PADERBORN UNIVERSITY

FACULTY FOR COMPUTER SCIENCE, ELECTRICAL ENGINEERING AND MATHEMATICS
DEPARTMENT OF ELECTRICAL ENGINEERING AND INFORMATION TECHNOLOGY

MODULE HANDBOOK
MASTER'S PROGRAM COMPUTER ENGINEERING V3 (CEMA V3)

DATE: 8. SEPTEMBER 2026

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1 Preamble and references

For technical reasons, the preamble of the module manual has been moved. It can be found under Examination Regulations and Module Handbooks under the item “Module Handbooks” on the pages of the Institute EIM-E. We kindly ask you to pay attention to this preamble.

If you have any questions regarding this module handbook or the preamble, please contact either.

- to the Examination Board Computer Engineering,
- to the Computer Engineering Student Advisors,
- to the Electrical Engineering Student Advisor, or
- to the PAUL Electrical Engineering Student Services.

Please also note that

1. this module handbook lists all modules provided according to the examination regulations, even if they are not offered in the corresponding semester.
2. this module manual contains the data of the date of creation. All information is without guarantee.

2 Compulsory Area

Compulsory Area	
Modules	* Pflichtmodul Informatik I * Pflichtmodul Informatik I * Pflichtmodul Elektrotechnik I * Pflichtmodul Elektrotechnik II * Projektgruppe * Wissenschaftliches Arbeiten
Catalogue advisor	
Credits ECTS	6
Learning objectives	

Pflichtmodul Informatik I			
Computer Science I			
Module number: M.079.01251	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: beliebig	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05738 Networked Embedded Systems	L3 Ex2	75	105	CE	60/20

2 **Options within the module:**
none

3 **Admission requirements:**

Prerequisites of course Networked Embedded Systems:
Recommended Proficiencies
System software and system-level programming

4 **Contents:**

Contents of the course Networked Embedded Systems:
The objective of this course is gain insights into the operation and programming of embedded systems. A strong focus is on wireless sensor networks. We study the fundamentals of such sensor networks. In the scope of the exercises, we discuss selected topics in more detail.

- Design and architecture of embedded systems - Architecture of embedded systems, programming paradigms
- Sensor networks - Principles and applications
- Wireless communications - Concepts of modulation and encoding on the physical layer
- Wireless access - Typical medium access protocols for low-power sensor nodes
- Routing - Ad hoc routing and data centric communication
- Cooperation and clustering - Clustering algorithms, guaranteed connectivity

5 **Learning outcomes and competences:**

The learning objective is to unserstand the fundamental concepts of networded embedded systems. Students understand these concepts and are able to apply this knowledge.
Non-cognitive Skills

- Commitment
- Learning competence

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 minutes or 40 minutes	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Written exercises		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination was passed.
10	**Weighing for overall grade:** The module is weighted as 6 credits.
11	**Reuse in degree courses or degree course versions :** Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch
12	**Module coordinator:** Dr. Florian Klingler
13	**Other Notes:** *Remarks of course Networked Embedded Systems:* **Implementation method** Lecture with practical exercises **Learning Material, Literature** Slides, textbooks, papers

<table>
<tr><td colspan="5">Pflichtmodul Informatik II</td></tr>
<tr><td colspan="5">Computer Science II</td></tr>
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M.079.01252</td><td>Workload (h):
180</td><td>Credits:
6</td><td>Regular Cycle:
module.frequency.en</td></tr>
<tr><td colspan="2"></td><td>Semester number:
beliebig</td><td>Duration (in sem.):
1</td><td>Teaching Language:
en</td></tr>
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<tr><th></th><th>Course</th><th>form of teachin</th><th>contact-time (h)</th><th>self-study (h)</th><th>status (C/CE)</th><th>group size (TN)</th></tr>
<tr><td>a)</td><td>L.079.05724
Advanced Computer Architecture</td><td>L3
Ex2</td><td>75</td><td>105</td><td>CE</td><td>50/25</td></tr>
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<tr><td>2</td><td colspan="4">Options within the module:
none</td></tr>
<tr><td>3</td><td colspan="4">Admission requirements:
Prerequisites of course Advanced Computer Architecture:
Recommended Proficiencies
Basic knowledge in computer architecture.</td></tr>
<tr><td>4</td><td colspan="4">Contents:
Contents of the course Advanced Computer Architecture:
The course teaches concepts and methods used in modern processor architecture to exploit the available parallelism at the levels of instructions, data and threads.
• Fundamentals of computer architectures (refresher)
• Memory hierarchy design
• Instruction-level parallelism
• Data-level parallelism: Vector, SIMD and GPU architectures
• Thread-level parallelism
• Warehouse-scale computer</td></tr>
</table>

5 **Learning outcomes and competences:**

After attending the course, the students

- are able to explain principles of modern memory hierarchies,
- to analyze different levels of parallelism,
- to assess the suitability of different architectural concepts and thus
- to evaluate modern developments in computer architecture.

Non-cognitive Skills

- Team work
- Learning competence

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 minutes or 40 minutes	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Written exercises		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr. Marco Platzner

13	**Other Notes:** *Remarks of course Advanced Computer Architecture:* **Implementation method** • Lecture with projector and board • Interactive exercises in the lecture room item Computer-based exercises with simulation tools • Analysis of case studies **Learning Material, Literature** • Lecture slides and exercise sheets • Exercise sheets and technical documentation for the for the computer-based exercises • Hennessey, Patterson: Computer Architecture: A Quantitative Approach (5th edition or newer), Morgan Kauf- mann, 2012. • Information about alternative and additional literature as well as teaching material on the course's website and in the lecture slides

Pflichtmodul Elektrotechnik I			
Compulsory Module Electrical Engineering I			
Module number: M.048.45001	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1. Semester	**Duration (in sem.):** 1	**Teaching Language:** de / en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.21004 Statistical Signal Processing	2L 2Ex, WS	60	120	C	60/30
b)	L.048.24014 Statistical Signal Processing	2L 2Ex, WS	60	120	C	40/40

2 **Options within the module:**

1 of 2

3 **Admission requirements:**

None

Prerequisites of course Verarbeitung statistischer Signale:
Recommended: Basic knowledge of statistical signal description as learned in a bachelor's degree program in electrical engineering or related disciplines.

Prerequisites of course Statistical Signal Processing:
Recommended: Undergraduate courses in signal processing and probability

4 **Contents:**

Contents of the course Verarbeitung statistischer Signale:
Short description
With the course Processing of Statistical Signals, students gain an understanding of the importance of descriptive and inferential statistics for many areas of electrical engineering. They consolidate their basic knowledge of probability calculus and statistics and gain an insight into estimation and detection theory, as well as statistical time series analysis. In addition, procedures are presented with the help of which estimated values obtained from data can be evaluated with regard to statistical significance. Knowledge of detection and estimation theory, as well as time series analysis, and critical evaluation of experimental results are essential for understanding and critically applying modern signal processing techniques.
Contents

- Random experiment, axiomatic notion of probability.
- Concept of random variables, distribution function, important distributions of discrete and continuous random variables, random variable transformation.
- Maximum likelihood parameter estimation, linear estimators, quality assessment of estimators, Cramer-Rao bound.
- Bayesian estimation, (L)MMSE estimation, special case Gaussian distribution
- Stochastic processes, stationarity, ergodicity, correlation function and power density spectrum, white noise, Markov chains
- Optimal filter according to Wiener, autoregressive processes
- Maximum-a-Posteriori and Neyman-Pearson decision rule, receiver operating characteristic, statistical hypothesis tests

Contents of the course Statistical Signal Processing:
Short Description
Statistical signal processing comprises the techniques that engineers and statisticians use to draw inference from imperfect and incomplete measurements. This course covers a selection of topics from the major domains of detection, estimation, and time series analysis.
Contents
Topics that may be covered in this course include correlation analysis, linear minimum mean-squared error estimation, performance bounds for parameter estimation, Neyman-Pearson detectors, wide-sense stationary, nonstationary and cyclostationary time series, and complex-valued random signals.

5 **Learning outcomes and competences:**

-

6 **Assessments:**

□Final module exam (MAP) □Module exam (MP) ⊠Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination	120-180 min or 30-45 min	100
b)	Written or Oral Examination	120-180 min or 30-45 min	100

7	**Study Achievement:** none
8	**Prerequisites for participation in examinations:** None
9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch
12	**Module coordinator:** Prof. Dr. Bho Matthiesen

13	**Other Notes:**
	
	Remarks of course Verarbeitung statistischer Signale:
	Course Homepage
	`https://ei.uni-paderborn.de/en/nt/teaching/veranstaltungen/statistical-signal-processing`
	Methodical implementation
	
	• lectures with predominant use of blackboard, occasionally slide presentation
	• Classroom exercises with exercise sheets and demonstrations on the computer
	• Practical exercises with Python, in which students independently develop and implement an experimental setup, and apply statistical analysis methods to the obtained results
	
	Learning materials, references
	Provision of lecture notes, extended chapter by chapter during the course. Provision of exercise problems including sample solutions and example implementations in Python.
	Further literature:
	
	• S. M. Kay, Fundamentals of Statistical Signal Processing — Estimation Theory, Prentice Hall, 1993
	• S. M. Kay, Fundamentals of Statistical Signal Processing — Detection Theory, Prentice Hall, 1998
	• R. G. Gallager, Stochastic Processes — Theory for Applications, Cambridge University Press, 2013
	• R. L. Schilling, Wahrscheinlichkeit — Stochastik von Abweichungen bis Zufall, De Gruyter, 2025
	• N. Henze, Stochastik für Einsteiger, 11th edition, Springer Spektrum, 2017
	• E. Hänsler, Statistische Signale — Grundlagen und Anwendungen, 3rd edition, Springer, 2001
	• J. L. Melsa, D. L. Cohn, Decision and Estimation Theory, McGraw-Hill, Kogakusha, 1987
	• A. Papoulis, Probability, Random Variables, and Stochastic Processes, 2nd edition, McGraw-Hill, New York, 1984
	
	Remarks of course Statistical Signal Processing:
	Course Homepage
	`http://sst.upb.de/teaching`
	Implementation
	Lectures and tutorials
	Teaching Material, Literature
	Literature references are given in the first lecture.

Pflichtmodul Elektrotechnik II

Compulsory Module Electrical Engineering II

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.048.45002	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	1. Semester	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.90100 Circuit and Systems Design	2L 2Ex, WS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Circuit and Systems Design:
Recommended:
Good knowledge in differential equations, Laplace transform, Fourier transform, electrical network analysis (Kirchhoff's laws, Norton equivalent, Thevenin equivalent, transfer functions, Bode diagram etc.), semiconductor device physics (band diagram, conduction mechanisms in semiconductors, minority and majority charge carriers, n-type, p-type semiconductor, physics of pn junction, physics of MOS capacitance), semiconductor devices (physical operation and device equations of pn-diode, MOS transistor, and bipolar transistor), basic digital design (boolean algebra, truth tables, combinational logic)

4 **Contents:**

Contents of the course Circuit and Systems Design:
Short Description
The lecture gives an introduction to analysis and design of analog and digital circuits and systems. It builds on basic knowledge of electron devices (bachelor-level) and the compulsory lectures “Advanced System Theory” and “Modeling and Simulation”. The lecture presents a modern approach for analysis and design of electronic circuits and system which combines mathematical analysis and circuit simulation.
Contents

- Nonlinear, large-signal modeling of pn diode, bipolar junction transistor (BJT), and MOS transistor
- Nonlinear, large-signal analysis of circuits with diodes, BJTs, MOS transistors
- Linear modeling and one-/two-port representations of diodes, transistors, and amplifiers
- Linear small-signal analysis of BJT and MOS transistor amplifiers
- Single-transistor amplifier analysis
- Differential amplifier analysis
- Modeling and analysis of operational amplifier circuits
- CMOS logic
- Analysis and design of combinational logic circuits
- Analysis and design of sequential logic circuits
- Application examples

5 **Learning outcomes and competences:**

Domain competence:
The students will be able to

- describe appropriate methods for analysis and design of analog systems
- describe appropriate methods for analysis and design of digital systems
- assess the limitations of the different methods
- understand and calculate the behaviour of simple analog and digital circuits
- use a numeric simulation tool for electronic systems and circuit simulation
- describe typical components and subsystems

Key qualifications:
The lecture conveys an understanding of the interaction of different modeling techniques, mathematical analysis approaches, and numerical simulation, as well as how to apply these effectively to the design of electronic systems. The methods for analog electronic design are transferrable to the design of continuous-time, continuous-amplitude systems. The methods for digital design are transferrable to the design of discrete-time, discrete-amplitude systems.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	90-150 min or 20-30 min or 30-60 min	100%

7	**Study Achievement:** none
8	**Prerequisites for participation in examinations:** None
9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch
12	**Module coordinator:** Prof. Dr.-Ing. J. Christoph Scheytt
13	**Other Notes:** *Remarks of course Circuit and Systems Design:* **Course Homepage** `https://www.hni.uni-paderborn.de/en/system-and-circuit-technology/teaching/circuit-and-system-design/` **Implementation** • Lecture with Powerpoint presentation and handwritten mathematical derivations using tablet and beamer • One part of the exercises as handwritten calculation exercises using tablet and beamer • Other part of exercises as practical design tasks using using LTspice simulation **Teaching Material, Literature** Lecture slides and videos; Exercise slides. Additional literature references will be given in the first lecture • Richard C. Jaeger, Travis N. Blalock, “Microelectronic Circuit Design”, McGraw Hill, 4th edition, 2010 • Neil H. E. Weste, David Money Harris, “CMOS VLSI Design”, Addison Wesley, 4th edition, 2010

Projektgruppe			
Project Group			
Module number: M.079.01254	**Workload (h):** 540	**Credits:** 18	**Regular Cycle:** module.frequency.en
	Semester number: 2-3	**Duration (in sem.):** 2	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	Project Group	PG	240	360	C	15

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Projektgruppe:
Recommended Proficiencies
Depending on the topic.

4 **Contents:**

Contents of the course Projektgruppe:
In a project group a group of usually 8-16 students works together over a period of one year (two semesters) on a research topic determined by the group organizer. Project groups introduce students to current research topics that are usually related to the group organizer's special area of interest and the team working of the project group should be a preparation for industrial practice. Topics of project groups cover the whole range of research interests of the research groups in the Department of Computer Science.

5 **Learning outcomes and competences:**

In project groups, participating students gain first-hand practical experience in working in a team and organizing a project; in doing so, they become prepared for daily work in their later professions. The students personally experience how to carry out extensive development processes in a team. Since the tasks are divided among the individual team members, the participating students become skilled in reporting their progress and research findings to the other group members.
Non-cognitive Skills

- Commitment
- Team work
- Learning competence
- Learning motivation
- Motivation
- Literacy (scientific)
- Self-monitoring

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Partial Module Exam		100%

In the Project Group module, the successful completion of projects must be demonstrated by submitting software and documentation as a phase-related examination. A grade is awarded for the entirety of the projects worked on.
The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Practical work		CA

8 **Prerequisites for participation in examinations:**

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 9 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr. Marco Platzner

13	**Other Notes:** *Remarks of course Projektgruppe:* **Implementation method** • The number of participants is limited to 16 people. • Developing knowledge on the selected systematic approaches, methods and tools relevant to the research topic- usually done in an introductory seminar phase. • Logical assigning "jobs" (assigning responsibilities to the individual group members). • Discovering and promoting the participants' special individual talents, which are either already apparent or which can be developed throughout the project - such as through seminar presentations or appropriate job assignments. • Setting up a process-oriented personnel structure, similar to the structure of an industrial design team; delegating subtasks to smaller subgroups who report their findings. • Regular progress reports made by individuals and subgroups. • Writing a highly distributed interim report and final report. **Learning Material, Literature** Depending on the topic.

Wissenschaftliches Arbeiten			
Scientific Work Style			
Module number: M.048.42941	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 2. Semester	**Duration (in sem.):** 1	**Teaching Language:** de

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.90801 Languages, Writing and Presentation Techniques		30	30	C	15
b)	Seminar (CE)	S2	30	90	C	15

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Sprachen, Schreib- und Präsentationstechnik:
None

Prerequisites of course Seminar (CE):
Recommended Proficiencies
Depending on the seminar topic.

4 **Contents:**

Contents of the course Sprachen, Schreib- und Präsentationstechnik:
Depending on their previous knowledge and interest, students choose a course from the range of courses offered by the University of Paderborn in the field of modern languages, scientific writing or presenting scientific topics.

Contents of the course Seminar (CE):
A seminar is intended for in-depth, independent familiarization with a complex scientific issue, the necessary literature research, and the presentation of the results in spoken and written form. It also helps to familiarize students with the essential mechanisms of the scientific community (conferences, reviewing principles, . . .). Seminars are offered by all lecturers; topics change from semester to semester and originate from the research area of the respective lecturer.

5 **Learning outcomes and competences:**

The goal of this module is to enable students to autonomously familiarize themselves with complex technical and scientifc material and to effectively and efficiently communicate such material in speech and writing. To this end, the module comprises a seminar on scientific topics from computer engineering and an elective class on language, technical writing, presentation techniques, etc.

- Commitment and dedication
- Cooperation competence
- learning competence
- media competence
- Writing and reading competence (scientific)

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a) - b)	Presentation	30 min	100%

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)			QP
b)			

Qualified participation in the course a)of the module according to § 39 Special Regulations. Details on the form and scope or duration will be announced by the instructor within the first three weeks of the lecture period at the latest.

8 **Prerequisites for participation in examinations:**

None

9 **Prerequisites for assigning credits:**

The credit points are awarded after passing the module examination (MAP) and providing proof of the qualified participation.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch

12 **Module coordinator:**

Prof. Dr.-Ing. Katrin Temmen

13	**Other Notes:** *Remarks of course Sprachen, Schreib- und Präsentationstechnik:* Registration Note: For the course “Languages, Writing and Presentation Techniques”, please proceed as follows for pragmatic reasons: Select a course from the overall university course program matching the conditions specified in the module handbook, obtain a written confirmation of your successful participation and pass this proof on to me (letterbox next to room P1.6.09.2 or pdf-file to Katrin.Temmen@upb.de) before start of • Winter semester: by 31 March or • Summer semester: by 30 September. I will then have this registered in PAUL. Please ensure that besides your matriculation number the respective module (Bachelor v2: L.048.90802 / M.079.0116; Bachelor v3 & v3b: L.048.90802 / M.079.01209; Master v3: L.048.90801 / M.048.42941) is also mentioned on the proof of registration. Katrin Temmen *Remarks of course Seminar (CE):* **Implementation method** Seminars are based on a list of given topics from which students can make a selection. After a topic is assigned, there are usually a few appointments to discuss literature research, literature selection, presentation technique, technical writing, etc. At the same time, students begin the literature search. In constant interaction with the supervisor and the other seminar participants, a seminar paper and a presentation are developed through some milestones, which are then presented to the group and discussed. **Learning Material, Literature** Scientific publications.

3 Specialisation Area

3.1 Specialisation Area “Communication and Networks”

Specialisation Area	Communication and Networks
Modules	* Advanced Distributed Algorithms and Data Structures * Foundations of Cryptography * Integrierte Schaltungen für die drahtlose Kommunikation * Information Theory * Machine Learning I * Modern Semiconductor Lasers * Optical Communication A * Optical Communication B * Optical Communication C * Optimale und Adaptive Filter * Optoelectronics * Real World Crypto Engineering * Routing and Data Management in Networks * Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation * Theory and Design of Integrated Photonic Devices * Theory and Design of Phase-locked Loops * Topics in Signal Processing * Web Security
Catalogue advisor	Head of Examination Board CE (PAV CE)
Credits ECTS	6
Learning objectives	

The modules from this specialisation area enable specialisation in the field of communication and networks.

Advanced Distributed Algorithms and Data Structures

Advanced Distributed Algorithms and Data Structures

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.01256	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	beliebig	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05700 Advanced Distributed Algorithms and Data Structures	L3 Ex2	75	105	C	30

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Advanced Distributed Algorithms and Data Structures:
Recommended Proficiencies
Algorithms and data structures, distributed algorithms and data structures

4 **Contents:**

Contents of the course Advanced Distributed Algorithms and Data Structures:
The lecture will cover advanced topics in distributed algorithms and data structures. Topics covered in the course are access control, synchronization, consensus, information dissemination, hybrid networks, scheduling, and optimization. In addition to presenting solutions to these topics, also concrete applications will be presented.

5 **Learning outcomes and competences:**

Students get to know advanced methods and algorithms for currently very relevant distributed systems. They are able to adapt algorithms to new situations and to determine their complexity. They can implement basic distributed algorithms.
Non-cognitive Skills

- Team work
- Learning competence
- Literacy (scientific)
- Self-monitoring

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 minutes or 40 minutes	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Written exercises		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr. Christian Scheideler

13 **Other Notes:**

Remarks of course Advanced Distributed Algorithms and Data Structures:
Implementation method
Lecture with tutorials and software project
Learning Material, Literature
Lectures notes

Foundations of Cryptography

Foundations of Cryptography

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.01262	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	beliebig	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05801 Foundations of Cryptography	L3 Ex2	75	105	C	25

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Foundations of Cryptography:
Recommended Proficiencies
Basic Knowledge in IT-Security and cryptography useful but not necessary, basic concepts of complexity theory and probability theory

4 **Contents:**

Contents of the course Foundations of Cryptography:
The most important primitives of modern cryptography will be presented. These include encryption schemes, digital signatures, identification protocols, and multiparty computations. In each case we will define precise security notions. Starting from precisely stated assumptions, we develop constructions that provably satisfy these security definitions.

- Symmetric and asymmetric encryption schemes
- Pseudorandom generators, one-way functions, trapdoor permutations
- Hashfunctions and message authentication codes
- Digital signatures, one-time signatures, random oracles
- Identification protocols, Σ protocols
- Secure multiparty computation

5 **Learning outcomes and competences:**

Students understand fundamental concepts and methods of modern cryptography. They are able to choose appropriate cryptographic tools for various security problems. Students are able to combine and modify basic cryptographic primitives, they are able to define new security concepts, they are able to the the security of new constructions with respect to the security concepts.
Non-cognitive Skills

- Commitment
- Team work
- Learning motivation
- Literacy (scientific)
- Self-monitoring

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 minutes or 40 minutes	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Written exercises		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr. Johannes Blömer

13	**Other Notes:** *Remarks of course Foundations of Cryptography:* **Implementation method** Lectures, exercises, reading groups **Learning Material, Literature** • Oded Gorldreich, Foundations of Cryptography I,II, • Jonathan Katz, Yehuda Lindell, Introduction to Modern Cryptogtraphy • Slides from the lectures

Integrierte Schaltungen für die drahtlose Kommunikation

Integrated Circuits for Wireless Communications

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.048.25017	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	1.-3. Semester	1	de / en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.25017 Integrated Circuits for Wireless Communications	2L 2Ex, SS	60	120	C	40/40

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Integrierte Schaltungen für die drahtlose Kommunikation:
Recommended: Lecture Schaltungstechnik rsp. Circuit and System Design. Helpful supplement: Lecture “Wireless Communications” of Prof. Hab-Umbach.

4 **Contents:**

Contents of the course Integrierte Schaltungen für die drahtlose Kommunikation:
Short Description
Mobile communications, wireless networks, and RFID technology are application examples of wireless communications. Wireless communications has found widespread use in everyday life and will become even more important in the future. The design of electronic circuits for radio frequencies requires a good system knowledge with respect to typical transmitter and receiver architectures in wireless communications, components, and radio signal properties. Furthermore a thorough understanding of integrated circuit design as well as precise high-frequency modeling of passive and active devices are required. Goal of the lecture is to convey a methodical approach to the design of integrated circuits for wireless communications. A part of the exercises will pertain to calculation of circuit design problems another will be performed in small teams as a hands-on exercise using modern IC design software.
Contents
The lecture deals with analysis and design of radio frequency integrated circuits for wireless communication systems. A part of the exercises will be performed using modern chip design CAD tools. The lecture is based on the compulsory lectures “Schaltungstechnik” rsp. “Circuit and System Design”. The following topics will be addressed:

- Transmitter and receiver architectures for wireless communications
- System Theory Basics
  - Signals and noise
  - Modulation and demodulation
  - Transmission properties of wireless communcations systems
- Semiconductor technologies and integrated high-frequency devices
- Amplifiers (low-noise and variable-gain amplifiers)
- Mixers
- Oscillators
- Frequency synthesizer PLLs

5 **Learning outcomes and competences:**

The students will be able

- to describe architectures and circuits of wireless communication systems
- to describe and calculate fundamental signal transmission properties of wireless systems
- to apply design methods to design components of radio frequency ICs

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Oral Examination	30-45 min	100%

7 **Study Achievement:**

none

8	**Prerequisites for participation in examinations:** None
9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4
12	**Module coordinator:** Prof. Dr.-Ing. J. Christoph Scheytt
13	**Other Notes:** *Remarks of course Integrierte Schaltungen für die drahtlose Kommunikation:* **Course Homepage** `https://www.hni.uni-paderborn.de/en/system-and-circuit-technology/teaching/integrierte-schaltungen-fuer-die-drahtlose-kommunikation/` **Implementation** • Lecture with Powerpoint presentation and handwritten mathematical derivations using tablet and beamer • Exercises partly as handwritten calculation exercises using tablet and beamer and partly as practical IC design exercises using IC design software **Teaching Material, Literature** Lecture slides and videos as well as exercise slides will be made available. • Behzad Razavi “RF Microelectronics”, Prentice Hall, 2011 • Thomas Lee “The Design of CMOS Radio-Frequency Integrated Circuits”, Cambridge University Press 2003

<table>
<tr><th colspan="8">Information Theory</th></tr>
<tr><td colspan="8">Information Theory</td></tr>
<tr><td colspan="2">Module number:
M.048.24021</td><td>Workload (h):
180</td><td colspan="2">Credits:
6</td><td colspan="3">Regular Cycle:
module.frequency.en</td></tr>
<tr><td colspan="2"></td><td>Semester number:
2.-4. Semester</td><td colspan="2">Duration (in sem.):
1</td><td colspan="3">Teaching Language:
en</td></tr>
<tr><td>1</td><td colspan="7">Module structure:
<table>
<tr><th></th><th>Course</th><th>form of teachin</th><th>contact-time (h)</th><th>self-study (h)</th><th>status (C/CE)</th><th>group size (TN)</th></tr>
<tr><td>a)</td><td>L.048.24021
Information Theory</td><td>2L
2Ex,
SS</td><td>60</td><td>120</td><td>CE</td><td>30/30</td></tr>
</table></td></tr>
<tr><td>2</td><td colspan="7">Options within the module:
None</td></tr>
<tr><td>3</td><td colspan="7">Admission requirements:
None

Prerequisites of course Information Theory:
**Recommended:*
Prior knowledge from the modules Signal and Information Transmission, and Probability for Engineers.</td></tr>
<tr><td>4</td><td colspan="7">Contents:

Contents of the course Information Theory:
Information theory is the mathematical foundation of modern communication, data compression, and statistical inference. Originally developed by Claude Shannon, information theory quantifies information, uncertainty, and the fundamental limits of data transmission and storage.
This course provides a first rigorous introduction to information theory. Students will learn the core concepts of entropy, mutual information, relative entropy, and typicality, and understand their operational meaning in compression and communication systems. The course covers lossless and lossy source coding, channel capacity, and the fundamental limits of reliable communication over noisy channels. Classical results such as Shannon’s source coding theorem and channel coding theorem are derived from first principles. Strong emphasis will be placed on an intuitive understanding of mathematical concepts and the practical interpretation of these results in the context of real-world systems.
Beyond communication systems, the course highlights connections to machine learning, statistics, signal processing, and networked systems.</td></tr>
</table>

5 **Learning outcomes and competences:**

Domain competence:
After completion of the course students will be able to

- explain fundamental questions, models, tools, and results of Shannon's information theory;
- apply information-theoretic measures to assess the quality processing blocks of communication systems and explain the operational meaning;
- explain the relationship between abstract communication-theoretic models and realistic physical systems and apply them purposefully in system design;
- understand scientific documents in information theory.

Key qualifications:
The students

- can abstract complex problems and decompose them into solvable subproblems;
- are able to understand and apply mathematics as a universal language for describing the physical world;
- can transfer information-theoretic concepts and results to problems beyond the field of communications engineering.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11 **Reuse in degree courses or degree course versions :**

BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4, Master's Program Electrical Systems Engineering v3 (ESEMA v3)

12	**Module coordinator:** Prof. Dr. Bho Matthiesen
13	**Other Notes:** **Module Homepage** `https://www.hni.uni-paderborn.de/en/nt` **Implementation** Lectures and exercises (including some computer simulations) **Teaching Material, Literature** Handouts and tutorial questions; literature references will be given in the first lecture

Machine Learning I

Machine Learning I

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.01274	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	beliebig	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05701 Machine Learning 1	L3 Ex2	75	105	C	75/25

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Machine Learning 1:
Recommended Proficiencies
Basic knowledge in mathematics (linear algebra, statistics), programming and algorithms.

4 **Contents:**

Contents of the course Machine Learning 1:
Due to the ever increasing amount of data that is routinely produced in our information society, the topic of machine learning has become increasingly important in the recent years, not only as a scientific discipline but also as a key technology of modern software and intelligent systems. This lecture provides an introduction to the topic of machine learning, with a specific focus on supervised learning for classification and regression. The lecture covers theoretical foundations of generalisation as well as practical topics and concrete learning algorithms.

- Introduction
- Foundations (e.g., the learning problem, generalization theory, bias-variance tradeoff)
- Techniques (e.g., The linear model, non-linear techniques, SVM, tree-based methods, ensembles, deep learning)
- Validation and practical implementations (e.g., metrics, training vs testing, cross-validation, AutoML)

5 **Learning outcomes and competences:**

The students understand the statistical foundations of generalisation, i.e., the induction of models from data, as well as practical tools for model validation. They are able to apply basic methods of supervised learning to problems of classification and regression.

Non-cognitive Skills

- Learning competence
- Learning motivation
- Literacy (scientific)

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 minutes or 40 minutes	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Assignments, course paper or progress reports		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr. Eyke Hüllermeier

13	**Other Notes:** *Remarks of course Machine Learning 1:* **Implementation method** Theoretical foundations and concepts of machine learning will be taught in the form of a lecture and deepened in practical exercise courses, group work as well as individual homework. **Learning Material, Literature** • Script • Y.S. Abu-Mostafa, M. Magdon-Ismail, H.T. Lin. Learning from Data, AMLBook, 2012. • P. Flach. Machine Learning, Cambridge Univ. Press, 2012. • E. Alpaydin. Machine Learning, Oldenbourg, 2008. • C.M. Bishop. Pattern Recognition and Machine Learning, Springer, 2006.

Modern Semiconductor Lasers			
Modern Semiconductor Lasers			
Module number: M.048.26012	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.26012 Modern Semiconductor Lasers	2L 2Ex, WS	60	120	C	40/40

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Modern Semiconductor Lasers:
Recommended:
The familiarity with basic concepts from optics, quantum mechanics and semiconductor physics is highly recommended.

4 **Contents:**

Contents of the course Modern Semiconductor Lasers:
Semiconductor lasers are the key light sources of modern photonics, enabling applications ranging from optical communications and sensing to quantum technologies. While reviewing the fundamental principles of semiconductor laser operation, this course focuses on recent advances and emerging directions that are reshaping the field. Participants will explore novel laser concepts based on photonic crystals, nanophotonics, spintronics, topology, and non-Hermitian physics, as well as the theoretical frameworks required to describe these devices beyond conventional laser theory.
Topics covered include:

- Fundamentals of semiconductor laser operation: gain media, laser dynamics, modulation response, and linewidth
- State-of-the-art semiconductor laser technologies and their performance limits
- Photonic-crystal surface-emitting lasers (PCSELs) and scalable single-mode high-power emission
- Nanolasers, cavity quantum electrodynamics, and thresholdless lasing
- Spin lasers and new approaches to ultrafast information encoding
- Bound-state-in-continuum (BIC) lasers and topological lasers
- Emerging concepts including supersymmetric, PT-symmetric, Dirac, polaritonic, and plasmonic lasers
- Advanced theoretical topics: non-Hermitian effects, quantum noise, complex gain media, and modern computational approaches for large-scale laser systems

5 **Learning outcomes and competences:**

Upon successful completion of this course, participants will be able to explain the physical principles governing semiconductor laser operation, including optical gain, laser dynamics, modulation response, and origin of linewidth. They will be able to analyze and compare established semiconductor laser technologies and evaluate their performance limitations. Furthermore, participants will develop a critical understanding of emerging laser concepts, including photonic-crystal, nano-, spin-, BIC, and topological lasers, and will be able to relate their operation to contemporary concepts in photonics such as cavity quantum electrodynamics, non-Hermitian physics, and topology. Finally, participants will gain familiarity with advanced theoretical and computational approaches used to describe modern semiconductor lasers and will be able to assess current research literature in this rapidly evolving field.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8	**Prerequisites for participation in examinations:** None
9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4
12	**Module coordinator:** Dr. Mariusz Drong
13	**Other Notes:** **Module Homepage** `https://panda.uni-paderborn.de/` **Implementation** Lectures and exercises **Teaching Material, Literature** Handouts and tutorial questions; literature references will be given in the first lecture

Optical Communication A

Optical Communication A

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.048.92019	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	1.-3. Semester	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.92019 Optical Communication A	2L 2Ex, SS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Optical Communication A:
None

4 **Contents:**

Contents of the course Optical Communication A:
Short Description
The lecture Optical Communication A gives basic knowledge in Optical Communication and the components used in this field.
Contents
Maxwell's equations, wave propagation, polarization, dielectric slab and cylindrical waveguides, dispersion, laser, photodiodes, optical amplifiers, modulation, signal formats, optical receivers, noise, regenerators, wavelength division multiplex. Here the most important knowledge is taught.

5 **Learning outcomes and competences:**

Professional Competence
After attending the course, the students will be able, in the taught subjects, to

- describe, model and apply the function of components, systems and effects of optical communications and
- apply knowledge of optoelectronics

(Soft) Skills
The students

- are able to apply the knowledge and skills to a wide range of disciplines,
- are able to make use of a methodical procedure when undertaking systematic analysis and
- are, due to the abstract and precise treatment of the contents, in a position to continue and develop their learning themselves

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Master's Program Electrical Systems Engineering v2 (ESEMA v2), Master's Program Electrical Systems Engineering v3 (ESEMA v3)

12 **Module coordinator:**

Prof. Dr. Reinhold Noé

13	**Other Notes:** *Remarks of course Optical Communication A:* **Course Homepage** `http://ont.upb.de` **Teaching Material, Literature** Scripts, exercise sheets and advanced literature (excerpt): • R. Noe, Essentials of Modern Optical Fiber Communication, Springer, 2. Auflage / 2nd Edition, 2016, ISBN 978-3-662-49621-3, ISBN ISBN 978-3-662-49623-7 • Petermann/Voges, Optische Kommunikationstechnik, Springer-Verlag (modernes Nachschlagewerk) 2002 • D. As, Univ. Paderborn, Vorlesung Optoelektronik • W. Sohler, Univ. Paderborn, Vorlesung Integrierte Optik • G. Grau, W. Freude, Optische Nachrichtentechnik, Springer-Verlag, Heidelberg, 1991, (umfassend, viele Zwischenschritte fehlen) • K.J. Ebeling, Integrierte Optoelektronik, Springer-Verlag, Heidelberg, 1992 • H.-G. Unger, Optische Nachrichtentechnik, Teile I und II, Hüthig-Verlag Heidelberg, 1984 und 1985, (Schwerpunkt optische Wellenleiter) • Yariv, Optical Electronics, Holt, 1984 (und weitere Werke, sehr physikalisch, kaum Nachrichtentechnik) • R. Th. Kersten, Einführung in die Optische Nachrichtentechnik, Springer-Verlag

Optical Communication B			
Optical Communication B			
Module number: M.048.92020	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.92020 Optical Communication B	2L 2Ex, SS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Optical Communication B:
None

4 **Contents:**

Contents of the course Optical Communication B:
Short Description
The lecture Optical Communication B gives some knowledge about mode coupling in Optical Communication and explains the function of many optical components.
Contents
Mode Coupling: Polarization mode dispersion, moden orthogonality, constant and periodic, co- and counterdirectional mode coupling, profiles of differential group delay, electrooptic effect. The function of many passive and active optical elements is thereby explained, among others amplitude and phase modulators, broadband and wavelength-selective couplers, Bragg gratings, polarization-maintaining fibers, polarization transformers, equalizers for polarization mode dispersion and chromatic dispersion.

5 **Learning outcomes and competences:**

Professional Competence
After attending the course, the students will be able, in the taught subjects, to

- describe, model and apply the function of components, systems and effects of optical communications and
- apply knowledge of optoelectronics

(Soft) Skills
The students

- are able to apply the knowledge and skills to a wide range of disciplines,
- are able to make use of a methodical procedure when undertaking systematic analysis and
- are, due to the abstract and precise treatment of the contents, in a position to continue and develop their learning themselves

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Master's Program Electrical Systems Engineering v2 (ESEMA v2), Master's Program Electrical Systems Engineering v3 (ESEMA v3)

12 **Module coordinator:**

Prof. Dr. Reinhold Noé

13 **Other Notes:**

Remarks of course Optical Communication B:

ATTENTION - IMPORTANT NOTICE
The course doesn't take place in winter term 2026/27 summer term 2026. Please see the notice boards of the group.

Course Homepage
`http://ont.upb.de`
Teaching Material, Literature
Scripts, exercise sheets and advanced literature (excerpt):

- Noe, Essentials of Modern Optical Fiber Communication, Springer, 2. Auflage / 2nd Edition, 2016, ISBN 978-3-662-49621-3, ISBN ISBN 978-3-662-49623-7
- Petermann/Voges, Optische Kommunikationstechnik, Springer-Verlag (modernes Nachschlagewerk) 2002
- D. As, Univ. Paderborn, Vorlesung Optoelektronik
- W. Sohler, Univ. Paderborn, Vorlesung Integrierte Optik
- G. Grau, W. Freude, Optische Nachrichtentechnik, Springer-Verlag, Heidelberg, 1991, (umfassend, viele Zwischenschritte fehlen)
- K.J. Ebeling, Integrierte Optoelektronik, Springer-Verlag, Heidelberg, 1992
- H.-G. Unger, Optische Nachrichtentechnik, Teile I und II, Hüthig-Verlag Heidelberg, 1984 und 1985, (Schwerpunkt optische Wellenleiter)
- Yariv, Optical Electronics, Holt, 1984 (und weitere Werke, sehr physikalisch, kaum Nachrichtentechnik)
- R. Th. Kersten, Einführung in die Optische Nachrichtentechnik, Springer-Verlag

Optical Communication C			
Optical Communication C			
Module number: M.048.92021	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.92021 Optical Communication C	2L 2Ex, WS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Optical Communication C:
None

4 **Contents:**

Contents of the course Optical Communication C:
Short Description
The lecture Optical Communication C gives knowledge in various optical modulation and demodulation techniques.
Contents
Modulation Formats: Data transmission by differential binary and quaternary phase shift keying in the presence of optical amplifiers, polarization division multiplex, coherent optical data transmission, synchronous and asynchronous demodulation, coherent baseband receivers, polarization diversity, electronic compensators of optical distortions like electronic polarization control and electronic compensation of polarization mode dispersion and chromatic dispersion, phase noise, other modulation formats. Advanced modulation formats are an important possibility for the upgrading of high-performance optical information transmission systems.

5 **Learning outcomes and competences:**

Professional Competence
After attending the course, the students will be able, in the taught subjects, to

- describe, model and apply the function of components, systems and effects of optical communications and
- apply knowledge of optoelectronics

(Soft) Skills
The students

- are able to apply the knowledge and skills to a wide range of disciplines,
- are able to make use of a methodical procedure when undertaking systematic analysis and
- are, due to the abstract and precise treatment of the contents, in a position to continue and develop their learning themselves

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Master's Program Electrical Systems Engineering v2 (ESEMA v2), Master's Program Electrical Systems Engineering v3 (ESEMA v3)

12 **Module coordinator:**

Prof. Dr. Reinhold Noé

13	**Other Notes:** *Remarks of course Optical Communication C:* --- **ATTENTION - IMPORTANT NOTICE** The course doesn't take place in winter term 2026/27 summer term 2026. Please see the notice boards of the group. --- **Teaching Material, Literature** Scripts, exercise sheets and advanced literature (excerpt): • Noe, Essentials of Modern Optical Fiber Communication, Springer, 2. Auflage / 2nd Edition, 2016, ISBN 978-3-662-49621-3, ISBN ISBN 978-3-662-49623-7 • Petermann/Voges, Optische Kommunikationstechnik, Springer-Verlag (modernes Nachschlagewerk) 2002 • D. As, Univ. Paderborn, Vorlesung Optoelektronik • W. Sohler, Univ. Paderborn, Vorlesung Integrierte Optik • G. Grau, W. Freude, Optische Nachrichtentechnik, Springer-Verlag, Heidelberg, 1991, (umfassend, viele Zwischenschritte fehlen) • K.J. Ebeling, Integrierte Optoelektronik, Springer-Verlag, Heidelberg, 1992 • H.-G. Unger, Optische Nachrichtentechnik, Teile I und II, Hüthig-Verlag Heidelberg, 1984 und 1985, (Schwerpunkt optische Wellenleiter) • Yariv, Optical Electronics, Holt, 1984 (und weitere Werke, sehr physikalisch, kaum Nachrichtentechnik) • R. Th. Kersten, Einführung in die Optische Nachrichtentechnik, Springer-Verlag

Optimale und Adaptive Filter			
Optimal and Adaptive Filters			
Module number: M.048.24010	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** de / en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.24010 Optimal and Adaptive Filters	2L 2Ex, WS	60	120	C	40/40

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Optimale und Adaptive Filter:
Recommended: Prior knowledge from the modules Higher Mathematics and Digital Signal Processing.

4	**Contents:** *Contents of the course Optimale und Adaptive Filter:* **Short Description** The course “Optimal and adaptive filters” gives an introduction to the basic techniques and theories of adaptive filters. Based upon the basics of estimation theory optimal filters are discussed. Subsequently the topics Wiener filter theory, deterministic optimization under constraints and stochastic gradient methods are regarded. Concluding the Least Squares approach for solving filter tasks and the Kalman filter are introduced. The latter is regarded as a brief introduction to state based filters. **Contents** • Classic parameter estimation – Estimators – MMSE-Estimation – Linear estimators – Orthogonality principle – Evaluation of estimators • Wiener filter – Wiener-Hopf equation – AR- and MA processes – Linear prediction • Iterative optimization methods – Gradient ascent/descent – Newton method • Linear adaptive filters – LMS algorithm – Least-Squares method – Blockwise and recursive adaptiv filters – Realization aspects • Statemodel based filters – Kalman filter • Applications – System identification – Channel estimation and equalization – Multi-channel speech signal processing – Noise and interference suppression

<table>
<tr><td>5</td><td>Learning outcomes and competences:

Domain competence:
After attending the course, the students will be able to

• analyze task on the field of adaptive filters and to formulate requirements mathematically,
• develop filter using cost functions and
• implement selected adaptive filters in the frequency or time domain.

Key qualifications:
The students

• are able to check theoretical results using practical realizations,
• are able to undertake theoretical approaches a systematic analysis using methodical procedures and
• are, due to the precise treatment of the contents, in a position to continue their learning themselves.</td></tr>
<tr><td>6</td><td>Assessments:

⊠Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

<table><tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr><tr><td>a)</td><td>Written or Oral Examination or Presentation</td><td>120-180 min or 30-45 min or 30 min</td><td>100%</td></tr></table></td></tr>
<tr><td>7</td><td>Study Achievement:

none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:

None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:

The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:

The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :

BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4</td></tr>
<tr><td>12</td><td>Module coordinator:

Dr.-Ing. Jörg Schmalenströer</td></tr>
</table>

13	**Other Notes:** *Remarks of course Optimale und Adaptive Filter:* **Course Homepage** `https://ei.uni-paderborn.de/en/nt/teaching/veranstaltungen/optimal-and-adaptive-filter` **Implementation** • Lectures using the blackboard and presentations, • Alternating theoretical and practical exercises classes with exercise sheets and computer and • Demonstration of real technical systems in the lecture hall. **Teaching Material, Literature** Allocation of a script; information on textbooks; matlab scripts

Optoelectronics			
Optoelectronics			
Module number: M.048.26011	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.26011 Optoelectronics	2L 2Ex, SS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Optoelectronics:
None

4 **Contents:**

Contents of the course Optoelectronics:
Short description
The lecture Optoelectronics covers the fundamental aspects of optoelectronic devices, starting with semiconductor materials and their interaction with light and photons, to the electronic aspects of the components, and finally to the use of quantum mechanical effects to optimise modern components for their respective areas of application, such as in lighting systems, renewable energy, broadband optical communication systems or in medical technology.
Contents
In the first part of the lecture, the basics of semiconductors (lattice structure, band structure, direct-indirect semiconductors, doping, degenerate and non-degenerate semiconductors, heterostructures, quantum effects in low-dimensional semiconductors) are recapitulated. The elementary interactions between light and semiconductors (absorption, stimulated emission, spontaneous emission) and the electronic aspects of the components (p-n junction, heterojunctions) are then covered. Finally, the most important devices such as solar cells, photodiodes, light-emitting diodes and semiconductor lasers are discussed in detail and their most important parameters and optimisation strategies are explained.

5 **Learning outcomes and competences:**

Domain competence:
After attending the course, the students will be able to

- explain the basic physical properties of optoelectronic semiconductor devices based on classical and fundamental quantum mechanical descriptions,
- to describe the main concepts of optoelectronic semiconductor devices (photodiodes, solar cells, light emitting diodes, semiconductor lasers),
- categorize different device designs according to their application requirements.

Key qualifications:
The students

- can use of methodic knowledge for systematic problem analysis for a wide range of disciplines,
- will be in position to familiarise themselves independently with new generations of semiconductor devices, thanks to the comprehensive fundamental training received,
- get familiar to rate-equation models to simulate steady-state and dynamic characteristics in coupled systems,
- and gain foreign language competences related to the field.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11 **Reuse in degree courses or degree course versions :**

BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4

12	**Module coordinator:** Prof. Dr.-Ing. Nils Christopher Gerhardt
13	**Other Notes:** **Course Homepage** [https://ei.uni-paderborn.de/hob/lehre] **Module Homepage** to be announced at the start of the lecture **Implementation** Lectures and exercises (including some computer simulations) **Teaching Material, Literature** Lecture notes and handouts for the tutorial; literature references will be given in the first lecture

Real World Crypto Engineering			
Real World Crypto Engineering			
Module number: M.079.01286	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: beliebig	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.079.05819 Real World Crypto Engineering	L3 Ex2	75	105	C	40

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Real World Crypto Engineering:
Recommended Proficiencies
Knowledge in programming, IT security and basic knowledge in cryptography

4 **Contents:**

Contents of the course Real World Crypto Engineering:
Strong cryptography is not always sufficient to protect primary security goals. Even if strong cryptographic algorithms are used, a lot can go wrong when they are implemented. This lecture will dive into the most important protocols and cryptographic protection mechanisms (e.g., TLS, SSH, WPA) and show their basic concepts. Then, we will present prominent attacks that ultimately break the desired security goals. Based on many cases, we will learn what is essential when designing and implementing cryptographic applications.

5 **Learning outcomes and competences:**

Upon successful completion, students have a comprehensive understanding of the technical aspects of applied cryptographic algorithms. They have recognized that cryptography alone is not sufficient to solve security-related problems. They have an overview of current cryptographic attacks and know how to practically prevent them.
Non-cognitive Skills

- Team work
- Literacy (scientific)

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 min or 40 min	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Written exercises		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr.-Ing. Juraj Somorovsky

13 **Other Notes:**

Remarks of course Real World Crypto Engineering:
Implementation method
Lectures, exercises
Learning Material, Literature
Lecture slides, scientific papers

Routing and Data Management in Networks

Routing and Data Management in Networks

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.01271	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	beliebig	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05806 Routing and Data Management in Networks	L3 Ex2	75	105	CE	40/20

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Routing and Data Management in Networks:
Recommended Proficiencies
Algorithm design, theoretical correctness and efficiency proofs, tools from combinatorics and probability theory.

4 **Contents:**

Contents of the course Routing and Data Management in Networks:
Routing and data management are fundamental tasks to be solved in order to ensure efficient use of large networks, e.g. the Internet, peer-to-peer systems, or wireless mobile ad-hoc networks. This lecture deals with algorithms and their analysis for routing and data management in such systems and describes, in particular, methods for dealing with their dynamics (movement of nodes, joining and exiting nodes). In particular, local, distributed algorithms, often as online algorithms, are considered.

- Offline and online routing strategies
- Scheduling strategies
- Data management strategies

5 **Learning outcomes and competences:**

The students get to know fundamental techniques in the area of routing and data management of large networks. They can decide in which situation which data management, scheduling, or routing algorithm is most appropriate. They can adapt algorithms to a new situation.
Non-cognitive Skills

- Attitude
- Self-monitoring

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 minutes or 40 minutes	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Written exercises		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr. Friedhelm Meyer auf der Heide

13	**Other Notes:** *Remarks of course Routing and Data Management in Networks:* **Implementation method** • Lecture with beamer and blackboard • Practice in small groups • Expected activities of the students: Solving homework exercises, contributing to the tutorials **Learning Material, Literature** • Introduction to Parallel Algorithms and Architectures: Arrays, Trees, Hypercubes, Frank Thomson Leighton, M. Kaufmann Publishers, 1992. • Research papers, script, slide set of the lecture, exercise sheets

Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation			
Fast Integrated Circuits for Wireline Communications			
Module number: M.048.25019	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** de / en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.25019 Fast Integrated Circuits for Wireline Communications	2L 2Ex, WS	60	120	C	40/40

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation:
Recommended: Module “Schaltungstechnik” of the Bachelor Electrical Engineering or module “Circuit and System Design” of the Master “Electrical Systems Engineering” or comparable modules / lectures

4	**Contents:** *Contents of the course Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation:* **Short Description** Nowadays commercial fiber-optic communication systems reach very high data rates of 100 Gb/s per optical channel and several Tb/s in a single fiber. In a similar way very high data rates of more than 10 Gb/s occur at a single package pin of electronic chips. These signals are to be transmitted over printed circuit boards and inexpensive serial cables. In the future the progress of CMOS technology and communication technology will push speed of fiber-optic and wire-line communication continuously to ever higher data rates. The design of electronic circuits for high bandwidth rsp. data rates requires a good system knowledge with respect to typical transmitter and receiver architectures, components, and signal properties. Furthermore a thorough understanding of integrated circuit design as well as precise high-frequency modeling of passive and active devices are required. Goal of the lecture is to enable the student to utilize a methodological approach for the design of fast integrated electronic circuits for digital wired communications. A part of the exercises will be carried out using modern industry-standard IC design software. **Contents** The lecture deals with analysis and design of fast integrated electronic circuits for digital broadband communication systems. A part of the exercises will be performed using modern chip design CAD tools. The lecture is based on the compulsory lectures “Schaltungstechnik” rsp. “Circuit and System Design”. The lecture deals with: • Transmitter and receiver architectures for fiber-optic communications • Transmitter and receiver architectrues for chip-to-chip communications • System design • Semiconductor technology and integrated high-frequency devices • Broadband amplifiers • Current-mode logic • Transmitter and receiver circuits • PLLs for frequency synthesis and clock recovery • Measurement methods
5	**Learning outcomes and competences:** **Domain competence:** The student will be able to: • describe and analyze transmitter and receiver architectures for broadband communication links • understand and describe semiconductor technologies and integrated high-frequency devices for broadband circuits • to analyze circuit design techniques for transmitter and receiver circuits and describe ways to optimize them • to describe circuits in PLL technique for frequency synthesis and clock recovery • to describe measurement methods **Key qualifications:** The students will learn how different interdisciplinary scientific domains and their methods - like mathematical signal and system analysis, non-linear and linear circuit analysis, semiconductor physics, semiconductor devices and high-frequency engineering - are applied together for the development of communications application.

<table>
<tr><td>6</td><td>Assessments:
☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table>
<tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr>
<tr><td>a)</td><td>Oral Examination</td><td>30-45 min</td><td>100%</td></tr>
</table></td></tr>
<tr><td>7</td><td>Study Achievement:
none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr.-Ing. J. Christoph Scheytt</td></tr>
<tr><td>13</td><td>Other Notes:
Remarks of course Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation:
Course Homepage
https://www.hni.uni-paderborn.de/en/system-and-circuit-technology/teaching/fast-integrated-circuits-for-wireline-communications/
Implementation
Lecture with Exercises (including computer-aided design using electronic design software)
Teaching Material, Literature
Handouts and literature references will be given in the lecture.
• E. Säckinger, “Broadband Circuits for Optical Fiber Communication”, Wiley, 2005
• B. Razavi, “Design of Integrated Circuits for Optical Communications”, McGraw-Hill, 2003
Comments
As part of the lecture a 2-day excursion to IHP Leibnizinstitute for High-Performance Microelectronics in Frankfurt (Oder) is offered which includes the visit of a modern chip fabrication facility (participation in the excursion is voluntary).</td></tr>
</table>

<table>
<tr><th colspan="5">Theory and Design of Integrated Photonic Devices</th></tr>
<tr><td colspan="5">Theory and Design of Integrated Photonic Devices</td></tr>
<tr><td colspan="2">Module number:
M.048.26013</td><td>Workload (h):
180</td><td>Credits:
6</td><td>Regular Cycle:
module.frequency.en</td></tr>
<tr><td colspan="2"></td><td>Semester number:
1.-.3 Semester</td><td>Duration (in sem.):
1</td><td>Teaching Language:
en</td></tr>
<tr><td>1</td><td colspan="4">Module structure:
<table>
<tr><th></th><th>Course</th><th>form of teachin</th><th>contact-time (h)</th><th>self-study (h)</th><th>status (C/CE)</th><th>group size (TN)</th></tr>
<tr><td>a)</td><td>L.048.26013
Theory and Design of Integrated Photonic Devices</td><td>2L
2Ex,
WS</td><td>60</td><td>120</td><td>C</td><td>30/30</td></tr>
</table></td></tr>
<tr><td>2</td><td colspan="4">Options within the module:
None</td></tr>
<tr><td>3</td><td colspan="4">Admission requirements:
None
Prerequisites of course Theory and Design of Integrated Photonic Devices:
Recommended:
Knowledge on electromagnetic fields and waves Experience with MATLAB/Python scripting would be beneficial</td></tr>
</table>

4 **Contents:**

Contents of the course Theory and Design of Integrated Photonic Devices:

- Introduction
  - Historical evolution of integrated photonics and relevance in today's world
  - Brief overview on the required background theory
    - Electromagnetic waves and Maxwell's equations
    - EM waves propagation in different media
- Theory of optical waveguides: Device #0
  - 1-D waveguide analysis
    - Ray optics model
    - Vector wave equation and boundary conditions
  - 2-D waveguide analysis
    - Overview of waveguide platforms and effective index method
    - Overview of the full vectorial method
    - Dispersion, polarization and orthogonality of guided modes
- Coupled-mode theory: analytical formulation
- Passive integrated photonic devices
  - Directional coupler (DC): Device #1
  - Multi-mode interferometers (MMI) : Device #2
  - Distributed Bragg reflector (DBR): Device #3
- Tunable/active integrated photonic devices
  - Mach-Zehnder interferometer (MZI) / modulator (MZM): Device #4
  - Microring resonators (MRR) / modulator (MRM): Device #5
  - Overview of phase shifters: thermal, electro-optic and MEMS-based
- Fabrication variability and tolerances of the integrated photonic devices
- Overview of photonic integrated circuit (PIC) analysis, introduction to compact-modeling and electronic-photonic design automation (EPDA)

5 **Learning outcomes and competences:**

Understanding the working and fundamental theory of integrated photonic devices, constraints involved in the device designs and overcoming strategies.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7	**Study Achievement:** none
8	**Prerequisites for participation in examinations:** None
9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4
12	**Module coordinator:** Dr. Ashitosh Velamuri
13	**Other Notes:** **Module Homepage** **Implementation** Lectures and exercises (including some computer simulations) **Teaching Material, Literature** Handouts and tutorial questions; literature references will be given in the first lecture

Theory and Design of Phase-locked Loops

Theory and Design of Phase-locked Loops

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.048.24020	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	1.-3. Semester	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.24020 Theory and Design of Phase-locked Loops	2L 2Ex, WS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Theory and Design of Phase-locked Loops:
Recommended:

- Advanced Signal Theory
- Statistical Signal Processing (or another course with comparable syllabus in their bachelor)
- Circuit and system design (or another course with comparable syllabus in their bachelor)

4 **Contents:**

Contents of the course Theory and Design of Phase-locked Loops:
Chapter 1: Motivation

- Time and frequency definition – definition in SI units – static frequency error
- random fluctuations – Amplitude/Phase (AM/PM) noise

Chapter 2: Mathematical formalism of signals

- baseband and bandpass signals
- time and frequency domain

Chapter 3: introduction to random processes

- baseband random processes and noise – correlation functions in time and frequency domain – some basedband random processes (thermal noise, shot noise, flicker noise . . .)
- bandpass random processes – correlation functions – relation to baseband processes – phase noise and amplitude noise

Chapter 4: PLL building blocks

- Phase detector – Phase detector model – phase noise of phase detector
- VCO – VCO model – phase noise of VCO
- Frequency translators – frequency divider – frequency multiplier – phase noise of frequency translators
- transistor level design of PLL blocks

Chapter 5: Integer N PLLs: – Time domain – frequency domain – phase noise – spurious frequencies
Chapter 6: Fractional PLLs – Time domain – frequency domain – phase noise – spurious frequencies

5 **Learning outcomes and competences:**

Understanding of static/dynamic error in frequency standards. Mathematical modeling of amplitude/phase noise. Modeling random processes in time and frequency domain. Basic and modern PLL architecture and its building blocks. Systematic design of PLLs. Design and Modeling of Integer/Fractional N PLL.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4
12	**Module coordinator:** Dr. Meysam Bahmanian
13	**Other Notes:** **Module Homepage** `https://www.hni.uni-paderborn.de/en/sct/teaching/theory-and-design-of-plls` **Implementation** Lectures and exercises (including some computer simulations) **Teaching Material, Literature** Handouts and tutorial questions; literature references will be given in the first lecture

Topics in Signal Processing

Topics in Signal Processing

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.048.92014	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	1.-3. Semester	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.92014 Topics in Signal Processing	2L 2Ex, WS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Topics in Signal Processing:
Recommended: Signal and system theory, at least a basic understanding of probability and linear algebra

4 **Contents:**

Contents of the course Topics in Signal Processing:
Short Description
This course covers a selection of current topics in signal processing. One part of this course will follow a regular lecture format, while the other part will require active student participation.
Contents
This course will first review relevant aspects of linear algebra and probability theory. Then students will learn how to read, analyze, and present recent papers from the signal processing literature.

5 **Learning outcomes and competences:**

In this course, students will familiarize themselves with some current research topics in signal processing. They will learn to read and understand scientific publications and to critically evaluate results. Students will develop confidence in their ability to solve mathematical problems of analysis and design. They will be able to apply the principles they have learnt in this course to other areas.

<table>
<tr><td>6</td><td>Assessments:
☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table>
<tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr>
<tr><td>a)</td><td>Written or Oral Examination or Presentation</td><td>120-180 min or 30-45 min or 30 min</td><td>100%</td></tr>
</table></td></tr>
<tr><td>7</td><td>Study Achievement:
none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Informatik v3, Masterstudiengang Informatik v4, Master's Program Electrical Systems Engineering v2 (ESEMA v2), Master's Program Electrical Systems Engineering v3 (ESEMA v3)</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr. Peter Schreier</td></tr>
<tr><td>13</td><td>Other Notes:
Remarks of course Topics in Signal Processing:
Course Homepage
http://sst.uni-paderborn.de/teaching/courses/
Implementation
Lectures and tutorials with active student participation, student presentations
Teaching Material, Literature
References will be given in the first lecture.</td></tr>
</table>

Web Security

Web Security

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.01284	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	beliebig	1	de

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05820 Web Security	L3 Ex2	75	105	C	40

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Web Security:
Recommended Proficiencies
Knowledge in programming, IT security and basic knowledge in cryptography

4 **Contents:**

Contents of the course Web Security:
Modern web applications and web services usually consist of multiple layers. They are based on different (often complex) technologies that are constantly being developed. Their complexity is often the reason for new types of attacks that can be observed on the web every day.
In this lecture, we will focus on the most important technologies and learn what you have to consider while securing your web applications. We will introduce prominent and widespread attacks and show how to prevent them. These range from typical attacks from the OWASP Top 10 list, such as XSS or SQL Injection, to attacks on web services and Single Sign-On standards (e.g., on SAML and OpenID Connect). Based on many cases, we will learn what is important in the design and implementation of secure web applications.

5 **Learning outcomes and competences:**

After successful completion, students have a comprehensive understanding of the technical aspects of web applications, web services, and various authentication mechanisms. They have learned that the web technologies used today are complex and that their complexity poses many security problems. Students have an overview of current web attacks and know how to prevent them practically.
Non-cognitive Skills

- Team work
- Literacy (scientific)

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 min or 40 min	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Written exercises		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr.-Ing. Juraj Somorovsky

13 **Other Notes:**

Remarks of course Web Security:
Implementation method
Lecture with exercises
Learning Material, Literature

- Lecture slides
- Scientific papers

Wireless Communications			
Wireless Communications			
Module number: M.048.24022	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 2.-4. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.24022 Wireless Communications	2L 2Ex, SS	60	120	CE	30 / 30

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Wireless Communications:
Recommended:
Prior knowledge from the modules Signal and Information Transmission, Signal Theory, and Probability for Engineers.

4 **Contents:**

Contents of the course Wireless Communications:
The course provides students with important basic knowledge necessary for understanding the transmission concepts of modern mobile communication systems. Starting with a physical understanding of the mobile communications channel, in particular the phenomena of multipath propagation and the Doppler effect, the physical and statistical modeling of time-varying communication systems is presented. Subsequently, important diversity techniques for channel-adaptive transmission and multiple access techniques are introduced.

5 **Learning outcomes and competences:**

Domain competence:
After completion of the course students will be able to

- understand the fundamental propagation mechanisms in mobile radio channels;
- describe and apply physical and statistical modeling principles to time-varying communication channels;
- analyze fading processes and asses their impact on transmission reliability;
- explain diversity techniques, apply them to design physical layer signal processing algorithms, and assess their impact on transmission reliability;
- explain, compare, and evaluate common multiple access schemes;
- assess transmission concepts employed in contemporary mobile communication systems;
- connect theoretical channel models with practical system design considerations.

Key qualifications:
The students

- have strong analytical and mathematical reasoning skills;
- have the ability to abstract complex physical phenomena into engineering models;
- can interpret analytical results at the system level;
- have experience in clear and precise technical communication (oral and written)
- can learn independently and engage critically with technical literature.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11	**Reuse in degree courses or degree course versions :** BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4
12	**Module coordinator:** Prof. Dr. Bho Matthiesen
13	**Other Notes:** **Module Homepage** `https://www.hni.uni-paderborn.de/en/nt` **Implementation** Lectures and exercises **Teaching Material, Literature** Lecture slides and reading assignments for each lecture; additional reading suggestions.

3.2 Specialisation Area “Computer Systems”

Specialisation Area	Computer Systems
Modules	* Advanced VLSI Design
	* Algorithms and Tools for Test and Diagnosis of Systems on a Chip
	* Approximate Computing
	* Databases and Information Systems
	* Introduction to Quantum Computation
	* Machine Learning I
	* Reconfigurable Computing
	* Resource-Efficient AI: Architectures and Methodologies
	* Usable Security and Privacy
	* VLSI Testing
Catalogue advisor	Head of Examination Board CE (PAV CE)
Credits ECTS	6
Learning objectives	

The modules from this specialisation area enable specialisation in the field of computer systems. The focus is on the analysis and evaluation of computer architectures, systematic methods for the design and optimisation of computer systems, in particular the interaction of hardware and software, as well as programming models and methods for the parallel and specialised computer architectures that are gaining strongly in importance.

Advanced VLSI Design			
Advanced VLSI Design			
Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.048.92043	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	1.-3. Semester	1	en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.92043 Advanced VLSI Design	2L 2Ex, SS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Advanced VLSI Design:
Recommended: Fundamentals of Digital Circuits / Fundamentals of VLSI Design
Information: Unless otherwise specified, these are recommendations.

4 **Contents:**

Contents of the course Advanced VLSI Design:
Short Description
The course provides basic knowledge about the modern application-oriented modeling, simulation, analysis, and synthesis of digital systems at different abstraction levels to chip layout.
Contents
In today's practice, chip design consists of the combined application of various languages, methods, and tools for the modeling, simulation, and synthesis of electronic circuits. Along the modern abstraction-based design flow of digital systems (electronic system level to chip layout), the course provides basic knowledge of the main description languages and their application in modeling, simulation, analysis and synthesis. This includes basic principles and application of the IEEE standard system/hardware description languages SystemVerilog, SystemC, Verilog, and VHDL, in conjunction with additional formats, e.g., SDF and UPF for time and power annotation. For their application, the fundamental principles of test environments for simulation, timing and power analysis, logic synthesis and physical design of digital circuits. Exercises will provide hands-on labs based on commercial tools from Mentor Graphics, Synopsys and, Cadence Design Systems.

<table>
<tr><td>5</td><td>Learning outcomes and competences:

Domain competence:
After the course students are able

• to model, simulate, analyze and synthesize simple digital circuits at different abstraction levels and
• to apply the most important commercial tools for simulation, analysis and synthesis of digital circuits.

Key qualifications:
After the course students are able

• to assess, select and apply modern digital circuit description languages for their different applications,
• apply the different methods and tools in the modern VLSI design.</td></tr>
<tr><td>6</td><td>Assessments:

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

<table><tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr><tr><td>a)</td><td>Written or Oral Examination or Presentation</td><td>120-180 min or 30-45 min or 30 min</td><td>100%</td></tr></table></td></tr>
<tr><td>7</td><td>Study Achievement:

none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:

None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:

The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:

The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Master’s Program Electrical Systems Engineering v2 (ESEMA v2), Master’s Program Electrical Systems Engineering v3 (ESEMA v3)</td></tr>
<tr><td>12</td><td>Module coordinator:

apl. Prof. Dr. Wolfgang Mueller</td></tr>
</table>

13	**Other Notes:** *Remarks of course Advanced VLSI Design:* **Course Homepage** `www.hni.uni-paderborn.de/en/system-and-circuit-technology/teaching/advanced-vlsi-design` **Implementation** * Vorlesung mit Beamer und White-Board * Übungen mit Übungsblättern am Computer * Lecture with LCD projector and white board * Exercises with assignments and hands-on labs **Teaching Material, Literature** • Lecture notes and exercise sheets will be provided via PAUL • IEEE standard reference manuals: IEEE Std 1800/1685/1666/1364/1076/1801/1497 • Specific references for individual teaching units

Approximate Computing

Approximate Computing

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.01278	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	1-3	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.09758 Approximate Computing	L3 Ex2	75	105	C	100/30

2 **Options within the module:**

none

3 **Admission requirements:**

none

Prerequisites of course Approximate Computing:
Recommended Proficiencies
Knowledge of the Bachelor-level courses Digital Design and Computer Architecture are beneficial.

4 **Contents:**

Contents of the course Approximate Computing:
Approximate Computing is an emerging paradigm that trades-off computational accuracy for a significant reduction in energy, execution time, or chip area. This research-oriented course introduces to the field of Approximate Computing and its most remarkable aspects, and explains the main methods used to implement efficient computing systems by reducing accuracy. The course discusses approximations at all levels of a computing system, from applications down to hardware technologies. In exercise/tutorial sessions the efficiency of these techniques in various domains are examined, including deep learning and digital signal processing.

- Introduction and motivation for approximate computing
- Approximation at the application level, e.g., in machine learning and digital signal processing
- Programming languages/compilers for approximate computing
- Approximate microarchitectures
- Automated synthesis of approximate circuits
- Inexact arithmetic components and performance optimization via accuracy trade-offs
- Approximation techniques at the technology level
- Exercises/tutorial: Approximating deep learning and digital signal processing algorithms

5 **Learning outcomes and competences:**

After attending this course, the students are able

- to name and explain approximation techniques at all levels of a computing system,
- to identify major engineering/research problems when building approximate computing systems,
- to judge the suitability of approximation techniques for different application domains, and
- to apply approximation techniques to realize efficient hardware accelerators, in particular for deep learning and digital signal processing

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination or report	90-120 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Assignments, course paper or progress reports		CA

8 **Prerequisites for participation in examinations:**

Prerequisite for the participation in the examination is the study achievement in the course “Approximate Computing”.

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr. Marco Platzner

13	**Other Notes:** *Remarks of course Approximate Computing:* **Implementation method** • Lecture with projector and black/white board • Interactive exercises/discussions in the lecture room • Computer-based tutorials **Learning Material, Literature** • Lecture slides, exercise sheets, and tutorial assignments • Adrian Sampson, Luis Ceze, and Dan Grossman: Good-Enough Computing. IEEE Spectrum, 50(10):54-59, 2013 • Ravi Nair. Big Data Needs Approximate Computing: Technical Perspective. Communications of the ACM, 58(1): 104, 2015. • Sparsh Mittal. A Survey of Techniques for Approximate Computing. ACM Computing Surveys, 48(4), 2016. • Qiang Xu, Todd Mytkowitz, and Nam Sung Kim. Approximate Computing: A Survey. IEEE Design & Test, 33(1):8-22, 2016. • Weiqiang Liu and Fabrizio Lombardi (Editors), Approximate Computing. Springer, 2022. • Additional resources and links to current research papers are provided in the lecture.

Databases and Information Systems

Databases and Information Systems

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.01260	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	beliebig	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05532 Databases and Information Systems	L3 Ex2	75	105	CE	120/30

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Databases and Information Systems:
Recommended Proficiencies
Students are required to have previous knowledge of relational database systems and SQL comparable to the course “Datanbanksysteme” and programming knowledge and skills comparable to the courses “Programming” and “Grundlagen der Programmiersprachen”.

4 **Contents:**

Contents of the course Databases and Information Systems:
Data storage and data management play a central role in enterprises since a large part of the companies' knowledge is stored as data. Furthermore, data collections are rapidly growing, and an efficient processing of these big data collections requires know how beyond that of SQL and traditional database systems. Examples for these big data collections are genome databases, text document collections, sensor data, satellite data, data from cameras, microphones, and RFID tags, telecommunication data, weather data, finance data, news readers, data from messengers, etc.. To develop applications or information systems that lead to acceptable response times on these big data collections requires knowledge about non-standard data models, main-memory databases, compression, indexing of big data, and efficient search in these data collections.
This module focusses on algorithms for compression and for efficient processing of complex structured massive data, including text data, genome data, tree structured data, and graph data. The content of this module covers:

- Overview of search engines and information systems
- Main memory databases and succinct encoding techniques
- String compression algorithms
- Genome databases
- Processing of huge tree data collections (XML and JSON) and tree compression
- Graph databases and graph compression
- Search Algorithms for Big Data and for data streams

5 **Learning outcomes and competences:**

After completing the module students can comprehend, design, implement and assess (with respect to time and space complexity) XML processing in software systems. They known pivotal search and query techniques to acquire information in uncompressed and compressed XML data. They can appropriately process infinite data streams. They can acquire new research results from scientific publications.
Non-cognitive Skills:

- Team work
- Learning competence
- Learning motivation

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 minutes or 40 minutes	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

<table>
<tr><td>7</td><td>Study Achievement:
<table>
<tr><th>zu</th><th>Type of achievement</th><th>Duration or Scope</th><th>SL / QT</th></tr>
<tr><td>a)</td><td>Written exercises</td><td></td><td>CA</td></tr>
</table>
Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
Passing of course achievement</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The module is weighted as 6 credits.</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr. Stefan Böttcher</td></tr>
<tr><td>13</td><td>Other Notes:
Remarks of course Databases and Information Systems:
Implementation method
The fundamental concepts are presented in a lecture. Additioanlly, theoretical concepts are deepened in small groups during class-based tutorials. This method is used in particular for core concepts of databases (searching in and querying Big Data, distributed databases, and mobile data and manangement). Additionally, practical skills are acquired through computer-based exercises, where the students have to develop their own information systems, search or compression algorthms, based on the introduction given in the lecture.
Learning Material, Literature
Links to material will be provided during the lecture.</td></tr>
</table>

<table>
<tr><th colspan="5">Introduction to Quantum Computation</th></tr>
<tr><td colspan="5">Introduction to Quantum Computation</td></tr>
<tr><td colspan="2">Module number:
M.079.01279</td><td>Workload (h):
180</td><td>Credits:
6</td><td>Regular Cycle:
module.frequency.en</td></tr>
<tr><td colspan="2"></td><td>Semester number:
beliebig</td><td>Duration (in sem.):
1</td><td>Teaching Language:
en</td></tr>
<tr><td>1</td><td colspan="4">Module structure:
<table>
<tr><th></th><th>Course</th><th>form of teachin</th><th>contact-time (h)</th><th>self-study (h)</th><th>status (C/CE)</th><th>group size (TN)</th></tr>
<tr><td>a)</td><td>L.079.05807 Introduction to Quantum Computation</td><td>L3 Ex2</td><td>75</td><td>105</td><td>C</td><td>40</td></tr>
</table></td></tr>
<tr><td>2</td><td colspan="4">Options within the module:
none</td></tr>
<tr><td>3</td><td colspan="4">Admission requirements:
Prerequisites of course Introduction to Quantum Computation:
Recommended Proficiencies
Linear Algebra, algorithms.</td></tr>
<tr><td>4</td><td colspan="4">Contents:
Contents of the course Introduction to Quantum Computation:
This lecture introduces the fundamental concepts of quantum computation and information from a computer science perspective. This includes an introduction to quantum mechanics, quantum entanglement, quantum algorithms, quantum error correction, and quantum information theory.
Quantum mechanics
Quantum entanglement
Quantum algorithms
Quantum error correction
Quantum information</td></tr>
</table>

5 **Learning outcomes and competences:**

Students are able to:

- Describe and apply the postulates of quantum mechanics
- Understand the use of entanglement as a resource
- Design and analyze fundamental quantum algorithms
- Apply the theory of error-correcting codes
- Understand and apply basic quantum information theory concepts such as entropy

Non-cognitive Skills

- Learning competence
- Self-monitoring

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 minutes or 40 minutes	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Written exercises		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr. Sevag Gharibian

13	**Other Notes:** *Remarks of course Introduction to Quantum Computation:* **Implementation method** Slides and blackboard writing. All important concepts and techniques are further deepened with examples in exercises. **Learning Material, Literature** • Michael A. Nielsen, Isaac L. Chuang, Quantum Computation and Quantum Information, Cambridge University Press • Lecture slides, exercises

Machine Learning I

Machine Learning I

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.01274	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	beliebig	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05701 Machine Learning 1	L3 Ex2	75	105	C	75/25

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Machine Learning 1:
Recommended Proficiencies
Basic knowledge in mathematics (linear algebra, statistics), programming and algorithms.

4 **Contents:**

Contents of the course Machine Learning 1:
Due to the ever increasing amount of data that is routinely produced in our information society, the topic of machine learning has become increasingly important in the recent years, not only as a scientific discipline but also as a key technology of modern software and intelligent systems. This lecture provides an introduction to the topic of machine learning, with a specific focus on supervised learning for classification and regression. The lecture covers theoretical foundations of generalisation as well as practical topics and concrete learning algorithms.

- Introduction
- Foundations (e.g., the learning problem, generalization theory, bias-variance tradeoff)
- Techniques (e.g., The linear model, non-linear techniques, SVM, tree-based methods, ensembles, deep learning)
- Validation and practical implementations (e.g., metrics, training vs testing, cross-validation, AutoML)

5 **Learning outcomes and competences:**

The students understand the statistical foundations of generalisation, i.e., the induction of models from data, as well as practical tools for model validation. They are able to apply basic methods of supervised learning to problems of classification and regression.

Non-cognitive Skills

- Learning competence
- Learning motivation
- Literacy (scientific)

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 minutes or 40 minutes	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Assignments, course paper or progress reports		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr. Eyke Hüllermeier

13	**Other Notes:** *Remarks of course Machine Learning 1:* **Implementation method** Theoretical foundations and concepts of machine learning will be taught in the form of a lecture and deepened in practical exercise courses, group work as well as individual homework. **Learning Material, Literature** • Script • Y.S. Abu-Mostafa, M. Magdon-Ismail, H.T. Lin. Learning from Data, AMLBook, 2012. • P. Flach. Machine Learning, Cambridge Univ. Press, 2012. • E. Alpaydin. Machine Learning, Oldenbourg, 2008. • C.M. Bishop. Pattern Recognition and Machine Learning, Springer, 2006.

Reconfigurable Computing

Reconfigurable Computing

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.01270	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	beliebig	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05703 Reconfigurable Computing	L2 Ex3	75	105	CE	50/20

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Reconfigurable Computing:
Recommended Proficiencies
Knowledge of “Digital Design” and “Computer Architecture” is beneficial.

4 **Contents:**

Contents of the course Reconfigurable Computing:
This lecture provides an understanding of architectures and design methods for reconfigurable hardware systems and presents applications in the areas of high performance computing and embedded systems.

- Introduction: evolution of programmable logic devices, market economics
- Architectures: FPGA architectures, reconfigurable devices, reconfigurable systems
- Design methods: CAD for FPGAs, high-level languages and compilers, system-level design
- Applications: custom computing machines, embedded systems

5 **Learning outcomes and competences:**

After attending the course, the students are able to

- explain the architectures of reconfigurable hardware devices,
- name and analyze the main design methods and
- judge the suitability of reconfigurable hardware for different application domains.

Non-cognitive Skills

- Team work
- Learning competence

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 minutes or 40 minutes	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Written exercises		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr. Marco Platzner

13	**Other Notes:** *Remarks of course Reconfigurable Computing:* **Implementation method** • Lecture with projector and board • Interactive exercises in the lecture room • Computer-based exercises with reconfigurable systems **Learning Material, Literature** • Lecture slides and exercise sheets • Exercise sheets and technical documentation for the for the computer-based exercises • S. Hauck and A. DeHon (editors): Reconfigurable Computing, Volume 1: The Theory and Practice of FPGA-Based Computation, Morgan Kaufmann, 2008 • Information about alternative and additional literature as well as teaching material on the course's website and in the lecture slides

<table>
<tr><th colspan="5">Resource-Efficient AI: Architectures and Methodologies</th></tr>
<tr><td colspan="5">Resource-Efficient AI: Architectures and Methodologies</td></tr>
<tr><td colspan="2">Module number:
M.048.23023</td><td>Workload (h):
180</td><td>Credits:
6</td><td>Regular Cycle:
module.frequency.en</td></tr>
<tr><td colspan="2"></td><td>Semester number:
1.-3. Semester</td><td>Duration (in sem.):
1</td><td>Teaching Language:
en</td></tr>
<tr><td>1</td><td colspan="4">Module structure:
<table>
<tr><th></th><th>Course</th><th>form of teachin</th><th>contact-time (h)</th><th>self-study (h)</th><th>status (C/CE)</th><th>group size (TN)</th></tr>
<tr><td>a)</td><td>L.048.23023 Resource-Efficient AI: Architectures and Methodologies</td><td>2L 2Ex, WS</td><td>60</td><td>120</td><td>C</td><td>30/30</td></tr>
</table></td></tr>
<tr><td>2</td><td colspan="4">Options within the module:
None</td></tr>
<tr><td>3</td><td colspan="4">Admission requirements:
None
Prerequisites of course Resource-Efficient AI: Architectures and Methodologies:
None</td></tr>
</table>

4 **Contents:**

Contents of the course Resource-Efficient AI: Architectures and Methodologies:
The course introduces methods and architectures for resource-efficient execution of modern artificial intelligence applications under performance, energy, and memory constraints. Topics include:

- Fundamentals of deep learning and training methodologies
- Characteristics of modern AI workloads (e.g., CNNs and transformers)
- Computational, memory, and energy bottlenecks during AI inference
- Techniques for efficient model design and optimization:
  - Quantization
  - Pruning and sparsity
  - Knowledge distillation
  - Efficient neural network architectures (e.g., MobileNet)
- Mapping AI workloads onto hardware platforms
- Architectures for AI acceleration:
  - SIMD and vector architectures
  - GPU architectures
  - Dataflow architectures and systolic arrays
  - Neural Processing Units (NPUs) and domain-specific accelerators
- Hardware-software co-design for efficient AI systems

5 **Learning outcomes and competences:**

After successful completion of the module, students are able to:

- explain fundamental principles of deep learning from a systems perspective,
- analyze AI workloads with respect to computational, memory, and communication requirements,
- identify performance, energy, and memory bottlenecks,
- apply model optimization techniques to improve efficiency,
- map AI workloads onto different hardware platforms and evaluate their suitability,
- compare different architectures for AI acceleration,
- analyze trade-offs between accuracy, latency, throughput, and energy efficiency,
- apply hardware-software co-design methodologies for resource-efficient AI systems.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8	**Prerequisites for participation in examinations:** None
9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** BF Automatisierungstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4
12	**Module coordinator:** Prof. Dr.-Ing. Lennart Bamberg
13	**Other Notes:** **Module Homepage** PANDA (more information will be provided in the first lecture) **Implementation** Lectures and exercises (including some computer simulations) **Teaching Material, Literature** Handouts and tutorial questions; literature references will be given in the first lecture

Usable Security and Privacy			
Usable Security and Privacy			
Module number: M.079.01285	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: beliebig	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05804 Usable Security and Privacy	L2 Ex3	75	105	CE	40

2 **Options within the module:**
none

3 **Admission requirements:**
keine

4	**Contents:** *Contents of the course Usable Security and Privacy:* Human factors and usability issues have traditionally played a limited role in security research and secure systems development. Usability issues have been largely disregarded by security experts due to their failure to acknowledge their significance and their insufficient knowledge to tackle them. Today there is consensus on the importance of understanding users behavior and improving usability to achieve true security. This course provides practical and research-oriented knowledge about usable security and privacy. Students will gain practical experience through focused presence exercises and work in small teams to conduct a semester-wide research project with the goal of designing and pretesting a user study on human-centered security and privacy. For that, the course will present research methods and give an introduction into HCI and usability concepts. The course will also address foundational and state-of-the-art research topics in the area, such as privacy and transparency enhancing tools, usable authentication, and developer-centered security. By reviewing relevant papers and giving presentations, the students will get familiar with the latest research in the field and gain knowledge about how to work scientifically. The course includes the following contents: • Security and privacy concepts • Foundations of cryptography • Privacy and transparency enhacing tools • HCI and usability research methods • Ethics in technology • Quantitative and qualitative data analysis • Usable authentication • Usable privacy • Developer-centered security
5	**Learning outcomes and competences:** Participants of the course • gain an appreciation for the importance of usable security and privacy • learn about the history of the field and main research areas and challenges • are able to apply methodologies to conduct user research in security and privacy **Non-cognitive Skills** • Literacy (scientific) • Self-monitoring • Team work

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 min or 40 min	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Practical work with written report and discussion		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr. Patricia Arias Cabarcos

13	**Other Notes:** *Remarks of course Usable Security and Privacy:* **Implementation method** Basic concepts are presented in a lecture style format. By engaging in presence exercises and conducting a research project in small groups focused on a user-study for usable security and privacy research throughout the semester, students can acquire more profound theoretical and practical knowledge. **Learning Material, Literature** • Lazar, J., Feng, J.H. and Hochheiser, H., 2017. Research methods in human-computer interaction. Morgan Kaufmann. • Redmiles, E.M., Acar, Y., Fahl, S. and Mazurek, M.L., 2017. A summary of survey methodology best practices for security and privacy researchers. • Slides and scientific literature references will be given during the course.

VLSI-Testing

VLSI-Testing

Module number:	Workload (h):	Credits:	Regular Cycle:
M.048.92027	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	1.-3. Semester	1	en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.92027 VLSI Testing	2L 2Ex, WS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course VLSI Testing:
Recommended: Digital Design

4 **Contents:**

Contents of the course VLSI Testing:
Short Description
The course “VLSI Testing” focuses on techniques for detecting hardware defects in micro-electronic circuits. Algorithms for test data generation and test response evaluation as well as hardware structures for design for test (DFT) and on-chip test implementation (BIST) are presented.
Contents
In detail the following topics are covered:

- Fault models
- Testability measures and design for test (DFT)
- Logic and fault simulation
- Automatic test pattern generation (ATPG)
- Built-in self-test (BIST), in particular test data compression and test response compaction
- Memory test

5 **Learning outcomes and competences:**

Domain competence:
After attending the course, the students will be able

- to describe fault models, DFT techniques, and test tools,
- to explain and apply the underlying models and algorithms for fault simulation and test generation,
- to analyze systems with respect to their testability and to derive appropriate test strategies.

Key qualifications:
The students

- are able to apply the practiced strategies for problem solving across varying disciplines,
- have experience in presenting their solutions to their fellow students, and
- know how to improve their competences by private study.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Informatik v3, Masterstudiengang Informatik v4, Master's Program Electrical Systems Engineering v2 (ESEMA v2), Master's Program Electrical Systems Engineering v3 (ESEMA v3)

12 **Module coordinator:**

Prof. Dr. Sybille Hellebrand

13	**Other Notes:** *Remarks of course VLSI Testing:* --- **ATTENTION - IMPORTANT NOTICE** The course doesn't take place in winter term 2026/27 summer term 2026. Please see the notice boards of the group. --- **Course Homepage** `https://ei.uni-paderborn.de/en/electrical-engineering/date/teaching/electrical-engineering/overview` **Implementation** • Lecture based on slide presentation, extensions on blackboard • Exercises in small groups based on exercise sheets with students presenting their own solutions • Hands-on exercises using various software tools **Teaching Material, Literature** Additional material can be found in panda • Michael L. Bushnell, Vishwani D. Agrawal, „Essentials of Electronic Testing for Digital, Memory, and Mixed-Signal VLSI Circuits,"Boston, Dordrecht, London: Kluwer Academic Publishers, 2000 • Laung-Terng Wang, Cheng-Wen Wu, Xiaoqing Wen, „VLSI Test Principles and Architectures: Design for Testability," Morgan Kaufmann Series in Systems on Silicon, ISBN: 0123705975

3.3 Specialisation Area “Control and Automation”

Specialisation Area	Control and Automation
Modules	* Advanced System Theory * Advanced Topics in Robotics * Control of Grid-Tied Converters * Gekoppelte Felder * Geregelte Drehstromantriebe * Machine Learning I * Nonlinear control of autonomous and robotic systems * Optimization-Based Control Methods * Robotics * Ultraschallmesstechnik
Catalogue advisor	Head of Examination Board CE (PAV CE).
Credits ECTS	6
Learning objectives	

The modules from this specialisation area enable specialisation in the field of control and automation technology.

Advanced System Theory			
Advanced System Theory			
Module number: M.048.92001	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1. Semester	**Duration (in sem.):** 1	**Teaching Language:** de / en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.92001 Advanced System Theory	2L 2Ex, WS/SS	60	120	C	60/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Advanced System Theory:
Recommended:
Prerequisites are a basic understanding of differential equations, linear algebra, and Laplace transforms, as they are covered in a typical undergraduate course on system theory.

4 **Contents:**

Contents of the course Advanced System Theory:
Short Description
Building on an undergraduate system theory course, this course studies the dynamical behavior of linear systems with greater mathematical rigor. The course is primarily intended to serve students in engineering, but it can also be useful to students in physics and other natural sciences.
Contents

- System models and differential equations
- State-space and I/O descriptions
- Relations between internal and external descriptions
- Response of continuous- and discrete-time systems
- Stability, controllability, observability
- State-space realizations of external descriptions

5 **Learning outcomes and competences:**

After attending this course, students will be familiar with the most important concepts and results in linear system theory. Students will develop confidence in their ability to solve mathematical problems of analysis and design. Many of their timeless insights and intuitions about the dynamical behavior of systems will be drawn from this course. This course presents material broad enough so that students will have a clear understanding of the dynamical behavior of linear systems, including their power and limitations. This will allow students to apply the theory to other fields.

<table>
<tr><td>6</td><td>Assessments:
☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table>
<tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr>
<tr><td>a)</td><td>Written or Oral Examination or Presentation</td><td>120-180 min or 30-45 min or 30 min</td><td>100%</td></tr>
</table></td></tr>
<tr><td>7</td><td>Study Achievement:
none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Master’s Program Electrical Systems Engineering v2 (ESEMA v2), Master’s Program Electrical Systems Engineering v3 (ESEMA v3)</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr. Erdal Kayacan</td></tr>
<tr><td>13</td><td>Other Notes:
Remarks of course Advanced System Theory:
Course Homepage
https://en.ei.uni-paderborn.de/rat
Implementation
Lectures and exercises (including some computer simulations) Panda course for communication and material distribution
Teaching Material, Literature
Handouts and exercise / tutorial questions; literature references will be given in the first lecture</td></tr>
</table>

Advanced Topics in Robotics			
Advanced Topics in Robotics			
Module number: M.048.92006	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.92006 Advanced Topics in Robotics	2L 2Ex, WS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Advanced Topics in Robotics:
None

4 **Contents:**

Contents of the course Advanced Topics in Robotics:
Short Description
The course Advanced Topics in Robotics is based on the course Robotics. The students are introduced to current research topics in the field of autonomous and teleoperated mobile robots to solve interdisciplinary issues. The challenges encountered in developing intelligent mobile systems are analyzed and current solutions presented.
Contents

- Architectures of robot systems
- Middleware for hardware abstraction
- Device drivers and libraries
- Visualization
- Local navigation processes (collision avoidance)
- Global navigation processes (pathfinding)
- Navigation and self-localization methods (SLAM)
- Fundamentals of task planning

<table>
<tr><td>5</td><td>Learning outcomes and competences:

Domain competence:
The students

• are able to name and analyze the basic robot architectures for mobile robots,
• have a good command of the methods for the navigation and control of mobile robots and
• are able to implement, test and apply them.

Key qualifications:
The students have a good command of programming in the C language</td></tr>
<tr><td>6</td><td>Assessments:

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

<table><tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr><tr><td>a)</td><td>Written or Oral Examination or Presentation</td><td>120-180 min or 30-45 min or 30 min</td><td>100%</td></tr></table></td></tr>
<tr><td>7</td><td>Study Achievement:

none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:

None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:

The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:

The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Master’s Program Electrical Systems Engineering v2 (ESEMA v2), Master’s Program Electrical Systems Engineering v3 (ESEMA v3)</td></tr>
<tr><td>12</td><td>Module coordinator:

Prof. Dr. Bärbel Mertsching</td></tr>
</table>

13	**Other Notes:** *Remarks of course Advanced Topics in Robotics:* --- **ATTENTION - IMPORTANT NOTICE** The course doesn't take place in winter term 2026/27 summer term 2026. Please see the notice boards of the group. --- **Course Homepage** `http://getwww.uni-paderborn.de/teaching/atir` **Implementation** • The theoretical and methodical fundamentals will be introduced during the lecture. • The methods presented will be practiced during the subsequent exercise / lab part. • Finally, the participants will implement, test, and apply simple algorithms. • The necessary programming skills will be taught during the practical, this is explicitly not considered a programming course. **Teaching Material, Literature** Allocation of lecture notes; information on textbooks stocked in the textbook collection will be announced later. • Mertsching, Bärbel: Robotics (lecture notes) • McKerrow, Phillip J.: Introduction to Robotics. Addison-Wesley, 1991 • Siegwart, Roland; Nourbakhsh, Illah R. and Scaramuzza, David: Introduction to Autonomous Mobile Robots. The MIT Press, 2011, ISBN-13: 978-0262015356

Gekoppelte Felder			
Coupled Fields			
Module number: M.048.27028	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** de

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.27028 Coupled Fields	2L 2Ex, SS	60	120	C	40/40

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Gekoppelte Felder:
Recommended: Basic knowledge from the area of classical field theory, for example from the modules “Field Theory”, “Electromagnetic Waves” and “Theoretical Electrical Engineering”.

4 **Contents:**

Contents of the course Gekoppelte Felder:
The focus of the course Coupled Fields is the classical field theory of interacting electromagnetic, thermal and mechanical phenomena as well as their application in sensors and actuators. After an introduction to the mathematical description of the individual fields, the following topics are covered:

- Electromechanical coupling based on examples in piezoelectricity, electrostriction and magnetostriction.
- Thermomechanical coupling such as thermoelasticity and lossy acoustic waves.
- Thermoelectric coupling, for example pyroelectricity.
- Phenomena with electromagnetic-thermal-mechanical coupling such as the photoacoustic effect. In addition to the description of the effects, analogies as well as similarities and differences are considered and aspects of numerical simulation are discussed.

5	**Learning outcomes and competences:** After attending the course, students will be able to • describe the discussed physical effects phenomenologically and with differential equations. • interpret the results of numerical simulations of coupled fields and check them for plausibility. • select suitable components for sensor and actuator applications of coupled fields. • infer an acting physical effect from observations.
6	**Assessments:** ☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	Type of examination	Duration or scope	Weighting for the module grade
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the examination will be conducted.

7	**Study Achievement:** none
8	**Prerequisites for participation in examinations:** None
9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** BF Automatisierungstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4
12	**Module coordinator:** Dr.-Ing. Leander Claes

13	**Other Notes:** **Module Homepage** `https://emt.upb.de` **Implementation** Lectures and exercises (including some computer simulations) **Teaching Material, Literature** Lecture slides and exercises will be provided. Additional literature references will be given throughout the course.

Regelung elektrischer Antriebe			
Control of Electric Drives			
Module number: M.048.27013	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.27013 Control of Electric Drives	2L 2Ex, SS	60	120	C	40/40

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Regelung elektrischer Antriebe:
Recommended:

- basics of control theory
- basics of electrical machines
- basics of power electronics

4 **Contents:**

Contents of the course Regelung elektrischer Antriebe:
Short Description
The course teaches the closed-loop control for electrical machines (DC machines, synchronous machines, and induction machines). The presented content is tested in simulations within the exercises.
Contents

- machine models (dc machines, synchronous machines, and induction machines)
- coordinate transformations
- field-oriented control for particular machines
- observers
- advanced control techniques (direct torque control, model-predictive control)

<table>
<tr><td>5</td><td>Learning outcomes and competences:
After successfully completing the module, students will be able to
• explain the functionality of electric drives (based on dc machines, synchronous machines, and induction machines)
• set up a simulation model for the target application
• design a suitable control system for the particular electric machines and implement it as a simulation model</td></tr>
<tr><td>6</td><td>Assessments:
☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table>
<tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr>
<tr><td>a)</td><td>Written or Oral Examination or Presentation</td><td>120-180 min or 30-45 min or 30 min</td><td>100%</td></tr>
</table></td></tr>
<tr><td>7</td><td>Study Achievement:
none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
BF Automatisierungstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr.-Ing. Jakub Kucka</td></tr>
<tr><td>13</td><td>Other Notes:
Remarks of course Regelung elektrischer Antriebe:
Implementation
Parts of the course are organized as computer-based simulation exercises.
Teaching Material
Lecture slides.</td></tr>
</table>

Geregelte Netzumrichter			
Control of Grid-Tied Converters			
Module number: M.048.22021	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** de

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.22021 Control of Grid-Tied Converters	2L 2Ex, WS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Geregelte Netzumrichter:
Recommended:

- Basics of Power Electronics (recommended)
- Basics of Control Theory (recommended)

4 **Contents:**

Contents of the course Geregelte Netzumrichter:
The goal of this module is to develop application-oriented skills regarding the operation of grid-tied converters. The focus is on the operational principles, requirements, and control.

- grid codes and other requirements
- three-phase and single-phase voltage converter topologies for grid operation
- modeling the inverter components for simulation purposes
- voltage and current transformations utilized for control
- the control algorithms for these topologies
- different PLLs and their properties

<table>
<tr><td>5</td><td>Learning outcomes and competences:
After successfully completing the module, students will be able to
• explain the functionality of grid-tied converters
• set up a simulation model for the target application
• design a suitable control system for the grid operation of the single-phase and three-phase inverters and implement it as a simulation model
• explain essential grid code requirements</td></tr>
<tr><td>6</td><td>Assessments:
⊠Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table>
<tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr>
<tr><td>a)</td><td>Written or Oral Examination or Presentation</td><td>120-180 min or 30-45 min or 30 min</td><td>100%</td></tr>
</table></td></tr>
<tr><td>7</td><td>Study Achievement:
none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
BF Automatisierungstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr.-Ing. Jakub Kucka</td></tr>
<tr><td>13</td><td>Other Notes:
Implementation
Lectures and exercises (including some computer simulations)
Teaching Material, Literature
Handouts and tutorial questions; literature references will be given in the first lecture</td></tr>
</table>

Machine Learning I

Machine Learning I

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.01274	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	beliebig	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05701 Machine Learning 1	L3 Ex2	75	105	C	75/25

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Machine Learning 1:
Recommended Proficiencies
Basic knowledge in mathematics (linear algebra, statistics), programming and algorithms.

4 **Contents:**

Contents of the course Machine Learning 1:
Due to the ever increasing amount of data that is routinely produced in our information society, the topic of machine learning has become increasingly important in the recent years, not only as a scientific discipline but also as a key technology of modern software and intelligent systems. This lecture provides an introduction to the topic of machine learning, with a specific focus on supervised learning for classification and regression. The lecture covers theoretical foundations of generalisation as well as practical topics and concrete learning algorithms.

- Introduction
- Foundations (e.g., the learning problem, generalization theory, bias-variance tradeoff)
- Techniques (e.g., The linear model, non-linear techniques, SVM, tree-based methods, ensembles, deep learning)
- Validation and practical implementations (e.g., metrics, training vs testing, cross-validation, AutoML)

5 **Learning outcomes and competences:**

The students understand the statistical foundations of generalisation, i.e., the induction of models from data, as well as practical tools for model validation. They are able to apply basic methods of supervised learning to problems of classification and regression.

Non-cognitive Skills

- Learning competence
- Learning motivation
- Literacy (scientific)

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 minutes or 40 minutes	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Assignments, course paper or progress reports		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr. Eyke Hüllermeier

13	**Other Notes:** *Remarks of course Machine Learning 1:* **Implementation method** Theoretical foundations and concepts of machine learning will be taught in the form of a lecture and deepened in practical exercise courses, group work as well as individual homework. **Learning Material, Literature** • Script • Y.S. Abu-Mostafa, M. Magdon-Ismail, H.T. Lin. Learning from Data, AMLBook, 2012. • P. Flach. Machine Learning, Cambridge Univ. Press, 2012. • E. Alpaydin. Machine Learning, Oldenbourg, 2008. • C.M. Bishop. Pattern Recognition and Machine Learning, Springer, 2006.

<table>
<tr><th colspan="5">Nonlinear control of autonomous and robotic systems</th></tr>
<tr><td colspan="5">Nonlinear control of autonomous and robotic systems</td></tr>
<tr><td colspan="2">Module number:
M.048.27032</td><td>Workload (h):
180</td><td>Credits:
6</td><td>Regular Cycle:
module.frequency.en</td></tr>
<tr><td colspan="2"></td><td>Semester number:
1.-3. Semester</td><td>Duration (in sem.):
1</td><td>Teaching Language:
en</td></tr>
<tr><td>1</td><td colspan="4">Module structure:
<table>
<tr><th></th><th>Course</th><th>form of teachin</th><th>contact-time (h)</th><th>self-study (h)</th><th>status (C/CE)</th><th>group size (TN)</th></tr>
<tr><td>a)</td><td>L.048.27032
Nonlinear control of autonomous and robotic systems</td><td>2L
2Ex,
SS</td><td>60</td><td>120</td><td>C</td><td>30/30</td></tr>
</table></td></tr>
<tr><td>2</td><td colspan="4">Options within the module:
None</td></tr>
<tr><td>3</td><td colspan="4">Admission requirements:
None

Prerequisites of course Nonlinear control of autonomous and robotic systems:
Recommended:
Prerequisites are a basic understanding of linear algebra, linear system theory, and control theory as they are covered in a typical undergraduate course on control theory.</td></tr>
<tr><td>4</td><td colspan="4">Contents:

Contents of the course Nonlinear control of autonomous and robotic systems:
Building on an undergraduate control theory course, this course introduces the analysis and control of nonlinear dynamical systems. The course focuses on fundamental nonlinear control concepts and methods, with particular emphasis on their application to autonomous and robotic systems. It is primarily intended for engineering students but may also be useful to students in physics and other natural sciences.
Contents

• Nonlinear system modeling and state-space representations
• Phase-plane analysis and nonlinear system behavior
• Equilibrium points and local stability analysis
• Lyapunov stability theory
• Feedback linearization and nonlinear controller design
• Nonlinear control applications in autonomous and robotic systems</td></tr>
<tr><td>5</td><td colspan="4">Learning outcomes and competences:
-</td></tr>
</table>

<table>
<tr><td>6</td><td>Assessments:
☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table><tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr><tr><td>a)</td><td>Written or Oral Examination or Presentation</td><td>120-180 min or 30-45 min or 30 min</td><td>100%</td></tr></table>The credit points are awarded after the module examination (MAP) was passed.
The credit points are awarded after all module examinations (MTP) were passed.</td></tr>
<tr><td>7</td><td>Study Achievement:
none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
Module Homepage
http://sst.upb.de/teaching
Implementation
Lectures and exercises (including some computer simulations)
Teaching Material, Literature
Handouts and tutorial questions; literature references will be given in the first lecture</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The credit points are awarded after all module examinations (MTP) were passed.</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr. Erdal Kayacan</td></tr>
<tr><td>13</td><td>Other Notes:
Module Homepage
http://sst.upb.de/teaching
Implementation
Lectures and exercises (including some computer simulations)
Teaching Material, Literature
Handouts and tutorial questions; literature references will be given in the first lecture</td></tr>
</table>

Optimization-Based Control Methods			
Optimization-Based Control Methods			
Module number: M.048.27031	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.27031 Optimization-Based Control Methods	2L 2Ex, WS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Optimization-Based Control Methods:
None

4 **Contents:**

Contents of the course Optimization-Based Control Methods:
The course begins with Bellman's Principle of Optimality and introduces the foundations of Dynamic Programming (DP) techniques for solving optimization problems in finite and infinite time horizons. Based on this framework, students will study Finite and Infinite Horizon Optimal Control Problems, learning how to apply DP to real-world control problems over different time scales. A significant portion of the course is then devoted to linear quadratic regulator (LQR) and linear quadratic estimator (LQE) problems, focusing on designing Optimal State Feedback controllers and estimators for linear systems. The linear quadratic Gaussian (LQG) framework then combines LQR and LQE into a robust framework for Gaussian state and measurement noise. To address optimization problems with state and input constraints, students will be introduced to Quadratic Programming (QP) and the fundamentals of Convex Optimization, which are essential for handling real-world control applications that impose limits on system inputs and states. A section on Model Predictive Control (MPC) will then focus on designing optimal control strategies for constrained linear systems by solving a series of optimization problems in real-time, offering a bridge between theory and industrial applications. The course then covers Approximate Dynamic Programming (ADP) and its connection to MPC, exploring methods to approximate optimal solutions for computationally intractable problems using traditional DP techniques. Lastly, students will use modern methods for designing Convex Optimization Control Policies, learning to create efficient and scalable control solutions using convexity and optimization frameworks. Finally, if time permits, the course will close with a short introduction to Proximal Policy Optimization methods.

<table>
<tr><td>5</td><td>Learning outcomes and competences:
-</td></tr>
<tr><td>6</td><td>Assessments:
☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table>
<tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr>
<tr><td>a)</td><td>Written or Oral Examination or Presentation</td><td>120-180 min or 30-45 min or 30 min</td><td>100%</td></tr>
</table></td></tr>
<tr><td>7</td><td>Study Achievement:
none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5)</td></tr>
<tr><td>12</td><td>Module coordinator:
Dr. Adrian Redder</td></tr>
<tr><td>13</td><td>Other Notes:
Module Homepage
http://sst.upb.de/teaching
Implementation
Lectures and exercises (including some computer simulations)
Teaching Material, Literature
Handouts and tutorial questions; literature references will be given in the first lecture</td></tr>
</table>

<table>
<tr><th colspan="5">Robotics</th></tr>
<tr><td colspan="5">Robotics</td></tr>
<tr><td colspan="2">Module number:
M.048.92012</td><td>Workload (h):
180</td><td>Credits:
6</td><td>Regular Cycle:
module.frequency.en</td></tr>
<tr><td colspan="2"></td><td>Semester number:
1.-3. Semester</td><td>Duration (in sem.):
1</td><td>Teaching Language:
en</td></tr>
<tr><td>1</td><td colspan="4">Module structure:
<table>
<tr><th></th><th>Course</th><th>form of teachin</th><th>contact-time (h)</th><th>self-study (h)</th><th>status (C/CE)</th><th>group size (TN)</th></tr>
<tr><td>a)</td><td>L.048.92012
Robotics</td><td>2L
2Ex,
SS</td><td>60</td><td>120</td><td>C</td><td>30/30</td></tr>
</table></td></tr>
<tr><td>2</td><td colspan="4">Options within the module:
None</td></tr>
<tr><td>3</td><td colspan="4">Admission requirements:
None
Prerequisites of course Robotics:
None</td></tr>
<tr><td>4</td><td colspan="4">Contents:
Contents of the course Robotics:
Short Description
The course “Robotics” is a fundamental module in the catalog “Cognitive Systems” of the Electrical Engineering Master’s program and related degree programs. It is the first of two courses that cover the relevant concepts and techniques in the field of robot manipulators and mobile robots. This course concentrates on modeling and controlling robot arms, while its successor in the winter semester (Advanced Topics in Robotics (L.048.23020 / L.048.92006) focuses on mobile robots. The challenges for the development of autonomous intelligent systems will be analyzed and the current solutions will be presented.
Contents
• Sensors, effectors, actuators
• Homogenous coordinates, general transformations, Denavit-Hartenberg parameters
• Kinematics and dynamics of robot arms and mobile robots
After the presentation of methods in the lecture, the students will use Matlab and Octave to implement them.</td></tr>
</table>

<table>
<tr><td>5</td><td>Learning outcomes and competences:

Domain competence:
The students

• know how to transfer basic methods from control and system theory to robotics and
• are able to apply adequate methods to model as well as plan and control the movements of robot arms.

Key qualifications:
The students are able to identify and evaluate the function and behavior of robots and their integration into the social and economic environment while also considering ethical aspects.</td></tr>
<tr><td>6</td><td>Assessments:

⊠Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

<table><tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr><tr><td>a)</td><td>Written or Oral Examination or Presentation</td><td>120-180 min or 30-45 min or 30 min</td><td>100%</td></tr></table></td></tr>
<tr><td>7</td><td>Study Achievement:

none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:

None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:

The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:

The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Master’s Program Electrical Systems Engineering v2 (ESEMA v2), Master’s Program Electrical Systems Engineering v3 (ESEMA v3)</td></tr>
<tr><td>12</td><td>Module coordinator:

Prof. Dr. Bärbel Mertsching</td></tr>
</table>

13	**Other Notes:** *Remarks of course Robotics:* --- **ATTENTION - IMPORTANT NOTICE** The course doesn't take place in winter term 2026/27 summer term 2026. Please see the notice boards of the group. --- **Course Homepage** [http://getwww.uni-paderborn.de/teaching/robotik] **Course Documents** see PANDA ([https://panda.uni-paderborn.de]) **References (excerpt)** • Mertsching, Bärbel: Robotics (lecture notes) • McKerrow, Phillip J.: Introduction to Robotics. Addison-Wesley, 1991 • Lynch, Kevin M. and Park, Frank C.: Modern Robotics: Mechanics, Planning, and Control. Cambridge University Press, 2017. ISBN-13 : 978-1107156302

Ultraschallmesstechnik			
Ultrasonic measurement technology			
Module number: M.048.27015	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** de

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.27015 Ultrasonic Measurement Technology	2L 2Ex, SS	60	120	C	40/40

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Ultraschallmesstechnik:
None

4 **Contents:**

Contents of the course Ultraschallmesstechnik:
Short description
The course Ultrasonic Measurement Technology deals with the phenomena of propagation of mechanical waves in solids, liquids and gases. Based on this the most important acoustic measurement principles for the determination of acoustic material parameters, geometric and technical process parameters as well as their application in process and production engineering are described. The application of sound and ultrasound for non-destructive material diagnostics as well as for ultrasonic tomography are covered in detail.
Contents
The Ultrasonic Metrology lecture covers the following topics:

- Acoustic and sound field characteristics.
- Fundamentals of wave propagation
- Ultrasonic sensor design (experimental realization)
- Methods for measurement and visualization of ultrasonic fields (needle and membrane hydrophone, schlieren measuring station, laser vibrometry. . .)
- Metrological methods for acoustic material data determination (sound velocity, sound characteristic impedance. . .)
- Application of ultrasound for non-destructive testing (NDT) and acoustic emission analysis
- Application of ultrasound and in process measurement technology (distance, flow, level. . .)

5	**Learning outcomes and competences:** **Specialized competence:** After attending the course, students will be able to, • use ultrasound to determine acoustic and non-acoustic quantities. **Cross-disciplinary competencies:** The students • are able to apply the knowledge and skills across disciplines and to complex problems, • are able to develop targeted solutions on the basis of systematic problem analysis, • are able to familiarize themselves with tangential fields of work due to the method-oriented knowledge transfer.
6	**Assessments:** ☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	Type of examination	Duration or scope	Weighting for the module grade
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7	**Study Achievement:** none
8	**Prerequisites for participation in examinations:** None
9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** BF Automatisierungstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4
12	**Module coordinator:** Prof. Dr. Bernd Henning

13	**Other Notes:** *Remarks of course Ultraschallmesstechnik:* **Course Homepage** `http://emt.upb.de` **Methodical implementation** • Lectures with slide presentation of extensive correlations • Practical work in groups using measurement techniques in the laboratory **Learning materials, references** • Provision of a script; references to textbooks from the textbook collection will be announced.

3.4 Specialisation Area “Embedded Systems”

Specialisation Area	Embedded Systems
Modules	* Advanced VLSI Design * Approximate Computing * Hardware/Software Codesign (EIM-I) * Integrierte Schaltungen für die drahtlose Kommunikation * Hardware Security * Machine Learning I * Model-Based Systems Engineering * Reconfigurable Computing * Resource-Efficient AI: Architectures and Methodologies * Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation * Software Quality Assurance * VLSI Testing
Catalogue advisor	Head of Examination Board CE (PAV CE).
Credits ECTS	6
Learning objectives	

The modules from this specialisation area enable specialisation in the field of embedded systems.

Advanced VLSI Design			
Advanced VLSI Design			
Module number: M.048.92043	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.92043 Advanced VLSI Design	2L 2Ex, SS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Advanced VLSI Design:
Recommended: Fundamentals of Digital Circuits / Fundamentals of VLSI Design
Information: Unless otherwise specified, these are recommendations.

4 **Contents:**

Contents of the course Advanced VLSI Design:
Short Description
The course provides basic knowledge about the modern application-oriented modeling, simulation, analysis, and synthesis of digital systems at different abstraction levels to chip layout.
Contents
In today's practice, chip design consists of the combined application of various languages, methods, and tools for the modeling, simulation, and synthesis of electronic circuits. Along the modern abstraction-based design flow of digital systems (electronic system level to chip layout), the course provides basic knowledge of the main description languages and their application in modeling, simulation, analysis and synthesis. This includes basic principles and application of the IEEE standard system/hardware description languages SystemVerilog, SystemC, Verilog, and VHDL, in conjunction with additional formats, e.g., SDF and UPF for time and power annotation. For their application, the fundamental principles of test environments for simulation, timing and power analysis, logic synthesis and physical design of digital circuits. Exercises will provide hands-on labs based on commercial tools from Mentor Graphics, Synopsys and, Cadence Design Systems.

5	**Learning outcomes and competences:** **Domain competence:** After the course students are able • to model, simulate, analyze and synthesize simple digital circuits at different abstraction levels and • to apply the most important commercial tools for simulation, analysis and synthesis of digital circuits. **Key qualifications:** After the course students are able • to assess, select and apply modern digital circuit description languages for their different applications, • apply the different methods and tools in the modern VLSI design.
6	**Assessments:** ☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7	**Study Achievement:** none
8	**Prerequisites for participation in examinations:** None
9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Master's Program Electrical Systems Engineering v2 (ESEMA v2), Master's Program Electrical Systems Engineering v3 (ESEMA v3)
12	**Module coordinator:** apl. Prof. Dr. Wolfgang Mueller

13	**Other Notes:** *Remarks of course Advanced VLSI Design:* **Course Homepage** `www.hni.uni-paderborn.de/en/system-and-circuit-technology/teaching/advanced-vlsi-design` **Implementation** * Vorlesung mit Beamer und White-Board * Übungen mit Übungsblättern am Computer * Lecture with LCD projector and white board * Exercises with assignments and hands-on labs **Teaching Material, Literature** • Lecture notes and exercise sheets will be provided via PAUL • IEEE standard reference manuals: IEEE Std 1800/1685/1666/1364/1076/1801/1497 • Specific references for individual teaching units

Approximate Computing

Approximate Computing

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.01278	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	1-3	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.09758 Approximate Computing	L3 Ex2	75	105	C	100/30

2 **Options within the module:**

none

3 **Admission requirements:**

none

Prerequisites of course Approximate Computing:
Recommended Proficiencies
Knowledge of the Bachelor-level courses Digital Design and Computer Architecture are beneficial.

4 **Contents:**

Contents of the course Approximate Computing:
Approximate Computing is an emerging paradigm that trades-off computational accuracy for a significant reduction in energy, execution time, or chip area. This research-oriented course introduces to the field of Approximate Computing and its most remarkable aspects, and explains the main methods used to implement efficient computing systems by reducing accuracy. The course discusses approximations at all levels of a computing system, from applications down to hardware technologies. In exercise/tutorial sessions the efficiency of these techniques in various domains are examined, including deep learning and digital signal processing.

- Introduction and motivation for approximate computing
- Approximation at the application level, e.g., in machine learning and digital signal processing
- Programming languages/compilers for approximate computing
- Approximate microarchitectures
- Automated synthesis of approximate circuits
- Inexact arithmetic components and performance optimization via accuracy trade-offs
- Approximation techniques at the technology level
- Exercises/tutorial: Approximating deep learning and digital signal processing algorithms

5 **Learning outcomes and competences:**

After attending this course, the students are able

- to name and explain approximation techniques at all levels of a computing system,
- to identify major engineering/research problems when building approximate computing systems,
- to judge the suitability of approximation techniques for different application domains, and
- to apply approximation techniques to realize efficient hardware accelerators, in particular for deep learning and digital signal processing

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination or report	90-120 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Assignments, course paper or progress reports		CA

8 **Prerequisites for participation in examinations:**

Prerequisite for the participation in the examination is the study achievement in the course “Approximate Computing”.

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr. Marco Platzner

13	**Other Notes:** *Remarks of course Approximate Computing:* **Implementation method** • Lecture with projector and black/white board • Interactive exercises/discussions in the lecture room • Computer-based tutorials **Learning Material, Literature** • Lecture slides, exercise sheets, and tutorial assignments • Adrian Sampson, Luis Ceze, and Dan Grossman: Good-Enough Computing. IEEE Spectrum, 50(10):54-59, 2013 • Ravi Nair. Big Data Needs Approximate Computing: Technical Perspective. Communications of the ACM, 58(1): 104, 2015. • Sparsh Mittal. A Survey of Techniques for Approximate Computing. ACM Computing Surveys, 48(4), 2016. • Qiang Xu, Todd Mytkowitz, and Nam Sung Kim. Approximate Computing: A Survey. IEEE Design & Test, 33(1):8-22, 2016. • Weiqiang Liu and Fabrizio Lombardi (Editors), Approximate Computing. Springer, 2022. • Additional resources and links to current research papers are provided in the lecture.

Integrierte Schaltungen für die drahtlose Kommunikation

Integrated Circuits for Wireless Communications

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.048.25017	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	1.-3. Semester	1	de / en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.25017 Integrated Circuits for Wireless Communications	2L 2Ex, SS	60	120	C	40/40

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Integrierte Schaltungen für die drahtlose Kommunikation:
Recommended: Lecture Schaltungstechnik rsp. Circuit and System Design. Helpful supplement: Lecture “Wireless Communications” of Prof. Hab-Umbach.

4 **Contents:**

Contents of the course Integrierte Schaltungen für die drahtlose Kommunikation:
Short Description
Mobile communications, wireless networks, and RFID technology are application examples of wireless communications. Wireless communications has found widespread use in everyday life and will become even more important in the future. The design of electronic circuits for radio frequencies requires a good system knowledge with respect to typical transmitter and receiver architectures in wireless communications, components, and radio signal properties. Furthermore a thorough understanding of integrated circuit design as well as precise high-frequency modeling of passive and active devices are required. Goal of the lecture is to convey a methodical approach to the design of integrated circuits for wireless communications. A part of the exercises will pertain to calculation of circuit design problems another will be performed in small teams as a hands-on exercise using modern IC design software.
Contents
The lecture deals with analysis and design of radio frequency integrated circuits for wireless communication systems. A part of the exercises will be performed using modern chip design CAD tools. The lecture is based on the compulsory lectures “Schaltungstechnik” rsp. “Circuit and System Design”. The following topics will be addressed:

- Transmitter and receiver architectures for wireless communications
- System Theory Basics
  - Signals and noise
  - Modulation and demodulation
  - Transmission properties of wireless communcations systems
- Semiconductor technologies and integrated high-frequency devices
- Amplifiers (low-noise and variable-gain amplifiers)
- Mixers
- Oscillators
- Frequency synthesizer PLLs

5 **Learning outcomes and competences:**

The students will be able

- to describe architectures and circuits of wireless communication systems
- to describe and calculate fundamental signal transmission properties of wireless systems
- to apply design methods to design components of radio frequency ICs

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Oral Examination	30-45 min	100%

7 **Study Achievement:**

none

8	**Prerequisites for participation in examinations:** None
9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4
12	**Module coordinator:** Prof. Dr.-Ing. J. Christoph Scheytt
13	**Other Notes:** *Remarks of course Integrierte Schaltungen für die drahtlose Kommunikation:* **Course Homepage** `https://www.hni.uni-paderborn.de/en/system-and-circuit-technology/teaching/integrierte-schaltungen-fuer-die-drahtlose-kommunikation/` **Implementation** • Lecture with Powerpoint presentation and handwritten mathematical derivations using tablet and beamer • Exercises partly as handwritten calculation exercises using tablet and beamer and partly as practical IC design exercises using IC design software **Teaching Material, Literature** Lecture slides and videos as well as exercise slides will be made available. • Behzad Razavi “RF Microelectronics”, Prentice Hall, 2011 • Thomas Lee “The Design of CMOS Radio-Frequency Integrated Circuits”, Cambridge University Press 2003

Hardware Security

Hardware Security

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.4211	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	1-3	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	K.079.42111 Hardware Security	L3 Ex2	75	105	C	30

2 **Options within the module:**

none

3 **Admission requirements:**

none

Prerequisites of course Hardware Security:
Knowledge in programming, IT security and basic knowledge in cryptography

4 **Contents:**

Contents of the course Hardware Security:
All of the software we use and rely on ends up being executed on actual hardware. The interactions between software and hardware it runs on are becoming more and more complex. Thus, secure software may turn out to be insecure when ran on particular hardware. Attackers can utilize implementation bugs, logic bugs, or side-channels like timing or cache access to break applications or extract secrets out of cryptographic implementations. This lecture will cover various topics of securing and using secure hardware. The course includes the following contents:

- Brief background in cryptography
- Secure programming and implementation bugs
- Embedded and secure hardware
- Smartcards, U2F tokens
- Timing and micro-architectural attacks
- Passive and active side-channel attacks
- Side-channel attack defences
- Trusted Platform Modules, Secure boot
- Trusted Execution Environments
- Hardware Security Modules

5 **Learning outcomes and competences:**

Students will be able to

- Identify common software and hardware vulnerabilities that undermine secure systems, including memory bugs and API misuse.
- Explain the basic ideas behind side-channel and timing attacks.
- Identify general approaches to protecting implementations against these attacks.
- Describe the architecture, threat models, and security properties of trusted hardware components like TPMs, TEEs, and smartcards.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination or report	90-120 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Assignments, course paper or progress reports		

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Informatik v3, Masterstudiengang Informatik v4

12 **Module coordinator:**

Jan Jancar

13	**Other Notes:** *Remarks of course Hardware Security:* **Implementation Method** The topics are conveyed through lecture presentations with student participation and questions expected. Tutorials add hands-on tasks involving the material. Finally, homework assignments require individual work and self-study of additional material. **Learning Material, Literature** • Lecture and tutorial slides • The Hardware Hacking Handbook (ISBN: 9781593278748) and its associated notebooks at hardwarehacking.io • Power Analysis Attacks: Revealing the Secrets of Smart Cards (ISBN 9780387308579) • Embedded Cryptography 1 (ISBN: 9781394351879) • Embedded Cryptography 2 (ISBN: 9781394351909) • Embedded Cryptography 3 (ISBN: 9781394351930)

Machine Learning I

Machine Learning I

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.01274	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	beliebig	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05701 Machine Learning 1	L3 Ex2	75	105	C	75/25

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Machine Learning 1:
Recommended Proficiencies
Basic knowledge in mathematics (linear algebra, statistics), programming and algorithms.

4 **Contents:**

Contents of the course Machine Learning 1:
Due to the ever increasing amount of data that is routinely produced in our information society, the topic of machine learning has become increasingly important in the recent years, not only as a scientific discipline but also as a key technology of modern software and intelligent systems. This lecture provides an introduction to the topic of machine learning, with a specific focus on supervised learning for classification and regression. The lecture covers theoretical foundations of generalisation as well as practical topics and concrete learning algorithms.

- Introduction
- Foundations (e.g., the learning problem, generalization theory, bias-variance tradeoff)
- Techniques (e.g., The linear model, non-linear techniques, SVM, tree-based methods, ensembles, deep learning)
- Validation and practical implementations (e.g., metrics, training vs testing, cross-validation, AutoML)

5 **Learning outcomes and competences:**

The students understand the statistical foundations of generalisation, i.e., the induction of models from data, as well as practical tools for model validation. They are able to apply basic methods of supervised learning to problems of classification and regression.

Non-cognitive Skills

- Learning competence
- Learning motivation
- Literacy (scientific)

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 minutes or 40 minutes	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Assignments, course paper or progress reports		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr. Eyke Hüllermeier

13	**Other Notes:** *Remarks of course Machine Learning 1:* **Implementation method** Theoretical foundations and concepts of machine learning will be taught in the form of a lecture and deepened in practical exercise courses, group work as well as individual homework. **Learning Material, Literature** • Script • Y.S. Abu-Mostafa, M. Magdon-Ismail, H.T. Lin. Learning from Data, AMLBook, 2012. • P. Flach. Machine Learning, Cambridge Univ. Press, 2012. • E. Alpaydin. Machine Learning, Oldenbourg, 2008. • C.M. Bishop. Pattern Recognition and Machine Learning, Springer, 2006.

Model-Based Systems Engineering			
Model-Based Systems Engineering			
Module number: M.079.01277	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: beliebig	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.079.05815 Model-Based Systems Engineering	L3 Ex2	75	105	C	70/35

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Model-Based Systems Engineering:
Recommended Proficiencies
Basics of Systems Engineerings

4 **Contents:**

Contents of the course Model-Based Systems Engineering:
The goal of the lecture is a comprehensive understanding of Model-Based Systems Engineering (MBSE) and its components. The students are taught the essential topics of MBSE. This includes fundamentals including languages, methods and IT tools, which are also tested in practice. The benefits of MBSE (an understanding of the system by all involved actors, a basis for communication and cooperation between different disciplines but also functional areas, . . .) will be conveyed to the students. Furthermore, essential analysis methods for testing system designs are covered. The focus is on multidisciplinary, software-intensive systems from the mechanical and plant engineering and automotive industries.

- Basics of MBSE
- SysML for multidisciplinary systems
- CONSENS
- further MBSE approaches
- design patterns
- MBSE Tools
- analysis methods based on the system model

<table>
<tr><td>5</td><td>Learning outcomes and competences:

Learning Outcomes
Students will be able to,

• Work in a model-based manner
• Apply systems thinking
• Create system architectures & derive requirements.

Non-Cognitive Competencies

• Self-monitoring
• Literacy (scientific)
• Learning competence
• Learning motivation</td></tr>
<tr><td>6</td><td>Assessments:

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

<table><tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr><tr><td>a)</td><td>Written or oral examination</td><td>90-120 minutes or 40 minutes</td><td>100%</td></tr></table>
The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.</td></tr>
<tr><td>7</td><td>Study Achievement:

none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:

The credit points are awarded after the module examination was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:

The module is weighted as 6 credits.</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch</td></tr>
<tr><td>12</td><td>Module coordinator:

Prof. Dr.-Ing. Roman Dumitrescu</td></tr>
</table>

13	**Other Notes:** *Remarks of course Model-Based Systems Engineering:* **Implementation method** The module consists of three parts 1. lecture with slides: basics and concepts are explained in the lecture and illustrated with examples. 2. exercises (tutorial): In the exercises, knowledge is transferred and the concepts are applied. The exercises have to be prepared by the students themselves. 3. practical course (labs): In the practical course, the application of what has been learned takes place in group work. **Learning Material, Literature** • Friedenthal, S.; Moore, A.; Steiner, R.: A Practical Guide to SysML. The Systems Modeling Language. Morgan Kaufmann, Waltham, 2. Auflage, 2012 • Gausemeier, J.; Rammig, J.; Schäfer, W. (Eds.): Design Methodology for Intelligent Technical Systems. Develop Intelligent Technical Systems of the Future. Springer-Verlag, 2014 • Gausemeier, J.; Dumitrescu, R.; Steffen, D.; Czaja, A.; Wiederkehr, O.; Tschirner, C.: Systems Engineering in industrial practice. Heinz Nixdorf Institute, University • Haberfellner, R., L., D. W. O., Fricke, E., & Voössnersiegfried. (2019). Systems engineering: fundamentals and applications. Cham: Springer International Publishing • Incose Systemsengineeringhandbook: A Guide for System Life Cycle Processes and Activities(2015) • Weilkiens, Tim: Systems Engineering with SysML/UML: Modeling, Analysis, Design (The MK/OMG Press) (English Edition) • Dumitrescu, R.; Albers, A.; Riedel, O.; Stark, R.; Gausemeier, J. (Hrsg.): Engineering in Deutschland – Status quo in Wirtschaft und Wissenschaft, Ein Beitrag zum Advanced Systems Engineering, Paderborn, 2021 – English Version: www.advanced-systems-engineering.de

Reconfigurable Computing

Reconfigurable Computing

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.01270	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	beliebig	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05703 Reconfigurable Computing	L2 Ex3	75	105	CE	50/20

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Reconfigurable Computing:
Recommended Proficiencies
Knowledge of “Digital Design” and “Computer Architecture” is beneficial.

4 **Contents:**

Contents of the course Reconfigurable Computing:
This lecture provides an understanding of architectures and design methods for reconfigurable hardware systems and presents applications in the areas of high performance computing and embedded systems.

- Introduction: evolution of programmable logic devices, market economics
- Architectures: FPGA architectures, reconfigurable devices, reconfigurable systems
- Design methods: CAD for FPGAs, high-level languages and compilers, system-level design
- Applications: custom computing machines, embedded systems

5 **Learning outcomes and competences:**

After attending the course, the students are able to

- explain the architectures of reconfigurable hardware devices,
- name and analyze the main design methods and
- judge the suitability of reconfigurable hardware for different application domains.

Non-cognitive Skills

- Team work
- Learning competence

<table>
<tr><td>6</td><td>Assessments:
☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table>
<tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr>
<tr><td>a)</td><td>Written or oral examination</td><td>90-120 minutes or 40 minutes</td><td>100%</td></tr>
</table>
The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.</td></tr>
<tr><td>7</td><td>Study Achievement:
<table>
<tr><th>zu</th><th>Type of achievement</th><th>Duration or Scope</th><th>SL / QT</th></tr>
<tr><td>a)</td><td>Written exercises</td><td></td><td>CA</td></tr>
</table>
Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
Passing of course achievement</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The module is weighted as 6 credits.</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr. Marco Platzner</td></tr>
</table>

13	**Other Notes:** *Remarks of course Reconfigurable Computing:* **Implementation method** • Lecture with projector and board • Interactive exercises in the lecture room • Computer-based exercises with reconfigurable systems **Learning Material, Literature** • Lecture slides and exercise sheets • Exercise sheets and technical documentation for the for the computer-based exercises • S. Hauck and A. DeHon (editors): Reconfigurable Computing, Volume 1: The Theory and Practice of FPGA-Based Computation, Morgan Kaufmann, 2008 • Information about alternative and additional literature as well as teaching material on the course's website and in the lecture slides

<table>
<tr><th colspan="5">Resource-Efficient AI: Architectures and Methodologies</th></tr>
<tr><td colspan="5">Resource-Efficient AI: Architectures and Methodologies</td></tr>
<tr><td colspan="2">Module number:
M.048.23023</td><td>Workload (h):
180</td><td>Credits:
6</td><td>Regular Cycle:
module.frequency.en</td></tr>
<tr><td colspan="2"></td><td>Semester number:
1.-3. Semester</td><td>Duration (in sem.):
1</td><td>Teaching Language:
en</td></tr>
<tr><td>1</td><td colspan="4">Module structure:
<table>
<tr><th></th><th>Course</th><th>form of teachin</th><th>contact-time (h)</th><th>self-study (h)</th><th>status (C/CE)</th><th>group size (TN)</th></tr>
<tr><td>a)</td><td>L.048.23023 Resource-Efficient AI: Architectures and Methodologies</td><td>2L 2Ex, WS</td><td>60</td><td>120</td><td>C</td><td>30/30</td></tr>
</table></td></tr>
<tr><td>2</td><td colspan="4">Options within the module:
None</td></tr>
<tr><td>3</td><td colspan="4">Admission requirements:
None
Prerequisites of course Resource-Efficient AI: Architectures and Methodologies:
None</td></tr>
</table>

4 **Contents:**

Contents of the course Resource-Efficient AI: Architectures and Methodologies:
The course introduces methods and architectures for resource-efficient execution of modern artificial intelligence applications under performance, energy, and memory constraints. Topics include:

- Fundamentals of deep learning and training methodologies
- Characteristics of modern AI workloads (e.g., CNNs and transformers)
- Computational, memory, and energy bottlenecks during AI inference
- Techniques for efficient model design and optimization:
  - Quantization
  - Pruning and sparsity
  - Knowledge distillation
  - Efficient neural network architectures (e.g., MobileNet)
- Mapping AI workloads onto hardware platforms
- Architectures for AI acceleration:
  - SIMD and vector architectures
  - GPU architectures
  - Dataflow architectures and systolic arrays
  - Neural Processing Units (NPUs) and domain-specific accelerators
- Hardware-software co-design for efficient AI systems

5 **Learning outcomes and competences:**

After successful completion of the module, students are able to:

- explain fundamental principles of deep learning from a systems perspective,
- analyze AI workloads with respect to computational, memory, and communication requirements,
- identify performance, energy, and memory bottlenecks,
- apply model optimization techniques to improve efficiency,
- map AI workloads onto different hardware platforms and evaluate their suitability,
- compare different architectures for AI acceleration,
- analyze trade-offs between accuracy, latency, throughput, and energy efficiency,
- apply hardware-software co-design methodologies for resource-efficient AI systems.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8	**Prerequisites for participation in examinations:** None
9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** BF Automatisierungstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4
12	**Module coordinator:** Prof. Dr.-Ing. Lennart Bamberg
13	**Other Notes:** **Module Homepage** PANDA (more information will be provided in the first lecture) **Implementation** Lectures and exercises (including some computer simulations) **Teaching Material, Literature** Handouts and tutorial questions; literature references will be given in the first lecture

Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation			
Fast Integrated Circuits for Wireline Communications			
Module number: M.048.25019	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** de / en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.25019 Fast Integrated Circuits for Wireline Communications	2L 2Ex, WS	60	120	C	40/40

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation:
Recommended: Module “Schaltungstechnik” of the Bachelor Electrical Engineering or module “Circuit and System Design” of the Master “Electrical Systems Engineering” or comparable modules / lectures

4	**Contents:** *Contents of the course Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation:* **Short Description** Nowadays commercial fiber-optic communication systems reach very high data rates of 100 Gb/s per optical channel and several Tb/s in a single fiber. In a similar way very high data rates of more than 10 Gb/s occur at a single package pin of electronic chips. These signals are to be transmitted over printed circuit boards and inexpensive serial cables. In the future the progress of CMOS technology and communication technology will push speed of fiber-optic and wire-line communication continuously to ever higher data rates. The design of electronic circuits for high bandwidth rsp. data rates requires a good system knowledge with respect to typical transmitter and receiver architectures, components, and signal properties. Furthermore a thorough understanding of integrated circuit design as well as precise high-frequency modeling of passive and active devices are required. Goal of the lecture is to enable the student to utilize a methodological approach for the design of fast integrated electronic circuits for digital wired communications. A part of the exercises will be carried out using modern industry-standard IC design software. **Contents** The lecture deals with analysis and design of fast integrated electronic circuits for digital broadband communication systems. A part of the exercises will be performed using modern chip design CAD tools. The lecture is based on the compulsory lectures “Schaltungstechnik” rsp. “Circuit and System Design”. The lecture deals with: • Transmitter and receiver architectures for fiber-optic communications • Transmitter and receiver architectrues for chip-to-chip communications • System design • Semiconductor technology and integrated high-frequency devices • Broadband amplifiers • Current-mode logic • Transmitter and receiver circuits • PLLs for frequency synthesis and clock recovery • Measurement methods
5	**Learning outcomes and competences:** **Domain competence:** The student will be able to: • describe and analyze transmitter and receiver architectures for broadband communication links • understand and describe semiconductor technologies and integrated high-frequency devices for broadband circuits • to analyze circuit design techniques for transmitter and receiver circuits and describe ways to optimize them • to describe circuits in PLL technique for frequency synthesis and clock recovery • to describe measurement methods **Key qualifications:** The students will learn how different interdisciplinary scientific domains and their methods - like mathematical signal and system analysis, non-linear and linear circuit analysis, semiconductor physics, semiconductor devices and high-frequency engineering - are applied together for the development of communications application.

<table>
<tr><td>6</td><td>Assessments:
☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table>
<tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr>
<tr><td>a)</td><td>Oral Examination</td><td>30-45 min</td><td>100%</td></tr>
</table></td></tr>
<tr><td>7</td><td>Study Achievement:
none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr.-Ing. J. Christoph Scheytt</td></tr>
<tr><td>13</td><td>Other Notes:
Remarks of course Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation:
Course Homepage
https://www.hni.uni-paderborn.de/en/system-and-circuit-technology/teaching/fast-integrated-circuits-for-wireline-communications/
Implementation
Lecture with Exercises (including computer-aided design using electronic design software)
Teaching Material, Literature
Handouts and literature references will be given in the lecture.
• E. Säckinger, “Broadband Circuits for Optical Fiber Communication”, Wiley, 2005
• B. Razavi, “Design of Integrated Circuits for Optical Communications”, McGraw-Hill, 2003
Comments
As part of the lecture a 2-day excursion to IHP Leibnizinstitute for High-Performance Microelectronics in Frankfurt (Oder) is offered which includes the visit of a modern chip fabrication facility (participation in the excursion is voluntary).</td></tr>
</table>

<table>
<tr><th colspan="5">Software Quality Assurance</th></tr>
<tr><td colspan="5">Software Quality Assurance</td></tr>
<tr><td colspan="2">Module number:
M.079.01272</td><td>Workload (h):
180</td><td>Credits:
6</td><td>Regular Cycle:
module.frequency.en</td></tr>
<tr><td colspan="2"></td><td>Semester number:
beliebig</td><td>Duration (in sem.):
1</td><td>Teaching Language:
en</td></tr>
<tr><td>1</td><td colspan="4">Module structure:
<table>
<tr><th></th><th>Course</th><th>form of teachin</th><th>contact-time (h)</th><th>self-study (h)</th><th>status (C/CE)</th><th>group size (TN)</th></tr>
<tr><td>a)</td><td>L.079.05805
Software Quality Assurance</td><td>L3
Ex2</td><td>75</td><td>105</td><td>CE</td><td>90/30</td></tr>
</table></td></tr>
<tr><td>2</td><td colspan="4">Options within the module:
none</td></tr>
<tr><td>3</td><td colspan="4">Admission requirements:
Prerequisites of course Software Quality Assurance:
Recommended Proficiencies
Programming, Modeling, Model-based software development</td></tr>
</table>

4	**Contents:** *Contents of the course Software Quality Assurance:* The aim of the lecture is to cover approaches, technologies and strategies related to quality assurance for software systems. These include on the one hand constructive approaches such as design patterns, anti-patterns, domain-specific languages, model driven development, model quality analysis, and architectural styles, and on the other hand analytic approaches such as static reviewing techniques and dynamic testing techniques.. Furthermore, approaches for the improvement of the software development process and international standards like ISO 9001, 9126, CMM etc. are covered. • Introduction to software quality assurance • Standards – Product-related Standards: ISO 9126 – Process-related Standards: ISO 9001, CMM • Constructive approaches – Patterns and styles: Design patterns, Anti-Patterns, Architectural styles – Model-driven development – Metamodeling – Domain Specific Languages – Design by contract – Research: Process constraints • Analytical approaches – Reviews, inspections – Testing: Fundamental Test Process, Black Box Testing, White Box Testing
5	**Learning outcomes and competences:** The students are able to explain quality characteristics of software development processes, software models as well as software systems. They have understood constructive and analytical techniques used to ensure quality properties, and they are able to apply them. They can describe standards for measuring process and product quality. They are able to understand new research approaches in the area of process and product quality. **Non-cognitive Skills** • Empathy • Learning competence • Learning motivation • Motivation

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	Type of examination	Duration or scope	Weighting for the module grade
a)	Written or oral examination	90-120 minutes or 40 minutes	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	Type of achievement	Duration or Scope	SL / QT
a)	Assignments, course paper or progress reports		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Dr. Enes Yigitbas

13 **Other Notes:**

Remarks of course Software Quality Assurance:
Implementation method
Partially slides and partially board writing. All essential concepts and techniques will be repeatedly applied in examples during the tutorial. In a lab part, the techniques will be employed using tools, particularly testing tools.
Learning Material, Literature

- Daniel Galin: Software Quality Assurance: From Theory to Implementation, Pearson / Addison Wesley, 2004
- Slides, Exercises

VLSI-Testing			
VLSI-Testing			
Module number: M.048.92027	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.92027 VLSI Testing	2L 2Ex, WS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course VLSI Testing:
Recommended: Digital Design

4 **Contents:**

Contents of the course VLSI Testing:
Short Description
The course “VLSI Testing” focuses on techniques for detecting hardware defects in micro-electronic circuits. Algorithms for test data generation and test response evaluation as well as hardware structures for design for test (DFT) and on-chip test implementation (BIST) are presented.
Contents
In detail the following topics are covered:

- Fault models
- Testability measures and design for test (DFT)
- Logic and fault simulation
- Automatic test pattern generation (ATPG)
- Built-in self-test (BIST), in particular test data compression and test response compaction
- Memory test

5 **Learning outcomes and competences:**

Domain competence:
After attending the course, the students will be able

- to describe fault models, DFT techniques, and test tools,
- to explain and apply the underlying models and algorithms for fault simulation and test generation,
- to analyze systems with respect to their testability and to derive appropriate test strategies.

Key qualifications:
The students

- are able to apply the practiced strategies for problem solving across varying disciplines,
- have experience in presenting their solutions to their fellow students, and
- know how to improve their competences by private study.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Informatik v3, Masterstudiengang Informatik v4, Master's Program Electrical Systems Engineering v2 (ESEMA v2), Master's Program Electrical Systems Engineering v3 (ESEMA v3)

12 **Module coordinator:**

Prof. Dr. Sybille Hellebrand

13	**Other Notes:** *Remarks of course VLSI Testing:* --- **ATTENTION - IMPORTANT NOTICE** The course doesn't take place in winter term 2026/27 summer term 2026. Please see the notice boards of the group. --- **Course Homepage** `https://ei.uni-paderborn.de/en/electrical-engineering/date/teaching/electrical-engineering/overview` **Implementation** • Lecture based on slide presentation, extensions on blackboard • Exercises in small groups based on exercise sheets with students presenting their own solutions • Hands-on exercises using various software tools **Teaching Material, Literature** Additional material can be found in panda • Michael L. Bushnell, Vishwani D. Agrawal, „Essentials of Electronic Testing for Digital, Memory, and Mixed-Signal VLSI Circuits,"Boston, Dordrecht, London: Kluwer Academic Publishers, 2000 • Laung-Terng Wang, Cheng-Wen Wu, Xiaoqing Wen, „VLSI Test Principles and Architectures: Design for Testability," Morgan Kaufmann Series in Systems on Silicon, ISBN: 0123705975

3.5 Specialisation Area “Nano/Microelectronics”

Specialisation Area	Nano/Microelectronics
Modules	* Advanced VLSI Design * Algorithms for Synthesis and Optimization of Integrated Circuits * High Frequency Engineering * Integrierte Schaltungen für die drahtlose Kommunikation * Machine Learning I * Modern Semiconductor Lasers * Optoelectronics * Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation * Theory and Design of Integrated Photonic Devices * Theory and Design of Phase-locked Loops * VLSI Testing
Catalogue advisor	Head of Examination Board CE (PAV CE)
Credits ECTS	6
Learning objectives	

The modules from this specialisation area enable specialisation in the field of nano- and microelectronics.

Advanced VLSI Design			
Advanced VLSI Design			
Module number: M.048.92043	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.92043 Advanced VLSI Design	2L 2Ex, SS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Advanced VLSI Design:
Recommended: Fundamentals of Digital Circuits / Fundamentals of VLSI Design
Information: Unless otherwise specified, these are recommendations.

4 **Contents:**

Contents of the course Advanced VLSI Design:
Short Description
The course provides basic knowledge about the modern application-oriented modeling, simulation, analysis, and synthesis of digital systems at different abstraction levels to chip layout.
Contents
In today's practice, chip design consists of the combined application of various languages, methods, and tools for the modeling, simulation, and synthesis of electronic circuits. Along the modern abstraction-based design flow of digital systems (electronic system level to chip layout), the course provides basic knowledge of the main description languages and their application in modeling, simulation, analysis and synthesis. This includes basic principles and application of the IEEE standard system/hardware description languages SystemVerilog, SystemC, Verilog, and VHDL, in conjunction with additional formats, e.g., SDF and UPF for time and power annotation. For their application, the fundamental principles of test environments for simulation, timing and power analysis, logic synthesis and physical design of digital circuits. Exercises will provide hands-on labs based on commercial tools from Mentor Graphics, Synopsys and, Cadence Design Systems.

<table>
<tr><td>5</td><td>Learning outcomes and competences:

Domain competence:
After the course students are able

• to model, simulate, analyze and synthesize simple digital circuits at different abstraction levels and
• to apply the most important commercial tools for simulation, analysis and synthesis of digital circuits.

Key qualifications:
After the course students are able

• to assess, select and apply modern digital circuit description languages for their different applications,
• apply the different methods and tools in the modern VLSI design.</td></tr>
<tr><td>6</td><td>Assessments:

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table><tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr><tr><td>a)</td><td>Written or Oral Examination or Presentation</td><td>120-180 min or 30-45 min or 30 min</td><td>100%</td></tr></table></td></tr>
<tr><td>7</td><td>Study Achievement:

none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:

None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:

The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:

The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Master’s Program Electrical Systems Engineering v2 (ESEMA v2), Master’s Program Electrical Systems Engineering v3 (ESEMA v3)</td></tr>
<tr><td>12</td><td>Module coordinator:

apl. Prof. Dr. Wolfgang Mueller</td></tr>
</table>

13	**Other Notes:** *Remarks of course Advanced VLSI Design:* **Course Homepage** `www.hni.uni-paderborn.de/en/system-and-circuit-technology/teaching/advanced-vlsi-design` **Implementation** * Vorlesung mit Beamer und White-Board * Übungen mit Übungsblättern am Computer * Lecture with LCD projector and white board * Exercises with assignments and hands-on labs **Teaching Material, Literature** • Lecture notes and exercise sheets will be provided via PAUL • IEEE standard reference manuals: IEEE Std 1800/1685/1666/1364/1076/1801/1497 • Specific references for individual teaching units

High Frequency Engineering			
High Frequency Engineering			
Module number: M.048.92002	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.92002 High Frequency Engineering	2L 2Ex, WS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course High Frequency Engineering:
None

4 **Contents:**

Contents of the course High Frequency Engineering:
Short Description
This lecture gives application-oriented knowledge in high frequency engineering. Furthermore, it gives knowledge in active and passive high-frequency circuits.
Contents
The lecture High-Frequency Engineering extends the content of the lecture Theoretische Elektrotechnik by further application-relevant knowledge. The aim is to qualify the students for development tasks for example in the radio frequency part of a mobile telephone. But considerations of high-frequency engineering are also needed in prevalent digital circuits. The emphases of the lecture are passive devices, high-frequency properties of fundamental transistor circuits, linear and nonlinear amplifiers, noisy multiports, mixers, oscillators, injection-locking and phase-locked loop.

5 **Learning outcomes and competences:**

Professional Competence
After attending the course, the students will be able, in the taught extent, to understand the function of components, circuits and systems of high-frequency engineering, to model and to apply them.
(Soft) Skills
The students

- are able to apply the knowledge and skills to a wide range of disciplines,
- are able to make use of a methodical procedure when undertaking systematic analysis and
- are, due to the abstract and precise treatment of the contents, in a position to continue and develop their learning themselves

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Master's Program Electrical Systems Engineering v2 (ESEMA v2), Master's Program Electrical Systems Engineering v3 (ESEMA v3)

12 **Module coordinator:**

Prof. Dr. Reinhold Noé

13	**Other Notes:** *Remarks of course High Frequency Engineering:* --- **ATTENTION - IMPORTANT NOTICE** The course doesn't take place in winter term 2026/27 summer term 2026. Please see the notice boards of the group. --- **Course Homepage** `http://ont.upb.de` **Implementation** Lecture and exercise **Teaching Material, Literature** Scripts, exercise sheets and advanced literature (excerpt): • Thiede, A.: Skriptum Hochfrequenzelektronik/High-Frequency Electronics, Universität Paderborn • Sze, S. M.: High Speed Semiconductor Devices, John Wiley & Sons, 1990 • Herbst, L. J.: Integrated Circuit Engineering, Oxford University Press, 1996 • Yip, P. C. L.: High-Frequency Circuit Design and Measurement, Chapman & Hall, 1996 • Gonzalez, G.: Microwave Transistor Amplifiers, Prentice Hall, 1997 • Hoffmann, M.: Hochfrequenztechnik, Springer, 1997

Integrierte Schaltungen für die drahtlose Kommunikation			
Integrated Circuits for Wireless Communications			
Module number: M.048.25017	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** de / en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.25017 Integrated Circuits for Wireless Communications	2L 2Ex, SS	60	120	C	40/40

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Integrierte Schaltungen für die drahtlose Kommunikation:
Recommended: Lecture Schaltungstechnik rsp. Circuit and System Design. Helpful supplement: Lecture “Wireless Communications” of Prof. Hab-Umbach.

4 **Contents:**

Contents of the course Integrierte Schaltungen für die drahtlose Kommunikation:
Short Description
Mobile communications, wireless networks, and RFID technology are application examples of wireless communications. Wireless communications has found widespread use in everyday life and will become even more important in the future. The design of electronic circuits for radio frequencies requires a good system knowledge with respect to typical transmitter and receiver architectures in wireless communications, components, and radio signal properties. Furthermore a thorough understanding of integrated circuit design as well as precise high-frequency modeling of passive and active devices are required. Goal of the lecture is to convey a methodical approach to the design of integrated circuits for wireless communications. A part of the exercises will pertain to calculation of circuit design problems another will be performed in small teams as a hands-on exercise using modern IC design software.
Contents
The lecture deals with analysis and design of radio frequency integrated circuits for wireless communication systems. A part of the exercises will be performed using modern chip design CAD tools. The lecture is based on the compulsory lectures “Schaltungstechnik” rsp. “Circuit and System Design”. The following topics will be addressed:

- Transmitter and receiver architectures for wireless communications
- System Theory Basics
  - Signals and noise
  - Modulation and demodulation
  - Transmission properties of wireless communcations systems
- Semiconductor technologies and integrated high-frequency devices
- Amplifiers (low-noise and variable-gain amplifiers)
- Mixers
- Oscillators
- Frequency synthesizer PLLs

5 **Learning outcomes and competences:**

The students will be able

- to describe architectures and circuits of wireless communication systems
- to describe and calculate fundamental signal transmission properties of wireless systems
- to apply design methods to design components of radio frequency ICs

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Oral Examination	30-45 min	100%

7 **Study Achievement:**

none

8	**Prerequisites for participation in examinations:** None
9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4
12	**Module coordinator:** Prof. Dr.-Ing. J. Christoph Scheytt
13	**Other Notes:** *Remarks of course Integrierte Schaltungen für die drahtlose Kommunikation:* **Course Homepage** `https://www.hni.uni-paderborn.de/en/system-and-circuit-technology/teaching/integrierte-schaltungen-fuer-die-drahtlose-kommunikation/` **Implementation** • Lecture with Powerpoint presentation and handwritten mathematical derivations using tablet and beamer • Exercises partly as handwritten calculation exercises using tablet and beamer and partly as practical IC design exercises using IC design software **Teaching Material, Literature** Lecture slides and videos as well as exercise slides will be made available. • Behzad Razavi “RF Microelectronics”, Prentice Hall, 2011 • Thomas Lee “The Design of CMOS Radio-Frequency Integrated Circuits”, Cambridge University Press 2003

Machine Learning I

Machine Learning I

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.01274	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	beliebig	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05701 Machine Learning 1	L3 Ex2	75	105	C	75/25

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Machine Learning 1:
Recommended Proficiencies
Basic knowledge in mathematics (linear algebra, statistics), programming and algorithms.

4 **Contents:**

Contents of the course Machine Learning 1:
Due to the ever increasing amount of data that is routinely produced in our information society, the topic of machine learning has become increasingly important in the recent years, not only as a scientific discipline but also as a key technology of modern software and intelligent systems. This lecture provides an introduction to the topic of machine learning, with a specific focus on supervised learning for classification and regression. The lecture covers theoretical foundations of generalisation as well as practical topics and concrete learning algorithms.

- Introduction
- Foundations (e.g., the learning problem, generalization theory, bias-variance tradeoff)
- Techniques (e.g., The linear model, non-linear techniques, SVM, tree-based methods, ensembles, deep learning)
- Validation and practical implementations (e.g., metrics, training vs testing, cross-validation, AutoML)

5 **Learning outcomes and competences:**

The students understand the statistical foundations of generalisation, i.e., the induction of models from data, as well as practical tools for model validation. They are able to apply basic methods of supervised learning to problems of classification and regression.

Non-cognitive Skills

- Learning competence
- Learning motivation
- Literacy (scientific)

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 minutes or 40 minutes	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Assignments, course paper or progress reports		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr. Eyke Hüllermeier

13	**Other Notes:** *Remarks of course Machine Learning 1:* **Implementation method** Theoretical foundations and concepts of machine learning will be taught in the form of a lecture and deepened in practical exercise courses, group work as well as individual homework. **Learning Material, Literature** • Script • Y.S. Abu-Mostafa, M. Magdon-Ismail, H.T. Lin. Learning from Data, AMLBook, 2012. • P. Flach. Machine Learning, Cambridge Univ. Press, 2012. • E. Alpaydin. Machine Learning, Oldenbourg, 2008. • C.M. Bishop. Pattern Recognition and Machine Learning, Springer, 2006.

<table>
<tr><th colspan="5">Modern Semiconductor Lasers</th></tr>
<tr><td colspan="5">Modern Semiconductor Lasers</td></tr>
<tr><td colspan="2">Module number:
M.048.26012</td><td>Workload (h):
180</td><td>Credits:
6</td><td>Regular Cycle:
module.frequency.en</td></tr>
<tr><td colspan="2"></td><td>Semester number:
1.-3. Semester</td><td>Duration (in sem.):
1</td><td>Teaching Language:
en</td></tr>
<tr><td>1</td><td colspan="4">Module structure:
<table>
<tr><th></th><th>Course</th><th>form of teachin</th><th>contact-time (h)</th><th>self-study (h)</th><th>status (C/CE)</th><th>group size (TN)</th></tr>
<tr><td>a)</td><td>L.048.26012
Modern Semiconductor Lasers</td><td>2L
2Ex,
WS</td><td>60</td><td>120</td><td>C</td><td>40/40</td></tr>
</table></td></tr>
<tr><td>2</td><td colspan="4">Options within the module:
None</td></tr>
<tr><td>3</td><td colspan="4">Admission requirements:
None
Prerequisites of course Modern Semiconductor Lasers:
Recommended:
The familiarity with basic concepts from optics, quantum mechanics and semiconductor physics is highly recommended.</td></tr>
</table>

4 **Contents:**

Contents of the course Modern Semiconductor Lasers:
Semiconductor lasers are the key light sources of modern photonics, enabling applications ranging from optical communications and sensing to quantum technologies. While reviewing the fundamental principles of semiconductor laser operation, this course focuses on recent advances and emerging directions that are reshaping the field. Participants will explore novel laser concepts based on photonic crystals, nanophotonics, spintronics, topology, and non-Hermitian physics, as well as the theoretical frameworks required to describe these devices beyond conventional laser theory.
Topics covered include:

- Fundamentals of semiconductor laser operation: gain media, laser dynamics, modulation response, and linewidth
- State-of-the-art semiconductor laser technologies and their performance limits
- Photonic-crystal surface-emitting lasers (PCSELs) and scalable single-mode high-power emission
- Nanolasers, cavity quantum electrodynamics, and thresholdless lasing
- Spin lasers and new approaches to ultrafast information encoding
- Bound-state-in-continuum (BIC) lasers and topological lasers
- Emerging concepts including supersymmetric, PT-symmetric, Dirac, polaritonic, and plasmonic lasers
- Advanced theoretical topics: non-Hermitian effects, quantum noise, complex gain media, and modern computational approaches for large-scale laser systems

5 **Learning outcomes and competences:**

Upon successful completion of this course, participants will be able to explain the physical principles governing semiconductor laser operation, including optical gain, laser dynamics, modulation response, and origin of linewidth. They will be able to analyze and compare established semiconductor laser technologies and evaluate their performance limitations. Furthermore, participants will develop a critical understanding of emerging laser concepts, including photonic-crystal, nano-, spin-, BIC, and topological lasers, and will be able to relate their operation to contemporary concepts in photonics such as cavity quantum electrodynamics, non-Hermitian physics, and topology. Finally, participants will gain familiarity with advanced theoretical and computational approaches used to describe modern semiconductor lasers and will be able to assess current research literature in this rapidly evolving field.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8	**Prerequisites for participation in examinations:** None
9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4
12	**Module coordinator:** Dr. Mariusz Drong
13	**Other Notes:** **Module Homepage** `https://panda.uni-paderborn.de/` **Implementation** Lectures and exercises **Teaching Material, Literature** Handouts and tutorial questions; literature references will be given in the first lecture

Optoelectronics			
Optoelectronics			
Module number: M.048.26011	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.26011 Optoelectronics	2L 2Ex, SS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Optoelectronics:
None

4 **Contents:**

Contents of the course Optoelectronics:
Short description
The lecture Optoelectronics covers the fundamental aspects of optoelectronic devices, starting with semiconductor materials and their interaction with light and photons, to the electronic aspects of the components, and finally to the use of quantum mechanical effects to optimise modern components for their respective areas of application, such as in lighting systems, renewable energy, broadband optical communication systems or in medical technology.
Contents
In the first part of the lecture, the basics of semiconductors (lattice structure, band structure, direct-indirect semiconductors, doping, degenerate and non-degenerate semiconductors, heterostructures, quantum effects in low-dimensional semiconductors) are recapitulated. The elementary interactions between light and semiconductors (absorption, stimulated emission, spontaneous emission) and the electronic aspects of the components (p-n junction, heterojunctions) are then covered. Finally, the most important devices such as solar cells, photodiodes, light-emitting diodes and semiconductor lasers are discussed in detail and their most important parameters and optimisation strategies are explained.

5 **Learning outcomes and competences:**

Domain competence:
After attending the course, the students will be able to

- explain the basic physical properties of optoelectronic semiconductor devices based on classical and fundamental quantum mechanical descriptions,
- to describe the main concepts of optoelectronic semiconductor devices (photodiodes, solar cells, light emitting diodes, semiconductor lasers),
- categorize different device designs according to their application requirements.

Key qualifications:
The students

- can use of methodic knowledge for systematic problem analysis for a wide range of disciplines,
- will be in position to familiarise themselves independently with new generations of semiconductor devices, thanks to the comprehensive fundamental training received,
- get familiar to rate-equation models to simulate steady-state and dynamic characteristics in coupled systems,
- and gain foreign language competences related to the field.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11 **Reuse in degree courses or degree course versions :**

BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4

12	**Module coordinator:** Prof. Dr.-Ing. Nils Christopher Gerhardt
13	**Other Notes:** **Course Homepage** [https://ei.uni-paderborn.de/hob/lehre] **Module Homepage** to be announced at the start of the lecture **Implementation** Lectures and exercises (including some computer simulations) **Teaching Material, Literature** Lecture notes and handouts for the tutorial; literature references will be given in the first lecture

Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation			
Fast Integrated Circuits for Wireline Communications			
Module number: M.048.25019	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** de / en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.25019 Fast Integrated Circuits for Wireline Communications	2L 2Ex, WS	60	120	C	40/40

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation:
Recommended: Module “Schaltungstechnik” of the Bachelor Electrical Engineering or module “Circuit and System Design” of the Master “Electrical Systems Engineering” or comparable modules / lectures

4	**Contents:** *Contents of the course Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation:* **Short Description** Nowadays commercial fiber-optic communication systems reach very high data rates of 100 Gb/s per optical channel and several Tb/s in a single fiber. In a similar way very high data rates of more than 10 Gb/s occur at a single package pin of electronic chips. These signals are to be transmitted over printed circuit boards and inexpensive serial cables. In the future the progress of CMOS technology and communication technology will push speed of fiber-optic and wire-line communication continuously to ever higher data rates. The design of electronic circuits for high bandwidth rsp. data rates requires a good system knowledge with respect to typical transmitter and receiver architectures, components, and signal properties. Furthermore a thorough understanding of integrated circuit design as well as precise high-frequency modeling of passive and active devices are required. Goal of the lecture is to enable the student to utilize a methodological approach for the design of fast integrated electronic circuits for digital wired communications. A part of the exercises will be carried out using modern industry-standard IC design software. **Contents** The lecture deals with analysis and design of fast integrated electronic circuits for digital broadband communication systems. A part of the exercises will be performed using modern chip design CAD tools. The lecture is based on the compulsory lectures “Schaltungstechnik” rsp. “Circuit and System Design”. The lecture deals with: • Transmitter and receiver architectures for fiber-optic communications • Transmitter and receiver architectrues for chip-to-chip communications • System design • Semiconductor technology and integrated high-frequency devices • Broadband amplifiers • Current-mode logic • Transmitter and receiver circuits • PLLs for frequency synthesis and clock recovery • Measurement methods
5	**Learning outcomes and competences:** **Domain competence:** The student will be able to: • describe and analyze transmitter and receiver architectures for broadband communication links • understand and describe semiconductor technologies and integrated high-frequency devices for broadband circuits • to analyze circuit design techniques for transmitter and receiver circuits and describe ways to optimize them • to describe circuits in PLL technique for frequency synthesis and clock recovery • to describe measurement methods **Key qualifications:** The students will learn how different interdisciplinary scientific domains and their methods - like mathematical signal and system analysis, non-linear and linear circuit analysis, semiconductor physics, semiconductor devices and high-frequency engineering - are applied together for the development of communications application.

<table>
<tr><td>6</td><td>Assessments:
☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table>
<tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr>
<tr><td>a)</td><td>Oral Examination</td><td>30-45 min</td><td>100%</td></tr>
</table></td></tr>
<tr><td>7</td><td>Study Achievement:
none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr.-Ing. J. Christoph Scheytt</td></tr>
<tr><td>13</td><td>Other Notes:
Remarks of course Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation:
Course Homepage
https://www.hni.uni-paderborn.de/en/system-and-circuit-technology/teaching/fast-integrated-circuits-for-wireline-communications/
Implementation
Lecture with Exercises (including computer-aided design using electronic design software)
Teaching Material, Literature
Handouts and literature references will be given in the lecture.
• E. Säckinger, “Broadband Circuits for Optical Fiber Communication”, Wiley, 2005
• B. Razavi, “Design of Integrated Circuits for Optical Communications”, McGraw-Hill, 2003
Comments
As part of the lecture a 2-day excursion to IHP Leibnizinstitute for High-Performance Microelectronics in Frankfurt (Oder) is offered which includes the visit of a modern chip fabrication facility (participation in the excursion is voluntary).</td></tr>
</table>

Theory and Design of Integrated Photonic Devices			
Theory and Design of Integrated Photonic Devices			
Module number: M.048.26013	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-.3 Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.26013 Theory and Design of Integrated Photonic Devices	2L 2Ex, WS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Theory and Design of Integrated Photonic Devices:
Recommended:
Knowledge on electromagnetic fields and waves Experience with MATLAB/Python scripting would be beneficial

4 **Contents:**

Contents of the course Theory and Design of Integrated Photonic Devices:

- Introduction
  - Historical evolution of integrated photonics and relevance in today's world
  - Brief overview on the required background theory
    - Electromagnetic waves and Maxwell's equations
    - EM waves propagation in different media
- Theory of optical waveguides: Device #0
  - 1-D waveguide analysis
    - Ray optics model
    - Vector wave equation and boundary conditions
  - 2-D waveguide analysis
    - Overview of waveguide platforms and effective index method
    - Overview of the full vectorial method
    - Dispersion, polarization and orthogonality of guided modes
- Coupled-mode theory: analytical formulation
- Passive integrated photonic devices
  - Directional coupler (DC): Device #1
  - Multi-mode interferometers (MMI) : Device #2
  - Distributed Bragg reflector (DBR): Device #3
- Tunable/active integrated photonic devices
  - Mach-Zehnder interferometer (MZI) / modulator (MZM): Device #4
  - Microring resonators (MRR) / modulator (MRM): Device #5
  - Overview of phase shifters: thermal, electro-optic and MEMS-based
- Fabrication variability and tolerances of the integrated photonic devices
- Overview of photonic integrated circuit (PIC) analysis, introduction to compact-modeling and electronic-photonic design automation (EPDA)

5 **Learning outcomes and competences:**

Understanding the working and fundamental theory of integrated photonic devices, constraints involved in the device designs and overcoming strategies.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7	**Study Achievement:** none
8	**Prerequisites for participation in examinations:** None
9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4
12	**Module coordinator:** Dr. Ashitosh Velamuri
13	**Other Notes:** **Module Homepage** **Implementation** Lectures and exercises (including some computer simulations) **Teaching Material, Literature** Handouts and tutorial questions; literature references will be given in the first lecture

Theory and Design of Phase-locked Loops

Theory and Design of Phase-locked Loops

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.048.24020	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	1.-3. Semester	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.24020 Theory and Design of Phase-locked Loops	2L 2Ex, WS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Theory and Design of Phase-locked Loops:
Recommended:

- Advanced Signal Theory
- Statistical Signal Processing (or another course with comparable syllabus in their bachelor)
- Circuit and system design (or another course with comparable syllabus in their bachelor)

4 **Contents:**

Contents of the course Theory and Design of Phase-locked Loops:
Chapter 1: Motivation

- Time and frequency definition – definition in SI units – static frequency error
- random fluctuations – Amplitude/Phase (AM/PM) noise

Chapter 2: Mathematical formalism of signals

- baseband and bandpass signals
- time and frequency domain

Chapter 3: introduction to random processes

- baseband random processes and noise – correlation functions in time and frequency domain – some basedband random processes (thermal noise, shot noise, flicker noise . . .)
- bandpass random processes – correlation functions – relation to baseband processes – phase noise and amplitude noise

Chapter 4: PLL building blocks

- Phase detector – Phase detector model – phase noise of phase detector
- VCO – VCO model – phase noise of VCO
- Frequency translators – frequency divider – frequency multiplier – phase noise of frequency translators
- transistor level design of PLL blocks

Chapter 5: Integer N PLLs: – Time domain – frequency domain – phase noise – spurious frequencies
Chapter 6: Fractional PLLs – Time domain – frequency domain – phase noise – spurious frequencies

5 **Learning outcomes and competences:**

Understanding of static/dynamic error in frequency standards. Mathematical modeling of amplitude/phase noise. Modeling random processes in time and frequency domain. Basic and modern PLL architecture and its building blocks. Systematic design of PLLs. Design and Modeling of Integer/Fractional N PLL.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4
12	**Module coordinator:** Dr. Meysam Bahmanian
13	**Other Notes:** **Module Homepage** `https://www.hni.uni-paderborn.de/en/sct/teaching/theory-and-design-of-plls` **Implementation** Lectures and exercises (including some computer simulations) **Teaching Material, Literature** Handouts and tutorial questions; literature references will be given in the first lecture

VLSI-Testing

VLSI-Testing

Module number:	Workload (h):	Credits:	Regular Cycle:
M.048.92027	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	1.-3. Semester	1	en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.92027 VLSI Testing	2L 2Ex, WS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course VLSI Testing:
Recommended: Digital Design

4 **Contents:**

Contents of the course VLSI Testing:
Short Description
The course “VLSI Testing” focuses on techniques for detecting hardware defects in micro-electronic circuits. Algorithms for test data generation and test response evaluation as well as hardware structures for design for test (DFT) and on-chip test implementation (BIST) are presented.
Contents
In detail the following topics are covered:

- Fault models
- Testability measures and design for test (DFT)
- Logic and fault simulation
- Automatic test pattern generation (ATPG)
- Built-in self-test (BIST), in particular test data compression and test response compaction
- Memory test

5 **Learning outcomes and competences:**

Domain competence:
After attending the course, the students will be able

- to describe fault models, DFT techniques, and test tools,
- to explain and apply the underlying models and algorithms for fault simulation and test generation,
- to analyze systems with respect to their testability and to derive appropriate test strategies.

Key qualifications:
The students

- are able to apply the practiced strategies for problem solving across varying disciplines,
- have experience in presenting their solutions to their fellow students, and
- know how to improve their competences by private study.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Informatik v3, Masterstudiengang Informatik v4, Master's Program Electrical Systems Engineering v2 (ESEMA v2), Master's Program Electrical Systems Engineering v3 (ESEMA v3)

12 **Module coordinator:**

Prof. Dr. Sybille Hellebrand

13	**Other Notes:** *Remarks of course VLSI Testing:* --- **ATTENTION - IMPORTANT NOTICE** The course doesn't take place in winter term 2026/27 summer term 2026. Please see the notice boards of the group. --- **Course Homepage** `https://ei.uni-paderborn.de/en/electrical-engineering/date/teaching/electrical-engineering/overview` **Implementation** • Lecture based on slide presentation, extensions on blackboard • Exercises in small groups based on exercise sheets with students presenting their own solutions • Hands-on exercises using various software tools **Teaching Material, Literature** Additional material can be found in panda • Michael L. Bushnell, Vishwani D. Agrawal, „Essentials of Electronic Testing for Digital, Memory, and Mixed-Signal VLSI Circuits,"Boston, Dordrecht, London: Kluwer Academic Publishers, 2000 • Laung-Terng Wang, Cheng-Wen Wu, Xiaoqing Wen, „VLSI Test Principles and Architectures: Design for Testability," Morgan Kaufmann Series in Systems on Silicon, ISBN: 0123705975

3.6 Specialisation Area “Signal, Image, and Speech Processing”

Specialisation Area	Signal, Image, and Speech Processing
Modules	* Advanced System Theory) * Digital Image Processing I * Digital Image Processing II * Digitale Sprachsignalverarbeitung * Machine Learning I * Machine Learning II * Machine Learning for Biometrics * Optimale und Adaptive Filter * Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation * Statistical and Machine Learning * Statistical Natural Language Processing * Technische kognitive Systeme * Topics in Signal Processing
Catalogue advisor	Head of Examination Board CE (PAV CE)
Credits ECTS	6
Learning objectives	

The modules from this specialisation area enable specialisation in the field of signal, image and language processing.

Advanced System Theory			
Advanced System Theory			
Module number: M.048.92001	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1. Semester	**Duration (in sem.):** 1	**Teaching Language:** de / en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.92001 Advanced System Theory	2L 2Ex, WS/SS	60	120	C	60/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Advanced System Theory:
Recommended:
Prerequisites are a basic understanding of differential equations, linear algebra, and Laplace transforms, as they are covered in a typical undergraduate course on system theory.

4 **Contents:**

Contents of the course Advanced System Theory:
Short Description
Building on an undergraduate system theory course, this course studies the dynamical behavior of linear systems with greater mathematical rigor. The course is primarily intended to serve students in engineering, but it can also be useful to students in physics and other natural sciences.
Contents

- System models and differential equations
- State-space and I/O descriptions
- Relations between internal and external descriptions
- Response of continuous- and discrete-time systems
- Stability, controllability, observability
- State-space realizations of external descriptions

5 **Learning outcomes and competences:**

After attending this course, students will be familiar with the most important concepts and results in linear system theory. Students will develop confidence in their ability to solve mathematical problems of analysis and design. Many of their timeless insights and intuitions about the dynamical behavior of systems will be drawn from this course. This course presents material broad enough so that students will have a clear understanding of the dynamical behavior of linear systems, including their power and limitations. This will allow students to apply the theory to other fields.

<table>
<tr><td>6</td><td>Assessments:
☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table>
<tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr>
<tr><td>a)</td><td>Written or Oral Examination or Presentation</td><td>120-180 min or 30-45 min or 30 min</td><td>100%</td></tr>
</table></td></tr>
<tr><td>7</td><td>Study Achievement:
none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Master’s Program Electrical Systems Engineering v2 (ESEMA v2), Master’s Program Electrical Systems Engineering v3 (ESEMA v3)</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr. Erdal Kayacan</td></tr>
<tr><td>13</td><td>Other Notes:
Remarks of course Advanced System Theory:
Course Homepage
https://en.ei.uni-paderborn.de/rat
Implementation
Lectures and exercises (including some computer simulations) Panda course for communication and material distribution
Teaching Material, Literature
Handouts and exercise / tutorial questions; literature references will be given in the first lecture</td></tr>
</table>

<table>
<tr><th colspan="5">Digital Image Processing I</th></tr>
<tr><td colspan="5">Digital Image Processing I</td></tr>
<tr><td colspan="2">Module number:
M.048.92008</td><td>Workload (h):
180</td><td>Credits:
6</td><td>Regular Cycle:
module.frequency.en</td></tr>
<tr><td colspan="2"></td><td>Semester number:
1.-3. Semester</td><td>Duration (in sem.):
1</td><td>Teaching Language:
en</td></tr>
<tr><td>1</td><td colspan="4">Module structure:
<table>
<tr><th></th><th>Course</th><th>form of teachin</th><th>contact-time (h)</th><th>self-study (h)</th><th>status (C/CE)</th><th>group size (TN)</th></tr>
<tr><td>a)</td><td>L.048.92008
Digital Image Processing I</td><td>2L
2Ex,
SS</td><td>60</td><td>120</td><td>C</td><td>30/30</td></tr>
</table></td></tr>
<tr><td>2</td><td colspan="4">Options within the module:
None</td></tr>
<tr><td>3</td><td colspan="4">Admission requirements:
None
Prerequisites of course Digital Image Processing I:
None. Basic programming knowledge is an advantage.</td></tr>
</table>

4	**Contents:** *Contents of the course Digital Image Processing I:* **Short Description** This course provides a fundamental introduction to digital image processing. Upon successful completion, students will be able to thoroughly describe the basic concepts of image generation and representation. Additionally, they will acquire the skills to apply methods for enhancing and segmenting grayscale and color images in both the spatial and frequency domains, as well as techniques for image compression. Students will be capable of independently selecting, implementing, testing, and applying these techniques to complex image processing tasks. A typical application area is automation technology. **Contents** 1. Introduction (Graphics File Formats, Application Examples, Human Vision) 2.Image Formation and Image Models (Camera Models, Image Formation, Image Sampling and Quantization) 2. Image Enhancement in the Spatial Domain (Gray-Level Transformation Functions, Histogram Processing, Spatial Filtering) 3. Image Enhancement in the Frequency Domain (2D Fourier Transform, Smoothing and Sharpening Filters, Implementation Details) 4. Color Image Processing (Color Spaces, Color and Pseudo-Color Image Processing, Spatial Filtering) 5. Image Compression and Reduction (Types of Redundancy, Compression Models, Lossless and Lossy Compression)
5	**Learning outcomes and competences:** **Domain competence** The students • are able to describe the basics of image generation and image digitization and • are able to select, implement, test and apply methods for the enhancement of images in the spatial and frequency domain, image segmentation and data reduction independently for complex image processing tasks. **Key qualifications** The students have a good command of programming in Python.
6	**Assessments:** ☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7	**Study Achievement:** none
8	**Prerequisites for participation in examinations:**

9	**Prerequisites for assigning credits:** The credit points are awarded after the module examination (MAP) was passed.
10	**Weighing for overall grade:** The module is weighted according to the number of credits (factor 1).
11	**Reuse in degree courses or degree course versions :** Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Master's Program Electrical Systems Engineering v2 (ESEMA v2), Master's Program Electrical Systems Engineering v3 (ESEMA v3)
12	**Module coordinator:** Dr.-Ing. Markus Hennig
13	**Other Notes:** *Remarks of course Digital Image Processing I:* **Target group** Master's students in electrical engineering and related fields. **Course Homepage** `https://ei.uni-paderborn.de/get/teaching/dip-i` **Literature** • Gonzalez, R., & Woods, R. (2017). Digital Image Processing (4th Global Ed.). Pearson. Print ISBN: 978-1-292-22304-9, E-ISBN: 978-1-292-22307-0. • Mertsching, B. (2024). Digital Image Processing I (Lecture Notes). • Jähne, B. (2024). Digitale Bildverarbeitung (8th Edition, German Language). Springer. Print ISBN: 978-3-662-59509-1, E-ISBN: 978-3-662-59510-7. **Comment** The material presented in the lecture is implemented in the exercises using Python. The first exercise provides an introduction to this, so that it is possible to get started with limited programming knowledge. Regular and active participation in lectures and exercises is expected.

Digital Image Processing II

Digital Image Processing II

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.048.92010	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	1.-3. Semester	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.92010 Digital Image Processing II	2L 2Ex, SS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Digital Image Processing II:
Recommended:
Basic knowledge of image processing, (e. g. from the course Digital Image Processing I (L.048.23002 / L.048.92008)

4 **Contents:**

Contents of the course Digital Image Processing II:
Short Description
The course “Digital Image Processing II” is a module in the catalog “Cognitive Systems” for advanced students of the Electrical Engineering Master’s program and related degree programs. It follows the fundamental course “Digital Image Processing I” and covers methods for high-level image processing.
Contents
The following topics will be discussed during the semester:

- Image segmentation (line and edge detection, segmentation by region, superpixels)
- Feature extraction (feature descriptors, principal components, Scale-Invariant-Feature-Transform (SIFT))
- Stereo image analysis (depth perception, stereo geometry, correspondence problem)
- Motion (motion detection, optical flow, motion models, motion segmentation)
- Object recognition and image pattern classification (patterns, classifiers, neural networks and deep learning, convolutional neural networks (CNN))

After learning about the methods in the lecture, the students will implement them in Jupyter Notebooks.

<table>
<tr><td>5</td><td>Learning outcomes and competences:

Domain competence:
The students

• can apply methods for image segmentation, representation and description of features, stereo and motion image analyis, objection recognition and machine learning,
• are able to transfer the acquired knowledge of image processing to the processing of other multi-dimensional signals,
• are able to describe the state-of-the-art of the presented topics, and
• are able to implement the presented methods.

Key qualifications:
The students are able to identify and evaluate the function and the behavior of complex technical processes and their integration into the social environment while also considering ethical aspects.</td></tr>
<tr><td>6</td><td>Assessments:

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table><tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr><tr><td>a)</td><td>Written or Oral Examination or Presentation</td><td>120-180 min or 30-45 min or 30 min</td><td>100%</td></tr></table></td></tr>
<tr><td>7</td><td>Study Achievement:

none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:

None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:

The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:

The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Master’s Program Electrical Systems Engineering v2 (ESEMA v2), Master’s Program Electrical Systems Engineering v3 (ESEMA v3)</td></tr>
<tr><td>12</td><td>Module coordinator:

Dr.-Ing. Markus Hennig</td></tr>
</table>

13	**Other Notes:** *Remarks of course Digital Image Processing II:* --- **ATTENTION - IMPORTANT NOTICE** The course doesn't take place in winter term 2026/27 summer term 2026. Please see the notice boards of the group. --- **Course Homepage** [http://getwww.uni-paderborn.de/teaching/dip-II] **Course Documents** see PANDA ([https://panda.uni-paderborn.de]) **References (excerpt)** • Mertsching, Bärbel: Digital Image Processing (lecture notes) • Forsyth, David and Ponce, Jean: Computer Vision - A Modern Approach. Prentice-Hall, 2nd ed., 2011. ASIN: B006V372KG • Gonzalez, Rafael C. and Woods, Richard E.: Digital Image Processing. Pearson Education Limited, 4th ed., 2018. ISBN-13: 978-1-292-22304-9 • Jähne, Bernd: Digitale Bildverarbeitung. Springer, 7. Aufl., 2012. ISBN-13: 978-3642049514

Digitale Sprachsignalverarbeitung			
Digital Speech Signal Processing			
Module number: M.048.24001	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** de / en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.24001 Digital Speech Signal Processing	2L 2Ex, SS	60	120	C	40/40

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Digitale Sprachsignalverarbeitung:
Recommended: Prior knowledge from the module Higher Mathematics.

4	**Contents:** *Contents of the course Digitale Sprachsignalverarbeitung:* **Short Description** The course introduces the basic techniques and theories of digital speech signal processing. A focal point of the first part of the lecture is the topic “Listening and Speaking”, which is concerned with psychological effects of human sound perception and speech production. Subsequently, time discrete signals and systems, as well as computer based data processing are discussed. Further topics are non-parametric short-time analysis of speech signals, speech coding and IP-phones. **Contents** • Listen and talk – Generating voice: human vocal tract, source filter model, vocoder – Acoustic waves – Listen: human ear, psycho acoustics and physiology of listening, loudness, acoustic occlusion, frequency groups • Time-discrete signals and systems – Basics: Elementary signals, LTI systems – Transformations: Fourier transformation of time-discrete signals, DFT, FFT – Time-discrete filtering in frequency domain: Overlap-Add, overlap-Save • Statistical speech signal analysis – Basics in theory of probabilities – Short-run analysis of speech signals: Spectrogram, cepstrum • Estimation of speech signals – Optimal filters – LPC analysis – Spectral filtering for noise suppression: spectral subtraction, Wiener filter – Adaptive Filters: LMS adaptation algorithm, echo compensation • Speech coding – Time domain coding: signal shape coding, parametric coding, hybride coding techniques – Frequency domain coding – Amplitude quantization: uniform quantization, quantization with companders (ulaw, alaw)

5 **Learning outcomes and competences:**

Domain competence:
After attending the course, the students will be able to

- analyze digital signals, e.g., audio signals, in the time or frequency domain,
- represent audio signals efficiently and
- implement widely-used algorithms for speech analysis and speech processing in the frequency or time domain.

Key qualifications:
The students

- are able to explain effects in real signals based on the theoretical knowledge,
- are able to investigate theoretical approaches by a systematic analysis and
- are, due to the precise treatment of the contents, in a position to continue their learning themselves

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11 **Reuse in degree courses or degree course versions :**

BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Informatik v3, Masterstudiengang Informatik v4, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4

12 **Module coordinator:**

Dr.-Ing. Jörg Schmalenströer

13	**Other Notes:** *Remarks of course Digitale Sprachsignalverarbeitung:* **Course Homepage** `https://ei.uni-paderborn.de/en/nt/teaching/veranstaltungen/digital-speech-signal-processing` **Implementation** • Lectures using the blackboard and presentations, • Alternating theoretical and practical exercise classes with exercise sheets and computer and • Demonstration of real technical systems in the lecture hall. **Teaching Material, Literature** Allocation of a script; information on textbooks ; matlab scripts

Machine Learning I

Machine Learning I

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.01274	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	beliebig	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05701 Machine Learning 1	L3 Ex2	75	105	C	75/25

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Machine Learning 1:
Recommended Proficiencies
Basic knowledge in mathematics (linear algebra, statistics), programming and algorithms.

4 **Contents:**

Contents of the course Machine Learning 1:
Due to the ever increasing amount of data that is routinely produced in our information society, the topic of machine learning has become increasingly important in the recent years, not only as a scientific discipline but also as a key technology of modern software and intelligent systems. This lecture provides an introduction to the topic of machine learning, with a specific focus on supervised learning for classification and regression. The lecture covers theoretical foundations of generalisation as well as practical topics and concrete learning algorithms.

- Introduction
- Foundations (e.g., the learning problem, generalization theory, bias-variance tradeoff)
- Techniques (e.g., The linear model, non-linear techniques, SVM, tree-based methods, ensembles, deep learning)
- Validation and practical implementations (e.g., metrics, training vs testing, cross-validation, AutoML)

5 **Learning outcomes and competences:**

The students understand the statistical foundations of generalisation, i.e., the induction of models from data, as well as practical tools for model validation. They are able to apply basic methods of supervised learning to problems of classification and regression.

Non-cognitive Skills

- Learning competence
- Learning motivation
- Literacy (scientific)

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 minutes or 40 minutes	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Assignments, course paper or progress reports		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11 **Reuse in degree courses or degree course versions :**

Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch

12 **Module coordinator:**

Prof. Dr. Eyke Hüllermeier

13	**Other Notes:** *Remarks of course Machine Learning 1:* **Implementation method** Theoretical foundations and concepts of machine learning will be taught in the form of a lecture and deepened in practical exercise courses, group work as well as individual homework. **Learning Material, Literature** • Script • Y.S. Abu-Mostafa, M. Magdon-Ismail, H.T. Lin. Learning from Data, AMLBook, 2012. • P. Flach. Machine Learning, Cambridge Univ. Press, 2012. • E. Alpaydin. Machine Learning, Oldenbourg, 2008. • C.M. Bishop. Pattern Recognition and Machine Learning, Springer, 2006.

Machine Learning II

Machine Learning II

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.01275	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	beliebig	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05810 Machine Learning II	L3 Ex2	75	105	CE	20

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Machine Learning II:
Recommended Proficiencies
Basic knowledge in machine learning (as conveyed, for example, by the Machine Learning I lecture).

4 **Contents:**

Contents of the course Machine Learning II:
This lecture, which is conceived as a continuation of the Machine Learning I, covers advanced topics in contemporary machine learning research, such as reinforcement learning, online learning and bandit algorithms, multi-task learning, multi-target and structured output prediction, preference learning, learning from weak supervision, and uncertainty in machine learning. The focus of the lecture will be on methods and algorithms, though theoretical issues and applications will be addressed, too.

- From binary to multi-class classification
- Ordinal and hierarchical classification
- Ensemble methods
- Nonlinear models and kernel machines
- Multi-target prediction
- Semi-supervised learning
- Active learning
- Online learning
- Multi-armed bandits
- Reinforcement learning
- Preference learning and ranking

<table>
<tr><td>5</td><td>Learning outcomes and competences:
The students have an overview of methods for multi-class classification, the learning of nonlinear models, and extensions of the simple setting of supervised learning. They understand algorithmic concepts of corresponding methods and are able to apply them to real problems.
Non-cognitive Skills
• Learning competence
• Learning motivation
• Literacy (scientific)</td></tr>
<tr><td>6</td><td>Assessments:
☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table>
<tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr>
<tr><td>a)</td><td>Written or oral examination</td><td>90-120 minutes or 40 minutes</td><td>100%</td></tr>
</table>
The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.</td></tr>
<tr><td>7</td><td>Study Achievement:
none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
Passing of course achievement</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The module is weighted as 6 credits.</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr. Eyke Hüllermeier</td></tr>
</table>

13	**Other Notes:** *Remarks of course Machine Learning II:* **Implementation method** Theoretical foundations and concepts of machine learning will be taught in the form of a lecture and deepened in practical exercise courses, group work as well as individual homework. **Learning Material, Literature** • Script • Y.S. Abu-Mostafa, M. Magdon-Ismail, H.T. Lin. Learning from Data, AMLBook, 2012. • P. Flach. Machine Learning, Cambridge Univ. Press, 2012. • E. Alpaydin. Machine Learning, Oldenbourg, 2008. • C.M. Bishop. Pattern Recognition and Machine Learning, Springer, 2006.

Machine Learning for Biometrics

Machine Learning for Biometrics

Module number:	**Workload (h):**	**Credits:**	**Regular Cycle:**
M.079.4088	180	6	module.frequency.en
	Semester number:	**Duration (in sem.):**	**Teaching Language:**
	1-3	1	en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.079.05709 Machine Learning for Biometrics	L2 Ex3	75	105	C	70/35

2 **Options within the module:**

none

3 **Admission requirements:**

none

4 **Contents:**

Contents of the course Machine Learning for Biometrics:
Biometric verification is defined as the automated recognition of individuals based on their behavioral or biological characteristics. The course will give an overview of modern biometric systems and specifically address their functionality and challenges. For this purpose, various approaches of machine learning will be introduced, which aim at enabling reliable biometric recognition (e.g. by means of face recognition). At the same time, biometric applications place very specific requirements on the underlying algorithms. The course will specifically address these requirements and how they can be met algorithmically and in the algorithmic learning process. This includes the topics of privacy, fairness, explainability, uncertainties, efficiency, attacks and their automated detection.
The course includes the following content:

- Biometric systems, operation modes, and evaluation
- Recap on traditional and deep learning
- Face, Iris, and fingerprint recognition
- Soft-biometrics and privacy
- Fairness and bias in biometric systems
- Explainability and confidence in biometric systems
- Biometric sample quality
- Efficient biometric systems
- Presentation attacks and detection
- Multi-biometric fusion
- Biometric indexing

<table>
<tr><td>5</td><td>Learning outcomes and competences:
Students will be able to
• independently evaluate biometric systems,
• train biometric recognition models for different modalities,
• automatically detect biometric attacks and make systems robust against such attacks,
• explain various challenges of biometric systems and name solution strategies to counter them,
• name and explain open research questions in biometrics.</td></tr>
<tr><td>6</td><td>Assessments:
☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table>
<tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr>
<tr><td>a)</td><td>Written or oral examination or report</td><td>120-180 min or 30-45 min or 30 min</td><td>100%</td></tr>
</table></td></tr>
<tr><td>7</td><td>Study Achievement:
none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch</td></tr>
<tr><td>12</td><td>Module coordinator:
Dr.-Ing. Philipp Terhörst</td></tr>
</table>

13	**Other Notes:** *Remarks of course Machine Learning for Biometrics:* **Implementation Method** First, students are given an overview of biometrics and its applications and basic functionalities. Then, required concepts of machine learning are introduced in a compact way. These will be applied and developed in context when dealing with specific biometric requirements. Parallel to the lecture, the theoretical concepts are practiced in the exercises using facial data. This is done in the form of short hand-written and implementation tasks. **Learning Material, Literature** • Anil K. Jain, Patrick Flynn, and Arun A. Ross. 2010. Handbook of Biometrics (1st. ed.). Springer Publishing Company, Incorporated. • Further literature will be announced in the lecture.

Optimale und Adaptive Filter			
Optimal and Adaptive Filters			
Module number: M.048.24010	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** de / en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.24010 Optimal and Adaptive Filters	2L 2Ex, WS	60	120	C	40/40

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Optimale und Adaptive Filter:
Recommended: Prior knowledge from the modules Higher Mathematics and Digital Signal Processing.

4	**Contents:** *Contents of the course Optimale und Adaptive Filter:* **Short Description** The course “Optimal and adaptive filters” gives an introduction to the basic techniques and theories of adaptive filters. Based upon the basics of estimation theory optimal filters are discussed. Subsequently the topics Wiener filter theory, deterministic optimization under constraints and stochastic gradient methods are regarded. Concluding the Least Squares approach for solving filter tasks and the Kalman filter are introduced. The latter is regarded as a brief introduction to state based filters. **Contents** • Classic parameter estimation – Estimators – MMSE-Estimation – Linear estimators – Orthogonality principle – Evaluation of estimators • Wiener filter – Wiener-Hopf equation – AR- and MA processes – Linear prediction • Iterative optimization methods – Gradient ascent/descent – Newton method • Linear adaptive filters – LMS algorithm – Least-Squares method – Blockwise and recursive adaptiv filters – Realization aspects • Statemodel based filters – Kalman filter • Applications – System identification – Channel estimation and equalization – Multi-channel speech signal processing – Noise and interference suppression

5 **Learning outcomes and competences:**

Domain competence:
After attending the course, the students will be able to

- analyze task on the field of adaptive filters and to formulate requirements mathematically,
- develop filter using cost functions and
- implement selected adaptive filters in the frequency or time domain.

Key qualifications:
The students

- are able to check theoretical results using practical realizations,
- are able to undertake theoretical approaches a systematic analysis using methodical procedures and
- are, due to the precise treatment of the contents, in a position to continue their learning themselves.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11 **Reuse in degree courses or degree course versions :**

BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4

12 **Module coordinator:**

Dr.-Ing. Jörg Schmalenströer

13	**Other Notes:** *Remarks of course Optimale und Adaptive Filter:* **Course Homepage** `https://ei.uni-paderborn.de/en/nt/teaching/veranstaltungen/optimal-and-adaptive-filter` **Implementation** • Lectures using the blackboard and presentations, • Alternating theoretical and practical exercises classes with exercise sheets and computer and • Demonstration of real technical systems in the lecture hall. **Teaching Material, Literature** Allocation of a script; information on textbooks; matlab scripts

Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation			
Fast Integrated Circuits for Wireline Communications			
Module number: M.048.25019	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** de / en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.25019 Fast Integrated Circuits for Wireline Communications	2L 2Ex, WS	60	120	C	40/40

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation:
Recommended: Module “Schaltungstechnik” of the Bachelor Electrical Engineering or module “Circuit and System Design” of the Master “Electrical Systems Engineering” or comparable modules / lectures

4	**Contents:** *Contents of the course Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation:* **Short Description** Nowadays commercial fiber-optic communication systems reach very high data rates of 100 Gb/s per optical channel and several Tb/s in a single fiber. In a similar way very high data rates of more than 10 Gb/s occur at a single package pin of electronic chips. These signals are to be transmitted over printed circuit boards and inexpensive serial cables. In the future the progress of CMOS technology and communication technology will push speed of fiber-optic and wire-line communication continuously to ever higher data rates. The design of electronic circuits for high bandwidth rsp. data rates requires a good system knowledge with respect to typical transmitter and receiver architectures, components, and signal properties. Furthermore a thorough understanding of integrated circuit design as well as precise high-frequency modeling of passive and active devices are required. Goal of the lecture is to enable the student to utilize a methodological approach for the design of fast integrated electronic circuits for digital wired communications. A part of the exercises will be carried out using modern industry-standard IC design software. **Contents** The lecture deals with analysis and design of fast integrated electronic circuits for digital broadband communication systems. A part of the exercises will be performed using modern chip design CAD tools. The lecture is based on the compulsory lectures “Schaltungstechnik” rsp. “Circuit and System Design”. The lecture deals with: • Transmitter and receiver architectures for fiber-optic communications • Transmitter and receiver architectrues for chip-to-chip communications • System design • Semiconductor technology and integrated high-frequency devices • Broadband amplifiers • Current-mode logic • Transmitter and receiver circuits • PLLs for frequency synthesis and clock recovery • Measurement methods
5	**Learning outcomes and competences:** **Domain competence:** The student will be able to: • describe and analyze transmitter and receiver architectures for broadband communication links • understand and describe semiconductor technologies and integrated high-frequency devices for broadband circuits • to analyze circuit design techniques for transmitter and receiver circuits and describe ways to optimize them • to describe circuits in PLL technique for frequency synthesis and clock recovery • to describe measurement methods **Key qualifications:** The students will learn how different interdisciplinary scientific domains and their methods - like mathematical signal and system analysis, non-linear and linear circuit analysis, semiconductor physics, semiconductor devices and high-frequency engineering - are applied together for the development of communications application.

<table>
<tr><td>6</td><td>Assessments:
☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table><tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr><tr><td>a)</td><td>Oral Examination</td><td>30-45 min</td><td>100%</td></tr></table></td></tr>
<tr><td>7</td><td>Study Achievement:
none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr.-Ing. J. Christoph Scheytt</td></tr>
<tr><td>13</td><td>Other Notes:
Remarks of course Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation:
Course Homepage
https://www.hni.uni-paderborn.de/en/system-and-circuit-technology/teaching/fast-integrated-circuits-for-wireline-communications/
Implementation
Lecture with Exercises (including computer-aided design using electronic design software)
Teaching Material, Literature
Handouts and literature references will be given in the lecture.
• E. Säckinger, “Broadband Circuits for Optical Fiber Communication”, Wiley, 2005
• B. Razavi, “Design of Integrated Circuits for Optical Communications”, McGraw-Hill, 2003
Comments
As part of the lecture a 2-day excursion to IHP Leibnizinstitute for High-Performance Microelectronics in Frankfurt (Oder) is offered which includes the visit of a modern chip fabrication facility (participation in the excursion is voluntary).</td></tr>
</table>

Statistical and Machine Learning			
Statistical and Machine Learning			
Module number: M.048.23012	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.23012 Statistical and Machine Learning	2L 2Ex, SS	60	120	C	40/40

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Statistical and Machine Learning:
Recommended: Elementary knowledge in probability theory, as is taught in the course Statistical Signal Processing. Basic programming skills are desirable.

4 **Contents:**

Contents of the course Statistical and Machine Learning:
Short Description
The course on Statistical and Machine Learning presents an introduction into the components and algorithms prevalent in statistical and machine learning. Modern techniques will be presented for gleaning information from data. Both supervised and unsupervised learning algorithms will be discussed. The presented techniques can be applied to a variety of classification and regression problems, both for one-dimensional input data (e.g., speech), two-dimensional (e.g., image) or symbolic input data (e.g., documents).
Contents
Introduction to classification problems, Bayesian and other decision rules Optimization: gradient descent, algorithmic differentiation, optimization with constraints *Linear classifiers, Support Vector Machines* Deep neural networks (deep learning) *Dimensionality reduction (PCA, LDA)* Unsupervised learning (mixture densities, clustering techniques)

5 **Learning outcomes and competences:**

Domain competence:
After completion of the module students will be able to

- Find an appropriate approach to solving a given classification or regression problem
- Apply supervised or unsupervised learning techniques to data of various kinds and critically assess the outcome of the learning algorithms
- Can appreciate the power and limitations of machine learning algorithms
- Work with software for solving machine learning problems and write own software components, apply them to given data sets and optimize parameter settings
- Find, for a given training set size, an appropriate choice of classifier complexity und feature vector dimensionality

Key qualifications:
The students

- Have gathered sufficient proficiency in Python, which is valuable well beyond this course
- Can assess the importance of the principle of parsimony and are able to transfer it to other
- Are able to analyse a given classification or regression problem, synthesize a solution, and evaluate the performance on test data
- Are able to apply the knowledge and skills learnt in this course to a wide range of disciplines
- Can work cooperatively in a team and subdivide an overall task into manageable subtasks and work packages
- Acquired a general understanding of the power and limitations of machine learning algorithms

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11	**Reuse in degree courses or degree course versions :** BF Automatisierungstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4
12	**Module coordinator:** Dr.-Ing. Mohammad Soleymani
13	**Other Notes:** *Remarks of course Statistical and Machine Learning:* **Course Homepage** `https://ei.uni-paderborn.de/en/statistical-and-machine-learning` **Implementation** *Lectures predominantly using the blackboard or overhead projector, occasional presentations of (powerpoint) slides ,* Exercise classes with exercise sheets and demonstrations on computer *Implementation of learning and classification algorithms on a computer by the students themselves; use of algorithms on real-world data or data generated on the computer, evaluation of the simulation results **Teaching Material, Literature** Course script and summary slides are provided to the students. Exercises and solutions to exercises, as well as sample implementations of algorithms are provided to the students *R.O. Duda, P.E. Hart, D.G.~ Stork, Pattern Classification, Wiley, 2001* I. Goodfellow, Y. Bengio, A. Courville: Deep Learning, MIT Press, 2016 *S. Theodoridis: Machine Learning, Academic Press, 2015* K. Fukunaga, Introduction to Statistical Pattern Recognition, Academic Press, 1990

Statistical Natural Language Processing			
Statistical Natural Language Processing			
Module number: M.079.01281	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: beliebig	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.079.05702 Statistical Natural Language Processing	L2 Ex3	75	105	CE	30

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Statistical Natural Language Processing:
Recommended Proficiencies
Vector spaces, grammar of natural languages, probability theory

4 **Contents:**

Contents of the course Statistical Natural Language Processing:
The goal of this lecture is to present students with the foundational tools and methods necessary to implement natural language processing pipelines. The course includes content pertaining to text preprocessing, parsing, distributional semantics, dedicated machine learning approaches and applications such as question answering.

- Text normalization
- Language modeling
- Spelling correction
- Machine Learning
- POS Tagging
- Parsing
- Distributional semantics
- Word senses
- Knowledge Extraction
- Question Answering

5 **Learning outcomes and competences:**

Students can list relevant problems and identify solution requirements for the following areas:

- Text preprocessing
- Language modelling
- Spelling correction
- Text and document classification
- Distributional Semantics
- Question Answering

They are aware of basic techniques in these areas, can identify limitations and shortcomings of these techniques when applied to concrete problem situations, and develop modifications of these techniques for specific areas. They can evaluate such modifications qualitatively and quantitatively.

Non-cognitive Skills

- Team work
- Learning competence
- Media competence
- Literacy (scientific)

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or oral examination	90-120 minutes or 40 minutes	100%

The responsible lecturer announces type and duration of assessment modalities in the first three weeks of the lecture period at latest.

7 **Study Achievement:**

zu	**Type of achievement**	**Duration or Scope**	**SL / QT**
a)	Written exercises		CA

Within the first three weeks of the lecture period each respective lecturer will specify the manner in which the course achievement will be conducted.

8 **Prerequisites for participation in examinations:**

Passing of course achievement

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination was passed.

10 **Weighing for overall grade:**

The module is weighted as 6 credits.

11	**Reuse in degree courses or degree course versions :** Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch
12	**Module coordinator:** Prof. Dr. Axel-Cyrille Ngonga Ngomo
13	**Other Notes:** *Remarks of course Statistical Natural Language Processing:* **Implementation method** The weekly lectures (2SWS) cover new content on a weekly basis. In addition to the formal considerations, we will cover applications and corresponding limitations of the methods presented throughout the course. The exercises (1SWS) are both theoretical and practical in nature. The learners are to show that they understood the concepts and can apply them to practical problems. The mini-project (2SWS) give the students a holistic view of how to solve complex problems using Semantic Web technologies. **Learning Material, Literature** Slides and homework assignments

Technische kognitive Systeme			
Cognitive Systems Engineering			
Module number: M.048.43019	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	**form of teachin**	**contact-time (h)**	**self-study (h)**	**status (C/CE)**	**group size (TN)**
a)	L.048.23019 Cognitive Systems Engineering - Special Topics	2L 2Ex, WS	60	120	C	40/40

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Technische kognitive Systeme - Ausgewählte Kapitel:
Recommended: Interest in the subject-matter and interdisciplinary work.

4	**Contents:** This module is offered in three parts. Students have to choose **two out of three**. Each part lasts two hours per week and yields three credits. *Contents of the course Technische kognitive Systeme - Ausgewählte Kapitel:* **Part A** At any given time, the sensory receptors of living beings are exposed to a very large amount of information, of which only a small proportion can be consciously processed. Visual attention is understood as the pooling of available cognitive resources for optimal processing of visual stimuli. The seminar introduces the modeling and experimental investigation of visual attention and the transfer to intelligent technical systems. It will be shown how research can be conducted jointly across disciplinary boundaries. The current focus is on the topic of saliency. The course always takes place in the winter semester. **Part B** While “sensation” describes the signals from the physical world that reach our sensory receptors, “perception” refers to the processes by which our brain selects, organizes, and interprets the signals. This seminar provides students in technical courses with an overview of the fundamentals of biological sensory systems and perception. In addition to the exciting and (sometimes non-intuitive) background of these topics, there will be a critical discussion of the transferability of biological concepts and mechanisms to technical systems. This seminar is always in the summer semester. **Part C** In this seminar, current interim reports and results from ongoing bachelor’s and master’s theses, research projects, and third-party funded projects from the GETLab - Technical Cognitive Systems department will be presented. Furthermore, there will be presentations by guests of the research group. The seminar is offered in the summer and winter semester.
5	**Learning outcomes and competences:** **Domain competence:** The students • are able to name basic research topics related to the design and the implementation of technical cognitive systems, • can apply and evaluate technical cognitive systems, and • are able to understand, design, implement and evaluate basic psychophysical experiments. **Key qualifications:** The students • are able to research and evaluate technical literature, • have developed an understanding of the discipline-related research approaches (computer science, electrical engineering, psychology) and • are able to carefully consider the potential use of bio-inspired mechanisms in technical systems.

<table>
<tr><td>6</td><td>Assessments:
☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)<table><tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr><tr><td>a)</td><td>Written or Oral Examination or Presentation</td><td>90-150 min or 20-30 min or 30-60 min</td><td>100%</td></tr></table></td></tr>
<tr><td>7</td><td>Study Achievement:
none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr. Bärbel Mertsching</td></tr>
<tr><td>13</td><td>Other Notes:
Module Homepage
[http://getwww.uni-paderborn.de/teaching/cse]
Teaching Material, Literature
Literature references will be given at the first dates of the seminar.
Remarks of course Technische kognitive Systeme - Ausgewählte Kapitel:
———
ATTENTION - IMPORTANT NOTICE
The course doesn’t take place in winter term 2026/27 summer term 2026. Please see the notice boards of the group.
———</td></tr>
</table>

Topics in Signal Processing			
Topics in Signal Processing			
Module number: M.048.92014	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 1.-3. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.92014 Topics in Signal Processing	2L 2Ex, WS	60	120	C	30/30

2 **Options within the module:**

None

3 **Admission requirements:**

None

Prerequisites of course Topics in Signal Processing:
Recommended: Signal and system theory, at least a basic understanding of probability and linear algebra

4 **Contents:**

Contents of the course Topics in Signal Processing:
Short Description
This course covers a selection of current topics in signal processing. One part of this course will follow a regular lecture format, while the other part will require active student participation.
Contents
This course will first review relevant aspects of linear algebra and probability theory. Then students will learn how to read, analyze, and present recent papers from the signal processing literature.

5 **Learning outcomes and competences:**

In this course, students will familiarize themselves with some current research topics in signal processing. They will learn to read and understand scientific publications and to critically evaluate results. Students will develop confidence in their ability to solve mathematical problems of analysis and design. They will be able to apply the principles they have learnt in this course to other areas.

<table>
<tr><td>6</td><td>Assessments:
☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)
<table>
<tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr>
<tr><td>a)</td><td>Written or Oral Examination or Presentation</td><td>120-180 min or 30-45 min or 30 min</td><td>100%</td></tr>
</table></td></tr>
<tr><td>7</td><td>Study Achievement:
none</td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
The credit points are awarded after the module examination (MAP) was passed.</td></tr>
<tr><td>10</td><td>Weighing for overall grade:
The module is weighted according to the number of credits (factor 1).</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Informatik v3, Masterstudiengang Informatik v4, Master's Program Electrical Systems Engineering v2 (ESEMA v2), Master's Program Electrical Systems Engineering v3 (ESEMA v3)</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr. Peter Schreier</td></tr>
<tr><td>13</td><td>Other Notes:
Remarks of course Topics in Signal Processing:
Course Homepage
http://sst.uni-paderborn.de/teaching/courses/
Implementation
Lectures and tutorials with active student participation, student presentations
Teaching Material, Literature
References will be given in the first lecture.</td></tr>
</table>

Wireless Communications			
Wireless Communications			
Module number: M.048.24022	**Workload (h):** 180	**Credits:** 6	**Regular Cycle:** module.frequency.en
	Semester number: 2.-4. Semester	**Duration (in sem.):** 1	**Teaching Language:** en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	L.048.24022 Wireless Communications	2L 2Ex, SS	60	120	CE	30 / 30

2 **Options within the module:**

none

3 **Admission requirements:**

Prerequisites of course Wireless Communications:
Recommended:
Prior knowledge from the modules Signal and Information Transmission, Signal Theory, and Probability for Engineers.

4 **Contents:**

Contents of the course Wireless Communications:
The course provides students with important basic knowledge necessary for understanding the transmission concepts of modern mobile communication systems. Starting with a physical understanding of the mobile communications channel, in particular the phenomena of multipath propagation and the Doppler effect, the physical and statistical modeling of time-varying communication systems is presented. Subsequently, important diversity techniques for channel-adaptive transmission and multiple access techniques are introduced.

5 **Learning outcomes and competences:**

Domain competence:
After completion of the course students will be able to

- understand the fundamental propagation mechanisms in mobile radio channels;
- describe and apply physical and statistical modeling principles to time-varying communication channels;
- analyze fading processes and asses their impact on transmission reliability;
- explain diversity techniques, apply them to design physical layer signal processing algorithms, and assess their impact on transmission reliability;
- explain, compare, and evaluate common multiple access schemes;
- assess transmission concepts employed in contemporary mobile communication systems;
- connect theoretical channel models with practical system design considerations.

Key qualifications:
The students

- have strong analytical and mathematical reasoning skills;
- have the ability to abstract complex physical phenomena into engineering models;
- can interpret analytical results at the system level;
- have experience in clear and precise technical communication (oral and written)
- can learn independently and engage critically with technical literature.

6 **Assessments:**

☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)

zu	**Type of examination**	**Duration or scope**	**Weighting for the module grade**
a)	Written or Oral Examination or Presentation	120-180 min or 30-45 min or 30 min	100%

7 **Study Achievement:**

none

8 **Prerequisites for participation in examinations:**

None

9 **Prerequisites for assigning credits:**

The credit points are awarded after the module examination (MAP) was passed.

10 **Weighing for overall grade:**

The module is weighted according to the number of credits (factor 1).

11	**Reuse in degree courses or degree course versions :** BF Informationstechnik Lehramt BK affine Fächer Master v5, Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch, Masterstudiengang Computer Engineering v4 (CEMA v4), Masterstudiengang Computer Engineering v4 (CEMA v4), englisch, Masterstudiengang Elektrotechnik v4/v4b (EMA v4/v4b), Masterstudiengang Elektrotechnik v5 (EMA v5), Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik, Masterstudiengang Wirtschaftsingenieurwesen Studienrichtung Elektrotechnik V4
12	**Module coordinator:** Prof. Dr. Bho Matthiesen
13	**Other Notes:** **Module Homepage** `https://www.hni.uni-paderborn.de/en/nt` **Implementation** Lectures and exercises **Teaching Material, Literature** Lecture slides and reading assignments for each lecture; additional reading suggestions.

4 Master's Thesis

Abschlussarbeit			
Master's Project			
Module number: A.048.17001	**Workload (h):** 900	**Credits:** 30	**Regular Cycle:** module.frequency.en
	Semester number: 4. Semester	**Duration (in sem.):** 1	**Teaching Language:** de / en

1 **Module structure:**

	Course	form of teachin	contact-time (h)	self-study (h)	status (C/CE)	group size (TN)
a)	Working Plan (CEMA)		15	135	C	
b)	Master Thesis (CE)		30	720	C	

2 **Options within the module:**

None

3 **Admission requirements:**

Prerequisites of course Arbeitsplan (CEMA):
Recommended: Depending on the chosen topic, knowledge from the chosen specialization module.

Prerequisites of course Masterarbeit (CE):
Recommended: Depending on the topic chosen, knowledge of the chosen area of specialization.

4 **Contents:**

5 **Learning outcomes and competences:**

-

<table>
<tr><td>6</td><td>Assessments:
☒Final module exam (MAP) □Module exam (MP) □Partial module exams (MTP)<table><tr><th>zu</th><th>Type of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr><tr><td>a) - b)</td><td></td><td></td><td>100%</td></tr></table></td></tr>
<tr><td>7</td><td>Study Achievement:<table><tr><th>zu</th><th>Type of achievement</th><th>Duration or Scope</th><th>SL / QT</th></tr><tr><td>a)</td><td>Working Plan</td><td>150h</td><td>QP</td></tr><tr><td>b)</td><td></td><td></td><td></td></tr></table></td></tr>
<tr><td>8</td><td>Prerequisites for participation in examinations:
None</td></tr>
<tr><td>9</td><td>Prerequisites for assigning credits:
keine</td></tr>
<tr><td>10</td><td>Weighing for overall grade:</td></tr>
<tr><td>11</td><td>Reuse in degree courses or degree course versions :
Masterstudiengang Computer Engineering v3 (CEMA v3), Masterstudiengang Computer Engineering v3 (CEMA v3), englisch</td></tr>
<tr><td>12</td><td>Module coordinator:
Dr.-Ing. Carsten Balewski</td></tr>
<tr><td>13</td><td>Other Notes:</td></tr>
</table>

5 Overview of the modules offered in the winter semester

- A.048.17001 Abschlussarbeit 241
- M.048.22021 Geregelte Netzumrichter 118
- M.048.23023 Resource-Efficient AI: Architectures and Methodologies 155
- M.048.24010 Optimale und Adaptive Filter 220
- M.048.24020 Theory and Design of Phase-locked Loops 192
- M.048.25019 Schnelle integrierte Schaltungen für die leitungsgebundene Kommunikation . 224
- M.048.26012 Modern Semiconductor Lasers 180
- M.048.26013 Theory and Design of Integrated Photonic Devices 189
- M.048.27031 Optimization-Based Control Methods 125
- M.048.43019 Technische kognitive Systeme 233
- M.048.45001 Pflichtmodul Elektrotechnik I 10
- M.048.45002 Pflichtmodul Elektrotechnik II 14
- M.048.92001 Advanced System Theory 198
- M.048.92002 High Frequency Engineering 171
- M.048.92006 Advanced Topics in Robotics 110
- M.048.92014 Topics in Signal Processing 236
- M.048.92021 Optical Communication C 47
- M.048.92027 VLSI-Testing 195
- M.079.01251 Pflichtmodul Informatik I 4
- M.079.01252 Pflichtmodul Informatik II 7
- M.079.01256 Advanced Distributed Algorithms and Data Structures 24
- M.079.01260 Databases and Information Systems 85
- M.079.01270 Reconfigurable Computing 152
- M.079.01274 Machine Learning I 211
- M.079.01277 Model-Based Systems Engineering 149
- M.079.01279 Introduction to Quantum Computation 88
- M.079.01281 Statistical Natural Language Processing 230
- M.079.01286 Real World Crypto Engineering 57
- M.079.4088 Machine Learning for Biometrics 217

6 Overview of the modules offered in the summer semester

- A.048.17001 Abschlussarbeit 241
- M.048.23012 Statistical and Machine Learning 227
- M.048.24001 Digitale Sprachsignalverarbeitung 207
- M.048.24021 Information Theory 32
- M.048.24022 Wireless Communications 238
- M.048.25017 Integrierte Schaltungen für die drahtlose Kommunikation 174
- M.048.26011 Optoelectronics 183
- M.048.27013 Regelung elektrischer Antriebe 116
- M.048.27015 Ultraschallmesstechnik 130
- M.048.27028 Gekoppelte Felder 113
- M.048.27032 Nonlinear control of autonomous and robotic systems 123
- M.048.42941 Wissenschaftliches Arbeiten 20
- M.048.92001 Advanced System Theory 198
- M.048.92008 Digital Image Processing I 201
- M.048.92010 Digital Image Processing II 204
- M.048.92012 Robotics 127
- M.048.92019 Optical Communication A 41
- M.048.92020 Optical Communication B 44
- M.048.92043 Advanced VLSI Design 167
- M.079.01254 Projektgruppe 17
- M.079.01262 Foundations of Cryptography 26
- M.079.01271 Routing and Data Management in Networks 59
- M.079.01272 Software Quality Assurance 161
- M.079.01275 Machine Learning II 214
- M.079.01278 Approximate Computing 137
- M.079.01284 Web Security 73
- M.079.01285 Usable Security and Privacy 100
- M.079.4211 Hardware Security 143

7 Overview of module offerings in English

- A.048.17001 Master's Project 241
- M.048.23012 Statistical and Machine Learning 227
- M.048.23021 Topics in Audio, Speech and Language Processing ..... **??**
- M.048.23023 Resource-Efficient AI: Architectures and Methodologies 155
- M.048.24001 Digital Speech Signal Processing 207
- M.048.24010 Optimal and Adaptive Filters 220
- M.048.24020 Theory and Design of Phase-locked Loops 192
- M.048.24021 Information Theory 32
- M.048.24022 Wireless Communications 238
- M.048.25017 Integrated Circuits for Wireless Communications 174
- M.048.25019 Fast Integrated Circuits for Wireline Communications 224
- M.048.26011 Optoelectronics 183
- M.048.26012 Modern Semiconductor Lasers 180
- M.048.26013 Theory and Design of Integrated Photonic Devices 189
- M.048.27013 Control of Electric Drives 116
- M.048.27031 Optimization-Based Control Methods 125
- M.048.27032 Nonlinear control of autonomous and robotic systems 123
- M.048.43019 Cognitive Systems Engineering 233
- M.048.45001 Compulsory Module Electrical Engineering I 10
- M.048.45002 Compulsory Module Electrical Engineering II 14
- M.048.92001 Advanced System Theory 198
- M.048.92002 High Frequency Engineering 171
- M.048.92006 Advanced Topics in Robotics 110
- M.048.92007 Algorithms and Tools for Test and Diagnosis of Systems on a Chip ..... **??**
- M.048.92008 Digital Image Processing I 201
- M.048.92010 Digital Image Processing II 204
- M.048.92012 Robotics 127
- M.048.92014 Topics in Signal Processing 236
- M.048.92019 Optical Communication A 41
- M.048.92020 Optical Communication B 44
- M.048.92021 Optical Communication C 47
- M.048.92027 VLSI-Testing 195
- M.048.92030 Topics in Pattern Recognition and Machine Learning ..... **??**
- M.048.92037 Advanced Control ..... **??**
- M.048.92043 Advanced VLSI Design 167
- M.048.92045 Reinforcement Learning ..... **??**
- M.079.01251 Computer Science I 4
- M.079.01252 Computer Science II 7
- M.079.01254 Project Group 17
- M.079.01256 Advanced Distributed Algorithms and Data Structures 24

- M.079.01260 Databases and Information Systems 85
- M.079.01262 Foundations of Cryptography 26
- M.079.01270 Reconfigurable Computing 152
- M.079.01271 Routing and Data Management in Networks 59
- M.079.01272 Software Quality Assurance 161
- M.079.01274 Machine Learning I 211
- M.079.01275 Machine Learning II 214
- M.079.01277 Model-Based Systems Engineering 149
- M.079.01278 Approximate Computing 137
- M.079.01279 Introduction to Quantum Computation 88
- M.079.01281 Statistical Natural Language Processing 230
- M.079.01285 Usable Security and Privacy 100
- M.079.01286 Real World Crypto Engineering 57
- M.079.4088 Machine Learning for Biometrics 217
- M.079.4211 Hardware Security 143

Erzeugt am 8. September 2026 um 12:27.