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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1 Ausbildungsziele

Der Studiengang „Master of Science in Electrical Communication Engineering“ (M.Sc. ECE) baut als zweiter universitärer Abschluss auf einer Ausbildung zum Bachelor of Science Elektrotechnik oder auf einem gleichwertigen Abschluss auf. Die Absolventinnen und Absolventen des M.Sc. ECE sollen über solides disziplinäres und interdisziplinäres Hintergrundwissen verfügen und auf dieser Basis neue Verfahren und Prinzipien an der Schnittstelle moderner Kommunikationssysteme und deren elektrotechnischer Umsetzung, z. B. in drahtlosen Funksystemen und breitbandigen Backbones, unter Verwendung der Informations- und Kommunikationstechnik, der Mikro- und Nanoelektronik sowie der Internettechnologien entwickeln, um damit die Lebensqualität der Menschen nachhaltig zu verbessern.

Der Masterstudiengang ist konsekutiv und forschungsorientiert. Er befähigt damit zu einem Beruf auf dem Gebiet der Kommunikationstechnik mit deutlichem Forschungsbezug. Angestrebt werden die Vermittlung von tiefgehendem Verständnis der Zusammenhänge in Kommunikationssystemen, von der Nanotechnologie bis zu Protokollentwürfen in den oberen Schichten des OSI-Modell, und die Befähigung zur Anwendung und Entwicklung von Methoden statt reinem Faktenwissen sowie ein Heranführen an interdisziplinäre Sicht- und Arbeitsweisen.

Ziel des Masterstudiengangs ist es, den Studierenden ein nachhaltiges Ingenieurwissen sowie die Befähigung zum selbstständigen wissenschaftlichen Arbeiten zu vermitteln. Realisiert wird dies u.a. durch eine frühzeitige Einbindung der Studierenden in Forschungs- und Entwicklungsprojekte sowie der Ausbildung dienende Projekte. Die Absolventen erhalten die wissenschaftliche Qualifikation für eine Promotion.

Die Absolventinnen und Absolventen können national und international im Bereich der Forschung und Entwicklung eingesetzt werden. Sie besitzen Kompetenz im Bereich der Entwicklung, Beratung und Unterhalt moderner Kommunikationssysteme. Sie sind für Führungsaufgaben einsetzbar.

Die angestrebten Lernziele des Studiengangs M.Sc. ECE stellen sich im Einzelnen wie folgt dar:

- **Ziel Wissens- und Kenntnisstand:** Die Absolventinnen und Absolventen
  - verfügen über ein vertieftes Wissen in mathematisch-naturwissenschaftlichen Bereichen.
  - erlangen vertiefte Kenntnisse in den Grundlagen des OSI-Schichtenmodells.
  - verfügen über erweiterte und angewandte fachspezifische Grundlagen der Elektrotechnik.
- **Ziel Analyse- und Methodenkompetenz:** Die Absolventinnen und Absolventen
  - sind in der Lage, komplexe kommunikationstechnische, elektrotechnische und interdisziplinäre Aufgabenstellungen zu erkennen und einzuordnen.
  - besitzen die Fähigkeit zur Bewertung und sicheren Anwendung analytischer Methoden.
  - können selbständig Lösungsmethoden entwickeln und beurteilen.
  - können sich in neue Wissensgebiete einarbeiten und dazu entsprechende Recherchen durchführen und die Ergebnisse bewerten.
- **Ziel Ingenieuranwendung und Ingenieurpraxis:** Die Absolventinnen und Absolventen
  - sammeln tiefgehende wichtige Erfahrungen in praktischen technischen und ingenieurwissenschaftlichen Tätigkeiten.
- **Ziel Soziale Kompetenz:** Die Absolventinnen und Absolventen
  - bilden eine stabile Persönlichkeit.
  - erlangen die Fähigkeit zur effektiven Führung interdisziplinärer Teams.
  - besitzen die Fähigkeit zu allein verantwortlicher Leitung und Führung.
  - arbeiten und forschen in nationalen und internationalen Kontexten.

Die tabellarische Übersicht der Ausbildungsziele findet sich in Abschnitt 11.

2 Study Objectives

The Master of Science in Electrical Communication Engineering (M.Sc. ECE) programme is a second university degree that builds on a Bachelor of Science in Electrical Engineering or an equivalent qualification. Graduates of the M.Sc. ECE should have solid disciplinary and interdisciplinary background knowledge and, on this basis, develop new processes and principles at the interface of modern communication systems and their electrical engineering implementation, e.g., in wireless radio systems and broadband backbones, using information and communication technology, micro- and nanoelectronics, and Internet technologies, in order to sustainably improve people's quality of life.

The Master's degree programme is consecutive and research-oriented. It thus qualifies students for a career in the field of communications technology with a clear focus on research. The aim is to impart a deep understanding of the relationships in communications systems, from nanotechnology to protocol designs in the upper layers of the OSI model, and to enable students to apply and develop methods instead of pure factual knowledge, as well as to introduce them to interdisciplinary perspectives and working methods.

The aim of the master's programme is to provide students with sustainable engineering knowledge and the ability to work independently in scientific research. This is achieved, among other things, by involving students in research and development projects as well as training projects at an early stage. Graduates receive the scientific qualifications for a doctorate.

Graduates can be employed nationally and internationally in the field of research and development. They have expertise in the development, consulting and maintenance of modern communication systems. They can be employed in management roles.

The learning objectives of the M.Sc. ECE degree programme are as follows:

- **Objective Knowledge and Understanding:** The graduates
  - have in-depth knowledge in mathematical and scientific areas.
  - gain in-depth knowledge of the basics of the OSI layer model.
  - have advanced and applied subject-specific fundamentals of electrical engineering.
- **Objective Analytical and Methodological Competency:** The graduates
  - are able to recognize and classify complex communications-related, electrical engineering and interdisciplinary tasks.
  - have the ability to evaluate and safely apply analytical methods.
  - can independently develop and evaluate solution methods.
  - can familiarize themselves with new areas of knowledge and conduct appropriate research and evaluate the results.
- **Objective Engineering Application and Engineering Practice:** The graduates
  - gain in-depth important experience in practical technical and engineering activities.
- **Objective Social Skills:** The graduates
  - develop a stable personality.
  - acquire the ability to effectively lead interdisciplinary teams.
  - have the ability to manage and lead independently.
  - work and research in national and international contexts.

A tabular overview of the study objectives can be found in Section 12.

3 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

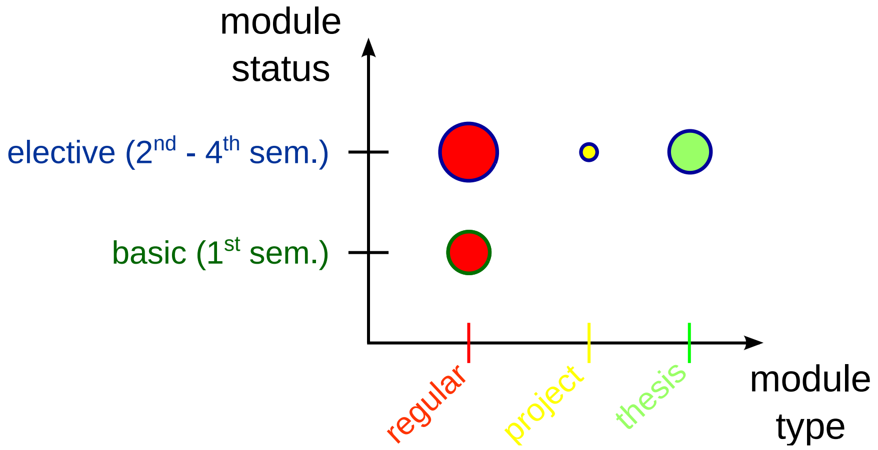

Fig. 1: Classification of modules according to status and type and workload representation.

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. 4 – Sect. 10).

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 of Digital Communications B1a*, is made up by the module title (here: *Fundamentals of 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. 4. Basic modules are offered in both winter and summer semesters.

Tab. 1: List of basic modules and granted ECTS

Module name	ECTS
Fundamentals of Digital Communications B1a	3
Fundamentals of 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. 4 contains the descriptions of the basic modules. Sect. 5 – Sect. 10 describe elective modules in

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

4 Basic Modules

4.1 Fundamentals of Digital Communications

module code	B1a				
module title	**Fundamentals of Digital Communications**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Introduction to Digital Communications (lec and ex)	lecture and exercises	2	**2**	written exam (60 min)
	Introduction to Digital Communications (lab)	lab training	1	**1**	lab attendance
module type	compulsory				
learning outcomes	▪ understanding fundamentals of digital communications and statistical signal processing				
competencies to be acquired	▪ development in the area of digital transmission systems ▪ design of hardware and software components in digital transmission system ▪ assessment of analog front-ends				
course contents	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.				
module usability	M.Sc. Electrical Communication Engineering				
module duration	one semester				
offered in	winter semester, summer semester				
requirements	undergraduate math (linear algebra, calculus, probability, random variables)				
workload	45 hours course attendance, 45 hours self-study				
granted ECTS	**3**				
responsible	Dahlhaus				
lecturers	Dahlhaus and team				
media (teaching and learning methods)	beamer (presentation), black board (derivations, explanations), paper (exercises), EMONA kit experiments				
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.				

4.2 Fundamentals of Optoelectronics

<table>
<tr><td>module code</td><td colspan="5">B2a</td></tr>
<tr><td>module title</td><td colspan="5">Fundamentals of Optoelectronics</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>Optoelectronic Devices (lec and ex)</td><td>lecture and exercises</td><td>3</td><td>4</td><td>oral exam (30 min)</td></tr>
<tr><td>Optoelectronic Devices (lab)</td><td>lab training</td><td>2</td><td>2</td><td>written report on measured data and presentation</td></tr>
<tr><td>module type</td><td colspan="5">compulsory</td></tr>
<tr><td>learning outcomes</td><td colspan="5">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</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">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)</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 knowledge on electronic semiconductor devices (diodes, transistors), material science</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 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">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.</td></tr>
</table>

4.3 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>

4.4 Scientific Publishing

module code	B4a				
module title	**Scientific Publishing**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Introduction to MATLAB (lab)	lab	2	**3**	lab training attendance, programming, written exam (120 min)
	Introduction to LaTeX (lec and ex)	lecture and exercises	1	**3**	writing a scientific report
module type	compulsory				
learning outcomes	▪ 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				
competencies to be acquired	▪ 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				
course contents	▪ 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				
module usability	M.Sc. Electrical Communication Engineering, M.Sc. Functional Safety Engineering				
module duration	one semester				
offered in	winter semester, summer semester				
requirements	undergraduate math (linear algebra, calculus, probability, random variables)				
workload	45 hours course attendance, 135 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				
literature	▪ lecturer slides ▪ further literature will be announced by the lecturers				

4.5 Social Communications

<table>
<tr><td>module code</td><td colspan="5">B5a</td></tr>
<tr><td>module title</td><td colspan="5">Social Communications</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 Communications (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 A1
using the language in everyday situations

objectives in terms of levels of the Common European Reference Framework (Gemeinsamer Europäischer Referenzrahmen, GERR) is the ability of student 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
understand and use familiar every-day expressions for satisfying concrete needs
introduce herself/himself/others and ask questions about a person
communicate on a simple level, if the conversational partner speaks slowly and distinctly and assist in case of a misunderstanding.
speak about her/his person, the job, the environment and elementary needs on a basic level
describe the living conditions and understand short simple messages
write simple texts and letters, read and understand and have brief chats in German

</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>
<tr><td>offered in</td><td colspan="5">winter semester, summer semester</td></tr>
<tr><td>requirements</td><td colspan="5">–</td></tr>
<tr><td>workload</td><td colspan="5">90 hours course attendance, 90 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>
</table>

lecturers	Team of German lecturers
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

5 Elective Modules in Wireless Communications

5.1 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 of 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.

5.2 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 of 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 of 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 of 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, 2^{nd} ed., 1998. ▪ Thomas M. Cover and Joy A. Thomas," Elements of Information Theory", Wiley,2^{nd} ed., ISBN 0-471-24195-4. ▪ Additional papers to be handed out according to seminar topics.

5.3 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 of 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.

5.4 Wireless Communications

<table>
<tr><td>module code</td><td colspan="5">R4a</td></tr>
<tr><td>module title</td><td colspan="5">Wireless 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>Mobile Radio 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>Software Defined Radio (lab)</td><td>lab</td><td>2</td><td>2</td><td>lab training attendance, programming, 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 channel characterization, interference phenomena and signal processing in advanced wireless and mobile radio systems
▪ ability to implement advanced radio protocols using SDR</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ 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</td></tr>
<tr><td>course contents</td><td colspan="5">▪ 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</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 of digital communications and basic in MATLAB</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">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 (lab training), SDR software</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.</td></tr>
</table>

	▪ 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.

5.5 Wireless Communications Project Work

<table>
<tr><td>module code</td><td colspan="5">P1a</td></tr>
<tr><td>module title</td><td colspan="5">Wireless Communications 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>Wireless Communications 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 digital communications 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">▪ 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 of digital communications</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">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 (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 project topics.</td></tr>
</table>

5.6 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 of 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>

6 Elective Modules in Electromagnetics

6.1 Electromagnetic Theory for Microwaves and Antennas

module code	R1a				
module title	**Electromagnetic Theory for Microwaves and Antennas**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Electromagnetic Theory for Microwaves and Antennas (lec and ex)	lecture and exercises	3	**6**	oral exam (30 min)
module type	elective				
learning outcomes	▪ understanding applications of electromagnetic field theory in microwave and antenna technology				
competencies to be acquired	▪ research and development in the area of electromagnetic field theory for microwaves, antennas and optoelectronic devices ▪ acquisition of in-depth and applied subject-specific principles of electrical engineering				
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 theor ▪ inverse scattering problems				
module usability	M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik				
module duration	one semester				
offered in	summer semester, winter semester				
requirements	▪ basic knowledge of vector calculus and electromagnetic field theory ▪ fundamentals of mathematical operations				
workload	45 hours course attendance, 135 hours self-study				
granted ECTS	**6**				
responsible	Adam				
lecturers	Adam and team				
media (teaching and learning methods)	beamer (presentation), black board (derivations, explanations), paper (exercises)				
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.				

6.2 Fields and Waves in Optoelectronic Devices

module code	R2a				
module title	**Fields and Waves in Optoelectronic Devices**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Fields and Waves in Optoelectronic Devices (lec and ex)	lecture and exercises	3	**6**	oral exam (30 min)
module type	elective				
learning outcomes	▪ understanding the concepts of fields and waves and their propagation in optoelectronic devices ▪ theoretical basics for photonics, electromagnetic problems, and wave guiding ▪ electromagnetic principles applied to the characteristics in the semiconductor devices				
competencies to be acquired	▪ research and development in electromagnetic field theory for optoelectronic components ▪ acquisition of in-depth and applied subject-specific principles of electrical engineering ▪ independently describe semiconductor resonators and waveguides for LEDs or photodiodes				
course contents	▪ fundamentals of ray- and wave optics ▪ fundamentals of light-matter interaction ▪ introduction to semiconductor and quantum theory ▪ fields and waves in optoelectronic components ▪ nanophononics and its theoretical description fundamentals metallic waveguides and resonators, transverse electric and transverse magnetic modes, wave-guide components				
module usability	M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik				
module duration	one semester				
offered in	winter semester				
requirements	▪ basic knowledge of vector calculus and electromagnetic field theory. ▪ fundamentals of mathematical operations ▪ basics of python programming				
workload	45 hours course attendance, 135 hours self-study				
granted ECTS	**6**				
responsible	Adam				
lecturers	Adam and team				
media (teaching and learning methods)	beamer (presentation), black board (derivations, explanations), paper (exercises)				
literature	▪ G. Lifante, *Integrated Photonics: Fundamentals.* ▪ 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. ▪ S.L. Chuang, *Physics of optoelectronic Devices,* Wiley. ▪ Coldren and Corzine, *Diode Lasers and Photonic Integrated Circuits*, Wiley, 1995. ▪ Saleh, Teich, Optics.				

6.3 Fundamentals of Computational Photonics

<table>
<tr><td>module code</td><td colspan="5">R3a</td></tr>
<tr><td>module title</td><td colspan="5">Fundamentals of Computational Photonics</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>Computational Photonics I (lec and ex)</td><td>lecture and exercises</td><td>3</td><td>4</td><td>oral exam (30 min)</td></tr>
<tr><td>Computational Photonics I (lab)</td><td>lecture and exercises</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">▪ detailed understanding of the materials behavior at nanoscale
▪ understanding the quantum transport and optoelectronic properties of the material.
▪ understanding the density functional theory for anticipation of the physical properties of the materials under different conditions
▪ modeling of characterization of the nanoscale devices using NEGF and semi-classical approaches
▪ quantum to classical modeling for optoelectronic materials and devices</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ research and development in the materials and device modeling for different applications in the area of electrical and photonics engineerings
▪ consulting in semiconducting technology
▪ operation and maintenance of devices in production processes</td></tr>
<tr><td>course contents</td><td colspan="5">▪ fundamentals of QM and nanoelectronics: basics of quantum mechanics, Schrodinger equation, finite-difference methods, discretization
▪ 2D materials beyond graphene: 2D materials, graphene, MXenes, emerging families: TMDCs.
▪ semiconductor transport: Boltzmann equation, drift-diffusion box method, boundary conditions
▪ density-functional Theory: many-bodies Schrodinger equation, density functional theory, first-principle calculations
▪ ptoelectronic properties of nanomaterials: electronic properties, transport properties (electron/hole mobility, effective masses of electrons/holes, thermal/ electronic conductivity), linear optical responses
▪ nanoscale device modeling: ballistic and diffusive transport, quasi-fermi levels, diffusion equation for ballistic transport, non-equilibrium green’s functions (NEGF), quantum to classical Modeling</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 of of semiconductor materials
▪ fundamentals of mathematical operations
▪ basics of python programming</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">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">Beamer (presentation), black board (derivations, explanations), paper (exercises), PC-based software development (lab training), Jupyter notebooks, Python, Comsol, PMCloud</td></tr>
</table>

literature	▪ David Sholl, *Density Functional Theory: A Practical Introduction.* ▪ Supriyo Datta, *Quantum Transport: Atom to Transistor.* ▪ June Gunn Lee, *Computational Materials Science.* ▪ Donald Neamen, *Physics of Semiconductor Devices.*

6.4 Photonic Semiconductors

<table>
<tr><td>module code</td><td colspan="5">R4a</td></tr>
<tr><td>module title</td><td colspan="5">Photonic Semiconductors</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>Computational Photonics II (lec and ex)</td><td>lecture and exercises</td><td>3</td><td>5</td><td>oral exam (30 min)</td></tr>
<tr><td>Computational Photonics II (lab)</td><td>lecture and exercises</td><td>2</td><td>2</td><td>lab training attendance, and conductance of experiments</td></tr>
<tr><td>Semiconductor Devices – Theory and Modelling (lec and ex)</td><td>lecture and exercises</td><td>3</td><td>5</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">▪ introduction to the principles of semiconductor devices
▪ understanding and analyzing the basic theory and the models that describe the characteristics of semiconductor devices
▪ understanding the impact of nanoscience on the latest device concepts (nanowires, monolayers)
▪ knowledge of various numerical methods for solution of Maxwell's equations in time and frequency domains by applying different methods</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ research and development in electromagnetic theory for photonic semiconductor devices
▪ computational algorithm implementation
▪ interpretation and evaluation of numerical results</td></tr>
<tr><td>course contents</td><td colspan="5">▪ introduction to semiconductors, quantum mechanics, numerical modeling, the pn diode, the transistor, the LED, the photovoltaic cell, nanostructures in device modeling
▪ electromagnetic field theory, electromagnetic waves, transmission line, time-dependent boundary value problems, metallic waveguides and resonators, periodic structures and coupled modes, dispersive and anisotropic media, electromagnetic source fields
▪ numerical methods in problems of electromagnetic field theory: transfer matrix method (TMM), finite-difference time-domain (FDTD) method, and finite-element methods (FEM)</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">Mathematical foundations in electromagnetic field theory, basic python programming skills, and basic quantum mechanics.</td></tr>
<tr><td>workload</td><td colspan="5">120 hours course attendance, 240 hours self-study</td></tr>
<tr><td>granted ECTS</td><td colspan="5">12</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">Beamer (presentation), black board (derivations, explanations), paper (exercises), PC-based software development (lab training), Jupyter notebooks, Python, Comsol, PMCloud</td></tr>
<tr><td>literature</td><td colspan="5">▪ Larson, G. M., Bengzon, F. The Finite Element Method: Theory, Implementation, and Applications, Springer, Berlin, 2013.
▪ Jin, J., The Finite Element Method in Electromagnetics, Wiley-IEEE Press, 2007
▪ Peterson, A. F., S. L. Ray, R. Mittra, Computational Methods for Electromagnetics, IEEE Press, Piscataway, New Jersey, USA, 1998.</td></tr>
</table>

	▪ Taflove, A., Hagness, S.: *Computational Electrodynamics, The Finite-Difference Time-Domain Method*, 3rd Edition, Artech House, Norwood, Mass., USA, 2005.

6.5 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 of 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>

6.6 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 of 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)				

7 Elective Modules in Hardware Components for Communication Systems

7.1 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 of 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)

7.2 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 of 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.

7.3 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 of 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.				

8 Elective Modules in Microwaves

8.1 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 of 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>

8.2 Microwave Integrated Circuits

<table>
<tr><td>module code</td><td colspan="5">R2a</td></tr>
<tr><td>module title</td><td colspan="5">Microwaves Integrated Circuits</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>Microwave Integrated Circuits 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>Microwave Integrated Circuits II (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">▪ ability to design non-linear microwave circuits</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ research and development in the area of microwave components
▪ design of microwave components for base stations (broadband power amplifiers)</td></tr>
<tr><td>course contents</td><td colspan="5">▪ 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)</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">▪ attendance of module Microwave Integrated Circuits I or comparable knowledge and skills
▪ 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>
</table>

8.3 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 of 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>

8.4 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 of 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>

8.5 Microwaves Project Work

<table>
<tr><td>module code</td><td colspan="5">P1a</td></tr>
<tr><td>module title</td><td colspan="5">Microwaves 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>Microwaves 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 microwave components to a specific technical/scientific problem
▪ solving a problem individually or in a team
▪ writing of a report and presentation of results</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ 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">▪ analysis of a problem according to project description
▪ 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 of microwave components</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">PC based software development and/or hardware development (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>

8.6 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 of 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>

9 Elective Modules in Optoelectronics

9.1 Optoelectronic Technologies

<table>
<tr><td>module code</td><td colspan="5">R1a</td></tr>
<tr><td>module title</td><td colspan="5">Optoelectronic Technologies</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>Microsystem Technology (lec)</td><td>lecture</td><td>2</td><td>3</td><td>oral exam (30 min)</td></tr>
<tr><td>Technology of Electronic and Optoelectronic Devices (lec)</td><td>lecture</td><td>2</td><td>3</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 fundamentals of 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”</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ 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</td></tr>
<tr><td>course contents</td><td colspan="5">▪ 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</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 (transistor, laser diode, LED, photo diode), material science and optics</td></tr>
<tr><td>workload</td><td colspan="5">60 hours course attendance, 120 hours self-study</td></tr>
</table>

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.

9.2 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.

9.3 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 of 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>

9.4 Optoelectronics Master Thesis

module code	T1a				
module title	**Optoelectronics Master Thesis**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Optoelectronics 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 ▪ 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				
competencies to be acquired	▪ 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				
course contents	▪ 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				
module usability	M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik				
module duration	one semester				
offered in	summer semester, winter semester				
requirements	▪ profound knowledge in optoelectronics ▪ 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	Hillmer				
lecturers	Hillmer 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)				
literature	papers/references according to thesis topic.				

10 Elective Modules in Enabling Technologies for Communication Systems

10.1 Pattern Recognition and Machine Learning

module code	R1a				
module title	**Pattern Recognition and Machine Learning**				
courses	**title**	**type**	**SWS**	**ECTS**	**performance requirements/ examination**
	Pattern Recognition and Machine Learning I (lec and ex)	lecture	4	**6**	oral exam (30 min)
module type	elective				
learning outcomes	▪ understanding the theoretical basics of pattern recognition and machine learning ▪ learning about parameter estimation techniques ▪ ability to develope of new models				
competencies to be acquired	▪ 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				
course contents	▪ 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				
module usability	M.Sc. Electrical Communication Engineering, M.Sc. Elektrotechnik				
module duration	one semester				
offered in	winter semester				
requirements	knowledge of some contents from mathematics lectures (stochastics or discrete structures, analysis, linear Algeba) or comparable knowledge and skills				
workload	60 hours course attendance, 120 hours self-study				
granted ECTS	**6**				
responsible	Sick				
lecturers	Sick and team				
media (teaching and learning methods)	beamer (presentation), black board (derivations, explanations), paper (exercises)				
literature	▪ 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				

10.2 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>

10.3 Internet of Things

This module is yet to be defined and finalized by October 2025.

10.4 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**	oral exam (30 minutes) or written exam (120 minutes)
module type	elective				
learning outcomes	▪ understand the fundamental concepts and theory of IT security and cryptography ▪ have in-depth knowledge of cryptographic schemes such as symmetric-key and public-key encryption, message authentication schemes and digital signature schemes				
competencies to be acquired	▪ explain various threats, attacker models, security goals and security services ▪ apply basic techniques and cryptographic algorithms to achieve security goals ▪ evaluate and analyze security of different schemes				
course contents	▪ security goals and attacker models ▪ mathematical foundations of cryptography (discrete probabilities and number theory) ▪ symmetric and public key cryptography (encryption, pseudorandom, hash functions, message authentication codes, authenticated encryption, key exchange, digital signatures) ▪ transport layer security ▪ selected topics in, e.g., network security, web security and system security				
module usability	M.Sc. Electrical Communication Engineering, B.Sc. Informatik				
module duration	one semester				
offered in	winter semester				
requirements	▪ undergrad mathematics, e.g., probability, random variables, linear algebra, abstract algebra ▪ modules “Computability and Complexity”, “Algorithms and Data Structures”				
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	▪ Rosulek: “*The Joy of Cryptography*”, (https://joyofcryptography.com/) ▪ Katz, Lindell:“*Introduction to Modern Cryptography*”, 3rd edition ▪ Stallings: “*Cryptography and Network Security: Principles and Practice*”, 8th edition ▪ Boneh and Shoup: „*A Graduate Course in Applied Cryptography*”, (https://toc.cryptobook.us/)				

10.5 Internet Measurements

<table>
<tr><td>module code</td><td colspan="5">R5a</td></tr>
<tr><td>module title</td><td colspan="5">Internet Measurements</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>Internet Measurements (lec)</td><td>lecture</td><td>4</td><td>6</td><td>oral exam (30 minuten) or written exam (120 minuten)</td></tr>
<tr><td>module type</td><td colspan="5">elective</td></tr>
<tr><td>learning outcomes</td><td colspan="5">▪ 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</td></tr>
<tr><td>competencies to be acquired</td><td colspan="5">▪ 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</td></tr>
<tr><td>course contents</td><td colspan="5">▪ 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?</td></tr>
<tr><td>module usability</td><td colspan="5">M.Sc. Electrical Communication Engineering, M.Sc. Informatik</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">Modules “Computer Networks”, “Internet Architecture and Services”.</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">Hohlfeld</td></tr>
<tr><td>lecturers</td><td colspan="5">Hohlfeld and team</td></tr>
<tr><td>media (teaching and learning methods)</td><td colspan="5">beamer (presentation), black board (explanations), slides, Moodle</td></tr>
<tr><td>literature</td><td colspan="5">▪ will be announced during the course</td></tr>
</table>

10.6 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				

11 Tabellarische Übersicht der Ausbildungsziele

	Ziel **W**issen und Kenntnisse
M-W1	Die Absolventinnen und Absolventen verfügen über ein vertieftes Wissen in den mathematisch-naturwissenschaftlichen und ökonomischen Bereichen.
M-W2	Die Absolventinnen und Absolventen besitzen vertiefte Kenntnisse in den elektrotechnischen Grundlagen oder untergeordneten und angrenzenden Disziplinen.
M-W3	Die Absolventinnen und Absolventen verfügen über erweiterte und angewandte fachspezifische Grundlagen in der Elektrotechnik oder untergeordneten und angrenzenden Disziplinen.
	Ziel **F**ertigkeiten
M-F1	Die Absolventinnen und Absolventen sind in der Lage, komplexe elektrotechnische oder fachübergreifende Aufgabenstellungen zu erkennen und einzuordnen.
M-F2	Die Absolventinnen und Absolventen besitzen die Fähigkeit zur sicheren Anwendung und Bewertung analytischer Methoden.
M-F3	Die Absolventinnen und Absolventen können selbstständig Lösungsmethoden entwickeln und beurteilen.
M-F4	Die Absolventinnen und Absolventen können sich in neue Wissensgebiete einarbeiten und dazu entsprechende Recherchen durchführen und die Ergebnisse beurteilen.
M-F5	Die Absolventinnen und Absolventen besitzen tiefgehende und wichtige Erfahrungen in praktischen technischen und ingenieurwissenschaftlichen Tätigkeiten.
	Ziel **K**ompetenzen in fachübergreifenden Bereichen
M-K1	Die Absolventinnen und Absolventen besitzen Vertrauen in ihr Wissen und Können und handeln selbstständig und verantwortungsbewusst.
M-K2	Die Absolventinnen und Absolventen besitzen die Fähigkeit zur effektiven Führung interdisziplinärer Teams.
M-K3	Die Absolventinnen und Absolventen erwerben die Fähigkeit zu allein verantwortlicher Leitung und Führung.
M-K4	Die Absolventinnen und Absolventen sind in der Lage, in nationalen und internationalen Kontexten zu arbeiten und zu forschen.

Abkürzungsverzeichnis der Lehrveranstaltungsarten	
Masterarbeit	MA_A
internes Praktikum	Pr_int
Seminar	S
Studienarbeit	St_A
Vorlesung	VL
Vorlesung mit Übung	VLmÜ
Vorlesung mit Praktikum	VLmP
Vorlesung mit Übung und Praktikum	VLmÜP

Modultyp	Modultitel	Modulcode	Lehrveranstaltung	Lehrveranstaltungsart	M-W1	M-W2	M-W3	M-F1	M-F2	M-F3	M-F4	M-F5	M-K1	M-K2	M-K3	M-K4
Basic Modules	Fundamentals of Digital Communications	B1a	Introduction to Digital Communications	VLmÜP	X	X	X		X							
	Fundamentals of Optoelectronics	B2a	Optoelectronic Devices	VLmÜP	X	X	X		X							
	Engineering Mathematics	B3a	Engineering Mathematics	VLmÜ	X	X		X	X							
	Scientific Publishing	B4a	Introduction to MATLAB	Pr_int			X	X	X							
			Introduction to LaTeX	VLmÜ						X						
	Social Communications	B5a	Social Communication	VLmÜ									X			X
Elective Modules in Wireless Communications	Physical Layer in Wireless Communications	R1a	Digital Communication Through Band-Limited Channels	VLmÜP	X	X	X	X	X	X						
			Digital Communication Over Fading Channels	VLmÜP	X	X	X	X	X	X						
	Reliable Transmission in Wireless Communications	R2a	Forward Error Correction in Wireless Communications	S	X	X	X	X	X	X	X					
			Medium Access Control Protocols in Wireless Communications	S	X	X	X	X	X	X	X					
			Introduction to Information Theory & Coding	VLmÜP	X	X	X	X	X	X						
	Signal Processing for Wireless Communications	R3a	Introduction to Signal Detection and Estimation	VLmÜP	X	X	X	X	X	X						
			Simulation of Digital Communication Systems using MATLAB	Pr_int	X	X	X	X	X	X						
			Signal Processing in Wireless Communications	S	X	X	X	X	X	X	X					
	Wireless Communications	R4a	Mobile Radio Systems	VLmÜ	X	X	X	X	X	X						
			Software Defined Radio	Pr_int	X	X	X	X	X	X						
	Wireless Communications Project Work	P1a	Wireless Communications Project Work	St_A	X	X	X	X	X	X	X		X			
	Wireless Communications Master Thesis	T1a	Wireless Communications Master Thesis	MA_A	X	X	X	X	X	X	X	X	X	X	X	X
Elective Modules in Electromagnetics	Electromagnetic Theory for Microwaves and Antennas	R1a	Electromagnetic Theory for Microwaves and Antennas	VLmÜ	X	X	X	X	X	X						
	Fields and Waves in Optoelectronic Devices	R2a	Fields and Waves in Optoelectronic Devices	VLmÜ	X	X	X	X	X	X						
	Fundamentals of Computational Photonics	R3a	Computational Photonics I	VLmÜP	X	X	X	X	X	X						
	Photonic Semiconductors	R4a	Computational Photonics II	VLmÜP	X	X	X	X	X	X						
			Semiconductor Devices – Theory and Modelling	VLmÜ	X	X	X	X	X	X	X					
	Electromagnetics Project Work	P1a	Electromagnetics Project Work	St_A	X	X	X	X	X	X	X		X			
	Electromagnetics Master Thesis	PT1a	Electromagnetics Master Thesis	MA_A	X	X	X	X	X	X	X	X		X	X	X
Elective Modules in Hardware Components for Communication Systems	Optical Metrology	R1a	Principles of Optical Metrology	S	X	X	X	X	X	X	X					
			Optical Metrology	Pr_int	X	X	X	X	X	X						
	Semiconductor Memories in Communication Systems	R2a	Semiconductor Memories: Technology, Design, Structures, Modeling and Simulation	VLmÜ	X	X	X	X	X	X						
			Concepts and Structures for Dynamic Runtime Reconfiguration	S	X	X	X	X	X	X	X					
	Optical Communication Systems	R3a	Optical Communication Systems	VLmP	X	X	X	X	X	X						
			Optical Communication Systems	S	X	X	X	X	X	X	X					
Elective Modules in Microwaves	Fundamentals of Linear Microwave Networks	R1a	Microwaves and Millimeter Waves I	VLmÜP	X	X	X	X	X	X						
	Microwave Integrated Circuits	R2a	Microwave Integrated Circuits II	VLmÜ	X	X	X	X	X	X						
		R2a	Microwave Integrated Circuits II	S	X	X	X	X	X	X	X					
	Microwave Engineering	R3a	Microwaves and Millimeter Waves I I	VLmÜP	X	X	X	X	X	X						
	Near-Range RADAR Sensors/RF Sensor Systems	R4a	RF Sensor Systems	VLmÜP	X	X	X	X	X	X						
	Microwaves Project Work	P1a	Microwaves Project Work	St_A	X	X	X	X	X	X	X		X			
	Microwaves Master Thesis	T1a	Microwaves Master Thesis	MA_A	X	X	X	X	X	X	X	X	X	X	X	X
Elective Modules in Optoelectronics	Optoelectronic Technologies	R1a	Microsystem Technology	VL	X	X	X	X	X	X						
			Technology of Electronic and Optoelectronic Devices	Pr_int	X	X	X	X	X	X						
	LASERs and Light Processing	R2a	Semiconductor Lasers	VLmÜ	X	X	X	X	X	X						
			Optoelectronics II	Pr_int	X	X	X	X	X	X						
			Optoelectronics I + II	S	X	X	X	X	X	X	X					
	Optoelectronics Project Work	P1a	Optoelectronics Project Work	St_A	X	X	X	X	X	X	X		X			
	Optoelectronics Master Thesis	T1a	Optoelectronics Master Thesis	MA_A	X	X	X	X	X	X	X	X	X	X	X	X
Elective Modules in Enabling Technologies for Communication Systems	Pattern Recognition and Machine Learning	R1a	Pattern Recognition and Machine Learning	VLmÜ	X	X	X	X	X	X						
	Temporal and Spatial Data Mining	R2a	Temporal and Spatial Data Mining	VL	X	X	X	X	X	X						
	Internet of Things	R3a	Internet of Things	VL	X	X	X	X	X	X						
	Introduction to Information Security	R4a	Introduction to Information Security	VL	X	X	X	X	X	X						
	Internet Measurements	R5a	Internet Measurements	VL	X	X	X	X	X	X						
	Internet Architecture and Services	R6a	Internet Architecture and Services	VL	X	X	X	X	X	X						

12 Tabular Overview of Study Objectives

	Objective **K**nowledge and Understanding
M-W1	The graduates have in-depth knowledge in mathematical and scientific areas.
M-W2	The graduates have in-depth knowledge of the fundamentals of communication and electrical engineering or subordinate and related disciplines.
M-W3	Graduates have advanced and applied subject-specific knowledge in communiation and electrical engineering or subordinate and related disciplines.
	Objective **S**kills
M-F1	Graduates are able to recognize and classify complex communiation and electrical engineering or interdisciplinary tasks.
M-F2	Graduates have the ability to confidently apply and evaluate analytical methods.
M-F3	The graduates can independently develop and evaluate solution methods.
M-F4	Graduates can familiarize themselves with new areas of knowledge, conduct appropriate research and evaluate the results.
M-F5	Graduates have in-depth and important experience in practical technical and engineering activities.
	Objective **C**ompetencies in Interdisciplinary Areas
M-K1	The graduates have confidence in their knowledge and skills and act independently and responsibly.
M-K2	Graduates have the ability to effectively lead interdisciplinary teams.
M-K3	The graduates acquire the ability to manage and lead independently.
M-K4	Graduates are able to work and research in national and international contexts.

List of abbreviations for course types	
Master Thesis	MT
Lab	Lab
Seminar	S
Study project	SP
Lecture	L
Lecture with exercise	L&E
Lecture with lab	L&Lab
Lecture with exercise and lab	L&E&Lab

Module Type	Module Title	Module Code	Course	Course Type	M-W1	M-W2	M-W3	M-F1	M-F2	M-F3	M-F4	M-F5	M-K1	M-K2	M-K3	M-K4
Basic Modules	Fundamentals of Digital Communications	B1a	Introduction to Digital Communications	L&E&Lab	X	X	X		X							
	Fundamentals of Optoelectronics	B2a	Optoelectronic Devices	L&E&Lab	X	X	X		X							
	Engineering Mathematics	B3a	Engineering Mathematics	L&E	X	X		X	X							
	Scientific Publishing	B4a	Introduction to MATLAB	Lab			X	X	X							
			Introduction to LaTeX	L&E						X						
	Social Communications	B5a	Social Communication	L&E									X			X
Elective Modules in Wireless Communications	Physical Layer in Wireless Communications	R1a	Digital Communication Through Band-Limited Channels	L&E&Lab	X	X	X	X	X	X						
			Digital Communication Over Fading Channels	L&E&Lab	X	X	X	X	X	X						
	Reliable Transmission in Wireless Communications	R2a	Forward Error Correction in Wireless Communications	S	X	X	X	X	X	X	X					
			Medium Access Control Protocols in Wireless Communications	S	X	X	X	X	X	X	X					
			Introduction to Information Theory & Coding	L&E&Lab	X	X	X	X	X	X						
	Signal Processing for Wireless Communications	R3a	Introduction to Signal Detection and Estimation	L&E&Lab	X	X	X	X	X	X						
			Simulation of Digital Communication Systems using MATLAB	Lab	X	X	X	X	X	X						
			Signal Processing in Wireless Communications	S	X	X	X	X	X	X	X					
	Wireless Communications	R4a	Mobile Radio Systems	L&E	X	X	X	X	X	X						
			Software Defined Radio	Lab	X	X	X	X	X	X						
	Wireless Communications Project Work	P1a	Wireless Communications Project Work	SP	X	X	X	X	X	X	X		X			
	Wireless Communications Master Thesis	T1a	Wireless Communications Master Thesis	MT	X	X	X	X	X	X	X	X	X	X	X	X
Elective Modules in Electromagnetics	Electromagnetic Theory for Microwaves and Antennas	R1a	Electromagnetic Theory for Microwaves and Antennas	L&E	X	X	X	X	X	X						
	Fields and Waves in Optoelectronic Devices	R2a	Fields and Waves in Optoelectronic Devices	L&E	X	X	X	X	X	X						
	Fundamentals of Computational Photonics	R3a	Computational Photonics I	L&E&Lab	X	X	X	X	X	X						
	Photonic Semiconductors	R4a	Computational Photonics II	L&E&Lab	X	X	X	X	X	X						
			Semiconductor Devices – Theory and Modelling	L&E	X	X	X	X	X	X	X					
	Electromagnetics Project Work	P1a	Electromagnetics Project Work	SP	X	X	X	X	X	X	X		X			
	Electromagnetics Master Thesis	PT1a	Electromagnetics Master Thesis	MT	X	X	X	X	X	X	X	X		X	X	X
Elective Modules in Hardware Components for Communication Systems	Optical Metrology	R1a	Principles of Optical Metrology	S	X	X	X	X	X	X	X					
			Optical Metrology	Lab	X	X	X	X	X	X						
	Semiconductor Memories in Communication Systems	R2a	Semiconductor Memories: Technology, Design, Structures, Modeling and Simulation	L&E	X	X	X	X	X	X						
			Concepts and Structures for Dynamic Runtime Reconfiguration	S	X	X	X	X	X	X	X					
	Optical Communication Systems	R3a	Optical Communication Systems	L&Lab	X	X	X	X	X	X						
			Optical Communication Systems	S	X	X	X	X	X	X	X					
Elective Modules in Microwaves	Fundamentals of Linear Microwave Networks	R1a	Microwaves and Millimeter Waves I	L&E&Lab	X	X	X	X	X	X						
	Microwave Integrated Circuits	R2a	Microwave Integrated Circuits II	L&E	X	X	X	X	X	X						
		R2a	Microwave Integrated Circuits II	S	X	X	X	X	X	X	X					
	Microwave Engineering	R3a	Microwaves and Millimeter Waves I I	L&E&Lab	X	X	X	X	X	X						
	Near-Range RADAR Sensors/RF Sensor Systems	R4a	RF Sensor Systems	L&E&Lab	X	X	X	X	X	X						
	Microwaves Project Work	P1a	Microwaves Project Work	SP	X	X	X	X	X	X	X		X			
	Microwaves Master Thesis	T1a	Microwaves Master Thesis	MT	X	X	X	X	X	X	X	X	X	X	X	X
Elective Modules in Optoelectronics	Optoelectronic Technologies	R1a	Microsystem Technology	L	X	X	X	X	X	X						
			Technology of Electronic and Optoelectronic Devices	Lab	X	X	X	X	X	X						
	LASERs and Light Processing	R2a	Semiconductor Lasers	L&E	X	X	X	X	X	X						
			Optoelectronics II	Lab	X	X	X	X	X	X						
			Optoelectronics I + II	S	X	X	X	X	X	X	X					
	Optoelectronics Project Work	P1a	Optoelectronics Project Work	SP	X	X	X	X	X	X	X		X			
	Optoelectronics Master Thesis	T1a	Optoelectronics Master Thesis	MT	X	X	X	X	X	X	X	X	X	X	X	X
Elective Modules in Enabling Technologies for Communication Systems	Pattern Recognition and Machine Learning	R1a	Pattern Recognition and Machine Learning	L&E	X	X	X	X	X	X						
	Temporal and Spatial Data Mining	R2a	Temporal and Spatial Data Mining	L	X	X	X	X	X	X						
	Internet of Things	R3a	Internet of Things	L	X	X	X	X	X	X						
	Introduction to Information Security	R4a	Introduction to Information Security	L	X	X	X	X	X	X						
	Internet Measurements	R5a	Internet Measurements	L	X	X	X	X	X	X						
	Internet Architecture and Services	R6a	Internet Architecture and Services	L	X	X	X	X	X	X						