Design of Microsystems using SystemC-AMS

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Microsystems consist of several parts such as a (perhaps nonelectrical) sensor, an electrical analog signal processing, digital hardware including several calculation algorithms and processors/ microcontrolles and additionally software running on it. In the last years new modeling techniques evolved allowing system description using AMS languages. A famous representative of an AMS language is VHDL-AMS (IEEE 1076.1). But this language lacks of supporting software modeling and possibilities in high-level system modeling. The last point leads to long calculation times for complex heterogeneous systems such as microsystems.
SystemC-AMS fills this gap in system level and algorithm level modeling. The presentation will show the SystemC-AMS models of four different microsystems: a micromirror-based projection system, two vibration detectors and an inertial navigation system. The modeling of these systems leads to several requirements for the principal modeling of microsystems on system level. SystemC-AMS fulfills most of these requirements in its current version. It is therefore included in a top-down methodology for MEMS design which is currently under development at Chemnitz University of Technology. Figure 1 shows this methodology.

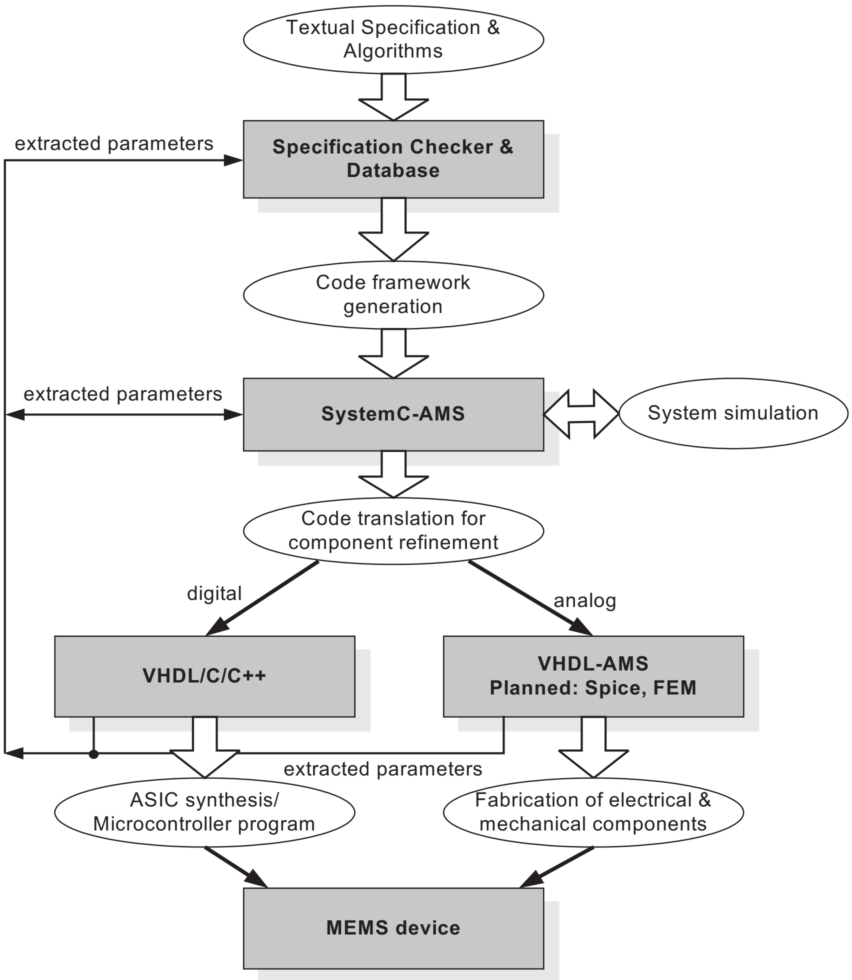

Figure 1: Methodology for microsystem design using SystemC-AMS

Chair Circuit and Systems Design

Design of Microsystems using SystemC-AMS

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CHEMNITZ UNIVERSITY OF TECHNOLOGY

Outline

- **Motivation**
- **Examples for Microsystems**
- **Requirements for simulation of heterogeneous systems**
- **Proposal of a design flow**

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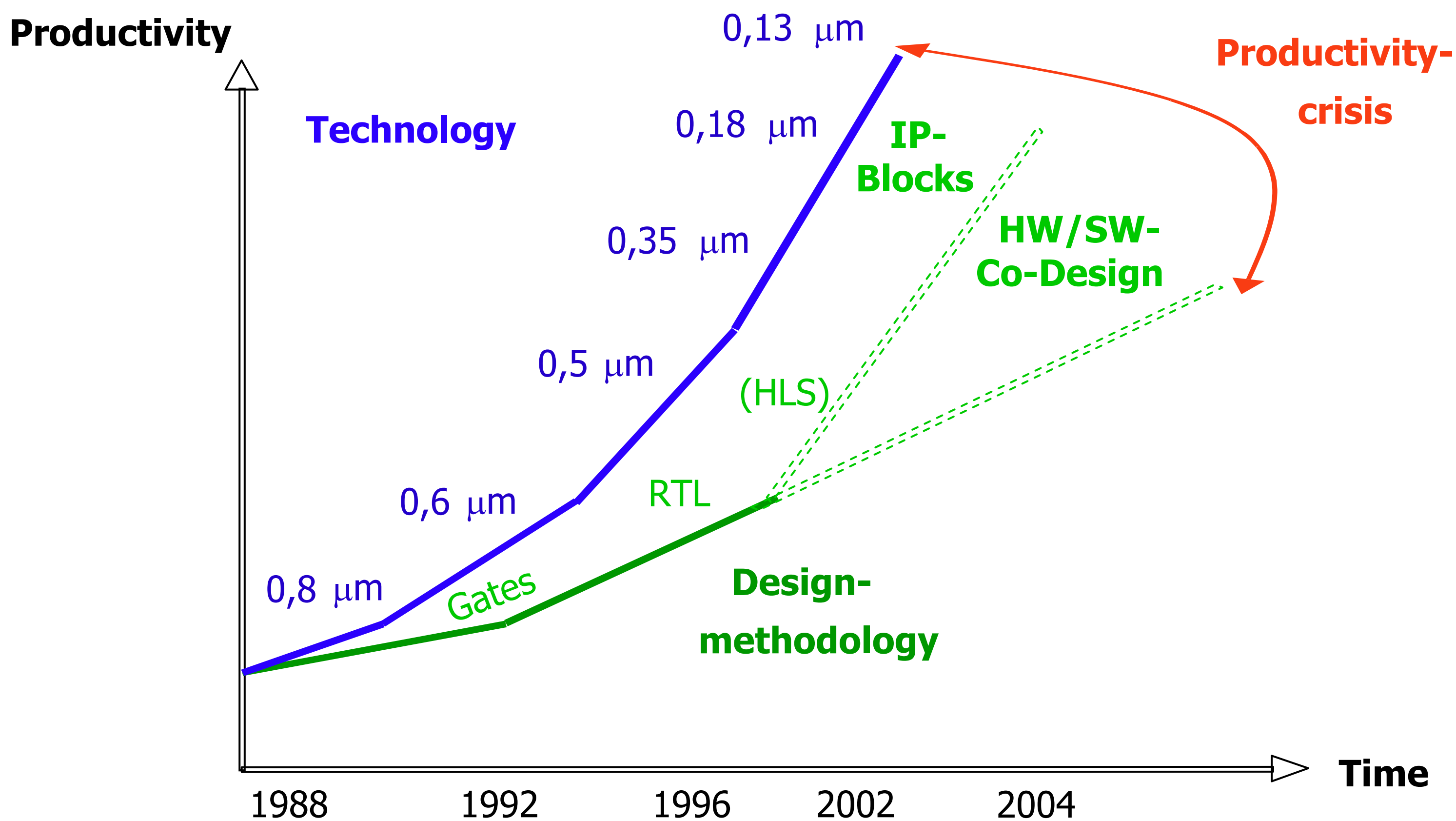
Motivation



Source: U. Heinkel, Lecture EDA-Tools

Motivation

- Rising System complexity in analogue und digital area (330.000 logic cells in FPGA)
- One-chip integration (hybrid)
- One-die integration (monolithic)

→ Systems consist of digital, analogue and nonelectrical parts

→ Necessity of AMS simulator

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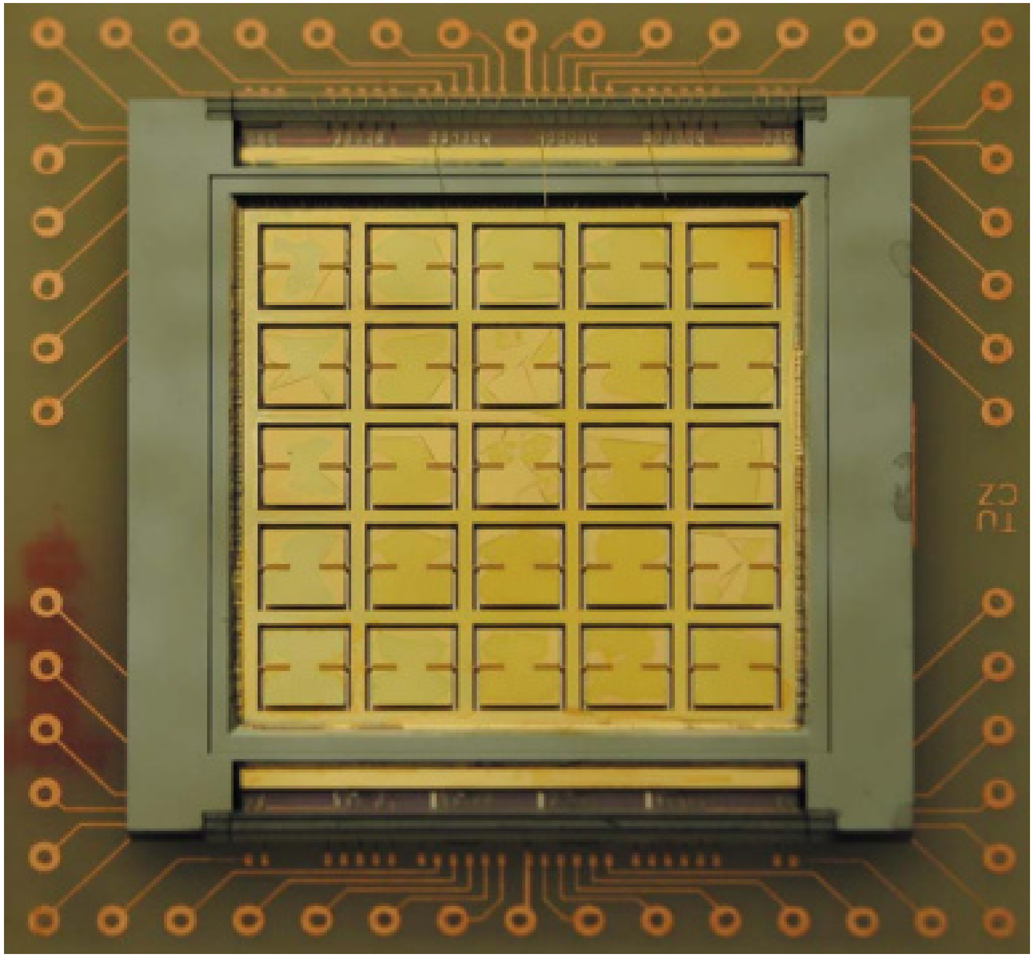
Examples

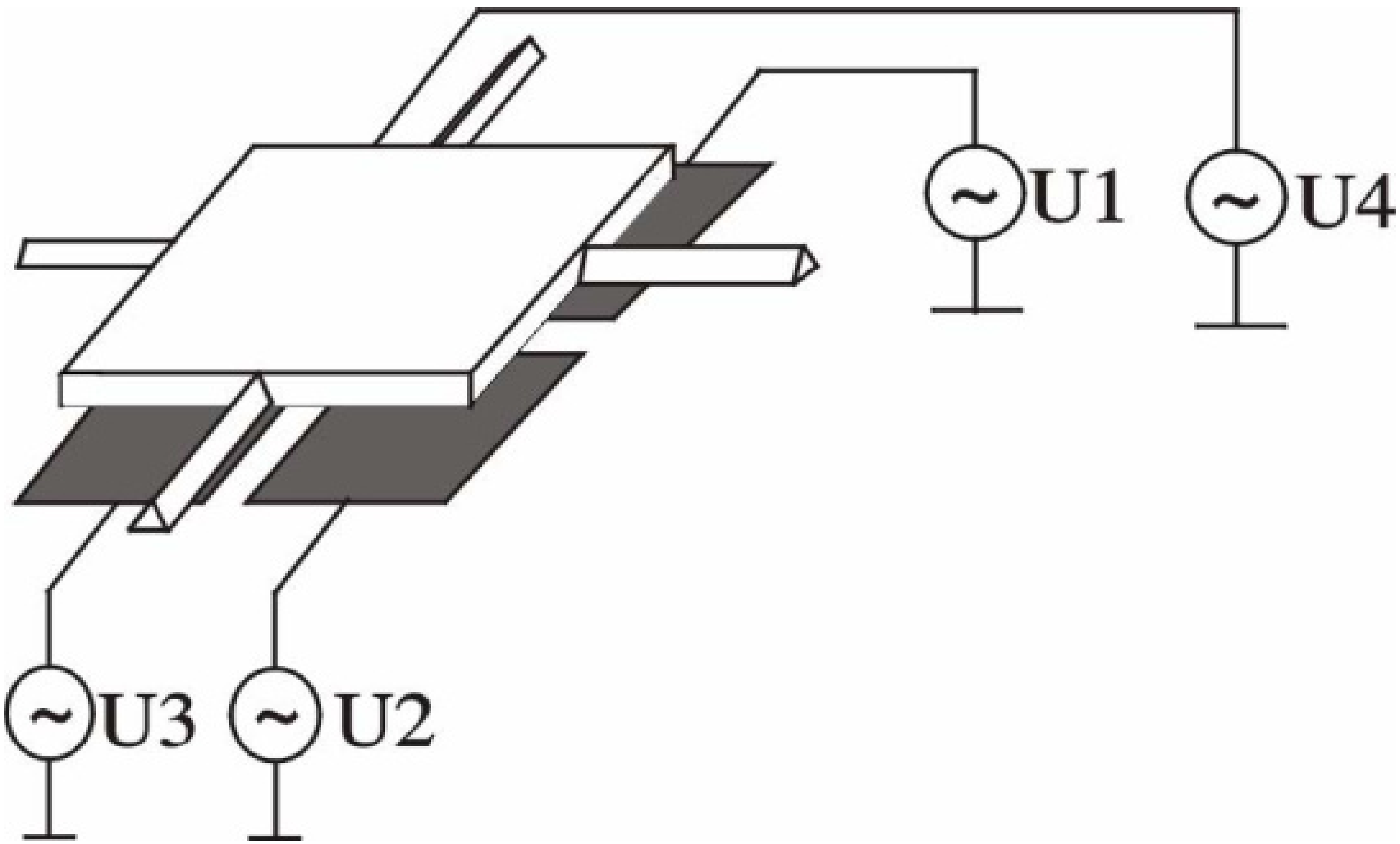
- Beam projection with micromirror array
- Vibration sensing
- Inertial navigation system

Micro mirror array

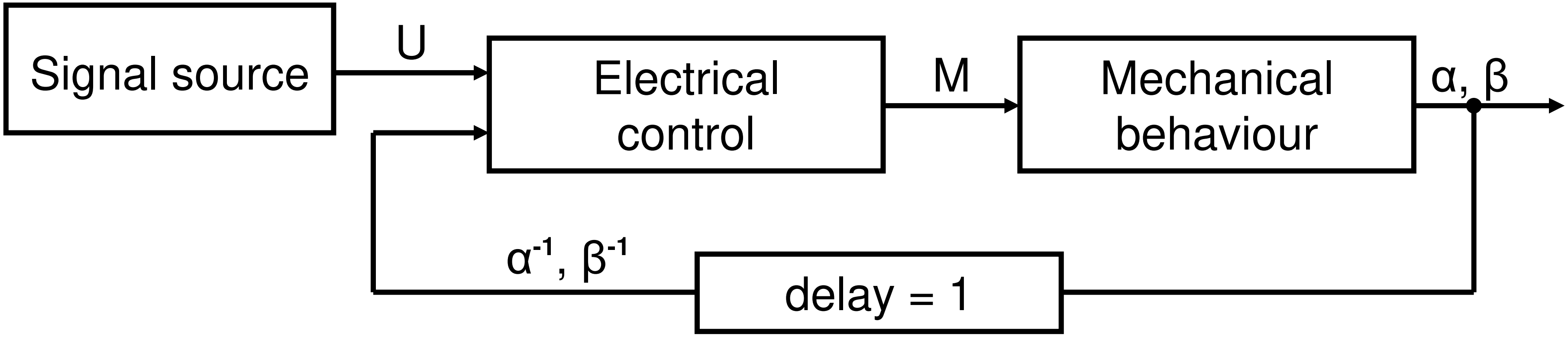


Source: SFB379 A4

Micro mirror

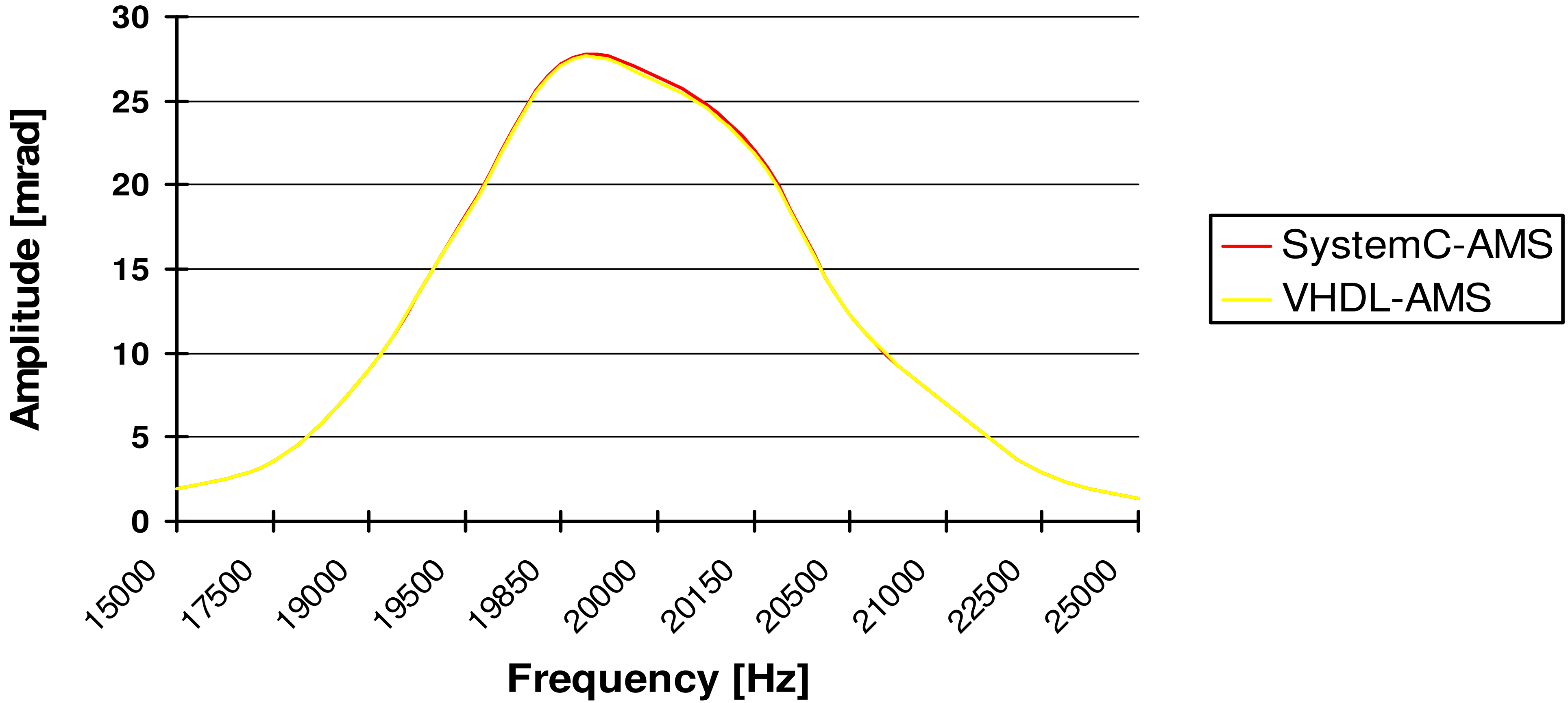


Model with feedback, static case

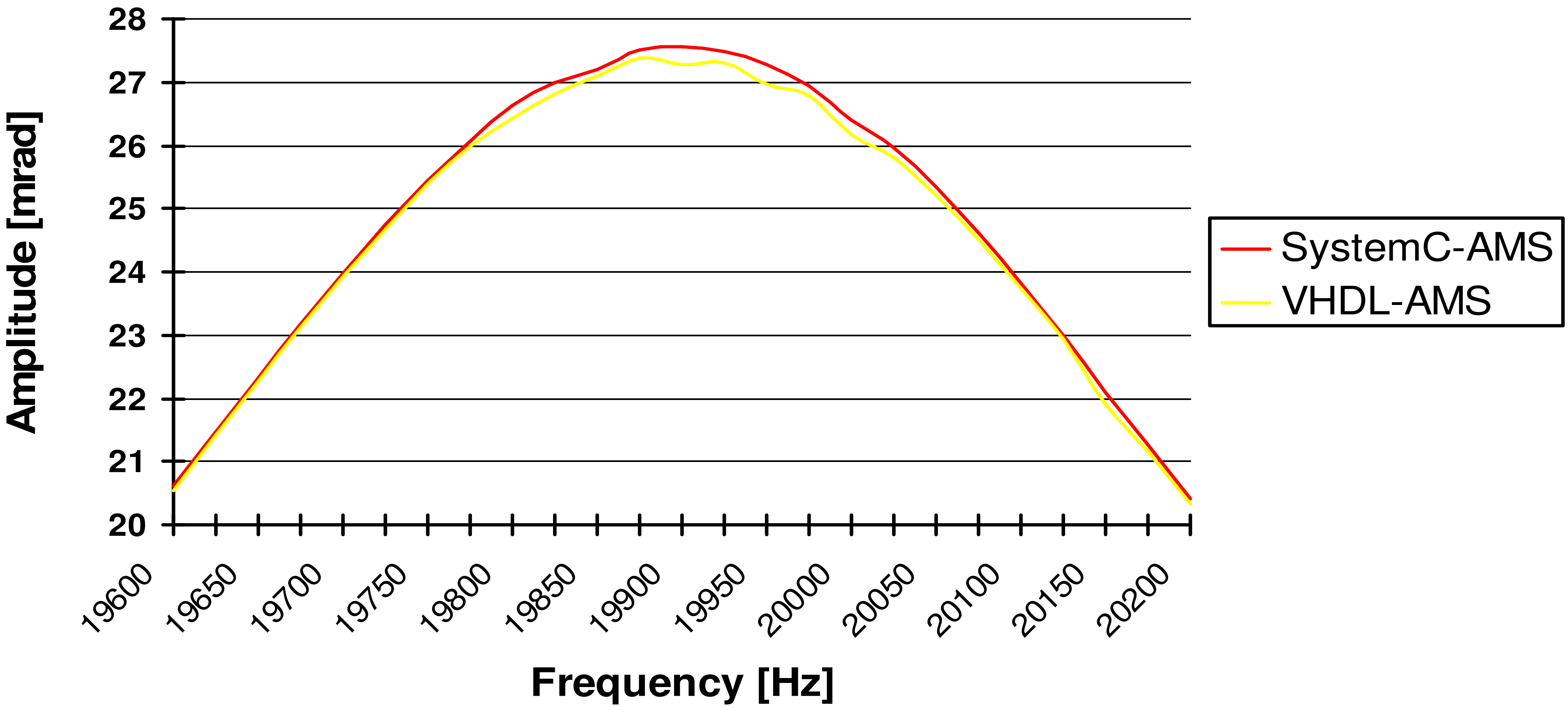


Control voltage		SystemC-AMS		VHDL-AMS	
U1 [V]	U2 [V]	α [mrad]	β [mrad]	α [mrad]	β [mrad]
300	150	-1,62	0,98	-1,66	1,00
300	300	-2,61	0	-2,72	0
500	0	-3,79	3,79	-4,09	4,09

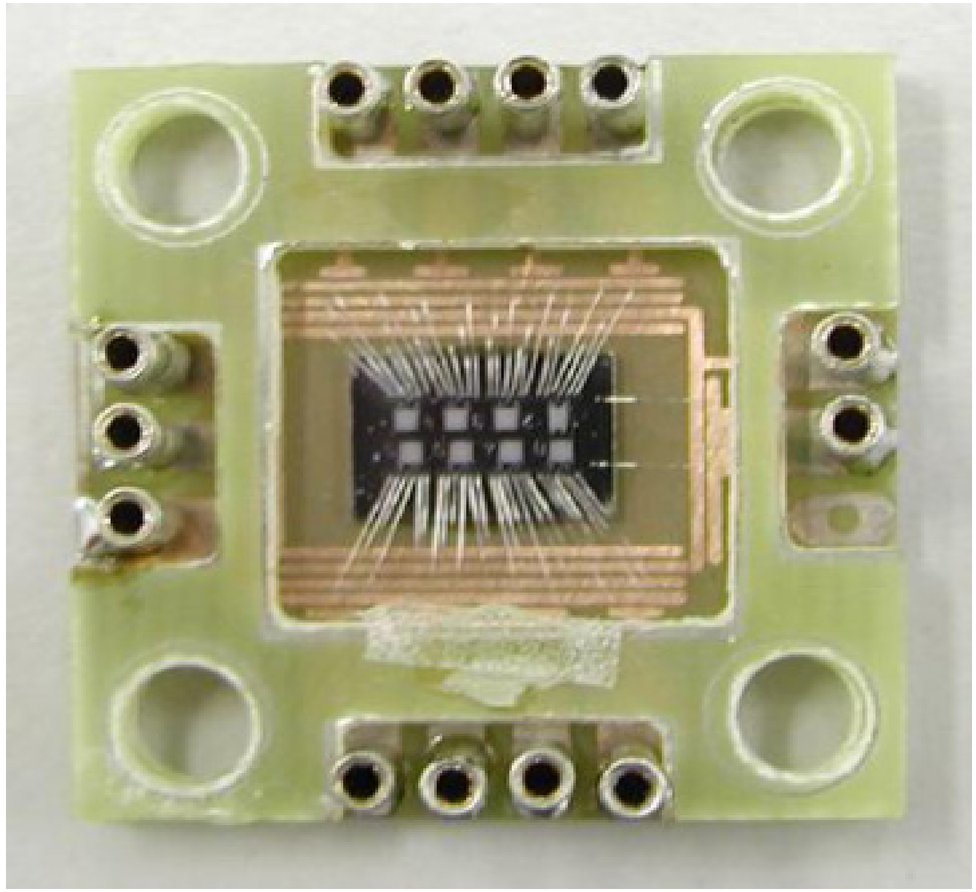
Simulation results, dynamic case



Simulation results, dynamic case

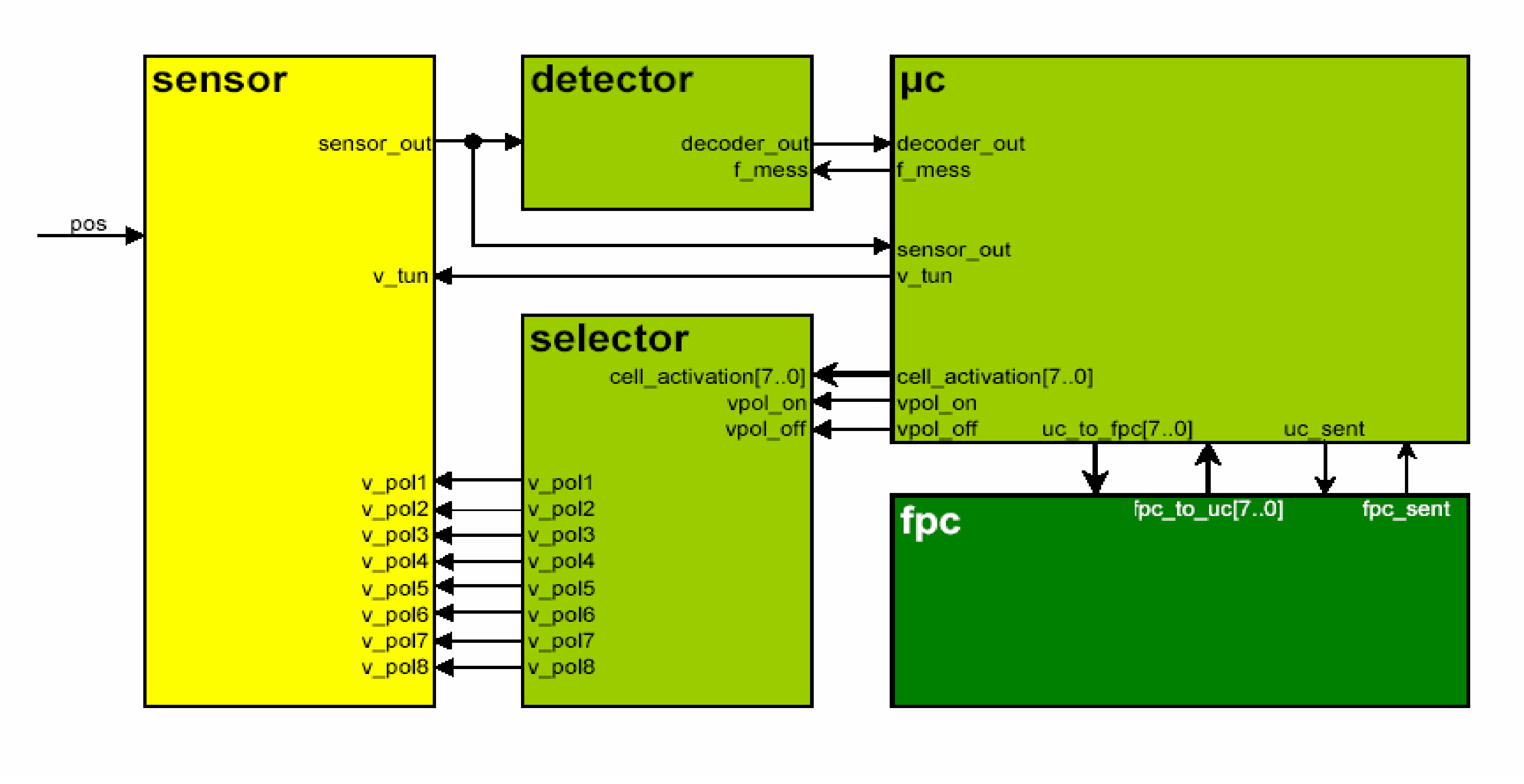


Vibration sensing (medium frequency 1-10 kHz)

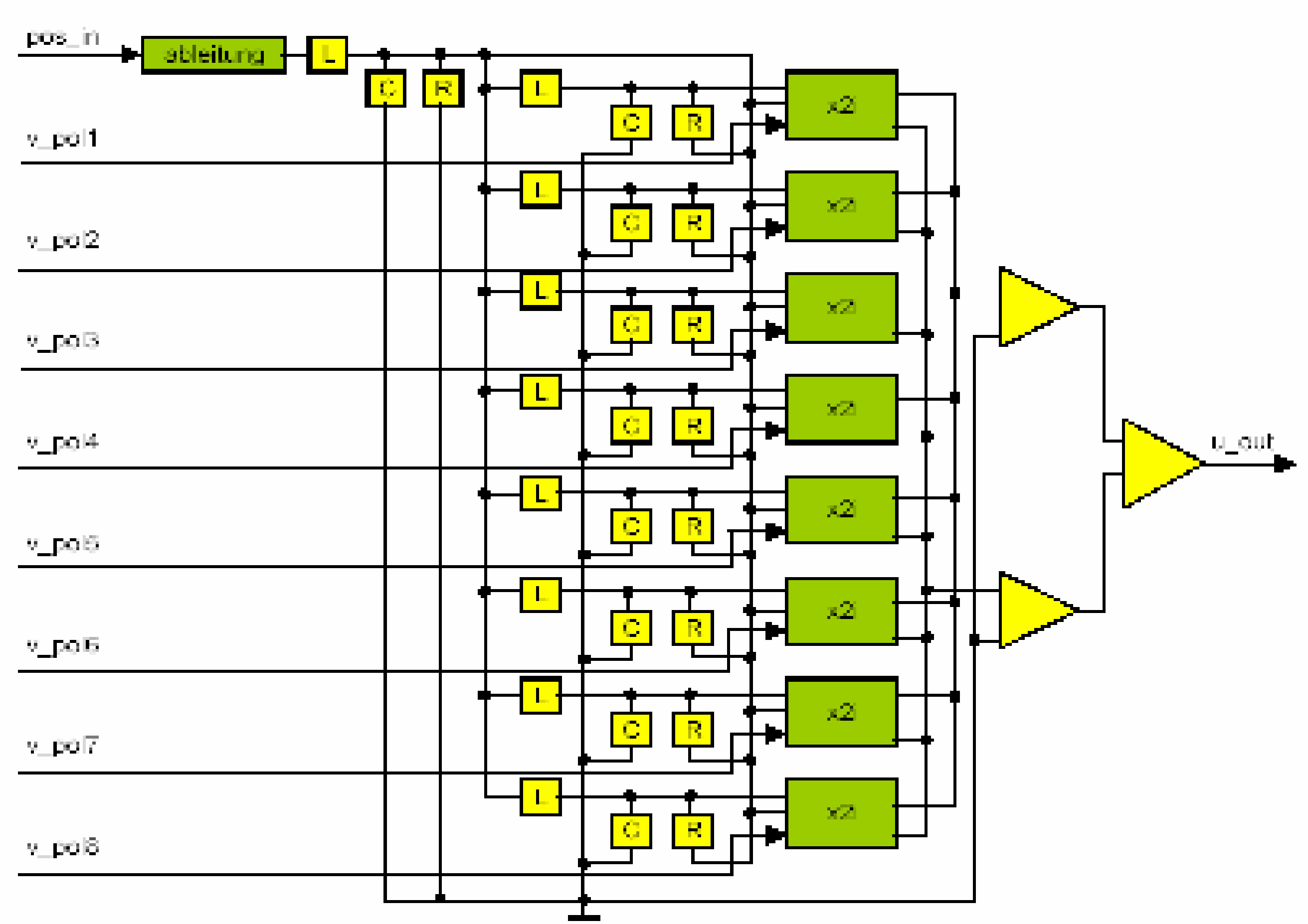


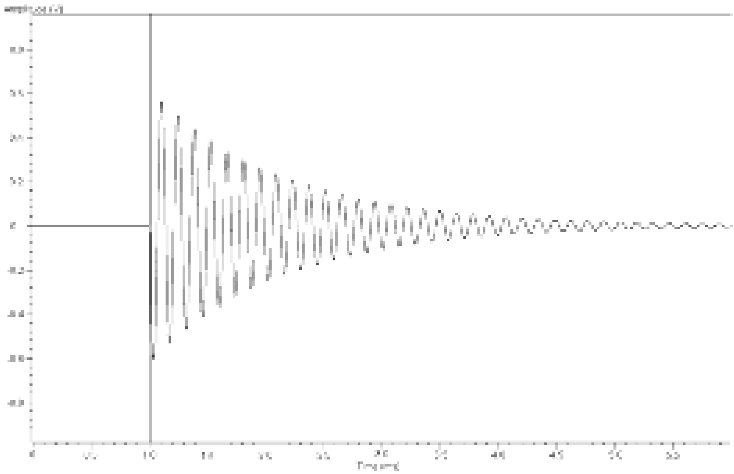
Source: Dirk Scheibner, SFB 379 A4

Vibration sensing

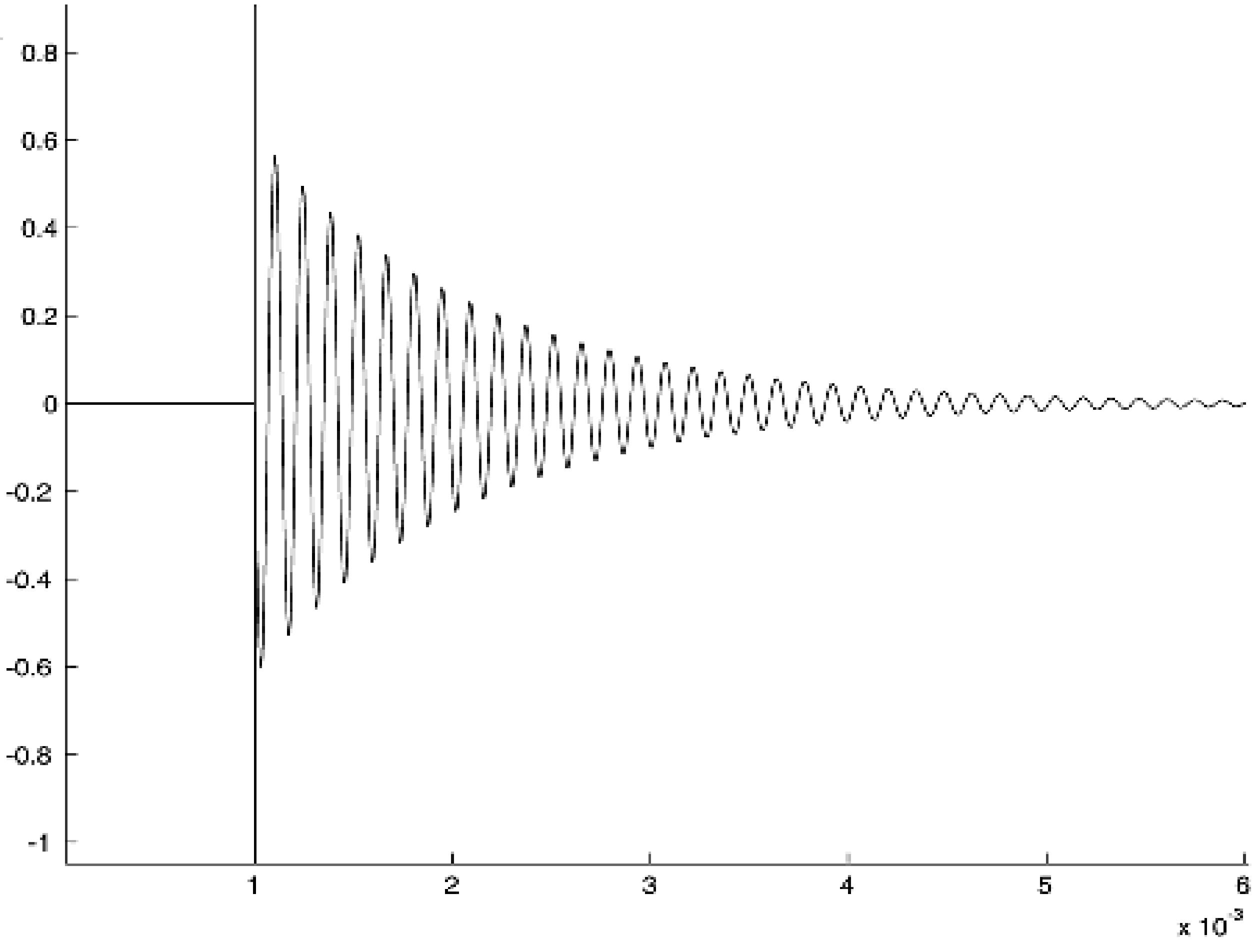


Vibration sensor





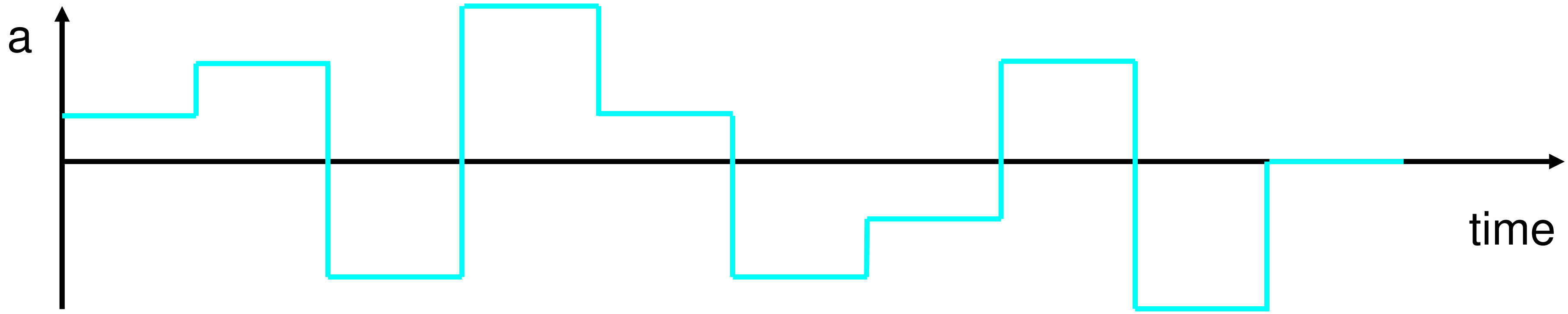
Results SystemC-AMS



< 2% deviation of amplitude

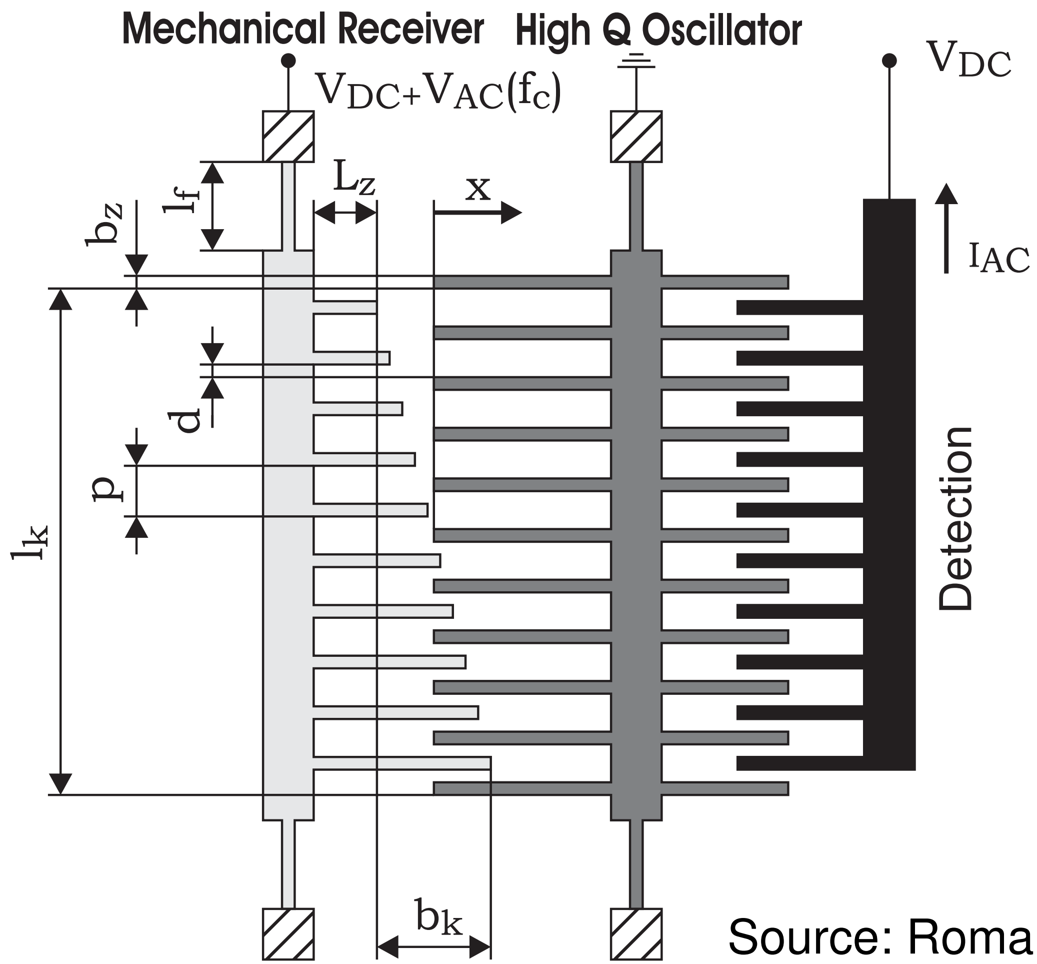
No frequency shift

Results of Fuzzy-Pattern-classifikation



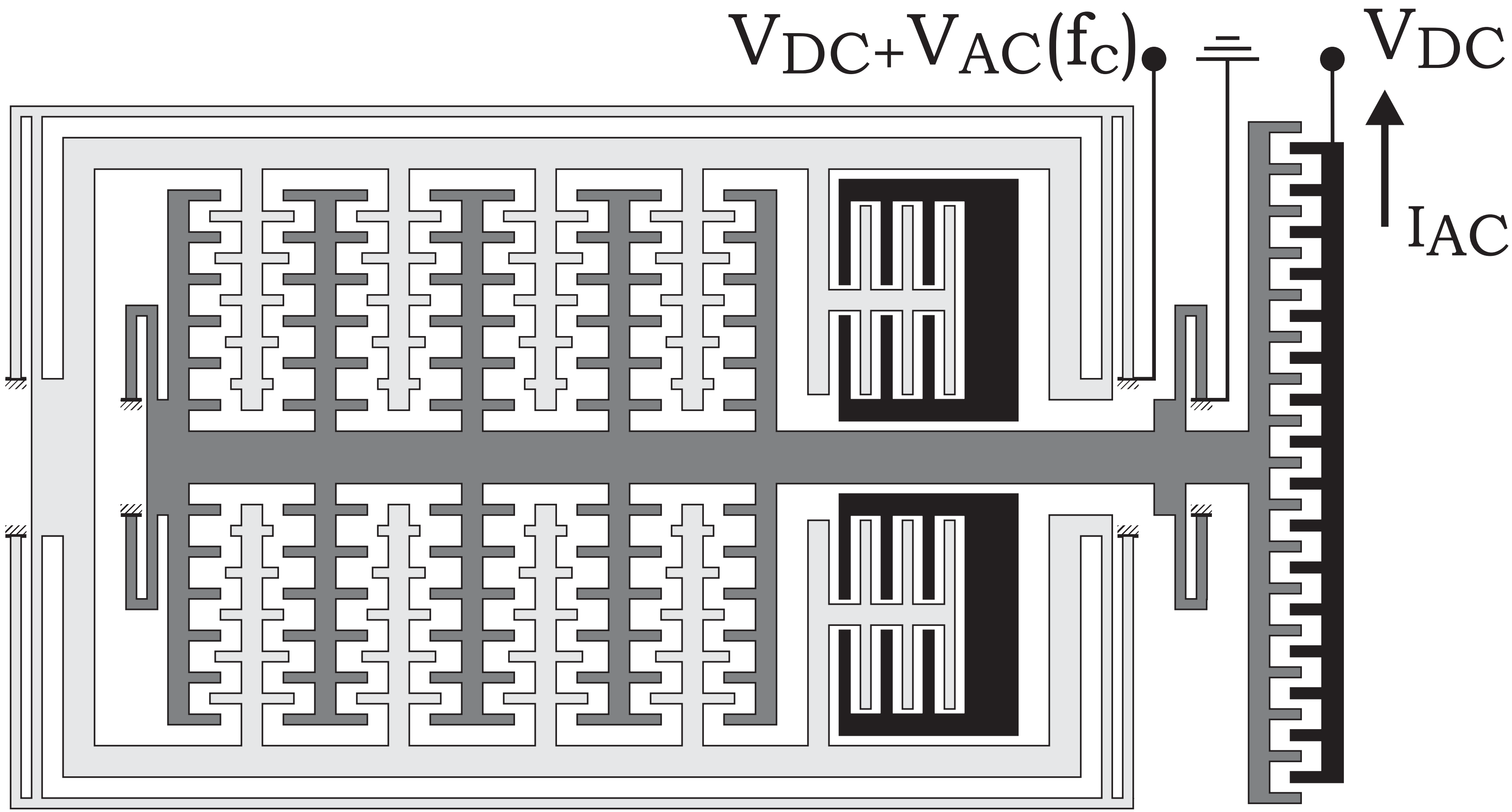
	VHDL-AMS	SystemC-AMS	Δ
class 1	0,0070686	0,0070696	0,01 %
class 2	0,0344840	0,0345094	0,07 %
Calc time	59 min 5 s	8 min 23 s	

Low frequency vibration detector (< 1 kHz)



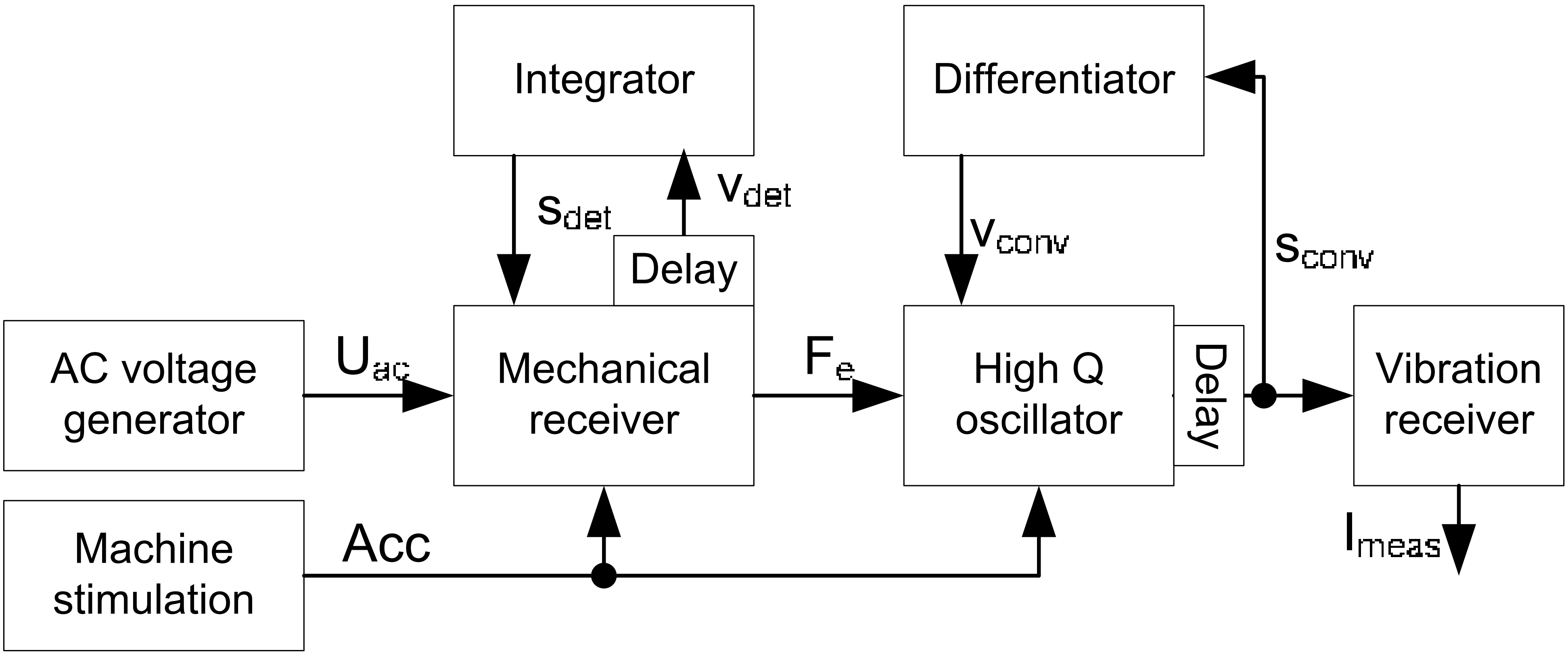
Source: Roman Forke, SFB379 A4

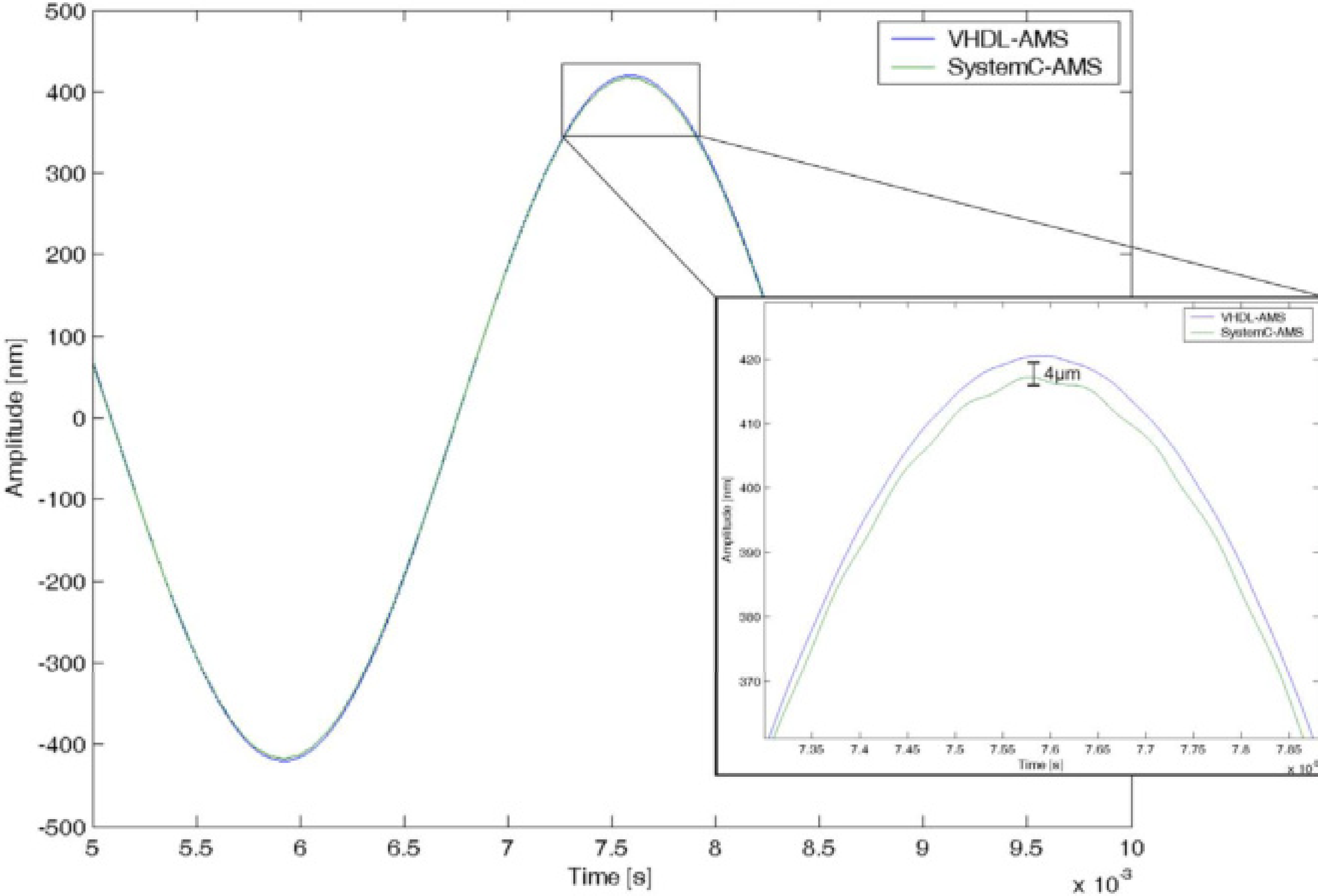
New vibration detector



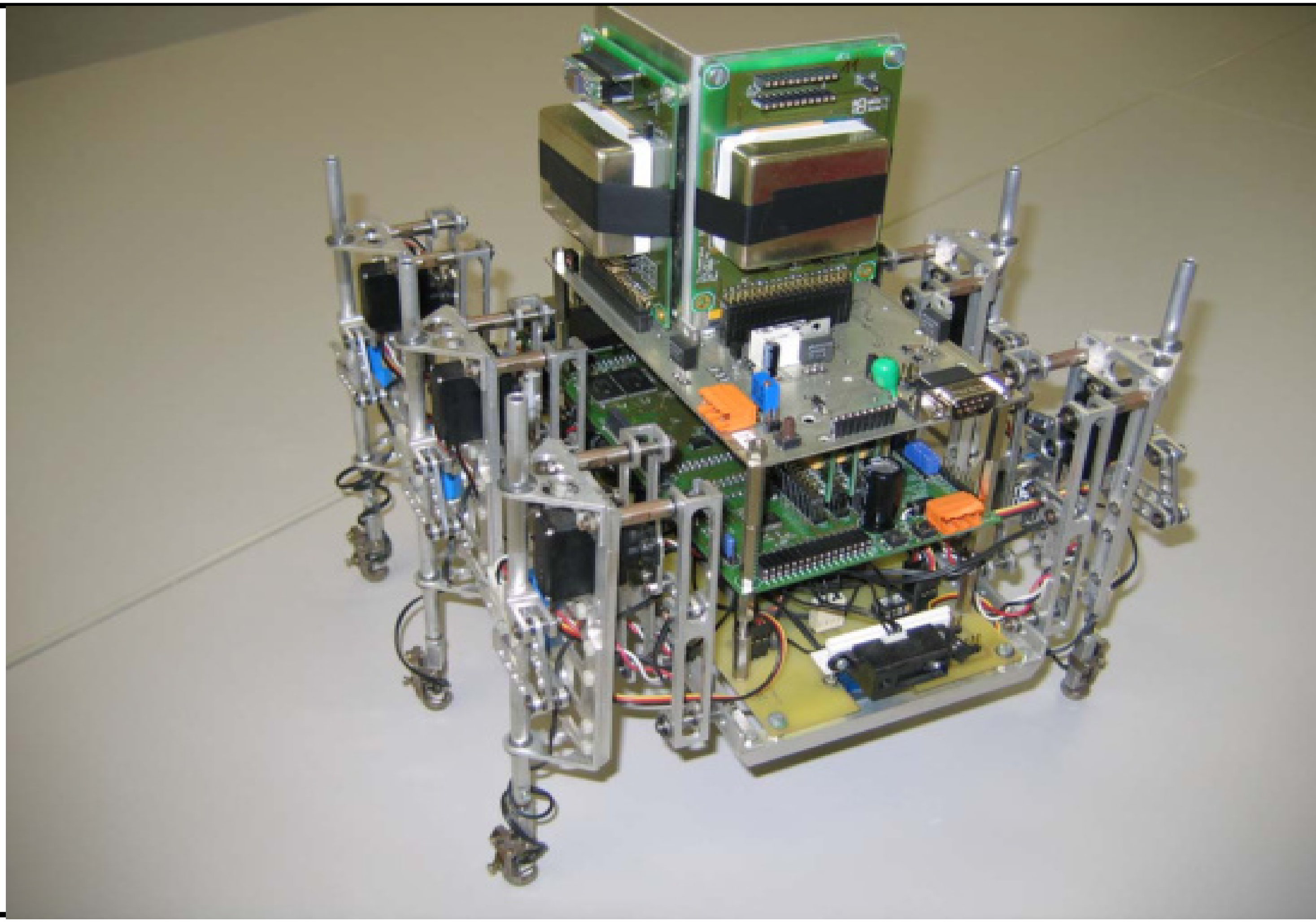
Source: Roman Forke, SFB379 A4

Low frequency vibration detector



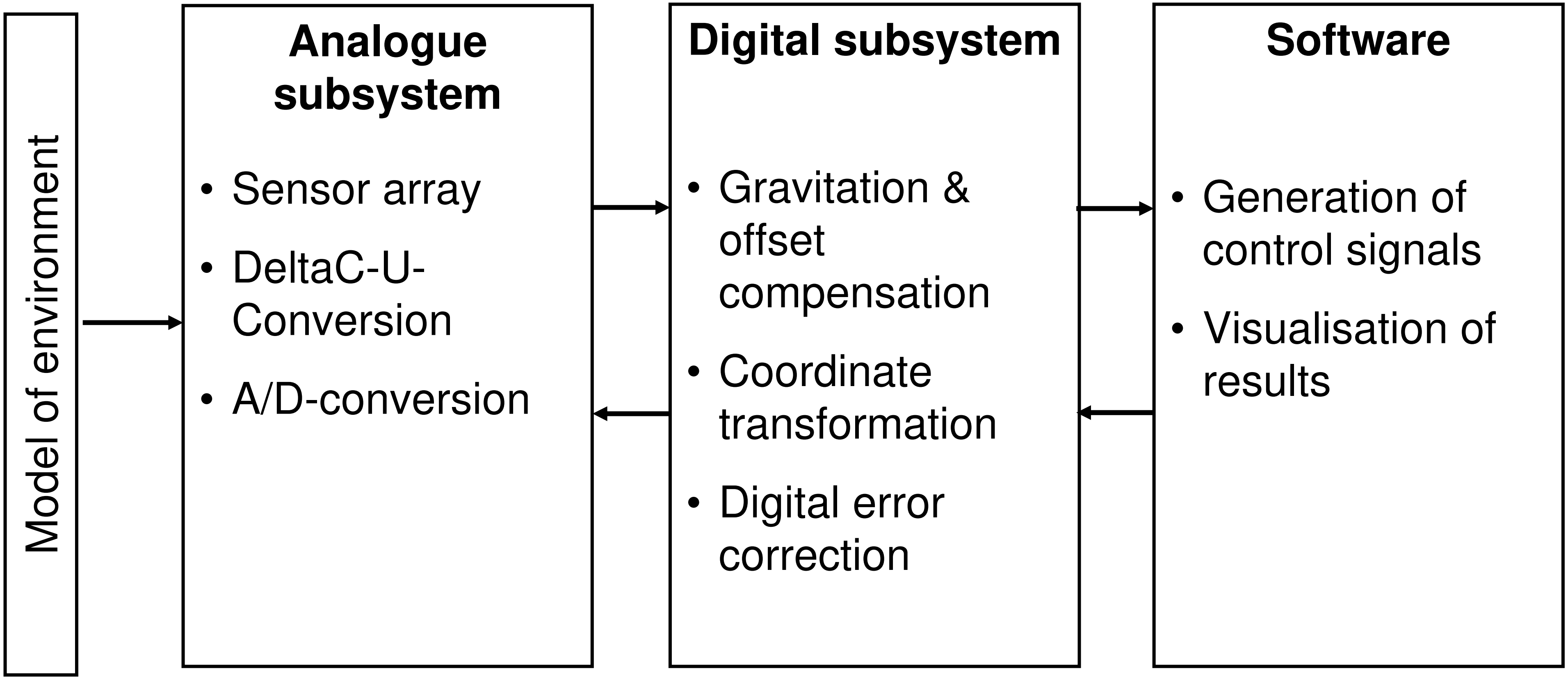

VHDL-AMS
SystemC-AMS
Amplitude [nm]
Time [s]
x 10^-3
500
400
300
200
100
0
-100
-200
-300
-400
-500
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
4µm
Time [s]
Amplitude [nm]

Overview of UBAS (Inertial navigation system)

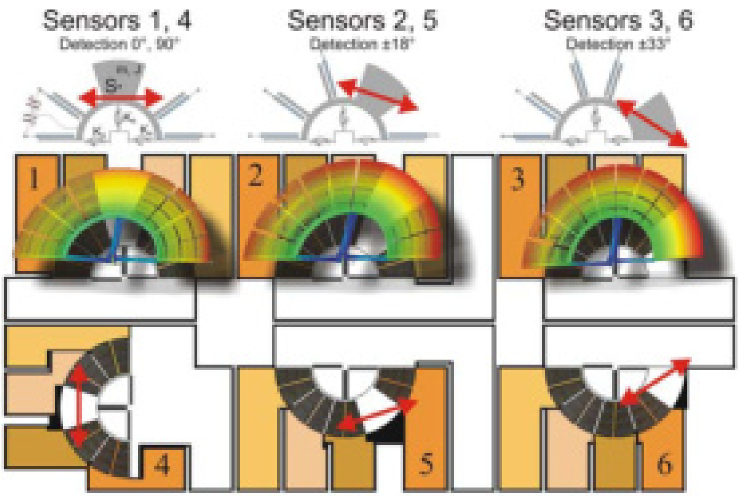


Mounted on a hexapod

Inertial navigation system

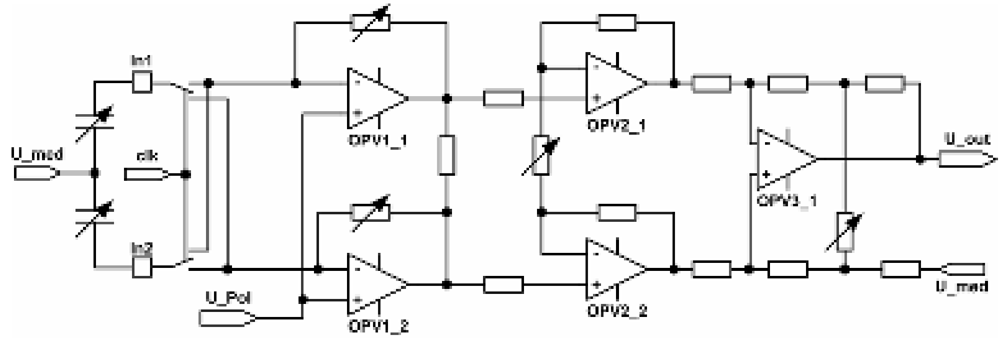


Analogue part



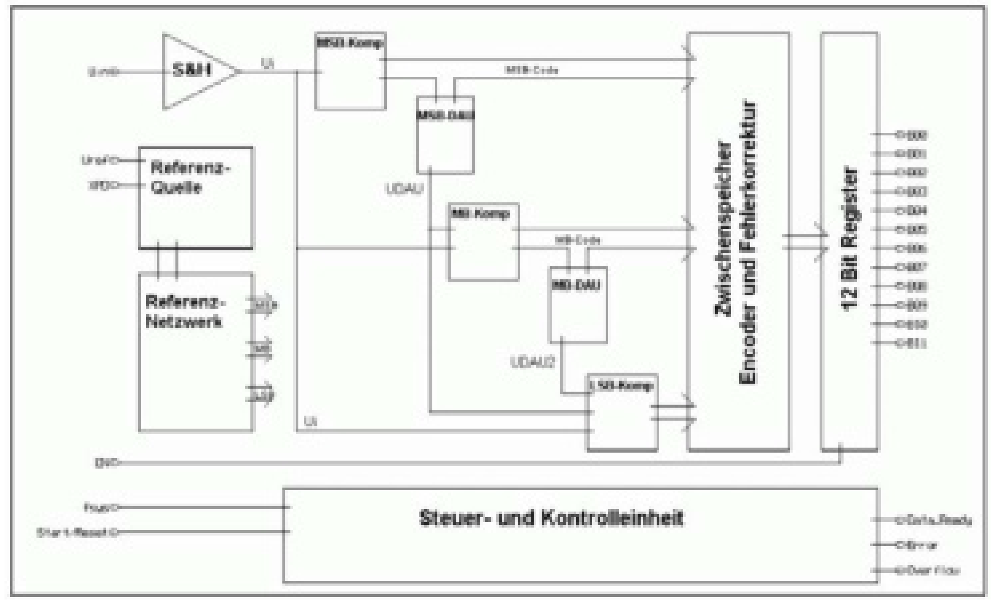
Sensorarray

+



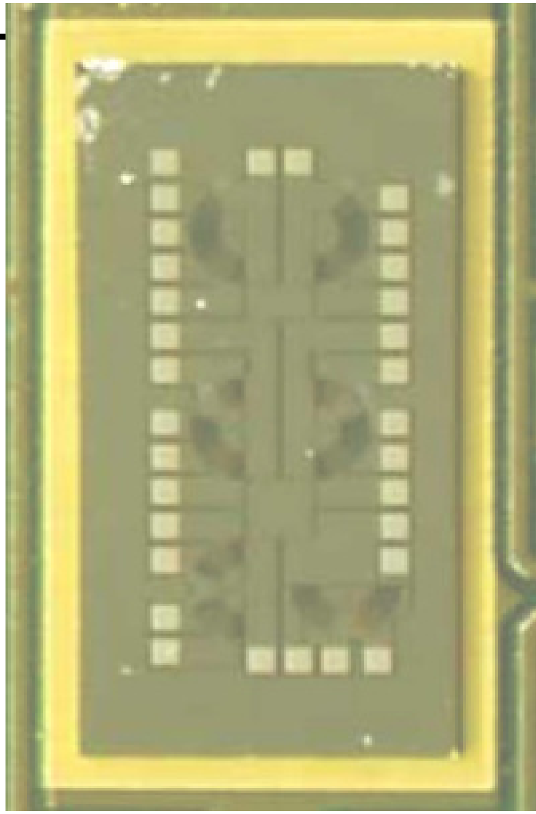
DeltaC-U-converter

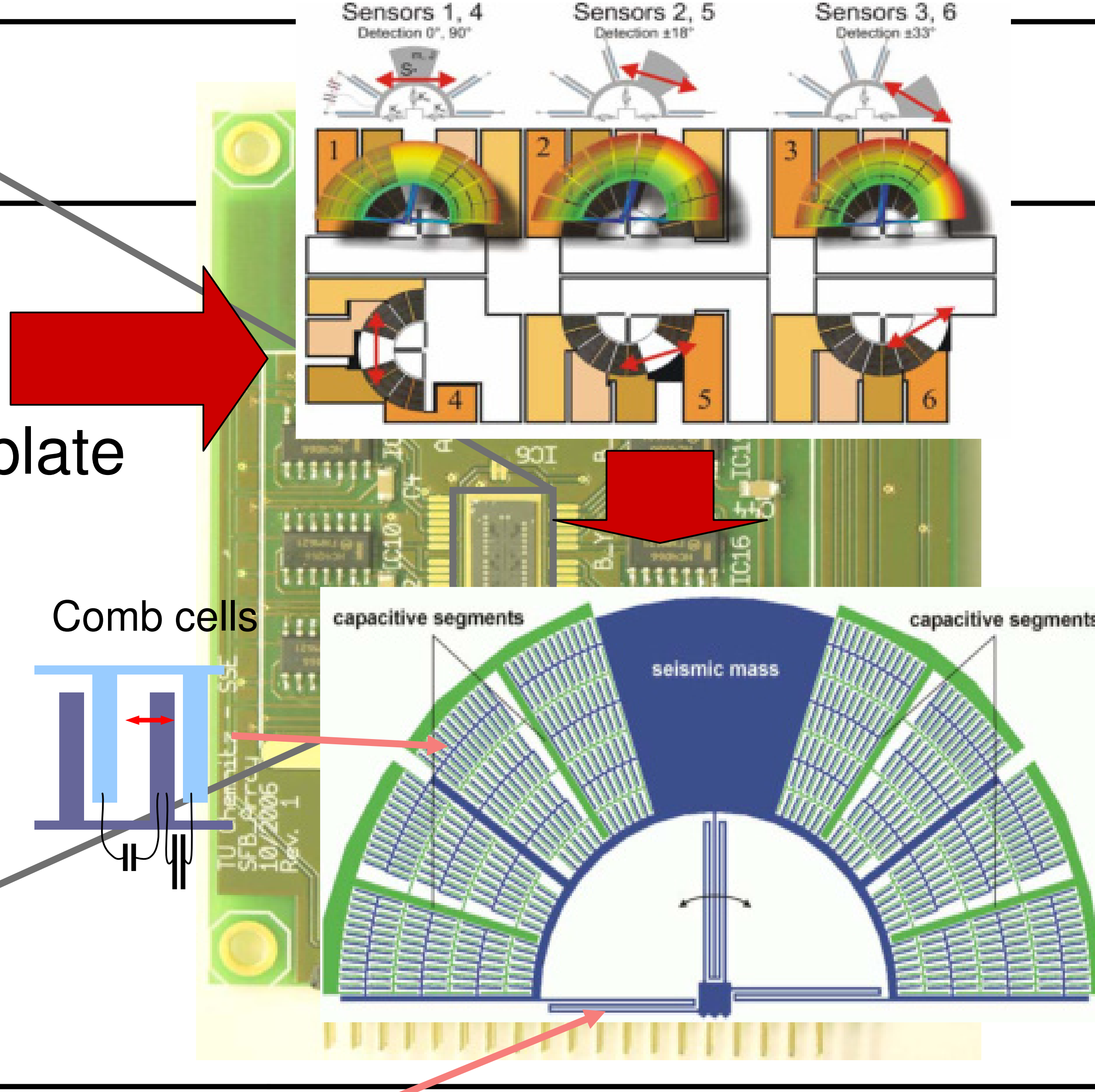
+



Analogue-Digital-Converter

Vi… plate




Sensors 1, 4
Detection 0°, 90°
Sensors 2, 5
Detection ±18°
Sensors 3, 6
Detection ±33°
1
2
3
4
5
6
Comb cells
capacitive segments
seismic mass
capacitive segments
springs

General modeling equations

Mechanical part:

$$M = J \cdot \frac{\partial^2 \alpha}{\partial t^2} + k \cdot \frac{\partial \alpha}{\partial t} + c \cdot \alpha$$

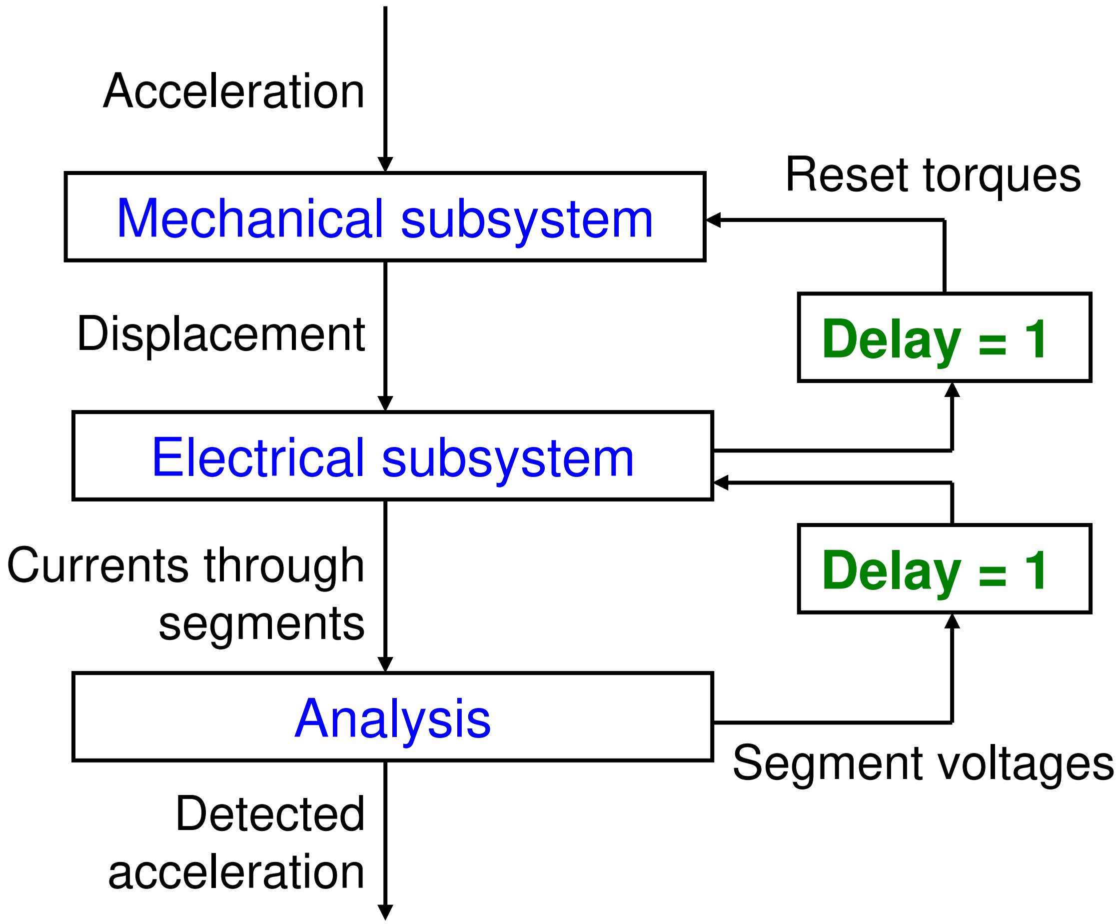
Problem: parameter extraction from geometry

Electrical part:

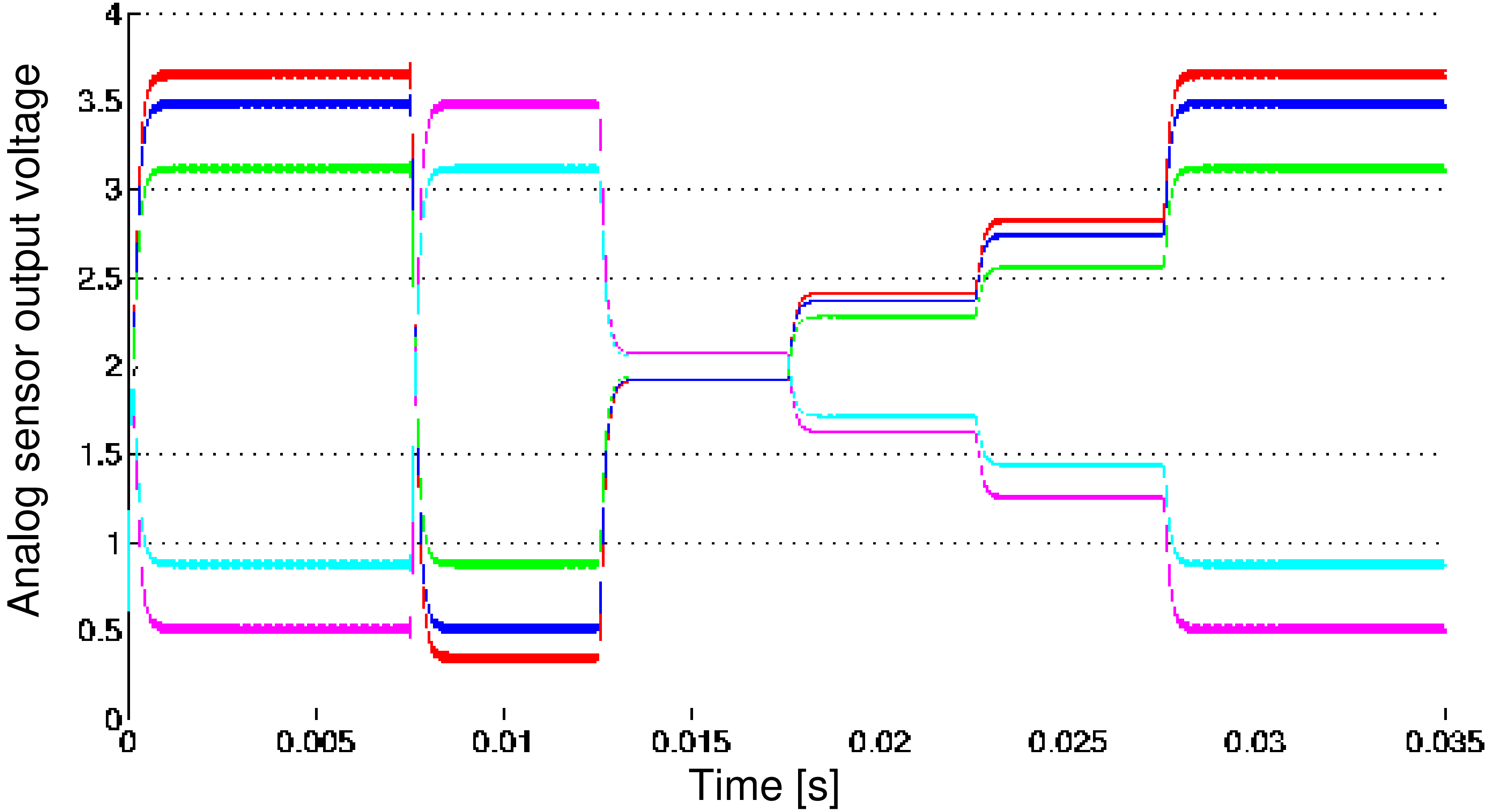
$$I = C \cdot \frac{\partial U}{\partial t} + U \cdot \frac{\partial C}{\partial t}$$

Feedback decoupling

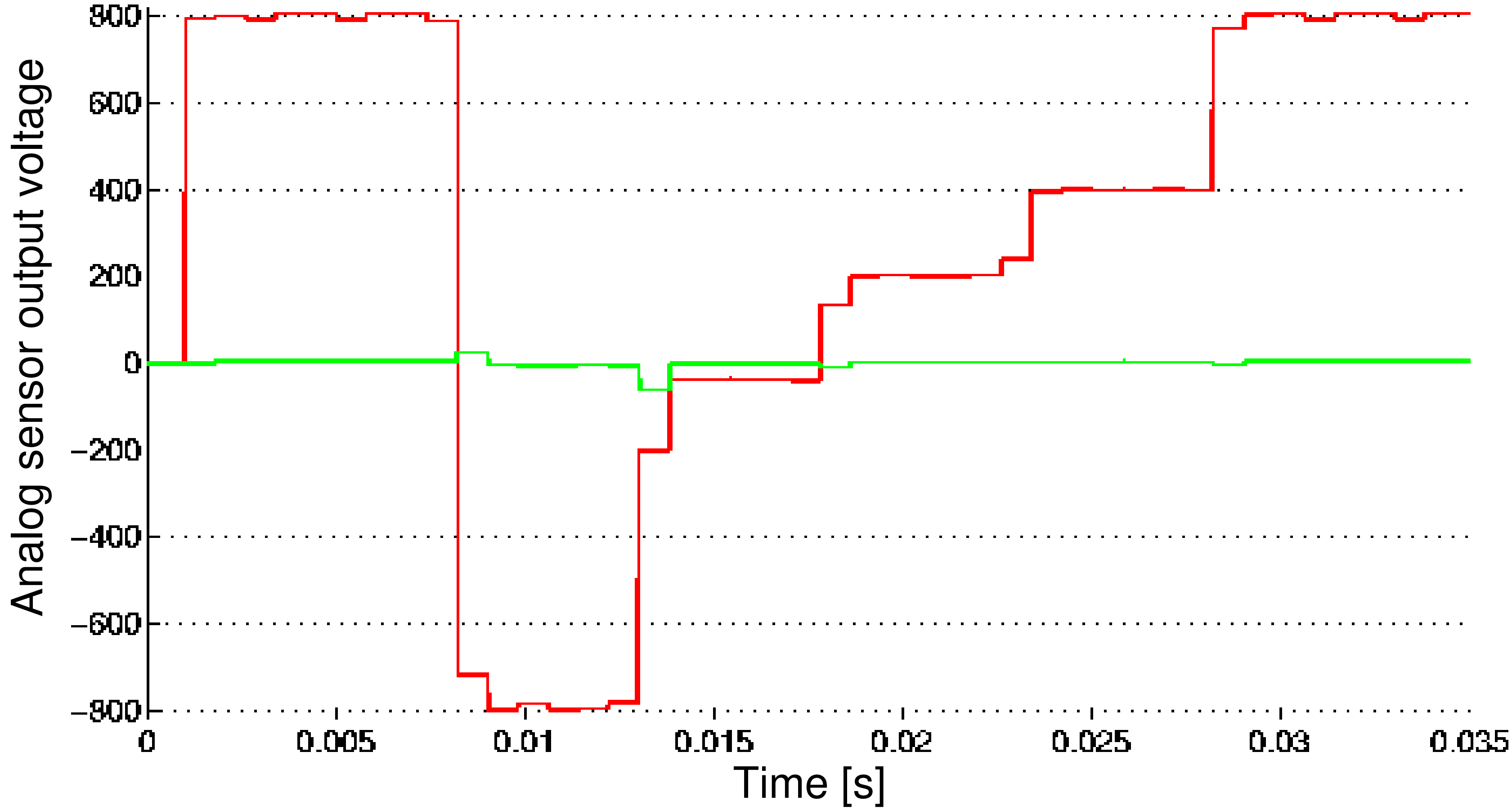
- SystemC-AMS v0.15 still needs decoupling in feedback paths (will be fixed in one of the next versions)
- Validation with VHDL-AMS model (no decoupling) shows only little differences (< 2%) but speedup



Simulation results of the sensor array



Simulation results of data fusion



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- Proposal of a design flow

Requirements for simulation of heterogeneous systems

- Continuity in time and value
- Feedback control
- Multi-domain modeling
  - electrical
  - mechanical
  - optical
  - thermal
  - fluidic
  - chemical
  - radiation

Requirements for simulation of heterogeneous systems

- Feedbacks between domains
  - Electrostatic forces
  - Piezoelectricity
  - Thermal effects
- Frequency domain handling
- Nonlinear behaviour (diodes, friction etc.)

→ But should be very fast and easy to handle!

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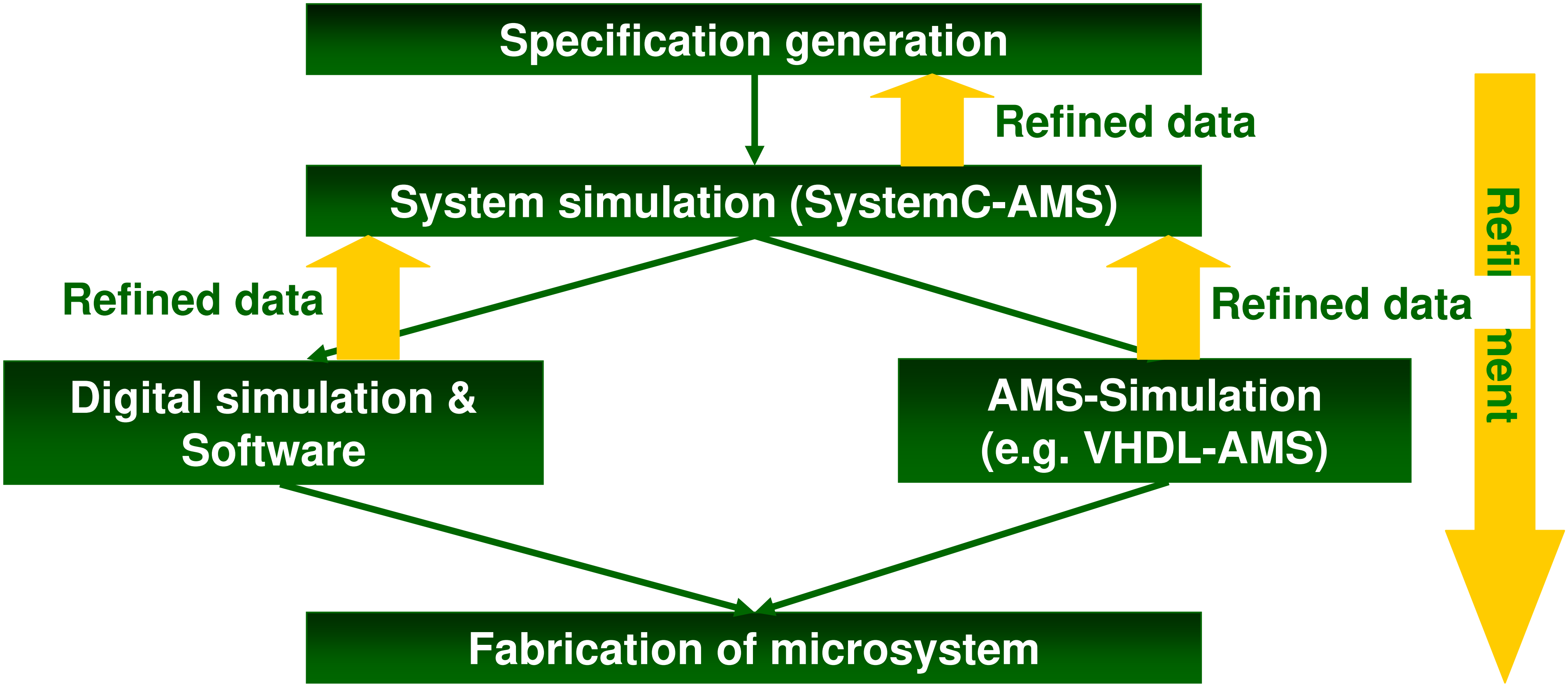
Top-Down-Designflow for Microsystems

- Specification capturing in machine-readable format
- Specification checking for consistency
- Generation of simulatable model (SystemC-AMS)
- Refinement of components for manufacturing (VHDL, VHDL-AMS, Spice)
- Handover of component parameters to system model and specification → Generation of datasheets and documentation

Top-Down-Designflow for Microsystems



Summary

- Presentation of four examples for microsystems
  - Micromirror array
  - Vibration sensing (low & medium frequency)
  - Inertial navigation system
- Requirements for simulation of heterogeneous systems
- Proposal of a design flow using SystemC-AMS

Thank you for your attention!