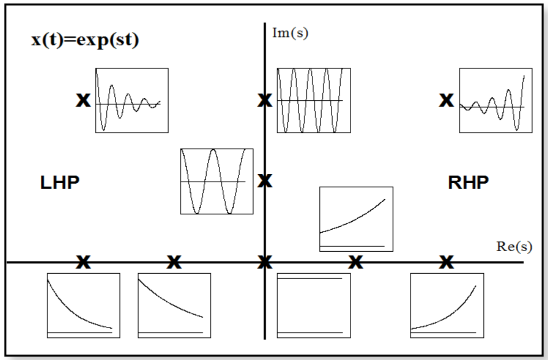
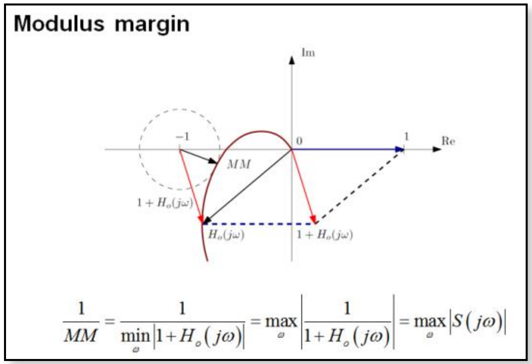
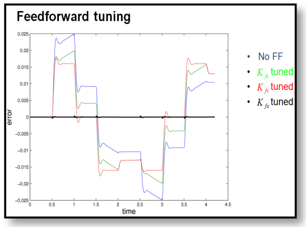
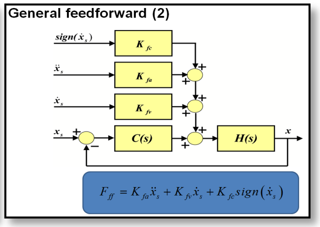
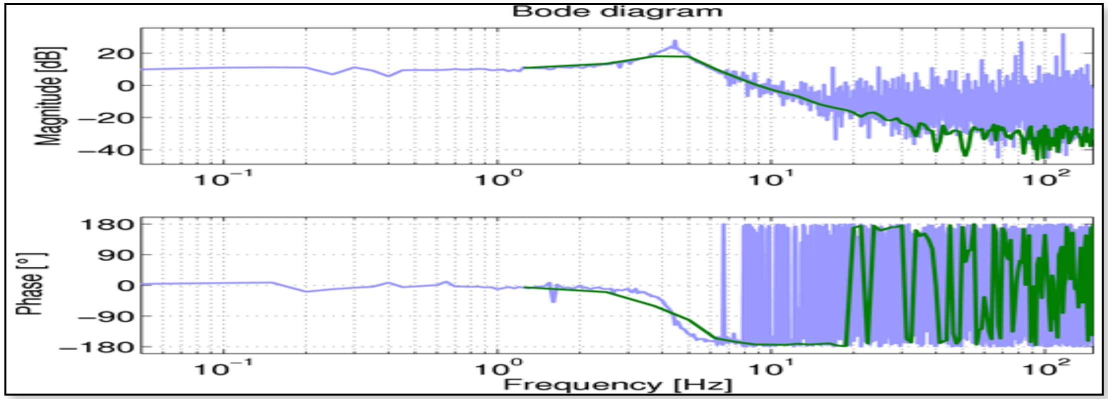
Motion Control Tuning







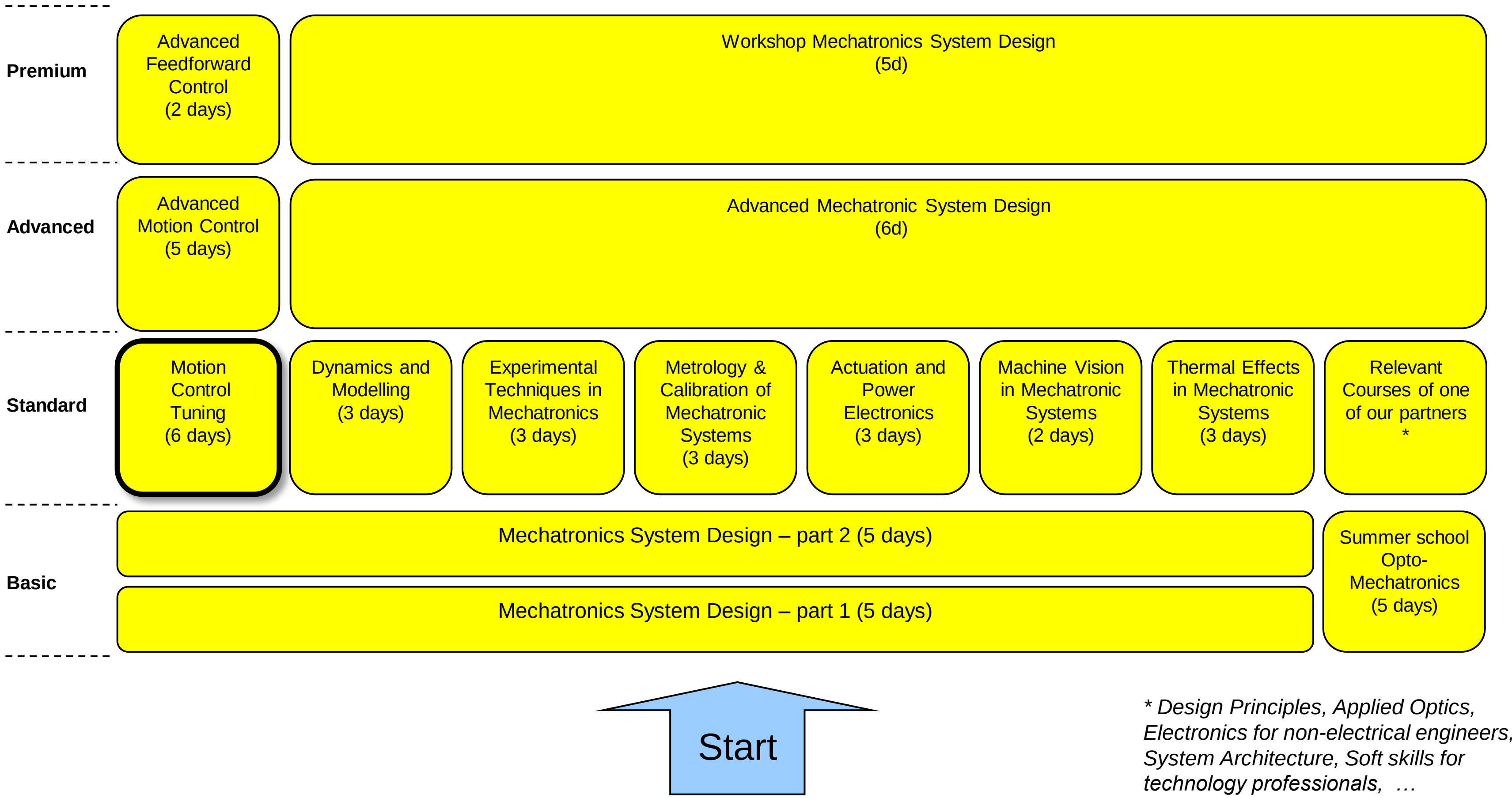




Contents

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

Mechatronics Training Curriculum



www.mechatronics-academy.nl

Mechatronics Training

- December 31, 2009 Philips decided to stop all its training activities, which were carried out by the *Philips Centre for Technical Training (CTT),* and all training programs were transferred to external parties.

- Currently, all former Philips trainings (and more) are offered to the market under the umbrella of The High Tech Institute (www.hightechinstitute.nl).

- Content partner for all Mechatronics courses is **Mechatronics Academy B.V.** (www.mechatronics-academy.nl) which is set-up and supervised by :

  - Professor Dr.ir. Jan van Eijk
  - Professor Dr.ir. Maarten Steinbuch
  - Dr.ir. Adrian Rankers

Motion Control Tuning

Course Directors / Trainers

Course Director(s)

- Prof.dr.ir. M. Steinbuch
- Dr.ir. A.J.J. van der Weiden

Teachers

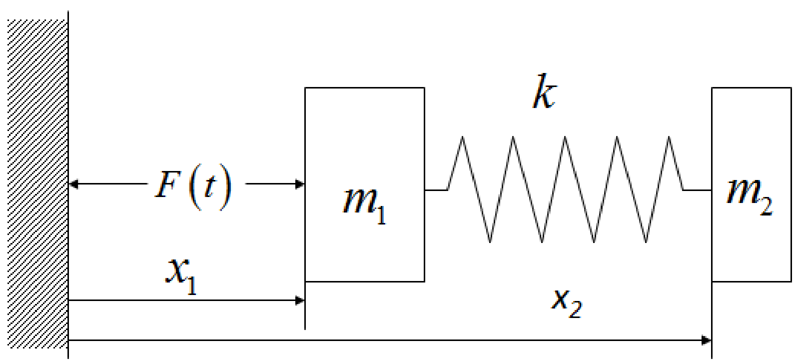
- TU/Eindhoven:
    - Prof.dr.ir. M. Steinbuch, Dr. ir. T. Oomen, Dr. ir. P. Nuij,
    - Ir. J.J. Bolder, Ir. T. Gommans, Ir. R. van der Maas
- Other:
    - Dr.ir. A.J.J. van der Weiden
    - Ir. P. Teerhuis
    - Dr.ir. E.P. van der Laan (OCE)
    - Dr.ir. M.J.M. van de Wal (ASML)
    - D.ir. D. Rijlaarsdam (NTS)
    - Ir. F.B. Sperling (Nobleo)
    - Ir. M. Vervoordeldonk (ASML)
    - Dr.ir. G. Witvoet (TNO)

Program

Day	Timing	Topic	Trainers
1	Morning	• Introduction / Who is who / Program / Goals… • Basic Modelling	Steinbuch Teerhuis
	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 Evening	• Loopshaping game • Dinner	Van der Weiden / v.d. Maas / Gommans
5	Morning	• Design for performance	v.d. Wal
	Afternoon	• Feedforward – theory & hands-on practice	Vd Laan/ Bolder
6	Morning	• Learning control • Non-linear identification / feedforward	Oomen Rijlaarsdam
	Afternoon	• Motion control research • Interaction in control systems	Steinbuch Van der Weiden

Day 1 (morning): Intro / Basic Modelling

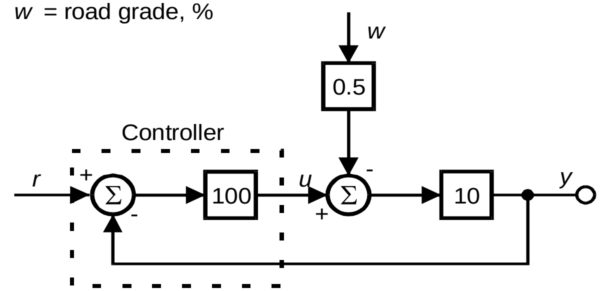
- Introduction / Goals
- Modelling of motion systems



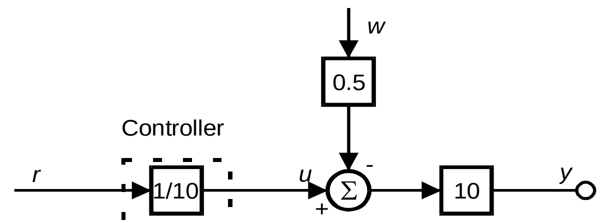
The equations of motion: $F - k(x_1 - x_2) = m_1\ddot{x}_1$

$$+k(x_1 - x_2) = m_2\ddot{x}_2$$

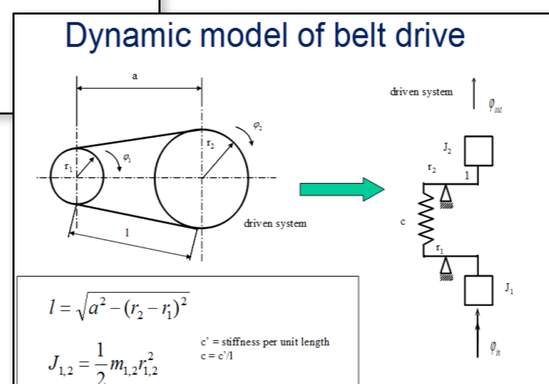
r = reference speed
u = throttle angle, degrees
y = actual speed, mph
w = road grade, %



With feedback $y = 0.999r - 0.005w$

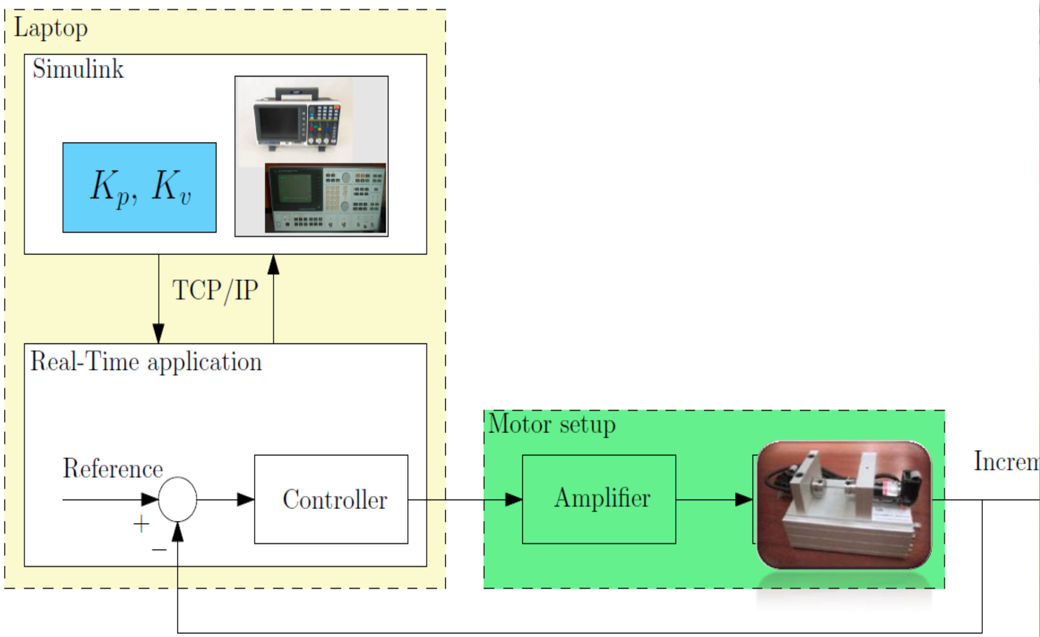


Without feedback $y = r - 5w$



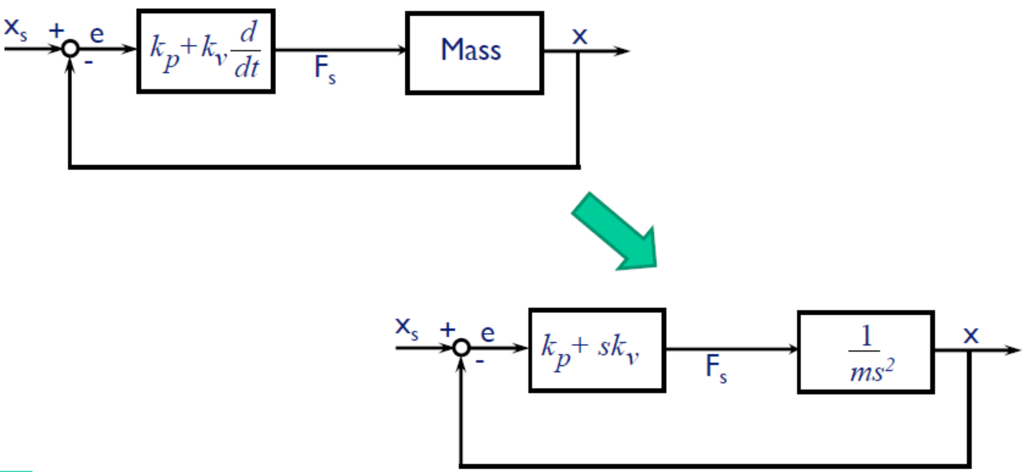
Day 1 (afternoon): Time domain tuning

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



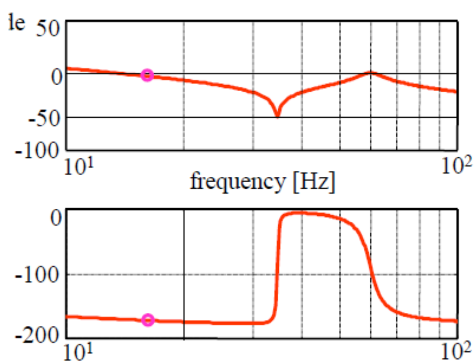
Day 2 (morning): Frequency domain

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

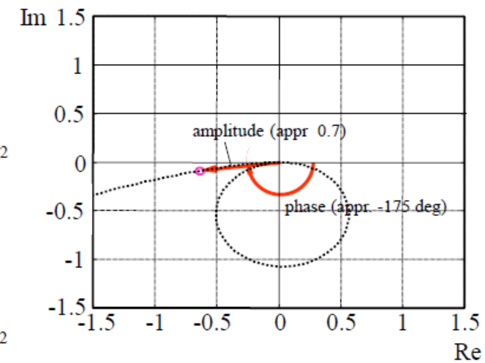


	PD controller	Mass spring system	Mass
1. equation of motion	$F_s(t)=k_pe(t)+k_v\dot{e}(t)$	$m\ddot{x}+d\dot{x}+kx=F$	$m\ddot{x}=F$
2. replace 'd/dt' by 's'	$F_s(s)=k_pe(s)+k_vse(s)$	$ms^2x+dsx+kx=F$	$ms^2x=F$
	$\frac{F_s}{e}(s)=k_p+k_vs$	$\frac{x}{F}(s)=\frac{1}{ms^2+ds+k}$	$\frac{x}{F}=\frac{1}{ms^2}$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

Bode plot

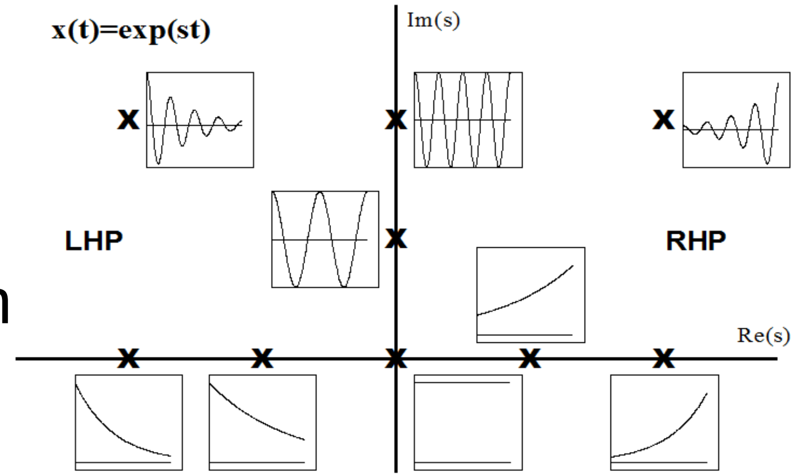


Nyquist plot

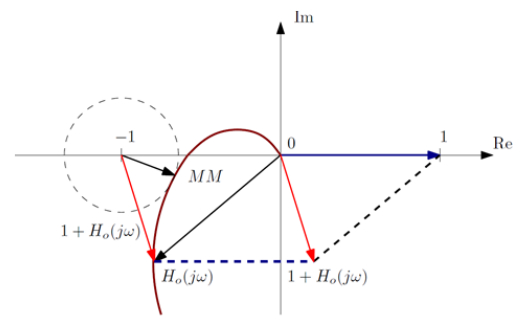


Day 2 (afternoon): Stability

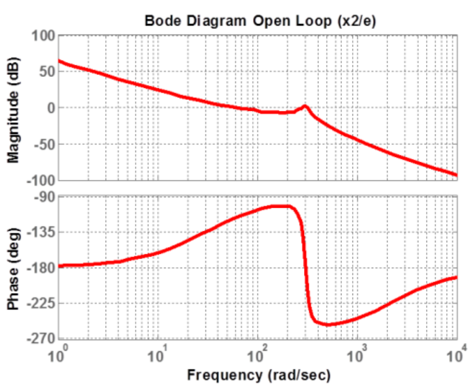
- Introduction
- Stability in the time domain
- Stability in the frequency domain
- Nyquist stability criterion
- Stability margins
- Modulus margin

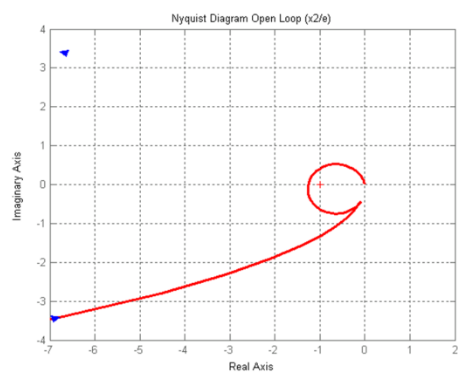


Modulus margin



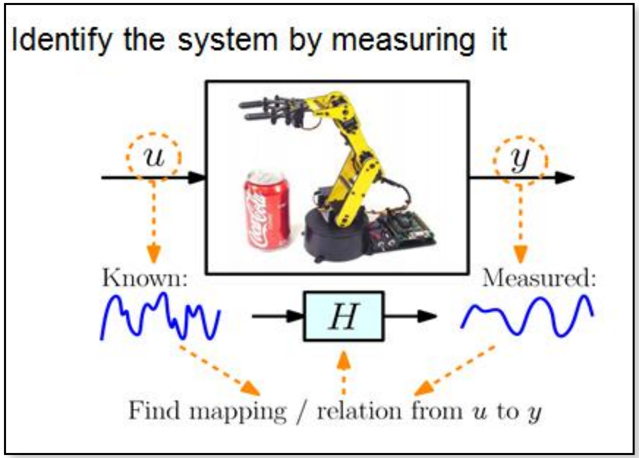
$$\frac{1}{MM}=\frac{1}{\min\limits_{\omega}\left|1+H_o(j\omega)\right|}=\max_{\omega}\left|\frac{1}{1+H_o(j\omega)}\right|=\max_{\omega}\left|S(j\omega)\right|$$



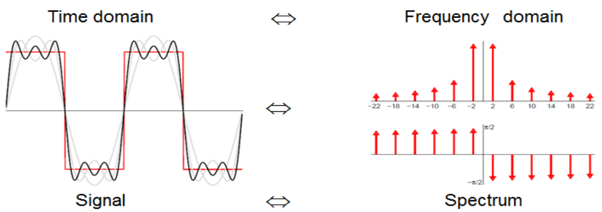


Day 3 (morning): FRF measurements

- 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.

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

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

where

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

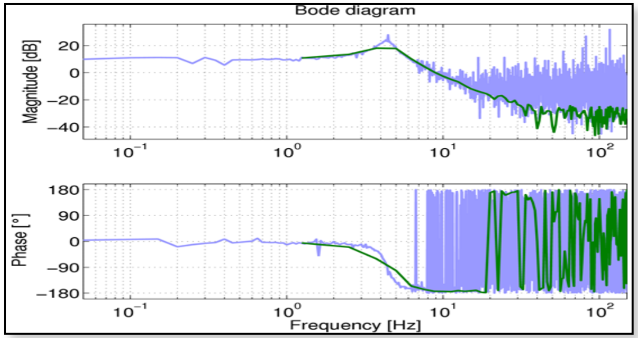
k : Harmonic number

$A_0 = a_0$: 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

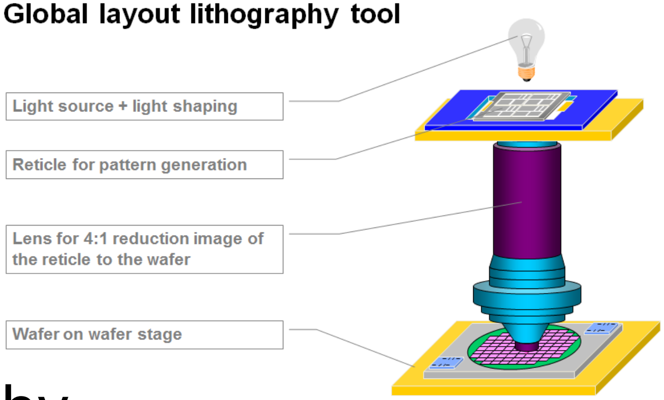
Note: assumes the signal is periodic: $x(t+T) = x(t)$

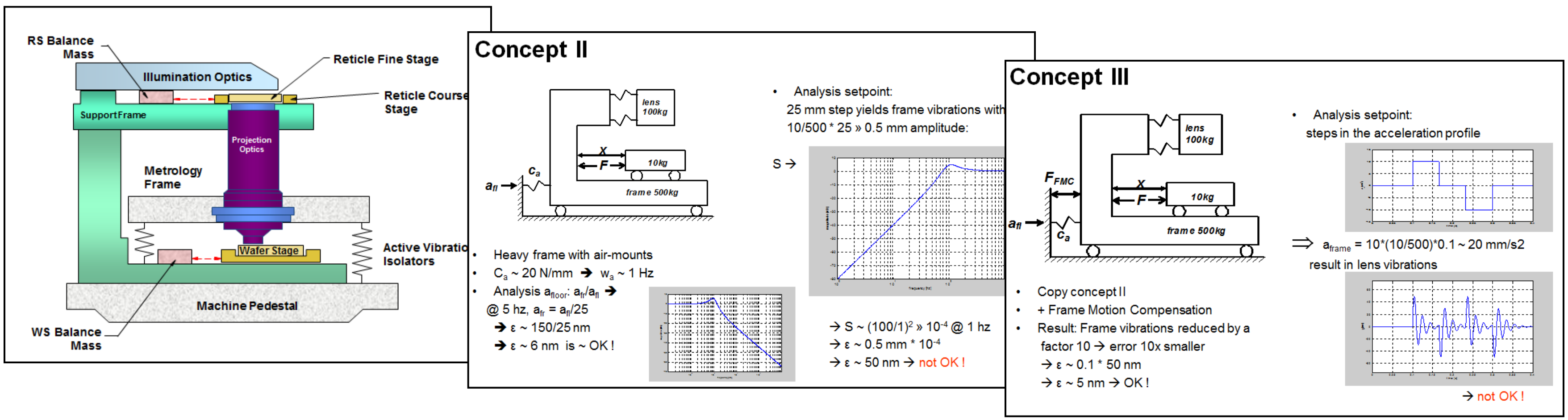


Day 3 (afternoon): Mechatronics

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

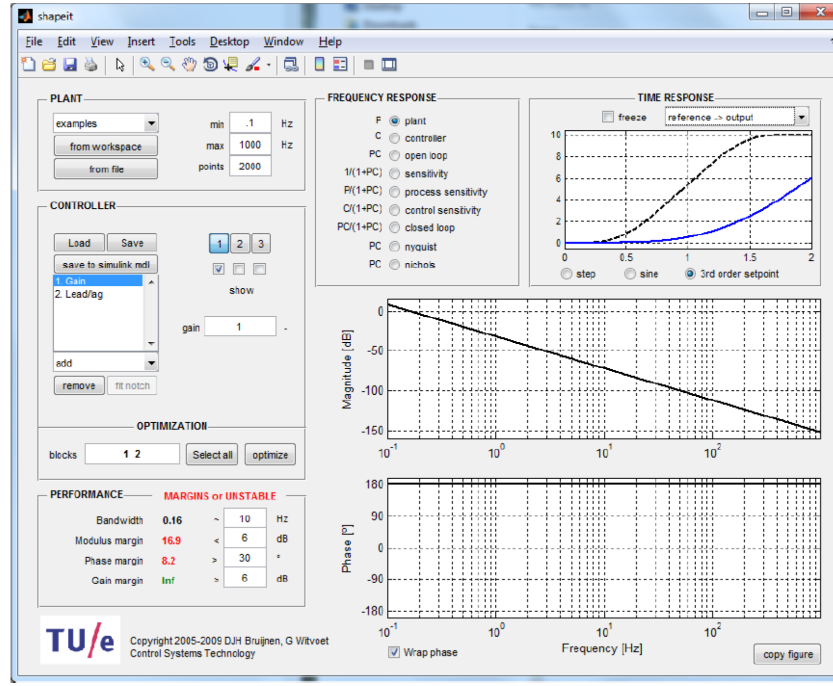
Global layout lithography tool

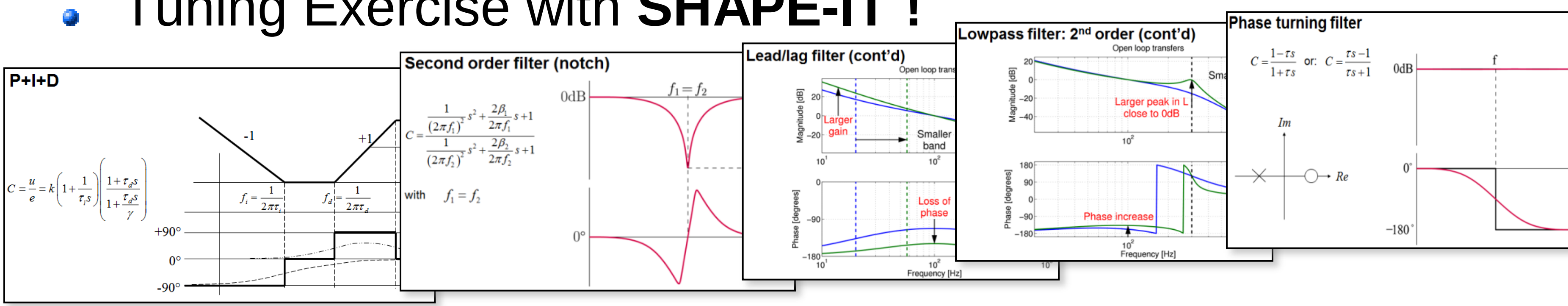




Day 4 (morning): Filters

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



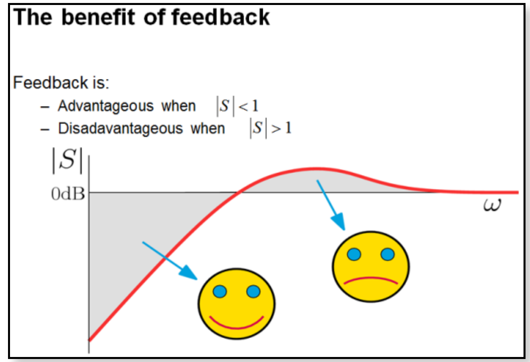


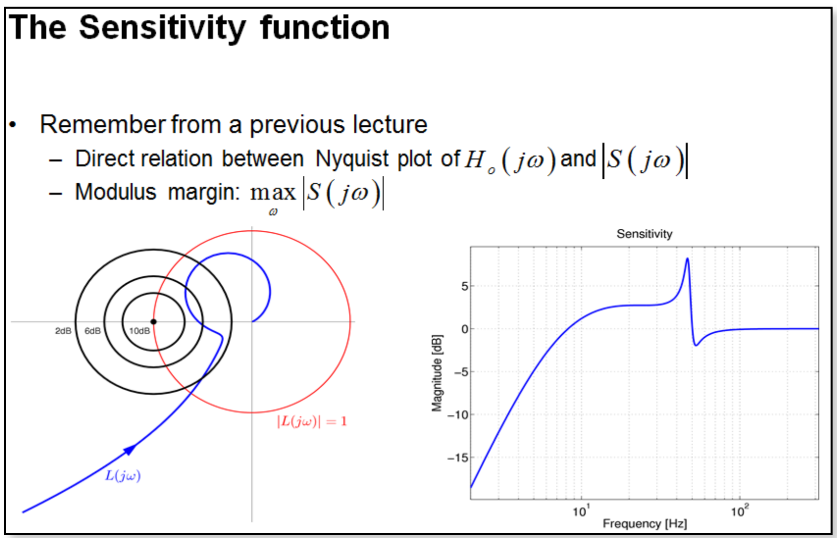
Day 4 (afternoon): Tuning Game

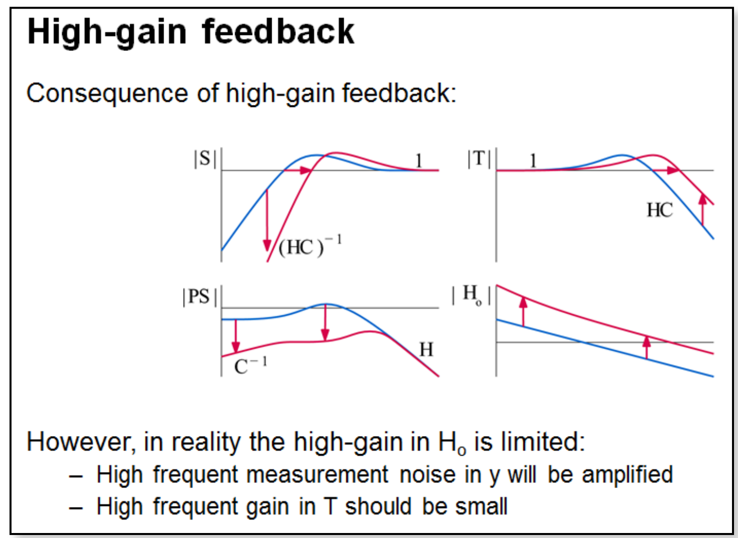
GO for the highest bandwidth. Winning team gets bottle of wine !

Day 5 (morning): Design for performance

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







Day 5 (afternoon): Feed forward

Feedback vs. Feedforward

General feefforward scheme

Practical guidelines

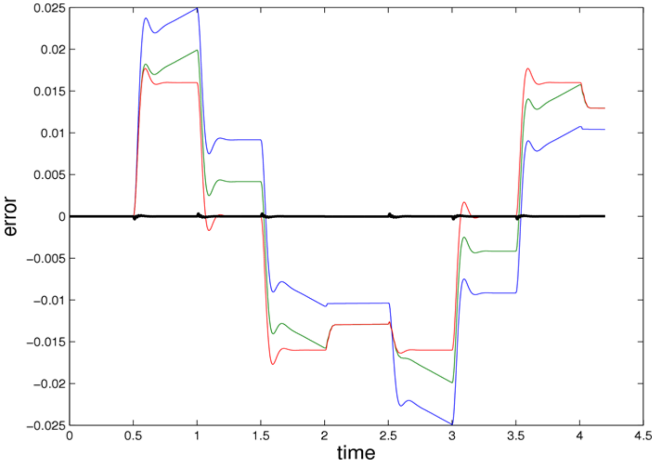
Hands-on exercise

Feedback vs feedforward

Feedback:
- Controller responds to an error
- Error thus already exists
- Feedback = looking back
  - you're always lagging behind

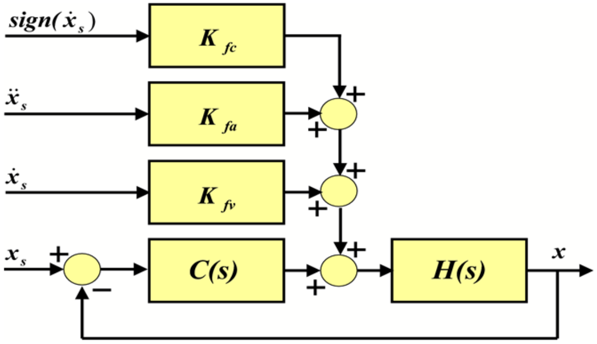
Feedforward:
- Use knowledge about the input
- Correct before the error can occur
- Feedforward = looking ahead
  - anticipate what happens or what is needed

Feedforward tuning



- No FF
- K_{fc} tuned
- K_{fv} tuned
- K_{fa} tuned

General feedforward (2)

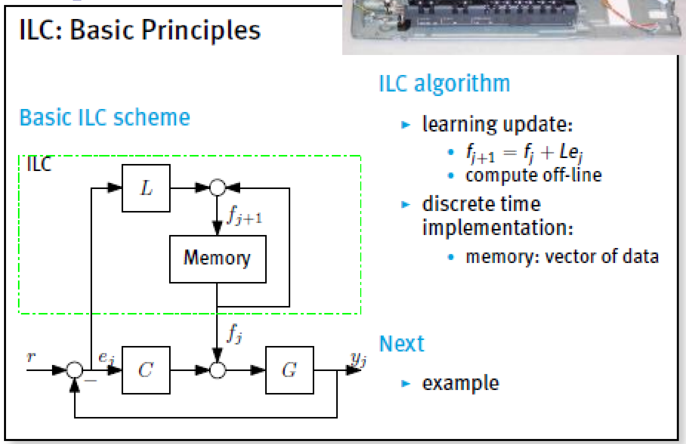


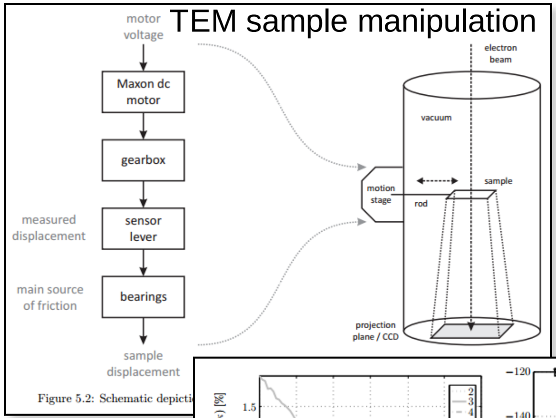
$$F_{ff} = K_{fa}\ddot{x}_s + K_{fv}\dot{x}_s + K_{fc}sign(\dot{x}_s)$$

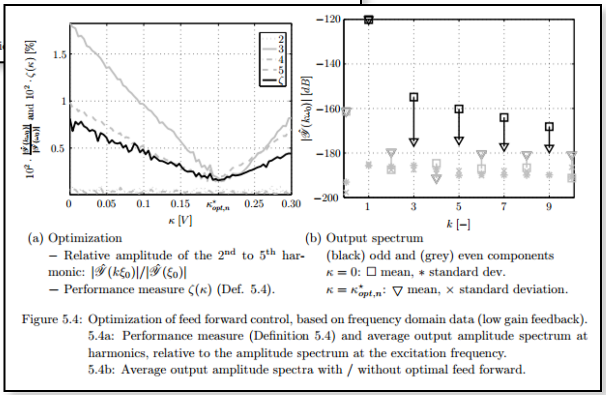
Day 6 (morning): Special topics-1

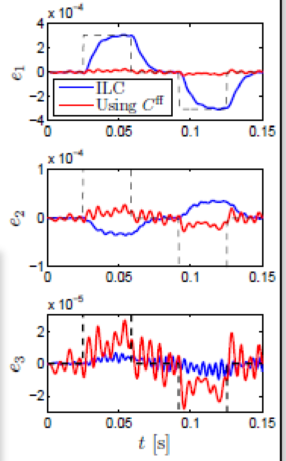
- Learning Feedforward + Demo
- Non-linear identification / FF

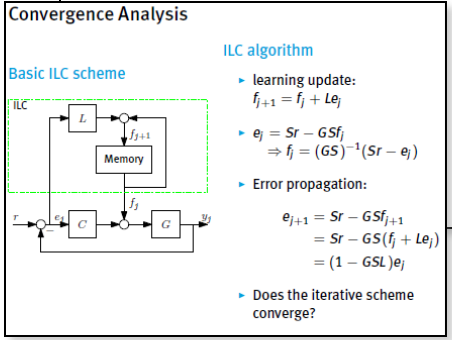
Printer demo







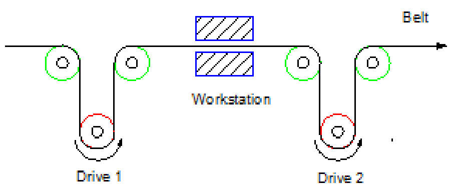


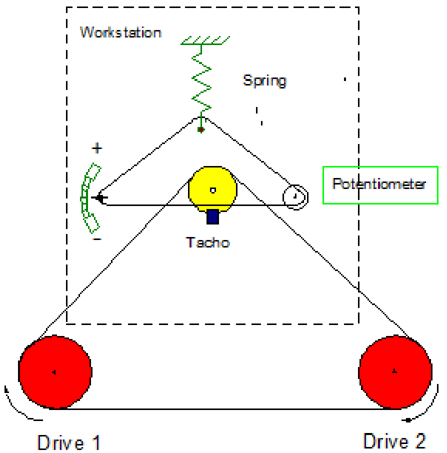


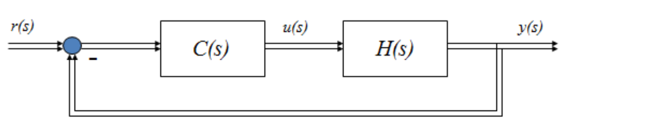
Day 6 (afternoon): Special topics-2

- Motion Control Research
- MiMo systems
  - Interaction analysis
  - Sequential loop closure
  - MiMo design
    - decoupling
    - model based multivariable control design

Coupled electrical drives



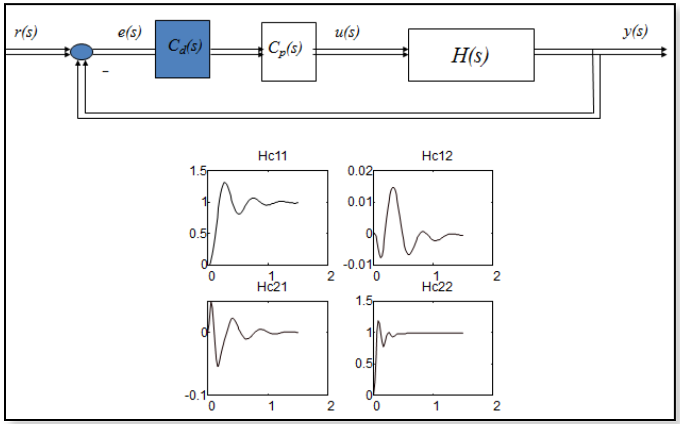




$$
\begin{aligned}
y_1(s) &= H_{11}(s)u_1(s) + H_{12}(s)u_2(s) + \cdots + H_{1m}(s)u_m(s)\\
y_2(s) &= H_{21}(s)u_1(s) + H_{22}(s)u_2(s) + \cdots + H_{2m}(s)u_m(s)\\
&\vdots\\
y_m(s) &= H_{m1}(s)u_1(s) + H_{m2}(s)u_2(s) + \cdots + H_{mm}(s)u_m(s)
\end{aligned}
$$

$$y(s) = H(s)u(s)$$

$H(s)$ = Transfer function matrix



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The High Tech Institute