BME 6421: Electrophysiological phenomena in biological tissues

Instructor: Dr. Jorge Riera Diaz, PhD

Phone: (305) 348-4948
Email: jrieradi@fiu.edu

Office Hours: 11:00am-12:00am Monday
Class Number: 21416
Period: Spring
Time: Tue & Thu – 5:00 pm – 6:15 pm
Place: Engineering Center 1109

Course description

Electrophysiology has been a part of medical history, with multiple contributions coming from clinical electroencephalography (EEG) and electrocardiography (EKG) as well as from their more contemporary versions, i.e. the magnetoencephalography (MEG) and magnetocardiography (MCG). These observation modalities are based on electromagnetic phenomena in biological tissues. Although they have had scientific value for the past 150 years, many of the fundamental contributions to the theory of bio-electromagnetism were made in the nineteenth century. This course will provide a detailed introduction to the anatomy and physiology of excitable tissues. It will also prepare the students to understand the main mechanisms by means of which electric and magnetic fields propagate inside biological tissues at both large and small physical scales.

Course Outcome:

No.	Course Learning Outcomes By the end of this course, students should know:
1	the synaptic origin of local field potentials and the extracellular electric field created by neuronal spiking
2	the macroscopic Maxwell equations for biological tissues with emphasis on the mechanisms for polarization and magnetization phenomena
3	the forward and inverse problems in electrophysiology, with the available tools to solve them
4	the hardware and software used to record and analyze electrophysiological data

Prerequisites

Permission of Instructor

Grading

45% Assignments (3), 1% will be deducted for assignments turned in late
15% Paper Reading and Presentation
40% Final Exam
Grading scale: 95-100 A; 90-94.9 A-; 86-89.9 B+; 82-85.9 B; 79-81.9 B-; 76-78.9 C+; 72-75.9 C; 69-71.9 C-; 67-68.9 D+; 63-66.9 D, 60-62.9 D

Attendance

Attendance is mandatory but up to three classes can be missed without incurring penalties.

Class Schedule

L1: Introduction
- Short History of Bio-electromagnetism
- Brain and Cardiac Functions
- Open Discussion

Part I- The Mathematics

L2: Vector Calculus: Revisited
- Divergence and Rotational Operators
- First and Second Green's Identities
- Helmholtz's Theorem

L3: The Maxwell Equations
- Integral and Differential Forms
- Charge Continuity Principles
- Electric and Magnetic Potentials: Gauge Theory

L4: Electrical Circuits
- Capacitors and Resistors
- Kirchhoff Laws
- Norton-Thévenin Theorem

Assignment 1: Problem Solving

L5: Recapitulation of Part I

Part II- The Microscopic Level

L6: The Cells
- Electrically Excitable Cells
- Glia Cells: Support and Modulation
- Nerves and Muscles

L7: Principles of Cellular Excitability
- Resting Membrane Potential
- Thermodynamics Approaches
- Electrical Equivalent Circuits
- Active Transport

L8: The Hodgkin-Huxley Membrane Model
- Voltage- and Ligand- Gated Ion Channels
- Borg-Graham's Generalizations
- The Action Potential: Axonal & Cardiac

L9: Information Propagation – Axons
- The Cable Equation
- Myelinated Fibers: Impulse Conduction
- Ranvier Nodes: Structure and Function

L10: Information Transmission - Synapses
- Types of Synapses
- Synaptic Vesicles
- Neurotransmiters
- Vesicle Docking and Exocytosis
- Post-synaptic Potentials: Excitatory and Inhibitory

Assignment 2: Simulation of an AP using NEURON Software
L11: Recapitulation of Part II

Part III- The Mesoscopic Level
L12: The Brain
- Different Types of Neurons
- Basic Circuits and Plasticity
- Oscillatory Activity: Phase-Locked Vs. Spectral Perturbations

L13: The Heart
- Anatomy and Physiology of the Heart
- Electric Activation of the Heart: Principles
- Electrical Defibrillation

L14: Biological Tissue: Electrical Properties
- Dispersion Mechanisms
- Electrical Conductivity and Permittivity
- Theoretical Considerations

L15: Electrical Activity at a Mesoscopic Scale
- Local Field Potentials
- Current Source Density (CSD) Analysis
- Single/Multi – Unit Activity: Spike Sorting and Classification

Assignment 3: Using Different Toolboxes for the Analysis of Extracellular Potentials (due TBD)
L16: Recapitulation of Part III

Midterm Exam

Part IV- The Macroscopic Level
L17: The Electro-cardiogram and Magneto-cardiogram
- History: Amplifiers and Sensors
- The QRS complex and Heart-Rate Measurements
- Applications to Study Heart Diseases

L18: The Electro-encephalogram and Magneto-encephalogram (I)
- History: Amplifiers and Sensors
- Alpha Rhythm
- The Sleeping Brain

L19: The Electro-encephalogram and Magneto-encephalogram (II)
- Neurological Disorders: Epilepsy
- Neuropsychiatric Disorders
- Role in Cognitive Neuroscience

Paper Reading and Presentation
L20: Recapitulation of Part III

Part V- The Forward and Inverse Problems in Electrophysiology
L21: Electric Current Sources in the Brain and Heart
- Quasi-static Approach
- Dipolar Model and Distributed Current Densities
- Surface Potentials

L22: Volume Conductor Models
- Concentric Spheres
- Piece-wise Isotropic and Homogeneous Compartments: Boundary Element Methods (BEM)

Finite Element Methods: Anisotropy

L23: Inverse Solutions - Parametric Models

Least-Squares Source Estimation

Beamforming Approach

From Classical to RAP-MUSIC

L24: Inverse Solutions – Imaging

Bayesian Formulation

Linear Imaging Methods

Non-Gaussian Prior

Assignment 4: MATLAB-Code to Localize Current Sources

L25: Recapitulation of Part V

L26: Recapitulation of Part I – V

Final Exam

Textbooks (Recommended, not mandatory)

Bioelectromagnetism. Jaakko Malmivuo and Robert Plonsey. Oxford, 1995.

Electric fields of the brain. Paul L Nunez and Ramesh Srinivasan. Oxford, 2006