# Interazione tra Campi Elettromagnetici e Biosistemi ICEmB

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**Proceedings del VI CONVEGNO NAZIONALE**
**Cagliari 8-10 giugno 2022**

**a cura di**
**Matteo Bruno Lodi, Alessandro Fanti, Rita Massa**

**RESOCONTI /3**

Il Centro Interuniversitario di ricerca sulle Interazioni fra Campi Elettromagnetici e Biosistemi (ICEmB) nasce ufficialmente alla fine degli anni '80 su iniziativa di un gruppo di docenti e ricercatori con diversa competenza scientifica (medicina, biologia, chimica, fisica, ingegneria) e afferenti a diverse sedi universitarie e Enti nazionali di ricerca pubblica che già da tempo stavano conducendo, come singoli gruppi, attività di ricerca riguardanti lo studio delle interazioni fra campi elettromagnetici e sistemi biologici. Consapevoli della necessità dell'apporto scientifico multidisciplinare integrato per il raggiungimento degli obiettivi della ricerca in tale settore nel 1985 fu dapprima avviato un gruppo informale di coordinamento nazionale e nel 1989 fu istituito ICEmB.
Oggi, il centro ICEmB è una realtà consolidata, inserita e riconosciuta a livello scientifico e organizzativo in un contesto sia nazionale che internazionale.

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**4. Biomedical Applications of EMF**



**5. Food Engineering**



**6. Applied Electromagnetics and Human Exposure**

# Prefazione

Questo volume raccoglie i contributi scientifici presentati nella VI edizione del convegno nazionale "Interazioni tra Campi Elettromagnetici e Biosistemi" svoltosi a Cagliari dall'8 al 10 Giugno 2022 presso la Facoltà di Ingegneria dell'Università degli Studi di Cagliari, organizzato dal Centro Interuniversitario ICEmB, l'Università di Genova e l'Università degli Studi di Cagliari.

L'obiettivo del convegno, in linea con le precedenti iniziative, è stato quello di stimolare il confronto tra i ricercatori che, nei rispettivi settori disciplinari (fisica, ingegneria, biologia, medicina, epidemiologia), contribuiscono attivamente allo sviluppo delle conoscenze nell'ambito del bioelettromagnetismo e delle interazione tra campi elettromagnetici e biosistemi.

I contributi riguardano le seguenti, ma non esclusive, tematiche: i) studio degli effetti dei campi elettromagnetici in vivo, in vitro, sull'uomo (studi di laboratorio e/o epidemiologici), ii) esposizione/dosimetria, iii) applicazioni biomedicali, iv) meccanismi di interazione e v) food engineering.

Il programma scientifico del convegno prevede contributi nell'ambito dello studio degli effetti biologici e sanitari dei campi elettromagnetici, della dosimetria elettromagnetica, dei modelli e meccanismi di interazione, delle applicazioni biomedicali e si articola in 3 relazioni ad invito, 8 sessioni orali per un totale di 32 interventi.

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# VI Convegno Nazionale

# "Interazione tra Campi Elettromagnetici e Biosistemi" ICEmB

8-10 Giugno 2022

Aula 2 Edificio N, Facoltà di Ingegneria, via Is Maglias 198, Cagliari

## Con il supporto di

# Programma - Short

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| **Mercoledì 8 Giugno 2022** | |
| 12:00-14:00 | Registrazione |
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| 16:20-17:00 | Coffee Break |
| 17:00-19:00 | Consiglio Scientifico |
| **Giovedì 9 Giugno 2022** | |
| 8:50-9:20 | Plenary I: **Measuring the 5G Field Level for Human Exposure Assessment: A Lesson for 6G (M. D. Migliore, Univ. Cassino)** |
| 9:20-10:40 | Session II: 5G Challenges |
| 10:40-11:00 | Coffee Break |
| 11:00-11:40 | Session III: 5G Challenges |
| 11:40-12:40 | Session IV: Occupational Exposure |
| 12:40-14:00 | Pausa Pranzo |
| 14:00-14:30 | Plenary II: **Electromagnetic Biosensing: Non-Invasive Biomedical Applications (S. Costanzo, Univ. della Calabria )** |
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| 9:00-9:30 | Plenary III: **Electromagnetic imaging for quality inspection in food industry (L. Crocco, IREA-CNR)** |
| 9:30-11:10 | Session VII: Food Engineering |
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| 11:30-12:30 | Session VIII: Applied Electromagnetics and Human Exposure |
| 12:30 | Saluti |

# Mercoledì 08/06/2022

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|---|---|
| **Registrazione** | **9:00-14:00** |

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|---|---|
| **Benvenuto e Saluti Istituzionali** | **14:00-14:20** |
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| ***Prediction of Exposure Levels in 5G Networks with an Electromagnetic Propagation Software***<br>G. Di Martino, M. Gargiulo, A. Iodice, D. Riccio, G. Ruello | **09:40-10:00** |
| ***Numerical Assessment of Human RF-EMF Exposure in 5G V2X Connected Vehicles***<br>M. Bonato, M. Benini, S. Gallucci, E. Chiaramello, S. Fiocchi, P. Ravazzani, M. Parazzini, G. Tognola | **10:00-10:20** |
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| ***Protection of Workers Exposed to EMFs above Occupational Limits***<br>A. Polichetti, G. M. Contessa, S. D'Agostino, R. Falsaperla, C. Grandi | **12:20-12:40** |
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# Giovedì 09/06/2022

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| **Plenary II: Electromagnetic Biosensing: Non-Invasive Biomedical Applications (S. Costanzo, Univ. della Calabria )** | **14:00-14:30** |
| ***Session V: EMF Biomedical Applications*** | **14:30-16:10** |
| ***Terahertz Imaging of Magnetic Scaffolds***<br>S. Zappia, I. Catapano, R. Scapaticci, L. Crocco | **14:30-14:50** |
| ***Microwave-Based Tomography of the Human Neck by Means of a Neural-Network Technique***<br>C. Dachena, A. Fanti, A. Fedeli, G. Fumera, M. B. Lodi, M. Pastorino, and A. Randazzo | **14:50-15:10** |
| ***Some Advances in Magnetic Resonance Imaging: Radiofrequency Shimming and Electrical Properties Tomography***<br>S. Zumbo, M. T. Bevacqua, T. Isernia | **15:10-15:30** |
| ***Design of Metamaterials for the Refinement of Mini-invasive Microwave Needle Applicator***<br>V. Portosi, A. M. Loconsole, M. Valori, V. Marrocco, I. Fassi, F. Bonelli, G. Pascazio, V. Lampignano, A. Fasano, F. Prudenzano | **15:30-15:50** |
| ***On the Development of a mm-Wave Imaging System for Breast Cancer Detection***<br>S. Di Meo, G. Matrone, M. Pasian | **15:50-16:10** |
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| ***Physical Interpretation of the Effects of High Permittivity Materials on the Field Distribution in Ultra High Field Magnetic Resonance Imaging***<br>G. Ruello, R. Lattanzi, R. Massa | **16:30-16:50** |
| ***Magnetic Scaffolds for Biomedical Applications of Electromagnetic Fields***<br>M. B. Lodi, N. Curreli, G. Mazzarella, A. Fanti | **16:50-17:10** |
| ***A Combined Strategy for Incident Field Characterization in Phaseless Microwave Imaging***<br>S. Costanzo, G. Lopez, G. Di Massa | **17:10-17:30** |
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# Venerdì 10/06/2022

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| **Plenary III: Electromagnetic imaging for quality inspection in food industry (L. Crocco, IREA-CNR)** | **9:00-9:30** |
| **Session VII: Food Engineering** | **09:30-11:10** |
| ***On the Design of a Microwave Moisture Content Sensor for Carasau Bread: A Feasibility Study***<br>G. Muntoni, A. Fedeli, M.B. Lodi, M. Simone, A. Randazzo, A. Fanti | **09:30-09:50** |
| ***Preliminary Design of a Double Ridge Waveguide Device for Monitoring the Complex Permittivity of Carasau Bread Doughs***<br>C. Macciò, M.B. Lodi, N. Curreli, G. Muntoni, M. Simone, M. Bozzi, G. Mazzarella, A. Fanti | **09:50-10:10** |
| ***Magneto-Priming Improves Germination in Caspicum annuum L.***<br>N. D'Ambrosio, G. Chirico, C. D'Elia, M. Rapesta, V. Mancuso, R. Massa | **10:10-10:30** |
| ***Microstructural investigation of Durum Wheat Dough through Low-Temperature Broadband Dielectric Spectroscopy (BDS): Influence of Water, Salt and Semolina properties***<br>F. Fanari, C. Iacob, G. Carboni, F. Desogus, M. Grosso, M. Wilhelm | **10:30-10:50** |
| ***Terahertz Imaging for Food Quality Inspection***<br>S. Zappia, I. Catapano, R. Scapaticci, L. Crocco | **10:50-11:10** |
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| **Session VIII: Applied Electromagnetics and Human Exposure** | **11:30 -12:30** |
| ***A review of the literature on the use of microwave heating for the conservation of works of art***<br>S. Romeo, O. Zeni | **11:30-11:50** |
| ***Human EMF Exposure Assessment due to Wearable Devices***<br>S. Gallucci, M. Benini, M. Bonato, E. Chiaramello, S. Fiocchi, P. Ravazzani, G. Tognola, M. Parazzini | **11:50-12:10** |
| ***Exposure Assessment of a WPT System to Recharge a Compact EV***<br>V. De Santis, L. Giaccone, F. Freschi | **12:10-12:30** |
| **Saluti** | **12:30** |

# 1. Invited Lectures

## Measuring the 5G Field Level for Human Exposure Assessment: A Lesson for 6G

Marco Donald Migliore

*DIEI, Università di Cassino e del Lazio Meridionale*

*IcemB*

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The problem of measuring the field level for the assessment of human exposure has been characterized by increasing difficulties in the transition from 2G to 5G, caused by an increasing flexibility of cellular communication systems. Although increased flexibility was the key factor in achieving higher performance, it had a major impact on field level measurement for human exposure assessment.

This is especially true in 5G, where new technologies such as MIMO make field level measurement a challenging problem. Indeed, during the development of the 5G standard, the impact of the introduction of beam steering and MIMO technologies on field level measurement for human exposure assessment was underestimated.

Future 6G communication systems will feature even greater flexibility, which will include partial control of the electromagnetic environment in which the communication system will operate.

The 5G experience suggests considering issues related to human exposure assessment from the outset, on the one hand considering the transmission of reporting data that can aid field-level measurement for human exposure assessment, and on the other hand considering the possibility of following a safety-on-design approach to exposure to electromagnetic fields from the very beginning of the development of the 6G standard.

**About the Speaker**

**Marco Donald Migliore** received the Laurea (Hons) and Ph.D. degrees in electronic engineering from the University of Naples, Naples, Italy. He is currently Full Professor with the University of Cassino and Southern Lazio, Cassino, Italy. His main scientific interests include the development of Maximum Power Extrapolation techniques for 5G, synthesis of antennas in complex environments, massive MIMO antennas and propagation, ad hoc wireless networks, antenna measurements, electromagnetic information theory, medical and energetic applications of microwaves. Prof.. Migliore is a member of the IEEE, Italian Electromagnetic Society (SIEM), the National Interuniversity Consortium for Telecommunication (CNIT) and of the ELEDIA@UniCAS. He serves as a referee for many scientific journals, including the IEEE Transactions on Antennas and Propagation, the IEEE Antennas and Wireless Propagation Letters, the IEEE Transactions on Vehicular Technology, the Journal of Optical Society of America, the IEEE Transactions on Signal Processing, and the IEEE Transactions on Information Theory. He has served as an Associate Editor for the IEEE Transactions on Antennas and Propagation. He is currently the director of the Microwave Laboratory in Cassino.

# Electromagnetic Biosensing: Non-Invasive Biomedical Applications

S. Costanzo

*Department of Computer Engineering, Modelling, Electronics, and Systems Science (DIMES), University of Calabria, Rende, Italy*

costanzo@dimes.unical.it

In this talk, physical mechanisms and design principles of electromagnetic biosensors and radar will be outlined, for specific applications in the framework of biomedical parameters.

## About the Speaker

**Sandra Costanzo** (Senior Member, IEEE) received the Laurea Degree (summa cum laude) in computer engineering from the Università della Calabria, Rende, Italy, in 1996, and the Ph.D. degree in electronic engineering from the Università Mediterranea di Reggio Calabria, Reggio Calabria, Italy, in 2000. In 2017, she awarded the Italian National Scientific Qualification for the Full Professor position. Since 2019, she has been an Associate with IREA-CNR, Naples, Italy. She is currently an Associate Professor with the Università della Calabria, where she is the Coordinator of master's degree in telecommunication engineering and the Rector's Delegate for security, protection, and control of electromagnetic fields. She teaches courses on electromagnetic waves propagation, antennas, remote sensing, radar, sensors, and electromagnetic diagnostics. She has authored or coauthored more than 190 contributions in international journals, books, and conferences. Her research interests include near-field/far-field techniques, antenna measurement techniques, antenna analysis and synthesis, numerical methods in electromagnetics, millimeter wave antennas, reflectarrays, synthesis methods for microwave structures, electromagnetic characterization of materials, biomedical applications, and radar technologies. She is Member of the IEEE MTT-28 Biological Effects and Medical Applications Committee, IEEE South Italy Geoscience and Remote Sensing Chapter, Consorzio Nazionale Interuniversitario per le Telecomunicazioni, Società Italiana di Elettromagnetismo, Centro Interuniversitario sulle Interazioni fra Campi Elettromagnetici e Biosistemi, and a Board Member of the IEEE AP/ED/MTT North Italy Chapter. She was the recipient of the Telecom Prize for the Best Laurea Thesis in 1996, and Best Academia and Research Application in Aerospace and Defense 2013 Award for the application Software Defined Radar using the NI USRP 2920 platform. She is an Associate Editor for the IEEE Access, IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology, Electronics (section "Microwave and Wireless Communications"), and Editorial Board Member of Radioengineering and International Journal of RF and Microwave Computer-Aided Engineering. She is the Editor of the books Microwave Materials Characterization (INTECH, 2012) and Wave Propagation Concepts for Near-Future Telecommunication Systems (INTECH, 2017). She was the Lead Editor of Special Issues titled: Reflectarray Antennas: Analysis and Synthesis Techniques

(2012), Advances in Radar Technologies (2013), Compressed Sensing: Applications in Radar and Communications (2016), Bioengineering Applications of Electromagnetic Wave Propagation (2019), and Microwave Sensors for Biomedical Applications (2020).

# Electromagnetic imaging for quality inspection in food industry

L. Crocco

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Food is one of the main and world-wide-recognized assets of "made in Italy". The overall economic impact of food industry in Italy in 2017 was almost 35 Billion € and such a figure is expected to further increase in the future. In food industry, foreign body contamination, packaging failures, or items with poor characteristics (texture, appearance) are among the main sources of costumers' complaint against manufacturers, resulting in loss of brand loyalty and large recall expenses. Food industry, and not only at national level, is particularly exposed to these issues, especially nowadays that aware consumers place much more attention to the quality and integrity of purchased food.

Currently, different technologies are adopted to cope with this problem, but, due to the limitations of each of the available solutions, the occurrence of incidents remains significant. In particular, most common monitoring devices are metal detectors and X-rays systems. However, metal detectors can only detect metallic objects, while X-rays have limitations in detecting low-density materials, such as those based on low-density polyethylene and polypropylene, the most common plastics (with a density below 1 g/cm$^3$) widely employed in food packaging. Finally, near infrared imaging techniques are also exploited, but they are limited by the short penetrating length and the strong absorption in water.

In this talk, the capabilities of electromagnetic technologies for contact-less non-invasive diagnostics of product quality within the food-production chain, i.e., with no need to interrupt the fabrication process, will be presented. In particular, it will be shown how the interplay among microwave and THz portions of the electromagnetic spectrum may enable the capability of an integrated multi-resolution sensing approach to detect foreign bodies (e.g., plastic or glass fragments), reveal packaging damages, and assess surface texture and internal properties. The basics aspects of the diagnostic technology will be illustrated, along with results from some relevant study cases.

## About the Speaker

**Lorenzo Crocco** is a Research Director with the Institute for the Electromagnetic Sensing of the Environment, National Research Council of Italy (IREA-CNR). His scientific activities mainly concern electromagnetic scattering, with a focus on diagnostic and therapeutic uses of EM fields, non-invasive electromagnetic inspections, through-the-wall radar and GPR. On these topics, he has published more than 120 papers, given keynote talks and lectures, and led or participated to national and international research projects. He is associate editor for the IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology (IEEE J-ERM) and has edited a book on Electromagnetic Technologies for Brain Diseases Diagnostics, Monitoring and Therapy. From 2013 he is Italian representative in the Management Committees of COST actions devoted to medical applications of EM fields (MiMed on microwave imaging and MyWAVE on therapeutic applications of electromagnetic waves). Since 2015, he has been member of the board for the European School of Antennas (ESOA). Since 2017, he is Member of the Board of Directors of the Italian Electromagnetic Society (SIEm). In 2018, he received the full professor habilitation in electromagnetic fields, by the Italian Ministry of Research and University. Since 2019, he is a member of the Italian URSI Commission (International Union of Radio Science). In 2019, he has been elected in the Scientific Board of the Engineering Department (DIITET) of CNR. Dr. Crocco has been the recipient of the SIEm "Barzilai" Award for Young Scientists (2004) and YSA at the URSI General Assembly held in New Delhi (India) in 2005. Dr. Crocco is a fellow of the Electromagnetic Academy (TEA) and a URSI Senior Member.

# 2. Mechanisms of Interactions

## Magnetic Field Effects on Adenosine $A_{2A}$ Receptor: a Molecular Dynamics Insight

Federico Del Signore*, Paolo Marracino +, Davide Cocco *, Simona Salati#, Stefania Setti #, Ruggero Cadossi #, Micaela Liberti *, Francesca Apollonio *

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Abstract—*This paper provides a new insight into the interaction between an external magnetic field and a transmembrane protein receptor adenosine $A_{2A}$ via molecular dynamics simulation in order to elucidate how magnetic field can influence the receptor at molecular level.*

### I. Introduction

Several experiments have shown how Pulsed Electromagnetic Fields (PEMFs), which are basically low-frequency magnetic fields applications, may have biological effects on cells function as anti-inflammatory agents [1,2]. Depending on the shape and intensity of the applied PEMFs, experimental data suggest a modulation of adenosine $A_{2A}$ receptor activity, which leads to an increase of receptors availability [1]. Nevertheless, the molecular mechanism behind this increase has not been elucidated yet.

Molecular Dynamics (MD) simulations are a powerful tool used to study complex biological structures at molecular level to understand the possible interactions among atoms and molecules over time. Gromacs software for MD simulations has been modified by the authors to properly introduce the application of a static magnetic field inside its internal routines and verify its presence [3].

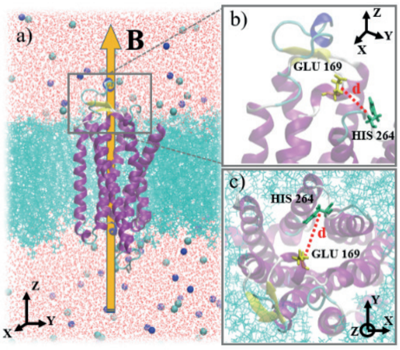


Fig. 1 a) Lateral view of the $A_{2A}$ embedded in a double lipid bilayer (cyan) surrounded by water molecules and ions. The arrow represents the direction of the magnetic field (B). b and c) A zoom of the extracellular part with residue Glu 169 and His 264 and their distance d.

### II. Methods

A specific model of the adenosine receptor $A_{2A}$ (http://mms.dsfarm.unipd.it/Adenosiland/list.php P11617 code from UniProtKB) was chosen and embedded in a POPC lipid bilayer (Fig. 1, a) and placed inside a simulation box with dimension 10x10x15 $nm^3$. Subsequently, the box was filled with TIP3P water molecules, sodium and chloride ions (overall, the system was neutral). The NPT (number of atoms, pressure and temperature constant) statistical ensemble was considered. Temperature and pressure were kept constant at 310 K and 1 atm, respectively.

Several simulations were carried out, without magnetic field applied and with a 1 T magnetic field B, perpendicular to the membrane surface (Fig. 1, a). Finally, various global and local observables were studied.

### III. Results and Conclusions

Our results show a local effect related to some key residues involved in the so called meta-binding site [4]. These residues are placed in the extracellular entrance mouth of the receptor pocket (Fig. 1, b and c), creating a kind of extracellular entrance area. In particular, the magnetic field seems to affect the distance between Glu 169 and His 264 (Fig. 2), keeping the entrance area in an open state when the magnetic field is applied. Moreover, global analysis confirmed that the protein doesn't suffer effects on its conformational stability with and without the magnetic field.

These findings support the idea that external magnetic perturbation can only alter local properties of the protein, promoting the enlargement of the extracellular part and thus the accessibility of ligands to the binding site.

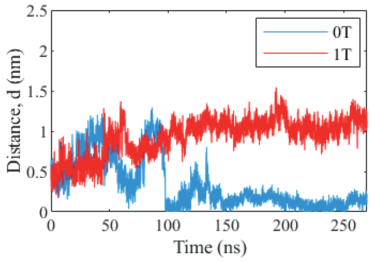


Fig. 2 Time evolution of the distance d between Glu 169 and His 264 in module between 0 T (blue) and 1 T (red) for 270 ns.

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# Frequency Analysis of Proteins in Water Exposed to Electromagnetic Fields: A Computational Study Using Molecular Dynamics Simulations

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Abstract— *This study aims to confirm in silico the frequency behavior of proteins (Havriliak-Negami equation) in aqueous environment induced by electric fields, in particular continuous wave signals (CW). Classical Molecular Dynamics simulations (MD) are performed applied to the molecular structure Human Pancreatic Ribonuclease in water.*

## I. Introduction

The interaction of biological systems with electromagnetic fields (EMF) has long been under investigation. Specifically, using EMF of varying frequency, it is possible to study the dielectric relaxation mechanism by means of Havriliak-Negami model (H-N) [1]. To provide more evidence on such effect, we studied the Human Pancreatic Ribonuclease, a globular protein with 127 aminoacid residues [2]. Its high dipole moment (about 600 D) involves a major response to the electric exposure [3].

## II. Material and Methods

MD simulations, using the software Gromacs, have been performed in a cubic box where the protein was placed surrounded by 15453 water molecules at a temperature of 300 K. Then, we applied a set of CW signals, along x-axis of Gromacs reference system with different intensity in a range of frequency from 0 to 20 GHz with tens of nanoseconds duration. After having obtained from Gromacs the dipole moment of the whole system, we fitted the data with the Langevin equation as a function of the field intensity. In this way, by subtracting the water simulations from those related to the water-protein system, we extracted the parameter δ of the protein that considers the percentage of dipoles oriented along the field. This allowed us to characterize the frequency behavior of the system.

## III. Preliminary Results And Discussion

In Fig.1 we present the frequency profile of the parameter δ with a focus on fitting through the real part of H-N equation, an extended version of Debye model [1].

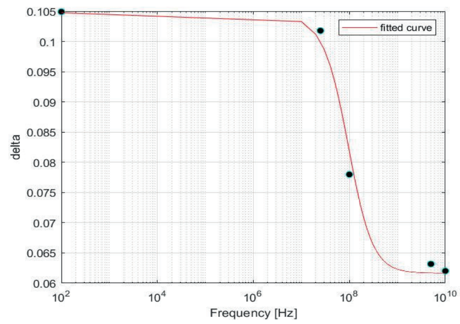


Fig. 1 Fitting δ with Havriliak-Negami equation (real part)

Fig. 2 represents the imaginary part that takes into account the dielectric loss where, at the peak, we extrapolated the value of the relaxation frequency.

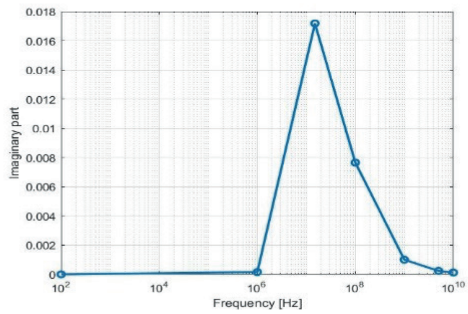


Fig. 2 Imaginary part of Havriliak-Negami equation

Carrying out the fitting with H-N function (real part), we estimated the relaxation time, α, β (exponents that describe the asymmetry and broadness of the dielectric dispersion curve), the permittivity at the high frequency limit and the low frequency permittivity as in Table I.

TABLE I

Parameters estimated with Havriliak-Negami equation

| | |
|---|---|
| $\varepsilon_\infty$ | 0.06165 |
| $\varepsilon_s$ | 0.1048 |
| α | 0.9000 |
| β | 1 |
| $\tau/f_c$ | $1\ 10^{-8}$s/15.92 MHz |
| R-square | 0.9879 |

## IV. Conclusions

These outcomes, reported in Table I, allowed us to prove that H-N equation reduces to Cole-Cole function with a relaxation frequency in very good accordance with the physical properties of protein [1]. This approach was also implemented for another protein, Myglobin, well characterized in previous work [4], thus confirming the importance of the model for providing the dielectric properties of proteins in water. Further analysis has been carried out to improve the quality of the fitting and to identify the differences between the two proteins.

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# Numerical Dosimetry of the PEMFs Neuroprotective Effect through a Semi-Specific Modeling: Comparison between an Active and a Placebo Patient

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Abstract—*The application of low intensity and low frequency pulsed electro-magnetic fields (PEMFs) may represent a neuroprotective treatment of acute ischemic stroke. This work proposes a dosimetric study on semi-specific models of a placebo and an active patient, recruited for the I-NIC project, with the aim to compare the different trend of the two dose-response curves.*

## I. Introduction

Ischemic stroke is a cerebrovascular disease that occurs due to partial or complete interruption of cerebral blood flow. Several in-vivo and in-vitro studies have suggested the interaction between the low frequency and low energy (1-3.5 mT) PEMFs with the A2a and A3 adenosine receptors, involved in human body's anti-inflammatory responses [1]. The results on safety and tolerability of an open-label study [2] laid the groundwork for the I-NIC project [3]: a multicentric, randomized, placebo-controlled, double-blind study, in which approximately 124 patients are under recruitment, to clarify the effectiveness of the PEMFs therapy. This work proposes a dosimetric study, following the patient's head semi-specific modelling approach assessed in [4], of a placebo and an active patient to evaluate the possible correlation between the evolution of the ischemic lesion and the magnetic induction (B) intensities.

## II. Materials and Methods

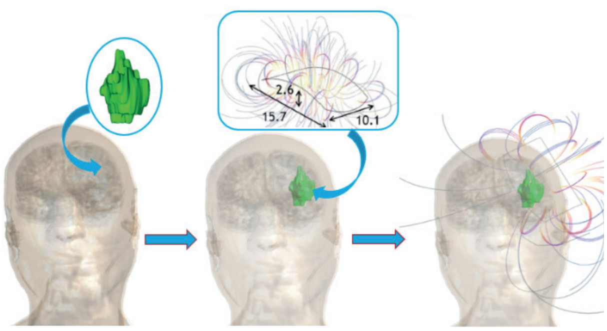


Figure 1. Example of the semi-specific model building: ischemic lesion model placement in Glenn, coil positioning and dosimetric evaluations.

For both the active and the placebo patients, the semi-specific model is built (Figure 1). This is done by precisely placing the 3D model of the ischemic lesion obtained from each patient's MRI scans at the time of the insult (i.e. pre-) inside a detailed generic head model (Glenn, ViP, V.3.0) [5]. The stimulating coil is reproduced in the simulation environment with a single turn rectangular wire, with no thickness, slightly bent to make it adaptable to the head shape and placed as it would be during the treatment. Such built models are simulated in Sim4Life (ZTM Zurich MedTech AG) using the magneto quasi-static module. To evaluate the ischemic volume progression after the PEMFs treatment and correlate it with the B intensities, the 3D model of the ischemic lesion at the 45 days follow-up is obtained as well (i.e. post-). B-field values ($B_{thr}$) in a range from 1 mT to 2 mT were selected and the amount of pre-treatment volume ($V_{pre}$) exposed to a $B \geq B_{thr}$, as well as the corresponding post- volume ($V_{post}$) were evaluated for each patient. The ratio $V_{post}/V_{pre}$ was computed with respect to $B_{thr}$ to attain the dose-response curve.

## III. Results

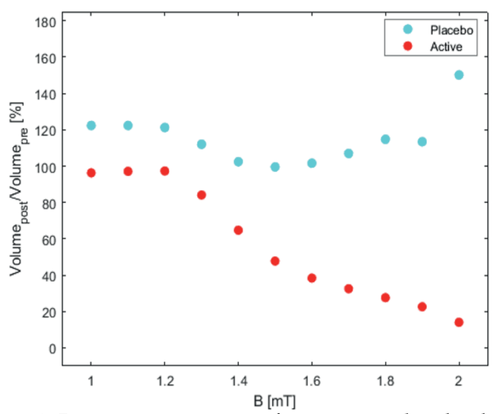


Figure 2. Dose-response curve of an active and a placebo patient.

Fig. 2 shows that the ratio between post- and pre-treatment volumes, as a function of B intensities, in one representative placebo patient (cyan dot) is about 122% and increases to 150%

at 2 mT; conversely, for the selected active patient (red dot) the ratio is always under 100%, addressing a possible reduction of the post-treatment lesion, and its curve decreases for higher $B_{thr}$ values.

## IV. Conclusions

In conclusion, these preliminary data are promising towards demonstrating the efficacy of LF-PEMFs as a treatment for acute ischemic strokes. The patients' recruitment is still ongoing and, once completed, the effectiveness of the PEMFs will be finally evaluated.

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# Computational Study of the Influence of Electromagnetic Field over the Deprotonation of Thiol group in Thioredoxin's Cysteine 35

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Abstract — *Thioredoxin is a small protein with a major antioxidant role in the intracellular environment. Its reactivity is linked to the acidity of its two cysteines (32 and 35) present in its active site. Through a hybrid Quantum Mechanics / Molecular Mechanics (QM/MM) approach we estimated the* $pK_a$ *values of Cysteine 35 and identified a strong non-thermal catalytic effect of the electric field towards the deprotonation of its thiol group.*

## I. Introduction

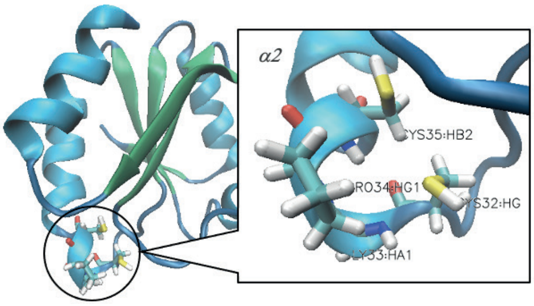


Fig. 1 Thioredoxin and its Active Site CGPC motif

Thioredoxin (TRX) is a small globular protein present in all types of cells, and it's well known to have a major antioxidant role, as it is expressed as a defense to different kinds of stress [1], [2]. Its active site can be found in the N-terminal part of its $\alpha_2$-helix and contains a CGPC motif: Cysteine 32, Glycine 33, Proline 34 and Cysteine 35 (Fig. 1) [2], [3]. The two lateral cysteines carry out the antioxidant role of TRX, cyclically passing from their reduced form of thiol ($R-SH$) to their oxidated form of disulphide bridge ($R-S-S-R'$) [2], [3]. The reactivity of TRX is strongly linked to the $pK_a$ values of Cysteine 32 and Cysteine 35 [3]. We aim to estimate such values under the exposure to electromagnetic fields (EMF) and evaluate a possible catalytic effect of EMF on the deprotonation of Cysteine 35, thus affecting its acidity.

## II. Methods

To study this system a hybrid approach QM/MM is needed. The quantum center (QC) is identified with the lateral chain of Cysteine 35 itself and treated with a quantum-mechanical approach, while the rest of the system is treated classically. The computational method used is Perturbed Matrix Method (PMM), in which the Hamiltonian of the QC, $\widehat{H}$, is obtained by perturbation of the unperturbed one, $\widehat{H}^0$, as in:

$$\widehat{H} = \widehat{H}^0 + \widehat{V} \tag{1}$$

Where $\widehat{V}$ is the perturbation due to the rest of the system evaluated by Molecular Dynamics' simulations.

We estimated the acidity of Cysteine 35 [4]:

$$pK_a = \frac{\Delta A_{el} - \Delta U_{el}^0 + constant\ term}{2.303\ k_B T} \tag{2}$$

where $\Delta A_{el}$ (electronic energy of deprotonization) is calculated with PMM, $\Delta U_{el}^0$ (unperturbed energy of QC) by quantum-mechanical calculation and the constant term is evaluated experimentally.

## III. Preliminary Results

We show results in terms of ΔA [kJ/mol] and $\Delta pK_a$, considering the $pK_a$ of single cysteine in water as base value.

Table II

Influence of Temperature over Cysteine 35's Acidity

| Temperature (K) | ΔA [kJ/mol] | $\Delta pK_a$ |
|---|---|---|
| T = 300 | 1198.8 | - 3.11 |
| T = 310 | 1193.1 | - 4.11 |
| T = 320 | 1193.6 | - 4.01 |
| T = 330 | 1204.5 | - 2.11 |

In Table I is shown how temperature doesn't have a significant effect on the $pK_a$ value (maximum variation 1).

TABLE III

INFLUENCE OF THE ELECTRIC FIELD OVER CYSTEINE 35'S ACIDITY

| **Electric Field (V/nm)** | **ΔA [kJ/mol]** | **$\Delta pK_a$** |
|---|---|---|
| E = 0.00 | 1198.8 | - 3.11 |
| E = 0.01 | 1178.8 | - 6.58 |
| E = 0.04 | 1154.6 | - 10.79 |
| E = 0.08 | 1120.8 | - 16.66 |

In Table II is shown how there is a substantial decrease (maximum variation of 13.55) of the $pK_a$ value with the increasing of the amplitude of the electric field applied.

## IV. CONCLUSIONS

The preliminary results show a relevant catalytic effect of the electric field toward the deprotonation of Cysteine 35's thiol group, this same influence isn't found under the effect of temperature. Thus, we identified a non-thermal mechanism of interaction of the electric field with the thiol group. We aim to further characterize such effect.

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# On the electrical behavior of PEF treated tissues

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Abstract— *Results concerning the electrical behavior of potato tissue subjected to Pulsed Electric Field treatment are presented and compared to the corresponding measured DC conductivity. The experimental setup is proposed as a platform to evaluate different stimuli effect by looking at the time behavior of the current given by the high-voltage distorted waveform adopted in electrochemotherapy.*

## I. Introduction

Electrochemotherapy (ECT) is a clinical treatment for cancer where the electric field is used to support and to improve the chemotherapy drug uptake. In ECT a sequence of 8 voltage pulses of one hundreds μs long is applied trough suitable plate electrodes to the tissue under-treatment, generating a pulsed electric field (PEF) between the electrodes which amplitude is inversely proportional to the plate distances. The PEF interacts with the tissue generating not only a current in the tissue but also morphological and physiological modifications when its amplitude overcomes a given threshold (i.e. hundreds of V/cm) that modify the cell membrane opening aqueous channels. The obtained phenomenon is called electroporation (EP): the PEF temporally permeabilizes the cancer cell membrane improving the drugs uptake and, therefore, increasing their effect [1]. The EP due to the applied voltage pulses is translated in an electrical conductivity of the tissue spatially dependent on the electric field, that is quite different form the DC measured electrical conductivity often used as an estimation of the EP degree. Nevertheless, the DC measure is obtained in off-line standard condition (SC) and leads to the manipulation of the sample under test that, in case of in vitro experiments, could affect the experimental results acting as an invasive experiment. In order to limit the influence of the measure on the sample under test, is interesting to evaluate alternative strategies helping in to detect EP phenomenon. Therefore, in this paper an experimental set-up usable to estimate electrical properties of a tissue in not-standard condition (NSC) linked to the high-voltage distorted waveform adopted in ECT treatment is explored as an alternative to the SC evaluation. The procedure is assessed on potato tuber tissue as phantom.

## II. Material and Methods

Electrical properties of the potato tuber were evaluated using SC by applying direct current in a low-voltage condition. In particular yellow potatoes samples are prepared filling the 8 well of a chamber slide of about 1x1x1 $mm^3$ volume like the ones reported in fig. 1. The DC electric proprieties are investigated with a KEITHLEY 6514A used as Ohmmeter, through which a resistance measurement R is carried out with respect to the samples that are in the chamber slide box supported by opportune electrodes. In Fig. 1b) the adopted configuration. Following the *R* measurements, the application of the second Ohm's law leads to obtain the electrical conductivity $\sigma_{SC}=S/(l*R)$ being $l$ the distances between the electrodes and *S* the surface of the sample directly interfaced with the electrodes.

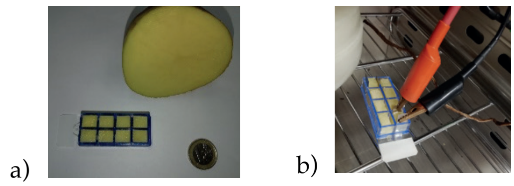

Fig. 1 a) Chamber slide filled with potatoes samples for electrical tests and b) systems under test.

The test is performed before and after PEF treatments at different condition deriving the corresponding SC electrical conductivity. As NSC, the voltage pulses were applied by means of a voltage pulse generator (EPS-01, manufactured by Igea S.p.A., Carpi (MO), Italy) that imposes 8 pulses 100 μs long, 5 kHz, at a given amplitude, which corresponds to a specific electric field amplitude, E, according to the electrodes distance. From the acquired voltage and current in the treated tissue, an estimation of the $\sigma_{NSC}(E)$ is obtained as in [2, 3] by looking at the plateau of the measured quantities.

## III. Results

Fig. 2 reports the electrical conductivity $\sigma_{NSC}(E)$ evaluated for the potato tubers as describe in [3]. The two curves represent two different tubers, and the band represents the variation ranges of the conductivity for different potato tubers. The conductivity of the same samples was evaluated using SC before and after the voltage pulse application leading to mS/m values which difference with respect to the NSC extrapolated ones will be discussion of the presentation.

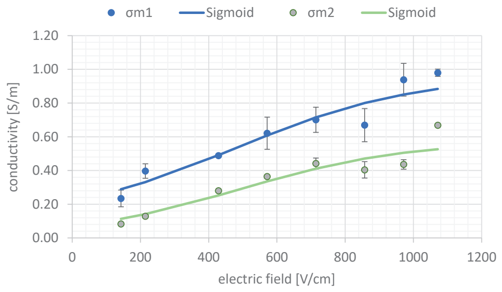


Fig. 2 Estimated conductivities in NSC $\sigma_{NSC}(E)$

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# Pulsed Electromagnetic Fields: a Novel Attractive Therapeutic Opportunity for Neuroprotection after Acute Stroke

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Abstract — *Stroke indicates a sudden and acute brain damage that occurs in an area of the brain due to a circulatory disorder causing the death of neuronal cells. In recent years, there has been considerable interest in the biological action of low frequency and low intensity pulsed magnetic fields (PEMFs). Pre-clinical data and preliminary clinical studies suggest that PEMFs could represent a novel non-invasive adjunctive treatment for acute ischemic stroke, providing neuroprotection and reducing functional deficits following ischemia.*

## I. Introduction

In recent years, numerous clinical trials tested the neuroprotective efficacy of different drug therapies. However, to date, no clinical pharmacological studies have been able to confirm in humans the results obtained in vitro or in animal models. The search for new and effective therapies for stroke patients remains an important unmet need.

The application of Pulsed ElectroMagnetic Fields (PEMFs) to cerebral ischemia is based on sound pre-clinical evidence showing that PEMFs exert a strong neuroprotective action on the Central Nervous System (CNS).

Recently, an early feasibility study designed to evaluate the effect of daily exposure to PEMFs on the MRI (Nuclear Magnetic Resonance Imaging) evolution of neurological lesions in patients with acute ischemic stroke, allowed the identification of the best treatment regimen: 120 minutes/day for 5 days [1].

This study opened the way to a randomized, placebo-controlled, double-blind study aimed at evaluating whether PEMFs exposure is able to promote recovery in acute ischemic stroke patients (NCT02767778, I-NIC study).

## II. Results

The primary aim of the study was to evaluate the effect of PEMFs on the size of the ischemic lesion measured by MRI at different follow-ups (7 and 45 days after stroke). Secondary objectives of the clinical trial include the clinical evaluation of brain stroke patients using NIHSS, mRS and Barthel Index clinical scores at 7, 45 and 90 days. Figure 1 shows the design of the I-NIC study.

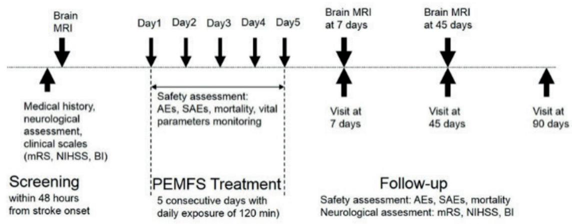


Fig. 1 I-NIC flow chart.

Recently, an interim analysis of the first 35 patients enrolled in the study was carried out: 19 in the placebo group and 16 in the active group.

The results of the interim analysis confirmed the safety of the I-NIC therapy: i) no serious adverse event was reported, ii) the MRI performed 7 days after the ischemic event excluded the haemorrhagic transformation of the lesion in all patients studied and iii) no patient presented worsening of the neurological conditions as evidenced by NIHSS values.

The MRI evaluation performed at 45 days showed a greater reduction in the average lesion size in the active group than in the placebo group. It is important to notice that, while the difference between the lesion volume at baseline and at 45 days in the placebo group is not statistically significant, such difference in the active group reaches the statistical significance (p=0.026).

Based on the scientific literature, the ischemic lesion volume decrease is predictive of substantial clinical improvement [2], thus I-NIC therapy by sparing cerebral tissue from the ischemic damage has the potential to significant improve the clinical outcome of brain stroke patients.

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# 3. 5G Challenges

## A Reverberation Chamber for *in Vitro* Exposures at 5G millimeter waves

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Abstract — *The aim of this contribution is to present a reverberation chamber specially designed and realized for in vitro exposures of cell cultures at frequencies in the FR2 5G band (26.5–27.5 GHz) in environmental controlled conditions*

### I. Introduction

Reverberation Chambers (RC) have become very popular in the last decades due to their peculiar properties. A RC is an electrically large, closed cavity with highly conductive walls, allowing statistical uniformity and isotropy of the field distribution. This can be achieved through mechanical or frequency stirring. RCs are currently widely used for conducting electromagnetic compatibility measurements [1], but the range of applications is ever increasing, including radiated power and antenna efficiency measurements [2], multipath environment simulation for wireless devices [3], characterization of material properties [4]. More recently biological effects studies added to the list [5, 6].

In the framework of PRIN Project MIRABILIS, funded by MUR in 2017, a mode-stirred RC has been specially designed and realized for exposures to 5G signals in the Frequency Range 2 (FR2) currently assigned in Italy (26.5-27.5 GHz). The aim of this contribution is to present a preliminary characterization of the manufactured RC.

### II. Cavity Design

A well-stirred RC must be electrically large to guarantee an effective stirring of the modes. For a rectangular shape, the mode density is given by the well-known formula [7]

$$\frac{dN}{df} = \frac{8\pi abd}{c^3} f^2 - \frac{a+b+d}{c} \qquad (1)$$

where $c$ is the speed of light in vacuum, $a$, $b$ and $d$ are the dimensions of the chamber, and $f$ is the operating frequency. The internal dimensions of the RC are $404\,mm \times 419\,mm \times 375\,mm$. Such dimensions were selected to maximize the volume of the chamber, according to available room in the incubator. In addition, avoiding a rational ratio of the chamber sizes allows improving the uniformity of the modes. The resulting theoretical mode density is 43 modes/MHz at 27 GHz.

The RC was fabricated using an aluminum alloy with conductivity $\sigma = 3.57 \times 10^7\ S/m$ and 4 mm thickness. The quality factor of the cavity associated to the losses in the walls resulted to be $Q = 1.92 \times 10^5$. The RC is equipped with two rectangular cross-shaped stirrers (dimensions: 300 mm × 22 mm) driven by two adjustable motors. A polystyrene sample holder was suitably designed to house up to either 8 Petri dishes 35 mm, or 4 Petri dishes 60 mm or 2 Petri dishes 100 mm. In this way different biological tests can be carried out in cell cultures exposed to mm-waves with a high homogeneity field distribution as resulted from numerical dosimetry [8].

The RC is fed by two WR28 waveguides, placed on the walls opposite to the stirrers. The double feed allows for the full characterization of the chamber, by means of both reflection and transmission coefficients measurements and their statistical analysis, as well as continuous power measurements during exposures for SAR control.

All the system will be hosted into an incubator in order to ensure a strict control of environmental parameters too (temperature, humidity, 95% air and 5% $CO_2$ atmosphere). In addition, a fiber optic thermometer can be inserted for the eventual temperature control of a dummy sample during the exposure. A similar, but not microwave fed, RC will be hosted in another identical incubator and adopted as sham exposures. In this way we satisfy at three of the five criteria proposed for a high Quality Score for good bioelectromagnetic laboratory practice: proper attention to dosimetry; use of shams, and temperature monitoring, being the other two complied in the biological protocol (use of positive controls and of blinding) [9].

ACKNOWLEDGEMENT

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# Prediction of Exposure Levels in 5G Networks with an Electromagnetic Propagation Software

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Abstract — *In this paper we present the application of an electromagnetic propagation software to the prediction of the exposure levels of the field radiated by 5G networks in complex environments like urban areas. The main characteristics of the software in terms of input-output interfaces and methodology will be presented along with meaningful simulations devoted to compare expected exposure of 5G with traditional networks.*

## I. Introduction

The new generations of mobile networks introduce a tremendous improvement of the actually available performances. This improvement is possible thank to disruptive technological evolutions. Indeed, the use of millimetre waves allow a significant increase of the available bandwidth and the exploitation of "massive multiple input multiple output" (massive MIMO), guarantee the beam-forming and beam-sweeping capability that enable a tremendous growth in the channel capacity. The new characteristics of the antenna diagrams in 5G networks influence the population exposure too. In this manuscript, we show how an electromagnetic propagation software tool, previously developed by some of the authors [1] for the planning of both mobile phone and wireless sensor [2] networks, can be used to evaluate the new characteristics of the exposure of the population to the upcoming mobile network fields.

## II. Methodology and Results

The proposed tool is based on a ray-launching approach [3]. The input data are crucial for the whole prediction accuracy. A digital description of the scene and of the transmitting antenna radiation diagram are required as input. The scene description must include buildings sizes and shapes, and a raster file providing the terrain topography (Digital Terrain Model, DTM). If available, buildings walls and terrain relative permittivity and conductivity can be also provided as input. In absence of specific information, default values for different building types can be used. The tool is based on a vertical-plane-lunching (VPL) raytracing algorithm that includes direct, reflected and diffracted rays. Reflections are evaluated via the Geometrical Optics (GO), by using the Fresnel reflection coefficients, diffraction is computed via the Uniform Theory of Diffraction (UTD). The algorithm stops propagating each ray when its field strength falls below a user-defined threshold. The output is represented by the electromagnetic field values on one or more regular 2-D grids ("layers") placed on surfaces at different fixed heights above the ground.

As example on how the tool can be used in exposure prediction, we compare the field levels in the cases of a directional and a sectorial antenna, as possible radiating systems in 5G and 4G (or earlier) base stations. The simulation output for each scene is given by the field values on a 1m x 1m grid map. An example of simulation for a directional antenna is shown in Fig. 1. With this result, it is possible to consider hypothetical users walking in a given area of interest, and to simulate both a sectorial antenna that illuminates the whole area and a directive antenna with an electronically steered beam that "follows" the user, as in a 5G system. We have observed in many scenarios that a higher average field, i.e. a higher exposure, is produced by the sectorial antenna. This is confirmed by the analysis of the field value that is not exceeded by 95% of the pixels in the whole scene. This value for the sectorial antenna is twice the value of the directional antenna in the considered cases. Several examples and quantitative results will be presented and critically discussed during the symposium.

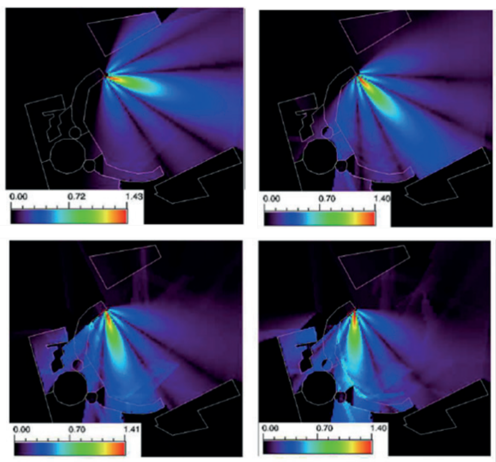


Fig.1 Simulated electromagnetic field levels at 1.5 m from the ground for four different control beams of a 5G base station.

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# Assessment of RF exposure in an urban scenario from 5.9 GHz vehicular connectivity

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Abstract — *This work aims to assess RF exposure generated by vehicle-to-vehicle (V2V) communication at 5.9 GHz. RF exposure was assessed in an urban scenario with a pedestrian near a car equipped with two V2V antennas. Exposure was evaluated in term of $SAR_{10g}$. The results showed that the dose absorbed by the pedestrian depended on the position and orientation and was below the ICNIRP limits.*

## I. Introduction

Nowadays much research is conducted toward the realization of technologies for vehicular connectivity. Their realization will allow to connect a vehicle which other vehicles to exchange warnings and safety road traffic messages. As a result, people in the car or in its vicinity will be exposed to RF generated by such technologies. In a recent study [1], we investigated RF exposure in passengers of a connected car. In this study we further explore RF exposure generated by V2V technology operated at 5.9 GHz on a pedestrian in an urban scenario.

## II. Materials and methods

The antennas used to operate the V2V communication with the standard IEEE 802.11p protocol [2] are quarter-wave monopoles operating at 5.9 GHz [1]. Fig. 1 shows one of the exposure scenarios we addressed. The V2V antennas were fed with an input power of 1W and were mounted on a CAD model of a city car, following the typical set-up [3]. A human phantom (Ella from the Virtual Family) was put close to the car in five different positions and two orientations: frontal (| |), i.e., face toward the car, and orthogonal (^), i.e., shoulder toward the car (Fig. 1 representes only the | | orientation).

The simulations were performed on Sim4Life [4] using the FDTD method implemented with the Huygens Source. The exposure assessment was performed calculating the $SAR_{10g}$ on the skin of the whole body, the genitals, and the head and in all the tissues of the eye.

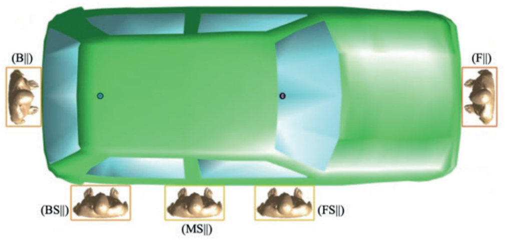


Fig. 1 Top view of the 5 positions near the car in the frontal (| |) orientation.

## III. Preliminary results

Figure 2 shows, as an example, the $SAR_{10g}$ distribution in the eyes tissues as a function of the ten configurations evaluated (i.e., five positions and two orientations of the phantom). The frontal orientation (| |) generated a higher exposure level compared to the orthogonal one (^). This trend was observed also for the other tissues investigated (here not reported). From Fig. 2, we can notice that the worst-case scenario is in the B| | position (phantom near the rear antenna) where we have the highest $SAR_{10g}$ value, i.e., 15 mW/kg, which is in any way well below the limits imposed by the ICNIRP guidelines [5]. We can also see that the median is far from the peak values (upper whisker), meaning that most of the $SAR_{10g}$ values were around low exposure levels.

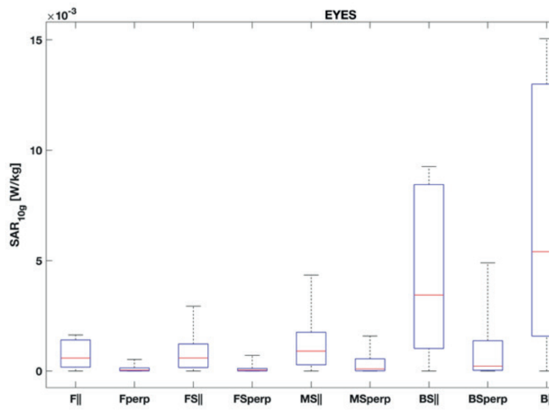


Fig. 2 Distribution of $SAR_{10g}$ generated by V2V 5.9 GHz antennas for the eyes tissues in the ten different configurations of the phantom near the car.

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# Numerical Assessment of Human RF-EMF Exposure in 5G V2X Connected Vehicles

M. Bonato[1], M. Benini[1, 2], S. Gallucci[1, 2], E. Chiaramello[1], S. Fiocchi[1], P. Ravazzani[1], M. Parazzini[1], G. Tognola[1]

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Abstract — *In this work, the RF human exposure assessment is evaluated in a specific case of forthcoming 5G exposure from connected vehicles. Two array antennas for 5G-V2X (vehicle-to-everything) communication at 3.5 GHz were modelled and mounted on a car model. The exposure levels were assessed in terms of SAR, evaluating different configurations and orientations between the car and the human model Ella.*

## I. Introduction

Intelligent Transportation Systems (ITS) will soon operate also using 5G New-Radio (NR) wireless communication [1]. 5G networks will indeed enable technology services, overcoming the limitations of the current cellular technologies (e.g., 3GPP LTE and IEEE 802.11p) and thus increasing road-safety and driving efficiency. This will involve changes on the RF-EMF exposure levels of people in a car and in the car vicinity [2]. In a recent study, we evaluated RF-EMF exposure in car from V2X antennas at 5.9 GHz using WiFi for mobility protocols [3]. In the present work we aim to further expand the knowledge about RF exposure in the connected car using computational approaches for vehicular 5G smart mobility scenarios, specifically focusing on outdoor exposure levels of pedestrians near a connected car.

## II. Materials and Methods

A model of 5G V2X antenna was modelled following the technical specifications of 3GPP [4], resulting in an array antenna with 8 patch elements with phase shift of 0° between the elements, at 3.5 GHz and input power of 1 W. The antenna was then mounted at the typical setting positions for V2X communications, i.e., at the back of car roof and on the windscreen [5]. Different configurations between the car and the human model Ella from Virtual Family [6] were evaluated. As example, in Fig.1 two different examined configurations are illustrated. All the simulations were performed with the FDTD method implemented in the Sim4Life platform. The exposure levels were assessed in terms of specific absorption rate averaged over 10 g ($SAR_{10g}$), as indicated in the ICNIRP guidelines [7].

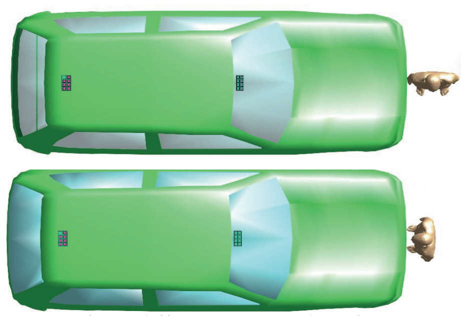


Fig. 1 Views of two different examined configurations of the phantom near the car: 'lateral' (top) and 'front' (bottom). The small rectangles at the back and front of the car are the two 5G V2X antennas.

## Preliminary Results

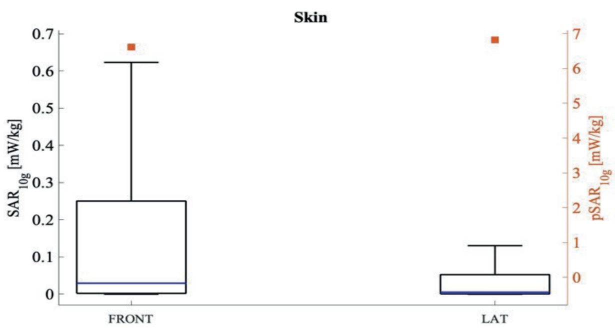


Fig. 2 Distribution of $SAR_{10g}$ evaluated for the skin tissues of the whole body for the two configurations.

In Fig. 2 the boxplot of the $SAR_{10g}$ distributions and the peaks values (red dots) are illustrated for the skin at the two different configurations reported in Fig.1. The peak values were equal to 6.62 and 6.82 mW/kg, for the frontal and lateral configurations, respectively, well below the limits indicated by the guidelines [7]. Furthermore, we noticed, that the median and upper whisker values deviated significantly from the peaks, which means that the majority of values is concentrated in really low range of exposure levels. Indeed, the percentage of values higher than the 90% of the peaks were below 0.01%.

### Acknowledgment

Project "EXPOAUTO - Cumulative real smart car exposure to radiofrequency electromagnetic fields in people of different ages from new technologies in automotive services and connected objects" [PNREST Anses, 2020/2 RF/05].

### Acknowledgment

The authors wish to thank ZMT Zurich MedTech AG (www.zmt.swiss) for having provided the simulation software SEMCAD X/SIM4Life.


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# Skin Thermal Modeling for Exposure Assessment of new 5G Applications

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Abstract — *This study deals with the analysis of different bio-heat thermal models for the evaluation of the exposure assessment at frequencies above 6 GHz, with a focus on the establishment of new safety standards for the 5th generation (5G) of electronic devices. A review of recent analytical and numerical skin thermal models has been conducted and the influence of different simplifying assumptions on the models results has been studied.*

## I. Introduction

The upcoming introduction of 5G electronic devices is generating a growing concern for possible health implications mainly due to the higher involved frequencies (i.e., above 6 GHz), sometimes improperly referred to as millimeter waves (mm-Waves). The effects of these frequencies on human beings are still poorly understood [1], although the most established effect of mm-Waves on biological tissues is of thermal nature, consisting in a temperature increase of the external tissues, mainly skin and eye. Since skin excessive heating may result in discomfort, pain sensation or even tissue damage, international committees are working on new safety standards to ensure the compliance of new 5G devices [2-3].

The need for reliable and easy to handle predictive models to support the establishment of safety limits led several authors to propose an analytical approach for the solution of the bio-heat equation (BHE) under several assumptions. For instance, in [4] Foster et al. proposed the exact analytical solution, both in terms of steady-state temperature increase and transient thermal response, to a semi-infinite 1D model of homogeneous skin tissue with insulated boundaries. In [5] Neufeld et al. made use of the Green's function method to obtain a closed form solution to a semi-infinite 3D homogeneous volume of tissue in terms of the steady-state peak temperature increase at the skin surface.

In this study, the influence of several assumptions made on the abovementioned analytical models have been addressed. These considerations could be very helpful for settling the exposure limits in the future safety standards.

## II. Models and Methods

Simplifying assumptions, e.g., at the boundary conditions (BCs), are usually introduced to make the analytical solution of the BHE easier. For example, Foster et al. proposed a complete analysis of a homogeneous single-layer 1-D skin model with insulated surface (*adiabatic BC*) subjected to an exponentially decaying PW exposure [4]. On the other end, the model proposed by Neufeld et al. in [5] assumed a homogeneous slab of tissue in a 3-D half-space domain for localized exposure in the form of an ideal Gaussian beam. Here, most important assumptions were adiabatic BCs at the skin surface, and no EM penetration depth into the tissue (*surface heat deposition*) due to the millimetric skin depths occurring at mm-Waves.

## III. Results and Conclusions

Figure 1 shows the effect of the convective BC compared to the adiabatic (insulated) condition at the air-skin interface, while the effect of the surface heat deposition is shown in Fig. 2. From these figures it can be stated that the latter assumption is valid only for frequencies above 30 GHz, while below (e.g., at 10 GHz) the combined effects of no energy deposition and insulation can reach values up to 32% (in a conservative way).

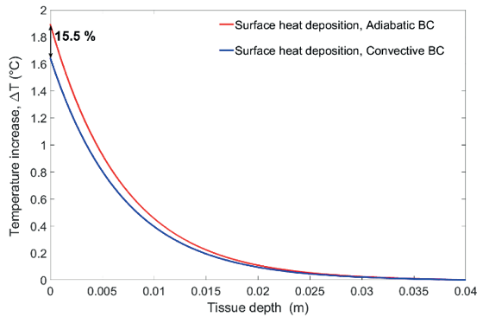


Fig. 1 Effect of convection on skin thermal response.

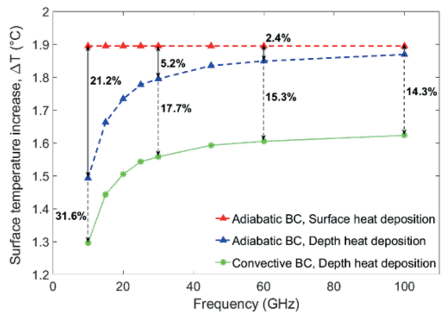


Fig. 2 Effect of EM energy penetration on skin thermal response.

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# Exposure Evaluation Study of *Danio rerio* Larvae and *Mytilus galloprovincialis* Sperm at 27 GHz

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Abstract— *We investigated possible short-term effects of electromagnetic exposure at 27 GHz (5G high frequency band) on Danio rerio larvae and Mytilus galloprovincialis sperm at very low incident density power (< 10 mW/cm²), as recommended by the ICNIRP international guidelines. As far as D. rerio is concerned, not statistically significant differences in the overall multi-marker evaluation approach have been found between exposed and control samples, while for M. galloprovincialis a statistically significant difference concerning sperm motility and vitality has been observed.*

## I. Introduction and Setup Description

Next generation 5G systems will exploit different frequency bands of the electromagnetic spectrum, taking advantage of higher frequencies than previous mobile radio standards. In particular, the mm-Waves band around 27 GHz should be dedicated to high-rate data transfer in short-mid range communications. For this reason, we started both *in vivo* and *in vitro* exposure studies at 27 GHz. The experiments were conducted by using a pyramidal horn antenna fed by a RF power generator (R&S SMB100A) with +20dBm (100mW). The distance between antenna aperture and 6-well microplates holding aqueous samples was set at 15cm, in correspondence of antenna boresight direction, to ensure an incident power density comparable with international guidelines limits for nonthermal effects above 6 GHz [1], although far-field conditions have not been complied with. Numerical dosimetry has been assessed through CST Microwave Studio by considering the whole experimental setup, i.e., horn antenna, polystyrene 6-well microplates and aqueous samples (distilled water for *Danio rerio* and seawater for *Mytilus galloprovincialis*).

## II. Exposure Procedure and Sample Evaluation

### A. Danio rerio (zebrafish)

Selected healthy embryos were placed in 6-well microplates (5 embryos/well) in 5ml distilled water at a controlled room temperature of 26 ± 1°C. During the exposure, started within 3h from egg fertilization and stopped after 96h, a multi-marker analysis was conducted. In particular, four endpoints were analysed (every 24 hours) by a stereomicroscope: embryo coagulation, lack of somite formation, lack of detachment of the tail-bud from the yolk sac and lack of heartbeat. Furthermore, hatching failure, post-hatching death and cardiological measurements were also recorded. In addition, intracellular reactive oxygen species (ROS) content has been detected by 2,7- dichlorodihydrofluorescein diacetate (DCFH 2-DA), and the immunofluorescence protocol was performed to detect positivity to HSP70 and P540 biomarkers. We found that 96 hours of exposure did not cause coagulation of eggs. Both exposed and unexposed embryos completed embryonic stage with an observed normal development of head, notochord, fin, pigmentation, heart and eyes. The hatching of larvae was observed at 48hpf for the exposed groups, while at 72hpf for the unexposed ones, however there was no statistically significant difference ($p > 0.05$). Instead, a statistically significant difference ($p < 0.05$) was observed for the heart rate only at 48hpf. In addition, the analysis confirmed a statistically significant difference ($p < 0.05$) for P540 biomarker and a not statistically significant difference ($p > 0.05$) for HSP70 biomarker. Nevertheless, post-hatching death was not observed and all embryos were vital up to the end of the test.

### B. Mytilus galloprovincialis

Sperm samples were collected from sexually mature males and placed in seawater. Once evaluated the number and quality of spermatozoa, they were exposed to electromagnetic field. The effect of exposure was evaluated after 10, 20, 30, 40 and 60 minutes with an optical microscope and by using Eosin test. Ten replications were performed for each time series, and statistical analysis was carried out by t-test. A significant decrease in sperm motility was observed after 10 minutes of exposure and after 30 minutes most of sperms were immobile and not vital [3].

## Acknowledgement

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# 4. Occupational Exposure

## Occupational health surveillance of workers exposed to electromagnetic fields according to the current Italian legislation

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Abstract — *The health surveillance (HS) of workers exposed to electromagnetic fields (EMF) aims at the prevention of known EMF adverse effects. No specific lab tests or medical investigations are useful for routine monitoring of exposure and/or in the prevention of adverse effects occurrence. The main HS scopes are the recognition of workers at particular risk and/or of the occurrence of unexpected symptoms.*

### I. Introduction

In Italy occupational Health Surveillance (HS) of workers exposed to Electromagnetic fields (EMF) is compulsory according to the Legislative Decree n. 81/2008, the consolidated norm for occupational health and safety prevention at work, as modified by the more recent Legislative Decree n. 159/2016, transposing the European Directive 2013/35/EU. Accordingly, the HS is aimed at the prevention of all known direct biophysical effects and indirect effects caused by EMF, while the suggested long-term effects of EMF are not addressed [1-3].

### II. Effects of EMF exposure of interest for the HS

According to the regulation, the direct biophysical effects are divided in thermal effects, related to exposure to high frequency (HF) fields, and non-thermal effects associated to the currents' induction with stimulation of muscles, nerves or sensory organs when exposed to static or extremely-low frequency magnetic fields (SMF, ELF-MF) [1-3]. For intermediate frequencies both the types of effects are possible. Direct biophysical effects are further classified into sensory and health effects. The formers, including nausea, vertigo, magneto-phosphenes and others, are reversible, and are considered less relevant, even if they can be associated to an increased risk of injuries. Health effects based on non-thermal mechanisms include changes in the limbs' hematic flow, modifications of the heart and brain functions (mainly related to SMF) and symptoms as involuntary contractions of muscles or nerves' stimulation, or changes in heart rhythm (mainly due to ELF-MF exposure). Health effects occurring with thermal mechanisms are e.g. skin burns or thermal cataracts [1-3] Health effects are induced only as a consequence of (very) high EMF exposure levels, while sensory effects may appear at lower levels. Indirect effects of relevance for HS mainly include EMF interference with active medical electronic devices as pacemakers, ICDs and others. An indirect interaction of EMF is possible also with passive devices, both medical or accidentally implanted objects, containing metal, with induction of currents, overheating or magnetic dislocation. Workers with these conditions are recognized as "workers at particular risk", to be specifically considered when designing training and information activities, performing risk evaluation and health surveillance aimed at the identification of the most appropriate preventive measures for EMF risk. It should be noted that, while exposure limit values (ELV) are adequately protective for direct biophysical effects related to EMF, for "workers at particular risk" the respect of the ELV in force may be not adequately protective for all, and e.g. interference problems are possible, especially in case of older active medical devices, with unipolar configuration [1-3].

### III. Indications for the Health Surveillance

In principle, occupational HS should usually include medical investigations, evaluations of exposure and relevant occupational and medical anamnesis, perhaps with ad-hoc questionnaires, and, when appropriate, other specific tests. Based on current scientific knowledge, in case of EMF related HS no specific lab tests or medical investigations prove being useful for the prevention and/or early detection of direct and indirect EMF associated effects. Even in the case of the extraordinary medical surveillance, specifically required when workers report unexpected symptoms possibly associated to EMF and/or in case of overexposures, no standard examination protocols can be a priori identified. Accordingly, the main objectives of HS have to be the adequate recognition, and following, of workers at particular risk, and the contents of HS include an in-depth medical investigation and a scrupulous anamnesis, while any other integrative examinations should be prescribed by the occupational physicians on an individual basis, and justified based on the exposure and on personal conditions [1].

## IV. Conclusions

Occupational HS of EMF-exposed workers is currently compulsory in Italy, as well as in other EU countries, according to a EU Directive aimed at the prevention of known direct and indirect EMF effects. Regarding the contents of HS of these workers, except on specific individual basis, no lab tests and/or medical examinations can be a priori identified as useful, while HS should mainly focus on the recognition of conditions determining a particular susceptibility of the workers to the EMF risk, such as the presence of active medical devices, possibly undergoing interference problems, and/or on the occurrence of unexpected symptoms.

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# Design of a Shield for a Spot Welder Magnetic Field

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Abstract — *This paper reports the design and the numerical validation of a shield for a spot welder. The main goal is to decrease the amplitude of the magnetic field generated during welding, so reducing the minimum distance at which an operator can safely stay during its working activity.*

## I. Introduction

Spot welding is a particular type of electric resistance welding used to weld various sheet metal products, through a process in which contacting metal surface points are joined by the heat obtained from resistance to electric current. The very high current intensity used for welding may expose workers to magnetic field levels exceeding the action levels defined by regulations [1]. It is therefore of paramount concern the reduction of the exposition mainly realized through shielding actions. Recently, a paper [2] proposed a metallic structure able to attenuate the magnetic field radiated by the spot welder. In the present contribution a copper shield is designed and theoretically evaluated using a commercial electromagnetic simulator. The operating principle is based on the current induced on the shield that, according to the Faraday law, generates a field that opposes to the one of the welder current. Encouraging results show a reduction of the order of about 7 dB.

## II. Scenario

The scenario analyzed in this paper is a spot welder. In particular, we focused the attention on the current that performs the welding action. The welding current is made by a train of pulses, each of them having a double exponential waveform with a peak of 12.4 kA and a rise time of 1 ms.

Fig.1 shows the implemented geometry. The path of the welding current is modeled as a rectangle (1 m × 0.5 m) and the magnetic field is monitored at a distance of 20 cm by the welding point.

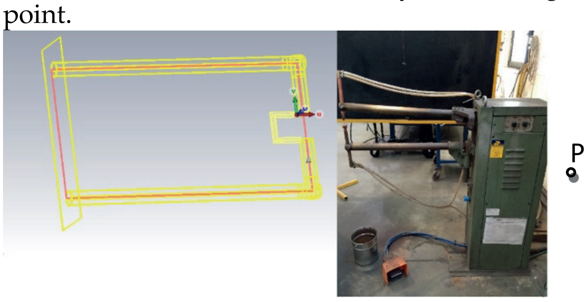


Fig. 1 Scenario: the model of current path (red) and the shield (yellow) on the left and the real welder on the right

The shield is a hollow cylinder, surrounding the current path, having the external radius equal to 27 mm and thickness equal to 1.5 mm. The shield structure was chosen to maximize the mutual magnetic coupling between the welder current circuit and the shield. A copper wire braids connects the two extremity of the shield near the welding point in order to allow the shield current flows. In the model, the braid assumes the shape of three sides of a square having a side of 10 cm. Three materials were considered: a perfect electric conductor (PEC) to simulate the best case, annealed copper ($\sigma = 5.8 \cdot 10^7$ S/m) and steel ($\sigma = 7.69 \cdot 10^6$ S/m, $\mu = 1.26 \times 10^{-4}$ @ 2 mT).

The simulations were performed using CST Low Frequency electromagnetic simulation solver [3] and the waveform of the magnetic field at the observation point P are compared, as reported in Fig. 2.

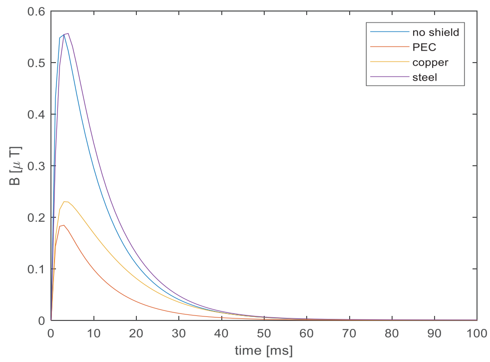


Fig. 2. Magnetic field in case of no shield (blue), PEC shield (red), copper shield (yellow) and steel shield (magenta).

It emerges that the conductibility of the material is a crucial parameter for the shielding efficiency. Copper shield reduces magnetic field of about 7 dB, so the minimum safety distance of the operator can be reduced by a half.

## III. Conclusions

A shield aimed to attenuate the magnetic field radiated by a spot welder was designed and theoretically tested. In order to maximize the current induced on the shield, so that the maximum attenuation is achieved, the shield impedance must be as low as possible, so material, shape and thickness play a crucial role and have to be accurately designed.

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# Protection of Workers Exposed to EMFs above Occupational Limits

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Summary — *In this contribution some applicative difficulties related to the management of overexposures to electromagnetic fields, allowed by the directive 2013/35/EU, are discussed. Critical features and possible solutions are addressed.*

## I. Introduction

Directive 2013/35/EU, setting the exposure limits values (ELVs) for the protection of workers against electromagnetic fields (EMFs), allows to exceed the ELVs (overexposure) in duly justified circumstances provided that the employer demonstrates that workers are still protected against adverse health effects and against safety risks [1].

In this contribution it will be discussed how the employer could demonstrate that workers are still protected against adverse health effects even when the ELVs set to protect against these effects are exceeded. For this purpose, it would be necessary to understand, in relation to how much the health effects ELVs are exceeded, which effects could be expected and if these effects cause just discomfort or real health risks for workers. This issue involves the type of exposure, the biological and/or dosimetric rationale supporting the ELVs as well as individual and environmental circumstances.

The approach to manage health and safety requirements in overexposure conditions may be different for static magnetic fields, low-frequency electric and magnetic fields and radiofrequency electromagnetic fields.

## II. Static magnetic fields

The health effects ELV for static magnetic fields, relative to controlled working conditions, set by the Directive 2013/35/EU, is equal to 8 T, as recommended by ICNIRP in 2009 [2]. Actually, based on an analysis of known action mechanisms, ICNIRP states that the major potential concerns with respect to limiting exposure to static magnetic fields are cardiovascular and neurological effects, but studies on humans exposed up to 8 T do not provide evidence of any irreversible or serious adverse health effects.

ICNIRP recommends restricting exposure below 8 T because for higher exposures there is no human experience and therefore there is lack of knowledge. We are not aware of further studies investigating the possibility of health effects in volunteers exposed over 8 T and ICNIRP has not updated its recommendations about static magnetic field exposures. Owing to the persistent lack of knowledge, we do not deem possible to guarantee the health of workers exposed to these levels [3].

## III. Low-frequency electric and magnetic fields

ELVs for non-thermal health effects of low-frequency electric and magnetic fields (1 Hz – 10 MHz) correspond to the basic restriction set by ICNIRP on the basis of biological thresholds of stimulation of excitable tissues introducing reduction factors to compensate for uncertainties [4].

In order to guarantee the health of workers exposed at levels exceeding the health effects ELVs for low-frequency fields, it is necessary to consider that the lowest biological effect threshold corresponds to the mere perception of the electric currents induced by external low-frequency fields at the body surface. It has also to be considered that the thresholds of painful perceptions, and of potentially dangerous effects, such as involuntary muscle contraction and cardiac stimulation up to the induction of ventricular fibrillation, are increasingly higher.

Protection of workers can be assured if it is guaranteed that just minor effects like non-painful perception can occur, as described in [3].

## IV. Radiofrequency electromagnetic fields

As in the case of low-frequency fields, basic restrictions for thermal effects of radiofrequency fields (100 kHz–300 GHz) have been derived by ICNIRP from biological thresholds introducing reduction factors to compensate for uncertainties.

For whole-body exposures, in the light of the recent pertinent ICNIRP guidelines [5], derogation from compliance to the ELV of 0.4 W/kg on the whole-body SAR, taken from the basic restrictions set by ICNIRP in 1998 [6], could be considered acceptable up to 2 W/kg, a value implying only a slight thermal stress, unless the worker operates in severe thermal environments and/or wears thermal insulating clothes, requiring a more detailed risk assessment.

For localized exposures, derogations from compliance to the local SAR ELVs, derived from biological thresholds with a very small reduction factor, do not seem justified [3].

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# 5. Biomedical Applications of Electromagnetic Fields

## Terahertz Imaging of Magnetic Scaffolds

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Abstract — *The work deals with the application of Terahertz (THz) imaging to characterize poly-caprolactone scaffolds. These latter are magnetized by loading with magnetic nanoparticles (MNPs) through a drop-casting impregnation technique, tuned to obtain different distribution in the polymeric matrix. THz imaging is used as an innovative diagnostic tool able to derive the 2D spatial distribution of MNPs.*

### I. Introduction

Magnetic scaffolds (MgS) are gained a huge attention due to their wide use in several medical applications such as cancer therapy, tissue engineering and bone regeneration [1]. Within this framework, deposition and impregnation of MNPs on suitable scaffolds becomes a crucial process as these approaches are often associated with a non-uniform final spatial distribution of MNPs in the biomaterial.

In order to assess their suitability, methods to routinely and reproducibly characterize scaffolds are needed. In this frame, several approaches are considered for characterizing the pore size, distribution, and architecture of biomaterials, as well as drug loading capabilities or functional properties [2].

Among these, THz imaging is of interest because it allows for sample characterization without compromising its integrity.

Herein, THz Time of flight (ToF) imaging technique has been exploited to estimate the 2D spatial distribution of MNPs in the poly-caprolactone (PCL) scaffolds.

### II. THz Imaging

THz data have been collected by means of the Zomega THz FiCO system available at the Institute for Electromagnetic Sensing of the Environment - National Research Council of Italy (IREA-CNR). The system is equipped with an ad hoc designed imaging module and collects data in normal reflection mode in 40 GHz up to 3 THz frequency range.

The system provides 3D data (2D in space + 1D in time) collected using an automatic planar scan, moving along x and y directions, within a 100 ps observation time window.

THz data have been processed by means of a multi-step procedure described in [3]. In brief, the developed approach is articulated in two main processing steps: i) Signal Filtering and ii) MNCs Distribution Estimate.

The Signal Filtering step consists in the application of a band pass filter followed by a singular value decomposition (SVD) procedure aiming to reduce low and high-frequency noise affecting collected data.

The MNCs Distribution Estimate aims at providing a 2D image representing a map of the MNCs distribution. First, the propagation time of the THz signal within the sample under test is compared with the one that would be measured in the reference conditions (that is without MNCs). Then, by subtracting the reference propagation time from the propagation time appraised in the sample under test, a 2D differential map is obtained. This map is referred to as THz Propagation Delay Map (PDM).

Finally, a threshold is obtained by taking the difference between two references times, i.e., the times of flight for the reference sample without MNCs and for the one homogeneously loaded with MNCs. This value is used to threshold the PDM and to obtain a binary magnetization map. In this map, the pixels where the propagation time is larger than the threshold are set to one, being the pixel where the presence of the MNCs significantly affects the THz signal propagation through the sample. Then, the 2D MNCs distribution map is obtained by multiplying pixel by pixel the binary magnetization map times and the map of the filtered THz signal amplitude (i.e., the output of the Signal Filtering step). Such map shows sample locations where MNPs are mostly concentrated and their distribution in the polymer matrix.

### III. Summary

Several experiments have been carried out in the laboratory and representative examples of MgS will be presented at the conference. The aim is to assess the capabilities of the proposed

THz imaging algorithm in terms of the detection of the 2D distribution of MNPs in the polymeric matrix. The designed strategy could be relevant to material scientists, bioengineers and clinicians who aim to manufacture, characterize, and use magnetic scaffolds as multi-functional tools. Further developments aiming at determining the 3D distribution of MNPs are considered as future work.

## Acknowledgment

This work has been supported by PRIN BEST-Food - Broadband Electromagnetic Sensing Technologies for Food quality and security assessment (grant n. 20179FLH4A).

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# Microwave-Based Tomography of the Human Neck by Means of a Neural-Network Technique

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Abstract — *In this contribution, a microwave-based tomographic approach by means of a neural network technique is applied to the human neck. The aim is to retrieve the dielectric and geometric properties of a cross section of the neck to detect the possible presence of tumors. A fully-connected neural network and a numerical model to create a neck phantom dataset are developed. A preliminary result shows the possibility to locate and identify a simulated tumor.*

## I. Introduction

In the medical field, microwave imaging is a promising diagnostic technique [1]. Several medical applications have been proposed, like detection of brain stroke [2] and breast cancer [3]. The inversion procedure requires the solution of an ill-posed and non-linear problem, i.e., to obtain the dielectric properties of the object under test starting from a set of measurements of the scattered electromagnetic field. In this framework, artificial neural networks (ANN) represent a useful technique to solve such an inverse problem [4]. In particular, the use of ANNs has increased in the last years significantly, with many promising and interesting results [5].

In this contribution, a neural network with a fully-connected architecture is proposed to detect the possible presence of neck tumors. Preliminary results are presented in order to check the feasibility of the developed approach.

## II. Preliminary Results

Let us assume a two-dimensional configuration where a horizontal cross section of the neck is considered. A multistatic and multi-illumination measurement setup is adopted, where neck is sequentially illuminated by $N = 10$ antennas located on a circular line around it of radius $r_m = 0.08$ m. The scattered electric field is collected in a measurement domain composed by $N - 1$ points for each view, and it is used as input data for the ANN. The expected output of the ANN is represented by the dielectric properties of the neck cross section (i.e., the relative dielectric permittivity and electric conductivity). In [6] the details about both the imaging method and the creation of the training set are described. In particular, to obtain the training dataset, a procedure to create realistic neck phantoms has been developed, and $D = 30{,}000$ simplified neck phantoms have been used. As described in [6], a preliminary analysis has been done to choose the best hyperparameters of the ANN.

In order to assess the capability of the ANN of detecting tumor presence, a numerical test case has been created, where a neck slice has been extracted from the Virtual Family [7]. Seven frequencies equally spaced between 600 and 900 MHz have been considered to acquire scattered-field data. A cylindrical inclusion with circular cross section of radius $r_t = 1.5$ cm and centered at $(0.04, -0.01)$ m has been introduced in the anterior part of the neck to emulate the tumor. Fig. 1 shows the reconstructed dielectric properties.

As can be seen, the reconstructed maps allow the detection of the tumor and the approximate identification of its size.

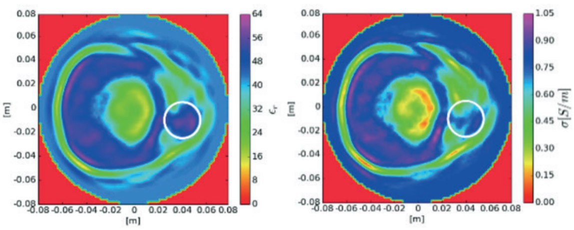


Fig. 1. Reconstructed (a) relative dielectric permittivity and (b) electric conductivity. Tumor location is highlighted by a white circle.

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# Some Advances in Magnetic Resonance Imaging: Radiofrequency Shimming and Electrical Properties Tomography

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Abstract — *In this contribution, we present two activities concerning the complex world of the magnetic resonance imaging. In particular, a new shaping procedure for shimming the radio frequency field* $\boldsymbol{B}_1^+$ *and a learning-based technique to retrieve the electrical properties of the living human tissues from the received radio frequency field are discussed.*

## I. Introduction

Magnetic resonance imaging (MRI) is one of the most popular imaging modalities in clinical practice. The development of MRI for medical research has led to a significant progress in the field of diagnostics, as it avoids potentially damaging ionizing radiation exposure. Indeed, unlike traditional X-rays imaging that uses potentially harmful ionizing radiations, it uses an intense magnetic field in the radio frequency (RF) range to obtain images of the body. However, it requires long acquisition times and high costs.

One of the main challenges for MRI at high and ultra-high fields is the significant inhomogeneity in the transmit RF field. Indeed, high frequency causes electromagnetic field variations and artifacts which significantly degrade the image quality severely limit the interpretation of the data collected. In this scenario, the issue of levelling (or shimming) the $B_1^+$ field has received considerable importance and several RF shimming approaches have been introduced in literature [1].

Moreover, in the last decades, MRI has been also proposed as tool to retrieve in a non-invasive way the electromagnetic properties (EPs) (i.e. conductivity and permittivity) of living biological tissues in the human body from measurements of the RF field $B_1^+$ collected inside the scanner. This technique can reach a spatial resolution of the order of a few millimetres and high accuracy in determining the EPs [2].

In the following, we briefly present the research activities carried out at Università Mediterranea of Reggio Calabria for MRI-shimming and MRI based EPs tomography (MRI-EPT).

## II. Shaping Paradigm for MRI Shimming

High resolution and excellent image quality are the main features in diagnostic imaging systems. This purpose can be achieved in different ways, depending on the imaging techniques at hand. In MRI, the quality and the resolution of the body scans are severely affected by the homogeneity of the amplitude of one of the polarizations of the RF Field $B_1^+$ [1]. Because of the non-homogeneity of the scenario and of the several constraints at hand, the field usually obtained is far from being uniform. This is especially the case for high and ultra-high field scanners [1].

In this scenario, we set up a new shimming approach for active shimming by relying on a completely different perspective with respect to the other presented in literature. In particular, the proposed method, hinging on the field intensity shaping paradigm [3] and inspired from the approach in [4], exploits different control points located in the region of interest and can take contemporaneously into account all constraints regarding polarization, strength of the $B_1^+$ Field and SAR levels. This shaping procedure can circumvent the non-convexity of the problem at hand and ensures to achieve the global optimum and, hence, an accurate, repeatable, and optimal solution of the shimming problem.

## III. MRI-based Electrical Properties Tomography

MRI-EPT involves the solution of a non-linear an ill-posed inverse scattering problem, whose solution represents a non-trivial task [2]. In literature, there are several methods aim at solving such kind of problems. The main issue of Helmholtz's based methods is the noise amplification, while iterative-based reconstruction methods, where the minimization of the cost function is achieved by gradient descent strategies, suffer from the problem of local minima and are time and memory consuming.

Recently, image reconstruction methods based on deep learning (DL) have been introduced, showing a great potential in speeding up the reconstruction process. Conversely, they are limited by the lack of physical information provided by the forward model. In this contest, we present a model-based iterative network based on a cascade of convolutional neural networks (CNNs), able to accelerate the iterative reconstruction process and bypass local solutions. At each iteration, the CNN has as input both the current predicted solution and the physical information provided by the gradient calculation, and learns an update of the EPs solution, which became the input of the next CNN and so on. Contrary to single-step direct DL approaches [5], the forward model and the physic by means of the gradient calculation.

More details about the two research activities as well as some numerical results will be given at the conference.

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# Design of Metamaterials for the Refinement of Mini-invasive Microwave Needle Applicator

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Abstract — *Different metamaterials and electromagnetic metal/dielectric structures are simulated with the aim to improve the characteristic of a low-cost mini-invasive needle applicator designed for hyperthermia therapy of cancer. Preliminary investigations, following different approaches, have been focused to increase the device feasibility and patient wellness. In particular, the starting applicator is a needle hosting a coaxial antenna operating at frequency* $\mathbf{f = 2.45\ GHz}$ *in the Industrial, Scientific, and Medical (ISM) frequency band. The constructed and characterized 16G prototype, allowing promising performance, could be further enhanced by considering suitable metamaterial layers covering the radiating slot made of Teflon.*

## I. Introduction

Cancer treatment via hyperthermia can be successfully combined with radio- and chemotherapy, as alternative technique to the surgical excision. It can be obtained by increasing the local temperature of the cancerous tissues, till their complete necrosis/ablation [1-5]. Ablation via microwave (MW) has attracted great interest because it can produce quick and localized temperature increase, causing the necrosis of the tumoral cells of mammary, hepatic, renal, and pancreatic tissue. In [2] various solutions for the design and fabrication of low-cost mini-invasive interstitial needle applicators have been investigated for hyperthermal treatment. The patient wellness was considered as primary goal with reference to the optimization of the needle operation in term of compactness and shape of necrosis region, avoiding the damage of the healthy tissue via undesired heating. To obtain this objective and to maintain a low-cost fabrication, an extensive comparison of different geometries was performed, in order to allow an easy fabrication process and to include a cooling system. The investigation of different materials by considering a wide range of permittivity, heat capacity, thermal conductivity was conducted till the exploitation of 3D-printing technique to construct a simplified dielectric section by employing the material E-Shell 300. Microwave applicators equipped with a metalens can be optimized for skin tumors treatment. A metamaterial lens based on a split ring resonator (SRR) array has been designed and characterized in [5], to improve the focusing and the penetration depth in human biological tissue. The obtained results indicated that a SRR based metamaterial could be a promising solution for external microwave applicators.

In this paper, the employment of metamaterials is investigated with the aim to further improve the thermal performance of the MW needle proposed in [2].

## II. Preliminary Results

The internal use of a metalens covering the radiating slot of the needle [2] is investigated, see Fig. 1. To perform realistic simulation all the geometrical and physical parameters, including the complex dielectric constants, the thermal and electric conductivities of the parts forming the fabricated applicator [2], have been accurately considered. The preliminary simulation performed by using CST Microwave Studio® promises improvement in impedance matching of the antenna loaded with human tissue and in shape/distribution of damage heating.

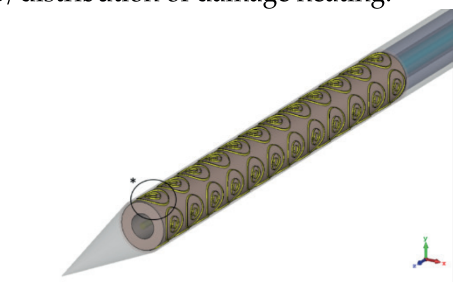

Fig. 1 Metalens covering the dielectric, radiating slot of the needle.

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# On the Development of a mm-Wave Imaging System for Breast Cancer Detection

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Abstract — *In this contribution, we present the work done at the Microwave Laboratory of the University of Pavia on the design of a millimeter-wave imaging system for breast cancer detection.*

## I. Introduction

Breast cancer is one of the most diagnosed diseases among women worldwide. Nowadays, X-ray mammography is considered the gold standard for breast cancer detection; however, its limitations are driving interest in new diagnostic modalities. Among the most promising techniques, the use of microwaves has been proposed for imaging of the breast [1], based on dielectric contrast between healthy and neoplastic tissues [2-3]. In order to improve the resolution of the currently proposed microwave imaging systems, at the University of Pavia we have been working for years on a new imaging system in the mm-wave regime. In particular, we (A.) measured the dielectric properties of human breast *ex-vivo* tissues up to 50 GHz; (B.) carried out a numerical and simulative feasibility study of such an imaging system; (C.) developed several recipes for the realization of tissue-mimicking breast phantoms and (D.) tested the mm-wave imaging prototype on our produced phantoms.

## II. Design Steps

### *A. Dielectric characterization of human breast ex-vivo tissues*

In collaboration with the European Institute of Oncology in Milan, we conducted two experimental campaigns on more than 300 *ex-vivo* healthy and cancerous breast samples from 100 women aged 14-89 years. Measurements were conducted with an open-ended coaxial probe between 500 MHz and 50 GHz on samples at room temperature. The results of these two experimental campaigns showed a significant dielectric contrast in the whole investigated bandwidth between healthy and malignant tissues, even when healthy tissues with high fibroglandular content are considered [2-3].

### *B. Numerical feasibility study of the mm-wave imaging system*

Based on the significant dielectric contrast between healthy and neoplastic tissues, we performed a numerical and simulative feasibility study of the mm-wave imaging system both in a linear and conformal configuration. In particular, through link-budget evaluation in different scenarios (i.e., different breast types), we evaluated aspects such as the optimal number of antennas in the array maximizing the signal-to-noise ratio, the maximum detectable depth of the lesion, as well as the achievable resolution for this type of system [3].

### *C. Tissue-mimicking breast phantoms*

To test the mm-wave imaging prototype, we studied and dielectrically characterized several recipes based on low-cost, easily handled and safe components, i.e. based on the use of deionized water, sunflower oil, dishwashing liquid and solidifying agent such as gelatin or agar. The dielectric properties of the produced phantoms were measured in the frequency range from 500 MHz to 50 GHz and were compared with those of the corresponding human breast *ex-vivo* tissues, showing the good capability of our recipes in mimicking all breast tissues types, by changing only the percentage of oil in the mixtures [4].

### *D. Experimental test of the mm-wave imaging prototype*

As a final step, we tested the mm-wave imaging prototype on these phantoms. In particular, we used two double-ridge waveguides with mono-modal frequency bandwidth from 18 to 40 GHz to synthesize an array consisting of 24 radiators. All measurements were made without the coupling medium and we experimentally demonstrated the possibility of reaching targets up to 3 cm in a phantom with losses. An example is shown in Figure 1. The imaging algorithm used here was Delay-And-Sum [5].

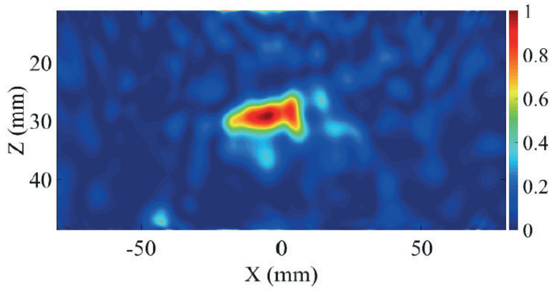

Fig. 1. Millimeter-wave image of agar-based target 3 cm under the phantom surface. DAS algorithm was used for image reconstruction.

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# Physical Interpretation of the Effects of High Permittivity Materials on the Field Distribution in Ultra High Field Magnetic Resonance Imaging

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Abstract - *The goal of this paper is to present an analytical tool to investigate the effects of High Permittivity Materials (HPM) in ultra-high field (UHF) Magnetic Resonance Imaging (MRI). The tool is based on a recently formulated representation of the fields in spherical samples and provides an innovative instrument for the design of coils for UHF MRI.*

## I. Introduction

A clear explanation of how HPMs influence the electromagnetic field distribution in MRI is not available in the open literature. Numerical and experimental results showed beneficial effects [1]-[2], but actually known approaches to the design of the HPM are still empirical. In this paper we present an analytical framework based on a recently introduced model of the scattering from stratified spheres, which relies on the expansion of the field in spherical vectorial functions [3]. The functions can be separated and the effect of a layer of HPM on the field inside the sample can be isolated by studying the radial component of the field. With such new formulation [3], the field in each layer of a spherical stratification can be expressed as a superposition of inward and outward travelling waves. Therefore, the field distribution can be expressed in terms of classical engineering entities, like impedances and reflection coefficients, whose interpretation is straightforward. This approach provides easily interpretable results that can be used to design future HPMs in the UHF-MRI context.

## II. Methodology and Results

The proposed analytical framework is used to show how an HPM layer around the spherical sample modify the amplitudes of the spherical waves used for the field expansion. This is obtained by matching the phases of outward and inward waves at the air-stratification interface. As an example, it can be shown that the field at the center of the sample is only due to the fundamental mode of the field expansion. In Fig. 1 we show that for a 7 tesla field, the fundamental mode amplitude at the origin of the sample can be controlled by a proper choice of the relative dielectric permittivity $\varepsilon_{r2}$ of the dielectric layer surrounding the spherical sample. In Fig. 1 we considered a lossless spherical sample with a radius $a$=9 cm, and a relative dielectric constant $\varepsilon_{rS}$=465 . The HPM thickness $d$= 2 cm.

Fig. 1 shows that the fundamental mode peaks at $\varepsilon_{r2}$=465 and suggests that this value can be used to maximize the field at the center of the sphere.

This result is confirmed in Fig. 2 by the comparison between the field distribution in the sample obtained with (dashed line) and without (dotted line) the HPM layer. Another less evident beneficial effect of this choice of the HPM relative permittivity allows to filter all the secondary modes that only contribute to expose the patient and do not contribute to the MRI quality. The proposed work is expected to provide an important tool for predicting and manipulating the field distribution in ultra-high field MRI applications.

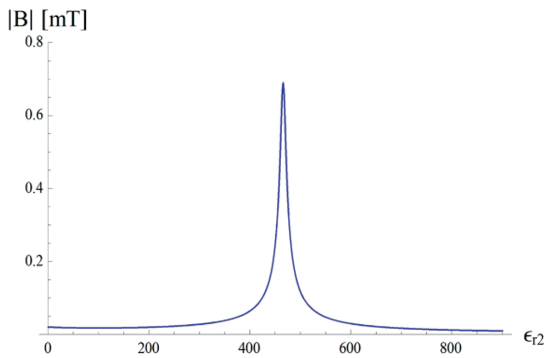


Fig. 1 Amplitude of the magnetic field of the fundamental mode in a spherical sample with radius $a$=9 cm surrounded by a layer of HPM with thickness $d$=2cm. The value is evaluated at the center of the sphere as a function of the HPM relative permittivity $\varepsilon_{r2}$=465.7.

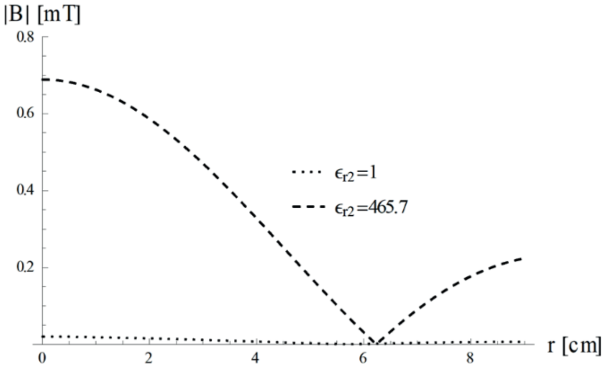


Fig. 2 RF magnetic field distribution: radial dependence of the transverse magnetic field in a spherical sample with radius *a*=9 cm with (dashed line9 and without (dotted line) a layer of HPM with thickness *d*=2cm and relative permittivity $\varepsilon_{r2}$=465.7.

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# Magnetic Scaffolds for Biomedical Applications of Electromagnetic Fields

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Abstract — *Biomedicine is seeking multifunctional tools for multimodal effective treatments. Biomaterials functionalized with magnetic nanoparticles are promising candidates for developing innovative tissue engineering, through magnetically targeted drug delivery strategies, and for radiofrequency magnetic hyperthermia against tumors, but also for diagnostic and monitoring. This work deals with the summary of the most recent advances about magnetic scaffolds, while providing theoretical and numerical models for studying their use for biomedical applications, and with the outline of the challenges and future perspective of this class of functional nanocomposite biomaterials.*

## I. Introduction

The development of smart, stimuli-responsive and multifunctional biomaterial is, nowadays, the aim to which materials scientist, doctors and engineers are focusing their research efforts. Devices capable of performing both diagnostics and therapeutics are needed to open new scenarios in modern medicine. Biomaterials and biocompatible artificial tissue scaffolds responsive to magnetic stimuli have gained attention as functional materials for several biomedical applications [1]-[3]. A magnetic scaffold (MagS) can be obtained by chemical doping of bioceramic using magnetic ions during hydrothermal synthesis or sol-gel procedures. Instead, a MagS can be manufactured by physical route, through the loading of magnetic nanoparticles (MNPs) in a biopolymer (e.g., PLA, PCL, PMMA) matrix [1]. Usually, γ-Fe2O3, Fe3O4, CoFe2O4 nanoparticles are used, and, depending also on their size, a MagS with ferri-, ferro- or superparamagnetic features can be derived [2]-[4], depending on the specific application needs. In any cases, a multifunctional and theranostic device is achieved. The device would be implanted in vivo and used as in situ object able to implement a specific biological action through an external electromagnetic field. MagS have the potential of being used to control the stem cells fate, to act as in situ magnet for regulating the delivery of drugs on magnetic carriers, while also allowing to devise innovative therapies at the site of implantation. This work deals with the review and analysis of the most recent findings from the literature about magnetic scaffolds. A critical interpretation and the highlight of the engineering aspects is provided. The challenges and future perspective are addressed and discussed.

## II. Hyperthermia

Hyperthermia is an oncological thermal therapy that aim at rising the temperature of a target tissue in the range 40-44°C, for a time $t \geq 60$ min. MagS can be the game changer in the hyperthermia treatment of bone tumors, since they can be used both as local heater, under the action of a radiofrequency magnetic field, and then as bone substitutes [1]-[3]. However, the multiphysics modelling of the treatment, as well as problem related to the manufacturing [1] and to the estimation of their specific absorption rate [2] are challenges to be faced with an electromagnetic engineering focus.

## III. Drug Delivery

Tissue engineering aims to develop devices, systems and strategies for favoring and controlling the physiological process of tissue healing to repair or regenerate an injured area. MagS are an example of these systems. However, MagS could play an additional, active role. In this work we will analyze, with a numerical multiphysics and nonlinear model, how and if MagS could target the drug delivery of magnetic nanoparticles carrying growth factors [3]. We will show that MagS could favor the bone healing process.

## IV. Diagnostic and Monitoring

The potential of MagS could be extended by studying imaging modalities which would turn the device into a theranostic one, capable of allowing a monitoring of the functional tasks, e.g. by monitoring the temperature changes during hyperthermia or the tissue healing state. An in-depth analysis of the state-of-the-art is carried out and future perspective will be discussed.

## V. Conclusions

The advancement in the design, modelling and characterization of magnetic scaffolds for biomedical applications is noticeable. To foster the development of the tools for biomedicine, the focused and synergistic efforts of material scientists, engineer, both biomedical and from the electromagnetics, and clinicians would be needed.

The value of MagS as therapeutic tools against solid tumors calls for the investigation of cancers different from bone tumors. To further support and translate the use of MagS as innovative drug delivery system, in vitro experimental tests has to be performed. In particular, to assess and validate the time required to attract with the static magnetic field a suitable MNPs concentration to the biomaterial, but also to evaluate the effectiveness of GFs release after the thermal shock during the RF heating step. Finally, the biological effects of this innovative drug delivery strategy must be properly investigated.

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# A Combined Strategy for Incident Field Characterization in Phaseless Microwave Imaging

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Abstract — *A combined strategy for the incident field modeling, suitable to phaseless microwave imaging applications, is presented in this work. The method exploits an indirect holography technique, used as phase retrieval stage for the incident field only. The proposed strategy, included within a phaseless inverse scattering method which is based on the contrast source formulation, is tested on a set of numerical breast targets.*

## I. Introduction

Phaseless microwave imaging is one of the most challenging inverse scattering strategy. In fact, the assumption of amplitude-only data increases the complexity of the inverse problem. One of the key-points in the successful inversion is given by the proper modelling of the incident field. Rather than considering a numerical model for the incident field, intensive measurements on a very dense grid can be done, or alternatively, incident field distribution can be retrieved from measured data. In the phaseless context, phase retrieval (PR) strategies can be adopted to estimate the incident field data in complex terms, starting from amplitude only-data. The authors believe that, rather than performing the PR stage to the total field data, i.e., the field measured in the presence of the target to be imaged, the phase recovery can be performed to the incident field data only, without affecting the reconstruction results, since the reconstruction error has a limited impact within the non-linear inverse strategy, as compared to the total field phase recovery, thus reducing the error propagation within the inversion process. More specifically, a spatial domain indirect holography technique (SDIHT) is considered in this work as PR strategy for the incident field data. The SDIHT is then combined to a field reconstruction method, based on the modal expansion (ME) strategy or, alternatively, on the source reconstruction method (SRM). Those methods are implemented in evaluating the incident field distribution starting from raw data. Therefore, the proposed inverse scattering problem can be summarized in two steps:

1) (Complex) incident field reconstruction inside the imaging domain, starting from amplitude-only data;
2) The effective non-linear inverse strategy, where the retrieved incident field data and the amplitude-only data of the total field are involved, according to a contrast source (CS) formulation of the inverse problem.

## II. Methods and Procedures

The SDIHT, used for the PR stage of the incident field data, directly operates in the spatial domain, thus avoiding the spectral component analysis of the samples. Secondly, the SDIHT approach performs a set of amplitude-only measurements for each probe location, by introducing a proper phase shift to the reference field data, as detailed in [1]. Once the incident field on the measured space is known, the incident field distribution in the imaging domain can be retrieved by applying a ME technique [2]. In the case of cylindrical acquisition surface, this is based on a polynomial expansion in terms of Hankel functions. Alternatively, the equivalent current distributions enclosing the transmitting source can be evaluated, by applying the SRM, commonly used in antenna diagnostic and extendable for imaging purposes [3]. The root mean square error (RMSE) for the incident field retrieved in the imaging domain D - $E_D^i$ - with the above methods (after applying the SDIHT) are indicated in Table I, and compared with a numerical TMz source.

TABLE I
INCIDENT FIELD RECONSTRUCTION – ROOT MEAN SQUARE ERROR (RMSE)

| Reconstruction Method | RMSE | |
|---|---|---|
| | $\mathrm{Re}\{E_D^i\}$ | $\mathrm{Im}\{E_D^i\}$ |
| SDIHT + ME | 0.0036 | 0.0028 |
| SDIHT + SRM | 0.0540 | 0.0461 |

The effectiveness of these strategies, and the combination of the incident field recovery stage within a phaseless inversion scheme [4], applied to the imaging of numerical breast targets, will be presented in the conference.

## Acknowledgment

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# Super-Resolution Spectral Approaches for the Accuracy Enhancement of Biomedical Resonant Microwave Sensors

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Abstract — *The response of biomedical resonant sensors is usually broaden, due to the presence of losses. Moreover, the actual resonance peak may be missed, due to the finite number of response samples. To face the above problem, an algorithm is presented to narrow the response of the resonant sensors, by exploiting super resolution spectral estimation methods. The algorithm is successfully tested on both numeric and experimental data.*

## I. Introduction

Microwave resonant sensors have been gaining great interest in recent years for biomedical applications. These devices found application in *microwave spectroscopy* [1] by exploiting the interaction between electromagnetic fields and biological tissues, so that the change in the biomedical parameter to be measured is reflected on the sensor response. In the case of blood glucose monitoring, they provide advantages over traditional methods, such as the non-invasiveness and the possibility of a continuous monitoring [1].

The above sensors generally exhibit a low quality factor, due to the presence of losses, as well as to their structure. This implies a low resolution, by affecting the minimum variation to be detected. Moreover, the actual resonance frequency may be missed during the acquisition, depending on the sampling frequency step. To face this problem, a data processing is required for the accurate estimation of the resonant frequency. In this work, the method proposed by the authors in [2] is further extended by applying super-resolution approaches [3]. The implemented algorithm is first verified on synthetic data mimicking the sensor response, and then it is further validated on measurements performed for non-invasive continuous blood glucose monitoring.

## II. Algorithm Description and Verification

In this section, an algorithm is presented to enhance the sensors response for a reliable estimation of the resonant frequency, which is related in turn with the biomedical parameter of interest. It consists in the determination of the (pseudo)-spectra [3] by means of the modified inverse Fourier transform of the processed sensor response.

Let us consider the solid blue line in Fig.1, giving the return loss RL(f) of a sensor, measured in the band $[f_{min},f_{MAX}]=[2,3]$ GHz. Here, $RL(f_{min}) < RL(f_{MAX})$ (the same applies if $RL(f_{min}) > RL(f_{MAX})$) and there is only one RL(f) supremum. The algorithm first restricts the definition interval of the acquired return loss, and then applies the inverse Fourier transform of the result. A proper modified version of the time-domain function obtained from this last step is considered to compute the correlation matrix [3], and to proceed to its eigen-decomposition. Finally, the resonance frequency is estimated from the pseudo-spectrum [3][4].

Fig.1 shows the final return losses relevant to the adopted methods, clearly revealing a marked increase in the sensor resolution. Moreover, looking at the percentage error values (PE) in Table I, the high accuracy of the resonance frequency estimation can be recognised.

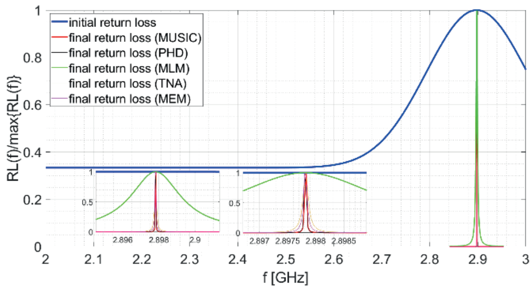


Fig. 1 Initial return loss and final return losses.

TABLE I

PERCENTAGE ERROR IN ESTIMATED RESONANCE FREQUENCY

| | MUSIC | PHD | MLM | TNA | MEM |
|---|---|---|---|---|---|
| PE | 0.0017 % | 0.0007 % | 0.0017 % | 0.0017 % | 0.0007 % |

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# 6. Food Engineering

## On the Design of a Microwave Moisture Content Sensor for Carasau Bread: A Feasibility Study

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Abstract — *The design and numerical simulations of a microwave sensor for the moisture content of traditional Carasau bread is presented in this paper. The results highlight the ability of a simple patch antenna to discriminate small percentage variations in water content in the food product, avoiding misinterpretations due to other parameters modifications, such as distance of the sensor and thickness of the bread sample.*

### I. Introduction

Microwave characterization of food and food related products offers undeniable advantages when considering dielectric constant estimation [1], adulteration or contamination detection [2], [3], and traceability [4]. This is true also for traditional food industry, such as in the case of the Carasau bread, a typical Italian bread characterized by a limited production (confined within the Sardinia island), but with large market potentialities. Carasau bread is made from include re-milled semolina of durum wheat, sea salt, natural yeast, and de-chlorinated drinking water [5], [6]. The obtained dough, after kneading, ferments at 28-32°C inside a metallic container, then is sheeted and cut in thin disks (Ø 18-36 cm) and left to leaven. The bread sheets are then baked in two sessions inside high-temperature ovens (ranging from 400 to 575°C) [5]. One of the most crucial passages in the production chain is between the leavening and the baking steps. The moisture of the bread must be adequate to ensure a good baking [5], [6]. The right water content is pivotal for the quality of the final product and to avoid wastes and reduced productivity.

The moisture of the dough can be estimated by means of a microwave sensor. Since the water content inside the bread dough varies in small percentages, the sensor used could not be able to spot the differences in terms of permittivity. From here, the necessity of an early feasibility study, that allows to figure out the scale of the problem. The first step consisted in the dielectric characterization of Carasau bread doughs with different water content (46%, 50% and 54%) using a commercial coaxial probe [7]. A large variability in the real and imaginary part of the dielectric permittivity has been observed between 4 and 6 GHz, thus the operating frequency of the sensor has been chosen within this range, more precisely at 5.8 GHz (ISM band). The selected sensor is a narrow band patch antenna with coaxial feed. The antenna has been designed and numerically simulated.

All the simulations herein presented have been performed using CST Microwave Studio. The simulation environment includes a portion of the rubber conveyor belt, a single sheet of Carasau bread with different water content and the antenna.

The results show that if the sensor is close enough to the Carasau sheet, it is possible to discriminate the moisture variation based on the antenna frequency response, and that this difference can be isolated from effects due to antenna-sheet distance or sheet thickness variations, in particular if the antenna is used in an array configuration.

### II. Preliminary Simulations

The preliminary results show that using a couple of identical patch antennas in close range (1 mm from the Carasau bread sheet) it is possible to discriminate doughs with 46%, 50% and 54% water content relying on the sole magnitude of the $S_{11}$ parameter. However, in order to avoid misinterpretation due to the variation of other parameters (e.g.: distance antenna-sheet and sheet thickness), it is useful consider also the $S_{11}$ phase as well as the magnitude and phase of the $S_{21}$.

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# Preliminary Design of a Double Ridge Waveguide Device for Monitoring the Complex Permittivity of Carasau Bread Doughs

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Abstract — *This work deals with the preliminary design of a microwave devices to perform indirect measurements of the complex permittivity of Carasau bread doughs. To this aim, the microwave response of the Sardinian traditional food product is measured with an open-ended coaxial probe in the range 0.5-8.5 GHz and the obtained spectra are fitted to a third-order Cole-Cole model. The data are then used to numerically study the microwave signal propagation in a double ridge waveguide, to investigate different sample positioning and configuration in order to obtain a wideband transmission performance.*

## I. Introduction

This work focuses on the industrial advancement of a traditional, small-scale bakery in Sardinia, which produces a typical product called Carasau bread, i.e., a flat, crisp bread whose demand from Italy and Europe is increasing. To reduce waist and, at the same time, increase the production and standardize the quality of the Carasau bread, we aim to design a wideband microwave (MW) sensor to monitor and test the food sample quality through the measurements of their dielectric permittivity during the manufacturing process. In particular, the preparation of the dough and the first leavening are the most critical steps of the production process and the information relating to these phases can therefore be used in order to monitor the quality of the product [1].

A methodology for studying the dielectric properties of the Carasau bread, for frequencies up to 8.5 GHz and during the first leavening, has been recently proposed in [1]. Following this approach, this work investigates the dielectric properties of various dough samples prepared according to the standard Carasau bread recipe [1]. The acquired data are then used to numerically study and design a small-size, cost-effective, wideband MW device to gain information about the product quality during its production. To meet the low-cost goal required for small-scale bakeries, the selected sensor is designed to be easily manufactured with rapid prototyping techniques.

## II. Preliminary Results & Conclusions

An open-ended coaxial probe dielectric assessment kit (DAK) system is used to measure the standard doughs complex permittivity. For each sample, ten measurements of the complex permittivity are performed in the range 0.5-8.5 GHz and the average complex dielectric permittivity is considered. A third-order Cole-Cole model, is then used to model the complex permittivity of the doughs and the model parameters are derived through a fitting based on genetic algorithm [1]. The fitting results are shown in Fig. 1, where the real and imaginary parts of the measured complex permittivity and the theoretical curves are shown. The third order Cole-Cole model well describes the trend of the measured data, with an average error of less than 2% on both real and imaginary parts, and the derived parameters are consistent with what reported in [1].

On the basis of the permittivity measurements and the industrial scenario under study, a standard 250 DRW (double ridge waveguide) was selected as a sensor for monitoring the quality of the doughs during the production phase. The proposed device, shown in Fig. 2, consists of three sections of which the central one, of length $l_2$, contains the sample holder (i.e., the inclined blue walls of thickness s) and the material under test. This design choice allows to find an adequate sample position so that the signal reflection at the air-teflon-sample interface is very low. To design the proposed device and study the variation of the scattering parameters in its working bandwidth, the CST STUDIO SUITE 2019 software is used. To this end, three sets of simulations are performed to study the influence of the construction parameters on the device performance, i.e., the inclination of the sample holder with respect to the cross section (β), the size of the sample ($l_{dough}$) and the thickness of the containment walls (s). The simulation results shows that the best parameters value that allows adequate performance, compactness, robustness and manageability of the device are β = 80°, $l_{dough}$ = 13 mm and s=3 mm.

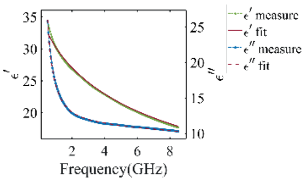


Fig. 1 Fitting of the complex dielectric permittivity of a Carasau dough sample.

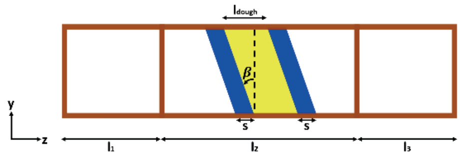


Fig. 2 Longitudinal section of the proposed device (Blue = PTFE, Yellow = dough sample).

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# Magneto-Priming Improves Germination in *Caspicum annuum* L.

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*Abstract — Aim of the work is to investigate magneto-priming treatments on seeds of crop plants particularly important in South Italy for a sustainable agriculture. In this contribution we present the preliminary results in terms of germination of Caspicum annuum L. (common name chili pepper) after 1 h exposure to 50 mT static magnetic induction B field.*

## I. Introduction

Seed priming is a physiological seed enhancement method for overcoming poor and erratic seed germination in many crop and flowering plants. Many techniques have been proposed like hydro-priming, osmo-priming, solid-matrix priming and halo-priming to improve the speed and synchrony of seed germination in plant crops cultivated in the field or in controlled environment. More recently, an increasing number of publications suggest a pre-sowing seed treatment with magnetic field (MF) defined ''magneto-priming'' [1, 2]. It is a promising method improving seed vigor, plant development and productivity under both normal and stressed environmental conditions. Interestingly, while other priming treatments requires mandatory the seed dehydration for storage before sowing, in the case of static or pulsed MF applications the magneto-priming does not require any treatment before storage or sowing. Other advantages are seed storage at room temperature, very low application costs and no environmental impact (eco-friendly).

Aim of the research is to investigate this technique, very suitable for a sustainable agriculture, on seeds of crop plants particularly important in South Italy. Preliminary results on the germination of *Caspicum annuum* L. (common name *chili pepper*) will be presented by comparing data obtained after 1 h exposure at 50 mT and controls. The experiments were carried out following the good practice requirements suggested in bioelectromagnetic research to assure reproducibility and comparability with other similar experiments.

## II. Materials and methods

The applicator design was driven by the following requirements: i) possibility to host samples of different sizes to be exposed at various B-field strength; ii) device based on permanent magnets, in such a way to avoid either confounding factors like electric field components or heating that could arise in the case of electro-magnets; iii) low cost realization and easy placement in laboratories/greenhouses; iv) possibility to confine the magnetic field in such a way to have the best trade-off between high B-field level and uniformity in the sample area, v) avoiding interference with other electromagnetic field sources (low/high frequencies).

The final design was based on numerical simulation results carried out with CST-Studios and experimental validations were performed in the realized prototype by mapping the B field levels in the area where the sample would lay by means of a Hall gauss-meter.

In this device seeds of *Caspicum annuum* L. (Semiorto Sementi, seed lot No. 278) were exposed to 50 mT for 1 h. The experiments were performed three times and 300 seeds (5 different sets each of which from 60 seeds) were treated for a single experiment. The germination of seeds exposed was compared to the that of unexposed seeds considered as a control. After exposure both exposed and unexposed seeds were put to germinate in transparent plastic trays on a spongy support and, after irrigation, placed in a growth chamber at controlled environmental parameters (irradiance, temperature and relative humidity). After sowing the trays were daily observed for 14 days to detect the occurred germination starting when the length of the radicle was at least 2 mm long.

## III. Results and discussion

Concerning the B field exposure system, a good agreement between numerical and experimental results has been found in all the scenarios planned (50-320 mT). The 1 h exposure of *Caspicum annuum* L. seeds to 50 mT induced a significant (50%) increase of germination *(P < 0.05*) in the short observation period (5° day after sowing); while in the long period observation both exposed and control seeds reached the 100% germination.

Thus, our data confirm that the magneto-priming treatment is a promising and eco-friendly approach to facilitate seed germination, being able to enhance the speed germination in a plant species characterized by an excellent basic germination capacity (around 98 %). We cannot exclude a species-specific response of magneto-priming application and we plan to apply this technique in other plant species with lower germination capacity than *C. annuum*.

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# Microstructural Investigation of Durum Wheat Dough through Low-Temperature Broadband Dielectric Spectroscopy (BDS)

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Abstract — *Broadband Dielectric Spectroscopy (BDS) was used to study the dielectric properties of semolina doughs prepared with different amounts of water (40, 50 and 60%) and three different semolina varieties. Dielectric measurements were conducted using a custom-made rheo-dielectric tool composed of a Broadband Dielectric/Impedance Spectrometer connected to a strain-controlled rheometer working at controlled temperature, in order to investigate possible connections between microstructure and rheological behaviour. The temperature range investigated was from -135°C to 25°C, with a step of 5 °C, while the frequency range was $10^{-1} – 10^{7}$ Hz. The technique revealed to be capable of distinguishing the carbohydrates contribution to the rheological properties and the different interactions between water and dough components.*

## I. Introduction

Broadband Dielectric Spectroscopy (BDS) has a great importance in studying food systems. Concerning bakery products, various transition states, resulting from molecular movements (translation and rotation) and flow dynamics, can be observed. The rates of these changes are dependent on the history of the food material (product formulation, storage condition, processing parameters etc.), and on its structural state (molecular mobility, water activity etc.) [1]. Despite the potentiality of this spectroscopic technique, the knowledge and understanding of the dielectric properties of food components are so far quite limited and need to be better investigated. Dough dielectric properties are strongly related to its microstructure, mostly consisting of the so-called gluten network formed by the hydration of four proteins [2]. Also starch has a relevant influence in determining the characteristics of dough, but its role is often underestimated compared to that of gluten. Indeed, when semolina is taken into account, starch is by far the most abundant component, and the surface characteristics of its granules may affect the protein–starch interaction and the viscoelastic behaviour of the dough [3]. Dielectric spectroscopy is capable of showing the presence of several molecular relaxations in starch and dough carbohydrates in general, especially at sub-zero temperatures [4-6].

Thus, the objective of the present study was to investigate the effect of the water content and semolina composition on the dielectric relaxations occurring at low (sub-zero) temperatures in the dough. In particular, at these temperatures, the dielectric response could be informative on carbohydrates and thus on their role, as gluten is expected to be not detectable in such conditions (according to the literature), and the water mobility is reduced as much as possible.

## II. Preliminary Results

It was observed that semolina dough displays two molecular relaxation phenomena whose characteristics depend on the semolina variety. The first is a β relaxation occurring in the temperature range between –40°C and –70°C, with an activation energy of about 60 – 80 kJ/mol. This process is probably associated with relaxations in glucosidic units. The second one is a γ-type and occurs in the temperature range between –115°C and –100°C, with an activation energy of about 30-40 kJ/mol. This process is likely due to localized chain motions in starch molecules, enabled by hydrogen bound water. These processes are not significantly affected by water amount.

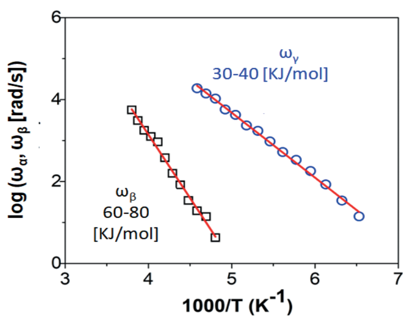


Fig. 1 Mobility map of semolina dough with β and γ processes and Arrhenius model regression for the activation energy calculation

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# Terahertz Imaging for Food Quality Inspection

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***Abstract*** *— One of the limitations of Terahertz (THz) Imaging is related to the amount of environmental noise affecting sample images. In this work, we propose a noise reduction approach based on the combined use of Band Pass Filter and Singular Value Decomposition. Numerical and visual analyses demonstrate the effectiveness of the proposed data processing strategy and demonstrate the ability to detect surface defect and foreign body in food samples.*

## I. Introduction

Nowadays, the agricultural and food (agri-food) industry plays an essential role for human life and the importance of diagnostic inspection has been growing due to an increasing demand for a high-quality life. This is the reason why the safety and quality of agri-food products have attracted significant attention worldwide.

Various techniques have been developed in order to investigate foreign body contamination in food that are the main sources of customers' complaint resulting in loss of brand loyalty and large recall expenses.

Currently, the most commonly used techniques for food inspection include X-ray imaging, thermal imaging, ultrasonic imaging and electrostatic techniques.

In this context, THz technologies are emerging as a viable alternative due to their unique properties [1].

THz radiation is electromagnetic wave ranging from 0.1 to 10 THz (0.03 – 3 mm in wavelength) having advantageous since it includes very short wavelengths and, therefore, provides high resolution images compared to traditional electromagnetic techniques. Besides, unlike X-ray radiation, THz waves can be more safely used because of their non-ionizing properties [2]. It is worth observing that the effectiveness of THz imaging is strongly dependent on the adopted data processing aimed at improving the imaging performance of the hardware device [3].

Herein, THz Time of flight (TOF) imaging technique has been exploited to detect surface defect and foreign body contamination in food sample. Furthermore, a data processing chain is presented aiming to reduce low and high frequency noise affecting the raw data.

## II. THz Imaging

The collected data have been gathered with the Zomega FiCO system available at the Institute for Electromagnetic Sensing of the Environment-National Research Council of Italy (IREA-CNR) [4]. The system is equipped with an ad hoc designed imaging module, which allows an automatic planar scan and constrains to perform measurement in normal reflection mode. In particular, the object under test is positioned on a movable platform and it is located at the focal distance by manually changing the height of the THz normal reflection module.

The system collects signals into a 100 ps observation time window, which can be moved along a time scan range of 1 ns according to the path length between transmitter and receiver. The waveform acquisition speed can be up to 500 Hz, and the maximum dynamic range (DNR) is 30 dB, while the typical DNR is 20 dB. The frequency range in normal environment condition is from about 40 GHz up to 3 THz. The FiCO system is enabled to scan a 150 mm x 150 mm area with physical resolution, i.e., smallest step size, of 120 $\mu$m along both x and y axes.

The data are collected in laboratory environmental condition without using devices to control humidity level and temperature value. Then, the data are visualized and processed.

Concerning data processing, an ad-hoc strategy has been designed in order to filter data and visualize THz images. This strategy involves two different steps in time-domain aimed at reducing noise and filtering out undesired signal introduced by the adopted THz system.

The first step aims at removing the undesired signal exploiting a Band Pass Filter [80 GHz - 3 THz]. The second step regards noise filtering and applies a procedure based on the Singular Value Decomposition (SVD) of the time-domain raw data matrix, which does not require knowledge of noise level and it does not involve the use of a reference signal.

Advantages and limits of the proposed approach are evaluated using visual and numerical analyses.

## III. Summary

Representative examples will be presented at the conference in order to assess the capabilities offered by the adopted hardware and software technology in different food case studies.

## Acknowledgment

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# 7. Applied Electromagnetic & In vivo, In vitro, Human Effects

# A review of the literature on the use of microwave heating for the conservation of works of art

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*Abstract*— **Microwave heating is a promising technology for the conservation of artworks from biodeterioration phenomena. It was demonstrated to be effective on different materials, and against various forms of pests, rapid and safe. A more systematic approach to treatment planning, involving electromagnetic characterization of materials and dosimetry analysis could boost its effective use in this field.**

## I. Introduction

The cultural heritage (CH) assets are invaluable, and their preservation require a careful and multi-disciplinary approach, with contributions from archaeologists, art historians, conservation architects, engineers, biologists. Biodeterioration phenomena are one of the main threats to integrity and authenticity of works of art. The main methods to control bio-deterioration are based on mechanical, chemical, biological or physical principles, but they all have limitations such as very long treatments, risk of pollution to the environment and the operator, and of damage to the treated object [1].

Microwave heating, with its ability to induce the death of the infesting agent by heating it up to a lethal temperature, without damaging the CH structure, may represent a valid alternative to the above-mentioned disinfestation techniques. Here we provide an overview of the literature regarding the use of microwave heating for the conservation of works of art, and we highlight the main approaches adopted and gaps-in-knowledge.

## II. Methods

We performed a literature search in Web of Science database by using the following keywords: "electromagnetic field", "microwave", "microwave heating", "cultural heritage", "work of art", "biodeteriogen", "biodeterioration", "monument", "preservation". We have considered original articles and conference proceedings reporting primary peer-reviewed data, in English language, and without date restriction until January 2021. We charted the following information to analyze the included papers: reference, infesting biological agent, material (artwork), EMF applicator, exposure conditions, temperature monitoring, analysis of effects on infesting agent and/or artwork material, effect.

## III. Results

The literature search and paper selection process yielded to 23 final records to be analysed.

The data extracted from the included papers can be synthetized as follows.

When the work of art could be physically moved from its location, MW treatment generally occurred inside a reverberation chamber [2]. Portable applicators have also been developed for *in situ* treatments. As an example, an applicator based on a short-circuited, rectangular waveguide was realized for the treatment of stone materials. A diaphragm termination allows to couple the applicator with the material to be treated, and its geometrical size determines the penetration depth [3]. Treatments were mainly performed at the frequency of 2.45 GHz, but also the 13.35 MHz frequency was used in one case [4], and temperature was monitored during irradiation by using wither fiber optic sensors or infrared cameras.

The studies considered different types of materials, mainly wood, stone (tuff, sandstone, masonry) marble, and paper, and treated various forms of biodeteriogens (woodworms, fungi, molds, lichens, bacteria). In all cases, microwave heating was effective for the total disinfestation of pests, with treatment times of the order of a few minutes, given in single applications or in multiple cycles.

## IV. Discussion

In this review microwave heating was found to be effective for total disinfestation, in the short and long term, of various infesting agents, for the prevention of conditions (humidity) favoring their growth, on different types of materials. The method is generally rapid (duration in the order of minutes), safe for operators and the environment, thanks to the absence of toxic residues of the treatment. In spite of these advantages, the introduction of this technology has not yet determined a breakthrough in the conservation of works of art. A possible explanation, is the overall lack of a systematic approach to the treatment planning. The latter should include:

- measurement of dielectric properties of artworks and biodeteriogen materials;
- identification of pests lethal doses;
- appropriate dosimetric analysis finalized to a careful definition of the treatment conditions, in order to optimize the homogeneity of field distribution in the different materials to obtain selective heating, and to avoid undesirable effects such as the presence of excessively heated areas (hot spots).

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# Human EMF Exposure Assessment due to Wearable Devices

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Abstract — This work aims to assess the human exposure due to a wearable device worn by the user. The wearable device involves a wide range of the frequency spectrum and the exposure changes with the frequency. For this reason, the exposure due to two different antennas posed on the trunk of a human male model (Duke) belonging to the Virtual Population has been studied: the first one tuned at f = 2.45 GHz (ISM-Band) and the second one at f = 26 GHz (5G). The assessment has been performed by the evaluation of the $SAR_{10g}$ values and the absorbed power density ($S_{ab}$), depending on the frequency.

## I. Introduction

In recent years, the wearable devices are growing as new technology able to monitor the user's conditions and communicate information related to it. The key feature of the wearable devices is the wide range of applicability, since they have many fields of application, such as the healthcare, the sport technology up to the military environment [1,2].

The characteristic frequency spectrum of the wearable devices comes from the typical frequencies of the GSM communications up to the 5G typical bands [3]. Due to the very close position of the antenna to the user's body, the assessment of the human exposure to the electromagnetic field (EMF) emitted by wearable devices is still needed. For this reason, in this preliminary work, two wearable antennas tuned at two different frequencies have been simulated, and the $SAR_{10g}$ values and the absorbed power density were analyzed and compared with the limits imposed by the ICNIRP Guidelines [4].

## II. Materials and Methods

To compare the exposure due to antennas tuned at different frequencies, two wearable antennas have been simulated: the first one proposed by Chahat et al. [5] tuned at the typical frequency of the Industrial-Scientific-Medical (ISM) band f = 2.45 GHz, and the second one from the work of El May et al. [6], tuned in the 5G band, around f = 26 GHz.

Both the antennas have been simulated in the same configuration: they were posed on the trunk of the human male model (Duke) belonging to the Virtual Population [7] (Fig. 1). The distance between the antenna and the human model was set equal to 2 mm, mimicking the presence of the user's clothes. The simulations have been performed through the FDTD method implemented in the SIM4Life simulation software. The human exposure assessment due to the two wearable antennas was estimated by the evaluation of the $SAR_{10g}$ and the absorbed power density ($S_{ab}$) for the first and the second antenna, respectively, depending on the frequency of the emitted EMF according to the ICNIRP Guidelines 2020 [4]. All the values have been extracted from a cubic box, with size of 250x250x250 mm.

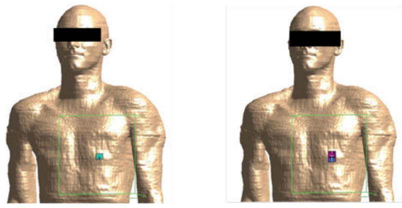

Fig. 1 The simulated configurations with, on the left, the antenna tuned at f = 26 GHz, and, on the right, the antenna tuned at f = 2.45 GHz.

## III. Results

For the numerical assessment, two different parameters have been focused on: the $SAR_{10g}$ for the f = 2.45 GHz, and the $S_{ab}$ for the antenna at f = 26 GHz, both with an input power of 1 W. In the first case, the peak $SAR_{10g}$ value was found in the skin equal to 13.6 W/kg, whereas with the second antenna the peak value of the $S_{ab}$ over 4 $cm^2$ was equal to 27.7 W/$cm^2$. Although the $SAR_{10g}$ values exceed the ICNIRP occupational limits for the, it is noteworthy that they have been obtained with an input power higher than the actual power used for this type of devices (10-20 mW). In both cases, in order to understand how much these peaks actually represent the distribution of the exposure data, the percentage of the data that are higher than the 90% of their peak was calculated in both cases. In the first configuration, this value was 6.9%, whereas in the second one, it was equal to 0.2%.

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# Exposure Assessment of a WPT System to Recharge a Compact EV

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Abstract — In this work, the magnetic field distribution emitted by a wireless power transfer system to recharge the batteries of a compact electric vehicle is addressed. From the obtained results it is observed as the reference levels are exceeded for the case of misaligned coils. In the extended version, basic restriction will be investigated pointing out that suitable and ad-hoc methodologies should be adopted due to the limitations of commercials software in modeling car bodies.

## I. Introduction

Due to the increasing environmental concerns, renewable energy sources have increasingly attracted attention from both industry and academia. A key technology following this trend would be the use of electric vehicles (EVs), which have been used for an extended period but are still limited by the on-board energy storage system, mainly batteries.

These drawbacks can be resolved through wireless power transfer (WPT) systems and their widespread applications in an improved charging infrastructure for EVs. Comparing to bulky cable charging, WPT-systems provide a safer and more convenient way of recharging vehicles and are increasingly utilized for stationary or dynamic charging. In this study, a stationary WPT system aimed to recharge the battery of a compact car, namely a FIAT 500, is investigated. Specifically, the EMF exposure assessment will be addressed.

## II. Models and Methods

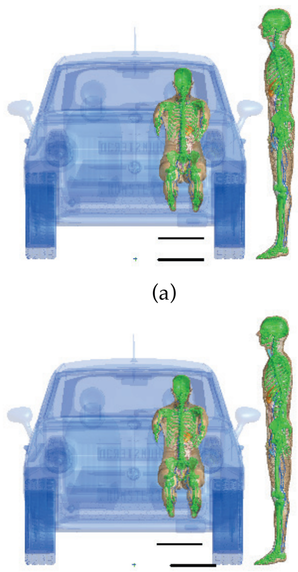
The CAD model of the FIAT 500 has been obtained by [1], while the WPT electro-geometrical details are taken by [2]. Both aligned and misaligned coils are considered (see Fig. 1).

Due to the limitations of commercial software a two-step approach will be used. The magnetic flux density and/or the magnetic vector potential is computed with a formulation that can handle the thin car body in an open domain (e.g., [3]). Then, the dosimetric assessment will be performed exploiting the fact that the presence of the human body does not perturb the applied external field [2].

Specifically, several dosimetric exposure scenario will be considered in the extended version. Posable models of the Virtual Population (ViP) from the IT'IS Foundation (Zurich, Switzerland) will be employed in the driving position (e.g., Ella or Duke) or lying in the posterior seats (e.g., Roberta).

## III. Results and Future Works

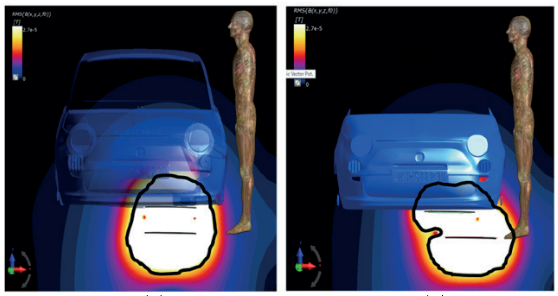
Figure 2 shows the magnetic field distribution of the WPT system. From this figure it is evident as ICNIRP reference levels are exceeded, requiring the assessment of compliance against basic restrictions [4]. A numerical dosimetric analysis will be therefore presented in the extended version.



(a)

(b)

Fig. 1 EV-WPT system: (a) aligned coils and (b) misaligned coils.



(a) (b)

Fig. 2 Magnetic field distribution for the aligned (a) and misaligned coils (b). Black line is the ICNIRP reference level limit.

## IV. Conclusions

In this work, the magnetic field distribution emitted by a wireless power transfer system to recharge the batteries of a compact electric vehicle has been addressed. From the obtained results it is observed as the reference levels are exceeded for the case of misaligned coils. In the extended version, basic restriction will be investigated.

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