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

Communication and Sensor Systems

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)
Communication and Sensor Systems
Date: 01.09.2021

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1 Fundamentals

Module name Digital Signal Processing					
Module Nr. 18-zo-2060	Credit Points 6 CP	Workload 180 h	Self study 120 h	Duration 1	Cycle offered WiSe
Language English			Module owner Prof. Dr.-Ing. Abdelhak Zoubir		
1	Content 1) Discrete-Time Signals and Linear Systems – Sampling and Reconstruction of Analog Signals 2) Digital Filter Design – Filter Design Principles; Linear Phase Filters; Finite Impulse Response Filters; Infinite Impulse Response Filters; Implementations 3) Digital Spectral Analysis - Random Signals; Nonparametric Methods for Spectrum Estimation; Parametric Spectrum Estimation; Applications; 4) Kalman Filter				
2	Learning objectives / Learning Outcomes Students will understand basic concepts of signal processing and analysis in time and frequency of deterministic and stochastic signals. They will have first experience with the standard software tool MATLAB.				
3	Recommended prerequisite for participation Deterministic signals and systems theory				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> Module Examination (Technical Examination, Written Examination, Duration: 180 min, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> Module Examination (Technical Examination, Written Examination, Weighting: 100%) 				
6	Usability of this module BSc ETiT, Wi-ETiT, MSc Medizintechnik				
7	Grade bonus compliant to §25 (2)				
8	References Course manuscript Additional References: <ul style="list-style-type: none"> A. Oppenheim, W. Schafer: Discrete-time Signal Processing, 2nd ed. J.F. Böhme: Stochastische Signale, Teubner Studienbücher, 1998 				
Courses					
	Course Nr. 18-zo-2060-vl	Course name Digital Signal Processing			
	Instructor Prof. Dr.-Ing. Abdelhak Zoubir, M.Sc. Martin Gölz			Type Lecture	SWS 3

	Course Nr. 18-zo-2060-ue	Course name Digital Signal Processing		
	Instructor Prof. Dr.-Ing. Abdelhak Zoubir, M.Sc. Martin Gözl		Type Practice	SWS 1

Module name Microwave Engineering II					
Module Nr. 18-jk-2130	Credit Points 6 CP	Workload 180 h	Self study 120 h	Duration 1	Cycle offered WiSe
Language English			Module owner Prof. Dr.-Ing. Rolf Jakoby		
1	Content Part 1 Passive microwave components: Calculation of the properties of simple passive components (microstrip line, filter, resonator, capacitor, inductance) for MMICs Part 2 Active microwave components: * Semiconductor material systems: properties, fabrication and requirements * Contacts to semiconductor devices: properties and characteristics * Charge carrier transport: characteristics and scattering processes * Field Effect Transistor (FET) and heterostructure transistors (HEMTs) Part 3 Active microwave circuits (main part): * Wave parameter and S-parameter * FET amplifier: operation, equivalent circuit, gain, matching circuit, stability and circuit implementation * Oscillator design * Mixer design Applications of these circuits range from communication systems such as cell phones to satellite transceivers as well as high-frequency sources up to Terahertz.				
2	Learning objectives / Learning Outcomes Students will gain knowledge on the physics of microwave waveguides, resonators, microwave components (passive and active) as well as microwave circuits.				
3	Recommended prerequisite for participation Desirable: Introduction to Electrodynamics, Microwave Engineering I				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> Module Examination (Technical Examination, Written Examination, Duration: 90 min, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> Module Examination (Technical Examination, Written Examination, Weighting: 100%) 				
6	Usability of this module MSc ETiT, MSc iCE, MSc IST, Wi-ETiT				
7	Grade bonus compliant to §25 (2)				
8	References Script and slides will be handed out. Literature will be recommended in the lecture.				
Courses					
	Course Nr. 18-jk-2130-vl	Course name Microwave Engineering II			
	Instructor PD Dr.-Ing. Oktay Yilmazoglu			Type Lecture	SWS 3
	Course Nr. 18-jk-2130-ue	Course name Microwave Engineering II			
	Instructor PD Dr.-Ing. Oktay Yilmazoglu			Type Practice	SWS 1

Module name Information Theory II					
Module Nr. 18-pe-2010	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 lecture course is devoted to advances of network information theory. Outline: overview of Shannon capacity, outage and ergodic capacity, capacity of channels with state, capacity of Gaussian vector channels, capacity regions of multi-user channels, capacity regions of multiple-access and broadcast fading channels, interference channel, relay channel, multiuser bounds, multi-user diversity, wiretap channel, secrecy rate and physical layer security.				
2	Learning objectives / Learning Outcomes Students will understand advanced concepts and strategies in network information theory.				
3	Recommended prerequisite for participation Knowledge of basic communication theory				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> Module Examination (Technical Examination, Optional, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> Module Examination (Technical Examination, Optional, Weighting: 100 %) 				
6	Usability of this module MSc ETiT, BSc iST, MSc Wi-ETiT, MSc iCE, BSc/MSc CE				
7	Grade bonus compliant to §25 (2)				
8	References 1. Abbas El Gamal and Young-Han Kim, Network Information Theory, Cambridge, 2011. 2.. T.M. Cover and J.A. Thomas, Elements of Information Theory, Wiley Sons, 1991. 3.. D. Tse and P. Vishwanath, Fundamentals of Wireless Communications, Cambridge University Press, 2005.				
Courses					
	Course Nr. 18-pe-2010-vl	Course name Information Theory II			
	Instructor Prof. Dr.-Ing. Marius Pesavento			Type Lecture	SWS 3
	Course Nr. 18-pe-2010-ue	Course name Information Theory II			
	Instructor Prof. Dr.-Ing. Marius Pesavento			Type Practice	SWS 1

Module name Communication Technology II					
Module Nr. 18-kl-2010	Credit Points 4 CP	Workload 120 h	Self study 75 h	Duration 1	Cycle offered WiSe
Language English			Module owner Prof. Dr.-Ing. Anja Klein		
1	Content linear and nonlinear digital modulation schemes, optimum receivers for AWGN channels, error probability, channel capacity, channel models, channel estimation and data detection for multipath channels, multicarrier schemes, OFDM				
2	Learning objectives / Learning Outcomes After completion of the lecture, students possess: <ul style="list-style-type: none"> • the ability of comparing, evaluating, classifying and analyzing linear and nonlinear modulation schemes by means of signal space representations; • the ability to understand, describe and analyze the influence of AWGN on the signal; • the ability to understand and derive optimum receivers in case of AWGN channels; • the ability to understand, describe and analyze the influence of multipath propagation on the signal; • the ability to describe the influence of a multipath channel mathematically (channel model) and estimate the multipath channel at the receiver; • the knowledge of equalizing the received signal in order to undo the influence of multipath propagation, as well as the ability to derive and design several equalizer structures; • the ability to analyze and evaluate the properties and application areas of multicarrier transmission systems, e.g. OFDM-systems; • the ability to design and evaluate the system parameters of multicarrier schemes for the application in realistic mobile radio scenarios; 				
3	Recommended prerequisite for participation Electrical Engineering I and II, Deterministische Signale und Systeme, Stochastische Signale und Systeme, Communication Technology I, Basics of Telecommunication, Mathematics I to IV				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Written Examination, Duration: 90 min, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Written Examination, Weighting: 100%) 				
6	Usability of this module MSc ETIT, MSc Wi-ETiT, MSc CE, MSc iCE, MSc iST, MSc MEC				
7	Grade bonus compliant to §25 (2)				
8	References will be announced in the lecture				
Courses					
	Course Nr. 18-kl-2010-vl	Course name Communication Technology II			
	Instructor Prof. Dr.-Ing. Anja Klein			Type Lecture	SWS 2



	Course Nr. 18-kl-2010-ue	Course name Communication Technology II		
	Instructor Prof. Dr.-Ing. Anja Klein		Type Practice	SWS 1

Module name Laboratory Communication and Sensor Systems					
Module Nr. 18-kt-2010	Credit Points 5 CP	Workload 150 h	Self study 105 h	Duration 1	Cycle offered WiSe
Language German and English			Module owner Prof. Dr.-Ing. Rolf Jakoby		
1	Content The student communications lab consist of 7 fundamental experiments out of the field of Communication Engineering: Mobile Radio Channel + Diversity (SW) Signal Detection and Parameter Estimation (Matlab) Digital Modulation (HW) Coding (SW) Parasitic Effects in Passive RF Devices (SW) RF FET Amplifier (HW) Polarization of Light (HW) Antennas: Fields and Impedance (HW)				
2	Learning objectives / Learning Outcomes The students are guided to acquaint themselves with given topics. They learn to perform prepared experiments within a defined frame and minute, analyze and discuss the results. In this training the fundamentals of free scientific work are practiced.				
3	Recommended prerequisite for participation Fundamentals of: <ul style="list-style-type: none"> • Communications • Microwave Engineering • Digital Signal Processing 				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Optional, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Optional, Weighting: 100 %) 				
6	Usability of this module MSc ETiT, MSc iCE, Wi-ETiT				
7	Grade bonus compliant to §25 (2)				
8	References A description of experiments is offered. It can be bought from Mr. Ziemann (S306/409) or being loaded from the WEB page.				
Courses					
	Course Nr. 18-kt-2010-pr	Course name Laboratory Communication and Sensor Systems			
	Instructor Prof. Dr.-Ing. Rolf Jakoby, Prof. Dr.-Ing. Anja Klein, Dr.-Ing. Martin Schüßler, Prof. Dr.-Ing. Abdelhak Zoubir, Prof. Dr.-Ing. Marius Pesavento, Prof. Dr. rer. nat. Sascha Preu, Prof. Dr.-Ing. Herbert De Gersem			Type Internship	SWS 3

2 Optional Modules

2.1 KTS I: Lectures

Module name Adaptive Filters					
Module Nr. 18-zo-2010	Credit Points 6 CP	Workload 180 h	Self study 120 h	Duration 1	Cycle offered SoSe
Language German and English			Module owner Prof. Dr.-Ing. Abdelhak Zoubir		
1	<p>Content</p> <p>Theory:</p> <ol style="list-style-type: none"> 1) Derivation of optimal filters for stochastic processes, e.g. Wiener filter or linear prediction filter based on suitable cost functions. 2) Elaboration of adaptive procedures, which allow to iteratively approach the optimal solution for non-stationary signals in non-stationary environments. Here, the adaptive procedures such as NLMS adaptation, affine projection, and the RLS algorithm are derived and extensively analysed. 3) Analysis of the adaptation behaviour and control procedures of adaptive filters based on the NLMS procedure. 4) Derivation and analysis of the Kalman filter as optimal filter for non-stationary input signals. 5) Procedures for the decomposition of signals into sub-bands for the realization of optimal filters in the frequency domain, e.g. noise reduction procedures. <p>Applications:</p> <p>Parallel to the theory, practical applications are explained. As an example for the Wiener filter, the acoustic noise reduction procedures are explained. Acoustic echo cancellation and feedback cancellation are given as examples for adaptive filters. Furthermore beamforming approaches are introduced.</p> <p>It is planned to offer an excursion to Siemens Audiology Engineering Group in Erlangen.</p> <p>In the 4 to 5 exercises, some content of the lecture will be implemented in MATLAB which allows the students to get familiar with practical realizations of the theoretical procedures.</p>				
2	<p>Learning objectives / Learning Outcomes</p> <p>During the lecture, basics of adaptive filters are taught. The necessary algorithms are derived, interpreted and applied to examples of speech, audio and video processing.</p> <p>Based on the content of the lecture you are able to apply adaptive filters to real practical applications.</p> <p>For the admission to the exam you give a talk about a topic in the domain of adaptive filters chosen by you. This will allow you to acquire the know-how to read and understand scientific literature, familiarize yourself with an unknown topic and present your knowledge, such as it will be certainly required from you in your professional life as an engineer.</p>				
3	<p>Recommended prerequisite for participation</p> <p>Digital Signal Processing</p>				
4	<p>Form of examination</p> <p>Module Final Examination:</p> <ul style="list-style-type: none"> • Module Examination (Technical Examination, Optional, Standard Grading System) 				
5	<p>Grading</p> <p>Module Final Examination:</p> <ul style="list-style-type: none"> • Module Examination (Technical Examination, Optional, Weighting: 100 %) 				
6	<p>Usability of this module</p>				

	MSc ETiT		
7	Grade bonus compliant to §25 (2)		
8	References Slides of the lecture. Literature: <ul style="list-style-type: none"> • E. Hänsler, G. Schmidt: Acoustic Echo and Noise Control, Wiley, 2004 (Textbook of this course); • S. Haykin: Adaptive Filter Theory, Prentice Hall, 2002; • A. Sayed: Fundamentals of Adaptive Filtering, Wiley, 2004; • P Vary, U. Heute, W. Hess: Digitale Sprachsignalverarbeitung, Teubner, 1998 (in German) 		
Courses			
	Course Nr. 18-zo-2010-vl	Course name Adaptive Filters	
	Instructor Prof. Dr.-Ing. Henning Puder		Type Lecture
			SWS 3
	Course Nr. 18-zo-2010-ue	Course name Adaptive Filters	
	Instructor Prof. Dr.-Ing. Henning Puder		Type Practice
			SWS 1

Module name Acoustics I					
Module Nr. 18-se-2010	Credit Points 3 CP	Workload 90 h	Self study 60 h	Duration 1	Cycle offered WiSe
Language German			Module owner Prof. (em.) Dr. Gerhard Sessler		
1	Content 1. Basic concepts of vibrations; impedance; electromechanical analogues, 2. sound field: wave equation; plane waves; sound absorption and dispersion; room absorption, 3. sound radiation: spherical, dipole, and cardioid source; linear arrays; circular piston membrane, 4. physiological and psychological acoustics: hearing organ; acoustic perception; speech production and speech intelligibility, 5. electroacoustic transducers; reciprocity relations; electrostatic, piezoelectric, electrodynamic, and other transducers; directional microphones; microphone calibration, 6. acoustic measuring methods: measurements of fundamental acoustic quantities; acoustic testing chambers; vibration measurements, 7. analogical and digital sound recording: digital and analogical disc and magnetic tape methods; movie sound, 8. ultrasound and hypersound: generation and detection; applications				
2	Learning objectives / Learning Outcomes After completion of the lecture, students possess: <ul style="list-style-type: none"> • the understanding of basic phenomena of generation, propagation, reception, storage and reproduction of sound; • the ability to analyze acoustic components and systems; • the ability to judge and design applications in the audio and ultrasonic frequency ranges. 				
3	Recommended prerequisite for participation Electrical Engineering I and II, Mathematics I to IV, Physics, Basics of Telecommunication				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Oral Examination, Duration: 30 min, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Oral Examination, Weighting: 100%) 				
6	Usability of this module MSc ETiT				
7	Grade bonus compliant to §25 (2)				
8	References H. Kuttruff, Akustik (Hilzel 2004); M. Zollner u. E. Zwicker, Elektroakustik, 3. Auflage (Springer, corrected reprint 1998); H. Fastl, E. Zwicker, Psychoacoustics (Springer 2005); J. Blauert, Communication Acoustics (Springer 2005); R. Lerch, G. Sessler u. D. Wolf, Technische Akustik (Springer 2009)				
Courses					
	Course Nr. 18-se-2010-vl	Course name Acoustics I			
	Instructor Prof. (em.) Dr. Gerhard Sessler, Prof. Dr. Mario Kupnik			Type Lecture	SWS 2

Module name Antennas and Adaptive Beamforming					
Module Nr. 18-jk-2020	Credit Points 6 CP	Workload 180 h	Self study 120 h	Duration 1	Cycle offered WiSe
Language English			Module owner Prof. Dr.-Ing. Rolf Jakoby		
1	Content Overview of most important antenna parameters types as well as their applications. Fundamental theories: Fourier transform for far-field pattern calculations, antenna modeling techniques, antenna synthesis methods, image theory, determination of field regions of line sources, of the average radiated power density and power, directivity and gain. Antennas as key elements in power budgets of radio links, introducing the effective aperture of an antenna, deriving the relation between gain and effective aperture. Array antennas are a key hardware for beamforming and smart antenna systems: fundamentals of phased-scanning arrays, non-uniformly excited, equally spaced linear arrays, multi-dimensional planar arrays and mutual coupling effects. Wire antennas: still the most prevalent of all antenna forms, relatively simple in concept, easy to construct, very inexpensive. Antenna radiation fields and antenna parameters for different types of antennas are derived from Maxwell's equations, applied for aperture antennas (horns, lenses or reflector antennas) and printed antennas (microstrip-patch and coplanar-slot antennas) Some basic numerical calculation methods: integral equation methods in the time and frequency domain, physical optics and uniform theory of diffraction are briefly summarized and compared for antennas and scattering problems. Smart antennas in communication and radar systems, with focus on beam steering and adaptive beamforming.				
2	Learning objectives / Learning Outcomes Students will know basic antenna parameters: pattern, gain, directivity, half-power beamwidth, side-lobe-level, efficiency and input impedance to compare, assess and evaluate different antennas for various applications and operating frequencies. The antenna field regions, reactive near-field, near-field and far-field, can be differentiated and the far-field pattern of an antenna can be determined from given current distributions along the antenna by using Fourier transformation or integral solutions with distributed ideal dipoles as basic elements (antenna analysis). To assess in general physical requirements, constraints and limitations of antennas, students can use fundamental antenna theory: impedance matching techniques, antenna modeling and far-field pattern analysis, antenna synthesis, image theory and fundamental limits of electrically small antennas. After being incorporated into the different adaptive beamforming techniques, the array theory enables the student to design antenna systems that are assembled of a certain number of separate elements, feeding network, beamforming network etc. for phased-scanning or smart antennas in communications and sensing. Moreover, students are able to determine, analyze and evaluate the most important classes of antennas in wireless technology for many applications, operating frequencies, desired requirements or practical constraints: (1.) wire-dipole antennas, (2.) planar antennas (microstrip, dipole and slot antennas), (3.) aperture antennas (horn antennas, parabolic reflector antennas, lens antennas, Cassegrain and Gregorian double-reflector configurations), (4.) broadband and frequency-independent antennas (V antennas, biconical antennas, helical antennas, spiral and log-periodic antennas).				
3	Recommended prerequisite for participation Fundamentals of Communications, Microwave Engineering 1				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> Module Examination (Technical Examination, Optional, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> Module Examination (Technical Examination, Optional, Weighting: 100 %) 				
6	Usability of this module BSc ETiT, MSc ETiT, MSc iCE, Wi-ETiT				
7	Grade bonus compliant to §25 (2)				

8	References		
	Jakoby, Skriptum Antennas and Adaptive Beamforming, wird am Beginn der Vorlesung verkauft und kann danach im FG-Sekretariat erworben werden		
Courses			
	Course Nr. 18-jk-2020-vl	Course name Antennas and Adaptive Beamforming	
	Instructor Prof. Dr.-Ing. Rolf Jakoby, M.Sc. Matthias Nickel	Type Lecture	SWS 3
	Course Nr. 18-jk-2020-ue	Course name Antennas and Adaptive Beamforming	
	Instructor Prof. Dr.-Ing. Rolf Jakoby, M.Sc. Matthias Nickel	Type Practice	SWS 1

Module name Convex Optimization in Signal Processing and Communications					
Module Nr. 18-pe-2020	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 introduces the basic theory of convex optimization and illustrates its use with many recent applications in communication systems and signal processing. Outline: Introduction, convex sets and convex functions, convex problems and classes of convex problems (LP, QP, SOCP, SDP, GP), Lagrange duality and KKT conditions, basics of numerical algorithms and interior point methods, optimization tools, convex inner and outer approximations for non convex problems, sparse optimization, distributed optimization, mixed integer linear and non-linear programming, applications.				
2	Learning objectives / Learning Outcomes Students will learn the basic theory of convex optimization and its applications.				
3	Recommended prerequisite for participation Knowledge in linear algebra and the basic concepts of signal processing and communications.				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> Module Examination (Technical Examination, Written/Oral Examination, Duration: 120 min, Standard Grading System) The examination takes place in form of a written exam (duration: 120 minutes). If one can estimate that less than 14 students register, the examination will be an oral examination (duration: 20 min.). The type of examination will be announced in the beginning of the lecture.				
5	Grading Module Final Examination: <ul style="list-style-type: none"> Module Examination (Technical Examination, Written/Oral Examination, Weighting: 100%) 				
6	Usability of this module MSc ETiT				
7	Grade bonus compliant to §25 (2)				
8	References 1. S. Boyd and L. Vandenberghe, Convex Optimization, Cambridge University Press, 2004. (online Verfügbar: http://www.stanford.edu/~boyd/cvxbook/) 2. D. P Bertsekas, Nonlinear Programming, Athena Scientific, Belmont, Massachusetts, 2nd Ed., 1999. 3. Daniel P Palomar and Yonina C. Eldar, Convex Optimization in Signal Processing and Communications, Cambridge University Press, 2009.				
Courses					
	Course Nr. 18-pe-2020-vl	Course name Convex Optimization in Signal Processing and Communications			
	Instructor Prof. Dr.-Ing. Marius Pesavento			Type Lecture	SWS 2
	Course Nr. 18-pe-2020-ue	Course name Convex Optimization in Signal Processing and Communications			
	Instructor Prof. Dr.-Ing. Marius Pesavento			Type Practice	SWS 1

	Course Nr. 18-pe-2020-pr	Course name Convex Optimization in Signal Processing and Communications Lab		
	Instructor Prof. Dr.-Ing. Marius Pesavento		Type Internship	SWS 1

Module name MIMO - Communication and Space-Time-Coding					
Module Nr. 18-pe-2030	Credit Points 4 CP	Workload 120 h	Self study 75 h	Duration 1	Cycle offered WiSe
Language English			Module owner Prof. Dr.-Ing. Marius Pesavento		
1	Content This lecture course introduces the principles of space-time and multiple-input multiple-output (MIMO) communications. Outline: Motivation and background; overview of space-time and MIMO communications; fading MIMO channel models, MIMO information theory, receive and transmit diversity; channel estimation, MIMO detectors, Alamouti space-time block code, orthogonal space-time block codes; linear dispersion codes; coherent and non-coherent decoders, differential space-time block coding; MIMO with limited feedback, Multiantenna- and multiuser diversity, BER performance analysis, MIMO in modern wireless communication networks, multicell and multiuser MIMO (coordinated multipoint).				
2	Learning objectives / Learning Outcomes Students will understand modern MIMO communications and existing space-time coding techniques.				
3	Recommended prerequisite for participation Knowledge of basic communication theory and basic information theory.				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> Module Examination (Technical Examination, Optional, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> Module Examination (Technical Examination, Optional, Weighting: 100 %) 				
6	Usability of this module MSc ETiT				
7	Grade bonus compliant to §25 (2)				
8	References <ol style="list-style-type: none"> A.B.Gershman and N.D.Sidiropoulos, Editors, Space-Time Processing for MIMO Communications, Wiley and Sons, 2005. E.G.Larsson and PStoica, Space-Time Block Coding for Wireless Communications, Cambridge University Press, 2003; A.Paulraj, R.Nabar, and D.Gore, Introduction to Space-Time Wireless Communications, Cambridge University Press, 2003. Lin Bai and Jinho Choi, Low Complexity MIMO detectors, Springer, 2012. Howard Huang, Constantinos B. Papadias, and Sivarama Venkatesan, MIMO Communication for Cellular Networks, Springer, 2012. 				
Courses					
	Course Nr. 18-pe-2030-vl	Course name MIMO - Communication and Space-Time-Coding			
	Instructor Prof. Dr.-Ing. Marius Pesavento			Type Lecture	SWS 2
	Course Nr. 18-pe-2030-ue	Course name MIMO - Communication and Space-Time-Coding			
	Instructor Prof. Dr.-Ing. Marius Pesavento, M.Sc. Fabio Nikolay, M.Sc. Tianyi Liu			Type Practice	SWS 1

Module name Mobile Communications					
Module Nr. 18-kl-2020	Credit Points 6 CP	Workload 180 h	Self study 120 h	Duration 1	Cycle offered SoSe
Language English			Module owner Prof. Dr.-Ing. Anja Klein		
1	Content The lecture covers aspects of mobile communication systems with particular focus on the physical layer. Mobile radio systems, services, market, standardization duplex and multiple access techniques, cellular concept mobile radio channel, deterministic and stochastic description modulation schemes code division multiple access (CDMA) orthogonal frequency division multiplexing (OFDM) optimum and suboptimum receiver techniques cellular radio capacity and spectrum efficiency diversity methods multiple input multiple output (MIMO) systems power control and handover architecture of mobile radio systems				
2	Learning objectives / Learning Outcomes After completion of the lecture, students possess <ul style="list-style-type: none"> • a profound understanding of physical layer aspects ,e.g., transmission schemes, multiple access schemes of mobile communication systems, duplex schemes, multi carrier schemes, receiver techniques, multi antenna schemes • a profound understanding of signal propagation in mobile radio systems (mobile radio channel) • the ability to understand and solve problems of the field of the physical layer • the ability to compare, analyse and evaluate different system concepts • knowledge on modelling of the transmission properties of the mobile radio channel 				
3	Recommended prerequisite for participation Deterministic Signals and Systems, Communication Technology I, Mathematics I to IV				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Written Examination, Duration: 90 min, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Written Examination, Weighting: 100%) 				
6	Usability of this module MSc ETIT, MSc Wi-ETiT, MSc CE, MSc iCE, MSc iST, MSc MEC				
7	Grade bonus compliant to §25 (2)				
8	References will be announced in the lecture				
Courses					

	Course Nr. 18-kl-2020-vl	Course name Mobile Communications		
	Instructor Prof. Dr.-Ing. Anja Klein		Type Lecture	SWS 3
	Course Nr. 18-kl-2020-ue	Course name Mobile Communications		
	Instructor Prof. Dr.-Ing. Anja Klein		Type Practice	SWS 1

Module name Digital Signal Processing Lab					
Module Nr.	Credit Points	Workload	Self study	Duration	Cycle offered
18-zo-2030	6 CP	180 h	135 h	1	WiSe/SoSe
Language English			Module owner Prof. Dr.-Ing. Abdelhak Zoubir		
1	Content 1) Introduction to MATLAB 2) Discrete-Time Signals and Systems 3) Frequency-Domain Analysis using the DFT 4) Digital FIR Filter Design 5) IIR Filter Design using Analog Prototypes 6) Nonparametric Spectrum Estimation 7) Parametric Spectrum Estimation.				
2	Learning objectives / Learning Outcomes The students are able to apply skills acquired in the course Digital Signal Processing. These include the design of digital FIR and IIR filters as well as non-parametric and parametric spectrum estimation. Students learn how MATLAB is used to apply theoretical concepts and to demonstrate signal processing techniques by using hands-on application examples.				
3	Recommended prerequisite for participation Deterministic signals and systems theory				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> Module Examination (Study Achievement, Written Examination, Duration: 120 min, Standard Grading System) Exam (Duration: 120 min) and a Report (Lab Reports), Details will be announced at the beginning of the lecture.				
5	Grading Module Final Examination: <ul style="list-style-type: none"> Module Examination (Study Achievement, Written Examination, Weighting: 100%) 				
6	Usability of this module MSc ETiT, MSc iCE				
7	Grade bonus compliant to §25 (2)				
8	References Lab manual				
Courses					
	Course Nr. 18-zo-2030-pr	Course name Digital Signal Processing Lab			
	Instructor Prof. Dr.-Ing. Abdelhak Zoubir			Type Internship	SWS 3

Module name Radar Techniques					
Module Nr. 18-jk-2040	Credit Points 3 CP	Workload 90 h	Self study 60 h	Duration 1	Cycle offered WiSe
Language German			Module owner Prof. Dr.-Ing. Rolf Jakoby		
1	Content First, there will be an introduction of different radar techniques, describing their concepts and principles, their applications and the operating frequency ranges. In a historical survey, the radar ranges and propagation effects will be dealt with. In the second part, various primary and secondary radar techniques will be investigated in detail, including specific techniques of radar signal processing and -analysis.				
2	Learning objectives / Learning Outcomes Students will know about concepts and principles to detect objects as well as to determine the angular position and range of objects. They learn about the functional principles of various radar systems, including signal processing. They will understand the major physical propagation effects.				
3	Recommended prerequisite for participation Fundamentals of Communications, Microwave Engineering I				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Oral Examination, Duration: 30 min, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Oral Examination, Weighting: 100%) 				
6	Usability of this module MSc ETiT, MSc iCE, MSc Wi-ETiT				
7	Grade bonus compliant to §25 (2)				
8	References Slides, Latest Publications and Books				
Courses					
	Course Nr. 18-jk-2040-v1	Course name Radar Techniques			
	Instructor PD Dr. habil. Holger Maune			Type Lecture	SWS 2

Module name Speech and Audio Signal Processing					
Module Nr. 18-zo-2070	Credit Points 6 CP	Workload 180 h	Self study 120 h	Duration 1	Cycle offered WiSe
Language German			Module owner Prof. Dr.-Ing. Abdelhak Zoubir		
1	Content Algorithms of speech and audio signal processing: Introduction to the models of speech and audio signals and basic methods of audio signal processing. Procedures of codebook based processing and audio coding. Beamforming for spatial filtering and noise reduction for spectral filtering. Cepstral filtering and fundamental frequency estimation. Mel-filterind cepstral coefficients (MFCCs) as basis for speaker detection and speech recognition. Classification methods based on GMM (Gaussian mixture models) and speech recognition with HMM (Hidden markov models). Introduction to the methods of music signal processing, e.g. Shazam-App or beat detection.				
2	Learning objectives / Learning Outcomes Based on the lecture you acquire an advanced knowledge of digital audio signal processing mainly with the help of the analysis of speech signals. You learn about different basic and advanced methods of audio signal processing, to range from the theory to practical applications. You will acquire knowledge about algorithms such as they are applied in mobile telephones, hearing aids, hands-free telephones, and man-machine-interfaces (MMI). The exercise will be organized as a talk given by each student with one self-selected topic of speech and audio processing. This will allow you to acquire the know-how to read and understand scientific literature, familiarize with an unknown topic and present your knowledge, such as it will be certainly required from you in your professional life as an engineer.				
3	Recommended prerequisite for participation Knowlegde about satistical signal processing is required (lecture „Digital Signal Processing“). Desired – but not mandatory – is knowledge about adaptive filters.				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> Module Examination (Technical Examination, Written/Oral Examination, Duration: 90 min, Standard Grading System) Seminar presentation: Scientific talk about a topic in the field of “Speech and Audio Signal Processing”, single (duration 10-15 min) or in groups of two students (15-20 min) or in a group of 20 students and more a written exam (duration 90 min)				
5	Grading Module Final Examination: <ul style="list-style-type: none"> Module Examination (Technical Examination, Written/Oral Examination, Weighting: 100 %) 				
6	Usability of this module MSc ETiT, MSc iCE				
7	Grade bonus compliant to §25 (2)				
8	References Slides (for further details see homepage of the lecture)				
Courses					
	Course Nr. 18-zo-2070-v1	Course name Speech and Audio Signal Processing			
	Instructor Prof. Dr.-Ing. Henning Puder			Type Lecture	SWS 2

	Course Nr. 18-zo-2070-ue	Course name Speech and Audio Signal Processing		
	Instructor Prof. Dr.-Ing. Henning Puder		Type Practice	SWS 1
	Course Nr. 18-zo-2070-se	Course name		
	Instructor Prof. Dr.-Ing. Henning Puder		Type Seminar	SWS 1

Module name Computational Methods for Systems and Synthetic Biology					
Module Nr.	Credit Points	Workload	Self study	Duration	Cycle offered
18-kp-2080	4 CP	120 h	75 h	1	SoSe
Language English			Module owner Prof. Dr. techn. Heinz Köppl		
1	<p>Content</p> <p>The course covers mathematical methods used in the area of systems and synthetic biology. On the one hand it deals with practical modeling of molecular processes but also with theoretical investigations that reveal general properties of those processes. The course follows a microscopic approach and introduces those processes using probabilistic methods. For that, necessary prerequisites are recapitulated, such as definition of Markov processes in different spaces and their properties. With this background, the dynamics of stochastic reaction kinetics in terms of population models is investigated. Limiting cases are introduced, such as the diffusion approximation or the deterministic approximation (fluid approximations) of those systems. Often methods from statistical physics are applied. Numerical methods for solving the corresponding Fokker-Planck and Master equations are discussed. For the limiting case of a deterministic approximation, traditional methods for the stability analysis of nonlinear differential equations are introduced and methods are discussed that just rely on the topology of the reaction network to determine stability properties. In this context, a derivation of the moment dynamics and approximation methods based on moment closure are given. Connections to queueing theory models are shown.</p> <p>Furthermore, the question is addressed of how the introduced dynamical models are calibrated to data from molecular biology. For that, general methods of statistical inference from statistics and of machine learning from computer science are discussed and specialized algorithms for the considered system class are presented. Additionally, a short introduction to the theory of nonlinear optimal filtering is given and special cases such as hidden Markov models are discussed.</p> <p>Beyond reaction kinetics, the course provides a basic introduction to the modeling and numerical methods used in molecular dynamics. Newtonian multi-body simulations and classical potentials and their use in molecular dynamics are discussed. Most of the topics in this course are introduced through practical examples from applied modeling in the domain of systems biology. The applicability of the respective methods in synthetic biology is highlighted.</p>				
2	<p>Learning objectives / Learning Outcomes</p> <p>Students that successfully passed that course should be able to perform practical modeling of molecular processes and to determine dynamical properties of model using mathematical methods. It relies on the understanding of the following topics:</p> <ul style="list-style-type: none"> • Mathematical abstraction of molecular mechanisms • General properties of stochastic processes • Approximation methods for Markovian population models • Stability analysis of nonlinear differential equations • Numerical methods for solving/simulating stochastic systems <p>System identification/machine learning for stochastic systems</p>				
3	<p>Recommended prerequisite for participation</p> <p>Basic knowledge of programming, Matlab.</p>				
4	<p>Form of examination</p> <p>Module Final Examination:</p> <ul style="list-style-type: none"> • Module Examination (Technical Examination, Optional, Standard Grading System) 				
5	<p>Grading</p> <p>Module Final Examination:</p> <ul style="list-style-type: none"> • Module Examination (Technical Examination, Optional, Weighting: 100 %) 				
6	<p>Usability of this module</p> <p>MSc ETiT, MSc iST, MSc Wi-ETiT, MSc MEC</p>				

7	Grade bonus compliant to §25 (2)		
8	References http://www.bcs.tu-darmstadt.de/		
Courses			
	Course Nr. 18-kp-2080-vl	Course name Computational Methods for Systems and Synthetic Biology	
	Instructor Prof. Dr. techn. Heinz Köppl		Type Lecture
			SWS 2
	Course Nr. 18-kp-2080-ue	Course name Computational Methods for Systems and Synthetic Biology	
	Instructor Prof. Dr. techn. Heinz Köppl		Type Practice
			SWS 1

Module name Sensor Array Processing and Adaptive Beamforming					
Module Nr. 18-pe-2060	Credit Points 4 CP	Workload 120 h	Self study 75 h	Duration 1	Cycle offered SoSe
Language English			Module owner Prof. Dr.-Ing. Marius Pesavento		
1	Content This lecture course introduces the principles of modern sensor array processing and adaptive beamforming. Outline: Motivation and background; applications, narrowband and wideband signal model <u>Direction-of-arrival estimation (DoA):</u> traditional methods based on beamforming, super resolution methods, Maximum-Likelihood methods, Subspace based methods, MUSIC, ESPRIT, MODE, root-MUSIC, multidimensional source localization, beamspace processing, array interpolation, partly calibrated arrays, wideband DOA estimation, spatial smoothing, forward-backward averaging, redundancy averaging, correlated sources, minimum redundancy arrays, compressed sensing and sparse reconstruction based DoA estimation, performance bounds <u>Adaptive beamforming:</u> Point-source model, covariance model, Wiener-Hopf equation, Minimum Variance Distortionless Response (MVDR) beamformer, Capon Beamformer, sample matrix inversion, signal self-nulling effect, robust adaptive beamforming, Hung-Turner projection beamformer, Generalized Sidelobe canceller beamformer, Eigenspace-based beamformer, non-stationary environments, modern convex optimization based beamforming, worst-case based beamforming, multiuser beamforming.				
2	Learning objectives / Learning Outcomes Students will standard and modern sensor array processing techniques for source localization and transmit/receive beamforming				
3	Recommended prerequisite for participation Knowledge in linear algebra.				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Optional, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Optional, Weighting: 100 %) 				
6	Usability of this module BSc / MSc etit, BSc / MSc WI-etit, MSc MEC, MSc iST, MSc iCE				
7	Grade bonus compliant to §25 (2)				
8	References <ul style="list-style-type: none"> • Academic Press Library in Signal Processing: Volume 3 Array and Statistical Signal Processing Edited by Rama Chellappa and Sergios Theodoridis, Section 2, Edited by Mats Viberg, Pages 457-967 (2014) <ul style="list-style-type: none"> – Chapter 12 - Adaptive and Robust Beamforming, Sergiy A. Vorobyov, Pages 503-552 – Chapter 14 - DOA Estimation Methods and Algorithms, Pei-Jung Chung, Mats Viberg, Jia Yu, Pages 599-650 – Chapter 15 - Subspace Methods and Exploitation of Special Array Structures, Martin Haardt, Marius Pesavento, Florian Roemer, Mohammed Nabil El Korso, Pages 651-717 • Spectral Analysis of Signals, Petre Stoica, Randolph Moses, Prentice Hall, April 2005 Optimum Array Processing: Part IV of Detection, Estimation, and Modulation Theory, Harry L. Van Trees, Wiley Online, 2002. 				
Courses					

	Course Nr. 18-pe-2060-vl	Course name Sensor Array Processing and Adaptive Beamforming		
	Instructor Prof. Dr.-Ing. Marius Pesavento		Type Lecture	SWS 2
	Course Nr. 18-pe-2060-ue	Course name Sensor Array Processing and Adaptive Beamforming		
	Instructor Prof. Dr.-Ing. Marius Pesavento		Type Practice	SWS 1

Module name Microwave Measurement Technologies					
Module Nr. 18-jk-2090	Credit Points 6 CP	Workload 180 h	Self study 120 h	Duration 1	Cycle offered SoSe
Language German and English			Module owner Prof. Dr.-Ing. Rolf Jakoby		
1	Content Introduction to microwave measurement technologies, high frequency components and their properties: rf power measurement, spectrum analysis, vector network analysis (s-parameter, x-parameter, calibration techniques), on-wafer measurements, load/source-pull, material characterization				
2	Learning objectives / Learning Outcomes By this module, Students will be enabled to understand the basic principles of microwave measurement technologies. They are able to use them in measurement applications. The following objectives are linked to the lecture: <ul style="list-style-type: none"> • The students understand the basic features of the power measurements and the effects of a mismatch or pulsed signals and can independently carry out and interpret measurements. • The students understand the basics of spectrum analysis and can carry out and interpret measurements independently. • The students understand the basics of s-parameter measurements and calibration of network analyzers and can carry out and interpret measurements independently • Students are familiar with various methods for material characterization 				
3	Recommended prerequisite for participation Recommended: Grundlagen der Nachrichtentechnik, Hochfrequenztechnik I				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Oral Examination, Duration: 45 min, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Oral Examination, Weighting: 100%) 				
6	Usability of this module MSc etit, MSc WI-etit, MSc iCE, MSc iST				
7	Grade bonus compliant to §25 (2)				
8	References				
Courses					
	Course Nr. 18-jk-2090-vl	Course name Microwave Measurement Technologies			
	Instructor Prof. Dr.-Ing. Rolf Jakoby			Type Lecture	SWS 2
	Course Nr. 18-jk-2090-ue	Course name Microwave Measurement Technologies			
	Instructor Prof. Dr.-Ing. Rolf Jakoby			Type Practice	SWS 1

	Course Nr. 18-jk-2090-pr	Course name Microwave Measurement Technologies Lab		
	Instructor PD Dr. habil. Holger Maune		Type Internship	SWS 1

Module name Machine Learning & Energy					
Module Nr. 18-st-2020	Credit Points 6 CP	Workload 180 h	Self study 120 h	Duration 1	Cycle offered WiSe
Language German			Module owner Prof. Dr. rer. nat. Florian Steinke		
1	<p>Content</p> <p>The analysis and interpretation of data becomes ever more important, also for engineers. Digitalization and Smart Grids are terms to describe a host of novel data-based services in the field of generation, distribution, consumption and marketing of (renewable) energy. The lecture presents the recent developments and their underlying principles of machine learning technology.</p> <p>For a start we will describe the different problem settings of machine learning in a structured way (classification, regression, clustering, dimensionality reductions, time series models, ...) and present for each setting relevant applications from the energy sector (prediction of renewable energy or consumption in multimodal energy systems, fault detection and prediction, data visualization, robust investments decisions, customer analysis, probabilistic load flow, ...).</p> <p>Thereafter we will briefly review necessary tools from optimization and probability theory, as well as introduce probabilistic graphical models. With these tools we will then study for each problem setting one or more machine learning algorithms in detail, together with use cases from the energy domain. Classic algorithms will be developed (e.g. linear regression, k-means, principal component analysis, ...) as well as modern ones (e.g. SVMs, Deep Learning, Collaborative filtering, ...). Practical exercise with Matlab will deepen the understanding and support student's active knowledge.</p>				
2	<p>Learning objectives / Learning Outcomes</p> <p>Students understand important machine learning problem settings and some key algorithms for each task. They know common applications thereof in the energy domain. Moreover, the students are able to apply and adapt those methods independently to new applications (not only from the energy domain).</p>				
3	<p>Recommended prerequisite for participation</p> <ul style="list-style-type: none"> • Good knowledge of linear algebra and the foundations of numerical optimization (e.g. from the course 18-st-2010 Energieanagement & Optimierung) • Using Matlab for programming the practical examples should pose no difficulty. A block tutorial on the use of Matlab is offered as 18-st-2030 Matlab Grundkurs. 				
4	<p>Form of examination</p> <p>Module Final Examination:</p> <ul style="list-style-type: none"> • Module Examination (Technical Examination, Optional, Standard Grading System) 				
5	<p>Grading</p> <p>Module Final Examination:</p> <ul style="list-style-type: none"> • Module Examination (Technical Examination, Optional, Weighting: 100 %) 				
6	<p>Usability of this module</p> <p>MSc etit, MSc iST, MSc Wi-etit, MSc CE</p>				
7	<p>Grade bonus compliant to §25 (2)</p> <p>Notenverbesserungen bis zu 0,4 nach APB §25(2) durch Bonus für regelmäßig besuchte Übungs-/Praktikumstermine und mindestens einmaliges Vorrechnen in den Übungen</p>				
8	<p>References</p> <ul style="list-style-type: none"> • A Géron: Hands on Machine Learning with scikit-learn and Tensorflow, 2017 • Friedman, Hastie, Tibshirani: The elements of statistical learning, 2001 • Koller, Friedmann: Graphical Models, 2009 				
Courses					

	Course Nr. 18-st-2020-vl	Course name Machine Learning & Energy		
	Instructor Prof. Dr. rer. nat. Florian Steinke, M.Sc. Tim Christian Janke		Type Lecture	SWS 2
	Course Nr. 18-st-2020-ue	Course name Machine Learning & Energy		
	Instructor Prof. Dr. rer. nat. Florian Steinke		Type Practice	SWS 1
	Course Nr. 18-st-2020-pr	Course name Machine Learning & Energy Lab		
	Instructor Prof. Dr. rer. nat. Florian Steinke, M.Sc. Tim Christian Janke		Type Internship	SWS 1

Module name Machine Learning in Information and Communication Technology (ICT)					
Module Nr. 18-kp-2110	Credit Points 6 CP	Workload 180 h	Self study 120 h	Duration 1	Cycle offered SoSe
Language English			Module owner Prof. Dr. techn. Heinz Köppl		
1	Content The module provides an introduction to the emerging field of machine learning from an engineering perspective. Important models and learning methods are presented and exemplified through problems from information and communication technology. <ul style="list-style-type: none"> • Fundamentals of probability theory and multivariate statistics • Taxonomy of machine learning problems and models (supervised, unsupervised, generative, discriminative) • Regression and classification: theory, methods and ICT applications • Dimensionality reduction, clustering and big data analytics: methods and application in communications and signal processing • Probabilistic graphical models: categories, inference and parameter estimation • Fundamentals of Bayesian inference, Monte Carlo methods, Bayesian non-parametrics • Fundamentals of convex optimization: Solution methods and application in communications • Approximate algorithms for scalable Bayesian inference; application in signal processing and information theory (e.g. decoding of LDPC codes) • Hidden Markov models (HMM): Theory, Algorithms and ICT applications (e.g. Viterbi decoding of convolutional codes) • High-dimensional statistics (“large p small n” setting), learning dependency structure in high-dimensional data, learning causality relations from observational data. • Sparse estimation, random projections, compressive sensing: Theory and applications in signal processing • Deep neural networks (deep learning): Models, learning algorithms, libraries and ICT applications 				
2	Learning objectives / Learning Outcomes Students are able to interpret and categorize specific engineering problems from the ICT domain in terms of machine learning problems. They are able to reduce such problems to standard machine learning problems and are able to determine suitable solution methods for them. They are able to implement all necessary algorithms from scratch, but they are also familiar with the state-of-the-art libraries in machine learning. They are able to determine the involved computational complexity of a method and choose an appropriate solution algorithms based on application constraints. They are able to apply the acquired methods to other domains, such as data analysis in biomedical engineering, analysis of social network data, etc.				
3	Recommended prerequisite for participation Good command of Matlab (for instance knowledge from course 18-st-2030 Matlab Grundkurs) and engineering mathematics				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Optional, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Optional, Weighting: 100 %) 				
6	Usability of this module MSc etit, BSc/MSc iST, MSc iCE, MSc CE				

7	Grade bonus compliant to §25 (2)		
8	References <ul style="list-style-type: none"> • Kevin P. Murphy. Machine Learning – A probabilistic perspective, MIT Press, 2012 • Christopher M. Bishop. Pattern recognition and Machine Learning, Springer, 2006 • Peter Bühlmann und Sara van de Geer. Statistics of high-dimensional data – Methods, theory and applications, Springer, 2011 		
Courses			
	Course Nr. 18-kp-2110-vl	Course name Machine Learning in Information and Communication Technology (ICT)	
	Instructor Prof. Dr. techn. Heinz Köppl, Prof. Dr.-Ing. Anja Klein		Type Lecture
	SWS 2		
	Course Nr. 18-kp-2110-pr	Course name Machine Learning in Information and Communication Technology (ICT) Lab	
	Instructor Prof. Dr. techn. Heinz Köppl, Prof. Dr.-Ing. Anja Klein		Type Internship
	SWS 1		
	Course Nr. 18-kp-2110-ue	Course name Machine Learning in Information and Communication Technology (ICT)	
	Instructor Prof. Dr. techn. Heinz Köppl, Prof. Dr.-Ing. Anja Klein		Type Practice
	SWS 1		

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 semidefinite 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: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Optional, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • 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. 18-pe-2070-ue	Course name Matrix Analysis and Computations		
	Instructor Prof. Dr.-Ing. Marius Pesavento		Type Practice	SWS 1

Module name Robust Signal Processing With Biomedical Applications					
Module Nr. 18-zo-2090	Credit Points 6 CP	Workload 180 h	Self study 120 h	Duration 1	Cycle offered SoSe
Language English			Module owner Dr.-Ing. Michael Muma		
1	<p>Content</p> <p>1. Robust Signal Processing and Learning</p> <ul style="list-style-type: none"> • Measuring robustness • Robust estimation of the mean and the variance • Robust regression models • Robust filtering • Robust location and covariance estimation • Robust clustering and classification • Robust time-series and spectral analysis <p>2. Biomedical Applications</p> <ul style="list-style-type: none"> • Body-worn sensing of physiological parameters • Electrocardiogram (ECG) • Photoplethysmogram (PPG) • Eye research • Intracranial Pressure (ICP) • Algorithms for cardiac activity monitoring <p>The lecture covers fundamental topics and recent developments in robust signal processing. Unlike classical signal processing, which relies strongly on the normal (Gaussian) distribution, robust methods can tolerate impulsive noise, outliers and artifacts that are frequently encountered in biomedical applications. Robust signal processing and biomedical application lectures alternate. Exercises revise the theory and apply robust signal processing algorithms to real world data.</p>				
2	<p>Learning objectives / Learning Outcomes</p> <p>Students understand the basics of robust signal processing and data science and are able to apply them to a variety of problems. They are familiar with various biomedical applications and know the causes of artifacts, outliers and impulsive noise. They can apply algorithms for robust regression, cluster analysis, classification and spectral analysis.</p>				
3	<p>Recommended prerequisite for participation</p> <p>Fundamental knowledge of statistical signal processing</p>				
4	<p>Form of examination</p> <p>Module Final Examination:</p> <ul style="list-style-type: none"> • Module Examination (Technical Examination, Written Examination, Duration: 180 min, Standard Grading System) 				
5	<p>Grading</p> <p>Module Final Examination:</p> <ul style="list-style-type: none"> • Module Examination (Technical Examination, Written Examination, Weighting: 100%) 				
6	<p>Usability of this module</p> <p>MSc ETiT, MSc Wi-ETiT, MSc iCE, MSc iST</p>				
7	<p>Grade bonus compliant to §25 (2)</p>				
8	<p>References</p>				

A manuscript and lecture slides can be downloaded via Moodle. Further reading

- Zoubir, A. M. and Koivunen, V. and Ollila, E. and Muma, M.: Robust Statistics for Signal Processing. Cambridge University Press, 2018.
- Zoubir, A. M. and Koivunen, V. and Chackchoukh J, and Muma, M. Robust Estimation in Signal Processing: A Tutorial-Style Treatment of Fundamental Concepts. IEEE Signal Proc. Mag. Vol. 29, No. 4, 2012, pp. 61-80.
- Huber, P. J. and Ronchetti, E. M.: Robust Statistics. Wiley Series in Probability and Statistics, 2009.
- Maronna, R. A. and Martin, R. D. and Yohai, V. J.: Robust Statistics: Theory and Methods. Wiley Series in Probability and Statistics, 2006.

Courses

Course Nr. 18-zo-2090-vl	Course name Robust Signal Processing With Biomedical Applications		
Instructor Dr.-Ing. Michael Muma		Type Lecture	SWS 3
Course Nr. 18-zo-2090-ue	Course name Robust Signal Processing With Biomedical Applications		
Instructor Dr.-Ing. Michael Muma		Type Practice	SWS 1

Module name Data Science I					
Module Nr.	Credit Points	Workload	Self study	Duration	Cycle offered
18-zo-2110	5 CP	150 h	90 h	1	SoSe
Language			Module owner		
English			Prof. Dr.-Ing. Abdelhak Zoubir		
1	Content The course covers the following topics: <ul style="list-style-type: none"> • Python programming basics • Data science introduction • Data storage and formats • Data exploration and visualization • Statistical methods and inference <ul style="list-style-type: none"> – Descriptive statistics (uni & bivariate) – Inferential statistics • Feature extraction <ul style="list-style-type: none"> – Time Series Data – Image data – Audio data • Statistical learning <ul style="list-style-type: none"> – Cross-validation, overfitting, annotation – Regression – Classification 				
2	Learning objectives / Learning Outcomes The course provides a full introduction to data science with an emphasis on hands-on examples. Students will acquire relevant knowledge of the whole data science chain: From storage/acquisition to statistical inference to visualization. It also serves as an introductory course to the Data Science project seminar.				
3	Recommended prerequisite for participation				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Written/Oral Examination, Duration: 90 min, Standard Grading System) The examination takes place in form of a written exam (duration: 90 minutes). If one can estimate that less than 16 students register, the examination will be an oral examination (duration: 45 min.). The type of examination will be announced in the beginning of the lecture.				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Written/Oral Examination, Weighting: 100%) 				
6	Usability of this module				
7	Grade bonus compliant to §25 (2) Yes				
8	References				

- Lecture notes and slides can be downloaded here:
 - <http://www.spg.tu-darmstadt.de>
 - moodle
- Further reading:
 - Wes McKinney: Python for Data Analysis, O'Reilly, 2017
 - Christopher M. Bishop: Pattern Recognition and Machine Learning, 2011
 - James, Witten, Hastie and Tibshirani, Introduction to Statistical Learning, Springer, 2017

Courses

	Course Nr. 18-zo-2110-vl	Course name Data Science I		
	Instructor Dr.-Ing. Christian Debes		Type Lecture	SWS 2
	Course Nr. 18-zo-2110-ue	Course name Data Science I		
	Instructor Dr.-Ing. Christian Debes		Type Practice	SWS 2

Module name Graph signal processing, learning and optimization					
Module Nr. 18-pe-2080	Credit Points 6 CP	Workload 180 h	Self study 120 h	Duration 1	Cycle offered WiSe
Language English			Module owner Prof. Dr.-Ing. Marius Pesavento		
1	<p>Content</p> <p>The course covers the following topics:</p> <ul style="list-style-type: none"> • Motivation, Applications • Fundamentals <ul style="list-style-type: none"> – definition of graphs, classes of graphs, properties of graphs, signals defined over graphs – Adjacency matrix, Graph Laplacian, Graph shift operator – Covariance matrix, conditional dependence, precision matrix • Graph signal processing <ul style="list-style-type: none"> – Consensus, Diffusion – Graph spectral analysis, Graph Fourier Transform – Total variational norm, Graph Frequencies – Bandlimited graph signals, smoothness – Graph filters, Graph sampling theorem – Applications • Network topology inference <ul style="list-style-type: none"> – Link prediction – Association network inference – Tomographic network topology inference – Pearson product-moment correlation – Causality, Partial correlation – Conditional independence graph – Gaussian Markov Random Fields – Graphical LASSO, Graphical LASSO with Laplacian constraint – Applications • Graph analysis <ul style="list-style-type: none"> – Subgraph identification – Cliques identification • Optimization over graphs <ul style="list-style-type: none"> – Average consensus, diffusion, exact diffusion – Gradient tracking, push-sum algorithm, etc. – Applications • Graph neuronal (convolutional) network 				
2	<p>Learning objectives / Learning Outcomes</p> <p>Graph signal processing (i.e., processing of signals defined over graphs) and network analysis form an interdisciplinary research area with many diverse applications. The course provides a systematic introduction to the theory of graph signal processing, graphical network analysis, graph topology learning, optimization over graphs and learning with graph neuronal networks. In this course the students will learn the main concepts, algorithms and application areas that are fundamental in graph signal processing.</p>				
3	<p>Recommended prerequisite for participation</p> <p>Basic knowledge in linear algebra and matrix analysis.</p>				
4	<p>Form of examination</p>				

	<p>Module Final Examination:</p> <ul style="list-style-type: none"> Module Examination (Technical Examination, Written/Oral Examination, Duration: 120 min, Standard Grading System) <p>In general, the examination takes place in form of a written exam (duration: 120 minutes). If up to 20 students register in semesters in which the lecture does not take place, there will be an oral examination (duration: 20 min.). The type of examination will be announced within one working weeks after the end of the examination registration phase.</p>		
5	<p>Grading</p> <p>Module Final Examination:</p> <ul style="list-style-type: none"> Module Examination (Technical Examination, Written/Oral Examination, Weighting: 100%) 		
6	<p>Usability of this module</p>		
7	<p>Grade bonus compliant to §25 (2)</p>		
8	<p>References</p> <ul style="list-style-type: none"> Lecture notes and slides can be downloaded here: <ul style="list-style-type: none"> www.nts.tu-darmstadt.de moodle Further reading: <ul style="list-style-type: none"> Petar M. Djuric, Cédric Richard, Cooperative and Graph Signal Processing, Academic Press, 2018, ISBN 9780128136775. 		
Courses			
	Course Nr. 18-pe-2080-vl	Course name Graph signal processing, learning and optimization	
	Instructor Prof. Dr.-Ing. Marius Pesavento		Type Lecture
			SWS 3
	Course Nr. 18-pe-2080-ue	Course name Graph signal processing, learning and optimization	
	Instructor Prof. Dr.-Ing. Marius Pesavento		Type Practice
			SWS 1

Module name Fundamentals of Reinforcement Learning					
Module Nr. 18-kl-2070	Credit Points 4 CP	Workload 120 h	Self study 75 h	Duration 1	Cycle offered SoSe
Language English			Module owner Prof. Dr.-Ing. Anja Klein		
1	Content <ul style="list-style-type: none"> • Review of Probability Theory • Markov Property and Markov Decision Processes • The Multi-Armed Bandit Problem vs. the Full Reinforcement Learning Problem • Taxonomy of Multi-Armed Bandit Problems (e.g., Stochastic vs. Adversarial Rewards, Contextual MAB) • Algorithms for Multi-Armed Bandit Problems (e.g., Upper Confidence Interval (UCB), Epsilon-Greedy, SoftMax, LinUCB) and their Application to Cyber-Physical Networking • Fundamentals of Dynamic Programming and Bellman Equations • Taxonomy of Approaches for the Full Reinforcement Learning Problem (e.g., Temporal-Difference Learning, Policy Gradient and Actor-Critic) • Algorithms for the Full Reinforcement Learning Problem (e.g., Q-Learning, SARSA, Policy Gradient, Actor-Critic) and their Application to Cyber-Physical Networking • Linear Function Approximation • Non-linear Function Approximation 				
2	Learning objectives / Learning Outcomes The students are able to <ul style="list-style-type: none"> • define the Markov property and identify the elements that constitute a Markov decision process. They will be able to use these concepts to model decision-making problems in Cyber-Physical Networking. • determine the characteristics of the Multi-Armed Bandit (MAB) Problem and compare them to the characteristics of the Full Reinforcement Learning (RL) Problem. • determine under which conditions the MAB or the full RL formulation should be used to solve decision-making problems. • differentiate the main MAB strategies, e.g., Upper Confidence Interval (UCB), Epsilon-Greedy and Softmax. • choose appropriate MAB strategies for the solution of MAB problems. • formulate and solve Contextual-MAB problems. • determine under which conditions Dynamic Programming can be used to solve decision-making problems. • explain the difference between Dynamic Programming and RL methods. • differentiate between Temporal-Difference, Policy Gradient and Actor-Critic RL techniques. • identify the limitations of MAB and full RL problems. • explain the need for generalization in MAB and full RL problems. • choose appropriate approximation techniques and use them in combination with MAB and full RL strategies. • apply algorithmic techniques to solve MAB and full RL problems and obtain valid solutions. • judge the reasonableness and consistency of the obtained solutions. 				
3	Recommended prerequisite for participation <ul style="list-style-type: none"> • Python or Matlab: basic knowledge • Engineering mathematics and probability theory 				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Technical Examination, Written/Oral Examination, Duration: 60 min, Standard Grading System) 				

	The examination takes place in form of a written exam (duration: 60 minutes). If one can estimate that less than 21 students register, the examination will be an oral examination (duration: 20 min.). The type of examination will be announced in the beginning of the lecture.
5	Grading Module Final Examination: <ul style="list-style-type: none"> Module Examination (Technical Examination, Written/Oral Examination, Weighting: 100%)
6	Usability of this module M.Sc. etit: AUT & KTS, M.Sc. ICE, B.Sc. / M.Sc. iST, M.Sc. WI-etit, M.Sc. MEC
7	Grade bonus compliant to §25 (2)
8	References <ul style="list-style-type: none"> Richard S. Sutton and Andrew G. Barto, "Reinforcement Learning: An Introduction", A Bradford Book, Cambridge, MA, USA, 2018. Aleksandrs Slivkins, "Introduction to Multi-Armed Bandits", Foundations and Trends in Machine Learning, Vol. 12: No. 1-2, 2019.

Courses

	<table border="1"> <tr> <td>Course Nr. 18-kl-2070-vl</td> <td>Course name Fundamentals of Reinforcement Learning</td> </tr> <tr> <td>Instructor Dr. rer. nat. Sabrina Klos, Dr.-Ing. Andrea Patricia Ortiz Jimenez</td> <td> <table border="1"> <tr> <td>Type Lecture</td> <td>SWS 2</td> </tr> </table> </td> </tr> </table>	Course Nr. 18-kl-2070-vl	Course name Fundamentals of Reinforcement Learning	Instructor Dr. rer. nat. Sabrina Klos, Dr.-Ing. Andrea Patricia Ortiz Jimenez	<table border="1"> <tr> <td>Type Lecture</td> <td>SWS 2</td> </tr> </table>	Type Lecture	SWS 2
Course Nr. 18-kl-2070-vl	Course name Fundamentals of Reinforcement Learning						
Instructor Dr. rer. nat. Sabrina Klos, Dr.-Ing. Andrea Patricia Ortiz Jimenez	<table border="1"> <tr> <td>Type Lecture</td> <td>SWS 2</td> </tr> </table>	Type Lecture	SWS 2				
Type Lecture	SWS 2						
	<table border="1"> <tr> <td>Course Nr. 18-kl-2070-ue</td> <td>Course name Fundamentals of Reinforcement Learning</td> </tr> <tr> <td>Instructor Dr. rer. nat. Sabrina Klos, Dr.-Ing. Andrea Patricia Ortiz Jimenez</td> <td> <table border="1"> <tr> <td>Type Practice</td> <td>SWS 1</td> </tr> </table> </td> </tr> </table>	Course Nr. 18-kl-2070-ue	Course name Fundamentals of Reinforcement Learning	Instructor Dr. rer. nat. Sabrina Klos, Dr.-Ing. Andrea Patricia Ortiz Jimenez	<table border="1"> <tr> <td>Type Practice</td> <td>SWS 1</td> </tr> </table>	Type Practice	SWS 1
Course Nr. 18-kl-2070-ue	Course name Fundamentals of Reinforcement Learning						
Instructor Dr. rer. nat. Sabrina Klos, Dr.-Ing. Andrea Patricia Ortiz Jimenez	<table border="1"> <tr> <td>Type Practice</td> <td>SWS 1</td> </tr> </table>	Type Practice	SWS 1				
Type Practice	SWS 1						

2.2 KTS II: Seminars and Project seminars

Module name Advanced Topics in Statistical Signal Processing					
Module Nr. 18-zo-2040	Credit Points 8 CP	Workload 240 h	Self study 180 h	Duration 1	Cycle offered WiSe
Language English			Module owner Prof. Dr.-Ing. Abdelhak Zoubir		
1	Content This course extends the signal processing fundamentals taught in DSP towards advanced topics that are the subject of current research. It is aimed at those with an interest in signal processing and a desire to extend their knowledge of signal processing theory in preparation for future project work (e.g. Diplomarbeit) and their working careers. This course consists of a series of five lectures followed by a supervised research seminar during two months approximately. The final evaluation includes students seminar presentations and a final exam. The main topics of the Seminar are: <ul style="list-style-type: none"> • Estimation Theory • Detection Theory • Robust Estimation Theory • Seminar projects: e.g. Microphone array beamforming, Geolocation and Tracking, Radar Imaging, Ultrasound Imaging, Acoustic source localization, Number of sources detection. 				
2	Learning objectives / Learning Outcomes Students obtain advanced knowledge in signal processing based on the fundamentals taught in DSP and ETiT 4. They will study advanced topics in statistical signal processing that are subject to current research. The acquired skills will be useful for their future research projects and professional careers.				
3	Recommended prerequisite for participation DSP, general interest in signal processing is desirable.				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Optional, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Optional, Weighting: 100 %) 				
6	Usability of this module MSc ETiT, BSc/MSc iST, MSc iCE, Wi-ETiT				
7	Grade bonus compliant to §25 (2)				
8	References <ul style="list-style-type: none"> • L. L. Scharf, Statistical Signal Processing: Detection, Estimation, and Time Series Analysis (New York: Addison-Wesley Publishing Co., 1990). • S. M. Kay, Fundamentals of Statistical Signal Processing: Estimation Theory (Book 1), Detection Theory (Book 2). • R. A. Maronna, D. R. Martin, V. J. Yohai, Robust Statistics: Theory and Methods, 2006. 				
Courses					

	Course Nr. 18-zo-2040-se	Course name Advanced Topics in Statistical Signal Processing		
	Instructor Prof. Dr.-Ing. Abdelhak Zoubir		Type Seminar	SWS 4

Module name Project Seminar Advanced μ Wave Components & Antennas					
Module Nr. 18-jk-2060	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. Rolf Jakoby		
1	Content Groups of 2-3 students per project. Students work out a well defined fundamental or actual research- related problem. The projects will be actualized in each cycle being offered and introduced at the beginning. Each group will be supervised individually. The projects comprises modern antennas for multitudinous applications, electronically-steerable antennas, RFIDs, RF sensors, adaptive tunable components such as matching networks, filter, passive mixer and modulator for next-generation mobile terminals and sensor systems.				
2	Learning objectives / Learning Outcomes Research-oriented Project Seminar in groups of 2-3 students per project with individual supervision. Students will learn <ul style="list-style-type: none"> • how to solve scientific hardware-oriented problems • working out concepts • how to design, realize and characterize RF devices • how to use commercial software and characterization tools • to evaluate and discuss their work in the context of the state-of-art in this field • to write a brief scientific report about their work • to present and discuss their results at the end of the Project Seminar 				
3	Recommended prerequisite for participation Fundamentals of Microwave Engineering I and Antennas and Adaptive Beamforming				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Oral Examination, Duration: 30 min, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Oral Examination, Weighting: 100 %) 				
6	Usability of this module MSc ETiT, MSc iCE, Wi-ETiT				
7	Grade bonus compliant to §25 (2)				
8	References Publications will be hand out to them. Software and characterization tools as well as tools to realize RF devices are available.				
Courses					
	Course Nr. 18-jk-2060-pj	Course name Project Seminar Advanced μ Wave Components & Antennas			
	Instructor Prof. Dr.-Ing. Rolf Jakoby, Dr.-Ing. Martin Schüßler			Type Project Seminar	SWS 4

Module name Project Seminar Wireless Communications					
Module Nr. 18-kl-2040	Credit Points 8 CP	Workload 240 h	Self study 180 h	Duration 1	Cycle offered SoSe
Language English			Module owner Prof. Dr.-Ing. Anja Klein		
1	Content Solving special Problems concerning mobile communications (problems concerning signal transmission and processing as well as problems concerning the network are possible, topics will be defined out of the current research topics of the lab), working on the project in teams together (2-3 students) organizing and structuring of a project dealing with scientific publications, reading up the theoretical background of the task practical work on a complex task scientific presentation of the results (report/presentation) defending the work in an oral discussion including an audience				
2	Learning objectives / Learning Outcomes After completion of the course, students possess <ul style="list-style-type: none"> • the ability to classify and analyze special problems concerning mobile communications, • the knowledge to plan and organize projects with temporal limitation, • the capability to setup and test methodologies for analysis and simulation- environments, • skills to evaluate and present achieved results and achieved conclusions. 				
3	Recommended prerequisite for participation Previous knowledge in digital communications, signal processing, mobile radio				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Oral Examination, Duration: 20 min, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Oral Examination, Weighting: 100 %) 				
6	Usability of this module MSc ETiT, MSc Wi-ETiT, MSc CE, MSc iCE, MSc iST, MSc MEC				
7	Grade bonus compliant to §25 (2)				
8	References Lecture documentation will be provided and specific literature will be announced during the course.				
Courses					
	Course Nr. 18-kl-2040-pj	Course name Project Seminar Wireless Communications			
	Instructor Prof. Dr.-Ing. Anja Klein, M.Sc. Sumedh Dongare			Type Project Seminar	SWS 4

Module name Project Seminar Emerging Topics in Sensor Array and Multichannel Processing					
Module Nr. 18-pe-2040	Credit Points 8 CP	Workload 240 h	Self study 180 h	Duration 1	Cycle offered WiSe
Language English			Module owner Prof. Dr.-Ing. Marius Pesavento		
1	Content This project-seminar addresses new trends in sensor array and multichannel processing with multidimensional tensor data representations. The specific thematic focus of the seminar will be adapted from year to year according to the latest trends in the research field. The topics will be announced on the course website well in advance.				
2	Learning objectives / Learning Outcomes Students will understand theory, algorithms and applications of sensor array and multichannel system.				
3	Recommended prerequisite for participation Basic knowledge in linear algebra.				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> Module Examination (Study Achievement, Oral Examination, Duration: 40 min, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> Module Examination (Study Achievement, Oral Examination, Weighting: 100 %) 				
6	Usability of this module MSc ETiT, MSc Wi-ETiT, MSc iCE				
7	Grade bonus compliant to §25 (2)				
8	References Harry L. Van Trees, Optimum Array Processing: Part IV of Detection, Estimation, and Modulation Theory, John Wiley & Sons, 2002. References include the latest scientific publications, seminars and books.				
Courses					
	Course Nr. 18-pe-2040-pj	Course name Project Seminar Emerging Topics in Sensor Array and Multichannel Processing			
	Instructor Prof. Dr.-Ing. Marius Pesavento, M.Sc. David Schenck			Type Project Seminar	SWS 4

Module name Signal Detection and Parameter Estimation					
Module Nr.	Credit Points	Workload	Self study	Duration	Cycle offered
18-zo-2050	8 CP	240 h	180 h	1	SoSe
Language English			Module owner Prof. Dr.-Ing. Abdelhak Zoubir		
1	Content Signal detection and parameter estimation are fundamental signal processing tasks. In fact, they appear in many common engineering operations under a variety of names. In this course, the theory behind detection and estimation will be presented, allowing a better understanding of how (and why) to design “good” detection and estimation schemes. These lectures will cover: Fundamentals Detection Theory Hypothesis Testing Bayesian Tests Ideal Observer Tests Neyman-Pearson Tests Receiver Operating Characteristics Uniformly Most Powerful Tests The Matched Filter Estimation Theory Types of Estimators Maximum Likelihood Estimators Sufficiency and the Fisher-Neyman/Factorisation Criterion Unbiasedness and Minimum variance Fisher Information and the CRB Asymptotic properties of the MLE				
2	Learning objectives / Learning Outcomes Students gain deeper knowledge in signal processing based on the fundamentals taught in DSP and ETiT 4. They will study advanced topics of statistical signal processing in the area of detection and estimation. In a sequence of 4 lectures, the basics and important concepts of detection and estimation theory will be taught. These will be studied in depth by implementation of the methods in MATLAB for practical examples. In sequel, students will perform an independent literature research, i.e. choosing an original work in detection and estimation theory which they will illustrate in a final presentation. This will support the students with the ability to work themselves into a topic based on literature research and to adequately present their knowledge. This is especially expected in the scope of the students' future research projects or in their professional career.				
3	Recommended prerequisite for participation DSP, general interest in signal processing				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Optional, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Optional, Weighting: 100%) 				
6	Usability of this module MSc ETiT, MSc iST, MSc iCE, Wi-ETiT				
7	Grade bonus compliant to §25 (2)				
8	References				

- Lecture slides
- Jerry D. Gibson and James L. Melsa. Introduction to Nonparametric Detection with Applications. IEEE Press, 1996.
- S. Kassam. Signal Detection in Non-Gaussian Noise. Springer Verlag, 1988.
- S. Kay. Fundamentals of Statistical Signal Processing: Estimation Theory. Prentice Hall, 1993.
- S. Kay. Fundamentals of Statistical Signal Processing: Detection Theory. Prentice Hall, 1998.
- E. L. Lehmann. Testing Statistical Hypotheses. Springer Verlag, 2nd edition, 1997.
- E. L. Lehmann and George Casella. Theory of Point Estimation. Springer Verlag, 2nd edition, 1999.
- Leon-Garcia. Probability and Random Processes for Electrical Engineering. Addison Wesley, 2nd edition, 1994.
- P. Peebles. Probability, Random Variables, and Random Signal Principles. McGraw-Hill, 3rd edition, 1993.
- H. Vincent Poor. An Introduction to Signal Detection and Estimation. Springer Verlag, 2nd edition, 1994.
- Louis L. Scharf. Statistical Signal Processing: Detection, Estimation, and Time Series Analysis. Pearson Education POD, 2002.
- Harry L. Van Trees. Detection, Estimation, and Modulation Theory, volume I,II,III,IV. John Wiley & Sons, 2003.
- A. M. Zoubir and D. R. Iskander. Bootstrap Techniques for Signal Processing. Cambridge University Press, May 2004.

Courses

Course Nr.	Course name		
18-zo-2050-se	Signal Detection and Parameter Estimation		
Instructor	Type	SWS	
Prof. Dr.-Ing. Abdelhak Zoubir	Seminar	4	

Module name Project Seminar Emerging topics in MIMO Communication Networks					
Module Nr. 18-pe-2050	Credit Points 8 CP	Workload 240 h	Self study 180 h	Duration 1	Cycle offered SoSe
Language English			Module owner Prof. Dr.-Ing. Marius Pesavento		
1	Content This project-seminar addresses new trends in MIMO communications for the next generation of wireless communication systems. The specific thematic focus of the seminar will be adapted from year to year according to the latest trends in wireless communications. The topics will be announced on the course website well in advance.				
2	Learning objectives / Learning Outcomes Students will learn the fundamental concepts, procedures, theories, algorithms and applications of Massive MIMO systems and 5 G mobile communication networks by the latest scientific publications.				
3	Recommended prerequisite for participation				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> Module Examination (Study Achievement, Oral Examination, Duration: 40 min, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> Module Examination (Study Achievement, Oral Examination, Weighting: 100 %) 				
6	Usability of this module MSc ETiT, MSc Wi-ETiT, MSc iCE				
7	Grade bonus compliant to §25 (2)				
8	References References include the latest scientific publications, seminars and books.				
Courses					
	Course Nr. 18-pe-2050-pj	Course name Project Seminar Emerging Topics in MIMO Communication Networks			
	Instructor Prof. Dr.-Ing. Marius Pesavento			Type Project Seminar	SWS 4

Module name Robust and Biomedical Signal Processing					
Module Nr. 18-zo-2100	Credit Points 8 CP	Workload 240 h	Self study 180 h	Duration 1	Cycle offered WiSe
Language English			Module owner Prof. Dr.-Ing. Abdelhak Zoubir		
1	<p>Content</p> <p>A series of 3 lectures provides the necessary background on robust signal processing and machine learning:</p> <ul style="list-style-type: none"> • Background on robust signal processing • Robust regression and robust filters for artifact cancellation • Robust location and covariance estimation and classification <p>They are followed by two lectures on selected biomedical applications, such as:</p> <ul style="list-style-type: none"> • Body-worn sensing of physiological parameters • Optical heart rate sensing (PPG) • Signal processing for the electrocardiogram (ECG) • Biomedical image processing <p>Students then work in groups to apply robust signal processing algorithms to real-world biomedical data. Depending on the application, the data is either recorded by the students, or provided to them. The group results are presented during a 20-minute presentation. The final assessment is based on the presentation and an oral examination.</p>				
2	Learning objectives / Learning Outcomes				
3	Recommended prerequisite for participation Fundamental knowledge of statistical signal processing				
4	<p>Form of examination</p> <p>Module Final Examination:</p> <ul style="list-style-type: none"> • Module Examination (Study Achievement, Oral Examination, Duration: 30 min, Standard Grading System) 				
5	<p>Grading</p> <p>Module Final Examination:</p> <ul style="list-style-type: none"> • Module Examination (Study Achievement, Oral Examination, Weighting: 100 %) 				
6	Usability of this module MSc ETiT, MSc Wi-ETiT, MSc iCE, MSc iST				
7	Grade bonus compliant to §25 (2)				
8	<p>References</p> <ul style="list-style-type: none"> • Slides can be downloaded via Moodle. <p>Further reading:</p> <ul style="list-style-type: none"> • Zoubir, A. M. and Koivunen, V. and Ollila, E. and Muma, M.: Robust Statistics for Signal Processing. Cambridge University Press, 2018. • Zoubir, A. M. and Koivunen, V. and Chackchouk J, and Muma, M. Robust Estimation in Signal Processing: A Tutorial-Style Treatment of Fundamental Concepts. IEEE Signal Proc. Mag. Vol. 29, No. 4, 2012, pp. 61-80. • Huber, P. J. and Ronchetti, E. M.: Robust Statistics. Wiley Series in Probability and Statistics, 2009. • Maronna, R. A. and Martin, R. D. and Yohai, V. J.: Robust Statistics: Theory and Methods. Wiley Series in Probability and Statistics, 2006. 				



Courses			
	Course Nr. 18-zo-2100-se	Course name Robust and Biomedical Signal Processing	
	Instructor Dr.-Ing. Michael Muma	Type Seminar	SWS 4

Module name International Summer School 'Microwaves and Lightwaves'					
Module Nr. 18-pr-2020	Credit Points 4 CP	Workload 120 h	Self study 90 h	Duration 1	Cycle offered SoSe
Language English			Module owner Prof. Dr. rer. nat. Sascha Preu		
1	Content This summer school covers the fundamentals and the latest developments of microwave electronics, THz technology, and optical communication systems with particular focus on the physical concepts involved.				
2	Learning objectives / Learning Outcomes Students understand the presented research topics, e.g. <ul style="list-style-type: none"> • topics of microwave engineering, THz engineering, and optical communications • of related electronics • the influence of the relevant properties of materials and of waveguides on signal processing. They gain inside into the latest developments in these fields.				
3	Recommended prerequisite for participation				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Oral Examination, Duration: 30 min, Standard Grading System) 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Oral Examination, Weighting: 100 %) 				
6	Usability of this module BSc ETiT, MSc ETiT				
7	Grade bonus compliant to §25 (2)				
8	References A script (English) will be distributed or slides can be downloaded.				
Courses					
	Course Nr. 18-pr-2020-se	Course name International Summer School "Microwaves and Lightwaves"			
	Instructor Prof. Dr. rer. nat. Sascha Preu, Prof. Dr.-Ing. Rolf Jakoby			Type Seminar	SWS 2

Module name Introduction to Scientific Computing with Python					
Module Nr. 18-st-2070	Credit Points 4 CP	Workload 120 h	Self study 90 h	Duration 1	Cycle offered SoSe
Language German			Module owner Prof. Dr. rer. nat. Florian Steinke		
1	Content Scientific computing is introduced via six case studies. Exemplary engineering problems that are known from basic engineering courses are solved on a computer using fundamental methods from numerical mathematics. Opportunities and limitations of this approach are highlighted. The required material on numerical mathematics is taught via preparatory scripts for each case study. During the practical exercises the methods are implemented in the current computing environment Python under the guidance of suitable teaching personnel. The case studies cover the following numerical topics: <ul style="list-style-type: none"> • Formulation and solution of systems of linear equations, sparse methods • Integration of ordinary differential equations (ODE) and their analysis based on eigenvalues • Mathematical optimization and automated differentiation • Linear regression and approximation, first Machine Learning algorithms • Discretization of simple partial differential equations (PDE) 				
2	Learning objectives / Learning Outcomes Students have a first experience of solving engineering problems on a computer. They know how to apply fundamental technologies of numerical mathematics and are familiar with an algorithmic approach to problem solving. They know opportunities and limitations of computer-aided solution methods.				
3	Recommended prerequisite for participation Etit 1 & 2, Mathe for etit 1-3				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Written/Oral Examination, Standard Grading System) The type of examination will be announced in the first lecture. Possible types could be: Creating reports and descriptions of experiments as well as presentations of experiments and results.				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Written/Oral Examination, Weighting: 100 %) 				
6	Usability of this module Etit B.A./M.Sc. with all options, as well as CE, ICE, IST				
7	Grade bonus compliant to §25 (2)				
8	References				
Courses					
	Course Nr. 18-st-2070-pr	Course name Introduction to Scientific Computing with Python			
	Instructor Prof. Dr. rer. nat. Florian Steinke, Prof. Dr. rer. nat. Sebastian Schöps, Prof. Dr. techn. Heinz Köppl, Prof. Dr.-Ing. Herbert De Gersem, Prof. Dr. rer. nat. Markus Meinert			Type Internship	SWS 2

Module name Data Science II					
Module Nr. 18-zo-2120	Credit Points 8 CP	Workload 240 h	Self study 180 h	Duration 1	Cycle offered WiSe
Language English			Module owner Prof. Dr.-Ing. Abdelhak Zoubir		
1	Content The course covers the following topics: <ul style="list-style-type: none"> • Data Science Advanced Methods • Data Management + Big data frameworks • Statistical Learning <ul style="list-style-type: none"> – Recommender Systems – Deep Learning – Unsupervised Learning – Text data analysis • Final application project. Flexibility to choose from list of projects or come up with own project. Examples: <ul style="list-style-type: none"> – Sound classification – Heart rate analysis – Activity recognition with acceleration data – Hyperspectral data – Image classification – Health survey 				
2	Learning objectives / Learning Outcomes This seminar provides an advanced understanding of data science with an emphasis on hands-on projects. Students will get to know latest data science technologies – from big data to advanced machine learning and apply them in a real-world project.				
3	Recommended prerequisite for participation Data Science I (Lecture)				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Written/Oral Examination, Duration: 90 min, Standard Grading System) In general, the examination takes place in form of a written exam (duration: 90 minutes). If up to 14 students register, there will be an oral examination (duration: 45 min.). The type of examination will be announced in the first lecture. Possible types include a project presentation, etc.				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Written/Oral Examination, Weighting: 100%) 				
6	Usability of this module				
7	Grade bonus compliant to §25 (2)				
8	References				

Lecture notes and slides can be downloaded here:

- <http://www.spg.tu-darmstadt.de>
- Moodle platform

Further reading:

- Wes McKinney: Python for Data Analysis, O'Reilly, 2017
- Christopher M. Bishop: Pattern Recognition and Machine Learning, 2011
- James, Witten, Hastie and Tibshirani, Introduction to Statistical Learning, Springer, 2017

Courses

	Course Nr. 18-zo-2120-se	Course name Data Science II		
	Instructor Dr.-Ing. Christian Debes		Type Seminar	SWS 4

Module name					
Artificial Intelligence in Medicine Challenge					
Module Nr.	Credit Points	Workload	Self study	Duration	Cycle offered
18-ha-2010	8 CP	240 h	180 h	1	WiSe/SoSe
Language			Module owner		
German			Prof. Dr.-Ing. Christoph Hoog Antink		
1	Content Within this module, students will work independently in small groups on a given problem from the realm of artificial intelligence (AI) in medicine. The nature of the problem can be the automatic classification or prediction of a disease from medical signals or data, the extraction of a physiological parameter, etc. All groups will be given the same problem but will have to develop their own algorithms, which will be evaluated on a hidden dataset. In the end, a ranking of the best-performing algorithms is provided.				
2	Learning objectives / Learning Outcomes Within this module, students will work independently in small groups on a given problem from the realm of artificial intelligence (AI) in medicine. The nature of the problem can be the automatic classification or prediction of a disease from medical signals or data, the extraction of a physiological parameter, etc. All groups will be given the same problem but will have to develop their own algorithms, which will be evaluated on a hidden dataset. In the end, a ranking of the best-performing algorithms is provided.				
3	Recommended prerequisite for participation <ul style="list-style-type: none"> • Basic programming skills in Python • 18-zo-1030 Fundamentals of Signal Processing 				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Written/Oral Examination, Standard Grading System) Report and/or Presentation. The type of examination will be announced in the beginning of the lecture. 				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Written/Oral Examination, Weighting: 100%) 				
6	Usability of this module BSc/MSc (WI-)etit, AUT, DT, KTS BSc/MSc iST MSc iCE				
7	Grade bonus compliant to §25 (2)				
8	References <ul style="list-style-type: none"> • Friedman, Jerome, Trevor Hastie, and Robert Tibshirani. The elements of statistical learning. Vol. 1. No. 10. New York: Springer series in statistics, 2001. • Bishop, Christopher M. Pattern recognition and machine learning. springer, 2006. 				
Courses					
Course Nr.	Course name				
18-ha-2010-pj	Artificial Intelligence in Medicine Challenge				
Instructor				Type	SWS
Prof. Dr.-Ing. Christoph Hoog Antink				Project Seminar	4

Module name Project seminar Terahertz Technology, Communication and Sensors					
Module Nr. 18-pr-2030	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. rer. nat. Sascha Preu		
1	Content Investigating and solving specific problems concerning the development of Terahertz devices, of applications of THz technology as well as topics of the area of Optics and communication technology. The specific task will be defined based on current research topics. The project seminar includes working on a given task by one's own, organizing and structuring of a seminar task, searching and analyzing of scientific reference publications, summarizing achieved results and conclusions by means of a written report, presenting achieved results and conclusions and defending them in an oral discussion including audience. Topics include, e.g.: <ul style="list-style-type: none"> • Terahertz Optics • Optics/photonics • Spectroscopy • Semiconductor devices • Light-matter interaction Link to current research topics at the FG Terahertz Devices and Systems: https://www.tsys.tu-darmstadt.de/home_2/forschung_17/index.en.jsp				
2	Learning objectives / Learning Outcomes After completion of the course, students possess: <ul style="list-style-type: none"> • the ability to apply theoretical models to practical problems • deep and special knowledge in a particular field related to THz science, optics or semiconductor physics • the skills to find, analyze and evaluate scientific reference papers for a particular topic • the capability to summarize the achieved scientific findings in the form of a concise report, and to present and discuss achieved results in the form of a presentation in front of an audience 				
3	Recommended prerequisite for participation Previous knowledge in at least one of the following disciplines: Optics, semiconductor physics, or THz technology				
4	Form of examination Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Written/Oral Examination, Standard Grading System) Report and/or Presentation. The type of examination will be announced in the beginning of the project.				
5	Grading Module Final Examination: <ul style="list-style-type: none"> • Module Examination (Study Achievement, Written/Oral Examination, Weighting: 100%) 				
6	Usability of this module MSc ETTT				
7	Grade bonus compliant to §25 (2)				
8	References Will be announced once the topic is defined.				
Courses					

	Course Nr. 18-pr-2030-pj	Course name Project seminar Terahertz Technology, Communication and Sensors		
	Instructor Prof. Dr. rer. nat. Sascha Preu		Type Project Seminar	SWS 4