universität freiburg

M.Sc. Microsystems Engineering-Introduction

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

Freiburg, 12/10/2023

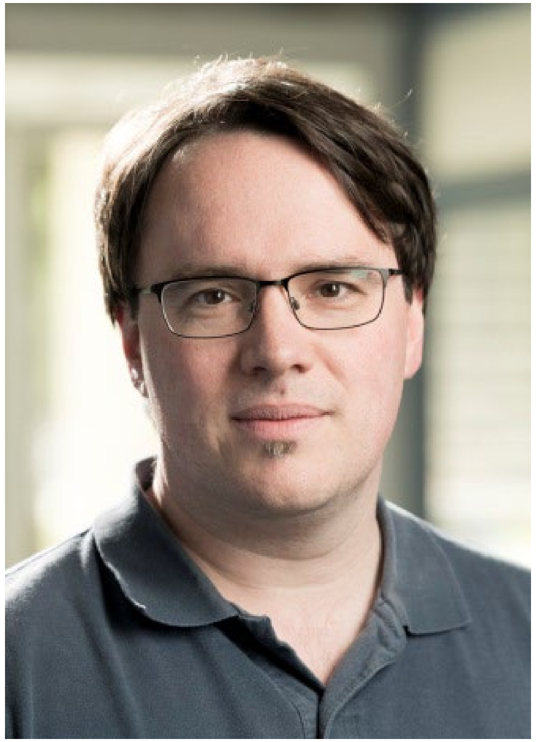
IMTEK

About me

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

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

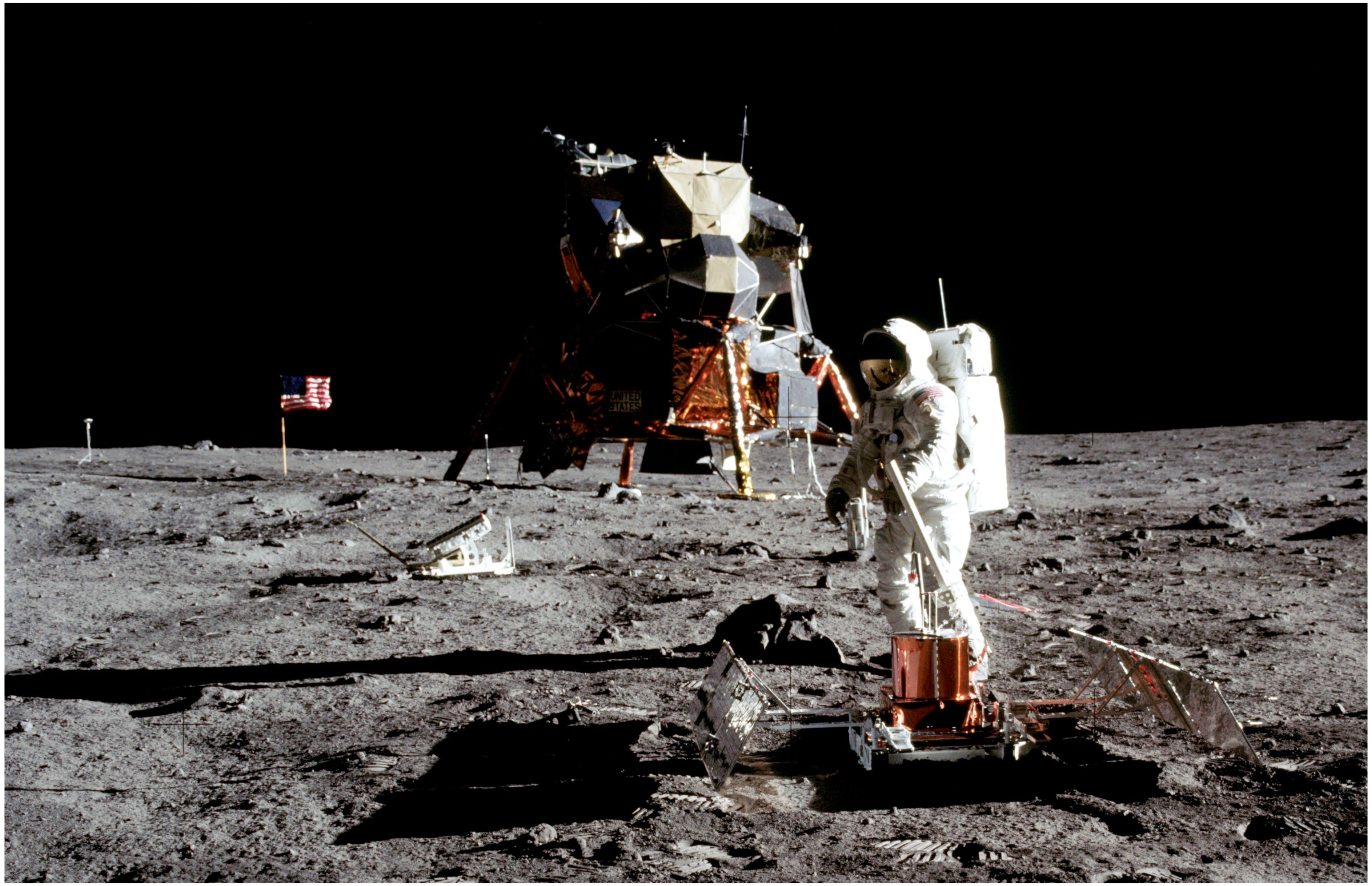
- 2005, mechanical engineering
  University of Karlsruhe
- 2008, PhD in Microfluidics and Biosensors
  University of Karlsruhe
- 2017, Habilitation on fluid mechanics and microfluidics
  Karlsruhe Institute of Technology (KIT)
- 2018, Full Professor Process Technology
  IMTEK, University of Freiburg
- 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



bastian.rapp@neptunlab.org
bastian.rapp@imtek.de
www.NeptunLab.org

The Technology

One of the greatest achievements of mankind

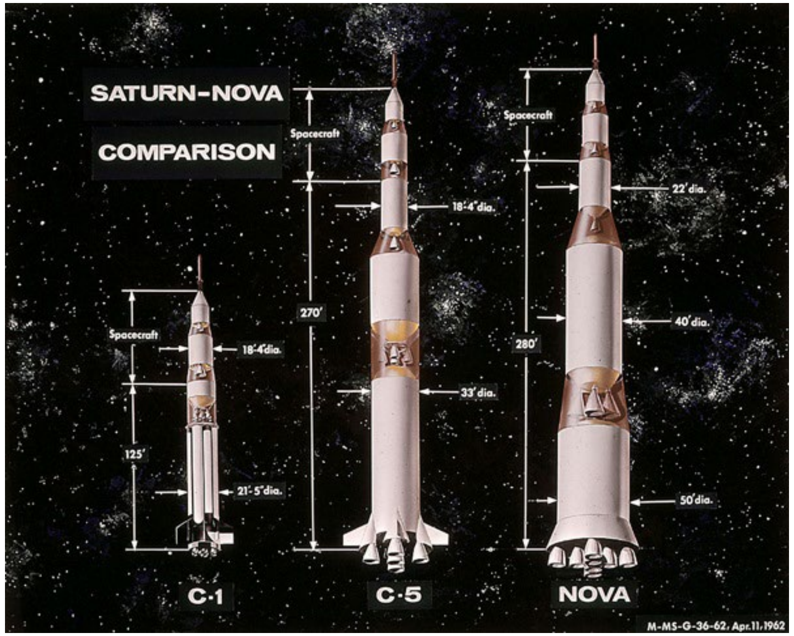


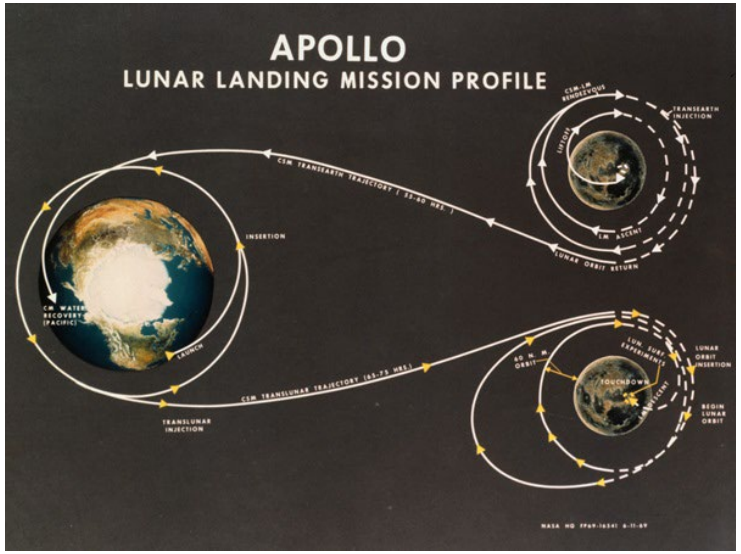
- the lunar landing of *Apollo 11* on July 20th, 1969
- you all know the story but how much do you know about the technology behind *Apollo*?

nasa,gov, media library, 17/10/2022

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

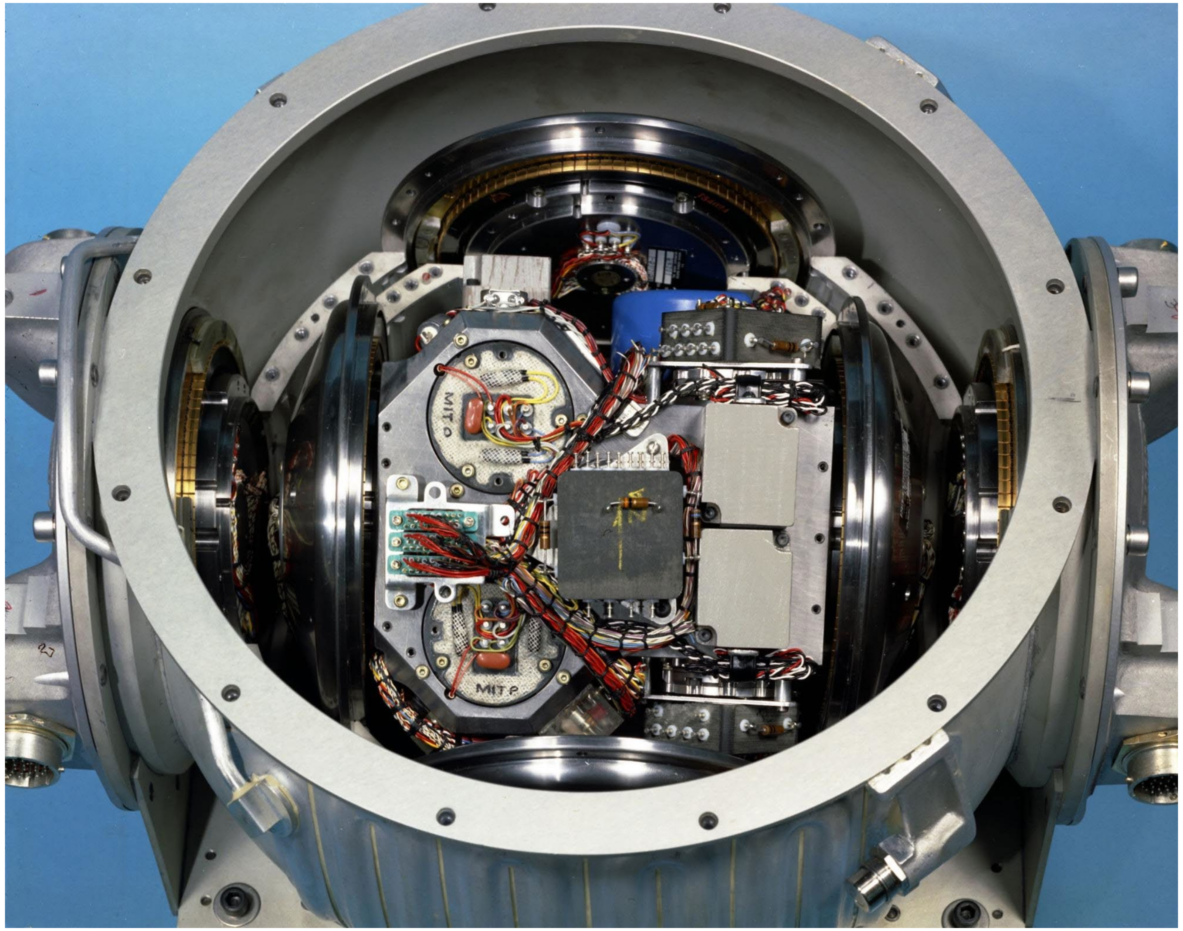




- how to you navigate that precisely, so far away from earth in 1969?
- satellites → out of range
- GPS → not invented yet
- the stars → way to imprecise

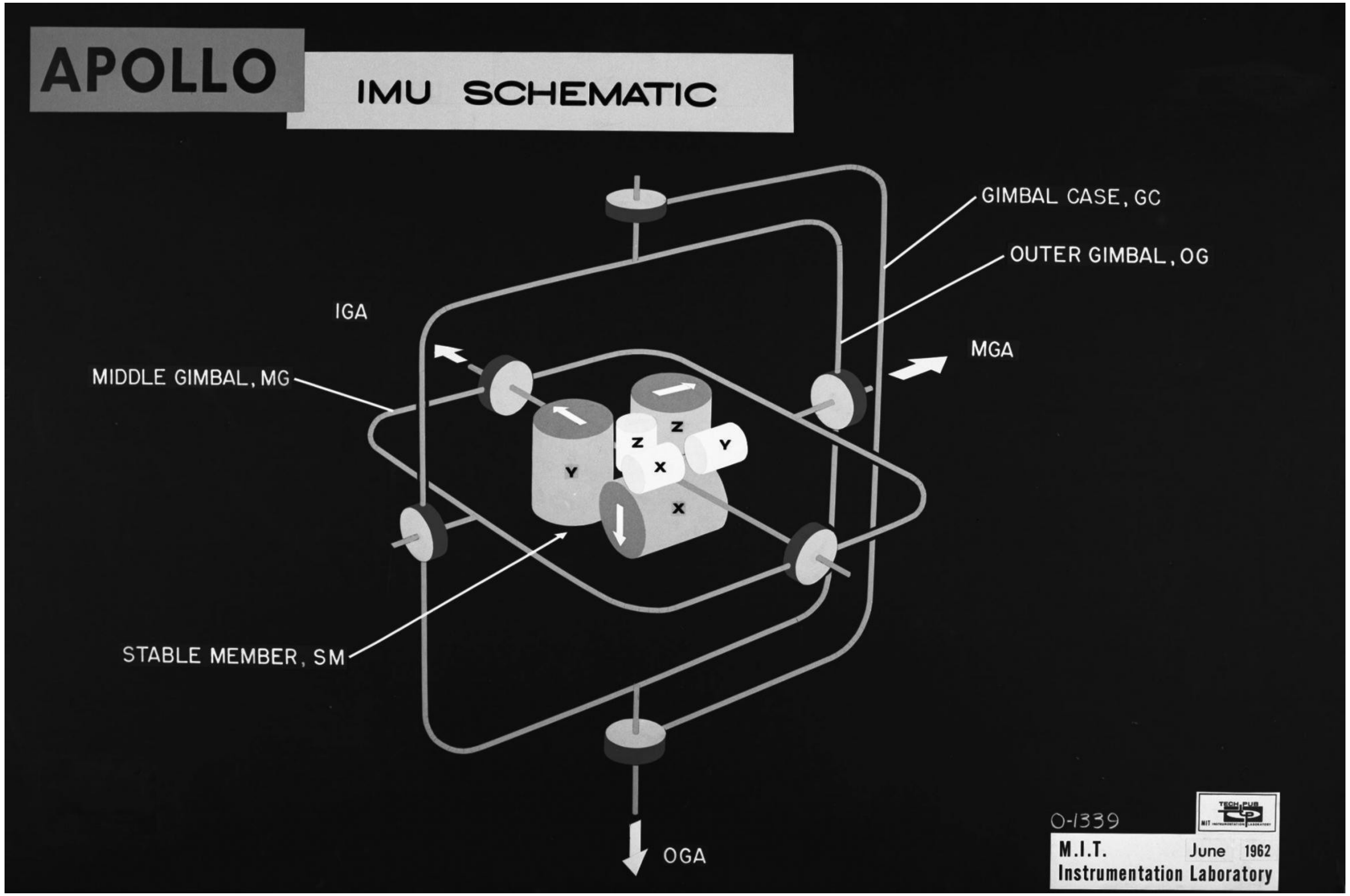
astronomy.com, 10/17/2022

This is how you do this: But what exactly is this?



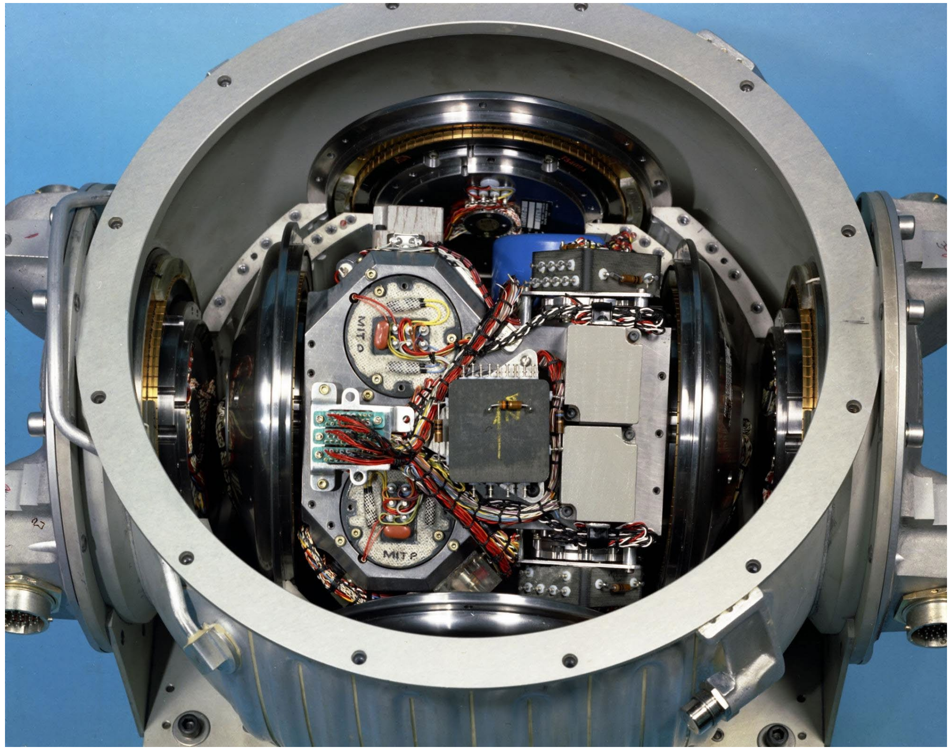
wehackthemoon.com, 17/10/2022

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
- this is because
$$\vec{a} = \frac{d\vec{v}}{t} = \frac{d^2\vec{s}}{dt^2}$$
- 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 ….

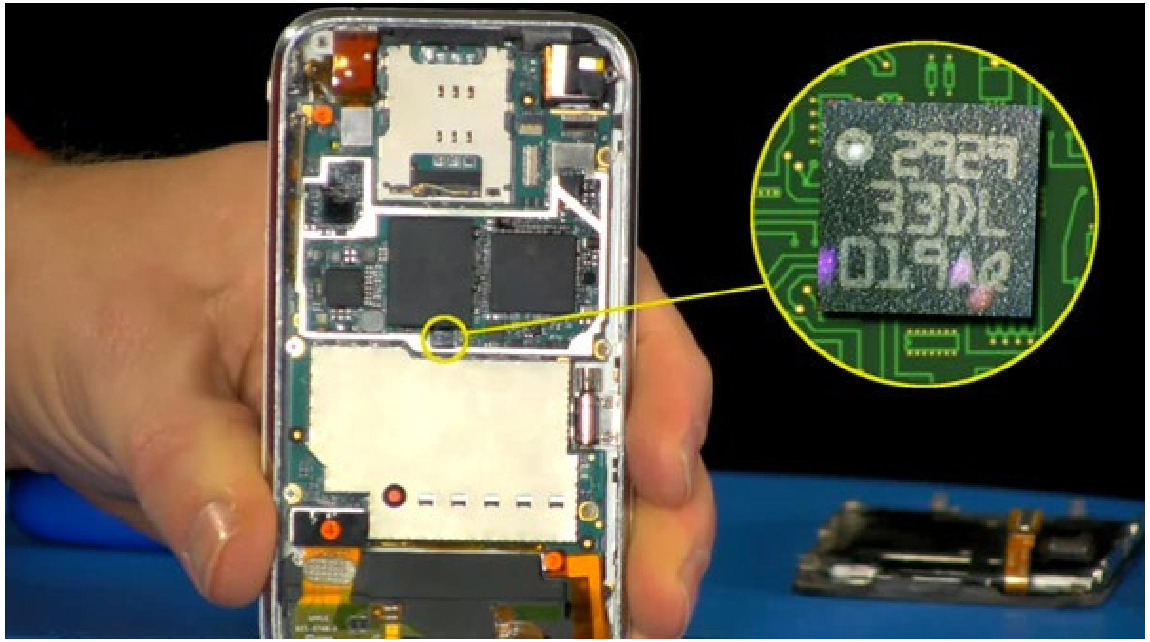


- 50 years later, the fridge-sized instruments is about the size of your pinky’s nail
- accelerometers can be shrunk to the size of needle pin

wehackthemoon.com, 17/10/2022; st.com, 17/10/2022

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.

engadget.com, 17/10/2022

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

AIRBUS

Can you imagine such a system with 2 Million parts?

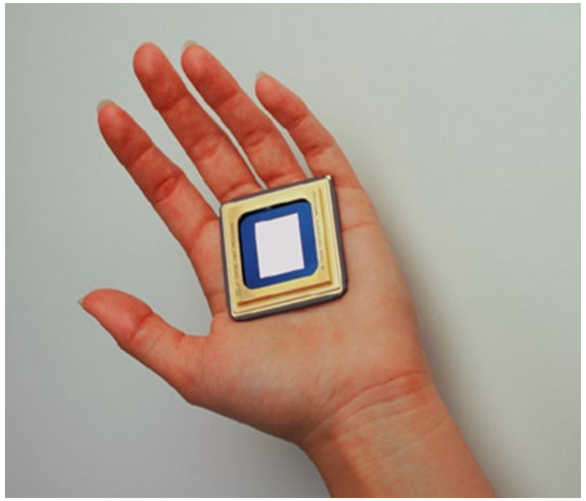
A microsystem

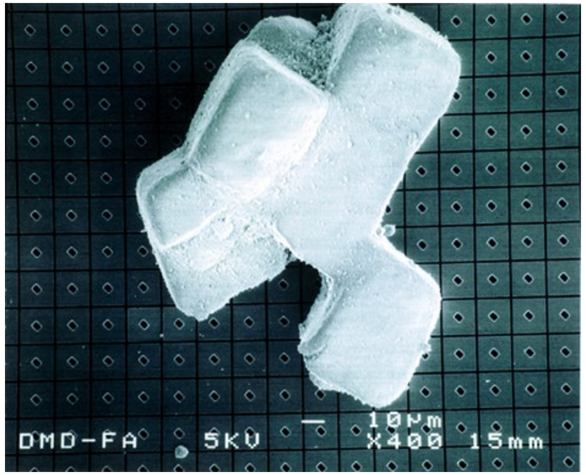
The DMD

- 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

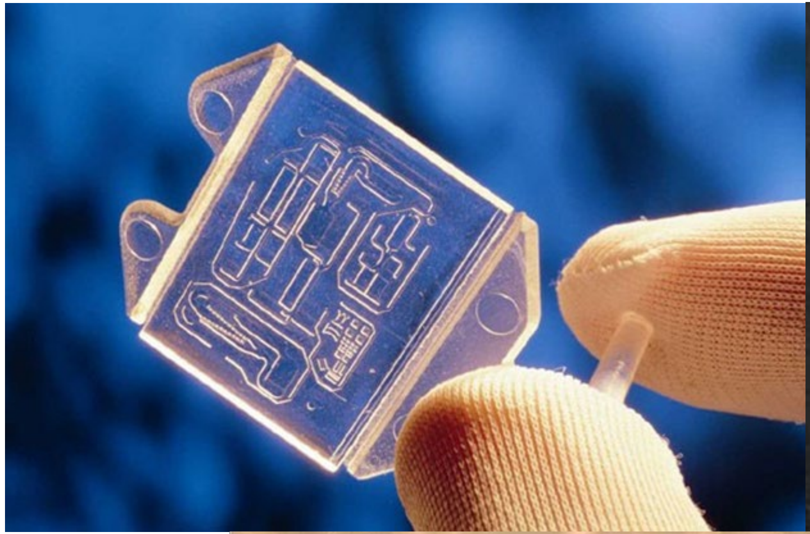
Microsystems

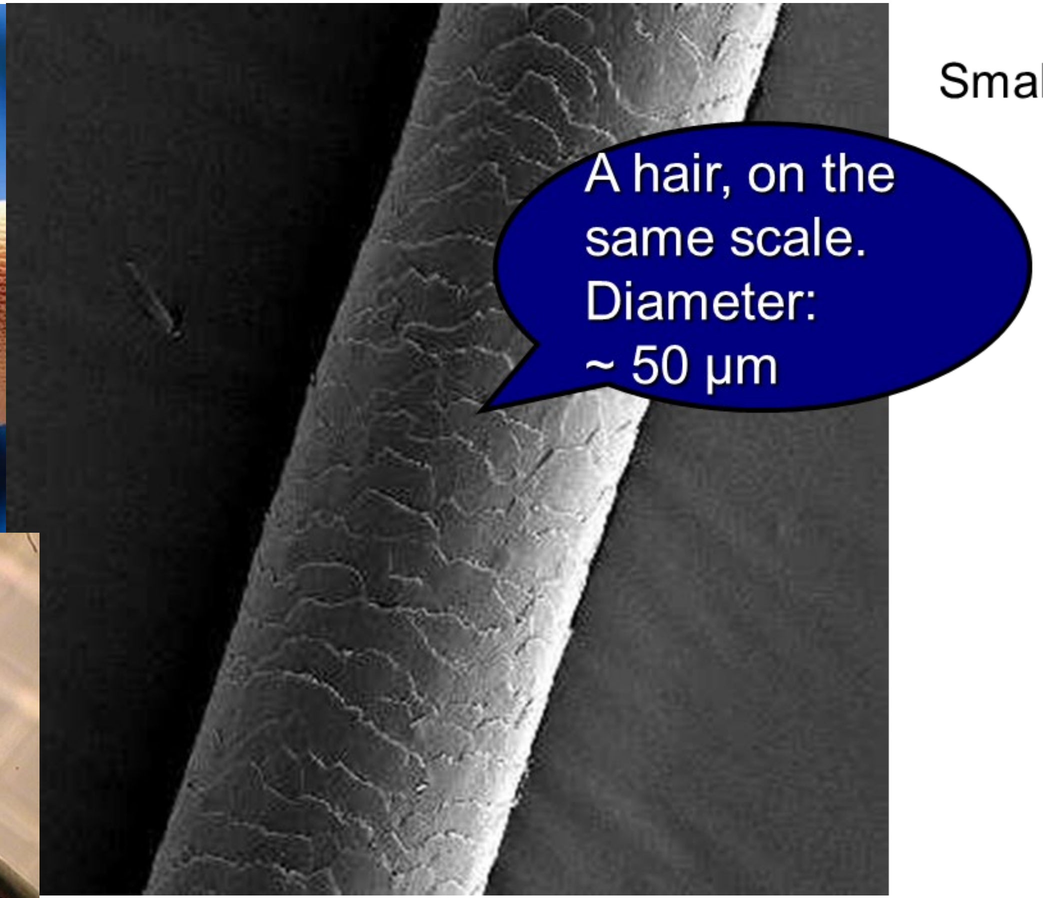
- Many functions
- Small volume





Microsystems are small

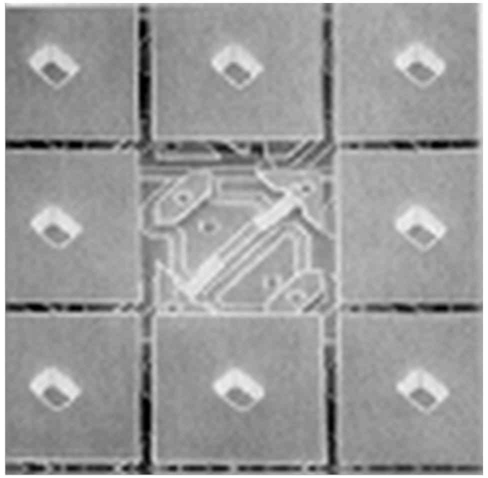




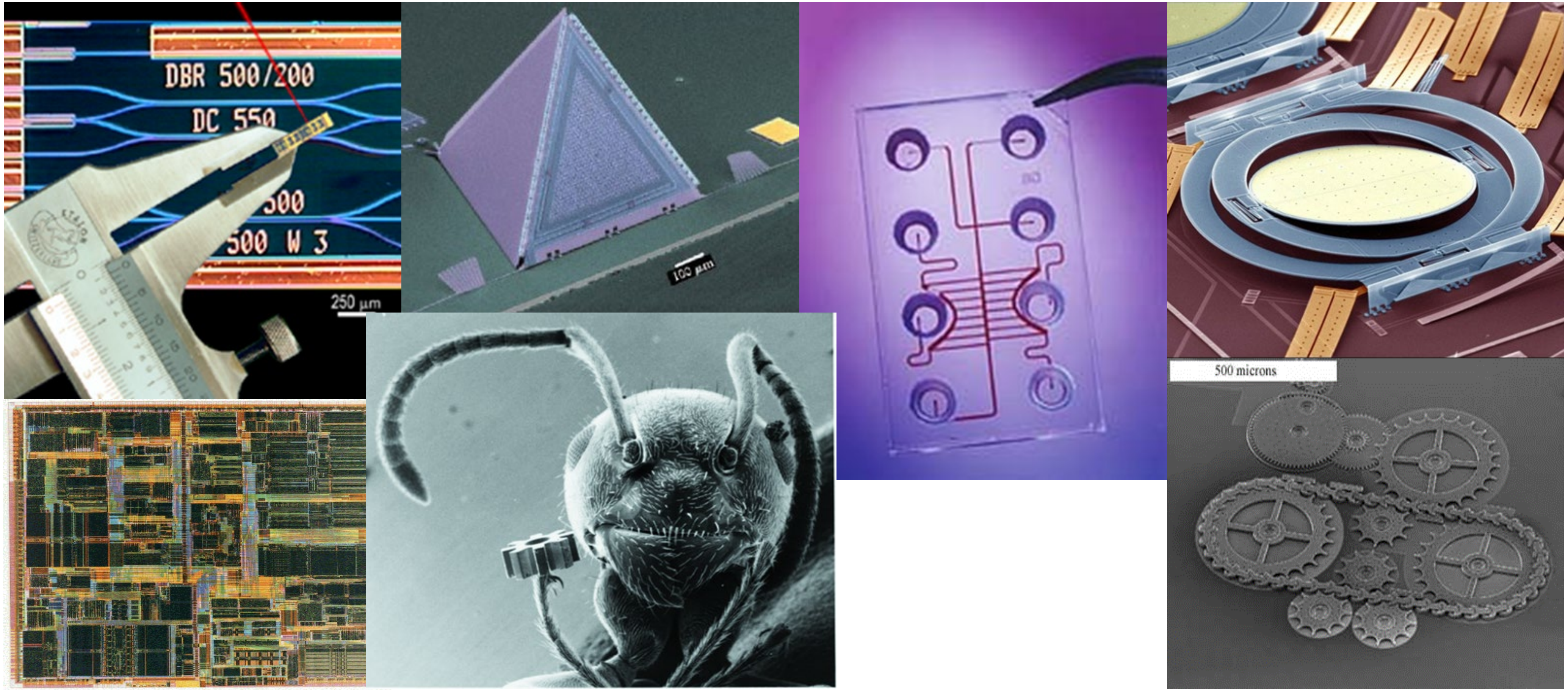
Small

Smaller

Tiny



A huge variety in microsystems



Microsystems are everywhere

Medicine

- Minimally-invasive surgery
- Diagnostics

Communications

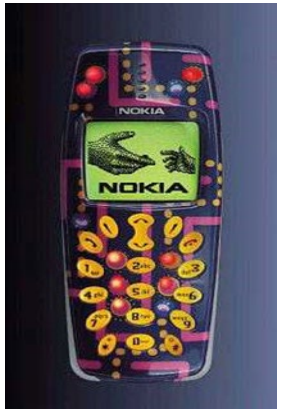
- Fiber optics
- Mobile phones

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

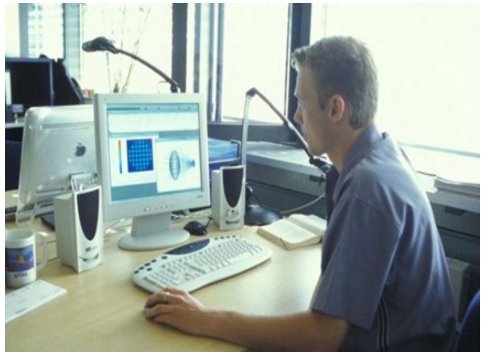
– Characterization & optimization

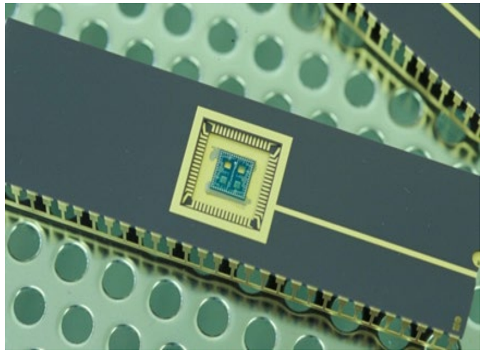
– Packaging

– 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:

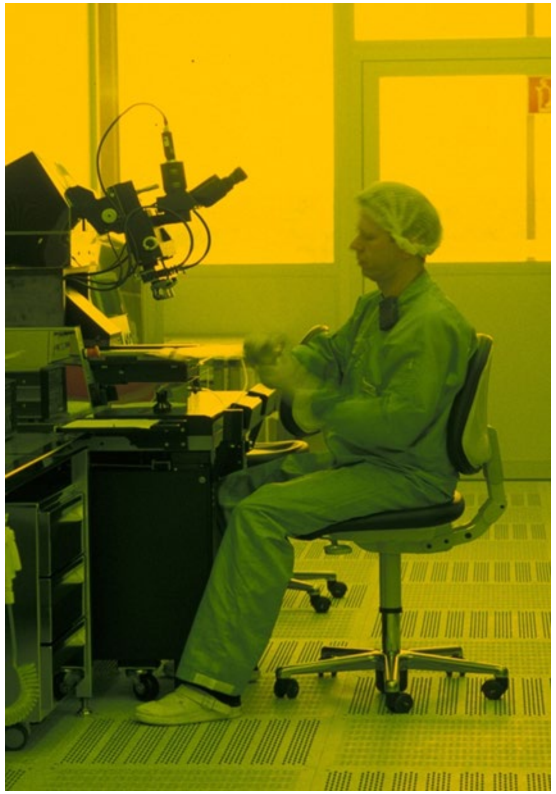
- Entrepreneurs, technicians, engineers, group leaders, managers, CEOs, astronauts,…

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

IMTEK chairs

Anwendungs entwicklung R. Zengerle	**Bio-und Nanophotonik** A. Rohrbach	**Biomedizinische Mikrotechnik** T. Stieglitz	**Biomikrotechnik** U. Egert	**Chemie und Physik von Grenzflächen** J. Rühe	**Konstruktion von Mikrosystemen** P. Woias	**Messtechnik u. Eingebettete Systeme** S. Rupitsch
Gas-sensoren (FhG-IPM) J. Wöllenstein	**Material-prozess-technik** T. Hanemann	**Mikro-und Werkstoff-mechanik** C. Eberl	**Mikroaktoren** U. Wallrabe	**Mikroelektronik** M. Kuhl	**Mikrooptik** H. Zappe	**Materialien der Mikrosystem-technik** O. Paul
Optische Systeme (FhG-IPM) K. Buse	**Prozess-technologie** B. Rapp	**Simulation** L. Pastewka	**Systemtheorie** M. Diehl	**Smart Systems Integration** A. Dehé	**Sensoren** A. Daus	**Soft Machines** E. Milana

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

Module	Type	Exam	ECTS	Semester
Micro-electronics	Le-E	Written exam	6	1
Micro-mechanics	Le+E	Written exam	6	1
MST Design Laboratory I for Microsystems Engineering	La	Pass/Fail assessment (Studienleistung)	6	1
MST Technologies and Processes	L+E	Pass/Fail assessment (Studienleistung) Written exam	6	1
Signal Processing	L+La	Written exam	6	2
Master‘s module (6 months)		Thesis and presentation	27+3	4

Compulsory elective modules

Module	Type	Exam	ECTS	Semester
Assembly and Packaging Technology	Le+E	Writen exam	6	1, 2 or 3
Mirco-optics	Le+E	Written exam	6	1 or 3
Modelling and Sytstem Identification	Le-E	Written exam	6	1 or 3
Probability and Statistics	Le-E	Written exam	6	1 or 3
Sensors	Le+La	Pass/fail assessment Written exam	6	1 or 3
Biomedical Microsystems	Le+E	Written exam	6	2
Micro-actuators	Le+E	Pass/fail assessment Written exam	6	2
Micro-fuidics	Le+E	Written exam	6	2
Total to be selected			**30**	

Concentration Areas and Customized Course Selection

Concentration Areas (21-30 ECTS)	ECTS
Circuits and Systems	Students have to choose ONE concentration area
Materials and Fabrication	
Biomedical Engineering	
Photonics	
Total	**21-30**
Customized Course Selection	**ECTS**
Courses from the MSE concentrations, other faculties at the University of Freiburg, also courses on German language, scientific writing, project management	Students can choose either 30 concentration or 21 concentration+9 CCS
Total	**9**

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
    Numerical Optimal Control in Engineering - Project
16. Numerical Optimization
17. Numerical Optimization Project
18. Race Car Control Laboratory
19. RF- and Microwave Devices and Circuits
20. RF- and Microwave Circuits and Systems
21. RF- and Microwave Systems- Design Course
22. Sensors and actuators circuit technology
23. State Space Control Systems
24. Thermoelektrik und thermische Messtechnik
25. Wind Energy Systems
26. 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

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

Photonics

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

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!