Lecture 5

FRTN10 Multivariable Control

Automatic Control LTH, 2019

Course Outline

L1–L5 Specifications, models and loop-shaping by hand

1. Introduction
2. Stability and robustness
3. Specifications and disturbance models
4. Control synthesis in frequency domain
5. **Case study: DVD player**

L6–L8 Limitations on achievable performance

L9–L11 Controller optimization: analytic approach

L12–L14 Controller optimization: numerical approach

L15 Course review

L5: Case Study: Control of a DVD player

1. Case study: Control of a DVD player
2. Review of cascade and midranging control

Case Study: Control of a DVD player

- The DVD player process
- Problem formulation
- Modeling
- Specifications
- Focus control loop shaping
- Radial control (track following)

Based on work by Bo Lincoln


TOOLEX ALPHA
DVD system
TOOLEX
ALPHA

The DVD player tracking problem

Scaled version of the control task in a DVD player:

- Imagine that you are traveling at half the speed of light,

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Scaled version of the control task in a DVD player:

- Imagine that you are traveling at half the speed of light, along a line from which you may only deviate 1 m
- The line is not straight but oscillates up to 4.5 km sideways up to 25 times per second

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- Imagine that you are traveling at half the speed of light, along a line from which you may only deviate 1 m
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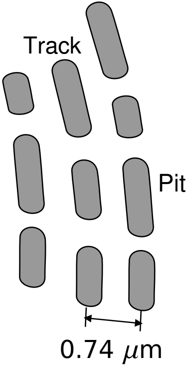
Good luck!

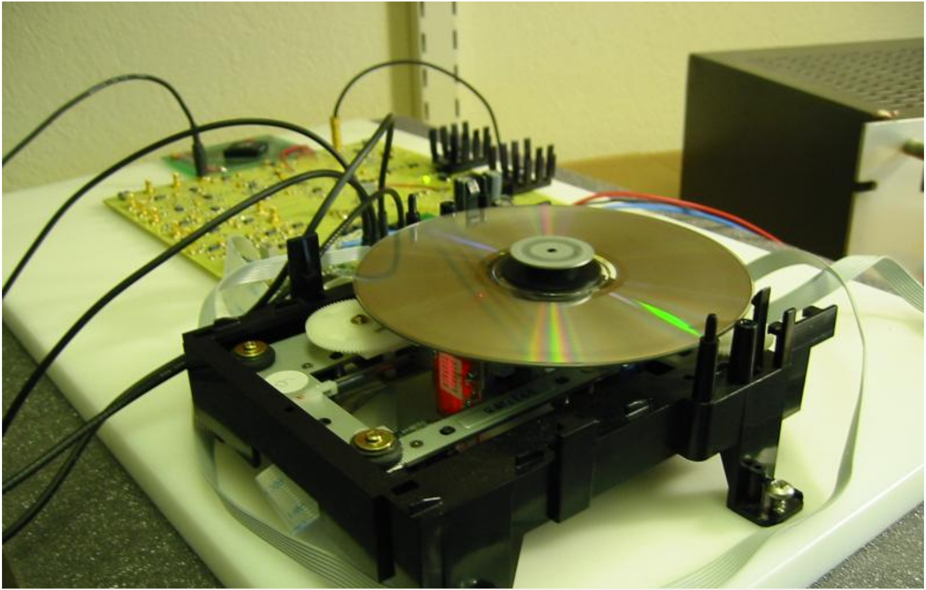
The DVD player tracking problem



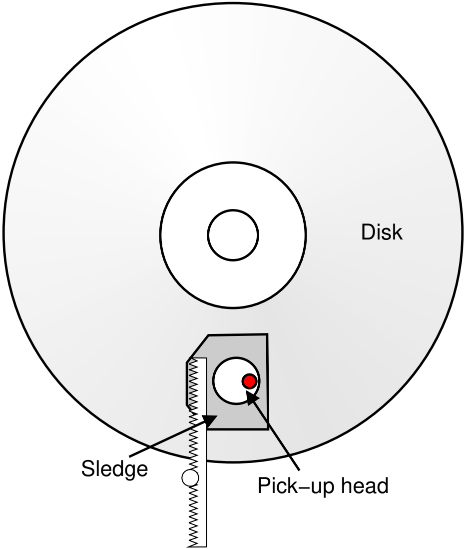
- 3.5 m/s speed along track
- 0.022 μm tracking tolerance
- 100 μm deviations at 10–25 Hz due to asymmetric discs

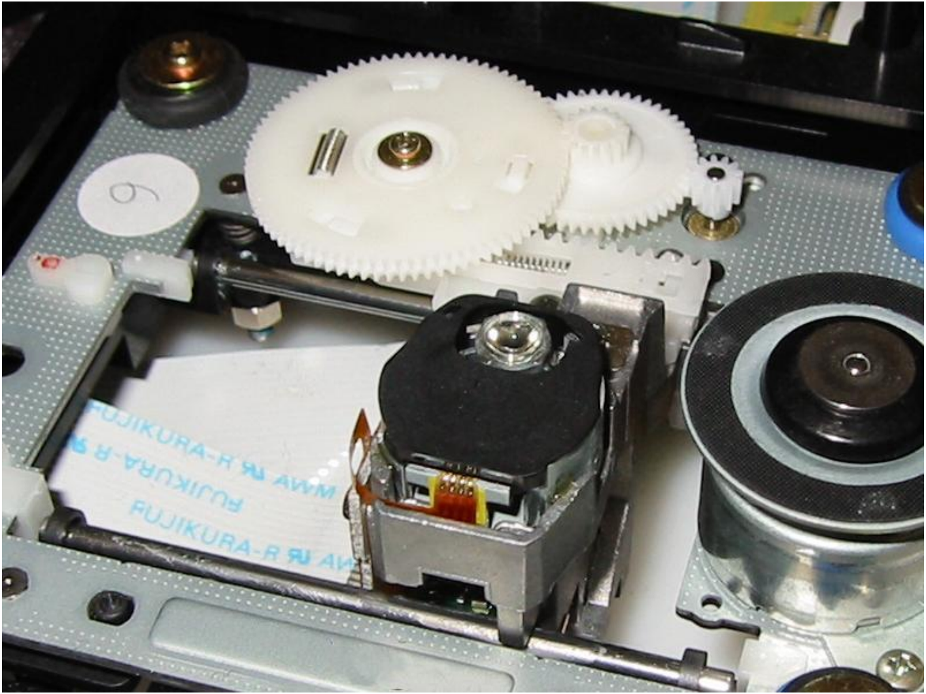
DVD	Digital Versatile Disc, 4.7–8.5 GB
CD	Compact Disc, 650–800 MB
Blu-ray	25–400 GB

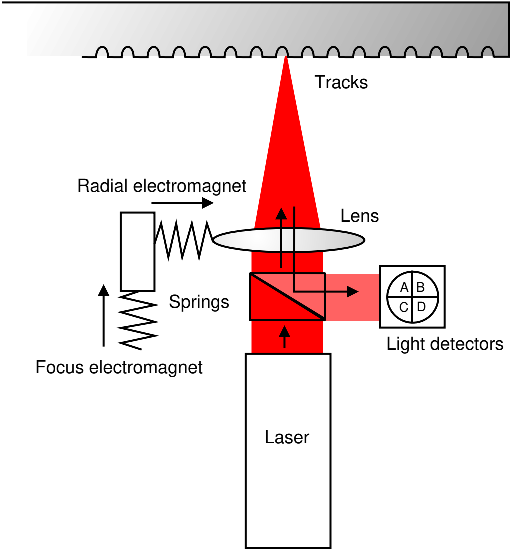
Can you see the laser spot?



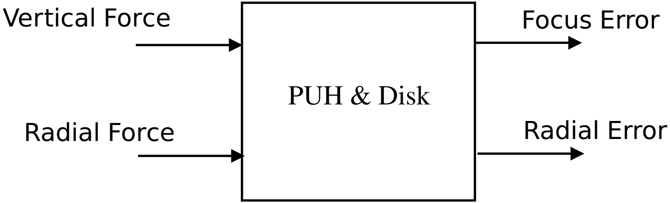
The DVD Pick-Up Head



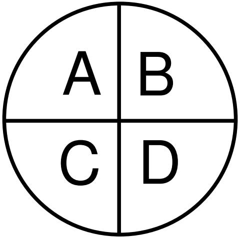

FUJIKURA-R


Tracks
Radial electromagnet
Lens
A
B
C
D
Springs
Light detectors
Focus electromagnet
Laser

Input-output diagram for DVD control



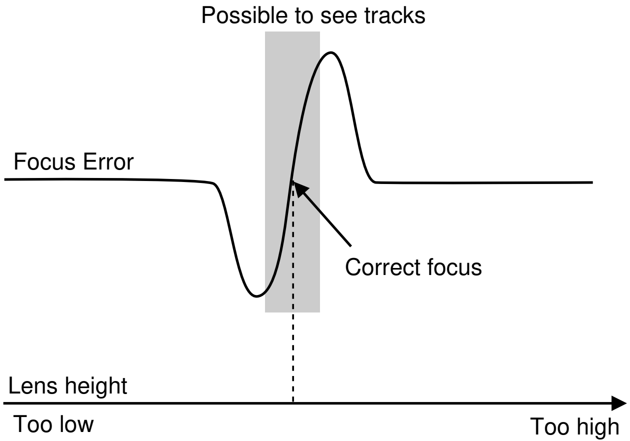
The four photo detectors



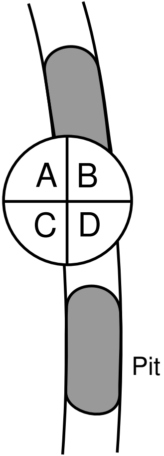
focus error = (A+D) – (B+C)

Note: *There are no other sensors in the pick-up head to help keep the laser in the track.*

Focus error signal



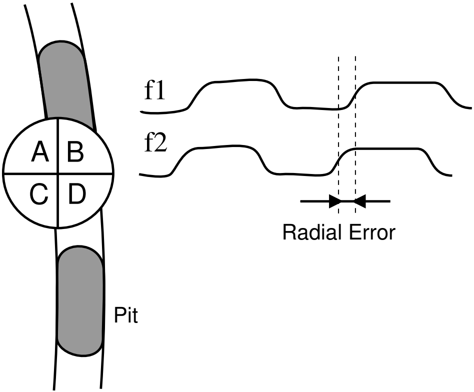
Radial error by push-pull



Look at

$$(A + C) - (B + D)$$

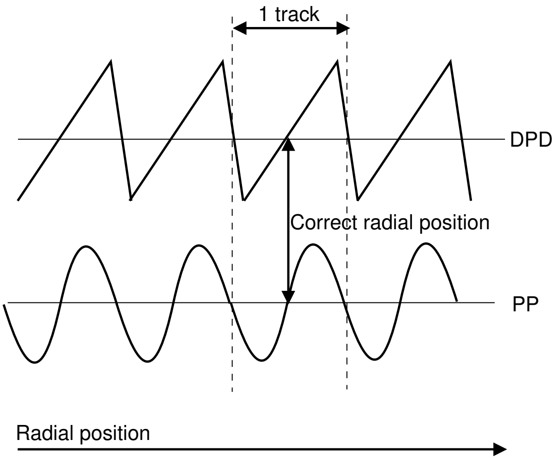
Radial error by phase difference



$$f_1 = A + D, \qquad f_2 = B + C$$

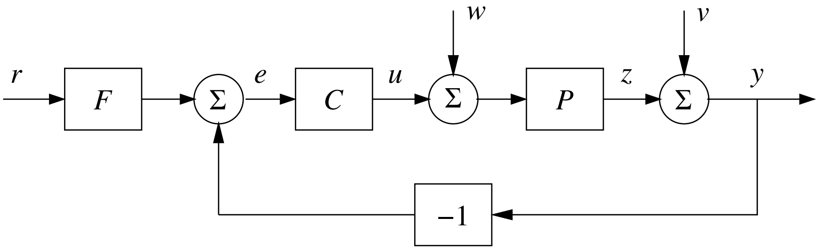
Error signal RE created by time difference

Radial error signals



Note: Larger linear error region if using phase difference.

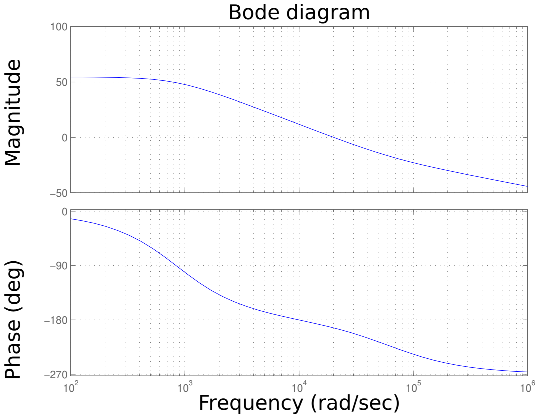
Focus control design



- What blocks and signals are relevant for focus control?
- What disturbances are there?

Focus process model

Model obtained using system identification:



$$P(s) = 6092 \frac{63168 - s}{s^2 + 1553s + 718214}$$

From DVD standard ECMA-267

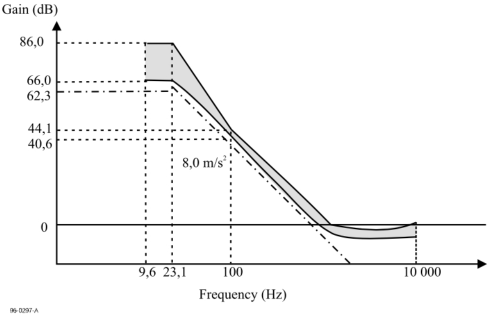


Figure 3 - Reference Servo for axial tracking

Bandwidth 100 Hz to 10 kHz

$|1 + H|$ shall be within 20 % of $|1+H_s|$.

The crossover frequency $f_o = \omega_o / 2\pi$ shall be specified by equation (II), where α_{max} shall be 1,5 times larger than the expected maximum axial acceleration of 8 m/s^2. The tracking error e_{max} shall not exceed 0,23 µm. Thus the crossover frequency f_o shall be

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{3\,\alpha_{max}}{e_{max}}} = \frac{1}{2\pi}\sqrt{\frac{8 \times 1{,}5 \times 3}{0{,}23 \times 10^{-6}}} = 2{,}0 \text{ kHz} \qquad \text{(II)}$$

http://www.ecma-international.org/publications/standards/Ecma-267.htm

Specifications

- Cancel disturbances due to disc asymmetry

$$|P(i\omega)C(i\omega)| \geq 2000 \qquad \text{for } f \leq 23 \text{ Hz}$$

- Robustness towards model errors, rejection of meas. noise

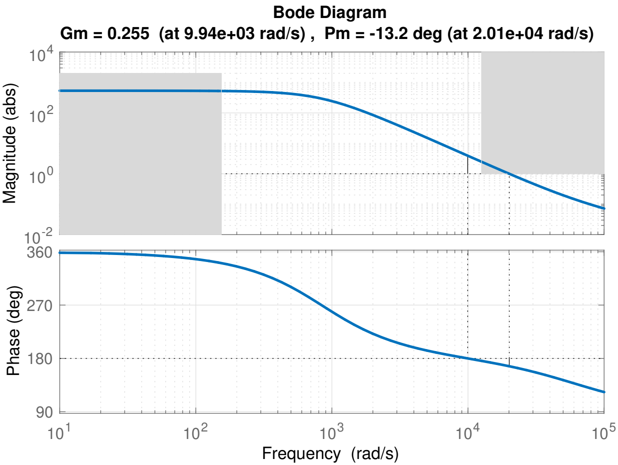
$$|P(i\omega)C(i\omega)| \leq 1 \qquad \text{for } f > 2 \text{ kHz}$$

(Compare to the bit rate, which is in the order of 1 MHz)

- Good stability margins

Open-loop system

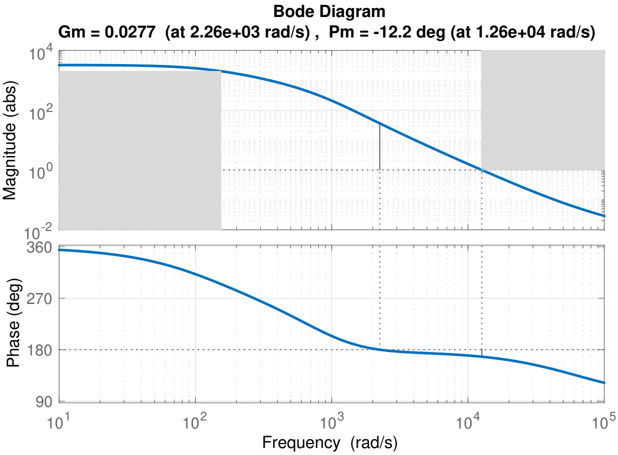
Bode plot of $P(s)$ with stability margins and specifications:



Q: Can a P-controller solve the problem?

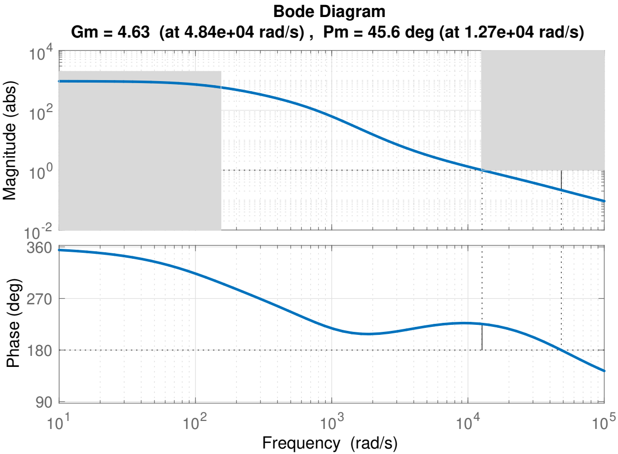
Add lag compensator

Use lag filter with $M = 15$ to increase gain below 23 Hz. The break point needs to be well below 2 kHz in order to avoid excessive phase lag at the cross-over frequency: $C = KC_{lag} = \frac{0.4037(s+1885)}{s+125.7}$



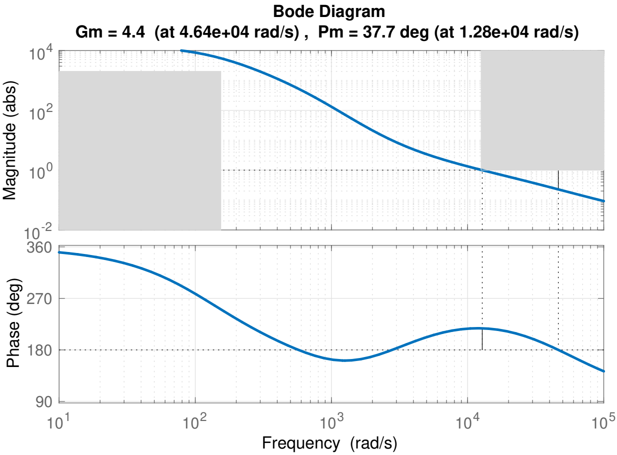
Add lead compensator

Use lead filter with $N = 12$ to increase phase by $57°$ at cross-over frequency. $C = KC_{lag}C_{lead} = \frac{1.398(s+1885)(s+3228)}{(s+125.7)(s+43530)}$



Add another lag compensator

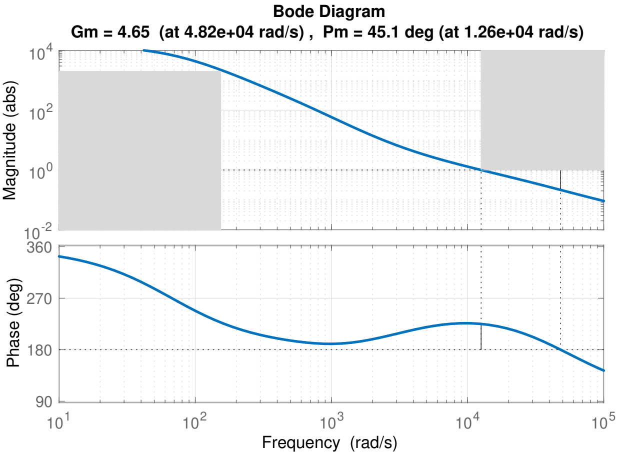
Low-frequency gain too low. Add another lag compensator with same parameters: $C = KC_{lag}^2 C_{lead} = \dfrac{1.398(s+1885)^2(s+3628)}{(s+125.7)^2(s+43530)}$



Final adjustments

Phase margin too small again. Lower the break frequency of the lag filters to recover some phase:

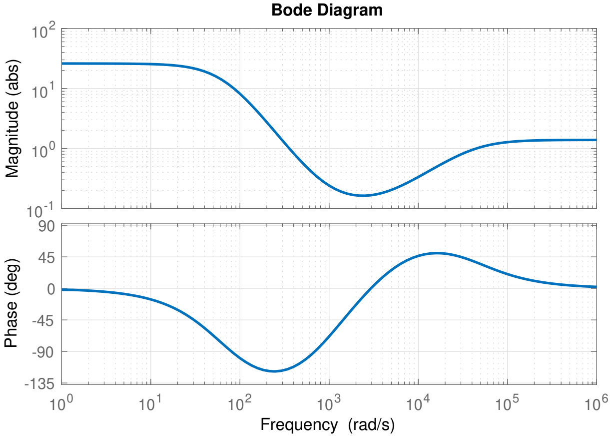
$$C = KC_{lag}^2 C_{lead} = \frac{1.397(s+1005)^2(s+3628)}{(s+67.02)^2(s+43530)}$$



Final controller

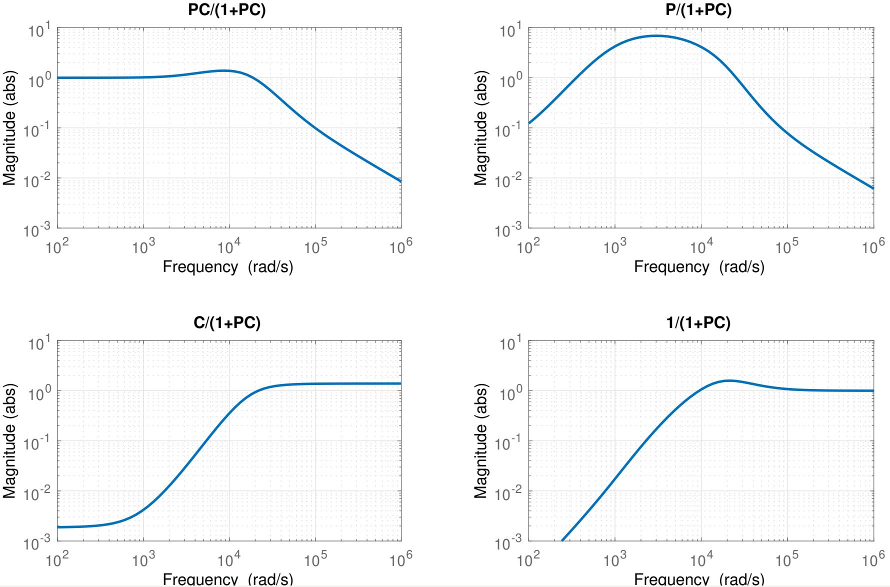
Bode diagram of final controller

$$C = KC_{lag}^2 C_{lead} = \frac{1.397(s+1005)^2(s+3628)}{(s+67.02)^2(s+43530)}$$

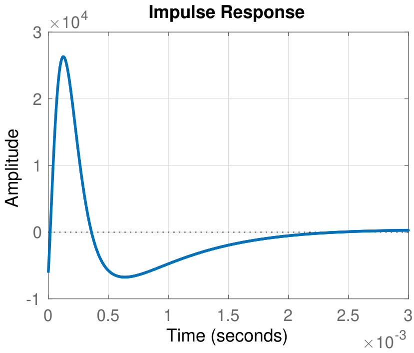


(Could add another pole to have high-frequency roll-off)

Gang of Four


PC/(1+PC)
P/(1+PC)
C/(1+PC)
1/(1+PC)
Magnitude (abs)
Frequency (rad/s)
10^1
10^0
10^-1
10^-2
10^-3
10^2
10^3
10^4
10^5
10^6

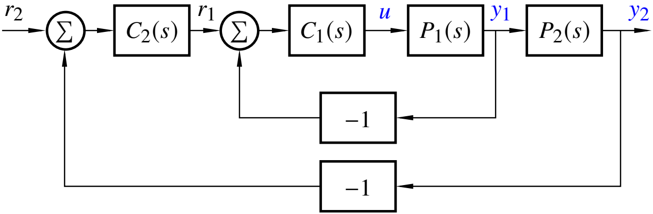
Response to impulse load disturbance



L5: Case Study: Control of a DVD player

Cascade control

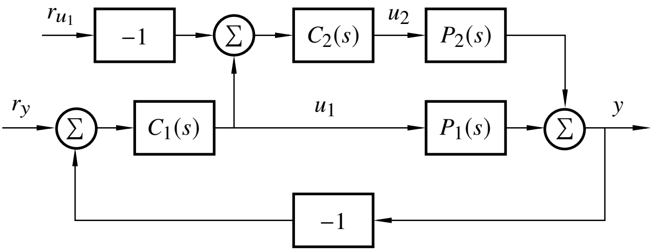
For systems with one control signal and two measurement signals:



- $C_1(s)$ controls the subsystem $P_1(s)$
  - Fast inner loop, $G_{y_1 r_1}(s) \approx 1$
- $C_2(s)$ controls the subsystem $P_2(s)$
  - Slow outer loop

Midranging control

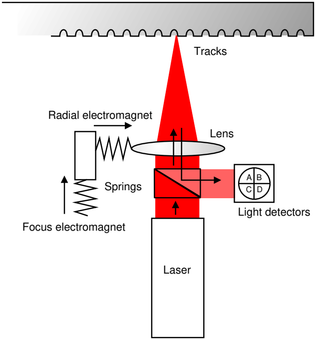
For systems with one measurement signal and two control signals (e.g. one large-range/slow and one small-range/fast actuator)

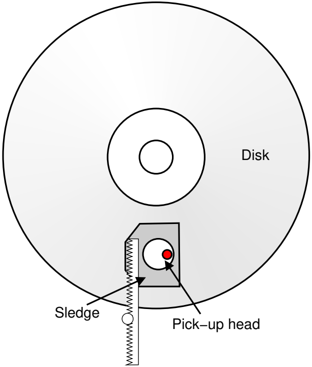


- $C_1(s)$ controls the process output y with fast actuator u_1
- $C_2(s)$ controls u_1 to the middle of its operating range using slow actuator u_2 (note reverse gain!)

Midranging control – example

Radial control of pick-up-head of DVD player





The pick-up-head has two electromagnets for fast positioning of the lens (left). Larger radial movements are taken care of by the sledge (right).