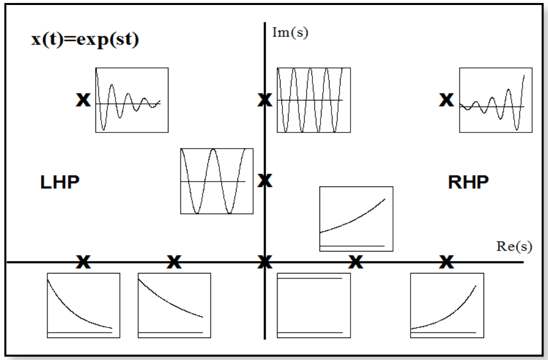
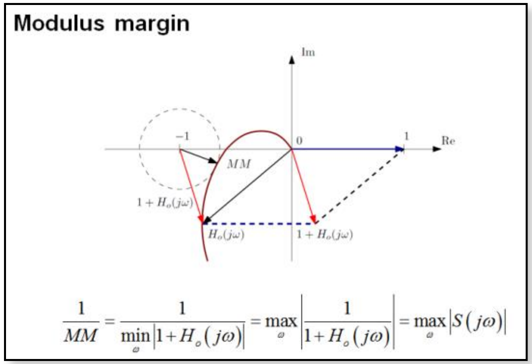
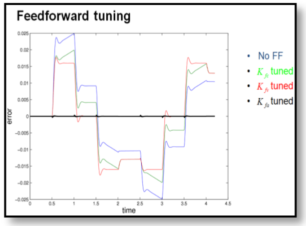
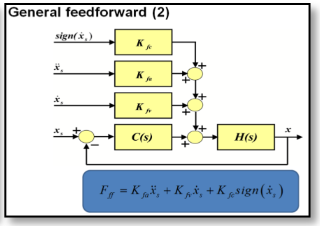
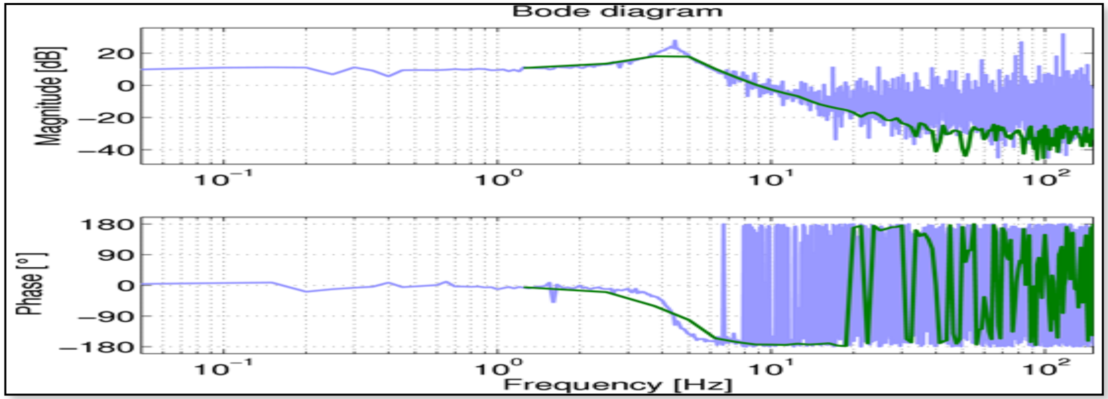
Motion Control Tuning











Contents

- Mechatronics Training Curriculum
- Details of Course *Motion Control Tuning*

Mechatronics Training Curriculum

Premium

- Workshop Mechatronics System Design — **On request**

Premium / Advanced

- Advanced Motion Control — **5 days**
- Advanced Feedforward & Learning Control — **3 days**
- Passive Damping for High Tech Systems — **3 days**
- Masterclass Design Principles — **On request**

Advanced

- Advanced Mechatronic System Design — **6 days**

Standard

- Motion Control Tuning — **5 days**
- Dynamics and Modelling — **3 days**
- Design Principles for Precision Eng. — **5 days**
- Basics and Design for Ultra Clean Vacuum — **4 days**
- Experimental Techniques in Mechatronics — **3 days**
- Metrology & Calibration of Mechatronic Systems — **3 days**
- Actuation and Power Electronics — **3 days**
- Machine Vision for Mechatronic Systems — **2 days**
- Thermal Effects in Mechatronic Systems — **3 days**

Basic

- Mechatronics System Design – part 2 — **5 days**
- Mechatronics System Design – part 1 — **5 days**

Start

Relevant partner trainings:
Applied Optics, Electronics for non-electrical engineers, System Architecture, Soft skills for technology professionals, …

www.mechatronics-academy.nl

Mechatronics Academy

- In the past, many trainings were developed within Philips to train own staff, but the training center CTT stopped.
- **Mechatronics Academy B.V.** has been setup to provide continuity of the existing trainings and develop new trainings in the field of precision mechatronics. It is founded and run by:
  - Prof. Maarten Steinbuch
  - Prof. Jan van Eijk
  - Dr. Adrian Rankers
- We cooperate in the **High Tech Institute** consortium that provides sales, marketing and back office functions.

Motion Control Tuning

Course Directors / Trainers

Course Director(s)

- Dr.ir. Tom Oomen (TU/e)
- Dr.ir. Gert Witvoet (TNO & TU/e)
- Dr.ir. Adrian Rankers (Mechatronics Academy)

Teachers

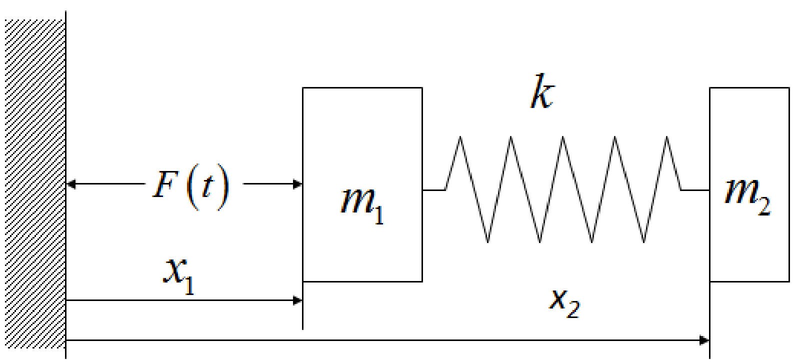
- TU/Eindhoven:
    - Prof.dr.ir. M. Steinbuch, Dr. ir. T. Oomen, Dr. ir. P. Nuij,
    - Dr.ir. J.J. Bolder, Ir. T. Gommans, Ir. R. van der Maas
- Other:
    - Dr.ir. E.P. van der Laan (Philips Innovation Services)
    - Dr.ir. M.J.M. van de Wal (ASML)
    - Dr..ir. D. Rijlaarsdam (Additive Industries)
    - Ir. F.B. Sperling (Nobleo)
    - Ir. M. Vervoordeldonk (ASML)
    - Dr.ir. G. Witvoet (TNO)
    - Dr.ir. A.M. Rankers (Mechatronics Academy)

Program

Day	Timing	Topic	Trainers
1	Morning	• Introduction / Who is who / Program / Goals… • Basic Modelling	Steinbuch Rankers
	Afternoon	• Time domain tuning - theory & hands-on practice	Nuij
2	Morning	• Frequency domain	Vervoordeldonk
	Afternoon	• Stability	Van der Weiden a.o.
3	Morning	• Frequency response measurements – theory & hands-on practice	Oomen / Bolder
	Afternoon	• Mechatronics	Sperling
4	Morning	• Filters	Witvoet
	Afternoon	• Loopshaping game	Van der Weiden / v.d. Maas / Gommans
5	Morning	• Design for performance	v.d. Wal
	Afternoon	• Special Topics	Steinbuch / Oomen / ...

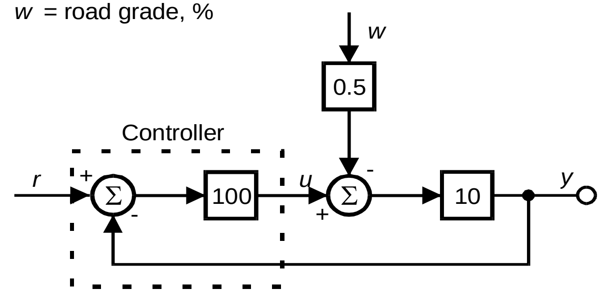
Day 1 (morning): Intro / Basic Modelling

- Introduction / Goals
- Modelling of motion systems



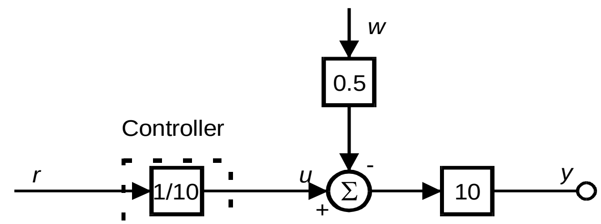
The equations of motion:
$$F - k(x_1 - x_2) = m_1 \ddot{x}_1$$
$$+k(x_1 - x_2) = m_2 \ddot{x}_2$$

r = reference speed
u = throttle angle, degrees
y = actual speed, mph
w = road grade, %



With feedback

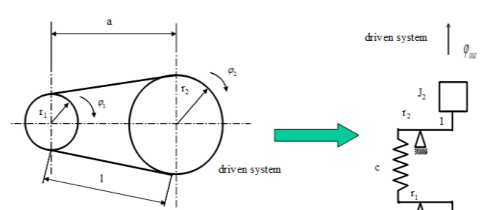
$y = 0.999r - 0.005w$



Without feedback

$y = r - 5w$

Dynamic model of belt drive

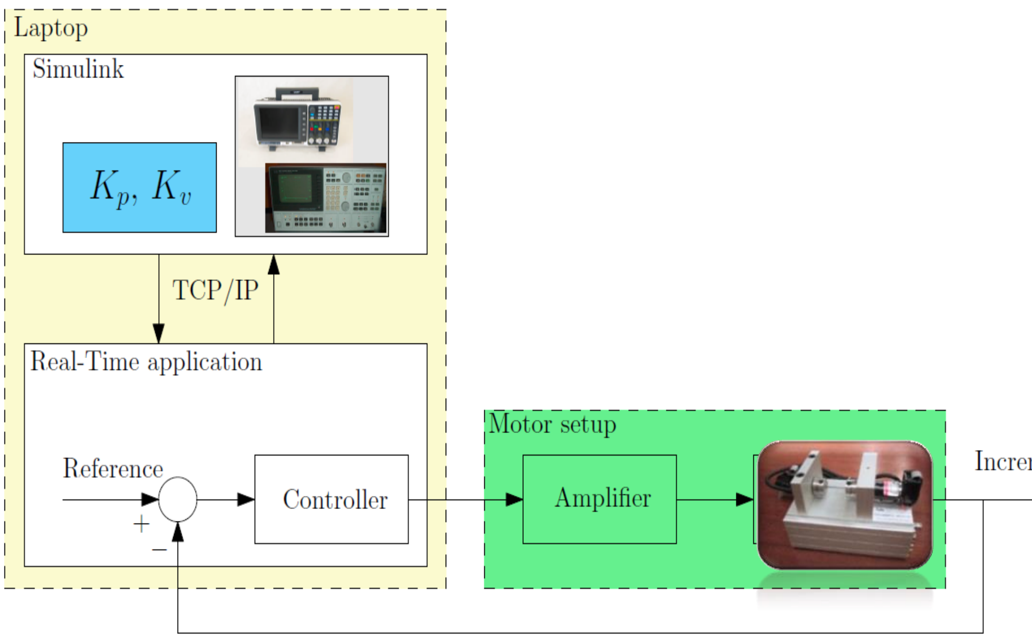


$$l = \sqrt{a^2 - (r_2 - r_1)^2}$$
$$J_{1,2} = \frac{1}{2} m_{1,2} r_{1,2}^2$$

c' = stiffness per unit length
c = c'/l

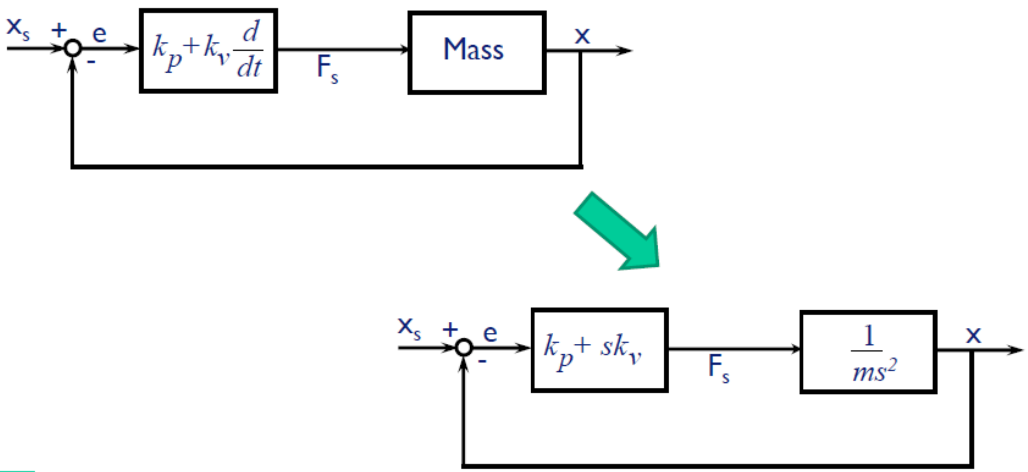
Day 1 (afternoon): Time domain tuning

- Tuning in time domain
- Theory & Hands-on
- Matlab/Simulink + exp. setup



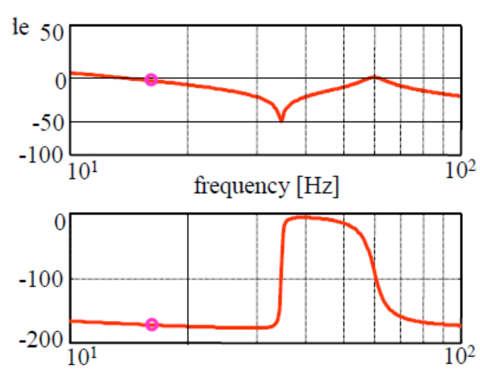
Day 2 (morning): Frequency domain

- Frequency domain
  - Transfer function
  - Frequency response functio
- Physical interpretation

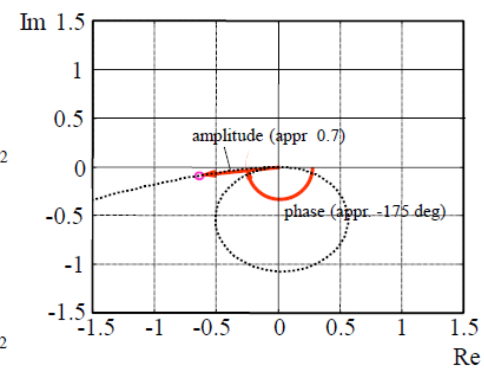


	PD controller	Mass spring system	Mass
1. equation of motion	$F_s(t) = k_p e(t) + k_v \dot{e}(t)$	$m\ddot{x} + d\dot{x} + kx = F$	$m\ddot{x} = F$
2. replace 'd/dt' by 's'	$F_s(s) = k_p e(s) + k_v s e(s)$	$ms^2 x + dsx + kx = F$	$ms^2 x = F$
	$\frac{F_s}{e}(s) = k_p + k_v s$	$\frac{x}{F}(s) = \frac{1}{ms^2 + ds + k}$	$\frac{x}{F} = \frac{1}{ms^2}$
3. replace 's' by 'jω'	$F_s = k_p e + k_v j\omega e$	$m(j\omega)^2 x + dj\omega x + kx = F$	$-m\omega^2 x = F$
FRF	$\frac{F_s}{e}(\omega) = k_p + k_v j\omega$	$\frac{x}{F}(\omega) = \frac{1}{-m\omega^2 + dj\omega + k}$	$\frac{x}{F} = \frac{-1}{m\omega^2}$

Bode plot

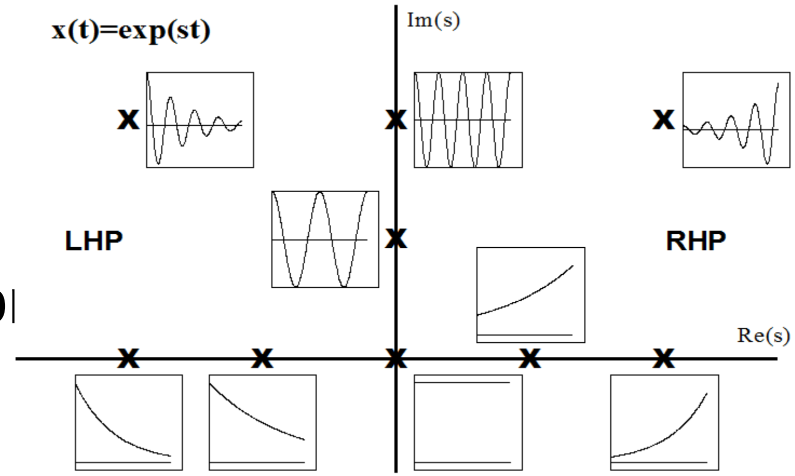


Nyquist plot

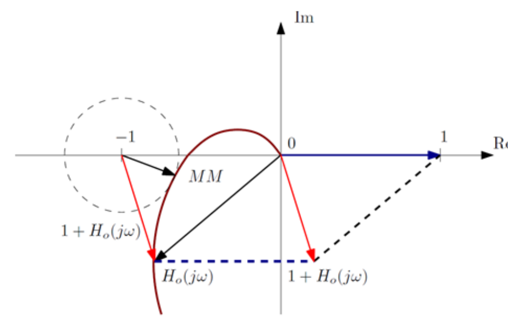


Day 2 (afternoon): Stability

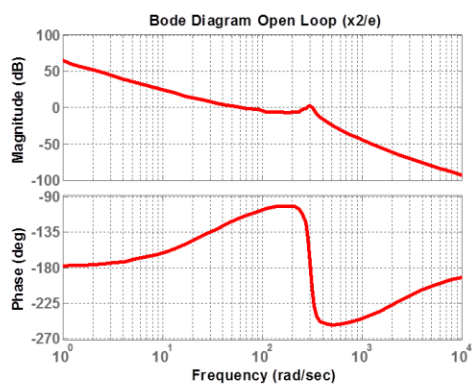
- Introduction
- Intro stability in the time domain
- Intro stability in the frequency do
- Nyquist stability criterion
- Stability margins
- Modulus margin

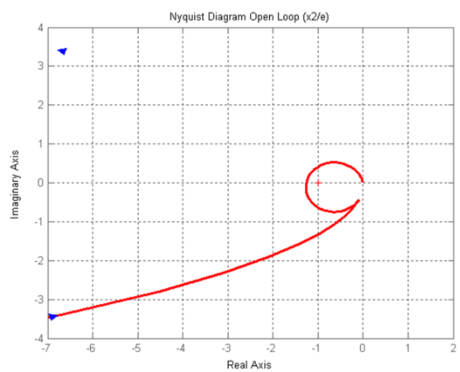


Modulus margin



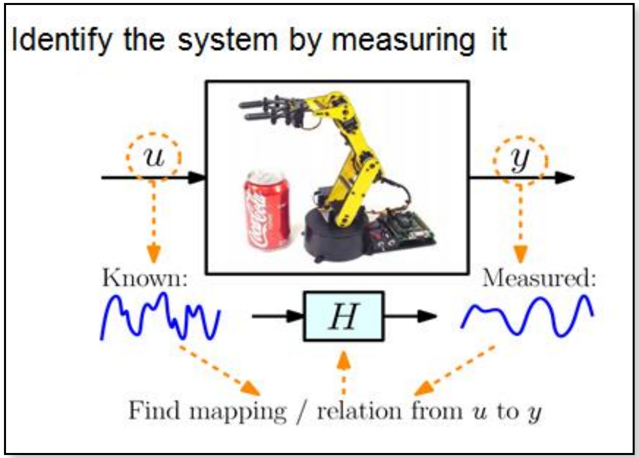
$$\frac{1}{MM} = \frac{1}{\min_{\omega}\left|1+H_o(j\omega)\right|} = \max_{\omega}\left|\frac{1}{1+H_o(j\omega)}\right| = \max_{\omega}\left|S(j\omega)\right|$$



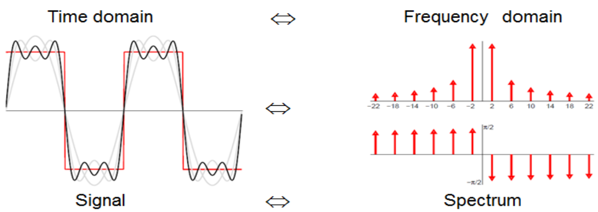


Day 3 (morning): FRF measurements

- Linear systems
- Non-parametric identification
  - Open loop
  - Closed loop (direct/indirect)
- Enhancing estimation quality
- Autopower/Crosspower
- Coherence



- Fourier series maps time into frequency:



Appendix: Signal analysis: Fourier series

Any signal x(t) of length T can be represented as a sum of harmonics.

$$x(t) = \sum_{k=0}^{\infty}\left[a_k \cos\left(2\pi \frac{k}{T} t\right) + b_k \sin\left(2\pi \frac{k}{T} t\right)\right] \qquad (1)$$

$$= A_0 + \sum_{k=1}^{\infty} A_k \cos\left(k \frac{2\pi}{T} t + \phi_k\right) \qquad (2)$$

where

$\frac{2\pi}{T}$: Fundamental frequency (period T)

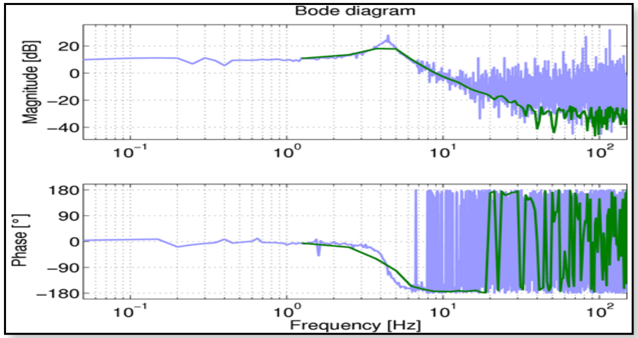
k : Harmonic number

$A_0 = a_0$: Constant signal offset

$A_k = \sqrt{a_k^2 + b_k^2}$: Amplitude of k-th harmonic

$\phi_k = -\arctan \frac{b_k}{a_k}$: Phase of k-th harmonic

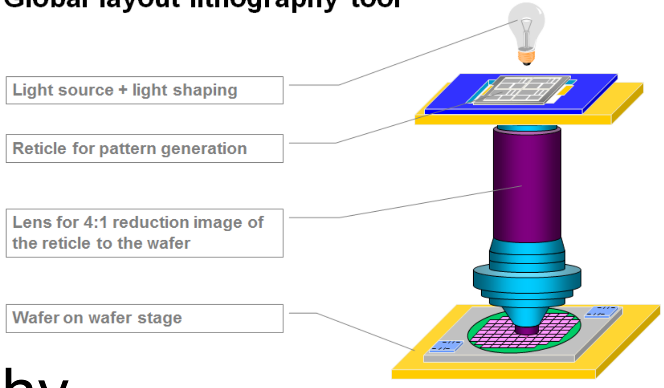
Note: assumes the signal is periodic: $x(t+T) = x(t)$

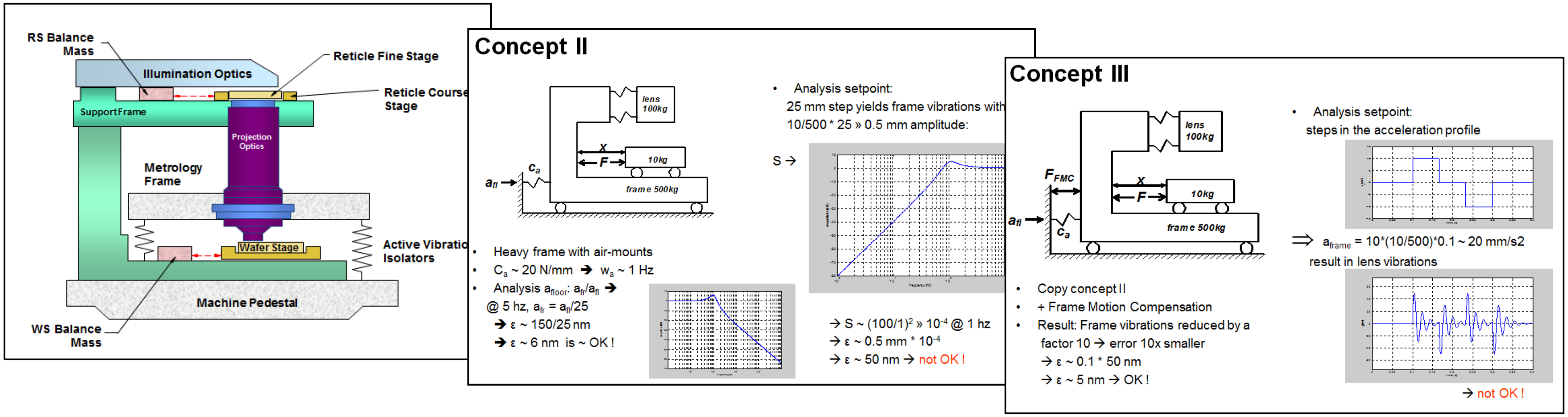


Day 3 (afternoon): Mechatronics

- Conceptual dynamics & servo control
- Modelbuilding
- Servo control basics
- Key specifications for 0.2 μm lithography
- Case: stepper concepts

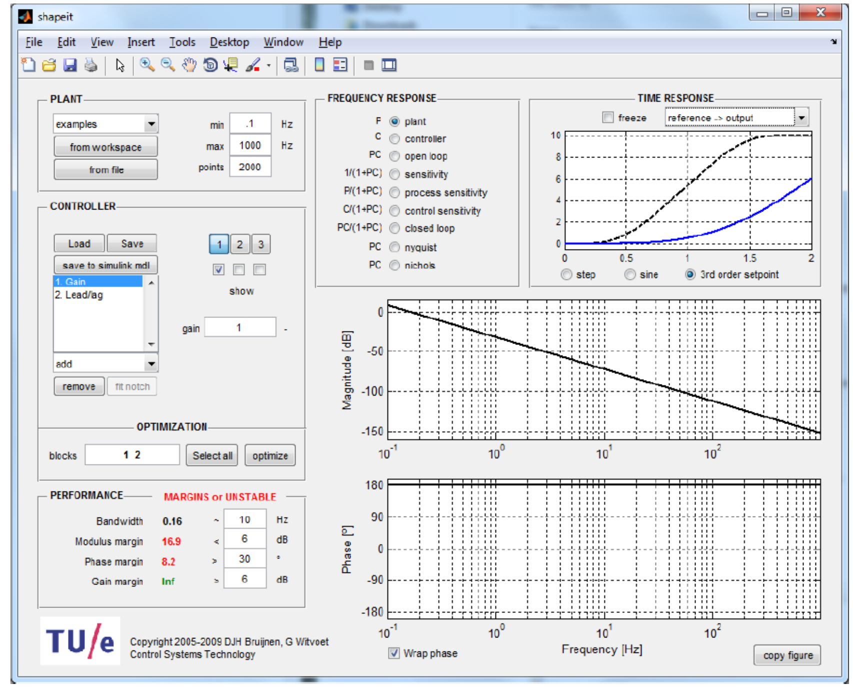
Global layout lithography tool

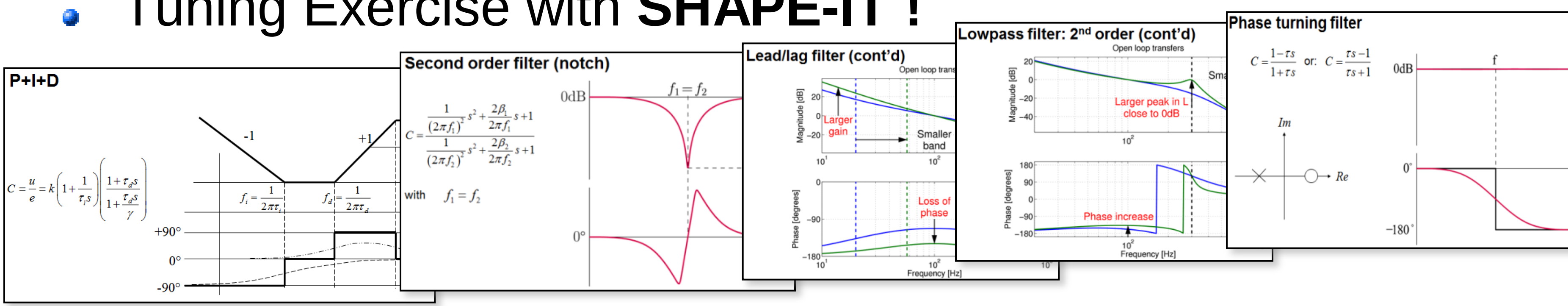




Day 4 (morning): Filters

- PID
- Lead/Lag
- General second order
- Second order notch
- Low pass filter
- Phase turning filter
- Tuning Exercise with **SHAPE-IT !**





mechatronics academy
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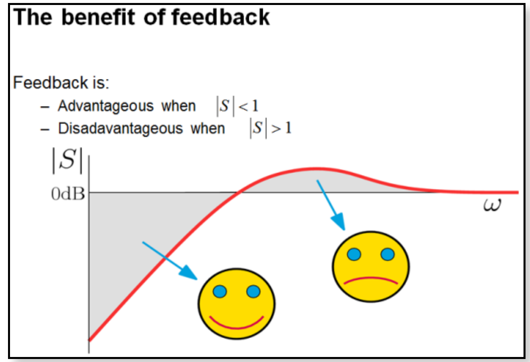
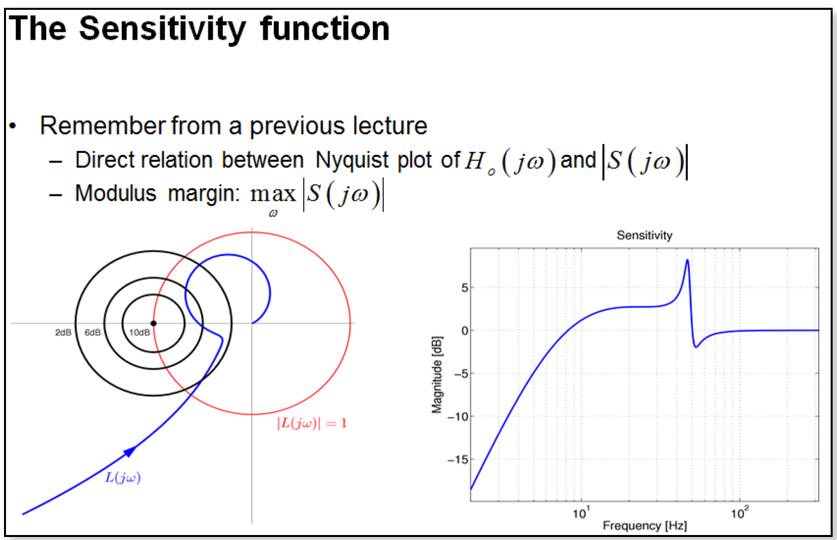
Day 4 (afternoon): Tuning Game

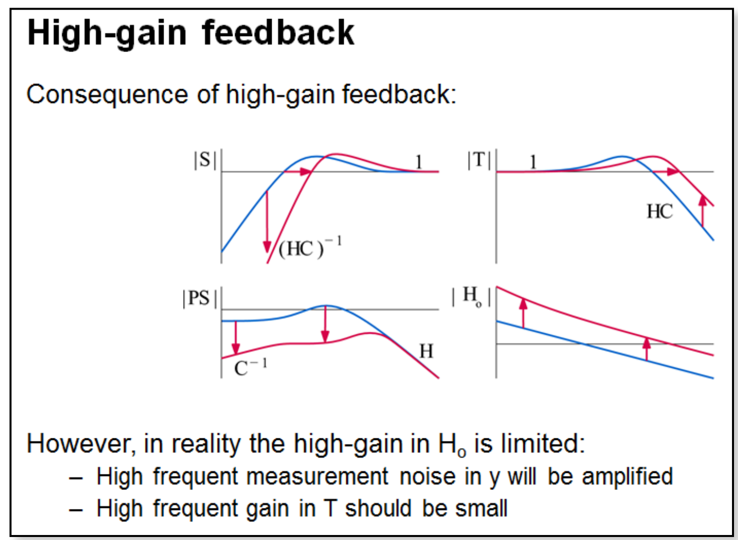
GO for the highest bandwidth. Winning team gets bottle of wine !

Day 5 (morning): Design for performance



- Waterbed effect
- Bandwidth definitions
- High-gain feedback
- Requirements + disturbance + system => best controller

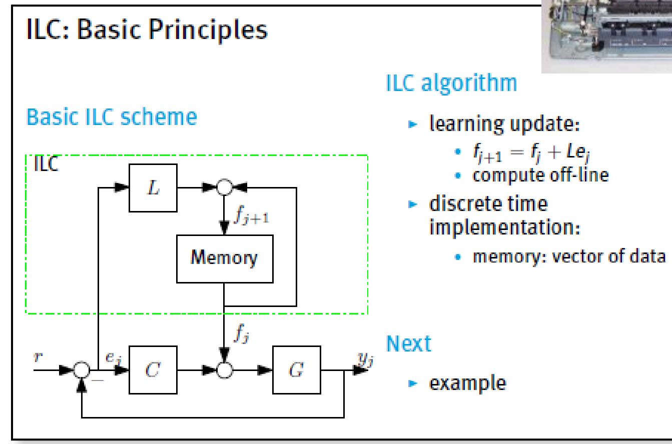


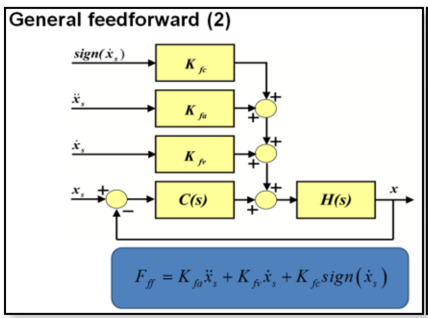


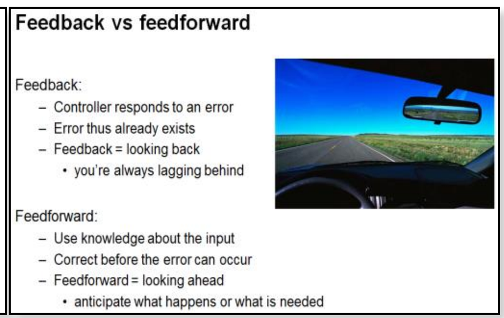
Day 5 (afternoon): Special Topics

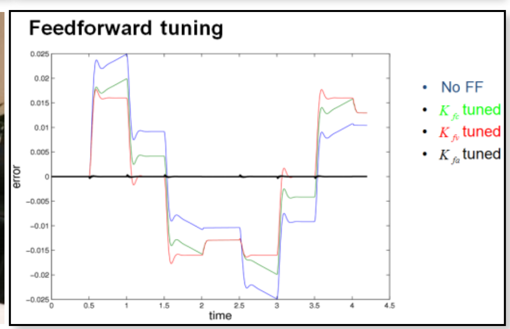
Printer demo

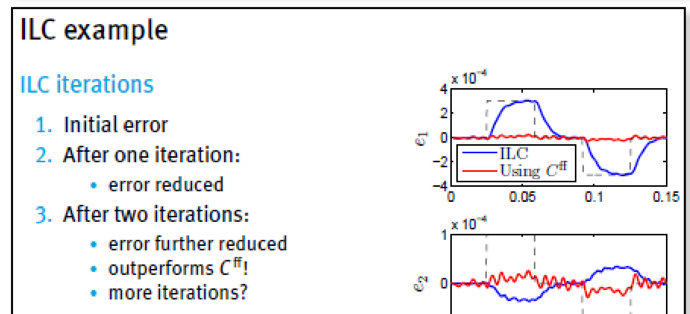
- Feedback vs. Feedforward
- Learning Feedforward + Demo
- Non-linear identification

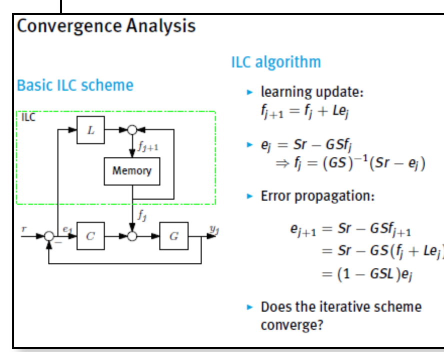












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