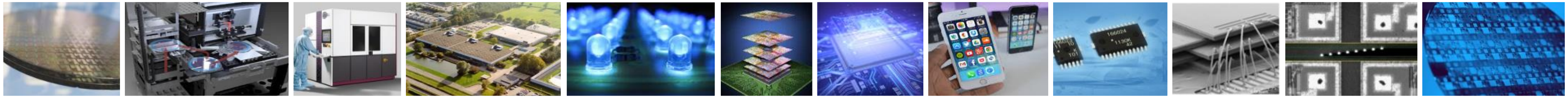
Mechatronics training

Closed-loop control- and time-domain simulations in Simulink / Simscape Multibody

CoC

January 16th, 2023

ASM



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Content

- XYZ-motion platform
- Controller design and implementation
- Time-domain control simulations
- Functional Mockup Unit

XYZ-MOTION PLATFORM

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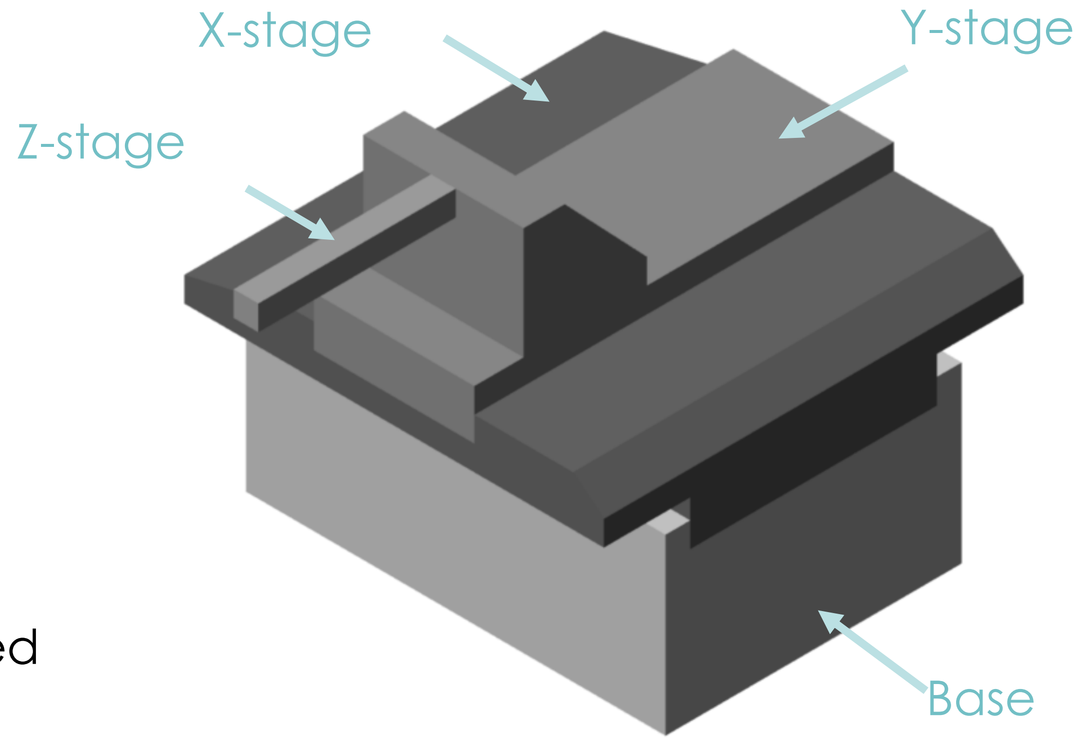
3-Dimensional Simscape Multibody model

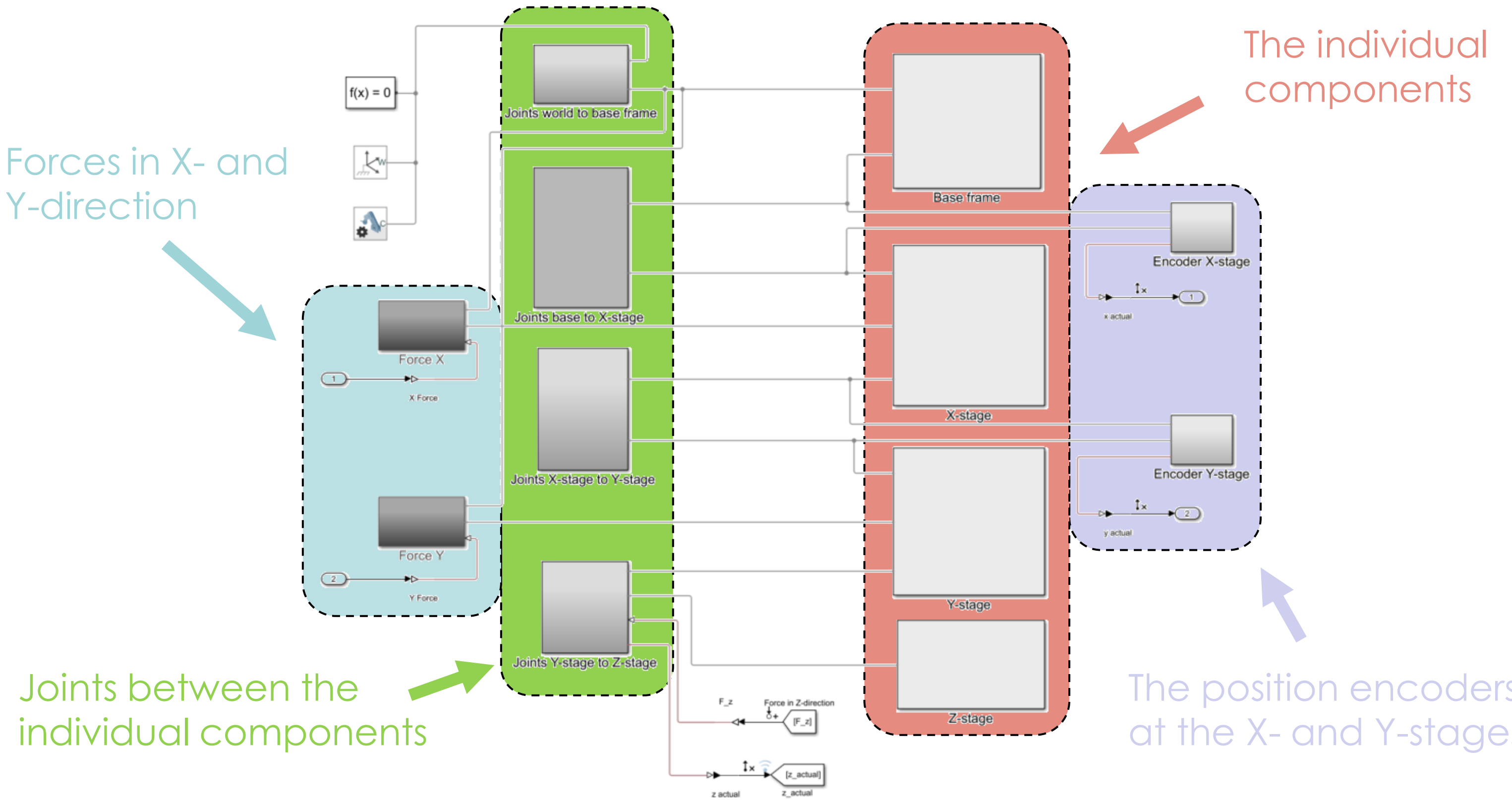
- During this training, we use the 3-Dimensional Simscape Multibody model of the XYZ-motion platform.



→ Slightly more complex than the 3D model used in Training Session 3.

Components of the Simscape Multibody model

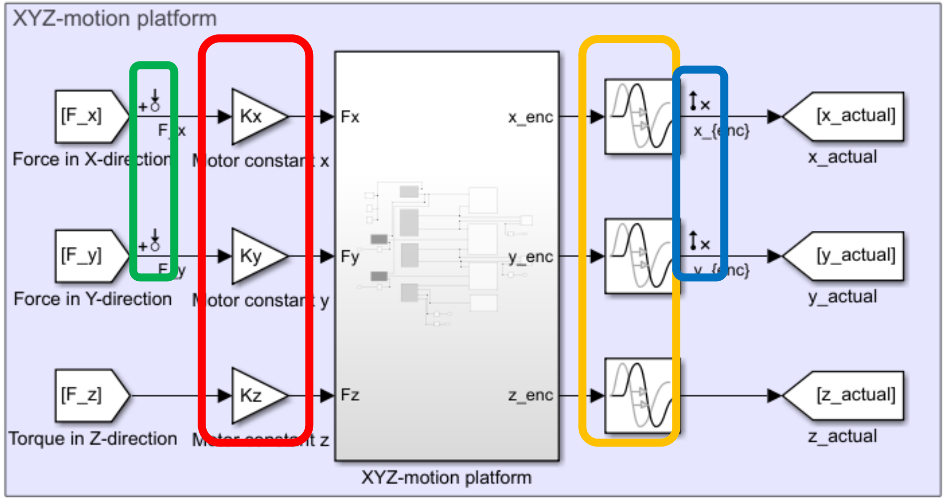
- Components of this Simscape Multibody model are highlighted below.



Subsystem of the Simscape Multibody model

- We create a subsystem of the 3-Dimensional Simscape Multibody model. This helps us making the model more structured.

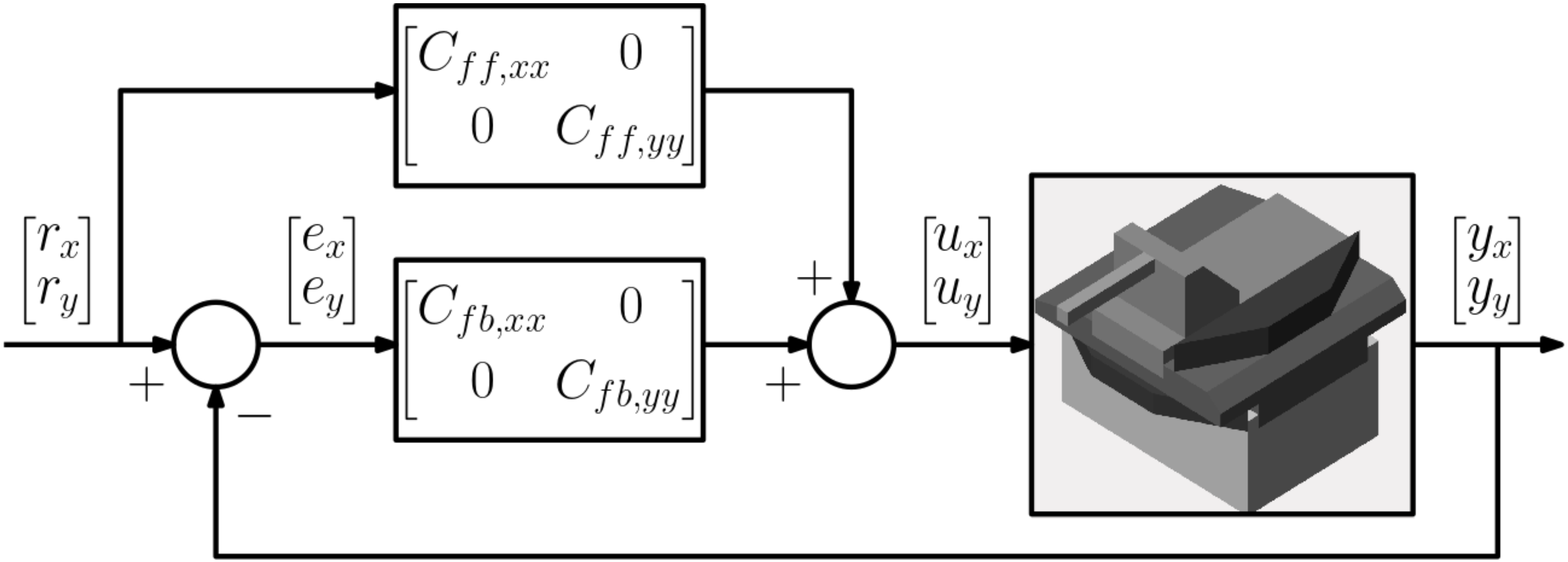
- set the motor force constants,
- set time-delays of the system,
- define inputs to the plant,
- define outputs of the plant.



- The Z-stage is present, but it is out of our consideration in this training.

Single-input-single-output (SISO) control structure

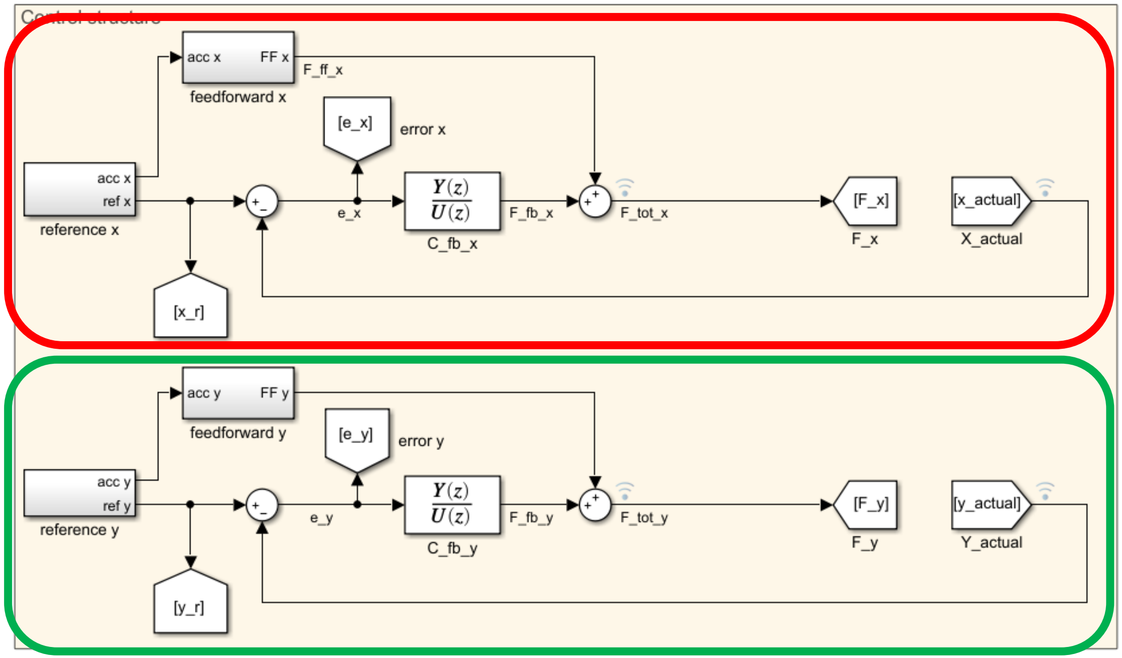
- The control model shown in the figure below contains
  - SISO feedforward controllers,
  - SISO feedback controllers.



SISO control implemented in the Simscape Multibody model

- The control structure shown on the previous slide is implemented in the Simulink model.

- This results in two control loops:
  - one loop for control of the X-stage and
  - one loop for control of the Y-stage.



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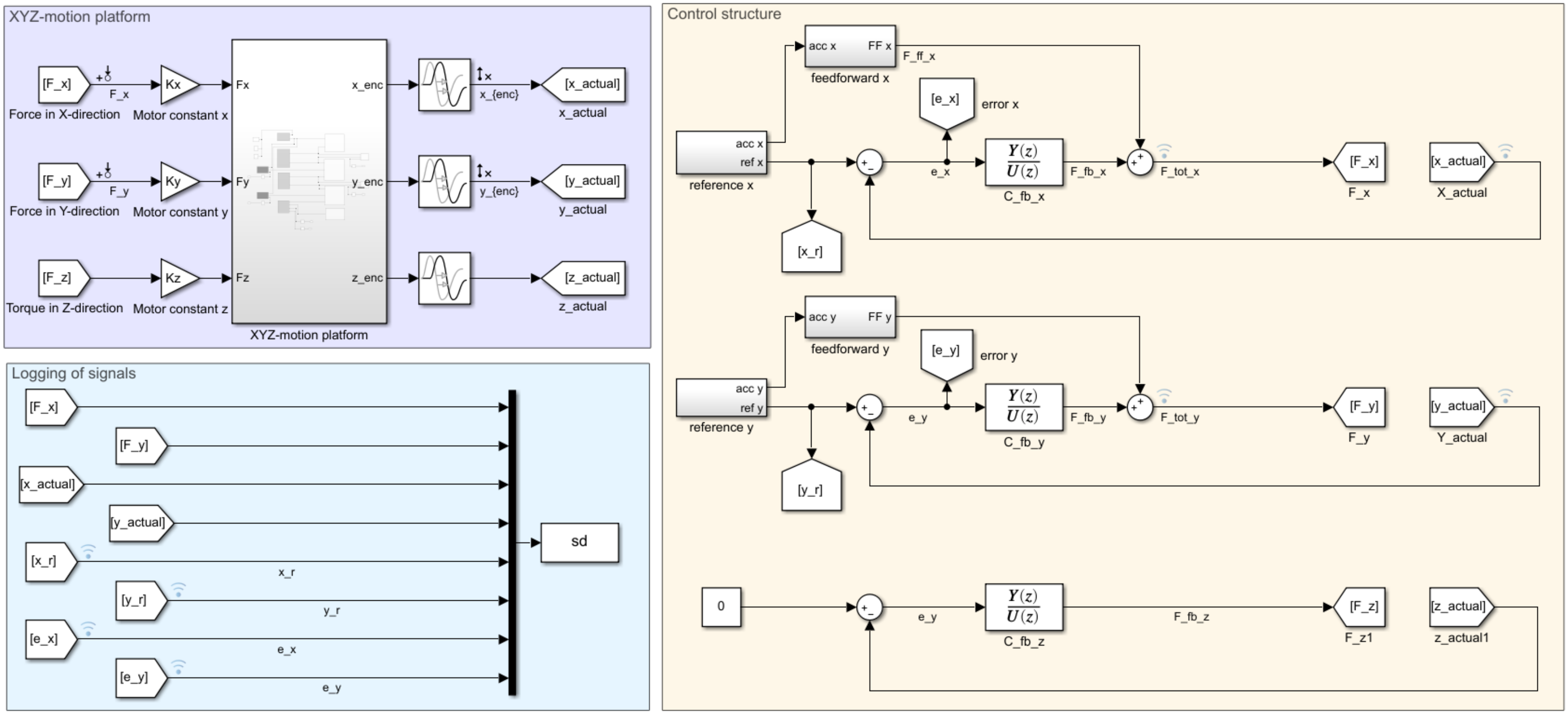
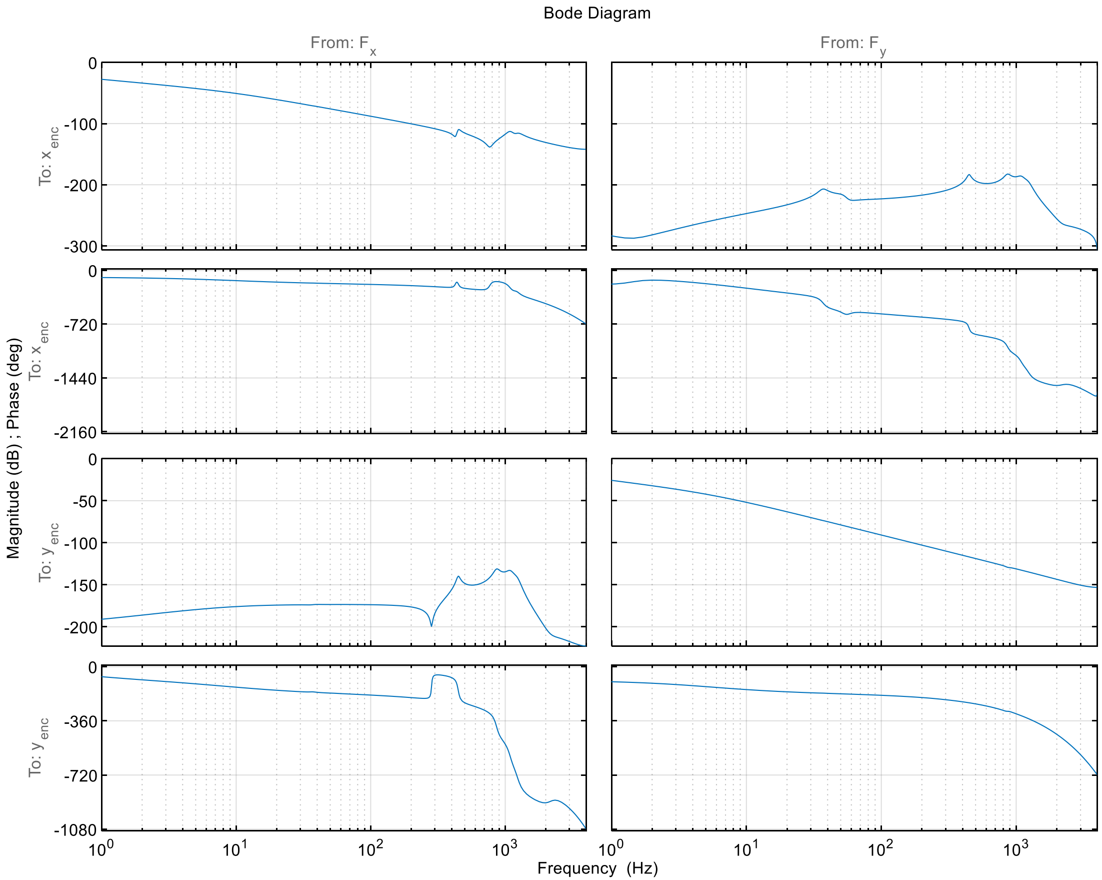
The complete Simscape Multibody model



CONTROLLER DESIGN AND IMPLEMENTATION

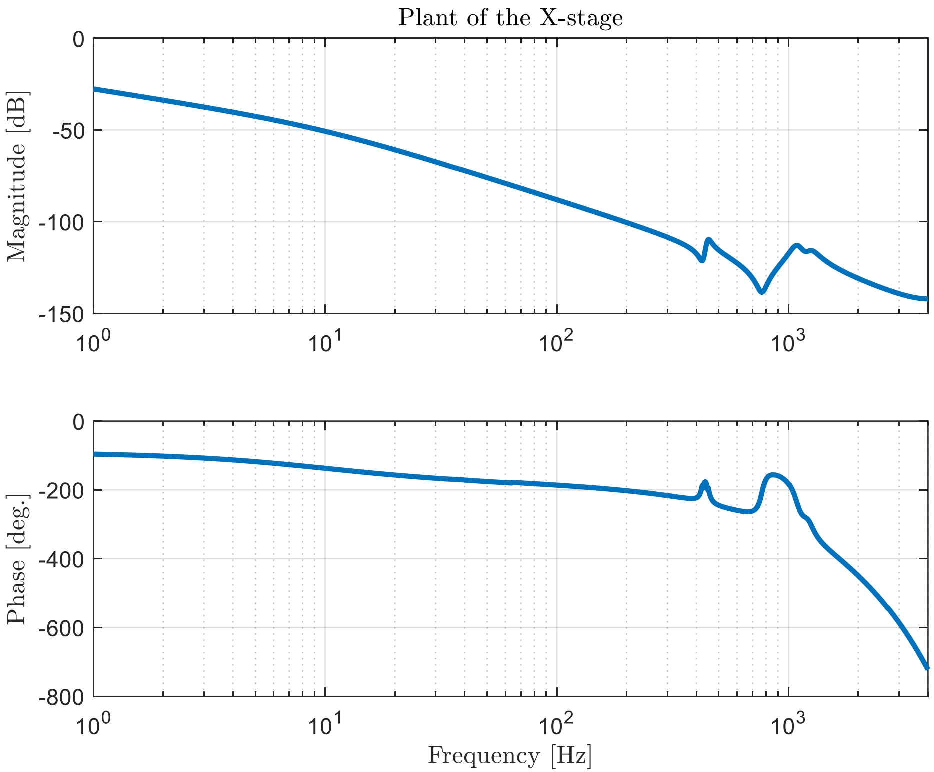
Frequency response of the MIMO Simscape Multibody model

- In training session 3, we explained an approach to obtain the frequency response function (FRF).
- Figure on the right-hand side shows the FRF of the MIMO Simscape Multibody system.
- Next, we will design the feedback and feedforward controllers for this system.



Frequency response of the x-stage of the XYZ-motion platform

- Figure on the right-hand side shows an FRF of the X-stage.
- In training session 4, an approach is explained to design the feedback controller for the X-stage.
- The goal of this feedback controller is to achieve a stable and good performing closed-loop system.



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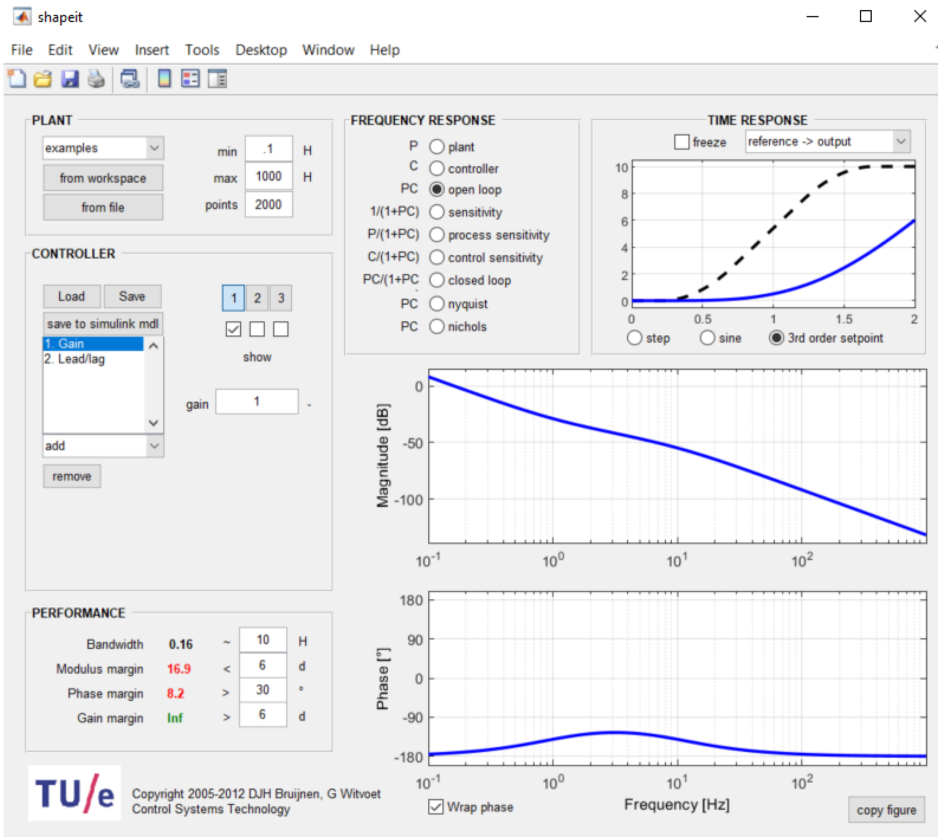
ShapeIt tool for design of a feedback controller

- A feedback controller designed in training session 4 consists of:
  - a gain of 11982,
  - a lead/lag filter with a zero at 40 Hz and a pole at 360 Hz,
  - an integrator with a zero at 12 Hz.

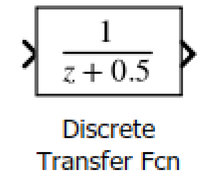
- In ShapeIt tool, we can assess both stability and expected performance of the designed controller.



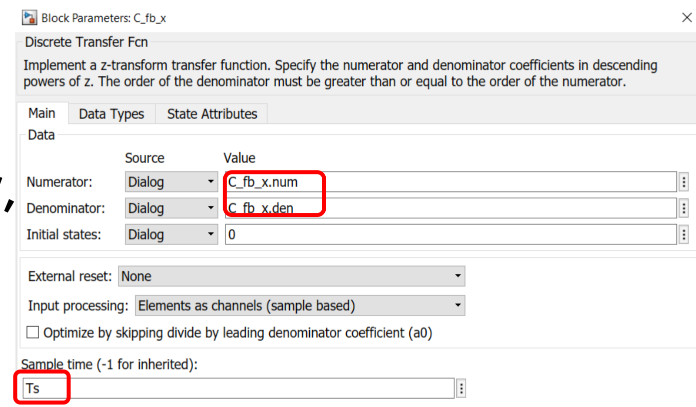
Download ShapeIt from ***http://cstwiki.wtb.tue.nl/index.php?title=Home_of_ShapeIt***

Steps to implement the feedback controller in Simulink

- Include feedback control in the model. Go to the **Simulink Library Browser > Simulink > Discrete** and drag a **Discrete Transfer Fcn** block into the Simulink model.



- Set the variables in the Discrete Transfer Fcn block. Double click on the **Discrete Transfer Fcn** block and set the **Numerator**, **Denominator** and **Sample time** variables.



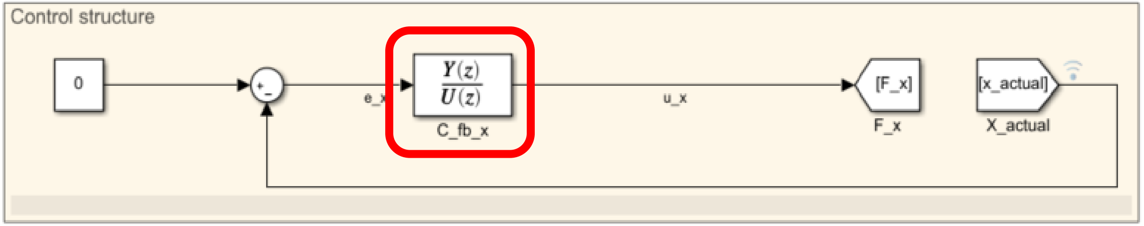
- Set the variables in a Matlab script.

```
load('./Controllers/C_fb_x_120Hz.mat');
[C_fb_x.num,C_fb_x.den] = tfdata(shapeit_data.C_tf_z,'v');

Fs          = 8000;     % Sampling frequency
Ts          = 1/Fs;     % Sampling time
```

Feedback controller implementation in Simulink

- The discrete-time feedback controller of the X-stage is highlighted in the figure below.

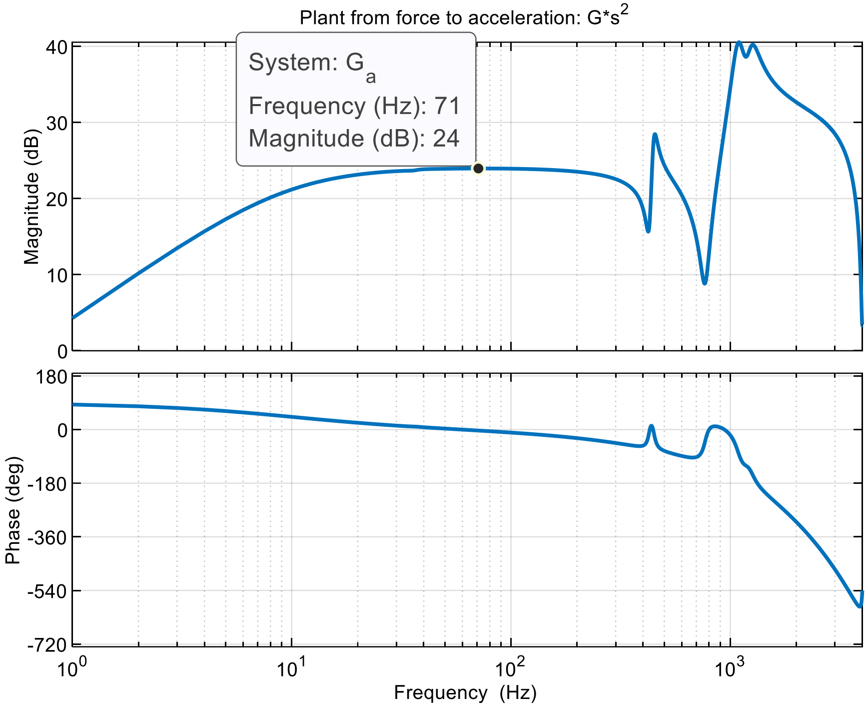


- Subsequently, we design a feedforward controller for the X-stage.

- Hereby, we take both the past (feedback) and the future (feedforward) into account.

Frequency response of the x-stage of the XYZ-motion platform

- Figure on the right-hand side shows the frequency response of the X-stage multiplied with the squared Laplace variable s^2.
- In training session 4, the approach is explained to design a feedforward controller of the X-stage.
- The goal of this feedforward controller is to achieve improved tracking performance of the closed-loop system.



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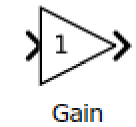
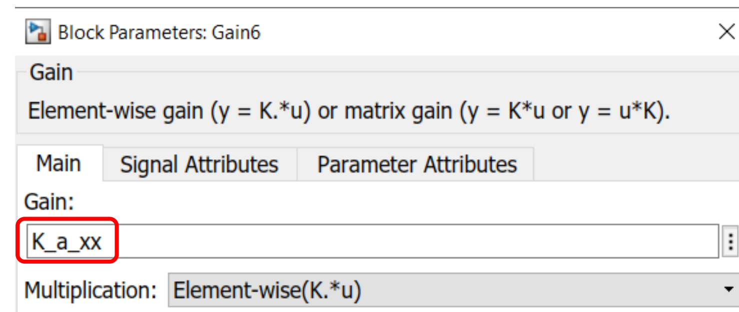
Steps to implement the feedforward controller in Simulink

- Include feedforward control in the model. Go to the **Simulink Library Browser > Simulink > Commonly Used Blocks** and drag a **Gain** block into the Simulink model.



- Set the Gain variable. Double click on the **Gain** block and set the gain variable.

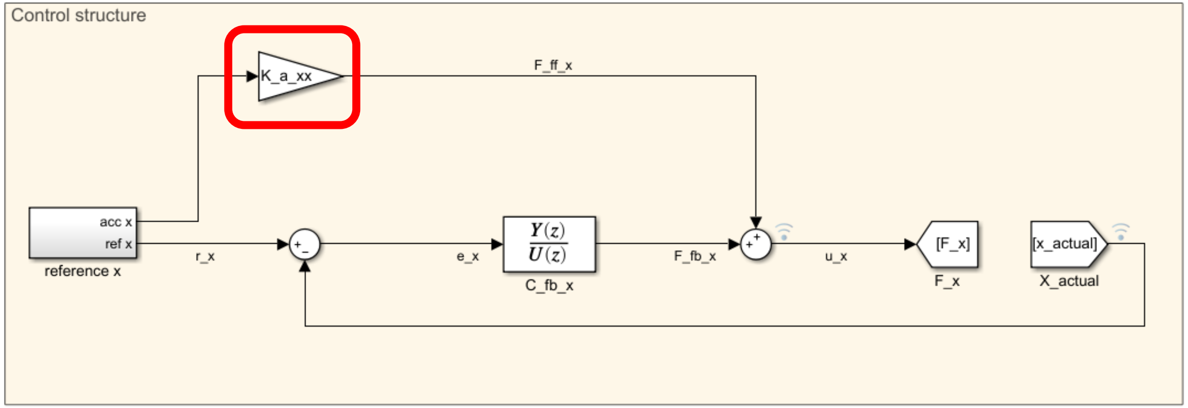


- Set the variables in a Matlab script.

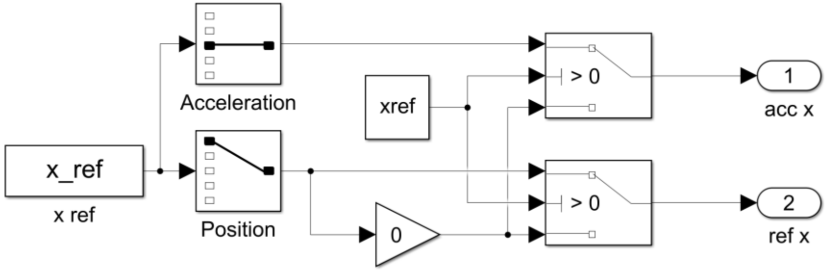
```
K_a_xx = 0.0631;          % acceleration FF in X-direction
```

Feedforward controller implementation in Simulink

- The feedforward controller of the X-stage is highlighted in the figure below.



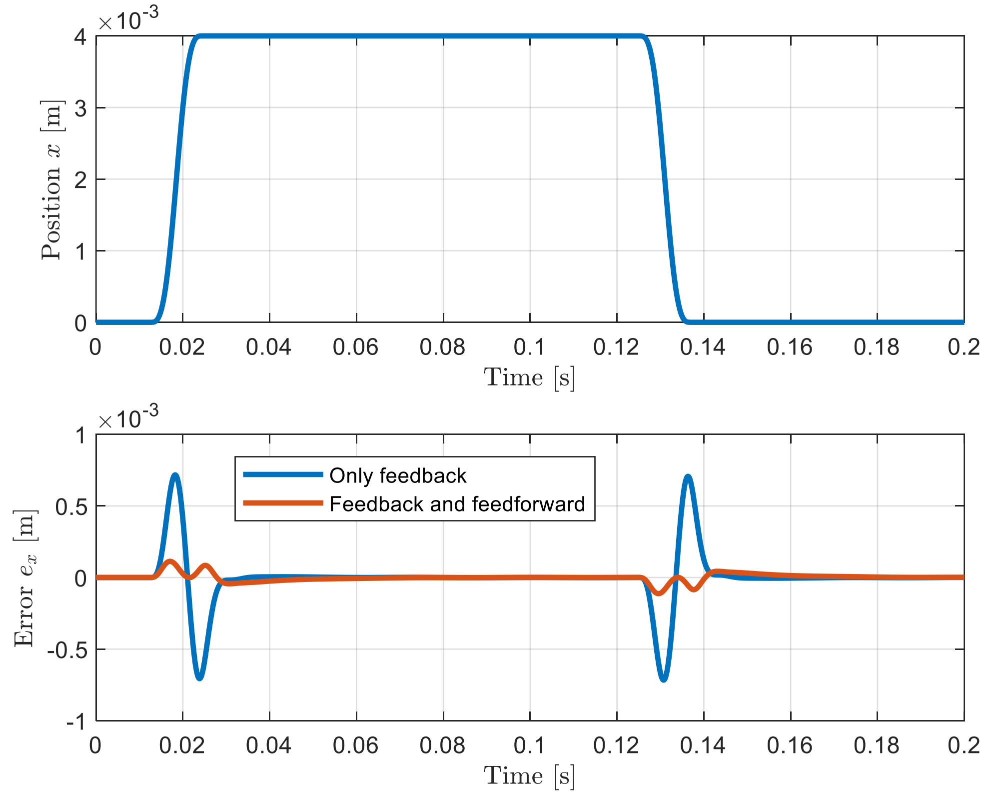
- One can note that this feedforward component depends on the reference trajectory. When we look inside the subsystem **reference x**, we observe the following:



TIME-DOMAIN SIMULATIONS

Time-domain simulations

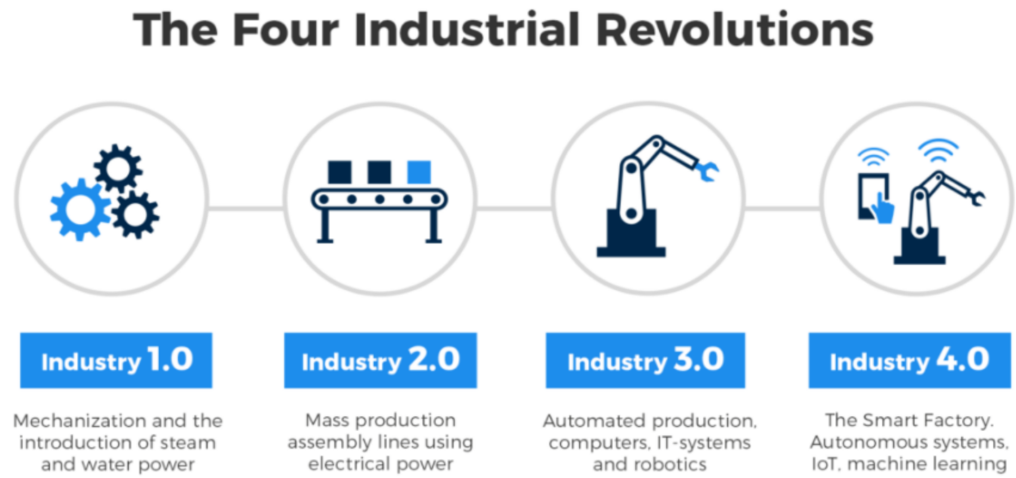
- The supplied reference trajectory consists of a forward and backward motion of 4 mm, see the top figure on the right-hand side.
- The error that we achieve with the designed feedback and feedforward controllers is shown in the bottom figure on the right-hand side:
  - blue curve is the error when we apply solely a feedback controller,
  - red curve is the error when we apply both feedback and feedforward control.



FUNCTIONAL MOCKUP UNIT

Moving towards industry 4.0

- Design challenges in the industry 4.0 era:
  - manage complexity,
  - increase efficiency,
  - shorten time-to-market.

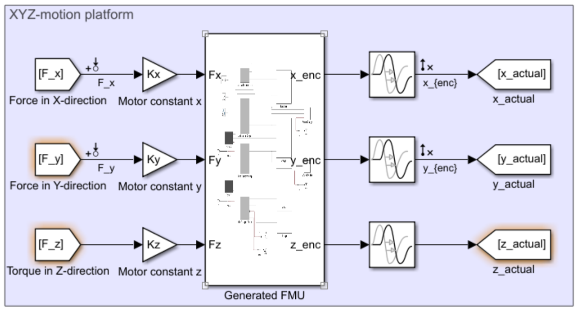


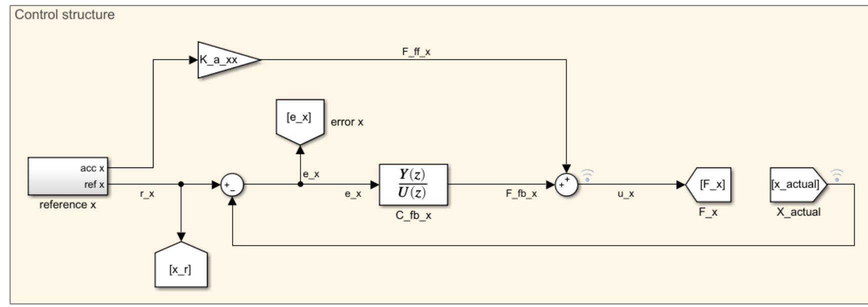
- To increase efficiency and reduce time-to-market, a lot can be gained during the concept phase and design phase.
  - during these phases, a cost to discover defects is relatively small,
  - moreover, the committed costs are smaller.

- Therefore, an expert in tool A and an expert in tool B must be able to work together, yet in parallel on the same project.

Functional Mockup Unit (FMU)

- In this case, the mechanical expert can produce an FMU of the new mechanical wire bonder design;
  - many software tools can export FMUs, e.g. 20-sim, Matlab and Ansys.





- Subsequently, the control expert can perform the control simulations. Hereby,
  - no knowledge about mechanical design is needed,
  - and no license of the Simscape Multibody toolbox is needed.

- Then both experts can discuss whether design changes are required to achieve the optimal wire bonder design.

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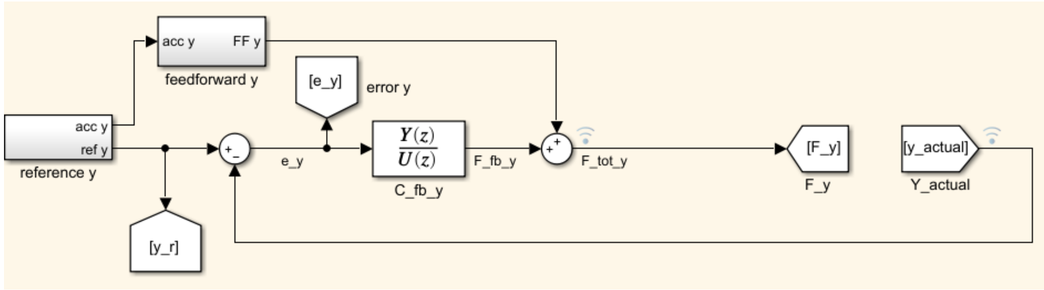
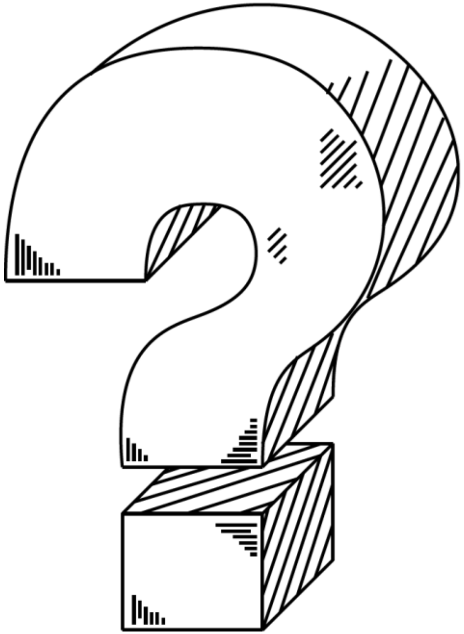
CASE STUDY EXERCISE

Case study: complete the control scheme for the y-stage

- Design stable feedback controller for the Y-stage;
  - this was already a part of the exercise of training session 4.
- Design stable feedback controller for the Z-stage.
- Design feedforward controller for the Y-stage.
  - this was already a part of the exercise of training session 4.
- Perform time-domain simulations with the Y-stage after finishing design of the controllers and their implementation.
  - Use the same 4 mm reference motion that we applied to the X-stage.





QUESTIONS