TUHH Hamburg University of Technology

Module Manual

Master of Science (M.Sc.)

Electrical Engineering

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Program description

Content

The electrical industry is the second largest industrial sector in Germany after mechanical engineering in terms of the number of employees. With approx. 847,000 employees, a turnover of approx. 179 billion euros is achieved (based on the year 2016, source: de.statista.com). Electrical engineering is thus not only one of the "classic engineering sciences" but also one of the main drivers of national and international technical progress in recent decades.

The Master's programme in Electrical Engineering with at TUHH prepares its graduates for leading positions in the electrical engineering industry and for independent work in research. Accordingly, the Master's education is characterised by a scientific orientation, a focus on content and the teaching of effective, structured, interdisciplinary working methods. The focal points in terms of content are closely linked to the research topics of the institutes of the Dean of Studies and reflect the unity of research and teaching. This always ensures up-to-date lecture content and opportunities to participate in research at the TUHH, e.g. in the context of theses, seminar papers and project work. Furthermore, the content foci of the Master's degree programme are linked to the core subjects of the Bachelor's degree programme in the sense of a consecutive overall degree programme.

Career prospects

Successful completion of the Master's degree in electrical engineering enables entry into the typical fields of activity in electrical engineering. These include communications engineering, measurement and control engineering, microsystems engineering and nanoelectronics, electrical power engineering, high-frequency engineering and optical systems.

Electrical engineers are among the most sought-after academics on the labour market. A current evaluation of the data of the Federal Employment Agency proves the increasing demand (Federal Employment Agency: "Berichte: Blickpunkt Arbeitsmarkt - Ingenieurinnen und Ingenieure", Nuremberg, 2018). While the number of registered unemployed continues to fall steadily, the number of registered vacancies is increasing significantly at the same time. At the same time, only a fraction of the advertised jobs are reported to the Federal Employment Agency, so that the supply of jobs currently exceeds the demand. Thus, as in previous years, the demand for electrical engineers - especially in the old federal states including Hamburg - cannot be met ("shortage of skilled workers").

The Master's degree also qualifies graduates to take up a doctorate.

Learning target

Graduates of the Master's programme in Electrical Engineering should be able to transfer the engineering, mathematical and scientific competences they have acquired during their studies into practice and - if necessary - expand them there independently. They can analyse problems with scientific methods and lead them to a solution, even if the problems are "open" or incompletely defined. They are qualified to work independently in electrical engineering and in related disciplines and can apply, critically question and further develop the methods and procedures required to solve technical and conceptual problems as well as new findings. Furthermore, graduates are qualified to develop designs for challenging projects in one of the specialisations

- RF technology, optics and electromagnetic compatibility,
- Medical technology,
- Communications engineering,
- Nanoelectronics and Microsystems Technology and
- Control and power engineering

and plan them, taking into account the necessary clarifications and examination of available information. The learning objectives are divided into the following categories: knowledge, skills, social competence and independence.

Knowledge

- Students can reproduce in-depth mathematical and scientific knowledge and underpin this with a broad theoretical and methodological foundation. This includes the fields of high-frequency engineering, control engineering, microsystems engineering and nanoelectronics, all of which are compulsory courses in the first semester.
- The students can explain the principles, methods and application areas of the specialisations in electrical engineering in detail. The specialisations are (1) RF technology, optics and electromagnetic compatibility, (2) medical engineering, (3) modelling and simulation, (4) communications engineering, (5) nanoelectronics and microsystems engineering and (6) control and power engineering.
- Students can name the basics in the field of operations and management and related subjects such as patenting and relate them to their subject
- Students can cite the elements of scientific work and research and can give an overview of their application in electrical engineering.

Skills

For all specialisations

- Graduates are able to assess complex control engineering systems, test their functionality and analyse and optimise microsystems engineering and nanoelectronic circuits. Furthermore, they are able to work out high-frequency solutions and give an overview of procedures and possible applications of digital message transmission (core qualifications).
- Students are able to investigate or assess future technologies and scientific developments and are qualified to conduct independent research (qualification for doctorate).

Specialization in RF technology, optics and electromagnetic compatibility

Students master the theory-based application of very demanding methods and procedures in RF technology, optics and electromagnetic compatibility.

- Students can describe more complex problems of antenna theory, work out solution procedures for subproblems with CAD simulations and create an overall solution from this. They are able to analyse, simulate and evaluate effects in RF circuits.
- Students are able to mathematically describe fibre-optic and integrated optical wave propagation, to derive approximate solutions in modelling and to estimate influencing factors on system components.
- Students are able to apply different methods for calculating electromagnetic fields and wave propagation and to discuss the results. They can also estimate and analyse the influence with regard to electromagnetic compatibility and weigh up different solutions against each other.

Specialisation in medical technology

Students master the theory-based application of very sophisticated methods and procedures in medical technology.

- Students can explain the mode of operation and possible applications of clinical imaging procedures and interpret effects of the most important classes of imaging sensors and displays using mathematical methods and physical models.
- Students can design and evaluate navigation and robotic systems for medical applications. They are able to justify a selection and adaptation of classification, regression and prediction methods and can evaluate these using clinical example data and implement the corresponding methods.
- Students are able to analyse medical electronic applications and the feasibility of microsystems, design process sequences for the production of microstructures and apply these.

Specialisation in Communications Engineering

Students master the theory-based application of very demanding methods and procedures in communications engineering.

- Students are able to evaluate the performance of message transmission procedures and communication networks and explain the effects that occur as well as solve typical planning and optimisation tasks.
- Students are able to compare, select and dimension transmission procedures, data compression procedures (source coding) and error correction procedures (channel coding) with the help of basic information-theoretical methods. They are able to implement these procedures in software. In particular, they can determine the limits of data compression or the data transmission rate and thus dimension a transmission procedure.
- Students can apply methods of statistics to problems in communication technology and signal processing. They can analyse feature evaluations and classifications in a theoretically and methodologically sound manner.

Specialisation in nanoelectronics and microsystems technology

- The students master the theory-based application of very demanding methods and procedures of nanoelectronics and microsystems technology.
- They can design electronic circuits (analogue and digital), calculate deviations of integrated components and noise spectra and verify them by simulation. They can determine the cost-benefit ratio of different design approaches.
- Students are able to analyse the feasibility of microsystems, carry out an analysis of the influences of process parameters, design process sequences for the manufacture of microstructures and apply these.
- The students can derive models and mathematical descriptions with regard to free wave propagation as well as quantum optical phenomena and processes and find approximate solutions.

Specialisation in Control and Power Engineering

The students master the theory-based application of very demanding methods and procedures of control and energy technology.

- Students are able to optimise processes and select methods for abstract tasks that lead to desired results.
- Students are able to apply technologies and procedures for planning or analysing electrical energy systems, to evaluate the results, to calculate and analyse the dynamic behaviour and stability of electrical energy systems using suitable modelling.
- Students are able to analyse complex linear and non-linear systems, apply and implement control engineering methods and carry out comprehensive mathematical simulations.

Social competence

- The students are able to present the procedure and results of their work in writing and orally in German and English in a comprehensible way.
- The students can communicate about advanced contents and problems of electrical engineering with specialists and laypersons in German and English. They can respond appropriately to queries, additions and comments.
- The students are able to work in groups. They can define, distribute and integrate subtasks. They can make time arrangements and interact socially. They have the ability and willingness to take on leadership responsibility.

Competence to work independently

- Students are able to obtain necessary information and put it into the context of their knowledge
- The students can realistically assess their existing competences, independently compensate for deficits and make meaningful additions
- The students can work out research areas in a self-organised and self-motivated manner and find or define new problems (lifelong research).

Program structure

The curriculum of the Master's programme in Electrical Engineering is structured as follows:

- Core qualification: 9 modules, 54 LP, 1st - 3rd semester.
- Consolidation: 36 LP, 2nd and 3rd semester
- Master's thesis: 30 LP, 4th semester

The subject-specific teaching of the core qualification is divided into:

- Theoretical foundations of the specialisation: 5 modules, 30 LP, 1st semester
- Technical supplementary courses: 2 modules, 12 LP, 2nd and 3rd semester

In addition to subject modules, the core qualification also includes interdisciplinary modules:

- Operations & Management: 6 LP, 1st - 3rd semester
- Non-technical supplementary courses in the Master's programme: 6 LP, 1st - 3rd semester

The choice of a specialisation is compulsory.

The specialisations of the Master's degree programme are:

- RF technology, optics and electromagnetic compatibility,
- Medical technology,
- Communications engineering,
- Nanoelectronics and Microsystems Technology and
- Control and Power Engineering.

Within a specialisation, students can and must select from an elective catalogue within the framework of the prescribed number of credit points of 36 LP, corresponding to a share of 30% of the curriculum. The subject modules of the specialisations are listed individually in the module handbook. Within each specialisation, at least one module "Research Project and Seminar" must be taken, whereby the assignment to the specialisation results from the topics worked on. In order to ensure a balanced ratio of formal and practical teaching content in the theoretical and application areas of the curriculum despite great individual freedom in the selection of courses, cross-sectional courses (theoretical foundations of the specialisations) amounting to 30 ECTS, corresponding to a share of 25% of the curriculum, are compulsory for all students in the first semester. These include the modules Digital Communications, Electrical Power Systems, High Frequency Technology, Microsystems Technology, Theory and Design of Control Systems. Further leeway in the individual design of the study plan is offered by the technical supplementary courses, which can be selected from the technical overall catalogue of all Master's lectures at the TUHH to the extent of 12 LP, corresponding to a share of 10% of the curriculum. The remaining part of the curriculum is made up of the non-technical subjects with a share of also 10% and the Master's thesis with a share of 25%.

The curriculum includes a mobility window such that students can complete the second or third semester abroad.

Core Qualification

Module M0523: Business & Management

Module Responsible	Prof. Matthias Meyer
Admission Requirements	None
Recommended Previous Knowledge	None
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students are able to find their way around selected special areas of management within the scope of business management. • Students are able to explain basic theories, categories, and models in selected special areas of business management. • Students are able to interrelate technical and management knowledge.
Skills	• Students are able to apply basic methods in selected areas of business management. • Students are able to explain and give reasons for decision proposals on practical issues in areas of business management.
Personal Competence	
Social Competence	• Students are able to communicate in small interdisciplinary groups and to jointly develop solutions for complex problems
Autonomy	• Students are capable of acquiring necessary knowledge independently by means of research and preparation of material.
Workload in Hours	Depends on choice of courses
Credit points	6

Courses
Information regarding lectures and courses can be found in the corresponding module handbook published separately.

Module M0524: Non-technical Courses for Master

Module Responsible	Dagmar Richter
Admission Requirements	None
Recommended Previous Knowledge	None
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	**The Nontechnical Academic Programms (NTA)** imparts skills that, in view of the TUHH's training profile, professional engineering studies require but are not able to cover fully. Self-reliance, self-management, collaboration and professional and personnel management competences. The department implements these training objectives in its **teaching architecture**, in its **teaching and learning arrangements**, in **teaching areas** and by means of teaching offerings in which students can qualify by opting for **specific competences** and a **competence level** at the Bachelor's or Master's level. The teaching offerings are pooled in two different catalogues for nontechnical complementary courses. **The Learning Architecture** consists of a cross-disciplinarily study offering. The centrally designed teaching offering ensures that courses in the nontechnical academic programms follow the specific profiling of TUHH degree courses. The learning architecture demands and trains independent educational planning as regards the individual development of competences. It also provides orientation knowledge in the form of "profiles". The subjects that can be studied in parallel throughout the student's entire study program - if need be, it can be studied in one to two semesters. In view of the adaptation problems that individuals commonly face in their first semesters after making the transition from school to university and in order to encourage individually planned semesters abroad, there is no obligation to study these subjects in one or two specific semesters during the course of studies. **Teaching and Learning Arrangements** provide for students, separated into B.Sc. and M.Sc., to learn with and from each other across semesters. The challenge of dealing with interdisciplinarity and a variety of stages of learning in courses are part of the learning architecture and are deliberately encouraged in specific courses. **Fields of Teaching** are based on research findings from the academic disciplines cultural studies, social studies, arts, historical studies, communication studies, migration studies and sustainability research, and from engineering didactics. In addition, from the winter semester 2014/15 students on all Bachelor's courses will have the opportunity to learn about business management and start-ups in a goal-oriented way. The fields of teaching are augmented by soft skills offers and a foreign language offer. Here, the focus is on encouraging goal-oriented communication skills, e.g. the skills required by outgoing engineers in international and intercultural situations. **The Competence Level** of the courses offered in this area is different as regards the basic training objective in the Bachelor's and Master's fields. These differences are reflected in the practical examples used, in content topics that refer to different professional application contexts, and in the higher scientific and theoretical level of abstraction in the B.Sc. This is also reflected in the different quality of soft skills, which relate to the different team positions and different group leadership functions of Bachelor's and Master's graduates in their future working life. **Specialized Competence (Knowledge)** Students can • explain specialized areas in context of the relevant non-technical disciplines, • outline basic theories, categories, terminology, models, concepts or artistic techniques in the disciplines represented in the learning area, • different specialist disciplines relate to their own discipline and differentiate it as well as make connections, • sketch the basic outlines of how scientific disciplines, paradigms, models, instruments, methods and forms of representation in the specialized sciences are subject to individual and socio-cultural interpretation and historicity, • Can communicate in a foreign language in a manner appropriate to the subject.
Skills	**Professional Competence (Skills)** In selected sub-areas students can • apply basic and specific methods of the said scientific disciplines, • aquestion a specific technical phenomena, models, theories from the viewpoint of another, aforementioned specialist discipline, • to handle simple and advanced questions in aforementioned scientific disciplines in a sucsessful manner, • justify their decisions on forms of organization and application in practical questions in contexts that go beyond the technical relationship to the subject.

Personal Competence	
Social Competence	**Personal Competences (Social Skills)** Students will be able • to learn to collaborate in different manner, • to present and analyze problems in the abovementioned fields in a partner or group situation in a manner appropriate to the addressees, • to express themselves competently, in a culturally appropriate and gender-sensitive manner in the language of the country (as far as this study-focus would be chosen), • to explain nontechnical items to auditorium with technical background knowledge.
Autonomy	**Personal Competences (Self-reliance)** Students are able in selected areas • to reflect on their own profession and professionalism in the context of real-life fields of application • to organize themselves and their own learning processes • to reflect and decide questions in front of a broad education background • to communicate a nontechnical item in a competent way in writen form or verbaly • to organize themselves as an entrepreneurial subject country (as far as this study-focus would be chosen)
Workload in Hours	Depends on choice of courses
Credit points	6

Courses
Information regarding lectures and courses can be found in the corresponding module handbook published separately.

Module M0676: Digital Communications

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Digital Communications (L0444)	Lecture	2	3
Digital Communications (L0445)	Recitation Section (large)	2	2
Laboratory Digital Communications (L0646)	Practical Course	1	1

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	• Mathematics 1-3 • Signals and Systems • Fundamentals of Communications and Random Processes
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are able to understand, compare and design modern digital information transmission schemes. They are familiar with the properties of linear and non-linear digital modulation methods. They can describe distortions caused by transmission channels and design and evaluate detectors including channel estimation and equalization. They know the principles of single carrier transmission and multi-carrier transmission as well as the fundamentals of basic multiple access schemes. The students are familiar with the contents of lecture and tutorials. They can explain and apply them to new problems.
Skills	The students are able to design and analyse a digital information transmission scheme including multiple access. They are able to choose a digital modulation scheme taking into account transmission rate, required bandwidth, error probability, and further signal properties. They can design an appropriate detector including channel estimation and equalization taking into account performance and complexity properties of suboptimum solutions. They are able to set parameters of a single carrier or multi carrier transmission scheme and trade the properties of both approaches against each other.
Personal Competence	
Social Competence	The students can jointly solve specific problems.
Autonomy	The students are able to acquire relevant information from appropriate literature sources. They can control their level of knowledge during the lecture period by solving tutorial problems, software tools, clicker system.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** None; **Form** Written elaboration; **Description**
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Electrical Engineering: Core Qualification: Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Microelectronics and Microsystems: Core Qualification: Elective Compulsory

Course L0444: Digital Communications

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	WiSe

Content	• Repetition: Baseband Transmission
	  ◦ Pulse shaping: Non-return to zero (NRZ) rectangular pulses, raised-cosine pulses, square-root raised-cosine pulses
	  ◦ Power spectral density (psd) of baseband signals
	  ◦ Intersymbol interference (ISI)
	  ◦ First and second Nyquist criterion
	  ◦ AWGN channel
	  ◦ Matched filter
	  ◦ Matched-filter receiver and correlation receiver
	  ◦ Noise whitening matched filter
	  ◦ Discrete-time AWGN channel model
	• Representation of bandpass signals and systems in the equivalent baseband
	  ◦ Quadrature amplitude modulation (QAM)
	  ◦ Equivalent baseband signal and system

- Analytical signal
- Equivalent baseband random process, equivalent baseband white Gaussian noise process
- Equivalent baseband AWGN channel
- Equivalent baseband channel model with frequency-offset and phase noise
- Equivalent baseband Rayleigh fading and Rice fading channel models
- Equivalent baseband frequency-selective channel model
- Discrete memoryless channels (DMC)

- Bandpass transmission via carrier modulation
  - Amplitude modulation, frequency modulation, phase modulation
  - Linear digital modulation methods
    - On-off keying, M-ary amplitude shift keying (M-ASK), M-ary phase shift keying (M-PSK), M-ary quadrature amplitude modulation (M-QAM), offset-QPSK
    - Signal space representation of transmit signal constellations and signals
    - Energy of linear digital modulated signals, average energy per symbol
    - Power spectral density of linear digital modulated signals
    - Bandwidth efficiency
    - Correlation coefficient of elementary signals
    - Error probabilities of linear digital modulation methods
      - Error functions
      - Gray mapping and natural mapping
      - Bit error probabilities, symbol error probabilities, pairwise symbol error probabilities
      - Euclidean distance and Hamming distance
      - Exact and approximate computation of error probabilities
      - Performance comparison of modulation schemes in terms of per bit SNR vs. per symbol SNR
    - Hierarchical modulation, multilevel modulation
    - Effects of carrier phase offset and carrier frequency offset
    - Differential modulation
      - M-ary differential phase shift keying (M-PSK)
      - Coherent and non-coherent detection of DPSK
      - p/M-differential phase shift keying (p/M-DPSK)
      - Differential amplitude and phase shift keying (DAPSK)
  - Non-linear digital modulation methods
    - Frequency shift keying (FSK)
    - Modulation index
    - Minimum shift keying (MSK)
      - Offset-QPSK representation of MSK
      - MSK with differential precoding and rotation
      - Bit error probabilities of MSK
      - Gaussian minimum shift keying (GMSK)
      - Power spectral density of MSK and GMSK
    - Continuous phase modulation (CPM)
      - General description of CPM signals
      - Frequency pulses and phase pulses
    - Coherent and non-coherent detection of FSK
  - Performance comparison of linear and non-linear digital modulation methods
- Frequency-selective channels, ISI channels
  - Intersymbol interference and frequency-selectivity
  - RMS delay spread
  - Narrowband and broadband channels
  - Equivalent baseband transmission model for frequency-selective channels
  - Receive filter design
- Equalization
  - Symbol-spaced and fractionally-spaced equalizers
  - Inverse system
  - Non-recursive linear equalizers
    - Linear zero-forcing (ZF) equalizer
    - Linear minimum mean squared error (MMSE) equalizer
  - Non-linear equalization:
    - Decision feedback equalizer (DFE)
    - Tomlinson-Harashima precoding
  - Maximum a posteriori probability (MAP) and maximum likelihood equalizer, Viterbi algorithm
- Single-carrier vs. multi-carrier transmission
- Multi-carrier transmission
  - General multicarrier transmission
  - Orthogonal frequency division multiplex (OFDM)
    - OFDM implementation using the Fast Fourier Transform (FFT)
    - Cyclic guard interval
    - Power spectral density of OFDM
    - Peak-to-average power ratio (PAPR)
- Multiple access

	- Principles of time division multiple access (TDMA), frequency division multiple access (FDMA), code division multiple access (CDMA), non-orthogonal multiple access (NOMA), hybrid multiple access - Spread spectrum communications - Direct sequence spread spectrum communications - Frequency hopping - Protection against eavesdropping - Protection against narrowband jammers - Short vs. long spreading codes - Direct sequence spread spectrum communications in frequency-selective channels - Rake receiver - Code division multiple access (CDMA) - Design criteria of spreading sequences, autocorrelation function and crosscorrelation function of spreading sequences - Intersymbol interference (ISI) and multiple access interference (MAI) - Pseudo noise (PN) sequences, maximum length sequences (m-sequences), Gold codes, Walsh-Hadamard codes, orthogonal variable spreading factor (OVSF) codes - Multicode transmission - CDMA in uplink and downlink of a wireless communications system - Single-user detection vs. multi-user detection
Literature	K. Kammeyer: Nachrichtenübertragung, Teubner P.A. Höher: Grundlagen der digitalen Informationsübertragung, Teubner. J.G. Proakis, M. Salehi: Digital Communications. McGraw-Hill. S. Haykin: Communication Systems. Wiley R.G. Gallager: Principles of Digital Communication. Cambridge A. Goldsmith: Wireless Communication. Cambridge. D. Tse, P. Viswanath: Fundamentals of Wireless Communication. Cambridge.

Course L0445: Digital Communications	
Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Course L0646: Laboratory Digital Communications	
Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Gerhard Bauch
Language	DE/EN
Cycle	WiSe
Content	- DSL transmission - Random processes - Digital data transmission
Literature	K. Kammeyer: Nachrichtenübertragung, Teubner P.A. Höher: Grundlagen der digitalen Informationsübertragung, Teubner. J.G. Proakis, M. Salehi: Digital Communications. McGraw-Hill. S. Haykin: Communication Systems. Wiley R.G. Gallager: Principles of Digital Communication. Cambridge A. Goldsmith: Wireless Communication. Cambridge. D. Tse, P. Viswanath: Fundamentals of Wireless Communication. Cambridge.

Module M0746: Microsystem Engineering

Courses

Title	Typ	Hrs/wk	CP
Microsystem Engineering (L0680)	Lecture	2	4
Microsystem Engineering (L0682)	Project-/problem-based Learning	2	2

Module Responsible	Dr. Thomas Kusserow
Admission Requirements	None
Recommended Previous Knowledge	Basic courses in physics, mathematics and electric engineering
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students know about the most important technologies and materials of MEMS as well as their applications in sensors and actuators.
Skills	Students are able to analyze and describe the functional behaviour of MEMS components and to evaluate the potential of microsystems.
Personal Competence	
Social Competence	Students are able to solve specific problems alone or in a group and to present the results accordingly.
Autonomy	Students are able to acquire particular knowledge using specialized literature and to integrate and associate this knowledge with other fields.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** No, **Bonus** 10 %, **Form** Presentation, **Description**
Examination	Written exam
Examination duration and scale	2h
Assignment for the Following Curricula	Electrical Engineering: Core Qualification: Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory International Management and Engineering: Specialisation II. Mechatronics: Elective Compulsory Mechanical Engineering and Management: Specialisation Mechatronics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Microelectronics and Microsystems: Core Qualification: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory

Course L0680: Microsystem Engineering	
Typ	Lecture
Hrs/wk	2
CP	4
Workload in Hours	Independent Study Time 92, Study Time in Lecture 28
Lecturer	Dr. Thomas Kusserow
Language	EN
Cycle	WiSe
Content	Object and goal of MEMS Scaling Rules Lithography Film deposition Structuring and etching Energy conversion and force generation Electromagnetic Actuators Reluctance motors Piezoelectric actuators, bi-metal-actuator Transducer principles Signal detection and signal processing Mechanical and physical sensors Acceleration sensor, pressure sensor Sensor arrays System integration Yield, test and reliability
Literature	M. Kasper: Mikrosystementwurf, Springer (2000) M. Madou: Fundamentals of Microfabrication, CRC Press (1997)

Course L0682: Microsystem Engineering	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Thomas Kusserow
Language	EN
Cycle	WiSe
Content	Examples of MEMS components Layout consideration Electric, thermal and mechanical behaviour Design aspects
Literature	Wird in der Veranstaltung bekannt gegeben

Module M0710: Microwave Engineering

Courses

Title	Typ	Hrs/wk	CP
Microwave Engineering (L0573)	Lecture	2	3
Microwave Engineering (L0574)	Recitation Section (large)	2	2
Microwave Engineering (L0575)	Practical Course	1	1

Module Responsible	Prof. Alexander Kölpin
Admission Requirements	None
Recommended Previous Knowledge	Fundamentals of communication engineering, semiconductor devices and circuits. Basics of Wave propagation from transmission line theory and theoretical electrical engineering.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can explain the propagation of electromagnetic waves and related phenomena. They can describe transmission systems and components. They can name different types of antennas and describe the main characteristics of antennas. They can explain noise in linear circuits, compare different circuits using characteristic numbers and select the best one for specific scenarios.
Skills	Students are able to calculate the propagation of electromagnetic waves. They can analyze complete transmission systems und configure simple receiver circuits. They can calculate the characteristic of simple antennas and arrays based on the geometry. They can calculate the noise of receivers and the signal-to-noise-ratio of transmission systems. They can apply their theoretical knowledge to the practical courses.
Personal Competence	
Social Competence	Students work together in small groups during the practical courses. Together they document, evaluate and discuss their results.
Autonomy	Students are able to relate the knowledge gained in the course to contents of previous lectures. With given instructions they can extract data needed to solve specific problems from external sources. They are able to apply their knowledge to the laboratory courses using the given instructions.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** None; **Form** Subject theoretical and practical work; **Description**
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Electrical Engineering: Core Qualification: Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

Course L0573: Microwave Engineering	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Alexander Kölpin
Language	DE/EN
Cycle	WiSe
Content	- Antennas: Analysis - Characteristics - Realizations - Radio Wave Propagation - Transmitter: Power Generation with Vacuum Tubes and Transistors - Receiver: Preamplifier - Heterodyning - Noise - Selected System Applications
Literature	H.-G. Unger, „Elektromagnetische Theorie für die Hochfrequenztechnik, Teil I“, Hüthig, Heidelberg, 1988 H.-G. Unger, „Hochfrequenztechnik in Funk und Radar“, Teubner, Stuttgart, 1994 E. Voges, „Hochfrequenztechnik - Teil II: Leistungsröhren, Antennen und Funkübertragung, Funk- und Radartechnik“, Hüthig, Heidelberg, 1991 E. Voges, „Hochfrequenztechnik“, Hüthig, Bonn, 2004 C.A. Balanis, “Antenna Theory”, John Wiley and Sons, 1982 R. E. Collin, “Foundations for Microwave Engineering”, McGraw-Hill, 1992 D. M. Pozar, “Microwave and RF Design of Wireless Systems”, John Wiley and Sons, 2001 D. M. Pozar, “Microwave Engineerin”, John Wiley and Sons, 2005

Course L0574: Microwave Engineering	
Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Alexander Kölpin
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Course L0575: Microwave Engineering	
Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Alexander Kölpin
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0846: Control Systems Theory and Design

Courses

Title	Typ	Hrs/wk	CP
Control Systems Theory and Design (L0656)	Lecture	2	4
Control Systems Theory and Design (L0657)	Recitation Section (small)	2	2

Module Responsible	Prof. Herbert Werner
Admission Requirements	None
Recommended Previous Knowledge	Introduction to Control Systems
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can explain how linear dynamic systems are represented as state space models; they can interpret the system response to initial states or external excitation as trajectories in state space • They can explain the system properties controllability and observability, and their relationship to state feedback and state estimation, respectively • They can explain the significance of a minimal realisation • They can explain observer-based state feedback and how it can be used to achieve tracking and disturbance rejection • They can extend all of the above to multi-input multi-output systems • They can explain the z-transform and its relationship with the Laplace Transform • They can explain state space models and transfer function models of discrete-time systems • They can explain the experimental identification of ARX models of dynamic systems, and how the identification problem can be solved by solving a normal equation • They can explain how a state space model can be constructed from a discrete-time impulse response
Skills	• Students can transform transfer function models into state space models and vice versa • They can assess controllability and observability and construct minimal realisations • They can design LQG controllers for multivariable plants • They can carry out a controller design both in continuous-time and discrete-time domain, and decide which is appropriate for a given sampling rate • They can identify transfer function models and state space models of dynamic systems from experimental data • They can carry out all these tasks using standard software tools (Matlab Control Toolbox, System Identification Toolbox, Simulink)
Personal Competence	
Social Competence	Students can work in small groups on specific problems to arrive at joint solutions.
Autonomy	Students can obtain information from provided sources (lecture notes, software documentation, experiment guides) and use it when solving given problems. They can assess their knowledge in weekly on-line tests and thereby control their learning progress.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Electrical Engineering: Core Qualification: Compulsory Energy Systems: Core Qualification: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory International Management and Engineering: Specialisation II. Mechatronics: Elective Compulsory Mechanical Engineering and Management: Specialisation Mechatronics: Elective Compulsory Mechatronics: Core Qualification: Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Product Development, Materials and Production: Core Qualification: Elective Compulsory Theoretical Mechanical Engineering: Core Qualification: Compulsory

Course L0656: Control Systems Theory and Design	
Typ	Lecture
Hrs/wk	2
CP	4
Workload in Hours	Independent Study Time 92, Study Time in Lecture 28
Lecturer	Prof. Herbert Werner
Language	EN
Cycle	WiSe
Content	State space methods (single-input single-output) • State space models and transfer functions, state feedback • Coordinate basis, similarity transformations • Solutions of state equations, matrix exponentials, Caley-Hamilton Theorem • Controllability and pole placement • State estimation, observability, Kalman decomposition • Observer-based state feedback control, reference tracking • Transmission zeros • Optimal pole placement, symmetric root locus Multi-input multi-output systems • Transfer function matrices, state space models of multivariable systems, Gilbert realization • Poles and zeros of multivariable systems, minimal realization • Closed-loop stability • Pole placement for multivariable systems, LQR design, Kalman filter Digital Control • Discrete-time systems: difference equations and z-transform • Discrete-time state space models, sampled data systems, poles and zeros • Frequency response of sampled data systems, choice of sampling rate System identification and model order reduction • Least squares estimation, ARX models, persistent excitation • Identification of state space models, subspace identification • Balanced realization and model order reduction Case study • Modelling and multivariable control of a process evaporator using Matlab and Simulink Software tools • Matlab/Simulink
Literature	• Werner, H., Lecture Notes „Control Systems Theory and Design“ • T. Kailath "Linear Systems", Prentice Hall, 1980 • K.J. Astrom, B. Wittenmark "Computer Controlled Systems" Prentice Hall, 1997 • L. Ljung "System Identification - Theory for the User", Prentice Hall, 1999

Course L0657: Control Systems Theory and Design	
Typ	Recitation Section (small)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Herbert Werner
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M1250: Electrical Power Systems II: Operation and Information Systems of Electrical Power Grids

Courses

Title	Typ	Hrs/wk	CP
Electrical Power Systems II: Operation and Information Systems of Electrical Power Grids (L1696)	Lecture	3	4
Electrical Power Systems II: Operation and Information Systems of Electrical Power Grids (L1697)	Recitation Section (large)	2	2

Module Responsible	Prof. Christian Becker
Admission Requirements	None
Recommended Previous Knowledge	Fundamentals of Electrical Engineering, Electrical Power Systems I, Mathematics I, II, III
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to explain in detail and critically evaluate technologies and information systems for operational management of conventional and modern electric power systems as well as methods and algorithms for steady-state network calculation, failure calculation, power system operation and optimization. They are additonally able to apply these methods to real electric power systems.
Skills	With completion of this module the students are able to apply the acquired skills for planning and analysis of real electric power systems and to critically evaluate the results.
Personal Competence	
Social Competence	The students can participate in specialized and interdisciplinary discussions, advance ideas and represent their own work results in front of others.
Autonomy	Students can independently tap knowledge of the emphasis of the lectures and apply it within further research activities.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	45 min
Assignment for the Following Curricula	Electrical Engineering: Core Qualification: Compulsory Energy Systems: Specialisation Energy Systems: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory

Course L1696: Electrical Power Systems II: Operation and Information Systems of Electrical Power Grids	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Christian Becker
Language	DE
Cycle	WiSe

Content	• steaedy-state modelling of electric power systems
	  ◦ conventional components
	  ◦ Flexible AC Transmission Systems (FACTS) and HVDC
	  ◦ grid modelling
	• grid operation
	  ◦ electric power supply processes
	  ◦ grid and power system management
	  ◦ grid provision
	• grid control systems
	  ◦ information and communication systems for power system management
	  ◦ IT architectures of bay-, substation and network control level
	  ◦ IT integration (energy market / supply shortfall management / asset management)
	  ◦ future trends of process control technology
	  ◦ smart grids
	• functions and steady-state computations for power system operation and plannung
	  ◦ load-flow calculations
	  ◦ sensitivity analysis and power flow control
	  ◦ power system optimization
	  ◦ short-circuit calculation
	  ◦ asymmetric failure calculation
	    ▪ symmetric components
	    ▪ calculation of asymmetric failures
	  ◦ state estimation

Literature	E. Handschin: Elektrische Energieübertragungssysteme, Hüthig Verlag B. R. Oswald: Berechnung von Drehstromnetzen, Springer-Vieweg Verlag V. Crastan: Elektrische Energieversorgung Bd. 1 & 3, Springer Verlag E.-G. Tietze: Netzleittechnik Bd. 1 & 2, VDE-Verlag

Course L1697: Electrical Power Systems II: Operation and Information Systems of Electrical Power Grids	
Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Christian Becker
Language	DE
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0798: Technical Complementary Course for ETMS (according to Subject Specific Regulations)

Courses			
Title	**Typ**	**Hrs/wk**	**CP**

Module Responsible	Prof. Christian Becker
Admission Requirements	None
Recommended Previous Knowledge	See selected module according to FSPO
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	see selected module according to FSPO
Skills	see selected module according to FSPO
Personal Competence	
Social Competence	see selected module according to FSPO
Autonomy	see selected module according to FSPO
Workload in Hours	Depends on choice of courses
Credit points	12
Assignment for the Following Curricula	Electrical Engineering: Core Qualification: Compulsory

Specialization Microwave Engineering, Optics, and Electromagnetic Compatibility

Module M0643: Optoelectronics I - Wave Optics

Courses

Title	Typ	Hrs/wk	CP
Optoelectronics I: Wave Optics (L0359)	Lecture	2	3
Optoelectronics I: Wave Optics (Problem Solving Course) (L0361)	Recitation Section (small)	1	1

Module Responsible	Dr. Alexander Petrov
Admission Requirements	None
Recommended Previous Knowledge	Basics in electrodynamics, calculus
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can explain the fundamental mathematical and physical relations of freely propagating optical waves. They can give an overview on wave optical phenomena such as diffraction, reflection and refraction, etc. Students can describe waveoptics based components such as electrooptical modulators in an application oriented way.
Skills	Students can generate models and derive mathematical descriptions in relation to free optical wave propagation. They can derive approximative solutions and judge factors influential on the components' performance.
Personal Competence	
Social Competence	Students can jointly solve subject related problems in groups. They can present their results effectively within the framework of the problem solving course.
Autonomy	Students are capable to extract relevant information from the provided references and to relate this information to the content of the lecture. They can reflect their acquired level of expertise with the help of lecture accompanying measures such as exam typical exam questions. Students are able to connect their knowledge with that acquired from other lectures.
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Credit points	4
Course achievement	None
Examination	Written exam
Examination duration and scale	60 minutes
Assignment for the Following Curricula	Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Materials Science: Specialisation Nano and Hybrid Materials: Elective Compulsory Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory Renewable Energies: Specialisation Solar Energy Systems: Elective Compulsory

Course L0359: Optoelectronics I: Wave Optics	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Alexander Petrov
Language	EN
Cycle	SoSe
Content	• Introduction to optics • Electromagnetic theory of light • Interference • Coherence • Diffraction • Fourier optics • Polarisation and Crystal optics • Matrix formalism • Reflection and transmission • Complex refractive index • Dispersion • Modulation and switching of light
Literature	Bahaa E. A. Saleh, Malvin Carl Teich, Fundamentals of Photonics, Wiley 2007 Hecht, E., Optics, Benjamin Cummings, 2001 Goodman, J.W. Statistical Optics, Wiley, 2000 Lauterborn, W., Kurz, T., Coherent Optics: Fundamentals and Applications, Springer, 2002

Course L0361: Optoelectronics I: Wave Optics (Problem Solving Course)	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Dr. Alexander Petrov
Language	EN
Cycle	SoSe
Content	see lecture Optoelectronics 1 - Wave Optics
Literature	see lecture Optoelectronics 1 - Wave Optics

Module M0645: Fibre and Integrated Optics

Courses

Title	Typ	Hrs/wk	CP
Fibre and Integrated Optics (L0363)	Lecture	2	3
Fibre and Integrated Optics (Problem Solving Course) (L0365)	Recitation Section (small)	1	1

Module Responsible	Prof. Manfred Eich
Admission Requirements	None
Recommended Previous Knowledge	Basic principles of electrodynamics and optics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can explain the fundamental mathematical and physical relations and technological basics of guided optical waves. They can describe integrated optical as well as fibre optical structures. They can give an overview on the applications of integrated optical components in optical signal processing.
Skills	Students can generate models and derive mathematical descriptions in relation to fibre optical and integrated optical wave propagation. They can derive approximative solutions and judge factors influential on the components' performance.
Personal Competence	
Social Competence	Students can jointly solve subject related problems in groups. They can present their results effectively within the framework of the problem solving course.
Autonomy	Students are capable to extract relevant information from the provided references and to relate this information to the content of the lecture. They can reflect their acquired level of expertise with the help of lecture accompanying measures such as exam typical exam questions. Students are able to connect their knowledge with that acquired from other lectures.
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Credit points	4
Course achievement	None
Examination	Written exam
Examination duration and scale	60 minutes
Assignment for the Following Curricula	Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory

Course L0363: Fibre and Integrated Optics

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Hagen Renner
Language	EN
Cycle	SoSe
Content	• Theory of optical waveguides • Coupling to and from waveguides • Losses • Linear and nonlinear dspersion • Components and technical applications
Literature	Bahaa E. A. Saleh, Malvin Carl Teich, Fundamentals of Photonics, Wiley 2007 Hunsperger, R.G., Integrated Optics: Theory and Technology, Springer, 2002 Agrawal, G.P.,Fiber-Optic Communication Systems, Wiley, 2002, ISBN 0471215716 Marcuse, D., Theory of Dielectric Optical Waveguides, Academic Press,1991, ISBN 0124709516 Tamir, T. (ed), Guided-Wave Optoelectronics, Springer, 1990

Course L0365: Fibre and Integrated Optics (Problem Solving Course)	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Dr. Hagen Renner
Language	EN
Cycle	SoSe
Content	See lecture Fibre and Integrated Optics
Literature	See lecture Fibre and Integrated Optics

Module M1016: Optical Communications

Courses

Title	Typ	Hrs/wk	CP
Optical Communication (L0477)	Lecture	2	3
Optical Communication (L0480)	Recitation Section (large)	1	1

Module Responsible	Dr. Hagen Renner
Admission Requirements	None
Recommended Previous Knowledge	Fundamentals of Electrical Engineering, Communication Engineering, Electronics Components
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The aim of this course is imparting profound knowledge and analytical skills in the following fields: - Fundamentals of Optical Waveguiding - Properties of Optical Silica Fibers - Passive Components for Optical Communications - Fundamentals of Photodiodes and LEDs - Noise in Photodetectors - Laser Diodes - Optical Amplifiers - Nonlinearities in Optical Fibers - Optical Communication Systems
Skills	Fundamental skills are imparted with respect to the modelling of basic optical communication systems and fundamental optical components as well as to estimating the influence of important causes of impairement.
Personal Competence	
Social Competence	
Autonomy	In the excersises the autonomous aplication of the knowledge gained in the lecture to specific problems of Optical Communications will be trained.
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Credit points	4
Course achievement	None
Examination	Oral exam
Examination duration and scale	20 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory

Course L0477: Optical Communication

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Hagen Renner
Language	EN
Cycle	SoSe

Content	**Optical Communications**
	
	• Optical waveguide fundamentals
	    ◦ total internal reflection at plane dielectric interfaces
	    ◦ slab waveguides
	    ◦ rays in step-index and graded-index “multi-mode” fibers
	    ◦ modes in optical fibers
	    ◦ single-mode fibers
	    ◦ fabrication of fibers
	• Properties of silica optical fiber relevant in communications
	    ◦ attenuation by scattering and absorption
	    ◦ dispersion and pulse broadening
	    ◦ polarization mode dispersion
	
	• Passive fiber optical components
	    ◦ excitation of fibers, splice/connector loss
	    ◦ fiber optical directional couplers
	    ◦ isolators, circulators, phased arrays, grating components

	• Photodiode and LED fundamentals
	  ◦ pin-photodiodes: responsivity, response time, equivalent circuit
	  ◦ avalanche photodiodes
	  ◦ light emitting diodes: spectra, output power, modulation
	• Noise in photodetectors
	  ◦ power spectral density of a train of randomly occuring events
	  ◦ shot noise and thermal noise
	  ◦ photodetector equivalent circuits with noise sources
	  ◦ basic receiver considerations
	• Laserdiodes
	  ◦ basic laser physics
	  ◦ Fabry-Perot laser diodes
	  ◦ rate equations and LD characteristics
	  ◦ special laser diodes
	• Optical fiber amplifiers
	  ◦ Erbium in silica fibers: energy levels, transitions, cross sections, amplification
	  ◦ noise in optical amplifiers: spontaneous emission, ASE, noise figure, periodic amplification
	  ◦ modelling of optical amplifiers
	  ◦ examples and applications
	• Nonlinearities in optical fibers
	  ◦ basic nonlinear effects
	  ◦ solitons for high bit rate transmission: dispersion vs. self phase modulation
	• Optical fiber systems

Literature	[1] G.P. Agrawal, "Fiber-optic communication systems", Wiley-Interscience, 2002 [2] J. Gowar: “Opical Communication Systems“, Prentice Hall 199 [3] I.P. Kaminov and L. Koch (ed.): “Optical Fiber Telecomminications“, volume IIIA and IIIB, Academic Press, 1997 [4] A. Yariv: “Optical Electronics“, Sauders College Publishing, 1997 [5] E.G. Neumann: “Single-Mode Fibers“, Springer 1988 [6] H.G. Unger: “Optische Nachrichtentechnik“, volume I and II, Hüthig 1992 (in German) [7] J.M. Senior: “Optical Fiber communications“, Prentice Hall 2009 [8] E. Voges and K. Petermann (ed.): “Optische Kommunikationstechnik”, Springer 2002 (in German)

Course L0480: Optical Communication	
Typ	Recitation Section (large)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Dr. Hagen Renner
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0712: Microwave Semiconductor Devices and Circuits I

Courses

Title	Typ	Hrs/wk	CP
Microwave Semiconductor Devices and Circuits I (L0580)	Lecture	3	4
Microwave Semiconductor Devices and Circuits I (L0581)	Recitation Section (large)	2	2

Module Responsible	Prof. Alexander Kölpin
Admission Requirements	None
Recommended Previous Knowledge	Electrical Engineering IV, Microwave Engineering, Fundamentals of Semiconductor Technology
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are capable of explaining the functionality of amplifier, mixer, and oscillator in detail. They can present theories, concepts, and reasonable assumptions for description and synthesis of these devices. They are able to apply thorough knowledge of semiconductor physics of selected microwave devices to amplifier, mixer, and oscillator. They can compare different devices with respect to various parameters (such as frequency range, power und efficiency).
Skills	The students can assess occurring linear and nonlinear effects in active microwave circuits and are capable of analyzing and evaluating them. They are able to develop passive and active linear microwave circuits with the help of modern software-tools, taking application requirements into account.
Personal Competence	
Social Competence	The students are able to carry out subject-specific tasks in small groups, and to adequately present solutions (e.g. in CAD-Exercises).
Autonomy	The students are able to obtain additional information from given literature sources and set the content in context with the lecture. They can link and deepen their knowledge of other courses, e.g., Electrical Engineering IV, Theoretical Engineering, Microwave Engineering, Semiconductor Devices. The students acquire the ability to communicate problems and solutions in the field of microwave semiconductor devices and circuits in English.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory

Course L0580: Microwave Semiconductor Devices and Circuits I	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Alexander Kölpin
Language	DE/EN
Cycle	SoSe
Content	- Amplifier: S-Parameters, stability, gain definitions; Bipolar Junction Transistor and HBT, MESFET and HEMT; Circuit applications, nonlinear distortions, low noise and power amplifier - Mixer: Conversion matrix analysis; pn- and Schottky-diode, FET; Circuit applications, conversion gain and noise figure - Oszillator: Oscillation start-up, steady state operation, stability; IMPATT-diode, Gunn-element, FET; oscillator stabilization - Linear passive circuits: Planar microwave circuits, quarterwave matching circuits and discontinuities, lowpass-filter and bandpass-filter synthesis - Design of active circuits
Literature	- E. Voges, „Hochfrequenztechnik“, Hüthig (2004) - H.-G. Unger, W. Harth, „Hochfrequenz-Halbleiterelektronik“, S. Hirzel Verlag (1972) - S.M. Sze, „Physics of Semiconductor Devices”, John Wiley & Sons (1981) - A. Jacob, „Lecture Notes Microwave Semiconductor Devices and Circuits Part I“

Course L0581: Microwave Semiconductor Devices and Circuits I	
Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Alexander Kölpin
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0769: EMC I: Coupling Mechanisms, Countermeasures and Test Procedures

Courses

Title	Typ	Hrs/wk	CP
EMC I: Coupling Mechanisms, Countermeasures, and Test Procedures (L0743)	Lecture	3	4
EMC I: Coupling Mechanisms, Countermeasures, and Test Procedures (L0744)	Recitation Section (small)	1	1
EMC I: Coupling Mechanisms, Countermeasures, and Test Procedures (L0745)	Practical Course	1	1

Module Responsible	Prof. Christian Schuster
Admission Requirements	None
Recommended Previous Knowledge	Fundamentals of Electrical Engineering
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to explain the fundamental principles, inter-dependencies, and methods of Electromagnetic Compatibility of electric and electronic systems and to ensure Electromagnetic Compatibility of such systems. They are able to classify and explain the common interference sources and coupling mechanisms. They are capable of explaining the basic principles of shielding and filtering. They are able of giving an overview over measurement and simulation methods for the characterization of Electromagnetic Compatibility in electrical engineering practice.
Skills	Students are able to apply a series of modeling methods for the Electromagnetic Compatibility of typical electric and electronic systems. They are able to determine the most important effects that these models are predicting in terms of Electromagnetic Compatibility. They can classify these effects and they can quantitatively analyze them. They are capable of deriving problem solving strategies from these predictions and they can adapt them to applications in electrical engineering practice. They can evaluate their problem solving strategies against each other.
Personal Competence	
Social Competence	Students are able to work together on subject related tasks in small groups. They are able to present their results effectively in English, during laboratory work and exercises, e.g..
Autonomy	Students are capable to gather necessary information from the references provided and relate that information to the context of the lecture. They are able to make a connection between their knowledge obtained in this lecture with the content of other lectures (e.g. Theoretical Electrical Engineering and Communication Theory). They can communicate problems and solutions in the field of Electromagnetic Compatibility in english language.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** None; **Form** Presentation; **Description**
Examination	Oral exam
Examination duration and scale	45 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Mechatronics: Technical Complementary Course: Elective Compulsory Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory

Course L0743: EMC I: Coupling Mechanisms, Countermeasures, and Test Procedures

Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Christian Schuster
Language	DE/EN
Cycle	SoSe
Content	• Introduction to Electromagnetic Compatibility (EMC) • Interference sources in time an frequency domain • Coupling mechanisms • Transmission lines and coupling to electromagnetic fields • Shielding • Filters • EMC test procedures
Literature	• C.R. Paul: "Introduction to Electromagnetic Compatibility", 2nd ed., (Wiley, New Jersey, 2006). • A.J. Schwab und W. Kürner: "Elektromagnetische Verträglichkeit", 6. Auflage, (Springer, Berlin 2010). • F.M. Tesche, M.V. Ianoz, and T. Karlsson: "EMC Analysis Methods and Computational Models", (Wiley, New York, 1997).

Course L0744: EMC I: Coupling Mechanisms, Countermeasures, and Test Procedures	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Christian Schuster
Language	DE/EN
Cycle	SoSe
Content	The exercise sessions serve to deepen the understanding of the concepts of the lecture.
Literature	• C.R. Paul: "Introduction to Electromagnetic Compatibility", 2nd ed., (Wiley, New Jersey, 2006). • A.J. Schwab und W. Kürner: "Elektromagnetische Verträglichkeit", 6. Auflage, (Springer, Berlin 2010). • F.M. Tesche, M.V. Ianoz, and T. Karlsson: "EMC Analysis Methods and Computational Models", (Wiley, New York, 1997). • Scientific articles and papers

Course L0745: EMC I: Coupling Mechanisms, Countermeasures, and Test Procedures	
Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Christian Schuster
Language	DE/EN
Cycle	SoSe
Content	Laboratory experiments serve to practically investigate the following EMC topics: • Shielding • Conducted EMC test procedures • The GTEM-cell as an environment for radiated EMC test
Literature	Versuchsbeschreibungen und zugehörige Literatur werden innerhalb der Veranstaltung bereit gestellt.

Module M1785: Machine Learning in Electrical Engineering and Information Technology

Courses

Title	Typ	Hrs/wk	CP
General Introduction Machine Learning (L3004)	Lecture	1	2
Machine Learning Applications in Electric Power Systems (L3008)	Lecture	1	1
Machine Learning in Electromagnetic Compatibility (EMC) Engineering (L3006)	Lecture	1	1
Machine Learning in High-Frequency Technology and Radar (L3007)	Lecture	1	1
Machine Learning in Wireless Communications (L3005)	Lecture	1	1

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	The module is designed for a diverse audience, i.e. students with different background. It shall be suitable for both students with deeper knowledge in machine learning methods but less knowledge in electrical engineering, e.g. math or computer science students, and students with deeper knowledge in electrical engineering but less knowledge in machine learning methods, e.g. electrical engineering students. Machine learning methods will be explained on a relatively high level indicating mainly principle ideas. The focus is on specific applications in electrical engineering and information technology. The chapters of the course will be understandable in different depth depending on the individual background of the student. The individual background of the students will be taken into consideration in the oral exam.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	
Skills	
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory

Course L3004: General Introduction Machine Learning	
Typ	Lecture
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Dr. Maximilian Stark
Language	EN
Cycle	SoSe
Content	• From Rule-Based Systems to Machine Learning ◦ Brief overview recent advances in ML in various domain ◦ Outline and expected learning outcomes ◦ Basics statistical inference and statistics ◦ Basics of information theory • The Notions of Learning in Machine Learning ◦ Unsupervised and supervised machine learning ◦ Model-based and data-driven machine learning ◦ Hybrid modelling ◦ Online/offline/meta/transfer learning ◦ General loss functions • Introduction to Deep Learning ◦ Variants of neural networks ◦ MLP ◦ Conv. neural networks ◦ Recurrent neural networks ◦ Training neural networks ◦ (Stochastic) Gradient Descent • Regression vs. Classification ◦ Classification as supervised learning problem ◦ Hands-On Session • Representation Learning and Generative Models ◦ AutoEncoders ◦ Directed Generative Models ◦ Undirected Generative Models ◦ Generative Adversarial Neural Networks • Probabilistic Graphical Models ◦ Bayesian Networks ◦ Variational inference (variational autoencoder)
Literature	

Course L3008: Machine Learning Applications in Electric Power Systems	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Christian Becker, Dr. Davood Babazadeh
Language	EN
Cycle	SoSe
Content	
Literature	

Course L3006: Machine Learning in Electromagnetic Compatibility (EMC) Engineering	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Christian Schuster, Dr. Cheng Yang
Language	EN
Cycle	SoSe
Content	Electromagnetic Compatibility (EMC) Engineering deals with design, simulation, measurement, and certification of electronic and electric components and systems in such a way that their operation is safe, reliable, and efficient in any possible application. Safety is hereby understood as safe with respect to parasitic effects of electromagnetic fields on humans as well as on the operation of other components and systems nearby. Examples for components and systems range from the wiring in aircraft and ships to high-speed interconnects in server systems and wirless interfaces for brain implants. In this part of the course we will give an introduction to the physical basics of EMC engineering and then show how methods of Machine Learning (ML) can be applied to expand todays physcis-based approaches in EMC Engineering.
Literature	

Course L3007: Machine Learning in High-Frequency Technology and Radar	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Alexander Kölpin, Dr. Fabian Lurz
Language	EN
Cycle	SoSe
Content	
Literature	

Course L3005: Machine Learning in Wireless Communications	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Dr. Maximilian Stark
Language	EN
Cycle	SoSe

Content	• Supervised Learning Application - Channel Coding
	  ◦ Recap channel coding and block codes
	  ◦ Block codes as trainable neural networks
	  ◦ Tanner graph with trainable weights
	  ◦ Hands-on session
	• Supervised Learning Application - Modulation Detection
	  ◦ Recap wireless modulation schemes
	  ◦ Convolutional neuronal networks for blind detection of modulation schemes
	  ◦ Hands-on session
	• Autoencoder Application - Constellation Shaping I
	  ◦ Recap channel capacity and constellation shaping,
	  ◦ Capacity achieving machine learning systems
	  ◦ Information theoretical explanation of the autoencoder training
	  ◦ Hands-on session
	• Autoencoder Application - Constellation Shaping II
	  ◦ Training without a channel model
	  ◦ Mutual information neural estimator
	  ◦ Hands-on session
	• Generative Adversarial Network Application - Channel Modelling
	  ◦ Recap realistic channels with non-linear hardware impairments
	  ◦ Training a digital twin of a realistic channel with insufficient training data
	  ◦ Hands-on session
	• Recurrent Neural Network Application - Channel prediction
	  ◦ Recap time-varying channel models
	  ◦ Recurrent neural networks for temporal prediction
	  ◦ Hands-on session

Literature	

Module M1689: Wireless Systems for Mobile Applications

Courses

Title	Typ	Hrs/wk	CP
Wireless Systems for Mobile Applications (L2680)	Lecture	2	3
Wireless Systems for Mobile Applications (L2681)	Recitation Section (large)	2	3

Module Responsible	Prof. Alexander Kölpin
Admission Requirements	None
Recommended Previous Knowledge	Microwave Engineering
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can explain in detail how mobile radio communication systems, radar and low-power sensor networks work. They can present theories, concepts and reasonable assumptions of the effects of radio wave propagation in mobile applications. They are able to apply in-depth knowledge of the physics of wave propagation in dynamic scenarios to the system design of mobile communications, radar and wireless sensor networks. They can compare different concepts of these applications with respect to different parameters (such as frequency range, robustness and efficiency).
Skills	The students are able to assess which principal dynamic effects can occur in mobile radio systems and can analyze and evaluate them. They can design regulation-compliant and performance-optimized radio systems taking into account application requirements.
Personal Competence	
Social Competence	Students can work together in small groups on subject-specific tasks and present results in a suitable manner (e.g. during practical exercises).
Autonomy	The students are able to obtain the necessary information from the given literature sources and to put it into the context of the lecture. They can link their acquired knowledge with the contents of other courses (e.g. Theoretical Electrical Engineering, Microwave Engineering and Microwace Systems and Circuits I). They are able to communicate problems and solutions in the field of wireless systems for mobile applications in English.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory

Course L2680: Wireless Systems for Mobile Applications

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Alexander Kölpin
Language	DE/EN
Cycle	SoSe
Content	- Mobile radio channel: radio channel properties, radio channel modeling, modulation techniques, digital modulation - Mobile communication systems: Car-2-X, hybrid and ultra-low power communication systems (wake-up receivers, sub-GHz systems, RFID) - Radar: Pulse, Doppler and Continuous Wave, FMCW radar,
Literature	• C.A. Balanis, “Antenna Theory”, John Wiley and Sons, 1982 • D. M. Pozar, “Microwave and RF Design of Wireless Systems”, John Wiley and Sons, 2001 • D. M. Pozar, “Microwave Engineering”, John Wiley and Sons, 2005 • B. Razavi, “RF Microelectronics”, Pearson, 2011

Course L2681: Wireless Systems for Mobile Applications	
Typ	Recitation Section (large)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Alexander Kölpin
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1695: Selected Topics in Microwave Engineering, Optics, and Electromagnetic Compatibility

Courses

Title	Typ	Hrs/wk	CP
Selected Topics in Microwave Engineering, Optics, and Electromagnetic Compatibility (L2696)	Lecture	2	4
Selected Topics in Microwave Engineering, Optics, and Electromagnetic Compatibility (L2697)	Recitation Section (large)	2	2

Module Responsible	Prof. Christian Becker
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	
Skills	
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Electrical Engineering: Specialisation Wireless and Sensor Technologies: Elective Compulsory

Course L2696: Selected Topics in Microwave Engineering, Optics, and Electromagnetic Compatibility

Typ	Lecture
Hrs/wk	2
CP	4
Workload in Hours	Independent Study Time 92, Study Time in Lecture 28
Lecturer	Dozenten des SD E
Language	DE/EN
Cycle	WiSe/SoSe
Content	
Literature	

Course L2697: Selected Topics in Microwave Engineering, Optics, and Electromagnetic Compatibility

Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dozenten des SD E
Language	DE/EN
Cycle	WiSe/SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0644: Optoelectronics II - Quantum Optics

Courses

Title	Typ	Hrs/wk	CP
Optoelectronics II: Quantum Optics (L0360)	Lecture	2	3
Optoelectronics II: Quantum Optics (Problem Solving Course) (L0362)	Recitation Section (small)	1	1

Module Responsible	Dr. Alexander Petrov
Admission Requirements	None
Recommended Previous Knowledge	Basic principles of electrodynamics, optics and quantum mechanics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can explain the fundamental mathematical and physical relations of quantum optical phenomena such as absorption, stimulated and spontanous emission. They can describe material properties as well as technical solutions. They can give an overview on quantum optical components in technical applications.
Skills	Students can generate models and derive mathematical descriptions in relation to quantum optical phenomena and processes. They can derive approximative solutions and judge factors influential on the components' performance.
Personal Competence	
Social Competence	Students can jointly solve subject related problems in groups. They can present their results effectively within the framework of the problem solving course.
Autonomy	Students are capable to extract relevant information from the provided references and to relate this information to the content of the lecture. They can reflect their acquired level of expertise with the help of lecture accompanying measures such as exam typical exam questions. Students are able to connect their knowledge with that acquired from other lectures.
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Credit points	4
Course achievement	None
Examination	Written exam
Examination duration and scale	60 minutes
Assignment for the Following Curricula	Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Materials Science: Specialisation Nano and Hybrid Materials: Elective Compulsory Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory

Course L0360: Optoelectronics II: Quantum Optics

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Alexander Petrov
Language	EN
Cycle	WiSe
Content	• Generation of light • Photons • Thermal and nonthermal light • Laser amplifier • Noise • Optical resonators • Spectral properties of laser light • CW-lasers (gas, solid state, semiconductor) • Pulsed lasers
Literature	Bahaa E. A. Saleh, Malvin Carl Teich, Fundamentals of Photonics, Wiley 2007 Demtröder, W., Laser Spectroscopy: Basic Concepts and Instrumentation, Springer, 2002 Kasap, S.O., Optoelectronics and Photonics: Principles and Practices, Prentice Hall, 2001 Yariv, A., Quantum Electronics, Wiley, 1988 Wilson, J., Hawkes, J., Optoelectronics: An Introduction, Prentice Hall, 1997, ISBN: 013103961X Siegman, A.E., Lasers, University Science Books, 1986

Course L0362: Optoelectronics II: Quantum Optics (Problem Solving Course)	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Dr. Alexander Petrov
Language	EN
Cycle	WiSe
Content	see lecture Optoelectronics 1 - Wave Optics
Literature	see lecture Optoelectronics 1 - Wave Optics

Module M0781: EMC II: Signal Integrity and Power Supply of Electronic Systems

Courses

Title	Typ	Hrs/wk	CP
EMC II: Signal Integrity and Power Supply of Electronic Systems (L0770)	Lecture	3	4
EMC II: Signal Integrity and Power Supply of Electronic Systems (L0771)	Recitation Section (small)	1	1
EMC II: Signal Integrity and Power Supply of Electronic Systems (L0774)	Practical Course	1	1

Module Responsible	Prof. Christian Schuster
Admission Requirements	None
Recommended Previous Knowledge	Fundamentals of electrical engineering
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to explain the fundamental principles, inter-dependencies, and methods of signal and power integrity of electronic systems. They are able to relate signal and power integrity to the context of interference-free design of such systems, i.e. their electromagnetic compatibility. They are capable of explaining the basic behavior of signals and power supply in typical packages and interconnects. They are able to propose and describe problem solving strategies for signal and power integrity issues. They are capable of giving an overview over measurement and simulation methods for characterization of signal and power integrity in electrical engineering practice.
Skills	Students are able to apply a series of modeling methods for characterization of electromagnetic field behavior in packages and interconnect structure of electronic systems. They are able to determine the most important effects that these models are predicting in terms of signal and power integrity. They can classify these effects and they can quantitatively analyze them. They are capable of deriving problem solving strategies from these predictions and they can adapt them to applications in electrical engineering practice. The can evaluate their problem solving strategies against each other.
Personal Competence	
Social Competence	Students are able to work together on subject related tasks in small groups. They are able to present their results effectively in English (e.g. during CAD exercises).
Autonomy	Students are capable to gather necessary information from the references provided and relate that information to the context of the lecture. They are able to make a connection between their knowledge obtained in this lecture with the content of other lectures (e.g. theory of electromagnetic fields, communications, and semiconductor circuit design). They can communicate problems and solutions in the field of signal integrity and power supply of interconnect and packages in English.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** Yes · **Bonus** None · **Form** Presentation · **Description**
Examination	Oral exam
Examination duration and scale	45 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory Electrical Engineering: Specialisation Wireless and Sensor Technologies: Elective Compulsory Mechatronics: Technical Complementary Course: Elective Compulsory Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory

Course L0770: EMC II: Signal Integrity and Power Supply of Electronic Systems	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Christian Schuster
Language	DE/EN
Cycle	WiSe
Content	- The role of packages and interconnects in electronic systems - Components of packages and interconnects in electronic systems - Main goals and concepts of signal and power integrity of electronic systems - Repeat of relevant concepts from the theory electromagnetic fields - Properties of digital signals and systems - Design and characterization of signal integrity - Design and characterization of power supply - Techniques and devices for measurements in time- and frequency-domain - CAD tools for electrical analysis and design of packages and interconnects - Connection to overall electromagnetic compatibility of electronic systems
Literature	- J. Franz, "EMV: Störungssicherer Aufbau elektronischer Schaltungen", Springer (2012) - R. Tummala, "Fundamentals of Microsystems Packaging", McGraw-Hill (2001) - S. Ramo, J. Whinnery, T. Van Duzer, "Fields and Waves in Communication Electronics", Wiley (1994) - S. Thierauf, "Understanding Signal Integrity", Artech House (2010) - M. Swaminathan, A. Engin, "Power Integrity Modeling and Design for Semiconductors and Systems", Prentice-Hall (2007)

Course L0771: EMC II: Signal Integrity and Power Supply of Electronic Systems	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Christian Schuster
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Course L0774: EMC II: Signal Integrity and Power Supply of Electronic Systems	
Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Christian Schuster
Language	DE/EN
Cycle	WiSe
Content	- The role of packages and interconnects in electronic systems - Components of packages and interconnects in electronic systems - Main goals and concepts of signal and power integrity of electronic systems - Repeat of relevant concepts from the theory electromagnetic fields - Properties of digital signals and systems - Design and characterization of signal integrity - Design and characterization of power supply - Techniques and devices for measurements in time- and frequency-domain - CAD tools for electrical analysis and design of packages and interconnects - Connection to overall electromagnetic compatibility of electronic systems
Literature	- J. Franz, "EMV: Störungssicherer Aufbau elektronischer Schaltungen", Springer (2012) - R. Tummala, "Fundamentals of Microsystems Packaging", McGraw-Hill (2001) - S. Ramo, J. Whinnery, T. Van Duzer, "Fields and Waves in Communication Electronics", Wiley (1994) - S. Thierauf, "Understanding Signal Integrity", Artech House (2010) - M. Swaminathan, A. Engin, "Power Integrity Modeling and Design for Semiconductors and Systems", Prentice-Hall (2007)

Module M1614: Optics for Engineers

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Optics for Engineers (L2437)	Lecture	3	3
Optics for Engineers (L2438)	Project-/problem-based Learning	3	3

Module Responsible	Prof. Thorsten Kern
Admission Requirements	None
Recommended Previous Knowledge	- Basics of physics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Teaching subject ist the design of simple optical systems for illumination and imaging optics • Basic values for optical systems and lighting technology • Spectrum, black-bodies, color-perception • Light-Sources und their characterization • Photometrics • Ray-Optics • Matrix-Optics • Stops, Pupils and Windows • Light-field Technology • Introduction to Wave-Optics • Introduction to Holography
Skills	Understandings of optics as part of light and electromagnetic spectrum. Design rules, approach to designing optics
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / None / Subject theoretical and practical work / Teilnahme an Laborübungen und Simulation
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Theoretical Mechanical Engineering: Core Qualification: Elective Compulsory

Course L2437: Optics for Engineers

Typ	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Thorsten Kern
Language	EN
Cycle	WiSe
Content	• Basic values for optical systems and lighting technology • Spectrum, black-bodies, color-perception • Light-Sources und their characterization • Photometrics • Ray-Optics • Matrix-Optics • Stops, Pupils and Windows • Light-field Technology • Introduction to Wave-Optics • Introduction to Holography
Literature	

Course L2438: Optics for Engineers	
Typ	Project-/problem-based Learning
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Thorsten Kern
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0788: Microwave Semiconductor Devices and Circuits II

Courses

Title	Typ	Hrs/wk	CP
Microwave Semiconductor Devices and Circuits II (L0788)	Lecture	1	1
Microwave Semiconductor Devices and Circuits II (L0789)	Recitation Section (large)	1	1
Microwave Circuit Design Laboratory (L0790)	Practical Course	4	4

Module Responsible	Prof. Alexander Kölpin
Admission Requirements	None
Recommended Previous Knowledge	Fundamentals of Semiconductor Technology, Microwave Engineering, Microwave Semiconductor Devices and Circuits I
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are capable of explaining the functionality of frequency multipliers in detail. They can present theories, concepts, and reasonable assumptions for description and synthesis. They are able to apply indepth knowledge on semiconductor physics of selected microwave devices to the frequency multiplier. Students can describe microwave measurement methods.
Skills	The students can assess effects occurring in active microwave circuits and are capable of analyzing and evaluating them. They are able to design and realize linear and nonlinear microwave circuits with help of modern software tools, taking application and manufacturing requirements into account. They are able to select and apply suitable measurement techniques.
Personal Competence	
Social Competence	The students are able to carry out subject-specific tasks in small groups, and to adequately present solutions (e.g. in microwave circuit design laboratory). They are capable of assessing and reflecting their contribution to the overall project (satellite receiver). They are able to communicate with different groups and with a supervisor, and to handle feedback on their own performance constructively.
Autonomy	The students are able to obtain additional information from given literature sources and set the content in context with the lecture. They can link and deepen their knowledge of other courses and translate their knowledge to practical situation. The students acquire the ability to communicate problems and solutions in the field of microwave semiconductor devices and circuits in English. They can assess their abilities and results of their work and evaluate the necessity of support.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory**: Yes; **Bonus**: None; **Form**: Subject theoretical and practical work; **Description**:
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Electrical Engineering: Specialisation Wireless and Sensor Technologies: Elective Compulsory

Course L0788: Microwave Semiconductor Devices and Circuits II	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Alexander Kölpin
Language	DE/EN
Cycle	WiSe
Content	- Frequency multiplier: Harmonic balance, noise in nonlinear circuits; Step Recovery Diode, FET; circuit synthesis, large signal, noise, and stability analysis - Low Noise Amplifier (LNA) circuit design: Stability and stability circles, gain and gain circles, noise, noise figure and noise figure circles - Mixer, oscillator: Measurement techniques (Network analyzer, Spectrum analyzer, Frequency generator)
Literature	- E. Voges, „Hochfrequenztechnik“, Hüthig (2004) - H.-G. Unger, W. Harth, „Hochfrequenz-Halbleiterelektronik“, S. Hirzel Verlag (1972) - S.M. Sze, "Physics of Semiconductor Devices", John Wiley & Sons (1981) - A. Jacob, "Lecture Notes Microwave Semiconductor Devices and Circuits Part II"

Course L0789: Microwave Semiconductor Devices and Circuits II	
Typ	Recitation Section (large)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Alexander Kölpin
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Course L0790: Microwave Circuit Design Laboratory	
Typ	Practical Course
Hrs/wk	4
CP	4
Workload in Hours	Independent Study Time 64, Study Time in Lecture 56
Lecturer	Prof. Alexander Kölpin
Language	DE/EN
Cycle	WiSe
Content	- Satellite receiver at X-Band (low noise amplifier, mixer, oscillator): Circuit and system design, realization, and characterization
Literature	- A. Jacob, "Microwave Circuit Design Laboratory Guide"

Module M1524: Research Project and Seminar in Microwave Engineering, Optics and Electromagnetic Compatibility

Courses			
Title	**Typ**	**Hrs/wk**	**CP**

Module Responsible	Dozenten des SD E
Admission Requirements	None
Recommended Previous Knowledge	Advanced state of knowledge in the electrical engineering master program
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students know current research topics oft institutes engaged in their specialization. They can name the fundamental scientific methods used for doing related reserach. They are furthermore able to use professional language in discussions. They are able to explain research topics.
Skills	Students are capable of completing a small, independent sub-project of currently ongoing research projects in the institutes engaged in their specialization. Students can justify and explain their approach for problem solving, they can draw conclusions from their results, and then can find new ways and methods for their work. Students are capable of comparing and assessing alterantive approaches with their own with regard to given criteria. Students are able to gain knowledge about a new field by themselves. In order to do that they make use of their existing knowledge and try to connect it with the topics of the new field. They close their knowledge gaps by discussing with research assistants and by their own literature and internet search. They are capable of summarizing and presenting scientific publications.
Personal Competence	
Social Competence	Students are able to discuss their work progress with research assistants of the supervising institute . They are capable of presenting their results in front of a professional audience. In cooperation with research assistants students are able to familiarize themselves with and discuss with others current research topics. They are capable of drafting, presenting, and explaining summaries of these topics in English in front of a professional audience.
Autonomy	Based on their competences gained so far students are capable of defining meaningful tasks within ongoing research project for themselves. They are able to develop the necessary understanding and problem solving methods. Students are capable of gathering information from subject related, professional publications and relate that information to the context of the seminar. They are able to find on their own new sources in the Internet. They are able to make a connection with the subject of their chosen specialization.
Workload in Hours	Independent Study Time 360, Study Time in Lecture 0
Credit points	12
Course achievement	None
Examination	Study work
Examination duration and scale	acc. to ASPO
Assignment for the Following Curricula	Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Compulsory

Module M0548: Bioelectromagnetics: Principles and Applications

Courses

Title	Typ	Hrs/wk	CP
Bioelectromagnetics: Principles and Applications (L0371)	Lecture	3	5
Bioelectromagnetics: Principles and Applications (L0373)	Recitation Section (small)	2	1

Module Responsible	Prof. Christian Schuster
Admission Requirements	None
Recommended Previous Knowledge	Basic principles of physics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can explain the basic principles, relationships, and methods of bioelectromagnetics, i.e. the quantification and application of electromagnetic fields in biological tissue. They can define and exemplify the most important physical phenomena and order them corresponding to wavelength and frequency of the fields. They can give an overview over measurement and numerical techniques for characterization of electromagnetic fields in practical applications . They can give examples for therapeutic and diagnostic utilization of electromagnetic fields in medical technology.
Skills	Students know how to apply various methods to characterize the behavior of electromagnetic fields in biological tissue. In order to do this they can relate to and make use of the elementary solutions of Maxwell’s Equations. They are able to assess the most important effects that these models predict for biological tissue, they can order the effects corresponding to wavelength and frequency, respectively, and they can analyze them in a quantitative way. They are able to develop validation strategies for their predictions. They are able to evaluate the effects of electromagnetic fields for therapeutic and diagnostic applications and make an appropriate choice.
Personal Competence	
Social Competence	Students are able to work together on subject related tasks in small groups. They are able to present their results effectively in English (e.g. during small group exercises).
Autonomy	Students are capable to gather information from subject related, professional publications and relate that information to the context of the lecture. They are able to make a connection between their knowledge obtained in this lecture with the content of other lectures (e.g. theory of electromagnetic fields, fundamentals of electrical engineering / physics). They can communicate problems and effects in the field of bioelectromagnetics in English.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** Yes · **Bonus** None · **Form** Presentation · **Description**
Examination	Oral exam
Examination duration and scale	45 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Electrical Engineering: Specialisation Wireless and Sensor Technologies: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory

Course L0371: Bioelectromagnetics: Principles and Applications	
Typ	Lecture
Hrs/wk	3
CP	5
Workload in Hours	Independent Study Time 108, Study Time in Lecture 42
Lecturer	Prof. Christian Schuster
Language	DE/EN
Cycle	WiSe
Content	- Fundamental properties of electromagnetic fields (phenomena) - Mathematical description of electromagnetic fields (Maxwell’s Equations) - Electromagnetic properties of biological tissue - Principles of energy absorption in biological tissue, dosimetry - Numerical methods for the computation of electromagnetic fields (especially FDTD) - Measurement techniques for characterization of electromagnetic fields - Behavior of electromagnetic fields of low frequency in biological tissue - Behavior of electromagnetic fields of medium frequency in biological tissue - Behavior of electromagnetic fields of high frequency in biological tissue - Behavior of electromagnetic fields of very high frequency in biological tissue - Diagnostic applications of electromagnetic fields in medical technology - Therapeutic applications of electromagnetic fields in medical technology - The human body as a generator of electromagnetic fields
Literature	- C. Furse, D. Christensen, C. Durney, "Basic Introduction to Bioelectromagnetics", CRC (2009) - A. Vorst, A. Rosen, Y. Kotsuka, "RF/Microwave Interaction with Biological Tissues", Wiley (2006) - S. Grimnes, O. Martinsen, "Bioelectricity and Bioimpedance Basics", Academic Press (2008) - F. Barnes, B. Greenebaum, "Bioengineering and Biophysical Aspects of Electromagnetic Fields", CRC (2006)

Course L0373: Bioelectromagnetics: Principles and Applications	
Typ	Recitation Section (small)
Hrs/wk	2
CP	1
Workload in Hours	Independent Study Time 2, Study Time in Lecture 28
Lecturer	Prof. Christian Schuster
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Specialization Medical Technology

The specialization ‚Medical Technology' offers students the opportunity to put an interdisciplinary focus in their studies. On the one hand, a series of technical modules foster an in-depth understanding of modern medical technology, particularly with respect to electrical engineering. On the other hand, modules on medical topics provide insight into clinical problems, environments and terminology. Students will be able to design, implement, and evaluate methods, algorithms and systems in the context of clinical scenarios. The assessment will be based on their knowledge of the complex system 'patient'. Hence, competencies developed in this specialization at the interface between electrical engineering and medicine prepare students for positions in industry and academia.

Module M0630: Robotics and Navigation in Medicine

Courses

Title	Typ	Hrs/wk	CP
Robotics and Navigation in Medicine (L0335)	Lecture	2	3
Robotics and Navigation in Medicine (L0338)	Project Seminar	2	2
Robotics and Navigation in Medicine (L0336)	Recitation Section (small)	1	1

Module Responsible	Prof. Alexander Schlaefer
Admission Requirements	None
Recommended Previous Knowledge	• principles of math (algebra, analysis/calculus) • principles of programming, e.g., in Java or C++ • solid R or Matlab skills
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students can explain kinematics and tracking systems in clinical contexts and illustrate systems and their components in detail. Systems can be evaluated with respect to collision detection and safety and regulations. Students can assess typical systems regarding design and limitations.
Skills	The students are able to design and evaluate navigation systems and robotic systems for medical applications.
Personal Competence	
Social Competence	The students are able to grasp practical tasks in groups, develop solution strategies independently, define work processes and work on them collaboratively. The students are able to collaboratively organize their work processes and software solutions using virtual communication and software management tools. The students can critically reflect on the results of other groups, make constructive suggestions for improvement, and also incorporate them into their own work.
Autonomy	The students can assess their level of knowledge and independently control their learning processes on this basis as well as document their work results. They can critically evaluate the results achieved and present them in an appropriate argumentative manner to the other groups.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / 10 % / Presentation Yes / 10 % / Written elaboration
Examination	Written exam
Examination duration and scale	90 minutes
Assignment for the Following Curricula	Computer Science: Specialisation II: Intelligence Engineering: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory International Management and Engineering: Specialisation II. Process Engineering and Biotechnology: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Product Development, Materials and Production: Specialisation Product Development: Elective Compulsory Product Development, Materials and Production: Specialisation Production: Elective Compulsory Product Development, Materials and Production: Specialisation Materials: Elective Compulsory

	Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory

Course L0335: Robotics and Navigation in Medicine	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Alexander Schlaefer
Language	EN
Cycle	SoSe
Content	- kinematics - calibration - tracking systems - navigation and image guidance - motion compensation The seminar extends and complements the contents of the lecture with respect to recent research results.
Literature	Spong et al.: Robot Modeling and Control, 2005 Troccaz: Medical Robotics, 2012 Further literature will be given in the lecture.

Course L0338: Robotics and Navigation in Medicine	
Typ	Project Seminar
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Alexander Schlaefer
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Course L0336: Robotics and Navigation in Medicine	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Alexander Schlaefer
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1280: MED II: Introduction to Physiology

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Introduction to Physiology (L0385)	Lecture	2	3

Module Responsible	Dr. Roger Zimmermann
Admission Requirements	None
Recommended Previous Knowledge	None
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students can • describe the basics of the energy metabolism; • describe physiological relations in selected fields of muscle, heart/circulation, neuro- and sensory physiology.
Skills	The students can describe the effects of basic bodily functions (sensory, transmission and processing of information, development of forces and vital functions) and relate them to similar technical systems.
Personal Competence	
Social Competence	The students can conduct discussions in research and medicine on a technical level. The students can find solutions to problems in the field of physiology, both analytical and metrological.
Autonomy	The students can derive answers to questions arising in the course and other physiological areas, using technical literature, by themselves.
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Credit points	3
Course achievement	None
Examination	Written exam
Examination duration and scale	60 minutes
Assignment for the Following Curricula	General Engineering Science (German program, 7 semester): Specialisation Biomedical Engineering: Compulsory General Engineering Science (German program, 7 semester): Specialisation Mechanical Engineering, Focus Biomechanics: Compulsory Data Science: Specialisation Medicine: Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Engineering Science: Specialisation Biomedical Engineering: Elective Compulsory General Engineering Science (English program, 7 semester): Specialisation Biomedical Engineering: Elective Compulsory Mechanical Engineering: Specialisation Biomechanics: Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Technomathematics: Specialisation III. Engineering Science: Elective Compulsory

Course L0385: Introduction to Physiology

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Gerhard Engler
Language	DE
Cycle	SoSe
Content	
Literature	Taschenatlas der Physiologie, Silbernagl Despopoulos, ISBN 978-3-135-67707-1, Thieme Repetitorium Physiologie, Speckmann, ISBN 978-3-437-42321-5, Elsevier

Module M0635: Medical Technology Lab

Courses

Title	Typ	Hrs/wk	CP
Medical Technology Lab (L1096)	Project-/problem-based Learning	6	6

Module Responsible	Prof. Alexander Schlaefer
Admission Requirements	None
Recommended Previous Knowledge	sound programming skills (Java / C++) skills in R/Matlab knowledge of image processing principles of math (algebra, analysis/calculus) principles of stochastics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students recognize the complexity of medical technology and can explain, which methods are appropriate to solve a problem at hand.
Skills	The students are able to analyze and solve problems in medical technology.
Personal Competence	
Social Competence	The students are able to conceptualize project goals in groups and organize the project process, taking into account a reasonable distribution of tasks within the group. The students are able to define and fill different roles within the group for the task at hand and are able to contribute to the group process according to that role. They can lead group processes responsibly and are able to develop ways of dealing with problems in the group and in the work process. The students are able to collaboratively organize their work processes and software solutions using virtual communication and software management tools (e.g., GitLab, Mattermost).
Autonomy	The students can independently develop solution strategies and adapt these when problems arise in the course of the project. The students can assess their level of knowledge and document their work results. They can critically evaluate the results achieved and present them to the target group in an appropriate manner.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / None / Group discussion /
Examination	Written elaboration
Examination duration and scale	approx. 8 pages, time frame: over the course of the semester
Assignment for the Following Curricula	Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory

Course L1096: Medical Technology Lab

Typ	Project-/problem-based Learning
Hrs/wk	6
CP	6
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Lecturer	Prof. Alexander Schlaefer
Language	DE/EN
Cycle	SoSe
Content	The actual project topic will be defined as part of the project.
Literature	Wird in der Veranstaltung bekannt gegeben.

Module M0845: Feedback Control in Medical Technology

Courses

Title	Typ	Hrs/wk	CP
Feedback Control in Medical Technology (L0664)	Lecture	2	3

Module Responsible	Johannes Kreuzer
Admission Requirements	None
Recommended Previous Knowledge	Basics in Control, Basics in Physiology
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The lecture will introduce into the fascinating area of medical technology with the engineering point of view. Fundamentals in human physiology will be similarly introduced like knowledge in control theory. Internal control loops of the human body will be discussed in the same way like the design of external closed loop system fo example in for anesthesia control. The handling of PID controllers and modern controller like predictive controller or fuzzy controller or neural networks will be illustrated. The operation of simple equivalent circuits will be discussed.
Skills	Application of modeling, identification, control technology in the field of medical technology.
Personal Competence	
Social Competence	Students can develop solutions to specific problems in small groups and present their results
Autonomy	Students are able to find necessary literature and to set it into the context of the lecture. They are able to continuously evaluate their knowledge and to take control of their learning process. They can combine knowledge from different courses to form a consistent whole.
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Credit points	3
Course achievement	None
Examination	Oral exam
Examination duration and scale	20 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Compulsory

Course L0664: Feedback Control in Medical Technology

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Johannes Kreuzer, Christian Neuhaus
Language	DE
Cycle	SoSe
Content	Always viewed from the engineer's point of view, the lecture is structured as follows: • Introduction to the topic • Fundamentals of physiological modelling • Introduction to Breathing and Ventilation • Physiology and Pathology in Cardiology • Introduction to the Regulation of Blood Glucose • kidney function and renal replacement therapy • Representation of the control technology on the concrete ventilator • Excursion to a medical technology company Techniques of modeling, simulation and controller development are discussed. In the models, simple equivalent block diagrams for physiological processes are derived and explained how sensors, controllers and actuators are operated. MATLAB and SIMULINK are used as development tools.
Literature	• Leonhardt, S., & Walter, M. (2016). Medizintechnische Systeme. Berlin, Heidelberg: Springer Vieweg. • Werner, J. (2005). Kooperative und autonome Systeme der Medizintechnik. München: Oldenbourg. • Oczenski, W. (2017). Atmen : Atemhilfen ; Atemphysiologie und Beatmungstechnik: Georg Thieme Verlag KG.

Module M0811: Medical Imaging Systems

Courses

Title	Typ	Hrs/wk	CP
Medical Imaging Systems (L0819)	Lecture	4	6

Module Responsible	Dr. Michael Grass
Admission Requirements	None
Recommended Previous Knowledge	none
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can: • Describe the system configuration and components of the main clinical imaging systems; • Explain how the system components and the overall system of the imaging systems function; • Explain and apply the physical processes that make imaging possible and use with the fundamental physical equations; • Name and describe the physical effects required to generate image contrasts; • Explain how spatial and temporal resolution can be influenced and how to characterize the images generated; • Explain which image reconstruction methods are used to generate images; Describe and explain the main clinical uses of the different systems.

Skills	Students are able to:
	• Explain the physical processes of images and assign to the systems the basic mathematical or physical equations required;
	  ◦ Calculate the parameters of imaging systems using the mathematical or physical equations;
	  ◦ Determine the influence of different system components on the spatial and temporal resolution of imaging systems;
	  ◦ Explain the importance of different imaging systems for a number of clinical applications;
	Select a suitable imaging system for an application.

Personal Competence	
Social Competence	none
Autonomy	Students can: • Understand which physical effects are used in medical imaging; • Decide independently for which clinical issue a measuring system can be used.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Biomedical Engineering: Core Qualification: Compulsory Product Development, Materials and Production: Specialisation Product Development: Elective Compulsory Product Development, Materials and Production: Specialisation Production: Elective Compulsory Product Development, Materials and Production: Specialisation Materials: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory

Course L0819: Medical Imaging Systems	
Typ	Lecture
Hrs/wk	4
CP	6
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Lecturer	Dr. Michael Grass, Dr. Frank Michael Weber, Dr. Michael Helle, Dr. Sven Prevrhal
Language	DE
Cycle	SoSe
Content	
Literature	Primary book: 1. P. Suetens, "Fundamentals of Medical Imaging", Cambridge Press Secondary books: - A. Webb, "Introduction to Biomedical Imaging", IEEE Press 2003. - W.R. Hendee and E.R. Ritenour, "Medical Imaging Physics", Wiley-Liss, New York, 2002. - H. Morneburg (Edt), "Bildgebende Systeme für die medizinische Diagnostik", Erlangen: Siemens Publicis MCD Verlag, 1995. - O. Dössel, "Bildgebende Verfahren in der Medizin", Springer Verlag Berlin, 2000.

Module M1277: MED I: Introduction to Anatomy

Courses

Title	Typ	Hrs/wk	CP
Introduction to Anatomy (L0384)	Lecture	2	3

Module Responsible	Prof. Udo Schumacher
Admission Requirements	None
Recommended Previous Knowledge	Students can listen to the lectures without any prior knowledge. Basic school knowledge of biology, chemistry / biochemistry, physics and Latin can be useful.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The lectures are about microscopic anatomy, describing the microscopic structure of tissues and organs, and about macroscopic anatomy which is about organs and organ systems. The lectures also contain an introduction to cell biology, human development and to the central nervous system. The fundamentals of radiologic imaging are described as well, using projectional x-ray and cross-sectional images. The Latin terms are introduced.
Skills	At the end of the lecture series the students are able to describe the microscopic as well as the macroscopic assembly and functions of the human body. The Latin terms are the prerequisite to understand medical literature. This knowledge is needed to understand und further develop medical devices. These insights in human anatomy are the fundamentals to explain the role of structure and function for the development of common diseases and their impact on the human body.
Personal Competence	
Social Competence	The students can participate in current discussions in biomedical research and medicine on a professional level. The Latin terms are prerequisite for communication with physicians on a professional level.
Autonomy	The lectures are an introduction to the basics of anatomy and should encourage students to improve their knowledge by themselves. Advice is given as to which further literature is suitable for this purpose. Likewise, the lecture series encourages students to recognize and think critically about biomedical problems.
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Credit points	3
Course achievement	None
Examination	Written exam
Examination duration and scale	90 minutes
Assignment for the Following Curricula	General Engineering Science (German program, 7 semester): Specialisation Biomedical Engineering: Compulsory General Engineering Science (German program, 7 semester): Specialisation Mechanical Engineering, Focus Biomechanics: Compulsory Data Science: Specialisation II. Application: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Engineering Science: Specialisation Biomedical Engineering: Compulsory General Engineering Science (English program, 7 semester): Specialisation Biomedical Engineering: Compulsory Mechanical Engineering: Specialisation Biomechanics: Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Technomathematics: Specialisation III. Engineering Science: Elective Compulsory

Course L0384: Introduction to Anatomy	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Tobias Lange, Dr. Thorsten Frenzel
Language	DE
Cycle	SoSe
Content	**General Anatomy** **1st week: The Eucaryote Cell** **2nd week: The Tissues** **3rd week: Cell Cycle, Basics in Development** **4th week: Musculoskeletal System** **5th week: Cardiovascular System** **6th week: Respiratory System** **7th week: Genito-urinary System** **8th week: Immune system** **9th week: Digestive System I** **10th week: Digestive System II** **11th week: Endocrine System** **12th week: Nervous System** **13th week: Exam**
Literature	Adolf Faller/Michael Schünke, Der Körper des Menschen, 17. Auflage, Thieme Verlag Stuttgart, 2016

Module M1278: MED I: Introduction to Radiology and Radiation Therapy

Courses

Title	Typ	Hrs/wk	CP
Introduction to Radiology and Radiation Therapy (L0383)	Lecture	2	3

Module Responsible	Prof. Ulrich Carl
Admission Requirements	None
Recommended Previous Knowledge	None
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	**Therapy** The students can distinguish different types of currently used equipment with respect to its use in radiation therapy. The students can explain treatment plans used in radiation therapy in interdisciplinary contexts (e.g. surgery, internal medicine). **The students can describe the patients' passage from their initial admittance through to follow-up care.** **Diagnostics** The students can illustrate the technical base concepts of projection radiography, including angiography and mammography, as well as sectional imaging techniques (CT, MRT, US). The students can explain the diagnostic as well as therapeutic use of imaging techniques, as well as the technical basis for those techniques. The students can choose the right treatment method depending on the patient's clinical history and needs. The student can explain the influence of technical errors on the imaging techniques. The student can draw the right conclusions based on the images' diagnostic findings or the error protocol.
Skills	**Therapy** The students can distinguish curative and palliative situations and motivate why they came to that conclusion. The students can develop adequate therapy concepts and relate it to the radiation biological aspects. The students can use the therapeutic principle (effects vs adverse effects) The students can distinguish different kinds of radiation, can choose the best one depending on the situation (location of the tumor) and choose the energy needed in that situation (irradiation planning). The student can assess what an individual psychosocial service should look like (e.g. follow-up treatment, sports, social help groups, self-help groups, social services, psycho-oncology). **Diagnostics** The students can suggest solutions for repairs of imaging instrumentation after having done error analyses. The students can classify results of imaging techniques according to different groups of diseases based on their knowledge of anatomy, pathology and pathophysiology.
Personal Competence	
Social Competence	The students can assess the special social situation of tumor patients and interact with them in a professional way. The students are aware of the special, often fear-dominated behavior of sick people caused by diagnostic and therapeutic measures and can meet them appropriately.
Autonomy	The students can apply their new knowledge and skills to a concrete therapy case. The students can introduce younger students to the clinical daily routine. The students are able to access anatomical knowledge by themselves, can participate competently in conversations on the topic and acquire the relevant knowledge themselves.
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Credit points	3
Course achievement	None
Examination	Written exam
Examination duration and scale	90 minutes
Assignment for the Following Curricula	General Engineering Science (German program, 7 semester): Specialisation Biomedical Engineering: Compulsory General Engineering Science (German program, 7 semester): Specialisation Mechanical Engineering, Focus Biomechanics: Compulsory Data Science: Specialisation II. Application: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Engineering Science: Specialisation Biomedical Engineering: Compulsory General Engineering Science (English program, 7 semester): Specialisation Biomedical Engineering: Compulsory Mechanical Engineering: Specialisation Biomechanics: Compulsory

	Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Technomathematics: Specialisation III. Engineering Science: Elective Compulsory

Course L0383: Introduction to Radiology and Radiation Therapy	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Ulrich Carl, Prof. Thomas Vestring
Language	DE
Cycle	SoSe
Content	The students will be given an understanding of the technological possibilities in the field of medical imaging, interventional radiology and radiation therapy/radiation oncology. It is assumed, that students in the beginning of the course have heard the word “X-ray” at best. It will be distinguished between the two arms of diagnostic (Prof. Dr. med. Thomas Vestring) and therapeutic (Prof. Dr. med. Ulrich Carl) use of X-rays. Both arms depend on special big units, which determine a predefined sequence in their respective departments
Literature	• "Technik der medizinischen Radiologie" von T. + J. Laubenberg – 7. Auflage – Deutscher Ärzteverlag – erschienen 1999 • "Klinische Strahlenbiologie" von Th. Herrmann, M. Baumann und W. Dörr – 4. Auflage - Verlag Urban & Fischer – erschienen 02.03.2006 ISBN: 978-3-437-23960-1 • "Strahlentherapie und Onkologie für MTA-R" von R. Sauer – 5. Auflage 2003 - Verlag Urban & Schwarzenberg – erschienen 08.12.2009 ISBN: 978-3-437-47501-6 • "Taschenatlas der Physiologie" von S. Silbernagel und A. Despopoulus- 8. Auflage – Georg Thieme Verlag - erschienen 19.09.2012 ISBN: 978-3-13-567708-8 • "Der Körper des Menschen " von A. Faller u. M. Schünke - 16. Auflage 2004 – Georg Thieme Verlag – erschienen 18.07.2012 ISBN: 978-3-13-329716-5 • „Praxismanual Strahlentherapie“ von Stöver / Feyer – 1. Auflage - Springer-Verlag GmbH – erschienen 02.06.2000

Module M1696: Selected Aspects in Medical Technology

Courses

Title	Typ	Hrs/wk	CP
Selected Aspects in Medical Technology (L2698)	Lecture	2	4
Selected Aspects in Medical Technology (L2699)	Recitation Section (large)	2	2

Module Responsible	Prof. Christian Becker
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	
Skills	
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Medical Technology: Elective Compulsory

Course L2698: Selected Aspects in Medical Technology

Typ	Lecture
Hrs/wk	2
CP	4
Workload in Hours	Independent Study Time 92, Study Time in Lecture 28
Lecturer	Dozenten des SD E
Language	DE/EN
Cycle	WiSe/SoSe
Content	
Literature	

Course L2699: Selected Aspects in Medical Technology

Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dozenten des SD E
Language	DE/EN
Cycle	WiSe/SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1279: MED II: Introduction to Biochemistry and Molecular Biology

Courses

Title	Typ	Hrs/wk	CP
Introduction to Biochemistry and Molecular Biology (L0386)	Lecture	2	3

Module Responsible	Prof. Hans-Jürgen Kreienkamp
Admission Requirements	None
Recommended Previous Knowledge	None
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students can • describe basic biomolecules; • explain how genetic information is coded in the DNA; • explain the connection between DNA and proteins;
Skills	The students can • recognize the importance of molecular parameters for the course of a disease; • describe selected molecular-diagnostic procedures; • explain the relevance of these procedures for some diseases
Personal Competence	
Social Competence	The students can participate in discussions in research and medicine on a technical level. Students will have an improved understanding of current medical problems (e.g. Corona pandemic)and will be able to explain these issues to others.
Autonomy	The students can develop an understanding of topics from the course, using technical literature, by themselves. Students will be better equipped to recognize fake news in the media regarding medical research topics.
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Credit points	3
Course achievement	None
Examination	Written exam
Examination duration and scale	60 minutes
Assignment for the Following Curricula	General Engineering Science (German program, 7 semester): Specialisation Biomedical Engineering: Compulsory General Engineering Science (German program, 7 semester): Specialisation Mechanical Engineering, Focus Biomechanics: Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Engineering Science: Specialisation Biomedical Engineering: Compulsory General Engineering Science (English program, 7 semester): Specialisation Biomedical Engineering: Compulsory Mechanical Engineering: Specialisation Biomechanics: Compulsory Mechatronics: Specialisation Medical Engineering: Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Technomathematics: Specialisation III. Engineering Science: Elective Compulsory

Course L0386: Introduction to Biochemistry and Molecular Biology	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Hans-Jürgen Kreienkamp
Language	DE
Cycle	WiSe
Content	
Literature	Müller-Esterl, Biochemie, Spektrum Verlag, 2010; 2. Auflage Löffler, Basiswissen Biochemie, 7. Auflage, Springer, 2008

Module M1249: Medical Imaging

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Medical Imaging (L1694)	Lecture	2	3
Medical Imaging (L1695)	Recitation Section (small)	2	3

Module Responsible	Prof. Tobias Knopp
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge in linear algebra, numerics, and signal processing
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	After successful completion of the module, students are able to describe reconstruction methods for different tomographic imaging modalities such as computed tomography and magnetic resonance imaging. They know the necessary basics from the fields of signal processing and inverse problems and are familiar with both analytical and iterative image reconstruction methods. The students have a deepened knowledge of the imaging operators of computed tomography and magnetic resonance imaging.
Skills	The students are able to implement reconstruction methods and test them using tomographic measurement data. They can visualize the reconstructed images and evaluate the quality of their data and results. In addition, students can estimate the temporal complexity of imaging algorithms.
Personal Competence	
Social Competence	Students can work on complex problems both independently and in teams. They can exchange ideas with each other and use their individual strengths to solve the problem.
Autonomy	Students are able to independently investigate a complex problem and assess which competencies are required to solve it.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation II: Intelligence Engineering: Elective Compulsory Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Interdisciplinary Mathematics: Specialisation Computational Methods in Biomedical Imaging: Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory Technomathematics: Specialisation II. Informatics: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory

Course L1694: Medical Imaging

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Tobias Knopp
Language	DE/EN
Cycle	WiSe
Content	• Overview about different imaging methods • Signal processing • Inverse problems • Computed tomography • Magnetic resonance imaging • Compressed Sensing • Magnetic particle imaging
Literature	**Bildgebende Verfahren in der Medizin**; O. Dössel; Springer, Berlin, 2000 **Bildgebende Systeme für die medizinische Diagnostik**; H. Morneburg (Hrsg.); Publicis MCD, München, 1995 **Introduction to the Mathematics of Medical Imaging**; C. L.Epstein; Siam, Philadelphia, 2008 **Medical Image Processing, Reconstruction and Restoration**; J. Jan; Taylor and Francis, Boca Raton, 2006 **Principles of Magnetic Resonance Imaging**; Z.-P. Liang and P. C. Lauterbur; IEEE Press, New York, 1999

Course L1695: Medical Imaging	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Tobias Knopp
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M1598: Image Processing

Courses

Title	Typ	Hrs/wk	CP
Image Processing (L2443)	Lecture	2	4
Image Processing (L2444)	Recitation Section (small)	2	2

Module Responsible	Prof. Tobias Knopp
Admission Requirements	None
Recommended Previous Knowledge	Signal and Systems
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students know about • visual perception • multidimensional signal processing • sampling and sampling theorem • filtering • image enhancement • edge detection • multi-resolution procedures: Gauss and Laplace pyramid, wavelets • image compression • image segmentation • morphological image processing
Skills	The students can • analyze, process, and improve multidimensional image data • implement simple compression algorithms • design custom filters for specific applications
Personal Competence	
Social Competence	Students can work on complex problems both independently and in teams. They can exchange ideas with each other and use their individual strengths to solve the problem.
Autonomy	Students are able to independently investigate a complex problem and assess which competencies are required to solve it.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Data Science: Core Qualification: Elective Compulsory Data Science: Specialisation I. Mathematics/Computer Science: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L2443: Image Processing	
Typ	Lecture
Hrs/wk	2
CP	4
Workload in Hours	Independent Study Time 92, Study Time in Lecture 28
Lecturer	Prof. Tobias Knopp
Language	DE/EN
Cycle	WiSe
Content	• Visual perception • Multidimensional signal processing • Sampling and sampling theorem • Filtering • Image enhancement • Edge detection • Multi-resolution procedures: Gauss and Laplace pyramid, wavelets • Image Compression • Segmentation • Morphological image processing
Literature	Bredies/Lorenz, Mathematische Bildverarbeitung, Vieweg, 2011 Pratt, Digital Image Processing, Wiley, 2001 Bernd Jähne: Digitale Bildverarbeitung - Springer, Berlin 2005

Course L2444: Image Processing	
Typ	Recitation Section (small)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Tobias Knopp
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0623: Intelligent Systems in Medicine

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Intelligent Systems in Medicine (L0331)	Lecture	2	3
Intelligent Systems in Medicine (L0334)	Project Seminar	2	2
Intelligent Systems in Medicine (L0333)	Recitation Section (small)	1	1

Module Responsible	Prof. Alexander Schlaefer
Admission Requirements	None
Recommended Previous Knowledge	• principles of math (algebra, analysis/calculus) • principles of stochastics • principles of programming, Java/C++ and R/Matlab • advanced programming skills
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are able to analyze and solve clinical treatment planning and decision support problems using methods for search, optimization, and planning. They are able to explain methods for classification and their respective advantages and disadvantages in clinical contexts. The students can compare different methods for representing medical knowledge. They can evaluate methods in the context of clinical data and explain challenges due to the clinical nature of the data and its acquisition and due to privacy and safety requirements.
Skills	The students can give reasons for selecting and adapting methods for classification, regression, and prediction. They can assess the methods based on actual patient data and evaluate the implemented methods.
Personal Competence	
Social Competence	The students are able to grasp practical tasks in groups, develop solution strategies independently, define work processes and work on them collaboratively. The students can critically reflect on the results of other groups, make constructive suggestions for improvement and also incorporate them into their own work.
Autonomy	The students can assess their level of knowledge and document their work results. They can critically evaluate the results achieved and present them in an appropriate argumentative manner to the other groups.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / 10 % / Written elaboration Yes / 10 % / Presentation
Examination	Written exam
Examination duration and scale	90 minutes
Assignment for the Following Curricula	Computer Science: Specialisation II: Intelligence Engineering: Elective Compulsory Data Science: Specialisation III. Applications: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Interdisciplinary Mathematics: Specialisation Computational Methods in Biomedical Imaging: Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Compulsory Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory

Course L0331: Intelligent Systems in Medicine	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Alexander Schlaefer
Language	EN
Cycle	WiSe
Content	- methods for search, optimization, planning, classification, regression and prediction in a clinical context - representation of medical knowledge - understanding challenges due to clinical and patient related data and data acquisition The students will work in groups to apply the methods introduced during the lecture using problem based learning.
Literature	Russel & Norvig: Artificial Intelligence: a Modern Approach, 2012 Berner: Clinical Decision Support Systems: Theory and Practice, 2007 Greenes: Clinical Decision Support: The Road Ahead, 2007 Further literature will be given in the lecture

Course L0334: Intelligent Systems in Medicine	
Typ	Project Seminar
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Alexander Schlaefer
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Course L0333: Intelligent Systems in Medicine	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Alexander Schlaefer
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0768: Microsystems Technology in Theory and Practice

Courses

Title	Typ	Hrs/wk	CP
Microsystems Technology (L0724)	Lecture	2	4
Microsystems Technology (L0725)	Project-/problem-based Learning	2	2

Module Responsible	Prof. Hoc Khiem Trieu
Admission Requirements	None
Recommended Previous Knowledge	Basics in physics, chemistry, mechanics and semiconductor technology
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able • to present and to explain current fabrication techniques for microstructures and especially methods for the fabrication of microsensors and microactuators, as well as the integration thereof in more complex systems • to explain in details operation principles of microsensors and microactuators and • to discuss the potential and limitation of microsystems in application.
Skills	Students are capable • to analyze the feasibility of microsystems, • to develop process flows for the fabrication of microstructures and • to apply them.
Personal Competence	
Social Competence	Students are able to plan and carry out experiments in groups, as well as present and represent the results in front of others. These social skills are practiced both during the preparation phase, in which the groups work out and present the theory, and during the follow-up phase, in which the groups prepare, document and present their practical experiences.
Autonomy	The independence of the students is demanded and promoted in that they have to transfer and apply what they have learned to ever new boundary conditions. This requirement is communicated at the beginning of the semester and consistently practiced until the exam. Students are encouraged to work independently by not being given a solution, but by learning to work out the solution step by step by asking specific questions. Students learn to ask questions independently when they are faced with a problem. They learn to independently break down problems into manageable sub-problems.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory:** Yes; **Bonus:** None; **Form:** Subject theoretical and practical work; **Description:** Studierenden führen in Kleingruppen ein Laborpraktikum durch. Jede Gruppe präsentiert und diskutiert die Theorie sowie die Ergebniise ihrer Labortätigkeit. vor dem gesamten Kurs.
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory International Management and Engineering: Specialisation II. Mechatronics: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory Microelectronics and Microsystems: Core Qualification: Elective Compulsory

Course L0724: Microsystems Technology	
Typ	Lecture
Hrs/wk	2
CP	4
Workload in Hours	Independent Study Time 92, Study Time in Lecture 28
Lecturer	Prof. Hoc Khiem Trieu
Language	EN
Cycle	WiSe
Content	• Introduction (historical view, scientific and economic relevance, scaling laws) • Semiconductor Technology Basics, Lithography (wafer fabrication, photolithography, improving resolution, next-generation lithography, nano-imprinting, molecular imprinting) • Deposition Techniques (thermal oxidation, epitaxy, electroplating, PVD techniques: evaporation and sputtering; CVD techniques: APCVD, LPCVD, PECVD and LECVD; screen printing) • Etching and Bulk Micromachining (definitions, wet chemical etching, isotropic etch with HNA, electrochemical etching, anisotropic etching with KOH/TMAH: theory, corner undercutting, measures for compensation and etch-stop techniques; plasma processes, dry etching: back sputtering, plasma etching, RIE, Bosch process, cryo process, XeF2 etching) • Surface Micromachining and alternative Techniques (sacrificial etching, film stress, stiction: theory and counter measures; Origami microstructures, Epi-Poly, porous silicon, SOI, SCREAM process, LIGA, SU8, rapid prototyping) • Thermal and Radiation Sensors (temperature measurement, self-generating sensors: Seebeck effect and thermopile; modulating sensors: thermo resistor, Pt-100, spreading resistance sensor, pn junction, NTC and PTC; thermal anemometer, mass flow sensor, photometry, radiometry, IR sensor: thermopile and bolometer) • Mechanical Sensors (strain based and stress based principle, capacitive readout, piezoresistivity, pressure sensor: piezoresistive, capacitive and fabrication process; accelerometer: piezoresistive, piezoelectric and capacitive; angular rate sensor: operating principle and fabrication process) • Magnetic Sensors (galvanomagnetic sensors: spinning current Hall sensor and magneto-transistor; magnetoresistive sensors: magneto resistance, AMR and GMR, fluxgate magnetometer) • Chemical and Bio Sensors (thermal gas sensors: pellistor and thermal conductivity sensor; metal oxide semiconductor gas sensor, organic semiconductor gas sensor, Lambda probe, MOSFET gas sensor, pH-FET, SAW sensor, principle of biosensor, Clark electrode, enzyme electrode, DNA chip) • Micro Actuators, Microfluidics and TAS (drives: thermal, electrostatic, piezo electric and electromagnetic; light modulators, DMD, adaptive optics, microscanner, microvalves: passive and active, micropumps, valveless micropump, electrokinetic micropumps, micromixer, filter, inkjet printhead, microdispenser, microfluidic switching elements, microreactor, lab-on-a-chip, microanalytics) • MEMS in medical Engineering (wireless energy and data transmission, smart pill, implantable drug delivery system, stimulators: microelectrodes, cochlear and retinal implant; implantable pressure sensors, intelligent osteosynthesis, implant for spinal cord regeneration) • Design, Simulation, Test (development and design flows, bottom-up approach, top-down approach, testability, modelling: multiphysics, FEM and equivalent circuit simulation; reliability test, physics-of-failure, Arrhenius equation, bath-tub relationship) • System Integration (monolithic and hybrid integration, assembly and packaging, dicing, electrical contact: wire bonding, TAB and flip chip bonding; packages, chip-on-board, wafer-level-package, 3D integration, wafer bonding: anodic bonding and silicon fusion bonding; micro electroplating, 3D-MID)
Literature	M. Madou: Fundamentals of Microfabrication, CRC Press, 2002 N. Schwesinger: Lehrbuch Mikrosystemtechnik, Oldenbourg Verlag, 2009 T. M. Adams, R. A. Layton:Introductory MEMS, Springer, 2010 G. Gerlach; W. Dötzel: Introduction to microsystem technology, Wiley, 2008

Course L0725: Microsystems Technology	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Hoc Khiem Trieu
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M1525: Research Project and Seminar in Medical Technology

Courses			
Title	**Typ**	**Hrs/wk**	**CP**

Module Responsible	Dozenten des SD E
Admission Requirements	None
Recommended Previous Knowledge	Advanced state of knowledge in the electrical engineering master program
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students know current research topics oft institutes engaged in their specialization. They can name the fundamental scientific methods used for doing related reserach. They are furthermore able to use professional language in discussions. They are able to explain research topics.
Skills	Students are capable of completing a small, independent sub-project of currently ongoing research projects in the institutes engaged in their specialization. Students can justify and explain their approach for problem solving, they can draw conclusions from their results, and then can find new ways and methods for their work. Students are capable of comparing and assessing alterantive approaches with their own with regard to given criteria. Students are able to gain knowledge about a new field by themselves. In order to do that they make use of their existing knowledge and try to connect it with the topics of the new field. They close their knowledge gaps by discussing with research assistants and by their own literature and internet search. They are capable of summarizing and presenting scientific publications.
Personal Competence	
Social Competence	Students are able to discuss their work progress with research assistants of the supervising institute . They are capable of presenting their results in front of a professional audience. In cooperation with research assistants students are able to familiarize themselves with and discuss with others current research topics. They are capable of drafting, presenting, and explaining summaries of these topics in English in front of a professional audience.
Autonomy	Based on their competences gained so far students are capable of defining meaningful tasks within ongoing research project for themselves. They are able to develop the necessary understanding and problem solving methods. Students are capable of gathering information from subject related, professional publications and relate that information to the context of the seminar. They are able to find on their own new sources in the Internet. They are able to make a connection with the subject of their chosen specialization.
Workload in Hours	Independent Study Time 360, Study Time in Lecture 0
Credit points	12
Course achievement	None
Examination	Study work
Examination duration and scale	acc. to ASPO
Assignment for the Following Curricula	Electrical Engineering: Specialisation Medical Technology: Compulsory

Module M0548: Bioelectromagnetics: Principles and Applications

Courses

Title	Typ	Hrs/wk	CP
Bioelectromagnetics: Principles and Applications (L0371)	Lecture	3	5
Bioelectromagnetics: Principles and Applications (L0373)	Recitation Section (small)	2	1

Module Responsible	Prof. Christian Schuster
Admission Requirements	None
Recommended Previous Knowledge	Basic principles of physics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can explain the basic principles, relationships, and methods of bioelectromagnetics, i.e. the quantification and application of electromagnetic fields in biological tissue. They can define and exemplify the most important physical phenomena and order them corresponding to wavelength and frequency of the fields. They can give an overview over measurement and numerical techniques for characterization of electromagnetic fields in practical applications . They can give examples for therapeutic and diagnostic utilization of electromagnetic fields in medical technology.
Skills	Students know how to apply various methods to characterize the behavior of electromagnetic fields in biological tissue. In order to do this they can relate to and make use of the elementary solutions of Maxwell's Equations. They are able to assess the most important effects that these models predict for biological tissue, they can order the effects corresponding to wavelength and frequency, respectively, and they can analyze them in a quantitative way. They are able to develop validation strategies for their predictions. They are able to evaluate the effects of electromagnetic fields for therapeutic and diagnostic applications and make an appropriate choice.
Personal Competence	
Social Competence	Students are able to work together on subject related tasks in small groups. They are able to present their results effectively in English (e.g. during small group exercises).
Autonomy	Students are capable to gather information from subject related, professional publications and relate that information to the context of the lecture. They are able to make a connection between their knowledge obtained in this lecture with the content of other lectures (e.g. theory of electromagnetic fields, fundamentals of electrical engineering / physics). They can communicate problems and effects in the field of bioelectromagnetics in English.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** None; **Form** Presentation; **Description**
Examination	Oral exam
Examination duration and scale	45 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Electrical Engineering: Specialisation Wireless and Sensor Technologies: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory

Course L0371: Bioelectromagnetics: Principles and Applications	
Typ	Lecture
Hrs/wk	3
CP	5
Workload in Hours	Independent Study Time 108, Study Time in Lecture 42
Lecturer	Prof. Christian Schuster
Language	DE/EN
Cycle	WiSe
Content	- Fundamental properties of electromagnetic fields (phenomena) - Mathematical description of electromagnetic fields (Maxwell's Equations) - Electromagnetic properties of biological tissue - Principles of energy absorption in biological tissue, dosimetry - Numerical methods for the computation of electromagnetic fields (especially FDTD) - Measurement techniques for characterization of electromagnetic fields - Behavior of electromagnetic fields of low frequency in biological tissue - Behavior of electromagnetic fields of medium frequency in biological tissue - Behavior of electromagnetic fields of high frequency in biological tissue - Behavior of electromagnetic fields of very high frequency in biological tissue - Diagnostic applications of electromagnetic fields in medical technology - Therapeutic applications of electromagnetic fields in medical technology - The human body as a generator of electromagnetic fields
Literature	- C. Furse, D. Christensen, C. Durney, "Basic Introduction to Bioelectromagnetics", CRC (2009) - A. Vorst, A. Rosen, Y. Kotsuka, "RF/Microwave Interaction with Biological Tissues", Wiley (2006) - S. Grimnes, O. Martinsen, "Bioelectricity and Bioimpedance Basics", Academic Press (2008) - F. Barnes, B. Greenebaum, "Bioengineering and Biophysical Aspects of Electromagnetic Fields", CRC (2006)

Course L0373: Bioelectromagnetics: Principles and Applications	
Typ	Recitation Section (small)
Hrs/wk	2
CP	1
Workload in Hours	Independent Study Time 2, Study Time in Lecture 28
Lecturer	Prof. Christian Schuster
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Specialization Information and Communication Systems

This specialization offers a wide range of topics with respect to various concepts of telecommunications, wireless and wired communication systems as well as methods of digital signal processing. Students are able to understand the characteristics of transmission channels and principles of wireless systems in detail. Moreover, they acquire a profound knowledge about fundamentals, structures and modelling of communication networks. In addition, know-how on digital speech, audio and image processing is provided. As a result, the students will have the skills to analyze, design and optimize all aspects of a communication system. In today’s information age, this expertise is of paramount importance for positions in industry and academia.

Module M0637: Advanced Concepts of Wireless Communications

Courses

Title	Typ	Hrs/wk	CP
Advanced Concepts of Wireless Communications (L0297)	Lecture	3	4
Advanced Concepts of Wireless Communications (L0298)	Recitation Section (large)	2	2

Module Responsible	Dr. Rainer Grünheid
Admission Requirements	None
Recommended Previous Knowledge	• Lecture "Signals and Systems" • Lecture "Fundamentals of Telecommunications and Stochastic Processes" • Lecture "Digital Communications"
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to explain the general as well as advanced principles and techniques that are applied to wireless communications. They understand the properties of wireless channels and the corresponding mathematical description. Furthermore, students are able to explain the physical layer of wireless transmission systems. In this context, they are proficient in the concepts of multicarrier transmission (OFDM), modulation, error control coding, channel estimation and multi-antenna techniques (MIMO). Students can also explain methods of multiple access. On the example of contemporary communication systems (LTE, 5G) they can put the learnt content into a larger context. The students are familiar with the contents of lecture and tutorials. They can explain and apply them to new problems.
Skills	Using the acquired knowledge, students are able to understand the design of current and future wireless systems. Moreover, given certain constraints, they can choose appropriate parameter settings of communication systems. Students are also able to assess the suitability of technical concepts for a given application.
Personal Competence	
Social Competence	Students can jointly elaborate tasks in small groups and present their results in an adequate fashion.
Autonomy	Students are able to extract necessary information from given literature sources and put it into the perspective of the lecture. They can continuously check their level of expertise with the help of accompanying measures (such as online tests, clicker questions, exercise tasks) and, based on that, to steer their learning process accordingly. They can relate their acquired knowledge to topics of other lectures, e.g., "Fundamentals of Communications and Stochastic Processes" and "Digital Communications".
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 minutes; scope: content of lecture and exercise
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

Course L0297: Advanced Concepts of Wireless Communications	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Dr. Rainer Grünheid
Language	EN
Cycle	SoSe
Content	The lecture deals with technical principles and related concepts of mobile communications. In this context, the main focus is put on the physical and data link layer of the ISO-OSI stack. In the lecture, the transmission medium, i.e., the mobile radio channel, serves as the starting point of all considerations. The characteristics and the mathematical descriptions of the radio channel are discussed in detail. Subsequently, various physical layer aspects of wireless transmission are covered, such as channel coding, modulation/demodulation, channel estimation, synchronization, and equalization. Moreover, the different uses of multiple antennas at the transmitter and receiver, known as MIMO techniques, are described. Besides these physical layer topics, concepts of multiple access schemes in a cellular network are outlined. In order to illustrate the above-mentioned technical solutions, the lecture will also provide a system view, highlighting the basics of some contemporary wireless systems, including LTE, LTE Advanced, and 5G New Radio.
Literature	John G. Proakis, Masoud Salehi: Digital Communications. 5th Edition, Irwin/McGraw Hill, 2007 David Tse, Pramod Viswanath: Fundamentals of Wireless Communication. Cambridge, 2005 Bernard Sklar: Digital Communications: Fundamentals and Applications. Second Edition, Pearson, 2013 Stefani Sesia, Issam Toufik, Matthew Baker: LTE - The UMTS Long Term Evolution. Second Edition, Wiley, 2011 Erik Dahlman, Stefan Parkvall, Johan Sköld: 5G NR - The Next Generation Wireless Access Technology. Second Edition, Academic Press, 2021

Course L0298: Advanced Concepts of Wireless Communications	
Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Rainer Grünheid
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1700: Satellite Communications and Navigation

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Radio-Based Positioning and Navigation (L2711)	Lecture	2	3
Satellite Communications (L2710)	Lecture	3	3

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	The module is designed for a diverse audience, i.e. students with different background. Basic knowledge of communications engineering and signal processing are of advantage but not required. The course intends to provide the chapters on communications techniques such that on the one hand students with a communications engineering background learn additional concepts and examples (e.g. modulation and coding schemes or signal processing concepts) which have not or in a different way been treated in our other bachelor and master courses. On the other hand, students with other background shall be able to grasp the ideas but may not be able to understand in the same depth. The individual background of the students will be taken into consideration in the oral exam.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are able to understand, compare and analyse digital satellite communications system as well as navigation techniques. They are familiar with principal ideas of the respective communications, signal processing and positioning methods. They can describe distortions and resulting limitations caused by transmission channels and hardware components. They can describe how fundamental communications and navigation techniques are applied in selected practical systems. The students are familiar with the contents of lecture and tutorials. They can explain and apply them to new problems.
Skills	The students are able to describe and analyse digital satellite communications systems and navigation systems. They are able to analyse transmission chains including link budget calculations. They are able to choose appropriate transmission technologies and system parameters for given scenarios.
Personal Competence	
Social Competence	The students can jointly solve specific problems.
Autonomy	The students are able to acquire relevant information from appropriate literature sources.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

Course L2711: Radio-Based Positioning and Navigation

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Gerhard Bauch, Dr. Rico Mendrzik
Language	EN
Cycle	SoSe

Content

- Information extraction from communication signals
  - Time-of-arrival principle
    - Ranging in additive white Gaussian noise (AWGN) channel
    - Correlation-based range estimation
    - Effect of multipath propagation on time-of-arrival principle
    - Zero-forcing range estimation in the presence of multipath
    - Optimum range estimation in the presence of multipath
    - Zero-forcing in presence of noise
  - Angle-of-arrival principle
    - Angle-of-arrival estimation in AWGN channel
    - Delay-and-sum estimator
    - Multiple Signal Classifier (MUSIC)

        - MUSIC-based angle-of-arrival estimation
        - Case study: Comparison of estimators in AWGN channels
        - Effect of multipath propagation on angle-of-arrival principle
        - Case study: Comparison of estimators in multipath channels
- Information fusion of extracted signals
    - Distance-based positioning
        - Principle of time-of-arrival positioning
        - Geometric interpretation
        - Positioning in the absence of noise
        - Linearization of the positioning problem
        - Positioning in the presence of noise
        - Optimality criteria
        - Least squares time-of-arrival positioning
        - Maximum likelihood time-of-arrival positioning
        - Interactive Matlab demo
        - Excursion: gradient descent solvers for nonlinear programs
        - Real-life positioning with embedded development board (Arduino)
        - Linearized least squares time-of-arrival positioning
        - Effect of clock offsets on distance-based positioning
        - Time-difference-of-arrival principle
        - Least squares time-difference-of-arrival positioning
        - Clock offset mitigation via two-way ranging
    - Performance limits of distance-based positioning
        - Fisher information and the Cramér-Rao lower bound
        - Fisher information in the AWGN case
        - Multi-variate Fisher information
        - Cramér-Rao lower bound for synchronized time-of-arrival positioning
        - Case study: Synchronized time-of-arrival positioning
        - Cramér-Rao lower bound for unsynchronized time-of-arrival positioning
        - Case study: Unsynchronized time-of-arrival positioning
    - Angle-based Positioning
        - Angle-of-arrival positioning principle
        - Geometric interpretation angle-of-arrival positioning principle
        - Noise-free angle-of-arrival positioning with known orientation
        - Effect of noise on angle-of-arrival positioning
        - Least squares angle-of-arrival positioning with known orientation
        - Linear least squares angle-of-arrival positioning
        - Effect of orientation uncertainty
        - Angle-difference-of-arrival positioning
        - Geometric interpretation angle difference of arrival positioning
        - Proof of angle-difference-of-arrival locus
        - Inscribed angle lemma
        - Case study: Angle-difference-of-arrival-positioning
    - Performance limits of angle-based positioning
        - Cramér-Rao lower bound for angle-of-arrival positioning with known orientation
        - Case study: Angle-of-arrival positioning with known orientation
- Information Filtering
    - Bayesian filtering
        - Principle of Bayesian filtering
        - General Problem Formulation
        - Solution to the linear Gaussian case
        - State transition in the linear Gaussian case
        - Proof of predicted posterior distribution of the Kalman filter
        - State update in the linear Gaussian case
        - Proof of marginal posterior distribution of the Kalman filter
        - Working with Gaussian random variables
            - Proof: Affine transformation
            - Proof: Marginalization
            - Proof: Conditioning
        - Kalman filter: Optimum Inference in the linear Gaussian case
        - Modeling of process noise
        - Modeling of measurement noise
        - Case study: Kalman filtering in the linear Gaussian case
        - Interactive Kalman filtering in Matlab
        - Dealing with nonlinearities in Bayesian filtering
        - Nonlinear Gaussian case
        - Extended Kalman filter
        - Proof of predicted posterior distribution of the extended Kalman filter
        - Proof of marginal posterior distribution of the extended Kalman filter
        - Example: Nonlinear state transition

        - Case study: Extended Kalman filtering
        - Practical considerations for filter design

- Satellite Navigation
    - Overview from positioning perspective
        - Earth-centered earth-fixed (ECEF) coordinate system
        - World geodetic system (WGS)
        - Satellite navigation systems
        - System-receiver clock offsets and pseudo-ranges
        - Unsynchronized time-of-arrival positioning revisited
    - GPS legacy signals and ranging
        - Signal overview
        - Time-of-arrival principle revisited
        - Direct sequence spread spectrum principle
        - Short and long codes
        - Satellite signal generation
        - Carriers and codes
        - Correlation properties of codes
        - Code division multiple access in flat fading channels
        - Navigation message
    - Velocity estimation
    - Hands-on case study: Design of an extended Kalman filter for satellite navigation based on recorded data

- Robust navigation
    - Multipath-assisted positioning in millimeter wave multiple antenna systems
    - Multi-sensor fusion

Literature	

Course L2710: Satellite Communications	
Typ	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	SoSe
Content	

- Introduction to satellite communications
    - What is a satellite
    - Overview orbits, Van Allen Belt, components of a satellite
    - Satellite services
    - Frequency bands for satellite services
    - International Telecommunications Union (ITU)
    - Influence of atmospheric impairments
    - Milestones in satellite communications
- Components of a satellite communications system
    - Ground segment
    - Space segment
    - Control segment
- Communication links
    - Uplink, downlink
    - Forward link, reverse link
    - Intersatellite links
    - Multiple access
    - Performance measures
        - Effective isotropic radiated power (EIRP), antenna gain, figure of merit, G/T, carrier to noise ratio
        - Signal to noise power ratio vs. carrier to noise ratio
- Single beam and multibeam satellites
    - Beam coverage
    - Examples for beam coverage of LEO and GEO satellites (Iridium, Viasat)
- Transparent vs. regenerative payload

- Orbits
    - Low earth orbot (LEO), medium earth orbit (MEO), geosynchroneous and geostationary orbits (GEO), highly elliptical orbits (HEO
    - Favourable orbits:
        - HEO orbits with 63-64^{o} inclination, Molnya and Tundra orbits
        - Circular LEO orbits
        - Circular MEO Orbits (Intermediate Circular Orbits (ICO))
        - Equatorial orbits, geostationary orbit (GEO)
    - Important aspects of LEO, MEO and GEO satellites

- Kepler's laws of planetary motion
- Gravitational force
- Parameters of ellipses and elliptical orbits
    - Major and minor half axis
    - Foci
    - Eccentricity
    - Eccentric anomaly, mean anomaly, true anomaly
    - Area
    - Orbit period
    - Perigee, apogee
    - Distance of satellite from center of earth
    - Construction of ellipses according to de La Hire
    - Orbital plane in space, inclination, right ascension (longitude) of ascending node, Vernal equinox
- Newton's laws of motion
- Newton's universal law of gravitation

- Energy of satellites: Potential energy, kinetic energy, total energy
- Instantaneous speed of a satellite
- Kepler's equation
- Satellite visibility, elevation
- Required number of LEO, MEO or GEO satellites for continuous earth coverage
- Satellite altitude and distance from a point on earth

- Choice of orbits
    - LEO, HEO, GEO
    - Elliptical orbits with non-zero inclination, Molnya orbits, Tundra orbits
    - Geosynchronous orbits
        - Parameters of geosynchronous orbits
        - Circular geosynchronous orbits
        - Inclined geosynchronous orbits
        - Quasi-zenith satellite systems (QZSS)
        - Syb-synchronous circular equatorial orbits
        - Geostationary orbit
            - Parameters of the geostationary orbit
            - Visibility
            - Propagation delay
            - Applications and system examples

- Perturbations of orbits
    - Station keeping
        - Station keeping box
        - Estimation of orbit parameters

- Fundamentals of digital communications techniques
    - Components of a digital communications system
    - Principles of encryption
    - Scrambling
    - Scrambling vs. interleaving for randomization of data sequences
    - Interleaving: Block interleaver, convolutional interleaver, random interleaver
    - Digital modulation methods
        - Linear and non-linear digital modulation methods
        - Linear digital modulation methods
            - QAM modulator and demodulator
            - Pulse shaping, square-root raised-cosine pulses
            - Average power spectral density
            - Signal space constellation
            - Examples: M-ary phase shift keying (M-PSK), M-ary quadrature amplitude shift keying (M-QAM)
            - M-PSK in noisy channels
            - Bit error probabilities of M-PSK and M-QAM
            - M-PSK vs. M-QAM
            - M-ary amplitude and phase shift keying (M-APSK)
            - M-APSK vs. M-QAM
            - Differential phase shift keying (DPSK)

Error control coding (channel coding)

- Error detecting and forward error correcting (FEC) codes
- Principle of channel coding
- Data rate, code rate, Baud rate, spectral efficiency of modulation and coding schemes
- Bandwidth-power trade-off, bandwidth-limited vs. power-limited transmission
- Coding and modulation for transparent vs. regenerative payload
- Block codes and convolutional codes
- Concatenated codes

- Bit-interleaved coded modulation
- Convolutional codes
- Low density parity check (LDPC) codes, principle of message passing decoding, bit error rate performance
- Cyclic block codes
    - Examples for cyclic block codes
    - Single errors vs. block errors, cyclic block codes for burst errors
    - Generator matrix, generator polynomials
    - Systematic encoding and syndrome determination with shift registers
    - Cyclic redundancy check (CRC) codes

- Automatic repeat request (ARQ)
    - Principle of ARQ
    - Stop-and-wait ARQ
    - Go-back-N ARQ
    - Selective-repeat ARQ
- Transmission gains and losses
    - Antenna gain
        - Antenna radiation pattern
        - Maximum antenna gain, 3dB beamwidth
        - Maximum antenna gain of circular aperture
        - Maximum antenna gain of a geostationary satellite with global coverage
    - Effective isotropic radiated power (EIRP)
    - Power flux density
    - Path loss
        - Free space loss, free space loss for geostationary satellites
        - Atmospheric loss
        - Received power
    - Losses in transmit and receive equipment
        - Feeder loss
        - Depointing loss
        - Polarization mismatch loss
    - Combined effect of losses
- Noise
    - Origins of noise
    - White noise
    - Noise power spectral density and noise power
    - Additive white Gaussian noise (AWGN) channel model
    - Antenna noise temperature
    - Earth brightness temperature
    - Signal to noise ratios
- Atmospheric distortions
    - Atmosphere of the earth: Troposphere, stratosphere, mesosphere, thermosphere, exosphere
    - Attenuation and depolarization due to rain, fog, rain and ice clouds, sandstorms
    - Scintillation
    - Faraday effect
    - Multipath contributions
- Link budget calculations
    - GEO clear sky uplink and downlink
    - GEO uplink and downlink under rain conditions
    - Transparent vs. regenerative payload
- Link availability improvement through site diversity and adaptive transmission
    - Transparent vs. regenerative payload
        - Non-linear amplifiers
            - Saleh model, Rapp model
            - Input and output back-off factor
        - Single carrier and multicarrier operation
        - Dimensioning of transmission parameters
        - Sources of noise: Thermal noise, interference, intermodulation products
        - Signal to noise ratio and bit error probability
        - Robustness against interference and non-linear channels

- Satellite networks
    - Satellite network reference architectures
    - Network topologies
    - Network connectivity
        - Types of network connectivity
        - On-board connectivity
        - Inter-satellite links
    - Broadcast networks
    - Satellite-based internet

	• Satellite communications systems and standards examples
	  ◦ The role of standards in satellite communications
	  ◦ The Digital Video Broadcast Satellite Standard: DVB-S, DVB-S2, DVB-S2X
	  ◦ Satellites in 3GPP mobile communications networks
	  ◦ LEO megaconstellations: SpaceX Starlink, Kuiper, OneWeb
	  ◦ Space debris
	  ◦ The German Heinrich Hertz mission

Literature	

Module M0673: Information Theory and Coding

Courses

Title	Typ	Hrs/wk	CP
Information Theory and Coding (L0436)	Lecture	3	4
Information Theory and Coding (L0438)	Recitation Section (large)	2	2

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	• Mathematics 1-3 • Probability theory and random processes • Basic knowledge of communications engineering (e.g. from lecture "Fundamentals of Communications and Random Processes")
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students know the basic definitions for quantification of information in the sense of information theory. They know Shannon's source coding theorem and channel coding theorem and are able to determine theoretical limits of data compression and error-free data transmission over noisy channels. They understand the principles of source coding as well as error-detecting and error-correcting channel coding. They are familiar with the principles of decoding, in particular with modern methods of iterative decoding. They know fundamental coding schemes, their properties and decoding algorithms. The students are familiar with the contents of lecture and tutorials. They can explain and apply them to new problems.
Skills	The students are able to determine the limits of data compression as well as of data transmission through noisy channels and based on those limits to design basic parameters of a transmission scheme. They can estimate the parameters of an error-detecting or error-correcting channel coding scheme for achieving certain performance targets. They are able to compare the properties of basic channel coding and decoding schemes regarding error correction capabilities, decoding delay, decoding complexity and to decide for a suitable method. They are capable of implementing basic coding and decoding schemes in software.
Personal Competence	
Social Competence	The students can jointly solve specific problems.
Autonomy	The students are able to acquire relevant information from appropriate literature sources. They can control their level of knowledge during the lecture period by solving tutorial problems, software tools, clicker system.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Core Qualification: Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Mechatronics: Technical Complementary Course: Elective Compulsory

Course L0436: Information Theory and Coding

Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	SoSe

Content	• Introduction to information theory and coding
	• Definitions of information: Self information, entropy
	• Binary entropy function
	• Source coding theorem
	• Entropy of continuous random variables: Differential entropy, differential entropy of uniformly and Gaussian distributed random variables
	• Source coding
	  ◦ Principles of lossless source coding
	  ◦ Optimal source codes
	  ◦ Prefix codes, prefix-free codes, instantaneous codes
	  ◦ Morse code
	  ◦ Huffman code
	  ◦ Shannon code

  - Bounds on the average codeword length
  - Relative entropy, Kullback-Leibler distance, Kullback-Leibler divergence
  - Cross entropy
  - Lempel-Ziv algorithm
  - Lempel-Ziv-Welch (LZW) algorithm
  - Text compression and image compression using variants of the Lempel-Ziv algorithm
- Channel models
  - AWGN channel
  - Binary-input AWGN channel
  - Binary symmetric channel (BSC)
  - Relationship between AWGN channel and BSC
  - Binary error and erasure channel (BEEC)
  - Binary erasure channel (BEC)
  - Discrete memoryless channels (DMC)
- Definitions of information for multiple random variables
  - Mutual information and channel capacity
  - Entropy, conditional entropy
  - Chain rules for entropy and mutual information
- Channel coding theorem
- Channel capacity of fundamental channels: BSC, BEC, AWGN channel, binary-input AWGN channel etc.
- Power-limited vs. bandlimited transmission
- Capacity of parallel AWGN channels
  - Waterfilling
  - Examples: Multiple input multiple output (MIMO) channels, complex equivalent baseband channels, orthogonal frequency division multiplex (OFDM)
- Source-channel coding theorem, separation theorem
- Multiuser information theory
  - Multiple access channel (MAC)
  - Broadcast channel
  - Principles of multiple access, time division multiple access (TDMA), frequency division multiple access (FDMA), non-orthogonal multiple access (NOMA), hybrid multiple access
  - Achievable rate regions of TDMA and FDMA with power constraint, energy constraint, power spectral density constraint, respectively
  - Achievable rate region of the two-user and K-user multiple access channels
  - Achievable rate region of the two-user and K user broadcast channels
  - Multiuser diversity
- Channel coding
  - Principles and types of channel coding
  - Code rate, data rate, Hamming distance, minimum Hamming distance, Hamming weight, minimum Hamming weight
  - Error detecting and error correcting codes
  - Simple block codes: Repetition codes, single parity check codes, Hamming code, etc.
  - Syndrome decoding
  - Representations of binary data
  - Non-binary symbol alphabets and non-binary codes
  - Code and encoder, systematic and non-systematic encoders
  - Properties of Hamming distance and Hamming weight
  - Decoding spheres
  - Perfect codes
  - Linear codes
  - Decoding principles
    - Syndrome decoding
    - Maximum a posteriori probability (MAP) decoding and maximum likelihood (ML) decoding
    - Hard decision and soft decision decoding
    - Log-likelihood ratios (LLRs), boxplus operation
    - MAP and ML decoding using log-likelihood ratios
    - Soft-in soft-out decoders
  - Error rate performance comparison of codes in terms of SNR per info bit vs. SNR per code bit
  - Linear block codes
    - Generator matrix and parity check matrix, properties of generator matrix and parity check matrix
    - Dual codes
  - Low density parity check (LDPC) codes
    - Sparse parity check matrix
    - Tanner graphs, cycles and girth
    - Degree distributions
    - Code rate and degree distribution
    - Regular and irregular LDPC codes
    - Message passing decoding
      - Message passing decoding in binary erasure channels (BEC)
      - Systematic encoding using erasure message passing decoding
      - Message passing decoding in binary symmetric channels (BSC)

- Extrinsic information
- Bit-flipping decoding
- Effects of short cycles in the Tanner graph
- Alternative bit-flipping decoding
- Soft decision message passing decoding: Sum product decoding
- Bit error rate performance of LDPC codes
- Repeat accumulate codes and variants of repeat accumulate codes
- Message passing decoding and turbo decoding of repeat accumulate codes
- Convolutional codes
  - Encoding using shift registers
  - Trellis representation
  - Hard decision and soft decision Viterbi decoding
  - Bit error rate performance of convolutional codes
  - Asymptotic coding gain
  - Viterbi decoding complexity
  - Free distance and optimum convolutional codes
  - Generator polynomial description and octal description
  - Catastrophic convolutional codes
  - Non-systematic and recursive systematic convolutional (RSC) encoders
  - Rate compatible punctured convolutional (RCPC) codes
  - Hybrid automatic repeat request (HARQ) with incremental redundancy
  - Unequal error protection with punctured convolutional codes
  - Error patterns of convolutional codes
- Concatenated codes
  - Serial concatenated codes
  - Parallel concatenated codes, Turbo codes
  - Iterative decoding, turbo decoding
  - Bit error rate performance of turbo codes
  - Interleaver design for turbo codes
- Coded modulation
  - Principle of coded modulation
  - Achievable rates with PSK/QAM modulation
  - Trellis coded modulation (TCM)
  - Set partitioning
  - Ungerböck codes
  - Multilevel coding
  - Bit-interleaved coded modulation

Literature

Bossert, M.: Kanalcodierung. Oldenbourg.

Friedrichs, B.: Kanalcodierung. Springer.

Lin, S., Costello, D.: Error Control Coding. Prentice Hall.

Roth, R.: Introduction to Coding Theory.

Johnson, S.: Iterative Error Correction. Cambridge.

Richardson, T., Urbanke, R.: Modern Coding Theory. Cambridge University Press.

Gallager, R. G.: Information theory and reliable communication. Whiley-VCH

Cover, T., Thomas, J.: Elements of information theory. Wiley.

Course L0438: Information Theory and Coding	
Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0837: Simulation of Communication Networks

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Simulation of Communication Networks (L0887)	Project-/problem-based Learning	5	6

Module Responsible	Prof. Andreas Timm-Giel
Admission Requirements	None
Recommended Previous Knowledge	• Knowledge of computer and communication networks • Basic programming skills
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to explain the necessary stochastics, the discrete event simulation technology and modelling of networks for performance evaluation.
Skills	Students are able to apply the method of simulation for performance evaluation to different, also not practiced, problems of communication networks. The students can analyse the obtained results and explain the effects observed in the network. They are able to question their own results.
Personal Competence	
Social Competence	Students are able to acquire expert knowledge in groups, present the results, and discuss solution approaches and results. They are able to work out solutions for new problems in small teams.
Autonomy	Students are able to transfer independently and in discussion with others the acquired method and expert knowledge to new problems. They can identify missing knowledge and acquire this knowledge independently.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Simulation Technology: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Simulation Technology: Elective Compulsory

Course L0887: Simulation of Communication Networks

Typ	Project-/problem-based Learning
Hrs/wk	5
CP	6
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Lecturer	Prof. Andreas Timm-Giel
Language	EN
Cycle	SoSe
Content	In the course necessary basic stochastics and the discrete event simulation are introduced. Also simulation models for communication networks, for example, traffic models, mobility models and radio channel models are presented in the lecture. Students work with a simulation tool, where they can directly try out the acquired skills, algorithms and models. At the end of the course increasingly complex networks and protocols are considered and their performance is determined by simulation.
Literature	• Skript des Instituts für Kommunikationsnetze Further literature is announced at the beginning of the lecture.

Module M1248: Compilers for Embedded Systems

Courses

Title	Typ	Hrs/wk	CP
Compilers for Embedded Systems (L1692)	Lecture	3	4
Compilers for Embedded Systems (L1693)	Project-/problem-based Learning	1	2

Module Responsible	Prof. Heiko Falk
Admission Requirements	None
Recommended Previous Knowledge	Module "Embedded Systems" C/C++ Programming skills
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The relevance of embedded systems increases from year to year. Within such systems, the amount of software to be executed on embedded processors grows continuously due to its lower costs and higher flexibility. Because of the particular application areas of embedded systems, highly optimized and application-specific processors are deployed. Such highly specialized processors impose high demands on compilers which have to generate code of highest quality. After the successful attendance of this course, the students are able • to illustrate the structure and organization of such compilers, • to distinguish and explain intermediate representations of various abstraction levels, and • to assess optimizations and their underlying problems in all compiler phases. The high demands on compilers for embedded systems make effective code optimizations mandatory. The students learn in particular, • which kinds of optimizations are applicable at the source code level, • how the translation from source code to assembly code is performed, • which kinds of optimizations are applicable at the assembly code level, • how register allocation is performed, and • how memory hierarchies can be exploited effectively. Since compilers for embedded systems often have to optimize for multiple objectives (e.g., average- or worst-case execution time, energy dissipation, code size), the students learn to evaluate the influence of optimizations on these different criteria.
Skills	After successful completion of the course, students shall be able to translate high-level program code into machine code. They will be enabled to assess which kind of code optimization should be applied most effectively at which abstraction level (e.g., source or assembly code) within a compiler. While attending the labs, the students will learn to implement a fully functional compiler including optimizations.
Personal Competence	
Social Competence	Students are able to solve similar problems alone or in a group and to present the results accordingly.
Autonomy	Students are able to acquire new knowledge from specific literature and to associate this knowledge with other classes.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Mechatronics: Technical Complementary Course: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L1692: Compilers for Embedded Systems	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Heiko Falk
Language	DE/EN
Cycle	SoSe
Content	• Introduction and Motivation • Compilers for Embedded Systems - Requirements and Dependencies • Internal Structure of Compilers • Pre-Pass Optimizations • HIR Optimizations and Transformations • Code Generation • LIR Optimizations and Transformations • Register Allocation • WCET-Aware Compilation • Outlook
Literature	• Peter Marwedel. Embedded System Design - Embedded Systems Foundations of Cyber-Physical Systems. 2 nd Edition, Springer, 2012. • Steven S. Muchnick. Advanced Compiler Design and Implementation. Morgan Kaufmann, 1997. • Andrew W. Appel. Modern compiler implementation in C. Oxford University Press, 1998.

Course L1693: Compilers for Embedded Systems	
Typ	Project-/problem-based Learning
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Heiko Falk
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1785: Machine Learning in Electrical Engineering and Information Technology

Courses

Title	Typ	Hrs/wk	CP
General Introduction Machine Learning (L3004)	Lecture	1	2
Machine Learning Applications in Electric Power Systems (L3008)	Lecture	1	1
Machine Learning in Electromagnetic Compatibility (EMC) Engineering (L3006)	Lecture	1	1
Machine Learning in High-Frequency Technology and Radar (L3007)	Lecture	1	1
Machine Learning in Wireless Communications (L3005)	Lecture	1	1

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	The module is designed for a diverse audience, i.e. students with different background. It shall be suitable for both students with deeper knowledge in machine learning methods but less knowledge in electrical engineering, e.g. math or computer science students, and students with deeper knowledge in electrical engineering but less knowledge in machine learning methods, e.g. electrical engineering students. Machine learning methods will be explained on a relatively high level indicating mainly principle ideas. The focus is on specific applications in electrical engineering and information technology. The chapters of the course will be understandable in different depth depending on the individual background of the student. The individual background of the students will be taken into consideration in the oral exam.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	
Skills	
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory

Course L3004: General Introduction Machine Learning	
Typ	Lecture
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Dr. Maximilian Stark
Language	EN
Cycle	SoSe

Content	• From Rule-Based Systems to Machine Learning
	  ◦ Brief overview recent advances in ML in various domain
	  ◦ Outline and expected learning outcomes
	  ◦ Basics statistical inference and statistics
	  ◦ Basics of information theory
	• The Notions of Learning in Machine Learning
	  ◦ Unsupervised and supervised machine learning
	  ◦ Model-based and data-driven machine learning
	  ◦ Hybrid modelling
	  ◦ Online/offline/meta/transfer learning
	  ◦ General loss functions
	• Introduction to Deep Learning
	  ◦ Variants of neural networks
	  ◦ MLP
	  ◦ Conv. neural networks
	  ◦ Recurrent neural networks
	  ◦ Training neural networks
	  ◦ (Stochastic) Gradient Descent
	• Regression vs. Classification
	  ◦ Classification as supervised learning problem
	  ◦ Hands-On Session
	• Representation Learning and Generative Models
	  ◦ AutoEncoders
	  ◦ Directed Generative Models
	  ◦ Undirected Generative Models
	  ◦ Generative Adversarial Neural Networks
	• Probabilistic Graphical Models
	  ◦ Bayesian Networks
	  ◦ Variational inference (variational autoencoder)

Literature	

Course L3008: Machine Learning Applications in Electric Power Systems	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Christian Becker, Dr. Davood Babazadeh
Language	EN
Cycle	SoSe
Content	
Literature	

Course L3006: Machine Learning in Electromagnetic Compatibility (EMC) Engineering	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Christian Schuster, Dr. Cheng Yang
Language	EN
Cycle	SoSe
Content	Electromagnetic Compatibility (EMC) Engineering deals with design, simulation, measurement, and certification of electronic and electric components and systems in such a way that their operation is safe, reliable, and efficient in any possible application. Safety is hereby understood as safe with respect to parasitic effects of electromagnetic fields on humans as well as on the operation of other components and systems nearby. Examples for components and systems range from the wiring in aircraft and ships to high-speed interconnects in server systems and wirless interfaces for brain implants. In this part of the course we will give an introduction to the physical basics of EMC engineering and then show how methods of Machine Learning (ML) can be applied to expand todays physcis-based approaches in EMC Engineering.
Literature	

Course L3007: Machine Learning in High-Frequency Technology and Radar	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Alexander Kölpin, Dr. Fabian Lurz
Language	EN
Cycle	SoSe
Content	
Literature	

Course L3005: Machine Learning in Wireless Communications	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Dr. Maximilian Stark
Language	EN
Cycle	SoSe
Content	• Supervised Learning Application - Channel Coding ◦ Recap channel coding and block codes ◦ Block codes as trainable neural networks ◦ Tanner graph with trainable weights ◦ Hands-on session • Supervised Learning Application - Modulation Detection ◦ Recap wireless modulation schemes ◦ Convolutional neuronal networks for blind detection of modulation schemes ◦ Hands-on session • Autoencoder Application - Constellation Shaping I ◦ Recap channel capacity and constellation shaping, ◦ Capacity achieving machine learning systems ◦ Information theoretical explanation of the autoencoder training ◦ Hands-on session • Autoencoder Application - Constellation Shaping II ◦ Training without a channel model ◦ Mutual information neural estimator ◦ Hands-on session • Generative Adversarial Network Application - Channel Modelling ◦ Recap realistic channels with non-linear hardware impairments ◦ Training a digital twin of a realistic channel with insufficient training data ◦ Hands-on session • Recurrent Neural Network Application - Channel prediction ◦ Recap time-varying channel models ◦ Recurrent neural networks for temporal prediction ◦ Hands-on session
Literature	

Module M0924: Software for Embedded Systems

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Software for Embdedded Systems (L1069)	Lecture	2	3
Software for Embdedded Systems (L1070)	Recitation Section (small)	3	3

Module Responsible	Prof. Bernd-Christian Renner
Admission Requirements	None
Recommended Previous Knowledge	• Very Good knowledge and practical experience in programming in the C language • Basic knowledge in software engineering • Basic understanding of assembly language
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students know the basic principles and procedures of software engineering for embedded systems. They are able to describe the usage and pros of event based programming using interrupts. They know the components and functions of a concrete microcontroller. The participants explain requirements of real time systems. They know at least three scheduling algorithms for real time operating systems including their pros and cons.
Skills	Students build interrupt-based programs for a concrete microcontroller. They build and use a preemptive scheduler. They use peripheral components (timer, ADC, EEPROM) to realize complex tasks for embedded systems. To interface with external components they utilize serial protocols.
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** No / **Bonus** 10 % / **Form** Attestation / **Description**
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory Mechatronics: Technical Complementary Course: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L1069: Software for Embdedded Systems

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Bernd-Christian Renner
Language	DE/EN
Cycle	SoSe
Content	• General-Purpose Processors • Programming the Atmel AVR • Interrupts • C for Embedded Systems • Standard Single Purpose Processors: Peripherals • Finite-State Machines • Memory • Operating Systems for Embedded Systems • Real-Time Embedded Systems • Boot loader and Power Management
Literature	1. Embedded System Design, F. Vahid and T. Givargis, John Wiley 2. Programming Embedded Systems: With C and Gnu Development Tools, M. Barr and A. Massa, O'Reilly 3. C und C++ für Embedded Systems, F. Bollow, M. Homann, K. Köhn, MITP 4. The Art of Designing Embedded Systems, J. Ganssle, Newnses 5. Mikrocomputertechnik mit Controllern der Atmel AVR-RISC-Familie, G. Schmitt, Oldenbourg 6. Making Embedded Systems: Design Patterns for Great Software, E. White, O'Reilly

Course L1070: Software for Embdedded Systems	
Typ	Recitation Section (small)
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Bernd-Christian Renner
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1697: Selected Aspects in Information and Communication Systems

Courses

Title	Typ	Hrs/wk	CP
Selected Aspects in Information and Communication Systems (L2700)	Lecture	2	4
Selected Aspects in Information and Communication Systems (L2701)	Recitation Section (large)	2	2

Module Responsible	Prof. Christian Becker
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	
Skills	
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory

Course L2700: Selected Aspects in Information and Communication Systems

Typ	Lecture
Hrs/wk	2
CP	4
Workload in Hours	Independent Study Time 92, Study Time in Lecture 28
Lecturer	Dozenten des SD E
Language	DE/EN
Cycle	WiSe/SoSe
Content	
Literature	

Course L2701: Selected Aspects in Information and Communication Systems

Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dozenten des SD E
Language	DE/EN
Cycle	WiSe/SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0836: Communication Networks

Courses

Title	Typ	Hrs/wk	CP
Selected Topics of Communication Networks (L0899)	Project-/problem-based Learning	2	2
Communication Networks (L0897)	Lecture	2	2
Communication Networks Excercise (L0898)	Project-/problem-based Learning	1	2

Module Responsible	Prof. Andreas Timm-Giel
Admission Requirements	None
Recommended Previous Knowledge	• Fundamental stochastics • Basic understanding of computer networks and/or communication technologies is beneficial
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to describe the principles and structures of communication networks in detail. They can explain the formal description methods of communication networks and their protocols. They are able to explain how current and complex communication networks work and describe the current research in these examples.
Skills	Students are able to evaluate the performance of communication networks using the learned methods. They are able to work out problems themselves and apply the learned methods. They can apply what they have learned autonomously on further and new communication networks.
Personal Competence	
Social Competence	Students are able to define tasks themselves in small teams and solve these problems together using the learned methods. They can present the obtained results. They are able to discuss and critically analyse the solutions.
Autonomy	Students are able to obtain the necessary expert knowledge for understanding the functionality and performance capabilities of new communication networks independently.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Presentation
Examination duration and scale	1.5 hours colloquium with three students, therefore about 30 min per student. Topics of the colloquium are the posters from the previous poster session and the topics of the module.
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory Aeronautics: Core Qualification: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L0899: Selected Topics of Communication Networks

Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Koojana Kuladinithi
Language	EN
Cycle	WiSe
Content	Example networks selected by the students will be researched on in a PBL course by the students in groups and will be presented in a poster session at the end of the term.
Literature	• see lecture

Course L0897: Communication Networks	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Koojana Kuladinithi
Language	EN
Cycle	WiSe
Content	
Literature	• Skript des Instituts für Kommunikationsnetze • Tannenbaum, Computernetzwerke, Pearson-Studium Further literature is announced at the beginning of the lecture.

Course L0898: Communication Networks Excercise	
Typ	Project-/problem-based Learning
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Dr. Koojana Kuladinithi
Language	EN
Cycle	WiSe
Content	Part of the content of the lecture Communication Networks are reflected in computing tasks in groups, others are motivated and addressed in the form of a PBL exercise.
Literature	• announced during lecture

Module M0638: Modern Wireless Systems

Courses

Title	Typ	Hrs/wk	CP
Selected Topics of Modern Wireless Systems (L1982)	Project-/problem-based Learning	2	3
Modern Wireless Systems (L0296)	Lecture	3	3

Module Responsible	Dr. Rainer Grünheid
Admission Requirements	None
Recommended Previous Knowledge	• Lecture "Digital Communications" • Lecture "Advanced Concepts of Wireless Communications"
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students have an overview of a variety of contemporary wireless systems of different size and complexity. They understand the technical solutions from the perspective of the physical and data link layer. They have developed a system view and are aware of the technical arguments, considering the respective applications and associated constraints. For several examples (e.g., 5G New Radio), students are able to explain different concepts in a very deep technical detail. The students are familiar with the contents of lecture and PBL course. They can explain and apply them to new problems.
Skills	Students have developed a system view. They can transfer their knowledge to evaluate other systems, not discussed in the lecture, and to understand the respective technical solutions. Given specific contraints and technical requirements, students are in a position to make proposals for certain design aspects by an appropriate assessment and the consideration of alternatives.
Personal Competence	
Social Competence	Students can jointly elaborate tasks in small groups and present their results in an adequate fashion.
Autonomy	Students are able to extract necessary information from given literature sources and put it into the perspective of the lecture. They can continuously check their level of expertise with the help of accompanying measures (such as online tests, clicker questions, exercise tasks) and, based on that, to steer their learning process accordingly. They can relate their acquired knowledge to topics of other lectures, e.g., "Digital Communications" and "Advanced Topics of Wireless Communications".
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** / **Bonus** / **Form** / **Description** Yes / None / Subject theoretical and practical work / PBL-Kurs mit Posterpräsentation
Examination	Oral exam
Examination duration and scale	40 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory

Course L1982: Selected Topics of Modern Wireless Systems	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Rainer Grünheid
Language	EN
Cycle	WiSe
Content	In this course, selected "hot" topics of modern wireless systems will be covererd. For that purpose, students work in small groups to elaborate a given subject, including a quantitative analysis with provided simulation tools. The results will be presented in a poster session or a talk towards the end of the semester. Possible topics can include various system concepts and related technical principles, such as: • WLAN sytems • 5G systems • Millimeter wave communication • Visible light communication • Cooperative Multipoint • Massive MIMO • Massive machine-type communication • Interference cancellation • Non-orthogonal multiple access • Heterogeneous networks • ...
Literature	will be provided, depending on the given topics

Course L0296: Modern Wireless Systems	
Typ	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Dr. Rainer Grünheid
Language	EN
Cycle	WiSe
Content	The lecture gives an overview of contemporary wireless communication concepts and related techniques from a system point of view. For that purpose, different systems, ranging from Wireless Personal to Wide Area Networks, are covered, mainly discussing the physical and data link layer. Systems under consideration include: - Near Field Communication (NFC) - ZigBee / IEEE 802.15.4 - Bluetooth - IEEE 802.11 family - L-band Digital Aeronautical Communication System (LDACS) - Long Term Evolution (LTE) and LTE Advanced - 5G New Radio A special focus is placed on 4th and 5th generation networks; in particular, an in-depth view into the technical principles of the 5G New Radio standard is given.
Literature	John G. Proakis, Masoud Salehi: Digital Communications. 5th Edition, Irwin/McGraw Hill, 2007 Stefani Sesia, Issam Toufik, Matthew Baker: LTE - The UMTS Long Term Evolution. Second Edition, Wiley, 2011 Erik Dahlman, Stefan Parkvall, Johan Sköld: 5G NR - The Next Generation Wireless Access Technology. Second Edition, Academic Press, 2021

Module M0839: Traffic Engineering

Courses

Title	Typ	Hrs/wk	CP
Seminar Traffic Engineering (L0902)	Seminar	2	2
Traffic Engineering (L0900)	Lecture	2	2
Traffic Engineering Exercises (L0901)	Recitation Section (small)	1	2

Module Responsible	Prof. Andreas Timm-Giel
Admission Requirements	None
Recommended Previous Knowledge	• Fundamentals of communication or computer networks • Stochastics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to describe methods for planning, optimisation and performance evaluation of communication networks.
Skills	Students are able to solve typical planning and optimisation tasks for communication networks. Furthermore they are able to evaluate the network performance using queuing theory. Students are able to apply independently what they have learned to other and new problems. They can present their results in front of experts and discuss them.
Personal Competence	
Social Competence	
Autonomy	Students are able to acquire the necessary expert knowledge to understand the functionality and performance of new communication networks independently.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory

Course L0902: Seminar Traffic Engineering

Typ	Seminar
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Andreas Timm-Giel, Dr. Phuong Nga Tran
Language	EN
Cycle	WiSe
Content	Selected applications of methods for planning, optimization, and performance evaluation of communication networks, which have been introduced in the traffic engineering lecture are prepared by the students and presented in a seminar.
Literature	• U. Killat, Entwurf und Analyse von Kommunikationsnetzen, Vieweg + Teubner • further literature announced in the lecture

Course L0900: Traffic Engineering	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Andreas Timm-Giel, Dr. Phuong Nga Tran
Language	EN
Cycle	WiSe
Content	Network Planning and Optimization • Linear Programming (LP) • Network planning with LP solvers • Planning of communication networks Queueing Theory for Communication Networks • Stochastic processes • Queueing systems • Switches (circuit- and packet switching) • Network of queues
Literature	Literatur: U. Killat, Entwurf und Analyse von Kommunikationsnetzen, Springer Weitere Literatur wird in der Lehrveranstaltung bekanntgegeben / Literature: U. Killat, Entwurf und Analyse von Kommunikationsnetzen, Springer further literature announced in the lecture

Course L0901: Traffic Engineering Exercises	
Typ	Recitation Section (small)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Andreas Timm-Giel
Language	EN
Cycle	WiSe
Content	Accompanying exercise for the traffic engineering course
Literature	Literatur: U. Killat, Entwurf und Analyse von Kommunikationsnetzen, Springer Weitere Literatur wird in der Lehrveranstaltung bekanntgegeben / Literature: U. Killat, Entwurf und Analyse von Kommunikationsnetzen, Springer further literature announced in the lecture

Module M1526: Research Project and Seminar in Information and Communication Systems

Courses			
Title	**Typ**	**Hrs/wk**	**CP**

Module Responsible	Dozenten des SD E
Admission Requirements	None
Recommended Previous Knowledge	Advanced state of knowledge in the electrical engineering master program
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students know current research topics oft institutes engaged in their specialization. They can name the fundamental scientific methods used for doing related reserach. They are furthermore able to use professional language in discussions. They are able to explain research topics.
Skills	Students are capable of completing a small, independent sub-project of currently ongoing research projects in the institutes engaged in their specialization. Students can justify and explain their approach for problem solving, they can draw conclusions from their results, and then can find new ways and methods for their work. Students are capable of comparing and assessing alterantive approaches with their own with regard to given criteria. Students are able to gain knowledge about a new field by themselves. In order to do that they make use of their existing knowledge and try to connect it with the topics of the new field. They close their knowledge gaps by discussing with research assistants and by their own literature and internet search. They are capable of summarizing and presenting scientific publications.
Personal Competence	
Social Competence	Students are able to discuss their work progress with research assistants of the supervising institute . They are capable of presenting their results in front of a professional audience. In cooperation with research assistants students are able to familiarize themselves with and discuss with others current research topics. They are capable of drafting, presenting, and explaining summaries of these topics in English in front of a professional audience.
Autonomy	Based on their competences gained so far students are capable of defining meaningful tasks within ongoing research project for themselves. They are able to develop the necessary understanding and problem solving methods. Students are capable of gathering information from subject related, professional publications and relate that information to the context of the seminar. They are able to find on their own new sources in the Internet. They are able to make a connection with the subject of their chosen specialization.
Workload in Hours	Independent Study Time 360, Study Time in Lecture 0
Credit points	12
Course achievement	None
Examination	Study work
Examination duration and scale	acc. to ASPO
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Compulsory

Module M1598: Image Processing

Courses

Title	Typ	Hrs/wk	CP
Image Processing (L2443)	Lecture	2	4
Image Processing (L2444)	Recitation Section (small)	2	2

Module Responsible	Prof. Tobias Knopp
Admission Requirements	None
Recommended Previous Knowledge	Signal and Systems
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students know about • visual perception • multidimensional signal processing • sampling and sampling theorem • filtering • image enhancement • edge detection • multi-resolution procedures: Gauss and Laplace pyramid, wavelets • image compression • image segmentation • morphological image processing
Skills	The students can • analyze, process, and improve multidimensional image data • implement simple compression algorithms • design custom filters for specific applications
Personal Competence	
Social Competence	Students can work on complex problems both independently and in teams. They can exchange ideas with each other and use their individual strengths to solve the problem.
Autonomy	Students are able to independently investigate a complex problem and assess which competencies are required to solve it.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Data Science: Core Qualification: Elective Compulsory Data Science: Specialisation I. Mathematics/Computer Science: Elective Compulsory Data Science: Specialisation II. Computer Science: Elective Compulsory Data Science: Specialisation IV. Special Focus Area: Elective Compulsory Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Software and Signal Processing: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L2443: Image Processing	
Typ	Lecture
Hrs/wk	2
CP	4
Workload in Hours	Independent Study Time 92, Study Time in Lecture 28
Lecturer	Prof. Tobias Knopp
Language	DE/EN
Cycle	WiSe
Content	• Visual perception • Multidimensional signal processing • Sampling and sampling theorem • Filtering • Image enhancement • Edge detection • Multi-resolution procedures: Gauss and Laplace pyramid, wavelets • Image Compression • Segmentation • Morphological image processing
Literature	Bredies/Lorenz, Mathematische Bildverarbeitung, Vieweg, 2011 Pratt, Digital Image Processing, Wiley, 2001 Bernd Jähne: Digitale Bildverarbeitung - Springer, Berlin 2005

Course L2444: Image Processing	
Typ	Recitation Section (small)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Tobias Knopp
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Specialization Nanoelectronics and Microsystems Technology

The students of this specialization are introduced into the design of CMOS integrated circuits and the most important manufacturing steps. They gain knowledge and competences regarding the software tools for simulation and of their structure by performing classroom projects. A solid awareness of possible reliability problems and how to prevent them belongs to the acquired competences. Furthermore, the students get competences in the field of microsystem technology and in the usage of software tools for the design of those microsystems. The students acquire the necessary knowledge to develop as well as challenging integrated circuits and microsystems and to combine both to innovative units.

Module M0643: Optoelectronics I - Wave Optics

Courses

Title	Typ	Hrs/wk	CP
Optoelectronics I: Wave Optics (L0359)	Lecture	2	3
Optoelectronics I: Wave Optics (Problem Solving Course) (L0361)	Recitation Section (small)	1	1

Module Responsible	Dr. Alexander Petrov
Admission Requirements	None
Recommended Previous Knowledge	Basics in electrodynamics, calculus
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can explain the fundamental mathematical and physical relations of freely propagating optical waves. They can give an overview on wave optical phenomena such as diffraction, reflection and refraction, etc. Students can describe waveoptics based components such as electrooptical modulators in an application oriented way.
Skills	Students can generate models and derive mathematical descriptions in relation to free optical wave propagation. They can derive approximative solutions and judge factors influential on the components' performance.
Personal Competence	
Social Competence	Students can jointly solve subject related problems in groups. They can present their results effectively within the framework of the problem solving course.
Autonomy	Students are capable to extract relevant information from the provided references and to relate this information to the content of the lecture. They can reflect their acquired level of expertise with the help of lecture accompanying measures such as exam typical exam questions. Students are able to connect their knowledge with that acquired from other lectures.
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Credit points	4
Course achievement	None
Examination	Written exam
Examination duration and scale	60 minutes
Assignment for the Following Curricula	Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Materials Science: Specialisation Nano and Hybrid Materials: Elective Compulsory Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory Renewable Energies: Specialisation Solar Energy Systems: Elective Compulsory

Course L0359: Optoelectronics I: Wave Optics	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Alexander Petrov
Language	EN
Cycle	SoSe
Content	• Introduction to optics • Electromagnetic theory of light • Interference • Coherence • Diffraction • Fourier optics • Polarisation and Crystal optics • Matrix formalism • Reflection and transmission • Complex refractive index • Dispersion • Modulation and switching of light
Literature	Bahaa E. A. Saleh, Malvin Carl Teich, Fundamentals of Photonics, Wiley 2007 Hecht, E., Optics, Benjamin Cummings, 2001 Goodman, J.W. Statistical Optics, Wiley, 2000 Lauterborn, W., Kurz, T., Coherent Optics: Fundamentals and Applications, Springer, 2002

Course L0361: Optoelectronics I: Wave Optics (Problem Solving Course)	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Dr. Alexander Petrov
Language	EN
Cycle	SoSe
Content	see lecture Optoelectronics 1 - Wave Optics
Literature	see lecture Optoelectronics 1 - Wave Optics

Module M0747: Microsystem Design

Courses

Title	Typ	Hrs/wk	CP
Microsystem Design (L0683)	Lecture	2	3
Microsystem Design (L0684)	Practical Course	3	3

Module Responsible	Dr. Thomas Kusserow
Admission Requirements	None
Recommended Previous Knowledge	Mathematical Calculus, Linear Algebra, Microsystem Engineering
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students know about the most important and most common simulation and design methods used in microsystem design. The scientific background of finite element methods and the basic theory of these methods are known.
Skills	Students are able to apply simulation methods and commercial simulators in a goal oriented approach to complex design tasks. Students know to apply the theory in order achieve estimates of expected accuracy and can judge and verify the correctness of results. Students are able to develop a design approach even if only incomplete information about material data or constraints are available. Student can make use of approximate and reduced order models in a preliminary design stage or a system simulation.
Personal Competence	
Social Competence	Students are able to solve specific problems alone or in a group and to present the results accordingly. Students can develop and explain their solution approach and subdivide the design task to subproblems which are solved separately by group members.
Autonomy	Students are able to acquire particular knowledge using specialized literature and to integrate and associate this knowledge with other fields.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** Yes / **Bonus** None / **Form** Written elaboration / **Description**
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory Microelectronics and Microsystems: Core Qualification: Elective Compulsory

Course L0683: Microsystem Design	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Timo Lipka
Language	EN
Cycle	SoSe
Content	Finite difference methods Approximation error Finite element method Order of convergence Error estimation, mesh refinement Makromodeling Reduced order modeling Black-box models System identification Multi-physics systems System simulation Levels of simulation, network simulation Transient problems Non-linear problems Introduction to Comsol Application to thermal, electric, electromagnetic, mechanical and fluidic problems
Literature	M. Kasper: Mikrosystementwurf, Springer (2000) S. Senturia: Microsystem Design, Kluwer (2001)

Course L0684: Microsystem Design	
Typ	Practical Course
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Dr. Timo Lipka
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0919: Laboratory: Digital Circuit Design

Courses

Title	Typ	Hrs/wk	CP
Laboratory: Digital Circuit Design (L0694)	Project-/problem-based Learning	2	6

Module Responsible	Prof. Matthias Kuhl
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge of semiconductor devices and circuit design
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can explain the structure and philosophy of the software framework for circuit design. • Students can determine all necessary input parameters for circuit simulation. • Students are able to explain the functions of the logic gates of their digital design. • Students can explain the algorithms of checking routines. • Students are able to select the appropriate transistor models for fast and accurate simulations.
Skills	• Students can activate and execute all necessary checking routines for verification of proper circuit functionality. • Students are able to run the input desks for definition of their electronic circuits. • Students can define the building blocks of digital systems.
Personal Competence	
Social Competence	• Students are trained to work through complex circuits in teams. • Students are able to share their knowledge for efficient design work. • Students can help each other to understand all the details and options of the design software. • Students are aware of their limitations regarding circuit design, so they do not go ahead, but they involve experts when required. • Students can present their design approaches for easy checking by more experienced experts.
Autonomy	• Students are able to realistically judge the status of their knowledge and to define actions for improvements when necessary. • Students can break down their design work in sub-tasks and can schedule the design work in a realistic way. • Students can handle the complex data structures of their design task and document it in consice but understandable way. • Students are able to judge the amount of work for a major design project.
Workload in Hours	Independent Study Time 152, Study Time in Lecture 28
Credit points	6
Course achievement	None
Examination	Subject theoretical and practical work
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory

Course L0694: Laboratory: Digital Circuit Design	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	6
Workload in Hours	Independent Study Time 152, Study Time in Lecture 28
Lecturer	Prof. Matthias Kuhl
Language	EN
Cycle	SoSe
Content	• Definition of specifications • Architecture studies • Digital simulation flow • Philosophy of standard cells • Placement and routing of standard cells • Layout generation • Design checking routines
Literature	Handouts will be distributed

Module M0761: Semiconductor Technology

Courses

Title	Typ	Hrs/wk	CP
Semiconductor Technology (L0722)	Lecture	4	4
Semiconductor Technology (L0723)	Practical Course	2	2

Module Responsible	Prof. Hoc Khiem Trieu
Admission Requirements	None
Recommended Previous Knowledge	Basics in physics, chemistry, material science and semiconductor devices
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able • to describe and to explain current fabrication techniques for Si and GaAs substrates, • to discuss in details the relevant fabrication processes, process flows and the impact thereof on the fabrication of semiconductor devices and integrated circuits and • to present integrated process flows.
Skills	Students are capable • to analyze the impact of process parameters on the processing results , • to select and to evaluate processes and • to develop process flows for the fabrication of semiconductor devices.
Personal Competence	
Social Competence	Students are able to plan and carry out experiments in groups, as well as present and represent the results in front of others. These social skills are practiced both during the preparation phase, in which the groups work out and present the theory, and during the follow-up phase, in which the groups prepare, document and present their practical experiences.
Autonomy	The independence of the students is demanded and promoted in that they have to transfer and apply what they have learned to ever new boundary conditions. This requirement is communicated at the beginning of the semester and consistently practiced until the exam. Students are encouraged to work independently by not being given a solution, but by learning to work out the solution step by step by asking specific questions. Students learn to ask questions independently when they are faced with a problem. They learn to independently break down problems into manageable sub-problems.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Microelectronics and Microsystems: Core Qualification: Elective Compulsory

Course L0722: Semiconductor Technology	
Typ	Lecture
Hrs/wk	4
CP	4
Workload in Hours	Independent Study Time 64, Study Time in Lecture 56
Lecturer	Prof. Hoc Khiem Trieu
Language	DE/EN
Cycle	SoSe
Content	• Introduction (historical view and trends in microelectronics) • Basics in material science (semiconductor, crystal, Miller indices, crystallographic defects) • Crystal fabrication (crystal pulling for Si and GaAs: impurities, purification, Czochralski , Bridgeman and float zone process) • Wafer fabrication (process flow, specification, SOI) • Fabrication processes • Doping (energy band diagram, doping, doping by alloying, doping by diffusion: transport processes, doping profile, higher order effects and process technology, ion implantation: theory, implantation profile, channeling, implantation damage, annealing and equipment) • Oxidation (silicon dioxide: structure, electrical properties and oxide charges, thermal oxidation: reactions, kinetics, influences on growth rate, process technology and equipment, anodic oxidation, plasma oxidation, thermal oxidation of GaAs) • Deposition techniques (theory: nucleation, film growth and structure zone model, film growth process, reaction kinetics, temperature dependence and equipment; epitaxy: gas phase, liquid phase, molecular beam epitaxy; CVD techniques: APCVD, LPCVD, deposition of metal silicide, PECVD and LECVD; basics of plasma, equipment, PVD techniques: high vacuum evaporation, sputtering) • Structuring techniques (subtractive methods, photolithography: resist properties, printing techniques: contact, proximity and projection printing, resolution limit, practical issues and equipment, additive methods: liftoff technique and electroplating, improving resolution: excimer laser light source, immersion lithography and phase shift lithography, electron beam lithography, X-ray lithography, EUV lithography, ion beam lithography, wet chemical etching: isotropic and anisotropic, corner undercutting, compensation masks and etch stop techniques; dry etching: plasma enhanced etching, backsputtering, ion milling, chemical dry etching, RIE, sidewall passivation) • Process integration (CMOS process, bipolar process) • Assembly and packaging technology (hierarchy of integration, packages, chip-on-board, chip assembly, electrical contact: wire bonding, TAB and flip chip, wafer level package, 3D stacking)
Literature	S.K. Ghandi: VLSI Fabrication principles - Silicon and Gallium Arsenide, John Wiley & Sons S.M. Sze: Semiconductor Devices - Physics and Technology, John Wiley & Sons U. Hilleringmann: Silizium-Halbleitertechnologie, Teubner Verlag H. Beneking: Halbleitertechnologie - Eine Einführung in die Prozeßtechnik von Silizium und III-V-Verbindungen, Teubner Verlag K. Schade: Mikroelektroniktechnologie, Verlag Technik Berlin S. Campbell: The Science and Engineering of Microelectronic Fabrication, Oxford University Press P. van Zant: Microchip Fabrication - A Practical Guide to Semiconductor Processing, McGraw-Hill

Course L0723: Semiconductor Technology	
Typ	Practical Course
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Hoc Khiem Trieu
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0925: Digital Circuit Design

Courses

Title	Typ	Hrs/wk	CP
Digital Circuit Design (L0698)	Lecture	2	3
Advanced Digital Circuit Design (L0699)	Lecture	2	3

Module Responsible	Prof. Matthias Kuhl
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	
Skills	
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	40 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Mechanical Engineering and Management: Specialisation Mechatronics: Elective Compulsory Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L0698: Digital Circuit Design

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Volkhard Klinger
Language	EN
Cycle	WiSe
Content	
Literature	

Course L0699: Advanced Digital Circuit Design

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Volkhard Klinger
Language	EN
Cycle	SoSe
Content	
Literature	

Module M0918: Advanced IC Design

Courses

Title	Typ	Hrs/wk	CP
Advanced IC Design (L0766)	Lecture	2	3
Advanced IC Design (L1057)	Project-/problem-based Learning	2	3

Module Responsible	Prof. Matthias Kuhl
Admission Requirements	None
Recommended Previous Knowledge	Fundamentals of electrical engineering, electronic devices and circuits
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can explain the basic structure of the circuit simulator SPICE. • Students are able to describe the differences between the MOS transistor models of the circuit simulator SPICE. • Students can discuss the different concept for realization the hardware of electronic circuits. • Students can exemplify the approaches for “Design for Testability”. • Students can specify models for calculation of the reliability of electronic circuits.
Skills	• Students can determine the input parameters for the circuit simulation program SPICE. • Students can select the most appropriate MOS modelling approaches for circuit simulations. • Students can quantify the trade-off of different design styles. • Students can determine the lot sizes and costs for reliability analysis.
Personal Competence	
Social Competence	• Students can compile design studies by themselves or together with partners. • Students are able to select the most efficient design methodology for a given task. • Students are able to define the work packages for design teams.
Autonomy	• Students are able to assess the strengths and weaknesses of their design work in a self-contained manner. • Students can name and bring together all the tools required for total design flow.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory Microelectronics and Microsystems: Core Qualification: Elective Compulsory

Course L0766: Advanced IC Design	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Matthias Kuhl
Language	EN
Cycle	SoSe
Content	• Circuit-Simulator SPICE • SPICE-Models for MOS transistors • IC design • Technology of MOS circuits • Standard cell design • Design of gate arrays • CMOS transconductance and transimpedance amplifiers • frequency behavior of CMOS circuits • Techniques for improved circuit behaviour (e.g. cascodes, gain boosting, folding, ...) • Examples for realization of ASICs in the institute of nanoelectronics • Reliability of integrated circuits • Testing of integrated circuits
Literature	R. J. Baker, „CMOS-Circuit Design, Layout, and Simulation“, Wiley & Sons, IEEE Press, 2010 B. Razavi,"Design of Analog CMOS Integrated Circuits", McGraw-Hill Education Ltd, 2000 X. Liu, VLSI-Design Methodology Demystified; IEEE, 2009

Course L1057: Advanced IC Design	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Matthias Kuhl, Weitere Mitarbeiter
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1698: Selected Aspects in Nanoelectronics and Microsystems Technology

Courses

Title	Typ	Hrs/wk	CP
Selected Aspects in Nanoelectronics and Microsystems Technology (L2702)	Lecture	2	4
Selected Aspects in Nanoelectronics and Microsystems Technology (L2703)	Recitation Section (large)	2	2

Module Responsible	Prof. Christian Becker
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	
Skills	
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory

Course L2702: Selected Aspects in Nanoelectronics and Microsystems Technology

Typ	Lecture
Hrs/wk	2
CP	4
Workload in Hours	Independent Study Time 92, Study Time in Lecture 28
Lecturer	Dozenten des SD E
Language	DE/EN
Cycle	WiSe/SoSe
Content	
Literature	

Course L2703: Selected Aspects in Nanoelectronics and Microsystems Technology

Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dozenten des SD E
Language	DE/EN
Cycle	WiSe/SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0644: Optoelectronics II - Quantum Optics

Courses

Title	Typ	Hrs/wk	CP
Optoelectronics II: Quantum Optics (L0360)	Lecture	2	3
Optoelectronics II: Quantum Optics (Problem Solving Course) (L0362)	Recitation Section (small)	1	1

Module Responsible	Dr. Alexander Petrov
Admission Requirements	None
Recommended Previous Knowledge	Basic principles of electrodynamics, optics and quantum mechanics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can explain the fundamental mathematical and physical relations of quantum optical phenomena such as absorption, stimulated and spontanous emission. They can describe material properties as well as technical solutions. They can give an overview on quantum optical components in technical applications.
Skills	Students can generate models and derive mathematical descriptions in relation to quantum optical phenomena and processes. They can derive approximative solutions and judge factors influential on the components' performance.
Personal Competence	
Social Competence	Students can jointly solve subject related problems in groups. They can present their results effectively within the framework of the problem solving course.
Autonomy	Students are capable to extract relevant information from the provided references and to relate this information to the content of the lecture. They can reflect their acquired level of expertise with the help of lecture accompanying measures such as exam typical exam questions. Students are able to connect their knowledge with that acquired from other lectures.
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Credit points	4
Course achievement	None
Examination	Written exam
Examination duration and scale	60 minutes
Assignment for the Following Curricula	Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Materials Science: Specialisation Nano and Hybrid Materials: Elective Compulsory Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory

Course L0360: Optoelectronics II: Quantum Optics

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Alexander Petrov
Language	EN
Cycle	WiSe
Content	• Generation of light • Photons • Thermal and nonthermal light • Laser amplifier • Noise • Optical resonators • Spectral properties of laser light • CW-lasers (gas, solid state, semiconductor) • Pulsed lasers
Literature	Bahaa E. A. Saleh, Malvin Carl Teich, Fundamentals of Photonics, Wiley 2007 Demtröder, W., Laser Spectroscopy: Basic Concepts and Instrumentation, Springer, 2002 Kasap, S.O., Optoelectronics and Photonics: Principles and Practices, Prentice Hall, 2001 Yariv, A., Quantum Electronics, Wiley, 1988 Wilson, J., Hawkes, J., Optoelectronics: An Introduction, Prentice Hall, 1997, ISBN: 013103961X Siegman, A.E., Lasers, University Science Books, 1986

Course L0362: Optoelectronics II: Quantum Optics (Problem Solving Course)	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Dr. Alexander Petrov
Language	EN
Cycle	WiSe
Content	see lecture Optoelectronics 1 - Wave Optics
Literature	see lecture Optoelectronics 1 - Wave Optics

Module M0768: Microsystems Technology in Theory and Practice

Courses

Title	Typ	Hrs/wk	CP
Microsystems Technology (L0724)	Lecture	2	4
Microsystems Technology (L0725)	Project-/problem-based Learning	2	2

Module Responsible	Prof. Hoc Khiem Trieu
Admission Requirements	None
Recommended Previous Knowledge	Basics in physics, chemistry, mechanics and semiconductor technology
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able • to present and to explain current fabrication techniques for microstructures and especially methods for the fabrication of microsensors and microactuators, as well as the integration thereof in more complex systems • to explain in details operation principles of microsensors and microactuators and • to discuss the potential and limitation of microsystems in application.
Skills	Students are capable • to analyze the feasibility of microsystems, • to develop process flows for the fabrication of microstructures and • to apply them.
Personal Competence	
Social Competence	Students are able to plan and carry out experiments in groups, as well as present and represent the results in front of others. These social skills are practiced both during the preparation phase, in which the groups work out and present the theory, and during the follow-up phase, in which the groups prepare, document and present their practical experiences.
Autonomy	The independence of the students is demanded and promoted in that they have to transfer and apply what they have learned to ever new boundary conditions. This requirement is communicated at the beginning of the semester and consistently practiced until the exam. Students are encouraged to work independently by not being given a solution, but by learning to work out the solution step by step by asking specific questions. Students learn to ask questions independently when they are faced with a problem. They learn to independently break down problems into manageable sub-problems.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory**: Yes; **Bonus**: None; **Form**: Subject theoretical and practical work; **Description**: Studierenden führen in Kleingruppen ein Laborpraktikum durch. Jede Gruppe präsentiert und diskutiert die Theorie sowie die Ergebniise ihrer Labortätigkeit. vor dem gesamten Kurs.
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: Elective Compulsory International Management and Engineering: Specialisation II. Mechatronics: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory Microelectronics and Microsystems: Core Qualification: Elective Compulsory

Course L0724: Microsystems Technology	
Typ	Lecture
Hrs/wk	2
CP	4
Workload in Hours	Independent Study Time 92, Study Time in Lecture 28
Lecturer	Prof. Hoc Khiem Trieu
Language	EN
Cycle	WiSe
Content	• Introduction (historical view, scientific and economic relevance, scaling laws) • Semiconductor Technology Basics, Lithography (wafer fabrication, photolithography, improving resolution, next-generation lithography, nano-imprinting, molecular imprinting) • Deposition Techniques (thermal oxidation, epitaxy, electroplating, PVD techniques: evaporation and sputtering; CVD techniques: APCVD, LPCVD, PECVD and LECVD; screen printing) • Etching and Bulk Micromachining (definitions, wet chemical etching, isotropic etch with HNA, electrochemical etching, anisotropic etching with KOH/TMAH: theory, corner undercutting, measures for compensation and etch-stop techniques; plasma processes, dry etching: back sputtering, plasma etching, RIE, Bosch process, cryo process, XeF2 etching) • Surface Micromachining and alternative Techniques (sacrificial etching, film stress, stiction: theory and counter measures; Origami microstructures, Epi-Poly, porous silicon, SOI, SCREAM process, LIGA, SU8, rapid prototyping) • Thermal and Radiation Sensors (temperature measurement, self-generating sensors: Seebeck effect and thermopile; modulating sensors: thermo resistor, Pt-100, spreading resistance sensor, pn junction, NTC and PTC; thermal anemometer, mass flow sensor, photometry, radiometry, IR sensor: thermopile and bolometer) • Mechanical Sensors (strain based and stress based principle, capacitive readout, piezoresistivity, pressure sensor: piezoresistive, capacitive and fabrication process; accelerometer: piezoresistive, piezoelectric and capacitive; angular rate sensor: operating principle and fabrication process) • Magnetic Sensors (galvanomagnetic sensors: spinning current Hall sensor and magneto-transistor; magnetoresistive sensors: magneto resistance, AMR and GMR, fluxgate magnetometer) • Chemical and Bio Sensors (thermal gas sensors: pellistor and thermal conductivity sensor; metal oxide semiconductor gas sensor, organic semiconductor gas sensor, Lambda probe, MOSFET gas sensor, pH-FET, SAW sensor, principle of biosensor, Clark electrode, enzyme electrode, DNA chip) • Micro Actuators, Microfluidics and TAS (drives: thermal, electrostatic, piezo electric and electromagnetic; light modulators, DMD, adaptive optics, microscanner, microvalves: passive and active, micropumps, valveless micropump, electrokinetic micropumps, micromixer, filter, inkjet printhead, microdispenser, microfluidic switching elements, microreactor, lab-on-a-chip, microanalytics) • MEMS in medical Engineering (wireless energy and data transmission, smart pill, implantable drug delivery system, stimulators: microelectrodes, cochlear and retinal implant; implantable pressure sensors, intelligent osteosynthesis, implant for spinal cord regeneration) • Design, Simulation, Test (development and design flows, bottom-up approach, top-down approach, testability, modelling: multiphysics, FEM and equivalent circuit simulation; reliability test, physics-of-failure, Arrhenius equation, bath-tub relationship) • System Integration (monolithic and hybrid integration, assembly and packaging, dicing, electrical contact: wire bonding, TAB and flip chip bonding; packages, chip-on-board, wafer-level-package, 3D integration, wafer bonding: anodic bonding and silicon fusion bonding; micro electroplating, 3D-MID)
Literature	M. Madou: Fundamentals of Microfabrication, CRC Press, 2002 N. Schwesinger: Lehrbuch Mikrosystemtechnik, Oldenbourg Verlag, 2009 T. M. Adams, R. A. Layton:Introductory MEMS, Springer, 2010 G. Gerlach; W. Dötzel: Introduction to microsystem technology, Wiley, 2008

Course L0725: Microsystems Technology	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Hoc Khiem Trieu
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M1527: Research Project and Seminar in Nanoelectronics and Microsystems Technology

Courses				
Title		**Typ**	**Hrs/wk**	**CP**

Module Responsible	Dozenten des SD E
Admission Requirements	None
Recommended Previous Knowledge	Advanced state of knowledge in the electrical engineering master program
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students know current research topics oft institutes engaged in their specialization. They can name the fundamental scientific methods used for doing related reserach. They are furthermore able to use professional language in discussions. They are able to explain research topics.
Skills	Students are capable of completing a small, independent sub-project of currently ongoing research projects in the institutes engaged in their specialization. Students can justify and explain their approach for problem solving, they can draw conclusions from their results, and then can find new ways and methods for their work. Students are capable of comparing and assessing alterantive approaches with their own with regard to given criteria. Students are able to gain knowledge about a new field by themselves. In order to do that they make use of their existing knowledge and try to connect it with the topics of the new field. They close their knowledge gaps by discussing with research assistants and by their own literature and internet search. They are capable of summarizing and presenting scientific publications.
Personal Competence	
Social Competence	Students are able to discuss their work progress with research assistants of the supervising institute . They are capable of presenting their results in front of a professional audience. In cooperation with research assistants students are able to familiarize themselves with and discuss with others current research topics. They are capable of drafting, presenting, and explaining summaries of these topics in English in front of a professional audience.
Autonomy	Based on their competences gained so far students are capable of defining meaningful tasks within ongoing research project for themselves. They are able to develop the necessary understanding and problem solving methods. Students are capable of gathering information from subject related, professional publications and relate that information to the context of the seminar. They are able to find on their own new sources in the Internet. They are able to make a connection with the subject of their chosen specialization.
Workload in Hours	Independent Study Time 360, Study Time in Lecture 0
Credit points	12
Course achievement	None
Examination	Study work
Examination duration and scale	acc. to ASPO
Assignment for the Following Curricula	Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Compulsory

Module M0781: EMC II: Signal Integrity and Power Supply of Electronic Systems

Courses

Title	Typ	Hrs/wk	CP
EMC II: Signal Integrity and Power Supply of Electronic Systems (L0770)	Lecture	3	4
EMC II: Signal Integrity and Power Supply of Electronic Systems (L0771)	Recitation Section (small)	1	1
EMC II: Signal Integrity and Power Supply of Electronic Systems (L0774)	Practical Course	1	1

Module Responsible	Prof. Christian Schuster
Admission Requirements	None
Recommended Previous Knowledge	Fundamentals of electrical engineering
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to explain the fundamental principles, inter-dependencies, and methods of signal and power integrity of electronic systems. They are able to relate signal and power integrity to the context of interference-free design of such systems, i.e. their electromagnetic compatibility. They are capable of explaining the basic behavior of signals and power supply in typical packages and interconnects. They are able to propose and describe problem solving strategies for signal and power integrity issues. They are capable of giving an overview over measurement and simulation methods for characterization of signal and power integrity in electrical engineering practice.
Skills	Students are able to apply a series of modeling methods for characterization of electromagnetic field behavior in packages and interconnect structure of electronic systems. They are able to determine the most important effects that these models are predicting in terms of signal and power integrity. They can classify these effects and they can quantitatively analyze them. They are capable of deriving problem solving strategies from these predictions and they can adapt them to applications in electrical engineering practice. The can evaluate their problem solving strategies against each other.
Personal Competence	
Social Competence	Students are able to work together on subject related tasks in small groups. They are able to present their results effectively in English (e.g. during CAD exercises).
Autonomy	Students are capable to gather necessary information from the references provided and relate that information to the context of the lecture. They are able to make a connection between their knowledge obtained in this lecture with the content of other lectures (e.g. theory of electromagnetic fields, communications, and semiconductor circuit design). They can communicate problems and solutions in the field of signal integrity and power supply of interconnect and packages in English.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** Yes, **Bonus** None, **Form** Presentation, **Description**
Examination	Oral exam
Examination duration and scale	45 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory Electrical Engineering: Specialisation Wireless and Sensor Technologies: Elective Compulsory Mechatronics: Technical Complementary Course: Elective Compulsory Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory

Course L0770: EMC II: Signal Integrity and Power Supply of Electronic Systems	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Christian Schuster
Language	DE/EN
Cycle	WiSe
Content	- The role of packages and interconnects in electronic systems - Components of packages and interconnects in electronic systems - Main goals and concepts of signal and power integrity of electronic systems - Repeat of relevant concepts from the theory electromagnetic fields - Properties of digital signals and systems - Design and characterization of signal integrity - Design and characterization of power supply - Techniques and devices for measurements in time- and frequency-domain - CAD tools for electrical analysis and design of packages and interconnects - Connection to overall electromagnetic compatibility of electronic systems
Literature	- J. Franz, "EMV: Störungssicherer Aufbau elektronischer Schaltungen", Springer (2012) - R. Tummala, "Fundamentals of Microsystems Packaging", McGraw-Hill (2001) - S. Ramo, J. Whinnery, T. Van Duzer, "Fields and Waves in Communication Electronics", Wiley (1994) - S. Thierauf, "Understanding Signal Integrity", Artech House (2010) - M. Swaminathan, A. Engin, "Power Integrity Modeling and Design for Semiconductors and Systems", Prentice-Hall (2007)

Course L0771: EMC II: Signal Integrity and Power Supply of Electronic Systems	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Christian Schuster
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Course L0774: EMC II: Signal Integrity and Power Supply of Electronic Systems	
Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Christian Schuster
Language	DE/EN
Cycle	WiSe
Content	- The role of packages and interconnects in electronic systems - Components of packages and interconnects in electronic systems - Main goals and concepts of signal and power integrity of electronic systems - Repeat of relevant concepts from the theory electromagnetic fields - Properties of digital signals and systems - Design and characterization of signal integrity - Design and characterization of power supply - Techniques and devices for measurements in time- and frequency-domain - CAD tools for electrical analysis and design of packages and interconnects - Connection to overall electromagnetic compatibility of electronic systems
Literature	- J. Franz, "EMV: Störungssicherer Aufbau elektronischer Schaltungen", Springer (2012) - R. Tummala, "Fundamentals of Microsystems Packaging", McGraw-Hill (2001) - S. Ramo, J. Whinnery, T. Van Duzer, "Fields and Waves in Communication Electronics", Wiley (1994) - S. Thierauf, "Understanding Signal Integrity", Artech House (2010) - M. Swaminathan, A. Engin, "Power Integrity Modeling and Design for Semiconductors and Systems", Prentice-Hall (2007)

Module M1048: Integrated Circuit Design

Courses

Title	Typ	Hrs/wk	CP
Integrated Circuit Design (L0691)	Lecture	3	4
Integrated Circuit Design (L0998)	Recitation Section (small)	1	2

Module Responsible	NN
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge of (solid-state) physics and mathematics. Knowledge in fundamentals of electrical engineering and electrical networks.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can explain basic concepts of electron transport in semiconductor devices (energy bands, generation/recombination, carrier concentrations, drift and diffusion current densities, semiconductor device equations). • Students are able to explain functional principles of pn-diodes, MOS capacitors, and MOSFETs using energy band diagrams. • Students can present and discuss current-voltage relationships and small-signal equivalent circuits of these devices. • Students can explain the physics and current-voltage behavior transistors based on charged carrier flow. • Students are able to explain the basic concepts for static and dynamic logic gates for integrated circuits • Students can exemplify approaches for low power consumption on the device and circuit level • Students can describe the potential and limitations of analytical expression for device and circuit analysis. • Students can explain characterization techniques for MOS devices.
Skills	• Students can qualitatively construct energy band diagrams of the devices for varying applied voltages. • Students are able to qualitatively determine electric field, carrier concentrations, and charge flow from energy band diagrams. • Students can understand scientific publications from the field of semiconductor devices. • Students can calculate the dimensions of MOS devices in dependence of the circuits properties • Students can design complex electronic circuits and anticipate possible problems. • Students know procedure for optimization regarding high performance and low power consumption
Personal Competence	
Social Competence	• Students can team up with other experts in the field to work out innovative solutions. • Students are able to work by their own or in small groups for solving problems and answer scientific questions. • Students have the ability to critically question the value of their contributions to working groups.
Autonomy	• Students are able to assess their knowledge in a realistic manner. • Students are able to define their personal approaches to solve challenging problems
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory International Management and Engineering: Specialisation II. Electrical Engineering: Elective Compulsory Mechanical Engineering and Management: Specialisation Mechatronics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Microelectronics and Microsystems: Core Qualification: Elective Compulsory

Course L0691: Integrated Circuit Design	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Matthias Kuhl
Language	EN
Cycle	WiSe
Content	• Electron transport in semiconductors • Electronic operating principles of diodes, MOS capacitors, and MOS field-effect transistors • MOS transistor as four terminal device • Performace degradation due to short channel effects • Scaling-down of MOS technology • Digital logic circuits • Basic analog circuits • Operational amplifiers • Bipolar and BiCMOS circuits
Literature	• Yuan Taur, Tak H. Ning: Fundamentals of Modern VLSI Devices, Cambridge University Press 1998 • R. Jacob Baker: CMOS, Circuit Design, Layout and Simulation, IEEE Press, Wiley Interscience, 3rd Edition, 2010 • Neil H.E. Weste and David Money Harris, Integrated Circuit Design, Pearson, 4th International Edition, 2013 • John E. Ayers, Digital Integrated Circuits: Analysis and Design, CRC Press, 2009 • Richard C. Jaeger and Travis N. Blalock: Microelectronic Circuit Design, Mc Graw-Hill, 4rd. Edition, 2010

Course L0998: Integrated Circuit Design	
Typ	Recitation Section (small)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Matthias Kuhl
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M1589: Laboratory: Analog Circuit Design

Courses

Title	Typ	Hrs/wk	CP
Laboratory: Analog Circuit Design (L0692)	Project-/problem-based Learning	2	6

Module Responsible	NN
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge of semiconductor devices and circuit design
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can explain the structure and philosophy of the software framework for circuit design. • Students can determine all necessary input parameters for circuit simulation. • Students know the basics physics of the analog behavior. • Students can explain the algorithms of circuit verification. • Students are able to select the appropriate transistor models for fast and accurate simulations.
Skills	• Students can activate and execute all necessary checking routines for verification of proper circuit functionality. • Students can define the specifications of the electronic circuits to be designed. • Students can optimize the electronic circuits for low-noise and low-power. • Students can develop analog circuits for specific applications.
Personal Competence	
Social Competence	• Students are trained to work through complex circuits in teams. • Students are able to share their knowledge for efficient design work. • Students can help each other to understand all the details and options of the design software. • Students are aware of their limitations regarding circuit design, so they do not go ahead, but they involve experts when required. • Students can present their design approaches for easy checking by more experienced experts.
Autonomy	• Students are able to realistically judge the status of their knowledge and to define actions for improvements when necessary. • Students can break down their design work in sub-tasks and can schedule the design work in a realistic way. • Students can handle the complex data structures of their design task and document it in consice but understandable way. • Students are able to judge the amount of work for a major design project.
Workload in Hours	Independent Study Time 152, Study Time in Lecture 28
Credit points	6
Course achievement	None
Examination	Subject theoretical and practical work
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory

Course L0692: Laboratory: Analog Circuit Design	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	6
Workload in Hours	Independent Study Time 152, Study Time in Lecture 28
Lecturer	Prof. Matthias Kuhl, Weitere Mitarbeiter
Language	EN
Cycle	WiSe
Content	• Input desk for circuits • Algorithms for simulation • MOS transistor model • Simulation of analog circuits • Placement and routing • Generation of layouts • Design checking routines • Postlayout simulations
Literature	Handouts to be distributed

Module M0913: Mixed-signal Circuit Design

Courses

Title	Typ	Hrs/wk	CP
Mixed-signal Circuit Design (L0764)	Lecture	2	3
Mixed-signal Circuit Design (L1063)	Project-/problem-based Learning	2	3

Module Responsible	NN
Admission Requirements	None
Recommended Previous Knowledge	Advanced knowledge of analog or digital MOS devices and circuits
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can explain the descriptive parameters of mixed-signal systems • Students can explain various architectures of analog-to-digital and digital-to-analog converters • Students are able to explain the fundamental limitations of different analog-to-digital and digital-to-analog converters
Skills	• Students can derive the fundamental limitations of different analog-to-digital and digital-to-analog converters • Students can select the most suitable architecture for a specific mixed-signal task • Students can describe complex mixed-signal systems by their functional blocks. • Students can calculate the specifications of mixed-signal circuits
Personal Competence	
Social Competence	• Students can team up with one or several partners who may have different professional backgrounds • Students are able to work by their own or in small groups for solving problems and answer scientific questions.
Autonomy	• Students are able to assess their knowledge in a realistic manner. • Students are able to draw scenarios for estimation of the impact of an increase of data vs. an increase of energy on the future lifestyle of the society.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** 5 %; **Form** Subject theoretical and practical work; **Description**
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory

Course L0764: Mixed-signal Circuit Design

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Matthias Kuhl
Language	EN
Cycle	WiSe
Content	• Differences between analog and digital filtering of electrical signals • Quantization error and its consideration in electrical circuits • Architectures of state-of-the-art digital-to-analog converters • Architectures of state-of-the-art analog-to-digital converters • Differentiation between Nyquist and oversampling converters • noise in ADCs and DACs
Literature	• R. J. Baker, „CMOS-Circuit Design, Layout, and Simulation“, Wiley & Sons, IEEE Press, 2010 • B. Razavi,"Design of Analog CMOS Integrated Circuits", McGraw-Hill Education Ltd, 2000

Course L1063: Mixed-signal Circuit Design	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Matthias Kuhl
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M1749: Energy Efficiency in Embedded Systems

Courses

Title	Typ	Hrs/wk	CP
Energy Efficiency in Embedded Systems (L2870)	Lecture	2	3
Energy Efficiency in Embedded Systems (L2872)	Project-/problem-based Learning	2	2
Energy Efficiency in Embedded Systems (L2871)	Recitation Section (large)	1	1

Module Responsible	Prof. Ulf Kulau
Admission Requirements	None
Recommended Previous Knowledge	• Computer Engineering (mandatory) • Programming Skills in C (mandatory) • Computer Architecture (recommended)
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	**Motivation:** In the field of computer science we have only limited possibilities to influence the efficiency of the hardware directly, respectively we are dependent on the manufacturers (e.g. of microcontrollers). However, in order to exploit the full potential of the hardware we are given at the system level, we need a deeper understanding of the background, processes and mechanisms of power dissipation in embedded systems. Where does the power dissipation come from, what happens at the hardware level, what mechanisms can I use directly/indirectly, what is the tradeoff between flexibility and efficiency,.... are only a few questions, which will be elaborated and discussed in this event. **Contents of teaching:** • Motivation and power dissipation on semiconductor level • Power dissipation of digital circuits, inparticular CMOS • Power Management in Hard- and Software (Sleep Modes, DVS, FS, Undervolting) • Energy efficient system design (applications) • Energy Harvesting and Transiently Powered Computing (TPC)
Skills	Upon completion of this module, students will have a deeper understanding of hardware and software mechanisms for evaluating and developing energy-efficient embedded systems • They have a deeper understanding of the electrotechnical basics of power dissipation in digital systems • They can analyze the power dissipation of systems at any level and apply appropriate methods to increase efficiency • They can use a variety of standard techniques to achieve "Energy Efficiency by Design" • They can model, evaluate as well as implement energy-autonomous systems
Personal Competence	
Social Competence	As part of the module, concepts learned in the lecture will be implemented on a hardware platform within small groups. Students learn to work in a team and to develop solutions together. Specific tasks are worked on within the group, whereby cross-group collaboration (exchange) also takes place. The second part is a challenge-based project in which the groups find the most energy-efficient solutions possible in healthy competition with each other. This strengthens the cohesion in the groups and reinforces mutual motivation, support and creativity.
Autonomy	After completing this module, students will be able to independently develop, optimize and evaluate solutions for embedded systems based on the knowledge they have acquired and further technical literature.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Electrical Engineering: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory Electrical Engineering: Specialisation Wireless and Sensor Technologies: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L2870: Energy Efficiency in Embedded Systems	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Ulf Kulau
Language	DE/EN
Cycle	WiSe
Content	**Motivation:** In the field of computer science we have only limited possibilities to influence the efficiency of the hardware directly, respectively we are dependent on the manufacturers (e.g. of microcontrollers). However, in order to exploit the full potential of the hardware we are given at the system level, we need a deeper understanding of the background, processes and mechanisms of power dissipation in embedded systems. Where does the power dissipation come from, what happens at the hardware level, what mechanisms can I use directly/indirectly, what is the tradeoff between flexibility and efficiency,.... are only a few questions, which will be elaborated and discussed in this event. **Contents of teaching:** • Motivation and power dissipation on semiconductor level • Power dissipation of digital circuits, inparticular CMOS • Power Management in Hard- and Software (Sleep Modes, DVS, FS, Undervolting) • Energy efficient system design (applications) • Energy Harvesting and Transiently Powered Computing (TPC)
Literature	DE: Die Vorlesung basiert af einer Vielzahl von Quellen, welche in [1.] angegeben sind. ENG: The lecture is based on multiple sources which are listed in [1.]. 1. Kulau, Ulf: **Course: Energy Efficiency in Embedded Systems-A System-Level Perspective for Computer Scientists**, EWME, 2018. 2. Harris, David, and N. Weste: **CMOS VLSI Design** ed., Pearson Education, 2010 3. Rabaey, Jan: **Low Power Design Essentials** (Integrated Circuits and Systems), Springer, 2009

Course L2872: Energy Efficiency in Embedded Systems	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Ulf Kulau
Language	DE/EN
Cycle	WiSe
Content	In this project-based exercise, the learned aspects for achieving energy-efficient embedded systems are implemented and consolidated in practical environments in a small project. First, a tool set for the implementation of energy efficiency mechanisms is implemented in common exercises by means of defined tasks. In the second part, a challenge-based exercise is carried out in which a system that is as efficient as possible is to be implemented independently. A system based on an AVR micro-controller is used, which can be operated autonomously by a Solar-Energy Harvester. 1. Task phase: 6 "hands-on" tasks to gain experience and to create a SW library. 2. Project phase: Implementation of an energy autonomous system with the goal of highest possible energy efficiency (Challenge)
Literature	

Course L2871: Energy Efficiency in Embedded Systems	
Typ	Recitation Section (large)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Ulf Kulau
Language	DE/EN
Cycle	WiSe
Content	In the lecture hall exercise, the theoertical basics taught in the lecture are deepened. This is done through in-depth discussion of relevant aspects, but also through calculation examples, in which a deeper understanding of the topic of energy efficiency in embedded systems is gained. Exercises will be distributed in advance and solutions will be presented in the lecture hall exercise. Contents of the exercise are as follows: • Basics and calculation of power dissipation on semiconductor • Power dissipation of CMOS using the example of an inverter • Influence of the activity factor and external components • DVS and scheduling • Evaluation to show the benefit of undervolting • Aspects of energy harvesting (MPPT) •
Literature	

Specialization Control and Power Systems Engineering

This specialization offers a wide range of topics with respect to various concepts of control and electric power systems, process measurement, robotics, communication networks and digital signal processing.

Students are enabled to analyze, to model and to simulate complex dynamical systems like electric power systems. Moreover, they acquire a profound knowledge about various methods to monitor and control complex systems and to specifically influence their dynamic behavior. In addition, they are able to understand information systems and their recent technologies used in electrical power engineering and develop innovative approaches for smart grids.

As a result, the students will have the skills to entirely analyze, design and optimize all aspects of control and electric power systems. In today's age of increasing digitalization, automation and communication within many branches of industry especially towards a sustainable electrical power supply, this expertise is of outstanding importance for positions in industry and academia.

Module M0692: Approximation and Stability

Courses

Title	Typ	Hrs/wk	CP
Approximation and Stability (L0487)	Lecture	3	4
Approximation and Stability (L0488)	Recitation Section (small)	1	2

Module Responsible	Prof. Marko Lindner
Admission Requirements	None
Recommended Previous Knowledge	• Linear Algebra: systems of linear equations, least squares problems, eigenvalues, singular values • Analysis: sequences, series, differentiation, integration
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to • sketch and interrelate basic concepts of functional analysis (Hilbert space, operators), • name and understand concrete approximation methods, • name and explain basic stability theorems, • discuss spectral quantities, conditions numbers and methods of regularisation
Skills	Students are able to • apply basic results from functional analysis, • apply approximation methods, • apply stability theorems, • compute spectral quantities, • apply regularisation methods.
Personal Competence	
Social Competence	Students are able to solve specific problems in groups and to present their results appropriately (e.g. as a seminar presentation).
Autonomy	• Students are capable of checking their understanding of complex concepts on their own. They can specify open questions precisely and know where to get help in solving them. • Students have developed sufficient persistence to be able to work for longer periods in a goal-oriented manner on hard problems.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** None; **Form** Presentation; **Description**
Examination	Oral exam
Examination duration and scale	20 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Technomathematics: Specialisation I. Mathematics: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L0487: Approximation and Stability	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Marko Lindner
Language	DE/EN
Cycle	SoSe
Content	This course is about solving the following basic problems of Linear Algebra, • systems of linear equations, • least squares problems, • eigenvalue problems but now in function spaces (i.e. vector spaces of infinite dimension) by a stable approximation of the problem in a space of finite dimension. **Contents:** • crash course on Hilbert spaces: metric, norm, scalar product, completeness • crash course on operators: boundedness, norm, compactness, projections • uniform vs. strong convergence, approximation methods • applicability and stability of approximation methods, Polski's theorem • Galerkin methods, collocation, spline interpolation, truncation • convolution and Toeplitz operators • crash course on C*-algebras • convergence of condition numbers • convergence of spectral quantities: spectrum, eigen values, singular values, pseudospectra • regularisation methods (truncated SVD, Tichonov)
Literature	• R. Hagen, S. Roch, B. Silbermann: C*-Algebras in Numerical Analysis • H. W. Alt: Lineare Funktionalanalysis • M. Lindner: Infinite matrices and their finite sections

Course L0488: Approximation and Stability	
Typ	Recitation Section (small)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Marko Lindner
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0838: Linear and Nonlinear System Identifikation

Courses

Title	Typ	Hrs/wk	CP
Linear and Nonlinear System Identification (L0660)	Lecture	2	3

Module Responsible	Prof. Herbert Werner
Admission Requirements	None
Recommended Previous Knowledge	• Classical control (frequency response, root locus) • State space methods • Discrete-time systems • Linear algebra, singular value decomposition • Basic knowledge about stochastic processes
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can explain the general framework of the prediction error method and its application to a variety of linear and nonlinear model structures • They can explain how multilayer perceptron networks are used to model nonlinear dynamics • They can explain how an approximate predictive control scheme can be based on neural network models • They can explain the idea of subspace identification and its relation to Kalman realisation theory
Skills	• Students are capable of applying the predicition error method to the experimental identification of linear and nonlinear models for dynamic systems • They are capable of implementing a nonlinear predictive control scheme based on a neural network model • They are capable of applying subspace algorithms to the experimental identification of linear models for dynamic systems • They can do the above using standard software tools (including the Matlab System Identification Toolbox)
Personal Competence	
Social Competence	Students can work in mixed groups on specific problems to arrive at joint solutions.
Autonomy	Students are able to find required information in sources provided (lecture notes, literature, software documentation) and use it to solve given problems.
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Credit points	3
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Theoretical Mechanical Engineering: Core Qualification: Elective Compulsory

Course L0660: Linear and Nonlinear System Identification

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Herbert Werner
Language	EN
Cycle	SoSe
Content	• Prediction error method • Linear and nonlinear model structures • Nonlinear model structure based on multilayer perceptron network • Approximate predictive control based on multilayer perceptron network model • Subspace identification
Literature	• Lennart Ljung, System Identification - Theory for the User, Prentice Hall 1999 • M. Norgaard, O. Ravn, N.K. Poulsen and L.K. Hansen, Neural Networks for Modeling and Control of Dynamic Systems, Springer Verlag, London 2003 • T. Kailath, A.H. Sayed and B. Hassibi, Linear Estimation, Prentice Hall 2000

Module M0840: Optimal and Robust Control

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Optimal and Robust Control (L0658)	Lecture	2	3
Optimal and Robust Control (L0659)	Recitation Section (small)	2	3

Module Responsible	Prof. Herbert Werner
Admission Requirements	None
Recommended Previous Knowledge	• Classical control (frequency response, root locus) • State space methods • Linear algebra, singular value decomposition
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can explain the significance of the matrix Riccati equation for the solution of LQ problems. • They can explain the duality between optimal state feedback and optimal state estimation. • They can explain how the H2 and H-infinity norms are used to represent stability and performance constraints. • They can explain how an LQG design problem can be formulated as special case of an H2 design problem. • They can explain how model uncertainty can be represented in a way that lends itself to robust controller design • They can explain how - based on the small gain theorem - a robust controller can guarantee stability and performance for an uncertain plant. • They understand how analysis and synthesis conditions on feedback loops can be represented as linear matrix inequalities.
Skills	• Students are capable of designing and tuning LQG controllers for multivariable plant models. • They are capable of representing a H2 or H-infinity design problem in the form of a generalized plant, and of using standard software tools for solving it. • They are capable of translating time and frequency domain specifications for control loops into constraints on closed-loop sensitivity functions, and of carrying out a mixed-sensitivity design. • They are capable of constructing an LFT uncertainty model for an uncertain system, and of designing a mixed-objective robust controller. • They are capable of formulating analysis and synthesis conditions as linear matrix inequalities (LMI), and of using standard LMI-solvers for solving them. • They can carry out all of the above using standard software tools (Matlab robust control toolbox).
Personal Competence	
Social Competence	Students can work in small groups on specific problems to arrive at joint solutions.
Autonomy	Students are able to find required information in sources provided (lecture notes, literature, software documentation) and use it to solve given problems.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Energy Systems: Core Qualification: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Product Development, Materials and Production: Specialisation Product Development: Elective Compulsory Product Development, Materials and Production: Specialisation Production: Elective Compulsory Product Development, Materials and Production: Specialisation Materials: Elective Compulsory Theoretical Mechanical Engineering: Core Qualification: Elective Compulsory

Course L0658: Optimal and Robust Control	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Herbert Werner
Language	EN
Cycle	SoSe
Content	• Optimal regulator problem with finite time horizon, Riccati differential equation • Time-varying and steady state solutions, algebraic Riccati equation, Hamiltonian system • Kalman's identity, phase margin of LQR controllers, spectral factorization • Optimal state estimation, Kalman filter, LQG control • Generalized plant, review of LQG control • Signal and system norms, computing H2 and H∞ norms • Singular value plots, input and output directions • Mixed sensitivity design, H∞ loop shaping, choice of weighting filters • Case study: design example flight control • Linear matrix inequalities, design specifications as LMI constraints (H2, H∞ and pole region) • Controller synthesis by solving LMI problems, multi-objective design • Robust control of uncertain systems, small gain theorem, representation of parameter uncertainty
Literature	• Werner, H., Lecture Notes: "Optimale und Robuste Regelung" • Boyd, S., L. El Ghaoui, E. Feron and V. Balakrishnan "Linear Matrix Inequalities in Systems and Control", SIAM, Philadelphia, PA, 1994 • Skogestad, S. and I. Postlewhaite "Multivariable Feedback Control", John Wiley, Chichester, England, 1996 • Strang, G. "Linear Algebra and its Applications", Harcourt Brace Jovanovic, Orlando, FA, 1988 • Zhou, K. and J. Doyle "Essentials of Robust Control", Prentice Hall International, Upper Saddle River, NJ, 1998

Course L0659: Optimal and Robust Control	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Herbert Werner
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0714: Numerical Methods for Ordinary Differential Equations

Courses

Title	Typ	Hrs/wk	CP
Numerical Treatment of Ordinary Differential Equations (L0576)	Lecture	2	3
Numerical Treatment of Ordinary Differential Equations (L0582)	Recitation Section (small)	2	3

Module Responsible	Prof. Daniel Ruprecht
Admission Requirements	None
Recommended Previous Knowledge	• Mathematik I, II, III für Ingenieurstudierende (deutsch oder englisch) oder Analysis & Lineare Algebra I + II sowie Analysis III für Technomathematiker • Basic knowledge of MATLAB, Python or a similar programming language
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to • list numerical methods for the solution of ordinary differential equations and explain their core ideas, • formulate convergence statements for the treated numerical methods (including the assumptions about the underlying problem), • explain aspects regarding the practical realisation of a method. • select the appropriate numerical method for concrete problems, implement the numerical algorithms efficiently and interpret the numerical results
Skills	Students are able to • implement, apply and compare numerical methods for the solution of ordinary differential equations, • justify the convergence behaviour of numerical methods with respect to the posed problem and selected algorithm, • develop a suitable solution approach for a given problem, if necessary by combining of several algorithms, and to realise this approach and critically evaluate the results.
Personal Competence	
Social Competence	Students are able to • work together in heterogeneously composed teams (i.e., teams from different study programs and background knowledge), explain theoretical foundations and support each other with practical aspects regarding the implementation of algorithms.
Autonomy	Students are capable • to assess whether the supporting theoretical and practical excercises are better solved individually or in a team, • to assess their individual progress and, if necessary, to ask questions and seek help.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory Computer Science: Specialisation III. Mathematics: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Energy Systems: Core Qualification: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory Interdisciplinary Mathematics: Specialisation II. Numerical - Modelling Training: Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Technomathematics: Specialisation I. Mathematics: Elective Compulsory Theoretical Mechanical Engineering: Core Qualification: Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L0576: Numerical Treatment of Ordinary Differential Equations	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Daniel Ruprecht
Language	DE/EN
Cycle	SoSe
Content	Numerical methods for Initial Value Problems • single step methods • multistep methods • stiff problems • differential algebraic equations (DAE) of index 1 Numerical methods for Boundary Value Problems • multiple shooting method • difference methods
Literature	• E. Hairer, S. Noersett, G. Wanner: Solving Ordinary Differential Equations I: Nonstiff Problems. • E. Hairer, G. Wanner: Solving Ordinary Differential Equations II: Stiff and Differential-Algebraic Problems. • D. Griffiths, D. Higham: Numerical Methods for Ordinary Differential Equations.

Course L0582: Numerical Treatment of Ordinary Differential Equations	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Daniel Ruprecht
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1236: Electrical Power Systems III: Dynamics and Stability of Electrical Power Systems

Courses

Title	Typ	Hrs/wk	CP
Electrical Power Systems III: Dynamics and Stability of Electrical Power Systems (L1683)	Lecture	3	4
Electrical Power Systems III: Dynamics and Stability of Electrical Power Systems (L1684)	Recitation Section (large)	2	2

Module Responsible	Prof. Christian Becker
Admission Requirements	None
Recommended Previous Knowledge	Fundamentals of Electrical Engineering, Introduction to Control Systems, Mathematics I, II, III Electrical Power Systems I, II
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to explain in detail and critically evaluate methods for modelling, control and stability analyses of electric power systems.
Skills	With completion of this module the students are able to calculate and analyze the dynamic bahaviour and stability of real electric power systems using appropriate models. They are furthermore able to design voltage and load frequency controllers.
Personal Competence	
Social Competence	The students can participate in specialized and interdisciplinary discussions, advance ideas and represent their own work results in front of others.
Autonomy	Students can independently tap knowledge of the emphasis of the lectures and apply it within further research activities.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 - 60 Minuten
Assignment for the Following Curricula	Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory

Course L1683: Electrical Power Systems III: Dynamics and Stability of Electrical Power Systems

Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Christian Becker
Language	DE
Cycle	SoSe

Content	• modelling of electric power system for dynamics and stability
	• small-signal angle stability
	  ◦ single-machine infinite-bus problem
	  ◦ multi-machine problem
	• transient angle stability
	  ◦ direct-quadrature-zero transformation
	  ◦ equal-area criterion
	  ◦ Ljapunov stability analysis
	  ◦ multi-machine problem
	• dynamical simulation
	  ◦ basics
	  ◦ numerical integration
	• frequency control
	  ◦ island systems
	  ◦ load-frequency control
	  ◦ grid control structures, energy exchange
	• voltage control
	• voltage stability
	• power system dynamics and control with FACTS and HVDC

Literature	E. Handschin: Elektrische Energieübertragungssysteme, Hüthig Verlag P. Kundur: Power System Stability and Control, McGraw-Hill, 1994

Course L1684: Electrical Power Systems III: Dynamics and Stability of Electrical Power Systems	
Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Christian Becker
Language	DE
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0932: Process Measurement Engineering

Courses

Title	Typ	Hrs/wk	CP
Process Measurement Engineering (L1077)	Lecture	2	3
Process Measurement Engineering (L1083)	Recitation Section (large)	1	1

Module Responsible	Prof. Roland Harig
Admission Requirements	None
Recommended Previous Knowledge	Fundamental principles of electrical engineering and measurement technology
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students possess an understanding of complex, state-of-the-art process measurement equipment. They can relate devices and procedures to a variety of commonly used measurement and communications technology.
Skills	The students are capable of modeling and evaluating complex systems of sensing devices as well as associated communications systems. An emphasis is placed on a system-oriented understanding of the measurement equipment.
Personal Competence	
Social Competence	Students can communicate the discussed technologies using the English language.
Autonomy	Students are capable of gathering necessary information from provided references and relate this information to the lecture. They are able to continually reflect their knowledge by means of activities that accompany the lecture. Based on respective feedback, students are expected to adjust their individual learning process. They are able to draw connections between their knowledge obtained in this lecture and the content of other lectures (e.g. Fundamentals of Electrical Engineering, Analysis, Stochastic Processes, Communication Systems).
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Credit points	4
Course achievement	None
Examination	Oral exam
Examination duration and scale	45 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Renewable Energies: Specialisation Solar Energy Systems: Elective Compulsory

Course L1077: Process Measurement Engineering	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Roland Harig
Language	DE/EN
Cycle	SoSe
Content	• Process measurement engineering in the context of process control engineering ∘ Challenges of process measurement engineering ∘ Instrumentation of processes ∘ Classification of pickups • Systems theory in process measurement engineering ∘ Generic linear description of pickups ∘ Mathematical description of two-port systems ∘ Fourier and Laplace transformation • Correlational measurement ∘ Wide band signals ∘ Auto- and cross-correlation function and their applications ∘ Fault-free operation of correlational methods • Transmission of analog and digital measurement signals ∘ Modulation process (amplitude and frequency modulation) ∘ Multiplexing ∘ Analog to digital converter
Literature	- Färber: „Prozeßrechentechnik“, Springer-Verlag 1994 - Kiencke, Kronmüller: „Meßtechnik“, Springer Verlag Berlin Heidelberg, 1995 - A. Ambardar: „Analog and Digital Signal Processing“ (1), PWS Publishing Company, 1995, NTC 339 - A. Papoulis: „Signal Analysis“ (1), McGraw-Hill, 1987, NTC 312 (LB) - M. Schwartz: „Information Transmission, Modulation and Noise“ (3,4), McGraw-Hill, 1980, 2402095 - S. Haykin: „Communication Systems“ (1,3), Wiley&Sons, 1983, 2419072 - H. Sheingold: „Analog-Digital Conversion Handbook“ (5), Prentice-Hall, 1986, 2440072 - J. Fraden: „AIP Handbook of Modern Sensors“ (5,6), American Institute of Physics, 1993, MTB 346

Course L1083: Process Measurement Engineering	
Typ	Recitation Section (large)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Roland Harig
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0939: Control Lab A

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Control Lab I (L1093)	Practical Course	1	1
Control Lab II (L1291)	Practical Course	1	1
Control Lab III (L1665)	Practical Course	1	1
Control Lab IV (L1666)	Practical Course	1	1

Module Responsible	Prof. Herbert Werner
Admission Requirements	None
Recommended Previous Knowledge	• State space methods • LQG control • H2 and H-infinity optimal control • uncertain plant models and robust control • LPV control
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can explain the difference between validation of a control lop in simulation and experimental validation
Skills	• Students are capable of applying basic system identification tools (Matlab System Identification Toolbox) to identify a dynamic model that can be used for controller synthesis • They are capable of using standard software tools (Matlab Control Toolbox) for the design and implementation of LQG controllers • They are capable of using standard software tools (Matlab Robust Control Toolbox) for the mixed-sensitivity design and the implementation of H-infinity optimal controllers • They are capable of representing model uncertainty, and of designing and implementing a robust controller • They are capable of using standard software tools (Matlab Robust Control Toolbox) for the design and the implementation of LPV gain-scheduled controllers
Personal Competence	
Social Competence	• Students can work in teams to conduct experiments and document the results
Autonomy	• Students can independently carry out simulation studies to design and validate control loops
Workload in Hours	Independent Study Time 64, Study Time in Lecture 56
Credit points	4
Course achievement	None
Examination	Written elaboration
Examination duration and scale	1
Assignment for the Following Curricula	Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L1093: Control Lab I

Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Herbert Werner, Adwait Datar, Patrick Göttsch
Language	EN
Cycle	WiSe/SoSe
Content	One of the offered experiments in control theory.
Literature	Experiment Guides

Course L1291: Control Lab II	
Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Herbert Werner, Adwait Datar, Patrick Göttsch
Language	EN
Cycle	WiSe/SoSe
Content	One of the offered experiments in control theory.
Literature	Experiment Guides

Course L1665: Control Lab III	
Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Herbert Werner, Adwait Datar, Patrick Göttsch
Language	EN
Cycle	WiSe/SoSe
Content	One of the offered experiments in control theory.
Literature	Experiment Guides

Course L1666: Control Lab IV	
Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Herbert Werner, Adwait Datar, Patrick Göttsch
Language	EN
Cycle	WiSe/SoSe
Content	One of the offered experiments in control theory.
Literature	Experiment Guides

Module M1425: Power electronics

Courses

Title	Typ	Hrs/wk	CP
Power electronics (L2053)	Lecture	2	4
Power electronics (L2054)	Recitation Section (small)	2	2

Module Responsible	Prof. Martin Kaltschmitt
Admission Requirements	None
Recommended Previous Knowledge	Basics of Electrical Engineering
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students are taught the basics of power converter technology and modern power electronics. Furthermore, the essential properties of conventional and modern power semiconductors will be presented and their driving techniques will be presented. The students also learn about the most important circuit topologies of self-commutated power converters and their control methods.
Skills	In addition to the basics of power converter commutation, the students learn methods for determining the on-state and switching losses of the components. Using simple examples, the participants will learn methods for the mathematical description of the transmission behavior of power electronic circuits.
Personal Competence	
Social Competence	Students will be able to discuss problems in related topics in the field of photovoltaics and power electronics with fellow students.
Autonomy	The students can independently access sources based on the main topics of the lectures and transfer the acquired knowledge to a wider field
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	120 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Renewable Energies: Specialisation Solar Energy Systems: Elective Compulsory

Course L2053: Power electronics

Typ	Lecture
Hrs/wk	2
CP	4
Workload in Hours	Independent Study Time 92, Study Time in Lecture 28
Lecturer	Prof. Klaus Hoffmann
Language	DE
Cycle	SoSe
Content	- Fundamentals of power electronics - Classification of the power converters according to their internal and external mode of operation - Presentation of modern converter systems - Introduction of power semiconductors - Fields of application and limits of use of modern power semiconductors - Power diodes and conventional power semiconductors (thyristor and GTO) - Modern power semiconductors: power MOSFET, IGBT and IGCT - On-state and switching losses - Commutation processes in modern power converter circuits - Development trends in the field of power semiconductors - Introduction to self-commutated converter circuits - DC converter with turn-off power semiconductors - Control method (pulse width modulation, tolerance band control) - H-bridge topology with modern turn-off power semiconductors in clocked inverter and rectifier operation - Three-phase bridge circuit with modern turn-off power semiconductors - Brief introduction to the line-commutated converter circuits
Literature	Hilfsblätter und Literaturhinweise werden im Rahmen der Vorlesung ausgeteilt.

Course L2054: Power electronics	
Typ	Recitation Section (small)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Klaus Hoffmann
Language	DE
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0845: Feedback Control in Medical Technology

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Feedback Control in Medical Technology (L0664)	Lecture	2	3

Module Responsible	Johannes Kreuzer
Admission Requirements	None
Recommended Previous Knowledge	Basics in Control, Basics in Physiology
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The lecture will introduce into the fascinating area of medical technology with the engineering point of view. Fundamentals in human physiology will be similarly introduced like knowledge in control theory. Internal control loops of the human body will be discussed in the same way like the design of external closed loop system fo example in for anesthesia control. The handling of PID controllers and modern controller like predictive controller or fuzzy controller or neural networks will be illustrated. The operation of simple equivalent circuits will be discussed.
Skills	Application of modeling, identification, control technology in the field of medical technology.
Personal Competence	
Social Competence	Students can develop solutions to specific problems in small groups and present their results
Autonomy	Students are able to find necessary literature and to set it into the context of the lecture. They are able to continuously evaluate their knowledge and to take control of their learning process. They can combine knowledge from different courses to form a consistent whole.
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Credit points	3
Course achievement	None
Examination	Oral exam
Examination duration and scale	20 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Medical Technology: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Compulsory

Course L0664: Feedback Control in Medical Technology

Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Johannes Kreuzer, Christian Neuhaus
Language	DE
Cycle	SoSe
Content	Always viewed from the engineer's point of view, the lecture is structured as follows: • Introduction to the topic • Fundamentals of physiological modelling • Introduction to Breathing and Ventilation • Physiology and Pathology in Cardiology • Introduction to the Regulation of Blood Glucose • kidney function and renal replacement therapy • Representation of the control technology on the concrete ventilator • Excursion to a medical technology company Techniques of modeling, simulation and controller development are discussed. In the models, simple equivalent block diagrams for physiological processes are derived and explained how sensors, controllers and actuators are operated. MATLAB and SIMULINK are used as development tools.
Literature	• Leonhardt, S., & Walter, M. (2016). Medizintechnische Systeme. Berlin, Heidelberg: Springer Vieweg. • Werner, J. (2005). Kooperative und autonome Systeme der Medizintechnik. München: Oldenbourg. • Oczenski, W. (2017). Atmen : Atemhilfen ; Atemphysiologie und Beatmungstechnik: Georg Thieme Verlag KG.

Module M1302: Applied Humanoid Robotics

Courses

Title	Typ	Hrs/wk	CP
Applied Humanoid Robotics (L1794)	Project-/problem-based Learning	6	6

Module Responsible	Patrick Göttsch
Admission Requirements	None
Recommended Previous Knowledge	• Object oriented programming; algorithms and data structures • Introduction to control systems • Control systems theory and design • Mechanics
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can explain humanoid robots. • Students can explain the basic concepts, relationships and methods of forward- and inverse kinematics • Students learn to apply basic control concepts for different tasks in humanoid robotics.
Skills	• Students can implement models for humanoid robotic systems in Matlab and C++, and use these models for robot motion or other tasks. • They are capable of using models in Matlab for simulation and testing these models if necessary with C++ code on the real robot system. • They are capable of selecting methods for solving abstract problems, for which no standard methods are available, and apply it successfully.
Personal Competence	
Social Competence	• Students can develop joint solutions in mixed teams and present these. • They can provide appropriate feedback to others, and constructively handle feedback on their own results
Autonomy	• Students are able to obtain required information from provided literature sources, and to put in into the context of the lecture. • They can independently define tasks and apply the appropriate means to solve them.
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Credit points	6
Course achievement	None
Examination	Written elaboration
Examination duration and scale	5-10 pages
Assignment for the Following Curricula	Computer Science: Specialisation II: Intelligence Engineering: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L1794: Applied Humanoid Robotics

Typ	Project-/problem-based Learning
Hrs/wk	6
CP	6
Workload in Hours	Independent Study Time 96, Study Time in Lecture 84
Lecturer	Patrick Göttsch
Language	DE/EN
Cycle	WiSe/SoSe
Content	• Fundamentals of kinematics • Static and dynamic stability of humanoid robotic systems • Combination of different software environments (Matlab, C++, etc.) • Introduction to the necessary software frameworks • Team project • Presentation and Demonstration of intermediate and final results
Literature	• B. Siciliano, O. Khatib. "Handbook of Robotics. Part A: Robotics Foundations", Springer (2008)

Module M1785: Machine Learning in Electrical Engineering and Information Technology

Courses

Title	Typ	Hrs/wk	CP
General Introduction Machine Learning (L3004)	Lecture	1	2
Machine Learning Applications in Electric Power Systems (L3008)	Lecture	1	1
Machine Learning in Electromagnetic Compatibility (EMC) Engineering (L3006)	Lecture	1	1
Machine Learning in High-Frequency Technology and Radar (L3007)	Lecture	1	1
Machine Learning in Wireless Communications (L3005)	Lecture	1	1

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	The module is designed for a diverse audience, i.e. students with different background. It shall be suitable for both students with deeper knowledge in machine learning methods but less knowledge in electrical engineering, e.g. math or computer science students, and students with deeper knowledge in electrical engineering but less knowledge in machine learning methods, e.g. electrical engineering students. Machine learning methods will be explained on a relatively high level indicating mainly principle ideas. The focus is on specific applications in electrical engineering and information technology. The chapters of the course will be understandable in different depth depending on the individual background of the student. The individual background of the students will be taken into consideration in the oral exam.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	
Skills	
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Software: Elective Compulsory

Course L3004: General Introduction Machine Learning	
Typ	Lecture
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Dr. Maximilian Stark
Language	EN
Cycle	SoSe
Content	• From Rule-Based Systems to Machine Learning ◦ Brief overview recent advances in ML in various domain ◦ Outline and expected learning outcomes ◦ Basics statistical inference and statistics ◦ Basics of information theory • The Notions of Learning in Machine Learning ◦ Unsupervised and supervised machine learning ◦ Model-based and data-driven machine learning ◦ Hybrid modelling ◦ Online/offline/meta/transfer learning ◦ General loss functions • Introduction to Deep Learning ◦ Variants of neural networks ◦ MLP ◦ Conv. neural networks ◦ Recurrent neural networks ◦ Training neural networks ◦ (Stochastic) Gradient Descent • Regression vs. Classification ◦ Classification as supervised learning problem ◦ Hands-On Session • Representation Learning and Generative Models ◦ AutoEncoders ◦ Directed Generative Models ◦ Undirected Generative Models ◦ Generative Adversarial Neural Networks • Probabilistic Graphical Models ◦ Bayesian Networks ◦ Variational inference (variational autoencoder)
Literature	

Course L3008: Machine Learning Applications in Electric Power Systems	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Christian Becker, Dr. Davood Babazadeh
Language	EN
Cycle	SoSe
Content	
Literature	

Course L3006: Machine Learning in Electromagnetic Compatibility (EMC) Engineering	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Christian Schuster, Dr. Cheng Yang
Language	EN
Cycle	SoSe
Content	Electromagnetic Compatibility (EMC) Engineering deals with design, simulation, measurement, and certification of electronic and electric components and systems in such a way that their operation is safe, reliable, and efficient in any possible application. Safety is hereby understood as safe with respect to parasitic effects of electromagnetic fields on humans as well as on the operation of other components and systems nearby. Examples for components and systems range from the wiring in aircraft and ships to high-speed interconnects in server systems and wirless interfaces for brain implants. In this part of the course we will give an introduction to the physical basics of EMC engineering and then show how methods of Machine Learning (ML) can be applied to expand todays physcis-based approaches in EMC Engineering.
Literature	

Course L3007: Machine Learning in High-Frequency Technology and Radar	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Alexander Kölpin, Dr. Fabian Lurz
Language	EN
Cycle	SoSe
Content	
Literature	

Course L3005: Machine Learning in Wireless Communications	
Typ	Lecture
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Dr. Maximilian Stark
Language	EN
Cycle	SoSe

Content	• Supervised Learning Application - Channel Coding
	  ◦ Recap channel coding and block codes
	  ◦ Block codes as trainable neural networks
	  ◦ Tanner graph with trainable weights
	  ◦ Hands-on session
	• Supervised Learning Application - Modulation Detection
	  ◦ Recap wireless modulation schemes
	  ◦ Convolutional neuronal networks for blind detection of modulation schemes
	  ◦ Hands-on session
	• Autoencoder Application - Constellation Shaping I
	  ◦ Recap channel capacity and constellation shaping,
	  ◦ Capacity achieving machine learning systems
	  ◦ Information theoretical explanation of the autoencoder training
	  ◦ Hands-on session
	• Autoencoder Application - Constellation Shaping II
	  ◦ Training without a channel model
	  ◦ Mutual information neural estimator
	  ◦ Hands-on session
	• Generative Adversarial Network Application - Channel Modelling
	  ◦ Recap realistic channels with non-linear hardware impairments
	  ◦ Training a digital twin of a realistic channel with insufficient training data
	  ◦ Hands-on session
	• Recurrent Neural Network Application - Channel prediction
	  ◦ Recap time-varying channel models
	  ◦ Recurrent neural networks for temporal prediction
	  ◦ Hands-on session

Literature	

Module M1699: Selected Aspects in Control and Power Systems Engineering

Courses

Title	Typ	Hrs/wk	CP
Selected Aspects in Control and Power Systems Engineering (L2704)	Lecture	2	4
Selected Aspects in Control and Power Systems Engineering (L2705)	Recitation Section (large)	2	2

Module Responsible	Prof. Christian Becker
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	
Skills	
Personal Competence	
Social Competence	
Autonomy	
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory

Course L2704: Selected Aspects in Control and Power Systems Engineering

Typ	Lecture
Hrs/wk	2
CP	4
Workload in Hours	Independent Study Time 92, Study Time in Lecture 28
Lecturer	Dozenten des SD E
Language	DE/EN
Cycle	WiSe/SoSe
Content	
Literature	

Course L2705: Selected Aspects in Control and Power Systems Engineering

Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dozenten des SD E
Language	DE/EN
Cycle	WiSe/SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0633: Industrial Process Automation

Courses

Title	Typ	Hrs/wk	CP
Industrial Process Automation (L0344)	Lecture	2	3
Industrial Process Automation (L0345)	Recitation Section (small)	2	3

Module Responsible	Prof. Alexander Schlaefer
Admission Requirements	None
Recommended Previous Knowledge	mathematics and optimization methods principles of automata principles of algorithms and data structures programming skills
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students can evaluate and assess discrete event systems. They can evaluate properties of processes and explain methods for process analysis. The students can compare methods for process modelling and select an appropriate method for actual problems. They can discuss scheduling methods in the context of actual problems and give a detailed explanation of advantages and disadvantages of different programming methods. The students can relate process automation to methods from robotics and sensor systems as well as to recent topics like 'cyberphysical systems' and 'industry 4.0'.
Skills	The students are able to develop and model processes and evaluate them accordingly. This involves taking into account optimal scheduling, understanding algorithmic complexity, and implementation using PLCs.
Personal Competence	
Social Competence	The students can independently define work processes within their groups, distribute tasks within the group and develop solutions collaboratively.
Autonomy	The students are able to assess their level of knowledge and to document their work results adequately.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	**Compulsory** No / **Bonus** 10 % / **Form** Excercises / **Description**
Examination	Written exam
Examination duration and scale	90 minutes
Assignment for the Following Curricula	Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory Computer Science: Specialisation II: Intelligence Engineering: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory International Management and Engineering: Specialisation II. Mechatronics: Elective Compulsory International Management and Engineering: Specialisation II. Product Development and Production: Elective Compulsory Aeronautics: Core Qualification: Elective Compulsory Mechanical Engineering and Management: Specialisation Mechatronics: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory Process Engineering: Specialisation Process Engineering: Elective Compulsory

Course L0344: Industrial Process Automation	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Alexander Schlaefer
Language	EN
Cycle	WiSe
Content	- foundations of problem solving and system modeling, discrete event systems - properties of processes, modeling using automata and Petri-nets - design considerations for processes (mutex, deadlock avoidance, liveness) - optimal scheduling for processes - optimal decisions when planning manufacturing systems, decisions under uncertainty - software design and software architectures for automation, PLCs
Literature	J. Lunze: „Automatisierungstechnik“, Oldenbourg Verlag, 2012 Reisig: Petrinetze: Modellierungstechnik, Analysemethoden, Fallstudien; Vieweg+Teubner 2010 Hrúz, Zhou: Modeling and Control of Discrete-event Dynamic Systems; Springer 2007 Li, Zhou: Deadlock Resolution in Automated Manufacturing Systems, Springer 2009 Pinedo: Planning and Scheduling in Manufacturing and Services, Springer 2009

Course L0345: Industrial Process Automation	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Alexander Schlaefer
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M0836: Communication Networks

Courses

Title	Typ	Hrs/wk	CP
Selected Topics of Communication Networks (L0899)	Project-/problem-based Learning	2	2
Communication Networks (L0897)	Lecture	2	2
Communication Networks Excercise (L0898)	Project-/problem-based Learning	1	2

Module Responsible	Prof. Andreas Timm-Giel
Admission Requirements	None
Recommended Previous Knowledge	• Fundamental stochastics • Basic understanding of computer networks and/or communication technologies is beneficial
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to describe the principles and structures of communication networks in detail. They can explain the formal description methods of communication networks and their protocols. They are able to explain how current and complex communication networks work and describe the current research in these examples.
Skills	Students are able to evaluate the performance of communication networks using the learned methods. They are able to work out problems themselves and apply the learned methods. They can apply what they have learned autonomously on further and new communication networks.
Personal Competence	
Social Competence	Students are able to define tasks themselves in small teams and solve these problems together using the learned methods. They can present the obtained results. They are able to discuss and critically analyse the solutions.
Autonomy	Students are able to obtain the necessary expert knowledge for understanding the functionality and performance capabilities of new communication networks independently.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Presentation
Examination duration and scale	1.5 hours colloquium with three students, therefore about 30 min per student. Topics of the colloquium are the posters from the previous poster session and the topics of the module.
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems, Focus Networks: Elective Compulsory International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory Aeronautics: Core Qualification: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L0899: Selected Topics of Communication Networks

Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Koojana Kuladinithi
Language	EN
Cycle	WiSe
Content	Example networks selected by the students will be researched on in a PBL course by the students in groups and will be presented in a poster session at the end of the term.
Literature	• see lecture

Course L0897: Communication Networks	
Typ	Lecture
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Koojana Kuladinithi
Language	EN
Cycle	WiSe
Content	
Literature	• Skript des Instituts für Kommunikationsnetze • Tannenbaum, Computernetzwerke, Pearson-Studium Further literature is announced at the beginning of the lecture.

Course L0898: Communication Networks Excercise	
Typ	Project-/problem-based Learning
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Dr. Koojana Kuladinithi
Language	EN
Cycle	WiSe
Content	Part of the content of the lecture Communication Networks are reflected in computing tasks in groups, others are motivated and addressed in the form of a PBL exercise.
Literature	• announced during lecture

Module M0677: Digital Signal Processing and Digital Filters

Courses

Title	Typ	Hrs/wk	CP
Digital Signal Processing and Digital Filters (L0446)	Lecture	3	4
Digital Signal Processing and Digital Filters (L0447)	Recitation Section (large)	2	2

Module Responsible	Prof. Gerhard Bauch
Admission Requirements	None
Recommended Previous Knowledge	• Mathematics 1-3 • Signals and Systems • Fundamentals of signal and system theory as well as random processes. • Fundamentals of spectral transforms (Fourier series, Fourier transform, Laplace transform)
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students know and understand basic algorithms of digital signal processing. They are familiar with the spectral transforms of discrete-time signals and are able to describe and analyse signals and systems in time and image domain. They know basic structures of digital filters and can identify and assess important properties including stability. They are aware of the effects caused by quantization of filter coefficients and signals. They are familiar with the basics of adaptive filters. They can perform traditional and parametric methods of spectrum estimation, also taking a limited observation window into account. The students are familiar with the contents of lecture and tutorials. They can explain and apply them to new problems.
Skills	The students are able to apply methods of digital signal processing to new problems. They can choose and parameterize suitable filter striuctures. In particular, the can design adaptive filters according to the minimum mean squared error (MMSE) criterion and develop an efficient implementation, e.g. based on the LMS or RLS algorithm. Furthermore, the students are able to apply methods of spectrum estimation and to take the effects of a limited observation window into account.
Personal Competence	
Social Competence	The students can jointly solve specific problems.
Autonomy	The students are able to acquire relevant information from appropriate literature sources. They can control their level of knowledge during the lecture period by solving tutorial problems, software tools, clicker system.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	90 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Computer Science in Engineering: Specialisation II. Engineering Science: Elective Compulsory Information and Communication Systems: Specialisation Communication Systems, Focus Signal Processing: Elective Compulsory Mechanical Engineering and Management: Specialisation Mechatronics: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L0446: Digital Signal Processing and Digital Filters	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	WiSe
Content	• Transforms of discrete-time signals: ◦ Discrete-time Fourier Transform (DTFT) ◦ Discrete Fourier-Transform (DFT), Fast Fourier Transform (FFT) ◦ Z-Transform • Correspondence of continuous-time and discrete-time signals, sampling, sampling theorem • Fast convolution, Overlap-Add-Method, Overlap-Save-Method • Fundamental structures and basic types of digital filters • Characterization of digital filters using pole-zero plots, important properties of digital filters • Quantization effects • Design of linear-phase filters • Fundamentals of stochastic signal processing and adaptive filters ◦ MMSE criterion ◦ Wiener Filter ◦ LMS- and RLS-algorithm • Traditional and parametric methods of spectrum estimation
Literature	K.-D. Kammeyer, K. Kroschel: Digitale Signalverarbeitung. Vieweg Teubner. V. Oppenheim, R. W. Schafer, J. R. Buck: Zeitdiskrete Signalverarbeitung. Pearson StudiumA. V. W. Hess: Digitale Filter. Teubner. Oppenheim, R. W. Schafer: Digital signal processing. Prentice Hall. S. Haykin: Adaptive flter theory. L. B. Jackson: Digital filters and signal processing. Kluwer. T.W. Parks, C.S. Burrus: Digital filter design. Wiley.

Course L0447: Digital Signal Processing and Digital Filters	
Typ	Recitation Section (large)
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Gerhard Bauch
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M1229: Control Lab B

Courses

Title	Typ	Hrs/wk	CP
Control Lab V (L1667)	Practical Course	1	1
Control Lab VI (L1668)	Practical Course	1	1

Module Responsible	NN
Admission Requirements	None
Recommended Previous Knowledge	• State space methods • LQG control • H2 and H-infinity optimal control • uncertain plant models and robust control • LPV control
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can explain the difference between validation of a control lop in simulation and experimental validation
Skills	• Students are capable of applying basic system identification tools (Matlab System Identification Toolbox) to identify a dynamic model that can be used for controller synthesis • They are capable of using standard software tools (Matlab Control Toolbox) for the design and implementation of LQG controllers • They are capable of using standard software tools (Matlab Robust Control Toolbox) for the mixed-sensitivity design and the implementation of H-infinity optimal controllers • They are capable of representing model uncertainty, and of designing and implementing a robust controller • They are capable of using standard software tools (Matlab Robust Control Toolbox) for the design and the implementation of LPV gain-scheduled controllers
Personal Competence	
Social Competence	• Students can work in teams to conduct experiments and document the results
Autonomy	• Students can independently carry out simulation studies to design and validate control loops
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Credit points	2
Course achievement	None
Examination	Written elaboration
Examination duration and scale	1
Assignment for the Following Curricula	Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory

Course L1667: Control Lab V

Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Herbert Werner, Adwait Datar, Patrick Göttsch
Language	EN
Cycle	WiSe/SoSe
Content	One of the offered experiments in control theory.
Literature	Experiment Guides

Course L1668: Control Lab VI

Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Herbert Werner, Adwait Datar, Patrick Göttsch
Language	EN
Cycle	WiSe/SoSe
Content	One of the offered experiments in control theory.
Literature	Experiment Guides

Module M1213: Avionics for safety-critical Systems

Courses

Title	Typ	Hrs/wk	CP
Avionics of Safty Critical Systems (L1640)	Lecture	2	3
Avionics of Safty Critical Systems (L1641)	Recitation Section (small)	1	1
Avionics of Safty Critical Systems (L1652)	Practical Course	1	2

Module Responsible: Dr. Martin Halle

Admission Requirements: None

Recommended Previous Knowledge: Basic knowledge in:

- Mathematics
- Electrical Engineering
- Informatics

Educational Objectives: After taking part successfully, students have reached the following learning results

Professional Competence

Knowledge

Students can:

- describe the most important principles and components of safety-critical avionics
- denote processes and standards of safety-critical software development
- depict the principles of Integrated Modular Avionics (IMA)
- can compare hardware and bus systems used in avionics
- assess the difficulties of developing a safety-critical avionics system correctly

Skills

Students can ...

- operate real-time hardware and simulations
- program A653 applications
- plan avionics architectures up to a certain extend
- create test scripts and assess test results

Personal Competence

Social Competence

Students can:

- jointly develop solutions in inhomogeneous teams
- exchange information formally with other teams
- present development results in a convenient way

Autonomy

Students can:

- understand the requirements for an avionics system
- autonomously derive concepts for systems based on safety-critical avionics

Workload in Hours: Independent Study Time 124, Study Time in Lecture 56

Credit points: 6

Course achievement:

Compulsory	Bonus	Form	Description
Yes	None	Subject theoretical and practical work	

Examination: Oral exam

Examination duration and scale: 30 min

Assignment for the Following Curricula:

Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory
Aircraft Systems Engineering: Core Qualification: Elective Compulsory
Aeronautics: Core Qualification: Elective Compulsory
Theoretical Mechanical Engineering: Specialisation Aircraft Systems Engineering: Elective Compulsory

Course L1640: Avionics of Safty Critical Systems	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Dr. Martin Halle
Language	DE
Cycle	WiSe
Content	Avionics are all kinds off flight electronics. Today there is no aircraft system function without avionics, and avionics are one main source of innovation in aerospace industry. Since many system functions are highly safety critical, the development of avionics hardware and software underlies mandatory constraints, technics, and processes. It is inevitable for system developers and computer engineers in aerospace industry to understand and master these. This lecture teaches the risks and techniques of developing safety critical hardware and software; major avionics components; integration; and test with a practical orientation. A focus is on Integrated Modular Avionics (IMA). The lecture is accompanied by a mandatory and laboratory exercises. Content: 1. Introduction and Fundamentals 2. History and Flight Control 3. Concepts and Redundancy 4. Digital Computers 5. Interfaces and Signals 6. Busses 7. Networks 8. Aircraft Cockpit 9. Software Development 10. Model-based Development 11. Integrated Modular Avionics I 12. Integrated Modular Avionics II
Literature	• Moir, I.; Seabridge, A. & Jukes, M., Civil Avionics Systems Civil Avionics Systems, John Wiley & Sons, Ltd, 2013 • Spitzer, C. R. Spitzer, Digital Avionics Handbook, CRC Press, 2007 • FAA, Advanced Avionics Handbook U.S. Department of Transportation Federal Aviation Administration, 2009 • Moir, I. & Seabridge, A. Aircraft Systems, Wiley, 2008, 3

Course L1641: Avionics of Safty Critical Systems	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Dr. Martin Halle
Language	DE
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Course L1652: Avionics of Safty Critical Systems	
Typ	Practical Course
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Dr. Martin Halle
Language	DE
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M1155: Aircraft Cabin Systems

Courses

Title	Typ	Hrs/wk	CP
Aircraft Cabin Systems (L1545)	Lecture	3	4
Aircraft Cabin Systems (L1546)	Recitation Section (large)	1	2

Module Responsible	Prof. Ralf God
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge in: • Mathematics • Mechanics • Thermodynamics • Electrical Engineering • Control Systems
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to: • describe cabin operations, equipment in the cabin and cabin Systems • explain the functional and non-functional requirements for cabin Systems • elucidate the necessity of cabin operating systems and emergency Systems • assess the challenges human factors integration in a cabin environment
Skills	Students are able to: • design a cabin layout for a given business model of an Airline • design cabin systems for safe operations • design emergency systems for safe man-machine interaction • solve comfort needs and entertainment requirements in the cabin
Personal Competence	
Social Competence	Students are able to: • comprehend existing system solutions and explain them on the basis of existing requirements • discuss with experts in technical language • explain system functions • classify the criticality of functions • describe systems as is
Autonomy	Students are able to: • independently reflect on lecture content and expert presentations • independently develop more in-depth content • recognize further areas of knowledge
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written exam
Examination duration and scale	120 Minutes
Assignment for the Following Curricula	Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Compulsory International Management and Engineering: Specialisation II. Aviation Systems: Elective Compulsory Aeronautics: Core Qualification: Compulsory Product Development, Materials and Production: Specialisation Product Development: Elective Compulsory Product Development, Materials and Production: Specialisation Production: Elective Compulsory Product Development, Materials and Production: Specialisation Materials: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Aircraft Systems Engineering: Elective Compulsory

Course L1545: Aircraft Cabin Systems	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Ralf God
Language	DE
Cycle	WiSe
Content	The objective of the lecture with the corresponding exercise is the acquisition of knowledge about aircraft cabin systems and cabin operations. A basic understanding of technological and systems engineering effort to maintain an artificial but comfortable and safe travel and working environment at cruising altitude is to be achieved. The course provides a comprehensive overview of current technology and cabin systems in modern passenger aircraft. The Fulfillment of requirements for the cabin as the central system of work are covered on the basis of the topics comfort, ergonomics, human factors, operational processes, maintenance and energy supply: • Materials used in the cabin • Ergonomics and human factors • Cabin interior and non-electrical systems • Cabin electrical systems and lights • Cabin electronics, communication-, information- and IFE-systems • Cabin and passenger process chains • RFID Aircraft Parts Marking • Energy sources and energy conversion
Literature	- Skript zur Vorlesung - Jenkinson, L.R., Simpkin, P., Rhodes, D.: Civil Jet Aircraft Design. London: Arnold, 1999 - Rossow, C.-C., Wolf, K., Horst, P. (Hrsg.): Handbuch der Luftfahrzeugtechnik. Carl Hanser Verlag, 2014 - Moir, I., Seabridge, A.: Aircraft Systems: Mechanical, Electrical and Avionics Subsystems Integration, Wiley 2008 - Davies, M.: The standard handbook for aeronautical and astronautical engineers. McGraw-Hill, 2003 - Kompendium der Flugmedizin. Verbesserte und ergänzte Neuauflage, Nachdruck April 2006. Fürstenfeldbruck, 2006 - Campbell, F.C.: Manufacturing Technology for Aerospace Structural Materials. Elsevier Ltd., 2006

Course L1546: Aircraft Cabin Systems	
Typ	Recitation Section (large)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Ralf God
Language	DE
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M1306: Control Lab C

Courses

Title	Typ	Hrs/wk	CP
Control Lab IX (L1836)	Practical Course	1	1
Control Lab VII (L1834)	Practical Course	1	1
Control Lab VIII (L1835)	Practical Course	1	1

Module Responsible	Prof. Herbert Werner
Admission Requirements	None
Recommended Previous Knowledge	• State space methods • LQG control • H2 and H-infinity optimal control • uncertain plant models and robust control • LPV control
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can explain the difference between validation of a control lop in simulation and experimental validation
Skills	• Students are capable of applying basic system identification tools (Matlab System Identification Toolbox) to identify a dynamic model that can be used for controller synthesis • They are capable of using standard software tools (Matlab Control Toolbox) for the design and implementation of LQG controllers • They are capable of using standard software tools (Matlab Robust Control Toolbox) for the mixed-sensitivity design and the implementation of H-infinity optimal controllers • They are capable of representing model uncertainty, and of designing and implementing a robust controller • They are capable of using standard software tools (Matlab Robust Control Toolbox) for the design and the implementation of LPV gain-scheduled controllers
Personal Competence	
Social Competence	• Students can work in teams to conduct experiments and document the results
Autonomy	• Students can independently carry out simulation studies to design and validate control loops
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Credit points	3
Course achievement	None
Examination	Written elaboration
Examination duration and scale	1
Assignment for the Following Curricula	Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Theoretical Mechanical Engineering: Core Qualification: Elective Compulsory

Course L1836: Control Lab IX

Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Herbert Werner, Adwait Datar, Patrick Göttsch
Language	EN
Cycle	WiSe/SoSe
Content	One of the offered experiments in control theory.
Literature	Experiment Guides

Course L1834: Control Lab VII	
Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Herbert Werner, Patrick Göttsch
Language	EN
Cycle	WiSe/SoSe
Content	One of the offered experiments in control theory.
Literature	Experiment Guides

Course L1835: Control Lab VIII	
Typ	Practical Course
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Herbert Werner, Adwait Datar, Patrick Göttsch
Language	EN
Cycle	WiSe/SoSe
Content	One of the offered experiments in control theory.
Literature	Experiment Guides

Module M1523: Research Project and Seminar in Control and Power Systems Engineering			
Courses			
Title	**Typ**	**Hrs/wk**	**CP**

Module Responsible	Dozenten des SD E
Admission Requirements	None
Recommended Previous Knowledge	Advanced state of knowledge in the electrical engineering master program
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students know current research topics oft institutes engaged in their specialization. They can name the fundamental scientific methods used for doing related reserach. They are furthermore able to use professional language in discussions. They are able to explain research topics.
Skills	Students are capable of completing a small, independent sub-project of currently ongoing research projects in the institutes engaged in their specialization. Students can justify and explain their approach for problem solving, they can draw conclusions from their results, and then can find new ways and methods for their work. Students are capable of comparing and assessing alterantive approaches with their own with regard to given criteria. Students are able to gain knowledge about a new field by themselves. In order to do that they make use of their existing knowledge and try to connect it with the topics of the new field. They close their knowledge gaps by discussing with research assistants and by their own literature and internet search. They are capable of summarizing and presenting scientific publications.
Personal Competence	
Social Competence	Students are able to discuss their work progress with research assistants of the supervising institute . They are capable of presenting their results in front of a professional audience. In cooperation with research assistants students are able to familiarize themselves with and discuss with others current research topics. They are capable of drafting, presenting, and explaining summaries of these topics in English in front of a professional audience.
Autonomy	Based on their competences gained so far students are capable of defining meaningful tasks within ongoing research project for themselves. They are able to develop the necessary understanding and problem solving methods. Students are capable of gathering information from subject related, professional publications and relate that information to the context of the seminar. They are able to find on their own new sources in the Internet. They are able to make a connection with the subject of their chosen specialization.
Workload in Hours	Independent Study Time 360, Study Time in Lecture 0
Credit points	12
Course achievement	None
Examination	Study work
Examination duration and scale	acc. to ASPO
Assignment for the Following Curricula	Electrical Engineering: Specialisation Control and Power Systems Engineering: Compulsory

Module M0832: Advanced Topics in Control

Courses

Title	Typ	Hrs/wk	CP
Advanced Topics in Control (L0661)	Lecture	2	3
Advanced Topics in Control (L0662)	Recitation Section (small)	2	3

Module Responsible	NN
Admission Requirements	None
Recommended Previous Knowledge	H-infinity optimal control, mixed-sensitivity design, linear matrix inequalities
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Students can explain the advantages and shortcomings of the classical gain scheduling approach • They can explain the representation of nonlinear systems in the form of quasi-LPV systems • They can explain how stability and performance conditions for LPV systems can be formulated as LMI conditions • They can explain how gridding techniques can be used to solve analysis and synthesis problems for LPV systems • They are familiar with polytopic and LFT representations of LPV systems and some of the basic synthesis techniques associated with each of these model structures • Students can explain how graph theoretic concepts are used to represent the communication topology of multiagent systems • They can explain the convergence properties of first order consensus protocols • They can explain analysis and synthesis conditions for formation control loops involving either LTI or LPV agent models • Students can explain concepts behind linear and qLPV Model Predictive Control (MPC)
Skills	• Students can construct LPV models of nonlinear plants and carry out a mixed-sensitivity design of gain-scheduled controllers; they can do this using polytopic, LFT or general LPV models • They can use standard software tools (Matlab robust control toolbox) for these tasks • Students can design distributed formation controllers for groups of agents with either LTI or LPV dynamics, using Matlab tools provided • Students can design MPC controllers for linear and non-linear systems using Matlab tools
Personal Competence	
Social Competence	Students can work in small groups and arrive at joint results.
Autonomy	Students can find required information in sources provided (lecture notes, literature, software documentation) and use it to solve given problems.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory Aeronautics: Core Qualification: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Mechatronics: Core Qualification: Elective Compulsory Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory Theoretical Mechanical Engineering: Specialisation Robotics and Computer Science: Elective Compulsory

Course L0661: Advanced Topics in Control	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	NN
Language	EN
Cycle	WiSe
Content	• Linear Parameter-Varying (LPV) Gain Scheduling - Linearizing gain scheduling, hidden coupling - Jacobian linearization vs. quasi-LPV models - Stability and induced L2 norm of LPV systems - Synthesis of LPV controllers based on the two-sided projection lemma - Simplifications: controller synthesis for polytopic and LFT models - Experimental identification of LPV models - Controller synthesis based on input/output models - Applications: LPV torque vectoring for electric vehicles, LPV control of a robotic manipulator • Control of Multi-Agent Systems - Communication graphs - Spectral properties of the graph Laplacian - First and second order consensus protocols - Formation control, stability and performance - LPV models for agents subject to nonholonomic constraints - Application: formation control for a team of quadrotor helicopters • Linear and Nonlinear Model Predictive Control based on LMIs
Literature	• Werner, H., Lecture Notes "Advanced Topics in Control" • Selection of relevant research papers made available as pdf documents via StudIP

Course L0662: Advanced Topics in Control	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	NN
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M1710: Smart Grid Technologies

Courses

Title	Typ	Hrs/wk	CP
Smart Grid Technologies (L2706)	Lecture	3	4
Smart Grid Technologies (L2707)	Project-/problem-based Learning	2	2

Module Responsible	Prof. Christian Becker
Admission Requirements	None
Recommended Previous Knowledge	Fundamentals of Electrical Engineering, Introduction to Control Systems, Mathematics I, II, III Electrical Power Systems I Electrical Power Systems II
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students are able to explain in detail and critically evaluate methods and technologies for operation of smart grids (i.e. intelligent distribution grids).
Skills	With completion of this module the students are able to analyze the impact of emerging technologies (such as renewables, energy storage and demand response) on the electric power system. They can formulate and apply computational intelligence techniques to power system operation problems. They can also explain what ICT technologies (such as digital twins and IoT) are relevant and suitable for distribution grid operation.
Personal Competence	
Social Competence	The students can participate in specialized and interdisciplinary discussions, advance ideas and represent their own work results in front of others.
Autonomy	Students can independently tap knowledge of the emphasis of the lectures and apply it within further research activities.
Workload in Hours	Independent Study Time 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Presentation
Examination duration and scale	30 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Control and Power Systems Engineering: Elective Compulsory Energy Systems: Specialisation Energy Systems: Elective Compulsory Renewable Energies: Specialisation Wind Energy Systems: Elective Compulsory Renewable Energies: Specialisation Solar Energy Systems: Elective Compulsory

Course L2706: Smart Grid Technologies	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Christian Becker, Dr. Davood Babazadeh
Language	DE/EN
Cycle	WiSe/SoSe

Content	**Introduction to Smart Grids**
	• Intelligent Distribution Grids
	• Paradigm shifts: Digitalization & Sustainability
	Emerging technologies in distribution grids
	• Distributed Energy Resource (DER)
	• Battery Energy Storage (BES) technologies
	• Sector-coupling & EV/V2G
	• Microgrids, Inverter-based Systems
	• Modelling and control of PV & BESS
	Distribution grid management & analysis
	• Distribution grid structure (Hamburg example)
	• Distribution grid management and operation architecture and functions
	    ◦ Fault Detection, Isolation & Restoration
	    ◦ Self-Healing in distribution systems
	    ◦ Volt-Var Optimization
	    ◦ Distribution Load Flow
	• Demand Side Management & Demand Response
	• Lab exercise (Smart Grid Operation)
	Computational intelligence and optimization techniques in Smart Grids
	• Computational challenges in Smart grid
	• Heuristic & Analytic Optimization Methods
	• Intelligent Systems (Expert Systems, ML/AL)
	• Applications (optimal load flow, reactive capacitor placement)
	• Lab exercise (optimization formulation)
	ICT Technologies for Smart Grids
	• Advanced Metering Technologies: Smart Meters, RTU, PMU
	• Telecommunication Systems in Smart Grids (network basics and technologies)
	• Interoperability in Smart grids
	    ◦ Smart Grid Architecture Model
	    ◦ Automation and Communication standards (IEC 61850, c37.118)
	• Cyber security
	• Lab exercise (Grid automation protocols)
	Practical lesson-learned: Stromnetz Hamburg (SNH) perspective
	• Definition of Smart Grid and its requirements from industry view
	• Grid digitalization - examples of industrial projects
	• Flexible load management
	• Electromobility & transportation sector integration
	Study visits:
	• Digital Substation in Harburg
	• Electric Bus charging station
	Stromnetz Hamburg Control Center

Literature	• Buchholz and Styczynski - 2020 - “Smart Grids: Fundamentals and Technologies in Electric Power Systems of the Future”, Springer • Bernardon and Garcia - 2018 - “Smart Operation for Power Distribution Systems: Concepts and Applications”, Springer • Momoh, 2012; “Smart Grid: Fundamentals of Design and Analysis”, Wiley

Course L2707: Smart Grid Technologies	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Christian Becker, Dr. Davood Babazadeh
Language	DE/EN
Cycle	WiSe/SoSe
Content	See interlocking course
Literature	See interlocking course

Thesis

Module M-002: Master Thesis

Courses			
Title	Typ	Hrs/wk	CP

Module Responsible	Professoren der TUHH
Admission Requirements	According to General Regulations §21 (1): At least 60 credit points have to be achieved in study programme. The examinations board decides on exceptions.
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	- The students can use specialized knowledge (facts, theories, and methods) of their subject competently on specialized issues. - The students can explain in depth the relevant approaches and terminologies in one or more areas of their subject, describing current developments and taking up a critical position on them. - The students can place a research task in their subject area in its context and describe and critically assess the state of research.
Skills	The students are able: - To select, apply and, if necessary, develop further methods that are suitable for solving the specialized problem in question. - To apply knowledge they have acquired and methods they have learnt in the course of their studies to complex and/or incompletely defined problems in a solution-oriented way. - To develop new scientific findings in their subject area and subject them to a critical assessment.
Personal Competence	
Social Competence	Students can - Both in writing and orally outline a scientific issue for an expert audience accurately, understandably and in a structured way. - Deal with issues competently in an expert discussion and answer them in a manner that is appropriate to the addressees while upholding their own assessments and viewpoints convincingly.
Autonomy	Students are able: - To structure a project of their own in work packages and to work them off accordingly. - To work their way in depth into a largely unknown subject and to access the information required for them to do so. - To apply the techniques of scientific work comprehensively in research of their own.
Workload in Hours	Independent Study Time 900, Study Time in Lecture 0
Credit points	30
Course achievement	None
Examination	Thesis
Examination duration and scale	According to General Regulations
Assignment for the Following Curricula	Civil Engineering: Thesis: Compulsory Bioprocess Engineering: Thesis: Compulsory Chemical and Bioprocess Engineering: Thesis: Compulsory Computer Science: Thesis: Compulsory Data Science: Thesis: Compulsory Electrical Engineering: Thesis: Compulsory Energy Systems: Thesis: Compulsory Environmental Engineering: Thesis: Compulsory Aircraft Systems Engineering: Thesis: Compulsory Global Innovation Management: Thesis: Compulsory Computer Science in Engineering: Thesis: Compulsory Information and Communication Systems: Thesis: Compulsory Interdisciplinary Mathematics: Thesis: Compulsory International Production Management: Thesis: Compulsory International Management and Engineering: Thesis: Compulsory Joint European Master in Environmental Studies - Cities and Sustainability: Thesis: Compulsory Logistics, Infrastructure and Mobility: Thesis: Compulsory Aeronautics: Thesis: Compulsory

	Materials Science and Engineering: Thesis: Compulsory Materials Science: Thesis: Compulsory Mechanical Engineering and Management: Thesis: Compulsory Mechatronics: Thesis: Compulsory Biomedical Engineering: Thesis: Compulsory Microelectronics and Microsystems: Thesis: Compulsory Product Development, Materials and Production: Thesis: Compulsory Renewable Energies: Thesis: Compulsory Naval Architecture and Ocean Engineering: Thesis: Compulsory Ship and Offshore Technology: Thesis: Compulsory Teilstudiengang Lehramt Metalltechnik: Thesis: Compulsory Theoretical Mechanical Engineering: Thesis: Compulsory Process Engineering: Thesis: Compulsory Water and Environmental Engineering: Thesis: Compulsory Certification in Engineering & Advisory in Aviation: Thesis: Compulsory