Portrayal of the RF & Microwaves Research Laboratory at Ilmenau University of Technology

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Content of the presentation

- Organisation of the HMT group
- Infrastructure
- Ongoing research activities
- Useful information

More details available at:
www.tu-ilmenau.de/hmt
www.wip-thueringen.de/actor/profile/ttk/read/100/
Ilmenau University of Technology

Region of Ilmenau
40 km south of Erfurt
Ilmenau ≈ 27,000 population
(plus 6,000 students)

University

• Founded in 1894
• Microwave research since 1961
• Status “University” since 1992
• Specialised in Technologies
  • Electrical Engineering & Information Technol.
  • Mechanical Engineering
  • Computer Science & Automation
  • Maths & Natural Sciences
  • Economy
Electrical Engineering & Information Technology

Organisation
- Department: four institutes plus two inter-departmental institutes
- Institutes: host individual research laboratories

Institute for Information Technology
Research Laboratories
- Communications, Martin Haardt
- Communication networks, Jochen Seitz
- Digital broadcasting, Albert Heuberger
- Digital signal processing, nn
- Electromagnetic fields, Hannes Töpfer
- Electronic measurements, Reiner Thomä
- RF & Microwaves, Matthias Hein
The RF & Microwave Research Laboratory …

- … covers research and education in the propagation, interactions and technical applications of electromagnetic waves, circuits, signals, and systems at frequencies between 100 kHz and 100 GHz

Research areas

- Mobile and satellite communications, wireless sensors, material issues
- Antenna engineering
- Circuit design and technologies
- RF-MEMS
- RF & Microwave measurements
We aim to provide ...
- ... broad basic knowledge
- ... interdisciplinarity
- ... topical specialisation
- ... foundation (for scholars)
- ... motivation (for students)
- ... profession (for alumni)

We aim to raise ...
- ... public and private funding

We aim to address ...
- ... social, environmental, and safety issues
HMT group: strategic position

Institute for Information Technology
- From PHY-layer to applications
- Mobile communications, radar, sensing, metrology

Institute for Micro- and Nano-Technologies
- Provides technological infrastructure
- Links materials with RF functionality and system aspects
- Stimulates interdisciplinary cooperation

Electronic Technology, Nanotechnology, Micromechanical Systems
Research labs within the Institute for Information Technology

- Electromagnetic fields
- RF & Microwaves
- Electronic Measurements
- Digital Signal Processing
- Communications and networks
- Digital Broadcasting

Networks
- Sensors and sensing
- Mobile and satellite communications
- Localisation and navigation
- Digital broadcasting
- UWB radar, biomedical imaging
- Ubiquitous computing and DSP

Protocols
- Signals

Applications
- Channel
- Antennas
- Circuit and design technologies
Content of the presentation

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• Useful information
Centre of Micro- and Nano-Technologies

Aims
• Novel materials → micro- and nano-devices → circuits and systems.
• Focus on interdisciplinary co-operative research projects.
• Basic and applied research for industrial technologies of tomorrow.

Facility
• 680 m² clean rooms (Class 100 to 10000).
• 1100 m² laboratories and offices.

Technologies and materials
• Deposition, patterning, multilayer, analytics
• Epitaxy, micromachining
• Optical and electron beam lithography
• Si plus oxides and nitrides
• Metals plus oxides, carbides, nitrides
• Polymers, printed circuit boards, low-temperature co-fired ceramics
Institute for Information Technologies

Mobile communications laboratory
- Investigation of mobile radio channel
- Configurable baseband signals
- Modulated signal sources, detectors, multi-channel simulator, de/modulators
- Vector network & spectrum analysis
- RUSK vector channel sounder

Antenna measurement laboratory
- Main frequency range 1...15 GHz
- Extension 15...77 GHz
- Quiet zone $1.5\,\text{m} \times 1.5\,\text{m}$
- Measurement distance 4.5 m
- Two high-precision positioners
Millimeter wave antenna measurements

- Frequency range: 0.8 ... 77 GHz
- Dynamic range: 35 ... 80 dB
- Measurement range: 4.5 m
- Max. antenna weight: 10 kg
- Angular resolution: 0.3°
- Shielding: 80 ... 100 dB
- Reflectivity: 30 ... 50 dB
Microwave measurement techniques

- Coplanar microwave prober
  - Systems: Two ambient and one vacuum
- Coaxial network analysers
  - Four-port, nonlinear, pulsed (70 GHz)
- Waveguide measurements (75…110 GHz)
- Spectrum analysis (50 GHz)
- Time domain measurements
  - Time-domain reflectometry
  - 70 GHz sampling oscilloscope
  - 11 GHz real-time oscilloscope
- High-precision bias controllers
- Contact-less optical profilometer
RF & Microwave Simulation Tools

Circuits, electromagnetic fields, and electromechanical transduction

- 2-dim and 3-dim microwave design
  - ADS, Ensemble, IE3D
  - HFSS, CST Microwave Studio, EMPIRE
- RF circuit design
  - MicroSim (PSpice), Serenade
- MEMS: ANSYS
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Overview of Research Projects

Concepts & Components
- High data rate WLAN EASY-A
- Ultra-wideband sensing SPP1202
- SOTM tracking antennas MoSaKa

Technology
- Planar periodic structures FhG-IIS

System aspects
- Reconfigurable RF systems GRK1487
- High-efficiency Power amplifier Class-S
- LTCC multilayer modules KERAMIS II
List of actual research projects

- **MoSaKa**: Tracking antennas and outdoor-unit for mobile satellite communications
  BMWi/DLR, 2009-2012
- **Mobicom**: Self-organised mobile communication systems for disaster scenarios
  Reconfigurable radio interfaces
  DFG-GRK 1487, Computer Sciences and Electrical Engineering, 2009-2015
- **ultraMEDIS**: UWB-Radar for biomedical sensors
  DFG-SPP1202, Medical partners, 2007-2010 (2012)
- **KERAMIS-II**: On-orbit verification, LTCC microwave multilayer modules Industry partners, BMWi/DLR, 2006-2011
- **AIRFUN**: Development and implementation of robust 60 GHz radio systems
  Industrial EASY-A consortium, BMBF/DLR, 2008-2010
- **HMoS**: Switched microwave amplifier and reconstruction filter
  Industrial Class-S consortium, BMBF/DLR, 2007-2010
- **MAPS**: Radiation properties and applications of periodic structures
  Fraunhofer-IIS, 2007-2009
MoSaKa – Project

Mobile satellite communications in Ka-band

Objectives

• Address challenges related to loss of terrestrial infrastructure (disaster scenarios)
• Establish communications between fixed, nomadic, and mobile nodes in a heterogeneous network
• Compact tracking antennas enabling reliable data transmission

Rationale

• Improved transmission links (forward and return links), robust satellite access in mobile channel
• Tracking with small-aperture antennas and technologies for compact user terminals
• Installation of a specific testbed (antenna mast and precise positioner)
MoSaKa – Details 1/2

VSAT Ka-band antenna
• High-gain antenna: > 40 dBi gain, 40-60 cm parabolic dual reflector antenna
• Low-profile antenna: small aperture, lower gain
• Signal acquisition and tracking

Ka-band transceiver frontend
• Modular construction
• Low-noise down-converter
• Suitable connection to antenna
MoSaKa – Details 2/2

Demonstration & evaluation of developed components

• Ka-band satellite internet access for reference measurements
• Testbed with channel & motion simulation
• Free-space testing of directional antennas
• Land-mobile satellite applications
• Extraction of channel parameters
Self-organised mobile communication systems for disaster scenarios

Self-organised Service Recovery
Reconfigurable Radio Interfaces
Cognitive Management of Transport Resources
Decentralised Information Management

Prof. Dr. Andreas Mitschele-Thiel
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Reconfigurable radio interfaces – project

Self-organised mobile communication systems for disaster scenarios (International Graduate School, DFG-GRK1487)

Objectives

• Self-organisation supported by reconfigurable RF hardware
• Selectivity, adaptivity and energy efficiency for fast disaster recovery
• Co-operation of 8 research labs in electrical engineering and computer sciences

Rationale

• Recovery from disaster scenario by identifying and exploiting available resources
• Reconfigurable antenna for RX sensing and RX/TX transmission with spatial and frequency selectivity (cognitive radio)
• Combination of analog hardware and software adaptivity for self-organised optimisation

Reconfigurable antenna – Initial details

Challenges of antenna design

• Antenna for sensing (receive only):
  • Wideband frequency operation
  • Capable to sense the entire solid angle

• Antenna for regular operation (RX and TX):
  • Single frequency, prescribed channel bandwidth
  • Directive (multipath, link budget)

• Reconfigurable antenna design
  • Wideband broad pattern antenna tunable to a single frequency directive beam

• Find optimum compromise between frequency and spatial selectivity
ultraMEDIS – Project

*Ultra-wideband medical sensor systems*
*DFG priority programme UKoLoS (SPP 1202)*

**Objectives**

- Develop ultra-wideband radar for medical applications
- Interdisciplinary approach: Engineers, physicists, medical doctors
- Cluster networking within priority programme
- Envisage UWB for human medical in-vivo diagnosis: MRI navigator and breast tumour detection

**Rationale**

- Intrinsically safe and bio-compatible
- Detection / localisation / imaging of dielectric contrast / malignant tissue
- Tracking of organ movement
- Long-term investigations of diseases
ultraMEDIS – Details 1/2

UWB antennas

• Compact antennas with stable radiation pattern
• Optimised and measured for dielectric medium
• Modified for use in combination with magnetic resonance imaging
• Adapted to clinical diagnostic studies
ultraMEDIS – Details 2/2

UWB-MRI compatibility
- Minimisation of current-loops for eddy currents
- Sustaining good matching and radiation properties over the entire band of operational frequencies (impulse response)

UWB-MRI functionality
- Monitoring of heart beat and breath frequencies with high precision
- UWB navigation of 3-T MRI
- Extraction of anatomic effects (myocardial dynamics, brain imaging, etc.)

KERAMIS – Project

Ceramic microwave circuits for satellite communication systems

Objectives

- Technology for Ka-band multimedia satellite applications
- Ceramic multilayer technology (LTCC)
- Embedded circuit elements and MMICs
- Verification of technology in space (Launch 2010)

Experiment: Reconfigurable switch matrix

- Reconfigurable (digitally controlled signal paths)
- Compact three-dimensional hermetic packaging
- Straight-forward low-cost development and fabrication
- Full space qualification

KERAMIS – Details 1/3

Reconfigurable switch matrix

• $f = 17\ldots22$ GHz, $|S_{21}| > -1$dB
• $|S_{ii}| < -20$ dB, isolation 50 dB.
• Broadband matching of switch-IC.
• Trade-off performance – complexity.

transition CPW – switch die
KERAMIS – Details 2/3

On-orbit verification

- OOV led by industrial partners (KT, GSOC)
- KERAMIS is one of eleven payload modules
- Self-consistent remotely controlled experiment
- Launch expected for 2010
- One year of operation
KERAMIS – Details 3/3

Advanced design of microwave modules

• Modular design flow incorporating previous results
• Time saving (CPU and design)
EASY-A consortium

Partners

- IHP Microelectronics
- Atmel
- BMW
- EADS-IW
- FHG-HHI und FHG-IAF
- IMST
- Infineon
- MEDAV
- Meytec
- Siemens
- TES
- TU Dresden
- Universität Ulm
- Unteraufträge: U Bo, TU B, TU I

Working groups at Ilmenau University of Technology

- Institute for Information Technology (Electronic measurement research lab, RF & Microwave research lab)
- Institute for Micro- and Nano-Technologies
AIRFUN – Project

*LTCC patch antennas for wireless Gbps transmission systems*

**Objectives**

- Increase data rate of wireless transmission systems (e.g., WIFE, data kiosk, WPAN).
- Range 1…10 m.
- Unlicensed frequency band around 60 GHz.
- Transceiver technology (SiGe) from project partners.

**Rationale**

- Patch antennas and –arrays (planar, hybrid integration)
- Multilayer ceramic technology (LTCC)
  - Three-dimensional, integration of transceiver chips.
- Symmetric feed networks
  - Advantages for millimetre wave applications.

Cooperation with Electronic Technology and Electronic Measurements
AIRFUN – Details

60 GHz patch antenna arrays

• Patch elements with symmetric feed (stacked patches)
• 10-dB bandwidth ≈ 11 GHz
• Gain ≈ 10 dBi (beamwidth 50...80 deg)
• Can be scaled to larger arrays
• Can be extended for dual polarisation
• Design adapted to LTCC technology
• Hybrid integration of antenna with MMICs and feed networks
HMoS – Project

High-frequency modulator for class-S amplifiers

Objectives

- Industrial Class-S consortium in R&D focus mobileGaN
- High-efficiency power amplifiers for mobile communications
- Employ latest technology (SiGe, GaN, “digital” amplifier).

Pulse-length modulator

- Switched amplifiers: arbitrary wave-forms, class-S.
- Optimise architecture: noise, linearity, power consumption.
- Implementation and integration: monolithic circuit design.

Reconstruction filter

- Focus: low insertion loss, impedance matching, wide stop-band
- Optimise quality-factor versus volume: miniaturisation.
- Implementation: system demonstrator module.
HMoS - Details: Pulse-length modulator

Design and characterisation of PLM circuit

- Triangle signal generator and comparator stage
- SiGe-HBT, IHP SG25H1
- 1.8 GHz clock-frequency
- 450 MHz input signal
- On-wafer differential measurements
HMoS - Details: Reconstruction filter

Reconstruction filter: Combline bandpass

- Passband insertion loss as low as possible (efficiency)
- Differential matched load for push-pull switching stage
- Stop-band as wide as possible (noise shaping, harmonic suppression)
- High power handling
MAPS – Project

Microwave antennas based on periodic structures

Objectives

• Anisotropic dispersion of 1d and 2d periodic structures
  • Including backward waves (left-handed)
  • Reduction of coupling
  • Leaky wave radiation (endfire, high gain)
• Compact antennas with specific radiation patterns
  • Angle and frequency dependent radiation
  • Reflection phase for arbitrary angles of incidence

Rationale

• Anisotropic propagation of bound and radiating TE/TM modes
• Simulate, characterise, and exploit the field distribution excited by appropriate feed structures
• Develop experimental techniques for optimisation
MAPS – Details

Unit Cell
- Multi-layer structure with engineered dispersion relation
- Consistent EM analysis and design procedure

Experimental studies
- Measured coupling between feed antenna and high-impedance surface
- Effects of truncation of the periodic structure
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Useful information 1/2

• High-ranking and other refereed journals: 57
• Inter/national conference papers: 98 / 151
• Recent patent applications (2006-2009): 4
  • LTCC UWB millimeter wave transmission lines
  • Combination of MR-imaging and UWB-radar
    PTB Berlin with TU Ilmenau, 10-2008-19-862.5
  • MRI-compatible UWB antennas
    TU Ilmenau with PTB Berlin, 10-2008-047-054.6
  • High-power filter for switched-mode amplifiers
    10-2008-053-013.1
• Diploma and PhD students (cumulative since 2003): 24 and 17
• Research projects (cumulative since 2003) 35 with a total budget of 7.8 M
Useful information 2/2

- Research lab
  www.tu-ilmenau.de
- Institute for information technology
  www.tu-ilmenau.de/init
- Institute for Micro- and Nano-Technologies
  www.tu-ilmenau.de/mnt
- International Graduate School
  www.tu-ilmenau.de/gs-mobicom

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Thank you for your attention.

Vielen Dank für Ihr Interesse.