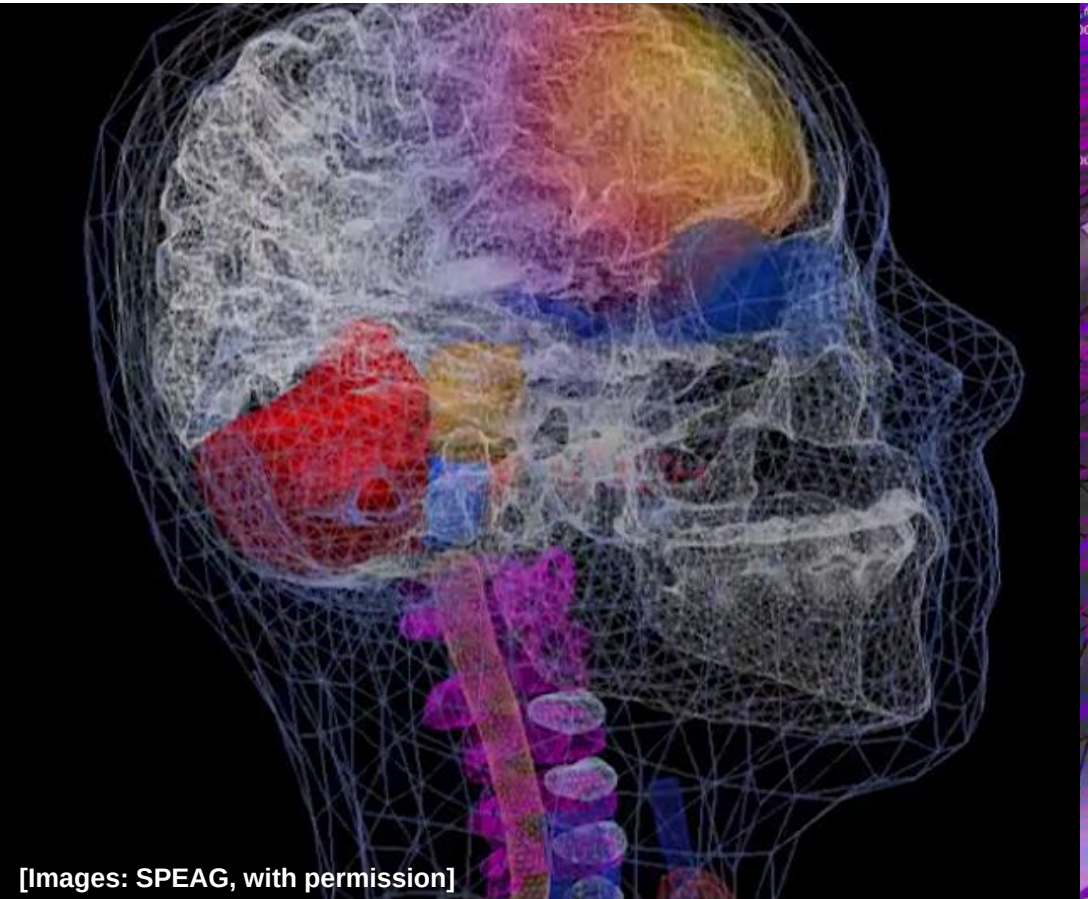
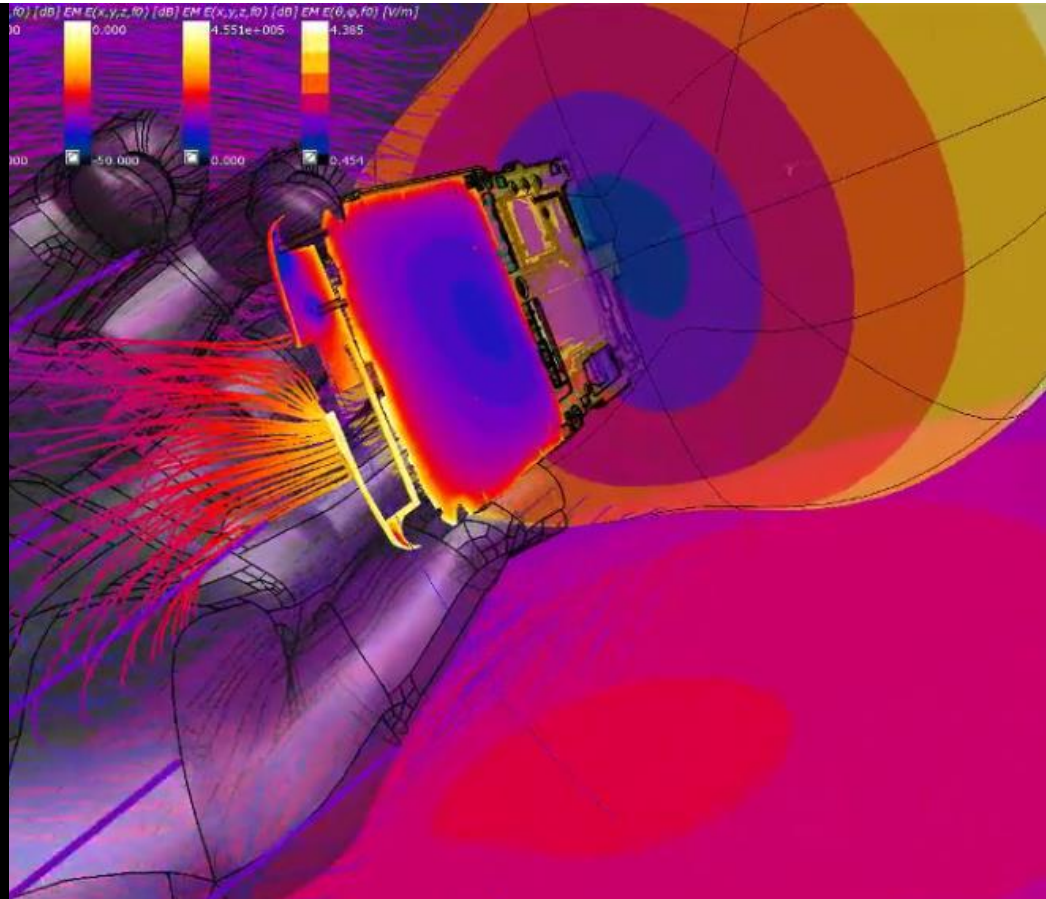
# Bioelectromagnetics: Principles and Applications

Prof. Dr. sc. techn. Christian Schuster

Course Overview, Winter Term 2021/22





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# What this is About

The field of biolectromagnetics can be loosely defined as:

**The science of electromagnetic field interaction with biological tissue**

It is a subdicipline of biomedical engineering and has many connections to e.g. medical / biological imaging, electrotherapy, electrophysiology, biophysics, bioelectronics, electromagnetic compatibility / safety, and electrochemistry.

In the following the main goals, contents, and resources for this course are shortly outlined.

# Goals of this Course

Students will be able to explain the basic principles, relationships, and methods of bioelectromagnetics, i.e. the science of electromagnetic field interaction with biological tissue. They can define and give examples for the most important physical phenomena and classify them corresponding to wavelength and frequency of the fields. They can give an overview over measurement and numerical techniques for characterization of electromagnetic fields in practical applications. They can give examples for therapeutic and diagnostic utilization of electromagnetic fields in medical technology.

In addition students will learn how to apply various methods to characterize the behavior of electromagnetic fields in biological tissue. In order to do this they can relate to and make use of the elementary solutions of Maxwell's Equations. They are able to assess the most important effects that these models predict for biological tissue, they can order the effects corresponding to wavelength and frequency, respectively, and they can analyze them in a quantitative way. They are able to evaluate the effects of electromagnetic fields for therapeutic and diagnostic applications and make an appropriate choice.

# Curriculum

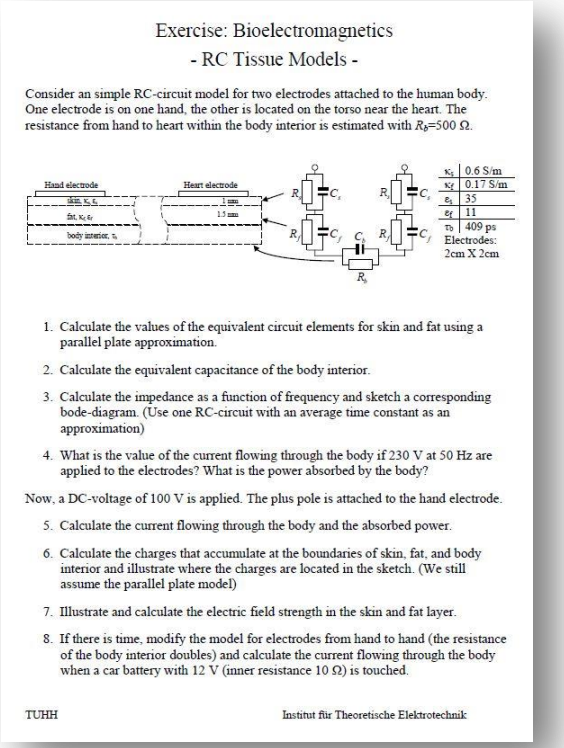
| Week | Topics | Lecture Notes |
|---|---|---|
| 1 | Course Overview, Introduction to Bioelectromagnetics, Introduction to Electromagnetics | [00] – [02] |
| 2 | Maxwell in Integral Form, Electrical Properties of Tissues | [03] – [04] |
| 3 | Time-Harmonic Boundary Conditions, | [05] |
| 4 | Properties of Electrolytic Solutions, Electric Double Layers | [06] – [07] |
| 5 | Polarized Cells and Action Potentials | [08] |
| 6 | Cellular Current Sources and Fields | [09] |
| 7 | Electrocardiography and Lead Fields, Electrical Therapies and Safety | [10] – [11] |
| 8 | Magnetic Fields and Their Effects, Coils and Their Magnetic Fields, | [12] – [13] |
| 9 | Low to Mid Frequency Field Coupling | [14] |
| 10 | Nuclear Magnetic Resonance | [15] |
| 11 | Power Flux, Power Density & SAR | [16] |
| 12 | Plane Wave Propagation, Plane Wave Superposition,<br>Plane Wave Reflection and Refraction | [17] – [19] |
| 13 | The FDTD Method, THz, IR & Visible Light | [20] – [21] |
| 14 | UV and X-Rays, Radiography and CT, Wrapping Up Bioelectromagnetics | [22] – [24] |

**The winter term 2021/22 will have ONLINE lectures (using Zoom) and an IN PERSON / ON SITE exercises.**

# Exercises

**Exercises of the winter term 2020/21 will be IN PERSON / ON SITE again.**

Students will have the opportunity to learn, discuss and work with simplified, quantitative models commonly used in bioelectromagnetics. Please be prepared to work in class by yourself or small groups!



Exercise: Bioelectromagnetics

- RC Tissue Models -

Consider an simple RC-circuit model for two electrodes attached to the human body. One electrode is on one hand, the other is located on the torso near the heart. The resistance from hand to heart within the body interior is estimated with $R_b$=500 Ω.



1. Calculate the values of the equivalent circuit elements for skin and fat using a parallel plate approximation.
2. Calculate the equivalent capacitance of the body interior.
3. Calculate the impedance as a function of frequency and sketch a corresponding bode-diagram. (Use one RC-circuit with an average time constant as an approximation)
4. What is the value of the current flowing through the body if 230 V at 50 Hz are applied to the electrodes? What is the power absorbed by the body?

Now, a DC-voltage of 100 V is applied. The plus pole is attached to the hand electrode.

5. Calculate the current flowing through the body and the absorbed power.
6. Calculate the charges that accumulate at the boundaries of skin, fat, and body interior and illustrate where the charges are located in the sketch. (We still assume the parallel plate model)
7. Illustrate and calculate the electric field strength in the skin and fat layer.
8. If there is time, modify the model for electrodes from hand to hand (the resistance of the body interior doubles) and calculate the current flowing through the body when a car battery with 12 V (inner resistance 10 Ω) is touched.

TUHH Institut für Theoretische Elektrotechnik

Exercises will be supervised by:

**M. Sc. Michael Wulff** (michael.wulff@tuhh.de)

Solutions to the exercises will posted to Stud.IP. after discussion.

# Literature

Course slides will be available for each lecture. In addition, the following books can be recommended:

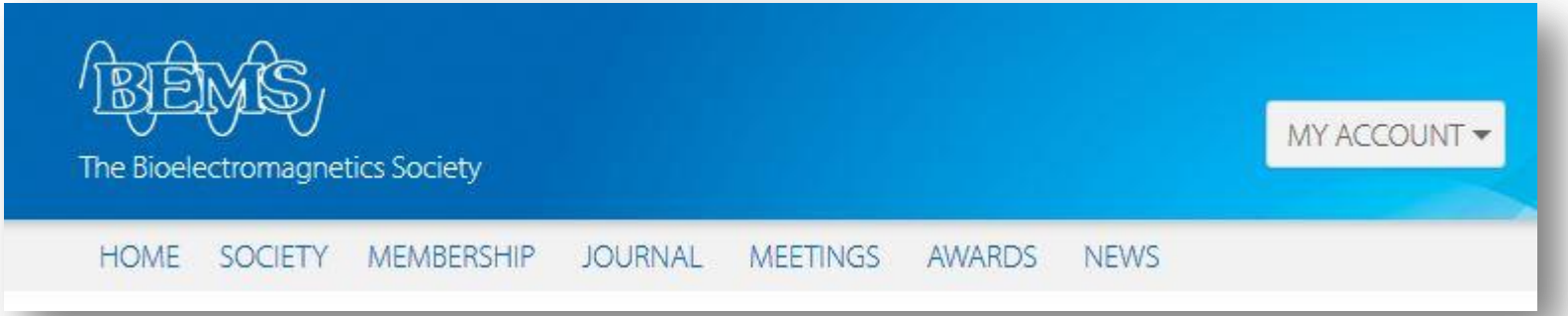
- C. Furse, D. A. Christensen, C. H. Durney, "**Basic Introduction to Biolelectromagnetics**", CRC Press
- S. Grimnes, O. G. Martinsen, "**Bioimpedance & Bioelectricity Basics**", Academic Publishers (E-Book TUHH)
- R. Plonsey, R. C. Barrr, "**Bioelectricity – A Quantitative Approach**", Springer (E-Book TUHH)
- J. C. Lin (Ed.), "**Electromagnetic Fields in Biological Systems**", CRC Press
- J. Malmivuo, R. Plonsey, " **Bioelectromagnetism**", available online at http://www.bem.fi/book/

All books can be made availabe by request.

# Internet Resources

The Bioelectromagnetic Society (BEMS) offers lots of information at:

**www.bems.org**




**[Source: www.bems.org]**

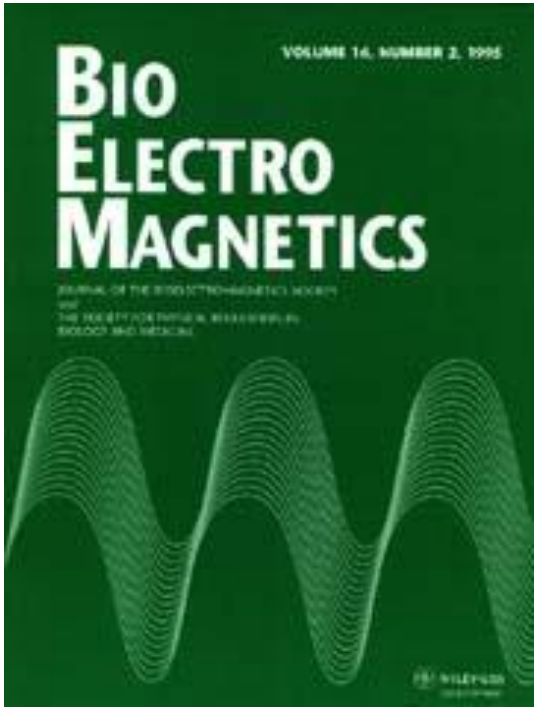
The European Virtual Campus for Biomedical Engineering can be found at:

**www.evicab.eu**

Among others it offers video lectures, slides, and exercises.

# Scientific Journals

Scientific journals with a focus on biomedical engineering and/or electro-magnetic fields in medicine and biology:

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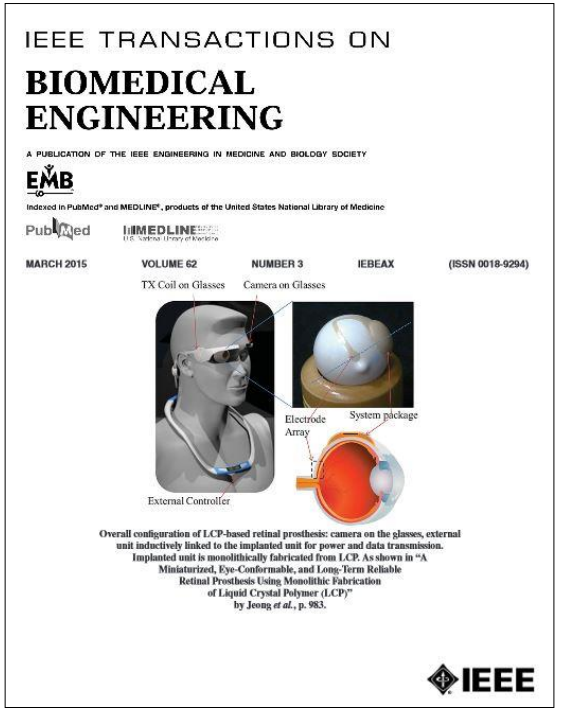


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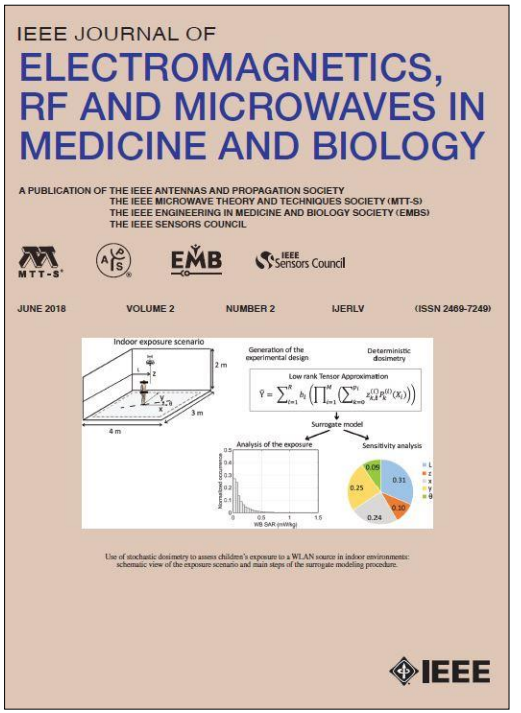


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# Scientific Journals

Scientific journals with a focus on electromagnetic fields in electromagnetic compatibility and microwave engineering:

IEEE TRANSACTIONS ON
**ELECTROMAGNETIC COMPATIBILITY**
A PUBLICATION OF THE IEEE ELECTROMAGNETIC COMPATIBILITY SOCIETY
EMC SOCIETY

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