

# Modulhandbuch

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## Master

# Communications and Signal Processing

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**Studienordnungsversion: 2013**

**gültig für das Wintersemester 2017/18**

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aus der POS Datenbank der TU Ilmenau

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URN: urn:nbn:de:gbv:ilm1-mhb-8284

# Inhaltsverzeichnis

| Name des Moduls/Fachs  | 1.FS | 2.FS | 3.FS | 4.FS  | 5.FS | 6.FS | 7.FS | 8.FS | 9.FS | 10.F | Ab-<br>schluss | LP |
|--|------|------|------|-------|------|------|------|------|------|------|----------------|----|
|  | V    | S    | P    | V     | S    | P    | V    | S    | P    | V    | S              | P  |
| <b>Advanced Digital Signal Processing</b>                      |      |      |      |       |      |      |      |      |      |      | FP             | 7  |
| Advanced Digital Signal Processing                             | 2    | 1    | 2    |       |      |      |      |      |      |      | PL             | 7  |
| <b>Information Theory and Coding</b>                           |      |      |      |       |      |      |      |      |      |      | FP             | 5  |
| Information Theory and Coding                                  | 2    | 2    | 0    |       |      |      |      |      |      |      | PL             | 5  |
| <b>Electromagnetic Signal Transmission</b>                     |      |      |      |       |      |      |      |      |      |      | FP             | 8  |
| Microwave Engineering  | 2    | 2    | 0    |       |      |      |      |      |      |      | PL 30min       | 4  |
| Antenna Engineering  |      | 2    | 1    | 0     |      |      |      |      |      |      | PL 30min       | 4  |
| <b>Communication Networks</b>                                  |      |      |      |       |      |      |      |      |      |      | FP             | 8  |
| Communication Networks   | 4    | 2    | 0    |       |      |      |      |      |      |      | PL 90min       | 8  |
| <b>Communications Engineering</b>                              |      |      |      |       |      |      |      |      |      |      | FP             | 6  |
| Communications Engineering                                     | 2    | 2    | 0    |       |      |      |      |      |      |      | PL             | 6  |
| <b>Advanced Mobile Communication Networks</b>                  |      |      |      |       |      |      |      |      |      |      | FP             | 5  |
| Advanced Mobile Communication Networks                         |      | 2    | 2    | 0     |      |      |      |      |      |      | PL             | 5  |
| <b>Multimedia</b>  |      |      |      |       |      |      |      |      |      |      | FP             | 7  |
| Multimedia Standards   |      | 2    | 0    | 0     |      |      |      |      |      |      | PL 90min       | 3  |
| Audio Coding   |      |      | 2    | 1     | 0    |      |      |      |      |      | PL 90min       | 4  |
| <b>Mobile Communications</b>                                   |      |      |      |       |      |      |      |      |      |      | FP             | 8  |
| Mobile Communications  |      | 3    | 2    | 0     |      |      |      |      |      |      | PL             | 8  |
| <b>Research Project</b>  |      |      |      |       |      |      |      |      |      |      | FP             | 5  |
| Research Project   |      | 0    | 3    | 0     |      |      |      |      |      |      | PL             | 5  |
| <b>Advanced Research Project</b>                               |      |      |      |       |      |      |      |      |      |      | FP             | 6  |
| Advanced Research Project                                      |      |      | 0    | 4     | 0    |      |      |      |      |      | PL             | 6  |
| <b>Cellular Communication Systems</b>                          |      |      |      |       |      |      |      |      |      |      | FP             | 5  |
| Cellular Communication Systems                                 |      |      | 2    | 2     | 0    |      |      |      |      |      | PL             | 5  |
| <b>Advanced Topics in Communications and Signal Processing</b> |      |      |      |       |      |      |      |      |      |      | FP             | 7  |
| Advanced Topics in Communications and Signal Processing        |      |      | 2    | 0     | 0    |      |      |      |      |      | PL             | 3  |
| Measurements in Communications                                 |      |      | 3    | 0     | 0    |      |      |      |      |      | PL 30min       | 4  |
| <b>Adaptive and Array Signal Processing</b>                    |      |      |      |       |      |      |      |      |      |      | FP             | 8  |
| Adaptive and Array Signal Processing                           |      |      | 3    | 2     | 0    |      |      |      |      |      | PL             | 8  |
| <b>Non-technical Elective Courses</b>                          |      |      |      |       |      |      |      |      |      |      | MO             | 5  |
|  |      |      |      |       |      |      |      |      |      |      | SL             | 0  |
|  |      |      |      |       |      |      |      |      |      |      | SL             | 0  |
|  |      |      |      |       |      |      |      |      |      |      | SL             | 0  |
| <b>Master-Arbeit mit Kolloquium</b>                            |      |      |      |       |      |      |      |      |      |      | FP             | 30 |
| Kolloquium zur Master-Arbeit                                   |      |      |      |       |      |      |      |      |      |      | PL 45min       | 5  |
| Masterarbeit   |      |      |      | 900 h |      |      |      |      |      |      | MA 6           | 25 |

## Modul: Advanced Digital Signal Processing

Modulnummer: 100510

Modulverantwortlich: Prof. Dr. Gerald Schuller

Modulabschluss: Fachprüfung/Modulprüfung generiert

### Lernergebnisse

Vermittlung von umfassenden Kenntnissen auf dem Gebiet der digitalen Signalverarbeitung.

The students learn to identify, solve and evaluate problems in the various fields of digital signal processing.

### Voraussetzungen für die Teilnahme

### Detailangaben zum Abschluss

## Advanced Digital Signal Processing

Fachabschluss: Prüfungsleistung alternativ

Art der Notengebung: Gestufte Noten

Sprache: Englisch

Pflichtkennz.: Pflichtfach

Turnus: Wintersemester

Fachnummer: 5831

Prüfungsnummer: 2100206

Fachverantwortlich: Prof. Dr. Gerald Schuller

|   |                   |                               |                  |
|---|-------------------|-------------------------------|------------------|
| Leistungspunkte: 7                                  | Workload (h): 210 | Anteil Selbststudium (h): 154 | SWS: 5.0         |
| Fakultät für Elektrotechnik und Informationstechnik |                   |                               | Fachgebiet: 2184 |

| SWS nach<br>Fach-<br>semester | 1.FS |   |   | 2.FS |   |   | 3.FS |   |   | 4.FS |   |   | 5.FS |   |   | 6.FS |   |   | 7.FS |   |   | 8.FS |   |   | 9.FS |   |   | 10.FS |   |   |  |  |  |
|-------------------------------|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|-------|---|---|--|--|--|
|                               | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V     | S | P |  |  |  |
|                               | 2    | 1 | 2 |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |       |   |   |  |  |  |

### Lernergebnisse / Kompetenzen

Vermittlung von umfassenden Kenntnissen auf dem Gebiet der digitalen Signalverarbeitung. The students learn to identify, solve and evaluate problems in the various fields of digital signal processing.

### Vorkenntnisse

Bachelorabschluß mit Kenntnissen zu den Grundlagen der digitalen Signalverarbeitung. Basic knowledge of signal processing.

### Inhalt

Quantization, Vector quantization, sampling, transforms, digital filter design, Wiener filter, matched filter, prediction

### Medienformen

Beamer, Script

### Literatur

siehe Internetseite see webpage

### Detailangaben zum Abschluss

Alternative course-related examination (examination registration at the beginning of the semester), consisting of 70 points written test (90 minutes), 30 points homework

### verwendet in folgenden Studiengängen:

- Master Communications and Signal Processing 2008
- Master Communications and Signal Processing 2013

## Modul: Information Theory and Coding

Modulnummer: 100509

Modulverantwortlich: Prof. Dr. Giovanni Del Galdo

Modulabschluss: Fachprüfung/Modulprüfung generiert

### Lernergebnisse

The students understand the the basic concept of information, i.e., entropy, differential entropy, mutual information, channel capacity. The students are able to apply their knowledge to communication systems and they are able to evaluate the effectiveness of source- and channel coding schemes. Besides the knowledge of block codes and convolutional codes the students are also familiar with the principles of Turbo codes and LDPC codes.

### Voraussetzungen für die Teilnahme

Bachelorabschluss

### Detailangaben zum Abschluss

## Information Theory and Coding

Fachabschluss: Prüfungsleistung schriftlich 120 min Art der Notengebung: Gestufte Noten  
 Sprache: Englisch Pflichtkennz.: Pflichtfach Turnus: Wintersemester

Fachnummer: 5832 Prüfungsnummer: 2100207

Fachverantwortlich: Prof. Dr. Giovanni Del Galdo

|   |                   |                               |                  |
|---|-------------------|-------------------------------|------------------|
| Leistungspunkte: 5                                  | Workload (h): 150 | Anteil Selbststudium (h): 105 | SWS: 4.0         |
| Fakultät für Elektrotechnik und Informationstechnik |                   |                               | Fachgebiet: 2118 |

| SWS nach<br>Fach-<br>semester | 1.FS |   |   | 2.FS |   |   | 3.FS |   |   | 4.FS |   |   | 5.FS |   |   | 6.FS |   |   | 7.FS |   |   | 8.FS |   |   | 9.FS |   |   | 10.FS |   |   |  |  |  |
|-------------------------------|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|-------|---|---|--|--|--|
|                               | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V     | S | P |  |  |  |
|                               | 2    | 2 | 0 |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |       |   |   |  |  |  |

### Lernergebnisse / Kompetenzen

The students understand the the basic concept of information, i.e., entropy, differential entropy, mutual information, channel capacity. The students are able to apply their knowledge to communication systems and they are able to evaluate the effectiveness of source- and channel coding schemes. Besides the knowledge of block codes and convolutional codes the students are also familiar with the principles of Turbo codes and LDPC codes.

### Vorkenntnisse

Bachelorabschluß Basic knowlege in statistics, stochastics

### Inhalt

#### Inhaltsverzeichnis

- Informationstheorie
- Übertragung codierter Signale über AWGN Kanäle
- Codierungsgewinn, Informationstheoretische Grenzen
- Shannon-Hartley Kanalcodierungs-Theorem
- Blockcodes und Faltungscodes
- Turbo-Codes
- LDPC-Codes

#### Table of contents

- Information theory
- Transmission of coded signals over AWGN channels
- Coding gain, information theoretic limits
- Shannon-Hartley channel coding theorem
- Blockcodes and convolutional codes
- Turbo-codes
- LDPC-codes

### Medienformen

Skript, Tafel

### Literatur

- John G. Proakis
- Thomas M. Cover, Joy A. Thomas, "Elements of Information Theory", Wiley series in telecommunications, Wiley & Sons, Inc., Canada, 1991

Detailangaben zum Abschluss

verwendet in folgenden Studiengängen:

Master Communications and Signal Processing 2008  
Master Communications and Signal Processing 2013

## Modul: Electromagnetic Signal Transmission

Modulnummer: 100454

Modulverantwortlich: Prof. Dr. Matthias Hein

Modulabschluss: Fachprüfung/Modulprüfung generiert

### Lernergebnisse

Vermittlung vertiefender Kenntnisse auf aktuellen Gebieten der Signalverarbeitung und Kommunikationstechnik, gemäß der im aktuellen Semester angebotenen Inhalte.

### Voraussetzungen für die Teilnahme

Bachelorabschluss

### Detailangaben zum Abschluss

- \* written exam (Part I): 50 % of the final grade
  - \* Homework (Part I) with presentation of the results: 30 % of the final grade
  - \* Homework (Part II): 10 % of the final grade
  - \* Homework (Part III): 10 % of the final grade
- homework results are valid for 2 semesters  
In order to pass the course, the students have to pass the final written exam, 90 min



## Microwave Engineering

Fachabschluss: Prüfungsleistung mündlich 30 min Art der Notengebung: Gestufte Noten

Sprache: English

Pflichtkennz.: Pflichtfach

Turnus: Wintersemester

Fachnummer: 5833

Prüfungsnummer: 2100208

Fachverantwortlich: Prof. Dr. Matthias Hein

|   |                   |                              |                  |       |       |       |       |       |       |       |
|---|-------------------|------------------------------|------------------|-------|-------|-------|-------|-------|-------|-------|
| Leistungspunkte: 4                                  | Workload (h): 120 | Anteil Selbststudium (h): 75 | SWS: 4.0         |       |       |       |       |       |       |       |
| Fakultät für Elektrotechnik und Informationstechnik |                   |                              | Fachgebiet: 2113 |       |       |       |       |       |       |       |
| SWS nach  | 1.FS              | 2.FS                         | 3.FS             | 4.FS  | 5.FS  | 6.FS  | 7.FS  | 8.FS  | 9.FS  | 10.FS |
| Fach-   | V S P             | V S P                        | V S P            | V S P | V S P | V S P | V S P | V S P | V S P | V S P |
| semester  | 2 2 0             |                              |                  |       |       |       |       |       |       |       |

### Lernergebnisse / Kompetenzen

The students analyse the basics of wave propagation, reflection and superposition of RF signals on transmission lines. They learn to design matching circuits based on lumped and distributed elements. The students are able to describe the operation of typical couplers and hybrids. They are able to choose optimal transmission line types and substrate materials. They know about the principles of RF measurement systems, e.g. the vector network analyser. The students will solve specific design and analysis Tasks in tutorial groups.

### Vorkenntnisse

Bachelor of Science in Electrical Engineering

### Inhalt

1. Waveguides, line propagation, reflections
2. Reflection coefficient, Smith diagram, scattering parameters
3. Special transmission lines
4. Couplers and hybrids
5. Microwave materials and line types
6. Impedance matching
7. Diode detectors, slotted line
8. Reflectometer, VSWR bridge, network analyzer
9. Multi-port measurements, mixed-mode S-parameters

### Medienformen

Blackboard, illustrations (projector), selected microwave components, work sheets (printable)

### Literatur

Chang Kai, "Handbook of microwave and optical components: Microwave passive and antenna components", vol. 1, Wiley, 1989

Bhartia, Prakash ; Bahl, Inder Jit, "Millimeter wave engineering and applications", Wiley, 1984.

Pozar, David M., "Microwave engineering", Wiley, 2005.

### Detailangaben zum Abschluss

verwendet in folgenden Studiengängen:

Master Communications and Signal Processing 2008

Master Communications and Signal Processing 2013

## Antenna Engineering

Fachabschluss: Prüfungsleistung mündlich 30 min      Art der Notengebung: Gestufte Noten  
 Sprache: English      Pflichtkennz.: Pflichtfach      Turnus: Sommersemester

Fachnummer: 5841      Prüfungsnummer: 2100213

Fachverantwortlich: Prof. Dr. Matthias Hein

Leistungspunkte: 4      Workload (h): 120      Anteil Selbststudium (h): 86      SWS: 3.0  
 Fakultät für Elektrotechnik und Informationstechnik      Fachgebiet: 2113

| SWS nach<br>Fach-<br>semester | 1.FS |   |   | 2.FS |   |   | 3.FS |   |   | 4.FS |   |   | 5.FS |   |   | 6.FS |   |   | 7.FS |   |   | 8.FS |   |   | 9.FS |   |   | 10.FS |   |   |  |  |  |
|-------------------------------|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|-------|---|---|--|--|--|
|                               | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V     | S | P |  |  |  |
|                               |      |   |   | 2    | 1 | 0 |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |       |   |   |  |  |  |

### Lernergebnisse / Kompetenzen

The students get an overview on the basics, applications, and trends in Kompetenzen the field of antenna engineering and its relation to communications and signal processing. The students get insight into theoretical foundations of antennas. They understand, describe, and apply antennas as wave transformers, microwave systems (including feed and beam forming networks), and systems for spatial signal processing. The students discuss and evaluate different types of elementary radiators, means to control and measure the radiation patterns, and approaches to employ antenna systems for signal processing (e.g., for MIMO applications). In the tutorials, selected examples are treated in detail.  
 The students will also have the opportunity to visit the anechoic chamber and perform, to some extent, own measurements.

### Vorkenntnisse

Bachelor of Science in Electrical Engineering and Information Technology, advanced knowledge of electromagnetic waves / microwave engineering.

### Inhalt

1. Mobile communications from an antenna's perspective: Propagation issues, air interface
2. Fundamentals of antenna engineering: Electrodynamical foundations, basic radiating elements, examples of practical radiating elements
3. Antenna arrays: Foundations of linear arrays, beam forming, spatial signal processing
4. Practical aspects of antenna engineering: Packaging and protection, design and numerical simulation, antenna measurements

### Medienformen

Development of contents using blackboard, supplementary illustrations using overhead transparencies (available in electronic form), electronic animations (where appropriate); problem solving for in-depth learning

### Literatur

S. Drabowitch, A. Papiernik, H. Griffiths, J. Encinas, B. L. Smith. Modern antennas. Chapman & Hill, 1998.  
 C.A. Balanis. Antenna theory: analysis and design. Wiley, 1997.  
 J.D. Kraus und R.J. Marhefka. Antennas for all applications. McGraw-Hill, 2002.

### Detailangaben zum Abschluss

### verwendet in folgenden Studiengängen:

- Master Communications and Signal Processing 2008
- Master Communications and Signal Processing 2013

## Modul: Communication Networks

Modulnummer: 100508

Modulverantwortlich: Prof. Dr. Jochen Seitz

Modulabschluss: Fachprüfung/Modulprüfung generiert

### Lernergebnisse

Telecommunication is an integral part of today's life. People are used to communicate with any person they would like to by phone, e-mail, chat, or skype at any time at any place. Students in this lecture will learn the basic characteristics of different communication networks. In a bottom-up approach, starting from the physical medium going up to the application, they are introduced into the functionality of different communication protocols and understand how these cooperate to achieve a communication service. Hence, they know different aspects of quality of service the users can expect from different protocols, and are able to specify protocols on their own based on the according protocol mechanisms. As the lecture deals with different networks (telephone network, Internet, mobile communication networks, broadband access networks), the students can characterize these networks and explain the differences.

### Voraussetzungen für die Teilnahme

no specific requirements

### Detailangaben zum Abschluss

## Communication Networks

Fachabschluss: Prüfungsleistung schriftlich 90 min Art der Notengebung: Gestufte Noten

Sprache: Englisch

Pflichtkennz.: Pflichtfach

Turnus: Wintersemester

Fachnummer: 5834

Prüfungsnummer: 2100209

Fachverantwortlich: Prof. Dr. Jochen Seitz

|   |                   |                               |                  |       |       |       |       |       |       |       |
|---|-------------------|-------------------------------|------------------|-------|-------|-------|-------|-------|-------|-------|
| Leistungspunkte: 8                                  | Workload (h): 240 | Anteil Selbststudium (h): 172 | SWS: 6.0         |       |       |       |       |       |       |       |
| Fakultät für Elektrotechnik und Informationstechnik |                   |                               | Fachgebiet: 2115 |       |       |       |       |       |       |       |
| SWS nach  | 1.FS              | 2.FS                          | 3.FS             | 4.FS  | 5.FS  | 6.FS  | 7.FS  | 8.FS  | 9.FS  | 10.FS |
| Fach-   | V S P             | V S P                         | V S P            | V S P | V S P | V S P | V S P | V S P | V S P | V S P |
| semester  | 4 2 0             |                               |                  |       |       |       |       |       |       |       |

### Lernergebnisse / Kompetenzen

Telecommunication is an integral part of today's life. People are used to communicate with any person they would like to by phone, e-mail, chat, or skype at any time at any place. Students in this lecture will learn the basic characteristics of different communication networks. In a bottom-up approach, starting from the physical medium going up to the application, they are introduced into the functionality of different communication layers and protocols and understand how these cooperate to achieve a communication service. Hence, they know different aspects of quality of service the users can expect from different protocols, and are able to specify protocols on their own based on the according protocol mechanisms. As the lecture deals with different networks (telephone network, Internet, mobile communication networks, broadband access networks), the students can characterize these networks and explain the differences.

### Vorkenntnisse

Bachelorabschluss

### Inhalt

1. Introduction: communication systems and networks
2. Fundamentals: communication service, communication protocol, quality of service, reference models
3. Protocol specification: finite state machine, message sequence chart
4. Transmission technique: physical signals, analog and digital signals, codes, multiplexing
5. Switching Technology: circuit switching (space division, time division), store and forward (message switching, packet switching [virtual connection, datagram])
6. Interconnection of networks: repeater, hub, bridge, switch, router, gateway
7. Digital Voice Communication [Integrated Services Digital Network ISDN]: reference model, signaling, protocols, subscriber installation, subscriber line, plesiochronous digital hierarchy, synchronous digital hierarchy
8. Global System for Mobile Communications (GSM)/ General Packet Radio Service (GPRS): reference model, channels at the air interface, signaling, circuit switching vs. packet switching, security
9. Universal Mobile Telecommunication System (UMTS): reference model, code division multiple access, migration to LTE
10. Connection-oriented Public Data Networks: reference models, X.25, Frame Relay, Asynchronous Transfer Mode, virtual circuits and quality of service
11. The Internet: reference model, Internet Protocol (IP) in different versions, auxiliary protocols in network layer, routing in the Internet, Transmission Control Protocol (TCP), User Datagram Protocol (UDP), Voice over IP (VoIP), Internet applications

### Medienformen

- Powerpoint slides (also available online)
- Writings on the board
- Exercises (presented by both students and lecturer)
- Intermediate bonus exams

### Literatur

- Flood, J.E. (1995). Telecommunications Switching, Traffic and Networks. New York; London; Toronto; Sydney; Tokyo; Singapore, Prentice Hall.
- Griffiths, J.M.; P. F. Adams (1998): ISDN Explained: Worldwide Network and Applications Technology. San

Francisco: Wiley & Sons.

- Halsall, F. (1996). Data Communications, Computer Networks, and Open Systems. Harlow, England; Reading, Massachusetts; Menlo Park, California, Addison-Wesley.
- Kasper, S. (2006): ATM Networks: Concepts and Protocols. New York: Irwin/Mcgraw Hill.
- Kurose, J. F. and K. W. Ross (2008). Computer Networking: A Top-Down Approach. Upper Saddle River, New Jersey, USA, Pearson Education.
- Perlman, R. (1999): Interconnections: Bridges and Routers. Boston; San Francisco; New York: Addison Wesley, 2nd edition.
- Peterson, L. L. and B. S. Davie (2007). Computer Networks: A Systems Approach. San Francisco, Morgan Kaufmann Publishers.
- Schiller, J. (2003): Mobile Communications, Harlow, England; Reading, Massachusetts; Menlo Park, California, Addison-Wesley, 2nd edition.
- Stallings, W. (2006). Data and Computer Communications. Upper Saddle River, New Jersey, USA, Prentice Hall.
- Tanenbaum, A. S. (2002). Computer Networks. Upper Saddle River, New Jersey, Pearson Education.

Detailangaben zum Abschluss

verwendet in folgenden Studiengängen:

Master Communications and Signal Processing 2008  
Master Communications and Signal Processing 2013  
Master Medientechnologie 2017

## Modul: Communications Engineering

Modulnummer: 100507

Modulverantwortlich: Prof. Dr. Martin Haardt

Modulabschluss: Fachprüfung/Modulprüfung generiert

### Lernergebnisse

Die Studierenden verstehen die wesentlichen Techniken der Nachrichtenübertragung und erlernen die wichtigsten Methoden für die Analyse und den Entwurf diskreter Datenübertragungssysteme. The students understand the fundamental techniques of data transmission and get to know the most important methods to design and analyze discrete data transmission systems.

### Voraussetzungen für die Teilnahme

Bachelorabschluss

### Detailangaben zum Abschluss

## Communications Engineering

Fachabschluss: Prüfungsleistung schriftlich 120 min      Art der Notengebung: Gestufte Noten  
 Sprache: Englisch      Pflichtkenn.: Pflichtfach      Turnus: Wintersemester

Fachnummer: 5835      Prüfungsnummer: 2100210

Fachverantwortlich: Prof. Dr. Martin Haardt

|   |                   |                               |          |
|---|-------------------|-------------------------------|----------|
| Leistungspunkte: 6                                  | Workload (h): 180 | Anteil Selbststudium (h): 135 | SWS: 4.0 |
| Fakultät für Elektrotechnik und Informationstechnik |                   | Fachgebiet: 2111              |          |

| SWS nach<br>Fach-<br>semester | 1.FS |   |   | 2.FS |   |   | 3.FS |   |   | 4.FS |   |   | 5.FS |   |   | 6.FS |   |   | 7.FS |   |   | 8.FS |   |   | 9.FS |   |   | 10.FS |   |   |  |  |  |
|-------------------------------|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|-------|---|---|--|--|--|
|                               | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V     | S | P |  |  |  |
|                               | 2    | 2 | 0 |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |       |   |   |  |  |  |

### Lernergebnisse / Kompetenzen

Die Studierenden verstehen die wesentlichen Techniken der Nachrichtenübertragung und erlernen die wichtigsten Methoden für die Analyse und den Entwurf diskreter Datenübertragungssysteme. The students understand the fundamental techniques of data transmission and get to know the most important methods to design and analyze discrete data transmission systems.

### Vorkenntnisse

Bachelorabschluß

### Inhalt

- System theoretic basics
  - Bandpass lowpass transformation for signals and systems
  - Correlation functions of deterministic signals
  - Correlation functions of stochastic signals
- Optimal filters
  - Matched filter
  - Wiener filter
- Signal space representation of waveforms
  - The signal space as a generalized Euklidian vector space
  - Gram-Schmidt procedure
- Discrete modulation and transmission in AWGN
  - Antipodal transmission
  - Optimal detection for M-ary modulation
  - Bit error rate for M-ary modulation
  - Bandpass modulation schemes
- Block transmission with Cyclic prefix
  - Multipath radio channel
  - Block transmission model
  - OFDM

### Medienformen

Skript, Tafel, Beamer Script, projector

### Literatur

- Simon Haykin. Communication Systems. John Wiley and Sons, 2000
- Bernard Sklar. Digital Communications. Prentice Hall, 2001
- J. Proakis, Digital Communications. McGraw-Hill, 4th edition, 2001.
- J. Proakis and M. Salehi, Communication Systems Engineering. Prentice Hall, 2nd edition, 2002.

Detailangaben zum Abschluss

verwendet in folgenden Studiengängen:

Master Communications and Signal Processing 2008  
Master Communications and Signal Processing 2013



## Modul: Advanced Mobile Communication Networks

Modulnummer: 5837

Modulverantwortlich: Prof. Dr. Andreas Mitschele-Thiel

Modulabschluss: Fachprüfung/Modulprüfung generiert

Lernergebnisse

see course description

Voraussetzungen für die Teilnahme

Detailangaben zum Abschluss

- The course consists of two parts: In the first part of the semester, lectures on the material are given. In the second part, individual studies (semester-long research projects that include a term paper and a presentation) help to improve understanding of the material.
- Grading scheme: 40% term paper plus presentation, 60% oral exam (20 min, registration at ICS office in Z1031).
- Binding registration for the exam (using Thoska or the registration form provided by the examination office IA) is required at the beginning of each semester (check the registration time window which is defined each semester) in order to participate in individual studies projects and the oral exam. As your course grade is a result of the individual studies and the oral exam, only formally registered students are eligible for participation in the individual studies and may receive credits for it.

## Advanced Mobile Communication Networks

Fachabschluss: Prüfungsleistung alternativ Art der Notengebung: Gestufte Noten  
 Sprache: Englisch Pflichtkennz.: Pflichtfach Turnus: Sommersemester

Fachnummer: 100500 Prüfungsnummer: 2200348

Fachverantwortlich: Prof. Dr. Andreas Mitschele-Thiel

Leistungspunkte: 5 Workload (h): 150 Anteil Selbststudium (h): 105 SWS: 4.0  
 Fakultät für Informatik und Automatisierung Fachgebiet: 2235

| SWS nach<br>Fach-<br>semester | 1.FS |   |   | 2.FS |   |   | 3.FS |   |   | 4.FS |   |   | 5.FS |   |   | 6.FS |   |   | 7.FS |   |   | 8.FS |   |   | 9.FS |   |   | 10.FS |   |   |   |   |   |
|-------------------------------|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|-------|---|---|---|---|---|
|                               | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V     | S | P | V | S | P |
|                               |      |   |   | 2    | 2 | 0 |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |       |   |   |   |   |   |

### Lernergebnisse / Kompetenzen

The course introduces students in advanced topics in mobile data communication. It enables students to understand the research issues from a protocol- and system point of view, resulting from the mobility and the wireless transmission.

### Vorkenntnisse

Bachelor degree, basics of communication networks

### Inhalt

- Introduction
- Medium Access Schemes
- Mobility Management
- TCP/IP
- Self-Organization
- IEEE 802.11
- Quality of Service
- Ad Hoc Networks
- Cognitive Radio Networks
- Overview on cellular systems

### Medienformen

Presentations

### Literatur

see webpage [www.tu-ilmenau.de/ics](http://www.tu-ilmenau.de/ics)

### Detailangaben zum Abschluss

- The course consists of two parts: In the first part of the semester, lectures on the material are given. In the second part, individual studies (semester-long research projects that include a term paper and a presentation) help to improve understanding of the material.
- Grading scheme: 40% term paper plus presentation, 60% oral exam (20 min, registration at ICS office in Z1031).
- Binding registration for the exam (using Thoska or the registration form provided by the examination office IA) is required at the beginning of each semester (check the registration time window which is defined each semester) in order to participate in individual studies projects and the oral exam. As your course grade is a result of the individual studies and the oral exam, only formally registered students are eligible for participation in the individual studies and may receive credits for it.

verwendet in folgenden Studiengängen:

Master Communications and Signal Processing 2013  
 Master Informatik 2013  
 Master Ingenieurinformatik 2009  
 Master Ingenieurinformatik 2014



## Modul: Multimedia

Modulnummer: 100455

Modulverantwortlich: Prof. Dr. Karlheinz Brandenburg

Modulabschluss: Fachprüfung/Modulprüfung generiert

### Lernergebnisse

MMStandards:

Educational Objectives:

To understand the process of standardisation and how to read major standards for media formats.

In the end the students should be prepared both for participation in a standards committee and to implement a media format standard from the description in the standards document.

Selection of Topics:

Introduction to standardisation of multimedia content, i.e. mainly standardisation of speech, high quality audio, picture and video information including standards for metadata and systems aspect.

The lecture starts with examples from standardisation and continues with the process of standardisation of media formats mainly in ITU and ISO/IEC organisations.

The lecture series does contain information about all the major standards series in media and at least one more detailed example (including introduction to the technology and bit stream details) for each major area of media standards, i.e. speech, audio, pictures, video, systems, metadata.

Audio Coding

Educational Objectives:

After attending the lecture and solving the homework assignments, the students should be able to have enough basic understanding of high quality audio coding to implement encoders and decoders or participate in ongoing research in the area.

Selection of Topics:

In depth introduction into coding of high quality audio signals. The lecture series comprises of three major parts:

- First, an introduction into the main algorithms used in high quality audio coding (filterbank, psychoacoustic model, quantization and coding)

- Second, an introduction into some of the most used formats for high quality audio coding with an emphasis on the MPEG Audio standards (MPEG-1 including MP3, MPEG-2 including AAC, MPEG-4 including HeAAC)

- Third, current research topics and specialized audio coding formats like lossless coding, very low delay coding, parametric coding etc.

### Vorraussetzungen für die Teilnahme

presuppositionless for MMStandards

Audio Coding

prerequisite:

Audio Systems Technology

and basic knowledge of MatLab

### Detailangaben zum Abschluss

## Multimedia Standards

Fachabschluss: Prüfungsleistung schriftlich 90 min

Art der Notengebung: Gestufte Noten

Sprache: Englisch

Pflichtkennz.: Pflichtfach

Turnus: Sommersemester

Fachnummer: 5838

Prüfungsnummer: 2100211

Fachverantwortlich: Prof. Dr. Karlheinz Brandenburg

|   |                  |                              |                  |      |      |      |      |      |      |       |   |   |   |   |   |   |   |   |   |   |   |  |
|---|------------------|------------------------------|------------------|------|------|------|------|------|------|-------|---|---|---|---|---|---|---|---|---|---|---|--|
| Leistungspunkte: 3                                  | Workload (h): 90 | Anteil Selbststudium (h): 68 | SWS: 2.0         |      |      |      |      |      |      |       |   |   |   |   |   |   |   |   |   |   |   |  |
| Fakultät für Elektrotechnik und Informationstechnik |                  |                              | Fachgebiet: 2181 |      |      |      |      |      |      |       |   |   |   |   |   |   |   |   |   |   |   |  |
| SWS nach  | 1.FS             | 2.FS                         | 3.FS             | 4.FS | 5.FS | 6.FS | 7.FS | 8.FS | 9.FS | 10.FS |   |   |   |   |   |   |   |   |   |   |   |  |
| Fach-   | V                | S                            | P                | V    | S    | P    | V    | S    | P    | V     | S | P | V | S | P | V | S | P | V | S | P |  |
| semester  |                  |                              |                  |      |      |      |      |      |      |       |   |   |   |   |   |   |   |   |   |   |   |  |
|   |                  | 2                            | 0                | 0    |      |      |      |      |      |       |   |   |   |   |   |   |   |   |   |   |   |  |

### Lernergebnisse / Kompetenzen

#### Educational Objectives:

To understand the process of standardisation and how to read major standards for media formats.

In the end the students should be prepared both for participation in a standards committee and to implement a media format standard from the description in the standards document.

### Vorkenntnisse

Basic understanding of digital signal processing

### Inhalt

#### Selection of Topics:

Introduction to standardisation of multimedia content, i.e. mainly standardisation of speech, high quality audio, picture and video information including standards for metadata and systems aspect.

The lecture starts with examples from standardisation and continues with the process of standardisation of media formats mainly in ITU and ISO/IEC organisations.

The lecture series does contain information about all the major standards series in media and at least one more detailed example (including introduction to the technology and bit stream details) for each major area of media standards, i.e. speech, audio, pictures, video, systems, metadata.

### Medienformen

Power Point slides, Beamer

### Literatur

for details see:

<http://www.tu-ilmenau.de/mt/lehrveranstaltungen/master-mt/multimedia-standards/>

### Detailangaben zum Abschluss

### verwendet in folgenden Studiengängen:

Master Communications and Signal Processing 2008

Master Communications and Signal Processing 2013

## Audio Coding

Fachabschluss: Prüfungsleistung alternativ 90 min Art der Notengebung: Gestufte Noten

Sprache: Englisch

Pflichtkennz.: Pflichtfach

Turnus: Wintersemester

Fachnummer: 5655

Prüfungsnummer: 2100240

Fachverantwortlich: Prof. Dr. Gerald Schuller

|   |                   |                              |                  |      |      |      |      |      |      |       |   |   |   |   |   |   |   |   |   |   |   |  |
|---|-------------------|------------------------------|------------------|------|------|------|------|------|------|-------|---|---|---|---|---|---|---|---|---|---|---|--|
| Leistungspunkte: 4                                  | Workload (h): 120 | Anteil Selbststudium (h): 86 | SWS: 3.0         |      |      |      |      |      |      |       |   |   |   |   |   |   |   |   |   |   |   |  |
| Fakultät für Elektrotechnik und Informationstechnik |                   |                              | Fachgebiet: 2184 |      |      |      |      |      |      |       |   |   |   |   |   |   |   |   |   |   |   |  |
| SWS nach  | 1.FS              | 2.FS                         | 3.FS             | 4.FS | 5.FS | 6.FS | 7.FS | 8.FS | 9.FS | 10.FS |   |   |   |   |   |   |   |   |   |   |   |  |
| Fach-   | V                 | S                            | P                | V    | S    | P    | V    | S    | P    | V     | S | P | V | S | P | V | S | P | V | S | P |  |
| semester  |                   |                              |                  |      |      |      |      |      |      |       |   |   |   |   |   |   |   |   |   |   |   |  |
|   |                   |                              | 2                | 1    | 0    |      |      |      |      |       |   |   |   |   |   |   |   |   |   |   |   |  |

### Lernergebnisse / Kompetenzen

In der Vorlesung und Übung soll in das Thema Audiocodierung mit genügender Tiefe eingeführt werden, daß die Hörer aktuelle Verfahren nicht nur verstehen und implementieren können, sondern über die Grundkenntnisse verfügen, um an der Entwicklung neuer Verfahren mitarbeiten zu können.

### Vorkenntnisse

Digitale Signalverarbeitung

### Inhalt

Vertiefende Einführung in die Codierung von Audiosignalen hoher Qualität. Grobgliederung: - Grundlegende Bausteine eines Audiocodierverfahrens - Standards - aktuelle Forschungsthemen in der Audiocodierung Details: 1. Overview 2. Psychoacoustics 3. Quantization and Coding 4. Filterbanks 1 5. Filterbanks 2; 6. MPEG-1/2 BC Audio 7. PAC 8. MPEG-2/4 AAC 9. Audio Quality Assessment 10. Parametric Coding 11. Stereo Coding 12. Prediction and Lossless Coding 13. IntMDCT 14. Ultra Low Delay Coder

### Medienformen

Skript, Overheadprojektor, Beamer Übungen mit Matlab

### Literatur

Marina Bosi, Richard E. Goldberg: "Introduction to Digital Audio Coding and Standards", Kluwer Academic Publishers; Auflage: 1 (Dez. 2002), ISBN: 1402073577

### Detailangaben zum Abschluss

- alternative studienbegleitende Prüfungsleistung (Prüfungsanmeldung zu Beginn des Semesters), zusammengesetzt aus 35 Punkten schriftlicher Test in Mitte des Semesters und 35 Punkten final schriftlicher Test und 30 Punkten Hausaufgaben/Hausarbeit, Test muss bestanden werden
- alternative course-related examination (examination registration at the beginning of the semester), consisting of 35 points writtten midterm (in the end of November) test and 35 points final written test and 30 points homework, test must be passed

### verwendet in folgenden Studiengängen:

Master Communications and Signal Processing 2013  
 Master Elektrotechnik und Informationstechnik 2014 Vertiefung IKT  
 Master Medientechnologie 2009  
 Master Medientechnologie 2013  
 Master Medientechnologie 2017

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## Modul: Mobile Communications

Modulnummer: 100506

Modulverantwortlich: Prof. Dr. Martin Haardt

Modulabschluss: Fachprüfung/Modulprüfung generiert

### Lernergebnisse

Vermittlung von vertiefenden Kenntnissen auf dem Gebiet der Mobilkommunikation. Sicherer Umgang mit Matlab/Octave zur Lösung komplexer Aufgaben.

### Voraussetzungen für die Teilnahme

Bachelorabschluss

### Detailangaben zum Abschluss

## Mobile Communications

Fachabschluss: Prüfungsleistung schriftlich 120 min

Art der Notengebung: Gestufte Noten

Sprache: Englisch

Pflichtkennz.: Pflichtfach

Turnus: Sommersemester

Fachnummer: 5840

Prüfungsnummer: 2100212

Fachverantwortlich: Prof. Dr. Martin Haardt

|   |                   |                               |                  |       |       |       |       |       |       |       |
|---|-------------------|-------------------------------|------------------|-------|-------|-------|-------|-------|-------|-------|
| Leistungspunkte: 8                                  | Workload (h): 240 | Anteil Selbststudium (h): 184 | SWS: 5.0         |       |       |       |       |       |       |       |
| Fakultät für Elektrotechnik und Informationstechnik |                   |                               | Fachgebiet: 2111 |       |       |       |       |       |       |       |
| SWS nach  | 1.FS              | 2.FS                          | 3.FS             | 4.FS  | 5.FS  | 6.FS  | 7.FS  | 8.FS  | 9.FS  | 10.FS |
| Fach-   | V S P             | V S P                         | V S P            | V S P | V S P | V S P | V S P | V S P | V S P | V S P |
| semester  |                   | 3 2 0                         |                  |       |       |       |       |       |       |       |

### Lernergebnisse / Kompetenzen

Vermittlung von vertiefenden Kenntnissen auf dem Gebiet der Mobilkommunikation. Sicherer Umgang mit Matlab zur Lösung komplexer Aufgaben.

The students get a deep insight into the physical layer aspects of mobile communication systems. The students know how to use modern engineering tools, such as, Matlab to solve challenging tasks.

### Vorkenntnisse

Bachelorabschluß Basics in stochastics and calculus

### Inhalt

- 1 Introduction
  - + Overview of mobile communication standards and applications (1G - 5G)
  - + 5G Vision and Requirements
  - + The Wireless Channel
    - Path loss
    - Shadowing
    - Fast fading
- 2 Mobile Communication Channels
  - + Review: Representation of Bandpass Signals and Systems
  - 2.1 Propagation Modelling
    - + Time variance (Doppler)
    - + Time-varying multipath channels
      - Transmission functions of the time-varying channel (1st set of Bello functions)
      - 4 ways to calculate the received signals
      - Identification of linear time-varying (LTV) systems
    - 2.2 Statistical Characterization of Multipath Channels
      - + Rayleigh channel (fading)
      - + Rician channel
      - + Channel Correlation Functions and Power Spectra of Fading Multipath Channels
        - Time-variations of the channel
      - Characterization of a WSSUS channel (2nd set of Bello functions)
    - 2.3 The effect of signal characteristics on the choice of a channel model
      - + Frequency non-selective channels
      - + Frequency selective channels
        - Truncated tapped delay line model of a frequency selective channel
    - 2.4 Space-Time Channel and Signal Models
      - + Generalization of the time-varying channel impulse response
        - First set of Bello functions extended to the spatial domain
        - Example: specular L paths model (continued)
      - + Homogeneous channels (WSSUS-HO model)
      - + Correlation functions and power spectra extended to the spatial domain
        - Second set of Bello functions extended to the spatial domain
        - Coherence time, coherence frequency, coherence distance
      - + Transmission functions extended to transmit and receive antenna arrays (MIMO)
        - Definition of the array manifold
      - + Notation for SISO, SIMO, MISO, and MIMO channels



- Example: L paths model (continued)
- + Classical IID Channel Model
- + Extended MIMO Channel Models
- Spatial fading correlation at the transmit and the receive arrays
- > Review of the eigenvalue decomposition (EVD)
- > General model
- > Kronecker model
- Additional Line-of-Sight (LOS) component
- + Sampled signal model for SISO, SIMO, MISO, and MIMO channels
- 3 Capacity of Space-Time Channels
- 3.1 Differential Entropy and Mutual Information for Continuous Ensembles (review)
- 3.2 Capacity Theorem for the AWGN SISO Case (review)
- 3.3 Capacity of the Flat Fading MIMO channel
- + Differential entropy for CSCG random vectors
- + Choosing  $R_{ss}$  (with and without CSI @ the transmitter)
- Singular Value Decomposition (SVD)
- Special case: uncorrelated Rayleigh fading and  $M_t$  very large
- + Parallel Spatial Sub-Channels
- Design of the precoder and the decoder for MIMO systems with CSI at the transmitter
- Optimum power allocation (waterpouring algorithm) with CSI at the transmitter
- + SIMO Channel Capacity
- + MISO Channel Capacity
- + Capacity of Random MIMO Channels
- Ergodic vs. non-ergodic channels
- Ergodic capacity
- > Examples, e.g., Rice, correlation
- Outage capacity
- 3.4 Capacity of the Frequency Selective MIMO channel
- + Space-Frequency Waterpouring
- 4 Transmission Techniques
- 4.1 Bit error probability
- + Binary signaling over Rayleigh fading channel
- 4.2 Diversity techniques for fading multipath channels
- + Frequency diversity
- + Time diversity
- + Space diversity
- + Post-processing techniques
- Selection combining, equal gain combining, maximum ratio combining, square-law combining
- 4.3 Approximation of the Probability of Symbol Error
- + Fading channel with D-fold diversity
- + Chernoff bound
- + Coding gain vs. diversity gain
- 5 Space-Time Processing
- 5.1 Receive antenna diversity (SIMO channel): MRC
- 5.2 Transmit antenna diversity
- + MISO channel unknown to the transmitter: Alamouti scheme (1998)
- + MISO channel known to the transmitter: MRT
- + MIMO channel unknown to the transmitter: Alamouti scheme (1998)
- + MIMO channel known to the transmitter: DET
- + Definition of the effective diversity order
- + Summary: Diversity of space-time-frequency selective channels
- 5.3 Space-Time Coding without channel state information (CSI) at the transmitter
- + Space-Time Coding for frequency flat channels
- + Space-Time codeword design criteria
- definition of the pairwise error probability (PEP)
- rank criterion
- determinant criterion
- + Orthogonal Space-Time Block Codes (OSTBCs)
- OSTBCs for real-valued constellations
- OSTBCs for complex-valued constellations
- + Spatial Multiplexing (SM) as a Space-Time Code
- + Encoder Structures for Spatial Multiplexing (SM)
- horizontal encoding
- vertical encoding
- diagonal encoding (D-BLAST transmission)
- 5.4 Gains achievable with smart antennas

- + Array Gain
- + Diversity Gain
- + Spatial Multiplexing Gain
- + Interference Reduction Gain
- frequency reuse and cluster sizes
- 5.5 Multi-User MIMO Systems
- + Block Diagonalization
- 5.6 Multiple access schemes
- + OFDM
- + Single carrier vs. OFDM vs. spread spectrum

## Medienformen

Skript, Overheadprojektor, Beamer Script, projector

## Literatur

- A. Goldsmith, *Wireless Communications*. Cambridge University Press, 2005.
- C. E. Shannon, A mathematical theory of communication. Bell System Technical Journal, vol. 27, pp. 379-423 and 623-656, July and October, 1948.
- G. Strang, *Introduction to Linear Algebra*. Wellesley - Cambridge Press, Fifth Edition, 2016.
- G. Strang, *Linear Algebra and Its Applications*. Thomson Brooks/Cole Cengage learning, 2006.
- A. Paulraj, R. Nabar, and D. Gore, *Introduction to Space-Time Wireless Communications*. Cambridge University Press, 2003.
- A. Hottinen, O. Tirkkonen, and R. Wichman, *Multi-antennas Transceiver Techniques for 3G and Beyond*. Wiley, 2003.
- S. Haykin, *Communication Systems*. John Wiley & Sons, 4th edition, 2001.
- S. Haykin and M. Moher, *Modern Wireless Communications*. Pearson Education, Inc., 2005.
- F. Jondral and A. Wiesler, *Grundlagen der Wahrscheinlichkeitsrechnung und stochastischer Prozesse für Ingenieure*. Teubner Verlag, Stuttgart/Leipzig, 2000.
- A. Papoulis, *Probability, Random Variables, and Stochastic Processes*. McGraw-Hill, 2nd edition, 1984.
- T. S. Rappaport, *Wireless Communications*. Prentice Hall, 1996.
- J. Proakis, *Digital Communications*. McGraw-Hill, 4th edition, 2001.
- G. L. Stüber, *Mobile Communication*. Kluwer Academic Publishers, 2nd edition, 2001.
- R. Steele and L. Hanzo, eds., *Mobile Radio Communications*. Wiley, 2nd edition, 1999.
- S. Saunders, *Antennas and Propagation for Wireless Communication Systems*. Wiley, 1999.
- A. Graham, *Kronecker Products and Matrix Calculus with Applications*. Halsted Press, 1981.
- E. G. Larson, P. Stoica, and G. Ganesan, *Space-Time Block Coding for Wireless Communications*. Cambridge University Press, 2003.
- H. Bölcskei, D. Gesbert, C. B. Papadias, and A.-J. van der Veen, eds., *Space-Time Wireless Systems From Array Processing to MIMO Communications*. Cambridge University Press, 2006.
- E. Biglieri, R. Calderbank, A. Constantinides, A. Goldsmith, A. Paulraj, and H. V. Poor, *MIMO Wireless Communications*. Cambridge University Press, 2007.
- C. Oestges and B. Clerckx, *MIMO wireless communications*. Academic Press, 1 ed., 2007.
- Q. H. Spencer, A. L. Swindlehurst, and M. Haardt, "Zero-forcing methods for downlink spatial multiplexing in multi-user MIMO channels," *IEEE Transactions on Signal Processing*, vol. 52, pp. 461-471, Feb. 2004, received the 2009 Best Paper Award of the IEEE Signal Processing Society.
- Q. H. Spencer, C. B. Peel, A. L. Swindlehurst, and M. Haardt, "An introduction to the multi-user MIMO downlink," *IEEE Communications Magazine*, pp. 60-67, Oct. 2004, special issue on MIMO Systems.

## Detailangaben zum Abschluss

verwendet in folgenden Studiengängen:

Master Communications and Signal Processing 2008

Master Communications and Signal Processing 2013

Master Elektrotechnik und Informationstechnik 2014 Vertiefung IKT

Master Medientechnologie 2017

## Modul: Research Project

Modulnummer: 100505

Modulverantwortlich: Prof. Dr. Martin Haardt

Modulabschluss: Fachprüfung/Modulprüfung generiert

### Lernergebnisse

Im Rahmen der Forschungsprojekte arbeiten die Studenten an Forschungsthemen mit den betreuenden Professoren und deren Mitarbeitern eng zusammen. Besonderer Wert liegt auf der sorgfältigen Planung und Umsetzung in Teamarbeit. Eigenständige Literaturrecherche auf der Basis aktueller Veröffentlichungen und Vorträge zu den einzelnen Teilaspekten und Meilensteinen des Projektes sorgen für eine Verfeinerung der Präsentationstechniken der Teilnehmer. Eine Evaluierung und Dokumentation der Ergebnisse in der Art einer wissenschaftlichen Veröffentlichung schließen das Projekt ab.

Within the research projects the students work closely together with the guiding professors or assistants. The accurate planning and implementation of the team work aspect is of particular interest. Autonomous literature review based on current publications for the subtasks and a detailed milestone plan for the project improve the student skills to function in projects successfully. The students learn to present their research results to the auditorium. An evaluation and a documentation of the results like a scientific publication complete the project.

### Voraussetzungen für die Teilnahme

Bachelorabschluss

### Detailangaben zum Abschluss

## Research Project

Fachabschluss: Prüfungsleistung alternativ

Art der Notengebung: Gestufte Noten

Sprache: Englisch

Pflichtkenn.: Pflichtfach

Turnus: ganzjährig

Fachnummer: 5842

Prüfungsnummer: 2100214

Fachverantwortlich: Prof. Dr. Martin Haardt

|   |                   |                               |                  |      |      |      |      |      |      |       |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|---|-------------------|-------------------------------|------------------|------|------|------|------|------|------|-------|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Leistungspunkte: 5                                  | Workload (h): 150 | Anteil Selbststudium (h): 116 | SWS: 3.0         |      |      |      |      |      |      |       |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Fakultät für Elektrotechnik und Informationstechnik |                   |                               | Fachgebiet: 2111 |      |      |      |      |      |      |       |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| SWS nach  | 1.FS              | 2.FS                          | 3.FS             | 4.FS | 5.FS | 6.FS | 7.FS | 8.FS | 9.FS | 10.FS |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Fach-   | V                 | S                             | P                | V    | S    | P    | V    | S    | P    | V     | S | P | V | S | P | V | S | P | V | S | P | V | S | P | V | S | P |
| semester  |                   |                               |                  | 0    | 3    | 0    |      |      |      |       |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

### Lernergebnisse / Kompetenzen

Im Rahmen der Forschungsprojekte arbeiten die Studenten an Forschungsthemen mit den betreuenden Professoren und deren Mitarbeitern eng zusammen. Besonderer Wert liegt auf der sorgfältigen Planung und Umsetzung in Teamarbeit. Eigenständige Literaturrecherche auf der Basis aktueller Veröffentlichungen und Vorträge zu den einzelnen Teilaspekten und Meilensteinen des Projektes sorgen für eine Verfeinerung der Präsentationstechniken der Teilnehmer. Eine Evaluierung und Dokumentation der Ergebnisse in der Art einer wissenschaftlichen Veröffentlichung schließen das Projekt ab.

Within the research projects the students work closely together with the guiding professors or assistants. The accurate planning and implementation of the team work aspect is of particular interest. Autonomous literature review based on current publications for the subtasks and a detailed milestone plan for the project improve the student skills to function in projects successfully. The students learn to present their research results to the auditorium. An evaluation and a documentation of the results like a scientific publication complete the project.

### Vorkenntnisse

Bachelorabschluss

### Inhalt

Abhängig von der Aufgabenstellung Depending on project topic

### Medienformen

Präsentation, Bericht Presentation, report

### Literatur

Abhängig von der Aufgabenstellung Depending on project topic

### Detailangaben zum Abschluss

- alternative studienbegleitende Prüfungsleistung (Prüfungsanmeldung zu Beginn des Semesters), zusammengesetzt aus 50 Prozent Projektarbeit und 50 Prozent mündliche Präsentation (15 min.); werden insgesamt weniger als 50 Prozent erreicht, müssen alle Teilleistungen wiederholt werden
  - alternative course-related examination (examination registration at the beginning of the semester), consisting of 50 per cent project work and 50 per cent oral presentation (15 minutes); with less than 50 per cent reached, all parts of the examination must be taken again

### verwendet in folgenden Studiengängen:

Master Communications and Signal Processing 2008

Master Communications and Signal Processing 2013

## Modul: Advanced Research Project

Modulnummer: 100504

Modulverantwortlich: Prof. Dr. Martin Haardt

Modulabschluss: Fachprüfung/Modulprüfung generiert

### Lernergebnisse

Im Rahmen der Forschungsprojekte arbeiten die Studenten an Forschungsthemen mit den betreuenden Professoren und deren Mitarbeitern eng zusammen. Besonderer Wert liegt auf der sorgfältigen Planung und Umsetzung in Teamarbeit. Eigenständige Literaturrecherche auf der Basis aktueller Veröffentlichungen und Vorträge zu den einzelnen Teilaspekten und Meilensteinen des Projektes sorgen für eine Verfeinerung der Präsentationstechniken der Teilnehmer. Eine Evaluierung und Dokumentation der Ergebnisse in der Art einer wissenschaftlichen Veröffentlichung schließen das Projekt ab.

Within the research projects the students work closely together with the guiding professors or assistants. The accurate planning and implementation of the team work aspect is of particular interest. Autonomous literature review based on current publications for the subtasks and a detailed milestone plan for the project improve the student skills to function in projects successfully. The students learn to present their research results to the auditorium. An evaluation and a documentation of the results like a scientific publication complete the project.

### Voraussetzungen für die Teilnahme

Bachelorabschluss

### Detailangaben zum Abschluss

## Advanced Research Project

Fachabschluss: Prüfungsleistung alternativ Art der Notengebung: Gestufte Noten  
 Sprache: Englisch Pflichtkennz.: Pflichtfach Turnus: ganzjährig

Fachnummer: 5849 Prüfungsnummer: 2100217

Fachverantwortlich: Prof. Dr. Martin Haardt

Leistungspunkte: 6 Workload (h): 180 Anteil Selbststudium (h): 135 SWS: 4.0  
 Fakultät für Elektrotechnik und Informationstechnik Fachgebiet: 2111

| SWS nach<br>Fach-<br>semester | 1.FS |   |   | 2.FS |   |   | 3.FS |   |   | 4.FS |   |   | 5.FS |   |   | 6.FS |   |   | 7.FS |   |   | 8.FS |   |   | 9.FS |   |   | 10.FS |   |   |
|-------------------------------|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|-------|---|---|
|                               | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V     | S | P |
|                               |      |   |   |      |   |   | 0    | 4 | 0 |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |       |   |   |

### Lernergebnisse / Kompetenzen

Im Rahmen der Forschungsprojekte arbeiten die Studenten an Forschungsthemen mit den betreuenden Professoren und deren Mitarbeitern eng zusammen. Besonderer Wert liegt auf der sorgfältigen Planung und Umsetzung in Teamarbeit. Eigenständige Literaturrecherche auf der Basis aktueller Veröffentlichungen und Vorträge zu den einzelnen Teilaspekten und Meilensteinen des Projektes sorgen für eine Verfeinerung der Präsentationstechniken der Teilnehmer. Eine Evaluierung und Dokumentation der Ergebnisse in der Art einer wissenschaftlichen Veröffentlichung schließen das Projekt ab.

Within the research projects the students work closely together with the guiding professors or assistants. The accurate planning and implementation of the team work aspect is of particular interest. Autonomous literature review based on current publications for the subtasks and a detailed milestone plan for the project improve the student skills to function in projects successfully. The students learn to present their research results to the auditorium. An evaluation and a documentation of the results like a scientific publication complete the project.

### Vorkenntnisse

Bachelor

### Inhalt

Abhängig von der Aufgabenstellung.  
 Depending on project topic.

### Medienformen

Präsentation, Bericht.  
 Presentation, report.

### Literatur

Abhängig von der Aufgabenstellung.  
 Depending on project topic.

### Detailangaben zum Abschluss

- alternative studienbegleitende Prüfungsleistung (Prüfungsanmeldung zu Beginn des Semesters), zusammengesetzt aus 50 Prozent Projektarbeit und 50 Prozent mündliche Präsentation (15 min.); werden insgesamt weniger als 50 Prozent erreicht, müssen alle Teilleistungen wiederholt werden
- alternative course-related examination (examination registration at the beginning of the semester), consisting of 50 per cent project work and 50 per cent oral presentation (15 minutes); with less than 50 per cent reached, all parts of the examination must be taken again

### verwendet in folgenden Studiengängen:

Master Communications and Signal Processing 2008  
 Master Communications and Signal Processing 2013

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## Modul: Cellular Communication Systems

Modulnummer: 5844

Modulverantwortlich: Prof. Dr. Andreas Mitschele-Thiel

Modulabschluss: Fachprüfung/Modulprüfung generiert

Lernergebnisse

see course description

Voraussetzungen für die Teilnahme

Detailangaben zum Abschluss



## Cellular Communication Systems

Fachabschluss: Prüfungsleistung alternativ

Art der Notengebung: Gestufte Noten

Sprache: Englisch

Pflichtkenn.: Pflichtfach

Turnus: Wintersemester

Fachnummer: 100501

Prüfungsnummer: 2200349

Fachverantwortlich: Prof. Dr. Andreas Mitschele-Thiel

|   |                   |                               |                  |       |       |       |       |       |       |       |
|---|-------------------|-------------------------------|------------------|-------|-------|-------|-------|-------|-------|-------|
| Leistungspunkte: 5                          | Workload (h): 150 | Anteil Selbststudium (h): 105 | SWS: 4.0         |       |       |       |       |       |       |       |
| Fakultät für Informatik und Automatisierung |                   |                               | Fachgebiet: 2235 |       |       |       |       |       |       |       |
| SWS nach                                    | 1.FS              | 2.FS                          | 3.FS             | 4.FS  | 5.FS  | 6.FS  | 7.FS  | 8.FS  | 9.FS  | 10.FS |
| Fach-                                       | V S P             | V S P                         | V S P            | V S P | V S P | V S P | V S P | V S P | V S P | V S P |
| semester                                    |                   |                               | 2 2 0            |       |       |       |       |       |       |       |

### Lernergebnisse / Kompetenzen

The course introduces students into the functionalities of cellular communication systems, esp. GSM/GPRS/EDGE, UMTS/HSPA, LTE/SAE. It enables students to understand network and protocol aspects of these system as well as aspects related to their deployment and management. Main topics are the network architecture, network elements, protocols, and services of these systems. The course allows students to understand main functions as mobility management, radio resource allocation, session management and QoS, as well as authentication, authorisation and network management.

### Vorkenntnisse

Communication protocols and networks, basics of mobile communication networks

### Inhalt

- Review of mobile communication basics
- Overview on GSM and GPRS
- UMTS architecture (mobility management, connection and session management, wideband CDMA, management of radio resources)
- UMTS radio access network
- High-Speed Packet Access (HSPA)
- Long-Term Evolution (LTE)
- System Architecture Evolution (SAE)
- Self-organization in LTE

### Medienformen

Presentations with beamer, presentation slides

### Literatur

- Kaaranen, Ahtiainen, Laitinen, Naghian, Niemi. UMTS Networks – Architecture, Mobility and Services. Wiley, 2001
- Holma, Toskala. WCDMA for UMTS. revised edition, Wiley, 2002
- Dahlmann, Parkvall, Sköld. 4G: LTE/LTE-Advanced for Mobile Broadband, AP, 2011
- Stefania Sesia, Issam Toufik, Matthew Baker. LTE - The UMTS Long Term Evolution: From Theory to Practice

### Detailangaben zum Abschluss

- The course consists of two parts: In the first part of the semester, lectures on the material are given. In the second part, individual studies (semester-long research projects that includes a presentation) help to improve understanding of the material.
- Grading scheme: 20% individuell studies, 80% oral exam (20 min, registration at ICS office in Z1031).
- Binding registration for the exam (using Thoska or the registration form provided by the examination office IA) is required at the beginning of each semester (check the registration time window which is defined each semester) in order to participate in individual studies projects and the oral exam. As your course grade is a result of the individual studies and the oral exam, only formally registered students are eligible for participation in the individual studies and may receive credits for it.

verwendet in folgenden Studiengängen:

Master Communications and Signal Processing 2013  
Master Informatik 2013  
Master Ingenieurinformatik 2009  
Master Ingenieurinformatik 2014  
Master Research in Computer & Systems Engineering 2012  
Master Research in Computer & Systems Engineering 2016

## **Modul: Advanced Topics in Communications and Signal Processing**

Modulnummer: 100454

Modulverantwortlich: Prof. Dr. Martin Haardt

Modulabschluss: Fachprüfung/Modulprüfung generiert

### **Lernergebnisse**

Vermittlung vertiefender Kenntnisse auf aktuellen Gebieten der Signalverarbeitung und Kommunikationstechnik, gemäß der im aktuellen Semester angebotenen Inhalte.

### **Vorraussetzungen für die Teilnahme**

Bachelorabschluss

### **Detailangaben zum Abschluss**

- \* written exam (Part I): 50 % of the final grade
  - \* Homework (Part I) with presentation of the results: 30 % of the final grade
  - \* Homework (Part II): 10 % of the final grade
  - \* Homework (Part III): 10 % of the final grade
- homework results are valid for 2 semesters  
In order to pass the course, the students have to pass the final written exam, 90 min

## Advanced Topics in Communications and Signal Processing

Fachabschluss: Prüfungsleistung alternativ Art der Notengebung: Gestufte Noten  
 Sprache: Englisch Pflichtkennz.: Pflichtfach Turnus: Wintersemester

Fachnummer: 100502 Prüfungsnummer: 2100461

Fachverantwortlich: Prof. Dr. Martin Haardt

|   |                  |                              |                  |       |       |       |       |       |       |       |
|---|------------------|------------------------------|------------------|-------|-------|-------|-------|-------|-------|-------|
| Leistungspunkte: 3                                  | Workload (h): 90 | Anteil Selbststudium (h): 68 | SWS: 2.0         |       |       |       |       |       |       |       |
| Fakultät für Elektrotechnik und Informationstechnik |                  |                              | Fachgebiet: 2111 |       |       |       |       |       |       |       |
| SWS nach  | 1.FS             | 2.FS                         | 3.FS             | 4.FS  | 5.FS  | 6.FS  | 7.FS  | 8.FS  | 9.FS  | 10.FS |
| Fach-   | V S P            | V S P                        | V S P            | V S P | V S P | V S P | V S P | V S P | V S P | V S P |
| semester  |                  |                              | 2 0 0            |       |       |       |       |       |       |       |

### Lernergebnisse / Kompetenzen

Vermittlung vertiefender Kenntnisse auf aktuellen Gebieten der Signalverarbeitung und Kommunikationstechnik, gemäß der im aktuellen Semester angebotenen Inhalte.

### Vorkenntnisse

Bachelorabschluss

### Inhalt

- \* PRELIMINARIES
- \* PART - I : Steady-State Optimization Problems and Applications
- \* PART - II : Convex Optimization
- \* PART - III : Compressed Sensing

### Medienformen

Unterschiedlich, je nach Dozent.

### Literatur

- Stephen Boyd and Lieven Vandenberghe, Convex Optimization, Cambridge, U.K.: Cambridge University Press, 2004.
- J.T. Betts: Practical methods for optimal control using nonlinear programming, SIAM 2001.
- A. E. Bryson, Y.-C. Ho: Applied optimal control : optimization, estimation, and control, Taylor & Francis, 1975.
- C. Chiang: Elements of dynamic optimization. McGraw-Hill, 1992.
- E. Eich-Soellner, C. Führer: Numerical methods in multibody dynamics. B.G Teubner, 1998.
- M. Gerds: Optimal control of ODEs and DAEs. De Gruyter, 2012.
- D.R. Kirk: Optimal Control theory: an introduction. Dover Publisher, 2004.
- J. Nocedal, S.J. Wright: Numerical methods of optimization. 2nd ed. Springer Verlag 2006.
- R.D. Rabinet III et al.: Applied dynamic programming for optimization of dynamical systems. SIAM 2005.
- S.S. Rao: Engineering optimization - theory and practice. Wiley, 1996.

### Detailangaben zum Abschluss

- \* written exam, 90 minutes (Part I): 70 % of the final grade
  - \* Homework (Part I) with presentation of the results: up to 10 % bonus points
  - \* Homework (Part II): 15 % of the final grade
  - \* Homework (Part III): 15 % of the final grade
- homework results are valid for 2 semesters  
 In order to pass the course, the students have to pass the final written exam, 90 min

verwendet in folgenden Studiengängen:

Master Communications and Signal Processing 2013

## Measurements in Communications

Fachabschluss: Prüfungsleistung mündlich 30 min Art der Notengebung: Gestufte Noten  
 Sprache: Englisch Pflichtkenn.: Pflichtfach Turnus: Wintersemester

Fachnummer: 5847 Prüfungsnummer: 2100216

Fachverantwortlich: Prof. Dr. Reiner Thomä

Leistungspunkte: 4 Workload (h): 120 Anteil Selbststudium (h): 86 SWS: 3.0  
 Fakultät für Elektrotechnik und Informationstechnik Fachgebiet: 2112

| SWS nach<br>Fach-<br>semester | 1.FS |   |   | 2.FS |   |   | 3.FS |   |   | 4.FS |   |   | 5.FS |   |   | 6.FS |   |   | 7.FS |   |   | 8.FS |   |   | 9.FS |   |   | 10.FS |   |   |   |   |   |
|-------------------------------|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|-------|---|---|---|---|---|
|                               | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V     | S | P | V | S | P |
|                               |      |   |   |      |   |   | 3    | 0 | 0 |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |       |   |   |   |   |   |

### Lernergebnisse / Kompetenzen

Vermittlung von vertiefenden Kenntnissen auf dem Gebiet Mobilfunkkanalmesstechnik, der zugehörigen Hardware sowie im Umgang bzw. der Anwendung von Messdaten zur Beurteilung der Leistungsfähigkeit von Funksystemen. The students get a deeper insight in radio frequency measurements in theory and applications with a main focus on mobile communications.

### Vorkenntnisse

Bachelor

### Inhalt

Lecturers: Prof. Reiner Thomä / Dr. Jürgen Sachs  
 - Netzwerkanalysator: Messungen von geleiteten elektromagnetischen Wellen, s-Parameter, Wellentrennung, Fehlerkorrektur - Signalgeneratoren: Synthesizer und Modulatoren, Arbitrary Waveform Generatoren - Breitband Empfangstechniken: Down Converter Architekturen, Korrelatoren, Sampling Empfänger - Anwendungen: Phasenrauschen, Rauschzahl, Antennenmessungen, Charakterisierung nichtlinearer Verzerrungen, Modulationsanalyse - Messung und Simulation der Wellenausbreitung im Mobilfunk: Breitband, gerichtete Kanalmodelle, schnelles und langsames Fading, MIMO Kanalmessungen, Antennenarray Architekturen, Kalibrierung, hochauflösende Parameterschätzung, Parameteranalyse, Link- und Systemlevel Simulationen zur Beurteilung der Leistungsfähigkeit, Echtzeitkanalsimulatoren  
 - RF network analyzer: Measurement of guided electromagnetic waves, Scattering parameters, Wave separation, Error correction - Signal generators: Synthesizers and modulators, Arbitrary waveform generators - Broadband Receiver Techniques: Down converter architectures, Correlators, Sampling receivers - Applications: Phase noise, Noise figure, Antenna measurement, Nonlinear distortion characterization, Modulation analysis - Measurement and simulation of wave propagation in mobile radio: Broadband, directional channel models, Fast and slow fading, MIMO channel sounding, Antenna array architecture, Calibration, Supersolution parameter estimation, Analysis of descriptive parameters, Link- and system level simulation for performance evaluation, Real-time channel simulators

### Medienformen

Skript, Overheadprojektor, Beamer Script, projector

### Literatur

- R. Pintelon, J. Schoukens. System Identifikation – A Frequency Domain Approach. IEEE Press, Piscata-way, NJ, 2001 - R.S. Thomä, M. Landmann, A. Richter, U. Trautwein. Multidimensional High-Resolution Channel Sounding. in T. Kaiser et. al. (Ed.), Smart Antennas in Europe – State-of-the-Art, EURASIP Book Series on SP&C, Vol. 3, Hindawi Publishing Corporation, 2005

### Detailangaben zum Abschluss

### verwendet in folgenden Studiengängen:

Master Communications and Signal Processing 2008  
 Master Communications and Signal Processing 2013

## Modul: Adaptive and Array Signal Processing

Modulnummer: 100503

Modulverantwortlich: Prof. Dr. Martin Haardt

Modulabschluss: Fachprüfung/Modulprüfung generiert

### Lernergebnisse

The fundamental concepts of adaptive filters and array signal processing are developed in class. The students understand the relationships between temporal and spatial filters, as well as the principle of high-resolution parameter estimation, and they are able to adapt their knowledge to other scientific disciplines. The students are able to develop or improve algorithms and to evaluate their performance in an analytical manner or by simulations. Furthermore, the students are enabled to read and understand current research publications in the areas of adaptive filters and array signal processing and they can use these concepts and results for their own research.

### Voraussetzungen für die Teilnahme

Bachelorabschluss

### Detailangaben zum Abschluss

## Adaptive and Array Signal Processing

Fachabschluss: Prüfungsleistung schriftlich 120 min Art der Notengebung: Gestufte Noten  
 Sprache: Englisch Pflichtkennz.: Pflichtfach Turnus: Wintersemester

Fachnummer: 5848 Prüfungsnummer: 2100218

Fachverantwortlich: Prof. Dr. Martin Haardt

|   |                   |                               |                  |       |       |       |       |       |       |       |
|---|-------------------|-------------------------------|------------------|-------|-------|-------|-------|-------|-------|-------|
| Leistungspunkte: 8                                  | Workload (h): 240 | Anteil Selbststudium (h): 184 | SWS: 5.0         |       |       |       |       |       |       |       |
| Fakultät für Elektrotechnik und Informationstechnik |                   |                               | Fachgebiet: 2111 |       |       |       |       |       |       |       |
| SWS nach  | 1.FS              | 2.FS                          | 3.FS             | 4.FS  | 5.FS  | 6.FS  | 7.FS  | 8.FS  | 9.FS  | 10.FS |
| Fach-   | V S P             | V S P                         | V S P            | V S P | V S P | V S P | V S P | V S P | V S P | V S P |
| semester  |                   |                               | 3 2 0            |       |       |       |       |       |       |       |

### Lernergebnisse / Kompetenzen

The fundamental concepts of adaptive filters and array signal processing are developed in class. The students understand the relationships between temporal and spatial filters, as well as the principle of high-resolution parameter estimation, and they are able to adapt their knowledge to other scientific disciplines. The students are able to develop or improve algorithms and to evaluate their performance in an analytical manner or by simulations. Furthermore, the students are enabled to read and understand current research publications in the areas of adaptive filters and array signal processing and they can use these concepts and results for their own research.

### Vorkenntnisse

Bachelor

### Inhalt

- 1 Introduction
  - Adaptive Filters
  - Single channel adaptive equalization (temporal filter)
  - Multi channel adaptive beamforming (spatial filter)
- 2 Mathematical Background
  - 2.1 Calculus
    - Gradients
    - Differentiation with respect to a complex vector
    - Quadratic optimization with linear constraints (method of Lagrangian multipliers)
  - 2.2 Stochastic processes
    - Stationary processes
    - Time averages
    - Ergodic processes
    - Correlation matrices
  - 2.3 Linear algebra
    - Eigenvalue decomposition
    - Eigenfilter
    - Linear system of equations
    - Four fundamental subspaces
    - Singular value decomposition
    - Generalized inverse of a matrix
    - Projections
    - Low rank modeling
- 3 Adaptive Filters
  - 3.1 Linear Optimum Filtering (Wiener Filters)
    - Principle of Orthogonality
    - Wiener-Hopf equations
    - Error-performance surface
    - MMSE (minimum mean-squared error)
    - Canonical form of the error-performance surface
    - MMSE filtering in case of linear Models
  - 3.2 Linearly Constrained Minimum Variance Filter

- LCMV beamformer
- Minimum Variance Distortionless Response (MVDR) spectrum: Capon's method
- LCMV beamforming with multiple linear constraints
- 3.3 Generalized Sidelobe Canceler
- 3.4 Iterative Solution of the Normal Equations
  - Steepest descent algorithm
  - Stability of the algorithm
  - Optimization of the step-size
- 3.5 Least Mean Square (LMS) Algorithm
- 3.6 Recursive Least Squares (RLS) Algorithm

#### 4 High-Resolution Parameter Estimation

- Data model (DOA estimation)
- Eigendecomposition of the spatial correlation matrix at the receive array
- Subspace estimates
- Estimation of the model order
- 4.1 Spectral MUSIC
  - DOA estimation
  - Example: uniform linear array (ULA)
  - Root-MUSIC for ULAs
  - Periodogram
  - MVDR spatial spectrum estimation (review)
- 4.2 Standard ESPRIT
  - Selection matrices
  - Shift invariance property
- 4.3 Signal Reconstruction
  - LS solution
  - MVDR / BLUE solution
  - Wiener solution (MMSE solution)
  - Antenna patterns
- 4.4 Spatial smoothing
- 4.5 Forward-backward averaging
- 4.6 Real-valued subspace estimation
- 4.7 1-D Unitary ESPRIT
  - Reliability test
  - Applications in Audio Coding
- 4.8 Multidimensional Extensions
  - 2-D MUSIC
  - 2-D Unitary ESPRIT
  - R-D Unitary ESPRIT
- 4.9 Multidimensional Real-Time Channel Sounding
- 4.10 Direction of Arrival Estimation with Hexagonal ESPAR Arrays

#### 5 Tensor-Based Signal Processing

- 5.1 Introduction and Motivation
- 5.2 Fundamental Concepts of Tensor Algebra
- 5.3 Elementary Tensor Decompositions
  - Higher Order SVD (HOSVD)
  - CANDECOMP / PARAFAC (CP) Decomposition
- 5.4 Tensors in Selected Signal Processing Applications

#### 6 Maximum Likelihood Estimators

- 6.1 Maximum Likelihood Principle
- 6.2 The Fisher Information Matrix and the Cramer Rao Lower Bound (CRLB)
  - Efficiency
  - CRLB for 1-D direction finding applications
  - Asymptotic CRLB

#### Medienformen

Skript, Overheadprojektor, Beamer Script, projector

#### Literatur

- T. Kaiser, A. Bourdoux, H. Boche, Smart Antennas State of The Art. Hindawi Publishing Corporation, 2005.
- A. H. Sayed, Fundamentals of Adaptive Filtering. John Wiley & Sons, Inc., New York, NY, 2003.
- T. K. Moon and W. C. Stirling, Mathematical Methods and Algorithms for Signal Processing.



Prentice-Hall, 2000.

- S. Haykin and M. Moher, Modern Wireless Communications.

Pearson Education, Inc., 2005.

- S. Haykin, Adaptive Filter Theory.

Prentice-Hall, 4th edition, 2002.

- A. Paulraj, R. Nabar, and D. Gore, Introduction to Space-Time Wireless Communications.

Cambridge University Press, 2003.

- H. L. V. Trees, Optimum Array Processing.

John Wiley & Sons, Inc., New York, NY, 2002.

- M. Haardt, Efficient One-, Two-, and Multidimensional High-Resolution Array Signal Processing.

Shaker Verlag GmbH, 1996, ISBN: 978-3-8265-2220-8.

- G. Strang, Linear Algebra and Its Applications.

Thomson Brooks/Cole Cengage learning.

- G. Strang, Introduction to Linear Algebra.

Wellesley - Cambridge Press, Fifth Edition.

- L. L. Scharf, Statistical Signal Processing.

Addison-Wesley Publishing Co., 1991.

- S. M. Kay, Fundamentals of Statistical Signal Processing, Estimation Theory.

Prentice-Hall, Englewood Cliffs, N.J., 1993.

• M. Haardt, M. Pesavento, F. Roemer, and M. N. El Korso, Subspace methods and exploitation of special array structures.

in Academic Press Library in Signal Processing: Volume 3 - Array and Statistical Signal Processing (A. M. Zoubir, M. Viberg, R. Chellappa, and S. Theodoridis, eds.), vol. 3, pp. 651 - 717, Elsevier Ltd., 2014, Chapter 15, ISBN 978-0-12-411597-2 ISBN: 978-3-8265-2220-8.

#### Detailangaben zum Abschluss

#### verwendet in folgenden Studiengängen:

Master Communications and Signal Processing 2008

Master Communications and Signal Processing 2013

Master Elektrotechnik und Informationstechnik 2014 Vertiefung IKT

Master Medientechnologie 2017

Master Wirtschaftsingenieurwesen 2013 Vertiefung ET

Master Wirtschaftsingenieurwesen 2014 Vertiefung ET

Master Wirtschaftsingenieurwesen 2015 Vertiefung ET

## **Modul: Non-technical Elective Courses(choose one or more non-technical courses - at least 5 LP)**

Modulnummer: 5839

Modulverantwortlich: Prof. Dr. Martin Haardt

Modulabschluss:

### Lernergebnisse

Innerhalb dieses Modul wählen die Studierenden ein oder mehrere nicht-technische Fächer (mindestens 4 LP). Die Studenten erlangen z.B.:

- weiterführende theoretische, empirische und methodische Kenntnisse der Kommunikationswissenschaft mit einer interdisziplinären Ausrichtung
- eine internationale Sichtweise auf die Probleme und Perspektiven der medienvermittelten Kommunikation
- analytische, strategische und evaluative Fähigkeiten zur Konzeption und Gestaltung medienvermittelter Kommunikationsprozesse.

Within this module the students choose one or more non-technical courses (at least 4 LP). The courses provide, e.g.:

- analytical, evaluative and strategic abilities for employing communication science to investigate complex technical, economic and political questions
- an international perception of the problems and perspectives of media-based communications
- an extended theoretical and methodological knowledge of communication and media science within an interdisciplinary framework

### Voraussetzungen für die Teilnahme

Bachelorabschluss

### Detailangaben zum Abschluss

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## Modul: Master-Arbeit mit Kolloquium

Modulnummer: 100677

Modulverantwortlich: Prof. Dr. Martin Haardt

Modulabschluss: Fachprüfung/Modulprüfung generiert

### Lernergebnisse

Die Studierenden werden befähigt, eine komplexe Aufgabenstellung zu beurteilen und unter Anwendung der bisher erworbenen Theorie- und Methodenkompetenzen selbstständig zu bearbeiten. Damit vertiefen sie in einem speziellen fachlichen Thema ihre bisher erworbenen Kompetenzen. Dieses Thema ist gemäß wissenschaftlicher Standards zu dokumentieren und die Studierenden werden befähigt, entsprechende wissenschaftlich fundierte Texte zu verfassen. Die Studierenden erwerben Problemlösungskompetenz und lernen es, die eigene Arbeit zu bewerten und einzuordnen.

### Voraussetzungen für die Teilnahme

Bachelorabschluss

### Detailangaben zum Abschluss

## Kolloquium zur Master-Arbeit

Fachabschluss: Prüfungsleistung mündlich 45 min Art der Notengebung: Gestufte Noten

Sprache: keine Angabe

Pflichtkennz.: Pflichtfach

Turnus: ganzjährig

Fachnummer: 8131

Prüfungsnummer: 99002

Fachverantwortlich: Prof. Dr. Martin Haardt

|   |                   |                               |                  |
|---|-------------------|-------------------------------|------------------|
| Leistungspunkte: 5                                  | Workload (h): 150 | Anteil Selbststudium (h): 150 | SWS: 0.0         |
| Fakultät für Elektrotechnik und Informationstechnik |                   |                               | Fachgebiet: 2111 |

| SWS nach<br>Fach-<br>semester | 1.FS |   |   | 2.FS |   |   | 3.FS |   |   | 4.FS |   |   | 5.FS |   |   | 6.FS |   |   | 7.FS |   |   | 8.FS |   |   | 9.FS |   |   | 10.FS |   |   |  |  |  |
|-------------------------------|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|-------|---|---|--|--|--|
|                               | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V     | S | P |  |  |  |
|                               |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |       |   |   |  |  |  |

### Lernergebnisse / Kompetenzen

Die Studierenden beherrschen die ergebnisorientierte Darstellung von Forschungsergebnissen in zeitlich komprimierter Form für ein Fachpublikum

### Vorkenntnisse

Bachelorabschluss

### Inhalt

Erstellung der Ergebnispräsentation Öffentliche Aussprache

### Medienformen

Powerpoint-Präsentation oder Gleichwertiges; falls möglich praktische Ergebnisdemonstration

### Literatur

gemäß Aufgabenstellung

### Detailangaben zum Abschluss

### verwendet in folgenden Studiengängen:

Master Communications and Signal Processing 2008

Master Communications and Signal Processing 2013

## Masterarbeit

Fachabschluss: Masterarbeit schriftlich 6 Monate Art der Notengebung: Generierte Noten  
 Sprache:keine Angabe Pflichtkennz.:Pflichtfach Turnus:ganzjährig

Fachnummer: 8451 Prüfungsnummer:99001

Fachverantwortlich: Prof. Dr. Martin Haardt

Leistungspunkte: 25 Workload (h):750 Anteil Selbststudium (h):750 SWS:0.0  
 Fakultät für Elektrotechnik und Informationstechnik Fachgebiet:2111

| SWS nach<br>Fach-<br>semester | 1.FS |   |   | 2.FS |   |   | 3.FS |   |   | 4.FS  |   |   | 5.FS |   |   | 6.FS |   |   | 7.FS |   |   | 8.FS |   |   | 9.FS |   |   | 10.FS |   |   |   |   |   |
|-------------------------------|------|---|---|------|---|---|------|---|---|-------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|------|---|---|-------|---|---|---|---|---|
|                               | V    | S | P | V    | S | P | V    | S | P | V     | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V    | S | P | V     | S | P | V | S | P |
|                               |      |   |   |      |   |   |      |   |   | 900 h |   |   |      |   |   |      |   |   |      |   |   |      |   |   |      |   |   |       |   |   |   |   |   |

### Lernergebnisse / Kompetenzen

Die Studierenden. werden befähigt, eine komplexe Aufgabenstellung zu beurteilen und unter Anwendung der bisher erworbenen Theorie- und Methodenkompetenzen selbstständig zu bearbeiten. Damit vertiefen sie in einem speziellen fachlichen Thema ihre bisher erworbenen Kompetenzen.  
 Dieses Thema ist gemäß wissenschaftlicher Standards zu dokumentieren und die Studierenden werden befähigt, entsprechende wissenschaftlich fundierte Texte zu verfassen. Die Studierenden erwerben Problemlösungskompetenz und lernen es, die eigene Arbeit zu bewerten und einzuordnen.

### Vorkenntnisse

Bachelorabschluss

### Inhalt

Selbstständige Bearbeitung eines fachspezifischen Themas unter Anleitung, Konzeption eines Arbeitsplanes, Einarbeitung in die Literatur, Erarbeitung der notwendigen wissenschaftlichen Methoden, Durchführung und Auswertung, Diskussion der Ergebnisse, Erstellung der Masterarbeit

### Medienformen

Schriftliche Arbeit einschließlich elektronisches Dokument

### Literatur

gemäß Aufgabenstellung

### Detailangaben zum Abschluss

### verwendet in folgenden Studiengängen:

Master Communications and Signal Processing 2008  
 Master Communications and Signal Processing 2013



## **Glossar und Abkürzungsverzeichnis:**

|                                      |   |
|--------------------------------------|---|
| LP                                   | Leistungspunkte   |
| SWS                                  | Semesterwochenstunden   |
| FS                                   | Fachsemester  |
| V S P                                | Angabe verteilt auf Vorlesungen, Seminare, Praktika                       |
| N.N.                                 | Nomen nominandum, Platzhalter für eine noch unbekannte Person (wikipedia) |
| Objektypen lt.<br>Inhaltsverzeichnis | K=Kompetenzfeld; M=Modul; P,L,U= Fach (Prüfung, Lehrveranstaltung, Unit)  |