Current research activities on electromagnetics and microwave technologies at ENSEEIHT Toulouse

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Toulouse INP - ENSEEIHT is one of the French engineering schools renowned for its training of engineers specialized in microwave techniques and wireless communications systems. In parallel, teachers conduct research activities related to microwave techniques: modeling and design of microwave devices, modeling and characterization of interactions between electromagnetic waves and real or artificial environments, development of specific numerical methods in electromagnetism for device design and inverse modeling for characterization.

Study of EM Wave/Living Environment Interactions

Human exposure to electric and magnetic fields (EMF) is an integral part of modern societies. Several studies have shown that exposure of living systems to EMF can affect vital cellular processes. However, many results from in vitro and in vivo studies remain controversial.

The lack of sufficient scientific data on animal models exposed to EMF has raised various concerns. As part of a research project funded by the French National Agency for Food, Environmental and Occupational Health and Safety (ANSES), our team partnered with the I2MC laboratory (Institute of Metabolic and Cardiovascular Diseases) to study the myocardial capacity for mitochondrial oxidative phosphorylation under prolonged electromagnetic stress (**Figure 1**).

To assess the biological effects of radiofrequency electromagnetic fields on living cardiac cells, we used a transverse electromagnetic cell (TEM cell). In order to define the dielectric properties of the biological medium, the technique of measuring samples reported on a microstrip transmission line was used. The TEM cell used in an in vitro experiment was modeled by a full-wave electromagnetic software, allowing the evaluation of the Specific Absorption Rate: the main parameter of exposure to electromagnetic fields.

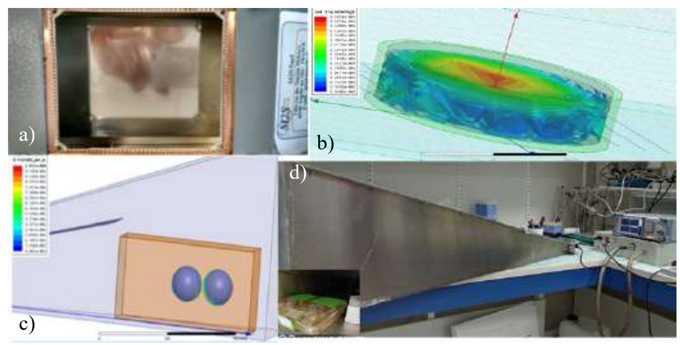

Fig. 1. (a) TEM cell. (b) SAR calculation for TEM Cell in vitro study. (c) SAR calculation of in vivo study in GTEM cell. (d) GTEM cell setup for in vivo study.

In vivo experiments were performed in a Giga-TEM (GTEM) cell to accommodate cages (up to 4) in which the animals were exposed to EMF. We used a solid-state radiofrequency generator with a fixed frequency of 915 MHz (WSPS-915–1000). In the construction of the numerical model, the Webster was modeled by the equivalent volume sphere. The first study uses a relative permittivity of 55 and an equivalent conductivity of 3S/m. Several exposure campaigns were carried out, with the exposure time varying between 48h and 72h.

Both in vitro and in vivo short-term studies found no evidence that EMFs affect antioxidant and apoptosis status in cardiac cells and tissues [1]. Further studies examining dynamic changes in oxidative stress and apoptosis after long-term cardiac cell exposure to EMFs are warranted. These data provide an important reference in relation to the cellular antioxidant defense system and programmed cell death in response to electromagnetic stress.

Development of RF devices based on metamaterials

Metamaterial-based devices have considerable potential in communication and sensing applications ranging from RF to THz frequencies.

In the field of sensors, the use of metamaterials often leads to high sensitivity of RF signals to changes in environmental parameters such as the presence or absence of chemical or molecular compounds. We are working with former PhD students of our team on the design of metamaterial-based sensors. The devices developed include several cancer cell detection devices, a cell for characterizing water-ethanol mixtures, and other types of sensors [2]. An example is given in **Figure 2** on the feasibility of cancer cell detection.

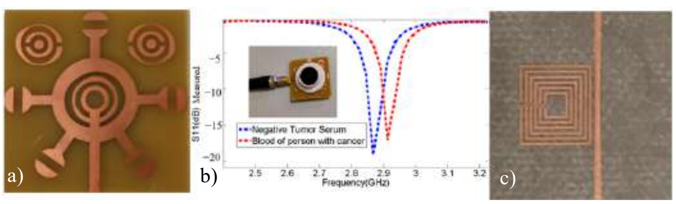

Fig. 2. a) Corona- shaped metamaterial biosensor. b) Resonant frequencies to distinguish negative/ positive tumor serums. c) Metamaterial biosensor for water ethanol mixture characterization.

Design of Metal Waveguide Devices for Power Microwaves

The ability to study and design devices in different shapes of waveguide and cavities is a legacy of our team for several decades, and one of the highlights of teaching in microwave engineering at Toulouse INP-ENSEEIHT.

An original design of a rectangular TE_{10}-to-circular TE_{01} mode converter was undertaken using small ridge elements (**Figure 3**). The result is a device compact enough for application at 915MHz. However, the stability of the circular TE_{01} mode as a function of payload variation remains to be studied.

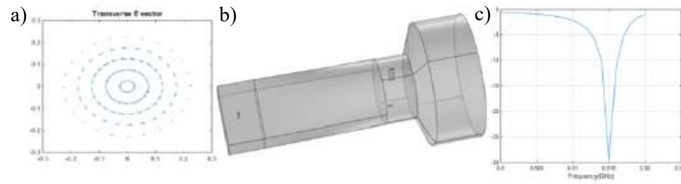

Fig. 3. Waveguide mode-converter (a) Output vector electric field. (b) Rectangular to circular waveguide transition. (c) Input reflection of rectangular TE_{10} mode.

Other research activities

Other recent research activities in our team include:

Modeling and numerical methods: improving existing numerical methods for electromagnetism and developing methods or models dedicated to innovative electromagnetic applications.

A collaboration between CNES (French National Space Agency), MVG (Microwave vision Group), and LAPLACE is taken for the study of Guided Structures with metamaterial Wall.

A model dedicated to this type of structure was developed based on a modal development. Initially allowing the calculation of propagating and evanescent modes in structures with rectangular or cylindrical cross-sections, the code has been improved in terms of computation time by relying solely on a finite element calculation for this part. The analytical functions defining the modes and their mode admittance matrix have been defined for use in a modal matching code. This code is therefore a hybrid code since it uses both a finite element and modal calculation. It now also allows the determination of reflection and transmission coefficients in different cylindrical waveguide arrangements including metamaterial walls, as well as the determination of an electric field map at a given position in the guide.

HF passive circuit design and characterization: developing new circuit topologies, technological implementation and integration/development of microwave filter syntheses, developing measurement methods, and characterizing homogeneous or inhomogeneous media.

One study carried out in collaboration with ONERA (Office Nation d'Etudes et de Recherches Aérospatiales) is transmit-Array Antennas. This is an interesting antenna topology based on the use of planar transmitting arrays, also called discrete lens antennas. These devices are typically illuminated by a primary source (single source or array of compact sources) illuminating a laminated metal-dielectric structure [3].

Microwave/plasma interaction: developing circuits integrating plasma zones, studying and improving plasma generation using RF sources [4].

For further reading

1. L. Savchenko, I. Martinelli, D. Marsal, V. Zhdan, J. Tao, O. Kunduzova, "*Myocardial capacity of mitochondrial oxidative phosphorylation in response to prolonged electromagnetic stress*," Frontiers in Cardiovascular Medicine 10, 1205893, Front. Cardiovasc. Med., 07 June 2023, Sec. Cardiovascular Biologics and Regenerative Medicine, Volume 10 – 2023.
2. N. Dadouche, Z. Mezache, J. Tao, E. Ali, M.d Alsharef, A. Alwabli, A. Jaffar, A. Alzahrani, A. Berazguia, "*Design and Fabrication of a Novel Corona-Shaped Metamaterial Biosensor for Cancer Cell Detection*," Micromachines 2023, 14(11), 2114; https://doi.org/10.3390/mi14112114.
3. A. de Oliveira Cabral Junior, H. Kaouach, A. Barka, "*Wideband and High-Efficiency Circularly Polarized Unit-Cell for X and Ka-Band Transmitarrays*," IEEE Open Journal of Antennas and Propagation, Vol. 5, Issue 4, August 2024.
4. V. Babitski, T. Callegari, L. Simonchik, J. Sokoloff, M. Usachonak,B. I. Stepanov, "*The transmission spectrum switching speed of electromagnetic band gap plasma structure*," Journal of Physics: Conference Series, Volume 1393, 14th International Conference "Gas Discharge Plasmas and Their Applications" 15–21 September 2019, Tomsk, Russia.

About the author

Junwu Tao received the B.Sc. degree in electronics from the Radio Engineering Department, Huazhong (Central China) University of Science and Technology, Wuhan, China, in 1982, the Ph.D degree (with honors) from the Institut National Polytechnique of Toulouse, France in 1988, and the Habilitation degree from the University of Savoie, France in 1999. From 1983 to 1991, he was with the electronics laboratory at INP, Toulouse, France, from 1991 to 2001 has was with the microwave laboratory (LAHC) at the university of Savoie, Chambéry, France, where he was an associate professor in electrical engineering. Since September 2001 he is a full professor at the Institut National Polytechnique of Toulouse. He is a research Fellow with Laboratory of Plasma and Conversion Energy (LAPLACE) and involved in the numerical methods for electromagnetics, microwave and RF components design, microwave and millimeter-wave measurements and microwave power applications. He was a member of the committee that moved the AMPERE association to France in 2008, and continued to take up a constructive role in the life of the association, being a member of the scientific committee up to the present day. He notably organized the 13th AMPERE conference in 2011 in Toulouse, France.

Microwave radiation: A breakthrough for nanotechnnology

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Microwave reactors are used for fast and simple synthesis of materials used in applications such as gas purification, water treatment, energy storage, and drug delivery. While microwave heating is commonly used in households to quickly warm food, microwave ovens can also be used by chemists in