About me

Prof. Dr.-Ing. habil. Bastian E. Rapp

• 2005, mechanical engineering
  University of Karlsruhe
• 2008, PhD in Microfluidics and Biosensors
  University of Karlsruhe
• 2017, Habilitation on fluid mechanics and microfluidics
  Karlsruhe Institute of Technology (KIT)
• 2018, Full Professor Process Technology
  IMTEK, University of Freiburg
• 2018, Founding CEO and current CTO of Glassomer GmbH
• several industry/academic awards (selection):
  GMM, Edison Award, Südwestmetallförderpreis, 2 of my former PhD students
  won the Deutsche Studienpreis
• since WS 2023/2024: Dean of Studies of IMTEK

Full Professor,
Laboratory of Process Technology
Department of Microsystem Technology (IMTEK)
University of Freiburg

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www.NeptunLab.org
The Technology
One of the greatest achievements of mankind

- the lunar landing of *Apollo 11* on July 20th, 1969
- you all know the story but how much do you know about the technology behind *Apollo*?
How do you actually get to the moon? In 1969?

- in order to reduce the rocket size NASA chose the so-called *Lunar orbit rendezvous* configuration instead of building a *Nova* rocket
- this meant that the Apollo 11 not only had to get to the moon (a 3-day = 300,000 miles journey) but also dis-engage (and later re-engage) the landing module

- how to you navigate that precisely, so far away from earth in 1969?
- satellites → out of range
- GPS → not invented yet
- the stars → way to imprecise
This is how you do this: But what exactly is this?
The Inertial Measurement Unit (IMU) via a sketch by Draper himself

- by precisely measuring the orientation (with a gyroscope) and the acceleration (using an accelerometer) you can precisely calculate your position

\[ \vec{a} = \frac{d\vec{v}}{dt} = \frac{d^2\vec{s}}{dt^2} \]

- this is because

- if you integrate the acceleration you will always now your position

- you need to integration constants:
  - \( \vec{s}_0 \) = location of Cape Canaveral
  - \( \vec{v}_0 = 0 \)
How do we navigate today? IMUs to the rescue again! However ....

- 50 years later, the fridge-sized instruments is about the size of your pinky’s nail
- accelerometers can be shrunk to the size of needle pin
Need proof? Phones out!

- this is an IMU which outperforms Apollo’s on-board IMU by two orders of magnitude!
- and this image is from 2012!
- costs? 0.08 Euro 😊

So how did we get from a fridge-sized devices to something which we all carry in our pockets?

Ladies and Gentlemen: Microsystems Technology

Next time somebody asks you what exactly you study, you could tell them:
We put space science in your pocket – and help return mankind to the moon (and beyond) – among many, many, many other things.
A macrosystem

The Airbus A380

- Approximately 1 Million single parts!
  - One Wing: 32,000 parts
- Costs: $275 Millions
  - Average per single part $275
- High effort for single part fabrication

Can you imagine such a system with 2 Million parts?
A microsystem

The DMD

- Digital Micro-mirror Device
- 1.6 cm x 1.6 cm
- 508,800 mirrors 17 µm x 24 µm
- ~ 2.2 million parts
- Price: ~ € 2 000
- Price / part: < 0.1 Cent
- Mass fabrications

Microsystems

- Many functions
- Small volume
Microsystems are small

A hair, on the same scale. Diameter: ~ 50 μm

Smaller

Tiny
A huge variety in microsystems
Microsystems are everywhere

**Medicine**
- Minimally-invasive surgery
- Diagnostics

**Communications**
- Fiber optics
- Mobile phones

**Consumer**
- Autonomous networks
- Sensors

**Industry**
- Process management
- Instrumentation

**Automobile**
- Gyroscope
- Airbags
The Career
Studies: technical skills

Educational goal:
- To graduate students who can go from idea to product

The required skills:
- Problem definition
- Solutions & evaluation

The challenge starts now

Design & development
- Fabrication
- Characterization & optimization
- Packaging
- System testing & qualification
- Transfer to production
- Marketing
Studies: Non-technical skills

Technical excellence is a given...

... but graduates also need:

- Ability to work in a team
- Social competence
- Creativity
- Openness to new ideas
- Self-confidence
- Communication skills
- Entrepreneurial thinking
- Ability to motivate, oneself and others
- Leadership capabilities
Where can I go with my degree?

Microsystems engineers become:

• Entrepreneurs, technicians, engineers, group leaders, managers, CEOs, astronauts,…

Potential employers:

• Large & small companies of all types
• Startups and spin-offs

What do employers want?

• Potential for development
• Ability to learn
• Communications ability
  (in English and German!)
• Experience, experience, experience
• Particular skills? Not so much…
The Department
Faculty of Engineering

- Faculty in operation since 1995
- Department of Computer Science (IIF)
  - 20 professors / ca. 100 scientific staff / ~ 950 students
- Department of Microsystems Engineering (IMTEK)
  - 22 professors / ca. 300 scientific staff / ~ 880 students
- Department of Sustainable Systems Engineering (INATECH)
  - 11 professors / ~ 380 students
IMTEK-Professors
<table>
<thead>
<tr>
<th>IMTEK chairs</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Optische Systeme (FhG-IPM)</td>
<td>K. Buse</td>
<td>Prozess-technologie</td>
<td>B. Rapp</td>
<td>Simulation</td>
<td>L. Pastewka</td>
<td>Systemtheorie</td>
<td>M. Diehl</td>
<td>Smart Systems Integration</td>
</tr>
<tr>
<td>Messtechnik u. Eingebettete Systeme</td>
<td>S. Rupitsch</td>
<td></td>
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</tbody>
</table>
IMTEK Laboratories

MEMS Applications
  Prof. Dr. Roland Zengerle

Bio- and Nano-Photonics
  Prof. Dr. Alexander Rohrbach

Biomedical Microtechnology
  Prof. Dr. Thomas Stieglitz

Biomicrotechnology
  Prof. Dr. Ulrich Egert

Chemistry and Physics of Interfaces
  Prof. Dr. Jürgen Rühe

Design of Microsystems
  Prof. Dr. Peter Woias

Electr. Instrumentation & Embedded Sys.
  Prof. Dr. Stefan Rupitsch

Gas Sensors
  Prof. Dr. Juergen Woellenstein

Materials Process Technology
  Prof. Dr. Thomas Hanemann

Micro- and Material Mechanics
  Prof. Dr. Christoph Eberl

Microactuators
  Prof. Dr. Ulrike Wallrabe

Microelectronics
  Prof. Dr. Matthias Kuhl

Micro-optics
  Prof. Dr. Hans Zappe

Microsystems Materials
  Prof. Dr. Oliver Paul

Optical Systems
  Prof. Dr. Carsten Buse

Sensors
  Jun.Prof. Dr. Alwin Daus

Simulation
  Prof. Dr. Lars Pastewka

Smart Systems Integration
  Prof. Dr. Alfons Dehé

Systems Theory
  Prof. Dr. Moritz Diehl

Process Technology
  Prof. Dr. Bastian E. Rapp

Soft Machines
  Jun.Prof. Dr. Edoardo Milana
The Curriculum
Structural principles

- M.Sc. Programme = 120 ECTS
- ~ 30 ECTS per semester
- 1 ECTS = 30 hours work load
- Mandatory courses are offered every other semester
- Exams are offered every semester
- The exam regulations stipulate which courses are to be completed to get the degree, but you can decide when you want to take the respective course and exam
- It is allowed to study more than 4 semesters
Modules

- All programs are organized in modules
- A module consists of one or several courses and course work

Module Components

- Lectures – German: Vorlesung (V)
- Exercises – German: Übung (Ü)
- Laboratories – German: Praktikum (Pr) oder Praktische Übung (PrÜ)
- Seminars – German: Seminar (S)
Course work

Non-graded course work ("Studienleistungen", SL)
- Exercises, reports, mid-term exams…
- Are not part of your final grade, but may be part of a module (for example weekly exercise sheets)
- May be graded, or judged only as “pass” or “fail”
- Unlimited number of attempts

Graded course work ("Prüfungsleistungen", PL)
- Written or oral exams, reports, presentations,…
- Are always graded and count into your final grade
- Limited number of attempts, normally only 2
## Mandatory modules

<table>
<thead>
<tr>
<th>Module</th>
<th>Type</th>
<th>Exam</th>
<th>ECTS</th>
<th>Semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro-electronics</td>
<td>Le-E</td>
<td>Written exam</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Micro-mechanics</td>
<td>Le+E</td>
<td>Written exam</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>MST Design Laboratory I for Microsystems Engineering</td>
<td>La</td>
<td>Pass/Fail assessment (Studienleistung)</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>MST Technologies and Processes</td>
<td>L+E</td>
<td>Pass/Fail assessment (Studienleistung) Written exam</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Signal Processing</td>
<td>L+La</td>
<td>Written exam</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Master’s module (6 months)</td>
<td></td>
<td>Thesis and presentation</td>
<td>27+3</td>
<td>4</td>
</tr>
</tbody>
</table>
### Compulsory elective modules

<table>
<thead>
<tr>
<th>Module</th>
<th>Type</th>
<th>Exam</th>
<th>ECTS</th>
<th>Semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly and Packaging Technology</td>
<td>Le+E</td>
<td>Written exam</td>
<td>6</td>
<td>1, 2 or 3</td>
</tr>
<tr>
<td>Mirco-optics</td>
<td>Le+E</td>
<td>Written exam</td>
<td>6</td>
<td>1 or 3</td>
</tr>
<tr>
<td>Modelling and System Identification</td>
<td>Le-E</td>
<td>Written exam</td>
<td>6</td>
<td>1 or 3</td>
</tr>
<tr>
<td>Probability and Statistics</td>
<td>Le-E</td>
<td>Written exam</td>
<td>6</td>
<td>1 or 3</td>
</tr>
<tr>
<td>Sensors</td>
<td>Le+La</td>
<td>Pass/fail assessment</td>
<td>6</td>
<td>1 or 3</td>
</tr>
<tr>
<td>Biomedical Microsystems</td>
<td>Le+E</td>
<td>Written exam</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Micro-actuators</td>
<td>Le+E</td>
<td>Pass/fail assessment</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Micro-fuidics</td>
<td>Le+E</td>
<td>Written exam</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Total to be selected</td>
<td></td>
<td></td>
<td><strong>30</strong></td>
<td></td>
</tr>
</tbody>
</table>
## Concentration Areas and Customized Course Selection

<table>
<thead>
<tr>
<th>Concentration Areas (21-30 ECTS)</th>
<th>ECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuits and Systems</td>
<td>Students have to choose ONE concentration area</td>
</tr>
<tr>
<td>Materials and Fabrication</td>
<td></td>
</tr>
<tr>
<td>Biomedical Engineering</td>
<td></td>
</tr>
<tr>
<td>Photonics</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>21-30</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customized Course Selection</th>
<th>ECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Courses from the MSE concentrations, other faculties at the University of Freiburg, also courses on German language, scientific writing, project management</td>
<td>Students can choose either 30 concentration or 21 concentration+9 CCS</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9</strong></td>
</tr>
</tbody>
</table>
Elective modules in concentrations

Circuits and Systems
1. Angewandte Sensorschaltungstechnik
2. Bayesian Methods for Sensing
3. CMOS MEMS
4. Wireless Sensor Systems
5. Energy harvesting
6. Analog CMOS Circuit Design
7. Mixed-Signal CMOS Circuit Design
8. Flight Control Laboratory
9. Advanced Assembly and Packaging Technology
10. Advanced Microcontroller Lab
11. Power Electronics for E-Mobility
12. Micro Acoustical Transducers
13. Microcontroller Techniques - Praktikum
14. Model Predictive Control and Reinforcement Learning
15. MST Design Lab II for Microsystems Engineering
16. Numerical Optimal Control in Engineering - Project
17. Numerical Optimization
18. Numerical Optimization Project
19. Race Car Control Laboratory
20. RF- and Microwave Devices and Circuits
21. RF- and Microwave Circuits and Systems
22. RF- and Microwave Systems- Design Course
23. Sensors and actuators circuit technology
24. State Space Control Systems
25. Thermoelektrik und thermische Messtechnik
26. Wind Energy Systems
27. Reliability Engineering

Materials and Fabrication
1. Computational physics: material science
2. Disposable sensors
3. Electrochemical energy applications: fuel cells and electrolysis
4. Electrochemical Methods for Engineers
5. Energy storage and conversion using fuel cells
6. Fortgeschrittene Siliziumtechnologie / Advanced Silicon Technology
7. Functional Safety, Security and Sustainability: Active Resilience
8. Hardware Design with the Finite-Element-Method
9. Ceramic Materials for Microsystems
10. Contact, Adhesion, Friction
11. Continuum mechanics I with exercises
12. Continuum mechanics II with exercises
13. Physics of Failure
14. Lithography
15. Materials for Electronic Systems
16. Mechanical Properties and Degradation Mechanisms
17. Methods of Material Analysis
18. Nanomaterials
19. Nanotechnology
20. Nano - Laboratory
21. Surface Analysis
22. Surface Analysis Laboratory
23. Optimierung
24. Advanced engineering
25. Polymer Processing and Microsystems Engineering
26. Quantum Mechanics for Engineers
27. Clean Room Laboratory for Engineers
28. Quantification of Resilience
29. Solar Energy
30. Techniken zur Oberflächenmodifizierung / Surface coating Techniques
31. Compound semiconductor devices
32. From Microsystems to the Nanoworld
33. Dynamics of Materials: Material Characterization
# Elective modules in concentrations

## Biomedical Engineering

<table>
<thead>
<tr>
<th>Module</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Analyse von Life Science Hochdurchsatzdaten mit Galaxy</td>
</tr>
<tr>
<td>2.</td>
<td>Selected Problems in Biosignal Processing</td>
</tr>
<tr>
<td>4.</td>
<td>Biomedical Instrumentation I</td>
</tr>
<tr>
<td>5.</td>
<td>Biomedical Instrumentation II</td>
</tr>
<tr>
<td>6.</td>
<td>Biomedical Instrumentation - Laboratory</td>
</tr>
<tr>
<td>7.</td>
<td>BioMEMS</td>
</tr>
<tr>
<td>8.</td>
<td>Bionic Sensors</td>
</tr>
<tr>
<td>9.</td>
<td>Biophysics of cardiac function and signals</td>
</tr>
<tr>
<td>10.</td>
<td>Biophysik - Grundlagen und Konzepte</td>
</tr>
<tr>
<td>11.</td>
<td>Biotechnologie für Ingenieure I: Einführung, Molekular-</td>
</tr>
<tr>
<td></td>
<td>Biotechnologie für Ingenieure I: Introduction, Molecular- and Microbiology</td>
</tr>
<tr>
<td>12.</td>
<td>Biotechnology for Engineers II</td>
</tr>
<tr>
<td>13.</td>
<td>Ethical Aspects of Neurotechnology</td>
</tr>
<tr>
<td>14.</td>
<td>Fundamentals of electrical stimulation</td>
</tr>
<tr>
<td>15.</td>
<td>Introduction to data driven life sciences</td>
</tr>
<tr>
<td>16.</td>
<td>Introduction to physiological control systems</td>
</tr>
<tr>
<td>17.</td>
<td>Machine Learning</td>
</tr>
<tr>
<td>18.</td>
<td>Microfluidics II: Miniaturize, automate and parallelize biochemical analysis: From idea to product launch</td>
</tr>
<tr>
<td>19.</td>
<td>Microsystems technology in Medicine</td>
</tr>
<tr>
<td>20.</td>
<td>Nanobiotechnology</td>
</tr>
<tr>
<td>21.</td>
<td>Neurophysiology - Laboratory</td>
</tr>
<tr>
<td>22.</td>
<td>Neuroprosthetics</td>
</tr>
<tr>
<td>23.</td>
<td>Neuroscience for Engineers</td>
</tr>
<tr>
<td>24.</td>
<td>Signal processing and analysis in brain signals</td>
</tr>
<tr>
<td>25.</td>
<td>Silicon-based Neural Technology</td>
</tr>
<tr>
<td>26.</td>
<td>Implant Manufacturing Technologies</td>
</tr>
<tr>
<td>27.</td>
<td>Implant Manufacturing Technologies - Laboratory</td>
</tr>
<tr>
<td>28.</td>
<td>Biointerfaces I - Basics for Bioanalytical Systems</td>
</tr>
</tbody>
</table>

## Photonics

<table>
<thead>
<tr>
<th>Module</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>Advanced Topics in Micro-Optics</td>
</tr>
<tr>
<td>2.</td>
<td>Lasers</td>
</tr>
<tr>
<td>3.</td>
<td>Basic Optics Lab</td>
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<tr>
<td>4.</td>
<td>Basic and Advanced Optics Lab</td>
</tr>
<tr>
<td>5.</td>
<td>Optical Materials</td>
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<tr>
<td>6.</td>
<td>Optical Properties of Micro and Nano Structures</td>
</tr>
<tr>
<td>7.</td>
<td>Optical Trapping and Particle Tracking</td>
</tr>
<tr>
<td>8.</td>
<td>Optical MEMS</td>
</tr>
<tr>
<td>9.</td>
<td>Optical Measurement Techniques</td>
</tr>
<tr>
<td>10.</td>
<td>Optical Micro-Sensors</td>
</tr>
<tr>
<td>11.</td>
<td>Optoelectronics</td>
</tr>
<tr>
<td>12.</td>
<td>Photonic Microscopy</td>
</tr>
<tr>
<td>13.</td>
<td>Photovoltaic Energy Conversion for engineers</td>
</tr>
<tr>
<td>14.</td>
<td>Photovoltaic Energy Conversion for engineers II</td>
</tr>
<tr>
<td>15.</td>
<td>Spektroskopische Methoden</td>
</tr>
<tr>
<td>16.</td>
<td>Wave Optics</td>
</tr>
</tbody>
</table>

Gesamtangebot: 26 + 33 + 28 + 16 = 103 Module
Exams: The most important rules

In addition to registering for a module, you need to...

Register for every exam you want to take:
https://www.tf.uni-freiburg.de/en/studies-and-teaching/a-to-z-study-faq/de-registration-of-exams

• If failed, you can repeat every exam once. Two exams can be repeated twice
• If you fail an exam, you will automatically be registered for the retake in the following semester
• You can only withdraw from an exam, if you are ill or if there is an emergency in your family
  https://www.tf.uni-freiburg.de/en/studies-and-teaching/a-to-z-study-faq/withdrawl-from-exams
• For more details, make sure to read the exam regulations
Plagiarism

- Plagiarism is:
  - Using someone else’s texts, pictures, reports, data, solutions, whatever….
  - ... without giving the source

- Sources include:
  - Books, the internet, colleagues, …

- To make it clear:
  - Plagiarism is illegal

- The simple „if...then“ loops:
  - If you plagiarize...(once)
  - … then you fail
  - If you plagiarize repeatedly (=twice)
  - … then your academic career is over.

Be careful with AI-generated texts – these are not your own thoughts.

- Lecturers use tools to detect plagiarism and AI-generated texts (> 98 % hit rate)
Mentoring

Every student has a faculty mentor

• A professor as a contact person
• Assigned by the Programme Coordinator

Student’s contact for:

• Problems, questions, clarifications, job searches, recommendations, or just general advising
After graduation
Apply for a job

In Industry

- Find out what you like during your MSc programme
- Use job portals and company websites to monitor the market
- Visit career workshops to gather tips how to apply
- Go to recruiting fairs
Ph.D. as research assistant

At the university

• Perform a research project (on your own)
• Look for an open position
• Apply
• Get paid for the PhD project
• Overtake responsibility as project assistant
• Support your professor with respect to educational tasks
• Duration: 3-5 years
Contact persons I

- **Dean of studies**
  - Prof. Dr.-Ing. habil. Bastian E. Rapp
    - 203 7350
    - bastian.rapp@imtek.uni-freiburg.de

- **Programme coordination**
  - Svenja Andresen
    - studiengangkoordination.mst@imtek.uni-freiburg.de
    - 203 97940

- **Study advisors**
  - Dr. Jochen Kieninger
    - 203 7265
  - Dr. Oswald Prucker
    - 203 7164
    - studienberatung@imtek.de
Contact persons II

Examination office

Susanne Stork
pruefungsamt@tf.uni-freiburg.de
203 8087

Anne-Julchen Müller
pruefungsamt@tf.uni-freiburg.de
203 8083

Student committee at the Faculty of Engineering

https://fachschaft.tf.uni-freiburg.de/
Thank you very much for your attention!