UNIKASSEL VERSITÄT | ELECTRICAL ENGINEERING COMPUTER SCIENCE

Module Handbook of the M.Sc. Programme

Electrical Communication Engineering (ECE)

at the Faculty of Electrical Engineering and Computer Science
University of Kassel

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Table of Contents

1 Overview of ECE Modules

The modules of the M.Sc. Electrical Communication Engineering (ECE) programme can be classified by

- **status** (basic, elective) and
- **type** (regular, project, thesis).

The classification is shown in Fig. 1 together with the relative workload in the different modules being

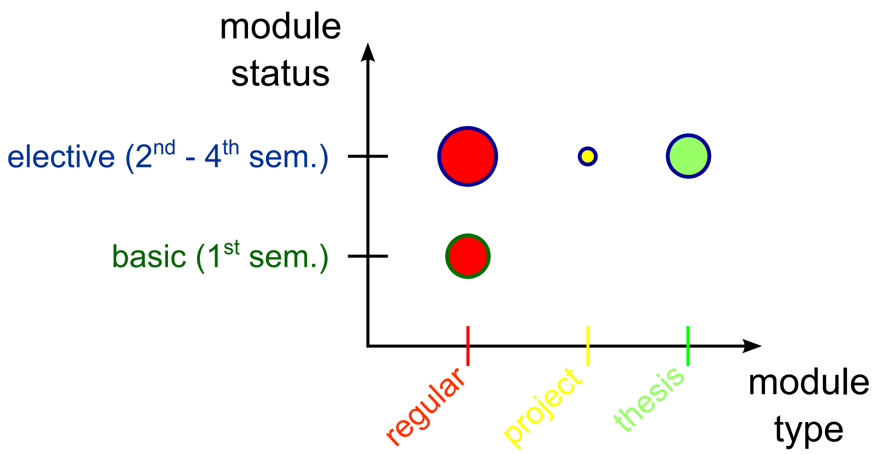

Fig. 1: Classification of modules according to status and type and workload representation.

represented as the area of the circles. Subsequently, the module status (cf. ordinate in Fig. 1) and the module type (cf. abscissa in Fig. 1) are explained.

Module status: Basic modules are compulsory and taught in the first semester. They serve for both equalizing different entry level skills and preparing students for subsequent elective. Basic modules are abbreviated by a 'B' in module codes (cf. module descriptions in Sect. 2 – Sect. 8).

Elective modules comprise all modules in the second, third and fourth semesters. Even though there are constraints in the selection of modules (cf. Article 8 of the exam regulations "Fachprüfungs-ordnung für den Masterstudiengang „M.Sc. Electrical Communication Engineering" (ECE) des Fachbereichs Elektrotechnik/Informatik der Universität Kassel"), elective modules can be selected from a certain group of modules.

Module type: The elective modules can be of different types, namely regular, project and thesis types. Here, a regular module may contain different course types, namely lectures (lec), exercises (ex), laboratories (labs) and seminars (sem). Note that the basic modules are only of regular type so that no labelling of the module type is contained in the basic module codes. At the same time, all elective modules have module codes containing the module type.

This gives rise to the following naming convention. The module name, for example *Fundamentals in Digital Communications B1a*, is made up by the module title (here: *Fundamentals in Digital Communications*) to associate corresponding contents with the module and the module code (here: *B1a*). In turn, the module code consists of the three attributes <CATEGORY NO LETTER>:

- CATEGORY is 'B' for basic, 'R' for regular, 'P' for project and 'T' for thesis modules
- NO is a consecutive natural number to uniquely identify the module
- LETTER characterizes the version of the module, where 'a' stands for the first version of the module, 'b' for a following version of the same module upon a possible change etc.

All basic modules comprising in total 30 European Credit Transfer System credits (ECTS) are presented in Tab. 1 and listed in Sect. 2. Basic modules are offered in both winter and summer semesters.

Tab. 1: List of basic modules and granted ECTS

Module name	ECTS
Fundamentals in Digital Communications B1a	3
Fundamentals in Optoelectronics B2a	6
Engineering Mathematics B3a	9
Scientific Publishing B4a	6
Social Communication B5a	6

During the second and the third semesters, each student is to select elective modules granting 60 ECTS including the project module granting 6 ECTS. The fourth semester is foreseen for the thesis module granting 30 ECTS.

Subsequently, the different modules are described. Sect. 2 contains the descriptions of the basic modules. Sect. 3 – Sect. 8 describe elective modules in

- Wireless Communications
- Electromagnetics
- Hardware Components for Communication Systems
- Microwaves
- Optoelectronics
- Enabling Technologies for Communication Systems.

Note that the descriptions in Sect. 4 are not finalized yet due to reasons mentioned at the beginning of the corresponding section.

2 Basic Modules

2.1 Fundamentals in Digital Communications

<table>
<tr><td>module code</td><td colspan="5">B1a</td></tr>
<tr><td>module title</td><td colspan="5">Fundamentals in Digital Communications</td></tr>
<tr><td rowspan="3">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Introduction to Digital Communications (lec and ex)</td><td>lecture and exercises</td><td>2</td><td>2</td><td>oral exam (30 min)</td></tr>
<tr><td>Introduction to Digital Communications (lab)</td><td>lab training</td><td>1</td><td>1</td><td>lab attendance</td></tr>
<tr><td>module type</td><td colspan="5">compulsory</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ understanding fundamentals in digital communications and statistical signal processing</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ development in the area of digital transmission systems
▪ design of hardware and software components in digital transmission system
▪ assessment of analog front-ends</td></tr>
<tr><td>course contents</td><td colspan="5">mathematical models for communication channels, complex baseband representation of bandpass signals, orthogonal expansions of signals, linear digital modulation schemes, optimum receivers for the additive white Gaussian noise channel.</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">winter semester, summer semester</td></tr>
<tr><td>requirements</td><td colspan="5">undergraduate math (linear algebra, calculus, probability, random variables)</td></tr>
<tr><td>workload</td><td colspan="5">45 hours course attendance, 45 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">3</td></tr>
<tr><td>responsible</td><td colspan="5">Dahlhaus</td></tr>
<tr><td>lecturers</td><td colspan="5">Dahlhaus and team</td></tr>
<tr><td>media (teaching and learning methods)</td><td colspan="5">beamer (presentation), black board (derivations, explanations), paper (exercises), EMONA kit experiments</td></tr>
<tr><td>literature</td><td colspan="5">▪ J.G. Proakis, Digital Communications, McGraw-Hill, 4th ed., ISBN 0-07-118183-0.
▪ Papoulis, S. U. Pillai, Probability, Random Variables, and Stochastic Processes, McGraw-Hill, 4th ed., ISBN 0071226613.</td></tr>
</table>

2.2 Fundamentals in Optoelectronics

module code	B2a				
module title	**Fundamentals in Optoelectronics**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Optoelectronic Devices (lec and ex)	lecture and exercises	3	**4**	oral exam (30 min)
	Optoelectronic Devices (lab)	lab training	2	**2**	written report on measured data and presentation
module type	compulsory				
learning outcomes	▪ to learn basic principles of optoelectronic devices and systems, structure and operating principles of optoelectronic components ▪ to learn the huge application potential of optoelectronic devices and photonic tools ▪ the engineer should learn to solve problems using interdisciplinary analogies. ▪ to understand the successful solutions of nature as a promising approach for an advanced working engineer. ▪ introduction to scientific working; the engineer learns how to interprete data from model calculations and how to compare experimental and theoretical results and to conclude methodology				
competencies to be acquired	▪ understanding the complex interaction of electronic, thermal and optical phenomena in laser diodes ▪ sustainable knowledge in operation and application of optoelectronic devices ▪ research and development in the area of optoelectronic components				
course contents	▪ introduction into ray- and quantum optics ▪ refractive index, polarization, interference, diffraction, coherence ▪ material properties of glass: dispersion, absorption ▪ optical waveguiding, detailed introduction into dispersion and absorption ▪ interferometers (Michelson, Fabry-Pérot, Mach-Zehnder) ▪ optical multilayer structures (e.g. DBR mirrors) ▪ introduction to lasers, LEDs, photo diodes and solar cells ▪ simulation of active and passive optical devices (e.g. Fabry-Pérot interferometers, VCSELs)				
module usability	M.Sc. Electrical Communication Engineering				
module duration	one semester				
offered in	winter semester, summer semester				
requirements	undergraduate knowledge on electronic semiconductor devices (diodes, transistors), material science				
workload	75 hours course attendance, 105 hours self-study				
granted ECTS	**6**				
responsible	Hillmer				
lecturers	Hillmer and team				
media (teaching and learning methods)	beamer (presentation), black board (derivations, explanations), paper (exercises)				
literature	▪ J. Gowar, Optical Communication Systems, 2nd ed., Prentice Hall, 1993. ▪ K. Iga, S. Kinoshita, Process technology for semiconductor lasers, Springer, Series in Material Science 30, 1996. ▪ S.L. Chuang, Physics of Optoelectronic Devices, John Wiley & Sons, New York, 1995. ▪ F. Träger (Editor), Springer Handbook of Lasers and Optics, Springer, 2007.				

2.3 Engineering Mathematics

<table>
<tr><td>module code</td><td colspan="5">B3a</td></tr>
<tr><td>module title</td><td colspan="5">Engineering Mathematics</td></tr>
<tr><td rowspan="2">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Engineering Mathematics (lec and ex)</td><td>lecture and exercises</td><td>5</td><td>9</td><td>written exam (120 min)</td></tr>
<tr><td>module type</td><td colspan="5">compulsory</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ formulation of deterministic and stochastic mathematical models for systems and algorithms using linear and non-linear operators
▪ interpreting functions as elements of Hilbert spaces
▪ recap of undergraduate math topics</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ using mathematical frameworks in view of design objectives based on quantitative system specifications
▪ simulating and validating communication systems
▪ making deterministic and statistical inference</td></tr>
<tr><td>course contents</td><td colspan="5">▪ fundamentals of linear algebra, basics in probability and statistics
▪ generalized functions and linear systems
▪ Fourier transforms and Shannon-Kotelnikov (sampling) theorem
▪ bounded-input bounded-output stability in time-discrete linear time-invariant systems
▪ probability, stochastic processes, stationary processes and the central limit theorem
▪ system description based on linear / non-linear operators (deterministic and stochastic)
▪ system design and simulation using numerical methods
▪ Monte-Carlo simulations
▪ single-/multi-variable calculus
▪ ordinary and partial differential equations
▪ optimization problems</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Functional Safety Engineering</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">winter semester, summer semester</td></tr>
<tr><td>requirements</td><td colspan="5">undergraduate math (linear algebra, calculus, probability, random variables)</td></tr>
<tr><td>workload</td><td colspan="5">75 hours course attendance, 195 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">9</td></tr>
<tr><td>responsible</td><td colspan="5">Dahlhaus</td></tr>
<tr><td>lecturers</td><td colspan="5">Dahlhaus and team</td></tr>
<tr><td>media (teaching and learning methods)</td><td colspan="5">beamer (presentation), black board (derivations, explanations), paper (exercises)</td></tr>
<tr><td>literature</td><td colspan="5">▪ A. Papoulis and S. U. Pilllai, Probabilty, Random Variables and Stochastic Processes, 4th ed., McGraw Hill, 2002
▪ Further literature will be announced by the lecturers.</td></tr>
</table>

2.4 Scientific Publishing

<table>
<tr><td>module code</td><td colspan="5">B4a</td></tr>
<tr><td>module title</td><td colspan="5">Scientific Publishing</td></tr>
<tr><td rowspan="3">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Introduction to MATLAB (lab)</td><td>lab</td><td>2</td><td>3</td><td>lab training attendance, programming, written exam (120 min)</td></tr>
<tr><td>Introduction to LaTeX (lec and ex)</td><td>lecture and exercises</td><td>1</td><td>3</td><td>writing a scientific report</td></tr>
<tr><td>module type</td><td colspan="5">compulsory</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ understand approaches for numerical simulation in the field of communications
▪ write a code for different problems
▪ map a mathematical problem to a corresponding math software
▪ use advanced and consistent math typesetting
▪ build a consistent scientific report or presentation without caring about formatting, but only about contents
▪ build the main structure of a scientific report
▪ learn different steps for writing a scientific report, from brainstorming to the final version</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ analyzing and validating communication systems using numerical approaches
▪ professionally customizing the look of the report
▪ learning how to build a consistent and more easily and changeable report or presentation</td></tr>
<tr><td>course contents</td><td colspan="5">▪ fundamentals of MATLAB programming concepts
▪ introduction to numerical computing
▪ drafting, organizing revising and editing
▪ learning the mathematical notion required for writing the scientific report, sophisticated structuring and building and elaborating, consistent and changeable report</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Functional Safety Engineering</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">winter semester, summer semester</td></tr>
<tr><td>requirements</td><td colspan="5">undergraduate math (linear algebra, calculus, probability, random variables)</td></tr>
<tr><td>workload</td><td colspan="5">45 hours course attendance, 135 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">6</td></tr>
<tr><td>responsible</td><td colspan="5">Dahlhaus</td></tr>
<tr><td>lecturers</td><td colspan="5">Dahlhaus and team</td></tr>
<tr><td>media (teaching and learning methods)</td><td colspan="5">beamer (presentation), black board (derivations, explanations), paper (exercises), PC-based software development</td></tr>
<tr><td>literature</td><td colspan="5">▪ lecturer slides
▪ further literature will be announced by the lecturers</td></tr>
</table>

2.5 Social Communication

<table>
<tr><td>module code</td><td colspan="5">B5a</td></tr>
<tr><td>module title</td><td colspan="5">Social Communication</td></tr>
<tr><td rowspan="2">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Social Communication (lec and ex)</td><td>lecture and seminar</td><td>6</td><td>6</td><td>written exam (120 min), oral exam (30 min) and presentation</td></tr>
<tr><td>module type</td><td colspan="5">compulsory</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ general topics:
  ▪ social integration
  ▪ knowing basic German language expressions up to level A2
  ▪ using the language in everyday situations
▪ objectives in terms of levels of the Common European Reference Framework (Gemeinsamer Europäischer Referenzrahmen, GERR):
  ▪ A1: the student is able to:
    ▪ understand usual expressions with immediate meaning (own person, family, shopping, working, schedule, displays, brochures, simple announcements, use of public transport)
    ▪ communicate in simple standard situations, enquire about and obtain information about familiar things and exchange information (looking for a way, accommodation, present activity, apologize if absent)
    ▪ understand and use familiar every-day expressions for satisfying concrete needs
    ▪ introduce herself/himself/others and ask questions about a person, e.g., about their living conditions, and answer corresponding questions
    ▪ communicate on a simple level, if the conversational partner speaks slowly and distinctly and assist in case of a misunderstanding.
  ▪ A2: the student is able to:
    ▪ speak about her/his person, the job, the environment and elementary needs on a basic level
    ▪ describe his living conditions and understand short simple messages
    ▪ write simple texts and letters, read and understand and have brief chats in German
    ▪ understand main topics of oral and written texts (in the context of familiar situations at work, administration, school, leisure and radio/TV reports on latest news, profession and interests)</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ learning and studying approaches, learning experience and problem solving as well as inter-cultural competence, scientific language
▪ elementary and independent use of German language
▪ communication competence
▪ inter-cultural competence
▪ social competence</td></tr>
<tr><td>course contents</td><td colspan="5">▪ orientation in the city, working day, study, professional every day life
▪ food, eating habits, body, health, disease
▪ sports, leisure, clubs
▪ accomodation, flat hunting, furnishing
▪ study, school, education, looking for a job, application
▪ daily routine, curriculum vitae
▪ shopping, magazines, consumption, environment protection
▪ parties and celebrations, ritual, meetings
▪ seasons, weather, travelling
▪ culture, politics and society
▪ relations, feelings, habits, behaviour</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Functional Safety Engineering</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
</table>

offered in	winter semester, summer semester
requirements	–
workload	90 hours course attendance, 90 hours self-study
granted ECTS	**6**
responsible	Dahlhaus
lecturers	lecturers from DIALOG-Institut
media (teaching and learning methods)	beamer (presentation), black board (explanations), paper (exercises), discussions on specific topics
literature	▪ lecturer slides ▪ further literature will be announced by the lecturers

3 Elective Modules in Wireless Communications

3.1 Physical Layer in Wireless Communications

<table>
<tr><td>module code</td><td colspan="6">R1a</td></tr>
<tr><td>module title</td><td colspan="6">Physical Layer in Wireless Communications</td></tr>
<tr><td rowspan="5">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/</td><td>offered in</td></tr>
<tr><td>Digital Communication Through Band-Limited Channels (lec and ex)</td><td>lecture and exercises</td><td>3</td><td>5</td><td>oral exam (30 min)</td><td>summer semester</td></tr>
<tr><td>Digital Communication Through Band-Limited Channels (lab)</td><td>lab</td><td>1</td><td>1</td><td>lab attendance and oral exam (30 min)</td><td>summer semester</td></tr>
<tr><td>Digital Communication Over Fading Channels (lec and ex)</td><td>lecture and exercises</td><td>3</td><td>5</td><td>oral exam (30 min)</td><td>winter semester</td></tr>
<tr><td>Digital Communication Over Fading Channels (lab)</td><td>lab</td><td>1</td><td>1</td><td>lab attendance and oral exam (30 min)</td><td>winter semester</td></tr>
<tr><td>module type</td><td colspan="6">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="6">▪ detailed understanding of schemes and receiver algorithms in the physical layer of real-world communication systems including aspects in the receiver design which characterize the trade-off between implementation effort and achievable performance
▪ understanding the channel characterization, interference phenomena and signal processing in advanced wireless and mobile radio systems</td></tr>
<tr><td>competencies to be acquired</td><td colspan="6">▪ research and development in the area of digital transmission systems, signal processing (e.g. transceivers, image processing), statistical inference (e.g. quality management) and simulation of communication systems (e.g. telecommunications)
▪ consulting in the area of information technology
▪ operation and maintenance of devices in production processes</td></tr>
<tr><td>course contents</td><td colspan="6">▪ carrier and timing recovery, signalling in band-limited channels, transmission over linear band-limited channels
▪ intersymbol interference and adaptive equalization
▪ multichannel and multicarrier transmission, orthogonal frequency-division multiplexing (OFDM), spread spectrum (direct sequence, frequency hopping), PN sequences
▪ transmission over fading multipath channels, channel coding for multipath channels
▪ multiple-input multiple-output (MIMO) and massive MIMO transmissions, multiuser detection and random access
▪ non-orthogonal multiple access (NOMA) and free-cell communications</td></tr>
<tr><td>module usability</td><td colspan="6">M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik</td></tr>
<tr><td>module duration</td><td colspan="6">two semesters</td></tr>
<tr><td>requirements</td><td colspan="6">knowledge of fundamentals in digital communications</td></tr>
<tr><td>workload</td><td colspan="6">120 hours course attendance, 240 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="6">12</td></tr>
<tr><td>responsible</td><td colspan="6">Dahlhaus</td></tr>
<tr><td>lecturers</td><td colspan="6">Dahlhaus and team</td></tr>
<tr><td>media (teaching and learning methods)</td><td colspan="6">beamer (presentation), black board (derivations, explanations), paper (exercises), PC based software development (lab training), GUI, LabVIEW, EMONA kit experiments, DSP</td></tr>
<tr><td>literature</td><td colspan="6">▪ J.G. Proakis, Digital Communications, McGraw-Hill, 4th ed., ISBN 0-07-118183-0.
▪ Papoulis, S. U. Pillai, Probability, Random Variables, and Stochastic Processes, McGraw-Hill, 4th ed., ISBN 0071226613.</td></tr>
</table>

	▪ W.C.Y. Lee, Mobile Communications Engineering, New York: McGraw-Hill, 2nd ed., 1998. ▪ S.Verdu, Multiuser Detection, Cambridge University Press, ISBN 0-521-59373-5, 1998. ▪ A.J. Viterbi, CDMA -Principles of Spread Spectrum Communications, Wireless Communications Series, Addison-Wesley, 1995.

3.2 Reliable Transmission in Wireless Communications

<table>
<tr><td>module code</td><td colspan="5">R2a</td></tr>
<tr><td>module title</td><td colspan="5">Reliable Transmission in Wireless Communications</td></tr>
<tr><td rowspan="5">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Forward Error Correction in Wireless Communications (sem)</td><td>seminar</td><td>2</td><td>3</td><td>seminar attendance, presentation and oral exam (20 min)</td></tr>
<tr><td>Medium Access Control Protocols in Wireless Communications (sem)</td><td>seminar</td><td>2</td><td>3</td><td>seminar attendance, presentation and oral exam (20 min)</td></tr>
<tr><td>Introduction to Information Theory & Coding (lec and ex)</td><td>lecture and exercises</td><td>4</td><td>5</td><td>oral exam (30 min)</td></tr>
<tr><td>Introduction to Information Theory & Coding (lab)</td><td>lab</td><td>1</td><td>1</td><td>lab attendance and oral exam (30 min)</td></tr>
<tr><td>module type</td><td colspan="5">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ understanding fundamentals in communication-related aspects of information theory
▪ ability to design source and channel coding schemes and implement them efficiently in software
▪ detailed understanding of schemes in the physical layer of digital communication systems
▪ literature-/internet-based investigation on a topic from medium access control and coding schemes in wireless communication systems
▪ presenting a scientific topic in a seminar</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ research and development in source and channel coding
▪ research and development in the area of digital transmission systems, signal processing (e.g. transceivers, image processing), statistical inference (e.g. quality management) and simulation of communication systems (e.g. telecommunications)</td></tr>
<tr><td>course contents</td><td colspan="5">▪ fundamentals in information theory, entropy and mutual information
▪ typical sequences and Shannon capacity for the discrete memoryless channel
▪ channel coding: block codes, cyclic block codes, systematic form
▪ soft and hard decisions and performance; interleaving and code concatenation
▪ convolutional codes: tree and state diagrams, transfer function, distance properties; the Viterbi algorithm
▪ source coding: fixed-length and variable-length codes, Huffman coding; the Lempel-Ziv algorithm; coding for analog sources, rate-distortion function; pulse-code modulation; delta-modulation, model-based source coding, linear predictive coding (LPC)
▪ low-density parity-check (LDPC) code, turbo code and different coding techniques for the fifth and sixth generations
▪ medium access control in wireless communication systems</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik, M.Sc. Functional Safety Engineering</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">winter semester</td></tr>
<tr><td>requirements</td><td colspan="5">knowledge of fundamentals in digital communications</td></tr>
<tr><td>workload</td><td colspan="5">135 hours course attendance, 225 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">12</td></tr>
<tr><td>responsible</td><td colspan="5">Dahlhaus</td></tr>
<tr><td>lecturers</td><td colspan="5">Dahlhaus and team</td></tr>
</table>

media (teaching and learning methods)	beamer (presentation), black board (derivations, explanations), paper (exercises), PC based software development (lab training), GUI, LabVIEW, EMONA kit experiments, DSP
literature	▪ J.G. Proakis, Digital Communications, McGraw-Hill, 4th ed., ISBN 0-07-118183-0. ▪ Papoulis, S. U. Pillai, Probability, Random Variables, and Stochastic Processes, McGraw-Hill, 4th ed., ISBN 0071226613. ▪ W.C.Y. Lee, Mobile Communications Engineering, New York: McGraw-Hill, 2nd ed., 1998. ▪ Thomas M. Cover and Joy A. Thomas," Elements of Information Theory", Wiley,2nd ed., ISBN 0-471-24195-4. ▪ Additional papers to be handed out according to seminar topics.

3.3 Signal Processing for Wireless Communications

<table>
<tr><td>module code</td><td colspan="5">R3a</td></tr>
<tr><td>module title</td><td colspan="5">Signal Processing for Wireless Communications</td></tr>
<tr><td rowspan="4">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Introduction to Signal Detection and Estimation (lec and ex)</td><td>lecture and exercises</td><td>3</td><td>6</td><td>oral exam (30 min)</td></tr>
<tr><td>Simulation of Digital Communication Systems using MATLAB (lab)</td><td>lab</td><td>2</td><td>3</td><td>lab training attendance, programming, oral exam (30 min)</td></tr>
<tr><td>Signal Processing in Wireless Communications (sem)</td><td>seminar</td><td>2</td><td>3</td><td>seminar attendance, presentation and oral exam (20 min)</td></tr>
<tr><td>module type</td><td colspan="5">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ making statistical inference in the context of optimum hypothesis testing and signal estimation schemes
▪ ability to derive optimum signal processing schemes
▪ understanding approaches for numerical simulation of transceivers in the physical layer of communication systems
▪ introduction to scientific work
▪ literature-/internet-based investigation to understand advanced topics in signal processing
▪ presentating a scientific topic in a seminar</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ research and development in the area of digital transmission systems, signal processing (e.g. transceivers, image processing), statistical inference (e.g. quality management) and simulation of communication systems (e.g. telecommunications)</td></tr>
<tr><td>course contents</td><td colspan="5">▪ elements of hypothesis testing; mean-squared estimation covering the principle of orthogonality, normal equations, Wiener filters, related efficient numerical methods like Levinson-Durbin recursion, Kalman filters, adaptive filters; classification methods based on linear discriminants, kernel methods, support vector machines; maximum-likelihood parameter estimation, Cramer-Rao bound, EM algorithm
▪ simulation of different transmission chains, channel coding (convolutional codes), coding gain, channels with multipath propagation, channel models with fading and bit-error rate performance for binary signallingtransmission with orthogonal frequency-division multiplexing (OFDM), interleaving, implementation of an OFDM modem, MIMO system, beamforming, NOMA and free-sell communications
▪ model, simulate and test fifth-generation (5G) wireless communication systems
▪ implement different techniches for synchronization and channel estimation
▪ overview of existing wireless communication systems, characterization of wireless channels and signal processing in wireless transceivers and systems beyond 5G
▪ standardization bodies and research trends in the area of signal processing in wireless communication systems</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">summer semester</td></tr>
<tr><td>requirements</td><td colspan="5">knowledge of fundamentals in digital communications and basic in MATLAB</td></tr>
<tr><td>workload</td><td colspan="5">105 hours course attendance, 255 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">12</td></tr>
<tr><td>responsible</td><td colspan="5">Dahlhaus</td></tr>
<tr><td>lecturers</td><td colspan="5">Dahlhaus and team</td></tr>
</table>

media (teaching and learning methods)	beamer (presentation), black board (derivations, explanations), paper (exercises), PC based software development (lab training)
literature	▪ J.G. Proakis, Digital Communications, McGraw-Hill, 4th ed., ISBN 0-07-118183-0. ▪ Papoulis, S. U. Pillai, Probability, Random Variables, and Stochastic Processes, McGraw-Hill, 4th ed., ISBN 0071226613. ▪ H. Vincent Poor, An Introduction to Signal Detection and Estimation, Springer, 2nd ed., ISBN 0-387-94173-8 or ISBN 3-540-94173-8. ▪ H.L. van Trees, Detection, Estimation, and Modulation Theory, vol. I, New York, NY: John Wiley & Sons, 1968. ▪ Additional papers to be handed out according to seminar topics.

3.4 Wireless Communications

module code	R4a				
module title	**Wireless Communications**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Mobile Radio Systems (lec and ex)	lecture and exercises	2	**3**	oral exam (30 min)
	Software Defined Radio (lab)	lab	2	**3**	lab training attendance, programming, oral exam (30 min)
module type	elective				
learning outcomes	▪ understanding channel characterization, interference phenomena and signal processing in advanced wireless and mobile radio systems ▪ ability to implement advanced radio protocols using SDR				
competencies to be acquired	▪ research and development in the area of mobile radio systems ▪ operation and maintenance of devices in production processes ▪ design of terminals and base stations, in particular for wireless communications based on multicarrier transmission ▪ design a radio transmission using SDR				
course contents	▪ deterministic and stochastic description of mobile radio channels, time-variant linear systems, probability density functions of complex amplitudes in fading channels, characterization of noise and interference, diversity, multichannel signalling and linear combining, spread spectrum signalling, hypothesis testing with minimum probability of error, sufficient statistics ▪ multi-antenna techniques such as adaptive beamforming to be adopted by LTE and LTEA systems; device-2-device (D2D) communication using LTE; cellular internet of things (IoT); LTE in V2X communication ▪ modulations and waveforms for 5G networks; massive-MIMO and basic channel measurement techniques; non orthogonal multiple access (NOMA); cognitive radio for 5G networks ▪ introduction to 6G specifications and fundamental enabling technologies of 6G introduction to software defined radio (SDR) hardware and different signal processing techniques including timing, carrier and frame synchronizations, channel estimation and equalization using SDR				
module usability	M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik				
module duration	one semester				
offered in	winter semester				
requirements	knowledge of fundamentals in digital communications and basic in MATLAB				
workload	60 hours course attendance, 120 hours self-study				
granted ECTS	**6**				
responsible	Dahlhaus				
lecturers	Dahlhaus and team				
media (teaching and learning methods)	beamer (presentation), black board (derivations, explanations), paper (exercises), PC based software development (lab training), SDR software				
literature	▪ J.G. Proakis, Digital Communications, McGraw-Hill, 4th ed., ISBN 0-07-118183-0. ▪ Papoulis, S. U. Pillai, Probability, Random Variables, and Stochastic Processes, McGraw-Hill, 4th ed., ISBN 0071226613. ▪ H. Vincent Poor, An Introduction to Signal Detection and Estimation, Springer, 2nd ed., ISBN 0-387-94173-8 or ISBN 3-540-94173-8.				

	▪ R.W. Stewart, K.W. Barlee and D.S.W. Atkinson, Software Defined Radio Using MATLAB & Simulink and the RTL-SDR, Strathclyde Academic Media, 2015, ISBN: 0992978726, 9780992978723.

3.5 Wireless Communications Project Work

module code	P1a				
module title	**Wireless Communications Project Work**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Wireless Communications Project Work	project	4	**6**	report and presentation
module type	elective				
learning outcomes	▪ application of knowledge acquired in the area of digital communications to a specific technical/scientific problem ▪ solving a problem individually or in a team ▪ writing a report and presentation of results				
competencies to be acquired	▪ literature-/internet-based investigation ▪ structured approach for solving a problem ▪ independent scientific work ▪ ability to work in a team and to exchange ideas ▪ presentation in the framework of a project				
course contents	▪ schemes in the physical and medium access control layers of the OSI model for wireless communication systems ▪ topics of digital communications				
module usability	M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik				
module duration	one semester				
offered in	summer semester, winter semester				
requirements	knowledge of fundamentals in digital communications				
workload	60 hours course attendance, 120 hours self-study				
granted ECTS	**6**				
responsible	Dahlhaus				
lecturers	Dahlhaus and team				
media (teaching and learning methods)	PC based software development and/or hardware development (project work), beamer (presentation of results), report (electronic form and hard copy)				
literature	▪ J.G. Proakis, Digital Communications, McGraw-Hill, 4th ed., ISBN 0-07-118183-0. ▪ Papoulis, S. U. Pillai, Probability, Random Variables, and Stochastic Processes, McGraw-Hill, 4th ed., ISBN 0071226613. ▪ H. Vincent Poor, An Introduction to Signal Detection and Estimation, Springer, 2nd ed., ISBN 0-387-94173-8 or ISBN 3-540-94173-8. ▪ R.W. Stewart, K.W. Barlee and D.S.W. Atkinson, Software Defined Radio Using MATLAB & Simulink and the RTL-SDR, Strathclyde Academic Media, 2015, ISBN: 0992978726, 9780992978723. ▪ H.L. van Trees, Detection, Estimation, and Modulation Theory, vol. I, New York, NY: John Wiley & Sons, 1968. ▪ Additional papers/references according to project topics.				

3.6 Wireless Communications Master Thesis

<table>
<tr><td>module code</td><td colspan="5">T1a</td></tr>
<tr><td>module title</td><td colspan="5">Wireless Communications Master Thesis</td></tr>
<tr><td rowspan="2">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Wireless Communications Master Thesis</td><td>master thesis</td><td>20</td><td>30</td><td>report and presentation</td></tr>
<tr><td>module type</td><td colspan="5">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ independent scientific approach to solve a problem in the physical and medium access control layers of the OSI model for wired/wireless communication systems and related topics
▪ writing a report and presentation of results in a colloquium</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ literature-/internet-based investigation
▪ independent scientific work
▪ compilation of a report, preparation of a talk and presentation of scientific results</td></tr>
<tr><td>course contents</td><td colspan="5">▪ schemes in the physical and medium access control layers of the OSI model for wireless communication systems
▪ topics of digital communications</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">summer semester, winter semester</td></tr>
<tr><td>requirements</td><td colspan="5">▪ knowledge of fundamentals in digital communications
▪ proof of fulfilled admission requirements for the Master thesis according to the ECE examination regulation</td></tr>
<tr><td>workload</td><td colspan="5">300 hours course attendance, 600 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">30</td></tr>
<tr><td>responsible</td><td colspan="5">Dahlhaus</td></tr>
<tr><td>lecturers</td><td colspan="5">Dahlhaus and team</td></tr>
<tr><td>media (teaching and learning methods)</td><td colspan="5">PC based software development and/or hardware development (thesis project work), beamer (presentation of results), report (electronic form and hard copy)</td></tr>
<tr><td>literature</td><td colspan="5">▪ J.G. Proakis, Digital Communications, McGraw-Hill, 4th ed., ISBN 0-07-118183-0.
▪ Papoulis, S. U. Pillai, Probability, Random Variables, and Stochastic Processes, McGraw-Hill, 4th ed., ISBN 0071226613.
▪ H. Vincent Poor, An Introduction to Signal Detection and Estimation, Springer, 2nd ed., ISBN 0-387-94173-8 or ISBN 3-540-94173-8.
▪ R.W. Stewart, K.W. Barlee and D.S.W. Atkinson, Software Defined Radio Using MATLAB & Simulink and the RTL-SDR, Strathclyde Academic Media, 2015, ISBN: 0992978726, 9780992978723.
▪ H.L. van Trees, Detection, Estimation, and Modulation Theory, vol. I, New York, NY: John Wiley & Sons, 1968.
▪ Additional papers/references according to thesis topic.</td></tr>
</table>

4 Elective Modules in Electromagnetics

Some modules in electromagnetics are yet to be defined and finalized by April 2023.

4.1 Computational Electromagnetics

module code	R1a					
module title	**Computational Electromagnetics**					
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**	**offered in**
	Electromagnetic Theory for Microwaves and Antennas (lec and ex)	lecture and exercises	3	**5**	oral exam (30 min)	Winter and summer semesters
	Fields and Waves in Optoelectronic Devices (lec and ex)	lecture and exercises	3	**5**	oral exam (30 min)	winter semester
	Current Topics in Electromagnetic Field Theory (sem)	seminar	2	**2**	seminar attendance and presentation	winter semester
module type	elective					
learning outcomes	▪ understanding applications of electromagnetic field theory in microwave and antenna technology ▪ understanding the fundamentals of optoelectronic devices and the principles of modelling and simulation of these devices ▪ presentation of a scientific topic in a seminar					
competencies to be acquired	▪ research and development in the area of electromagnetic field theory for microwaves, antennas and optoelectronic devices					
course contents	▪ fundamentals of electromagnetic field theory, electromagnetic waves, transmission line theory, theory of electromagnetic waves, time-dependent boundary value problems, metallic waveguides and resonators, periodic structures and coupled modes, dispersive and anisotropic media, electromagnetic source fields, antennas, Gaussian beam, integral equations, scattering theory, inverse scattering problems ▪ semiconductor basics, electromagnetics, fibre propagation, interaction of light and semiconductors, characteristics of state of the art optoelectronic devices ▪ topics in electromagnetic field theory					
module usability	M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik					
module duration	one semester					
requirements	Mathematical foundations in electromagnetic field theory					
workload	120 hours course attendance, 240 hours self-study					
granted ECTS	**12**					
responsible	Adam					
lecturers	Adam and team					
media (teaching and learning methods)	beamer (presentation), black board (derivations, explanations), paper (exercises), PC based software development (lab training), SDR software					
literature	▪ *Inhomogeneous Media*, Wiley-IEEE Press, New York, 1999. ▪ K.J. Langenberg, *Theorie elektromagnetischer Wellen*. Buchmanuskript, FG Theorie der Elektrotechnik und Photonik, FB Elektrotechnik/Informatik, Universität Kassel, Kassel, 2003. ▪ J.G. Van Bladel, *Electro Magnetic Fields*, Wiley-IEEE Press, New York, 2007.					

	▪ K. Zhang, Li, Deji, *Electromagnetic Theory for Microwaves and Optoelectronics*, 2nd Ed., Springer, Berlin, 2008. ▪ Shun Lien Chuang, *Physics of Optoelectronic Devices,* Wiley, 1995. ▪ Voges und Petermann, *Optische Kommunikationstechnik*, Springer, 2002. ▪ Coldren and Corzine, *Diode Lasers and Photonic Integrated Circuits*, Wiley, 1995. Additional papers to be handed out according to seminar topics.

4.2 Optimization and Image Processing

4.3 Electromagnetics Project Work

<table>
<tr><td>module code</td><td colspan="5">P1a</td></tr>
<tr><td>module title</td><td colspan="5">Electromagnetics Project Work</td></tr>
<tr><td rowspan="2">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Electromagnetics Project Work</td><td>project</td><td>4</td><td>6</td><td>report and presentation</td></tr>
<tr><td>module type</td><td colspan="5">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ application of knowledge acquired in the area of electromagnetics to a specific technical/scientific problem
▪ solving a problem individually or in a team
▪ writing a report and presentation of results</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ literature-/internet-based investigation
▪ structured approach for solving a problem
▪ independent scientific work
▪ ability to work in a team and to exchange ideas
▪ presentation in the framework of a project</td></tr>
<tr><td>course contents</td><td colspan="5">▪ analysis of a problem (project task) in the area of field theory
▪ structured approach to the solution</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">summer semester, winter semester</td></tr>
<tr><td>requirements</td><td colspan="5">knowledge of fundamentals in electromagnetic field theory</td></tr>
<tr><td>workload</td><td colspan="5">60 hours course attendance, 120 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">6</td></tr>
<tr><td>responsible</td><td colspan="5">Adam</td></tr>
<tr><td>Lecturers</td><td colspan="5">Adam and team</td></tr>
<tr><td>media (teaching and learning methods)</td><td colspan="5">PC based software development and/or hardware development (project work), beamer (presentation of results), report (electronic form and hard copy)</td></tr>
</table>

4.4 Electromagnetics Master Thesis

module code	T1a				
module title	**Electromagnetics Master Thesis**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Electromagnetics Master Thesis	master thesis	20	**30**	report and presentation
module type	elective				
learning outcomes	▪ independent scientific approach to solve a field theoretical problem and related topics ▪ writing a report and presentation of results in a colloquium				
competencies to be acquired	▪ literature-/internet-based investigation ▪ independent scientific work ▪ compilation of a report, preparation of a talk and presentation of scientific results				
course contents	▪ theoretic and practical problems in the area of wave propagation ▪ theoretic and practical inverse problems in the area of acoustic and electromagnetic fields ▪ non-destructive testing and remote sensing.				
module usability	M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik				
module duration	one semester				
offered in	summer semester, winter semester				
requirements	▪ knowledge of fundamentals in field theory ▪ proof of fulfilled admission requirements for the Master thesis according to the ECE examination regulation				
workload	300 hours course attendance, 600 hours self-study				
granted ECTS	**30**				
responsible	Adam				
lecturers	Adam and team				
media (teaching and learning methods)	PC based software development and/or hardware development (thesis project work), beamer (presentation of results), report (electronic form and hard copy)				

5 Elective Modules in Hardware Components for Communication Systems

5.1 Optical Metrology

<table>
<tr><td>module code</td><td colspan="5">R1a</td></tr>
<tr><td>module title</td><td colspan="5">Optical Metrology</td></tr>
<tr><td rowspan="3">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Principles of Optical Metrology (sem)</td><td>seminar</td><td>2</td><td>3</td><td>seminar attendance and presentation</td></tr>
<tr><td>Optical Metrology (lab)</td><td>lab</td><td>2</td><td>3</td><td>lab training attendance
and conductance of experiments</td></tr>
<tr><td>module type</td><td colspan="5">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ overview on measurement techniques and operating principles
▪ principals of optical sensors, scope of applications
▪ learning about modern concepts of precision metrology
▪ getting practical experience in optical measurement set-ups
▪ establishing synergies between engineering disciplines and natural sciences
▪ finding access to theses in the innovative field of optical technologies
▪ introduction to the 21st century as the “century of photonics and nano technology”</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ knowledge in modern measurement technologies used in current research and industrial applications
▪ ability to estimate potentials and limitations of optical measurement techniques
▪ experience in information gathering and presentation techniques of complex technical subjects</td></tr>
<tr><td>course contents</td><td colspan="5">▪ repetition of light wave and ray optical principles
▪ repetition of diffraction phenomena and Fourier optics
▪ microscopic imaging and image processing techniques
▪ confocal microscopy, Interferometry, white-light interferometer, integrated interferometers, interference microscopes
▪ fiber-Bragg-Grating sensors, repetition of optical fibers
▪ optical sensors and applied devices in optical sensors (including: microoptics, adaptive optics, diffractive optical elements)
▪ principles and application of optical in-process measurement
▪ thin-film preparation and measurement techniques (ellipsometry, RHEED)
▪ absorption, transmission, spectroscopy, gas-sensors
▪ intra-Cavity-Absorption-Spectroscopy, mode competition
▪ photoluminescence, Scanning Electron Microscope, Tunneling Electron Microscope
▪ atomic Force Microscope (AFM), cantilever based sensors
▪ scanning near-field optical sensors, Magneto Resistive Effects</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">winter semester</td></tr>
<tr><td>requirements</td><td colspan="5">knowledge in optics, material science and semiconductor devices (Fundamentals in Optoelectronics B2a); signal processing and sensors, e.g. “Sensoren und Messsysteme”</td></tr>
<tr><td>workload</td><td colspan="5">60 hours course attendance, 120 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">6</td></tr>
<tr><td>responsible</td><td colspan="5">Lehmann</td></tr>
<tr><td>lecturers</td><td colspan="5">Lehmann</td></tr>
</table>

media (teaching and learning methods)	beamer (presentation), black board (derivations, explanations), electronic documents, practical exercises, experiments (lab training)
literature	▪ W. Göpel, Sensors – A Comprehensive Survey, VCH, (1997) ▪ S.O. Kasap, Optoelectronics and Photonics, Prentice-Hall, (2001) ▪ B. Bhushan (Editor), Springer Handbook of Nanotechnology, Springer, (2004) ▪ J. W. Goodman: Fourier Optics; Roberts & Company Publishers; 3rd edition (2004) ▪ D. B. Murphy: Fundamentals of Light Microscopy and Electronic Imaging; John Wiley & Sons (2001) ▪ D. Malacara: Optical Shop Testing; Wiley-Interscience; 3rd edition (2007) ▪ P. Török, F.-J. Kao (Ed.): Optical Imaging and Microscopy; Springer-Verlag (2007)

5.2 Semiconductor Memories in Communication Systems

<table>
<tr><td>module code</td><td colspan="5">R2a</td></tr>
<tr><td>module title</td><td colspan="5">Semiconductor Memories in Communication Systems</td></tr>
<tr><td rowspan="3">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Semiconductor Memories: Technology, Design, Structures, Modeling and Simulation (lec and ex)</td><td>lecture and exercises</td><td>3</td><td>4</td><td>oral exam (30 min)</td></tr>
<tr><td>Concepts and Structures for Dynamic Runtime Reconfiguration (sem)</td><td>seminar</td><td>2</td><td>2</td><td>seminar attendance and presentation</td></tr>
<tr><td>module type</td><td colspan="5">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ understanding the fundamentals in semiconductor memories
▪ understanding the limits of fabrication processes
▪ gaining requisite knowledge for being introducted to practical tasks and projects of industry and research in the area of semiconductor memories, especially DRAM technology
▪ gaining an overview of dynamic runtime reconfiguration
▪ learning presentation techniques and obtaining presentation practice</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ research and development in the area of semiconductor memories and semiconductor process technology
▪ presentation techniques, optimum use of tools</td></tr>
<tr><td>course contents</td><td colspan="5">▪ introduction to semiconductor memories
▪ different types of semiconductor memories
▪ understanding MOSFET as a main element of memory cell
▪ process technology for semiconductor memories
▪ simulation and modeling of semiconductor memories
▪ advanced topics in semiconductor memories
▪ future semiconductor memories
▪ concepts of dynamic runtime reconfiguration</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">summer semester</td></tr>
<tr><td>requirements</td><td colspan="5">▪ basic knowledge on semiconductor devices, material science
▪ basics in computer architecture, microprocessors and FPGAs</td></tr>
<tr><td>workload</td><td colspan="5">75 hours course attendance, 105 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">6</td></tr>
<tr><td>responsible</td><td colspan="5">Hillmer</td></tr>
<tr><td>lecturers</td><td colspan="5">Hillmer, Zipf, Joodaki</td></tr>
<tr><td>media (teaching and learning methods)</td><td colspan="5">beamer (presentation), black board (derivations, explanations), paper (exercises).</td></tr>
<tr><td>literature</td><td colspan="5">▪ K. Sharma, Advanced Semiconductor Memories: Architectures, Designs and Applications, NJ, Wiley & Sons, 2002
▪ Y. Taur and T.K. Ning, Fundamental of Modern VLSI Devices, UK, Cambridge University Press, 1998.</td></tr>
</table>

	▪ Additional papers to be handed out according to seminar topics.

5.3 Optical Communication Systems

module code	R3a				
module title	**Optical Communication Systems**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Optical Communication Systems (lec)	lecture	2	**3**	oral exam (30 min)
	Optical Communication Systems (sem)	seminar	2	**2**	seminar attendance and presentation
	Optical Communication Systems (lab)	lab training	1	**1**	lab training attendance and conductance of experiments
module type	elective				
learning outcomes	▪ understanding fundamentals of optical communication systems ▪ ability to understand design guidelines for optical components to be used in optical communications				
competencies to be acquired	▪ research and development in optical broadband communications ▪ design of optical communication systems for broadcast and transport				
course contents	▪ fundamentals of fibre-optic transmission ▪ fibre-to-the-X (FTTX), all-optical transmission systems ▪ single and multimode fibres, dispersion shifted and dispersion compensating fibres ▪ coherent detection in fibre optics ▪ wavelength division multiplexing ▪ wavelength division multiple access ▪ optical amplifiers and switches ▪ single-mode fibre systems: optical backbones, cable TV, local area networks ▪ topics in optical communications and optical communication systems				
module usability	M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik				
module duration	one semester				
offered in	summer semester				
requirements	▪ fundamentals in digital and analog communications ▪ basic knowledge on semiconductor devices (transistor, laser diode, LED, photo diode), material science and optics				
workload	75 hours course attendance, 105 hours self-study				
granted ECTS	**6**				
responsible	Bangert				
lecturers	Bangert and team				
media (teaching and learning methods)	beamer (lecture, presentation), black board (derivations, explanations), PC including a simulation environment				
literature	▪ J.Gowar, Optical Communication Systems, 2nd ed., Prentice Hall, 1993. ▪ S.L.Chuang, Physics of Optoelectronic Devices, John Wiley & Sons, New York, 1995. ▪ G.P. Agrawal, Fiber-Optic Communication Systems, John Wiley & Sons, New York, 1997. ▪ J.P.Laude, DWDM: Fundamentals, Components and Applications, Artech House, 2002. ▪ Additional papers to be handed out according to seminar topics.				

6 Elective Modules in Microwaves

6.1 Fundamentals of Linear Microwaves Networks

<table>
<tr><td>module code</td><td colspan="5">R1a</td></tr>
<tr><td>module title</td><td colspan="5">Fundamentals of Linear Microwaves Networks</td></tr>
<tr><td rowspan="3">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Microwaves and Millimeter Waves I (lec and ex)</td><td>lecture and exercises</td><td>3</td><td>4</td><td>written exam (120 min)</td></tr>
<tr><td>Microwaves and Millimeter Waves I (lab)</td><td>lab training</td><td>2</td><td>2</td><td>lab training attendance and conductance of experiments</td></tr>
<tr><td>module type</td><td colspan="5">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ knowing the basics and applications of microwave circuit theory and the operation principles of technically relevant microwave devices
▪ ability to design linear microwave networks (e.g. linear amplifier, linear oscillator)
▪ understanding schemes for characterizing microwave devices based on measurements</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ use of instruments for microwave measurements
▪ analyse and synthesis of linear microwave systems
▪ research and development in the design of microwave components.</td></tr>
<tr><td>course contents</td><td colspan="5">▪ theory of microwave networks, n-ports, signal flow diagrams
▪ microwave devices, measurement of S-parameters, hetero structure components, microwave field-effect transistors (FETs), Shockley's model, 2-region model, saturation model, FET-equivalent network
▪ linear amplifiers and oscillators
▪ introduction to microwave measurement instruments, measurement of parameters of microwave components (lab).</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">summer semester</td></tr>
<tr><td>requirements</td><td colspan="5">knowledge of fundamentals in microwave technology</td></tr>
<tr><td>workload</td><td colspan="5">75 hours course attendance, 105 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">6</td></tr>
<tr><td>responsible</td><td colspan="5">Bangert</td></tr>
<tr><td>lecturers</td><td colspan="5">Bangert and team</td></tr>
<tr><td>media (teaching and learning methods)</td><td colspan="5">beamer (presentation), black board (derivations, explanations), paper (exercises), experiments (lab training)</td></tr>
<tr><td>literature</td><td colspan="5">▪ G. Kompa, Practical Microstrip Design and Applications, Artech House, 2006
▪ G. Kompa, Lecture Notes (in German)
▪ H. Brand, Schaltungslehre linearer Mikrowellennetze, S. Hirzel Verlag, 1970 (in German)
▪ Notes on lab training.</td></tr>
</table>

6.2 Microwave Integrated Circuits

module code	R2a				
module title	**Microwaves Integrated Circuits**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Microwave Integrated Circuits II (lec and ex)	lecture and exercises	3	**4**	oral exam (30 min)
	Microwave Integrated Circuits II (sem)	seminar	2	**2**	seminar attendance and presentation
module type	elective				
learning outcomes	▪ ability to design non-linear microwave circuits				
competencies to be acquired	▪ research and development in the area of microwave components ▪ design of microwave components for base stations (broadband power amplifiers)				
course contents	▪ III-V-Semiconductor devices ▪ classification of FET models, Shockley's model ▪ extraction of model parameters ▪ fundamentals of non-linear FET modelling ▪ large-scale signal description of devices ▪ non-linear circuit design (power amplifiers)				
module usability	M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik				
module duration	one semester				
offered in	winter semester				
requirements	▪ attendance of module Microwave Integrated Circuits I or comparable knowledge and skills ▪ knowledge of vector algebra and vector analysis				
workload	75 hours course attendance, 105 hours self-study				
granted ECTS	**6**				
responsible	Bangert				
lecturers	Bangert and team				
media (teaching and learning methods)	beamer (presentation), black board (derivations, explanations), paper (exercises), experiments (lab training)				

6.3 Microwave Engineering

<table>
<tr><td>module code</td><td colspan="5">R3a</td></tr>
<tr><td>module title</td><td colspan="5">Microwaves Engineering</td></tr>
<tr><td rowspan="3">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Microwaves and Millimeter Waves II (lec and ex)</td><td>lecture and exercises</td><td>3</td><td>4</td><td>oral exam (30 min)</td></tr>
<tr><td>Microwaves and Millimeter Waves II (lab)</td><td>lab training</td><td>2</td><td>2</td><td>lab training attendance and conductance of experiments</td></tr>
<tr><td>module type</td><td colspan="5">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ understanding the electrical and transmission properties of different types of microwave guides and resonators together with applications
▪ ability to calculate parameters of microwave guides based on the complete set of Maxwell’s equations</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ research and development in the area of microwave components
▪ characterization and modelling of microwave components based on measurements
▪ design of microwave networks</td></tr>
<tr><td>course contents</td><td colspan="5">▪ definitions and survey of wave guide structures
▪ transmission line theory and describing equations, reflection coefficient, input impedance, Maxwell’s equations, decoupling of Maxwell’s equations, electro-dynamic potential
▪ classification of field modes on wave guides
▪ field-theoretical analysis of hollow and dielectric wave guides (optical fibre)
▪ transmission line resonators and wave guide cavities (frequency stabilized oscillators)
▪ antennas</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">winter semester</td></tr>
<tr><td>requirements</td><td colspan="5">▪ knowledge of fundamentals in microwave technology
▪ knowledge of vector algebra and vector analysis</td></tr>
<tr><td>workload</td><td colspan="5">75 hours course attendance, 105 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">6</td></tr>
<tr><td>responsible</td><td colspan="5">Bangert</td></tr>
<tr><td>lecturers</td><td colspan="5">Bangert and team</td></tr>
<tr><td>media (teaching and learning methods)</td><td colspan="5">beamer (presentation), black board (derivations, explanations), paper (exercises), experiments (lab training)</td></tr>
<tr><td>literature</td><td colspan="5">▪ R.E. Collin, Foundations for Microwave Engineering, McGraw-Hill, 1992
▪ David M. Pozar, Microwave Engineering, 3rd ed., Wiley, 2005
▪ Notes on lab training</td></tr>
</table>

6.4 Near-Range RADAR Sensors

<table>
<tr><td>module code</td><td colspan="5">R4a</td></tr>
<tr><td>module title</td><td colspan="5">Near-Range RADAR Sensors</td></tr>
<tr><td rowspan="3">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>RF Sensor Systems (lec and ex)</td><td>lecture and exercises</td><td>3</td><td>4</td><td>oral exam (30 min)</td></tr>
<tr><td>RF Sensor Systems (lab)</td><td>lab training</td><td>1</td><td>2</td><td>lab training attendance and conductance of experiments</td></tr>
<tr><td>module type</td><td colspan="5">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="5">understanding the structure, functions and practical applications of near-range radar sensors (ultrasound, laser, microwave)</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">knowledge of RF sensor systems</td></tr>
<tr><td>course contents</td><td colspan="5">▪ motivation, definitions, basics in sensors
▪ RADAR procedures
▪ wave properties
▪ scanning, ultrasonic sensors, radar
▪ microwave sources, microwave antennas, laser radar
▪ protection and security</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">winter semester</td></tr>
<tr><td>requirements</td><td colspan="5">knowledge of fundamentals in microwave technology</td></tr>
<tr><td>workload</td><td colspan="5">60 hours course attendance, 120 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">6</td></tr>
<tr><td>responsible</td><td colspan="5">Bangert</td></tr>
<tr><td>lecturers</td><td colspan="5">Bangert and team</td></tr>
<tr><td>media (teaching and learning methods)</td><td colspan="5">beamer (presentation), black board (derivations, explanations), paper (exercises), experiments (lab training)</td></tr>
<tr><td>literature</td><td colspan="5">▪ I.H. Woodhouse, Introduction to Microwave Remote Sensing, Taylor & Francis, 2006
▪ E. Nyfors et al., Inductrial Microwave Sensors, Artech House, 1989
▪ J. Polivka, Overview of Microwave Sensor Technology, High Frequency Electronics, 2007</td></tr>
</table>

6.5 Microwaves Project Work

module code	P1a				
module title	**Microwaves Project Work**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Microwaves Project Work	project	4	**6**	report and presentation
module type	elective				
learning outcomes	▪ application of knowledge acquired in the area of microwave components to a specific technical/scientific problem ▪ solving a problem individually or in a team ▪ writing of a report and presentation of results				
competencies to be acquired	▪ literature and internet based investigation ▪ structured approach for solving a problem ▪ independent scientific work ▪ ability to work in a team and to exchange ideas ▪ presentation in the framework of a project				
course contents	▪ analysis of a problem according to project description ▪ structured approach to the solution				
module usability	M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik				
module duration	one semester				
offered in	summer semester, winter semester				
requirements	knowledge of fundamentals in microwave components				
workload	60 hours course attendance, 120 hours self-study				
granted ECTS	**6**				
responsible	Bangert				
lecturers	Bangert and team				
media (teaching and learning methods)	PC based software development and/or hardware development (project work), beamer (presentation of results), report (electronic form and hard copy)				
literature	scientific papers/books according to project topics				

6.6 Microwaves Master Thesis

<table>
<tr><td>module code</td><td colspan="5">T1a</td></tr>
<tr><td>module title</td><td colspan="5">Microwaves Master Thesis</td></tr>
<tr><td rowspan="2">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Microwaves Master Thesis</td><td>master thesis</td><td>20</td><td>30</td><td>report and presentation</td></tr>
<tr><td>module type</td><td colspan="5">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ independent scientific approach to solve a field theoretical problem and related topics
▪ writing of a report and presentation of results in a colloquium</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ literature-/internet-based investigation
▪ independent scientific work
▪ compilation of a report, preparation of a talk and presentation of scientific results</td></tr>
<tr><td>course contents</td><td colspan="5">▪ computer-aided circuit design
▪ device modelling
▪ microwave measurement approaches and instrumentation
▪ radar sensors
▪ topics in high-frequency technology</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">summer semester, winter semester</td></tr>
<tr><td>requirements</td><td colspan="5">▪ knowledge of fundamentals in microwave components
▪ proof of fulfilled admission requirements for the Master thesis according to the ECE examination regulation</td></tr>
<tr><td>workload</td><td colspan="5">300 hours course attendance, 600 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">30</td></tr>
<tr><td>responsible</td><td colspan="5">Bangert</td></tr>
<tr><td>lecturers</td><td colspan="5">Bangert and team</td></tr>
<tr><td>media (teaching and learning methods)</td><td colspan="5">PC based software development and/or hardware development (thesis project work), beamer (presentation of results), report (electronic form and hard copy)</td></tr>
<tr><td>literature</td><td colspan="5">▪ R.E. Collin, Foundations for Microwave Engineering, McGraw-Hill, 1992
▪ G. Kompa, Lecture Notes HF-Sensorik, (in German)
▪ G. Kompa, Practical Microstrip Design and Applications, Artech House, 2006
▪ Additional papers/references according to thesis topic.</td></tr>
</table>

7 Elective Modules in Optoelectronics

7.1 Optoelectronic Technologies

module code	R1a				
module title	**Optoelectronic Technologies**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Microsystem Technology (lec)	lecture	2	**3**	oral exam (30 min)
	Technology of Electronic and Optoelectronic Devices (lec)	lecture	2	**3**	oral exam (30 min)
module type	elective				
learning outcomes	▪ understanding the fundamentals in micromachining, micro-opto-electro-mechanical systems (MOEMS) and optical MOEMS ▪ understanding the fundamentals of semiconductor technology including specific processes, schemes and required instrumentation ▪ methodology, interdisciplinary aspects, future perspectives and market trends ▪ finding solutions using interdisciplinary analogies ▪ establishing synergies between engineering disciplines and natural sciences ▪ introduction to the 21st century as the “century of photonics and nano technology”				
competencies to be acquired	▪ knowledge in micromachining, devices, thin-layer and clean-room technologies ▪ methodology in specialized miniaturization schemes and integration of electronic and optoelectronic devices and systems ▪ knowledge of design, fabrication and use of nanoelectronic, (opto-)electronic and micromachined devices				
course contents	▪ introduction to modern fabrication processes, technology of fibers, wave guides, lasers ▪ crystal growth: semiconductor wafers, thin layer epitaxy ▪ lithography: optical, X-ray, electron-beam, ion-beam, EUVL, nano imprint ▪ plasma processing and vacuum technology ▪ deposition techniques: evaporation, sputtering, plasma assisted techniques ▪ dry and wet-chemical etching and clean room technology ▪ fabrication technology of electronic devices (planar transistor, electronic integrated chips), optoelectronic devices (semiconductor lasers, gratings) and micro-opto-electro-mechanical systems (MOEMS) ▪ introduction to micromachining, microsystem techniques, miniaturization, packaging and nanotechnology ▪ reasons for miniaturization and integration, types of micromachining ▪ sensors and actuators ▪ large variety of MEMS and MOEMS examples: membranes, springs, resonator elements, cantilevers, valves, manipulation elements, gripping tools, light modulators, optical switches, beam splitters, projection displays, micro optical bench, data distribution, micromachined tunable filters and lasers, ▪ displays: micromachined (micromirror) displays, laser display technology, vacuum-electronics ▪ lab tour in the clean room				
module usability	M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik				
module duration	one semester				
offered in	summer semester				
requirements	basic knowledge on semiconductor devices (transistor, laser diode, LED, photo diode), material science and optics				
workload	60 hours course attendance, 120 hours self-study				

granted ECTS	**6**
responsible	Hillmer
lecturers	Hillmer and team
media (teaching and learning methods)	beamer (presentation), black board (derivations, explanations), paper (exercises)
literature	▪ R. Williams, Modern GaAs Processing Methods, Artech House Inc., ISBN 0-89006-343-5, 1990. ▪ W. Menz, J. Mohr and O. Paul, Microsystem Technology, VCH-Verlag, 2001. ▪ K. Iga, S. Kinoshita, Process technology for semiconductor lasers, Springer, Series in Material Science 30, 1996. ▪ B. Bhushan (Editor), Springer Handbook of Nanotechnology, Springer, 2004.

7.2 LASERs and Light Processing

<table>
<tr><td>module code</td><td colspan="5">R2a</td></tr>
<tr><td>module title</td><td colspan="5">LASERs and Light Processing</td></tr>
<tr><td rowspan="4">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Semiconductor Lasers (lec and ex)</td><td>Lecture and exercises</td><td>3</td><td>6</td><td>oral exam (30 min)</td></tr>
<tr><td>Optoelectronics II (lab)</td><td>lab training</td><td>2</td><td>3</td><td>written report on measured data and presentation</td></tr>
<tr><td>Seminar in Optoelectronics I+II (sem)</td><td>seminar</td><td>2</td><td>3</td><td>seminar attendance and presentation</td></tr>
<tr><td>module type</td><td colspan="5">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ learn basic principles of optoelectronic devices and systems, structure and operating principles of optoelectronic components
▪ learn the huge application potential of optoelectronic devices and photonic tools
▪ learn to solve problems using interdisciplinary analogies
▪ understand the successful solutions of nature as a promising approach for an advanced working engineer
▪ learn presentation techniques and to obtain presentation practice
▪ learn to structure a talk to optimize the transfer of essentials to the audience
▪ learn how to analyze measured data and how to compare experimental and theoretical results and inferences
▪ learn to efficiently apply different set-up components for optical characterization</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ understanding the complex interaction of electronic, thermal and optical phenomena in laser diodes
▪ sustainable knowledge in operation and application of optoelectronic devices
▪ research and development in the area of optoelectronic components</td></tr>
<tr><td>course contents</td><td colspan="5">▪ diffractive elements: 1-, 2- and 3-dimensional gratings, Fresnel lenses and photonic crystals
▪ LASERs: gain, rate equations, DFB gratings, spectra, ultrafast lasers, tunable lasers, chirped gratings, microdisc lasers, quantum cascade lasers, DBR mirrors for vertical cavity lasers, VCSELs, blue semiconductor lasers
▪ light processing: switches, splitters, amplifiers, combiners, multiplexers, demultiplexers, beam transformers
▪ optical communication systems: WDM, TDM
▪ experimental modules such as DFB laser diodes, sample stages, optical spectrum analyzers and PC will be assembled to measure laser spectra as a function of injection current and temperature
▪ measured are: spectral shift of different modes of diode lasers with varying injection current and temperature, light power-versus-current characteristics, To.
▪ evaluation, interpretation, documentation and presentation of the measured data.
▪ advanced seminar topics in optoelectronics</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">winter semester</td></tr>
<tr><td>requirements</td><td colspan="5">basic knowledge on semiconductor devices, material science and optoelectronics</td></tr>
<tr><td>workload</td><td colspan="5">105 hours course attendance, 255 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">12</td></tr>
<tr><td>responsible</td><td colspan="5">Hillmer</td></tr>
<tr><td>lecturers</td><td colspan="5">Hillmer and team</td></tr>
</table>

media (teaching and learning methods)	beamer (presentation, seminar), black board (derivations, explanations), paper (exercises), measurement instrumentation (lab).
literature	▪ J. Gowar, Optical Communication Systems, 2nd ed., Prentice Hall, 1993. ▪ K. Iga, S. Kinoshita, Process technology for semiconductor lasers, Springer, Series in Material Science 30, 1996. ▪ S.L. Chuang, Physics of Optoelectronic Devices, Wiley & Sons, New York, 1995. ▪ F. Träger (Editor), Springer Handbook of Lasers and Optics, Springer, 2007.

7.3 Optoelectronics Project Work

<table>
<tr><td>module code</td><td colspan="5">P1a</td></tr>
<tr><td>module title</td><td colspan="5">Optoelectronics Project Work</td></tr>
<tr><td rowspan="2">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Optoelectronics Project Work</td><td>project</td><td>4</td><td>6</td><td>report and presentation</td></tr>
<tr><td>module type</td><td colspan="5">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ practice in theoretical model calculations
▪ learn to understand basics and fundamental interaction of effects by a variation of geometric and material parameters
▪ learn how to design advanced photonic devices
▪ learn how to analyze and to interpret calculated theoretical data.
▪ structure the analyzed data and parameter series in such a way that the uninvolved reader can understand and follow the argumentation
▪ methodology of project organization and project management, team work
▪ writing of a report and presentation of results</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ create new or modify existing models according to the given problem
▪ analyze data series with respect to the given problem
▪ experience synergies in knowledge during the comparison and analysis of theoretical and experimental data
▪ literature and internet based investigation
▪ structured approach for solving a problem
▪ independent scientific work
▪ ability to work in a team and to exchange ideas
▪ presentation in the framework of a project</td></tr>
<tr><td>course contents</td><td colspan="5">▪ theoretical model calculation using advanced software tools on problems at the research front. Example: calculation of laser spectra with the goal to optimize and design an advanced VCSEL with complex coupling (real and imaginary part in refractive index). This is done for a novel hybrid structure combining inorganic and organic materials
▪ variation of basic parameters, like Δn, measurements and evaluation of different characteristics
▪ the simulations are defined according to general and actual problems in optoelectronics and are related to research topics of the working group</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">summer semester, winter semester</td></tr>
<tr><td>requirements</td><td colspan="5">knowledge of fundamentals in optoelectronics</td></tr>
<tr><td>workload</td><td colspan="5">60 hours course attendance, 120 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">6</td></tr>
<tr><td>responsible</td><td colspan="5">Hillmer</td></tr>
<tr><td>lecturers</td><td colspan="5">Hillmer and team</td></tr>
<tr><td>media (teaching and learning methods)</td><td colspan="5">beamer (project work), beamer (presentation of results), report (electronic form and hard copy)</td></tr>
<tr><td>literature</td><td colspan="5">scientific papers/books according to project topics.</td></tr>
</table>

7.4 Optoelectronics Master Thesis

<table>
<tr><td>module code</td><td colspan="5">T1a</td></tr>
<tr><td>module title</td><td colspan="5">Optoelectronics Master Thesis</td></tr>
<tr><td rowspan="2">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Optoelectronics Master Thesis</td><td>master thesis</td><td>20</td><td>30</td><td>report and presentation</td></tr>
<tr><td>module type</td><td colspan="5">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ independent scientific approach to solve a field-theoretical problem and related topics
▪ creating models for a given problem
▪ obtaining practice in experimental work (technology or characterization) or theoretical model calculations
▪ analyzing and interpreting of measured data
▪ comparison of own results to actual literature
▪ writing of a report and presentation of results in a colloquium</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ experience in practical clean room technology
▪ literature and internet based investigation
▪ independent scientific work
▪ compilation of a report, preparation of a talk and presentation of scientific results</td></tr>
<tr><td>course contents</td><td colspan="5">▪ independent scientific work on a problem in photonics and related areas like design, technological fabrication in the clean room, characterization of optoelectronic devices or systems, nanotechnology and micromachining
▪ working on problems which have a pronounced application potential, partly in an consortium including industry
▪ the students are encouraged to create spin-off companies based on their own work</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">summer semester, winter semester</td></tr>
<tr><td>requirements</td><td colspan="5">▪ profound knowledge in optoelectronics
▪ proof of fulfilled admission requirements for the Master thesis according to the ECE examination regulation</td></tr>
<tr><td>workload</td><td colspan="5">300 hours course attendance, 600 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">30</td></tr>
<tr><td>responsible</td><td colspan="5">Hillmer</td></tr>
<tr><td>lecturers</td><td colspan="5">Hillmer and team</td></tr>
<tr><td>media (teaching and learning methods)</td><td colspan="5">PC-based software development and/or hardware development (thesis project work), beamer (presentation of results), report (electronic form and hard copy)</td></tr>
<tr><td>literature</td><td colspan="5">papers/references according to thesis topic.</td></tr>
</table>

8 Elective Modules in Enabling Technologies for Communication Systems

8.1 Pattern Recognition and Machine Learning

<table>
<tr><td>module code</td><td colspan="5">R1a</td></tr>
<tr><td>module title</td><td colspan="5">Pattern Recognition and Machine Learning</td></tr>
<tr><td rowspan="2">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Pattern Recognition and Machine Learning I (lec and ex)</td><td>lecture</td><td>4</td><td>6</td><td>oral exam (30 min)</td></tr>
<tr><td>module type</td><td colspan="5">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ understanding the theoretical basics of pattern recognition and machine learning
▪ learning about parameter estimation techniques
▪ ability to develope of new models</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ knowledge: theoretical basics of pattern recognition (probabilistic point of view)
▪ ability to use of parameter estimation techniques for different models
▪ development of new models
▪ evaluation of practical applications and independent development of new applications</td></tr>
<tr><td>course contents</td><td colspan="5">▪ fundamentals (e.g. stochastics, model selection, curse of dimensionality, decision and information theory), distributions (e.g. multinomial, dirichlet, Gaussian and student distribution, nonparametric estimation of distributions)
▪ linear models for regression, linear models for classification
▪ kernel functions and advanced neural networks (e.g. vonvolutional neural networks, radial basis function networks), Gaussian processes</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">winter semester</td></tr>
<tr><td>requirements</td><td colspan="5">knowledge of some contents from mathematics lectures (stochastics or discrete structures, analysis, linear Algeba) or comparable knowledge and skills</td></tr>
<tr><td>workload</td><td colspan="5">60 hours course attendance, 120 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">6</td></tr>
<tr><td>responsible</td><td colspan="5">Sick</td></tr>
<tr><td>lecturers</td><td colspan="5">Sick and team</td></tr>
<tr><td>media (teaching and learning methods)</td><td colspan="5">beamer (presentation), black board (derivations, explanations), paper (exercises)</td></tr>
<tr><td>literature</td><td colspan="5">▪ Christopher M. Bishop: Pattern Recognition and Machine Learning, Springer (2006)
▪ Richard O. Duda, Peter E. Hart, David G. Stork: Pattern Classification, Wiley & Sons; 2nd edition (2000)
▪ Other literatures will be provided during the lecture</td></tr>
</table>

8.2 Temporal and Spatial Data Mining

<table>
<tr><td>module code</td><td colspan="5">R2a</td></tr>
<tr><td>module title</td><td colspan="5">Temporal and Spatial Data Mining</td></tr>
<tr><td rowspan="2">courses</td><td>title</td><td>type</td><td>SWS</td><td>ECTS</td><td>performance requirements/ examination</td></tr>
<tr><td>Temporal and Spatial Data Mining (lec)</td><td>lecture</td><td>4</td><td>6</td><td>oral exam (20 minutes) or written exam (120 minutes)</td></tr>
<tr><td>module type</td><td colspan="5">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="5">explain various tasks, models, and algorithms of temporal and spatial data mining</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ develop new modeling approaches for problems such as time series classification, anomaly detection, or clustering
▪ plan and implement new applications of the learned paradigms
▪ critically question, compare, and evaluate existing approaches and applications</td></tr>
<tr><td>course contents</td><td colspan="5">▪ basic approaches of pattern recognition in time series (e.g., sensor signals) and spatially distributed data (e.g., in sensor networks)
▪ theoretical foundations (e.g., segmentation of time series, correlation of data)
▪ time series representation (e.g., features extraction for describing temporal and spatial data)
▪ distance and similarity measures for time series, clustering / classification, motifs, and anomaly/novelty detection using various techniques (e.g., nearest neighbor, neural networks, support vector regression)
▪ diverse sample applications (signature verification, collaborative hazard warning for automotive, activity recognition, etc.)</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik</td></tr>
<tr><td>module duration</td><td colspan="5">one semester</td></tr>
<tr><td>offered in</td><td colspan="5">winter semester</td></tr>
<tr><td>requirements</td><td colspan="5">▪ at least one Bachelor or Master module in machine learning should have been attended, knowledge gaps can be closed in online courses on machine learning
▪ basic knowledge of stochastic, analysis and linear algebra is assumed
▪ additional, Python knowledge is beneficial</td></tr>
<tr><td>workload</td><td colspan="5">60 hours course attendance, 120 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">6</td></tr>
<tr><td>responsible</td><td colspan="5">Sick</td></tr>
<tr><td>lecturers</td><td colspan="5">Sick and team</td></tr>
<tr><td>media (teaching and learning methods)</td><td colspan="5">beamer (presentation), black board (derivations, explanations), paper (exercises)</td></tr>
<tr><td>literature</td><td colspan="5">▪ Mitsa: Temporal Data Mining
▪ Gama: Knowledge Discovery from Data Streams
▪ Shekhar: Spatial and Spatiotemporal Data Mining
▪ Other literatures will be provided during the lecture</td></tr>
</table>

8.3 Internet of Things

8.4 Introduction to Information Security

module code	R4a				
module title	**Introduction to Information Security**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Introduction to Information Security (lec)	lecture	4	**6**	TBD
module type	elective				
learning outcomes	TBD				
competencies to be acquired	▪ TBD				
course contents	▪ TBD ▪ TBD				
module usability	M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik				
module duration	one semester				
offered in	winter semester				
requirements	▪ TBD				
workload	60 hours course attendance, 120 hours self-study				
granted ECTS	**6**				
responsible	Pan				
lecturers	Pan and team				
media (teaching and learning methods)	beamer (presentation), black board (derivations, explanations), paper (exercises)				
literature	▪ TBD				

8.5 Internet Measurements

module code	R5a				
module title	**Internet Measurements**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Internet Measurements (lec)	lecture	4	**6**	oral exam (30 minuten) or written exam (120 minuten)
module type	elective				
learning outcomes	▪ explain given distributed algorithms and analyse their properties ▪ evaluate the complexity of algorithms, develop extensions for given algorithms, implement distributed algorithms ▪ determine the applicability of given algorithms to new application scenarios ▪ explain methods for conducting massive internet measurements in order to o understand complex systems o evaluate their security properties ▪ be familiarized with the key aspects of internet traffic, the use of internet protocols and security, as well as the methods for conducting large-scale Internet measurements				
competencies to be acquired	▪ ability to confidently select and apply analytical methods and existing solution approaches ▪ develop and evaluate new solution methods ▪ be familiarized with new areas of knowledge and carry out relevant research and assess the results ▪ have important experience in practical technical and IT-related activities ▪ have confidence in knowledge and skills and act independently and responsibly				
course contents	▪ carrying out internet measurements (internet data science) ▪ analysis of the Domain Name System (DNS) and its security ▪ internet traffic characteristics and measurement methods (e.g. samples, aggregation) ▪ internet control plane analysis and robustness ▪ methodological concepts for carrying out internet measurements ▪ measurement strategies for internet application security ▪ what does internet traffic look like? how and where can you improve the internet, and how can these improvements be tested? The above questions are methodically realized. How can such measurements can be statistically evaluated?				
module usability	M.Sc. Electrical Communication Engineering, M.Sc. Informatik				
module duration	one semester				
offered in	summer semester				
requirements	▪ Modules “Computer Networks”, “Internet Architecture and Services”.				
workload	60 hours course attendance, 120 hours self-study				
granted ECTS	**6**				
responsible	Hohlfeld				
lecturers	Hohlfeld and team				
media (teaching and learning methods)	beamer (presentation), black board (explanations), slides, Moodle				
literature	▪ will be announced during the course				

8.6 Internet Architecture and Services

module code	R6a				
module title	**Internet Architecture and Services**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Internet Architecture and Services (lec)	lecture	4	**6**	written exam (120 minuten)
module type	elective				
learning outcomes	▪ have a practical experience in the application of elementary internet protocols and insight into current developments in practice and research ▪ have depth knowledge of the functionality of application-oriented protocols/services and elementary internet architectures				
competencies to be acquired	▪ ability to confidently select and apply analytical methods and solution approaches ▪ ability to independently develop computer science-relevant systems at a technical and model level and software-develepment level ▪ ability to be familiarized with new areas of knowledge and carry out relevant research ▪ ability to work on own initiative and in teams ▪ ability to apply and represent solution strategies				
course contents	▪ elementary design principles of internet architecture, application-oriented internet protocols/services ▪ principles of operation of the protocols ▪ internet economics ▪ basics of multimedia communication ▪ distribution networks and data center networks ▪ current developments in the internet architecture and protocol landscape				
module usability	M.Sc. Electrical Communication Engineering, B.Sc. Informatik, B.Sc. Elektrotechnik				
module duration	one semester				
offered in	summer semester				
requirements	▪ Module “Computer Networks” and “Computer Architecture”				
workload	60 hours course attendance, 120 hours self-study				
granted ECTS	**6**				
responsible	Hohlfeld				
lecturers	Hohlfeld and team				
media (teaching and learning methods)	beamer (presentation), black board (explanations), slides, Moodle				
literature	▪ will be announced during the course				