Module Descriptions

Master of Science Communications Technology

Absorption: Microelectronics

Examination Regulations in the Version of: 2011
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## Communications Engineering

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<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Robert Fischer</td>
</tr>
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</table>
| Instructor(s)      | Prof. Dr.-Ing. Robert Fischer  
                      Dr. Werner Teich |

### Allocation of study programmes
- Electrical Engineering, M.Sc., Elective Module
- Electrical Engineering, M.Sc., Elective Module, General Electrical Engineering
- Electrical Engineering, M.Sc., Compulsory Subject Module, Communication and System Technology
- Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology
- Information Systems Technology, M.Sc., Elective Module
- Communications Technology, M.Sc., Compulsory Subject Module

### Recommended prerequisites
- signals and systems (discrete and continuous-time signals and systems)
- fundamentals of random variables and random processes
- fundamentals of communications (analog and digital transmission)

### Learning objectives
The students will be able to assess, compare, and design state-of-the-art digital communication schemes. They can operate with equivalent complex baseband signals and systems and appraise the action of system on stochastic processes. Digital pulse amplitude modulation and its variants can be explained and devised. The representation of signals in a signal space can be formulated and applied for designing optimum receivers. Coherent and non-coherent approaches can be discriminated. Digital modulation formats can be assessed in the power-bandwidth plane. The students will identify and characterize the action of distorting channels and are able to design and evaluate suitable equalizers. The concepts of single- and multi-carrier transmission can be explained, justified and synthesized for new applications.

### Syllabus
- Introduction
- Equivalent complex baseband
- Fundamentals of digital communications / digital pulse amplitude modulation (PAM)
- Variants of PAM transmission (CAP, MSK, GMSK) / non-coherent transmission
- Signal space representation
- FSK, CPM
- Channel models and digital transmission over dispersive channels
- Orthogonal frequency-division multiplexing
- Multiple-input/multiple-output systems

**Literature**

**Teaching and learning methods**
- Lecture "Communications Engineering", 4 SWS
- Exercise "Communications Engineering", 2 SWS
- Laboratory "Communications Engineering", 2 SWS

**Workload**
- Active Time: 144 h
- Preparation and Evaluation: 100 h
- Self-Study: 56 h
- Sum: 300 h

**Assessment**
The grade of the module will be the grade of the oral or written (depending on the number of participants) exam. Successful participation at the lab course is prerequisites for exam registration.

**Grading procedure**
The grade of the module will be the grade of the exam.

**Basis for**
- Multuser Communications and MIMO Systems
- Iterative Methods for Wireless Communications
Optical Communications
Modules referring to Core Subjects

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<td>apl. Prof. Dr.-Ing. habil. Rainer Michalzik</td>
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<tr>
<td>Instructor(s)</td>
<td>apl. Prof. Dr.-Ing. habil. Rainer Michalzik</td>
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Allocation of study programmes
- Electrical Engineering, M.Sc., Elective Module
- Communications Technology, M.Sc., Compulsory Elective Module, Track Communications Engineering
- Communications Technology, M.Sc., Compulsory Module, Track Communications Circuits and Systems

Recommended prerequisites
Bachelor. No prerequisites from other modules required. Some basic knowledge of semiconductor physics and devices would be helpful

Learning objectives
The students are able to summarize the benefits of optical versus electrical data transmission. They can employ a ray-optical model to describe the light propagation in optical waveguides and can identify situations where a wave-optical model is needed. The students can name and sketch different kinds of optical fibers as well as discuss the associated dispersion mechanisms which lead to bandwidth limitations. Origins of loss in optical fibers can be listed and fiber fabrication be outlined. They can state boundary conditions of field variables to formulate characteristic equations for waveguide problems. The students can describe the structure of common semiconductor crystals as well as the composition dependence of parameters required to model the wave propagation. Appropriate semiconductor material systems for particular applications can be selected and interband transition mechanisms be sketched. They are able to explain the operation of a light emitting diode and rate their use in fiber-based optical communication systems. The students can illustrate the function of a laser diode and name the contributions to the laser rate equations. They master to solve the rate equations for static and dynamic operating conditions. The students can discuss the role of a pn-junction for light detection. Factors influencing the efficiency and the bandwidth of a photodiode can be pointed out. They can relate
the current noise in a photoreceiver to the measured bit error ratio of a digital optical communication link. The optical power budget can be calculated. The students are able to list and discuss multiplexing techniques for increasing the data throughput of an optical communication system. The basic function of optical (de-)multiplexing devices can be stated. They can moreover sketch the building blocks of an optical repeater and explain the operation of an optical fiber amplifier.

**Syllabus**

This module provides a solid basis for understanding fiber-optic data transmission systems. Important components like the silica optical fiber as transmission medium, light emitting diode or laser diode transmitters, optical amplifiers, as well as photodiode receivers are discussed in some detail. The entire system is characterized in terms of its bit error ratio performance and its power budget. The following topics are addressed:

- Properties of optical communication systems
- Optical fibers: ray-optical model, step-index and graded-index fibers, wave-optical model, chromatic dispersion
- Wave propagation in planar waveguides
- Loss in optical fibers: absorption and scattering
- Fabrication of fibers
- Semiconductor materials: crystal lattices, direct and indirect bandgaps, mixed compound semiconductors, absorption and refractive index, emission and absorption
- Light-emitting diodes for communications
- Laser diodes
- Photodiodes
- Optical communication systems: detection sensitivity for digital signals, optical power budget
- Signal multiplexing: electrical time division multiplexing (ETDM), dense and coarse wavelength division multiplexing (WDM), optical (de-)multiplexing devices, space division multiplexing (SDM)
- Signal restoration: electronic repeater, erbium-doped fiber amplifier (EDFA), alternative optical amplifiers
- Laser diodes
- Photodiodes
- Optical communication systems: detection sensitivity for digital signals, optical power budget
- Signal multiplexing: electrical time division multiplexing (ETDM), dense and coarse wavelength division multiplexing (WDM), optical (de-)multiplexing devices, space division multiplexing (SDM)
- Signal restoration: electronic repeater, erbium-doped fiber amplifier (EDFA), alternative optical amplifiers

**Literature**

A comprehensive English written manuscript is provided

**Teaching and learning methods**

Lecture “Optical Communications”, 3 hours per week
Exercise “Optical Communications”, 1 hours per week

**Workload**

Preparation and Evaluation: 56 h
Active Time: 49 h
Self-Study: 75 h
Sum: 180 h
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<td><strong>Grading procedure</strong></td>
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<tr>
<td><strong>Basis for</strong></td>
<td>Lecture &quot;Advanced Optoelectronic Communication Systems&quot;, Lecture &quot;Optoelectronic Devices&quot;, Laboratory &quot;Optoelectronics&quot;</td>
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### RF and Microwave Engineering

**Modules referring to Core Subjects**

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<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Christian Waldschmidt</td>
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</table>
| Instructor(s)       | Prof. Dr.-Ing. Christian Waldschmidt  
|                     | Dr.-Ing. Frank Bögelsack |
| Allocation of study programmes | Electrical Engineering, M.Sc., Elective Module  
|                      | Communications Technology, M.Sc., Compulsory Subject Module |
| Recommended prerequisites | -                 |
| Learning objectives | After successful completion of this module, students are able to identify and to describe important properties of components used in RF & microwave engineering. They know to apply basic methods for analyzing and designing RF & microwave circuits and systems. They are capable to find new approaches for unknown problems in RF & microwave engineering area. |
| Syllabus            | This lecture introduces students into basic linear systems of RF & microwave applications. Information and power is transported in these systems by means of electromagnetic waves. Consequently, the introduction of mathematical tools to describe waves on lines and their effects to components and systems is the main subject of this lecture. The module covers in particular the following subjects:  
|                     | - current and voltage waves on (TEM-) lines, power waves,  
|                     | - relations of these waves to field-waves, skin-effect,  
|                     | - reflection of waves at line-terminations, Smith-chart,  
|                     | - impedance transformation by lines and by other components,  
|                     | - realistic components,  
|                     | - description of linear time-invariant wave-N-ports by scattering parameters,  
|                     | - signal flow-graphs,  
|                     | - filters, couplers, amplifiers, linear distortions, |
- electronic noise,
- basics of antennas,

| Literature | - Lecture handout  
- Text books: see lecture handout |
|---|---|
| Teaching and learning methods | Lecture “RF & Microwave Engineering”, 3 SWS  
Exercise “RF & Microwave Engineering”, 1 SWS |
| Workload | Active Time: 60 h  
Preparation and Evaluation: 60 h  
Self-Study: 60 h |
| Assessment | The grade of the module will be the grade of the written exam. No prerequisites are necessary for exam registration. |
| Grading procedure | The grade of the module will be the grade of the exam. |
| Basis for | RF & Microwave Communication Systems, Lab RF Engineering |
Modern Semiconductor Devices
Modules referring to Track Specific Compulsory Subjects - Microelectronics

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<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Hermann Schumacher</td>
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| Instructor(s) | Prof. Dr.-Ing. Hermann Schumacher  
               | Jun.-Prof. Dr. Steffen Strehle |
| Allocation of study programmes | Electrical Engineering, M.Sc., Elective Module, Engineering Sciences  
                                         Electrical Engineering, M.Sc., Elective Module, Microelectronics  
                                         Electrical Engineering, M.Sc., Optional Module, Automation and EnergyTechnology  
                                         Communications Technology, M.Sc., Compulsory Subject Module, Communications Circuits and Systems |
| Recommended prerequisites | Basic knowledge of solid-state physics: semiconductors; band structure in real and in k-space; drift and diffusive transport |
| Learning objectives | Students recognize the importance of energy band diagrams for the analysis and appraisal of advanced electronic devices. They then discover how doping variations and heterostructures are used in current semiconductor devices to control the distribution and motion of free charge carriers. Relevant transistor structures are differentiated according to their charge control mechanism. Students then identify large signal and small signal equivalent circuits, and discuss how intrinsic physical mechanisms are reflected at the component and circuit level. They relate geometrical constraints of high speed transistor families to their economic importance, and briefly review important microfabrication techniques. |
| Syllabus | Semiconductor Fundamentals:  
- Energy band diagrams  
- Doping  
- MOS-, pn- and Schottky junctions  
- Semiconductor Heterostructures |
Electronic semiconductor devices:
- MOSFET
- MESFET
- HEMT
- BJT
- HBT
Application aspects of semiconductor devices in RF/microwave communications systems:
- Performance parameters
- System requirements
- Economical issues

**Literature**
- Simon Sze, Physics of Semiconductor Devices
- S. Prasad, H. Schumacher, A. Gopinath, High Speed Electronics and Optoelectronics (Chapter 1 and 2)
- Full set of slides, video sequences on e-learning platform

**Teaching and learning methods**
Lecture “Modern Semiconductor Devices”, 2 SWS
Exercise “Modern Semiconductor Devices”, 1 SWS
Laboratory “Modern Semiconductor Devices”, 1x2 hours (one event)

**Workload**
Active Time: 36 h
Preparation and Evaluation: 84 h
Sum: 120 h

**Assessment**
The grade of the module will be the grade of the oral or written (depending on the number of participants) exam. No prerequisites are necessary for exam registration

**Grading procedure**
The grade of the module will be the grade of the exam.

**Basis for**
Microfabrication lab (compulsory prerequisite)
Monolithic Microwave ICs in High-Speed Systems (recommended)
### Monolithic Microwave ICs in High-Speed Systems

Modules referring to Track Specific Compulsory Subjects - Microelectronics

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<td>Cycle</td>
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<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Hermann Schumacher</td>
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<tr>
<td>Instructor(s)</td>
<td>Prof. Dr.-Ing. Hermann Schumacher, Prof. Dr.-Ing. Heinrich Dämbkes</td>
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**Allocation of study programmes**
- Electrical Engineering, M.Sc., Elective Module, Microelectronics
- Electrical Engineering, M.Sc., Elective Module, Automation and Energy Technology
- Communications Technology, M.Sc., Communications Circuits and Systems Track
- Communications Technology, M.Sc., Communications Engineering Track

**Recommended prerequisites**
- Radio Frequency Engineering; Modern Semiconductor Devices

**Learning objectives**
Students recognize fundamental requirements of microwave and millimeter-wave communication and sensing systems. They review and analyze important circuit topologies and identify those which meet the requirements. They then synthesize circuits to meet the requirements of select examples, assess their performance using computer aided design tools, and compare the results obtained with the requirements.

**Syllabus**
- General overview of MMIC design techniques
- Important CAD tools and models
- Substrate properties and their impact on MMIC design techniques
- Fundamental building blocks
  - Low noise amplifiers
  - Wideband amplifiers
  - Distributed circuit topologies
  - Oscillators
  - Mixers
  - Frequency multipliers and dividers
- Phase locked loop concepts
- Introduction to practical design using the Keysight ADS design environment

**Literature**
- D.M. Pozar: Microwave Engineering , Addison-Wesley, 1990
- R.S. Elliott: An Introduction to Guided Waves and Microwave Circuits , Prentice-Hall, 1993
- G.Matthaei, L. Young & E. Jones: Microwave Filters, Impedance-Matching Networks & Coupling Structures , Artech House, 1980
- F.E.Gardiol: Introduction to Microwaves , Artech House, 1984
- S. Prasad, H. Schumacher, A. Gopinath, High Speed Electronics and Optoelectronics (Chapter 5)

**Teaching and learning methods**
The course is conducted in a flipped classroom setting. Students review video lectures in their own time, classroom time is devoted to discussing the lecture content, applying the subject matter to examples, and practical design exercises.

**Workload**
- Review of video lectures including online Q&A: 42 h
- Classroom discussions and design exercises: 26 h
- Preparation of design practice sessions (labs): 34 h
- Participation in design practice sessions: 27 h
- Exam preparation, incl. design: 50 h
- Exam participation: 1 h
- Total: 180 h

**Assessment**
The credit points will be awarded once the oral exam has been passed. No prerequisites are necessary for exam registration.

**Grading procedure**
The grade of the module will be the grade of the exam.

**Basis for**
- Master thesis on microwave IC design
Technology for Micro- and Nanostructures
Modules referring to Track Specific Compulsory Subjects - Microelectronics

Code 8822270458

ECTS credits 4

Attendance time 3

Language of instruction English

Duration 1 Semester

Cycle each Winter Semester

Coordinator Prof. Dr. Peter Unger

Instructor(s) Prof. Dr. Peter Unger

Allocation of study programmes
- Electrical Engineering, M.Sc., Elective Module
- Electrical Engineering, M.Sc., Elective Module, Microelectronics
- Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology
- Communications Technology, M.Sc., Optional technical module, Communications Circuits and Systems

Recommended prerequisites
- Bachelor
- Vordiplom

Learning objectives
The students can describe and explain the different lithography methods like optical, e-beam, and x-ray lithography. For a given lithographic problem, they are able to select a suitable exposure process and to choose a proper resist material. The students understand the physics of low-pressure non-equilibrium gas discharges, can give examples of commonly used process techniques using this type of plasma, and are able to sketch the construction of typical plasma-etching and plasma-deposition systems. The students are able to explain the physics of dry-etching and vacuum deposition processes used in semiconductor and thin-film technology.

Syllabus
At the beginning of the course, the basic technological processes for lithography and pattern transfer techniques are discussed. As applications of these technologies, fabrication processes are presented like CMOS and III-V technology, micromechanics, magnetic thin-film heads, flat-panel displays, micro optics, x-ray optics and quantum-effect electronic devices. The lectures are accompanied by exercises, where important original publications will be discussed and hands-on experiments in the clean room will be performed.
Main Topics:
- Resists
- Optical Lithography
- Electron-Beam Lithography
- X-Ray Lithography
- Wet-Chemical and Dry Etching Techniques
- Film Deposition Processes
- Micromechanics
- Thin-Film Technology
- Nanometer Structures Technology

Literature

Teaching and learning methods
Lecture “Technology for Micro- and Nanostructures”, 2 SWS
Exercise “Technology for Micro- and Nanostructures”, 1 SWS

Workload
Preparation and Evaluation: 45 h
Active Time: 75 h
Sum: 120 h

Assessment
The grade of the module will be the grade of the oral or written (depending on the number of participants) exam. No prerequisites are necessary for exam registration

Grading procedure
The grade of the module will be the grade of the exam.

Basis for
-
Cultural Crossroads for Communications Technology
Modules referring to Non-Technical Elective Subjects

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<td>Dr. phil. Sandra Mann</td>
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<td>Allocation of study programmes</td>
<td>minimum number of participants 8, maximum 24</td>
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<tr>
<td>Recommended prerequisites</td>
<td>- Basic skills in using presentation software (PowerPoint, Open Office Impress or similar)</td>
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<td>- Good knowledge of English</td>
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<tr>
<td>Learning objectives</td>
<td>Students acquire basic presentation skills. The student selects relevant topics about his or her home country, recognizes aspects of general interest and researches on them, and prepares an oral presentation. Peculiarities of the own home culture will be identified, desribed and reflected. Students will practice discussing issues and defending their own statements. Students acquire intercultural competence by relating to their peers of other countries in a multicultural group.</td>
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<tr>
<td>Syllabus</td>
<td>- Preparation of a presentation using guidelines</td>
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<tr>
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<td>- Oral presentation</td>
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<td>- Group discussion on content</td>
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<tr>
<td>Literature</td>
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<tr>
<td><strong>Teaching and learning methods</strong></td>
<td>Seminar “Cultural Crossroads”, 2 SWS</td>
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<td><strong>Workload</strong></td>
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<td>Preparation and Evaluation: 34 h</td>
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<td>Sum: 60 h</td>
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<td><strong>Assessment</strong></td>
<td>The award of the credit points for this ungraded module is based on completion of an assignment (presentation) and active participation in discussions. The required parts will be announced in time. No prerequisites are necessary for the registration.</td>
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<td><strong>Grading procedure</strong></td>
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### Non-Technical Subjects

**Modules referring to Non-Technical Elective Subjects**

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Technical Presentation Skills für Communications Technology
Modules referring to Non-Technical Elective Subjects

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<td>Duration</td>
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<tr>
<td>Cycle</td>
<td>each Summer Semester</td>
</tr>
<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Hermann Schumacher</td>
</tr>
</tbody>
</table>
| Instructor(s)      | Prof. Dr.-Ing. Hermann Schumacher  
                      | M.Sc. Filipe Tabarani            |
| Allocation of study programmes | Communications Technology, M.Sc., Optional Non-Technical Module |
| Recommended prerequisites | Basic knowledge of presentation software (e.g. PowerPoint, LibreOffice Impress)  
                      | Bachelor-level engineering background. |
| Learning objectives | Students recognize proven techniques for technical oral presentations supported by visual aids. In the preparation of their presentation, they distinguish different target audiences and devise their presentation strategy accordingly. They differentiate between different forms of presentation (oral, written, web-based) and develop suitable communication strategies. Students create an oral presentation on a topic of their choice within an annually changing topical framework, defend their ideas in front of their peers, and summarize their presentation in a three-page written report. |
| Syllabus           | - Presentation quality criteria  
                      | - Researching a subject          
                      | - Structuring oral presentations 
                      | - Visual aids preparation       
                      | - Multimedia techniques         
                      | - Public speaking               
                      | - Handling questions and critique |
                      | - Written presentations:        
                      | 1. Research reports             |

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Date printed: 29. November 2018  
page 18 of 125
2. Journal articles
3. Theses
   - Presenting technical matters on the web
   - Seminar trial presentations

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| Teaching and learning methods | Online lecture and supporting reading material  
Seminar in block format (2 dates of 6 hours each) |
|-------------------------------|------------------------------------------------|

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<th>Workload</th>
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| Online materials and assessments: 28 h  
Seminar participation: 12 h  
Researching and preparing seminar presentation: 30 h  
Preparing written report: 20 h  
Sum: 90 h |

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<tr>
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Technical Presentation Skills for Communications Technology without Scientific Writing Exercise
Modules referring to Non-Technical Elective Subjects

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<td>Prof. Dr.-Ing. Hermann Schumacher</td>
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</table>
| Instructor(s)             | Prof. Dr.-Ing. Hermann Schumacher  
                           | M.Sc. Filipe Tabarani |

**Allocation of study programmes**
Communications Technology, M.Sc., Optional Non-Technical Module

**Recommended prerequisites**
Basic knowledge of presentation software (e.g. PowerPoint, LibreOffice Impress)  
Bachelor-level engineering background.

**Learning objectives**
Students recognize proven techniques for technical oral presentations supported by visual aids. In the preparation of their presentation, they distinguish different target audiences and devise their presentation strategy accordingly. They differentiate between different forms of presentation (oral, written, web-based) and develop suitable communication strategies. Students create an oral presentation on a topic of their choice within an annually changing topical framework and defend their ideas in front of their peers.

**Syllabus**
- Presentation quality criteria  
- Researching a subject  
- Structuring oral presentations  
- Visual aids preparation  
- Multimedia techniques  
- Public speaking  
- Handling questions and critique  
- Written presentations:  
  - Research reports  
  - Journal articles
- Theses
- Presenting technical matters on the web
- Seminar trial presentations

<table>
<thead>
<tr>
<th>Literature</th>
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</table>

| Teaching and learning methods | Lecture “Technical Presentation Skills”, 1 SWS  
Seminar “Technical Presentation Skills”, 1 SWS |
|-----------------------------|------------------------------------------------|

| Workload | Lectures and Seminars: 26 h  
Review of lecture material: 14 h  
Researching and preparing seminar presentation: 20 h |
|-----------|-------------------------------------------------|

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<th>Assessment</th>
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**Advanced Channel Coding**  
Modules referring to Technical Elective Subjects

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<tr>
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<td>Prof. Dr.-Ing. Martin Bossert</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Prof. Dr.-Ing. Georg Schmidt</td>
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**Allocation of study programmes**  
- Electrical Engineering, M.Sc., Elective Module, Engineering Sciences  
- Electrical Engineering, M.Sc., Optional Module, Communication and System Technology  
- Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology  

**Recommended prerequisites**  
Bachelor. Linear Algebra, Probability Theory, Combinatorics, elementary Galois Theory

**Learning objectives**  
The students can analyze, evaluate and compare coding schemes for error detection and error correction which are currently and in future systems used for data transmission, data storage, and data processing. Especially different decoding algorithms, those based on iterative methods as well as those based on algebraic methods can be categorized and combined.

**Syllabus**  
The contents of the lecture can be grouped into two blocks: iterative decoding methods and algebraic decoding methods, which are suited for different kinds of applications. Iterative decoding methods are interesting for operating points close to capacity in applications where codes with large block lengths can be applied. In the lecture, two classes of iterative decoding schemes will be considered. The class of Turbo Codes was introduced 1993 by C. Berrou, A. Glavieux and P. Thitimajshima. A Turbo Code consists of simple parallel concatenated component codes, which can efficiently be decoded by a symbol-by-symbol A
Posteriori Probability (s/s APP) decoder. Such an s/s APP decoder is capable of utilizing reliability information from the channel and can compute reliabilities for the code symbols. After formally introducing the concept of reliabilities on the basis of probabilities, the principle of s/s APP decoding will be explained. After this, several tools for analyzing Turbo decoders are considered. Another class of iteratively decodable codes is the class of Low Density Single Parity Check (LDPC) codes. Such codes are either described by sparsely occupied matrices or by bipartite graphs. Both descriptions will be considered, and it will be explained how LDPC codes can be constructed on the basis of these descriptions. After explaining how LDPC codes can be decoded iteratively, tools for analyzing them will be considered. Algebraic decoding of Reed-Solomon (RS) codes is used in many technical data transmission and data storage systems like hard disks, CDs, DVDs, digital video broadcasting, and many other applications. Two types of decoding strategies will be considered: syndrome-based decoding and interpolation-based decoding. Syndrome-based techniques for decoding Reed-Solomon codes are known for more than 30 years, and allow for decoding errors up to half the minimum code distance. Since such methods can be implemented very efficiently, they are applied in many algebraic error correcting schemes. After introducing these classical syndrome-based methods, it will be explained how these techniques may be applied in interleaved Reed-Solomon (IRS) schemes for decoding errors beyond half the minimum code distance. In 1997, M. Sudan proposed a novel algorithm for decoding RS codes, which is based on bivariate polynomial interpolation. This algorithm can also decode errors beyond half the minimum code distance by creating lists of codewords to resolve ambiguous decoding situations. Moreover, derivatives of the Sudan algorithm are capable of using lists of symbols at their inputs. The principles behind such interpolation-based techniques will be considered in the last part of the lecture. It will be explained how the list decoding concept can be used for decoding errors beyond half the minimum code distance, and how the problem of list decoding is solved by the Sudan algorithm and its derivatives. In the exercise, students have the opportunity to implement selected algorithms from the lecture using MATLAB under guidance of a research assistant.

Topics:
Iterative Decoding Methods Turbo-Codes
- A Posteriori Probability (APP) Decoding
- Intrinsic and Extrinsic Information
- Statistical Analysis Methods like Monte-Carlo Simulation and Exit-Chart-Analysis
Low Density Single Parity Check (LDPC) Codes
- Matrix and Graph Representation of LDPC Codes
- Code Construction
- Iterative Decoding by "Message Passing"
- Statistical and Graph-Based Analysis Methods like Density Evolution and Stopping Sets
Algebraic Decoding Methods Syndrome-Based Techniques
- Reed-Solomon (RS) Codes
- Classical Decoding Approaches like the Peterson-Gorenstein-Zierler and Forney Algorithms
- Interleaved Reed-Solomon (IRS) Codes and Collaborative Decoding
- Interpretation of the Decoding Problem as a Polynomial Interpolation Problem
- The Sudan Algorithm and its Derivatives
- List Decoding Concepts

Literature
- Roth R., Introduction to Coding Theory, Cambridge University Press, 2006
- Justesen J. and Hoeholdt, T., A Course In Error Correcting Codes, EMS Publishing House, 2004
- Bossert M., Channel Coding for Telecommunications, John Wiley & Sons, 1999

**Teaching and learning methods**
Lecture “Advanced Channel Coding”, 2 SWS
Exercise “Advanced Channel Coding”, 1 SWS

**Workload**
Active Time: 38 h
Preparation and Evaluation: 32 h
Self-Study: 50 h
Total: 120 h

**Assessment**
The grade of the module will be the grade of the oral or written (depending on the number of participants) exam. No prerequisites are necessary for exam registration.

**Grading procedure**
The grade of the module will be the grade of the exam.

**Basis for**
-
Advanced Optoelectronic Communication Systems
Modules referring to Technical Elective Subjects

Code 8822270451

ECTS credits 6

Attendance time 4

Language of instruction English

Duration 1 Semester

Cycle each Winter Semester

Coordinator apl. Prof. Dr.-Ing. habil. Rainer Michalzik

Instructor(s) apl. Prof. Dr.-Ing. habil. Rainer Michalzik

Allocation of study programmes
- Electrical Engineering, M.Sc., Elective Module, Engineering Sciences
- Electrical Engineering, M.Sc., Elective Module, Microelectronics
- Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology
- Communications Technology, M.Sc., Optional Technical Module, Communications Circuits and Systems

Recommended prerequisites Optical Communications
- Modules “Optical Communications” or “Einführung in die Optoelektronik”

Learning objectives The students can outline the multiplexing techniques used in high-capacity optical transmission systems and discuss their pros and cons. They are able to list available types of single-mode optical fibers and explain how to make fibers more insensitive to bends. They can quantify the transmission distance limitations imposed by modal, chromatic, or polarization mode dispersion and can employ dispersion management as a remedy. The students are able to name and describe nonlinear effects in fibers. They can illustrate different types of optical amplifiers and point out their strengths and weaknesses. They are able to explain the principles of fiber Bragg gratings and select their parameters according to the application. The students can sketch devices suitable for optical multiplexing and demultiplexing and express the merits of planar lightwave circuits. They can illustrate various types of optical switches implemented as optical micro-electromechanical systems. The students are able to discuss the optical, electronic, and electrical confinement techniques used laser diodes. They recognize the importance of distributed Bragg reflector, distributed feedback, as well as vertical-cavity surface-emitting lasers and can sketch their layer structures and explain their operation. The students are able to show how serial data rates in optical links can be increased with modulator-assisted phase modulation allowing the implementation of higher-order modulation formats. They can also describe the
principles of corresponding optical receivers as well as the technique of coherent detection.

**Syllabus**

This module provides an advanced overview over modern optical telecommunication and datacom systems as well as associated optoelectronic devices. The students will be able to understand the operation principles, potentials as well as limitations of various technologies. The following topics are addressed:

- Introduction to optical communication systems
- Multiplexing techniques and high-capacity DWDM systems
- The CWDM approach
- Single-mode fiber types and bending-insensitive fibers
- Fiber dispersion limitations and dispersion management
- Polarization mode dispersion
- Nonlinear fiber transmission effects
- Optical amplifiers: EDFA, Raman and semiconductor optical amplifiers
- Fiber Bragg gratings
- Devices for optical multiplexing and demultiplexing
- Planar lightwave circuits
- Optical MEMS
- Photon, carrier, and current confinement in laser diodes
- Advanced laser diodes for use in telecommunications: DBR and DFB lasers
- Vertical-cavity surface-emitting lasers (VCSELs) for datacom applications
- 100 Gbit/s transmission systems: Mach–Zehnder modulators, higher-order modulation formats and coherent detection

**Literature**

A comprehensive English written manuscript is provided

**Teaching and learning methods**

Lecture “Advanced Optoelectronic Communication Systems”, 3 hours per week
Exercise “Advanced Optoelectronic Communication Systems”, 1 hours per week

**Workload**

Active Time: 40 h
Preparation and Evaluation: 64 h
Self-Study: 76 h
Total: 180

**Assessment**

The grade of the module will be the grade of the oral or written (depending on the number of participants) exam. No prerequisites are necessary for exam registration

**Grading procedure**

The grade of the module will be the grade of the exam.

**Basis for**

-
Applied Information Theory
Modules referring to Technical Elective Subjects

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<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Martin Bossert</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Prof. Dr.-Ing. Martin Bossert</td>
</tr>
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Allocation of study programmes

- Electrical Engineering, M.Sc., Elective Module, Engineering Sciences Technology
- Electrical Engineering, M.Sc., Elective Module, Communication and System Technology
- Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology
- Communications and Computer Engineering, M.Sc., Elective Module, Communications Technology, M.Sc., Optional Module, Communications Circuits and Systems
- Communications Technology, M.Sc., Compulsory Module, Communications Engineering
- Computer Science, M.Sc., Specialization Subject, Informationstheorie

Recommended prerequisites

- Bachelor
- Probability theory

Learning objectives

Information theory provides a measure for information and describes fundamental limits for communication and storage systems with respect to source coding, channel coding, multi-user communication, and cryptology. The students will be able to explain, apply and analyze lossless and lossy source coding algorithms (data compression). Furthermore, they will be able to evaluate the performance with respect to the source coding theorem which states that Shannons uncertainty is the fundamental limit for compression. They can describe and analyze the channel capacity as the fundamental limit of information which can be transmitted error free over a channel using an appropriate code with a certain rate. With this context they can categorize and evaluate channels and transmission methods. For the omnipresent Gaussian noise the channel capacity can be calculated and interpreted.
For basic multi-user communication scenarios (broadcast and multiple access) fundamental algorithms (Tomlinson-Harashima, superposition coding, etc.) and their application can be analyzed and evaluated based on the mutual information. These algorithms and methods enable the students to analyze and categorize also scenarios which are not treated in the module or will be developed in the future.

The information theoretic point-of-view of cryptology enables the students to compare, categorize, and evaluate crypto algorithms.

**Syllabus**

Information theory is the basis of modern telecommunication systems. Main topics of information theory are source coding, channel coding, multi-user communication systems, and cryptology. These topics are based on Shannons work on information theory, which allows to describe information with measures like entropy and redundancy. After a short overview of the whole area of information theory, we consider concepts for statistical modeling of information sources and derive the source coding theorem. Afterwards, important source coding algorithms like Huffman, Tunstall, Lempel-Ziv and Elias-Willems are described.

The second part of the lecture investigates channel coding. Important properties of codes and fundamental decoding strategies are explained. Moreover, we introduce possibilities for estimating the error probability and analyze the most important channel models according to the channel capacity introduced by Shannon. The Gaussian channel is very important, and therefore, described extensively. The third part deals with aspects of multi-user communication systems.

We introduce several models and investigate methods that can achieve the capacity regions. Finally, we give an introduction on data encryption and secure communication. In the projects, several information theoretic topics (e.g., Lempel-Ziv-coding) will be investigated by means of implementation tasks.

**Overview: Basics:**
- Uncertainty (entropy), mutual information
- Fanos lemma, data processing lemma, information theory inequality

**Source Coding:**
- Shannon’s source coding theorem
- Coding methods for memoryless sources: Shannon-Fano-, Huffman-, Tunstall, and arithmetic coding
- Coding for sources with memory

**Channel Coding:**
- Concepts of linear binary block codes
- Shannon’s channel coding theorem
- Random coding and error exponent
- MAP (maximum a-posteriori) and ML (maximum likelihood) decoding
- Bounds (Bhattacharriyya, union, etc.)

**Channels and capacities:**
- Gaussian channel, fading channel

**Multi-User Systems:**
- Duplex transmission
- MAC (multiple access) channel
- BC (broadcast) channel
- MIMO (multiple input multiple output) channel

**Cryptology:**
- Problem settings in cryptology
- IT-security

**Projects:**
- Universal Source Coding (Lempel-Ziv-coding)
- Mutual Information

**Literature**
- Cover, Thomas: Elements of Information Theory, Wiley
- Script 2009 (in German)
- Johannesson: Informationstheorie - Grundlagen der (Tele-) Kommunikation, Addison-Wesley

**Teaching and learning methods**
Lecture “Applied Information Theory”, 3 SWS
Exercise “Applied Information Theory”, 2 SWS
Project “Applied Information Theory”, 1 SWS

**Workload**
Active Time: 90 h
Preparation and Evaluation: 150 h
Sum: 240 h

**Assessment**
The grade of the module will be the grade of the oral or written (depending on the number of participants) exam. No prerequisites are necessary for exam registration

**Grading procedure**
The grade of the module will be the grade of the exam.

**Basis for**
Communication Engineering and Wireless
## Biosensors and Biochips

Modules referring to Technical Elective Subjects

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<tr>
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<td>Dr. Alberto Pasquarelli</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Dr. Alberto Pasquarelli</td>
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</table>

### Allocation of study programmes
- Advanced Materials, M.Sc., Advanced lecture
- Biophysics, M.Sc., Specialization Module
- Communications Technology, M.Sc., both tracks CE and CCS (FSPO2015/2017), Optional technical Module
- Electrical Engineering, M.Sc., In-depth Module

### Recommended prerequisites
- Basic knowledge of chemistry and biochemistry help to understand the biological part of biosensors.

### Learning objectives
- The world-wide need for chemical detection and analysis rise steadily. Several reasons lead to this trend, for instance, the rapid increase in the prevalence of diabetes, the increasing need for environmental and health monitoring, new legislative standards for food and drug quality control or even the early detection of biological and chemical terror attacks. Thanks to higher sensitivity and specificity, short response times and reduction of overall costs, biosensors can be very competitive in addressing these needs when compared to traditional methods.

- Students can describe basic principles, mechanisms of action and applications of biosensors in different scenarios. After taking this module, participants can analyze biosensors, break-down the elementary components and identify and illustrate every individual function in the information flow, from recognition to transduction and transmission. Students illustrate the clinical and industrial applications in different biosensor market sectors, e.g. commodities for everyday consumer needs or professional equipments for research. Furthermore, they are able to understand and critically analyze research in biosensors. Finally, students
are able to develop appropriate concepts and independently propose solutions for given problems.

**Syllabus**
- Introduction to biosensors
- Applications overview
- Biological detection methods: catalytic, immunologic, etc
- Physical transduction methods: electrochemical, optical, gravimetric, etc.
- Immobilization techniques: adsorption, entrapment, cross-linking, covalent bonds
- Biochip technologies: DNA and protein chips, ion-channel devices, MEA and MTA, Implants
- Laboratory practice with assigned projects carried-out in small groups with final report and demonstration in the class
- Extras: Student seminars, invited talk(s), excursion

**Literature**
- Lecture Notes

Further suggested books for deeper inside view:
- Handbook of Biosensors and Biochips, ISBN 9780470019054
- Jay: Modern Food Microbiology, ISBN: 9780387234137

**Teaching and learning methods**
- Lecture “Biosensors and Biochips”, 4 SWS
- Student seminar, 0.25 SWS
- Laboratory project, 20 h

Excursion complete day (Not compulsory)

**Workload**
- Active Time: 80 h
- Preparation and Evaluation: 120 h
- Self-Study: 40 h
- Sum: 240 h

**Assessment**
The grade of the module will be the grade of the written exam. Prerequisite for exam registration is passing the pre-course (to be defined by the examiner).

**Grading procedure**
The grade of the module will be the grade of the exam.

**Basis for**
Masters Thesis in the area of biosensors.
Biosensors
Modules referring to Technical Elective Subjects

Code 8822270903
ECTS credits 3
Attendance time 2
Language of instruction English
Duration 1 Semester
Cycle each Winter Semester
Coordinator Prof. Dr.-Ing. Hermann Schumacher
Dr. Alberto Pasquarelli
Instructor(s) Dr. Alberto Pasquarelli

Allocation of study programmes
- Electrical Engineering, M.Sc., Elective Module
- Electrical Engineering, M.Sc., Optional Module, General Electrical Engineering
- Electrical Engineering, M.Sc., Optional Module, Communication and System Technology
- Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology
- Electrical Engineering, M.Sc., Optional Module, Microelectronics
- Communications Technology, M.Sc., Elective Module, Microelectronics

Recommended prerequisites Basic knowledge of chemistry and biochemistry help understanding the biological part of biosensors.

Learning objectives The world-wide need for chemical detection and analysis rise steadily. Several reasons lead to this trend, for instance the rapid increase in the prevalence of diabetes, the increasing need for environmental and health monitoring, new legislative standards for food and drug quality control or even the early detection of biological and chemical terror attacks. Thanks to higher sensitivity and specificity, short response times and reduction of overall costs, biosensors can be very competitive in addressing these needs when compared to traditional methods.

Students can describe basic principles, mechanisms of action and applications of biosensors in different scenarios. After taking this module, participants can analyze biosensors, break-down the elementary components and identify and illustrate every individual function in the information flow, from recognition to transduction and transmission. Students illustrate the clinical and industrial applications in different biosensor market sectors, e.g. commodities for everyday consumer needs or professional equipments for research. Furthermore, they are able to understand and critically analyze research in biosensors. Finally, students
are able to develop appropriate concepts and independently propose solutions for given problems.

**Syllabus**
- Introduction to biosensors
- Applications overview
- Biological detection methods: catalitic, immunologic, etc.
- Physical transduction methods: electrochemical, optical, gravimetric, etc.
- Immobilization techniques: adsorption, entrapment, cross-linking, covalent bonds
- Biochip technologies: DNA and protein chips, Ion-channel devices, MEA and MTA
- Extras: invited talk(s), experimental exercise, excursion

**Literature**
Lecture Notes
For in-depth study, following books are recommended:
Springer e-Books (full pdf download at https://ulm.ibs-bw.de):
Jay: Modern Food Microbiology, ISBN: 9780387234137

**Teaching and learning methods**
Lecture “Biosensors”, lecture with demonstrations and seminars, 1,75 SWS
Seminar “Biosensors”, 0,25 SWS
Labor “Biosensors”, 2 x 2 h

**Workload**
Active Time: 28 h
Preparation and Evaluation: 50 h
Self-Study: 12 h
Sum: 90 h

**Assessment**
The grade of the module will be the grade of the written exam. No prerequisites are necessary for exam registration

**Grading procedure**
The grade of the module will be the grade of the exam.

**Basis for**
Masters Thesis in the area of biosensors.
# Circuit Design in Nanometer-Scaled CMOS Technologies
Modules referring to Technical Elective Subjects

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</tr>
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<td>Prof. Dr.-Ing. Maurits Ortmanns</td>
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<tr>
<td>Recommended prerequisites</td>
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<td>Learning objectives</td>
<td>The students are able to explain MOSFET operation in deep submicron technologies including short channel and narrow width effects using charge-based transistor modeling. They can identify situations in which a classical square-law based design approach is prone to fail and apply non-square law based design methodologies to synthesize circuits even under these conditions. The students can predict the effects of mismatch and process variations on the performance of integrated circuits and can select operating points to mitigate these effects. Furthermore, they are able to evaluate different layout styles regarding their robustness against mismatch and process variations and select an appropriate layout style for a given application. The students are able to apply advanced linear feedback theory in the form of the Middlebrook and Tian's method to electronic circuits to predict their stability. The students can analyze advanced single-ended and fully-differential op-amp structures and synthesize these structures for a given performance. The students can explain the need for on-chip references and power management and synthesize on-chip voltage references, current references and voltage regulators. The students can analyze CMOS subcircuits in the presence of noise and distinguish important noise related performance metrics. The students are able to identify main ideas of state-of-the-art</td>
</tr>
</tbody>
</table>
research articles and present those ideas to their fellow students.

**Syllabus**

- MOSFET operation and modern CMOS devices
- MOS device models
- Analog Design Styles in deep submicron technologies
- Feedback theory and closed loop feedback simulation
- Advanced differential amplifiers
- References and Power Management
- Analog filters
- Advanced A/D Converter Concepts

**Literature**


**Teaching and learning methods**

Lecture "Circuit Design in Nanometer-Scaled CMOS Technologies", 2 SWS
Recitation "Circuit Design in Nanometer-Scaled CMOS Technologies", 1 SWS

**Workload**

Lecture: 28 h
Lecture preparation and review: 28 h
Recitation: 14h
Recitation preparation and review: 32h
Exam preparation and exam participation: 48 h
Total: 150 h

**Assessment**

The grade of the module will be the grade of the oral or written exam. No prerequisites are necessary for exam registration.

**Grading procedure**

The grade of the module will be the grade of the exam.

**Basis for**

Master-Thesis
## Communication Systems

**Modules referring to Technical Elective Subjects**

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<td><strong>Cycle</strong></td>
<td>each Summer Semester</td>
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<tr>
<td><strong>Coordinator</strong></td>
<td>Prof. Dr.-Ing. Martin Bossert</td>
</tr>
<tr>
<td><strong>Instructor(s)</strong></td>
<td>Dr. Werner Teich</td>
</tr>
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</table>

### Allocation of study programmes

- Electrical Engineering, M.Sc., Elective Module, Engineering Sciences Technology
- Electrical Engineering, M.Sc., Optional Module, Communication and System Technology
- Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology
- Electrical Engineering, M.Sc., Optional Module, General Electrical Engineering
- Communications and Computer Engineering, M.Sc., Optional Module
- Communications Engineering Technology, M.Sc., Optional Technical Module, Communications Engineering
- Embedded Systems, M.Sc., Application Subject, Communication

### Recommended prerequisites

Bachelor

### Learning objectives

- Understanding the characteristics of the mobile radio channel and related transmission techniques.
- Network and protocol architecture, basic protocol procedures, physical layer, performance as well as network planning of mobile radio systems.
- Principles of OFDM based broadband systems.

### Syllabus

Communication systems play a major role in the modern society. Since the 1990ies especially wireless communications is of increasing interest worldwide. For the definition of such systems lots of aspects need to be taken into consideration. Among others frequency band allocation, efficient use of radio and network resources, number of sites required to provide radio coverage, targeted user service characteristics like maximum bit rate and quality and last but not
least cost of implementation. After a short presentation of the wireless communications history the characteristics of the terrestrial mobile radio channel are introduced followed by an overview of basic transmission techniques over such channels. The second part deals with the TDMA based GSM standard. The role of the network elements being part of the overall network architecture and the services available to the users are introduced. Mobility and security aspects, protocol architecture, signalling procedures are further topics. Lower layer specification and related performance which form the basis for cell planning are discussed in detail. In the third part the UMTS standard which is based on WCDMA is explained. The presentation follows a similar structure as compared to the GSM presentation which allows comparison of both systems. OFDM is the next topic and it will become evident why it is of special interest in the case of broadband transmission over dispersive multipath channels. Finally a brief look to market figures concludes the course, thereby demonstrating the huge potential behind the mobile radio market.

**Literature**

- Walke: Mobile Radio Networks, John Wiley & Sons, 1999
- Bossert: Channel Coding for Telecommunications, John Wiley&Sons, 1999
- 3GPP Recommendations, http://www.3gpp.org/specs/numbering.htm
- 3GPP Recommendations for UMTS Long Term Evolution (Evolved UTRA aspects), http://www.3gpp.org/ftp/Specs/html-info/36-series.htm
- CPRI (Common Public Radio Interface), http://www.cpri.info

**Teaching and learning methods**

Lecture “Communication Systems”, 2 SWS
Exercise “Communication Systems”, 1 SWS

**Workload**

Active Time: 36 h
Preparation and Evaluation: 46 h
Self-Study: 38 h
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<td>The grade of the module will be the grade of the exam. A grade bonus according to § 17 (3a) of the study and exam framework regulations is given if the exercise class is passed successfully.</td>
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Sum: 120 h
# Computer Networks

Modules referring to Technical Elective Subjects

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<td>Cycle</td>
<td>each Winter Semester</td>
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<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Stefan Wesner</td>
</tr>
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</table>
| Instructor(s)      | Dr. Jörg Domaschka  
                      | Prof. Dr.-Ing. Stefan Wesner |
| Allocation of study programmes | Electrical Engineering, M.Sc., Elective Module, Engineering Sciences  
                                      | Communications Technology, M.Sc., Optional Technical Module |
| Recommended prerequisites | Basic comprehension of electrical engineering and information technology. |

## Learning objectives

After completing the lecture students will be able to name and describe the major network protocols and technologies for building local and wide area networks. They will be able to explain the fundamental architectural principles in networks, such as the ISO/OSI model and the Internet protocol stack. Students will understand the challenges on each protocol layer and will be able to explain how the covered protocols in the lecture address them. Students participating in this lecture will be able to compare the different protocols as well to understand and explain their limitations. Participants of this lecture can name the different network topologies for data centre networks, describe the different protocols for interconnects or storage networks and are able to assess and select appropriate.

## Syllabus

The lecture “Computer Networks” is an introduction to networks used with today’s computers. It deals mostly with the construction, the functionality and the design of local networks and protocols. On the basis of the ISO/OSI Model as a commonly used layered reference model, network and computer protocols are discussed. Media Access Control protocols of the lower layer are discussed together with network topologies with respect to their medium access mechanism. Topics of discussion include classic technologies like Ethernet as well as technologies used by internet service providers. On OSI Layer 3 and 4 (network and transport layer),
the commonly encountered TCP/IP protocol is introduced and covered in detail. This builds the basis for discussing a set of application protocols based on TCP/IP such as RTP, HTTP or protocol patterns like REST. The lecture is concluded with a discussion of advanced topics such as Peer-to-Peer networks, concepts of software defined networking as well as network function virtualisation, and other specialised and experimental networks or protocols, e.g. the CAN bus or QUIC.

The Exercise component of the module will help students reflect the content of the lecture by the provisioning of questions and exercise sheets. In addition, the exercise will tackle practical aspects such as socket programming and the use of administrator tools including network sniffer.

**Literature**

- Comer, Douglas E.: Internetworking with TCP/IP. Principles, protocols, and architecture; London 1988
- Stevens, W. Richards: TCP/IP Illustrated, Volume 1. The Protocols; Reading(Massachusetts) 1994-
- Tannenbaum: Computer Networks; Prentice Hall
- Michel Dubois, Murali Annavaram, Per Stenström: Parallel Computer Organization and Design, 2012
- Ulf Troppens, Rainer Erkens, Wolfgang Mueller-Friedt, Rainer Wolafka, Nils Haustein: Storage Networks Explained: Basics and Application of Fibre Channel

**Teaching and learning methods**

- Lecture “Computer Networks”, 2 SWS
- Exercises “Computer Networks”, 1 SWS

**Workload**

- Active Time: 45 h
- Preparation and Evaluation: 75 h
- Sum: 120 h

**Assessment**

The credit points will be awarded once the written or oral exam has been passed (depending on the number of participants). The type of examination will be announced in time - at least 4 weeks prior to the date of the exam. No prerequisites are necessary for exam registration.

**Grading procedure**

The grade of the module will be the grade of the exam.

**Basis for**

-
Compressed Sensing
Modules referring to Technical Elective Subjects

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<tr>
<td>Coordinator</td>
<td>Dr. Dejan Lazich</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Dr. Dejan Lazich</td>
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**Allocation of study programmes**
- Electrical Engineering, M.Sc., Elective Module, Engineering Sciences
- Electrical Engineering, M.Sc., Optional Module, Communication and System Technology
- Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology
- Communications Technology, M.Sc., Optional Module
- Computer Science and Media, M.Sc., Optional Module

**Recommended prerequisites**
*Electrical engineering/computer science:*
- Basic knowledge in signal processing and system theory

*Mathematics:*
- Basic knowledge of linear algebra, probability and statistics

**Learning objectives**
By attending this course, the students are enabled to present a new, demanding and promising field of information processing, in an easy understandable way. At the end of the course the students will be able to analyze and discuss the underlying concept of compressed sensing based on solving underdetermined systems of linear equations. Likewise, they will be able to implement the main data recovery algorithms and to compare them according to various criteria. By the course, the students are enabled to interpret complex optimization approaches using the geometry of higher dimensions. In this way the students will be continuously motivated and supported to build their own approaches to the mater which may trigger new ideas for improvements. In addition, a variety of implementations of compressed sensing can be explained by the students and new application areas can be identified and discussed. Students will be enabled...
to deal with the very subject-specific literature and to classify this in the proper context.

**Syllabus**

This course will discuss the theoretical, numerical, and practical foundations of *Compressed Sensing* (CS) which has become a very important concept in recent years in information and signal processing. It allowed an alternative approach to conventional techniques for acquiring and reconstructing sensor input signals. CS is also known as *Compressive Sampling* because it allows sampling of compressible analog signals with sampling rates well below the Nyquist rate. This analog setting of CS allows significant performance improvements of analog-to-digital converters for a broad class of time continuous signals. It is therefore possible to design universal CS based data acquisition systems with compressive sensors for analog and digital sensor input signals, even if these signals are noisy.

The compressibility of certain signals can be exploited by developing novel CS methods which, in comparison to traditional approaches like the transform coding, involve far less processing effort for data compression. On the other hand, CS requires far more effort in order to reconstruct a sensor input signal. Accordingly, CS can help to resolve data deluge in complex sensing networks, where the number and resolution of the sensors grow to a point where the performance bottleneck moves to data processing in sensors. To avoid this raw data accumulation, new designs of data acquisition systems are proposed. They combine sensing and compression in one simple operation, replacing conventional sensors with compressive sensors. Instead of acquiring a massive amount of raw data and extracting the information afterwards, compressive sensors attempt to acquire the information directly.

Data compression using CS is performed by means of a simple linear superposition, while the decompression is based on optimization algorithms for finding the unique sparsest solution of an underdetermined system of linear equations. There are multiple approaches for solving this optimization problem, e.g. the generic *Basis Pursuit* algorithm. This fundamental CS de-compression method is based on an optimization with respect to the L1-norm.

The principles of compressed sensing are difficult to comprehend from the available literature without prior special knowledge, since they encompass specific aspects and languages of many mathematical fields. The most relevant subjects to CS are high-dimensional geometries of Euclidean and Banach spaces, random matrices, information and approximation theory, linear and convex programming, harmonic analysis, and combinatorics.

This highly challenging abstract approach to compressed sensing will be in these lectures replaced by a simpler, expressive and application-oriented approach easy understandable for engineers. The underlying principle of this new research field will be systematically explained. The lectures and exercises will illuminate the basic principles of CS using the elementary language of signal processing, linear algebra and geometry only.

The main topics of the course include:

- Big data research and development
- Signal representation using bases and frames
- Traditional and generalized sampling of analog signals
- Overview of sparse recovery - discrete and analog setting
- Recap of the necessary concepts from linear algebra
- Sparsity and measurement basis and frames (dictionaries)
- Sensing matrices and recovery equations
- Geometric interpretation of linear systems of equations
- Some terms of functional analysis and inner product spaces
Basics of multidimensional Euclidean geometry
Linear and affine subspaces,
convex polytopes
Arrangements of hyperplanes
Configurations of sparse solutions
Robustness of CS
Recap of linear optimization methods
Types of reconstruction algorithms in CS
L1-minimization
Basic pursuit
Orthogonal matching pursuit
Theoretical limits of CS
Mutual incoherence property
Null space property
Random matrices and the restricted isometry property
Stochastic geometry, the polytope model and face survival
Weak and strong phase transitions
Sensing matrix design, deterministic sensing matrices
CS using antipodal best spherical codes
CS for A/D converters and other RF applications
Application of CS to image processing and to medical imaging
Application of CS to channel coding and cryptography
Application of CS to radar technology
Application of CS to genetics: DNA-micro-arrays and DNA-sequencing
CS in femto photography
Perspectives of compressed sensing

Literature

There is no introductory textbook yet, nor a detailed tutorial on compressed sensing. Therefore, the lectures and exercises are completely accompanied with detailed slides available as downloads on the web-site of this course. Additional teaching materials and supplementing reading material are also placed on the course web-site. This webpage will provide general course information, resources (links to books, papers, presentations and tutorials) that augment the lectures, as well as homework assignments and creative exercises.

As a basic literature, the Chapter 1 from the following book is recommended:

Y. Eldar, G. Kutyniok (Editors): „Compressed Sensing“, Cambridge Univ. Press 2012, Chapter 1: M. A. Davenport, M. F. Duarte, Y. Eldar, G. Kutyniok: *Introduction to Compressed Sensing*. It is online available on:


or on


A similar text to the above with some more details is

R. Baraniuk, M. A. Davenport, M. F. Duarte, C. Hegde: „An Introduction to Compressive Sensing“, online available on:http://cnx.org/content/col11133/latest/

As a literature for advanced readings, the following review paper is recommended:


An extensive list of scientific contributions and other literature from the field of compressed sensing is on the website at Rice University: http://dsp.rice.edu. Further resources can be found on: The Nuit Blanche Blog http://nuit-blanchenight.blogspot.de

Teaching and learning methods

Lectures "Compressed Sensing", 2 SWS
Exercise "Compressed Sensing", 1 SWS
| **Workload** | Lecture: Attendance: 30 h, direct follow-up: 35 hours  
Exercise: Presence: 15 hours, direct follow-up: 25 hours  
Lecture follow-up as exam preparation and attendance during exam 45 h, total: 150 h |
| **Assessment** | The grade of the module will be the grade of the oral exam. No prerequisites are necessary for exam registration |
| **Grading procedure** | The grade of the module will be the grade of the exam. |
| **Basis for** | Master Thesis |
Compound Semiconductors
Modules referring to Technical Elective Subjects

**Code** 8822270461

**ECTS credits** 6

**Attendance time** 4

**Language of instruction** English

**Duration** 1 Semester

**Cycle** each Summer Semester

**Coordinator** Prof. Dr. Ferdinand Scholz

**Instructor(s)** Prof. Dr. Ferdinand Scholz

**Allocation of study programmes**
- Electrical Engineering, M.Sc., Elective Module, Advanced Materials, M.Sc., Optional Module
- Electrical Engineering, M.Sc., Optional Module, Microelectronics
- Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology

**Recommended prerequisites**

**Learning objectives**
After successfully having finished the module, the students are able to describe the basic physics of compound semiconductors and contrast them to those of elemental semiconductors. They are able to describe important characteristics like band gap, lattice constant or refractive index and identify their systematic trends. They are able to derive from those basics the application possibilities of compound semiconductors and discuss their advantages and disadvantages. They are able to describe and compare the most important fabrication and characterization methods. They are able to describe the constitution of the most important basic hetero structures and explain their mode of operation. Based on that, they are able to develop the structure of important representative devices like light emitting diodes or laser diodes and to describe in detail the function of the respective structural details.

**Syllabus**
- Basics of Semiconductors, Compound Semiconductors
- Bulk crystal growth, liquid phase epitaxy, vapor phase epitaxy, molecular beam epitaxy
- Optical processes, spectroscopic methods
- Electrical characterisation methods
- x-ray diffraction, microscopy methods, other characterisation methods
- Strain in semiconductor structures
- Low-dimensional structures: quantum wells, wires, dots
- Semiconductor Light emitters and Laser Diodes
- Short Wavelength materials: Group III nitrides
- Electronic devices: HEMTs, HBTs
- Solar Cells

Literature
- skript to lecture
- O. Madelung, Grundlagen der Halbleiterphysik, Springer
- S.M. Sze, Physics of Semiconductor Devices, John Wiley
- E. Rosencher, B. Vinter, Optoelectronics, Cambridge University Press 2002
- K.J. Ebeling; Integrated optoelectronics : waveguide optics, photonics, semiconductors
  Berlin ; Heidelberg [u.a.] : Springer, 1993

Teaching and learning methods
- Lecture “Compound Semiconductors”, 3 SWS
- Exercise “Compound Semiconductors”, 1 SWS

Workload
- Preparation and Evaluation: 56 h
- Active Time: 74 h
- Self-Study: 50 h
- Sum: 180 h

Assessment
- The award of the credit points for this ungraded module is based on completion of an assignment (presentation and optionally paper) and active participation in discussions. The required parts will be announced in time. No prerequisites are necessary for the registration.

Grading procedure
- The grade of the module will be the grade of the exam.

Basis for
-
# Cross - Organizational Distributed Systems and Clouds

Modules referring to Technical Elective Subjects

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<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Stefan Wesner</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Prof. Dr.-Ing. Stefan Wesner</td>
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</table>
| Allocation of study programmes | Electrical Engineering, M.Sc., Optional Module, Engineering Sciences  
Electrical Engineering, M.Sc., Optional Module, Communication and System Technology  
Communications and Computer Engineering, M.Sc., Recommended Optional Module,  
Communications Technology, M.Sc., Optional Technical Module |
| Recommended prerequisites | Basic knowledge of distributed systems and/or communication networks |
| Learning objectives | After this course students will have an in-depth understanding of cross-organisational and cloud-based systems and an overview over the state of the art. They will be able to name and describe the architectural principles from Infrastructure over Platform up to Software as a Service concepts. Students will have an understanding of the different cloud software stacks and solutions, and will be able to assess their advantages and limitations. Additionally, they will understand the challenges and solution approaches to deliver Cloud-based services not only from a consumer's, but also from a data centre operator's perspective. They will also learn how Service Level Agreements help in meeting business requirements. The students will be able to differentiate between cloud solutions and local systems and assess them from an economic viewpoint. At the end of the course, the students will have an understanding of the challenges addressed by current research projects. |
| Syllabus        | In the first part of this course, the basics and specific challenges of cross-organisational distributed systems will be discussed. Starting from approaches such as Metacomputing, Grid Computing and virtualisation technologies, the concepts behind Clouds will be introduced. The different layers of Cloud |
provisioning (XaaS) will be explained in the context of current Cloud-based solutions. It will be explained how the concept of Service Level Agreements affect Cloud service hosting and delivery, in particular in terms of performance and cost. The impact on networks and the relationship to Network Function Virtualization and Software Defined Networking will be discussed. The course will conclude with selected themes from “Future Clouds” and current research and development efforts in academia and industry. Lectures will be amended with guest speakers from collaborating institutions from academia and industry, where appropriate.

**Literature**

- Rajkumar Buyya, James Broberg, Andrzej M. Goscinski, Cloud Computing: Principles and Paradigms
- Nicholas Carr, The Big Switch: Rewiring the World, from Edison to Google
- Dimitrakos, Martrat, Wesner, Service Oriented Infrastructures and Cloud Service Platforms for the Enterprise: A selection of common capabilities validated in real-life business trials by the BEinGRID consortium
- Bill Wilder, Cloud Architecture Patterns: Using Microsoft Azure

**Teaching and learning methods**

- Lecture “Cross-organizational distributed systems and Clouds”, 2 SWS
- Exercise “Cross-organizational distributed systems and Clouds”, 1 SWS
- Seminar “Cross-organizational distributed systems and Clouds”, 1 SWS

**Workload**

- Active Time: 60 h
- Preparation and Evaluation: 40 h
- Self-Study: 80 h
- Sum: 180 h

**Assessment**

The grade of the module will be the grade of the oral exam. No prerequisites are necessary for exam registration.

**Grading procedure**

The grade of the module will be the grade of the exam.

**Basis for**

Master’s Thesis
# Data Centre Networks Architecture and Protocols

Modules referring to Technical Elective Subjects

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<td>Cycle</td>
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<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Stefan Wesner</td>
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<td>Prof. Dr.-Ing. Stefan Wesner</td>
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<td>Communications Technology, M.Sc., Elective</td>
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<tr>
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<td>Basic knowledge of distributed systems and/or communication networks</td>
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<table>
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<tr>
<th>Learning objectives</th>
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<tbody>
<tr>
<td>After this course students will have an extended understanding of network architecture and protocols with a focus on the specific challenges, approaches and technologies, products of storage and data-centre networks.</td>
</tr>
<tr>
<td>In order to achieve this the deployed protocols and topologies in the field of storage networks (e.g. iSCSI, SAN, NAS, iSER) and for the realization of large computing facilities and data centers (e.g. Infiniband, Data Centre TCP) are covered. Furthermore the basic design principles and architectures for large scale data centers, the available technologies and procedures (e.g. benchmarking, performance and power efficiency indicators, ...) to optimize such architectures are covered. This covers approaches to achieve low latency and high speed network components as well as emerging technologies such as Software Defined Networking (SDN).</td>
</tr>
<tr>
<td>The primary teaching goals are to allow course participants to name and describe the technologies and protocols used for low latency and high performance applications such as data centers. Participants will understand the pros and cons of different approaches and learn how to evaluate their applicability in different context and examples. The participants will learn to apply these technologies and background knowledge to design data centre networks and architectures for different applications (e.g. Big Data Analytics, Scientific Computing, Server Farming, Cloud Computing, ...)</td>
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</table>
As background material mostly protocol specifications and primary literature and publications are used.

The exams repeat the topics from the lecture with a more practical viewpoint and validate the knowledge based on exercises. The exercises will enable the participants to solve smaller design challenges for storage networks and will evolve over the course up to design of complete data centre systems using the technology introduced in the course for different application domains. The seminar allows participants to experiment with technology and to realize specific set-ups applying the knowledge.

**Syllabus**

The area of data centre and storage networks is characterized by a large focus on optimization for high speed and bandwidth as well as extreme requirements for low latencies. In particular for very large data centers in the field of Big Data analytics, scientific computing/simulation or server farming these requirements combined with the boundary conditions of cost optimizations and performance/cost balance are very challenging. The design of such systems does not only demand for selecting the most appropriate protocols but similarly asks for creative solutions combining them in order to achieve a balanced solution between performance and costs.

In this course mature and emerging technologies in the field of high performance and data centre networks are presented. The capabilities of the different technologies will be discussed along specific use cases e.g. for realizing high performance parallel filesystems, data centers to support large scale data analytics or compute intensive simulation applications from different fields such as automotive or chemistry.

**Literature**

- Troppens, Ulf: Storage networks explained: basics and application of Fibre Channel SAN, NAS, iSCSI, InfiniBand and FCoE, 2009
- Dally, W.: Principles and Practices of Interconnection Networks. (Morgan Kaufmann Series in Computer Architecture and Design)
- Kim, J.; Dally, W. ; Scott, S. ; Abts, D. Cost-Efficient Dragonfly Topology for Large-Scale Systems
- Peter Kogge et. al. ExaScale Computing Study: Technology Challenges in Achieving Exascale Systems- Selected Publications and specifications of the protocols

**Teaching and learning methods**

Data Centre Network Architecture and Protocols (L) , 2 SWS
Data Centre Network Architecture and Protocols (E), 1 SWS,
Data Centre Network Architecture and Protocols (S), 1 SWS

**Workload**

Active Time: 60 h
Preparation and Evaluation: 40 h
Self-Study: 80 h
Sum: 180h

**Assessment**

The grade of the module will be the grade of the oral exam. No prerequisites are necessary for exam registration.
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<td><strong>Basis for</strong></td>
<td>Master Thesis</td>
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Dialogue Systems
Modules referring to Technical Elective Subjects

Code 8822270423

ECTS credits 6

Attendance time 4

Language of instruction German

Duration 1 Semester

Cycle each Winter Semester

Coordinator Prof. Dr.-Ing. Dr. Wolfgang Minker

Instructor(s) Prof. Dr.-Ing. Dr. Wolfgang Minker

Allocation of study programmes
Elektrotechnik, M.Sc., Wahlpflichtmodul Ingenieurwissenschaften
Informatik, M.Sc., Vertiefungsfach Mensch-Maschine Dialogsysteme
Informatik, M.Sc., Kernfach Praktische und Angewandte Informatik
Medieninformatik, M.Sc., Kernfach Praktische und Angewandte Informatik
Medieninformatik, M.Sc., Anwendungsfach Dialogsysteme
Medieninformatik, M.Sc., Vertiefungsfach Mensch-Maschine Dialogsysteme
Elektrotechnik, M.Sc., Wahlpflichtmodul Komunikations- und Systemtechnik
Elektrotechnik, M.Sc., Wahlpflichtmodul Automatisierungs- und Energietechnik
Informationssystemtechnik, M.Sc., Wahlpflichtmodul (Ing/Inf)

Recommended prerequisites Bachelor. No prerequisites from other lectures required. Some basic knowledge in digital signal processing, computer science, cybernetics and statistics would be helpful.

Learning objectives
- achieve a general theoretical knowledge in the domain of multimodal spoken natural language dialogue technology,
- understand the interdisciplinary character of the field,
- achieve some practical knowledge through exercises with real systems and their components at different levels of processing.

Syllabus The lecture provides an introduction into the area of multimodal spoken natural language dialogue systems. A particular focus is placed on acoustic processing, speech signal analysis, recognition, spoken natural language understanding, dialogue processing and speech synthesis. The topics will be illustrated throughout practical sessions and demonstrations of applications and products. Local companies
working in the field of multimodal spoken natural language dialogue systems will provide guest lectures.

Topics:
- Human Communication. Speech communication, structure and properties of speech, speech production, and speech perception.
- Speech Synthesis. Relationship between phonetics and written language, speech synthesis steps, phonetic inventory, speech signal production, speech synthesis (concatenation), linear prediction, prosody control.
- Speech Recognition. Overview over the most commonly used techniques in speech recognition, such as feature extraction from speech, statistical modelling of speech, search and speaker adaptation techniques.
- Semantic Analysis and Dialogue Modelling. Theory of formal languages, Chomsky hierarchy, word problem, finite automata, parsing, syntactic vs. semantic grammars, rule-based vs. statistical approaches to semantic analysis, dialogue modelling and application control.
- Systems Evaluation, Applications and Products. Evaluation of speech recognition and spoken language dialogue systems, overview on research projects, commercially available and research prototypes.

Exercises and Practicals. Spoken natural language dialogue systems development with a focus on parsing and VoiceXML based dialogue management.

Literature
- copies of slides

Teaching and learning methods
Lecture "Dialogue Systems", 2 SWS
Laboratory "Dialogue Systems", 2 SWS

Workload
Active Time: 56 h
Preparation and Evaluation: 64 h
Self-Study: 60 h
Sum: 180 h

Assessment
The grade of the module will be the grade of the oral or written (depending on the number of participants) exam. Prerequisite for exam registration is passing the pre-course (to be defined by the examiner).

Grading procedure
The grade of the module will be the grade of the exam.

Basis for
Master’s Thesis with Dialogue Systems content
Electronic System Design using C and SystemC
Modules referring to Technical Elective Subjects

Code 8822270436

ECTS credits 6

Attendance time 4

Language of instruction english

Duration 1 Semester

Cycle each Winter Semester

Coordinator Prof. Dr.-Ing. Maurits Ortmanns

Instructor(s) Dr. Endric Schubert

Allocation of study programmes
Electrical Engineering, M.Sc., Elective Module, Engineering Sciences
Electrical Engineering, M.Sc., Elective Module, Communication and System Technology
Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology
Communications and Computer Engineering, M.Sc., Elective Module, (Ing)
Communications Technology, M.Sc., Optional Technical Module,
Embedded Systems, M.Sc., Application Subject, Mixed Signal Systems

Recommended prerequisites Bachelor

Learning objectives
In today's world of short product cycles the design of electronic systems demands concurrent design of the hardware and software components. IEEE 1666 SystemC has evolved as the de-facto industry standard for modeling and validating hardware and software components of electronic systems. SystemC builds upon the powerful ANSI/ISO C++ computer software language and adds means for modeling concurrency (parallelism), communication mechanisms, reactivity for synchronizing concurrent processing, and a concept of time. Thus SystemC can be seen as a C++ class library plus an event-based simulation kernel. Students will learn the elements of the ANSI/ISO programming languages C and C++. Their knowledge and understanding of the syntax, semantics and programming principles is applied to practical programming examples. Students reproduce modern techniques of generic programming using C++ templates and C++ class inheritance. Students will analyze electronic system level designs based on the IEEE 1666 SystemC language and the corresponding methodologies.
This includes the design and validation of electronic systems by modeling
time, concurrency (parallelism), reactivity, and communication. They apply these concepts by modifying and/or writing practical code examples. Students can identify state-of-the-art Models of Computation, and can distinguish between modeling concepts such as Untimed Functional Models (UFM), Timed Functional Models (TFM), Transaction-Level Modeling (TLM). Students will gain insight into the underlying event-driven OSCI simulation kernel and, thereby, can apply methodologies for trading-off between accuracy, programming effort and simulation speed.

**Syllabus**

In today’s world of short product cycles the design of electronic systems demands concurrent design of the hardware and software components. Over a very short time period SystemC has evolved as the de-facto industry standard for modeling and validating hardware and software components of electronic systems. SystemC builds upon the powerful ANSI C++ computer software language and adds means for modeling concurrency (parallelism), communication mechanisms, reactivity for synchronizing concurrent processing, and a concept of time. Thus SystemC can be seen as a C++ class library plus an event-based simulation kernel. After a refresher of the syntax of ANSI C++ and principles of object-oriented programming, the syntax of SystemC is introduced. Models of Computation are presented that are commonly used to model at various levels of abstraction: Register-Transfer Level, Behavioral Level, Transaction Level, etc. SystemC models may differ in their accuracy in certain aspects: Pin-level accuracy, timing accuracy, structural accuracy, functional accuracy, communication accuracy. The student will learn methods for trading-off fast development of a SystemC model vs. accuracy and simulation speed. Methods for refining models to gain more accuracy in certain areas are shown, together with formal processes that have proven to be efficient. To complement the class many examples of SystemC code will be shown during the lectures. Hands-on exercises will take those examples to the next level of understanding and will enable the student to develop, compile and debug own SystemC models.

**Literature**

- Ellis, Stroustrup, “The Annotated C++ Reference”, Addison-Wesley
- The manual pages for GNU gcc, GNU make, GNU gdb at www.gnu.org
- The SystemC Language Reference Manual (LRM) from the Open SystemC Initiative at www.osci.org

**Teaching and learning methods**

Lecture “Electronic System Design using C and SystemC”, 2 SWS
Exercise “Electronic System Design using C and SystemC”, 2 SWS

**Workload**

Lecture: participation: 28 h; wrap-up: 40 h; 
Exercises: participation: 28 h; wrap-up: 40 h; 
Exam preparation: 44 h; 
Total: 180 h

**Assessment**

The grade of the module will be the grade of the oral or written (depending on the number of participants) exam. No prerequisites are necessary for exam registration
Grading procedure  The grade of the module will be the grade of the exam.

Basis for  -
## Integrated Systems

Modules referring to Technical Elective Subjects

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Basis for

No english version available yet.
# Heterogeneous and Parallel Computing Infrastructures

Modules referring to Technical Elective Subjects

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<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Stefan Wesner</td>
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<tr>
<td>Instructor(s)</td>
<td>Prof. Dr.-Ing. Stefan Wesner, Lutz Schubert</td>
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<td>Communications Technology, M.Sc., Optional technical module</td>
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**Recommended prerequisites**

- Basic knowledge of distributed systems and/or communication networks, as well as computer architecture is desirable. Some programming knowledge in structured or object oriented programming languages is required for performing the exercises. Participation in the lectures Computer Networks and/or Cross-organizational distributed systems and Clouds or the Lab on Information Technology is desirable but no formal pre-condition.

**Learning objectives**

- After this course students will have an in-depth understanding of processor architectures and their differences in modern heterogeneous computing platforms. They will understand the impact of processor and system architecture on application performance and will know how this affects programming of such systems. They will be able to explain the benefits and drawbacks of specialisation, parallelisation and data locality, and can give examples of how and when to exploit these factors. They will understand the limitations of scalability based on communication costs and lack of parallelism/ amount of serial code and can interpret and explain scalability and speed-up diagrams for parallel applications. Participants will be able to argue where processor and system development is heading to, why and which problems will arise from this.
**Syllabus**

The course will start from an overview over current processor systems and development trends in computer hardware towards increased heterogeneity and specialisation, driven by the need for more computer performance and increased energy efficiency. The first section of the course will provide a base knowledge of processor architecture from a performance perspective.

In a second section, the principles of parallelisation will be elaborated on all levels, from large scale computing systems, such as high performance computing and clouds, down to multi- and many-core processors. This covers the principles of parallel programming and programming models, such as OpenMP, MPI and Partitioned Global Address Space (PGAS). This will also cover their limitations, such as Amdahl’s law and the impact of data locality.

The third section will address specialisation of systems, ranging from embedded devices and multi-core systems to specialised co-processors, such as GPUs. The impact of specialisation on performance and energy efficiency, but also on programmability and portability will be elaborated. The future trends towards completely heterogeneous setups on all levels will be examined and assessed.

The lecture will conclude with an outlook on how processors will likely develop in the future and what this means for the programmability and portability of software.

**Literature**


**Teaching and learning methods**

- Heterogeneous and Parallel computing Infrastructures (V), 2 SWS
- Heterogeneous and Parallel computing Infrastructures (S), 2 SWS

**Workload**

- Active Time: 60 h
- Preparation and Evaluation: 40 h
- Self-Study: 80 h
- Sum: 180 h

**Assessment**

The grade of the module will be the grade of the oral exam. No prerequisites are necessary for exam registration.

**Grading procedure**

The grade of the module will be the grade of the exam.

**Basis for**

Master Thesis
### Integrated Analog Circuits

*Modules referring to Technical Elective Subjects*

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<td>Coordinator</td>
<td>Prof. Dr.-Ing. Maurits Ortmanns</td>
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| Instructor(s)         | Prof. Dr.-Ing. Maurits Ortmanns  
|                       | Prof. Dr.-Ing. Hermann Schumacher  
|                       | Jun.-Prof. Dr. Jens Anders |
| Allocation of study programmes |
|                       | Elektrotechnik, M.Sc, PO2008, PO2010, PO2012, Wahlmodul  
|                       | Elektrotechnik, M.Sc, PO2014, Kernmodul  
|                       | Informationssystemtechnik, M.Sc, PO2008, PO2010, PO2012, PO2014, Kernmodul  
|                       | Communications Technology, M.Sc., PO 2015/2017, Track Communications Circuits and Systems, Compulsory Module  
|                       | Communications Technology, M.Sc., PO 2015/2017, Track Communications Engineering, Compulsory Elective Module |
| Recommended prerequisites | Basic knowledge of semiconductor devices, analog circuits, control theory and signal processing |
| Learning objectives | The students differentiate various semiconductor devices and technologies. They compare the behavior and application of the MOST and the BJT. They are able to compare various compact models. The students are able to describe the behavior of the MOS transistor, explain its operation and describe the impact and influence of electrical, manufacturing and environmental non-idealities. They describe and analyze a transistor level circuit using small signal parameters and derive transfer functions for the linearized model. The students differentiate the operation and application of single stage amplifiers and use circuit techniques for gain enhancement. They adopt these methods to design and analyze differential amplifiers. They use advanced concepts for frequency compensation and stabilization. The students can compare the advantages and application of several multistage differential amplifier concepts, analyze and design those amplifiers. They use circuit simulators in order to design these single stage and differential amplifiers for a given specification. The students describe the origin of electronic noise, analyze simple circuits concerning noise contribution, adopt... |
the principle of input referred noise in amplifiers, and explain design based as well as architectural noise reduction techniques. The students describe the concept of switched capacitor circuits, analyze their behavior and apply them for analog signal processing. They are able to apply the principles of analog integrated circuit design to further applications. They describe and compare the functionality of various concepts for analog-to-digital and digital-to-analog converters. The students describe the principal of oversampling and noise shaping and apply this to the concept of sigma-delta modulators.

**Syllabus**

- Devices and non-idealities
- MOS and Bipolar transistors including signal parameters and non-idealities
- On-chip bias generation
- Review of basic analog circuits
- Single-stage CMOS amplifiers
- Enhanced CMOS amplifier concepts
- Two-stage CMOS amplifiers with frequency compensation
- Introduction to electronic noise
- Switched-Capacitor Circuits
- A/D and D/A converters

**Literature**

- Baker, R.J. “CMOS Circuit Design, Layout, and Simulation”, Wiley
- Sansen, W. “Analog Design Essentials”, Springer

**Teaching and learning methods**

Lecture "Integrierte Analogschaltungen" (Integrated Analog Circuits), 3 SWS
Practical Exercises "Integrierte Analogschaltungen" (Integrated Analog Circuits), 1 SWS

**Workload**

Active Time: 60 h
Preparation and Evaluation: 120 h
Sum: 180 h

**Assessment**

The grade of the module will be the grade of the oral or written (depending on the number of participants) exam. No prerequisites are necessary for exam registration

**Grading procedure**

The grade of the module will be the grade of the exam.

**Basis for**

Project: Analog CMOS Circuit Design
Lecture: Circuit Design in Nanometer-Scaled CMOS Technologies
Elective Modules
Master-Thesis
Integrated Microwave Systems
Modules referring to Technical Elective Subjects

Code 8822272215
ECTS credits 4
Attendance time 3
Language of instruction English
Duration 1 Semester
Cycle each Summer Semester
Coordinator Prof. Dr.-Ing. Christian Waldschmidt
Instructor(s) Prof. Dr.-Ing. Christian Waldschmidt
Prof. Dr.-Ing. Christian Damm
Dr.-Ing. Frank Bögelsack
Dr.-Ing. Tobias Chaloun

Allocation of study programmes
Elektrotechnik MSc, Elective Module Ingenieurwissenschaften
Elektrotechnik MSc, Elective Module in Kommunikations- und Systemtechnik
Elektrotechnik MSc, Elective Module in Mikroelektronik
Elektrotechnik MSc, Elective Module in Automatisierungs- und Energietechnik
Elektrotechnik MSc, Elective Module in Allgemeine Elektrotechnik
Communications Technology, MSc, Elective Module in Communications Circuits
Communications Technology, MSc, Elective Module in Communications Engineering

Recommended prerequisites
Knowledge of the content of the lectures "Einführung in die Hochfrequenztechnik"
or "Introduction to Microwave Engineering"

Learning objectives
After successful completion of lecture and exercises, the students are familiar with the basics of planar transmission line techniques. They are capable to design simple planar components and circuits and are able to familiarize themselves quickly with the design of more complex circuit arrangements. In addition, they know the state-of-the-art interconnect and packaging techniques as well as technologies and methods to fabricate microwave circuits.

Syllabus
Today, microwave circuits are realized, to a great extent, as planar circuits printed on a dielectric substrate material, in specialized form, even in monolithic form on semiconductor material together with respective semiconductor...
devices (MIC or MMIC). In its first part, the lecture therefore deals with the used planar transmission lines. In addition to a general overview, formulas, and computational procedures are presented to calculate the respective transmission line parameters. As an example for a field theoretical computation method to calculate such parameters, the spectral domain method is presented.

To realize complete circuits, quasi-lumped devices, transmission line segments as well as semiconductor devices are necessary which are dealt with in the following sections. Another section presents planar integrated antennas. Finally, two chapters introduce packaging and interconnect techniques and fabrication methods for (hybrid) integrated planar circuits. In the exercises, the knowledge of this lecture is deepened, and the application of the methods is practiced. This includes some circuit design which is done with a CAD system at a computer these circuits finally are realized and tested experimentally.

**Literature**
- Lecture handout
- Text books: references to text books are provided in the lecture handouts

**Teaching and learning methods**
Lecture “Integrated Microwave Systems”, 2 SWS
Exercise “Integrated Microwave Systems”, 1 SWS

**Workload**
Active Time: 45 h
Preparation and Evaluation: 30 h
Self Study: 45 h
**Sum: 120 h**

**Assessment**
The grade of the module will be the grade of the oral or written (depending on the number of participants) exam. No prerequisites are necessary for exam registration

**Grading procedure**
The grade of the module will be the grade of the exam.

**Basis for**
-
# Integrated Interface Circuits

Modules referring to Technical Elective Subjects

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<td>Cycle</td>
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<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing Maurits Ortmanns</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Prof. Dr.-Ing Maurits Ortmanns</td>
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</table>

## Allocation of study programmes
- Electrical Engineering, M.Sc., Elective Module
- Communications Technology, M.Sc., Optional Technical Module, Communications Circuits and Systems

## Recommended prerequisites
Successful participation in the course "Integrated Analog Circuits" or a similar qualification are recommended for a successful course participation.

## Learning objectives
The students can identify the most relevant noise sources in sensors and sensor readout electronics and predict their effect on the achievable signal noise ratios. They can distinguish various sensor and transducer principles and apply appropriate readout electronic circuits. The students can differentiate open-loop and closed-loop readout concepts and apply concepts for offset and noise-reduction.

The students analyze and compare different A/D and D/A converter structures concerning their achievable specifications. The students can explain the concept of discrete-time and continuous-time noise-shaping Sigma-delta ADCs and of charge redistribution SAR ADC, as well as the concept of time-to-digital conversion.

The students are able to distinguish various biosignals and give an overview of implantable system requirements. The students can analyze circuit architectures for biosignal recording and neurostimulation circuits. The students identify the problems associated with residual stimulation charge and apply various methods for charge balancing.
The students analyze a research paper in the field of integrated interface circuits and give a presentation on the same.

**Syllabus**

1. Motivation and example sensor Applications
2. Sensors and Sensor Interface Circuits
   a. Noise in sensor interface circuits
   b. Transducers
   c. Bandgap references and integrated temperature sensors
   d. Resitive and inductive readouts circuits
   e. Capacitive readouts circuits, open and closed loop concepts, force feedback
   f. Autozeroing, Chopping, Correlated Double Sampling
3. Analog/Digital Interfaces
   a. Quantization and Sampling
   b. Spectral Metrics
   c. DAC overview
   d. Nyquist and oversampling DACs
   e. ADC overview
   f. Comparators
   g. SAR ADC
   h. Oversampling (Sigma-Delta) ADC
   i. Time-to-digital converts
4. Biomedical Interface Circuits
   a. Excitable cells and biosignals
   b. Overview on microelectrodes, biocompatibility, packaging
   c. Telemetry and inductive powering
   d. Neural recording, stimulation and modulation circuits and systems
   e. Charge Balancing Strategies
   f. Applications: Cardiac devices, Neuromuscular simulators, Gastrointestinal devices and obesity treatment, Drug delivery devices and infusion pumps, Diabetes treatment, Rehabilitation Engineering
   g. Examples for implantable biosensors

**Literature**

Teaching and learning methods

Integrated Interface Circuits (L), 3 SWS
Integrated Interface Circuits (S), 1 SWS

Workload

Lecture: Attendance: 42 h
Lecture review: 28 h
Seminar preparation: 16 h
Preparation of the oral presentation and written documentation: 44 h
Exam preparation and exam participation: 50 h
Total: 180 h

Assessment

Attendance of the lecture and the seminar (block seminar at the end of the term). Assessment will normally be in the form of an oral exam, or otherwise a written exam of 90 minutes duration. Successful participation in the seminar (seminar attendance certificate) is a requirement for admission to the exam.

Grading procedure

The grade of the module will be the grade of the exam.

Basis for

Master-Thesis
Iterative Methods for Wireless Communications
Modules referring to Technical Elective Subjects

Code 8822271150

ECTS credits 4

Attendance time 3

Language of instruction English

Duration 1 Semester

Cycle each Winter Semester

Coordinator Dr. Werner Teich

Instructor(s) Dr. Werner Teich


Recommended prerequisites Signale und Systeme, Einführung in die Nachrichtentechnik, Communications Engineering

Learning objectives The students can describe the basic principle of iterative methods, analyze convergence properties and give examples for the main areas of application. Based on the fix-point equation they are able to graphically illustrate and analyze an iterative method. The students can describe and discuss the block diagram of a vector-valued transmission model. They can design different vector equalization schemes (maximum-likelihood equalizer, block linear equalizer, block decision-feedback equalizer, multistage detector, recurrent neural network based equalizer) and they are able to analyze them with respect to performance and to computational complexity. The students are able to employ the probability theory for iterative decoding and analyze as well as create the Tanner graph for a specified linear code. They can discuss the fundamental properties of low-density parity-check codes and convolutional self-orthogonal codes. They can illustrate the basic principles of turbo codes and joint de-mapping, equalization, and decoding (turbo equalization).

Syllabus Iterative methods are motivated by considering two classical examples: Newtons method to find the roots of nonlinear functions and the Jacobi- and Gauss-Seidel
method to solve large systems of linear equations. Based on these examples convergence and convergence rates of iterative methods are discussed. The concept of the fix point iteration is used to provide a graphical interpretation of iterative processes. In chapter two the concept of vector-valued transmission is introduced. Based on this, we derive the optimum receiver structure for general linear modulation methods. Besides the optimum vector equalizer also various suboptimum methods (block linear equalizer, block decision feedback equalizer, multistage detector) are discussed. Furthermore iterative equalizer are introduced and the relation to recurrent neural networks is described. Chapter three first introduces the basic concepts for iterative decoding: maximum a posteriori decoding, probability theory for iterative decoding and Tanner graphs as a means to graphically represent iterative decoding. As applications we consider low-density parity-check codes and convolutional self-orthogonal codes. In chapter four iterative methods for concatenated systems are considered. This includes a discussion of classical turbo codes as well as receiver concepts based on a joint demapping, equalization and decoding (turbo equalization). As a further example we consider the basic principle of interleave division multiplexing. The iterative methods are analysed using EXIT charts.

Literature

Teaching and learning methods
Lecture “Iterative Methods for Wireless Communications”, 2 SWS
Exercise “Iterative Methods for Wireless Communications”, 1 SWS

Workload
Active Time: 45 h
Preparation and Evaluation: 75 h
Sum: 120 h

Assessment
The grade of the module will be the grade of the oral or written (depending on the number of participants) exam. No prerequisites are necessary for exam registration

Grading procedure
The grade of the module will be the grade of the exam. In case of successful participation in the Matlab project a bonus to the exam mark will be given (exam regulations for the bachelor and master courses in Electrical Engineering (Elektrotechnik) and Computer Systems Engineering (Informationssystemtechnik) resp. of the exam regulations for the master course Communications Technology)

Basis for
-
Mixed-Signal CMOS Chip Design
Modules referring to Technical Elective Subjects

Code 8822271045

ECTS credits 4

Attendance time 2.5

Language of instruction English (german upon verbal agreement)

Duration 1 Semester

Cycle each Winter Semester

Coordinator Prof. Dr.-Ing. Maurits Ortmanns

Instructor(s) Dr.-Ing. Joachim Becker
Prof. Dr.-Ing. Maurits Ortmanns

Allocation of study programmes
- Electrical Engineering, M.Sc., Elective Module,
  Electrical Engineering, M.Sc., Elective Module, Communication and SystemTechnology
- Electrical Engineering, M.Sc., Elective Module, Microelectronics
- Electrical Engineering, M.Sc., Optional Module, Automation and EnergyTechnology
- Communications Technology, M.Sc., Optional Technical Module, Communications Circuits and Systems
- Embedded Systems, M.Sc., Application Subject, Mixed Signal Systems

Recommended prerequisites Basic knowledge of semiconductor devices, analog circuits, control theory and signal processing

Learning objectives This lecture goes along with the analog and digital CMOS circuit design lectures offered by the institute of microelectronics. In contrast to these more theoretical lectures on circuit design techniques, this lecture is focused on the implementation issues of application specific integrated circuits (ASICs). After successful pass of this course, students understand the working principles of analog and digital circuit simulation techniques. They are able to set up a node admittance matrix from a given circuit and know the working principles and applications of the three main analog simulation types: DC, AC, and transient. They understand linearization of device models and Newton-Raphson integration for
solution of differential equations, update and residue criteria, and equilibrium points. Furthermore, they understand process variation and device mismatch and their influence on CMOS circuits and are able to use worst case corner modeling and statistical evaluation methods like Monte Carlo analysis for yield optimization and design centering. They can elaborate the difference between cycle-based and event-driven digital simulation techniques, including half-step simulation and time-wheel scheduling. They are able to use setup- and hold-time constraints as well as contamination- and propagation-delays for calculation of slack times in a static timing analysis and can explain the effect of clock skew and jitter on synchronous circuits. They can elaborate how table-based models and circuit-partitioning is able to significantly speed up simulations and enables mixed-signal verification. They can estimate the tradeoff between manual modeling, compiled-model interface, and coupled co-simulation for mixed-mode analyses. They understand synthesis of combinational and synchronous behavioral hardware description into generic gates. Furthermore, they are able to use the stuck-at fault-model and the D-algorithm in order to analyze testability and include boundary-scan Flip-Flops for improved testability. They know principles of placement and routing of standard-cells including min-cut algorithm, maze and channel-routing, and layout compaction, as well as design-rule-check and layout-versus-schematic-check. They are able to build a clock-distribution network and make use of timing aware placement, as well as build a power-grid and apply I/O-cells in order to improve the reliability of digital circuits. Finally, they know various bonding-techniques and printed-circuit-board design practices in order to connect the final ASIC to other chips and measurement equipment. There is a strong emphasis on the computer aided design (CAD) support and algorithms, which are integral part of todays chip implementation. The exercises will be used to give hands-on experience with industry-standart CAD design tools.

**Syllabus**
- analog simulation
- digital simulation
- mixed-signal and co-simulation
- design for reliability
- design for testability
- CMOS layout, floorplanning, standart-cells
- layout parasitic extraction and verification
- packaging and board design

**Literature**
- Baker - CMOS : Circuit design, layout, and simulation
- Razavi - Design of Analog CMOS Integrated Circuits
- Allen, Holberg - CMOS Analog Circuit Design
- Sedra, Smith - Microelectronic Circuits

**Teaching and learning methods**
- Lecture “Mixed-Signal CMOS Circuit Design”, 2 SWS
- Exercise “Mixed-Signal CMOS Circuit Design”, 0.5 SWS

**Workload**
- Active Time: 38 h
- Preparation and Evaluation: 82 h
- Sum: 120 h
<table>
<thead>
<tr>
<th><strong>Assessment</strong></th>
<th>The credit points will be awarded once the oral exam has been passed. No prerequisites are necessary for exam registration.</th>
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<td><strong>Grading procedure</strong></td>
<td>The grade of the module will be the grade of the exam.</td>
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<td><strong>Basis for</strong></td>
<td>Elective Modules, Master-Thesis</td>
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Multiuser Communications and MIMO Systems
Modules referring to Technical Elective Subjects

Code 8822271727

ECTS credits 6

Attendance time 4

Language of instruction German or English

Duration 1 Semester

Cycle each Summer Semester

Coordinator Prof. Dr.-Ing. Robert Fischer

Instructor(s) Prof. Dr.-Ing. Robert Fischer

Allocation of study programmes
- Electrical Engineering, M.Sc., Elective Module, Engineering Sciences
- Electrical Engineering, M.Sc., Elective Module, Communication and System Technology
- Information Systems Technology, M.Sc., Elective Module, (Ing)
- Communications Technology, M.Sc., Optional Technical Module, Communications Engineering

Recommended prerequisites Module “Einführung in die Nachrichtentechnik”, “Communications Engineering” und “Signale und Systeme”.

Learning objectives The students will be able to assess, compare, and design digital transmission systems where a number of users/signals are treated jointly. They can distinguish the different performance measures and explain the trade-off between them. Equalization and pre-equalization schemes can be assessed and designed according to pre-described criteria. The role of lattices in the present context can be outlined. Advanced state-of-the-art precoding approaches can be appraised. The information-theoretical foundation of multiuser communications can be described and applied for their evaluation. The role of interference in such schemes can be illustrated.

Syllabus Introduction into the field of multiuser communications and multiple-input/multiple-output systems. Both, practical transmission schemes, as well as fundamental limits from information theory are covered.
- Introduction
- MIMO Communications
- Introduction to Lattices
- Lattice Decoding and the “Sphere Decoder”
- Equalization via Lattice Reduction
- “Writing on Dirty Paper”
- Multiuser Communications
- Advanced Transmitter-Side Techniques
- Interference Channel

**Literature**


**Teaching and learning methods**

Lecture “Multiuser Communications and MIMO Systems”, 3 SWS
Exercise “Multiuser Communications and MIMO Systems”, 1 SWS

**Workload**

Active Time: 60 h
Preparation and Evaluation: 120 h
Sum: 180 h

**Assessment**

The grade of the module will be the grade of the oral or written (depending on the number of participants) exam. No prerequisites are necessary for exam registration

**Grading procedure**

The grade of the module will be the grade of the exam.

**Basis for**

-
# Neuronal Networks and Pattern Recognition

Modules referring to Technical Elective Subjects

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</tr>
<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Klaus Dietmayer</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Dr.-Ing. Ulrich Kreßel</td>
</tr>
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| Allocation of study programmes | Electrical Engineering, M.Sc., Elective Module  
Electrical Engineering, M.Sc., Optional Module, Communication and System Technology  
Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology  
Electrical Engineering, M.Sc., Optional Module, General Electrical Engineering  
Information Systems Technology, M.Sc., Optional Module  
Communications Technology, M.Sc., Optional Technical Module, Communications Engineering |
| Recommended prerequisites | - Basics of Stochastic  
- Basics of Linear Algebra  
- Basics of Digital Signal Processing |
| Learning objectives | The students are able to analyze a real world pattern recognition problem, to transform the problem into a schematic processing chain of recognition and to identify the main steps: data acquisition, segmentation, feature extraction, classification and context based interpretation. They know in detail the three basic theories: decision, approximation, and learning theory, and can explain, how these mathematical theories support the engineering approach to pattern recognition. The students also can distinguish between different approaches to function approximation, such as polynomial classifier, multilayer perceptron, and radial basis functions, can apply all of them, select the most appropriate one for a given problem and design (structure) and adapt (parameters) them accordingly. They also know further concepts of classification, such as cluster analysis, normal distribution hypothesis, support vector machine and cascade classifiers, in order to differentiate them from each other and also to argue, where and when to use them. The students know, how to collect data for a pattern recognition task, and |
how to compose, evaluate and compare different approaches. They are able to apply these data bases to real world classification problems.

**Syllabus**

| Processing chain for pattern recognition as data acquisition, segmentation, feature extraction, classification and context based Interpretation, feature definition, classes, learning from examples, generalization, function approximations |
| Fundamental Theories: Decision Theory, Approximation Theory and Learning Theory |
| General Algorithms: Bayes Classifier and Least Mean Squares Approach, Polynomial Classifier, Multilayer Perceptron: Multi References Classifiers: Radial Basis Functions, Nearest Neighbor Classifier |
| Cluster Analysis: K-Means, Vector Quantization, Divisive Clustering Normal Distribution |

**Literature**


**Teaching and learning methods**

| Lecture “Neural Networks and Pattern Classification”, 2 SWS |
| Exercise “Neural Networks and Pattern Classification”, 1 SWS |

**Workload**

| Active Time: 45 h |
| Preparation and Evaluation: 45 h |
| Self-Study: 30 h |
| Sum: 120 h |

**Assessment**

The grade of the module will be the grade of the oral exam. No prerequisites are necessary for exam registration

**Grading procedure**

The grade of the module will be the grade of the exam.

**Basis for**

-
## Optoelectronic Devices

Modules referring to Technical Elective Subjects

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<td>Cycle</td>
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<tr>
<td>Coordinator</td>
<td>apl. Prof. Dr.-Ing. habil. Rainer Michalzik</td>
</tr>
<tr>
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<td>apl. Prof. Dr.-Ing. habil. Rainer Michalzik</td>
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### Allocation of study programmes
- Electrical Engineering, M.Sc., Elective Module
- Electrical Engineering, M.Sc., Elective Module, Microelectronics
- Electrical Engineering, M.Sc., Elective Module, Communication and System Technology
- Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology
- Information Systems Technology, M.Sc., Optional Module
- Communications Technology, M.Sc., Optional Module

### Recommended prerequisites
- Modules “Optical Communications” or “Einführung in die Optoelektronik”

### Learning objectives
- The students are able to describe the modal properties of laser diodes in all three spatial directions and can summarize the temperature-related effects. They can distinguish between gain and index guiding and can relate optical near- and far-fields. The students can describe the origin of parasitic frequency modulation and explain the influence of spontaneous emission noise. They can express the motivation and practical implementation of mirror coatings. They are able to design Bragg mirrors for use in edge-emitting distributed feedback (DFB) and distributed Bragg reflector (DBR) laser diodes as well as for vertical-cavity surface-emitting lasers (VCSELs). They can sketch the layer structures of these three laser diode types and select their layout to achieve dynamic single-mode emission. The students can name the mechanisms of wavelength tuning of laser diodes and illustrate suitable device implementations. They are able to discuss the designs and operating principles of various types of photodetectors and to identify strengths and weaknesses for their use in optical communication systems. The students can moreover list and describe physical effects that are employed to realize optical phase and amplitude modulators with high operation bandwidth exceeding that of directly modulated laser diodes. Corresponding devices can
be sketched and their function be explained. The students are able to show how phase modulation is converted into amplitude modulation in a Mach–Zehnder interferometer configuration. They master to employ such devices for the generation of higher-order optical modulation formats.

**Syllabus**

- Edge-emitting semiconductor lasers: longitudinal multimode, lateral and transverse mode behavior, temperature effects, optical near- and far-fields, frequency modulation, mirror coatings, laser noise, high-power lasers, DBR and DFB lasers for use in telecommunications, tunable laser diodes
- Vertical-cavity surface-emitting lasers (VCSELs): principles and applications
- Photodetectors: PIN-type, avalanche photodiode (APD), metal–semiconductor–metal (MSM), resonant-cavity-enhanced, waveguide-type, high-speed designs
- Optical modulators: physical effects (plasma, electroabsorption (Franz–Keldysh), quantum-confined Stark (QCSE), electro-optic (Pockels)), phase modulators, Mach–Zehnder interferometer (MZI) modulators, absorption modulators, generation of higher-order modulation formats such as quaternary phase shift keying (QPSK) used in modern optical communication systems

**Literature**

A comprehensive English written manuscript is provided

**Teaching and learning methods**

Lecture “Optoelectronic Devices”, 3 hours per week

**Workload**

Preparation and Evaluation: 78 h
Active Time: 42 h
Sum: 120 h

**Assessment**

The grade of the module will be the grade of the oral exam. No prerequisites are necessary for exam registration

**Grading procedure**

The grade of the module will be the grade of the exam.

**Basis for**

-
Radio- Frequency Power- Amplifier Design
Modules referring to Technical Elective Subjects

Code 8822272075

ECTS credits 4

Attendance time 3

Language of instruction English

Duration 1 Semester

Cycle each Summer Semester

Coordinator Dr.-Ing. Christoph Bromberger

Instructor(s) Dr.-Ing. Christoph Bromberger

Allocation of study programmes Electrical Engineering, M.Sc., Optional Module
Communications Technology, M.Sc., Optional Module
Information Systems Technology, M.Sc., Optional Module

Recommended prerequisites Bachelor-Level
Analog Design Skills
Some understanding of S-parameters is helpful

Learning objectives After the first half of the lecture, the students identify the requirements from mobile communication systems for power amplifier design. Attendees recognize potential challenges in applying HF measurement equipment and employ techniques to circumvent them. Students differentiate between small- and large-signal operation and examine the respective strengths and limitations of time-domain and of S-parameter methods. They appraise for the real-world limitations to PA design, HF bandwidth and signal bandwidth. After the second half, participants discriminate different efficiency enhancement concepts and apply load modulation amplifier design techniques.

Syllabus - Data encoding, signal statistics and consequences for power amplifiers
- Measuring power devices
- Small-signal vs. large-signal operation, LF vs. HF behavior
- Matching power devices using measurement and small-signal tools
- Some nasty shortcomings of nice theoretical approaches
- The Doherty amplifier and it’s design
- Outphasing, pre-distortion, feed-forward and switching mode Pas
- In the exercises, students engross in the concepts by applying them with the help of ADS to real-world designs.

**Literature**
- A script is available in the lecture
- Steve Cripps, RF Power Amplifiers

**Teaching and learning methods**
- Lecture "Radio-Frequency Power-Amplifier Design", 2SWS
- Exercise "Radio-Frequency Power-Amplifier Design", 1SWS

**Workload**
- Lectures: 30 h
- Exercises: 10 h
- Self-Study: 20 h
- Homework: 30 h
- Exam Preparation and Evaluation: 30 h
- Sum: 120 h

**Assessment**
The grade of the module will be the grade of the oral or written (depending on the number of participants) exam. Prerequisite for exam registration is passing the pre-course (to be defined by the examiner).

**Grading procedure**
The grade of the module will be the grade of the exam.

**Basis for**
Master thesis with radio frequency electronics content
## Satellite Communications and Navigation

Modules referring to Technical Elective Subjects

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<tr>
<td><strong>Coordinator</strong></td>
<td>Prof. Dr.-Ing. Uwe-Carsten Fiebig</td>
</tr>
<tr>
<td><strong>Instructor(s)</strong></td>
<td>Prof. Dr.-Ing. Uwe-Carsten Fiebig</td>
</tr>
</tbody>
</table>

### Allocation of study programmes

- Electrical Engineering, M.Sc., Elective Module
- Electrical Engineering, M.Sc., Optional Module, Communication and System Technology
- Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology
- Electrical Engineering, M.Sc., Optional Module, General Electrical Engineering
- Information Systems Technology, M.Sc., Optional Module
- Communications Technology, M.Sc., Optional Technical Module

### Recommended prerequisites

Communications Engineering

### Learning objectives

The students are able to understand the various types of satellite orbits: from the Earth-satellite geometry the students can determine all parameters which are relevant for satellite communications such as coverage, distance, visibility of the satellite, elevation angle, and Doppler effects.

The students get an idea about satellite installation, space conditions, and orbital perturbations and, thus, understand all major differences between satellite communications and terrestrial mobile radio.

Link budgets are in the very focus of the lecture. The students are able to calculate complete link budgets for satellite communications for both uplink and downlink, for station-to-station links and also for interplanetary links. The students assess the findings of link budgets; they can design satellite communications systems encompassing transmit power, antenna size, bit rate constraints,
frequency issues, link margins and the like. The students analyse the influence of communication parameters on the link budget and point out the consequences on the system design if the requirements on the communications link are changed.  

Operational satellite communication systems are treated in the lecture. The students understand their basic concepts and are able to identify their advantages and drawbacks.  

The final subject is satellite navigation. The students understand the basic concept of satellite navigation. They can describe the challenges satellite navigation is faced with and apply methods and techniques to cope with this challenges. The students can explain the various components of satellite navigation systems and understand concepts to further improve the performance of such systems.

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**Syllabus**

The lecture treats both communication aspects of modern satellite communications systems and satellite navigation. The topics are: Satellite orbits (Kepler’s laws, Earth-satellite geometry, types of orbits), satellite installation into the target orbit, space conditions, satellite communications payload, modulation and multiple access for satellite communications, adjacent channel interference, intermodulation, satellite channel (frequency bands, atmospheric effects, fade margin design), link budgets (description of all parameters which are required to calculate the signal-to-noise ratio at the receiver; examples of link budgets), mobile satellite communication systems (Iridium, Globalstar) and satellite navigation (principle, navigation equation, error budget, GPS, Galileo).

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**Literature**

- G. Maral and M. Bousquet: Satellite Communications System, Wiley

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**Teaching and learning methods**

Lecture “Satellite Communications”, 2 SWS  
Exercise “Satellite Communications”, 1 SWS

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**Workload**

Active Time: 36 h  
Preparation and Evaluation: 36 h  
Self-Study: 48 h  
Sum: 120 h

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**Assessment**

The grade of the module will be the grade of the oral or written (depending on the number of participants) exam. No prerequisites are necessary for exam registration.

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**Grading procedure**

The grade of the module will be the grade of the exam.

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**Basis for**

-
# Semiconductor Sensors

Modules referring to Technical Elective Subjects

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</tr>
<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Hermann Schumacher</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Dr. Alberto Pasquarelli</td>
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</table>

## Allocation of study programmes

- Electrical Engineering, M.Sc., Elective Module
- Electrical Engineering, M.Sc., Compulsory Subject Module, Microelectronics
- Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology
- Communications Technology, M.Sc., Optional Technical Module, Communications Circuits and Systems
- Embedded Systems, M.Sc., Application Subject, Mixed Signal Systems

## Recommended prerequisites

- Halbleiterbauelemente

## Learning objectives

The advances in microelectronics and micro electro-mechanical systems (MEMS) have revolutionized the scenario of sensor technology. Thanks to new materials and processes, traditional bulky, slow and expensive sensor systems could be replaced by miniaturized and integrated smart sensors based on semiconductors. With the help of semiconductor sensors various application areas have been developed. In everyday life we encounter them, for example, in the form of navigation and control systems in vehicles or as microphones, accelerometers, compass and cameras in mobile phones and tablets. In addition to the automotive industry and the mobile communications, semiconductor sensors are used in many other areas, for example, in health care to record the blood pressure or body temperature in real time.

The students describe and classify principles of operation, technological implementations and application areas of different sensors. They recognize and discuss the various physical phenomena in semiconductors, which are used for the detection of physical quantities and their conversion to electrical signals. They know various semiconductor materials suitable for the production of sensors, analyze the peculiarities of each one, explain and predict their response under different conditions and can calculate sensor examples for different measurement...
needs. The students can design a semiconductor sensor choosing the right material among several semiconductors. They are able to analyze a measurement problem, compare appropriate sensing techniques and develop their own solution. Doing this they can properly dimension the sensor unit to meet the design specifications.

**Syllabus**

Semiconductor-based detection methods for:
- radiation (ionizing and non-ionizing)
- magnetic fields
- mechanical forces
- temperature
Basics on operational amplifiers
Basics on MST (micro system technology)
Basics on MEMS (micro electro-mechanical systems)

**Literature**

Lecture Notes

For in-depth study, following books (University library) are recommended:

Pierret: Field effect devices - TK 7871.95/1990 P
Michalski: Temperature measurement - I: QC 291/1991 M
Glück: MEMS in der Mikrosystemtechnik - T99: TK 7875/2005 G
Hilleringmann: Mikro systemtechnik - T99: TK 7875/2006 H
Middelhoek: Silicon sensors - I: T 50/1989 M
Sze: Semiconductor sensors - T99: T 50/1994 Sc
Fraden, Jacob - Handbook of modern sensors – I: T 50/1993 F

**Teaching and learning methods**

Lecture "Semiconductor Sensors", 3 SWS
Exercise “Semiconductor Sensors”, 1 SWS

**Workload**

Active Time: 45 h
Preparation and Evaluation: 105 h
Sum: 150 h

**Assessment**

The grade of the module will be the grade of the written exam. No prerequisites are necessary for exam registration

**Grading procedure**

The grade of the module will be the grade of the exam.

**Basis for**

Master thesis in the area of semiconductor sensors.
# Signal Theory

Modules referring to Technical Elective Subjects

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<tr>
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<td>Prof. Dr.-Ing. Robert Fischer</td>
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## Allocation of study programmes

- Elektrotechnik MSc, Kernmodul
- Informationssystemtechnik MSc, Kernmodul
- Communications Technology MSc, Optional technical module

## Recommended prerequisites

- signals and systems (discrete and continuous-time signals and systems)
- fundamentals of random variables and random processes (e.g., modul "Signale und Systeme")

## Learning objectives

The students will be able to operate with stochastic and deterministic signals. The concept of real and complex-valued stochastic processes and its characteristic quantities can be explained and applied. Spectral representations of processes can be formulated and discriminated. The students will be able to assess and devise mean-square estimators and appraise the fundamental limits. They can explain the characterization and approximation of deterministic signals. The students can operate with the description of signals in a signal space and are able to identify suited bases. Signals with structure can be characterized and categorized. The students can assess and design adequate reconstruction algorithm. The principles of localization and uncertainty can be explained and justified in the time-frequency plane. Adopted transformations can be assessed and discriminated.

## Syllabus

<table>
<thead>
<tr>
<th>Part I: Stochastic Signals</th>
</tr>
</thead>
<tbody>
<tr>
<td>* The Concept of Stochastic Processes</td>
</tr>
<tr>
<td>- basic concepts</td>
</tr>
</tbody>
</table>
characteristic quantities
- complex processes (equivalent baseband signals)
  * Spectral Representation and Spectral Estimation
    - innovations
    - Fourier and Karhunen-Loeve expansion
    - spectral estimation / periodogram
    - parameter estimation
  * Mean-Square Estimation
    - prediction and filtering
    - unbiased estimation
    - Cramer-Rao bound

Part II: Deterministic Signals
  * Approximation of Signals
    - sampling and equivalent sequences
    - series expansion
    - signal spaces and bases
    - signals with structure / low-dimensional bases
    - compressed sensing
  * Localization and Uncertainty
    - time-frequency plane
    - local (short-time) Fourier Spectrum / Wavelets

Literature

Teaching and learning methods
Lecture "Signal Theory", 3 SWS
Exercise "Signal Theory", 1 SWS

Workload
Active Time: 50 h
Preparation and Evaluation: 80 h
Self-Study: 50 h
Sum: 180 h

Assessment
The grade of the module will be the grade of the oral or written (depending on the number of participants) exam. No prerequisites are necessary for exam registration
Grading procedure

The grade of the module will be the grade of the exam.

Basis for
tbd
Using the Advanced Design System (ADS) in Electronic Design
Modules referring to Technical Elective Subjects

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<td>Coordinator</td>
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<tr>
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<td>Dr.-Ing. Christoph Bromberger</td>
</tr>
<tr>
<td>Recommended prerequisites</td>
<td>Bachelor-Level Analog Design Skills Some understanding of S-parameters is helpful</td>
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<tr>
<td>Learning objectives</td>
<td>The students gain an in-depth understanding of a significant analog simulation tool. They demonstrate their abilities to set up as well as to stream-line circuit simulations. Attendees employ ADS in high-frequency layout. They are used to ADS data structures and recognize ways to fully exploit their composition. Participants regularly scrutinize and critically judge their simulation results.</td>
</tr>
<tr>
<td>Syllabus</td>
<td>- The ADS project structure - Setting up, performing and simplifying schematics simulations - Using the data display - Understanding ADS data structures - Measurement Equations - Optimizing circuits with the help of ADS - (Semi-) automatic layout generation</td>
</tr>
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</table>
- 2d electromagnetic simulation
- Exporting the layout

| Literature | - ADS handbooks and tutorials
- A script is available for this lecture |

| Teaching and learning methods | Lecture “Using the Advanced Design System (ADS) in Electronic Design”, 2 SWS
Exercise “Using the Advanced Design System (ADS) in Electronic Design”, 1 SWS |

| Workload | Lectures: 10 h
Exercises: 30 h
Self-Study: 20 h
Homework: 30 h
Exam Preparation and Evaluation: 30 h
Sum: 120 h |

| Assessment | Usually written exam of 120 minutes, |

| Grading procedure | The grade of the module will be the grade of the exam. |

| Basis for | Masters Thesis in the area of biosensors. |
## Advanced Concepts of Communication Networks

Modules referring to Technical Elective Subjects

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No english version available yet.
Grading procedure

The grade of the module will be the grade of the exam. If the pertaining classes (Übungen) were attended and passed, a bonus is added to the grade (§ 17 (3a) General Framework). If the module examination is passed, the awarded grade is raised by one level; however, the upper limit is 1.0. It is not possible to raise a grade from 5.0 to 4.0.

Basis for

No english version available yet.
### Security and Privacy in Mobile Systems

Modules referring to Technical Elective Subjects

<table>
<thead>
<tr>
<th>Code</th>
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</tr>
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<tbody>
<tr>
<td>ECTS credits</td>
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<tr>
<td>Attendance time</td>
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<tr>
<td>Language of instruction</td>
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<tr>
<td>Duration</td>
<td>1 Semester</td>
</tr>
<tr>
<td>Cycle</td>
<td>each Summer Semester</td>
</tr>
<tr>
<td>Coordinator</td>
<td>No english version available yet.</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>No english version available yet.</td>
</tr>
<tr>
<td>Allocation of study programmes</td>
<td>No english version available yet.</td>
</tr>
<tr>
<td>Recommended prerequisites</td>
<td>No english version available yet.</td>
</tr>
<tr>
<td>Learning objectives</td>
<td>Participants know the major threats to security and privacy in mobile systems and know how to select and design suitable security mechanisms to protect from them. They are capable of analyzing the security of mobile communication systems and wireless networks on all layers. They can identify and analyze weaknesses and understand the presented attacks. Furthermore, students can propose and discuss possible security solutions to protect systems appropriately. Beyond, they understand the role and importance of location privacy and data protection in mobile systems and are familiar with the most important privacy enhancing technologies. Recent research topics in mobile systems security and privacy are discussed based on current scientific publications and by that the course also introduces students into the skills required to work with and discuss about scientific literature. The lab recapitulates the topics of the lecture with a more practical approach and also verifies learned knowledge in more theoretical assignments. At the same time, the lab also includes practical hands-on exercises where students have the opportunity to apply the learned knowledge on real mobile communication systems.</td>
</tr>
<tr>
<td>Syllabus</td>
<td>The course provides a deepened discussion of security and privacy for mobile systems. After an introduction into the specifics of mobile systems, the course continues with discussing specific security and privacy requirements. The lecture is composed of two main blocks. The first block introduces and discusses security issues and security mechanisms of established mobile communication systems</td>
</tr>
</tbody>
</table>
such as WLAN, cellular networks, Bluetooth, or RFID. In the second part, the lecture provides an introduction to current research topics related to mobile security and privacy, e.g., in the areas of mobile ad-hoc networks or VANETs.

<table>
<thead>
<tr>
<th><strong>Literature</strong></th>
<th>Selected literature and online resources.</th>
</tr>
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<tbody>
<tr>
<td><strong>Teaching and learning methods</strong></td>
<td>No english version available yet.</td>
</tr>
<tr>
<td><strong>Workload</strong></td>
<td>No english version available yet.</td>
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<tr>
<td><strong>Assessment</strong></td>
<td>The grade of the module will be the grade of the oral or written (depending on the number of participants) exam. No prerequisites are necessary for exam registration</td>
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<tr>
<td><strong>Grading procedure</strong></td>
<td>The grade of the module will be the grade of the exam. A grade bonus according to § 17 (3a) of the study and exam framework regulations is given if the exercise class is passed successfully.</td>
</tr>
<tr>
<td><strong>Basis for</strong></td>
<td>No english version available yet.</td>
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### Industrial Practical
Modules referring to Lab Courses

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<td><strong>ECTS credits</strong></td>
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<td><strong>Attendance time</strong></td>
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<tr>
<td><strong>Language of instruction</strong></td>
<td>german or english</td>
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<tr>
<td><strong>Duration</strong></td>
<td>1 Semester</td>
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<tr>
<td><strong>Cycle</strong></td>
<td>each Semester</td>
</tr>
<tr>
<td><strong>Coordinator</strong></td>
<td>Prof. Dr.-Ing. Dr. Wolfgang Minker</td>
</tr>
<tr>
<td><strong>Instructor(s)</strong></td>
<td>Prof. Dr.-Ing. Dr. Wolfgang Minker</td>
</tr>
</tbody>
</table>

#### Allocation of study programmes
- Bachelor of Science Elektrotechnik, Wahlpflichtmodul
- Master of Science Elektrotechnik, Wahlpflichtmodul
- Bachelor of Science Informationssystemtechnik, Wahlpflichtmodul
- Master of Science Informationssystemtechnik, Wahlpflichtmodul
- Communications Technology, M.Sc., Wahlpraktikum

#### Recommended prerequisites
Approval by the Industrial Internship office

#### Learning objectives
The Industrial Internship aims at gathering subject knowledge and experience in a private company. Furthermore, the Industrial Internship conveys insights into workaday life and prepares the student for entering his/her professional career.

#### Syllabus
The Industrial Internship comprises activities in the engineering field, notably in the area of Electronics Systems Engineering, Information and Communication Technology as well as at the margin between Computer Science and Engineering Sciences.

#### Literature
No

#### Teaching and learning methods
External internship in a private company, seminar with presentations.
| **Workload** | 9 weeks of practical activities  
10 minutes seminar presentation  
Participation in two additional seminar meetings  
Short report 15 pages maximum |
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Assessment</strong></td>
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<tr>
<td><strong>Grading procedure</strong></td>
<td>No english version available yet.</td>
</tr>
<tr>
<td><strong>Basis for</strong></td>
<td>-</td>
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Lab - Optoelectronics
Modules referring to Lab Courses

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<tr>
<td>Language of instruction</td>
<td>English / German</td>
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<tr>
<td>Duration</td>
<td>1 Semester</td>
</tr>
<tr>
<td>Cycle</td>
<td>each Summer Semester</td>
</tr>
<tr>
<td>Coordinator</td>
<td>Prof. Dr. Peter Unger</td>
</tr>
</tbody>
</table>
| Instructor(s)         | Prof. Dr. Ferdinand Scholz  
|                       | Prof. Dr. Peter Unger  
|                       | apl. Prof. Dr.-Ing. habil. Rainer Michalzik |
| Allocation of study programmes | Electrical Engineering, M.Sc., Elective Module  
|                       | Communications Technology, M.Sc., Optional Lab Course, Communications Circuits and Systems  
|                       | Electrical Engineering, M.Sc., Compulsory Subject Module, Microelectronics  
|                       | Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology |
| Recommended prerequisites | No english version available yet. |
| Learning objectives   | The students are able to explain the physics of commonly used optoelectronic devices and systems like optical waveguides, optical couplers, photodiodes, semiconductor lasers, tunable laser diodes, erbium-doped fiber amplifiers, optical fibers, and optical data transmission systems. They are able to prepare experiments to measure the basic device and system characteristics. They can extract the relevant data describing the device or system performance. The students are able to critically interpret their measurements and to write a scientifically profound illustrated report on their measurements and their interpretation. |
| Syllabus              | The laboratory course gives students an excellent opportunity to explore the exciting microworld of laser diodes, optical fibers, photodetectors, fiber amplifiers, and optical transmission systems. Seven half-day experiments are performed, which deal with the following topics:  
|                       | - Light propagation and coupling  
|                       | - Optical fiber characterization |
- Photodiodes
- Semiconductor lasers
- Tunable laser diodes
- Erbium-doped fiber amplifier
- Optical data transmission

<table>
<thead>
<tr>
<th>Literature</th>
<th>For each experiment, a detailed manuscript is provided which describes the theoretical background and guides through the experimental part.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching and learning methods</td>
<td>Labor “Optoelectronics”, 4 hours per week</td>
</tr>
<tr>
<td>Workload</td>
<td>Active Time: 28 h  Preparation and Evaluation: 84 h  Self-Study: 38 h  Sum: 150 h</td>
</tr>
<tr>
<td>Assessment</td>
<td>The award of the credit points for this ungraded module is based on regular attendance and the active participation in discussions. No prerequisites are necessary for exam registration.</td>
</tr>
<tr>
<td>Grading procedure</td>
<td>The module is not graded.</td>
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<td>Basis for</td>
<td>-</td>
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<tr>
<td><strong>LAB - RF Engineering</strong></td>
<td></td>
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<td>--------------------------</td>
<td>------------------------</td>
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<tr>
<td>Modules referring to Lab Courses</td>
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<table>
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<td><strong>Attendance time</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>Language of instruction</strong></td>
<td>English</td>
</tr>
<tr>
<td><strong>Duration</strong></td>
<td>1 Semester</td>
</tr>
<tr>
<td><strong>Cycle</strong></td>
<td>each Summer Semester</td>
</tr>
<tr>
<td><strong>Coordinator</strong></td>
<td>Dr.-Ing. Frank Bögelsack</td>
</tr>
</tbody>
</table>
| **Instructor(s)** | Prof. Dr.-Ing. Christian Waldschmidt  
Prof. Dr.-Ing. Christian Damm  
Dr.-Ing. Frank Bögelsack  
Dr.-Ing. Tobias Chaloun |

**Allocation of study programmes**

Communications Technology, M.Sc., Optional Lab Course

**Recommended prerequisites**

Participation at the lecture "Introduction to Microwave Engineering"

**Learning objectives**

After successful completion of this lab course the students are familiar with the most important measurement devices of the RF and microwave technique and to judge the results correctly, in the first place the vector network analyzer and the spectrum analyzer.  
They are familiar with measurements of analogue modulation schemes and the related topics like intermodulation products.  
They are able to apply a modern CAD system on linear circuits and systems.  
The students are able to determine the properties of phase-locked loops with help of modern measurement equipment.  
They are familiar with the measuring methods to determine scalar scattering parameters of both coaxial and planar circuits.  
They are able to measure antenna patterns and to evaluate the results critically.

**Syllabus**

The experiments deal with:  
1. Waves on transmission lines  
   - Characterization of unknown complex impedances by determination of the voltages  
   distribution on a TEM transmission line  
2. Modulation
- Basics of amplitude, frequency, and phase modulation, intermodulations
3. CAD (Analysis and optimization of linear circuits)
- Analysis and optimization of passive and active circuits using an up-to-date commercial microwave CAD tool (HPEESOF ADS)
4. Scalar scattering parameter measurements (coaxial)
- Introduction to coaxial measurement techniques, filters, impedance transformers
5. Planar circuits
- Characterization of glass fiber reinforced Teflon (PTFE) substrates by measurement of planar resonators, 4-port coupler
6. Frequency synthesis
- Oscillator, phase-locked loop, hold-in range, lough-in range, signal source analyzer, spectrum analyzer
7. Scalar scattering parameter measurements (waveguide)
- Introduction to waveguide measurement techniques, circulators, irises, inverter, filters
8. Antenna measurements
- Measurements of the radiation diagrams of a K-band horn antenna, a parabolic antenna, patch antennas, and a phased array antenna with a vector network analyser

Literature
Will be given in the written handouts of each experiment

Teaching and learning methods
Laboratory “RF Engineering”, 4 SWS

Workload
Preparation and Evaluation: 110 h
Active Time: 40 h
Sum: 150 h

Assessment
The credit points will be awarded once all phases of the course have been passed. The exact modalities will be announced at the beginning of the course.

Grading procedure
The module is not graded.

Basis for
-
Lab - Vector Network Analysis
Modules referring to Lab Courses

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<tr>
<th>Code</th>
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<td>Language of instruction</td>
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<td>Duration</td>
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</tr>
<tr>
<td>Cycle</td>
<td>each Winter Semester</td>
</tr>
<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Hermann Schumacher</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Prof. Dr.-Ing. Hermann Schumacher, Dr.-Ing. Andreas Trasser</td>
</tr>
<tr>
<td>Allocation of study programmes</td>
<td>Electrical Engineering, M.Sc., Elective Module, Communications Technology, M.Sc., Optional Lab Course, Information Systems Technology, M.Sc., Optional Lab Course</td>
</tr>
<tr>
<td>Recommended prerequisites</td>
<td>Basic knowledge of RF engineering</td>
</tr>
<tr>
<td>Learning objectives</td>
<td>Students describe the most important concepts of vectorial measurements at radio frequencies and assess key tradeoffs between diverse measurement techniques, choice of measurement parameters and error correction procedures. Students employ accurate calibration techniques and operate a vector network analyzer, distinguishing between frequency and time domain characterization techniques. They demonstrate time domain reflectometry using vector network analysis. Measurement results are interpreted and used to prepare equivalent circuit models of the measured components or to carry out deembedding of test fixtures of active devices.</td>
</tr>
<tr>
<td>Syllabus</td>
<td>Vector Network Analyzers (VNAs) are indispensable instruments in every RF laboratory as they provide the most common way to characterize network parameters (e.g. scattering parameters, impedance or admittance parameters, etc.) of electrical networks (power amplifiers, filters and other n-port networks). As a result, understanding the fundamental principles of VNA measurements belongs to the essential knowledge of an RF engineer. The main goal of this laboratory</td>
</tr>
</tbody>
</table>
course is to introduce students the fundamental RF VNA measurement techniques, principles, manipulations and measurement procedures. Throughout different measurement exercises, this course will provide students firm grasp and validation of the common theory gained in previous electro-technical courses. List of experiments:
- R, L, C measurements
- Measurements on a bias tee (RF/DC coupler)
- Measurements on a radio frequency filter
- Measurements on a semiconductor diode
- De-embedding procedures and measurements of FET and BJT transistors in a test fixture
- Measurements on coaxial cables (dielectric constant, length)
- Time domain reflectometry: measurements on passive components, localizations of faults in transmission lines
- Time domain reflectometry: measurements on passive
- Introduction to the time gating as a deembedding technique

<table>
<thead>
<tr>
<th>Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scattering parameter tutorial (Prof. Schumacher, provided online); detailed descriptions for each experiment</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Teaching and learning methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory “Vector Network Analysis”, 3 SWS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Workload</th>
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<tbody>
<tr>
<td>Active Time: 29 h</td>
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<td>Preparation and Evaluation: 121 h</td>
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<table>
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<tr>
<th>Assessment</th>
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</thead>
<tbody>
<tr>
<td>The credit points will be awarded once all phases of the course have been passed. The exact modalities will be announced at the beginning of the course.</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Grading procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>The module is not graded.</td>
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<table>
<thead>
<tr>
<th>Basis for</th>
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</thead>
<tbody>
<tr>
<td>Master thesis with topics requiring vector network analysis</td>
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### Project Advanced Analog and Mixed-Signal CMOS Circuit Design

Modules referring to Lab Courses

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<td>English/German</td>
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<td>Duration</td>
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</tr>
<tr>
<td>Cycle</td>
<td>each Semester</td>
</tr>
<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Maurits Ortmanns</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Prof. Dr.-Ing. Maurits Ortmanns</td>
</tr>
</tbody>
</table>

#### Allocation of study programmes

- Electrical Engineering, M.Sc., Praxismodul
- Information Systems Technology, M.Sc., Praxismodul
- Communications Technology, M.Sc., Optional Lab Course, Track: Communications Circuits and Systems (CCS)

#### Recommended prerequisites

Course and above average exam in "Integrated Analog Circuits/Integrierte Analogschaltungen" or proven equivalent knowledge. Highly successful participation in "Project - Analog CMOS Circuit Design". Recommended is the course and above average exam in "Circuit Design in Nanometer CMOS". Depending on the project focus it is recommended to have successfully completed the "Project - Design of Integrated Circuits". A written application including a proposed outline of the design goals is required from the student, and it will be evaluated for an admission to the project.

#### Learning objectives

The students are able to describe the overall flow of the design of mixed-signal integrated circuits in deep-submicron CMOS technologies. They can accurately operate a complex circuit simulator tool and understand its in depth functions. The students are able to identify the performance determining circuit parts in an analog CMOS design. They can compare different possibilities to improve a given analog circuit by means of selecting different architectures or alternative circuit implementations. The students are able to layout basic circuit blocks. They defend their circuit selection and circuit design against questions and criticism. The students now how to perform a mixed-signal simulation and discuss the partitioning of digital vs. analog functionality of a design.
**Syllabus**

Design project based on the "Project - Analog CMOS Circuit Design" with a content upon written project proposal and mutual agreement on the same. Thereby, project proposals might include the improvement of the circuit performance of the previous design project, the reduction of power consumption of the overall previously designed circuit, the transistor level layout of the designed project. Project proposals can also include follow-up projects e.g. considering A/D converters, differential amplifiers, mixed-signal circuits including digital co-design, RF CMOS, or others.

**Literature**

- "Project - Advanced Analog and Mixed-Signal CMOS Circuit Design", 3 SWS

**Teaching and learning methods**

"Project - Advanced Analog and Mixed-Signal CMOS Circuit Design", 3 SWS

**Workload**

Active Time: 80 h  
Preparation and Evaluation: 40 h  
Sum: 120 h

**Assessment**

- Successful completion of all given design and layout tasks  
- Submission of a design report  
- Passing a mid-term and a final Q&A on the designed circuit

**Grading procedure**

The module is not graded.

**Basis for**

-
### Project Dialogue Systems
 Modules referring to Lab Courses

<table>
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<tr>
<th>Code</th>
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<tr>
<td>Cycle</td>
<td>each Semester</td>
</tr>
<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Dr. Wolfgang Minker</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Prof. Dr.-Ing. Dr. Wolfgang Minker</td>
</tr>
</tbody>
</table>

#### Allocation of study programmes
- Electrical Engineering, M.Sc., Elective Module, Engineering Sciences Technology
- Electrical Engineering, M.Sc., Optional Module, Communication and System Technology
- Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology
- Electrical Engineering, M.Sc., Optional Module, General Electrical Engineering
- Communications and Computer Engineering, M.Sc., Optional Module, Communications Technology, M.Sc., Optional Lab Course
- Computer Science and Media, B.Sc., Application Subject, Sprachdialogische Benutzerschnittstellen
- Computer Science and Media, M.Sc., Projekt
- Computer Science and Media, M.Sc., Application Subject, Dialogsysteme

#### Recommended prerequisites
No prerequisites from other lectures required. Some programming (C/C++, Java) and operating systems (Unix/Linux) knowledge would be helpful.

#### Learning objectives
The student shows a practical understanding of multimodal spoken dialogue systems technology. He is aware of the the interdisciplinarity of the research field. He applies his acquired knowledge through project-oriented practical work.

#### Syllabus
Research in multimodal spoken language dialogue systems is performed on the basis of end-to-end systems including components for acoustic processing, speech signal analysis, recognition, spoken natural language understanding, dialogue processing and speech synthesis. In the framework of this component development several individual topics are proposed as practical studies. They may depend on the current development status of the prototype system.

<table>
<thead>
<tr>
<th>Literature</th>
<th>To be distributed during the project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching and learning methods</td>
<td>Projekt “Dialogue Systems”, 6 SWS</td>
</tr>
<tr>
<td>Workload</td>
<td>Project “Dialogue Systems”, 6 SWS</td>
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<tr>
<td></td>
<td>Estimation of effort: Active Time: 192 h</td>
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<td></td>
<td>Preparation and Evaluation: 48 h</td>
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<td>Assessment</td>
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<tr>
<td>Grading procedure</td>
<td>The module is not graded.</td>
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<tr>
<td>Basis for</td>
<td>Graduate theses in the area of spoken dialogue systems technology</td>
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# LAB - Laboratory Automation

Modules referring to Lab Courses

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<td>Cycle</td>
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<tr>
<td>Coordinator</td>
<td>Dr.-Ing. Andreas Trasser</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Dr.-Ing. Andreas Trasser, Dr. Václav Valenta</td>
</tr>
</tbody>
</table>

### Allocation of study programmes

- Electrical Engineering, M.Sc., Elective Module, Engineering Sciences
- Communications Technology, M.Sc., Optional Lab Course, Microelectronics

### Recommended prerequisites

- Fundamental knowledge of:
  - Physics of semiconductor devices
  - RF engineering and twoport parameters
  - Programming (structuring problems and implementation in a programming language)

### Learning objectives

Students recognize and describe the electrical and logical principles of operation of the GPIB bus. They are able to develop simple programs to control measurement equipment, and to assist in the interpretation of measurement results. Students discover the functional principles of sampling oscilloscopes through experiments, and use it to conduct measurements on transmission lines. They identify the operational concepts of vector network analyzers, including error correction techniques, measure scattering parameters of microwave transistors, and discriminate the results from those obtained from an equivalent circuit. Students recognize fundamental noise measurement techniques, apply them to active devices in the frequency domain, and interpret them, interpreting differences between their measurements and theoretical models.

### Syllabus

Students will get a practical view of special aspects of laboratory characterization techniques, with an application emphasis on the characterization of semiconductor devices. The experiments treat the DC characterization of
semiconductor devices using source measure-units and GPIB control, noise parameter measurements, scattering parameter characterization, equivalent-time sampling oscillography, and time-domain reflectometry.

**Literature**

Script describing experiments including theoretical background

**Teaching and learning methods**

Laboratory “Laboratory Automation”, 4 SWS

**Workload**

Active Time: 26 h
Preparation and Evaluation: 124 h
Sum: 150 h

**Assessment**

The award of the credit points for this ungraded module is based on regular attendance and active participation in discussions. No prerequisites are necessary for exam registration.

**Grading procedure**

The module is not graded.

**Basis for**

Master thesis research involving electrical characterization techniques, especially related to semiconductor devices and active microwave components
Project - Radio Frequency Electronics
Modules referring to Lab Courses

Code 8822271563
ECTS credits 5
Attendance time 3
Language of instruction English
Duration 1 Semester
Cycle each Semester
Coordinator Prof. Dr.-Ing. Hermann Schumacher
Instructor(s) Prof. Dr.-Ing. Hermann Schumacher
Dr.-Ing. Andreas Trasser

Allocation of study programmes
Electrical Engineering, M.Sc., Elective Module
Communications Technology, M.Sc., Optional Lab Course

Recommended prerequisites
Radio Frequency Engineering; recommended additionally: High Frequency Microsystems or Monolithic Microwave ICs in High-Speed Systems

Learning objectives
Students analyze an initially incomplete set of technical requirements. They discuss the requirements, identifying missing information and break down the project into individual tasks. Recognizing the necessary radio frequency electronics concepts to be employed, they sketch a solution path and design the necessary components using off-the-shelf components, appraising issues like availability and bill of materials. A prototype is finally fully developed, constructed and assessed. Along the way, common pitfalls of working in projects, and proven project management issues are reviewed.

Syllabus
This project will realize a different radio frequency subsystem each year. The docents will describe a set of requirements, students will then set out to develop a system concept, research suitable off-the-shelf components, perform the complete design, and finally build and characterize a prototype. A written report describing design decisions, all data relevant to replicate the prototype, and characterization results will finalize the project. Docents will act as design consultants; additionally, short lectures will introduce important project management approaches such as Scrum, students will use simple project management techniques during the design and implementation phases.
### Literature
- M. Hoffmann, Hochfrequenztechnik - ein systemtheoretischer Zugang (in German)
- Lecture notes for RF Engineering
- David Rutledge, The Electronics of Radio
- S. Prasad/H. Schumacher/A. Gopinath, High-Speed Electronics and Optoelectronics (Chapter 5)

### Teaching and learning methods
- Project "Radio Frequency Electronics", Introductory lectures, 1 SWS
- Project "Radio Frequency Electronics", design consulting sessions; guided design exercises; guided characterization exercises, 2 SWS

### Workload
- Active Time: 60 h
- Preparation and Evaluation: 60 h
- Self-Study: 30 h
- Sum: 150 h

### Assessment
The award of the credit points for this ungraded module is based on regular attendance, completion of an assignment (presentation and paper) and the active participation in discussions. No prerequisites are necessary for exam registration.

### Grading procedure
The module is not graded.

### Basis for
Master thesis with radio frequency electronics content
Laboratory Semiconductor Technology
Modules referring to Lab Courses

Code 8822270446

ECTS credits 5

Attendance time 4

Language of instruction english and german

Duration 1 week Semester

Cycle each Semester

Coordinator Jun.-Prof. Dr.-Ing. Steffen Strehle

Instructor(s) Dr. Wolfgang Ebert

Jun.-Prof. Dr.-Ing. Steffen Strehle

Allocation of study programmes
- Electrical Engineering, M.Sc., Elective Module
- Communications Technology, M.Sc., Optional Lab Course, Communications Circuits and Systems

Recommended prerequisites
Lecture "Semiconductor Technology" or "Modern Semiconductor Devices"

Learning objectives
Students discover how to work under clean-room conditions, recognizing how different technology steps may be combined to produce electron devices. Furthermore, they practice to operate complex semiconductor-technology equipment. Participants modify the surface of semiconductor wafers employing thermal evaporation of different metals like Aluminum and Gold. They create microstructured contacts by photo-lithography. Test structures, diodes, and transistors are evaluated using fundamental current-voltage and capacitancevoltage measurements. The students evaluate the influence of scaling parameters (geometry, size) on the electrical behaviour of the devices (output- and transfer-characteristics).

Syllabus
Aim of this lab course is the fabrication of field-effect-transistors (GaAs-MESFET’s) and their electrical characterization. The lab course takes place in a cleanroom facility specifically equipped for education. Main focuses this lab course are:
- deposition of metals by evaporation
- patterning of contacts by optical lithography
- patterning of contacts by wet etching
- manufacturing of ohmic- and Schottky contacts
- electrical characterization of the fabricated devices

**Literature**

**Teaching and learning methods**
Labor “Semiconductor Technology”, 4 SWS

**Workload**
Active Time: 28 h
Preparation and Evaluation: 122 h
Sum: 150 h

**Assessment**
Successful completion requires fulfillment of the following criteria: successful participation in the lab, active participation during the colloquium, submission and correction (where applicable) of the experiment notes.

**Grading procedure**
not graded

**Basis for**
Master's Thesis
Laboratory Microcomputers
Modules referring to Lab Courses

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<td>Cycle</td>
<td>each Semester</td>
</tr>
<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Stefan Wesner</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Prof. Dr.-Ing. Stefan Wesner</td>
</tr>
</tbody>
</table>

Allocation of study programmes: Communications Technology, M.Sc., Optional practical module

Recommended prerequisites: General knowledge of electrical engineering, digital technology, programming.

Learning objectives: The students are able to analyze the given task by means of a project specification. They can identify the different functional units of a specified microcontroller based control module, subdivide and convert them into a schematic using analog and digital circuitry. They also design a printed circuit board layout using a CAD tool and assemble the board themselves. During the design phase they also examine datasheets and choose several electronic parts for their circuit. Additional to the hardware design and assembly the students can separate their software design into a hardware abstraction layer (HAL) and a main program logic and illustrate it in a model by choosing suitable diagrams and state-charts. The students can write software using the programming language ‘C’. Programming and testing the board is done by operating a special integrated development environment (IDE) and a software tool for testing the CAN-Bus communication. The students solve errors in hardware and software by iteratively modifying and testing their code using a debugger tool and devices like multimeters and oscilloscopes. At the end of the lab the students demonstrate their working module and finally write a complete documentation that describes all work that has been done.

Syllabus: This lab course introduces the student to various applications of microcomputers and to the challenges faced in realizing those applications. The focus is on embedded systems, different kinds of microcontrollers, sensors and actuators,
and on bus communication. The students work on a common project, to which each team contributes an almost independently working module. The project itself is a sorting facility consisting of 10 motors and about 30 primarily digital sensors, like push-button switches or light barriers. The sorting facility classifies packages of different shapes, colors and heights and sorts them according a user’s request. Finally, a robot takes the sorted packages and stacks them up. The sorting facility is constructed with Fischertechnik elements. It is provided in a fully operational state, with wired actuators and sensors, but without electric control. The latter must be designed and implemented by the students. To each team a module within the overall system is assigned. The modules consist of an actuator, several sensors, a microcontroller, a CAN controller and other electronic parts needed to realize the board. With the help of the CAD software EAGLE, a circuit diagram and board layout have to be developed. After assembling the board and testing it, the team programs the microcontroller with a C program. Communication between modules and the main control unit is carried out by the field bus Controller Area Network (CAN). To enable user inputs and to display status information, an embedded web-server and a webclient are used. The main control unit and the web-server are on separate boards provided by the course staff. Each team receives a module consisting of an actuator, several sensors, a PIC microcontroller, a CAN controller and other electronic parts. With the help of the CAD software EAGLE, a circuit diagram and board layout have to be developed. After assembling the board and testing it, the team programs the microcontroller. Communication between modules and the main control unit is carried out by the field bus Controller Area Network (CAN). To enable user inputs and to display status information, an embedded web-server and a web-client are used. The main control unit and the web-server are on separate boards with "high end" Infineon C167 microcontrollers and the real-time operating system EUROS.

**Literature**

Background information and documentation provided in the course booklet.

**Teaching and learning methods**

Labor “Microcomputers”, 4 SWS

**Workload**

Active Time: 120 h

Preparation and Evaluation: 30 h

Sum: 150 h

**Assessment**

The credit points will be awarded once all phases of the course have been passed. The exact modalities will be announced at the beginning of the course.

**Grading procedure**

The module is not graded.

**Basis for**

-
## Communication Networks

### Modules referring to Lab Courses

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</tr>
<tr>
<td>Cycle</td>
<td>each Winter Semester</td>
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<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Stefan Wesner</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Prof. Dr.-Ing. Stefan Wesner</td>
</tr>
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### Allocation of study programmes
- MSc Elektrotechnik, optional module;
- MSc Informationssystemtechnik, optional module;
- MSc Communications Technology, optional practical course;

### Recommended prerequisites
Basic knowledge of computer networks from the lecture on Data Centre Networks Architecture and Protocols or similar courses (e.g. “Grundlagen der Rechnernetze”) is necessary. The students should be able to describe the basic architecture of networks using models such as ISO/OSI. Basic characteristics of typical local network protocols (Ethernet, TCP/IP, DHCP etc.) should be known and the student should be able to name them and their typical application areas.

### Learning objectives
After the course, the students will be able to design and configure computer networks on their own. The participants will have learned to compare different computer systems with respect to energy consumption and performance. The students will have the ability to assess which computer systems are suitable for which problem cases and apply them to new application domains. The participants will furthermore have learned to configure, compare and analyse different computer systems for their usability in a computer cluster, both on soft- and hardware-level. They will also be able to program small cluster applications.

### Syllabus
The course provides deeper insights into the area of communication networks, with a specific focus on IP-based network protocols. Further to this, design and architecture of computer cluster will be discussed. Diverse platforms are available to give the students a better insight into the differences and key characteristics of computer systems. With these platforms the students will be able to set up different systems themselves and examine them for their suitability for different usage and problem types.
<table>
<thead>
<tr>
<th>Literature</th>
</tr>
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<tbody>
<tr>
<td>- George Coulouris, Jean Dollimore, Tim Kindberg and Gordon Blair: Distributed Systems: Concepts and</td>
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<tr>
<td>Design, 5th edition</td>
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<tr>
<td>- Tanenbaum, Andrew S.: Computer Networks</td>
</tr>
<tr>
<td>- Comer, Douglas E: Internetworking with TCP/IP</td>
</tr>
<tr>
<td>- Michel Dubois, Murali Annavaram, Per Stenström: Parallel Computer Organization and Design</td>
</tr>
<tr>
<td>- Stevens Richard: TCP/IP Illustrated</td>
</tr>
<tr>
<td>- Request for Comments (RFC) Pages on <a href="http://www.ietf.org">www.ietf.org</a></td>
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<table>
<thead>
<tr>
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<table>
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<tr>
<th>Workload</th>
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<tbody>
<tr>
<td></td>
<td>preparation: 90 h</td>
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<tr>
<td></td>
<td>total: 150 h</td>
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</table>

| Assessment                   | The award of the credit points for   |
|-------------------------------| this ungraded module is based on     |
|                               | regular attendance and active        |
|                               | participation in discussions. All of  |
|                               | the experiments have to be           |
|                               | successfully completed, including    |
|                               | the correspondent protocols with the |
|                               | preparation questions.               |

| Grading procedure            | The module is not graded.            |

| Basis for                    | n/a                                  |
# Project Analog CMOS Circuit Design

**Modules referring to Lab Courses**

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<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Maurits Ortmanns</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Prof. Dr.-Ing. Maurits Ortmanns</td>
</tr>
</tbody>
</table>

## Allocation of study programmes
- Electrical Engineering, M.Sc., Elective Module,
- Electrical Engineering, M.Sc., Elective Module, Communication and System Technology
- Electrical Engineering, M.Sc., Elective Module, Microelectronics
- Electrical Engineering, M.Sc., Optional Module, Automation and Energy Technology
- Information Systems Technology, M.Sc., Elective Module
- Communications Technology, M.Sc., Optional Lab Course, Communications Circuits and Systems
- Embedded Systems, M.Sc., Application Subject, Mixed Signal Systems

## Recommended prerequisites
- Course and exam in Analog CMOS Circuit Design or proven equivalent knowledge.
- Written application for the project.

## Learning objectives
The students are able to describe the overall flow of the design of integrated circuits in deep-submicron CMOS technologies. They can accurately operate a complex circuit simulator tool. The students are able to apply hand calculation to extract basic design specifications for the operating point and transistor scaling. They compose and model toplevel system design and are able to setup dc, ac, transient and monte carlo simulations. They can give examples for various structures for operating point generation and are able to compare them. The students can distinguish differential amplifier structures and explain their behaviour.
and operation. They can further design, simulate and evaluate differential amplifier structures. The students are able to explain an electronic system, subdivide into and analyze the functionality of the subblocks, and theoretically as well as experimentally explain the transistor level design.

**Syllabus**

Yearly design project including
- Design of Biasing Networks
- Design of multistage Differential Amplifier
- Design of bandgap reference circuits
- Design of high-speed comparators
- Design of a Switched Capacitor Integrator
- Design of an Analog-Digital-Converter
- Toplevel design
- Layout of the modules

**Literature**

- Handouts for the various modules of the project and multimedia learning tool for the design environment
- Allen P.E., Holberg, D.R. “CMOS Analog Circuit Design”, Oxford University Press
- Baker, R.J. “CMOS Circuit Design, Layout, and Simulation”, Wiley

**Teaching and learning methods**

Project “Analog CMOS Circuit Design”, 5 SWS

**Workload**

Active Time: 60 h

Preparation and Evaluation: 120 h

Sum: 180 h

**Assessment**

The credit points will be awarded once all phases of the course have been passed. The exact modalities will be announced at the beginning of the course.

**Grading procedure**

The module is not graded.

**Basis for**

-
Project - Design of Integrated Systems
Modules referring to Lab Courses

Code 8822270428

ECTS credits 6

Attendance time 5

Language of instruction English (Winter Term) / German (Summer Term)

Duration 1 Semester

Cycle each Semester

Coordinator Prof. Dr.-Ing. Maurits Ortmanns

Instructor(s) Prof. Dr.-Ing. Maurits Ortmanns
Dr.-Ing. Joachim Becker

Allocation of study programmes
- Electrical Engineering, M.Sc. (FSPO 2014), Practical Module
- Electrical Engineering, M.Sc. (FSPO 2012), Elective Module
- Electrical Engineering, M.Sc. (FSPO 2012), Communication and SystemTechnology, Elective Module
- Electrical Engineering, M.Sc. (FSPO 2012), Automation and Energy Technology, Optional Module
- Information Systems Technology, M.Sc. (FSPO 2012), Elective Module
- Information Systems Technology, M.Sc. (FSPO 2014), Practical Module
- Communications Technology, M.Sc. (FSPO 2015/2017), Track Communications Engineering, (In-Depth) Practical Module
- Communications Technology, M.Sc. (FSPO 2015/2017), Track Communications Circuits and Systems, (In-Depth) Practical Module

Recommended prerequisites
- Good programming skills in one programming language
- Background in binary number systems, especially two's complement (BK2) number system
- Representation of fractional numbers with BK2
- Binary addition, binary subtraction and binary multiplication for integer and fractional numbers
- Pipelining
- Digital logic gates (transistor level is not required)
- Functionality of registers, multiplexers
- Functionality of adders, comparators, counters

Learning objectives
The students are able to describe the overall design flow of integrated digital circuits and perform the task based on a functional description towards a
hardware realization on programmable logic devices. They are able to analyse a circuit specification and to realize this as a hierarchical model on basis of the hardware description language Verilog. They are able to program the Verilog code, such that the hierarchical model is met. The students are able to operate a simulator for Verilog code, to set up a simulation for their code, to run such simulations and to evaluate the results. The students understand how to debug their code upon the simulation results. The students can subdivide the task into subblocks, are able to perform a task schedule and to fulfill the workpackages upon such schedule.

<table>
<thead>
<tr>
<th>Syllabus</th>
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</thead>
<tbody>
<tr>
<td>- basic knowledge of the hardware description language Verilog</td>
</tr>
<tr>
<td>- synthesizable subset of Verilog</td>
</tr>
<tr>
<td>- design rules for synthesizable Verilog</td>
</tr>
<tr>
<td>- complete design flow from specification to hardware realization</td>
</tr>
<tr>
<td>The contents are imparted using a small example project. This project has to be completed by the students by the end of the semester.</td>
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<table>
<thead>
<tr>
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<tr>
<td>Documents covering software and Verilog are provided.</td>
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<td>Project “Design of Integrated Systems”, 5 SWS</td>
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<td>Group Work: 60 h</td>
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### Additive Key Qualifications

Modules referring to Compulsory German

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<td>Recommended prerequisites</td>
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German as a Foreign Language for Communications Technology
Modules referring to Additive Key Qualifications

Code 8822271739

ECTS credits 8

Attendance time keine Angaben

Language of instruction English/German

Duration Semester

Cycle keine Angaben

Coordinator Prof. Robert Fischer

Instructor(s) Lecturer Language Center, Ulm University

Allocation of study programmes 1\textsuperscript{st}, 2\textsuperscript{nd} semester MSc Communications Technology

Recommended prerequisites Intensive German course offered by the Language Center before start of the 1\textsuperscript{st} semester. Three to four courses on different levels.

German courses I, II are based one on the other.

Learning objectives Development of language skills: Listening, speaking, reading, writing.

Each semester three to four courses with different levels run in parallel.

Language levels: Groups are partly heterogeneous.

German courses 1 and 2 are based one on the other.

German for CT I:

Possible levels: Working on A1.1, A1.2, A2.1, A2.2, B1.1, B1.2 (depending on entry level).

German for CT II:

General Description of the Language levels (CEFR):

**Level A1 (A1.1 + A1.2), CEFR** (Common European Framework of Reference for Languages)

Students should be able to

- understand and use familiar, everyday expressions and very simple sentences, which relate to the satisfying of concrete needs.
- introduce him/herself and others as well as ask others about themselves — e.g. where they live, who they know and what they own — and can respond to questions of this nature.
- communicate in a simple manner if the person they are speaking to speaks slowly and clearly and is willing to help.

Comment: To reach this level, candidates need to have completed between up to 200 45-minute units of teaching, depending on their previous knowledge and learning requirements (Goethe Institut).

**Level A2 (A2.1 + A2.2), CEFR**

Students should be able to

- understand sentences and commonly used expressions associated with topics directly related to his/her direct circumstances (e.g. personal information or information about his/her family, shopping, work, immediate surroundings).
- make him/herself understood in simple, routine situations dealing with a simple and direct exchange of information on familiar and common topics.
- describe his/her background and education, immediate surroundings and other things associated with immediate needs in a simple way.

Comment: To reach this level, candidates need to have completed between 200 and 350 45-minute units of teaching, depending on their previous knowledge and learning requirements (Goethe Institut).

**Level B1 (B1.1 + B1.2), CEFR**

Students should be able to

- understand the main points when clear, standard language is used and the focus is on familiar topics associated with work, school, leisure time, etc.
- deal with most situations typically encountered when travelling in the language region.
- express him/herself simply and coherently regarding familiar topics and areas of personal interest.
- report on experiences and events, describe dreams, hopes and goals as well as make short statements to justify or explain his/her own views and plans.
Comment: To reach this level, candidates need to have completed between 350 and 650 45-minute units of teaching, depending on their previous knowledge and learning requirements (Goethe Institut).

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<th>Syllabus</th>
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<td></td>
<td>- vocabulary training</td>
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<tr>
<td></td>
<td>- grammar training</td>
</tr>
<tr>
<td></td>
<td>- development of communication skills</td>
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<th>Literature</th>
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<tr>
<td></td>
<td>Menschen A1 (Deutsch als Fremdsprache), textbook &amp; workbook</td>
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<tr>
<td></td>
<td>(A1.1 = chapter 1-12, A1.2 = chapter 13-24)</td>
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<tr>
<td></td>
<td>Menschen A2 (Deutsch als Fremdsprache), textbook &amp; workbook</td>
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<tr>
<td></td>
<td>(A2.1 = chapter 1-12, A2.2 = chapter 13-24)</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>(B1.1 = chapter 1-12, B1.2 = chapter 13-24)</td>
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<tr>
<td></td>
<td>(Sicher B1+ (Deutsch als Fremdsprache), textbook &amp; workbook, chapter 1-8)</td>
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| Teaching and learning methods | Communication, grammar and vocabulary training in class |

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<th>Workload</th>
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<td>- 56 h exercise (presence)</td>
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<td></td>
<td>- 22 h revision homework</td>
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<td></td>
<td>- 12 h exam preparation</td>
</tr>
<tr>
<td>Deutsch für Communications Technology II (WS): Total 90 h</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 64 h exercise (presence)</td>
</tr>
<tr>
<td></td>
<td>- 14 h revision, homework</td>
</tr>
<tr>
<td></td>
<td>- 12 h exam preparation</td>
</tr>
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</table>

| Assessment             | The credit points will be awarded once the two written exams have been passed. No prerequisites are necessary for exam registration. |

| Grading procedure       | The grade of the module will be the arithmetic mean of the respective grades of the partial module exams weighted by their credit points. |

| Basis for               | - |
## Master's Thesis

Modules referring to Master Thesis

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<tr>
<td>Attendance time</td>
<td>keine Angaben</td>
</tr>
<tr>
<td>Language of instruction</td>
<td>English</td>
</tr>
<tr>
<td>Duration</td>
<td>1 Semester</td>
</tr>
<tr>
<td>Cycle</td>
<td>each Semester</td>
</tr>
<tr>
<td>Coordinator</td>
<td>Prof. Dr.-Ing. Maurits Ortmanns (Dean of Student Affairs)</td>
</tr>
<tr>
<td>Instructor(s)</td>
<td>Primary supervisor of thesis</td>
</tr>
<tr>
<td>Allocation of study programmes</td>
<td>Communications Technology, M.Sc., Thesis</td>
</tr>
<tr>
<td>Recommended prerequisites</td>
<td>Desired: specialized elective modules in the scientific area of the thesis</td>
</tr>
</tbody>
</table>
| Learning objectives   | Acquisition and demonstration of the following competencies:  
- Independent treatment of complex problems, using the skills acquired in the Master’s program as well as established scientific methods and knowledge, within a pre-set time frame  
- Setup of a project plan for the Master’s thesis, including assessment of progress using a continuously updated milestone plan  
- Compilation of a thesis in compliance with the established principles of scientific writing  
- Presentation of scientific results in comprehensible form before an audience of peers, including scientific discussion |
<p>| Syllabus              | dependent on topic |
| Literature            | dependent on topic |
| Teaching and learning methods | Masterarbeit Selection of a suitable topic at one of the institutes of the faculty, or exceptionally also outside of the faculty (requires permission of the Examination Committee); research of scientific literature, design work and/or experimental work dependent on topic; consultation with the guiding assistants and the primary supervisor |</p>
<table>
<thead>
<tr>
<th><strong>Workload</strong></th>
<th>Active Time: 10 h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sum: 900 h</td>
</tr>
</tbody>
</table>

| **Assessment** | Written thesis and final presentation |

| **Grading procedure** | Grading of results obtained, written thesis, and final presentations by two reviewers in accordance with rules and regulations |

| **Basis for** | - |

Master of Science Communications Technology