TUHH
Hamburg
University of
Technology

Module Manual

Master of Science (M.Sc.)

Microelectronics and Microsystems
Dual study program

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Program description

Content

Microelectronics, or better named nanoelectronics, because the minimum structure size of state-of-the-art integrated electronic circuits are in the range of 20 nm and below, is the base of the products that significantly influence the daily life of people almost anywhere on earth. Examples are personal computers and smartphones. Both of them open up new possibilities of communication and give access to almost unlimited sources of information, especially when those devices are connected to the world wide web. Another example are medical diagnostic tools for computer tomography or nuclear resonance tomography or intelligent medical implants as all these systems are based on the high computational performance and high data communication efficiency provided by advanced nanoelectronics.

The fundament for microelectronics and microsystems is semiconductor physics and technology. Thus, the objective of the International Master Program “Microelectronics and Microsystems” is to give the students a profound knowledge on physical level about electronic effects in semiconductor materials, especially silicon, and on the functionality of electronic devices. Furthermore, the students are taught about process technology for fabrication of integrated circuits and microsystems. This will enable the students to understand in depth the function of advanced electronic devices and fabrication processes. They will be able to comprehend in a critical way the problems accompanied with the transition to smaller minimum structure sizes. Thus, the students can conceive which possible solutions may exist or could be developed to overcome the problems of scaling-down the device minimum feature size. This will enable the students to understand the ongoing scaling-down of MOS transistors with its potential but also with its limitations.

Besides the essential role of physical basics the precise knowledge of process dependent manufacturing procedures are of key importance for training of the students in the field of nanoelectronics and microsystems. This will help them to develop during their professional life the ability to generate innovative concepts and bring them to practical applications.

The International Master Program “Microelectronics and Microsystems” qualifies the students for scientific professional work in the fields of electrical engineering and information technology. This professional work may extend from the development, production and application to the quality control of complex systems with highly integrated circuits and microsystems components. Both fields are coming closer and closer together, as a fast rising number of complex applications requires the integration of nanoelectronics and microsystems to one combined system.

In particular, this program enables the students not only to design new complex systems for innovative applications, but also to make them usable for practical applications. This can be realized by teaching the students engineering methods both on a physical and theoretical level and on an application oriented level.

In addition to the foundational curriculum taught at TUHH, seminars on developing personal skills are integrated into the dual study programme, in the context of transfer between theory and practice. These seminars correspond to the modern professional requirements expected of an engineer, as well as promoting the link between the two places of learning.

The intensive dual courses at TUHH integrating practical experience consist of an academic-oriented and a practice-oriented element, which are completed at two places of learning. The academic-oriented element comprises study at TUHH. The practice-oriented element is coordinated with the study programme in terms of content and time, and consists of practical modules and phases spent in an affiliate company during periods when there are no lectures.

Career prospects

The graduates of the International Master Program “Microelectronics and Microsystems” can find a wide variety of professional options as they have well founded knowledge about technology, design and application of highly integrated systems based on nanoelectronics and microsystems.

Thus, one group of possible employers are large companies with international sites for the production of integrated circuits, but also small or medium-sized companies for microsystems. Many job opportunities also exist in the field of development and design of integrated circuits and of microsystems. Because of the fast decline in prices of high-performance computer system, even small companies can conduct tasks that require many computational efforts such as the design of integrated circuits that, then, are fabricated by specialized companies, so-called silicon foundries. This allows many small companies to participate in the market for integrated circuits, so that they can contribute to a good job market for engineers in nanoelectronics and microsystems.

In addition, students acquire basic professional and personal skills as part of the dual study programme that enable them to enter professional practice at an early stage and to go on to further study. Students also gain practical work experience through the integrated practical modules. Graduates of the dual course have broad foundational knowledge, fundamental skills for academic work and relevant personal competences.

Learning target

Knowledge

- The students understand the basic physical principles of microelectronic devices and functional block of microsystems. Furthermore, they have solid knowledge regarding fabrication technologies, so that they can explain them in detail.
- They have gained solid knowledge in selected fields based on a broad theoretical and methodical fundament.
- The students possess in-depth knowledge of interdisciplinary relationships.
- They have the required background knowledge in order to position their professional subjects by appropriate means in the scientific and social environment.

Skills

The students are able

- to apply computational methods for quantitative analysis of design parameters and for development of innovative systems for microelectronics and microsystems.
- to solve complex problems and tasks in a self-dependent manner by basic methodical approaches that may be, if necessary, beyond the standard patterns
- to consider technological progress and scientific advancements by taking into account the technical, financial and ecological boundary conditions.

Social Skills

The students are capable of

- working in interdisciplinary teams and organizing their tasks in a process oriented manner to become prepared for conducting research based professional work and for taking management responsibilities.
- to present their results in a written or oral form effectively targeting the audience, on international stage also.

Autonomy

- The students can pervade in an effectively and self-dependently organized way special areas of their professional fields using scientific methods.
- They are able to present their knowledge by appropriate media techniques or to describe it by documents with reasonable lengths.
- The students are able to identify the need for additional information and to develop a strategy for self-dependent enhancement of their knowledge.

By continually switching places of learnings throughout the dual study programme, it is possible for theory and practice to be interlinked. Students reflect theoretically on their individual professional practical experience, and apply the results of their reflection to new forms of practice. They also test theoretical elements of the course in a practical setting, and use their findings as a stimulus for theoretical debate.

Program structure

The curriculum of the International Master Program „Microelectronics and Microsystems“ is structured as follows:

- Core Qualification:

- Main subject: The students choose one main subject out of the following two options:

-

The students have to take for their main subjects moduls totaling 18 CPs (1. - 3. semester).

- Master thesis with 30 CP (4. semester)

The sum of required credit points of this Master program is 150 CP.

The structural model of the dual study programme follows a module-differentiating approach. Given the practice-oriented element, the curriculum of the dual study programme is different compared to a standard Bachelor’s course. Five practical modules are completed at the dual students’ partner company as part of corresponding practical terms during lecture-free periods.

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 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 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	Prof. Matthias Kuhl
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 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 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. rer. nat. 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** / **Bonus** / **Form** / **Description** No / 10 % / Presentation /
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. rer. nat. 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. rer. nat. 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 M1137: Technical Elective Complementary Course for IMPMM - field ET (according to Subject Specific Regulations)

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

Module Responsible	Prof. Hoc Khiem Trieu
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge in electrical enginnering, physics, semiconductor devices and mathematics at Bachelor of Science level
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	As this modul can be chosen from the modul catalogue of the department E, the competence to be acquired is acccording to the chosen subject.
Skills	As this modul can be chosen from the modul catalogue of the department E, the skills to be acquired is acccording to the chosen subject.
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. • The students are able to draw scenarios for estimation of the impact of advanced mobile electronics on the future lifestyle of the society.
Workload in Hours	Depends on choice of courses
Credit points	6
Assignment for the Following Curricula	Microelectronics and Microsystems: Core Qualification: Elective Compulsory

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 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 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 M1759: Linking theory and practice (dual study program, Master's degree)

Module Responsible	Dr. Henning Haschke
Admission Requirements	None
Recommended Previous Knowledge	• Successful completion of practical modules as part of the dual Bachelor’s course • Module "interlinking theory and practice as part of the dual Master’s course"
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Dual students ... ... can describe and classify selected classic and current theories, concepts and methods • related to project management and • change and transformation management ... and apply them to specific situations, processes and plans in a personal, professional context.
Skills	Dual students ... • ... anticipate typical difficulties, positive and negative effects, as well as success and failure factors in the engineering sector, evaluate them and consider promising strategies and courses of action. • ... develop specialised technical and conceptual skills to solve complex tasks and problems in their professional field of activity/work.
Personal Competence	
Social Competence	Dual students ... • ... can responsibly lead interdisciplinary teams within the framework of complex tasks and problems. • ... engage in sector-specific and cross-sectoral discussions with experts, stakeholders and staff, representing their approaches, points of view and work results.
Autonomy	Dual students ... • ... define, reflect and evaluate goals and measures for complex application-oriented projects and change processes. • ... shape their professional area of responsibility independently and sustainably. • ... take responsibility for their actions and for the results of their work.
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	Studienbegleitende und semesterübergreifende Dokumentation: Die Leistungspunkte für das Modul werden durch die Anfertigung eines digitalen Lern- und Entwicklungsberichtes (E-Portfolio) erworben. Dabei handelt es sich um eine fortlaufende Dokumentation und Reflexion der Lernerfahrungen und der Kompetenzentwicklung im Bereich der Personalen Kompetenz.

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

Module M1756: Practical module 1 (dual study program, Master's degree)

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Practical term 1 (dual study program, Master's degree) (L2887)		0	10

Module Responsible	Dr. Henning Haschke
Admission Requirements	None
Recommended Previous Knowledge	• Successful completion of a compatible dual B.Sc. at TU Hamburg or comparable practical work experience and competences in the area of interlinking theory and practice • Course D from the module on interlinking theory and practice as part of the dual Master's course
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Dual students ... • ... combine their knowledge of facts, principles, theories and methods gained from previous study content with acquired practical knowledge - in particular their knowledge of practical professional procedures and approaches, in the current field of activity in engineering. • ... have a critical understanding of the practical applications of their engineering subject.
Skills	Dual students ... • ... apply technical theoretical knowledge to complex, interdisciplinary problems within the company, and evaluate the associated work processes and results, taking into account different possible courses of action. • ... implement the university's application recommendations with regard to their current tasks. • ... develop solutions as well as procedures and approaches in their field of activity and area of responsibility.
Personal Competence	
Social Competence	Dual students ... • ... work responsibly in project teams within their working area and proactively deal with problems within their team. • ... represent complex engineering viewpoints, facts, problems and solution approaches in discussions with internal and external stakeholders.
Autonomy	Dual students ... • ... define goals for their own learning and working processes as engineers. • ... reflect on learning and work processes in their area of responsibility. • ... reflect on the relevance of subject modules specialisations and specialisation for work as an engineer, and also implement the university's application recommendations and the associated challenges to positively transfer knowledge between theory and practice.
Workload in Hours	Independent Study Time 300, Study Time in Lecture 0
Credit points	10
Course achievement	None
Examination	Written elaboration
Examination duration and scale	Documentation accompanying studies and across semesters: Module credit points are earned by completing a digital learning and development report (e-portfolio). This documents and reflects individual learning experiences and skills development relating to interlinking theory and practice, as well as professional practice. In addition, the partner company provides proof to the dual@TUHH Coordination Office that the dual student has completed the practical phase.
Assignment for the Following Curricula	Civil Engineering: Core Qualification: Compulsory Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Core Qualification: Compulsory Computer Science: Core Qualification: Compulsory Electrical Engineering: Core Qualification: Compulsory Energy Systems: Core Qualification: Compulsory Environmental Engineering: Core Qualification: Compulsory Aircraft Systems Engineering: Core Qualification: Compulsory Computer Science in Engineering: Core Qualification: Compulsory Information and Communication Systems: Core Qualification: Compulsory International Management and Engineering: Core Qualification: Compulsory Logistics, Infrastructure and Mobility: Core Qualification: Compulsory Materials Science: Core Qualification: Compulsory Mechanical Engineering and Management: Core Qualification: Compulsory Mechatronics: Core Qualification: Compulsory Biomedical Engineering: Core Qualification: Compulsory Microelectronics and Microsystems: Core Qualification: Compulsory Product Development, Materials and Production: Core Qualification: Compulsory Renewable Energies: Core Qualification: Compulsory Naval Architecture and Ocean Engineering: Core Qualification: Compulsory Theoretical Mechanical Engineering: Core Qualification: Compulsory Process Engineering: Core Qualification: Compulsory

	Water and Environmental Engineering: Core Qualification: Compulsory

Course L2887: Practical term 1 (dual study program, Master's degree)	
Typ	
Hrs/wk	0
CP	10
Workload in Hours	Independent Study Time 300, Study Time in Lecture 0
Lecturer	Dr. Henning Haschke
Language	DE
Cycle	WiSe/SoSe
Content	**Company onboarding process** • Assigning a professional field of activity as an engineer (B.Sc.) and associated fields of work • Establishing responsibilities and authorisation of the dual student within the company as an engineer (B.Sc.) • Working independently in a team and on selected projects - across departments and, if applicable, across companies • Scheduling the current practical module with a clear correlation to work structures • Scheduling the examination phase/subsequent study semester **Operational knowledge and skills** • Company-specific: Responsibility as an engineer (B.Sc.) in their own area of work, coordinating team and project work, dealing with complex contexts and unsolved problems, developing and implementing innovative solutions • Subject specialisation (corresponding to the chosen course [M.Sc.]) in the field of activity • Systemic skills • Implementing the university’s application recommendations (theory-practice transfer) in corresponding work and task areas across the company **Sharing/reflecting on learning** • Creating an e-portfolio • Importance of course contents (M.Sc.) when working as an engineer • Importance of development and innovation when working as an engineer
Literature	• Studierendenhandbuch • Betriebliche Dokumente • Hochschulseitige Handlungsempfehlungen zum Theorie-Praxis-Transfer

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. rer. nat. 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. rer. nat. Thomas Kusserow
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. rer. nat. Thomas Kusserow
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

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 M1131: Technical Elective Complementary Course for IMPMM - field TUHH (according to Subject Specific Regulations)

Courses	
Title	**Typ** **Hrs/wk** **CP**
Module Responsible	Prof. Hoc Khiem Trieu
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge in electrical enginnering, physics, semiconductor devices, software and mathematics at Bachelor of Science level.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	As this module can be chosen from the module catalogue of the TUHH, the competence to be acquired is according to the chosen subject.
Skills	As this module can be chosen from the module catalogue of the TUHH, the skills to be acquired is according to the chosen subject.
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	
Workload in Hours	Depends on choice of courses
Credit points	6
Assignment for the Following Curricula	Microelectronics and Microsystems: Core Qualification: Elective Compulsory

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 M1757: Practical module 2 (dual study program, Master's degree)

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Practical term 2 (dual study program, Master's degree) (L2888)		0	10

Module Responsible	Dr. Henning Haschke
Admission Requirements	None
Recommended Previous Knowledge	• Successful completion of practical module 1 as part of the dual Master's course • course D from the module on interlinking theory and practice as part of the dual Master's course
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Dual students ... • ... combine their knowledge of facts, principles, theories and methods gained from previous study content with acquired practical knowledge - in particular their knowledge of practical professional procedures and approaches, in the current field of activity in engineering. • ... have a critical understanding of the practical applications of their engineering subject.
Skills	Dual students ... • ... apply technical theoretical knowledge to complex, interdisciplinary problems within the company, and evaluate the associated work processes and results, taking into account different possible courses of action. • ... implement the university's application recommendations with regard to their current tasks. • ... develop (new) solutions as well as procedures and approaches in their field of activity and area of responsibility - including in the case of frequently changing requirements (systemic skills).
Personal Competence	
Social Competence	Dual students ... • ... work responsibly in cross-departmental and interdisciplinary project teams and proactively deal with problems within their team. • ... represent complex engineering viewpoints, facts, problems and solution approaches in discussions with internal and external stakeholders and develop these further together.
Autonomy	Dual students ... • ... define goals for their own learning and working processes as engineers. • ... reflect on learning and work processes in their area of responsibility. • ... reflect on the relevance of subject modules specialisations and specialisation for work as an engineer, and also implement the university's application recommendations and the associated challenges to positively transfer knowledge between theory and practice.
Workload in Hours	Independent Study Time 300, Study Time in Lecture 0
Credit points	10
Course achievement	None
Examination	Written elaboration
Examination duration and scale	Documentation accompanying studies and across semesters: Module credit points are earned by completing a digital learning and development report (e-portfolio). This documents and reflects individual learning experiences and skills development relating to interlinking theory and practice, as well as professional practice. In addition, the partner company provides proof to the dual@TUHH Coordination Office that the dual student has completed the practical phase.
Assignment for the Following Curricula	Civil Engineering: Core Qualification: Compulsory Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Core Qualification: Compulsory Computer Science: Core Qualification: Compulsory Electrical Engineering: Core Qualification: Compulsory Energy Systems: Core Qualification: Compulsory Environmental Engineering: Core Qualification: Compulsory Aircraft Systems Engineering: Core Qualification: Compulsory Computer Science in Engineering: Core Qualification: Compulsory Information and Communication Systems: Core Qualification: Compulsory International Management and Engineering: Core Qualification: Compulsory Logistics, Infrastructure and Mobility: Core Qualification: Compulsory Materials Science: Core Qualification: Compulsory Mechanical Engineering and Management: Core Qualification: Compulsory Mechatronics: Core Qualification: Compulsory Biomedical Engineering: Core Qualification: Compulsory Microelectronics and Microsystems: Core Qualification: Compulsory Product Development, Materials and Production: Core Qualification: Compulsory Renewable Energies: Core Qualification: Compulsory Naval Architecture and Ocean Engineering: Core Qualification: Compulsory Theoretical Mechanical Engineering: Core Qualification: Compulsory

	Process Engineering: Core Qualification: Compulsory Water and Environmental Engineering: Core Qualification: Compulsory

Course L2888: Practical term 2 (dual study program, Master's degree)	
Typ	
Hrs/wk	0
CP	10
Workload in Hours	Independent Study Time 300, Study Time in Lecture 0
Lecturer	Dr. Henning Haschke
Language	DE
Cycle	WiSe/SoSe
Content	**Company onboarding process** • Assigning a professional field of activity as an engineer (B.Sc.) and associated fields of work • Establishing responsibilities and authorisation of the dual student within the company as an engineer (B.Sc.) • Taking personal responsibility within a team and on selected projects - across departments and, if applicable, across companies • Scheduling the current practical module with a clear correlation to work structures • Scheduling the examination phase/subsequent study semester **Operational knowledge and skills** • Company-specific: Responsibility as an engineer (B.Sc.) in their own area of work, coordinating team and project work, dealing with complex contexts and unsolved problems, developing and implementing innovative solutions • Subject specialisation (corresponding to the chosen course [M.Sc.]) in the field of activity • Systemic skills • Implementing the university’s application recommendations (theory-practice transfer) in corresponding work and task areas across the company **Sharing/reflecting on learning** • Updating their e-portfolio • Importance of course contents (M.Sc.) when working as an engineer • Importance of development and innovation when working as an engineer
Literature	• Studierendenhandbuch • Betriebliche Dokumente • Hochschulseitige Anwendungsempfehlungen zum Theorie-Praxis-Transfer

Module M1130: Project Work IMPMM

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

Module Responsible	Dozenten des SD E
Admission Requirements	None
Recommended Previous Knowledge	Good knowledge in the design of electronic circuits, microprocessor systems, systems for signal processing and the handling of software packages for simulation of electrical and physical processes.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The student is able to achieve in a specific scientific field special knowledge and she or he can independently acquire in this field the skills necessary for solving these scientific problems.
Skills	The student is able to formulate the scientific problems to be solved and to work out solutions in an independent manner and to realize them.
Personal Competence	
Social Competence	The student can integrate herself or himself into small teams of researchers and she or he can discuss proposals for solutions of scientific problems within the team. She or he is able to present the results in a clear and well structured manner.
Autonomy	The student can perform scientific work in a timely manner and document the results in a detailed and well readable form. She or he is able to anticipate possible problems well in advance and to prepare proposals for their solutions.
Workload in Hours	Independent Study Time 450, Study Time in Lecture 0
Credit points	15
Course achievement	None
Examination	Study work
Examination duration and scale	see FSPO
Assignment for the Following Curricula	Microelectronics and Microsystems: Core Qualification: Compulsory

Module M1591: Seminar for IMPMM

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Seminar for IMPMM (L2428)	Seminar	2	3

Module Responsible	Prof. Hoc Khiem Trieu
Admission Requirements	None
Recommended Previous Knowledge	Basics from the field of the seminar
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Students can explain the most important facts and relationships of a specific topic from the field of the seminar.
Skills	Students are able to compile a specified topic from the field of the seminar and to give a clear, structured and comprehensible presentation of the subject. They can comply with a given duration of the presentation. They can write in English a summary including illustrations that contains the most important results, relationships and explanations of the subject.
Personal Competence	
Social Competence	Students are able to adapt their presentation with respect to content, detailedness, and presentation style to the composition and previous knowledge of the audience. They can answer questions from the audience in a curt and precise manner.
Autonomy	Students are able to autonomously carry out a literature research concerning a given topic. They can independently evaluate the material. They can self-reliantly decide which parts of the material should be included in the presentation.
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Credit points	3
Course achievement	None
Examination	Presentation
Examination duration and scale	15 minutes presentation + 5-10 minutes discussion + 2 pages written abstract
Assignment for the Following Curricula	Microelectronics and Microsystems: Core Qualification: Compulsory

Course L2428: Seminar for IMPMM

Typ	Seminar
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Hoc Khiem Trieu
Language	EN
Cycle	WiSe/SoSe
Content	Prepare, present, and discuss talks about recent topics from the field of semiconductors. The presentations must be given in English. ***Evaluation Criteria:*** • understanding of subject, discussion, response to questions • structure and logic of presentation (clarity, precision) • coverage of the topic, selection of subjects presented • linguistic presentation (clarity, comprehensibility) • visual presentation (clarity, comprehensibility) • handout (see below) • compliance with timing requirement. ***Handout:*** A printed handout (short abstract) of your presentation in English language is mandatory. This should not be longer than two pages A4, and include the most important results, conclusions, explanations and diagrams.
Literature	Aktuelle Veröffentlichungen zu dem gewählten Thema. Recent publications of the selected topics.

Module M1758: Practical module 3 (dual study program, Master's degree)

Courses

Title	Typ	Hrs/wk	CP
Practical term 3 (dual study program, Master's degree) (L2889)		0	10

Module Responsible	Dr. Henning Haschke
Admission Requirements	None
Recommended Previous Knowledge	• Successful completion of practical module 2 as part of the dual Master's course • course E from the module on interlinking theory and practice as part of the dual Master's course
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Dual students ... • ... combine their comprehensive and specialised engineering knowledge acquired from previous study contents with the strategy-oriented practical knowledge gained from their current field of work and area of responsibility. • ... have a critical understanding of the practical applications of their engineering subject, as well as related fields when implementing innovations.
Skills	Dual students ... • ... apply specialised and conceptual skills to solve complex, sometimes interdisciplinary problems within the company, and evaluate the associated work processes and results, taking into account different possible courses of action. • ... implement the university's application recommendations with regard to their current tasks. • ... develop new solutions as well as procedures and approaches to implement operational projects and assignments - even when facing frequently changing requirements and unpredictable changes (systemic skills). • ... can use academic methods to develop new ideas and procedures for operational problems and issues, and to assess these with regard to their usability.
Personal Competence	
Social Competence	Dual students ... • ... work responsibly in cross-departmental and interdisciplinary project teams and proactively deal with problems within their team. • ... can promote the professional development of others in a targeted manner. • ... represent complex and interdisciplinary engineering viewpoints, facts, problems and solution approaches in discussions with internal and external stakeholders and develop these further together.
Autonomy	Dual students ... • ... reflect on learning and work processes in their area of responsibility. • ... define goals for new application-oriented tasks, projects and innovation plans while reflecting on potential effects on the company and the public. • ... reflect on the relevance of areas of specialisation and research for work as an engineer, and also implement the university's application recommendations and the associated challenges to positively transfer knowledge between theory and practice.
Workload in Hours	Independent Study Time 300, Study Time in Lecture 0
Credit points	10
Course achievement	None
Examination	Written elaboration
Examination duration and scale	Documentation accompanying studies and across semesters: Module credit points are earned by completing a digital learning and development report (e-portfolio). This documents and reflects individual learning experiences and skills development relating to interlinking theory and practice, as well as professional practice. In addition, the partner company provides proof to the dual@TUHH Coordination Office that the dual student has completed the practical phase.
Assignment for the Following Curricula	Civil Engineering: Core Qualification: Compulsory Bioprocess Engineering: Core Qualification: Compulsory Chemical and Bioprocess Engineering: Core Qualification: Compulsory Computer Science: Core Qualification: Compulsory Electrical Engineering: Core Qualification: Compulsory Energy Systems: Core Qualification: Compulsory Environmental Engineering: Core Qualification: Compulsory Aircraft Systems Engineering: Core Qualification: Compulsory Computer Science in Engineering: Core Qualification: Compulsory Information and Communication Systems: Core Qualification: Compulsory International Management and Engineering: Core Qualification: Compulsory Logistics, Infrastructure and Mobility: Core Qualification: Compulsory Materials Science: Core Qualification: Compulsory Mechanical Engineering and Management: Core Qualification: Compulsory Mechatronics: Core Qualification: Compulsory

	Biomedical Engineering: Core Qualification: Compulsory Microelectronics and Microsystems: Core Qualification: Compulsory Product Development, Materials and Production: Core Qualification: Compulsory Renewable Energies: Core Qualification: Compulsory Naval Architecture and Ocean Engineering: Core Qualification: Compulsory Theoretical Mechanical Engineering: Core Qualification: Compulsory Process Engineering: Core Qualification: Compulsory Water and Environmental Engineering: Core Qualification: Compulsory

Course L2889: Practical term 3 (dual study program, Master's degree)	
Typ	
Hrs/wk	0
CP	10
Workload in Hours	Independent Study Time 300, Study Time in Lecture 0
Lecturer	Dr. Henning Haschke
Language	DE
Cycle	WiSe/SoSe
Content	**Company onboarding process** • Assigning a future professional field of activity as an engineer (M.Sc.) and associated fields of work • Extending responsibilities and authorisation of the dual student within the company up to the intended first assignment after completing their studies • Working responsibly in a team; project responsibility within own area - as well as across divisions and companies if necessary • Scheduling the final practical module with a clear correlation to work structures • Internal agreement on a potential topic or innovation project for the Master’s dissertation • Planning the Master’s dissertation within the company in cooperation with TU Hamburg • Scheduling the examination phase/subsequent study semester **Operational knowledge and skills** • Company-specific: dealing with change, project and team development, responsibility as an engineer in their future field of work (M.Sc.), dealing with complex contexts, frequent and unpredictable changes, developing and implementing innovative solutions • Specialising in one field of work (final dissertation) • Systemic skills • Implementing the university’s application recommendations (theory-practice transfer) in corresponding work and task areas across the company **Sharing/reflecting on learning** • E-portfolio • Relevance of study content and personal specialisation when working as an engineer • Relevance of research and innovation when working as an engineer
Literature	• Studierendenhandbuch • betriebliche Dokumente • Hochschulseitige Anwendungsempfehlungen zum Theorie-Praxis-Transfer

Specialization Communication and Signal Processing

Students of the specialization Communication and Signal Processing learn both physical and technical basics of state-of-the-art wired and wireless communication systems and the hardware realization of those systems. They can deepen their knowledge towards core areas such as systems for audio or video signal processing. The students understand the fundamental concepts of those systems and can identify their limitations. Based on this knowledge they are able to determine possible improvements and to implement them.

Students have to choose lectures with a total of 18 credit points from the catalog of this specialization.

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 Mechatronics: Technical Complementary Course: 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	Prof. Andreas Timm-Giel
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	Prof. Andreas Timm-Giel, Dr.-Ing. 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	Prof. Andreas Timm-Giel
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 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 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. Ing. 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 M0738: Digital Audio Signal Processing

Courses

Title	Typ	Hrs/wk	CP
Digital Audio Signal Processing (L0650)	Lecture	3	4
Digital Audio Signal Processing (L0651)	Recitation Section (large)	1	2

Module Responsible	Prof. Udo Zölzer
Admission Requirements	None
Recommended Previous Knowledge	Signals and Systems
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Die Studierenden können die grundlegenden Verfahren und Methoden der digitalen Audiosignalverarbeitung erklären. Sie können die wesentlichen physikalischen Effekte bei der Sprach- und Audiosignalverarbeitung erläutern und in Kategorien einordnen. Sie können einen Überblick der numerischen Methoden und messtechnischen Charakterisierung von Algorithmen zur Audiosignalverarbeitung geben. Sie können die erarbeiteten Algorithmen auf weitere Anwendungen im Bereich der Informationstechnik und Informatik abstrahieren.
Skills	The students will be able to apply methods and techniques from audio signal processing in the fields of mobile and internet communication. They can rely on elementary algorithms of audio signal processing in form of Matlab code and interactive JAVA applets. They can study parameter modifications and evaluate the influence on human perception and technical applications in a variety of applications beyond audio signal processing. Students can perform measurements in time and frequency domain in order to give objective and subjective quality measures with respect to the methods and applications.
Personal Competence	
Social Competence	The students can work in small groups to study special tasks and problems and will be enforced to present their results with adequate methods during the exercise.
Autonomy	The students will be able to retrieve information out of the relevant literature in the field and putt hem into the context of the lecture. They can relate their gathered knowledge and relate them to other lectures (signals and systems, digital communication systems, image and video processing, and pattern recognition). They will be prepared to understand and communicate problems and effects in the field audio signal processing.
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	60 min
Assignment for the Following Curricula	Electrical Engineering: Specialisation Information and Communication Systems: 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 Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

Course L0650: Digital Audio Signal Processing	
Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Udo Zölzer
Language	EN
Cycle	WiSe
Content	• Introduction (Studio Technology, Digital Transmission Systems, Storage Media, Audio Components at Home) • Quantization (Signal Quantization, Dither, Noise Shaping, Number Representation) • AD/DA Conversion (Methods, AD Converters, DA Converters, Audio Processing Systems, Digital Signal Processors, Digital Audio Interfaces, Single-Processor Systems, Multiprocessor Systems) • Equalizers (Recursive Audio Filters, Nonrecursive Audio Filters, Multi-Complementary Filter Bank) • Room Simulation (Early Reflections, Subsequent Reverberation, Approximation of Room Impulse Responses) • Dynamic Range Control (Static Curve, Dynamic Behavior, Implementation, Realization Aspects) • Sampling Rate Conversion (Synchronous Conversion, Asynchronous Conversion, Interpolation Methods) • Data Compression (Lossless Data Compression, Lossy Data Compression, Psychoacoustics, ISO-MPEG1 Audio Coding)
Literature	- U. Zölzer, Digitale Audiosignalverarbeitung, 3. Aufl., B.G. Teubner, 2005 . - U. Zölzer, Digitale Audio Signal Processing, 2nd Edition, J. Wiley & Sons, 2005. - U. Zölzer (Ed), Digital Audio Effects, 2nd Edition, J. Wiley & Sons, 2011.

Course L0651: Digital Audio Signal Processing	
Typ	Recitation Section (large)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Udo Zölzer
Language	EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Module M1686: Selected Aspects of Communication and Signal Processing

Courses

Title	Typ	Hrs/wk	CP
Selected Aspects of Communication and Signal Processing (L2674)	Lecture	3	4
Selected Aspects of Communication and Signal Processing (L2675)	Recitation Section (small)	1	2

Module Responsible	Prof. Hoc Khiem Trieu
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	Microelectronics and Microsystems: Specialisation Communication and Signal Processing: Elective Compulsory

Course L2674: Selected Aspects of Communication and Signal Processing

Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Dozenten des SD E
Language	EN
Cycle	WiSe/SoSe
Content	
Literature	

Course L2675: Selected Aspects of Communication and Signal Processing

Typ	Recitation Section (small)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Dozenten des SD E
Language	EN
Cycle	WiSe/SoSe
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 Electrical Engineering: Specialisation Information and Communication Systems: Elective Compulsory Electrical Engineering: Specialisation Medical Technology: 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 International Management and Engineering: Specialisation II. Information Technology: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Mechatronics: Specialisation System Design: 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 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 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 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 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 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

Specialization Embedded Systems

Module M0791: Computer Architecture

Courses

Title	Typ	Hrs/wk	CP
Computer Architecture (L0793)	Lecture	2	3
Computer Architecture (L0794)	Project-/problem-based Learning	2	2
Computer Architecture (L1864)	Recitation Section (small)	1	1

Module Responsible	Prof. Heiko Falk
Admission Requirements	None
Recommended Previous Knowledge	Module "Computer Engineering"
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	This module presents advanced concepts from the discipline of computer architecture. In the beginning, a broad overview over various programming models is given, both for general-purpose computers and for special-purpose machines (e.g., signal processors). Next, foundational aspects of the micro-architecture of processors are covered. Here, the focus particularly lies on the so-called pipelining and the methods used for the acceleration of instruction execution used in this context. The students get to know concepts for dynamic scheduling, branch prediction, superscalar execution of machine instructions and for memory hierarchies.
Skills	The students are able to describe the organization of processors. They know the different architectural principles and programming models. The students examine various structures of pipelined processor architectures and are able to explain their concepts and to analyze them w.r.t. criteria like, e.g., performance or energy efficiency. They evaluate different structures of memory hierarchies, know parallel computer architectures and are able to distinguish between instruction- and data-level parallelism.
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 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** No, **Bonus** 15 %, **Form** Subject theoretical and practical work, **Description**
Examination	Written exam
Examination duration and scale	90 minutes, contents of course and 4 attestations from the PBL "Computer architecture"
Assignment for the Following Curricula	General Engineering Science (German program, 7 semester): Specialisation Computer Science: Elective Compulsory Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L0793: Computer Architecture	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Heiko Falk
Language	DE/EN
Cycle	WiSe
Content	• Introduction • VHDL Basics • Programming Models • Realization of Elementary Data Types • Dynamic Scheduling • Branch Prediction • Superscalar Machines • Memory Hierarchies The theoretical tutorials amplify the lecture's content by solving and discussing exercise sheets and thus serve as exam preparation. Practical aspects of computer architecture are taught in the FPGA-based PBL on computer architecture whose attendance is mandatory.
Literature	• D. Patterson, J. Hennessy. Rechnerorganisation und -entwurf. Elsevier, 2005. • A. Tanenbaum, J. Goodman. Computerarchitektur. Pearson, 2001.

Course L0794: Computer Architecture	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Prof. Heiko Falk
Language	DE/EN
Cycle	WiSe
Content	See interlocking course
Literature	See interlocking course

Course L1864: Computer Architecture	
Typ	Recitation Section (small)
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Heiko Falk
Language	DE/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	Oral exam
Examination duration and scale	25 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 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	

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** / **Bonus** / **Form** / **Description** No / 10 % / Attestation /
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 M1400: Design of Dependable Systems

Courses

Title	Typ	Hrs/wk	CP
Designing Dependable Systems (L2000)	Lecture	2	3
Designing Dependable Systems (L2001)	Recitation Section (small)	2	3

Module Responsible	Prof. Görschwin Fey
Admission Requirements	None
Recommended Previous Knowledge	Basic knowledge about data structures and algorithms
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	In the following "dependable" summarizes the concepts Reliability, Availability, Maintainability, Safety and Security. Knowledge about approaches for designing dependable systems, e.g., • Structural solutions like modular redundancy • Algorithmic solutions like handling byzantine faults or checkpointing Knowledge about methods for the analysis of dependable systems
Skills	Ability to implement dependable systems using the above approaches. Ability to analyzs the dependability of systems using the above methods for analysis.
Personal Competence	
Social Competence	Students • discuss relevant topics in class and • present their solutions orally.
Autonomy	Using accompanying material students independently learn in-depth relations between concepts explained in the lecture and additional solution strategies.
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** Die Lösung einer Aufgabe ist Zulassungsvoraussetzung für die Prüfung. Die Aufgabe wird in Vorlesung und Übung definiert.
Examination	Oral exam
Examination duration and scale	30 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Computer Science in Engineering: Specialisation I. Computer Science: Elective Compulsory Information and Communication Systems: Specialisation Secure and Dependable IT Systems: Elective Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L2000: Designing Dependable Systems	
Typ	Lecture
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Görschwin Fey
Language	DE/EN
Cycle	SoSe
Content	Description The term dependability comprises various aspects of a system. These are typically: • Reliability • Availability • Maintainability • Safety • Security This makes dependability a core aspect that has to be considered early in system design, no matter whether software, embedded systems or full scale cyber-physical systems are considered. Contents The module introduces the basic concepts for the design and the analysis of dependable systems. Design examples for getting practical hands-on-experience in dependable design techniques. The module focuses towards embedded systems. The following topics are covered: • Modelling • Fault Tolerance • Design Concepts • Analysis Techniques
Literature	

Course L2001: Designing Dependable Systems	
Typ	Recitation Section (small)
Hrs/wk	2
CP	3
Workload in Hours	Independent Study Time 62, Study Time in Lecture 28
Lecturer	Prof. Görschwin Fey
Language	DE/EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1772: Smart Sensors

Courses

Title	Typ	Hrs/wk	CP
Smart Sensors (L2904)	Lecture	2	2
Smart Sensors Lab (L2905)	Project-/problem-based Learning	3	4

Module Responsible	Prof. Ulf Kulau
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 110, Study Time in Lecture 70
Credit points	6
Course achievement	None
Examination	Oral exam
Examination duration and scale	25 min
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L2904: Smart Sensors

Typ	Lecture
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	SoSe
Content	
Literature	

Course L2905: Smart Sensors Lab

Typ	Project-/problem-based Learning
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Prof. Ulf Kulau
Language	DE/EN
Cycle	SoSe
Content	
Literature	

Module M0803: Embedded Systems

Courses

Title	Typ	Hrs/wk	CP
Embedded Systems (L0805)	Lecture	3	3
Embedded Systems (L2938)	Project-/problem-based Learning	1	1
Embedded Systems (L0806)	Recitation Section (small)	1	2

Module Responsible	Prof. Heiko Falk
Admission Requirements	None
Recommended Previous Knowledge	Computer Engineering
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Embedded systems can be defined as information processing systems embedded into enclosing products. This course teaches the foundations of such systems. In particular, it deals with an introduction into these systems (notions, common characteristics) and their specification languages (models of computation, hierarchical automata, specification of distributed systems, task graphs, specification of real-time applications, translations between different models). Another part covers the hardware of embedded systems: Sonsors, A/D and D/A converters, real-time capable communication hardware, embedded processors, memories, energy dissipation, reconfigurable logic and actuators. The course also features an introduction into real-time operating systems, middleware and real-time scheduling. Finally, the implementation of embedded systems using hardware/software co-design (hardware/software partitioning, high-level transformations of specifications, energy-efficient realizations, compilers for embedded processors) is covered.
Skills	After having attended the course, students shall be able to realize simple embedded systems. The students shall realize which relevant parts of technological competences to use in order to obtain a functional embedded systems. In particular, they shall be able to compare different models of computations and feasible techniques for system-level design. They shall be able to judge in which areas of embedded system design specific risks exist.
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 110, Study Time in Lecture 70
Credit points	6
Course achievement	**Compulsory** Yes; **Bonus** 10 %; **Form** Subject theoretical and practical work; **Description**
Examination	Written exam
Examination duration and scale	90 minutes, contents of course and labs
Assignment for the Following Curricula	General Engineering Science (German program, 7 semester): Specialisation Computer Science: Compulsory Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Electrical Engineering: Core Qualification: Elective Compulsory Engineering Science: Specialisation Mechatronics: Elective Compulsory Engineering Science: Specialisation Electrical Engineering: Elective Compulsory Aircraft Systems Engineering: Core Qualification: Elective Compulsory General Engineering Science (English program, 7 semester): Specialisation Mechatronics: Elective Compulsory Computer Science in Engineering: Core Qualification: Compulsory Mechatronics: Specialisation System Design: Elective Compulsory Mechatronics: Specialisation Intelligent Systems and Robotics: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L0805: Embedded Systems	
Typ	Lecture
Hrs/wk	3
CP	3
Workload in Hours	Independent Study Time 48, Study Time in Lecture 42
Lecturer	Prof. Heiko Falk
Language	EN
Cycle	SoSe
Content	• Introduction • Specifications and Modeling • Embedded/Cyber-Physical Systems Hardware • System Software • Evaluation and Validation • Mapping of Applications to Execution Platforms • Optimization
Literature	• Peter Marwedel. Embedded System Design - Embedded Systems Foundations of Cyber-Physical Systems. 2 nd Edition, Springer, 2012., Springer, 2012.

Course L2938: Embedded Systems	
Typ	Project-/problem-based Learning
Hrs/wk	1
CP	1
Workload in Hours	Independent Study Time 16, Study Time in Lecture 14
Lecturer	Prof. Heiko Falk
Language	EN
Cycle	SoSe
Content	• Introduction • Specifications and Modeling • Embedded/Cyber-Physical Systems Hardware • System Software • Evaluation and Validation • Mapping of Applications to Execution Platforms • Optimization
Literature	• Peter Marwedel. Embedded System Design - Embedded Systems Foundations of Cyber-Physical Systems. 2 nd Edition, Springer, 2012., Springer, 2012.

Course L0806: Embedded Systems	
Typ	Recitation Section (small)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Prof. Heiko Falk
Language	EN
Cycle	SoSe
Content	See interlocking course
Literature	See interlocking course

Module M1771: Research Based Learning - Smart Sensing Applications

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Research Based Learning - Smart Sensing Applications (L2903)	Project-/problem-based Learning	4	6

Module Responsible	Prof. Ulf Kulau
Admission Requirements	None
Recommended Previous Knowledge	• Embedded Systems • Smart Sensors • Technische Informatik
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	• Involvement of students in real research topic. • Topics may change depending on timeliness. BCG offers itself as a topic: It is relevant, current and interdisciplinary. • Create interdisciplinary connection points / colloquium with project-related, but also with institutes/universities from other disciplines • Generate or provide data sets • Find methods derive develop for integrated signal processing for the respective project reference • Soft skills in the area of communication & interdisciplinarity (learning to understand each other's language)
Skills	After completing the module, students are able to better understand and actively accompany scientific processes. Thereby, the involvement in a real research project (topic depending on topicality) is a high motivation and is given. Students receive a general understanding of the respective research project, iundem basics and backgrounds are conveyed. In order to be able to provide own research contributions within the set framework, methods for scientific practice are taught. • Teaching of fundamentals (interdisciplinary, smart sensors / other disciplines) • Design of experiments / hypotheses (framework is given -> methodology should be taught) • Execution of experiments (execution of experiments / generation of measurement data) • Scientific evaluation of the data • Presentation of results Discussion of further utilization (publication if necessary)
Personal Competence	
Social Competence	The work is done in groups and close cooperation and coordination within the individual teams is required. Through the interface "sensors" it is possible to select topics with a strong interdisciplinary share. Mutual understanding (finding a common language) is learned through this. Since real scientific problems are to be investigated, students acquire the ability to implement good scientific practice in a disciplined, objective and critical manner.
Autonomy	After completing the module, students will be able to independently plan and carry out scientific processes. In group work, organization, idea generation, derivation of hypotheses and thought processes are to be independently moderated and carried out.
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Credit points	6
Course achievement	None
Examination	Written elaboration
Examination duration and scale	Paper including the achieved results
Assignment for the Following Curricula	Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L2903: Research Based Learning - Smart Sensing Applications

Typ	Project-/problem-based Learning
Hrs/wk	4
CP	6
Workload in Hours	Independent Study Time 124, Study Time in Lecture 56
Lecturer	Prof. Ulf Kulau
Language	DE/EN
Cycle	SoSe
Content	
Literature	

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 M1687: Selected Aspects of Embedded Systems

Courses

Title	Typ	Hrs/wk	CP
Selected Aspects of Embedded Systems (L2676)	Lecture	3	4
Selected Aspects of Embedded Systems (L2677)	Recitation Section (small)	1	2

Module Responsible	Prof. Hoc Khiem Trieu
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	Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L2676: Selected Aspects of Embedded Systems

Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Dozenten des SD E
Language	EN
Cycle	WiSe/SoSe
Content	
Literature	

Course L2677: Selected Aspects of Embedded Systems

Typ	Recitation Section (small)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Dozenten des SD E
Language	EN
Cycle	WiSe/SoSe
Content	See interlocking course
Literature	See interlocking course

Module M0910: Advanced System-on-Chip Design (Lab)

Courses			
Title	**Typ**	**Hrs/wk**	**CP**
Advanced System-on-Chip Design (L1061)	Project-/problem-based Learning	3	6

Module Responsible	Prof. Heiko Falk
Admission Requirements	None
Recommended Previous Knowledge	Successful completion of the practical FPGA lab of module "Computer Architecture" is a mandatory prerequisite.
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	This module provides in-depth, hands-on experience on advanced concepts of computer architecture. Using the Hardware Description Language VHDL and using reconfigurable FPGA hardware boards, students learn how to design complex computer systems (so-called systems-on-chip, SoCs), that are commonly found in the domain of embedded systems, in actual hardware. Starting with a simple processor architecture, the students learn to how realize instruction-processing of a computer processor according to the principle of pipelining. They implement different styles of cache-based memory hierarchies, examine strategies for dynamic scheduling of machine instructions and for branch prediction, and finally construct a complex MPSoC system (multi-processor system-on-chip) that consists of multiple processor cores that are connected via a shared bus.
Skills	Students will be able to analyze, how highly specific and individual computer systems can be constructed using a library of given standard components. They evaluate the interferences between the physical structure of a computer system and the software executed thereon. This way, they will be enabled to estimate the effects of design decision at the hardware level on the performance of the entire system, to evaluate the whole and complex system and to propose design options to improve a system.
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, to transform this knowledge into actual implementations of complex hardware structures, and to associate this knowledge with contents of other classes.
Workload in Hours	Independent Study Time 138, Study Time in Lecture 42
Credit points	6
Course achievement	None
Examination	Subject theoretical and practical work
Examination duration and scale	VHDL Codes and FPGA-based implementations
Assignment for the Following Curricula	Computer Science: Specialisation I. Computer and Software Engineering: Elective Compulsory Microelectronics and Microsystems: Specialisation Embedded Systems: Elective Compulsory

Course L1061: Advanced System-on-Chip Design

Typ	Project-/problem-based Learning
Hrs/wk	3
CP	6
Workload in Hours	Independent Study Time 138, Study Time in Lecture 42
Lecturer	Prof. Heiko Falk
Language	DE/EN
Cycle	WiSe
Content	• Introduction into fundamental technologies (FPGAs, MIPS single-cycle machine) • Pipelined instruction execution • Cache-based memory hierarchies • Busses and their arbitration • Multi-Processor Systems-on-Chip • Optional: Advanced pipelining concepts (dynamic scheduling, branch prediction)
Literature	• D. Patterson, J. Hennessy. Rechnerorganisation und -entwurf. Elsevier, 2005. • A. Tanenbaum, J. Goodman. Computerarchitektur. Pearson, 2001. • A. Clements. The Principles of Computer Hardware. 3. Auflage, Oxford University Press, 2000.

Specialization Microelectronics Complements

Students of the specialization Microelectronics Complements expand their knowledge towards the application of microelectronics and microsystems for medical use, the processing of digital signals, the development and design of highly complex integrated systems and networks for optical communication. Thus, they strengthen their knowledge by analyzing practical applications and link it up with the requirements of technical realizations.

Students have to choose lectures with a total of 18 credit points from the catalog of this specialization.

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 M1611: Silicon Photonics

Courses

Title	Typ	Hrs/wk	CP
Silicon Photonics (L2408)	Lecture	2	4
Silicon Photonics (L2418)	Project-/problem-based Learning	2	2

Module Responsible	Dr. Timo Lipka
Admission Requirements	None
Recommended Previous Knowledge	Basics in physics, optics, microsystem and semiconductor technology
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	The students know the fundamentals of silicon photonics and about the most important and commonly used materials and fabrication techniques. Students are able • to explain the basic principles of silicon photonics technology and to discuss theoretical and practical aspects • to describe photonic circuit devices and their working principle • to describe the manufacturing of silicon photonic devices and to discuss in details the relevant fabrication processes, process flows and the impact thereof on the fabrication of photonic integrated circuit components
Skills	Students are capable to • analyze the feasibility of integrated photonic circuit components • choose appropriate tools and methods to design them • develop process flows for the fabrication
Personal Competence	
Social Competence	Students are able to prepare and perform their lab experiments in team work as well as to present and discuss the results in front of audience.
Autonomy	none
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	Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory

Course L2408: Silicon Photonics	
Typ	Lecture
Hrs/wk	2
CP	4
Workload in Hours	Independent Study Time 92, Study Time in Lecture 28
Lecturer	Dr. Timo Lipka
Language	EN
Cycle	WiSe
Content	• Introduction (historical view and trends in der Silicon Photonics) • Fabrication Technology (SOI-Wafer, Deposition, Sputtering and Evaporation, Epitaxy, MOCVD, Lithography) • Planar Waveguide Fundamentals • Optical Materials in silicon Photonics • Waveguide Types (Loss Mechanisms, Dispersion and Polarisation in Waveguides) • Coupling of Silicon Photonic Devices and Systems • Silicon Photonic Circuit Devices and Building Blocks (Passive Devices: Resonators, Interferometers, Mode Converters, Power Splitters, Gratings, Polarizers and Rotators) • Material fundamentals and components for tuning and switching • Integration of active Devices (Laser, Detector, Modulators) • Photonics and Electronics Integration • Photonic Interconnects • Optical Multiplexing • Switch Fabrics and Routers • Silicon Photonics for Sensing
Literature	• Graham T. Reed, Andrew Knights, Silicon Photonics - An Introduction, John Wiley & Sons Ltd (2004) • Clifford R. Pollocka and Michal Lipson, Integrated Photonics, Springer-Verlag (2003) • Sami Franssila, Introduction to microfabrication, Chichester, West Sussex Wiley (2010) • Dominik G. Rabus, Integrated Ring Resonators: The Compendium, in Springer Series in Optical Sciences (2007)

Course L2418: Silicon Photonics	
Typ	Project-/problem-based Learning
Hrs/wk	2
CP	2
Workload in Hours	Independent Study Time 32, Study Time in Lecture 28
Lecturer	Dr. Timo Lipka
Language	EN
Cycle	WiSe
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 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 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 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 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 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 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	Prof. Matthias Kuhl
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 M1688: Selected Aspects of Microelectronics and Microsystems

Courses

Title	Typ	Hrs/wk	CP
Selected Aspects of Microelectronics and Microsystems (L2678)	Lecture	3	4
Selected Aspects of Microelectronics and Microsystems (L2679)	Recitation Section (small)	1	2

Module Responsible	Prof. Hoc Khiem Trieu
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	Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory

Course L2678: Selected Aspects of Microelectronics and Microsystems

Typ	Lecture
Hrs/wk	3
CP	4
Workload in Hours	Independent Study Time 78, Study Time in Lecture 42
Lecturer	Dozenten des SD E
Language	EN
Cycle	WiSe/SoSe
Content	
Literature	

Course L2679: Selected Aspects of Microelectronics and Microsystems

Typ	Recitation Section (small)
Hrs/wk	1
CP	2
Workload in Hours	Independent Study Time 46, Study Time in Lecture 14
Lecturer	Dozenten des SD E
Language	EN
Cycle	WiSe/SoSe
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	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 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 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

Thesis

Module M1801: Master thesis (dual study program)

Courses			
Title	Typ	Hrs/wk	CP

Module Responsible	Professoren der TUHH
Admission Requirements	None
Recommended Previous Knowledge	
Educational Objectives	After taking part successfully, students have reached the following learning results
Professional Competence	
Knowledge	Dual students ... • ... use the specialised knowledge (facts, theories and methods) from their field of study and the acquired professional knowledge confidently to deal with technical and practical professional issues. • ... can explain the relevant approaches and terminologies in depth in one or more of their subject’s specialist areas, describe current developments and take a critical stance. • ... formulate their own research assignment to tackle a professional problem and contextualise it within their subject area. They ascertain the current state of research and critically assess it.
Skills	Dual students ... • ... can select suitable methods for the respective subject-related professional problem, apply them and develop them further as required. • ... assess knowledge and methods acquired during their studies (including practical phases) and apply their expertise to complex and/or incompletely defined problems in a solution- and application-oriented manner. • ... acquire new academic knowledge in their subject area and critically evaluate it.
Personal Competence	
Social Competence	Dual students ... • ... can present a professional problem in the form of an academic question in a structured, comprehensible and factually correct manner, both in writing and orally, for a specialist audience and for professional stakeholders. • ... answer questions as part of a professional discussion in an expert, appropriate manner. They represent their own points of view and assessments convincingly.
Autonomy	Dual students ... • ... can structure their own project into work packages, work through them at an academic level and reflect on them with regard to feasible courses of action for professional practice. • ... work in-depth in a partially unknown area within the discipline and acquire the information required to do so. • ... apply the techniques of academic work comprehensively in their own research work when dealing with an operational problem and question.
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 Electrical Engineering: Thesis: Compulsory Energy Systems: Thesis: Compulsory Environmental Engineering: Thesis: Compulsory Aircraft Systems Engineering: Thesis: Compulsory Computer Science in Engineering: Thesis: Compulsory Information and Communication Systems: Thesis: Compulsory International Management and Engineering: Thesis: Compulsory Logistics, Infrastructure and Mobility: 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

	Theoretical Mechanical Engineering: Thesis: Compulsory Process Engineering: Thesis: Compulsory Water and Environmental Engineering: Thesis: Compulsory