M.Sc. Electrical Engineering and Information Technology (PO 2014)

Computer-Aided Electrodynamics
Date: 01.09.2021

TECHNISCHE UNIVERSITÄT DARMSTADT

Department of Electrical Engineering and Information Technology

Module manual: M.Sc. Electrical Engineering and Information Technology (PO 2014)
Computer-Aided Electrodynamics
Date: 01.09.2021

Department of Electrical Engineering and Information Technology
Email: servicezentrum@etit.tu-darmstadt.de

Contents

1 Fundamentals

Module name Science in Practice I					
Module Nr. 18-dg-2130	**Credit Points** 8 CP	**Workload** 240 h	**Self study** 180 h	**Duration** 1	**Cycle offered** WiSe/SoSe
Language German and English			**Module owner** Prof. Dr.-Ing. Herbert De Gersem		

1	**Content** Acquiring basic scientific skills based on concrete examples from the literature.
2	**Learning objectives / Learning Outcomes** The students possess basic scientific skills. They are able to discover important literature for a given topic and to judge critically the corresponding content. They are familiar with numerical techniques, especially convergence studies relevant for praxis. The students are capable of analyzing errors within simulations and of judging accuracy requirements, e.g., with respect to errors in input data.
3	**Recommended prerequisite for participation** Good understanding of electromagnetic fields, knowledge about numerical simulation methods.
4	**Form of examination** Module Final Examination: • Module Examination (Study Achievement, Oral Examination, Duration: 20 min, Standard Grading System)
5	**Grading** Module Final Examination: • Module Examination (Study Achievement, Oral Examination, Weighting: 100 %)
6	**Usability of this module** MSc ETiT
7	**Grade bonus compliant to §25 (2)**
8	**References** Material related to the topic is provided.

Courses

Course Nr.	Course name		
18-dg-2130-pj	Science in Practice I		
Instructor		**Type**	**SWS**
Prof. Dr.-Ing. Herbert De Gersem		Project Seminar	4

Module name Science in Practice II					
Module Nr. 18-dg-2140	**Credit Points** 8 CP	**Workload** 240 h	**Self study** 180 h	**Duration** 1	**Cycle offered** WiSe/SoSe
Language German and English			**Module owner** Prof. Dr.-Ing. Herbert De Gersem		

1	**Content** Working on different scientific topics based on techniques acquired in Science in Practice I.
2	**Learning objectives / Learning Outcomes** The students are capable of succesfully working on new scientific topics from the numerical field simulation in a reasonable time. They are able to understand new methods, to implement them if necessary and to carry out simulations. Thereby methodologies discussed in Science in Practice I, especially concerning the solution of systems of equations, as well as convergence and error analysis are employed. They know how to document the results by means of a report and how to present them.
3	**Recommended prerequisite for participation** Good understanding of electromagnetic fields, knowledge about numerical simulation methods.
4	**Form of examination** Module Final Examination: • Module Examination (Study Achievement, Oral Examination, Duration: 20 min, Standard Grading System)
5	**Grading** Module Final Examination: • Module Examination (Study Achievement, Oral Examination, Weighting: 100 %)
6	**Usability of this module** MSc ETiT
7	**Grade bonus compliant to §25 (2)**
8	**References** Material related to the topic is provided.

Courses

Course Nr.	Course name		
18-dg-2140-pj	Science in Practice II		
Instructor		**Type**	**SWS**
Prof. Dr.-Ing. Herbert De Gersem		Project Seminar	4

Module name Functional Analysis					
Module Nr. 04-10-0036/de	**Credit Points** 9 CP	**Workload** 270 h	**Self study** 180 h	**Duration** 1	**Cycle offered** Every 2. Sem.
Language German			**Module owner** Prof. Dr. rer. nat. Reinhard Farwig		

1	**Content** Normed vector spaces, completion; Theorem of Hahn-Banach, Theorem of Banach-Steinhaus, Open Mapping Theorem, Closed Graph Theorem; Hilbert spaces; reflexive spaces, weak convergence; Sobolev spaces, weak solution of the Dirichlet problem; spectral properties of linear operators; compact operators on Banach spaces, spectral theorem for compact operators.
2	**Learning objectives / Learning Outcomes** Students learn to - combine ideas from linear algebra, analysis and topology - understand and explain basic principles of functional analysis - explain methods from functional analysis in the context of partial differential equations
3	**Recommended prerequisite for participation** recommended: Analysis, Integration Theory, Complex Analysis, Linear Algebra or comparable prerequisites acquired in mathematics courses in engineering programmes
4	**Form of examination** Module Final Examination: • Module Examination (Study Achievement, Special Form, Pass/Fail Grading System) • Module Examination (Technical Examination, Optional, Standard Grading System) Fachprüfung: Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam. Studienleistung: Usually this means that the student successfully completes a certain proportion of the homework assignments. The precise proportion of necessary assignments and the marking scheme will be communicated by the instructor during the first lecture.
5	**Grading** Module Final Examination: • Module Examination (Study Achievement, Special Form, Weighting: 0 %) • Module Examination (Technical Examination, Optional, Weighting: 100 %)
6	**Usability of this module** B.Sc. Mathematik, M.Sc Mathematik, M.Sc. Mathematics
7	**Grade bonus compliant to §25 (2)**
8	**References** Alt: Lineare Funktionalanalysis; Conway: A Course in Functional Analysis; Reed, Simon: Functional Analysis: Methods of Modern Mathematical Physics I; Rudin: Functional Analysis; Werner: Funktionalanalysis; Ciarlet: Functional Analysis;
Courses	

	Course Nr.	Course name		
	04-00-0069-vu	Functional Analysis		
	Instructor		**Type**	**SWS**
	Prof. Dr. rer. nat. Reinhard Farwig		Lecture & Practice	6

Module name Computational Electromagnetics and Applications II					
Module Nr. 18-dg-2010	**Credit Points** 3 CP	**Workload** 90 h	**Self study** 60 h	**Duration** 1	**Cycle offered** SoSe
Language English			**Module owner** Prof. Dr.-Ing. Herbert De Gersem		

1	**Content** • Fundamentals of the Finite Element Method: weighted residuals, projection methods, variational formulations, weak formulations; Finite elements: definitions, classification, first order Whitney element complex, higher order elements; convergence and precision; • Implementation details: data structures, matrix assembly, postprocessing of the solution; • FEM application to electromagnetic problems: electrostatics, magnetostatics, stationary currents, quasistatics, wave propagation.
2	**Learning objectives / Learning Outcomes** Students will master the theoretical basics of finite element methods. They understand details regarding the implementation of the method for stationary and quasistationary fields. They can apply the finite element method in electrical engineering.
3	**Recommended prerequisite for participation** Maxwell's equations, infinitesimal calculus, vector calculus. Basics of differential equations and linear algebra.
4	**Form of examination** Module Final Examination: • Module Examination (Technical Examination, Oral Examination, Duration: 30 min, Standard Grading System)
5	**Grading** Module Final Examination: • Module Examination (Technical Examination, Oral Examination, Weighting: 100 %)
6	**Usability of this module** MSc ETiT
7	**Grade bonus compliant to §25 (2)**
8	**References** • Lecture slides. • Willi Törnig, Michael Gipser, Bernhard Kaspar. Numerische Lösung von partiellen Differentialgleichungen der Technik: Differenzenverfahren, Finite Elemente und die Behandlung großer Gleichungssysteme. Teubner, 1991 • Rolf Steinbuch. Finite Elemente - Ein Einstieg. Springer, 1998. • Alain Bossavit. Computational electromagnetism: variational formulations, complementarity, edge elements. Academic Press, 1997 • Klaus Knothe, Heribert Wessels. Finite Elemente: Eine Einführung für Ingenieure (3. Aufl.). Springer, 1999. • P. P. Silvester, R. L. Ferrari. Finite Elements for Electrical Engineers, Cambridge Universtity Press, 1991 • O. C. Zienkiewicz, R. L. Taylor. The finite element method (4. ed.). McGraw-Hill, 1989

Courses

<table>
<tr><td rowspan="2"></td><td>Course Nr.
18-dg-2010-vl</td><td colspan="3">Course name
Computational Electromagnetics and Applications II</td></tr>
<tr><td colspan="2">Instructor
Prof. Dr. Irina Munteanu</td><td>Type
Lecture</td><td>SWS
2</td></tr>
</table>

Module name					
Computational Electromagnetics and Applications III					
Module Nr. 18-dg-2020	**Credit Points** 3 CP	**Workload** 90 h	**Self study** 60 h	**Duration** 1	**Cycle offered** WiSe
Language German and English			**Module owner** Prof. Dr.-Ing. Herbert De Gersem		

1	**Content** Finite Difference, Finite Volume and Finite Element Methods for the solution of Maxwell equations in the time domain. High order Discontinuous Galerkin methods. Stability and convergence analysis. High performance computing. Particle based simulations for beams and plasmas.
2	**Learning objectives / Learning Outcomes** Students lern the theoretical basis of advanced simulation techniques for time dependent electromagnetic fields. Furthermore, the lecture mediates practical skills for the implementation, analysis and application of simulation codes for common problems of Electrical Engineering
3	**Recommended prerequisite for participation** Maxwell's equations, infinitesimal calculus, vector calculus. Basics of differential equations and linear algebra
4	**Form of examination** Module Final Examination: • Module Examination (Technical Examination, Oral Examination, Duration: 30 min, Standard Grading System)
5	**Grading** Module Final Examination: • Module Examination (Technical Examination, Oral Examination, Weighting: 100 %)
6	**Usability of this module** MSc ETiT
7	**Grade bonus compliant to §25 (2)**
8	**References** Lecture slides, matlab scripts, various literature sources

Courses

Course Nr.	Course name		
18-dg-2020-vl	Computational Electromagnetics and Applications III		
Instructor		**Type**	**SWS**
Privatdozent Dr. rer. nat. Erion Gjonaj		Lecture	2

Module name Relativistic Electrodynamics					
Module Nr. 18-kb-2020	**Credit Points** 5 CP	**Workload** 150 h	**Self study** 90 h	**Duration** 1	**Cycle offered** WiSe
Language German and English			**Module owner** Prof. Dr.-Ing. Harald Klingbeil		

1	**Content** Basics of tensor analysis (tensor fields, transformation behavior, invariance, Ricci calculus, covariant derivative, differential operators), Lorentz transform, fundamental relativistic effects (time dilation, length contraction, Doppler effect), covariant form of Maxwell's equations, induction law from relativistic point of view, relation to relativistic mechanics, four-vectors and four-tensors, electromagnetic energy-momentum tensor and Maxwell's stress tensor, applications of relativistic electrodynamics
2	**Learning objectives / Learning Outcomes** The students understand the basic ideas of Special Relativity and are familiar with the scientific vocabulary. They are able to derive and interpret fundamental formulas, and they are familiar with the mathematical tools. The students understand the concept of covariance and a coordinate-free description of physical theories. They are able to quantitatively compute electromagnetic phenomena in the context of Special Relativity.
3	**Recommended prerequisite for participation** Recommended: "Grundlagen der Elektrodynamik" (18-dg-1010)
4	**Form of examination** Module Final Examination: • Module Examination (Technical Examination, Oral Examination, Duration: 30 min, Standard Grading System)
5	**Grading** Module Final Examination: • Module Examination (Technical Examination, Oral Examination, Weighting: 100 %)
6	**Usability of this module**
7	**Grade bonus compliant to §25 (2)**
8	**References** Lecture slides are offered for download. Further references are given in the lecture.

Courses

Course Nr.	Course name	Instructor	Type	SWS
18-kb-2020-vl	Relativistic Electrodynamics	Prof. Dr.-Ing. Harald Klingbeil	Lecture	2
18-kb-2020-ue	Relativistic Electrodynamics	Prof. Dr.-Ing. Harald Klingbeil	Practice	2

2 Optional Modules

2.1 CED I: Accelerator Technology

Module name Accelerator Physics					
Module Nr. 18-bf-2010	**Credit Points** 3 CP	**Workload** 90 h	**Self study** 60 h	**Duration** 1	**Cycle offered** SoSe
Language German			**Module owner** Prof. Dr. Oliver Boine-Frankenheim		

1	**Content** Beam dynamics in linear- and circular accelerators, working principles of different accelerator types and of accelerator components, measurement of beam properties, high-intensity effects and beam current limits.
2	**Learning objectives / Learning Outcomes** The students will learn the working principles of modern accelerators. The design of accelerator magnets and radio-frequency cavities will discussed. The mathematical foundations of beam dynamics in linear and circular accelerators will be introduced. Finally the origin of beam current limitations will be explained.
3	**Recommended prerequisite for participation** BSc in ETiT or Physics
4	**Form of examination** Module Final Examination: • Module Examination (Technical Examination, Oral Examination, Duration: 30 min, Standard Grading System)
5	**Grading** Module Final Examination: • Module Examination (Technical Examination, Oral Examination, Weighting: 100 %)
6	**Usability of this module** MSc ETiT, MSc Physics
7	**Grade bonus compliant to §25 (2)**
8	**References** Lecture notes, transparencies

Courses

Course Nr.	**Course name**		
18-bf-2010-vl	Accelerator Physics		
Instructor Prof. Dr. Oliver Boine-Frankenheim		**Type** Lecture	**SWS** 2

Module name Project Seminar Particle Accelerator Technology					
Module Nr. 18-kb-1020	**Credit Points** 9 CP	**Workload** 270 h	**Self study** 210 h	**Duration** 1	**Cycle offered** WiSe/SoSe
Language German and English			**Module owner** Prof. Dr.-Ing. Harald Klingbeil		

1	**Content** Work on a more complex project in the field of particle accelerator technology. Depending on the specific problem, measurement aspects, analytical aspects, and simulation aspects will be included.
2	**Learning objectives / Learning Outcomes** Students will be able to solve complex engineering problems with different measurement techniques, analytical approaches or simulation methods. They are able to estimate measurement errors and modeling and simulation errors. They know how to present the results on a scientific level in talks and a paper. Students are able to organize teamwork.
3	**Recommended prerequisite for participation** Good understanding of electromagnetic fields, broad knowledge of different electrical engineering disciplines.
4	**Form of examination** Module Final Examination: • Module Examination (Study Achievement, Oral Examination, Duration: 20 min, Standard Grading System)
5	**Grading** Module Final Examination: • Module Examination (Study Achievement, Oral Examination, Weighting: 100 %)
6	**Usability of this module** BSc ETiT
7	**Grade bonus compliant to §25 (2)**
8	**References** Suitable material is provided based on specific problem.

Courses

Course Nr.	**Course name**		
18-kb-1020-pj	Project Seminar Particle Accelerator Technology		
Instructor		**Type**	**SWS**
Prof. Dr.-Ing. Harald Klingbeil		Project Seminar	4

Module name					
X-Ray Free Electron Lasers					
Module Nr. 18-dg-2110	**Credit Points** 4 CP	**Workload** 120 h	**Self study** 75 h	**Duration** 1	**Cycle offered** SoSe
Language English			**Module owner** Prof. Dr.-Ing. Herbert De Gersem		

1	**Content** Optical lasers cannot produce x-rays of photons and high-gain free-electron lasers (FELs) are being developed as extremely bright sources of x-ray radiation. The peak brightness of these facilities exceeds that of other sources by more than ten orders of magnitude. FELs produce hard x-ray beams with very high transverse coherence and femtosecond pulse length. These characteristics open up new areas of x-ray science, such as femtosecond time-domain spectroscopy etc. In this course an overview of the basics of FEL physics is given. We start our discussion from basics principles of particle acceleration and synchrotron radiation, consider the electron motion in an undulator and explain the most important steps to derive the high-gain FEL model. The performance of the high-gain FEL in the linear and the non-linear regimes is considered. The self-amplified spontaneous emission (SASE) option is introduced and characterized. We discuss new schemes for enhancing of the FEL performance. The theoretical considerations in the course are partially illustrated by the results of numerical simulations and experiments. The numerical algorithms are shortly discussed.
2	**Learning objectives / Learning Outcomes** The student should understand the basics of physics of free electron lasers.
3	**Recommended prerequisite for participation** Maxwell's equations, integral and differential calculus, vector analysis
4	**Form of examination** Module Final Examination: • Module Examination (Technical Examination, Oral Examination, Duration: 30 min, Standard Grading System)
5	**Grading** Module Final Examination: • Module Examination (Technical Examination, Oral Examination, Weighting: 100 %)
6	**Usability of this module** MSc ETiT, MSc iST, MSc iCE, MSc Wi-ETiT
7	**Grade bonus compliant to §25 (2)**
8	**References** The foils of the lecture will be available at: http://www.desy.de/~zagor/lecturesFEL K. Wille, Physik der Teilchenbeschleuniger und Synchrotron- strahlungsquellen, Teuner Verlag, 1996. P. Schmüser, M. Dohlus, J. Rossbach, Ultraviolet and Soft X-Ray Free-Electron Lasers, Springer, 2008. E. L. Saldin, E. A. Schneidmiller, M. V. Yurkov, The Physics of Free Electron Lasers, Springer, 1999.

Courses

Course Nr.	Course name		
18-dg-2110-vl	X-Ray Free Electron Lasers		
Instructor PD Dr. Igor Zagorodnov		**Type** Lecture	**SWS** 2
Course Nr. 18-dg-2110-ue	**Course name** X-Ray Free Electron Lasers		
Instructor PD Dr. Igor Zagorodnov		**Type** Practice	**SWS** 1

Module name Accelerator Physics and Technology					
Module Nr. 18-dg-2070	**Credit Points** 2 CP	**Workload** 60 h	**Self study** 45 h	**Duration** 1	**Cycle offered** WiSe/SoSe
Language German and English			**Module owner** Prof. Dr.-Ing. Herbert De Gersem		

1	**Content** Learn and understand the theoretical contexts in the field of accelerator physics; application of the theoretical background to practical examples related to current projects in the field.
2	**Learning objectives / Learning Outcomes** The seminar addresses various topics relevant to accelerator physics and technology which in detail depend on the guest lecturers. So, insight into the current developments as well as into the different projects in the area is given. Moreover, the focus is put on the practical challenges arising during the design, construction and commissioning phase of the particular accelerator projects.
3	**Recommended prerequisite for participation** Basic knowledge in the field of accelerator physics and technology is useful, though not mandatory.
4	**Form of examination** Module Final Examination: • Module Examination (Study Achievement, Oral Examination, Duration: 30 min, Standard Grading System)
5	**Grading** Module Final Examination: • Module Examination (Study Achievement, Oral Examination, Weighting: 100 %)
6	**Usability of this module** MSc ETiT
7	**Grade bonus compliant to §25 (2)**
8	**References**

Courses

Course Nr.	**Course name**		
18-dg-2070-se	Accelerator Physics and Technology		
Instructor		**Type**	**SWS**
Prof. Dr.-Ing. Herbert De Gersem, Prof. Dr. rer. nat. Norbert Pietralla		Seminar	1

Module name Simulation of beam dynamics and electtromagnetic fields in accelerators					
Module Nr. 18-dg-2170	**Credit Points** 3 CP	**Workload** 90 h	**Self study** 60 h	**Duration** 1	**Cycle offered** SoSe
Language German and English			**Module owner** Prof. Dr.-Ing. Herbert De Gersem		

1	**Content** Particle tracking methods: types of particle methods, relationship to Vlasov model – Integration of equations of motion: Boris pusher, numerical stability, symplecticity – Electrostatic PIC: Green functions, FFT and FD methods, charge deposition, field interpolation, spline shape functions – DC-gun simulation: space charge limited emission – Tracking in the Lorenz frame – Map based tracking methods – Electromagnetic PIC: FDTD method, charge-conserving current deposition, Boris scheme, low dispersion methods – Wakefields and impedances: simulation of ultra-relativistic beams – Plasma Wakefield Acceleration – Parallel computing
2	**Learning objectives / Learning Outcomes** The lecture gives an overview on the numerical modeling of charged particle beams and electromagnetic fields in acceerators. Emphasis is given to the simulation of collective effects caused by space-charge and electromagnetic wakefields. The lecture targets master students focusing on different discilines of electrical engineering and physics. These include the theory of electromagnetic fields, computational engineering as well as computational and experimental accelerator physics. The level is sufficient to provide a solid foundation for contemporary simulation methods for particle beams in accelerators. Furthermre, for experimental accelerator physicists, the lecture provides insight into the different simulation tools, their application, their advantages and also their pitfalls and ranges of validity. During the course, practical simulation examples referring to actual problems at DESY, GSI and the S-DALINAC will be presented.
3	**Recommended prerequisite for participation**
4	**Form of examination** Module Final Examination: • Module Examination (Technical Examination, Oral Examination, Duration: 30 min, Standard Grading System)
5	**Grading** Module Final Examination: • Module Examination (Technical Examination, Oral Examination, Weighting: 100 %)
6	**Usability of this module** MSc ETiT, MSc Physik
7	**Grade bonus compliant to §25 (2)**
8	**References**

Courses

Course Nr.	**Course name**		
18-dg-2170-vl	Simulation of beam dynamics and electtromagnetic fields in accelerators		
Instructor		**Type**	**SWS**
Privatdozent Dr. rer. nat. Erion Gjonaj, Prof. Dr. Oliver Boine-Frankenheim		Lecture	2

Module name Applied Superconductivity					
Module Nr. 18-bf-2030	**Credit Points** 3 CP	**Workload** 90 h	**Self study** 60 h	**Duration** 1	**Cycle offered** SoSe
Language German and English			**Module owner** Prof. Dr. Oliver Boine-Frankenheim		

1 Content

- Basics of electrical conductivity at DC and RF
- Kamerligh-Onnes experiment, Meissner effect
- Superconductor state diagram
- London equations, Typ I / II Superconductor
- Cooper pairs (briefly: BCS theory, GL theory)
- Flux quantization, Flux vortices
- AC superconductivity, two fluid model, RF cavities
- Cooper pair tunneling, Josephson junctions
- Metrology: SQUIDs, (quantum-) Hall effect
- Superconductor magnetization, Hysteresis, Bean‘s model
- Applications: Magnets in accelerator and medical technology, precision field and current measurements, energy engineering

2 Learning objectives / Learning Outcomes

The students obtain a phenomenological understanding of superconductivity, which enables them to apply superconductors in engineering practice. Starting from Maxwellian electrodynamics, superconductors are in introduced as perfect conductors at zero frequency. Both their DC and AC properties are discussed. Theory shall be reduced as much as possible. Quantum mechanics is not a requirement for the course, however, simplified quantum mechanical models will be introduced. The focus of the lecture is put on applications, e.g. magnet technology or precision metrology.

3 Recommended prerequisite for participation

Electrodynamics (Maxwell’s equations)

4 Form of examination

Module Final Examination:

- Module Examination (Technical Examination, Oral Examination, Duration: 30 min, Standard Grading System)

5 Grading

Module Final Examination:

- Module Examination (Technical Examination, Oral Examination, Weighting: 100 %)

6 Usability of this module

MSc ETiT, MSc WI-ETiT, MSc iCE, BSc/MSc CE

7 Grade bonus compliant to §25 (2)

8 References

- W. Buckel, R. Kleiner: „Supraleitung Grundlagen und Anwendungen“; Wiley VCH, 7. Auflage 2013.
- R.G. Sharma; „Superconductivity, Basics and Applications to Magnets“; Springer International Publishing, 2015 (online available).
- H. Padamsee, J. Knobloch, T. Hays: „RF-Superconductivity for Accelerators“; 2nd edition; Wiley VCH Weinheim, 2011.
- P. Seidel (Ed.), „Applied Superconductivity“, Wiley VCH Weinheim, 2015.

Courses

<table>
<tr><td rowspan="2"></td><td>Course Nr.
18-bf-2030-vl</td><td colspan="3">Course name
Applied Superconductivity</td></tr>
<tr><td colspan="2">Instructor
Dr.-Ing. Uwe Niedermayer</td><td>Type
Lecture</td><td>SWS
2</td></tr>
</table>

Module name Introduction to Numerical Analysis					
Module Nr. 04-10-0013/de	**Credit Points** 9 CP	**Workload** 270 h	**Self study** 180 h	**Duration** 1	**Cycle offered** Every 2. Sem.
Language German			**Module owner** Prof. Dr. rer. nat. Jens Lang		

1	**Content** Condition, systems of linear and nonlinear equations, least squares minimization, interpolation, integration and differentiation, differential equations, difference schemes, programming exercises.
2	**Learning objectives / Learning Outcomes** The students are able to describe, explain and apply basic elememtary numerical methods. They should have the ability to compare, modify and combine them.
3	**Recommended prerequisite for participation** recommended: Analysis and Linear Algebra, Introduction to Scientific Programming
4	**Form of examination** Module Final Examination: • Module Examination (Study Achievement, Special Form, Pass/Fail Grading System) • Module Examination (Technical Examination, Optional, Standard Grading System) Fachprüfung: Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam. Studienleistung: Usually this means that the student successfully completes a certain proportion of the homework assignments. The precise proportion of necessary assignments and the marking scheme will be communicated by the instructor during the first lecture.
5	**Grading** Module Final Examination: • Module Examination (Study Achievement, Special Form, Weighting: 0 %) • Module Examination (Technical Examination, Optional, Weighting: 100 %)
6	**Usability of this module** B.Sc. Mathematik, LaG Mathematik
7	**Grade bonus compliant to §25 (2)**
8	**References** Deuflhard, Hohmann: Numerical Analysis in Modern Scientific Computing: An Introduction; Texts in Applied Mathematics 43, Springer 2003. Stoer, Bulirsch: Introduction to Numerical Analysis; Texts in Applied Mathematics 12, Springer 2002 Matlab User Guide

Courses

Course Nr.	**Course name**		
04-00-0056-vu	Introduction to Numerical Analysis		
Instructor		**Type**	**SWS**
Prof. Dr. rer. nat. Jens Lang		Lecture & Practice	6

Module name Introduction to Optimization					
Module Nr. 04-10-0040/de	**Credit Points** 9 CP	**Workload** 270 h	**Self study** 180 h	**Duration** 1	**Cycle offered** Every 2. Sem.
Language German			**Module owner** Prof. Dr. rer. nat. Marc Pfetsch		

1	**Content** convex sets and functions; introduction to the theory of polyhedra; theory of optimality and duality in linear optimization; simplex method for the solution of linear optimization problems; polynomial complexity of linear optimization; procedure for problems of quadratic optimization
2	**Learning objectives / Learning Outcomes** Students - are proficient in optimality and duality theory in linear optimization. - are familiar with the basics of the theory of polyedra and convex functions.. - know basic numerical methods for the solution of linear and quadratic optimization problems. - are able to solve and model applications with linear and quadratic optimization problems.
3	**Recommended prerequisite for participation** recommended: Analysis, Linear Algebra
4	**Form of examination** Module Final Examination: • Module Examination (Study Achievement, Special Form, Pass/Fail Grading System) • Module Examination (Technical Examination, Optional, Standard Grading System) Fachprüfung: Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam. Studienleistung: Usually this means that the student successfully completes a certain proportion of the homework assignments. The precise proportion of necessary assignments and the marking scheme will be communicated by the instructor during the first lecture.
5	**Grading** Module Final Examination: • Module Examination (Study Achievement, Special Form, Weighting: 0 %) • Module Examination (Technical Examination, Optional, Weighting: 100 %)
6	**Usability of this module** B.Sc. Mathematik, M.Sc Mathematik, M.Sc. Mathematics, LaG Mathematik
7	**Grade bonus compliant to §25 (2)**
8	**References** Chvatal: Linear Programming Geiger, Kanzow: Theorie und Numerik restringierter Optimierungsaufgaben; Jarre, Stoer: Optimierung Nocedal; Wright: Numerical Optimization; Schrijver: Theory of Linear and Integer Programming; Ziegler: Lectures on Polytopes

Courses

Course Nr.	**Course name**		
04-00-0023-vu	Introduction to Optimization		
Instructor		**Type**	**SWS**
Prof. Dr. rer.nat. Winnifried Wollner		Lecture & Practice	6

Module name					
Numerical Methods for Ordinary Differential Equations for Engineers					
Module Nr. 04-10-0042/de	**Credit Points** 5 CP	**Workload** 150 h	**Self study** 105 h	**Duration** 1	**Cycle offered** Every 2. Sem.
Language German			**Module owner** Prof. Dr. rer. nat. Jens Lang		

1	**Content** initial value problems: one-step methods, multi-step methods; convergence analysis, notions of stability; boundary-value problems: Shooting methods, finite difference methods, stability and convergence;
2	**Learning objectives / Learning Outcomes** Students know the basic numerical solution concepts for ordinary differential equations and they are able to analyze, compare, and apply them.
3	**Recommended prerequisite for participation** recommended: Analysis, Linear Algebra, Ordinary Differential Equations, Introduction to Numerical Analysis or similar knowledge as taught in an engineering programme.
4	**Form of examination** Module Final Examination: • Module Examination (Technical Examination, Technical Examination, Standard Grading System) • Module Examination (Study Achievement, Special Form, Pass/Fail Grading System) Fachprüfung: Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam. Studienleistung: Usually this means that the student successfully completes a certain proportion of the homework assignments. The precise proportion of necessary assignments and the marking scheme will be communicated by the instructor during the first lecture.
5	**Grading** Module Final Examination: • Module Examination (Technical Examination, Technical Examination, Weighting: 100 %) • Module Examination (Study Achievement, Special Form, Weighting: 0 %)
6	**Usability of this module** B.Sc. Mathematik, M.Sc Mathematik, M.Sc. Mathematics
7	**Grade bonus compliant to §25 (2)**
8	**References** Deuflhard, Bornemann: Numerische Mathematik 2 Stoer, Bulirsch: Numerische Mathematik 2

Courses

Course Nr.	Course name		
04-10-0134-vu			
Instructor		**Type**	**SWS**
Prof. Dr. techn. Herbert Egger		Lecture & Practice	3

Module name Numerical Linear Algebra					
Module Nr. 04-10-0043/de	**Credit Points** 5 CP	**Workload** 150 h	**Self study** 105 h	**Duration** 1	**Cycle offered** Every 2. Sem.
Language German			**Module owner** Dr. rer. nat. Alf Gerisch		

1	**Content** Systems of linear equations: iterative methods, singular value decomposition, eigenvalue problems.
2	**Learning objectives / Learning Outcomes** Students know about the most important numerical methods of linear algebra and they are able to explain, classify, and apply them.
3	**Recommended prerequisite for participation** recommended: Linear Algebra, Introduction to Numerical Analysis or similar knowledge
4	**Form of examination** Module Final Examination: • Module Examination (Technical Examination, Technical Examination, Standard Grading System) • Module Examination (Study Achievement, Special Form, Pass/Fail Grading System) Fachprüfung: Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam. Studienleistung: Usually this means that the student successfully completes a certain proportion of the homework assignments. The precise proportion of necessary assignments and the marking scheme will be communicated by the instructor during the first lecture.
5	**Grading** Module Final Examination: • Module Examination (Technical Examination, Technical Examination, Weighting: 100 %) • Module Examination (Study Achievement, Special Form, Weighting: 0 %)
6	**Usability of this module** B.Sc. Mathematik, M.Sc Mathematik, M.Sc. Mathematics
7	**Grade bonus compliant to §25 (2)**
8	**References** Trefethen/Bau: Numerical Linear Algebra, SIAM Demmel: Applied Numerical Linear Algebra, SIAM Stoer/Bulirsch: Numerische Mathematik 2, Springer

Courses

Course Nr.	**Course name**		
04-00-0139-vu	Numerical Linear Algebra		
Instructor		**Type**	**SWS**
Dr. rer. nat. Alf Gerisch		Lecture & Practice	3

Module name Partial Differential Equations I					
Module Nr. 04-10-0037	**Credit Points** 9 CP	**Workload** 270 h	**Self study** 180 h	**Duration** 1	**Cycle offered** Every 2. Sem.
Language German and English			**Module owner** Prof. Dr. rer. nat. Matthias Hieber		

1	**Content** Classical treatment of the fundamental types (e.g. elliptic, parabolic, hyperbolic, dispersive), formulation of elliptic boundary value problems as variational problems, regularity theory, theory of Sobolev spaces, Galerkin methods, fixed point methods and nonlinear elliptic and parabolic equations
2	**Learning objectives / Learning Outcomes** Students - understand and are able to apply the notions, methods and results treated in the course - develop an advanced level of understanding of partial differental equations - are able to extend their knowledge in this field
3	**Recommended prerequisite for participation** recommended: Functional Analysis
4	**Form of examination** Module Final Examination: • Module Examination (Technical Examination, Optional, Standard Grading System) Fachprüfung: Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam.
5	**Grading** Module Final Examination: • Module Examination (Technical Examination, Optional, Weighting: 100 %)
6	**Usability of this module** B.Sc Mathematik, M.Sc. Mathematik, M.Sc. Mathematics
7	**Grade bonus compliant to §25 (2)**
8	**References** L.C. Evans: Partial Differential Equations (AMS) D. Gilbarg, N.S. Trudinger: Elliptic Partial Differential Equations of Second Order (Springer) M. Renardy, R.C. Rogers: An Introduction to Partial Differential Equations (Springer)

Courses

Course Nr.	**Course name**		
04-00-0184-vu	Partial Differential Equations I		
Instructor		**Type**	**SWS**
Prof. Dr. rer. nat. Matthias Hieber		Lecture & Practice	6

Module name Simulation of beam dynamics and electtromagnetic fields in accelerators					
Module Nr. 18-dg-2170	**Credit Points** 3 CP	**Workload** 90 h	**Self study** 60 h	**Duration** 1	**Cycle offered** SoSe
Language German and English			**Module owner** Prof. Dr.-Ing. Herbert De Gersem		

1	**Content** Particle tracking methods: types of particle methods, relationship to Vlasov model – Integration of equations of motion: Boris pusher, numerical stability, symplecticity – Electrostatic PIC: Green functions, FFT and FD methods, charge deposition, field interpolation, spline shape functions – DC-gun simulation: space charge limited emission – Tracking in the Lorenz frame – Map based tracking methods – Electromagnetic PIC: FDTD method, charge-conserving current deposition, Boris scheme, low dispersion methods – Wakefields and impedances: simulation of ultra-relativistic beams – Plasma Wakefield Acceleration – Parallel computing
2	**Learning objectives / Learning Outcomes** The lecture gives an overview on the numerical modeling of charged particle beams and electromagnetic fields in acceerators. Emphasis is given to the simulation of collective effects caused by space-charge and electromagnetic wakefields. The lecture targets master students focusing on different discilines of electrical engineering and physics. These include the theory of electromagnetic fields, computational engineering as well as computational and experimental accelerator physics. The level is sufficient to provide a solid foundation for contemporary simulation methods for particle beams in accelerators. Furthermre, for experimental accelerator physicists, the lecture provides insight into the different simulation tools, their application, their advantages and also their pitfalls and ranges of validity. During the course, practical simulation examples referring to actual problems at DESY, GSI and the S-DALINAC will be presented.
3	**Recommended prerequisite for participation**
4	**Form of examination** Module Final Examination: • Module Examination (Technical Examination, Oral Examination, Duration: 30 min, Standard Grading System)
5	**Grading** Module Final Examination: • Module Examination (Technical Examination, Oral Examination, Weighting: 100 %)
6	**Usability of this module** MSc ETiT, MSc Physik
7	**Grade bonus compliant to §25 (2)**
8	**References**

Courses

	Course Nr. 18-dg-2170-vl	**Course name** Simulation of beam dynamics and electtromagnetic fields in accelerators		
	Instructor Privatdozent Dr. rer. nat. Erion Gjonaj, Prof. Dr. Oliver Boine-Frankenheim		**Type** Lecture	**SWS** 2

Module name					
Matrix Analysis and Computations					
Module Nr. 18-pe-2070	**Credit Points** 6 CP	**Workload** 180 h	**Self study** 120 h	**Duration** 1	**Cycle offered** SoSe
Language English			**Module owner** Prof. Dr.-Ing. Marius Pesavento		

1	**Content** This graduate course is a foundation class on matrix analysis and computations, which are widely used in many different fields, e.g., machine learning, computer vision, systems and control, signal and image processing, communications, networks, optimization, and many more... Apart from the theory this course will also cover the design of efficient algorithm and it considers many different examples from the aforementioned fields including examples from social media and big data analysis, image processing and medical imaging, communication network optimization, and written text classification. Specific topics: (i) basic matrix concepts, subspace, norms, (ii) linear least squares (iii) eigendecomposition, singular value decomposition, positive semidenite matrices, (iv) linear system of equations, LU decomposition, Cholesky decomposition (v) pseudo-inverse, QR decomposition (vi) advanced tensor decomposition, advanced matrix calculus, compressive sensing, structured matrix factorization
2	**Learning objectives / Learning Outcomes** Students will learn matrix analysis and computations at an advanced or research level.
3	**Recommended prerequisite for participation** Basic knowledge in linear algebra.
4	**Form of examination** Module Final Examination: • Module Examination (Technical Examination, Optional, Standard Grading System)
5	**Grading** Module Final Examination: • Module Examination (Technical Examination, Optional, Weighting: 100 %)
6	**Usability of this module**
7	**Grade bonus compliant to §25 (2)**
8	**References** 1.Gene H. Golub and Charles F. van Loan, Matrix Computations (Fourth Edition), John Hopkins University Press, 2013. 2.Roger A. Horn and Charles R. Johnson, Matrix Analysis (Second Edition), Cambridge University Press, 2012. 3.Jan R. Magnus and Heinz Neudecker, Matrix Differential Calculus with Applications in Statistics and Econometrics (Third Edition), John Wiley and Sons, New York, 2007. 4.Giuseppe Calaore and Laurent El Ghaoui, Optimization Models, Cambridge University Press, 2014. ECE 712 Course Notes by Prof. Jim Reilly, McMaster University, Canada (friendly notes for engineers) http://www.ece.mcmaster.ca/faculty/reilly/ece712/course_notes.htm

Courses

Course Nr. 18-pe-2070-vl	**Course name** Matrix Analysis and Computations		
Instructor Prof. Dr.-Ing. Marius Pesavento		**Type** Lecture	**SWS** 3

	Course Nr.	Course name		
	18-pe-2070-ue	Matrix Analysis and Computations		
	Instructor		**Type**	**SWS**
	Prof. Dr.-Ing. Marius Pesavento		Practice	1

2.3 CED III: Modules of other ETiT focus areas