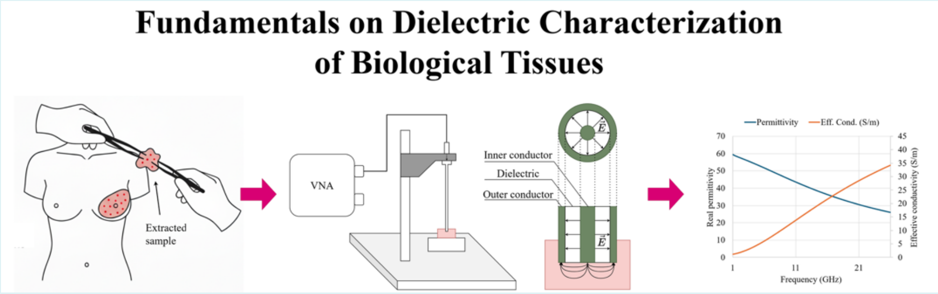
SC15 - Fundamentals on Dielectric Characterization of Biological Tissues



Abstract:

Understanding the dielectric properties of biological tissues is fundamental for advancing microwave sensing, imaging, therapeutic heating, and the development of safe and effective medical devices. This short course introduces the physics governing tissue–field interactions, the dielectric models used to describe biological phenomena, and the main techniques for measuring tissue properties, with a particular focus on the open-ended coaxial probe method. Participants will gain foundational knowledge on practical aspects, findability, accessibility, interoperability, reusability, common pitfalls, and the importance of rigorous metadata. The course promotes community adoption of the current best-practice guidelines.

Recommended pre-requisites:

Electromagnetics, and MATLAB or similar

Learning Objectives:

After the course, participants will be able to:

• Explain the physical principles governing the dielectric behavior of biological tissues, including the influence of water content, ionic conductivity, and tissue microstructure, and how these factors shape tissue interaction with electromagnetic fields across frequencies. Participants will understand the origins of dielectric dispersion and apply classical dielectric models—Debye, and Cole–Cole—to interpret frequency-dependent permittivity and conductivity data.

• Compare and evaluate major measurement techniques, such as coaxial probes, transmission lines, free-space systems, resonant cavities, parallel-plate fixtures, and impedance/inductive methods. Emphasis will be given to the open-ended coaxial probe, the most used method for measuring biological tissues, including advantages, limitations, calibration requirements, and frequency-dependent challenges.

• Describe measurement procedures, covering system configuration, calibration, measurement execution, validation strategies, post-processing, and data analysis for reliable dielectric characterization and modeling.

• Identify and mitigate confounding factors, including equipment- and system-related effects, sample- and tissue-related issues (hydration, temperature, pressure), and modelling- or analysis-related uncertainties.

• Adopt best practices for reporting dielectric property data, following community-driven standards and FAIR principles (Findability, Accessibility, Interoperability, Reusability), and implement structured metadata approaches such as the Minimum Information Model for Dielectric Measurements of Biological Tissues (MINDER).

SC15 - Fundamentals on Dielectric Characterization of Biological Tissues

Course Outline:

1. Introduction and Motivation
- Importance of dielectric properties (DPs) in biomedical electromagnetics.
- Applications: microwave sensing and imaging (MW-IS), hyperthermia and ablation, pathology characterization, safety and exposure studies, and medical device design/validation.
- Historical evolution of DP measurements and links to biological modelling.

2. Fundamentals and Modelling of Dielectric Behavior in Biological Tissues
- Composition-dependent mechanisms: bound water, free water, ions, cellular structure.
- Tissue–field interaction: polarization mechanisms and dispersion regions.
- Debye relaxation and multipole extensions.
- Cole–Cole model and its interpretation in biological systems.

3. Measurement Techniques for Dielectric Properties
- Principles of EM propagation, S-parameters (S11, S22), and material extraction.
- Comparative review: coaxial probe, transmission lines, free-space setups, resonant cavities, parallel-plate cells, and impedance/inductive methods.
- Special focus on microwave ranges and challenges at higher frequencies, including penetration depth, alignment, and calibration issues.

4. Open-Ended Coaxial Probe: Theory and Practice
- Physical and mathematical foundations; sensing volume and field penetration.
- Practical protocols: calibration, cleaning, contact pressure, drift control, and repeatability.
- Typical use cases (liquids, tissues, gels) and common confounders: temperature, hydration, ex-vivo vs in-vivo conditions, equipment stability, and cable handling.

5. Data Quality, Reporting, and Community Standards
- Confounders of dielectric properties measurements on biological tissues.
- Current repositories and initiatives for biological dielectric data.
- Best-practice guidelines, metadata requirements, and reproducibility principles.
- Minimum information frameworks, FAIR guidelines, and promoting standardization.

The participants need to bring a laptop.

SC15 - Fundamentals on Dielectric Characterization of Biological Tissues

Instructors:

Daniela Marques Godinho is an Invited Assistant Professor at Physics Department in Faculdade de Ciências, Universidade de Lisboa (FCUL), Portugal, and a researcher and Science Communicator at Instituto de Biofísica e Engenharia Biomédica, FCUL. She holds a Ph.D. in Biomedical Engineering and Biophysics from FCUL (2022) and an Integrated Master degree in Biomedical Engineering from Universidade Nova de Lisboa, Portugal (2016). She has been working on Microwave Imaging to aid breast cancer diagnosis and staging since 2017. She has worked in the revision of the state-of-the-art on dielectric properties of breast and lymph nodes tissues, the development of a methodology to estimate dielectric properties of lymph nodes, and the dielectric property measurement of materials used for phantom development with traditional techniques. She has recently developed an open-access repository of dielectric and thermal properties of biological tissues and tissue mimicking materials. She received 10 awards for her scientific work and 3 awards for her academic merit. She is the author of 14 journal papers, 4 of them as first author and 4 as senior author, and 29 conference papers. She has supervised the research of 38 students and peer-reviewed for 19 scientific journals and 13 conferences, and organised convened sessions in conferences, including EuCAP.

SC15 - Fundamentals on Dielectric Characterization of Biological Tissues

Instructors:

David O. Rodriguez-Duarte received the B.Sc. and M.Sc. degrees in electronic engineering from Universidad Nacional de Colombia, Bogota, Colombia, in 2013 and 2018, respectively, and the Ph.D. degree from the Department of Electronics and Telecommunications, Politecnico di Torino, Turin, Italy, in 2022, where he is currently Assistant Professor, focusing on applied electromagnetics to biomedical and agro-industrial problems. He is training leader on Antennas system for the European Project “Bone, Brain, Breast and Axillary Medical Microwave Imaging (3BATwin)”, and pre-clinical testing leader in the Interreg European Project “MedWaveImage, Microwave imaging technology transfer to innovate the medical He is technical programme chair of the first “International Conference on Medical Microwave Imaging Applications (ICMWIA, 2026),” and has been convener of the sessions “Advancements on Electromagnetic-based Medical Techniques and Devices” at the Latin American Conference on Antennas and Propagation (LACAP2024), and “Advances in Electromagnetic Diagnostics, Therapeutics and Biomedical Sensors” at the European Conference on Antennas and Propagation (EuCAP2023). He was invited professor at the XIX International Chair of Engineering at Universidad Nacional de Colombia, 2025, presenting the course “Biomaterials and their application in health.” He has been a Marie Sklodowska-Curie Early-Stage-Research Fellow in the European project EMERALD, 2018-21, being visiting research at Keysight Technologies GmbH (Austria), iLumens-Health Simulation Center (France), King’s College London (UK), WIPL-D d.o.o.(Serbia). In 2017, he was a visiting researcher at the University of British Columbia, Okanagan, BC, Canada, funded by the Emerging Leaders in the Americas Program. He received the Individual Grant for Young Researcher to follow high-risk and high-gain research in 2025, 1st/70 candidates, funded by Politecnico di Torino and Fondazione Compagnia di San Paolo. He received the IEEE APS Postdoctoral Fellowship in 2022. He was awarded the best undergraduate thesis of the electronics department in 2013, the Second Prize in the Student Paper Competition in the 2021 URSI GASS, the AP-S Tapan Sarkar Best Student Paper in 2021 IEEE CAMA, the C. J. Reddy Travel Grant for Graduate Students in IEEE AP-S/URSI 2021, the best Propagation Paper finalist in EuCAP2022, the Young Scientist Award (YSA) at the URSI AT-AP-RASC in 2022, and a finalist for YSA at 2023 URSI Spain National Symposium.

Key Bibliography

[1] La Gioia et al., ‘Open-Ended Coaxial Probe Technique for Dielectric Measurement of Biological Tissues: Challenges and Common Practices’, Diagnostics, vol. 8, no. 2, p. 40, Jun. 2018

[2] S. Gabriel, R. W. Lau, and C. Gabriel, ‘The dielectric properties of biological tissues: II. Measurements in the frequency range 10 Hz to 20 GHz’, Phys. Med. Biol., vol. 41, no. 11, p. 2251, Nov. 1996.

[3] S. Gabriel, R. W. Lau, and C. Gabriel, ‘The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues’, Phys. Med. Biol., vol. 41, no. 11, p. 2271, Nov. 1996

[4] E. Porter et al., ‘Minimum information for dielectric measurements of biological tissues (MINDER): A framework for repeatable and reusable data’, International Journal of RF and Microwave Computer-Aided Engineering, vol. 28, no. 3, p. e21201, 2018.

[5] L. Farrugia et al., ‘The Complex Permittivity of Biological Tissues: A Practical Measurement Guideline’, IEEE Access, vol. 12, pp. 10296– 10314, 2024.

[6] M. D. Wilkinson et al., ‘The FAIR Guiding Principles for scientific data management and stewardship’, Sci Data, vol. 3, no. 1, p. 160018, Mar. 2016.

[7] E. Porter, S. Mandija, R. C. Conceição, M. Cavagnaro, P. Prakash, and S. Curto, ‘Progress and Challenges towards a Standard Approach for Dielectric Measurement and Reporting of Biological Tissues’, in 2024 IEEE MTT-S International Microwave Biomedical Conference (IMBioC), Jun. 2024, pp. 99–101.