M 1.9 Concept Engineering Mixed-Technology Systems (CEMS)

M. Meiners

2024-11-23

Table of contents

List of Figures

List of Tables

Unsyllabus

Name	Description
Course	M 1.9 Concept Engineering Mixed-Technology Systems (CEMS)
Term	Winter 2024/25
Instructor	Prof. Dr.-Ing. M. Meiners, Dipl.-Ing. (FH) T. Ziemann
Lectures	Thu., 9:45 h - 13:00 h
Room	E 507 ELIE Lab

Part I.

Lecture

1. Introduction and Survey

1.1. Course Objectives

- Interfacing Microsystems
  - Mixed-technology systems (System-on-Chip, SoC)
  - System analysis
  - System specification
- Design Methodology
  - Seamlessly modeling and design over all physical domains
- PCB (System) and IC Design
  - Architecture
  - Partitioning
  - Layout

1.2. Scientific Computing

- Python (Anaconda)
- Matlab (Campus Lizenz)
- Command-line tools

1.3. EDA Tools

- PCB / System Design
  - LTspice
  - KiCad EDA
  - Altium Designer
  - SiemensEDA PCB tools
  - cadence System Design & Analysis
- IC / Silicon Design

    - IIC-OSIC-TOOLS (open-source)
    - SiemensEDA IC tools
    - cadence IC Design & Verification
    - synopsys silicon design (IC)

1.4. OS-Tools

- Microsoft-Terminal
- Microsoft-PowerShell
- MacOS-Terminal
- Linux/MacOS Shell zsh-tools,
- git (Versionskontrolle)

1.5. Code Editors

- Visual Studio Code
- Spyder IDE
- Thonny (Micro-)Python IDE
- Emacs
- Vim

1.6. Data Science

- File system: Files and directories
- Tabular data: Comma/Tab-Separated-Values (CSV/TSV), Spreadsheet (.xlsx, .ods)
- Special formats, e.g. MATLAB mat, HDF5
- Embedded Databases
    - SQL, z.B. SQlite
    - OLAP, z.B. DuckDB

1.7. Publish Computational Content

- Jupyter-Book
- quarto
  - Manuscripts

1.8. Are you writing or TeXing?

- MikTeX (Windows, MacOS, Linux)
- MacTeX (MacOS)
- TeXLive (Linux)

1.9. LaTeX Editors

- IDE's
  - TeXStudio
  - TeXMaker
- Collaborative Frameworks
  - Overleaf, Online LaTeX
  - CoCalc - Online LaTeX

1.10. Bibliography and LaTeX

- Citavi im Detail > Titel exportieren > Export nach BibTeX
- RefWorks - Library Guide Univ. Melbourne
- Benutzerdefinierte BibTex-Keys mit Zotero | nerdpause
- JabRef - Library Guide Univ. Melbourne
- EndNote - Library Guide Univ. Melbourne

1.11. Design Project

Model-Based Systems Engineering of an Inertial Sensor System (MBSE).

- System level, behavioural model
  - Matlab/Simulink,
  - Python
  - HDL (Verilog-ams, VHDL-AMS)
- Circuit level, SPICE with behavioural blocks, e.g. OTA and comparator
- PCB level
  - ESP8266 NodeMCU,
  - TIs ADS1115,
  - ADs ADXL335
- IC level
- **Final Oral Exam/Project Presentation**

1.12. Course Prerequisites

- Fundamentals of linux operating systems
- Fundamentals of microelectronics
  - Device physics and models
  - Transistor level analog circuits, elementary gain stages
- Fundamentals of analog circuit design
  - Operational amplifier
  - Active filter design
  - Noise analysis
  - Switched-capacitor techniques
- Prior exposure to SPICE, Matlab, Python or equivalent.

1.13. Brave New World

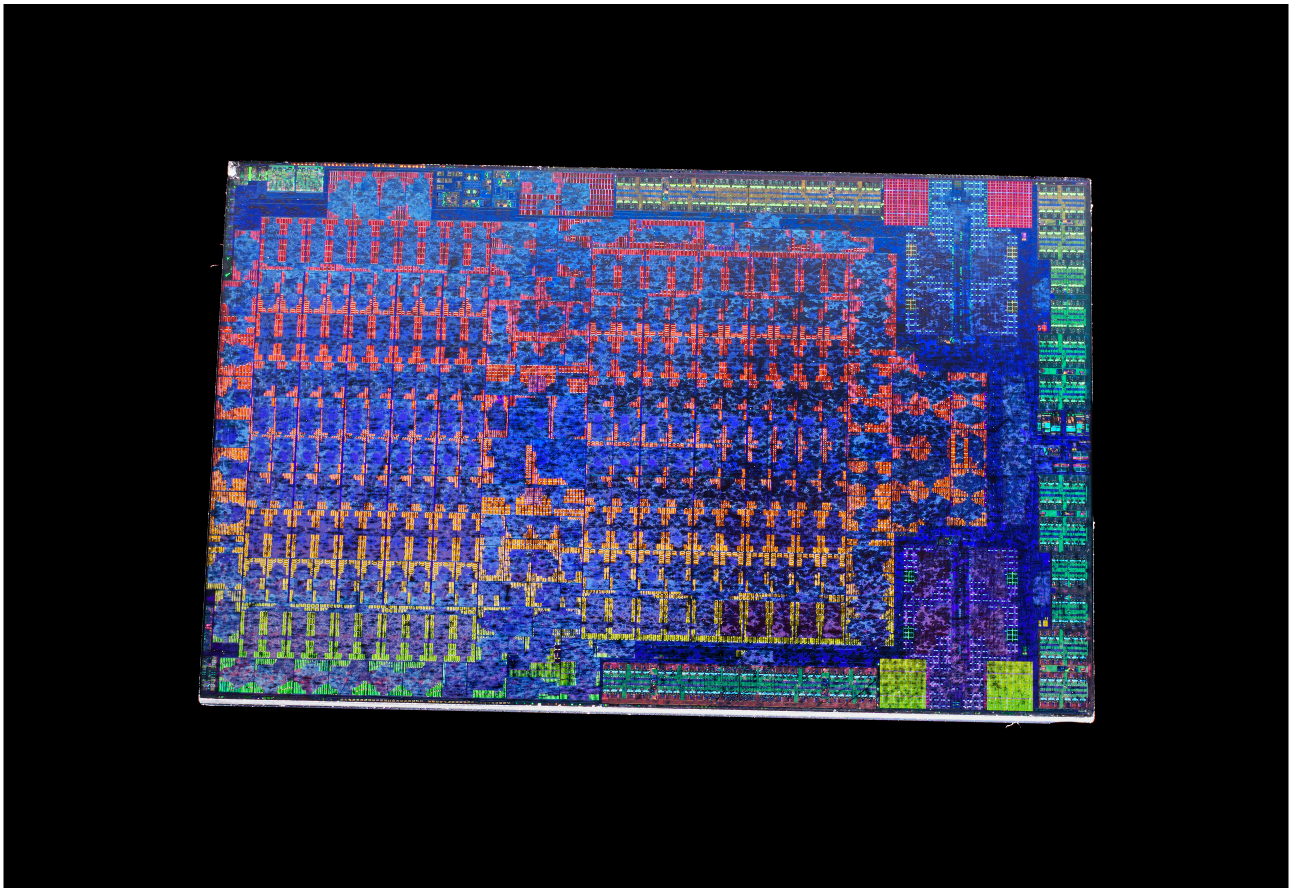


Figure 1.1.: AMD Jaguar APU (CPU/GPU), 16 nm, 325 sqmm, 2016

1.14. From Sand to Silicon (Infineon, Dresden)

https://youtu.be/bor0qLifjz4?list=PLO_wT97BGA6xC6hNy9VGtt1bKwVuQXI5B

1.15. Sand to Silicon (GlobalFoundries, Desden)

https://www.youtube.com/embed/UvluuAIiA50?list=PLO_wT97BGA6xC6hNy9VGtt1bKwVuQX I5B

1.16. FinFET (Intel)

https://www.youtube.com/embed/_VMYPLXnd7E

1.17. TSMC Fab (Next Gen 7/5 nm)

https://www.youtube.com/embed/Hb1WDxSoSec

1.18. Once upon a time ...

Figure 1.2.: 1906 Electron Tube

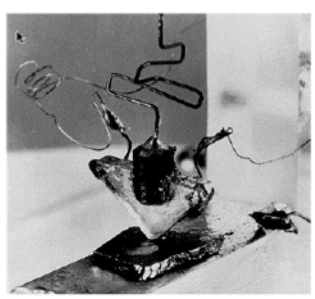


Figure 1.3.: 1947 1st Transistor, Bell Labs

1.19. First IC and today's chips

Figure 1.4.: 1958 Jack Kilby's 1st IC

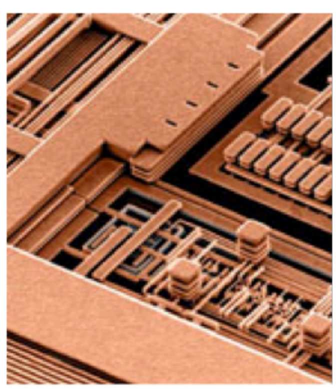


Figure 1.5.: Modern IC

1.20. Packaging Densities

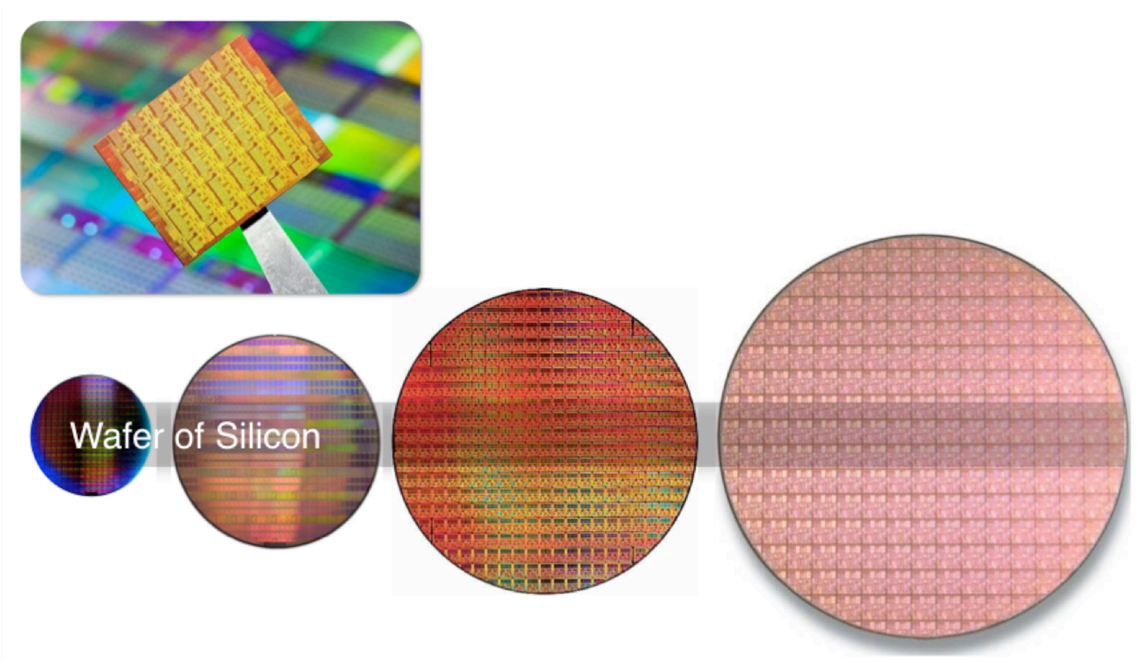


Figure 1.6.: Wafer generations

1.21. Moore's Law

https://www.youtube.com/embed/basGrfRDqts?list=PLO_wT97BGA6xC6hNy9VGtt1bKwVuQXI5B

1.22. System Hierarchy

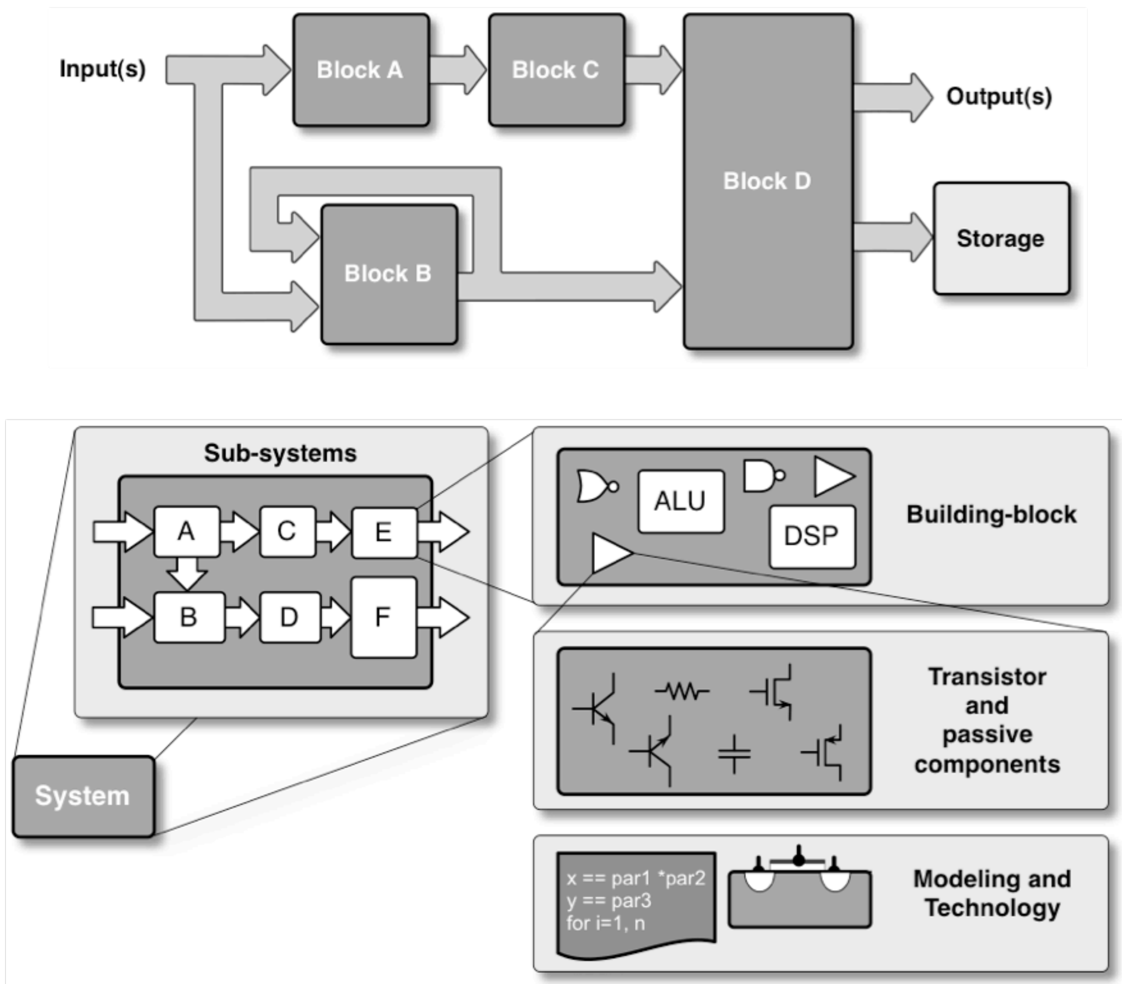


Figure 1.7.: Blocks of an electronic system.

- Use hierarchy to describe complex systems
- Devide and conquer

1.23. System Assembly

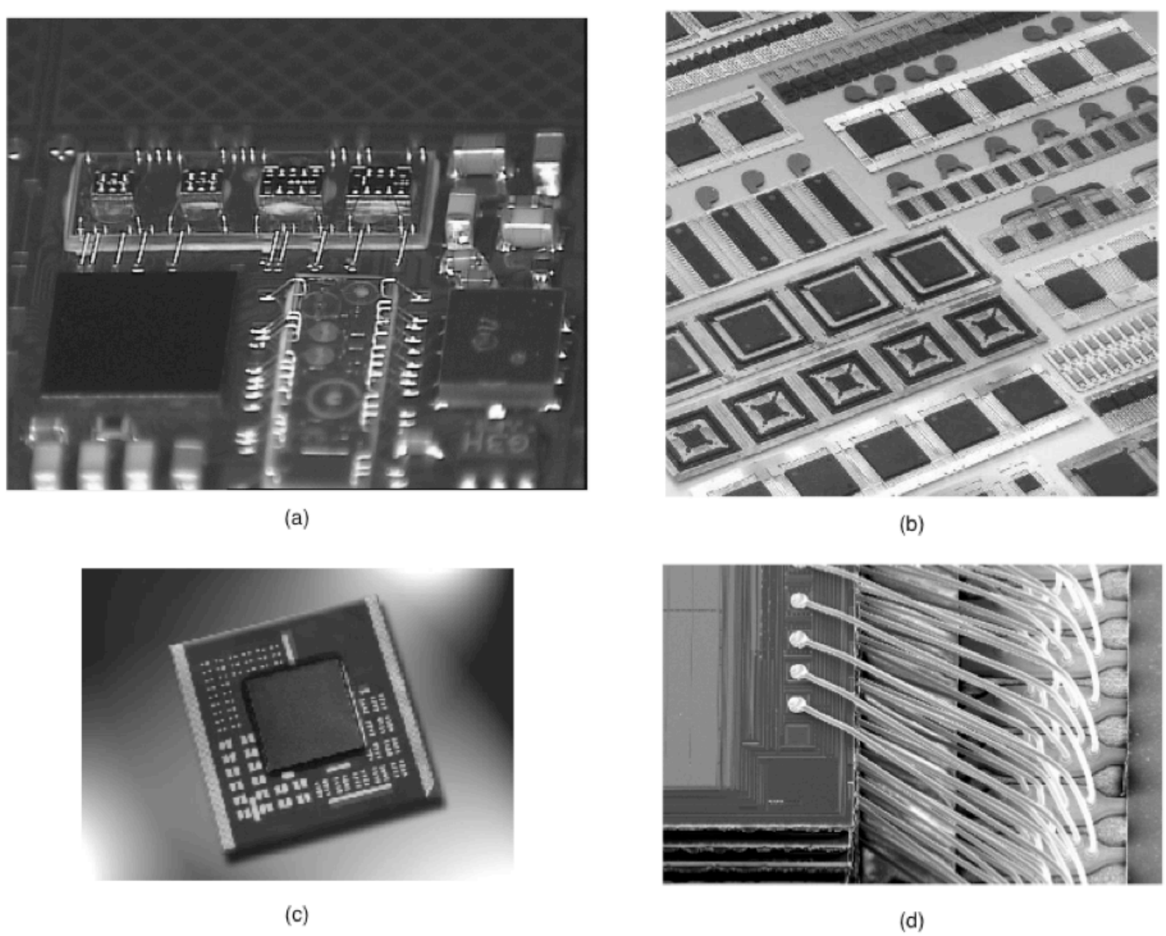
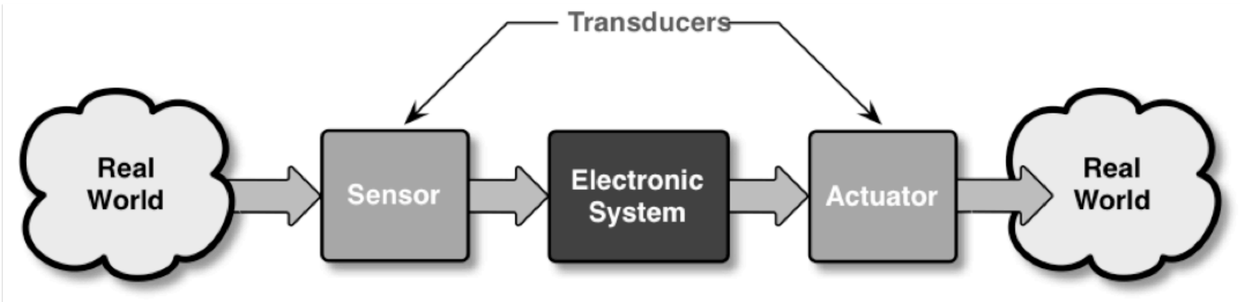


Figure 1.8.: Bottom-up Prozess, Integration.

1.24. Interfacing



Entire system involving signals of real world.

Figure 1.9.: Interfacing.

1.25. Meeting a System (1)

Block diagram of a wireless communication system

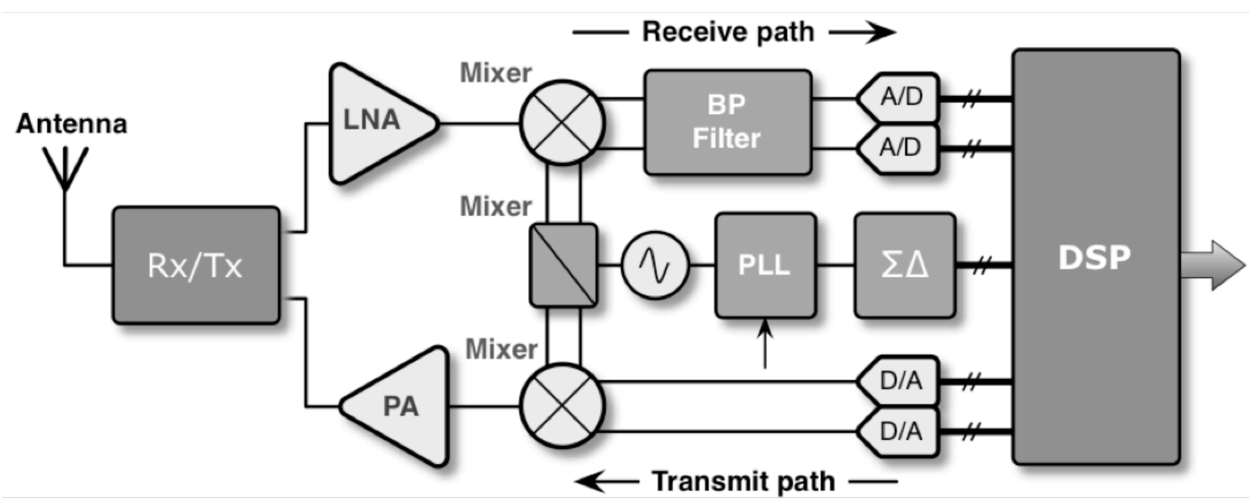
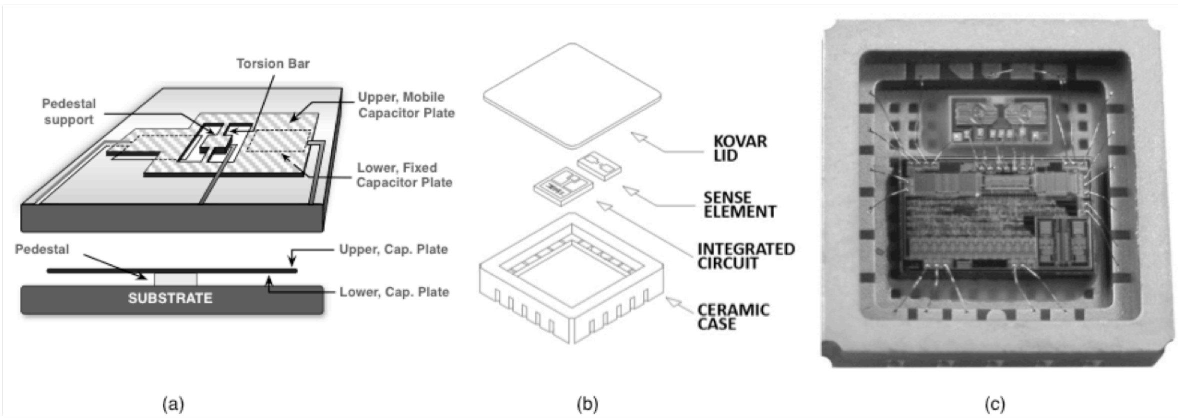


Figure 1.10.: Wireless Communication System.

1.26. System in a Package (SiP)



(a) Micro structure of an accelerometer.

(b) Assembling diagram of the system-on- package.

(c) Microphotograph. (*Courtesy of Silicon Designs, Inc.*).

Figure 1.11.: Accelerometer.

1.27. You will become an expert

Indicators.

- Background Knowledge
  - System Knowledge, Architecture, Processing, Implementation
- Subconscious Knowledge
  - Memorized experiences of success stories and dead ends
- Special Knowledge
  - Dicipline related knowledge, e.g. physics, hardware, software
- Teamwork
  - Communication abilities, reporting and presentation
- Creativity
- Tool-Knowlege

1.28. Views on Hardware

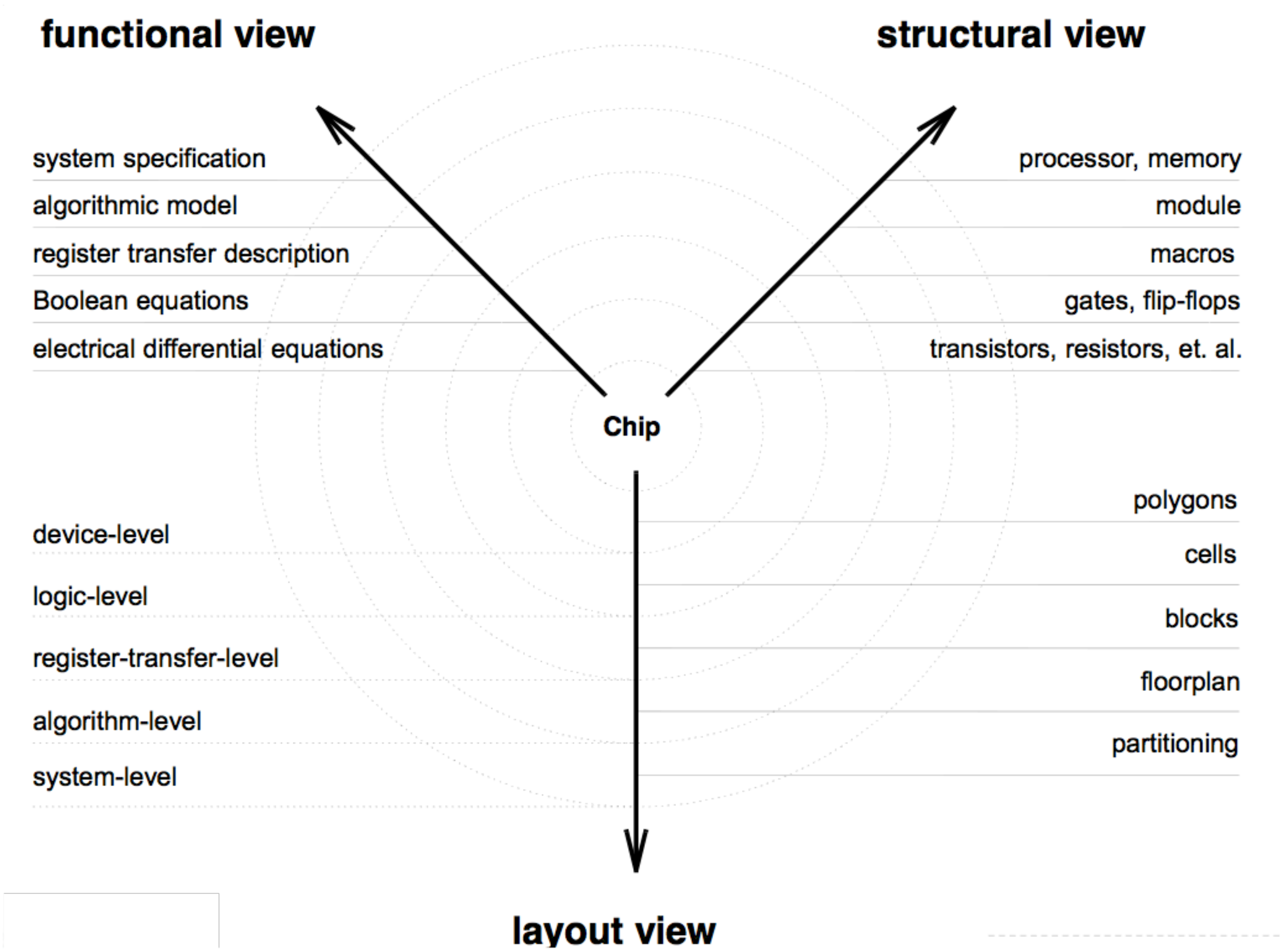


Figure 1.12.: (c) M. Ortmanns, Univ. Ulm.

1.29. Abstraction Layer

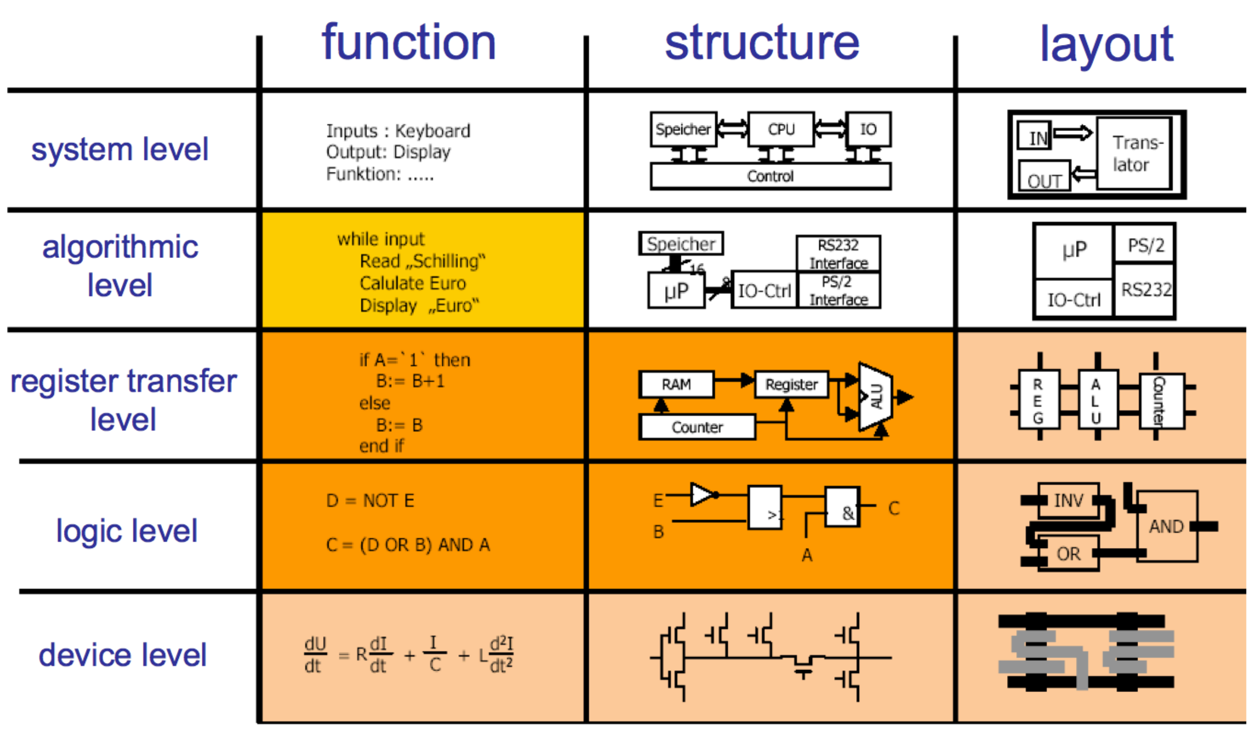


Figure 1.13.: (c) M. Ortmanns, Univ. Ulm.

1.30. Design Flow

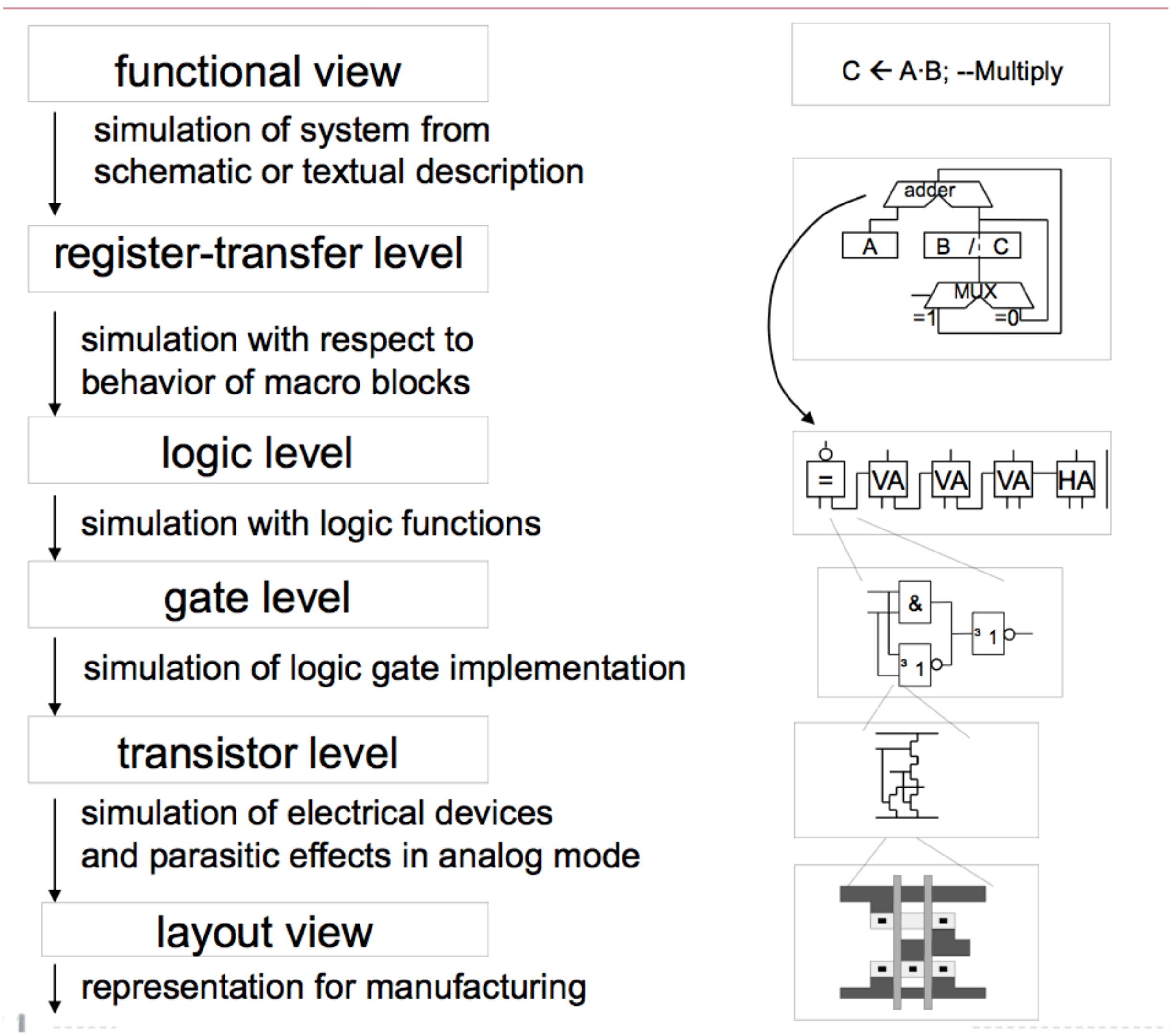


Figure 1.14.: (c) M. Ortmanns, Univ. Ulm.

1.31. Verification

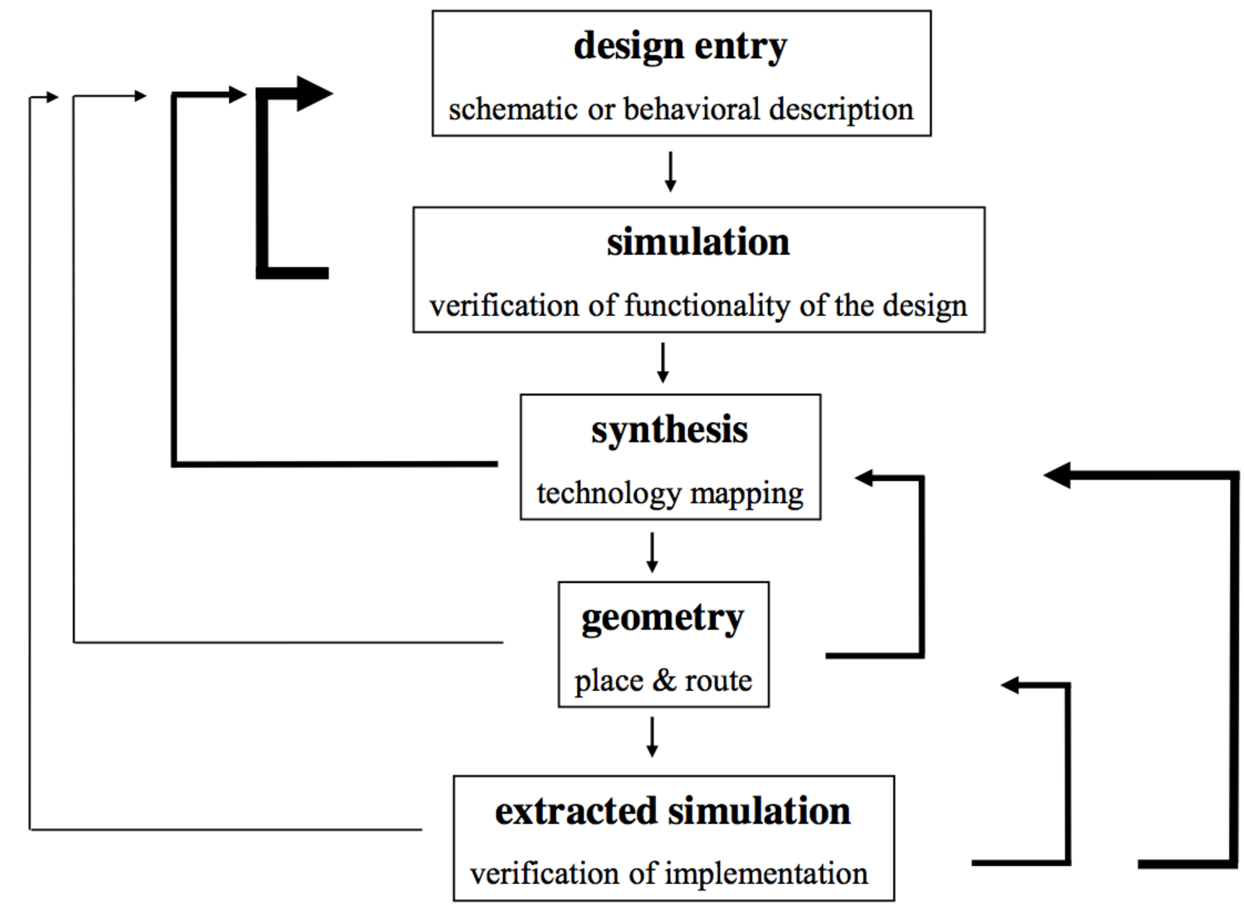


Figure 1.15.: (c) M. Ortmanns, Univ. Ulm.

1.32. Frontend vs. Backend (analog)

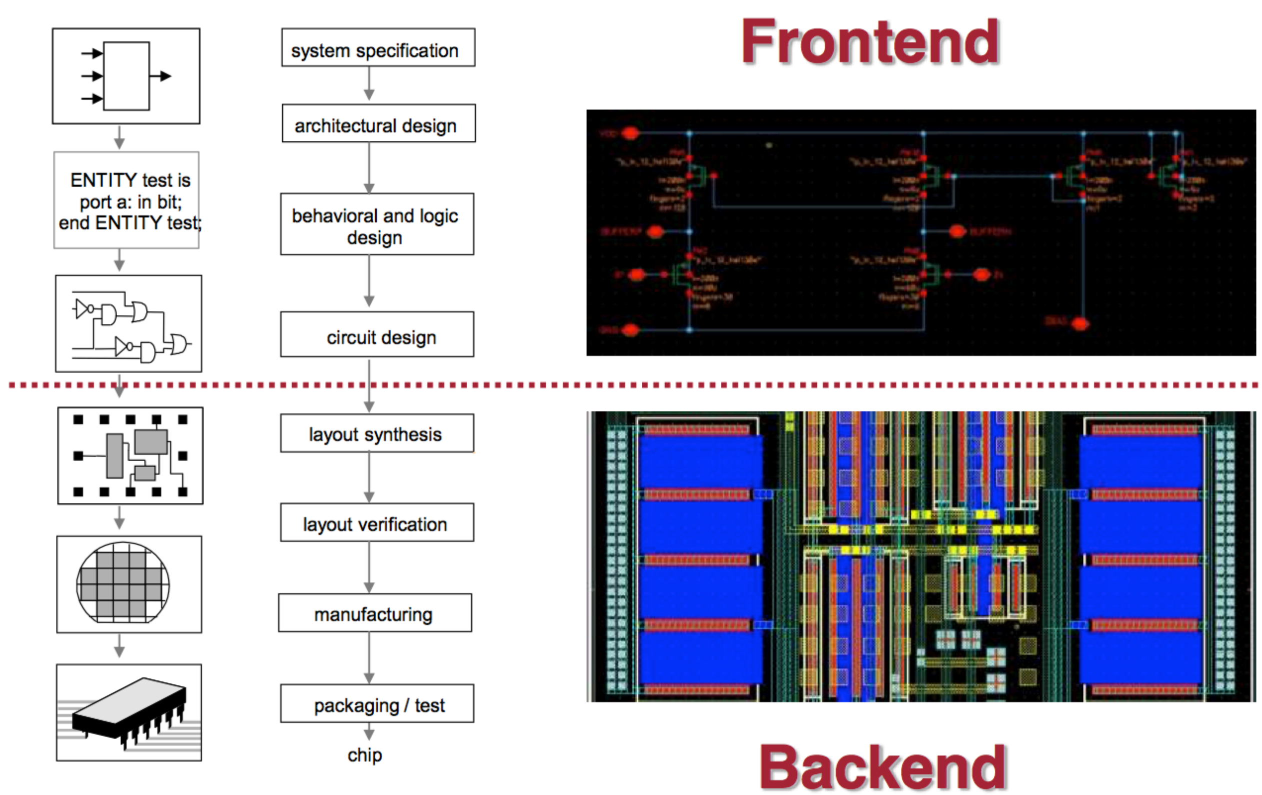


Figure 1.16.: (c) M. Ortmanns, Univ. Ulm.

1.33. Frontend vs. Backend (digital)

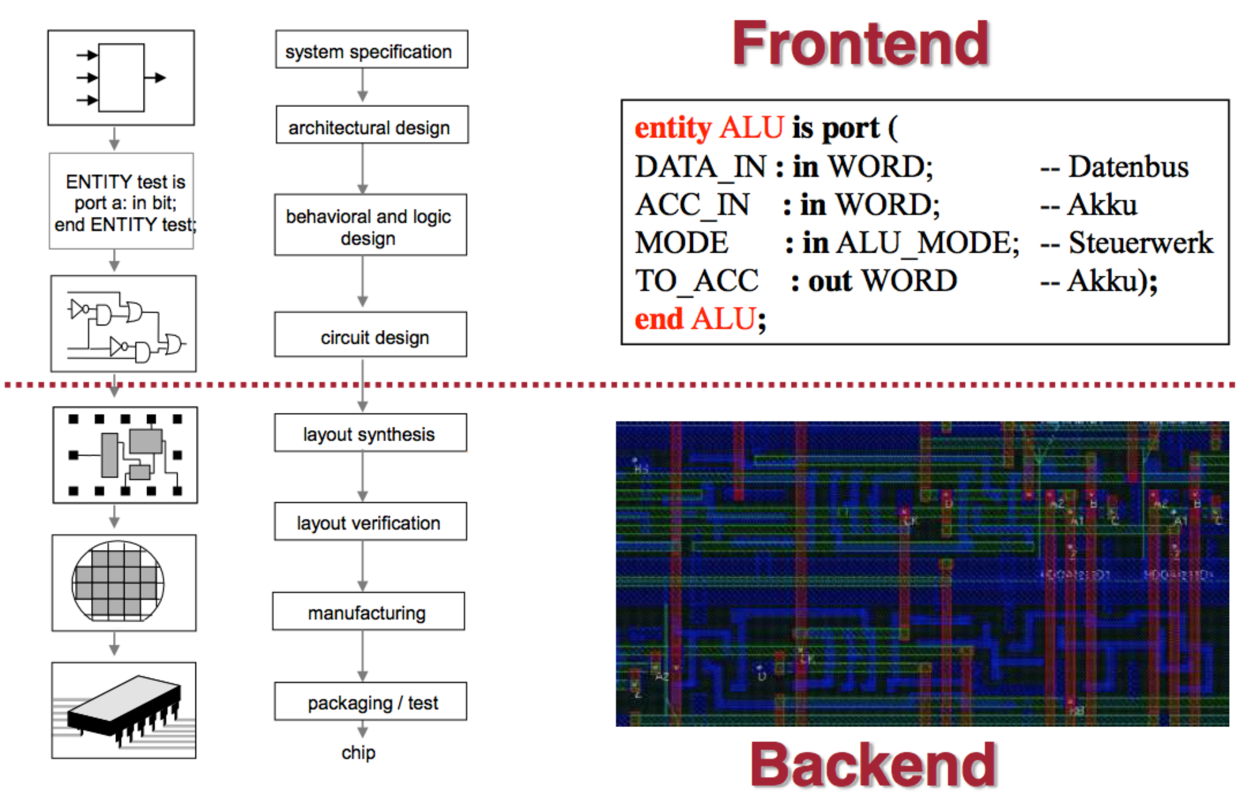
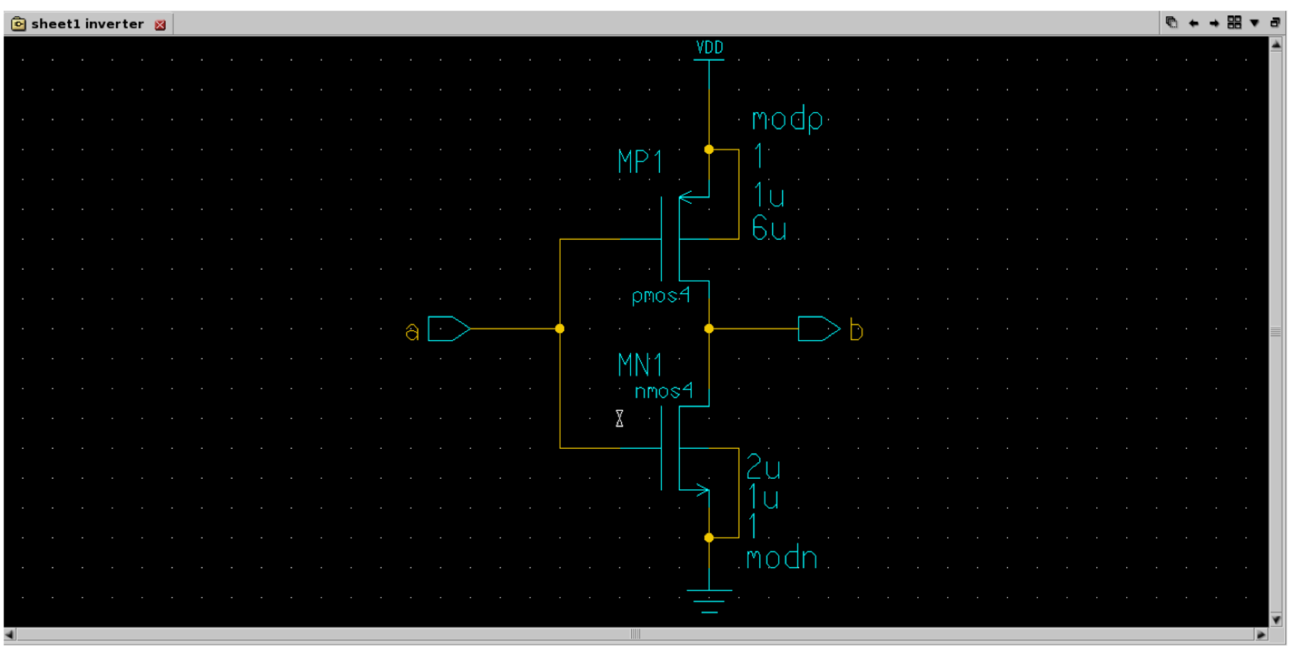
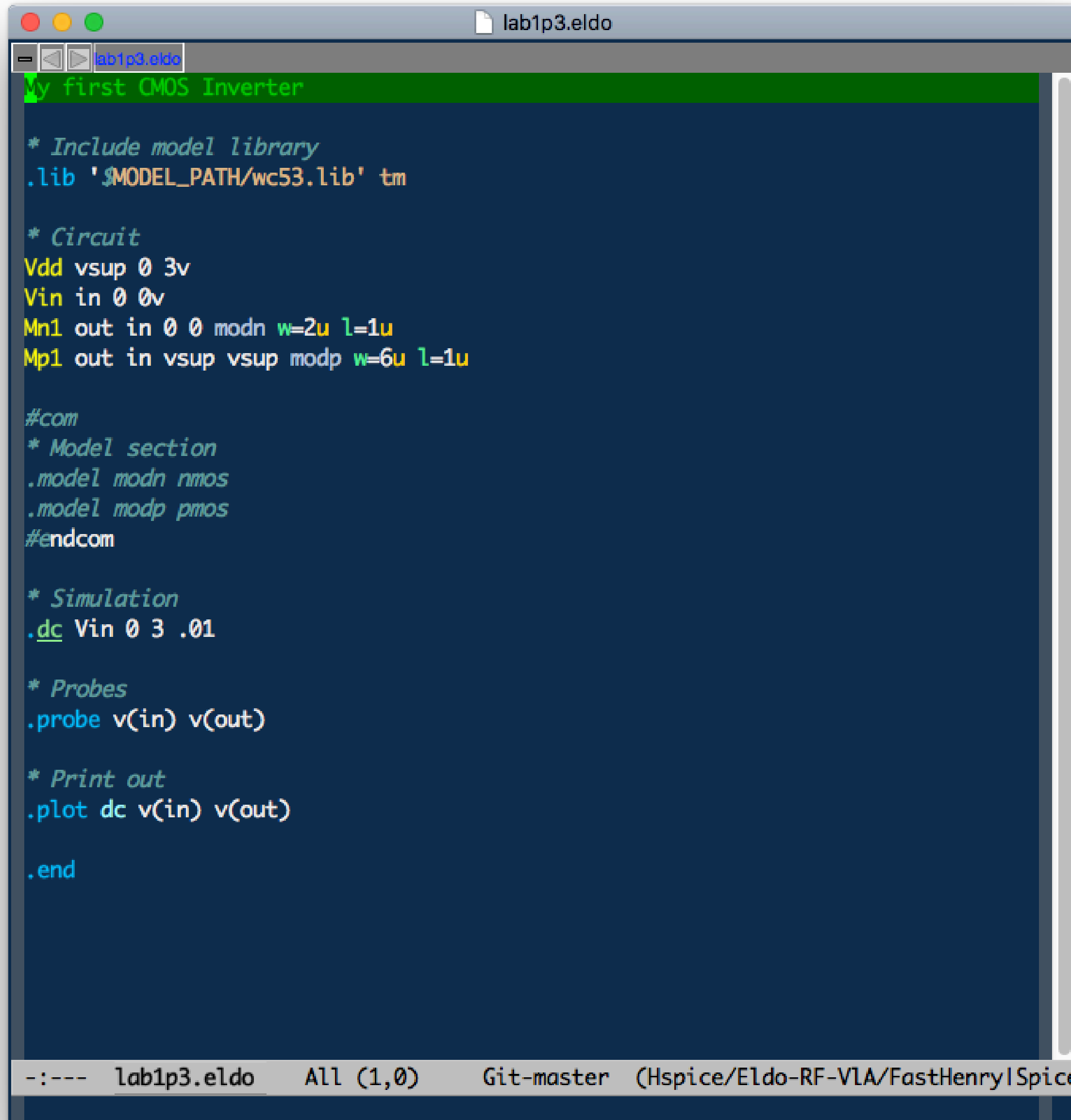


Figure 1.17.: (c) M. Ortmanns, Univ. Ulm.

1.34. Analog Design Entry

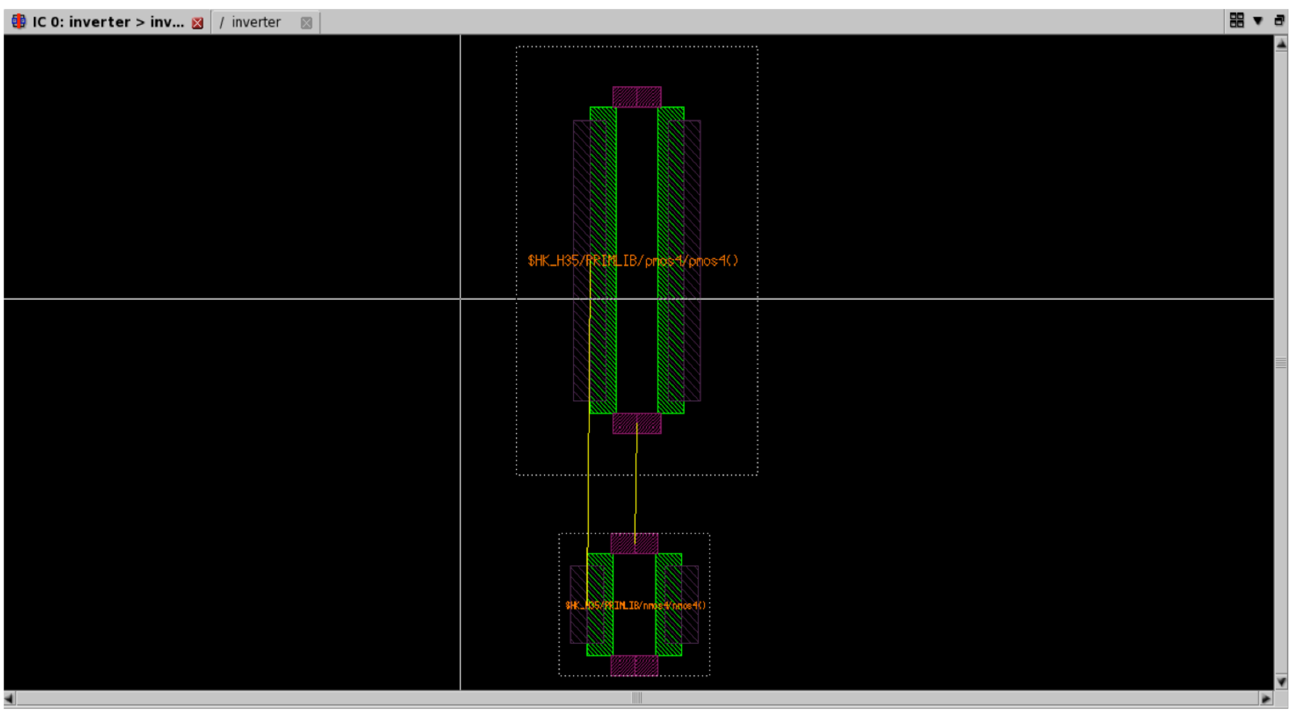


1.35. Netlist

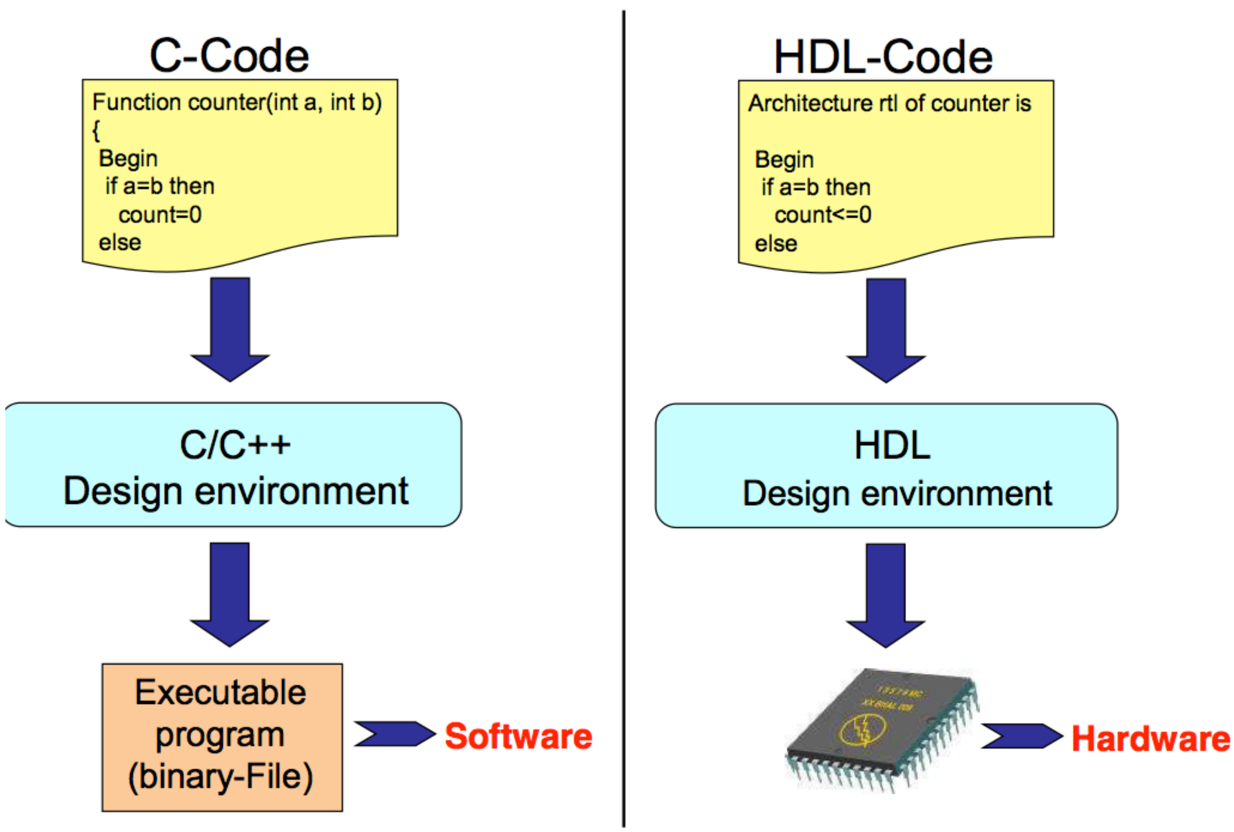


```
My first CMOS Inverter

* Include model library
.lib '$MODEL_PATH/wc53.lib' tm

* Circuit
Vdd vsup 0 3v
Vin in 0 0v
Mn1 out in 0 0 modn w=2u l=1u
Mp1 out in vsup vsup modp w=6u l=1u

#com
* Model section
.model modn nmos
.model modp pmos
#endcom

* Simulation
.dc Vin 0 3 .01

* Probes
.probe v(in) v(out)

* Print out
.plot dc v(in) v(out)

.end
```

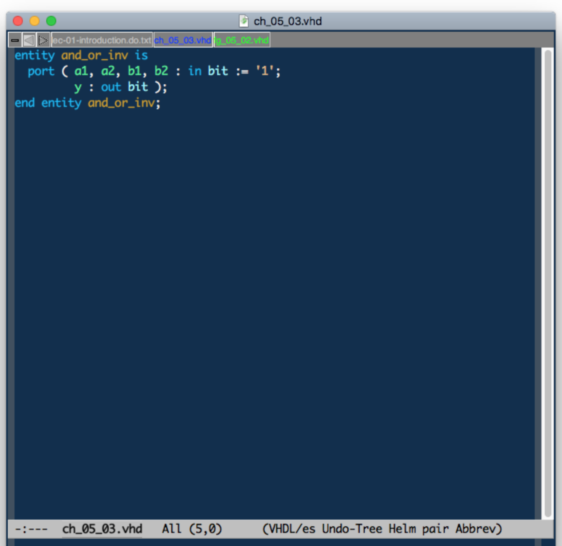
1.36. Layout

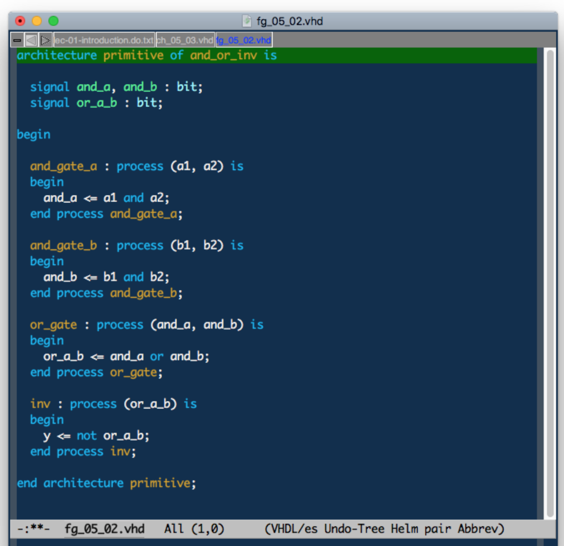


1.37. Digital Design Entry

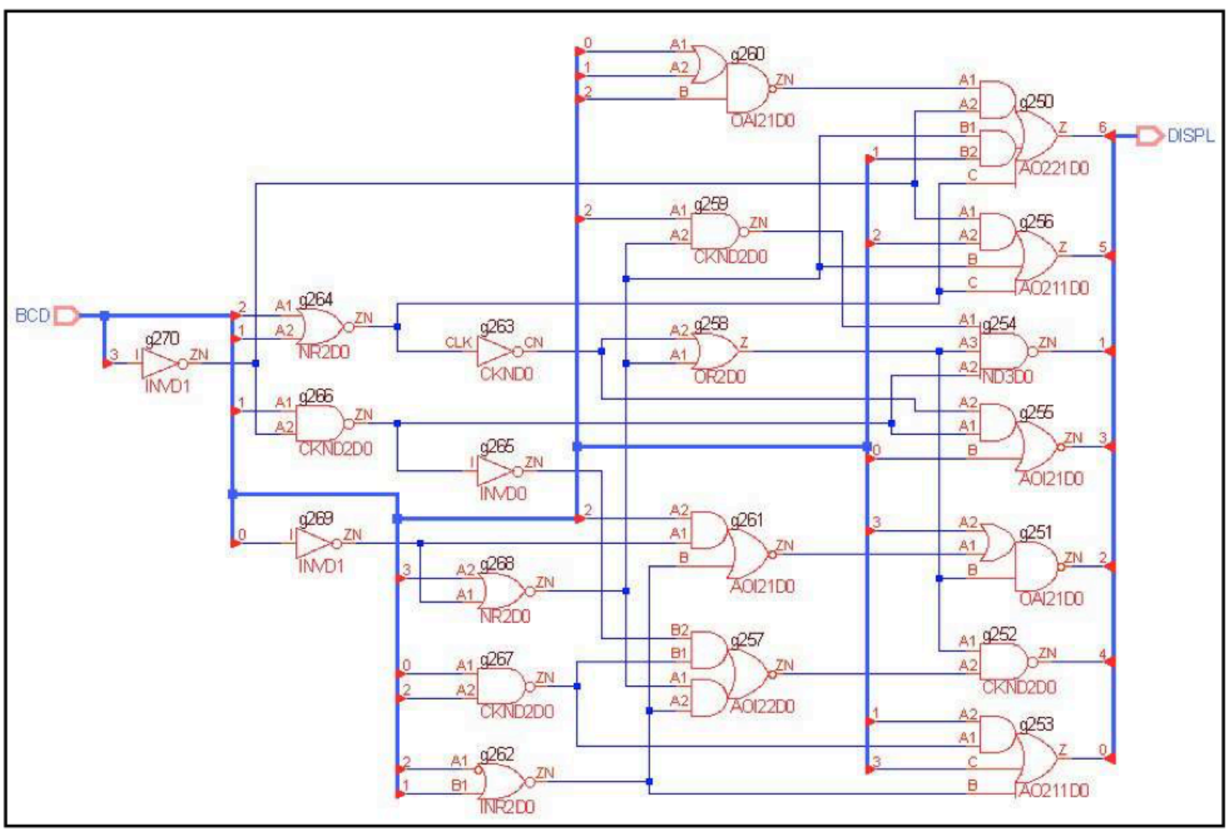


1.38. Hardware Desciption Language

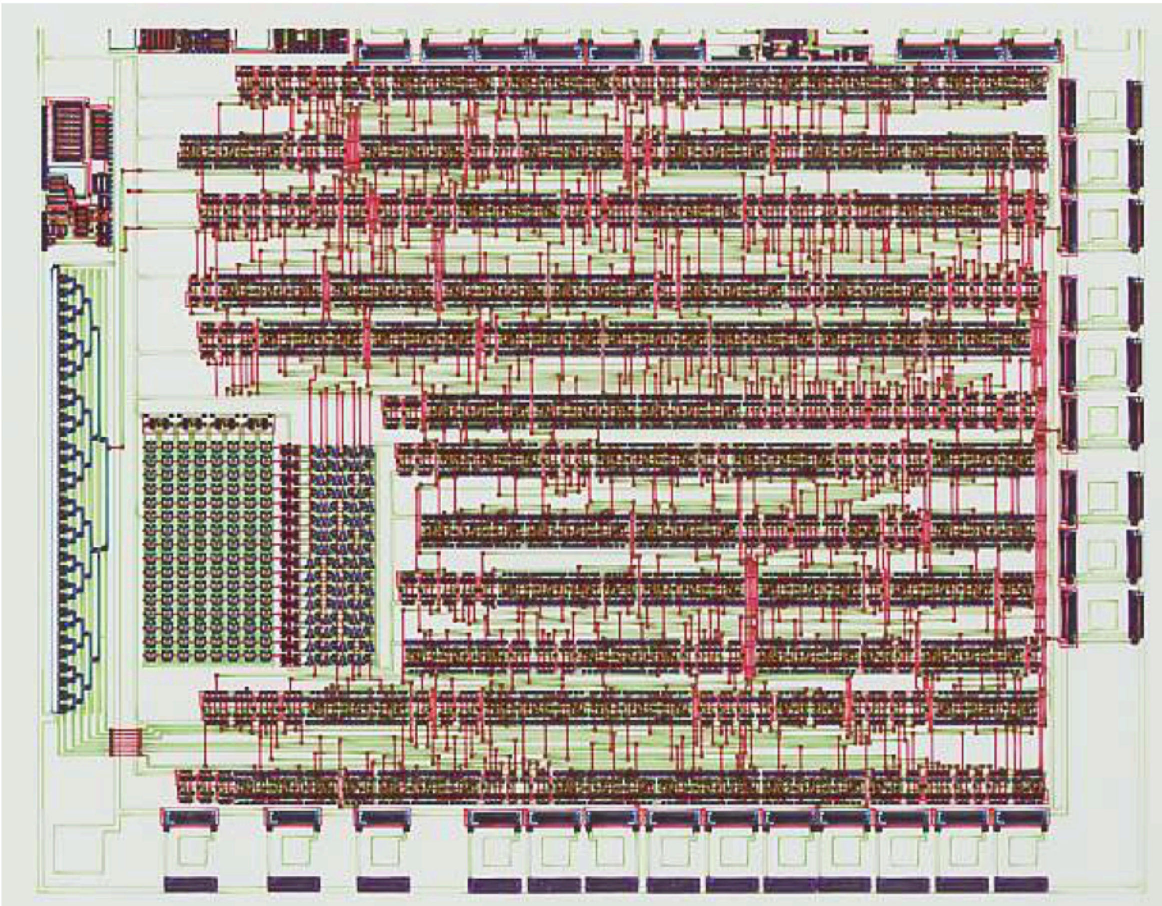




1.39. Technology-Gates and Netlisting



1.40. Standard Cell Layout



1.41. Sustainable Electronics ...

https://www.youtube.com/embed/7S5IuaKiZIY

1.42. Why it is worth ...

https://www.youtube.com/embed/SwPGxwBZw6I

1.43. Let's go to the beach ...

https://www.youtube.com/embed/ekkJlQf-K4I

2. Systems Engineering for Gyros

2.1. Vehicles without ESP

Figure 2.1.: The moose test / elk test.

2.2. Vehicle Dynamics Controls Systems - ESP

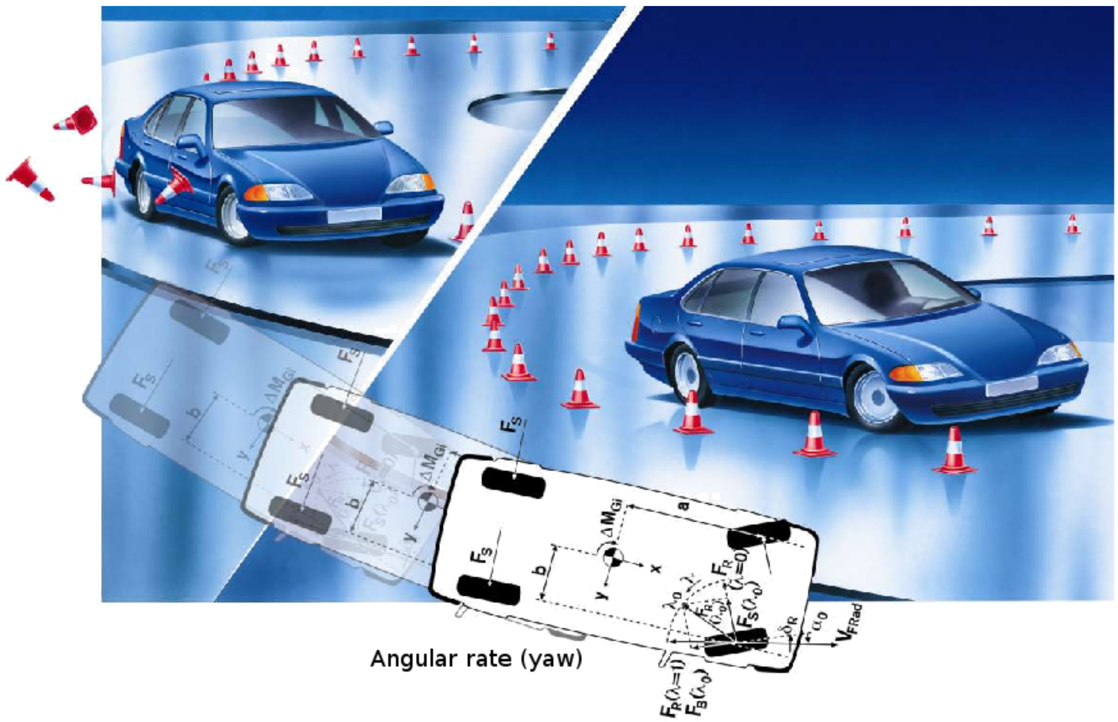


Figure 2.2.: Market launch of gyros.

2.3. Consumer Gyroscopes

Market segments. * Mobile phones * Digital cameras * Pointing devices * Gaming consoles * GPS portables


Newsstand
Notification Center
Messages


SAMSUNG
12:45 PM
Edit
Logs
A-Store
Smart search
Internet
Navigation
My files
Voice
Exchange
System
Backup
Settings
SIM AT
Dialer
Contacts
Menu


500ft
Michigan Ave
airbanks Ct
N St Clair St
:01
Michigan Ave
N Rush St
N Wabash Ave
30
mph
Speed
30mi/h
Menu
Arrival
10:33am
GARMIN nüvi

2.4. MEMS for Automotive and Consumer Applications

- Jiri Marek, Senior Vice President, Robert Bosch, Reutlingen, Germany

https://www.youtube.com/embed/5MKnlsLtK34

2.5. MEMS Gyroscope in Action

../mov/lec-02-mm3drive.mp4

../mov/lec-02-mm3sense.mp4

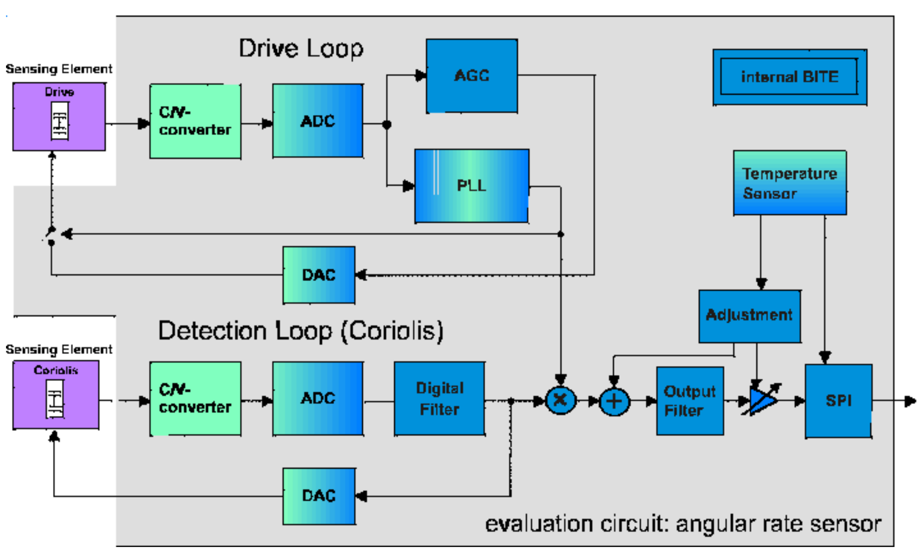
2.6. Spring-Mass-Damping System

- 1-D equation of motion (EoM) $F = m\ddot{x} + d\dot{x} + kx$
- Laplace transformation

$$H(s) = \frac{1}{ms^2 + ds + k} \tag{2.1}$$

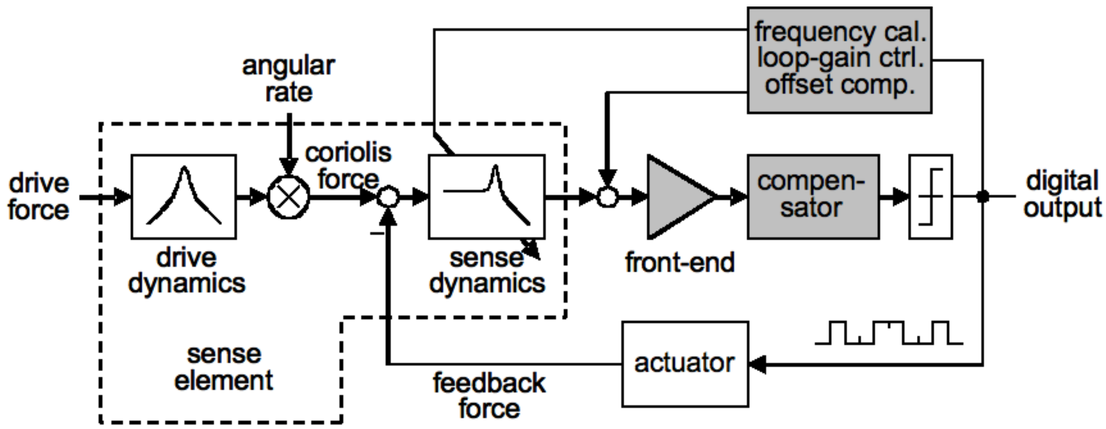
$$= \frac{\frac{1}{m}}{s^2 + \frac{\omega_0}{Q}s + \omega_0^2} \tag{2.2}$$

2.7. Functional Block Diagram



- Coriolis force principle, $F_C = 2m\,(\mathbf{v} \times \Omega)$
- Drive loop to have an accelerated mass
- Sense loop to detect angular rate
- Distinction of closed-loop and open-loop system

2.8. Multi-Domain Readout Block Diagram



$$H_s(s) = \frac{\frac{1}{m}}{s^2 + \frac{\omega_0}{Q}s + \omega_0^2} \qquad \text{sensor} \qquad (2.3)$$

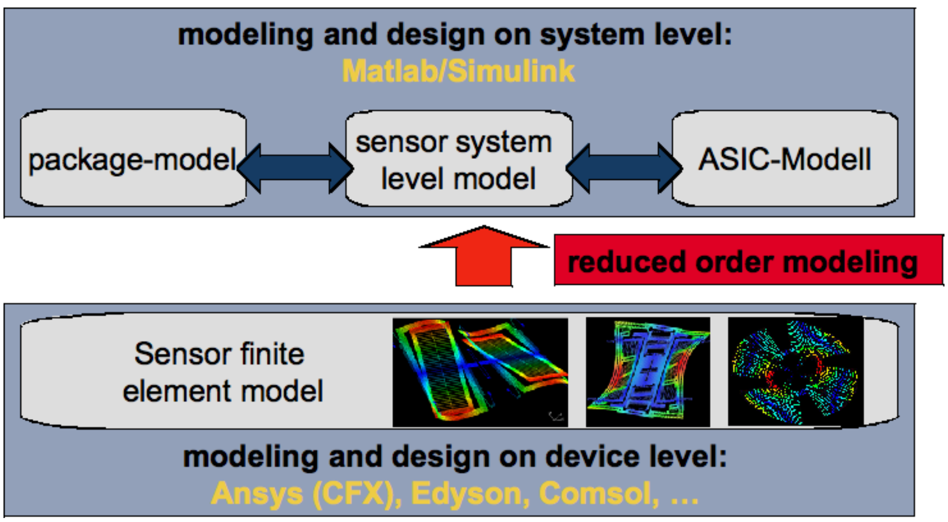
$$H_{CV}(s) = \frac{g_m}{C_L}\frac{1 - e^{-sT_{int}}}{s} \qquad \text{CV converter} \qquad (2.4)$$

$$H_{lf}(z) = -\frac{z}{z+a}\frac{z^2 + b_1 z + b_0}{z^2 + c_1 z + c_0} \qquad \text{loop filter} \qquad (2.5)$$

2.9. Multi-Domain Modelling

- Describing kinematic and electrical behaviour with the help of HDL
  - VHDL, VHDL-AMS
  - Verilog, Verilog-a, Verilog-ams
- Using ROM for a MATLAB/SIMULINK model and real-time workshop to port model for use with Cadence → Verilog-AMS is used for wrapping.
- Parasitic SPICE circuit equivalent from FEM sensor model and layout extraction

2.10. ROM Modelling - Coordinate transformation



$$
\begin{aligned}
M\ddot{x} + Kx &= F \quad \text{FEM, 100.000 DOF} && (2.6)\\
M\phi\ddot{q} + K\phi q &= F && (2.7)\\
\underbrace{\phi' M \phi}\,\ddot{q} + \underbrace{\phi' K \phi}\, q &= \phi' F && (2.8)\\
\tilde{M}\ddot{q} + \tilde{K}q &= \tilde{F} \quad \text{ROM, approx. 10 DOF} && (2.9)
\end{aligned}
$$

2.11. Gyro Behavioural Modelling

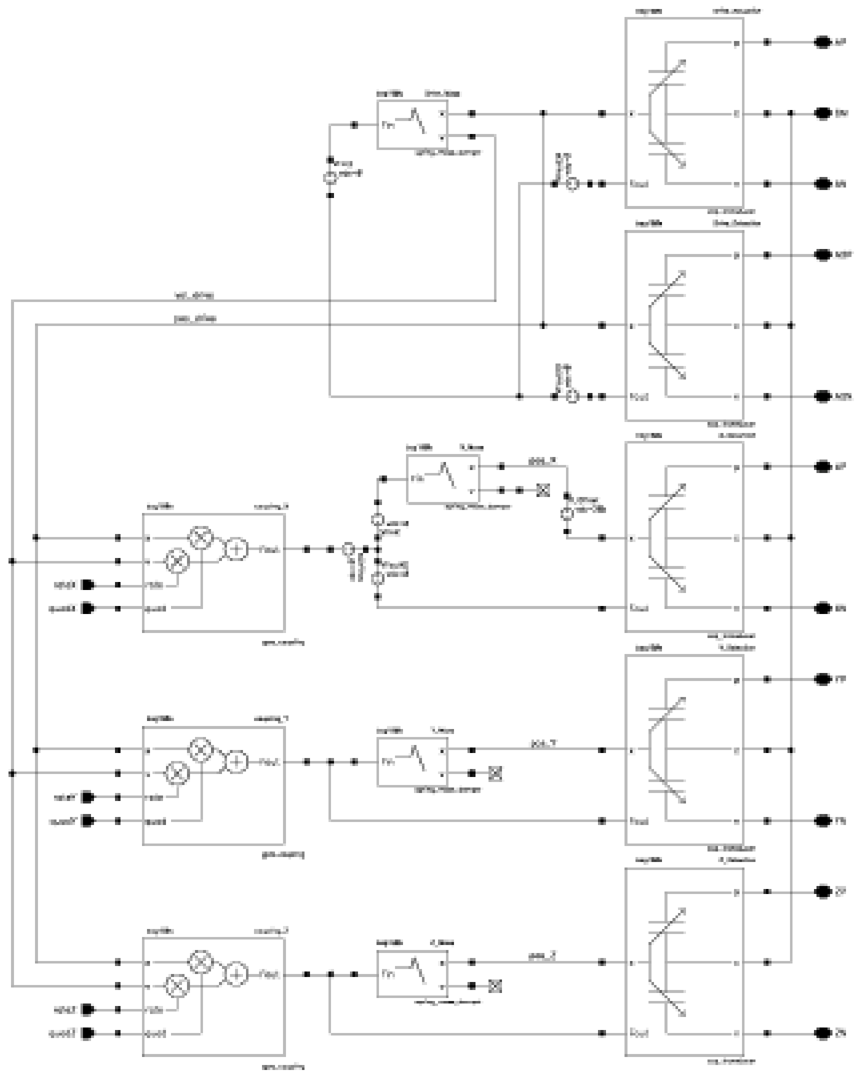


Figure 2.3.: Model of gyroscope.

2.12. Mixed-domain simulation

- All models from previous slide can be used in Cadence design frame work
- Pure analog closed-loop transient simulation with Spectre (turbo, aps), circuits and verilog-a model
- Pure analog closed-loop simulation with SPICE circuit equivalent

- Mixed-domain, mixed-mode simulation with AMSDesigner (ncsim, spectre-turbo/aps)

2.13. Analog Closed-Loop Simulation

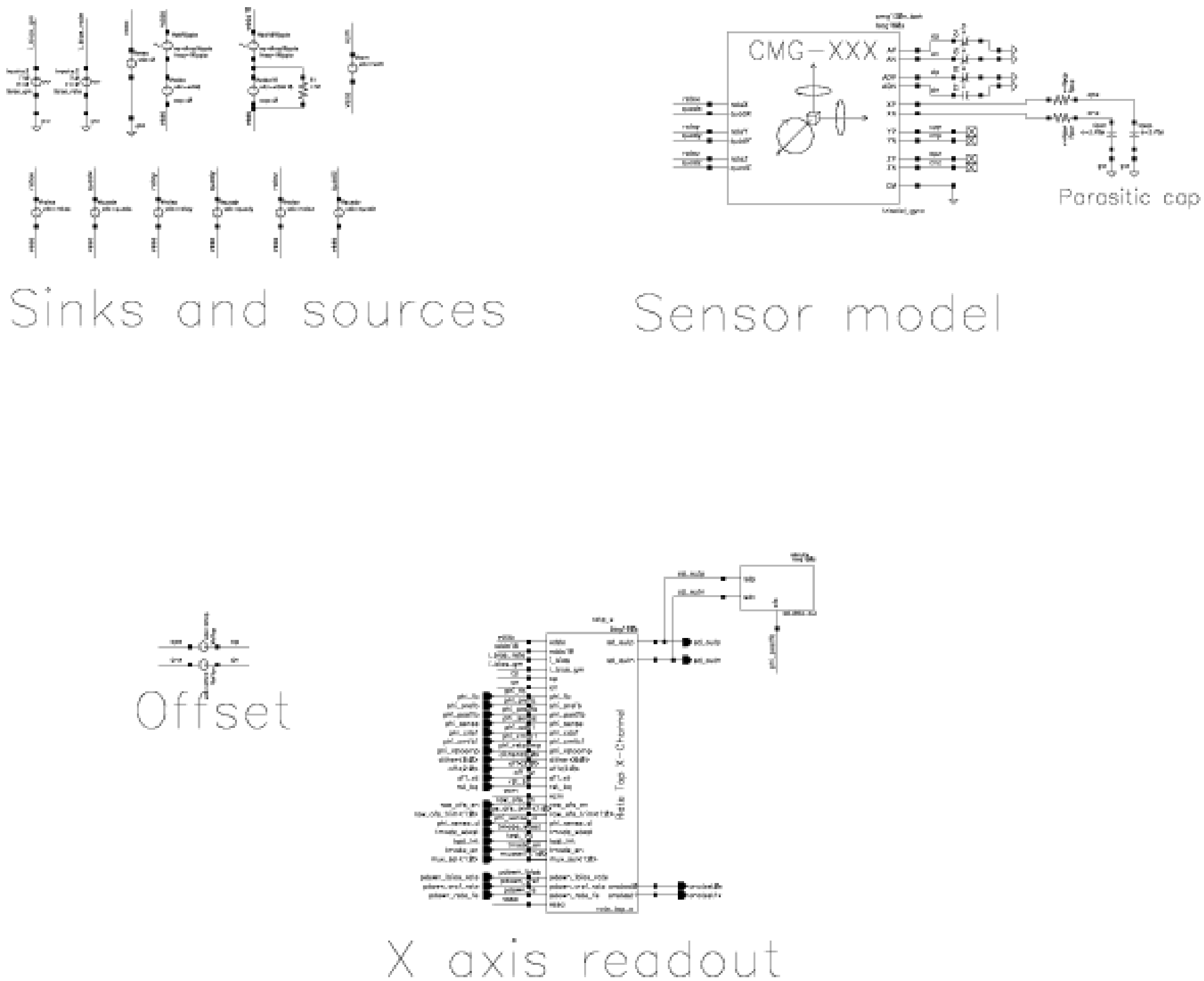


Figure 2.4.: Analog simulation with Cadence.

2.14. AMS Closed-Loop Simulation

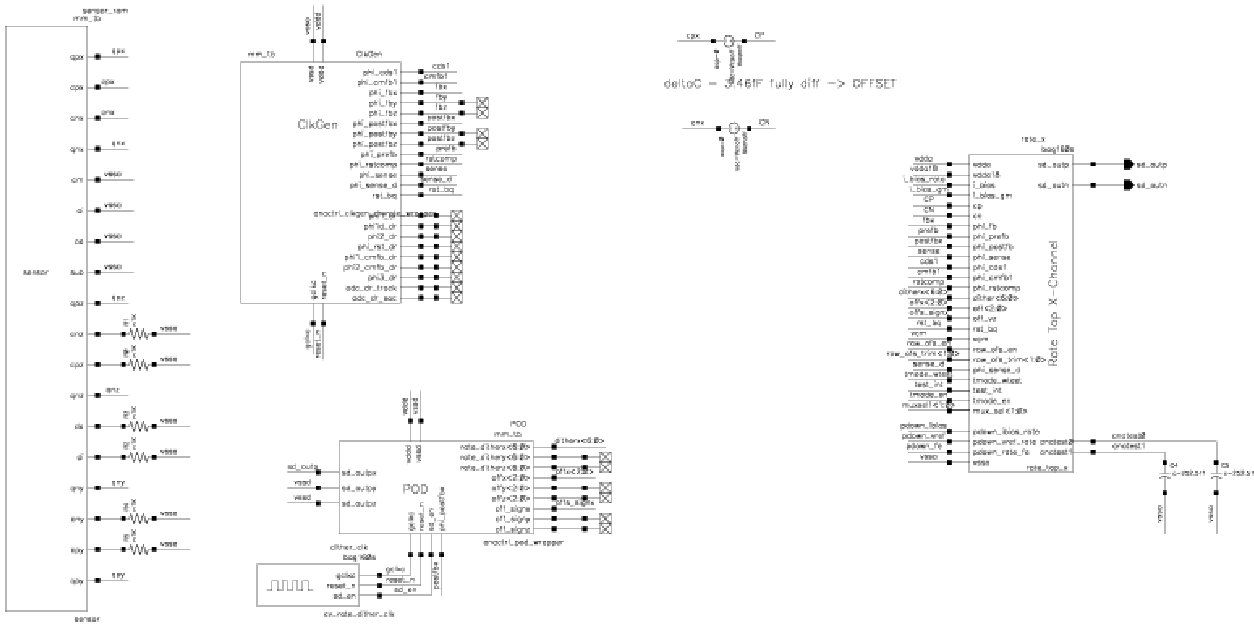


Figure 2.5.: AMS simulation with Cadence.

2.15. Conclusion

Vibratory Gyroscopes.

- Automotive and consumer applications
- System architectures
- Mixed-domain, mixed-mode analysis
- Interdisciplinarity → IC Systems Engineering Control theory, signal theory, process technology and micromechanics

More DOF's.

- Acceleration and angular rate (6 DOF's)
- Angulare rate and magneto sensors (6 DOF's)
- Acceleration, angular and magneto (9 DOF's)

Part II.

Lab

3. MBSE and Design of an Inertial Sensor System

3.1. Design Project

- System level, behavioural model
  - Matlab/Simulink,
  - Python
  - HDL (Verilog-ams, VHDL-AMS)
- Circuit level, SPICE with behavioural blocks, e.g. OTA and comparator
- PCB level
  - ESP8266 NodeMCU,
  - TIs ADS1115,
  - ADs ADXL335
- IC level

3.2. Design Project Flow

- Literature research in journals, professional (serious) internet forums (e.g. application notes of semiconductor companies) and library
- Set-up bibliography, e.g. JabRef, Citavi
- Concept of your system
  - Partitioning
  - Functions
  - Work packages
- Design, implementation and validation
  - Mathmatical description, e.g. Matlab/Simulink model
  - SPICE modeling and simulation, LTspice circuit
  - Data analysis and validation, Serial monitor