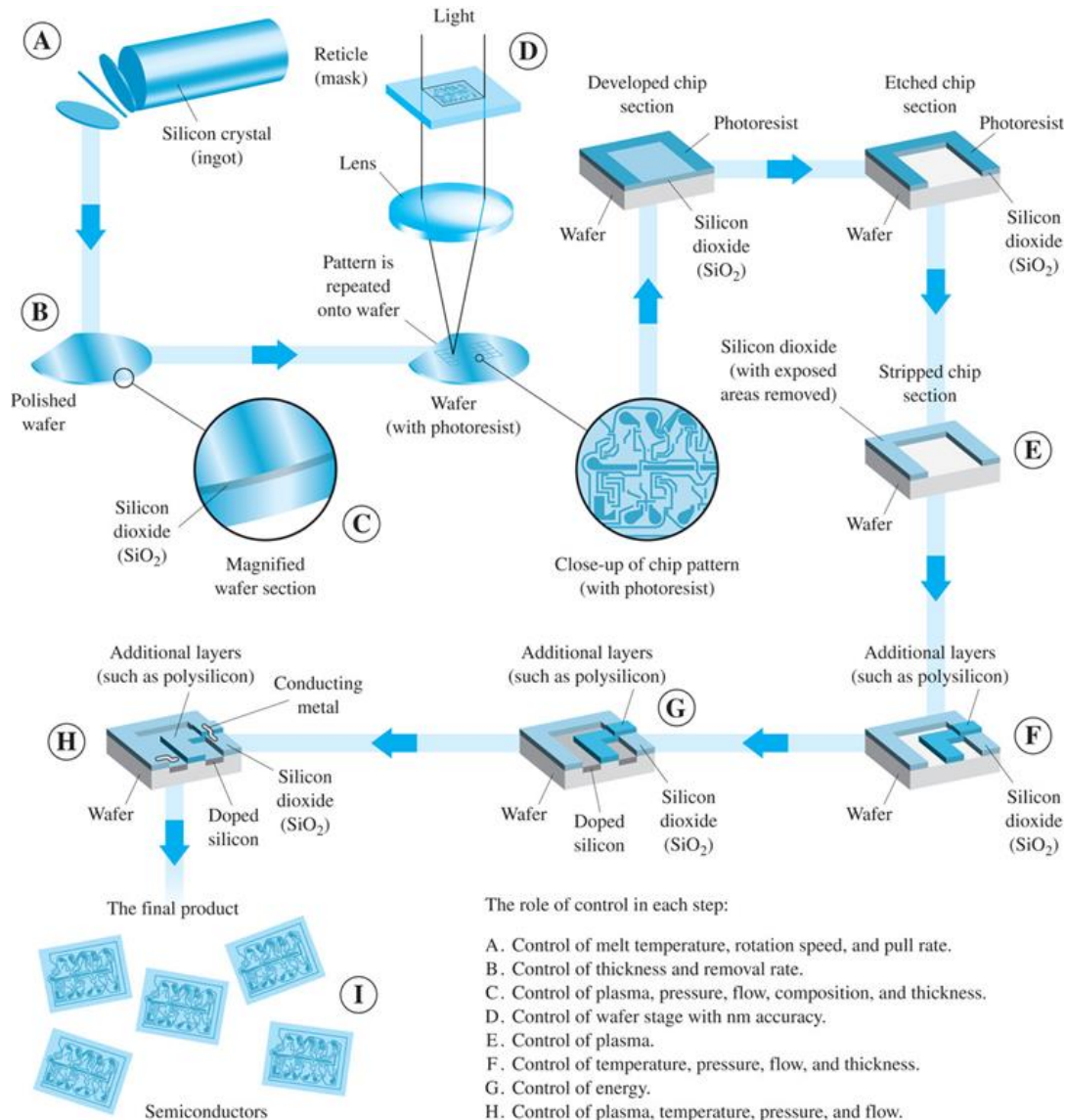
$$\zeta = 0.05, \quad \omega_1 = 2.5$$

- (STEP 5) Try a lead-lag or P/D controller
 - Leadcompensation to have 50° phase margin, factor of 4 gain margin

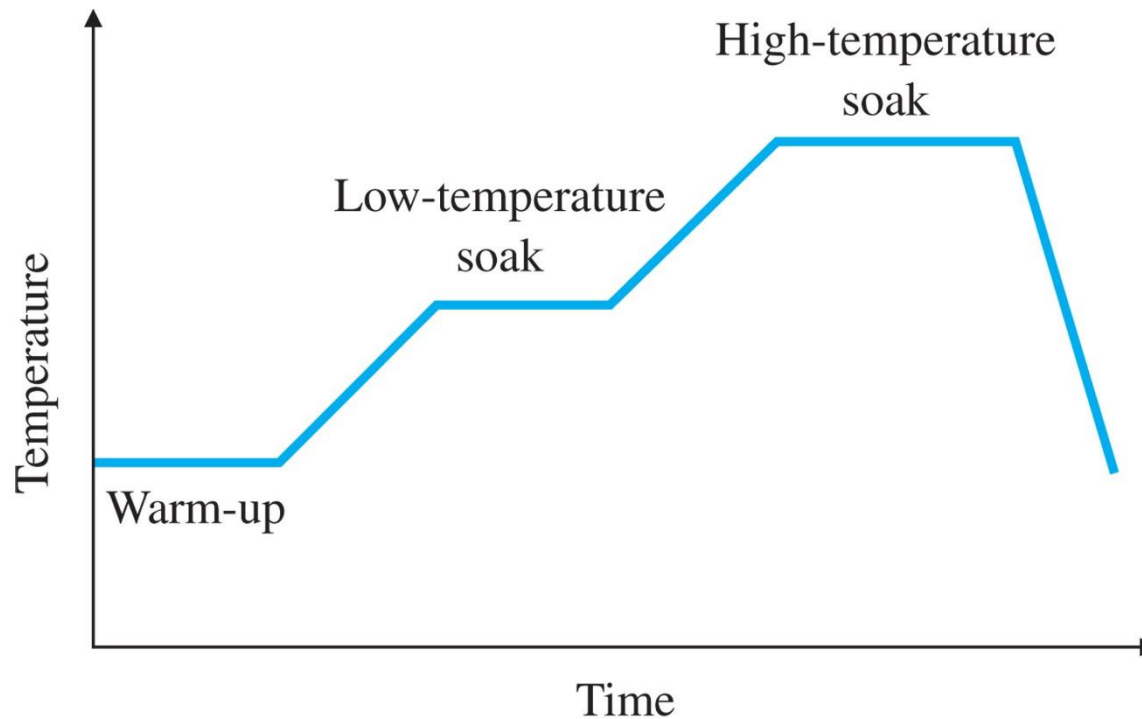
$$D_c(s) = 0.617 \frac{(2.22s + 1)}{(0.222s + 1)}$$



■ Rapid Thermal Processing (RTP)



- (STEP 1) Understand the process and its performance specifications
 - The temperature of the wafer needs to be rapidly increased or decreased by the profile



- (STEP 1) Understand the process and its performance specifications
 - A feedback control system is required to maintain the F/A within 1% of the desired level

- (STEP 2) Select sensors
 - Temperature measurement

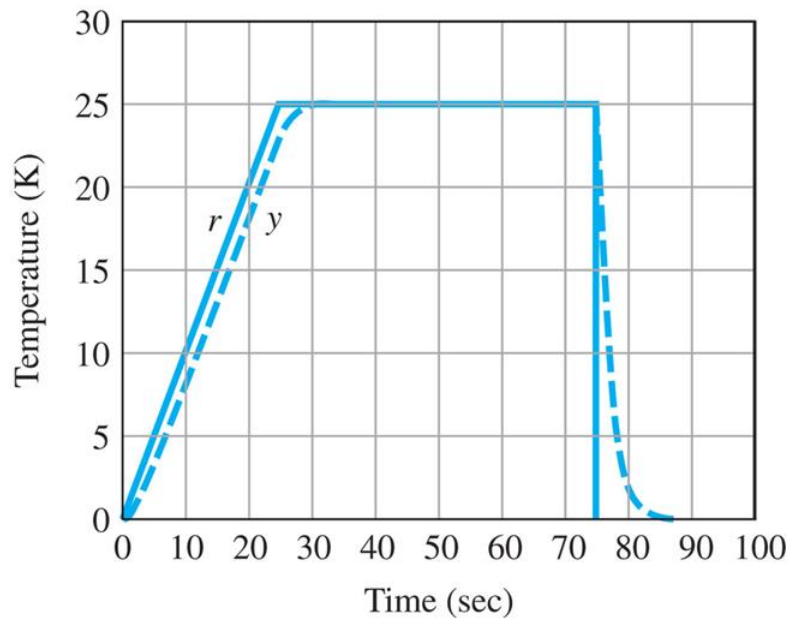
- (STEP 3) Select actuators
 - Heating (lamp)

- (STEP 4) Make a linear model

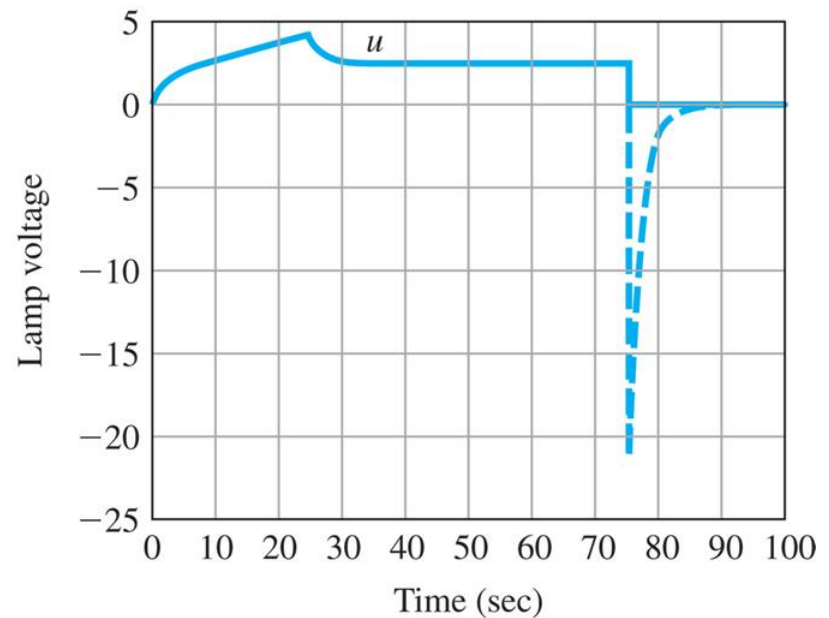
$$G(s) = \frac{T_{y2}(s)}{V_{cmd}(s)} = \frac{0.5226(s + 0.0876)(s + 0.1438)}{(s + 0.1482)(s + 0.0527)(s + 0.0863)}$$

- (STEP 5) Try a lead-lag or P/D controller
 - PI Control

$$D_c(s) = \frac{(s + 0.0527)}{s}$$



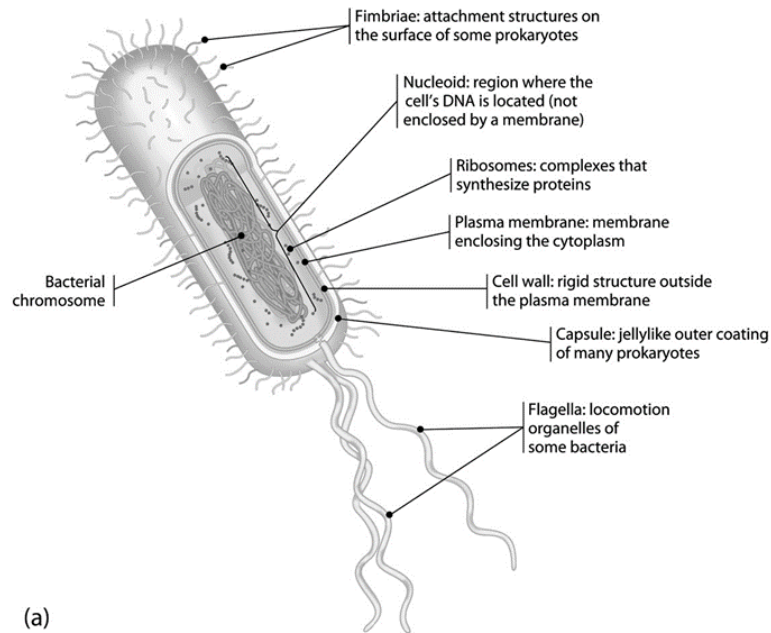
(a) Temperature tracking response



(b) Control effort

■ System Biology

- How shifting variables in one part impact the whole



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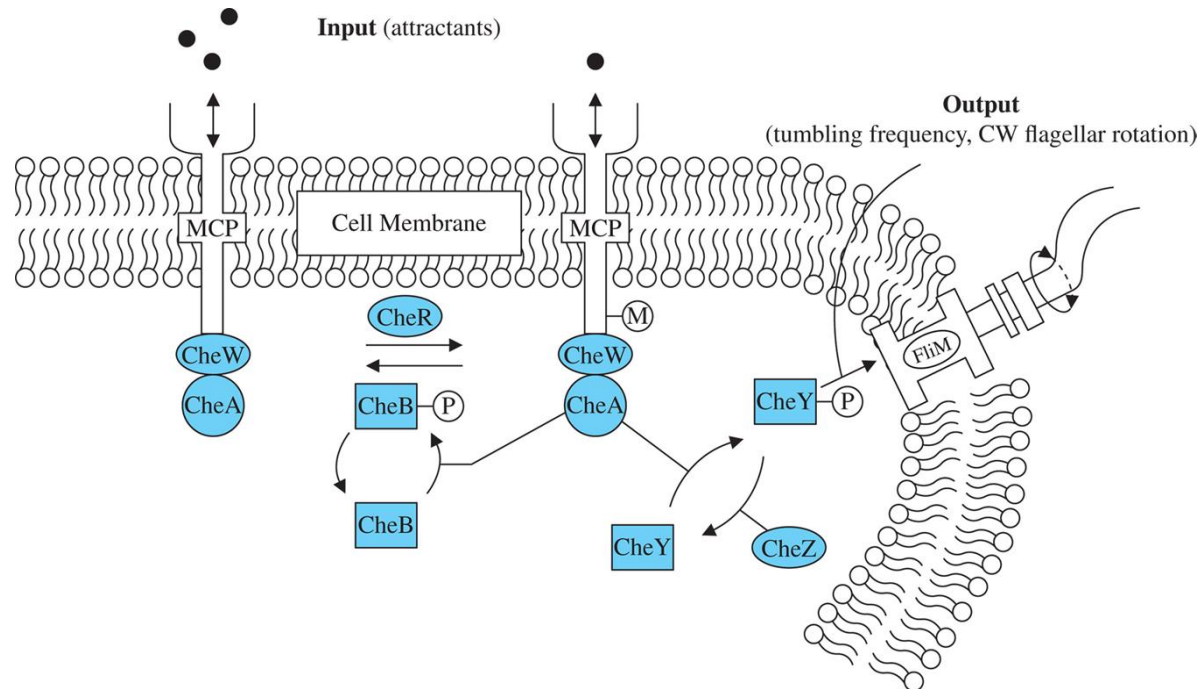
(a) A typical bacterium;

(b) TEM of bacterium *Bacillus coagulans*

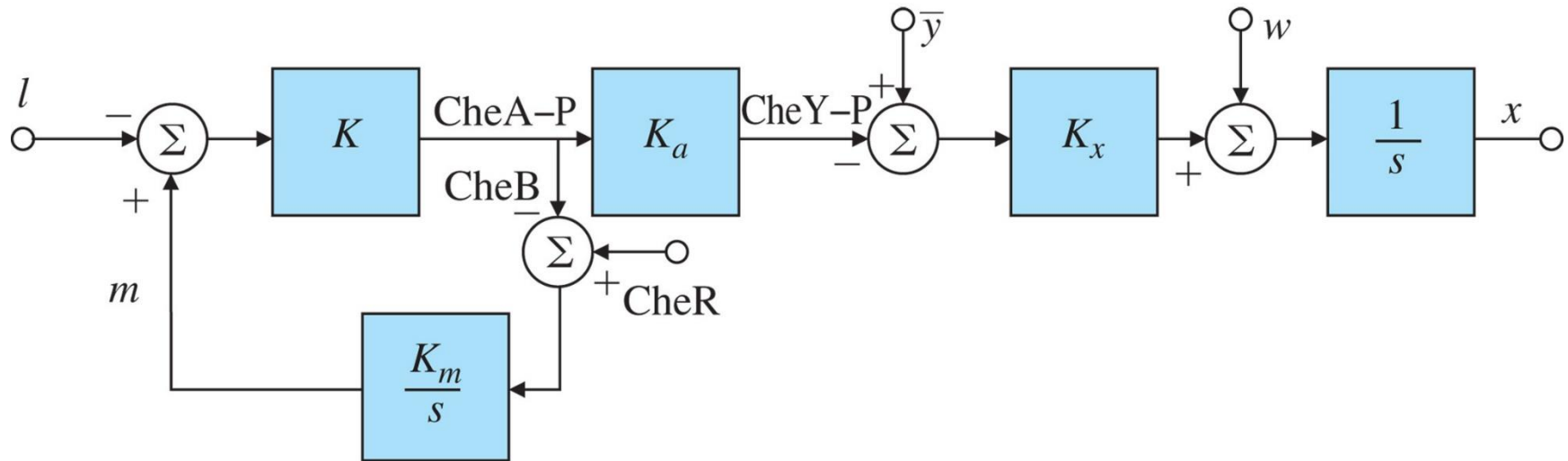
Source: (a) Campbell and Reece, page 98, 2008. (b) © 2014 Stanley C. Holt/Biological Photo Service.

- Understand the process and its performance specifications
 - Chemotaxis is the name given to the process by which a motile bacterium senses the changes in its environment and moves toward places with a more favorable environment.
 - The dynamics of this chemotaxis are the subject of case study.

- Model

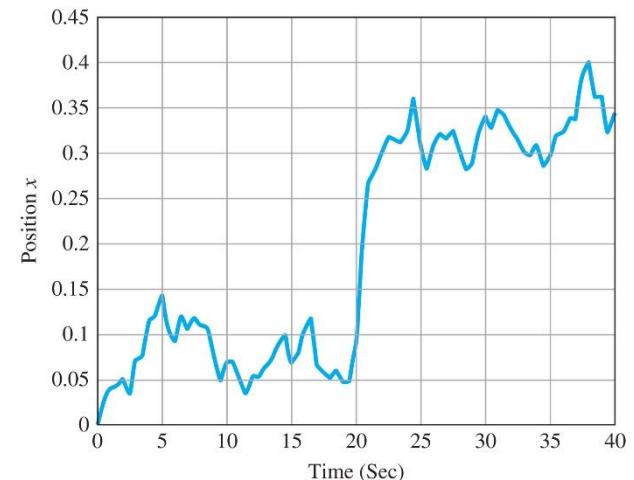


- Simplified block diagram of E.coli chemotaxis. l represents ligand, m the methylation, CheR the steady-state rate of methylation, y the steady-state activity, and w the steady-state random walk motion



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- Motion response of the chemotaxis model following insertion of attractant at $t = 20$ sec



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- **Make a system model and determine the required performance specifications.**
 - The purpose of this step is to answer the question. What is the system, and what is it supposed to do?
- **Select sensors (measurement output)**
 - A basic rule of control is that if you can't observe it, you can't control it.
- **Select actuators.**
 - The actuators must be capable of driving the system so as to meet the required performance specifications.
- **Make a linear model.**
 - All our design methods are based on linear models. Both small-signal perturbation models and feedback linearization methods can be used.
- **Try a simple P/D controller.**
 - An effort to meet the specifications with a PIO or its cousin, the lead-lag compensator, may succeed; in any case such an effort will expose the nature of the control problem.

- Evaluate/modify plant.
 - Evaluate whether plant modifications enhance closed-loop performance; if so, return to Step 1 or 4. Make a system model and determine the required performance specifications.
- Simulate the design, and verify its performance.
 - All the tools of analysis should be used here, including the root locus, the frequency response, $G\omega$ and PM measurements, and transient responses.
 - Also, the performance of the design can be tested in simulation against changes in model parameters and the effects of approximating the compensator with a discrete model if digital control is to be used.
- Build a prototype and measure their performance with typical input signals