Module handbook of the master's program in

Electrical Communication Engineering

at the Dept. of Electrical Engineering/Computer Science

University of Kassel

Status: Summer Semester 2016

Table of Contents

1 Course scheme samples

In the following, course scheme samples are listed which serve as examples for selecting modules with a certain overall focus. The foci include

- **Digital Communications**
- **Electromagnetics**
- **Hardware Components for Communication Systems**
- **Microwaves**
- **Mobile Internet**
- **Optoelectronics**
- **OSI Model**
- **Software Components for Communication Systems.**

The samples for a certain focus include **two versions of course schemes**, namely

- one **starting in the summer semester** and
- one **starting in the winter semester**.

Note that neither of these sample versions is mandatory in any way, but both versions rather represent reasonable choices recommended for the corresponding focus. Clearly, each student is free to select other combinations from the modules listed in Sect. 2 complying with the examination rules and corresponding to the individual knowledge in the different areas.

Each course scheme sample contains the corresponding recommended modules which are described in greater detail in Sect. 2. Note that unlike Sect. 2, Sect. 3 contains qualification modules which represent additional mandatory modules in case the examination board grants a conditional admission according to §4 par.(5) of the ECE examination regulation. See Sect. 3 for further details.

1.1 Digital Communications

Course scheme sample with focus on *Digital Communications*							
Start in *summer semester*							
semester	winter semester (WS)/ summer semester (SS)	Credits					
		6	12	18	24	30	
1	SS	Digital Communications R1a		Digital Communications R2a	Mobile Internet R1a	Social Communication NT1a	
2	WS	Digital Communications R3a		Digital Communications R4a	Digital Communications P1a	Mobile Internet R2a	
3	SS	Digital Communications T1a (Master's Thesis)					

Course scheme sample with focus on *Digital Communications*							
Start in *winter semester*							
semester	winter semester (WS)/ summer semester (SS)	Credits					
		6	12	18	24	30	
1	WS	Digital Communications R3a		Digital Communications R4a	Microwaves R3a	Social Communication NT1a	
2	SS	Digital Communications R1a		Digital Communications P1a	Digital Communications R2a	Mobile Internet R1a	
3	WS	Digital Communications T1a (Master's Thesis)					

1.2 Electromagnetics

Course scheme sample with focus on *Electromagnetics*						
Start in *summer semester*						
semester	winter semester (WS)/ summer semester (SS)	Credits				
		6	12	18	24	30
1	SS	Electromagnetics R1a		Microwaves R1a	Microwaves R2a	Social Communication NT1a
2	WS	Electromagnetics R2a		Electromagnetics R3a	Electromagnetics P1a	Microwaves R3a
3	SS	Electromagnetics T1a (Master's Thesis)				

Course scheme sample with focus on *Electromagnetics*						
Start in *winter semester*						
semester	winter semester (WS)/ summer semester (SS)	Credits				
		6	12	18	24	30
1	WS	Electromagnetics R2a		Electromagnetics R3a	Microwaves R3a	Social Communication NT1a
2	SS	Electromagnetics R1a		Electromagnetics P1a	Microwaves R1a	Microwaves R2a
3	WS	Electromagnetics T1a (Master's Thesis)				

1.3 Hardware Components for Communication Systems

Course scheme sample with focus on *Hardware Components for Communication Systems*						
Start in *summer semester*						
semester	winter semester (WS)/ summer semester (SS)	Credits				
		6	12	18	24	30
1	SS	Hardware Components for Communication Systems R1a	Hardware Components for Communication Systems R4a		Microwaves R1a	Social Communication NT1a
2	WS	Microwaves R3a	Hardware Components for Communication Systems R3a		Microwaves P1a *or* Optoelectronics P1a	Microwaves R4a
3	SS	Microwaves T1a *or* Optoelectronics T1a (Master's Thesis)				

Course scheme sample with focus on *Hardware Components for Communication Systems*						
Start in *winter semester*						
semester	winter semester (WS)/ summer semester (SS)	Credits				
		6	12	18	24	30
1	WS	Microwaves R3a	Hardware Components for Communication Systems R3a		Microwaves R4a	Social Communication NT1a
2	SS	Hardware Components for Communication Systems R1a	Hardware Components for Communication Systems R4a		Microwaves R1a	Microwaves P1a *or* Optoelectronics P1a
3	WS	Microwaves T1a *or* Optoelectronics T1a (Master's Thesis)				

1.4 Microwaves

Course scheme sample with focus on *Microwaves*						
Start in *summer semester*						
semester	winter semester (WS)/ summer semester (SS)	Credits				
		6	12	18	24	30
1	SS	Microwaves R1a	Microwaves R2a	Electromagnetics R1a		Social Communication NT1a
2	WS	Microwaves R3a	Microwaves R4a	Electromagnetics R2a		Microwaves P1a
3	SS	Microwaves T1a (Master's Thesis)				

Course scheme sample with focus on *Microwaves*						
Start in *winter semester*						
semester	winter semester (WS)/ summer semester (SS)	Credits				
		6	12	18	24	30
1	WS	Microwaves R3a	Microwaves R4a	Electromagnetics R2a		Social Communication NT1a
2	SS	Microwaves R1a	Microwaves R2a	Microwaves P1a	Electromagnetics R1a	
3	WS	Microwaves T1a (Master's Thesis)				

1.5 Mobile Internet

Course scheme sample with focus on *Mobile Internet*						
Start in *summer semester*						
semester	winter semester (WS)/ summer semester (SS)	Credits				
		6	12	18	24	30
1	SS	Mobile Internet R1a	Digital Communications R1a		Digital Communications R2a	Social Communication NT1a
2	WS	Mobile Internet R2a	Mobile Internet P1a	Digital Communications R3a		Digital Communications R4a
3	SS	Mobile Internet T1a (Master's Thesis)				

Course scheme sample with focus on *Mobile Internet*						
Start in *winter semester*						
semester	winter semester (WS)/ summer semester (SS)	Credits				
		6	12	18	24	30
1	WS	Digital Communications R3a		Digital Communications R4a	Microwaves R3a	Social Communication NT1a
2	SS	Mobile Internet R1a	Mobile Internet P1a	Digital Communications R1a		Digital Communications R2a
3	WS	Mobile Internet T1a (Master's Thesis)				

1.6 Optoelectronics

Course scheme sample with focus on *Optoelectronics*						
Start in *summer semester*						
semester	winter semester (WS)/ summer semester (SS)	Credits				
		6	12	18	24	30
1	SS	Optoelectronics R1a	Electromagnetics R1a		Hardware Components for Communication Systems R1a	Social Communication NT1a
2	WS	Optoelectronics R2a		Hardware Components for Communication Systems R3a		Optoelectronics P1a
3	SS	Optoelectronics T1a (Master's Thesis)				

Course scheme sample with focus on *Optoelectronics*						
Start in *winter semester*						
semester	winter semester (WS)/ summer semester (SS)	Credits				
		6	12	18	24	30
1	WS	Optoelectronics R2a		Hardware Components for Communication Systems R3a		Social Communication NT1a
2	SS	Electromagnetics R1a		Optoelectronics R1a	Optoelectronics P1a	Hardware Components for Communication Systems R1a
3	WS	Optoelectronics T1a (Master's Thesis)				

1.7 OSI Model

Course scheme sample with focus on *Different Layers of the OSI Model*						
Start in *summer semester*						
semester	winter semester (WS)/ summer semester (SS)	Credits				
		6	12	18	24	30
1	SS	Mobile Internet R1a	Microwaves R1a	Hardware Components for Communication Systems R1a	Optoelectronics R1a	Social Communication NT1a
2	WS	Digital Communications R4a	Electromagnetics R3a	DC P1a *or* EM P1a *or* MW P1a *or* MI P1a *or* OE P1a	Optoelectronics R2a	
3	SS	DC T1a *or* EM T1a *or* MW T1a *or* MI T1a *or* OE T1a (Master's Thesis)				

Course scheme sample with focus on *Different Layers of the OSI Model*						
Start in *winter semester*						
semester	winter semester (WS)/ summer semester (SS)	Credits				
		6	12	18	24	30
1	WS	Digital Communications R4a	Electromagnetics R3a	Optoelectronics R2a		Social Communication NT1a
2	SS	Mobile Internet R1a	Microwaves R1a	DC P1a *or* EM P1a *or* MW P1a *or* MI P1a *or* OE P1a	Optoelectronics R1a	Hardware Components for Communication Systems R1a
3	WS	DC T1a *or* EM T1a *or* MW T1a *or* MI T1a *or* OE T1a (Master's Thesis)				

1.8 Software Components for Communication Systems

Course scheme sample with focus on *Software Components for Communication Systems*						
Start in *summer semester*						
semester	winter semester (WS)/ summer semester (SS)	Credits				
		6	12	18	24	30
1	SS	Software Components for Communication Systems R1a		Digital Communications R2a	Software Components for Communication Systems R3b	Social Communication NT1a
2	WS	Software Components for Communication Systems R2a		Mobile Internet P1a *or* Digital Communications P1a	Digital Communications R3a	
3	SS	Digital Communications T1a *or* Mobile Internet T1a (Master's Thesis)				

Course scheme sample with focus on *Software Components for Communication Systems*						
Start in *winter semester*						
semester	winter semester (WS)/ summer semester (SS)	Credits				
		6	12	18	24	30
1	WS	Digital Communications R3a		Software Components for Communication Systems R2a		Social Communication NT1a
2	SS	Software Components for Communication Systems R1a		Mobile Internet P1a *or* Digital Communications P1a	Digital Communications R2a	Software Components for Communication Systems R3b
3	WS	Digital Communications T1a *or* Mobile Internet T1a (Master's Thesis)				

2 Modules of the ECE master's program

In this section, all modules which can be selected during the three semesters of the ECE master's program are listed. The modules cover the areas of

- Digital Communications
- Electromagnetics
- Hardware Components for Communication Systems
- Microwaves
- Mobile Internet
- Optoelectronics
- Software Components for Communication Systems.

Within each area, we have the following naming convention: The label of a module, for example *Digital Communications R1*, is made up by the three attributes <AREA TYPE NO>. While AREA and NO denote one of the aforementioned areas and a consecutive numbering, resp., TYPE takes one of the following values:

R **r**egular modules consisting of lectures, exercises, lab trainings and seminars
P **p**roject module
T **t**hesis module (master thesis)
NT **n**on-**t**echnichal module *Social Communication NT1*.

2.1 Digital Communications

<table>
<tr><td>Module title</td><td colspan="5">Digital Communications R1b</td></tr>
<tr><td rowspan="5">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Digital Communication Through Band-Limited Channels (lec and ex)</td><td>lecture and exercises</td><td>2</td><td>4</td><td rowspan="2">lab attendance and oral exam (30 minutes)</td></tr>
<tr><td>Digital Communication Through Band-Limited Channels (lab)</td><td>lab training</td><td>1</td><td>2</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 minutes)</td></tr>
<tr><td>Simulation of Digital Communication Systems using MATLAB (lab)</td><td>lab training</td><td>2</td><td>3</td><td>lab training attendance, programming, oral exam (30 minutes)</td></tr>
<tr><td>Module credits</td><td colspan="5">12</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in summer semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Dahlhaus, Mansour, Mohamad</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Dahlhaus</td></tr>
<tr><td>Required qualifications</td><td colspan="5">Knowledge of fundamentals in digital communications</td></tr>
<tr><td>Workload</td><td colspan="5">115 hours course attendance
245 hours self-study</td></tr>
<tr><td>Contents</td><td colspan="5">▪ Carrier and timing recovery, signalling in band-limited channels, transmission over linear band-limited channels, intersymbol interference, adaptive equalization, multicarrier transmission
▪ Medium access control in wireless communication systems.
▪ Introduction to MATLAB and its most important commands, simulation of a simple transmission chain, channel coding (convolutional codes), coding gain, channels with multipath propagation, channel models with fading and bit-error rate performance for binary signalling, transmission with orthogonal frequency-division multiplexing (OFDM), interleaving, implementation of an OFDM modem.</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.
▪ Additional papers to be handed out according to seminar topics.</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (presentation, seminar), black board (derivations, explanations), paper (exercises), PC based software development (lab training), EMONA kit experiments.</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ Understanding receiver algorithms in the physical layer of real-world communication systems including aspects in the receiver design which characterize the trade-off
▪ Literature and internet based investigation on a topic from medium access control in wireless communication systems
▪ Introduction to scientific work in the field of medium access control in wireless transmission systems
▪ Presentation of a scientific topic in a seminar.
▪ Understanding approaches for numerical simulation of transceivers in the physical layer of communication systems.</td></tr>
<tr><td>Competences 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)
▪ Design of terminals and base stations, in particular for wireless communications based on multicarrier transmission
▪ Operation and maintenance of devices in production processes.</td></tr>
</table>

<table>
<tr><td>Module title</td><td colspan="5">Digital Communications R2a</td></tr>
<tr><td rowspan="3">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Introduction to Signal Detection and Estimation (lec)</td><td>lecture</td><td>2</td><td>4</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>Introduction to Signal Detection and Estimation (ex)</td><td>exercises</td><td>1</td><td>2</td></tr>
<tr><td>Module credits</td><td colspan="5">6</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in summer semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Dahlhaus</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Dahlhaus</td></tr>
<tr><td>Required qualifications</td><td colspan="5">Knowledge of fundamentals in digital communications</td></tr>
<tr><td>Workload</td><td colspan="5">45 hours course attendance
135 hours self-study</td></tr>
<tr><td>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</td></tr>
<tr><td>Literature</td><td colspan="5">▪ H. Vincent Poor, An Introduction to Signal Detection and Estimation, Springer, 2nd ed., ISBN 0-387-94173-8 or ISBN 3-540-94173-8.
▪ Papoulis, S. U. Pillai, Probability, Random Variables, and Stochastic Processes, McGraw-Hill, 4th ed., ISBN 0071226613.
▪ H.L. van Trees, Detection, Estimation, and Modulation Theory, vol. I, New York, NY: John Wiley & Sons, 1968.</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (presentation), black board (derivations, explanations), paper (exercises).</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ Statistical inference in the context of optimum hypothesis testing and signal estimation schemes
▪ Ability to derive optimum signal processing schemes</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">▪ Research and development in the area of digital transmission systems and statistical inference (e.g. quality management)
▪ Research and development in the area of signal processing for wireless and wired digital communication systems.</td></tr>
</table>

<table>
<tr><td>Module title</td><td colspan="5">Digital Communications R3b</td></tr>
<tr><td rowspan="5">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Mobile Radio (lec)</td><td>lecture</td><td>2</td><td>4</td><td>oral exam (30 minutes)</td></tr>
<tr><td>Digital Communication Over Fading Channels (lec and ex)</td><td>lecture and exercises</td><td>2</td><td>3</td><td rowspan="2">lab attendance and oral exam (30 minutes)</td></tr>
<tr><td>Digital Communication Over Fading Channels (lab)</td><td>lab training</td><td>1</td><td>2</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 minutes)</td></tr>
<tr><td>Module credits</td><td colspan="5">12</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in winter semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Dahlhaus, Mansour, Mohamad</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Dahlhaus</td></tr>
<tr><td>Required qualifications</td><td colspan="5">Knowledge of fundamentals in digital and wireless communications</td></tr>
<tr><td>Workload</td><td colspan="5">115 hours course attendance
245 hours self-study</td></tr>
<tr><td>Contents</td><td colspan="5">▪ 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) transmission, multiuser detection, code-division multiple access (CDMA) and random access
▪ 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, conventional detection, near-far problem, joint detection, overview of UMTS and elements of the UTRA-FDD air interface; multi-antenna techniques such as adaptive beamforming to be adopted by LTE
▪ Overview of existing wireless communication systems, basics in the characterization of wireless channels and signal processing in wireless transceivers, channel modelling, signal processing at the transmitter with/without channel coding for different wireless systems, selected topics from signal processing (e.g. radio frequency identification (RFID)), short-range radio, satellite communications, radio broadcast with analog modulation, Wireless Personal Area Networks (WPANs), Wireless Local Area Networks (WLANs), cellular radio of second (2G), third generation (3G) and systems beyond 3G, software tools for research and development, standardization bodies and research trends in the area of signal processing in wireless communication systems.</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.
▪ 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.
▪ Additional papers to be handed out according to seminar topics.</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (lecture, seminar), black board (derivations, explanations), paper (exercises), EMONA kit experiments.</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ Detailed understanding of schemes in the physical layer of digital communication systems
▪ Understanding the channel characterization, interference phenomena and signal processing in advanced wireless and mobile radio systems</td></tr>
</table>

	▪ Introduction to scientific work ▪ Literature and internet based investigation to understand advanced topics in signal processing ▪ Presentation of a scientific topic in a seminar.
Competences to be acquired	▪ Research and development in the area of signal processing for wireless and wired digital communication systems ▪ Operation and maintenance of devices in communication systems ▪ Consulting in the area of information technology.

<table>
<tr><td>Module title</td><td colspan="5">Digital Communications R4b</td></tr>
<tr><td rowspan="3">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Introduction to Information Theory & Coding (lec and ex)</td><td>lecture and exercises</td><td>3</td><td>5</td><td rowspan="2">lab attendance and oral exam (30 minutes)</td></tr>
<tr><td>Introduction to Information Theory & Coding (lab)</td><td>lab training</td><td>1</td><td>1</td></tr>
<tr><td>Module credits</td><td colspan="5">6</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in winter semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Mohamad</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Dahlhaus</td></tr>
<tr><td>Required qualifications</td><td colspan="5">Knowledge of fundamentals in digital communications</td></tr>
<tr><td>Workload</td><td colspan="5">70 hours course attendance
110 hours self-study</td></tr>
<tr><td>Contents</td><td colspan="5">▪ Fundamentals in information theory, entropy, 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)</td></tr>
<tr><td>Literature</td><td colspan="5">▪ T. Cover and J.A. Thomas, Elements of Information Theory, 2nd ed., Wiley, ISBN: 978-0-471-24195-9
▪ 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>
<tr><td>Media</td><td colspan="5">Beamer (presentation), black board (derivations, explanations), paper (exercises), EMONA kit experiments.</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ Understanding fundamentals in communications 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.</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">▪ Research and development in source and channel coding
▪ Research and development in the area of signal processing for wireless and wired digital communication systems.</td></tr>
</table>

Module title	**Digital Communications P1a**				
Courses	**Title**	**Type**	**SWS**	**Credits**	**Performance requirements/ Examination**
	Digital Communications Project Work	project	4	6	Report and presentation
Module credits	6				
Language	English				
Held	in summer and winter semesters, topics on demand anytime				
Lecturer(s)	Dahlhaus and team				
Responsible(s)	Dahlhaus				
Required qualifications	Knowledge of fundamentals in digital communications				
Workload	60 hours course attendance 120 hours self-study				
Contents	▪ Schemes in the physical and medium access control layers of the OSI model for wired/wireless communication systems ▪ Topics of digital communications.				
Literature	▪ J.G. Proakis, *Digital Communications*, McGraw-Hill, 4th ed., ISBN 0-07-118183-0. ▪ H. Vincent Poor, *An Introduction to Signal Detection and Estimation*, Springer, 2nd ed., ISBN 0-387-94173-8 or ISBN 3-540-94173-8. ▪ Papoulis, S. U. Pillai, *Probability, Random Variables, and Stochastic Processes*, McGraw-Hill, 4th ed., ISBN 0071226613. ▪ 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.				
Media	PC based software development and/or hardware development (project work), beamer (presentation of results), report (electronic form and hard copy).				
Objectives	▪ 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 of a report and presentation of results.				
Competences to be acquired	▪ Literature and internet based investigation ▪ Structured approach for solving a problem ▪ Independent scientific work ▪ Ability to work in a team and to exchange ideas ▪ Presentation in the framework of a project.				

<table>
<tr><td>Module title</td><td colspan="5">Digital Communications T1a</td></tr>
<tr><td rowspan="2">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Digital Communications
Master Thesis</td><td>master thesis</td><td>20</td><td>30</td><td>Report and presentation</td></tr>
<tr><td>Module credits</td><td colspan="5">30</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in summer and winter semesters, topics on demand anytime</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Dahlhaus and team</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Dahlhaus</td></tr>
<tr><td>Required qualifications</td><td colspan="5">▪ Knowledge of fundamentals in digital communications
▪ Proof of fulfilled admission requirements for the Master thesis according to the ECE examination regulation</td></tr>
<tr><td>Workload</td><td colspan="5">300 hours course attendance
600 hours self-study</td></tr>
<tr><td>Contents</td><td colspan="5">▪ Schemes in the physical and medium access control layers of the OSI model for wired/wireless communication systems
▪ Topics of digital communications.</td></tr>
<tr><td>Literature</td><td colspan="5">▪ J.G. Proakis, Digital Communications, McGraw-Hill, 4th ed., ISBN 0-07-118183-0.
▪ H. Vincent Poor, An Introduction to Signal Detection and Estimation, Springer, 2nd ed., ISBN 0-387-94173-8 or ISBN 3-540-94173-8.
▪ Papoulis, S. U. Pillai, Probability, Random Variables, and Stochastic Processes, McGraw-Hill, 4th ed., ISBN 0071226613.
▪ H.L. van Trees, Detection, Estimation, and Modulation Theory, vol. I, New York, NY: John Wiley & Sons, 1968.
▪ Additional papers/references according to thesis topics.</td></tr>
<tr><td>Media</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>Objectives</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 of a report and presentation of results in a colloquium.</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">▪ Literature and internet based investigation
▪ Independent scientific work
▪ Compilation of a report, preparation of a talk and presentation of scientific results.</td></tr>
</table>

2.2 Electromagnetics

<table>
<tr><td>Module title</td><td colspan="5">Electromagnetics R1a</td></tr>
<tr><td rowspan="6">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Semiconductor Devices – Theory and Modelling (lec)</td><td>lecture</td><td>2</td><td>4</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>Semiconductor Devices – Theory and Modelling (ex)</td><td>exercises</td><td>1</td><td>1</td></tr>
<tr><td>Numerical Methods in Electromagnetic Field Theory II (lec)</td><td>lecture</td><td>2</td><td>4</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>Numerical Methods in Electromagnetic Field Theory II (ex)</td><td>exercises</td><td>1</td><td>1</td></tr>
<tr><td>Numerical Methods in Electromagnetic Field Theory 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 credits</td><td colspan="5">12</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in summer semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Witzigmann, Römer, Mayer</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Witzigmann</td></tr>
<tr><td>Required qualifications</td><td colspan="5">Mathematical foundations in electromagnetic field theory</td></tr>
<tr><td>Workload</td><td colspan="5">120 hours course attendance
240 hours self-study</td></tr>
<tr><td>Contents</td><td colspan="5">▪ Introduction to semiconductors, quantum mechanics, numerical modeling, the pn diode, the transistor, the LED, the photovoltaic cell, nanostructures
▪ Introduction to the theory and application of various numerical methods in problems of electromagnetic field theory: finite difference method (FDM), finite difference time domain (FDTD), Finite Integration Technique (FIT), finite element method (FEM), finite volume method (FVM), moments method and boundary element method.</td></tr>
<tr><td>Literature</td><td colspan="5">▪ Harrington, R. F., Field Computation by Moment Methods, IEEE Press, Piscataway, New Jersey, USA, 1993 (reprint of original edition: R. E. Krieger Pub. Company, Fla., USA, 1968)
▪ 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.
▪ Taflove, A., Hagness, S.: Computational Electrodynamics, The Finite-Difference Time-Domain Method, 3rd Edition, Artech House, Norwood, Mass., USA, 2005.</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (presentation), black board (derivations, explanations), paper (exercises), PC based software development (exercises).</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ Introduction to the principles of semiconductor devices.
▪ Understand and analyze the basic theory and the models that describe the characteristics of semiconductor devices.
▪ Understand the impact of nanoscience on the latest device concepts (nanowires, quantum dots).
▪ Knowledge of various numerical methods for solution of Maxwell's equations in time and Frequency domains by applying different methods.</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">▪ Research and development in electromagnetic theory for semiconductor devices
▪ Implementation of algorithms on a PC
▪ Interpretation and evaluation of numerical results.</td></tr>
</table>

<table>
<tr><td>Module title</td><td colspan="5">Electromagnetics R2a</td></tr>
<tr><td rowspan="8">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Electromagnetic Theory for Microwaves and Antennas (lec)</td><td>lecture</td><td>2</td><td>4</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>Electromagnetic Theory for Microwaves and Antennas (ex)</td><td>exercises</td><td>1</td><td>1</td></tr>
<tr><td>Fields and Waves in Optoelectronic Devices (lec)</td><td>lecture</td><td>2</td><td>4</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>Fields and Waves in Optoelectronic Devices (ex)</td><td>exercises</td><td>1</td><td>1</td></tr>
<tr><td>Current Topics in Electromagnetic Field Theory (sem)</td><td>seminar</td><td>2</td><td>2</td><td>seminar attendance and presentation</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td colspan="5"></td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>Module credits</td><td colspan="5">12</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in winter semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Witzigmann, Marklein, Römer, Mayer</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Witzigmann</td></tr>
<tr><td>Required qualifications</td><td colspan="5">Mathematical foundations in electromagnetic field theory</td></tr>
<tr><td>Workload</td><td colspan="5">120 hours course attendance
240 hours self-study</td></tr>
<tr><td>Contents</td><td colspan="5">▪ Fundamentals of Electromagnetic Field Theory, Electromagnetic waves, Transmission Line Theory, Theory of Electromagnetic Waves, Time-dependent boundary value problems, metallic waveguides and resonators, periodic structures and coupled modes, dispersive and anisotropic media, electromagnetic source fields, antennas, Gaussian beam, integral equations, scattering theory, inverse scattering problems.
▪ Semiconductor Basics, Electromagnetics, Fibre Propagation, Interaction of Light and Semiconductors, Characteristics of State of the Art Optoelectronic Devices
▪ Topics in electromagnetic field theory.</td></tr>
<tr><td>Literature</td><td colspan="5">▪ Inhomogeneous Media, Wiley-IEEE Press, New York, 1999.
▪ K.J. Langenberg, Theorie elektromagnetischer Wellen. Buchmanuskript, FG Theorie der Elektrotechnik und Photonik, FB Elektrotechnik/Informatik, Universität Kassel, Kassel, 2003.
▪ J.G. Van Bladel, Electro Magnetic Fields, Wiley-IEEE Press, New York, 2007.
▪ K. Zhang, Li, Deji, Electromagnetic Theory for Microwaves and Optoelectronics, 2nd Ed., Springer, Berlin, 2008.
▪ Shun Lien Chuang, Physics of Optoelectronic Devices, Wiley, 1995.
▪ Voges und Petermann, Optische Kommunikationstechnik, Springer, 2002.
▪ Coldren and Corzine, Diode Lasers and Photonic Integrated Circuits, Wiley, 1995.
▪ Additional papers to be handed out according to seminar topics.</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (presentation), black board (derivations, explanations), paper (exercises), PC based software development (exercises).</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ Understanding applications of electromagnetic field theory in microwave and antenna technology.
▪ Understanding the fundamentals of optoelectronic devices and the principles of modelling and simulation of these devices.
▪ Presentation of a scientific topic in a seminar.</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">Research and development in the area of electromagnetic field theory for microwaves, antennas and optoelectronic devices.</td></tr>
</table>

Module title	**Electromagnetics R3a**				
Courses	**Title**	**Type**	**SWS**	**Credits**	**Performance requirements/ Examination**
	Numerical Methods in Electromagnetic Field Theory I (lec)	lecture	2	3	oral exam (30 minutes)
	Numerical Methods in Electromagnetic Field Theory I (ex)	exercises	1	1	
	Numerical Methods in Electromagnetic Field Theory I (lab)	lab training	2	2	lab training attendance and conductance of experiments
Module credits	6				
Language	English				
Held	in winter semester, annually				
Lecturer(s)	Witzigmann, Römer				
Responsible(s)	Witzigmann				
Required qualifications	▪ Mathematical foundations in electromagnetic field theory ▪ Basic knowledge of semiconductor materials				
Workload	75 hours course attendance 105 hours self-study				
Contents	▪ Semiconductor Transport: Boltzmann equation, drift-diffusion box method, boundary conditions ▪ Schrodinger equation: finite-difference method, eigen value problems, finite element method ▪ Continuum mechanics: basic equations, application to nanostructures, discretization				
Literature	▪ S. Selberherr, *Analysis and Simulation of Semiconductor Devices* ▪ J. Jin, *The Finite Element Method in Electromagnetics*				
Media	Beamer (presentation), black board (derivations, explanations), paper (exercises), PC based software development (exercises).				
Objectives	▪ Knowledge of discretization of the semiconductor transport equations, Schrödinger equation and continuum mechanics ▪ Application of commercial device simulators, independent programming of numerical problems				
Competences to be acquired	▪ Research and development in the area of analysis and numerical approaches for electromagnetics ▪ Interpretation and evaluation of numerical results.				

Module title	Electromagnetics P1a				
Courses	**Title**	**Type**	**SWS**	**Credits**	**Performance requirements/ Examination**
	Electromagnetics Project Work	project	4	6	Report and presentation
Module credits	6				
Language	English				
Held	in summer and winter semesters, topics on demand anytime				
Lecturer(s)	Witzigmann and team				
Responsible(s)	Witzigmann				
Required qualifications	Knowledge of fundamentals in electromagnetic field theory				
Workload	60 hours course attendance 120 hours self-study				
Contents	▪ Analysis of a problem (project task) in the area of field theory ▪ Structured approach to the solution.				
Literature	Scientific papers/books according to project topics.				
Media	PC based software development and/or hardware development (project work), beamer (presentation of results), report (electronic form and hard copy).				
Objectives	▪ Application of knowledge acquired in the area of field theory to a specific technical/scientific problem ▪ Solving a problem individually or in a team ▪ Writing of a report and presentation of results.				
Competences to be acquired	▪ Literature and internet based investigation ▪ Structured approach for solving a problem ▪ Independent scientific work ▪ Ability to work in a team and to exchange ideas ▪ Presentation in the framework of a project.				

Module title	Electromagnetics T1a				
Courses	**Title**	**Type**	**SWS**	**Credits**	**Performance requirements/ Examination**
	Electromagnetics Master Thesis	master thesis	20	30	Report and presentation
Module credits	30				
Language	English				
Held	in summer and winter semesters, topics on demand anytime				
Lecturer(s)	Witzigmann and team				
Responsible(s)	Witzigmann				
Required qualifications	▪ Knowledge of fundamentals in field theory ▪ Proof of fulfilled admission requirements for the Master thesis according to the ECE examination regulation				
Workload	300 hours course attendance 600 hours self-study				
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.				
Literature	▪ Langenberg, *Skriptum Elektromagnetische Feldtheorie*, Kassel 2000 (in German) ▪ Marklein, *Numerische Modellierung von Wellenausbreitungsproblemen im Zeitbereich*, Dissertation, Kassel, 1998, (in German) ▪ Hollins C. Chen, *Theory of Electromagnetic Waves*, McGraw Hill 1983 ▪ Additional papers/references according to thesis topics.				
Media	PC based software development and/or hardware development, beamer (presentation of results), report (electronic form and hard copy).				
Objectives	▪ Independent scientific approach to solve a field theoretical problem and related topics ▪ Writing of a report and presentation of results in a colloquium.				
Competences to be acquired	▪ Literature and internet based investigation ▪ Independent scientific work ▪ Compilation of a report, preparation of a talk and presentation of scientific results.				

2.3 Hardware Components for Communication Systems

<table>
<tr><td>Module title</td><td colspan="5">Hardware Components for Communication Systems R1a</td></tr>
<tr><td rowspan="4">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Optical Communication Systems (lec)</td><td>lecture</td><td>2</td><td>3</td><td>oral exam (30 minutes)</td></tr>
<tr><td>Optical Communication Systems (sem)</td><td>seminar</td><td>2</td><td>2</td><td>seminar attendance and presentation</td></tr>
<tr><td>Optical Communication Systems (lab)</td><td>lab training</td><td>1</td><td>1</td><td>lab training attendance and conductance of experiments</td></tr>
<tr><td>Module credits</td><td colspan="5">6</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in summer semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Bangert, Chatim</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Bangert</td></tr>
<tr><td>Required qualifications</td><td colspan="5">▪ Fundamentals in digital and analog communications
▪ Basic knowledge on semiconductor devices (transistor, laser diode, LED, photo diode), material science and optics.</td></tr>
<tr><td>Workload</td><td colspan="5">75 hours course attendance
105 hours self-study</td></tr>
<tr><td>Contents</td><td colspan="5">▪ 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</td></tr>
<tr><td>Literature</td><td colspan="5">▪ A. Bangert, Optical Communications, Lecture Notes, 2008.
▪ J.-P. Laude, DWDM: Fundamentals, Components and Applications, Artech-House, 2002.
▪ W. Goralski, Optical Networking & WDM, McGraw-Hill, 2001
▪ G. Cancellieri (ed.), Single-Mode Optical Fiber Measurement: Characterization and Sensing, Artech-House, 1993.
▪ R. Williams, Modern GaAs Processing Methods, Artech House Inc., ISBN 0-89006-343-5, 1990.
▪ Additional papers to be handed out according to seminar topics.</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (lecture and seminar presentations), black board (derivations, explanations), paper (exercises), experiments (lab training).</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ Understanding the fundamentals in optical communication systems
▪ Ability to understand design guidelines for optical components to be used in optical communications</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">▪ Research and development in optical broadband communications
▪ Design of optical communication systems for broadcast and transport</td></tr>
</table>

<table>
<tr><td>Module title</td><td colspan="5">Hardware Components for Communication Systems R2a</td></tr>
<tr><td rowspan="4">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Semiconductor memories (lec)</td><td>lecture</td><td>2</td><td>3</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>Semiconductor memories (ex)</td><td>exercises</td><td>1</td><td>1</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 credits</td><td colspan="5">6</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in summer semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Joodaki, Zipf</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Hillmer, Zipf</td></tr>
<tr><td>Required qualifications</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>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>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.
▪ Additional papers to be handed out according to seminar topics.</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (lecture, seminar), black board (derivations, explanations), paper (exercises).</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ Understanding the fundamentals in semiconductor memories
▪ Understanding the limits of fabrication processes
▪ Gaining requisite knowledge for being initiated into the practical tasks and projects of industry and research in the area of semiconductor memories, especially DRAM technology.
▪ Gaining an overview of dynamic runtime reconfiguration.
▪ To learn presentation techniques and to obtain presentation practice.</td></tr>
<tr><td>Competences 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>
</table>

Module title	Hardware Components for Communication Systems R3a				
Courses	**Title**	**Type**	**SWS**	**Credits**	**Performance requirements/ Examination**
	Nanosensorics (lec)	lecture	2	3	oral exam (30 minutes)
	Nanosensorics (lab)	lab training	2	3	lab training attendance and conductance of experiments
	Principles of Optical Metrology (sem)	seminar	2	3	seminar attendance and presentation
	Optical Metrology (lab)	lab training	2	3	lab training attendance and conductance of experiments
Module credits	12				
Language	English				
Held	in winter semester, annually				
Lecturer(s)	Kusserow, Lehmann				
Responsible(s)	Hillmer, Lehmann				
Required qualifications	Knowledge in optics, material science and semiconductor devices (Optoelectronics Q1); signal processing and sensors, e.g. “Sensoren und Messsysteme” would be helpful				
Workload	120 hours course attendance 240 hours self-study				
Contents	▪ 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.				
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)				
Media	Beamer (presentation), black board (derivations, explanations), electronic documents (seminar-reports), practical exercises, experiments (lab training).				
Objectives	▪ 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”.				
Competences to be acquired	▪ 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				

<table>
<tr><td>Module title</td><td colspan="5">Hardware Components for Communication Systems R4a</td></tr>
<tr><td rowspan="7">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</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 minutes)</td></tr>
<tr><td>Microsystem technology (lec)</td><td>lecture</td><td>2</td><td>3</td><td>oral exam (30 minutes)</td></tr>
<tr><td>Microsystem technology (lab)</td><td>lab training</td><td>2</td><td>2</td><td>lab training attendance and conductance of experiments</td></tr>
<tr><td>Semiconductor memories (lec)</td><td>lecture</td><td>2</td><td>3</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>Semiconductor memories (ex)</td><td>exercises</td><td>1</td><td>1</td></tr>
<tr><td>Module credits</td><td colspan="5">12</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in summer semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Hillmer, Esayi, Joodaki</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Hillmer</td></tr>
<tr><td>Required qualifications</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">135 hours course attendance
225 hours self-study</td></tr>
<tr><td>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
▪ The fundamentals of amorphous and cristalline materials and their behavior in use for microsystem technology.
▪ 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.</td></tr>
<tr><td>Literature</td><td colspan="5">▪ 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.
▪ K. Sharma, Advanced Semiconductor Memories: Architectures, Designs and Applications, NJ, Wiley & Sons, 2002</td></tr>
</table>

	▪ Y. Taur and T.K. Ning, *Fundamental of Modern VLSI Devices*, UK, Cambridge University Press, 1998. ▪ H. I. Smith, *Submicron- and Nanometer-Structures Technology*, 2nd edition, NanoStructures Press, 1994 ▪ D. V. Morgan and K. Board, *An Introduction to Semiconductor Microtechnology*, 2nd edition, John Wiley & Sons, 1994
Media	Beamer (lecture), black board (derivations, explanations), paper (exercises), experiments (lab training).
Objectives	▪ Understanding the fundamentals in micromachining, micro-opto-electro-mechanical systems (MOEMS) and optical MOEMS ▪ Understanding the fundamentals of semiconductor technology including specific processes, schemes and required instrumentation ▪ Methodology, interdisciplinary aspects, future perspectives and market trends ▪ Finding solutions using interdisciplinary analogies ▪ Establishing synergies between engineering disciplines and natural sciences ▪ Introduction to the 21st century as the "century of photonics and nano technology". ▪ Understanding structure miniaturization ▪ Preparing for clean room working ▪ Cleaving wafers and substrates correctly ▪ Accurate measurements: calibration of the set-up (Microscope) ▪ Understanding the fundamentals in semiconductor memories ▪ Understanding the limits of fabrication processes ▪ Gaining requisite knowledge for being initiated into the practical tasks and projects of industry and research in the area of semiconductor memories, especially DRAM technology.
Competences to be acquired	▪ Knowledge in micromachining, devices, thin layer and clean room technologies ▪ Methodology in specialized miniaturization schemes and integration of electronic and optoelectronic devices and systems ▪ Knowledge of design, fabrication and use of nanoelectronic, (opto-)electronic and micromachined devices ▪ Team-based working experience in a modern research environment ▪ Research and development in the area of semiconductor memories and semiconductor process technology.

2.4 Microwaves

<table>
<tr><td>Module title</td><td colspan="5">Microwaves R1a</td></tr>
<tr><td rowspan="4">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Microwaves and Millimeter Waves I (lec)</td><td>lecture</td><td>2</td><td>3</td><td rowspan="2">written exam (2 hours)</td></tr>
<tr><td>Microwaves and Millimeter Waves I (ex)</td><td>exercises</td><td>1</td><td>1</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 credits</td><td colspan="5">6</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in summer semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Bangert</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Bangert</td></tr>
<tr><td>Required qualifications</td><td colspan="5">Knowledge of fundamentals in microwave technology</td></tr>
<tr><td>Workload</td><td colspan="5">75 hours course attendance
105 hours self-study</td></tr>
<tr><td>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>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>
<tr><td>Media</td><td colspan="5">Beamer (presentation), black board (derivations, explanations), paper (exercises), experiments (lab training).</td></tr>
<tr><td>Objectives</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 (lab training).</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">▪ Use of instruments for microwave measurements
▪ Analysis and synthesis of linear microwave systems
▪ Research and development in the design of microwave components.</td></tr>
</table>

Module title	Microwaves R2a				
Courses	**Title**	**Type**	**SWS**	**Credits**	**Performance requirements/ Examination**
	Microwave Integrated Circuits II (lec)	lecture	2	3	oral exam (30 minutes)
	Microwave Integrated Circuits II (ex)	exercises	1	1	
	Microwave Integrated Circuits II (sem)	seminar	2	2	seminar attendance and presentation
Module credits	6				
Language	English				
Held	in summer semester, annually				
Lecturer(s)	Bangert				
Responsible(s)	Bangert				
Required qualifications	▪ Attendance of module *Microwaves Q1* or comparable knowledge and skills ▪ Knowledge of vector algebra and vector analysis.				
Workload	75 hours course attendance 105 hours self-study				
Contents	▪ III-V-Semiconductor devices ▪ Classification of FET models, Shockley's model ▪ Extraction of model parameters ▪ Fundamentals of non-linear FET modelling ▪ Large-scale signal description of devices ▪ Non-linear circuit design (power amplifiers).				
Literature	▪ G. Kompa, *Lecture Notes* ▪ R.E. Collin, *Foundations for Microwave Engineering*, McGraw-Hill, 1992 ▪ David M. Pozar, *Microwave Engineering*, 3rd ed., Wiley, 2005 ▪ Additional papers to be handed out according to seminar topics.				
Media	Beamer (lecture and seminar presentations), black board (derivations, explanations), paper (exercises).				
Objectives	Ability to design non-linear microwave circuits.				
Competences to be acquired	▪ Research and development in the area of microwave components ▪ Design of microwave components for base stations (broadband power amplifiers).				

<table>
<tr><td>Module title</td><td colspan="5">Microwaves R3a</td></tr>
<tr><td rowspan="4">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Microwaves and Millimeter Waves II (lec)</td><td>lecture</td><td>2</td><td>3</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>Microwaves and Millimeter Waves II (ex)</td><td>exercises</td><td>1</td><td>1</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 credits</td><td colspan="5">6</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in winter semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Bangert, Chatim</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Bangert</td></tr>
<tr><td>Required qualifications</td><td colspan="5">▪ Attendance of module Microwaves R1 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>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>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>
<tr><td>Media</td><td colspan="5">Beamer (presentation), black board (derivations, explanations), paper (exercises), experiments (lab training).</td></tr>
<tr><td>Objectives</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>Competences 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>
</table>

<table>
<tr><td>Module title</td><td colspan="5">Microwaves R4a</td></tr>
<tr><td rowspan="4">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>RF Sensor Systems (lec)</td><td>lecture</td><td>2</td><td>3</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>RF Sensor Systems (ex)</td><td>exercises</td><td>1</td><td>1</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 credits</td><td colspan="5">6</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in winter semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Bangert, Chatim</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Bangert</td></tr>
<tr><td>Required qualifications</td><td colspan="5">Knowledge of fundamentals in microwave technology</td></tr>
<tr><td>Workload</td><td colspan="5">60 hours course attendance
120 hours self-study</td></tr>
<tr><td>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>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>
<tr><td>Media</td><td colspan="5">Beamer (presentation), black board (derivations, explanations), paper (exercises), experiments (lab training).</td></tr>
<tr><td>Objectives</td><td colspan="5">Understanding the structure, functions and practical applications of near-range radar sensors (ultrasound, laser, microwave).</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">Knowledge of RF sensor systems</td></tr>
</table>

Module title	Microwaves P1a				
Courses	**Title**	**Type**	**SWS**	**Credits**	**Performance requirements/ Examination**
	Microwaves Project Work	project	4	6	Report and presentation
Module credits	6				
Language	English				
Held	in summer and winter semesters, topics on demand anytime				
Lecturer(s)	Bangert and team				
Responsible(s)	Bangert				
Required qualifications	Knowledge of fundamentals in microwave components				
Workload	60 hours course attendance 120 hours self-study				
Contents	▪ Analysis of a problem according to project description ▪ Structured approach to the solution.				
Literature	Scientific papers/books according to project topics.				
Media	PC based software development and/or hardware development (project work), beamer (presentation of results), report (electronic form and hard copy).				
Objectives	▪ 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.				
Competences to be acquired	▪ Literature and internet based investigation ▪ Structured approach for solving a problem ▪ Independent scientific work ▪ Ability to work in a team and to exchange ideas ▪ Presentation in the framework of a project.				

Module title	Microwaves T1a				
Courses	**Title**	**Type**	**SWS**	**Credits**	**Performance requirements/ Examination**
	Microwave Master Thesis	master thesis	20	30	Report and presentation
Module credits	30				
Language	English				
Held	in summer and winter semesters, topics on demand anytime				
Lecturer(s)	Bangert and team				
Responsible(s)	Bangert				
Required qualifications	▪ Knowledge of fundamentals in microwave components ▪ Proof of fulfilled admission requirements for the Master thesis according to the ECE examination regulation				
Workload	300 hours course attendance 600 hours self-study				
Contents	▪ Computer-aided circuit design ▪ Device modelling ▪ Microwave measurement approaches and instrumentation ▪ Radar sensors ▪ Topics in high frequency technology.				
Literature	▪ 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 to be handed out according to thesis topics.				
Media	PC based software development and/or hardware development, beamer (presentation of results), report (electronic form and hard copy).				
Objectives	▪ Independent scientific approach to solve a problem in microwave technology and related topics ▪ Writing of a report and presentation of results in a colloquium.				
Competences to be acquired	▪ Literature and internet based investigation ▪ Independent scientific work ▪ Compilation of a report, preparation of a talk and presentation of scientific results.				

2.5 Mobile Internet

<table>
<tr><td>Module title</td><td colspan="5">Mobile Internet R1a</td></tr>
<tr><td rowspan="4">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Communication Technologies I (lec)</td><td>lecture</td><td>2</td><td>3</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>Communication Technologies I (ex)</td><td>exercises</td><td>1</td><td>1</td></tr>
<tr><td>Communication Technologies I (lab)</td><td>lab training</td><td>1</td><td>2</td><td>lab training attendance and conductance of experiments,
oral exam (30 minutes)</td></tr>
<tr><td>Module credits</td><td colspan="5">6</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in summer semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">David, Bolz</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">David</td></tr>
<tr><td>Required qualifications</td><td colspan="5">▪ Knowledge of contents of the module Mobile Internet Q1 or comparable knowledge and skills.
▪ Knowledge in programming, preferably in Java</td></tr>
<tr><td>Workload</td><td colspan="5">60 hours course attendance
120 hours self-study</td></tr>
<tr><td>Contents</td><td colspan="5">▪ Advanced and recent topics in the area of networks and applications (IPv6, QoS, Voice over IP, traffic theory, distributed systems)
▪ Firewalls, file/print/web server.</td></tr>
<tr><td>Literature</td><td colspan="5">▪ Kurose/Ross, Computer Networks, Addison Wesley, 2nd edition
▪ Douglas E. Comer, Internetworking with TCP/IP, Prentice Hall, 4th edition
▪ Dimitri Bertsekas, Robert Gallager, Data networks, Prentice Hall, 1992
▪ Andrew S. Tanenbaum, Computer Networks, Prentice Hall, 1996, last edition
▪ Klaus David und Thorsten Benkner, Digitale Mobilfunksysteme, B.G. Teubner, 1996 (in German)
▪ Harri Holma und Antti Toskala, WCDMA for UMTS, Wiley, 2002.</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (presentation), black board (derivations, explanations), paper (exercises), PC based software development (lab training).</td></tr>
<tr><td>Objectives</td><td colspan="5">Understanding internet applications, services and protocols.</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">▪ Research and development in the area of mobile internet
▪ Ability to design schemes for server based services in networks.</td></tr>
</table>

<table>
<tr><td>Module title</td><td colspan="5">Mobile Internet R2a</td></tr>
<tr><td rowspan="4">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Communication Technologies II (lec)</td><td>lecture</td><td>2</td><td>3</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>Communication Technologies II (ex)</td><td>exercises</td><td>1</td><td>1</td></tr>
<tr><td>Communication Technologies II (lab)</td><td>lab training</td><td>1</td><td>2</td><td>lab training attendance and conductance of experiments,
oral exam (30 minutes)</td></tr>
<tr><td>Module credits</td><td colspan="5">6</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in winter semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Kusber, Bolz</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">David</td></tr>
<tr><td>Required qualifications</td><td colspan="5">▪ Knowledge of contents of the module Mobile Internet R1 or comparable knowledge and skills.
▪ Knowledge in programming, preferably in Java</td></tr>
<tr><td>Workload</td><td colspan="5">60 hours course attendance
120 hours self-study</td></tr>
<tr><td>Contents</td><td colspan="5">▪ Mobile distributed systems, middleware, pervasive computing, context awareness
▪ Basic configuration, cryptography, transmission range, data rates for WLANs and Bluetooth systems.</td></tr>
<tr><td>Literature</td><td colspan="5">▪ Kurose/Ross, Computer Networks, Addison Wesley, 2nd edition
▪ Douglas E. Comer, Internetworking with TCP/IP, Prentice Hall, 4th edition
▪ Dimitri Bertsekas, Robert Gallager, Data networks, Prentice Hall, 1992
▪ Andrew S. Tanenbaum, Computer Networks, Prentice Hall, 1996, last edition
▪ Uwe Hansmann, Lothar Merk, Martin S. Nicklous, and Thomas Stober, Pervasive Computing, 2nd edition, Springer 2003
▪ R. Chow and T. Johnson, Distributed Operating Systems & Algorithms, Addison Wesley, 1998.</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (presentation), black board (derivations, explanations), paper (exercises), PC based software development (lab training).</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ Knowing advanced and recent topics in the area of mobile networks and applications including pervasive computing
▪ Understanding the potentials and limitations of wireless based services.</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">Research and development in the area of mobile internet</td></tr>
</table>

Module title	Mobile Internet P1a				
Courses	**Title**	**Type**	**SWS**	**Credits**	**Performance requirements/ Examination**
	Mobile Internet Project Work	project	4	6	Report and presentation
Module credits	6				
Language	English				
Held	in summer and winter semesters, topics on demand anytime				
Lecturer(s)	David and team				
Responsible(s)	David				
Required qualifications	▪ Knowledge of contents of the modules *Mobile Internet R1* and *Mobile Internet R2* or comparable knowledge and skills. ▪ Knowledge in programming, preferably in Java				
Workload	60 hours course attendance 120 hours self-study				
Contents	Mobile internet				
Literature	Scientific papers/books according to project topics.				
Media	PC based software development (project work), beamer (presentation of results), report (electronic form and hard copy).				
Objectives	▪ Solving a problem in the area of mobile internet individually ▪ Writing of a report and presentation of results.				
Competences to be acquired	▪ Literature and internet based investigation ▪ Independent scientific work ▪ Presentation in the framework of a project.				

<table>
<tr><td>Module title</td><td colspan="5">Mobile Internet T1a</td></tr>
<tr><td rowspan="2">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Mobile Internet Master Thesis</td><td>master thesis</td><td>20</td><td>30</td><td>Report and presentation</td></tr>
<tr><td>Module credits</td><td colspan="5">30</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in summer and winter semesters, topics on demand anytime</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">David and team</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">David</td></tr>
<tr><td>Required qualifications</td><td colspan="5">▪ Knowledge of contents of the modules Mobile Internet R1 and Mobile Internet R2 or comparable knowledge and skills.
▪ Knowledge in programming, preferably in Java
▪ 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>Contents</td><td colspan="5">Topics from the area of mobile internet.</td></tr>
<tr><td>Literature</td><td colspan="5">Papers according to thesis topics.</td></tr>
<tr><td>Media</td><td colspan="5">PC based software development, beamer (presentation of results), report (electronic form and hard copy).</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ Independent scientific approach to solve a problem in the area of mobile internet
▪ Writing of a report and presentation of results in a colloquium.</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">▪ Literature and internet based investigation
▪ Independent scientific work
▪ Compilation of a report, preparation of a talk and presentation of scientific results.</td></tr>
</table>

2.6 Optoelectronics

Module title	**Optoelectronics R1a**				
Courses	**Title**	**Type**	**SWS**	**Credits**	**Performance requirements/ Examination**
	Microsystem technology (lec)	lecture	2	3	oral exam (30 minutes)
	Technology of electronic and optoelectronic devices (lec)	lecture	2	3	oral exam (30 minutes)
Module credits	6				
Language	English				
Held	in summer semester, annually				
Lecturer(s)	Hillmer				
Responsible(s)	Hillmer				
Required qualifications	Basic knowledge on semiconductor devices (transistor, laser diode, LED, photo diode), material science and optics				
Workload	60 hours course attendance 120 hours self-study				
Contents	▪ Introduction to modern fabrication processes, technology of fibers, wave guides, lasers ▪ Crystal growth: semiconductor wafers, thin layer epitaxy ▪ Lithography: optical, X-ray, electron-beam, ion-beam, EUVL, nano imprint ▪ Plasma processing and vacuum technology ▪ Deposition techniques: evaporation, sputtering, plasma assisted techniques ▪ Dry and wet-chemical etching and clean room technology ▪ Fabrication technology of electronic devices (planar transistor, electronic integrated chips), optoelectronic devices (semiconductor lasers, gratings) and micro-opto-electro-mechanical systems (MOEMS) ▪ Introduction to micromachining, microsystem techniques, miniaturization, packaging and nanotechnology ▪ Reasons for miniaturization and integration, types of micromachining ▪ Sensors and actuators ▪ Large variety of MEMS and MOEMS examples: membranes, springs, resonator elements, cantilevers, valves, manipulation elements, gripping tools, light modulators, optical switches, beam splitters, projection displays, micro optical bench, data distribution, micromachined tunable filters and lasers, ▪ Displays: micromachined (micromirror) displays, laser display technology, vacuum-electronics ▪ Lab tour in the clean room.				
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.				
Media	Beamer (presentation), black board (derivations, explanations), paper (exercises).				
Objectives	▪ Understanding the fundamentals in micromachining, micro-opto-electro-mechanical systems (MOEMS) and optical MOEMS ▪ Understanding the fundamentals of semiconductor technology including specific processes, schemes and required instrumentation ▪ Methodology, interdisciplinary aspects, future perspectives and market trends ▪ Finding solutions using interdisciplinary analogies ▪ Establishing synergies between engineering disciplines and natural sciences ▪ Introduction to the 21st century as the “century of photonics and nano technology”.				
Competences to be acquired	▪ Knowledge in micromachining, devices, thin layer and clean room technologies ▪ Methodology in specialized miniaturization schemes and integration of electronic and optoelectronic devices and systems ▪ Knowledge of design, fabrication and use of nanoelectronic, (opto-)electronic and micromachined devices				

<table>
<tr><td>Module title</td><td colspan="5">Optoelectronics R2a</td></tr>
<tr><td rowspan="5">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Semiconductor Lasers (lec)</td><td>lecture</td><td>2</td><td>4</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>Semiconductor Lasers (ex)</td><td>exercises</td><td>1</td><td>2</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 credits</td><td colspan="5">12</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in winter semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Hillmer, Shrestha</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Hillmer</td></tr>
<tr><td>Required qualifications</td><td colspan="5">Basic knowledge on semiconductor devices, material science, optoelectronics</td></tr>
<tr><td>Workload</td><td colspan="5">105 hours course attendance
255 hours self-study</td></tr>
<tr><td>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, T_o.
▪ Evaluation, interpretation, documentation and presentation of the measured data.
▪ Advanced seminar topics in optoelectronics</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, Wiley & Sons, New York, 1995.
▪ F. Träger (Editor), Springer Handbook of Lasers and Optics, Springer, 2007.</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (presentation,seminar), black board (derivations, explanations), paper (exercises), measurement instrumentation (lab).</td></tr>
<tr><td>Objectives</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.
▪ To learn presentation techniques and to obtain presentation practice.
▪ To learn to structure a talk to optimize the transfer of essentials to the audience.
▪ Introduction to scientific working. The engineer learns how to analyze measured data and how to compare experimental and theoretical results and inferences.
▪ To learn to efficiently apply different set-up components for optical characterization.</td></tr>
<tr><td>Competences 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>
</table>

Module title	Optoelectronics P1a				
Courses	**Title**	**Type**	**SWS**	**Credits**	**Performance requirements/ Examination**
	Optoelectronics Project Work	project	4	6	Report and presentation
Module credits	6				
Language	English				
Held	in summer and winter semesters, topics on demand anytime				
Lecturer(s)	Hillmer and team				
Responsible(s)	Hillmer				
Required qualifications	Profound knowledge in optoelectronics				
Workload	60 hours course attendance 120 hours self-study				
Contents	▪ 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.				
Literature	Scientific papers/books according to project topics.				
Media	Beamer (presentation of results), report (electronic form and hard copy).				
Objectives	▪ Practice in theoretical model calculations. The engineer should learn to understand basics and fundamental interaction of effects by a variation of geometric and material parameters. ▪ The student will learn how to design advanced photonic devices. ▪ Introduction to scientific work. The engineer learns how to analyze and to interpret calculated theoretical data. ▪ To 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.				
Competences to be acquired	▪ To create new or modify existing models according to the given problem. ▪ To analyze data series with respect to the given problem. ▪ To experience synergies in knowledge during the comparison and analysis of theoretical and experimental data. ▪ Introduction into appropriate scientific working.				

Module title	Optoelectronics T1a				
Courses	**Title**	**Type**	**SWS**	**Credits**	**Performance requirements/ Examination**
	Optoelectronics Master Thesis	master thesis	20	30	Report and presentation
Module credits	30				
Language	English				
Held	in summer and winter semesters, topics on demand anytime				
Lecturer(s)	Hillmer and team				
Responsible(s)	Hillmer				
Required qualifications	▪ 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				
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 ▪ The students are 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.				
Literature	Papers according to thesis topics.				
Media	PC based software development and/or hardware development, instruments for measurements and experiments, beamer (presentation of results), report (electronic form and hard copy).				
Objectives	▪ Creating models for a given problem ▪ To obtain 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 ▪ Team work and efficient in projects.				
Competences to be acquired	▪ Experience in practical clean room technology ▪ Profound knowledge in theoretical model calculations ▪ Independent scientific work ▪ Compilation of a report, preparation of a talk and presentation of scientific results.				

2.7 Social Communication

<table>
<tr><td>Module title</td><td colspan="5">Social Communication NT1a</td></tr>
<tr><td rowspan="2">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>German Language Course (lec)</td><td>lecture</td><td>6</td><td>6</td><td>lecture
exams: written (2 hours) and oral (30 minutes)</td></tr>
<tr><td>Module credits</td><td colspan="5">6</td></tr>
<tr><td>Language</td><td colspan="5">English and German</td></tr>
<tr><td>Held</td><td colspan="5">in summer and winter semesters, semi-annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Assigned by Dialog-Institut</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">B. Warnke-Kilian</td></tr>
<tr><td>Required qualifications</td><td colspan="5">Admission requirements for the ECE program fulfilled according to the examination regulation</td></tr>
<tr><td>Workload</td><td colspan="5">90 hours course attendance
90 hours self-study</td></tr>
<tr><td>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>Literature</td><td colspan="5">▪ Tangram, Deutsch als Fremdsprache, Lehrwerk für die Grundstufe, Max Hueber Verlag
▪ Themen, Hueber Verlag
▪ Eurolingua, Deutsch als Fremdsprache, Cornelsen Verlag.</td></tr>
<tr><td>Media</td><td colspan="5">Beamer and black board (explanations), internet based search (computer), paper (exercises), films, DVDs.</td></tr>
<tr><td>Objectives</td><td colspan="5">General topics:
▪ Social integration
▪ Knowing basic German language expressions up to level A2
▪ Using the language in everyday situations.
Objectives in terms of levels of the Common European Reference Framework (Gemeinsamer Europäischer Referenzrahmen, GERR):
A1 The student is able to
▪ understand usual expressions with immediate meaning (own person, family, shopping, working, schedule, displays, brochures, simple announcements, use of public transport)
▪ communicate in simple standard situations, enquire about and obtain information about familiar things and exchange information (looking for a way, accomodation, present activity, apologize if absent).
▪ understand and use familiar every-day expressions for satisfying concrete needs
▪ introduce herself/himself/others and ask questions about a person, e.g. about their living conditions, and answer corresponding questions
▪ communicate on a simple level, if the conversational partner speaks slowly and distinctly and assist in case of a misunderstanding.
A2 The student is able to
▪ speak about her/his person, the job, the environment and elementary needs on a basic level
▪ describe his living conditions and understand short simple messages
▪ write simple texts and letters, read and understand and have brief chats in German
▪ understand main topics of oral and written texts (in the context of familiar situations at work, administration, school, leisure and radio/TV reports on latest news,</td></tr>
</table>

	profession and interests).
Competences to be acquired	▪ Soft skills: learning and study techniques, 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.

2.8 Software Components for Communication Systems

<table>
<tr><td>Module title</td><td colspan="5">Software Components for Communication Systems R1a</td></tr>
<tr><td rowspan="5">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Communication Technologies I (lec)</td><td>lecture</td><td>2</td><td>3</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>Communication Technologies I (ex)</td><td>exercises</td><td>1</td><td>1</td></tr>
<tr><td>Communication Technologies I (lab)</td><td>lab training</td><td>1</td><td>2</td><td>lab training attendance and conductance of experiments,
oral exam (30 minutes)</td></tr>
<tr><td>Java Code Camp – Context Awareness 2</td><td>Lecture</td><td>4</td><td>6</td><td>lecture and programming,
oral exam (30 minutes)</td></tr>
<tr><td>Module credits</td><td colspan="5">12</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in summer semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">David, Bolz, Klein</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">David</td></tr>
<tr><td>Required qualifications</td><td colspan="5">▪ Knowledge of contents of the module Mobile Internet Q1 or comparable knowledge and skills.
▪ Knowledge in programming, preferably in Java</td></tr>
<tr><td>Workload</td><td colspan="5">120 hours course attendance
240 hours self-study</td></tr>
<tr><td>Contents</td><td colspan="5">▪ Advanced and recent topics in the area of networks and applications (IPv6, QoS, Voice over IP, traffic theory, distributed systems)
▪ Firewalls, file/print/web server.
▪ Programming of Phidget sensors and SunSPOTs with Java ME</td></tr>
<tr><td>Literature</td><td colspan="5">▪ Kurose/Ross, Computer Networks, Addison Wesley, 2nd edition
▪ Douglas E. Comer, Internetworking with TCP/IP, Prentice Hall, 4th edition
▪ Dimitri Bertsekas, Robert Gallager, Data networks, Prentice Hall, 1992
▪ Andrew S. Tanenbaum, Computer Networks, Prentice Hall, 1996, last edition
▪ Klaus David und Thorsten Benkner, Digitale Mobilfunksysteme, B.G. Teubner, 1996 (in German)
▪ Timothy A. Budd, Understanding Object-Oriented Programming.</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (presentation), black board (derivations, explanations), paper (exercises), PC based software development (lab training).</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ Understanding internet applications, services and protocols.
▪ Learn about sensor equipment and grasp the object oriented paradigm in Java in particular.</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">▪ Research and development in the area of mobile internet
▪ Ability to design schemes for server based services in networks.
▪ Consulting in the area of information technology.</td></tr>
</table>

<table>
<tr><td>Module title</td><td colspan="5">Software Components for Communication Systems R2a</td></tr>
<tr><td rowspan="6">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Communication Technologies II (lec)</td><td>lecture</td><td>2</td><td>3</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>Communication Technologies II (ex)</td><td>exercises</td><td>1</td><td>1</td></tr>
<tr><td>Communication Technologies II (lab)</td><td>lab training</td><td>1</td><td>2</td><td>lab training attendance and conductance of experiments,
oral exam (30 minutes)</td></tr>
<tr><td>Seminar in Communication Technologies (sem)</td><td>seminar</td><td>2</td><td>3</td><td>seminar attendance and presentation</td></tr>
<tr><td>Simulation of Digital Communication Systems using MATLAB (lab)</td><td>lab training</td><td>2</td><td>3</td><td>lab training attendance, programming, oral exam (30 minutes)</td></tr>
<tr><td>Module credits</td><td colspan="5">12</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in winter semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">David, Klein, Bolz, Sharma</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">David, Dahlhaus</td></tr>
<tr><td>Required qualifications</td><td colspan="5">▪ Knowledge of contents of the module Mobile Internet R1 or comparable knowledge and skills.
▪ Knowledge of fundamentals in digital communications</td></tr>
<tr><td>Workload</td><td colspan="5">120 hours course attendance
240 hours self-study</td></tr>
<tr><td>Contents</td><td colspan="5">▪ Mobile distributed systems, middleware, pervasive computing, context awareness
▪ Basic configuration, cryptography, transmission range, data rates for WLANs and Bluetooth systems.
▪ Topics in communication technologies.
▪ Introduction to MATLAB and its most important commands, simulation of a simple transmission chain, channel coding (convolutional codes), coding gain, channels with multipath propagation, channel models with fading and bit-error rate performance for binary signalling, transmission with orthogonal frequency-division multiplexing (OFDM), interleaving, implementation of an OFDM modem.</td></tr>
<tr><td>Literature</td><td colspan="5">▪ Kurose/Ross, Computer Networks, Addison Wesley, 2nd edition
▪ Douglas E. Comer, Internetworking with TCP/IP, Prentice Hall, 4th edition
▪ Dimitri Bertsekas, Robert Gallager, Data networks, Prentice Hall, 1992
▪ Andrew S. Tanenbaum, Computer Networks, Prentice Hall, 1996, last edition
▪ Uwe Hansmann, Lothar Merk, Martin S. Nicklous, and Thomas Stober, Pervasive Computing, 2nd edition, Springer 2003
▪ R. Chow and T. Johnson, Distributed Operating Systems & Algorithms, Addison Wesley, 1998.
▪ Additional papers to be handed out according to seminar topics.</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (lecture,seminar), black board (derivations, explanations), paper (exercises), PC based software development (lab training).</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ Knowing advanced and recent topics in the area of mobile networks and applications including pervasive computing
▪ Understanding the potentials and limitations of wireless based services.
▪ Understanding approaches for numerical simulation of transceivers in the physical layer of communication systems.</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">▪ Research and development in the area of mobile internet</td></tr>
</table>

<table>
<tr><td>Module title</td><td colspan="5">Software Components for Communication Systems R3b</td></tr>
<tr><td rowspan="4">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Network Security (lec)</td><td>lecture</td><td>2</td><td>2</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>Network Security (ex)</td><td>exercises</td><td>2</td><td>2</td></tr>
<tr><td>Routing Protocols in Wireless Communications (lec)</td><td>lecture</td><td>2</td><td>2</td><td>oral exam (30 minutes)</td></tr>
<tr><td>Module credits</td><td colspan="5">6</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in summer semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Wacker, Dominiak</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Wacker, Dominiak</td></tr>
<tr><td>Required qualifications</td><td colspan="5">▪ Basics in applied cryptology, computer networks, internet technology, programming
▪ Basics in computer communication networks and layered network architectures</td></tr>
<tr><td>Workload</td><td colspan="5">60 hours course attendance
120 hours self-study</td></tr>
<tr><td>Contents</td><td colspan="5">▪ Analysis of several methods for secure communications in modern communication networks (e.g. the Internet)
▪ Protocols for authentication (e.g. Needham-Schroeder, Kerberos)
▪ Protocols for secure data exchange on the Internet (e.g. IPSec, SSL / TLS, SSH, PKI, SMIME),
▪ Protocols for securing wireless traffic (e.g. WEP, WPA)
▪ Secure protocols for data exchange in optical networks (e.g. BB84 based on quantum cryptography)
▪ Analysis of the functionality and the currently known weaknesses in the protocols: Needham-Schroeder and WEP
▪ Introduction to network router and routing protocol fundamentals
▪ Path selection algorithms – Dijkstra, Bellman-Ford, multi-path
▪ Distance vector and link state routing algorithms
▪ Common protocols for dynamic routing in the Internet (e.g. OSPF, RIP)
▪ Fundamentals of routing in wireless multi-hop networks
▪ Practical simulation of wireless routing protocols using Discrete Event Simulation (DES)
▪ Analysis and comparison of selected wireless multi-hop routing protocols (e.g. AODV, OLSR)</td></tr>
<tr><td>Literature</td><td colspan="5">▪ Albrecht Beutelspacher, Cryptology
▪ Bruce Schneier, Applied Cryptography
▪ Medhi, Ramasamy, Network Routing: Algorithms, Protocols and Architectures
▪ Hamid, Hassanein, Takahara, Routing for Wireless Multi-Hop Networks
▪ Various Protocol specifications and Internet RFCs</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (lecture), black board (derivations, explanations), paper (exercises)</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ Understanding the basics of protocols for secure communications
▪ To understand the functionalities and abilities of state-of-the-art secure communication protocols
▪ To analyze and assess the safety of different protocols
▪ To understand the role and basic functionality of a network router
▪ To understand the detailed functionality and advantages/disadvantages of specific selected routing protocols</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">▪ Evaluation of the safety of secure communication protocols currently in use, increase safety awareness in the daily use of modern communication networks such as the Internet.
▪ Evaluation of existing routing protocols for Internet and wireless multi-hop networks
▪ Ability to design, simulate and evaluate network routing protocols</td></tr>
</table>

3 Qualification modules

If a student does not fulfill the admission requirements for the ECE program, the examination board can grant a conditional admission according to §4 par.(5) of the ECE examination regulation. The condition requires that the student has to earn credits (totalling at most 24 credits) from the modules listed below prior to starting the master thesis.

As in Section 1, the modules cover the areas of

- Digital Communications
- Mobile Internet
- Microwaves
- Optoelectronics
- Software Components for Communication Systems

Within each area, we have the aforementioned naming convention <AREA TYPE NO> such as *Digital Communications Q1*, where, unlike in Section 1, TYPE takes the value **Q** for **q**ualification.

3.1 Digital Communications

<table>
<tr><td>Module title</td><td colspan="5">Digital Communications Q1b</td></tr>
<tr><td rowspan="3">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Introduction to Digital Communications (lec and ex)</td><td>lecture and exercises</td><td>3</td><td>4</td><td rowspan="2">lab attendance and oral exam (30 minutes)</td></tr>
<tr><td>Introduction to Digital Communications (lab)</td><td>lab training</td><td>1</td><td>2</td></tr>
<tr><td>Module credits</td><td colspan="5">6</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in summer and winter semesters</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Dahlhaus, Mansour, Mohamad</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Dahlhaus</td></tr>
<tr><td>Required qualifications</td><td colspan="5">Knowledge of fundamentals in communications</td></tr>
<tr><td>Workload</td><td colspan="5">70 hours course attendance
110 hours self-study</td></tr>
<tr><td>Contents</td><td colspan="5">▪ Introduction, mathematical models for communication channels, linear systems, basics of probability and random variables, the central limit theorem, Fourier transforms, Shannon-Kotelnikov (sampling) theorem, stochastic processes, stationary processes and linear time-invariant systems, complex baseband representation of bandpass signals, orthogonal expansions of signals, linear digital modulation schemes, optimum receivers for the additive white Gaussian noise channel.</td></tr>
<tr><td>Literature</td><td colspan="5">▪ J.G. Proakis, Digital Communications, McGraw-Hill, 4th ed., ISBN 0-07-118183-0.
▪ Papoulis, S. U. Pillai, Probability, Random Variables, and Stochastic Processes, McGraw-Hill, 4th ed., ISBN 0071226613</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (presentation), black board (derivations, explanations), paper (exercises), EMONA kit experiments.</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ Understanding fundamentals in digital communications and statistical signal processing</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">▪ Development in the area of digital transmission systems
▪ Design of hardware and software components in digital transmission systems
▪ Assessment of analog front-ends.</td></tr>
</table>

3.2 Mobile Internet

<table>
<tr><td>Module title</td><td colspan="5">Mobile Internet Q1a</td></tr>
<tr><td rowspan="4">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Mobile Computing (lec)</td><td>lecture</td><td>2</td><td>3</td><td rowspan="2">written exam (2 hours)</td></tr>
<tr><td>Mobile Computing (ex)</td><td>exercises</td><td>1</td><td>1</td></tr>
<tr><td>Introduction to Communication II (lab)</td><td>lab training</td><td>1</td><td>2</td><td>lab training attendance and conductance of experiments,
oral exam (30 mins)</td></tr>
<tr><td>Module credits</td><td colspan="5">6</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in summer semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">David, Bolz</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">David</td></tr>
<tr><td>Required qualifications</td><td colspan="5">Knowledge of fundamentals in communications</td></tr>
<tr><td>Workload</td><td colspan="5">60 hours course attendance
120 hours self-study</td></tr>
<tr><td>Contents</td><td colspan="5">▪ Mobile communication: theoretical basics, present systems and applications (mobile radio channel, GSM services, GSM system, UMTS, WAP)
▪ Other services like MMS, pervasive computing and ubiquitous systems including practical experiments with real products
▪ Measurements of mobile radio channels.</td></tr>
<tr><td>Literature</td><td colspan="5">▪ Kurose/Ross, Computer Networks, Addison Wesley, 2nd edition
▪ Douglas E. Comer, Internetworking with TCP/IP, Prentice Hall, 4th edition
▪ Dimitri Bertsekas, Robert Gallager, Data networks, Prentice Hall, 1992
▪ Andrew S. Tanenbaum, Computer Networks, Prentice Hall, 1996, last edition
▪ Klaus David und Thorsten Benkner, Digitale Mobilfunksysteme, B.G. Teubner, 1996 (in German)
▪ Harri Holma und Antti Toskala, WCDMA for UMTS, Wiley, 2002.</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (presentation), black board (derivations, explanations), paper (exercises), PC based software development (lab training).</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ Understanding the mobile radio channel, mobile radio systems and services
▪ Understanding the interaction of individual components in mobile radio systems.</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">▪ Research and development in the area of mobile internet
▪ Ability to use mobile radio measurement equipment.</td></tr>
</table>

3.3 Microwaves

<table>
<tr><td>Module title</td><td colspan="5">Microwaves Q1a</td></tr>
<tr><td rowspan="4">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Microwave Integrated Circuits I (lec)</td><td>lecture</td><td>2</td><td>3</td><td rowspan="2">written exam (2 hours)</td></tr>
<tr><td>Microwave Integrated Circuits I (ex)</td><td>exercises</td><td>1</td><td>1</td></tr>
<tr><td>Microwave Integrated Circuits 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 credits</td><td colspan="5">6</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in winter semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Bangert, Chatim</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Bangert</td></tr>
<tr><td>Required qualifications</td><td colspan="5">▪ Knowledge of fundamentals of high frequency 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>Contents</td><td colspan="5">▪ Methods for designing networks
▪ Survey of striplines
▪ Methods of micro-strip analysis
▪ Dispersion in micro-striplines, dispersion measurements
▪ Planar wave guide models
▪ Micro-strip discontinuities and losses, technology
▪ Introduction to Agilent Advanced Design System (ADS), harmonic analysis, simulation of S-parameters in microwave networks, micro-strip resonators and discontinuties.</td></tr>
<tr><td>Literature</td><td colspan="5">▪ G. Kompa, Practical Microstrip Design and Applications, Artech House, 2006
▪ H. Brand, Schaltungslehre linearer Mikrowellennetze, S. Hirzel Verlag, 1970 (in German)
▪ Notes on lab training.</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (presentation), black board (derivations, explanations), paper (exercises), experiments (lab training).</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ Understanding schemes for computer-aided design of integrated microwave and millimeter wave circuits
▪ Ability to model the electrical properties of planas lines, line discontinuities and branchings in integrated circuits
▪ Ability to design integrated circuits
▪ Ability to apply commercial design software and to simulate linear and non-linear microwave circuits.</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">▪ Research and development in the area of microwave components
▪ Characterization and modeling of microwave components based on measurements
▪ Design of microwave networks.</td></tr>
</table>

3.4 Optoelectronics

<table>
<tr><td>Module title</td><td colspan="5">Optoelectronics Q1a</td></tr>
<tr><td rowspan="4">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Optoelectronic devices (lec)</td><td>lecture</td><td>2</td><td>3</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>Optoelectronic devices (ex)</td><td>exercises</td><td>1</td><td>1</td></tr>
<tr><td>Optoelectronics-I (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 credits</td><td colspan="5">6</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in winter semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Hillmer, Memon</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Hillmer</td></tr>
<tr><td>Required qualifications</td><td colspan="5">Basic knowledge on electronic semiconductor devices (diodes, transistor), material science</td></tr>
<tr><td>Workload</td><td colspan="5">60 hours course attendance
120 hours self-study</td></tr>
<tr><td>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>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>
<tr><td>Media</td><td colspan="5">Beamer (presentation), black board (derivations, explanations), paper (exercises).</td></tr>
<tr><td>Objectives</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>Competences 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>
</table>

3.5 Software Components for Communication Systems

<table>
<tr><td>Module title</td><td colspan="5">Software Components for Communication Systems Q1b</td></tr>
<tr><td rowspan="3">Courses</td><td>Title</td><td>Type</td><td>SWS</td><td>Credits</td><td>Performance requirements/ Examination</td></tr>
<tr><td>Introduction to Applied Cryptology (lec)</td><td>lecture</td><td>2</td><td>3</td><td rowspan="2">oral exam (30 minutes)</td></tr>
<tr><td>Introduction to Applied Cryptology (ex)</td><td>exercises</td><td>2</td><td>3</td></tr>
<tr><td>Module credits</td><td colspan="5">6</td></tr>
<tr><td>Language</td><td colspan="5">English</td></tr>
<tr><td>Held</td><td colspan="5">in winter semester, annually</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Wacker</td></tr>
<tr><td>Responsible(s)</td><td colspan="5">Wacker</td></tr>
<tr><td>Required qualifications</td><td colspan="5">▪ Knowledge of fundamentals in Discrete Structures
▪ Basic knowledge in Programming</td></tr>
<tr><td>Workload</td><td colspan="5">60 hours course attendance
120 hours self-study</td></tr>
<tr><td>Contents</td><td colspan="5">▪ Introduction to different methods for encrypting messages (cryptography)
▪ Classical methods (e.g. Caesar, Vigener, Playfair), mechanical methods (Enigma) modern symmetric (DES, AES, RC4) and asymmetric methods (DH, RSA, ElGamal).
▪ Cryptanalysis</td></tr>
<tr><td>Literature</td><td colspan="5">▪ Albrecht Beutelspacher, Cryptology
▪ Bruce Schneier, Applied Cryptography</td></tr>
<tr><td>Media</td><td colspan="5">Beamer (presentation), black board (derivations, explanations), paper (exercises).</td></tr>
<tr><td>Objectives</td><td colspan="5">▪ To learn the basics of how different algorithms encrypt messages
▪ To understand substitution/transposition and the mathematical foundations of the modern asymmetric methods.
▪ To understand the various facets of security concepts e.g. encryption algorithms, key generation and digital signatures, secure hashes, authentication protocols and Zero-Knowledge proofs
▪ To analyze and assess the safety of different methods</td></tr>
<tr><td>Competences to be acquired</td><td colspan="5">▪ Evaluation of the safety of the different methods for message encryption, and for increasing safety awareness</td></tr>
</table>