Module Manual

to the examination regulations

Study program Smart Materials and Systems
with the degree Master of Science

Date of issue: 15.12.2023

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The original version in German is legally binding.

FBE0297	Thesis	PF/WP **PF**	Weight of the Grade **30**	Workload **30 CP**	Expenditure **900 h**
Qualification Goals: Graduates are able to analyze scientific problems. They are able to plan and manage projects in a structured, systematic and independent manner. They can write comprehensive scientific texts, reflect on their own scientific work and evaluate and present the results achieved.					
Duration of the Module: 1	**Frequency:** every semester	**Recommended semester:** 4			

Evidence	**Form**	**Duration/Scope**	**Repeatability**	**CP**
Prerequisite for the final module examination: The prerequisite for the issue of the topic of the final thesis is proof of at least 36 CP from the compulsory area in accordance with § 10 of the examination regulations.				
Final module examination ID: 81846	**Thesis**	6 months	1	27
Ungraded achievement ID: 81847	Form according to explanation		unlimited	3
Explanation: Presentation with colloquium				

Component(s)		PF/WP	Form of Teaching	Semester hours per week	Expenditure
FBE0297-a	**Preparation of the thesis**	PF	Project	0	900 h

Contents:

The Master's thesis is a written final project with a theoretical, practical, programming or experimental focus, depending on the task. The task and objective of the thesis are communicated between the student and one or more university lecturers. The thesis should demonstrate the student's ability to independently analyze problems and issues in electrical engineering or materials science using engineering working methods and to find a solution - preferably a generally valid and scientific one. The Master's thesis is generally organized and conducted in the following phases:

1. Preparation
   - Preparation of the schedule and resource requirements,
   - Description of the given problem and/or task,
   - Determination/presentation of the relevant state of the art,
   - Development and description of one or more solution concepts,
   - preference for one or more solutions.

2. Implementation
   - Realization/implementation of the selected solution,
   - Preparation of the written elaboration with validation and evaluation of the results achieved.

3. Presentation
   - Presentation of the problem/task, the solution concept and its realization, the results and their evaluation with subsequent discussion.

Mandatory Part

<table>
<tr><td rowspan="2">FBE012
0</td><td rowspan="2">Electromagnetic Theory I</td><td>PF/WP</td><td>Weight of grade</td><td>Work Load</td><td>Expenditure</td></tr>
<tr><td>PF</td><td>6</td><td>6 CP</td><td>180 h</td></tr>
<tr><td colspan="6">Qualification goals:
Students have in-depth scientific knowledge of electric, magnetic and electromagnetic fields, their mathematical-physical modeling within the framework of Maxwell's field theory and the associated taxonomy of field models relevant to technical practice, incorporating simplified models from basic electrical engineering training. They are familiar with the terminology of electromagnetic field theory. Students understand Poynting's theorem as a conservation law of electrodynamics and the associated concepts of electromagnetic energy transport along line structures and in free space. Students will be able to calculate simple electric, magnetic and electromagnetic field arrangements using analytical methods.</td></tr>
<tr><td colspan="6">General remarks:
Good knowledge of mathematics and electrical engineering is expected.</td></tr>
<tr><td colspan="2">Duration of module: 1 semester</td><td colspan="2">Frequency: every 2nd semester</td><td colspan="2">Recommended semester: 1</td></tr>
</table>

Evidence	Form	Duration/Scope	Repeatability	CP
Final module examination ID: 39029	Written exam	180 minutes	unlimited	6

<table>
<tr><td colspan="2">Component(s)</td><td>PF/WF</td><td>Form of Teaching</td><td>Semester hours per week</td><td>Expenditure</td></tr>
<tr><td>FBE0120-a</td><td>Theoretical Electrical Engineering I</td><td>PF</td><td>Lecture/ Exercise</td><td>5</td><td>180 h</td></tr>
<tr><td colspan="6">Contents:
Terms and concepts of electromagnetic field theory: Maxwell's equations; formal methods for calculating electrostatic and magnetostatic fields as well as slowly and rapidly changing electromagnetic fields. Concept of the (complex) Poynting vector and Poynting's theorem</td></tr>
</table>

FBE0290	**Sustainable Electromagnetic Materials and Devices**	PF/WP **PF**	Weight of the grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualifikationsziele:

Students know properties of the most important materials for solar cells, light-emitting diodes, semiconductor lasers, photo detectors, as well as for thermoelectric energy generation, and understand the detailed functioning of the components. Students will have a basic knowledge and understanding of the requirements in the field of sustainable electrical power generation, lighting and light detection. The fundamentals of photonic components and their possible applications in quantum technologies are taught.

General remarks:

Sound knowledge from the modules "Werkstoffe und Grundschaltungen" and "Elektronische Bauelemente" is expected.

Duration of the module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 1

Evidence	**Form**	**Duration/Scope**	**Repeatability**	**CP**
Final module examination ID: 82155	**Written exam**	90 minutes	unlimited	6

Component(s)		**PF/WF**	**Form of Teaching**	**Semester hours per week**	**Expenditure**
FBE0290-a	**Sustainable Electromagnetic Materials and Devices**	PF	Lecture/ Exercise	5	180 h

Contents:

- Monocrystalline and polycrystalline silicon
- GaAs, GaN and other III/V compound semiconductors
- Metal oxide semiconductors
- Perovskites
- Organic semiconductors
- Two-dimensional materials
- Functionality of solar cells, light-emitting diodes, semiconductor lasers, photodetectors and thermoelectric power generation
- Power transistors for inverters/rectifiers
- Components of optical data communication
- Photonic systems (single photon sources, interferometers, integrated optoelectronics, modulators, single photon detection, entanglement, non-linearities)

FBE0086	Communication Technology	PF/WP **WP**	Weight of the grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goal:

Students know the basics of communication technology, including in particular knowledge of message transmission via different channels and networks. Students will be familiar with the basics of source, channel and line coding and know what influence channel characteristics and channel interference can have on transmission. In particular, they are familiar with procedures to minimize these influences if necessary. Students will be familiar with multiplex techniques as well as analog and digital modulation methods. Students are familiar with network structures, switching principles and the basics of protocol architectures. The basic knowledge gained can be transferred to existing systems and networks by way of example.

General remarks:

If offered in this degree program, knowledge from the modules "Signals and Systems" and "Fundamentals of Electrical Engineering I, II" is expected; if the module is / was credited in the Bachelor's degree program, it may not be taken in the Master's degree program.

Duration of module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 1

Evidence	Form	Duration/Scope	Repeatability	CP
Final module examination ID: 39288	Written exam	180 minutes	unlimited	6

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE0120-a	**Communication Technology**	PF	Lecture/ Exercise	5	180 h

Contents:

Introduction:
Elements of an electrical communication system, communication channels and their properties, signal transmission, modelling of communication channels, structure of digital networks
Source coding:
Digital processing of physical signals, quantization, basic concepts of information theory, entropy, redundancy and irrelevance reduction, data reduction methods
Channel coding:
Block codes, cyclic codes, convolutional codes, CRC codes. Code space, arithmetic with residual classes, residual error probability
Digital message transmission in the baseband:
line coding, data transmission via a disturbed and band-limited channel, intersymbol interference and Nyquist pulse shaping, signal-matched filtering, channel capacity
Modulation methods and multiplexing techniques:
Bandpass signals, Analog modulation techniques (AM, FM, PM), Digital modulation techniques (ASK, FSK, PSK, multistage techniques, OFDM), Multiplexing techniques (FDMA, TDMA, CDMA, SDMA, MIMO).
Communication networks:
Network structures, basic protocols, PDH and SDH, OSI layer model, Internet Protocol
Mobile radio systems:
Basics, GSM, UMTS/HSPA, LTE, wireless technologies, WLAN

FBE0291	**Characterisation Techniques in Material Science**	PF/WP **PF**	Weight of the grade **6**	Workload **6 CP**	Expenditure **180 h**
Qualification Goals: Students know the most important electrical and optical measurement methods in materials science and understand how the characteristic parameters of materials and components can be determined using these methods. Students have the knowledge to independently apply basic measuring methods.					
Duration of the module: 1 semester		**Frequency:** every 2nd semester		**Recommended semester:** 2	

Evidence	Form	Duration/Scope	Repeatability	CP
Final module examination ID: 82158	Written exam	90 minutes	unlimited	6

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE0291-a	**Characterisation Techniques in Material Science**	PF	Lecture/ Exercise	3	120 h

Contents:

- Electrical characterisation of semiconductors
- •4-point probe, transmission-line, Hall effect; impedance spectroscopy, C-V
- •Introduction to optical spectroscopy (tools and set-ups)
- •Absorption, transmission and reflection measurements
- •Photoluminescence measurements; quantum efficiency
- •Ultrafast spectroscopy
- •Raman spectroscopy
- •Infrared spectroscopy
- •Scanning probe microscopy
- •Electron microscopy (incl. EDX, EBSD)
- •X-ray diffraction techniques
- •Photoelectron spectroscopy (UPS, XPS)
- •Ellipsometry
- •Electrical and optical characterisation of devices ((photo-; light-; laser-) diodes and transistors)
- •Characterisation of solar cells

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE0291-b	**Practical Training**	PF	Practical Training	2	60 h

Contents:

Three experiments on electrical and optical measurement methods.

<table>
<tr><td>FBE0292</td><td>Computer Science for Engineers</td><td>PF/WF
PF</td><td>Weight of the grade
6</td><td>Work Load
6 CP</td><td>Expenditure
180 h</td></tr>
<tr><td colspan="6">Qualification goals:
Course participants have an overview of the state-of-the-art technologies and tools in computer science. Through lectures, exercises and individual work, students will train their ability to:
• analyze a given problem from a computing perspective,
• research programmatical methods to solve the problem,
• implement a solution for the problem using suitable tools,
• structure, write, and format documentation for the software developed,
• present their work using appropriate presentation techniques and presentation aids,
• answer questions and discuss their work with peers.
Through practical work on a projects, students will dive deeper into selected topics and technologies and acquire essential skills to solve applied research problems in computer science. By completing the course, participants will acquire the knowledge and the skills required to perform research in computer science and to complete a range of applied problems related to the computer science field.</td></tr>
<tr><td colspan="2">Duration of module: 1 semester</td><td colspan="2">Frequency: every 2nd semester</td><td colspan="2">Recommended semester: 1</td></tr>
</table>

<table>
<tr><td>Evidence</td><td>Form</td><td>Duration/Scope</td><td>Repeatability</td><td>CP</td></tr>
<tr><td>Final module examination ID: 82162</td><td>Written exam</td><td>90 minutes</td><td>unlimited</td><td>3</td></tr>
<tr><td colspan="5">Organization of the ungraded course achievement(s):
The ungraded course achievement 82164 has to be fulfilled in component b.</td></tr>
<tr><td>Ungraded achievement ID: 82164</td><td>Form according to announcement</td><td></td><td>unlimited</td><td>3</td></tr>
</table>

<table>
<tr><th colspan="2">Component(s)</th><th>PF/WF</th><th>Form of Teaching</th><th>Semester hours per week</th><th>Expenditure</th></tr>
<tr><td>FBE0292-a</td><td>Key Competences in Computer Science</td><td>PF</td><td>Lecture/ Exercise</td><td>4</td><td>120 h</td></tr>
<tr><td colspan="6">Contents:
The lecture will cover the following topics:
• command-line & scripting
• shell, ssh, sftp
• grep, sed, regular expressions,
• shell scripting
• Python basics
• unit testing
• logging
• parallelization
• database interaction
• web technologies and web frameworks
• HTML & CSS - JavaScript infrastructure & support tools
• IDEs
• version control using git
• LaTeX, OverLeaf and reference management tools

The exercise sessions will mix assignments and a comprehensive applied research project. The assignments will consolidate the key concepts introduced in the lecture. The applied research project (see component b) will address a basic problem in computer science.</td></tr>
<tr><td>FBE0292-b</td><td>Applied Research Project</td><td>PF</td><td>Practical Training</td><td>0</td><td>60 h</td></tr>
<tr><td colspan="6">Contents:
Participants will carry out a comprehensive applied research project that addresses a basic problem in computer science. Project suggestions will be provided; suggesting own projects is possible. Teamwork is possible. Presenting the intermediate and final results of the projects during the exercise sessions is mandatory.</td></tr>
</table>

FBE0299	**Advanced Mathematics**	PF/WP **PF**	Weight of the grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goals:
Students are familiar with advanced mathematical methods and know how to use them in an application-oriented manner. They have the mathematical basics for advanced courses. They possess the ability for mathematical modeling and scientific reasoning.

General remarks:
Knowledge from the modules Mathematics A and B is expected.

Duration of the module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 1

Evidence	**Form**	**Duration/Scope**	**Repeatability**	**CP**
Final module examination ID: 82192	Written exam	120 minutes	unlimited	6

Component(s)		**PF/WF**	**Form of Teaching**	**Semester hours per week**	**Expenditure**
FBE0299-a	**Advanced Mathematics**	PF	Lecture/ Exercise	5	180 h

Contents:
- Multiple integrals
- Vector analysis
- Theory of Functions
- Differential equations

FBE0293	Seminar - Smart Materials and Systems	PF/WP PF	Weight of the grade 0	Workload 6 CP	Expenditure 180 h

Qualification Goals:

Students are able to apply the knowledge of a research or application area from the fields of electrical engineering, information technology and material sciences acquired during the course of study to prepare a scientific presentation on a given topic and to present it to a specialist audience.The students

- master methods of literature research,
- have mastered the basic rules of presentation techniques in a scientific context,
- are essentially capable of scientific discourse,
- master the scientific elaboration of new topics.

Duration of the module: 1 semester	**Frequency:** every semester	**Recommended semester:** 2

Evidence	Form	Duration/Scope	Repeatability	CP
Final module examination ID: 82168	Portfolio with assessment		unlimited	6

Explanation concerning the final module examination:

Two presentations each with a duration of approx. 30 min.

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE0293-a	**Seminar - Smart Materials and Systems**	PF	Seminar	2	180 h

Remarks:

For students of the degree programmes Smart Materials and Systems with the degree Master of Science attendance is compulsory in the course in accordance with the guideline for dealing with compulsory attendance (current Amtliche Mitteilungen der Bergischen Universität Wuppertal).

Contents:

Current complex topics in electrical engineering, material sciences, information technology and related fields are dealt with.

Elective area Materials and Fundamentals

<table>
<tr><td>FBE0279</td><td>Two-dimensional Materials: Properties and Applications</td><td>PF/WP
WP</td><td>Weight of the grade
6</td><td>Workload
6 CP</td><td>Expenditure
180 h</td></tr>
<tr><td colspan="6">Qualification Goals:
The students will have a comprehensive overview of various two-dimensional materials such as graphene or transition-metaldichalcogenides (TMDCs). They know the basic electrical and optical properties of these materials. Based on this, the students can apply these properties in various applications, with an emphasis on applications in microelectronics, photonics, and sensors. The students know how to conduct independent scientific literature research as well as how to process and present the results of this research.</td></tr>
<tr><td colspan="6">General remarks:
Good knowledge from the lectures „Werkstoffe und Grundschaltungen" (Materials and Basic Circuits) or „Elektronische Bauelemente" (Electronic devices) is expected. The module is offered in English.</td></tr>
<tr><td colspan="2">Duration of the module: 1 semester</td><td colspan="2">Frequency: every 2nd semester</td><td colspan="2">Recommended semester: 2</td></tr>
</table>

Evidence	**Form**	**Duration/Scope**	**Repeatability**	**CP**
Final module examination ID: 73699	Oral exam	30 min	unlimited	6

<table>
<tr><td colspan="2">Component(s)</td><td>PF/WF</td><td>Form of Teaching</td><td>Semester hours per week</td><td>Expenditure</td></tr>
<tr><td>FBE0279-a</td><td>Two-dimensional Materials: Properties and Applications</td><td>PF</td><td>Lecture/ Exercise</td><td>5</td><td>180 h</td></tr>
<tr><td colspan="6">Contents:
Two-dimensional materials like graphene have become a dynamic field in research within the past 15 years. This module will give an overview on the properties of 2D materials and address possible applications in the fields of microelectronics, sensors and photonics.Content:
• Overview on different 2D Materials: Graphene, hBN, Mo$2 and other TMDC.
• Characterisation methods for 2D materials
• Synthesis of Graphene and TMDCs
• Electronic and photonic applications of graphene
• Photonic and electronic applications ofTMDCs
• Sensor applications of 2D materials
• Composite materials
• Market perspectives for 2D materials</td></tr>
</table>

<table>
<tr><td>FBE0189</td><td>Advanced Thin Film Technologies</td><td>PF/WP
WP</td><td>Weight of the grade
6</td><td>Workload
6 CP</td><td>Expenditure
180 h</td></tr>
<tr><td colspan="6">Qualification Goals:
The students
are familiar with the practical and theoretical principles of key processes, including plasma-assisted processes, for the production of thin films,
are able to assess the essential interactions between process parameters and layer properties and are familiar with the fundamental problems of process scaling from laboratory to production scale,
are familiar with examples of systems and applications in the industrial production of thin films, particularly in electrical engineering,
are familiar with essential methods for analyzing thin films,
are able to recognize and understand interdisciplinary interfaces with other areas,
are able to independently acquire further specialist knowledge, including from related fields, using specialist literature (especially primary literature).
Students are able to structure and present complex issues in a targeted and target-oriented manner in the time available to them.</td></tr>
<tr><td colspan="6">General remarks:
Good knowledge of the contents of the Materials and Basic Circuits module is recommended.</td></tr>
<tr><td colspan="2">Duration of the module: 1 semester</td><td colspan="2">Frequency: every 2nd semester</td><td colspan="2">Recommended semester: 2</td></tr>
</table>

Evidence	**Form**	**Duration/Scope**	**Repeatability**	**CP**
Final module examination ID: 1910	Oral exam	30 min	unlimited	6

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE0189-a	**Advanced Thin Film Technologies**	PF	Lecture/ Exercise	5	180 h

Contents:

Repetition / Introduction
- Why thin layers?
- Classification and basics of the processes: PVD, CVD, others
- Vacuum vs. atmospheric pressure processes
- inert vs. reactive processes
- Fundamentals of layer growth and crystallinity

Coating properties and process influences
- Roughness, crystallinity, adhesion, stress in layers, chemical composition, density, optical/electrical properties, diffusion properties, impurities, hardness and other influences of process parameters such as growth rate, temperature, substrate, ambient pressure, ambient atmosphere, particle energy and other ways of influencing extrinsic and intrinsic parameters

Plasma-assisted thin-film processes
- Introduction Plasma
- Sputtering, reactive sputtering
- Plasma CVD
- ALD, Plasma ALD

Industrial systems and applications
- Scaling issues
- Examples of systems and applications

Selected analysis methods for thin films

FBE0149	Organic Electronics	PF/WP **WP**	Weight of the grade **6**	Workload **6 CP**	Expenditure **180 h**
Qualification Goals: Students have an overview of organic semiconductors and organic electronics in general. They are familiar with electrical and optical processes in organic materials and the functioning of important components such as organic light-emitting diodes, organic transistors and organic solar cells. Students will be able to carry out independent scientific literature research and process and present the results of this research.					
General remarks: Good knowledge of materials and basic circuits is expected.					
Duration of the module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 2			

Evidence	Form	Duration/Scope	Repeatability	CP
Final module examination ID: 44041	Oral exam	45 min	unlimited	5
Organization of the ungraded course achievement(s): Ungraded achievement 59109 must be completed in component b.				
Ungraded achievement ID: 59109	Form according to explanation		unlimited	1
Explanation: Laboratory practical and lecture in English.				

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE0149-a	Organic Electronics	PF	Lecture/ Exercise	4	150 h

Contents:

Fundamentals of organic semiconductors

- Organic materials (polymers, oligomers, dendrimers, small molecules)
- Characteristics of organic semiconductors
- Optical properties
- Electrical properties

Technological aspects

- Production of thin films
- Vacuum processing/printing processes

Functionality of organic components

- Organic transistors
- Organic memories
- Large area electronics
- Photovoltaics
- Organic light-emitting diodes OLEDs for general lighting and displays
- Organic lasers

Market prospects for organic components

FBE0149-b	**Practical Training in Organic Electronics**	PF	Practical Training	1	30 h

Remarks:

- Laboratory practical course for the lecture in Organic Electronics with presentation in English.

SAFM	Synthesis and analysis of functional material layers	PF/WP **WP**	Weight of the grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goals:

Graduates have an overview of modern manufacturing and preparation processes for thin layers and structured films, as well as their applications in various fields. They are familiar with vacuum processes as well as liquid phase deposition and electrochemical methods for surface and thin film preparation. They are familiar with the possibilities of using coatings for various applications, as well as the special properties of thin-film systems. They have knowledge of adequate methods and procedures for thin film analysis. These include high-resolution, possibly atomic-resolution microscopic methods as well as spectroscopic methods, including the use of photons, electrons and neutrons, but also the possibilities and limitations of the various methods.

General remarks:

The first semester focuses on presenting and discussing the various manufacturing processes, while the second semester focuses on the analytical methods that can be used for this purpose.

Duration of the module: 2 semesters	**Frequency:** every 2nd semester	**Recommended semester:** 1

Evidence	**Form**	**Duration/Scope**	**Repeatability**	**CP**
Final module examination ID: 41011	Oral exam	30 min	unlimited	6

Component(s)		**PF/WF**	**Form of Teaching**	**Semester hours per week**	**Expenditure**
SAFM-a	**Synthesis of functional material layers**	PF	Lecture	2	90 h

Remarks:

Real surfaces; cleaning processes; pulsed laser deposition; sol-gel techniques; electrochemical deposition; sputtering techniques; chemical vapor deposition; evaporation processes; structuring; lithography; nanoimprint; bottom-up growth. Applications of the various coating processes for the production of functional coatings, e.g. in microelectronics, in photovoltaic components, as corrosion protection, for data and energy storage.

FBE02	**Analysis of functional material layers**	PF	Lecture	2	90 h

Remarks:

Optical methods, microscopy, ellipsometry, interferometry, infrared spectroscopy, photoluminescence, optical emission and absorption spectroscopy; electron microscopy; scanning probe methods; Auger electron spectroscopy, electron energy loss spectroscopy, photoelectron spectroscopy; mass spectrometry; Rutherford backscattering; X-ray and electron diffraction; X-ray absorption spectroscopy; energy-dispersive X-ray spectrometry. Applications of the methods to current problems and issues in nanoscience and thin-film physics.

SL1	Superconductivity I	PF/WP **WP**	Weight of the grade **3**	Workload **3 CP**	Expenditure **90 h**

Qualification Goals:

Students are familiar with the phenomenology of superconductivity and the corresponding central theories and understand their interrelationships. They are also familiar with central theories and models of the mechanism of superconductivity and their relationship to experiments. Students will be able to apply the theories to key experiments and understand the fundamentals of technological applications based on superconductivity.

Duration of the module: 1 semester	**Frequency:** irregular	**Recommended semester:** 1

Evidence	Form	Duration/Scope	Repeatability	CP
Final module examination ID: 75143	Oral exam	30 min	unlimited	3

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE02	**Superconductivity I**	PF	Lecture	2	60 h

Contents:

1. Basic phenomena of superconductivity
Disappearing resistance; Meissner-Ochsenfeld effect; London's equations; Flux quantization; Critical magnetic fields; Energy gap

2. Fundamentals of BCS theory
Cooper pairing; phonons and attractive interaction; BCS ground state; excited states; determination of critical temperature; energy gap; density of states and electron tunneling; thermodynamics; isotope effect

3. Basic features of the Ginzburg-Landau theory
Ginzburg-Landau differential equations; Characteristic lengths; Material properties

4. Superconductors in a magnetic field
Thermodynamics of the Meissner state; critical magnetic field of thin films; intermediate state; phase boundary energy; Shubnikov phase; magnetization curves, magnetic phase diagram; Abrikosov-Vortices

5 Josephson effects
Josephson equations in the magnetic field; Superconducting quantum interferometers

SL2	**Superconductivity II**	PF/WP **WP**	Weight of the grade **3**	Workload **3 CP**	Expenditure **90 h**

Qualification Goals:
Students are familiar with various superconducting material classes and can describe the differences between conventional and unconventional superconductivity. They are also familiar with the phenomenology of several classes of unconventional superconductors and important corresponding experimental results. Students know and understand basic models of correlated electrons and can apply them to current research questions on the physics of unconventional superconductors.

General remarks:
Knowledge of the contents of the course "Advanced Experimental Solid State Physics" is an advantage.

Duration of the module: 1 semester	**Frequency:** irregular	**Recommended semester:** 2

Evidence	Form	Duration/Scope	Repeatability	CP
Final module examination ID: 75147	Oral exam	30 min	unlimited	3

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE02	**Superconductivity II**	PF	Lecture	2	60 h

Contents:

1. Fundamentals of superconductivity
General phenomenology; Attractive interaction of conventional superconductors; Symmetry of the pair wave function and related experiments; Conventional superconductors with high critical temperature

2. Cuprate superconductors
Material aspects; Generic phase diagram; Electronic correlations; Crystal fields; Jahn-Teller effect; Mott-Hubbard insulator; Hubbard model; t-J model; Hole doping in cuprates; Transport properties; Pseudo energy gap; Streak correlations; Experiments

3. Iron-based superconductors
Material aspects; general phase diagram; orbitals and crystal fields; magnetism and superconductivity; electronic instabilities, order parameters; nematic order; experiments

ADM	**Additive Manufacturing**	PF/WP **WP**	Weight of the grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goals:
Students gain a basic understanding of additive manufacturing processes and are able to assess additive manufacturing processes and use them for specific projects. Students are familiar with the process-related properties and are able to take these into account in product development and design. In addition, students gain experience in the area of cooperation with other students in the preparation of a term paper. They learn about project management, self-organization and group work. They are taught how to work together in a team on a complex scientific task. At the same time, the written assignment is intended to promote the ability to produce scientific documentation. Students are able to work independently on a complex scientific topic over a longer period of time. They learn to organize themselves and to allocate time for given content and to adhere to it.

General remark:
The course can be held in German or English, a decision will be made at the beginning of the semester.

Duration of the module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 3

Evidence	**Form**	**Duration/Scope**	**Repeatability**	**CP**
Final module examination ID: 38420	Written term paper		unlimited	6

Composition of the module completion:
Duration: 6 - 8 weeks
Scope: 20 - 40 pages

Component(s)		**PF/WF**	**Form of Teaching**	**Semester hours per week**	**Expenditure**
ADM-a	**Additive Manufacturing**	PF	Lecture / Practice	3	150 h

Remarks:
The current literature references for preparation for the courses are published on the homepage, via Moodle or in StudiLöwe.

Contents:
- Prototyping in product development
- Technological basics
- Quality assurance and standardization
- Additive manufacturing processes (direct energy deposition, powder bed fusion, sheet lamination, binder jetting, material extrusion, material jetting, VAT photopolymerization)
- Post processing
- Economic efficiency

FBE0298	Functional Printing	PF/WP WP	Weight of the grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goals:

The students acquire knowledge in

- Specification of decision criteria for the application of printing processes for the production of electronic components.
- Discussion of the advantages and disadvantages of printing processes compared to alternative coating methods.
- The students will have outstanding and comprehensive competences of
- basic drying methods for functional printing applications.
- design of wetting processes regarding substrate and fluid properties for the optimization of final coating characteristics, particularly coating thickness and homogeneity.
- selection of applicable printing processes depending on lateral resolution and ink properties.

Duration of the module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 2

Evidence	**Form**	**Duration/Scope**	**Repeatability**	**CP**
Final module examination ID: 82171	Oral exam	30 min	unlimited	6

Component(s)		**PF/WF**	**Form of Teaching**	**Semester hours per week**	**Expenditure**
FBE0298-a	**Functional Printing**	PF	Lecture / Practice	5	180 h

Contents:

- Fundamentals of wetting theory and wetting phenomena
- Physical Basics of Surface energy of liquids and solids
- Metrology of surface energies by contact angle measurements
- Fundamentals of polar an non polar properties of Solids and Liquids
- Pretreatment methods to modify and control wetting and adhesion properties of substrats and liquids
- Fundamentals of Inkjet and Screen printing processes and euqipment
- Physical Basics of Droplet Generation
- Basic understanding if drying technologies

FBE0294	**Project Materials and Fundamentals**	PF/WP **WP**	Weight of the grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goals:

The students possess subject-related knowledge and experience from practice with regard to a completed research project.The students are competent:

- in the analysis of scientific problems
- in working with scientific literature
- in structured and systematic teamwork
- in project planning, project management
- in writing short texts with scientific content
- recognizing and using creative skills, and
- in the presentation of achieved results and their evaluation.

Duration of the module: 1 semester	**Frequency:** every semester	**Recommended semester:** 1

Evidence	Form	Duration/Scope	Repeatability	CP
Final module examination ID: 82177	Written exam	30 min	unlimited	6

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE0294-a	**Project Materials and Fundamentals**	PF	Project	5	180 h

Remarks:

The project can also be worked on in a team of a maximum of 2 students.

Contents:

Participation in a research internship in the field of materials science, in which a task is worked on.The following subsections are to be worked on:

- Analysis of the problem
- Decomposition into sub-problems and definition of interfaces
- Planning and organisation
- Realisation of subprojects
- Combination of the partial solution into an overall solution
- Documentation and presentation of the results

Compulsory elective area Devices, Circuits and Systems

FBE0138	Integrated high-frequency circuits in communication technology	PF/WP WP	Weight of the grade 6	Workload 6 CP	Expenditure 180 h
Qualification Goals: Students are proficient in the analysis and design of integrated circuits at chip level (design competence), in particular the implementation of high-frequency systems in communication technology (technical competence). Students have the ability to understand and write scientific publications in English (competence for the scientific approach).					
General remarks: Successful participation in the module "High Frequency Systems" is recommended; the course will be held in English.					
Duration of the module: 1 semester	**Frequency:** every 2^{nd} semester	**Recommended semester:** 2			

Evidence	Form	Duration/Scope	Repeatability	CP
Final module examination ID: 34969	Oral exam	45 min	unlimited	6

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE0138-a	**Integrated high-frequency circuits in communication technology**	PF	Lecture / Practice	5	180 h
Remarks: The course is held in English.					
Contents: Review of MOS and BJT technologies for high-speed applications, FET small-signal model, important device parameters, transconductance, unity-gain-frequency, bipolar small-signal model, bipolar unity-gain-frequency, high-speed amplifiers and two-port design, RLC-networks, Q-factors, tuned amplifiers, general properties of twoport networks, two-port networks, S Y H G parameters, input/output Admittance of two-ports, series feedback, course work introduction, power gain definitions, stability, k-factor, circuit design project description, simultaneous conjugated match, maximum power gain definitions, Cadence software introduction, impedance matching networks, L-Sections, T-Sections, Pi-Sections, harmonic distortion, project work, inter-modulation distortion, distortion, HD2, HD3, THD, IM2, IM3, IP2, IP3, P1dB, BJT example, electronic noise, Johnson-noise, Spot-Noise, available-noise power, Shot-noise, BJT/FET equivalent noise model, SNR, noise-figure, noise-factor, NF, BJT noise sources, optimum source resistance, Fmin, BJT NF, noise correlation, FET noise figure, design of LNA, mixer, image problem/rejection, direct conversion, I/Q-modulators.					

FBE0068	Electromagnetic Compatibility of Smart Systems	PF/WP **WP**	Weight of the grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goals:
Students know the definitions and basic concepts of EMC and the electromagnetic interference of technical systems. This includes examples of interference sources and interference mechanisms, examples of environments in which disturbed systems are located, the definition of EMC (source, sink, coupling paths) as well as interference suppression measures (earthing / grounding / equipotential bonding, filtering, shielding) and examples of further measures in EMC planning to avoid interference. Students are familiar with current methods of numerical simulation in EMC, the possibilities and limitations as well as their role in EMC planning.

General remarks:
Knowledge of the modules Mathematics A, B, Fundamentals of Electrical Engineering I and II is expected.

Duration of the module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 3

Evidence	Form	Duration/Scope	Repeatability	CP
Final module examination ID: 41399	Written exam	120 min	unlimited	6
Final module examination ID: 41408	Oral exam	30 min	unlimited	6

Explanation concerning the final module examination:
The form of the final module examination will be announced at the beginning of the semester in which the final module examination takes place.

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE02	**Electromagnetic Compatibility of Technical Systems**	PF	Lecture / Practice	5	180 h

Contents:
Terms and presentation methods, sources of interference, mechanisms of galvanic, capacitive, inductive and electromechanical coupling, interference suppression components, shielding, typical EMC problems in practice, basics of computer-aided EMC investigations.

FBE0188	Reliability of electronic devices and systems	PF/WP **WP**	Weight 25ft he grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goals:

Students know methods for detection and S/N improvement in the time, frequency and modulation range and can apply them.

Duration of the module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 3

Evidence	Form	Duration/Scope	Repeatability	CP
Final module examination ID: 44381	Oral exam	45 min	unlimited	6

Explanation concerning the final module examination:

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE0188-a	**Reliability of electronic devices and systems**	PF	Lecture	5	180 h

Contents:

1. Introduction
1.1 Detection of signals within different measurement domains (Time Domain, Frequency Domain, Modulation Domain)
1.2 Noise sources, noise figures (1/f, Schot noise, thermal noise) and S/N
1.3 Description and determination of life times and failure distributions of electronic devices (Weibull statistic)
2. Measurement and signal recovery of electrical signals
2.1 Sampling-Techniques / Mixing Techniques
2.2 S/N improvement: Lock-In-Amplifier Dualphase, Heterodyn (VCO)),
2.3 Time resolved measurements of fast signals in time domain: Averaging (Boxcar-Integrator, sampling heads), (Single event multichannel Oscilloscope)
2.4 Measurements in Frequency Domain (Spectrum Analyser, Network Analyser) S-Parameter
3 Reliability investigations by use of optical radiation
3.1 Photon Emission Microscopy (Photo Detectors (PMT (Photo-cathodes, QE, Dark-current), CCD)
3.2 Generation of short laser-pulse and its characterization (correlation technique (Streak-Camera, Optical Auto-Correlation))
3.3 Optical Testing (Electro-Optic Sampling (Kerr-effect), Optical Beam Induced Resistance Change (OBIRCH), Thermally Induced Voltage Alteration (TIVA) Picosecond Imaging Circuit Analysis (PICA)

FBE0148	**Microcharacterization of materials and components in electronics**	PF/WP **WP**	Weight 26ft he grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goals:
Students know the types of fault analysis and criteria for selecting suitable measuring probes and their interaction products.

Duration of the module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 3

Evidence	**Form**	**Duration/Scope**	**Repeatability**	**CP**
Final module examination ID: 1892	Oral exam	45 min	unlimited	6

Component(s)		**PF/WF**	**Form of Teaching**	**Semester hours per week**	**Expenditure**
FBE0148-a	**Microcharacterization of materials and components in electronics**	PF	Lecture	5	180 h

Contents:
1 Basics
1.1 General principles of scanning microscopy techniques
2 Scanning electron microscopy
2.1 Production of focused electron beams: Work function, working mode, magnetic lenses, electron beam parameters
2.2 Interaction of electrons with solids: elastic and inelastic scattering, energy dissipation, penetration depth, secondary and backscattered electrons, enviromental mode, material and stress contrast, Bragg reflection
2.3 TEM (STEM): bright and dark field imaging, electron energy loss spectroscopy
2.4 Electron beam techniques: cathodoluminescence, electron beam-induced currents, Auger spectroscopy, X-ray spectroscopy
2.5 Modulation techniques
3 Scanning probe microscopy
3.1 General mode of operation
3.2 Scanning tunneling microscopy
3.3 Scanning force microscopy
3.4 Optical scanning near-field microscopy
3.5 Complementary scanning probe microscope techniques

FBE0191	**Efficient use of energy**	PF/WP **WP**	Weight 27ft he grade **3**	Workload **3 CP**	Expenditure **90 h**

Qualification Goals:
Students are familiar with procedures and business models for reducing commercial energy consumption for economic and ecological reasons. Furthermore, they are familiar with the governmental steering methods for increasing energy efficiency and reducing energy consumption.

Duration of the module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 2

Evidence	**Form**	**Duration/Scope**	**Repeatability**	**CP**
Final module examination ID: 2018	Oral exam	30 min	unlimited	3

Explanation concerning the final module examination:

Component(s)		**PF/WF**	**Form of Teaching**	**Semester hours per week**	**Expenditure**
FBE0191-a	**Efficient use of energy**	PF	Lecture / Practice	3	90 h

Remarks:

Contents:

Definition and principles of rational energy use

Contracting
- Energy consumption analysis and potential assessment
- Energy costs -> performance and labor prices
- Concepts for reducing energy (costs)

Technical building management
- Redundancy systems
- Building automation

Energy utilization in production
- Evaluation of the energy efficiency of process chains
- Optimizing the energy efficiency of process chains

Energy use in transportation and traffic
- Evaluation of the energy efficiency of different means of transportation/transport routes
- Selection of suitable means of transportation according to economic and ecological criteria

Government measures to increase energy efficiency
- Energy efficiency classes

FBE0283	**Terahertz Electronics and Photonics**	PF/WP **WP**	Weight 28ft he grade **6**	Workload **6 CP**	Expenditure **180 h**
Qualification Goals: Students have basic interdisciplinary knowledge in the field of electronics and photonics in order to develop modern terahertz systems. They have a basic understanding of the functional principles of electronic-photonic components and can describe them quantitatively. Students are able to apply the concepts in the development of industrial terahertz systems.					
General remarks: Lectures are held in German or English by arrangement.					
Duration of the module: 1 semester		**Frequency:** every 2nd semester		**Recommended semester:** 3	

Evidence	Form	Duration/Scope	Repeatability	CP
Final module examination ID: 77813	Oral exam	45 min	unlimited	6
Explanation concerning the final module examination:				

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE0283-a	**Terahertz Electronics and Photonics**	PF	Lecture / Practice	5	180 h

Contents:

This course is divided into the following four sections.
Building blocks of THz frequency synthesis: Rectification process and its implications on electronic and photonic transport properties; Fourier analysis of rectification, Semiconductor band structure introduction, artificial bandgap nano-engineering in generated semiconductor heterostructures, electron transports (junction, interband-, intraband-, intersubband- transitions), introduction to transistors and their multi-functions.
Principles of Terahertz generation: Electronic sources - Transistors as a THz frequency synthesizer -> harmonic generators, oscillators; Photonic sources - THz lasing in semiconductor heterostructures -> quantum cascade lasers; Optoelectronic source - Thz photomixing.
Principles of Terahertz detection: radiation coupling, Terahertz wave propagation, detector figures of merits, direct detection, heterodyne detection.
Defining Terahertz systems specifications: broadband vs narrowband, active vs passive, frequency domain vs time domain, coherent vs incoherent, power vs field, far-field vs near-field, Terahertz Imaging examples, Terahertz spectroscopy examples, Terahertz communications examples.

FBE0288	Chip Design - Layout and Simulation	PF/WP **WP**	Weight 29ft he grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goals:
Students acquire fundamental knowledge in the value chain of high-frequency circuit design at semiconductor level (chip design) from the areas of circuit theory, analogue and digital electronics, semiconductor components and signal processing. The circuit design includes chip packaging and PCB design as well as verification and production testing. After successful completion of the module, students have theoretical knowledge, practical experience as well as the ability to solve circuit design problems taking into account industry standards.

Duration of the module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 3

Evidence	Form	Duration/Scope	Repeatability	CP
Final module examination ID: 82181	Oral exam	45 min	unlimited	6

Prerequisite for the final module examination:
The registration to the final module exam is possible only when module "Integrierte Hochfrequenzschaltungen in der Kommunikationstechnik" successfully completed.

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE0288-a	**Chip Design - Layout and Simulation**	PF	Lecture / Practice	5	180 h

Contents:
This course includes the following parts:Circuit Analysis and Design:This involves understanding circuit components, their characteristics, and how they interact within a circuit. This inludes skills in schematic capture and circuit simulation software. It allows engineers to design and capture the logical connections and components of a circuit including validation of circuit functionality and performance before physical implementation. It supports both analog and digital simulations. Circuit examples include RF amplifiers, mixers, filters, oscillators, and digital logic circuits using appropriate components and design techniques.Layout Design:This involves the physical layout of integrated circuits. It covers the placement of components, routing interconnects, and ensuring design rule compliance. Advanced features include automated placement and routing algorithms to improve design efficiency in digital design. This includes knowledge of layout guidelines, understanding of signal integrity and power distribution considerations, and proficiency in using circuit design software.Design Flow and Design Tools:This includes commercial electronic design automation (EDA) software like Cadence as well as open-source digital design toolset developed by The OpenROAD Project by UC Berkeley. OpenLane aims to automate and streamline the process of designing digital integrated circuits (ICs) by providing a complete end-to-end design flow.Circuit Verification:Various physical verification features, including Design Rule Checking (DRC) and Layout versus Schematic (LVS) checks. These checks ensure that the layout matches the intended circuit design and complies with manufacturing rules. Students will learn how to checks for violations such as minimum spacing, minimum feature size, and other geometric rules.Extraction and Analysis:This includes the extraction of accurate EM models of parasitic elements (e.g., resistors, capacitors) that affect circuit performance. These extracted models can be used for further analysis, such as signal integrity analysis.).

FBE0295	Project Devices, Circuits and Systems	PF/WP **WP**	Weight 30ft he grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goals:

The students possess subject-related knowledge and experience from practice with regard to a completed research project.The students are competent:
in the analysis of scientific problems
in working with scientific literature
in structured and systematic teamwork
in project planning, project management
in writing short texts with scientific content
recognizing and using creative skills, and
in the presentation of achieved results and their evaluation.

Duration of the module: 1 semester	**Frequency:** every semester	**Recommended semester:** 1

Evidence	Form	Duration/Scope	Repeatability	CP
Final module examination ID: 82184	**Presentation with colloquium**	30 min	unlimited	6

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE0295-a	**Project Devices, Circuits and Systems**	PF	Project	5	180 h

Remarks:

The project can also be worked on in a team of a maximum of 2 students.

Contents:

Participation in a research internship in the field of electronic devices, circuits or systems, in which a task is worked on.The following subsections are to be worked on:

- Analysis of the problem
- Decomposition into sub-problems and definition of interfaces
- Planning and organisation
- Realisation of subprojects
- Combination of the partial solution into an overall solution
- Documentation and presentation of the results

Compulsory elective area Information System and Science

FBE0085	**Information processing**	PF/WP **WP**	Weight 31ft he grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goals:
Students master the basics of modern information processing, including source coding. They have the ability to analyze complex systems. Students are able to analyze and compare different methods for source coding in application cases. In addition, they are able to design analog filters according to given specifications using scientific methods and implement them with different technologies. Furthermore, they are able to develop an in-depth scientific view of the theoretically possible transmission rate of different communication systems.

General remarks:
Good knowledge of the modules Mathematics A, Mathematics B and Signals and Systems is expected. Parallel attendance of the module Theoretical Communications Engineering is recommended.

Duration of the module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 3

Evidence	**Form**	**Duration/Scope**	**Repeatability**	**CP**
Final module examination ID: 34949	Oral exam	45 min	unlimited	5
Organization of the ungraded course achievement(s): The ungraded coursework 34893 must be completed in component b.				
Ungraded Coursework ID: 34893	Form by announcement		unlimited	1

Component(s)		**PF/WF**	**Form of Teaching**	**Semester hours per week**	**Expenditure**
FBE0085-a	**Information processing**	PF	Practical Training	0	30 h

Contents:
Practical exercises for the lecture with report.

FBE0093	**Multidimensional signals and systems**	PF/WP **WP**	Weight 32ft he grade **6**	Workload **6 CP**	Expenditure **180 h**
Qualification Goals: Students are familiar with the theory and applications of multidimensional signal and system technology in image and audio processing as well as computer-generated image generation.					
Duration of the module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 3			

Evidence	Form	Duration/Scope	Repeatability	CP
Final module examination ID: 43834	Oral exam	45 min	unlimited	6

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE0093-a	**Multidimensional signals and systems**	PF	Lecture / Practice	5	180 h

Contents:
Linear sampling, Fourier series, Fourier transform of number sequences, z-transform, sampling theorem, linear transformation.
Systems:
Transfer functions, impulse response, causality, difference equations, reconstructability.
Networks
Filters
Probability density functions
Tomography:
Radon transformation, reconstruction.
Image processing:
Edge detection, grayscale transformation, histogram leveling, filtering, morphological operations.
Waves
Computer Graphics

FBE0251	Applied Machine Learning	PF/WP **WP**	Weight 33ft he grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goals:
Students know how various data-driven methods from the field of machine learning work and their possible applications in various information technology areas. They are familiar with the process of preparing and analyzing different types of data. In addition, they are familiar with the areas of supervised, unsupervised and reinforcement learning and the combination of methods from these areas into method pipelines. They are familiar with the concepts of implementing these methods and are able to develop simple machine learning applications in the Python programming language.

Duration of the module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 2

Evidence	**Form**	**Duration/Scope**	**Repeatability**	**CP**
Final module examination ID: 74644	Written exam	120 min	unlimited	6

Component(s)		**PF/WF**	**Form of Teaching**	**Semester hours per week**	**Expenditure**
FBE0251	**Lecture Applied Machine Learning**	PF	Lecture	4	180 h

Contents:
Data-driven methods from the field of machine learning, possible applications of these methods and required implementation techniques.
Practical exercise of the lecture content.

FBE0252	**Deep Learning**	PF/WP **WP**	Weight 34ft he grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goals:

Students know how modern methods from the field of deep learning work. They are familiar with the functionality of various architectures of artificial neural networks and know the appropriate applications of the respective architecture types. They understand modern and advanced concepts for training complex architectures and are able to design suitable models and training methods for new problems. In addition, they are familiar with the concepts of implementing these methods and are able to develop complex deep learning applications with modern and up-to-date deep learning frameworks.

Duration of the module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 2

Evidence	**Form**	**Duration/Scope**	**Repeatability**	**CP**
Final module examination ID: 34922	Written exam	90 min	unlimited	6
Final module examination ID: 34894	Oral exam	30 min	unlimited	6

Explanation concerning the final module examination:

The form of the final module examination is announced at the beginning of the semester in which the final module examination takes place.

Component(s)		**PF/WF**	**Form of Teaching**	**Semester hours per week**	**Expenditure**
FBE0252-a	**Deep Learning**	PF	Lecture / Practice	4	180 h

Contents:

The lecture provides in-depth knowledge about the structure, function and use of deep neural networks.
The following topics are covered:
Mathematical building blocks of neural networks
Training of deep neural networks
Architecture and topologies of deep neural networks
Convolutional Neural Networks (CNN)
Recurrent Neural Networks (RNN) and Long Short Term Memory Networks (LSTM)
Applications and recent developments around deep neural networks

FBE0289	**Advanced Cryptography**	PF/WP **WP**	Weight 35ft he grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goals:
Students know advanced topics in cryptography that go beyond fundamental basic topics, including modern cryptographic techniques to protect and enhance the privacy of people.

General remarks:
Basic knowledge of cryptography, as taught in an introductory course on computer security or cryptography, is recommended, but not required.

Duration of the module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 3

Evidence	**Form**	**Duration/Scope**	**Repeatability**	**CP**
Final module examination ID: 82198	Written exam	120 min	unlimited	6
Final module examination ID: 82199	Oral exam	30 min	unlimited	6

Explanation concerning the final module examination:
The form of the examination of the module is announced at the beginning of the semester in which the examination will be conducted.

Component(s)		**PF/WF**	**Form of Teaching**	**Semester hours per week**	**Expenditure**
FBE0289-a	**Advanced Cryptography**	PF	Lecture / Practice	4	180 h

Contents:
Formal security definitions are used to analyse and prove security of advanced cryptographic primitives under computational hardness assumptions and in the information-theoretic setting. Topics include for example:

- A brief recap of the general methodology of formally defining and analysing security of cryptographic primitives.
- Secure computation and classical primitives used to build cryptographic protocols, such as oblivious transfer and garbled circuits, the GMW protocol and the BGW protocol.
- Witness/functional/attribute-based or fully homomorphic encryption.
- Modern cryptographic techniques to protect the privacy of people.
- Enhanced digital signature schemes.

FBE0259	**Communication security for modern applications**	PF/WP **WP**	Weight 36ft he grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goals:
Students are familiar with application-specific security mechanisms such as secure communication between web services, key exchange and security mechanisms in industrial communication networks.

Duration of the module: 1 semester	**Frequency:** every 2nd semester	**Recommended semester:** 2

Evidence	**Form**	**Duration/Scope**	**Repeatability**	**CP**
Final module examination ID: 35052	Written exam	120 min	unlimited	6
Final module examination ID: 34947	Oral exam	30 min	unlimited	6

Explanation concerning the final module examination:
The form of the final module examination is announced at the beginning of the semester in which the final module examination takes place.

Component(s)		**PF/WF**	**Form of Teaching**	**Semester hours per week**	**Expenditure**
FBE0259-a	**Communication security for modern applications**	PF	Lecture / Practice	4	180 h

Contents:
In this course, application-specific security mechanisms are presented and analyzed. This includes secure communication between web services, key exchange with minimal latency in TLS 1.3, as well as security mechanisms in UPC UA and their correct use. Topics from current research are also addressed, such as techniques for implementing encrypted control in the cloud.
In applications with "lightweight requirements", such as the Internet of Things and cyber-physical systems, secure communication protocols must be implemented as efficiently as possible in order to be usable on cost-effective hardware. The second thematic block therefore also presents basic techniques and algorithms for efficient implementation.

CEM1	Computational Electromagnetics 1	PF/WP **PF**	Weight 37ft he grade **8**	Workload **8 CP**	Expenditure **240 h**

Qualification Goals:
Acquistion of an insight into various techniques to numerically simulate electromagnetic and coupled multiphysics field problems in highly complex technical systems or biological organisms.

Duration of the module: 2 semesters	**Frequency:** every 2nd semester	**Recommended semester:** 2

Evidence	Form	Duration/Scope	Repeatability	CP
Composition of the module degree: The form of the final module exam will be announced at the beginning of the lecture.				
Final module examination ID: 46958	Written exam	120 min	unlimited	8
Final module examination ID: 46968	Oral exam	30 min	unlimited	8

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
CEM1-a	**Computational Electromagnetics**	PF	Lecture / Practice	5	240h

Contents:
Discrete electromagnetic field theory: Continuous geometric discretization methods for Maxwell’s equations (Finite-Difference-method, Finite Integration Technique, Cell Method, Whitney Finite Element Method), discrete field formulations, implementations (commercial/research) and practical applications for electromagnetic/multiphysical field problems in complex systems/biological organisms

FBE0296	Project Information System and Science	PF/WP **WP**	Weight 38ft he grade **6**	Workload **6 CP**	Expenditure **180 h**

Qualification Goals:

The students possess subject-related knowledge and experience from practice with regard to a completed research project.
The students are competent:
in the analysis of scientific problems
in working with scientific literature
in structured and systematic teamwork
in project planning, project management
in writing short texts with scientific content
recognizing and using creative skills, and
in the presentation of achieved results and their evaluation.

Duration of the module: 1 semester	**Frequency:** every semester	**Recommended semester:** 1

Evidence	Form	Duration/Scope	Repeatability	CP
Final module examination ID: 82187	Presentation with Colloquium	30 min	unlimited	6

Component(s)		PF/WF	Form of Teaching	Semester hours per week	Expenditure
FBE0296-a	**Project Information System and Science**	PF	Project	5	180 h

Remarks:

The project can also be worked on in a team of a maximum of 2 students.

Contents:

Participation in a research internship in the field of Information Systems and Science, in which a task is worked on.
The following subsections are to be worked on:
Analysis of the problem
Decomposition into sub-problems and definition of interfaces
Planning and organization
Realisation of subprojects
Combination of the partial solution into an overall solution
Documentation and presentation of the results

Key

PF	Compulsory subject
WP	Compulsory elective subject
CP	Credit Points