Communication, Systems, and Electronics

MSc, Integrated PhD Program

School of Engineering and Science

Graduate Handbook

Electrical Engineering

— Communications, Systems, and Electronics —

Disclaimer

Although care has been taken to describe the Engineering and Science majors in their respective handbooks as close as possible to the actual course offerings, titles, and scheduling, Jacobs University Bremen reserves the right to make changes, substitutions, and corrections as deemed appropriate.

The authoritative version of this handbook can be found at
`http://www.jacobs-university.de/cse`

It references the following three documents, which form an integral part of this handbook

- *Research Profile Engineering and Computer Science*
  `http://www.jacobs-university.de/eecs-research`
- *Undergraduate Handbook Electrical Engineering and Computer Science*
  `http://www.jacobs-university.de/eecs`
- *Undergraduate Handbook Electrical and Computer Engineering*
  `http://www.jacobs-university.de/ece`

Contents

Disclaimer

As of September 1, 2014 the School of Engineering and Science and the School of Humanities and Social Sciences have been replaced by the Focus Areas Health, Mobility and Diversity. Handbooks and policies might still refer to the old structure of Schools.

If this is the case, references to the School of Engineering and Science include courses offered within the following disciplines:

- Electrical Engineering and Computer Science
- Life Sciences
- Logistics
- Mathematical Sciences
- Natural and Environmental Sciences

References to the School of Humanities and Social Sciences include courses offered within the following disciplines:

- Economics and Management
- History
- Humanities
- Law
- Psychology
- Social Sciences
- Statistics and Methods

1 Introduction to the Program

The graduate program "Communications, Systems, and Electronics — CSE" is an interdisciplinary graduate program in Electrical Engineering with strong links to other graduate programs, in particular the Computer Science and Physical Science program.

1.1 Philosophy

The CSE graduate program follows a twofold approach: Integration of and specialisation in traditional electrical engineering disciplines. During the initial 3 semesters special emphasis is placed on the integration of three major fields of EE, namely Communications, Systems, and Electronics. This integration is deemed essential given the ever increasing complexity of engineering tasks. While it is recognised that a high degree of specialisation is necessary to enable the development of sophisticated solutions in particular fields, an additional challenge of EE nowadays is to make single highly specialised components work together most effectively and efficiently. This is best explained with an example. One could see RFID (radio frequency identification) tags replacing the well known bar-code, and due to the inherent flexibility in storing data, the range of applications is greatly enlarged. These little tags are complete systems which, for example, require low power integrated circuits (ICs) – ideally organic devices (bendable), energy storing elements, radio frequency components such as an antenna, digital signal processing units, communication protocols and transmission technologies, and mathematical modelling methods in order to be able to study the behaviour of the system prior to any real deployment. Therefore, everyone who is engaged in research on and development of such complex systems requires expertise in all the fields mentioned. To cater for the required breadth and depth, the graduate program has three key components: (a) brought course offerings in all of the mentioned EE fields during the first three semesters (to support the idea of specialisation and integration), (b) intensive cross-area project work during the first three semesters (to support the idea of integration), and (c) intensive specialisation in one of the above mentioned areas during the subsequent 3 years of Ph.D studies (to support the idea of specialisation).

1.2 Degrees

The CSE graduate program in Electrical Engineering offers the following two degrees:

1.2.1 Master of Science

The M.Sc program at Jacobs University Bremen takes two years or four semesters. In particular the first three semesters (1.5 years of study) of the Master's degree include regular course work, i.e., lectures, projects and seminars, and the opportunity to engage in scientific work. Provided that at least ten graduate courses are passed, that the research projects are successfully completed, and that the thesis proposal is approved, the student is permitted to complete a Master's thesis during semester four.

1.2.2 Doctor of Philosophy (PhD)

Students who have already achieved a Master's degree may apply to pursue a PhD degree at Jacobs University Bremen. Students with a Bachelor's degree may apply for the Integrated PhD track. Students with a Master's degree will be immediately admitted to the PhD phase, whereas Bachelor students have to start with course work, before entering the PhD phase.

1.3 Prospects and Career Options for Graduates

The prime goals of this program is to prepare students for a scientific career (PhD or postdoctoral research) or leading positions in industry, where the skills of *communication engineering*, *mathematical modeling and simulation*, *manufacturing process optimisation* and the *development of electronic components and circuits* form the basis for professional excellence. In addition to these fundamental skills, the program provides training that covers the knowledge from the industrial and academic fields of *wireless communications*, *transmission technologies and coding*, *electronic devices*, *microelectronics*, *photovoltaics*, *mathematical modeling and model reduction*, *control theory*, *digital signal processing*, *very large scale integration (VLSI) design*, and *quality management*.

1.4 Target Audience

The target audience of the CSE graduate program are as follows:

- students who have completed their B.Sc. in EE, ECE, EECS or related disciplines and who want to deepen their knowledge and proceed to research oriented work towards a Master or PhD degree,
- graduate students who have completed their Master's degree and would like to continue their graduate education.

1.5 Structure

The CSE graduate program in Electrical Engineering offers the MSc and PhD degrees in various separate tracks.

Depending on the qualifications students are free to apply for the different tracks. Students who are interested in the Master and the Integrated PhD track are encouraged to directly apply online for the programs. Students with a Master degree are encouraged to first contact a potential supervisor of the PhD project.

The Fast Track option is available only for Jacobs undergraduate students, who have already successfully obtained a Bachelor degree at Jacobs University Bremen. Jacobs University students have to indicate in their application or after admission to the program if they want to apply for the fast track option.

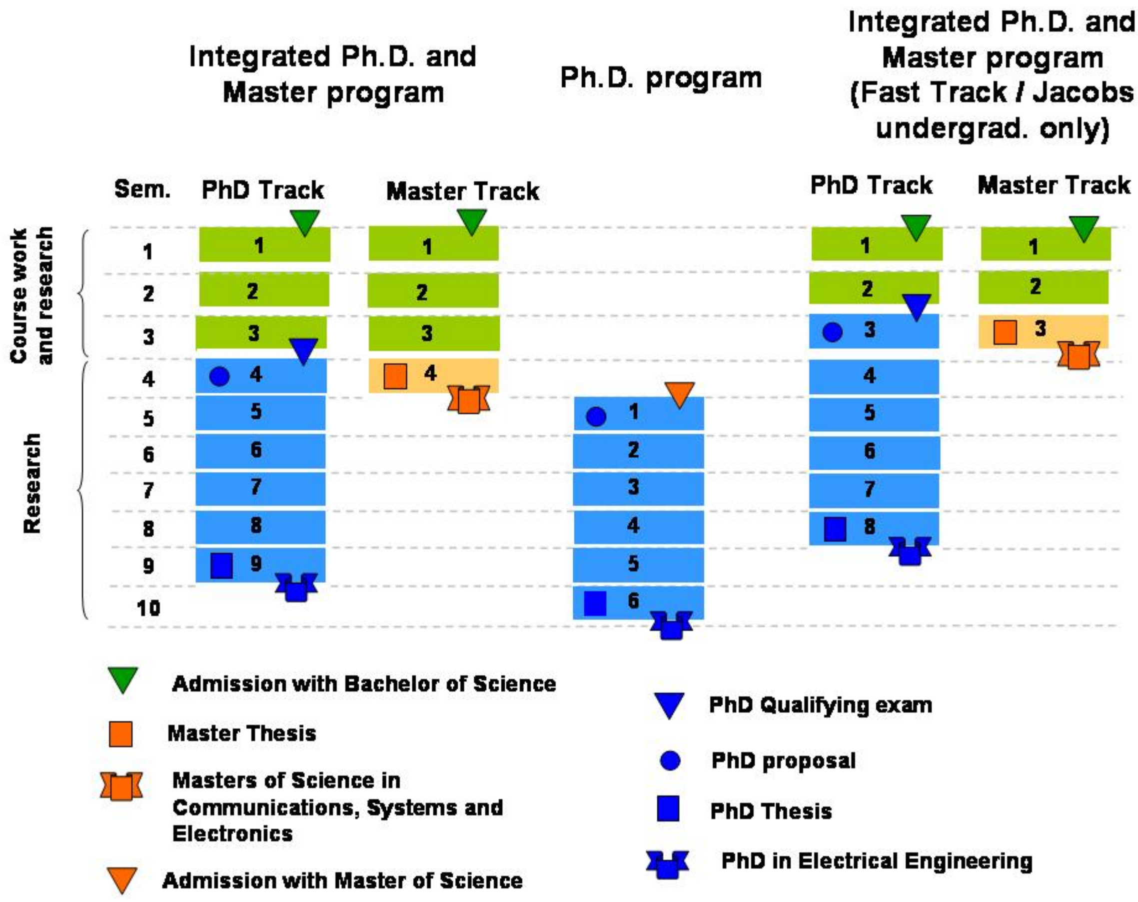

Figure 1: Overview of different tracks within the graduate program Communications, Systems and Electronics

1.5.1 The Master Program

The Master's program aims to provide an advanced engineering education. It comprises different elements: lectures, laboratory courses, and research projects (semester projects), the CSE seminar, and the Master's thesis during the fourth semester.

Figure 2 displays a typical structure of a Master's program; all credits involved are ECTS credits. For a detailed description of course contents, see Sections 2.1,2.2, and 2.3.

Semester	Element	Category	Credits
1	3 Courses - Lectures, Seminars or Laboratories -	C	3 x 5
	CSE Research project I	P	12.0
	CSE Seminar I	S	1.0
	total		**28.0**
2	3 Courses - Lectures, Seminars or Laboratories -	C	3 x 5
	CSE Research project II	P	12.0
	CSE Seminar II	S	3.0
	total		**30.0**
3	2 Courses - Lectures, Seminars or Laboratories -	C	2 x 5
	Master Thesis Proposal	MTP	18.0
	CSE Seminar III	S	3.0
	total		**31.0**
4	2 Courses - Lectures, Seminars or Laboratories -	C	2 x 5
	Master Thesis	MT	18.0
	CSE Seminar IV	S	3.0
	total		**31.0**
	Master's program		**120**

Figure 2: Typical structure of the Master's track

Courses (C) Master's students need to enroll in and pass at least ten courses from the core CSE curriculum detailed in Section 2.1. These courses require a substantial amount of preparation including analysis, design, experiment, or lab work, and are typically rated 5 credits each. In some cases, up to two 3rd year Jacobs University undergraduate courses, or courses from other Jacobs University graduate programs like the Computer Science or the Physical Science program can be applied towards the requirement, subject to approval by the CSE faculty. Language courses and university study courses are not admissible here, except the university study course on "Management-Quality-Success". Required: **50** credits

Research Projects (P) In addition to the regular course work, students also have to engage in research projects within the first two semesters of the Master's track. The projects, which are rated 12.0 credits each, serve as a platform to learn about research-oriented methodologies. Students will acquire and apply in-depth knowledge of a topic selected and supervised by a CSE professor. At the completion of each project, the student must also present an overview of the research topic as well as his or her specific research and findings in a short oral presentation. The presentations will be held in the CSE Seminar. In the case of particularly successful projects, students may be guided towards conference participation and publication of their results. Required: **24.0** credits

CSE Seminar (S) Students are required to participate in the CSE seminar, which is a colloquium series for Electrical Engineering Master and Integrated PhD students at Jacobs University Bremen. In this seminar, students have the opportunity to present their research, which is an important skill for any scientific or engineering career. Additionally, students obtain an overview of current research projects carried out in the different Electrical Engineering research groups. Attendance of the CSE seminar is mandatory. Required: **10.0** credits.

Master's Thesis Proposal (MTP) and Master's Thesis (MT) In the third and fourth semester the student performs the required research and writes the Master's thesis proposal and the Master's thesis guided and supported by the academic supervisor. The thesis is the culmination of the student's research completed during the MSc program. At the end of the fourth semester, key results from the thesis are presented in a public lecture. The thesis and the lecture will be jointly judged by the thesis examination committee in order to determine the thesis grade according to Jacobs University Bremen grading system. Together, the Master's thesis proposal and the thesis (with passing grades) earn 36 credits for the student. Required: **36** credits

1.5.2 The Integrated PhD Program

The structure of the Integrated PhD program is highly research oriente. It is divided into two parts: During the first three semesters (1st part of the program) students will attend lectures, seminars, and laboratory courses, and carry out research projects (semester projects). Furthermore, students have to attend the CSE seminar. During the second part integrated PhD students are fully engaged in research. Figure 3 displays a typical structure of the Integrated PhD program; all credits involved are ECTS credits. For a detailed account of course contents, see sections 2.1, 2.2, and 2.3.

Semester	Element	Category	Credits
1	3 Courses - Lectures, Seminars or Laboratories -	C	3 x 5
	CSE Research project I	P	12.0
	CSE Seminar IV	S	3.0
	total		**30.0**
2	3 Courses - Lectures, Seminars or Laboratories -	C	3 x 5
	CSE Research project II	P	12.0
	CSE Seminar II	S	3.0
	total		**30.0**
3	3 Courses - Lectures, Seminars or Laboratories -	C	3 x 5
	CSE Research Project III	P	12.0
	CSE Seminar III	S	3.0
	total		**30.0**
	Coursework total	-	**90**
	PhD qualifying exam	E	-
4	PhD Thesis Proposal	TP	-
5-8	PhD Research	R	-
9	Write-up of PhD thesis and Defence	PT	-

Figure 3: Typical structure of the Integrated PhD track

Courses (C) During the first three semesters, Integrated PhD students need to enroll in and pass at least nine courses from the core CSE curriculum detailed in Section 2.1. These courses require a substantial amount of preparation including analysis, design, experiment, or lab work, and are typically rated 5 credits each. In some cases, up to two 3rd year Jacobs University undergraduate courses, or courses from other Jacobs University graduate programs like the Computer Science or the Physical Science program can be applied towards the requirement, subject to approval by the CSE faculty. Language courses and university study courses are not admissible here, except the university study course on ”Management-Quality-Success”. Required: **45** credits

Research Projects (P) In addition to the regular course work, students also have to engage in research projects within the first three semesters of the Master's track. The projects, which are rated 12.0 credits each, serve as a platform to learn about research-oriented methodologies. Students will acquire and apply in-depth knowledge of a topic selected and supervised by a CSE professor. At the completion of each project, the student must also present an overview of the research topic as well as his or her specific research and findings in a short oral presentation. The presentation will be part of the CSE seminar. In the case of particularly successful projects, students may be guided towards conference participation and publication of their results. Required: **36.0** credits

CSE Seminar (S) In the first three semesters, students are required to participate in the CSE seminar, which is a colloquium series for Electrical Engineering Master and Integrated PhD students at Jacobs University Bremen. In this seminar, students have the opportunity to present their research, which is an important skill for any scientific or engineering career. Additionally, students obtain an overview of current research projects carried out in the different Electrical Engineering research groups. Attendance of the CSE seminar is mandatory.
Required: **9.0** credits.

PhD qualifying exam (E) A PhD qualifying exam will take place at the end of the third semester. A minimum of 90 ECTS credits are required to attend the PhD qualifying exam. The PhD qualifying exam will be an oral exam offered by the CSE faculty. Students have to demonstrate an advanced knowledge of Electrical Engineering. Different fields of Electrical Engineering will be covered during the exam. Students have to pass the PhD qualifying exam to continue with the PhD thesis proposal.

PhD Thesis Proposal (TP) Assuming the PhD qualifiying exam is passed successfully the student completes a research proposal in the 4th semester. The PhD proposal is prepared in collaboration with her/his academic advisor. This proposal must

- demonstrate that the student masters the professional terminology in the research domain and has sufficient background knowledge,
- show that the student is capable of conducting her/his own independent research,
- identify and motivate a relevant and feasible research question,
- connect the question to the state of the art by a focussed and illustrative review of current literature,
- provide a plan for experiments, theoretical investigations, design work or implementations, including a schedule,
- and describe criteria for evaluating the eventual success of the project.

At the end of the 4th semester, a dissertation committee is constituted and the proposal is defended in a public presentation.

PhD Research (R) Assuming the research proposal is successfully presented and approved, the student begins working on her/his research project.

It is only natural that the originally stated objectives are refined or even re-defined in this process. Progress is monitored based on presentations within the graduate program, typically in the context of a seminar, publications by the student, availability and quality of research results, and by continuous interaction with the advisor.

Students are encouraged to present and publish their work or parts of their work at scientific conferences and workshops or publish research papers in scientific journals.

In the case of insufficient progress, the Dean and the dissertation committee decide, in consultation with the steering committee of the program, whether the student is allowed to continue his or her education at Jacobs University Bremen, and if so, under what additional conditions.

PhD Thesis write-up (PT) The last semester is devoted to completing the written thesis, which usually takes place during the 9th semester. At the end of the program, the thesis is presented to the PhD thesis committee and the university at large in a public PhD thesis defense. The thesis committee judges the defense as well as the content and form of the written thesis to determine whether to accept or reject the thesis. The PhD thesis is not graded but in the case of exceptional achievement a Special Distinction is awarded.

1.5.3 The PhD Program

The Ph.D. track is devoted to focused research within the research group of an academic supervisor. Students who enter the PhD program from the CSE Master's track will usually choose their advisor after the third Master's semester, whereas students who enter the program by direct application typically choose the advisor during the application/acceptance process.

Figure 4 shows a typical structure of a PhD program. In addition to their own research work, PhD students are required to participate in the research seminar of their respective advisor. They are also expected to attend the CSE seminar and the SES colloquium. Furthermore, PhD students are encouraged but not required to enlist in courses offered in the CSE or related programs that can deepen and expand their perspective of their own chosen area of research.

Semester	Element	Category	Credits
1	PhD Thesis Proposal	TP	-
2-5	PhD Research	R	-
6	Write-up of PhD thesis and Defence	PT	-

Figure 4: Typical structure of the PhD track

PhD Thesis Proposal (TP) Assuming the PhD qualifiying exam is passed successfully the student completes a research proposal in the first semester. The PhD proposal is prepared in collaboration with her/his academic advisor. This proposal must

- demonstrate that the student masters the professional terminology in the research domain and has sufficient background knowledge,
- show that the student is capable of conducting her/his own independent research,
- identify and motivate a relevant and feasible research question,
- connect the question to the state of the art by a focussed and illustrative review of current literature,
- provide a plan for experiments, theoretical investigations, design work or implementations, including a schedule,
- and describe criteria for evaluating the eventual success of the project.

At the end of the frist semester, a dissertation committee is constituted and the proposal is defended in a public presentation.

PhD Research (R) Assuming the research proposal is successfully presented and approved, the student begins working on her/his research project.

It is only natural that the originally stated objectives are refined or even re-defined in this process. Progress is monitored based on presentations within the graduate program, typically in the context of a seminar, publications by the student, availability and quality of research results, and by continuous interaction with the advisor.

Students are encouraged to present and publish their work or parts of their work at scientific conferences and workshops or publish research papers in scientific journals.

In the case of insufficient progress, the Dean and the dissertation committee decide, in consultation with the steering committee of the program, whether the student is allowed to continue his or her education at Jacobs University Bremen, and if so, under what additional conditions.

PhD Thesis write-up (PT) The last semester is devoted to completing the written thesis, which usually takes place during the 6th semester. At the end of the program, the thesis is presented to the PhD thesis committee and the university at large in a public PhD thesis defense. The thesis committee judges the defense as well as the content and form of the written thesis to determine whether to accept or reject the thesis. The PhD thesis is not graded but in the case of exceptional achievement a Special Distinction is awarded.

1.5.4 Teaching

Teaching experience is part of graduate education. All graduate students are encouraged to work in graduate courses as teaching assistants (TAs). This involves among other activities giving tutorials, grading exercises, and supervising lab or undergraduate project work. According to their experience, PhD students may also develop exercises or define undergraduate projects and offer seminars. TA work is paid according to the general Jacobs University policies.

2 Curriculum of the Integrated PhD and Master's Program

This section introduces the contents of the courses, semester projects and seminars in the Integrated PhD and Master's track of the EE graduate program Communications, Systems, and Electronics.

Disclaimer

Jacobs University Bremen reserves the right to substitute courses by replacements and/or reduce the number of mandatory/mandatory elective courses offered.

2.1 Graduate Courses

The following courses will be offered on a regular basis in the program. All courses are counted as master courses.

Course No.	Type	Title	Responsible
300401	Lecture	Model order reduction with application to CAD of circuits and systems	A.C. Antoulas
300402	Lecture	Antennas and Propagation	M. Schneider
300411	Lecture	Digital Communications with a focus on Wireline Communications	W. Henkel
300412	Lecture	RF and Microwave Component and System Design	S. Peik
300462	Laboratory	RF and Microwave Component and System Design Laboratory	S. Peik
300422	Lecture	Detection and Estimation	D. Kraus
300472	Laboratory	Detection and Estimation Laboratory	D. Kraus
300441	Lecture	Wireless Communications II	G. Abreu
300551	Seminar	Wireless Communications II	G. Abreu
300451	Lecture	Speech Signal Processing	M. Bode
300561	Laboratory	Speech Signal Processing Laboratory	M. Bode
300491	Lecture	Convex Optimization	M. Bode
300493	Laboratory	Optimization Laboratory	M. Bode
300501	Lecture	Computational Electromagnetics	N.N
300571	Laboratory	Computational Electromagnetics Laboratory	N.N
300322	Lecture	Advanced Random Processes	M. Bode
300351	Lecture	Advanced Digital Design	F. Hu
300362	Lecture	Coding Theory	W. Henkel
300371	Lecture	Wavelets and their Applications	A.C. Antoulas
300511	Lecture	Renewable Energy Systems Optimization and Management	N.N.
050312	Lecture	Quality Management and Environmental Management	N.N.

These courses form the core of the Integrated PhD and Master's track of the CSE graduate program. They are also open to students from other graduate programs. Bachelor's students will be admitted to lectures and laboratories on an individual basis.

In addition to the courses listed above, there are graduate courses in Mathematics, Computer Science, Physical Sciences, and possibly other disciplines of relevance for CSE graduate students, depending on their chosen specialization area.

The course descriptions below specify prerequisites both internal to the program as well as in terms of Jacobs University undergraduate courses. The meaning of the latter is that Master's students who have obtained their Bachelor's degree at other universities should have passed courses whose content is equivalent to the respective Jacobs University courses[1]. Students need to talk to the instructor of record and obtain a prerequisite waiver to be able to register for the course.

300401 – Model order reduction with application to CAD of circuits and systems

Short Name:	ModRed
Type:	lecture
Semester:	1-3
Credit Points:	5
Prerequisites:	t.b.d.
Corequisites:	300521
Tutorial:	None

Course contents Model-order reduction methods explore ways in which the complexity of the mathematical models of physical systems can be reduced for the purposes of expedient, yet accurate, computer-aided analysis. Recently, these methods are being pursued by the electromagnetics and circuits computer-aided design (CAD) communities in their efforts to develop efficient modeling tools capable of tackling the escalating complexity of the design and virtual prototyping of integrated mixed-signal systems. This course offers a comprehensive view of the development and application of model-order reduction methods in the analysis and CAD of complex circuits and systems.

In particular, the first half of the course will be dedicated to the fundamentals of linear dynamical systems, their representation both in state space and input-output terms, and their approximation. The methods developed will then be applied to model-order reduction for large linear circuits arising in modeling the interconnection networks in high-density integrated circuits. Applications include the reduction of both lumped RLC and transmission-line-based circuit models.

The course is based on the book: "Approximation of large-scale systems", by A.C. Antoulas, published by SIAM, Philadelphia, 2005.

[1] see `http://www.jacobs-university.de/eecs`,
and `http://www.jacobs-university.de/ece`

300402 – Antennas and Propagation

Short Name:	AntProp
Type:	lecture
Semester:	1-3
Credit Points:	5
Prerequisites:	t.b.d.
Corequisites:	t.b.d.
Tutorial:	None

Course contents In recent years, wireless technologies, ranging from personal cellular communications and wireless LAN to geolocation and RFID have experienced amazing growth. At the lowest level, these technologies depend not only on transmit and receive antenna elements that properly convert signals to electromagnetic (EM) waves and vice versa, but also propagation channels that carry electromagnetic waves from one location to another.

This course provides a fundamental treatment of both antenna theory and propagation channels and applies this understanding to the design and analysis of advanced wireless technologies. On one hand, the principles taught in this course are directly applicable for students interested in designing antennas and simulating their performance in realistic environments. On the other hand, those more interested in communications and signal processing will also benefit by understanding how the underlying antennas and channels can be best exploited by advanced algorithms to optimize overall system performance. This lecture course stresses a mathematical treatment of antennas and propagation channels. Students interested in gaining practical experience simulating antennas and propagation channels on computers using custom and/or commercial CAD packages are encouraged to take the Antennas and Propagation Lab in parallel.

Concepts Covered:

- **Basic electromagnetic analysis**: Electric and magnetic fields, vector potentials, the wave equation, far-field radiation, duality, reciprocity
- **Antenna parameters**: radiation patterns, directivity, gain, antenna efficiency, bandwidth, polarization, input impedance
- **Antenna structures**: linear wire antennas, loops, horn antennas, planar structures, reflector antennas, and broadband elements
- **Antenna arrays**: Element and array factors, mutual coupling, beamforming and nulling, super-resolution methods, super-gain phenomena, pattern synthesis
- **Propagation and channel modeling**: Free-space propagation, radar range equation, Doppler, multipath propagation, statistical fading models, path-based models, multipath clustering, deterministic ray tracing, multiple-input multiple-output (MIMO) channels, non-stationary channel models, channel capacity

300411 – Digital Communications with a focus on Wireline Communications

Short Name: WLineComI
Type: lecture
Semester: 1-3
Credit Points: 5
Prerequisites: t.b.d
Corequisites: t.b.d
Tutorial: None

Course contents Starting from basic knowledge in Digital Communications, this course will discuss Digital Subscriber Line transmission in quite some detail, still providing insights into counterpart wireless transmission schemes, such as WLAN and DVB-T.

In order to obtain the basic foundation for digital communications, the course discusses matched filter, whitened matched filter, equalizer structures (linear, DFE, Tomlinson-Harashima) and equalizer adaptation with zero forcing and MMSE/LMS. We will apply these concepts to baseband and single-carrier transmission. Multicarrier transmission (OFDM/DMT) as the most current technology in wireline and wireless transmission will be treated thoroughly.

The wireline channel will be highlighted. Starting from channel properties of twisted pair and coaxial cables, all current wireline transmission methods will be studied in detail. Although the focus will be on twisted-pair transmission, cable modems (including hybrid fiber-coax) will be touched, as well. In xDSL and cable modems, we find almost every transmission method, like PAM, QAM, CAP, and multicarrier.

We will also discuss different MIMO (multiple-input multiple-output) approaches as spatial counterparts of equalization. MIMO is not only applied for antenna arrays but also in multipair twisted-pair transmission. Additional to modulation schemes, system and protocol aspects will be taught, as well.

300412 – RF and Microwave Component and System Design

Short Name: RFDesign
Type: lecture
Semester: 1-3
Credit Points: 5
Prerequisites: t.b.d.
Corequisites: t.b.d.
Tutorial: None

Course contents Microwave systems play a fundamental role in some of the most exciting fields in electrical engineering like modern communications wireless systems, satellite communication, radar, remote sensing, or medical applications. In contrast to the extensive use of digital technology elsewhere, microwave systems are still and will ever be predominantly analog in nature. This course focuses on RF components and systems of modern wireless telecommunications and data transmission systems. The course addresses mainly the theory of operation and prac- tical design of RF and microwave components and their implementation into RF subsystems for telecommunications. The course covers a review of transmission lines, microwave networks, and impedance match- ing. Further topics are microwave passive and active components, noise and distortion in mi- crowave systems, RF modulation techniques and RF receiver design. The course concludes with Examples of current RF applications in wireless communications, e.g. cellular telephone, broadband communication, satellite, LAN. The participants of the course are also introduced to the microwave circuit design software packages AWR Microwave Office, AWR-VSS and Sonnet em. The design of a receiver subsystem is part of the course curriculum.

Contents:

- Review of Maxwell's equations and transmission line theory, circuit models.
- Microwave network analysis: Scattering matrices and mulitport analysis techniques.
- Impedance Matching: Design of matching networks including lumped elements, stubs and transmission line sections, circuit tuning
- Passive Components: Theory of operation, practical design and implementation of power dividers, directional couplers and hybrids, resonators as well as system applications of these devices.
- Noise and distortion in RF Systems: Theory of noise in RF circuits, distortion of RF signals, dynamic range limitations, effects on channel capacity
- Active Circuits: Theory of operation, practical design and implementation of amplifiers for low-noise or power applications, detectors, mixers;
- Non-Reciprocal Devices: Theory of operation and implementation of isolators, circulators and variable attenuators and phase shifters
- Microwave Systems: Receiver and system performance calculations, RF link analysis, end-to-end microwave system (”the physical channel”) analysis.
- Applications: GSM, RF Subsystems, satellite communication

300462 – RF and Microwave Component and System Design Laboratory

Short Name:	RFD Lab
Type:	laboratory
Semester:	1-3
Credit Points:	5
Prerequisites:	t.b.d.
Corequisites:	300412
Tutorial:	None

Course contents During the lab sessions the participants apply the theoretical knowledge of microwave engineering to the design of a detailed specified microwave device. Each student designs, analyses, manufactures and tests one device. Possible devices to develop during the course are a patch antenna array, a down conversion mixer, a bandpass filter, a low-noise amplifier, a power amplifier, or a GHz oscillator. The designed devices of a group of students are cascaded to form a microwave S-band receiver.

300422 – Detection and Estimation

Short Name: Det&Est
Type: lecture
Semester: 1-3
Credit Points: 5
Prerequisites: t.b.d.
Corequisites: t.b.d.
Tutorial: None

Course contents The objective of this course is to introduce the student to the fundamental concepts of estimation and detection theory with applications to communication, control as well asradar and sonar signal processing, wheredecision-theory concepts and optimum-receiver principles, detection of random signals in noise, linear and nonlinear parameter estimation and filtering are addressed. Topics covered include: vector spaces of random variables; representations for stochastic processes, shaping and whitening filters;least squares, maximum likelihood and Bayesian parameter estimation; minimum-variance unbiased estimators and the Cramer-Rao bounds;Neyman-Pearson and Bayesian hypothesis testing; and detection and estimation from waveform observations. Advanced topics include: linear prediction and parametric and non-parametric spectrum estimation, and Wiener and Kalman filtering.

300472 – Detection and Estimation Laboratory

Short Name: Det&Est Lab
Type: lecture
Semester: 1-3
Credit Points: 5
Prerequisites: t.b.d.
Corequisites: 300422
Tutorial: None

Course contents After a brief reviewof probability theory and stochastic processes the core objective of the Laboratoryis to provide practical insights and experiences in the implementation and assessment of estimation and detection concepts theoretically considered in the accompanying course estimation and detection theory.The Laboratory work comprises 10 assignments. Each assignment consists of a theoretical and an experimental contribution. The experimental part always requires the development of Matlab programs for simulation purposes.

300441 – Wireless Communications II

Short Name: WLessCom II
Type: lecture
Semester: 1-3
Credit Points: 5
Prerequisites: 300311
Corequisites: None
Tutorial: None

Course contents Course contents: The course focus on a multiuser perspective of wireless communications and describes the 4 fundamental principles through which multiple users can access the wireless medium, namely: time-domain multiple access (TDMA), code-domain multiple access (CDMA), orthogonal frequency-domain multiple access (OFDMA) and multiple-input multiple-output (MIMO) schemes. The course is based on a selection of book chapters written by world-renowned authorities on respective techniques, specifically, Ch.4 of ”Data Networks” by Bertsekas and Gallager; Ch. 6 (and time allowing Ch. 2) of ”CDMA Principles of SS Communications” by Viterbi; Ch. 6 (and time allowing Ch. 2) of ”OFDM for Wireless Networs” by Li and Stber; and Ch.10 (and time allowing also Chs.8 and 9) of ”Fundamentals of Wireless Communications” by Tse and Viswanath. Students will learn the mathematical foundations of these multi-access techniques, their advantages and limitations, instrumenting them with the necessary know-how to conduct future research on Wireless Communications.

300551 – Wireless Communications II

Short Name: WLessCom II
Type: Seminar
Semester: 1-3
Credit Points: 5
Prerequisites: 300311
Corequisites: 300441
Tutorial: None

Course contents Course contents: In this seminar course, students will pursue the state-of-the-art of research on a selected and current topic of wireless communications. Students are expected to study and discuss classic and recent articles on the topic of their choice, implement and /or simulate the techniques (when applicable) and will be encouraged and guided towards potentially making an original contribution to the latter. Students will be required to submit simulation/implementation files to demonstrate individuality of their work, and to present on the subject of their study in class.

300451 – Speech Signal Processing

Short Name:	Speech Sign Proc
Type:	lecture
Semester:	1-3
Credit Points:	5
Prerequisites:	300321, 300201 or equivalent knowledge on probability topics
Corequisites:	None
Tutorial:	None

Course contents Speech signal processing is important in fields like intercom, telephony, VoIP, user authentication, and man-machine interfaces ranging from speech dialing and dictation to human-robot communication. The course treats the signal chain including the generation of speech, distortions due to reverberation, echo and background noise, as well as techniques to recover the original signal.

Other important topics are fundamentals of speech compression, coding, speaker identification, and automatic speech recognition including a discussion of feature vectors, vector quantizers, time warping and stochastic word modeling with HMMs.

300561 – Speech Signal Processing Laboratory

Short Name:	SSP Lab
Type:	laboratory
Semester:	1-3
Credit Points:	5
Prerequisites:	300321, 300201 or equivalent knowledge on probability topics
Corequisites:	300451
Tutorial:	None

Course contents This is a challenging extension to the lecture on speech signal processing. Based on solving several design problems, the students develop broad practical experience concerning signal-processing techniques as they relate to speech signals. Topics covered include manipulation of voice signals, phoneme and word recognition.

300491 – Convex Optimization

Short Name:	ConOpt
Type:	lecture
Semester:	1 and 3
Credit Points:	5
Prerequisites:	Calculus and linear algebra
Corequisites:	None
Tutorial:	None

Course contents Convex optimization is an important part of optimization in general. It deals with convex functions on convex domains. Convex problems are more general than linear ones but although convex optimization is about non-linear problems, optimum solutions are still globally optimal. The course is an introduction to the theory and application of convex optimization. It provides a wide variety of examples and discusses different optimization algorithms.

300493 – Optimization Lab

Short Name: OptLab
Type: Laboratory
Semester: 1 and 3
Credit Points: 5
Prerequisites: Calculus and linear algebra
Corequisites: 300491
Tutorial: None

Course contents This is a hands-on extension to the optimization lecture. Based on solving several optimization problems, students develop broad practical experience concerning implementation and application of optimization techniques. Topics covered include standard optimization tools but also genetic algorithms and learning algorithms. A large part of the lab focuses on algorithms for games (like reversi).

300501 – Computational Electromagnetics

Short Name: t.b.d.
Type: Lecture
Semester: 1-3
Credit Points: 5
Prerequisites: t.b.d.
Corequisites: t.b.d.
Tutorial: None

Course contents Recent advances in diverse engineering and scientific disciplines, such as optical and wireless communications, electronic computing, medical imaging, radar, and remote sensing, have been enabled by high-frequency electronic devices operating in the radio-frequency, microwave, and optical regimes. Although the behavior of such devices is completely described by Maxwell's equations, direct analytical solutions are only possible for very simple structures. With the advent of powerful computers, however, exact numerical solutions of Maxwell's equations have been developed, allowing highly accurate characterization of nearly arbitrary structures. Inclusion of these computational electromagnetic (CEM) techniques in powerful computer assisted design (CAD) packages allows the engineer to test and modify potential high-frequency designs conveniently on a computer, shortening the design cycle and saving valuable resources.

This course covers the most important developments in CEM, allowing students to visualize the behavior of complex devices, to understand the benefits/limitations of commercial packages, and to develop new CEM codes when needed. Although the target application is electromagnetics, the same methods for obtaining numerical solutions to partial differential equations can be applied to general problems in physics and engineering. This lecture stresses an analytical treatment of the various CEM techniques, where the lecture is complimented by a number of short assignments requiring derivations or closed-form analysis. Students interested in gaining practical experience writing and applying CEM codes are encouraged to take the Computational Electromagnetics Lab in parallel.

Concepts Covered:

- **Basic numerical techniques**: numerical integration, Monte-Carlo analysis, solutions of simultaneous equations
- **Finite-difference techniques**: Laplace equation, the wave equation, finite-difference time-domain (FDTD), absorbing boundary conditions (ABC), eigenvalue problems and mode solutions
- **Method-of-moments**: Green's functions, expansion and weighting functions, surface and volume methods
- **Variational methods**: variational calculus, functionals, weighted residual method
- **Finite-element method (FEM)**: element equations, mesh generation, solutions
- **Introduction to modern developments**: multipole techniques, ray-tracing, domain decomposition, hybrid methods

300571 – Computational Electromagnetics Laboratory

Short Name:	t.b.d.
Type:	Laboratory
Semester:	1-3
Credit Points:	5
Prerequisites:	t.b.d.
Corequisites:	300501
Tutorial:	None

Course contents This laboratory course compliments the Computational Electromagnetics (CEM) lecture, providing the student with practical experience implementing and applying CEM codes to analyze electromagnetic structures. The lab is designed to run in parallel with the lecture course, providing a more in-depth understanding of the techniques covered. Although students are encouraged to use a mathematical environment, such as MATLAB or Mathematica to complete the assignments, other programming languages are also acceptable. Example applications include capacitive structures, quasi-static transmission lines, transmission/reflection of layered media, electromagnetic scattering from conductive shells and random media, antenna radiation/reception, impedance computations, mutual coupling, optical waveguides, and wireless propagation. Near the end of the lab, the students will also select and complete a short project on a recent research topic in electromagnetics.

300322 – Advanced Random Processes

Short Name: EEARP
Type: Lecture
Semester: 1-3
Credit Points: 5
Prerequisites: 300321
Corequisites: None
Tutorial: None

Course contents This course covers advanced topics in the field of random processes and introduces the students to a number of applications to statistical signal processing such as Wiener Filtering, Kalman Filtering, and Hidden Markov Models.

300351 – Advanced Dgital Design

Short Name: ADD
Type: Lecture
Semester: 1-3
Credit Points: 5
Prerequisites: 300212 ans 300222
Corequisites: None
Tutorial: None

Course contents As the feature size of semiconductor devices continues to shrink at a staggering rate, the increasing degree of integration allows very complex digital systems to be realized on a single chip. Such systems can either be fabricated in application specific integrated circuits (ASICs) using very high scale integration (VLSI) techniques or implemented in programmable devices, such as field programmable gate arrays (FPGAs). In both cases, very large designs are partitioned into a hierarchy of logical blocks, and by adhering to a set of standard design rules, the difficulty of integrating these blocks is dramatically reduced. The most popular approach is synchronous design with register transfer level (RTL) logic, but asynchronous designs are also possible.

Although digital systems were traditionally designed at the schematic level, the current trend is toward hardware description languages (HDLs) that allow compact description of very complex hardware constructs. The appearance of sophisticated automatic hardware synthesis engines that implement logic directly from HDL have made HDLs the choice for new logic designs.

Although the target language of this class is VHDL, other languages such as Verilog and SystemC apply the same design strategies. This course stresses the importance of viewing HDL as a way of describing real hardware, and not “just another programming language”.

300362 – Coding Theory

Short Name: t.b.d
Type: Lecture
Semester: 1-3
Credit Points: 5
Prerequisites: 300201, 300202
Corequisites: None
Tutorial: None

Course contents Error correction codes (conventional codes, block codes, turbo codes etc.) and related combinatorial constructs play an important role in modern digital high data-rate transmission systems as well as storage devices. This course will focus on theory, construction, and algorithms for error correcting codes, and will highlight the application in communication systems.

300371 – Wavelets and their Applications

Short Name: Wavelet
Type: Lecture
Semester: 1-3
Credit Points: 5
Prerequisites: 300201
Corequisites: None
Tutorial: None

Course contents In signal processing, the first step is the analysis of a signal, usually in terms of frequency components or various combinations of time and frequency components. The second step is to modify some of the components of the original signal by eliminating undesirable features, or, to compress the signal for more efficient transmission and storage. Examples are audio compression, video compression, denoising, etc.. Finally, the signal is reconstituted from its (altered) components.

In this course, we will examine the following methods for signal processing:

1. Fourier series and the Fourier transform (review).
2. Windowed Fourier transforms.
3. Continuous wavelet transforms.
4. Filter banks.

5. Discrete wavelet transforms (Haar and Daubechies wavelets).

Mathematically, all of these methods are based on the decomposition of square integrable (summable) functions into orthogonal components.

300511 – Renewable Energy Systems Optimization and Management

Short Name:	Energy Systems
Type:	Lecture
Semester:	1-3
Credit Points:	5
Prerequisites:	t.b.d.
Corequisites:	t.b.d.
Tutorial:	Yes

Course contents The global challenges of Climate Change, the rapid growth of energy consumption in the emerging economies like China and India and the need for affordable and dependable electric energy in sparsely populated third world countries can only be solved by rapid deployment of energy generation and distribution systems which mainly use renewable energies. The course Renewable Energy Systems Optimization and Management addresses this need in a way not covered by most renewable energy courses. It will focus on energy system aspects rather than dealing with the nitty gritty details of the individual technologies for generation (such as Photovoltaics and Wind Energy) and distribution (such as island systems, mini grids, smart grids etc.) of energy. It will be assumed that participants have a good understanding of semiconductor technologies, electrical engineering and the basic physics that is behind the various energy generation technologies. As part of the course, the knowledge about such systems will then be used for typical design, optimization and system management tasks. To support the development these skills, in the tutorials there will be technical case studies done in teams of 4 6 team members, the results of the teams will be presented in some of the lecture slots and will be 40

Concepts and Topics covered include:

- Energy consumption: Electrical home and industrial systems, heating, transport, material production, desalination.
- Primary energy sources: Renewable Energies vs. fossil and nuclear sources.
- System Aspects which result from industrial, ecological, economic or societal, political boundary conditions
- Renewable energy generation systems by photovoltaics, wind energy, hydro energy, biogas and algae, wave energy, thermoelectric power, Organic Rankin Cycle (ORC) engines, solar thermal systems, geo energy
- ISO 50001 Energy Management and ISO 14001 Environmental Management Standards
- Energy storage systems: Batteries, capacitors, pumped hydro, compressed gas storage, hydrogen or methane conversion storage, gravity and kinetic energy storage

- Energy distribution systems: Island solution, minigrid, smart grid, national and continental grid, high voltage DC grid
- Connection to electromobility and other megatrends
- The Big Picture and the next 25 years of energy systems

2.2 Research Projects

Research is considered to be an essential part of the education at Jacobs University Bremen. Therefore Master's and integrated PhD students will be continually involved in research projects. During the first part of the respective tracks research is organized in terms of CSE Research Projects, as shown in the table below. Research within the CSE program is focused on innovative fields in Electrical Engineering, embedded into the Research Profile of the School of Engineering and Science under its interdisciplinary research area "*Information and Communication Science and Technologies*" and has strong links to the "Computer Science" and the "Physical Sciences" programs.

Course No.	Type	Title	Responsible
300461	Project	CSE Research Project I	all faculty CSE
300471	Project	CSE Research Project II	all faculty CSE
300481	Project	CSE Research Project III	all faculty CSE

Research projects are organized on an individual level. Students address a CSE professor to discuss possible topics, and, after the choice is made, are advised by her or him on the corresponding research for the time of one semester.

As an overview, the current CSE research topics cover the following areas:

- Simulation and Control of Complex Systems (A. C. Antoulas)
- Signal Processing and Coding in Communications (W. Henkel)
- Microelectronics, Photovoltaics Technology and Quality Management (W. Bergholz)
- Electronic Devices and Nanophotonics (D. Knipp)
- Digital Transmission Methods and Coding (W. Henkel)
- Wireless Communications (G. Abreu)
- Speech Signal Processing and Random Processes (M. Bode)
- Nonlinear Dynamical Systems and Neural Network Models (M. Bode)
- Networks and Protocols (J. Schoenwaelder)

2.3 The CSE Seminar

The CSE seminar is a public lecture series on Electrical Engineering. Lectures are given by faculty from the interdisciplinary research area "*Information and Communication Science and*

Technologies"[1], their research collaborators from all over the world, and especially by selected graduate students from the CSE graduate program. This colloquium gives students a unique opportunity to present their own research and gain an insight into current research topics, as well as establish contacts with external researchers.

Course No.	Type	Title	Responsible
300431	Seminar	CSE Seminar I	all faculty CSE
300432	Seminar	CSE Seminar II	all faculty CSE
300531	Seminar	CSE Seminar III	all faculty CSE
300541	Seminar	CSE Seminar IV	all faculty CSE