July 3rd – 7th, 2023
Costa Dorada - Spain

International Workshop on Microwave Research and Applications

BOOK OF ABSTRACTS

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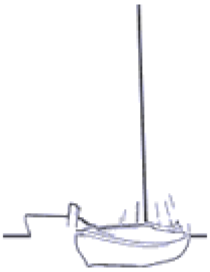
INTERNACIONAL WORKSHOP ON MICROWAVES RESEARCH AND APPLICATIONS

BOOK OF ABSTRACTS



COMA-RUGA (EL VENDRELL)

JULY 3rd – 7th, 2023

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Welcome to

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Coma-ruga 2023

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COMA-RUGA 2023 | International Workshop on Microwave Research and Applications

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Final Schedule

	Sunday, July 2nd	Monday, July 3rd	Tuesday, July 4th	Wednesday, July 5th	Thursday, July 6th	Friday, July 7th	
9:30 - 10:15		KEYNOTE SPEAKER **Eugene M. Chudnovsky** Random Magnets for Microwave Absorption	KEYNOTE SPEAKER **Joan O'Callaghan** Dielectric permittivity analysis of human tissues. Current status and prospects	KEYNOTE SPEAKER **Gloria Platero** Quantum Dot arrays for Quantum Information Transfer	KEYNOTE SPEAKER **Paulo Ventura Santos** GHz control of solid-state spins using acoustic fields	KEYNOTE SPEAKER **David Citrin** Terahertz Nondestructive Evaluation: From Art to Industry	9:30 - 10:15
10:15 - 10:45		**Antoni García-Santiago** Random-field ferrite-based nanocomposites as microwave absorbers	**Jordi Romeu** Microwave Wireless Sensing of Single Bioparticles in a Microfluidic Platform	**Pol Forn-Díaz** Microwave control of superconducting qubits for quantum computation	**David Fernández-Fernández** Photo-assisted spin transport in double quantum dots with spin-orbit interaction	**Jose Maria Lopez-Villegas** Characterization of 3D printing dielectric materials for RF and Microwave applications	10:15 - 10:45
10:45 - 11:15		**Ferran Martín** Highly sensitive microwave sensors based on weakly coupled resonators	**José Manuel Fernández González** Contribution on Antennas with 3D Printing Technology	**Xiao Xue** Two-qubit logic between distant spins in silicon	**Beatriz Pérez-González** Topology detection in cavity QED	**Alberto Castellano-Soria** Importance of physical particle size and dielectric host selection for the designs of carbon-based microwave absorbers	10:45 - 11:15
11:15 - 11:45		**COFFEE BREAK**					11:15 - 11:45
11:45 - 12:15		**Michael Foerster** Experiments with microwave sample excitation at the ALBA XPEEM	**Dmitry Garanin** Integral Absorption of Microwave Power by Random-Anisotropy Magnets	KEYNOTE SPEAKER **Georg Schmidt** Strong magnon-photon coupling in a single yttrium iron garnet microstructure on a superconducting microwave resonator	**Stephen R. McMillan** Spin-based direct-CNOT via virtual photons in a superconducting microwave resonator	**Jorge Luis Martínez Valencia** Computer Vision-Based Estimation of 3D Microwave Microscopy Probe Position	11:45 - 12:15
12:15 - 12:45		**Joris Van de Vondel** Catastrophic magnetic flux avalanches in NbTiN superconducting resonators	**Sigmund Kohler** Dispersive Readout of Floquet-State Populations	**Susana Amorós** Stent monitoring using microwaves: from in vitro to in vivo	**Eran Ginossar** Designing scalable robust optimal control for superconducting qubits	**Nico Dix** High Anisotropy Magnetic Oxides with mm-Wave Natural Ferromagnetic Resonances	12:15 - 12:45
12:45 - 13:00		**LUNCH**				**Closing remarks**	12:45 - 13:00
13:00 - 16:00							13:00 - 16:00
16:00 - 16:30		**Rafael Molina** Surface chiral currents in irradiated topological semimetals	**Mikel Laso** Smooth Profiled Microwave Filters	**Clement Ferise** Anti-reflection structure for perfect transmission through complex media	**Ferran Macià** Exploring the synergy of GHz acoustic waves and spin waves at the nano scale		16:00 - 16:30
16:30 - 17:00		**Pilar Marín** Emerging Radar Absorbing Materials and Magnetic Sensors based on amorphous magnetic microwires	**Luis Jofre Roca** Pulsed Microwave Imaging for Human Brain Functional Monitoring	**Jaume Calvo-de la Rosa** Enhanced microwave absorption by bi-layered systems	**Marc Rovirola Metcalfe** Microwave excitation with surface acoustic waves (SAWs) in magnetic thin films		16:30 - 17:00
17:00 - 17:30		**COFFEE BREAK**					17:00 - 17:30
17:30 - 18:00		**Álvaro Gómez León** Topological amplification	**Snezana Lazic** Strain tuned non-classical light emission from 2D layered semiconductors	**Álvaro Peña** Use of graphene-based materials in electromagnetic shielding applications	**Winfried Hensinger** Building quantum computers for disruptive industry applications		17:30 - 18:00
18:00 - 18:30		**Marius Costache** Cavity optomagnonics with Yttrium Iron Garnet	**Sandra López-Prades** | Dielectric permittivity analysis of human tissues **Kristian Feliz** | Magnon Bose-Einstein condensation and Optomechanics	**Benjamín Martínez** Spin injection and spin-charge conversion processes in all-oxide heterostructures	**Petros Zantis** Towards High-Fidelity Entanglement Gates on Microfabricated Ion-Trap Chips		18:00 - 18:30
18:30 - 19:00				**Joan O'Callaghan** Novel approaches for RF testing of HTS coated-conductors for the FCC-hh			18:30 - 19:00
19:00 - 20:00	**Welcome party**						19:00 - 20:00

Random Magnets for Microwave Absorption

Eugene M. Chudnovsky
CUNY Lehman College and Graduate School

Research supported by the U.S. Air Force Office of Scientific Research

Insulating magnetic systems with quenched randomness, random-anisotropy amorphous and sintered ferromagnets in particular, can be powerful absorbers of microwaves. Their static features have been investigated for decades in connection with numerous applications as soft magnetic materials. Only recently, however, unique microwave properties of random magnets have been elucidated. Compared to systems comprised of small particles, they represent the ultimate limit of the magnetic volume available for microwave absorption. Their ability to absorb microwave power is intimately related to their magnetic structure determined by the interplay of local magnetic anisotropy, ferromagnetic exchange and other interactions. It depends strongly on temperature and dimensionality (1D wires, 2D layers, 3D systems). Fundamental spin physics accompanied by large-scale computer simulations allows one to establish the scaling of microwave properties of random magnets on parameters and make suggestions for manufacturing strong microwave absorbers. The talk will be aimed at researchers with no special knowledge of theoretical magnetism.

Literature (recent articles acknowledging AFOSR support)

1. D. A. Garanin and E. M. Chudnovsky, *Absorption of Microwaves by Random Anisotropy Magnets*, Physical Review B **103**, 214414-(11) (2021).
2. D. A. Garanin, *Energy Balance and Energy Correction in Dynamics of Classical Spin Systems*, Physical Review E **104**, 055306-(8) (2021).
3. D. A. Garanin and E. M. Chudnovsky, *Nonlinear and Thermal Effects in the Absorption of Microwaves by Random Magnets*, Physical Review B **105**, 064402-(8) (2022).
4. D. A. Garanin and E. M. Chudnovsky, *Random Anisotropy Magnet at Finite Temperature*, Journal of Physics: Condensed Matter **34**, 285801-(15) (2022).
5. D. A. Garanin and E. M. Chudnovsky, *Localized Spin-Wave Modes and Microwave Absorption in Random-Anisotropy Ferromagnets*, Physical Review B **107**, 134411-(13) (2023).
6. E. M. Chudnovsky and D. A. Garanin, *Integral Absorption of Microwave Power by Random-Anisotropy Ferromagnets*, arXiv:2304.04121 (2023).

Random-field ferrite-based nanocomposites as microwave absorbers

Antoni García-Santiago, [a,b] **Jaume Calvo-de la Rosa,**[a,b] **Joan Manel Hernàndez,**[a,b] **Jose Maria Lopez-Villegas,**[c] **Javier Tejada,**[a]

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[b]*Institut de Nanociència i Nanotecnologia (IN2UB), Universitat de Barcelona,*
08028 Barcelona, Spain
[c]*Dept. d'Enginyeria Electrònica i Biomèdica, Universitat de Barcelona, 08028 Barcelona, Spain*

We present experimental evidence of the application of modified hexaferrites as microwave absorbers in the GHz range. We prepared ceramic nanocomposites by adding either copper or manganese divalent cations to common barium hexaferrites. We performed magnetic measurements and structural characterization and found that the modified samples consisted in multiple magnetic phases, between which an exchange interaction occurs [1, 2]. We verified the modified materials behave as random field magnets both at low and high magnetic fields [3], in contrast to the original hexaferrites, which did not show any of the characteristics of such state. Recent theoretical developments postulated random field magnets as strong microwave absorbers [4]. To test such idea in our samples, we measured the two-port *S* parameters in the GHz range using a network analyzer with coaxial connectors. From these measurements, we deduced the complex permittivity and permeability using the Nicolson-Ross-Weir model and observed that such magnitudes changed with the addition of the divalent cations to the hexaferrite. We therefore calculated the reflection loss coefficient (R_L) and found remarkable changes in the position and intensity of the signal with the thickness and composition of the samples. These findings strongly support the practical application of our ceramic nanocomposites as radar absorbing materials [5].

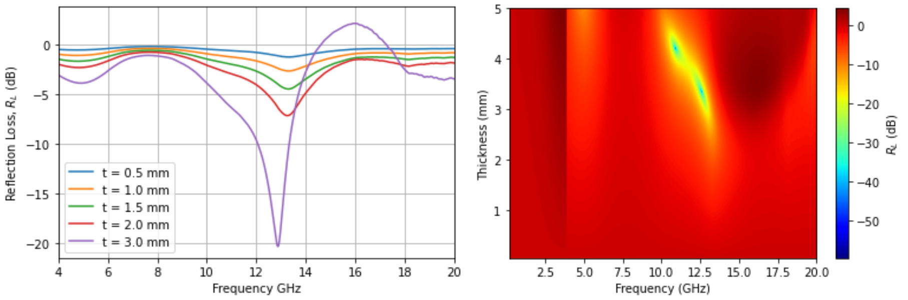


Figure. Left panel: R_L spectra for different thicknesses (*t*) of a modified sample; right panel: RL simulation for a wide (and continuous) range of thicknesses, between 0.17 and 20 GHz.

This work was supported by the Air Force Office of Scientific Research.

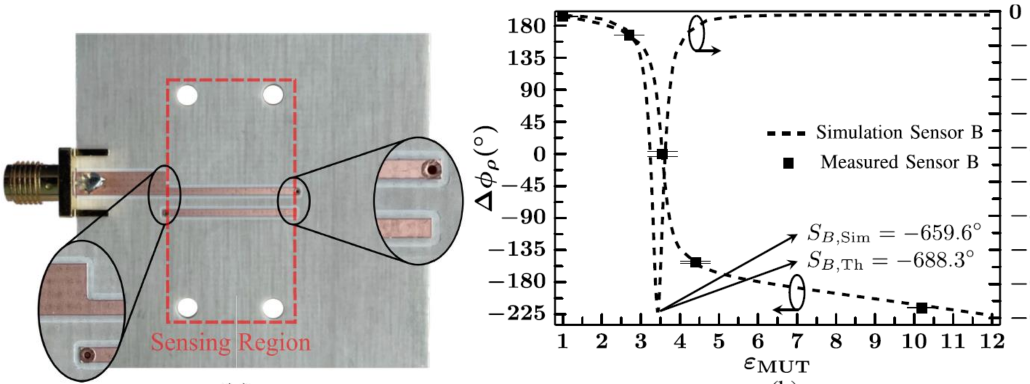
[1] T. Maeda *et al.*, J. Magn. Magn. Mater. 281, 195 (2004); S. Tyagi *et al.*, Ceram. Int. 37, 2631 (2011).
[2] R. Martínez García *et al.*, J. Magn. Magn. Mater. 574, 168934 (2022).
[3] E. M. Chudnovsky, J. Appl. Phys. 64, 5770 (1988); J. Magn. Magn. Mater. 79, 127-130 (1989).
[4] D. A. Garanin and E. M. Chudnovsky, Phys. Rev. B 103, 214414 (2021); Phys. Rev. B 105, 064402 (2022).
[5] A. Houbi *et. al.*, J. Magn. Magn. Mater. 529 (2021), 167839.

Highly sensitive microwave sensors based on weakly coupled resonators

Pau Casacuberta, Paris Vélez, Jonathan Muñoz-Enano, Lijuan Su and Ferran Martín

CIMITEC. Departament d'Enginyeria Electrònica, Universitat Autònoma de Barcelona, 08193 Bellaterra, Spain. Email: Ferran.Martin@uab.cat

It is shown in this talk that the sensitivity of one-port reflective-mode phase-variation permittivity sensors can be made unprecedentedly high by using weakly coupled resonators as sensitive elements. The key aspect to boost up the sensitivity (or derivative of the phase of the reflection coefficient with the dielectric constant of the material under test –MUT) in these single-frequency sensors is to achieve a high phase slope at the operating frequency [1]. Since a pair of coupled resonators exhibit resonance frequency splitting, and the phase of the reflection coefficient experiences an excursion of 360º between the split frequencies, it follows that between such frequencies, a significant phase variation is expected. Moreover, such phase variation is enhanced by weakly coupling the resonators, since the split frequencies are closely spaced if the coupling is weak. Thus, highly sensitive sensors can be implemented by means of this strategy. Figure 1 reports one example, consisting of a reflective-mode phase-variation sensor implemented with a pair of coupled quarter-wavelength resonators, including the phase response (of the reflection coefficient) and the sensitivity [2]. The maximum sensitivity is as high as 659.6º, which is a very competitive value, and coincides to a good approximation with the theoretical prediction, based on the results of the sensitivity analysis that will be succinctly presented in the talk. Further prototype device sensors will be presented in the conference. These sensors are of special interest in applications where tiny variation in the dielectric properties of samples should be resolved (e.g., defect detection, measurement of solute content in diluted solutions, etc.).



(a) (b)

Fig. 1. Example of a reflective-mode phase-variation sensor based on a pair of coupled quarter-wavelength resonators (a) and dependence of the phase of the reflection coefficient with the dielectric constant of the MUT and sensitivity (b).

[1] F. Martín, P. Vélez, J. Muñoz-Enano, L. Su, *Planar Microwave Sensors*, Wiley/IEEE Press, Hoboken, NJ, USA, 2022.

[2] P. Casacuberta, P. Vélez, J. Muñoz-Enano, L. Su and F. Martín, "Highly Sensitive Reflective-Mode Phase-Variation Permittivity Sensors Using Coupled Line Sections," *IEEE Trans. Microw. Theory Techn.*, doi: 10.1109/TMTT.2023.3234272.

Experiments with microwave sample excitation at the ALBA XPEEM

Michael Foerster,[a] Muhammad Waqas Khaliq,[a] Sandra Ruiz-Gomez,[a,b] Lucia Aballe,[a] Miguel Angel Niño[a]

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The Photoemission Electron Microscope (PEEM) of the ALBA synchrotron is a versatile surface characterization tool for X-ray nanospectroscopy and spectromicroscopy. It uses photoemitted electrons to form an image of the sample under X-ray illumination and provides element-specific magnetic contrast through the X-ray magnetic circular or linear dichroic effects (XMCD/XMLD).

Beyond imaging under static conditions, experiments where the sample response to an external stimulus is investigated are of increasing interest. In particular, using the Synchrotron beam time structure (repetition rate 500 MHz), stroboscopic pump-probe measurements are possible. We will present our instrumentation developments for the sample stage and connections, as well as electronics integrated into the systems´ ultra-high vacuum and high voltage environment that allow users to perform time resolved PEEM experiments with up to 4 GHz sample excitation (Figure 1(a)) [1].

We will present examples of studies using this set-up, ranging from magnetization dynamics driven by surface acoustic waves (Figure 1(b)) [2,3] or high frequency magnetic fields [4] to promotion of surface catalytic activity [5].

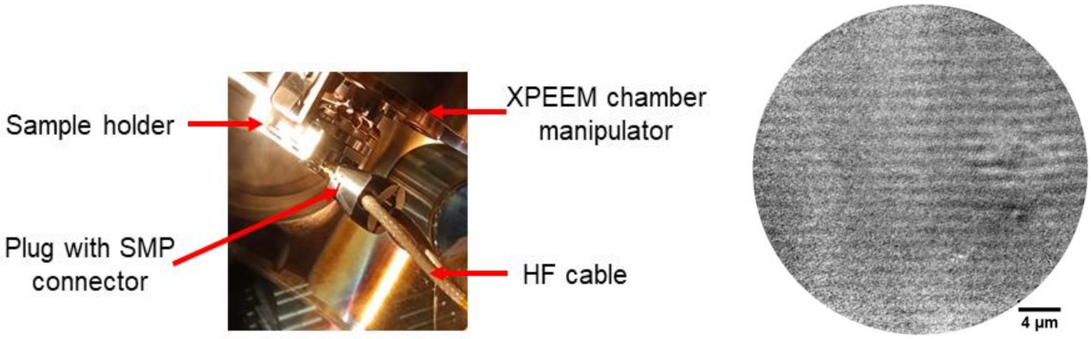

Figure 1(a) Photograph of the sample connection inside the PEEM analysis chamber using a specially designed lateral cable. (b) Magnetization wave in a Ni thin film, excited by a surface acoustic wave of 3 GHz.

[1] M.W. Khaliq et al., Ultramicroscopy 250, 113757 (2023).
[2] M. Foerster et al., Nature Communications 8, 407 (2017).
[3] B. Casals et al., Phys Rev. Lett. 124, 137202 (2020).
[4] M. Filianina et al., Appl. Phys. Lett. 115, 062404 (2019).
[5] B. v Boehn et al., Angew. Chem. Inter. Ed. 59, 20224 (2020).

Catastrophic magnetic flux avalanches in NbTiN superconducting resonators

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[b]Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, Université de Liège, Allée du 6 Août 19, Sart Tilman, B-4000, Belgium.
[c]Quantum Device Physics Labaratory, Department of Microtechnology and Nanoscience, Chalmers University of Technology, Goteborg, Kemivägen 9, SE-412 58, Sweden.

Superconducting coplanar waveguide (CPW) resonators have become an essential component of quantum circuits due to their ability to readout different qubit systems. These CPW resonators combine a conventional fabrication method with superior quality factors needed to perform circuit quantum electrodynamics [1]. In order to obtain this high performance, the CPW resonators must be screened from external damping sources among which magnetic flux quanta play a particularly detrimental role. Although efficient magnetic screening can be achieved, this is not always a viable option since some qubit implementation schemes require inevitable exposure to a magnetic field [2].

In this work, we investigate the impact of the magnetic field penetration on the resonance frequency of NbTiN superconducting resonators by a combination of magneto-optical imaging and high-frequency measurements. At temperatures below approximately half of the superconducting critical temperature, the development of magnetic flux avalanches manifests itself as jumps in the resonance frequency of the coplanar resonators. A clear change in the rate of decreasing resonance frequency with magnetic field is observed when a magnetic perforation event regime sets the transition between a Meissner-like phase in the ground plane and flux injection into the central feedline. These regimes are directly visualized by magneto-optical imaging and the impact of avalanches in the ground plane and the resonator is discerned (As shown in Figure 1). At high working temperatures, a smooth flux penetration is shown to prevail. We propose some hints and strategies to mitigate the influence of avalanches on the response of the resonators and to improve the magnetic resilience of coplanar resonators. Our findings demonstrate that superconducting resonators represent a valuable tool to investigate the magnetic flux dynamics in superconducting materials. Moreover, the current blooming of niobium based superconducting radio-frequency devices makes this report timely by unveiling the severe implications of magnetic flux dynamics.

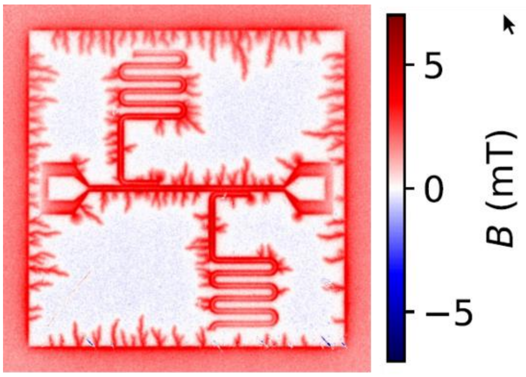

Figure 1: magneto-optical image taken at 5 K with a magnetic field of 1.3 mT.

[1] A. Megrant, et al., Applied Physics Letters **100**, 113510 (2012)
[2] Y. Kubo, et al., Physical Review Letters **105**, 140502 (2010)

Surface chiral currents in irradiated topological semimetals

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We study new types of surface states that appear in topological semimetals under irradiation with circularly polarized light. We observe a phenomenom similar to Landau quantization by which the surface states get a large degeneracy proportional to the radiation flux traversing the surface of the semimetal. We show that these surface states carry a rotating current that should manifest in a macroscopic chiral current in the irradiated surface[1]. These properties can be used for the design of a rectenna device working at THz frequencies. We also analyze the possibilities for control of the current generating states through THz pulses [2].

[1] J. González, R.A. Molina, Phys. Rev. Lett. 116, 156803 (2016).
[2] Y. Baba, J. González, R.A. Molina, in preparation.

Emerging Radar Absorbing Materials and Magnetic Sensors based on amorphous magnetic microwires

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Already today, but in the very near future our life will depend enormously on sensors. Robotic technologies, home automation, telemedicine, the autonomous car, the internet of things are developed around sensors. All these applications include gas sensors, biosensors and sensors for medical applications. In this type of devices the transducer plays a fundamental role but the most developed technologies are based on resistive materials and acoustic waves. However, the technologies based on magnetic materials, although being very promising for the development of contactless sensors, are still in is infancy.

In recent years, much interest and effort have been devoted to develop soft magnetic materials due to their technological potential [1]. Amorphous microwires are one of them most widely studied soft materials due to their outstanding properties as giant magnetoimpedance effect [2], bistability, ferromagnetic resonance, and magnetoelastic resonance [3]. It is easy, also, to find much literature regarding microwave-related applications of microwires [4]. This kind of work gives experimental evidence showing that the microwave scattering by a single microwire depends on the magnetic permeability with sufficient strength to be experimentally detected as an effect of the giant magnetoimpedance. This dependence is used to show the potential of such microwire as a wireless field and/or stress sensor. Experimental results are followed by a theoretical approach where the influence of the microwire magnetic state in its microwave reflection features is taken into account. The aim of the present work is to show the physical fundamentals and the possibilities offered by magnetoelastic materials as sensor transducers. In particular, biosensors based on magnetoelastic resonance are shown as well as the importance of the giant magnetoimpedance effect in microwaves domain for the development of remotely detectable safety labels, sensors with biomedical applications as for the detection of blood pressure or for the wireless detection of collagen concentration or even structural health monitoring of structures. On the other side the it has been demonstrated how amorphous microwires embedded with comercial paints with filling percentages of les than 3% give refletion loss of the order of -40 dB in X-band for active layers with a thickness lower than 1 mm [5].

Acknowledgements

The present work has been supported by the Ministerio Espanol de Ciencia e Innovacion (MICINN) through the projects:, RTI2018-095856-B-C21, and RTI2018-095303-A-C52; and Comunidad de Madrid, Spain, by S2018/NMT-4321 NANOMAGCOST.

References

[1] P. Marín, M. López, P. Agudo, M. Vázquez, and A. Hernando, *Sensors Actuators, A Phys.* **91** (2001) 1.

[2] A. Gonzalez, V. Zhukova, P. Corte-Leon, A. Chizhik, M. Ipatov, J. M. Blanco, A. Zhukov, *Sensors* **22(3)** (2022) 1053.

[3] C. Herrero-Gómez, P. Marín, and A. Hernando, *Appl. Phys. Lett.* **103** (2013) 14.

[4] C. Herrero-Gómez, A. M. Aragón, M. Hernando-Rydings, P. Marín, and A. Hernando, *Appl. Phys. Lett.* **105** (2014) 9.

[5] J. López-Sánchez, A. Peña, A. Serrano, A. del Campo, O. Rodríguez de la Fuente, N. Carmona, D. Matatagui, M.C. Horrillo, A. Rubio-Zuazo, E. Navarro, P. Marín. ACS Appl. Mater. Interfaces **15(2)**(2023) 3507–3521

Topological amplification

Álvaro Gómez-León, Tomás Ramos, Alejandro González Tudela and Diego Porras

Instituto de Física Fundamental-CSIC

Microwaves amplification is at the heart of many different technologies, and achieving large gain and low noise is one of the main objectives of their development. We will show that the ideas from topological condensed matter systems [1] can be used to design high-quality amplifiers where topology plays a crucial role: the robustness of amplification to disorder is linked to a topological invariant, phase-matching between modes is simplified, the gain is exponential with the number of sites in the system and its signal-to-noise ratio is quantum limited [2]. I will discuss the theory behind topological amplification and a possible experimental implementation using Josephson junctions [3].

[1] Á. Gómez-León, T. Ramos, A. González-Tudela and D. Porras. PRA **106**, L011501 (2021).
[2] Á. Gómez-León, T. Ramos, A. González-Tudela and D. Porras. arXiv:2207.13715.
[3] T. Ramos, Á. Gómez-León, J.J. García-Ripoll, A. González-Tudela and D. Porras. arXiv: 2207.13728.

Cavity optomagnonics with Yttrium Iron Garnet

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[a] *University of Barcelona (UB)*
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[c] *Catalan Institute of Nanoscience and Nanotechnology (ICN2)*
[d] *University of La Laguna*

Cavity optomagnonics, deals with the coupling between photons, phonons, and magnons (spin waves) in solid-state systems, using optical and microwave cavities. These novel hybrid systems could provide new avenues for quantum information transfer and exciting new physics arising from coherent photon-phonon-magnon interactions.

In this talk, I will present our efforts in the use of optomechanical cavities as extremely sensitive magnetic field detectors. We demonstrated [1] a hybrid magnetometer that exploits the coupling between the resonant excitation of spin waves in a ferromagnetic insulator and the resonant excitation of the breathing mechanical modes of a glass microsphere deposited on top. The magnetometer response relies on the spectral overlap between the ferromagnetic resonance and the mechanical modes of the sphere. By externally tuning the ferromagnetic resonance frequency with a static magnetic field, we demonstrate sensitivity values better than a nanoTesla /Hz^1/2 up to the gigahertz range. These results show that our hybrid system can be used to build a high-speed sensor of oscillating magnetic fields.

[1] M. F. Colombano, et al., Phys. Rev. Lett. 125, 147201 (2020)

Dielectric permittivity analysis of human tissues. Current status and prospects.

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[a] *Servicio de Anatomía Patológica, Hospital Clínic, Barcelona*
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The response of biological tissues to electromagnetic fields can be quantitatively characterized by their permittivity. At frequencies up to tens of GHz, this response depends on the motion of ions, on interfacial polarization effects across cellular membranes, and on the rotation of polar molecules (such as water) driven by an alternating electric field. By measuring the dependence of permittivity versus frequency, we can determine the ability of ions, polar molecules, and charges on membranes to move at the cadence imposed by the alternating electric field. This technique is known as “Dielectric Spectroscopy” (DS) and is an effective method to characterize materials and tissues by sensing the dynamics of the various mechanisms contributing to their permittivity. At the cellular scale, there is consistent evidence that biochemical processes associated with cancer development produce electrochemical changes that affect permittivity, such as higher ion concentration in the cytosol, higher surface charge density in the membrane and increased water content due to vascularization. Therefore, DS may become a useful technique to discern between normal, dysplastic, and cancerous tissues.

Dielectric Spectroscopy is compatible with current diagnosis protocols in pathology analysis, since it can be performed directly on fresh tissue and does not interfere with ulterior histological analysis. Despite its potential, DS has not yet been used in routine clinical practice for tissue diagnosis. In this context, we will describe our ongoing efforts to establish a database containing permittivity and histological data on human tissues and discuss the prospects of using it as a tool for pathology diagnosis.

Microwave Wireless Sensing of Single Bioparticles in a Microfluidic Platform

César Palacios[a] ,Marc Jofre Cruanyes [a, b] , Lluis Jofre Cruanyes [c] ,Jordi Romeu [a] ,Joan O'callaghan[a] , Luis Jofre-Roca [a]

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Advances in microtechnology offer new tools for designing microsystems capable of micrometric scaling. In this sense, two powerful technologies, such as microfluidics and microwaves, have merged to present new alternative methods for interaction with living microorganisms, facilitating their quantification and characterization. Microwave and microfluidic platforms provide speed, cost reduction, and miniaturization to IMS processes such as pharmaceuticals, medicine, and food, among others. Electromagnetic waves interact with microorganisms and collect information based on their changes into their dielectric properties [1]. Generally, they are based on devices that concentrate the electrical field in a certain small volume [2], through which a microfluidic channel transports microorganisms to be measured. This work presents a bio-particle sensing system based on a well-optimized superheterodyne receiver that allows counting and characterizing different bioparticles. The wireless sensing is made with bowtie electrodes whose dimensions in the sensing region are comparable to the dimensions of the bioparticles to be measured (3 to 5 um) and also show a bandwidth of 4 GHz at -10 dB. The electrodes cover an intentionally selected frequency range of 4 to 8 GHz to avoid losses due to the solution in which the bioparticles are transported (< 2GHz) and to avoid the effect of water relaxation properties (>10 GHz). The electric fields have been estimated and modeled using Python-based numerical calculations, which have allowed determining the optimal dimensions according to the electric field distribution within the channel. Preliminary microfluidic experiments have been performed to determine the optimal flow rate of 20 uL/min to achieve the focus of the particles in the center of the channel. The superheterodyne transceiver has been optimized in terms of local oscillator power and bandwidth. As a result, the system allows the individual counting of bioparticles and differentiation with a 6 dB SNR difference according to the measurement of intracellular content.

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Contribution on Antennas with 3D Printing Technology

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Additive manufacturing techniques are receiving attention from industry and academia in recent years due to the versatility of 3-D printing applied to complex engineering parts at a reduced cost. Also, 3-D-printing does not require the use of high-cost consumable parts, such as drills used in subtractive techniques, which are susceptible to breakage. These advantages are of interest for the fabrication of waveguide devices and antennas [1]. Recently, other simple additive manufacturing technologies, such as the stereolithographic (SLA) 3D-printing method, have emerged and are rapidly evolving, being a promising alternative to CNC milling in some applications and benefiting from the inherent general advantages of 3D-printing for RF components [2]. In this work we will present different design of antennas with 3D printing technology. As for example, a circularly polarized (CP) perforated gradient index (GRIN) flat lens antenna with directive beam-steering properties is presented for millimeter-wave applications at W-band (75–95 GHz) [3]. The dielectric lens, fed by an open-ended square waveguide (SWG) located in the lens focal plane, enhances the radiation in a particular direction, generating a high-directivity beam with planar wavefront. The integration of a dielectric polarizer with the lens allows the conversion from a linearly polarized (LP) incident wave to a CP-emitted wave over the whole bandwidth. A ±30° scan range in both azimuth and elevation planes is demonstrated for the whole frequency range, attained by displacing the feed along the focal plane of the lens. Lens and polarizer are manufactured as a single piece by stereolithography (SLA) 3-D printing technology with Form 3 Formlabs 3-D-printer. Measured results show maximum measured directivity values that range from 23.5 to 23.8 dB, a remarkable circular polarization purity as a wide axial ratio bandwidthof 20.58% (<3 dB), from 77.5 to 95 GHz, is achieved for the principal beam steers.

ACKNOWLEDGEMNTS

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Integral Absorption of Microwave Power by Random-Anisotropy Magnets

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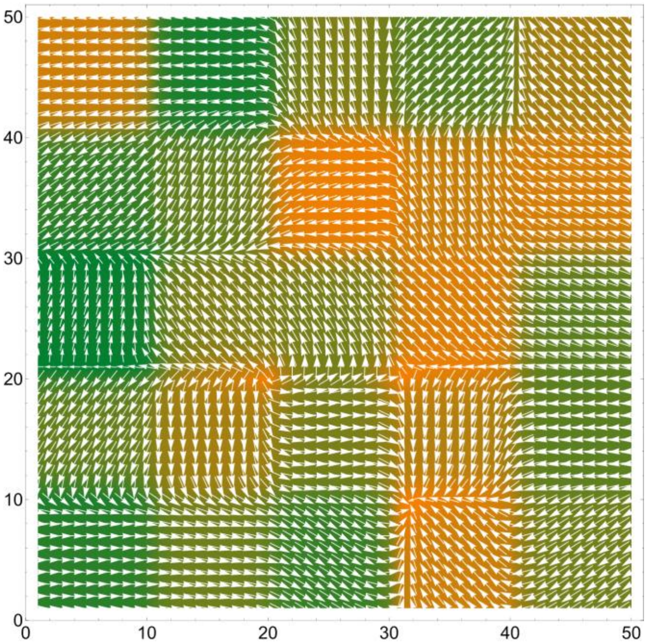
We study analytically and numerically the integral absorbed power IP= ∫dωP(ω) of microwaves by a granular random-anisotropy (RA) magnet. In the numerical work, we consider a 2D model with grains of $n\times n$ classical spins within which the random direction of the easy axis of the anisotropy is the same. A typical equilibrium spin configuration is shown in the figure, where *xy* spin components are shown by white arrows and *z* spin component is color coded.



Earlier we showed numerically by applying a harmonic magnetic field to the system that RA magnets are good broadband microwave absorbers [1]. Then with the help of the fluctuation-dissipation theorem these results were generalized for arbitrary temperatures [2]. The broadband absorption is due to the localization of spin waves in this random media, the localized modes having broadly distributed frequencies [3]. This numerical work requires lengthy computations of the dynamics of large systems of spins. Here we propose a method of calculating IP using a sum rule similar to those used in the quantum field theory. IP can be expressed via the autocorrelation function of the time derivative of the total spin that can be expressed in terms of the spin configuration with the help of the Landau-Lifshitz equation of motion. The resulting expression can be computed by Monte Carlo at a given temperature T. On the other hand, it can be calculated analytically by averaging over the RA realizations and using spin-wave theory, as well as scaling analysis for the granular model. The result is IP ~ D_R^2/J for the RA strength $D_R \ll J$. For large grains, IP ~ D_R. The optimal-absorption scenario is realized at the crossover between these regimes, grain width ~ $(J/D_R)^{1/2}$ lattice spacings. Research supported by the U.S. Air Force Office of Scientific Research.

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Dispersive Readout of Floquet-State Populations

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Landau-Zener-Stückelberg-Majorana interferometry refers to the equivalent of a Mach-Zehnder interferometer in the time domain, where avoided crossings in the adiabatic spectrum of a few-level system act as beam splitters. The resulting interference patterns can be observed in almost any observable. To this end, recent experiments employed strongly driven double quantum dots (DQDs) coupled to either biased electron reservoirs or superconducting cavities. Accordingly, interference patterns can be seen in the time-averaged current and the cavity transmission. A theory for the cavity transmission based on non-equilibrium linear response theory describes the signal in terms of a phase-averaged susceptibility of the DQD [1]. It not only reproduces the measured patterns, but also provides a resonance condition that includes the cavity frequency. Theory also predicts an interplay between the cavity response and the population of Floquet states, which eventually provides a way to measure this population. Specifically, gaps in the interference fringes indicate the depletion of the Floquet state with lowest mean energy when resonance conditions for both the cavity response and the population are fulfilled simultaneously. The resulting patterns have been observed with GaAs DQDs [2]. Strong DQD-cavity coupling or the presence of various DQDs may require a treatment beyond linear response in the DQD-cavity coupling. This becomes evident by the prediction of unphysical transmissions larger than unity. For this case, a modified theory based on a susceptibility of the full cavity-DQD compound has been proposed [3], which provides a faithful description in good agreement with experiments. Finally, the efficient computation of the required phase-averaged susceptibilities within Floquet theory will be addressed.

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Smooth-Profiled Microwave Filters

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The synthesis of filters/passive components following classical approaches exhibits important limitations. Just to name a few, the target frequency responses are limited to rational functions, a lumped-element circuit model is customarily used, and the resulting square-like profiles may lead to radiation and spurious effects. In the latest years, UPNA has developed different Inverse Scattering (IS) synthesis methods based on the Coupled-Mode-Theory (CMT), leading to devices with tailor-made frequency responses and smooth profiles [1-6]. These devices are ultimately better adapted, for instance, to the emerging layer-by-layer (3D) fabrication methods (such as Selective Layer Melting, SLM) in waveguide technology or to high-power payloads. This is due to their smooth profile, which could allow growing the device along its propagation axis and without supporting structures, its intrinsic robustness to manufacturing errors due to its distributed nature, and the non-presence of parallel surfaces that avoids the electron avalanche of the multipactor effect in vacuum conditions such as in space. IS synthesis methods have been also applied at UPNA to planar technologies, where the smooth profiles are very promising to reduce radiation and spurious effects in applications that need very high operation frequencies. During the conference, we will report on our group's approaches to the synthesis of filters and passive components in the microwave and millimeter-wave ranges at UPNA, for different applications and technologies.

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Pulsed Microwave Imaging for Human Brain Functional Monitoring

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Morphological microwave imaging has shown promising results in reconstructing physiological parts inside the human body, providing information about their actual biological condition. This uses to be a still image does not providing information about their functional activity.

In this study, we propose a novel microwave technique able to locate low-frequency (LF, f≃1 kHz) modulated signals produced by a microtag mimicking an action potential and to extract those LF signals. The proposed method was tested in a cylindrical phantom of the brain region. A set of two combined UWB microwave applicators [1] [2], operating in the 0.5 to 2.5 GHz frequency band and producing a nsec interrogation pulse, was used to focus its radiated field into a small region of the brain containing the microtag with a modulated photodiode. The illuminating UWB microwave field was first modulated by the low-frequency (f≃1 kHz) electrical signal produced by the photodiode, inducing modulated microwave currents into the microtag that reradiated back towards the focusing applicator. At the receiving end, the low-frequency (f≃1 kHz) modulated signal was first extracted from the full set of the backscattered signals and then focused into the corresponding region of the brain, resulting in a spatial resolution of the images in the order of 10 mm. Finally the LF modulating signal is extracted from the received UWB signal and processed for an early stage detection of the specific functional disease.

The proposed technique has the potential to locate and extract low-frequency modulated signals produced by microorganisms, which can provide valuable information about the functional state of biological tissues. This technique can be used for non-invasive monitoring of brain activity and has potential applications in the diagnosis and treatment of neurological disorders like Parkinson’s and Alzheimer disease.

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Strain tuned non-classical light emission from 2D layered semiconductors

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Localized defect states in two-dimensional (2D) van der Waals (vdW) materials, including semiconducting transition metal dichalcogenides, GaSe and insulating h-BN, have emerged as a promising physical system for scalable quantum technologies. In this work, the direct visualization of individual atomic-scale defects in h-BN flakes using atomic force microscopy under ambient conditions combined with density functional theory calculations of their band structures and electronic properties made it possible to associate the existence of several single-photon optical transitions to the observed defects [1], thus shedding light on the exact origin of quantum emitters in h-BN, which is still under debate. We also report on the dynamic real-time spectral tuning over a few-meV-wide range of the optical emission from individual non-classical light sources in h-BN flakes subjected to the radio frequency surface acoustic waves. Our approach provides an effective post-fabrication in situ tuning method capable of controlling otherwise random emission energy of 2D light sources that severely limits their suitability for any practical future applications in quantum photonics [2]. We also demonstrate a scalable and lithography-free approach toward creating large areas of localized emitters in 2D semiconductors. The proof-of-concept was achieved by placing WSe_2 and GaSe flakes over polystyrene or luminescent rare-earth ion doped micro/nano-particles. Altogether, this study opens the door to the use of static and dynamic strain engineering for scalable integration of vdW emitters in nanophotonic and related quantum information technologies.

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Dielectric permittivity analysis of human tissues

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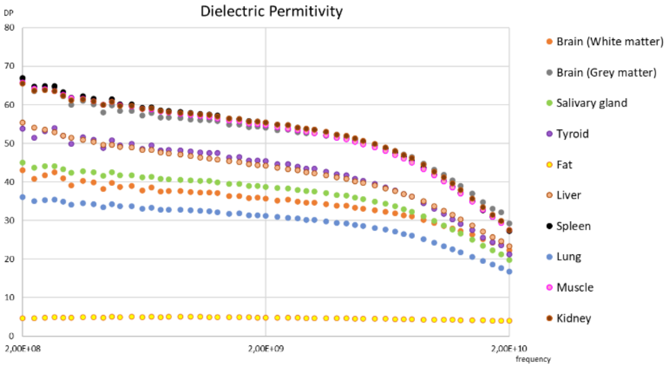
Dielectric permittivity (DP) characterizes the interaction of tissues when exposed to an external electric field. Tissues with different cellular composition will provide different DP values. We aim to determine DP values in healthy human tissues to create a database.

Prospective observational study of all types of healthy human tissues. Tissue samples are placed in a Teflon® base placed on a scale to ensure optimal pressure (1g) of the coaxial probe for real time DP analysis. Then, we select the analyzed area, and conventional FFPE process is performed. Hematoxilin-Eosin histologic slides are reviewed and annotated for any changes.

We analysed 110 healthy tissues from 27 patients, obtained from surgical specimens or autopsies of less than 12 hours: 6 CNS, 1 thyroid, 13 lung, 12 spleen, 15 liver, 7 kidney, 13 salivary gland, 15 fat, 13 skeletal muscle, 14 heart, and 1 tongue. The semi-logarithmic DP graphs showed different patterns depending on the type of tissue (Figure 1). Fat DP values were the most characteristic, showing an almost linear curve, with DP values between 0 and 5, significantly lower than other tissue values. Of notice, histologically visible intrahepatic and intramuscular fat could be predicted by DP measurements, which were lower than permittivity from other liver and muscle samples.

Figure 1:



There are differences in dielectric permittivity between different types of healthy human tissues. The DP analysis allows the identification of certain alterations, such as the presence of intrahepatic or intramuscular fat. A DP database of healthy tissues will provide the basis for future applications and could help in the discrimination between healthy and tumoral tissues, among other pathologies.

Magnon Bose-Einstein condensation and Optomechanics

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In recent years, it has become possible to demonstrate the existence of Bose-Einstein Condensates (BECs) of magnons, which are the collective quantized excitations of magnetizations, in ferrimagnetic insulators, such as yttrium-iron garnet (YIG) films, at room temperature [1]. So far, the only technique used to measure BEC is spatially resolved Brillouin light-scattering (BLS).

In this poster, we discuss the possibility of measuring magnon BEC using the cavity optomechanics technique. In particular, the formation of BECs can be measured by magnon-phonon-photon coupling [2].

We will present the results of optical (whispering-gallery modes), phonon (mechanical modes), and magnon (ferromagnetic resonance) resonances all measured in a single YIG sphere.

Our results indicate that cavity magnomechanical systems could provide a promising platform for the study of macroscopic quantum coherent phenomena at room temperature.

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Quantum Dot arrays for Quantum Information Transfer

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The fabrication and control of semiconductor quantum dot arrays open the possibility to use these systems as quantum links, for transferring quantum information between distant sites, an indispensable part of large-scale quantum information processing.

Great effort is currently being devoted to the investigation of hole spin qubits in quantum dots owing to their long coherence time and rapid operation time due to the inherently strong spin–orbit coupling (SOC) which allows to perform electron dipole spin resonance in the microwave regime [1]. In this talk I will discuss different pulse-based protocols to transfer spin holes between edges of a quantum dot chain with high fidelity. I will show how the spin polarization of the transferred holes can be controlled by tuning the ratio between the SOC and the spin conserving tunneling rate [2]. Also, I will discuss how to transfer entangled hole spin qubits between edge dots. Our theoretical results suggest the feasibility of quantum dot arrays as high-fidelity quantum buses to distribute information between distant sites and perform one qubit gates in parallel.

An alternative way to transfer quantum information between distant sites, is to use protected topological edge states in systems with non-trivial topology. I will discuss how to simulate a topological insulator in a quantum dot array by Floquet engineering in the microwave regime [3]. The long-range particle dynamics mediated by edge states in different quantum dot array configurations [4], opens a new avenue for quantum state transfer protocols in low dimensional topological lattices.

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Microwave control of superconducting qubits for quantum computation

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Superconducting qubits are among the most promising candidate systems to build a universal quantum processor. Both digital- and analog-based quantum processors have been proposed using superconducting circuits, and small-scale prototypes have already been implemented. These devices exhibit excitation energies in the microwave regime. Therefore, efforts in improving their control and quality rely strongly on engineering methods of microwave technology, both in the device design and the choice of materials. The Quantum Computing Technology group at IFAE develops superconducting circuits with the goal of enhancing their quality by fabrication and design methods to run gate-based algorithms [1] and develop quantum annealing prototypes, a type of analog quantum processor. We also study the simulation of quantum optical models using the circuit physics, such as the ultrastrongly coupled light-matter systems [2]. Finally, we are exploring the interaction between ionizing radiation, mostly from cosmic origin [3], and superconducting qubits, both to suppress the sensitivity of the qubits to this highly energetic source of noise, as well as to use the qubit to build a detector of rare events. In this presentation, I will give an overview of the topics researched at IFAE on superconducting qubits.

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Two-qubit logic between distant spins in silicon

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Coupling spin qubits to microwave photons provides an elegant approach for mediating long-range spin-spin interactions. The circuit quantum electrodynamics (QED) framework enables two-qubit gates which can be used for on-chip quantum links. In previous work, resonant spin-spin-resonator coupling in a silicon quantum device was demonstrated [1]. Most two-qubit gate schemes require a spin-spin coupling in the dispersive regime that is larger than the spin dephasing rates, as was recently observed in spectroscopic measurements [2]. In this work, we probe such a dispersive spin-spin interaction in the time-domain and demonstrate a two-qubit gate between spin qubits in silicon separated by 250 μm.

We form a double quantum dot (DQD) in a 28Si/SiGe heterostructure at each end of a 250 μm long high-impedance superconducting resonator [3]. We trap a single spin in each DQD, and we enable tunable spin-charge hybridization with micromagnets. Due to mitigation of microwave losses [4], we can tune the spin-charge hybridization to reach the strong-coupling regime with spin-photon couplings up to around $g_S/2\pi$ = 40 MHz. The readout is implemented by direct dispersive spin sensing using the same resonator, with the signal-to-noise ratio largely improved by a Josephson traveling-wave parametric amplifier [5].

We first show universal single-qubit control over two flopping-mode qubits [6] and characterize their coherence times. Next, we bring the two spins into resonance with each other, but detuned from the resonator photons, and observe exchange (iSWAP) oscillations between the two remote spins of 17 MHz. This frequency is consistent with the spectroscopic measurements [2]. Furthermore, we demonstrate that the coupling strength (2J) as well as the coherence times of the qubits can be tuned by two knobs: the inter-dot tunnel coupling and the spin-cavity detuning. In future work we intend to implement single-shot readout and improve the spin lifetimes while dispersively coupled to the resonator. These results pave the way for scalable networks of spin qubits on a chip.

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Strong magnon-photon coupling in a single yttrium iron garnet microstructure on a superconducting microwave resonator

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Strong coupling between microwaves and magnons has been demonstrated years ago. In [1] magnon modes in an yttrium iron garnet (YIG) sphere of several hundred micrometer diameter were successfully coupled to the microwave modes of a large microwave cavity. Also coupling of magnons in YIG to phonons[2] or to optical photons[3] has already been shown. These experiments have in common that macroscopic pieces of YIG were used. This is unfavorable if the effect is to be integrated for device purposes, both in terms of size and technology.

On the other hand coupling between magnetic microstructures and superconducting resonators has been reported making use of ferromagnetic metals that can easily be patterned[4,5]. Nevertheless, the lifetime of spin waves in ferromagnetic metals is rather small and although strong coupling could be demonstrated, it would be desirable to use microscopic YIG resonators instead.

We have realized coupling between microwave photons in superconducting lumped element resonators and magnons in Permalloy and YIG nanostructures, respectively. With YIG, we are able to reach the strong coupling regime. This is possible because of an optimized lumped element resonator that concentrates the magnetic field in the magnetic microstructure.

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STENT MONITORING USING MICROWAVES: FROM IN VITRO TO IN VIVO

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Cardiovascular diseases account for 30 % of deaths worldwide and coronary artery disease (CAD) takes 50 % of those deaths. In the event of CAD the blood flow and oxygen to the heart muscle decreases due to the narrowing of a coronary artery. Percutaneous coronary intervention is the gold standard procedure to treat CAD, performed by ballooning the narrowed segment of the ischemic artery and deploying a stent to keep it open.

Stents are metallic mesh tubes that have proven to be highly effective in preventing artery re-occlusion. However, 40 % of them may fail due to pathologies such as structural damage (stent fractures) or the re-narrowing of the artery (restenosis). Stent-related pathologies can be asymptomatic or lead to acute complications such as myocardial infarction, cardiac arrest, or sudden death putting patients' life at risk. Currently, there is no standard procedure to prevent these pathologies. NIMBLE Diagnostics is developing a first-in-class non-invasive and non-ionizing medical device to early diagnose stent-related pathologies before the onset of symptoms.

Given their cylindrical shape and their architectures, stents resonate at the microwave region of the electromagnetic spectrum. The NIMBLE System transmits, aided by a horn antenna, an electromagnetic wave from the surface of the patient's body that is conveyed through the tissues and to the stent, and scattered back to the surface of the body where a second horn antenna receives it. Using the information enclosed in the electromagnetic waves, the stent status is gathered.

To transform the electromagnetic waves received into stent status reliable information several experiments have been performed throughout the years with different prototypes to build the NIMBLE System: starting from spiral antennas all the way to near-field probes and horn antennas. In open-air conditions, biological emulated models and *in vivo* murine and swine specimens. From healthy to pathological stents. Altogether to prove that commercially available stents can be detected inside human cavities and that stent-related pathologies are traceable using the microwave resonance-based NIMBLE System.

Anti-reflection structure for perfect transmission through complex media

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In this talk, we show that counterintuitively a randomly disordered medium can be made translucent when placing a suitably engineered anti-reflection structure in front of it. Complete suppression of reflection can be achieved for all incoming wave fronts regardless of their spatial profile. To this end, the reflection matrices of the two media surfaces facing each other need to satisfy a matrix generalization of the condition for critical coupling. Interestingly, the internal structure of the disordered medium does not need to be known, only the reflection matrix is relevant for our novel design protocol.

We present the results of numerical and experimental demonstration of this idea, *i.e.* the design of disordered waveguides that transmit all incoming microwave radiation at a desired frequency. The initial scattering region composed of randomly located cylinders within the waveguide initially transmits 64% of the incoming field. When the complementary medium is placed in front of it, an average transmission on all incoming wavefronts is achieved reaching 96%.

In addition, we show that the translucent scattering media we introduced here also provides a remarkable enhancement of the energy stored in their interior.

The results presented in this talk have been published in Nature [1].

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Enhanced microwave absorption by bi-layered systems

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The present work deepens on the geometry optimization and use of different materials for maximizing electromagnetic shielding capacities in different systems.

A broad analysis of all the materials and structures used is presented, starting from the electromagnetic properties of all the constituents used moving to the total absorption of the multilayered systems. Reflection experiments, performed between 0.1 and 20 GHz in an anechoic chamber, have been done to measure the reflection loss (R_L) of each sample under real radar conditions. All the experimental results are, additionally, compared to a traditional single-layer model and a novel double-layer one, which are capable to simulate the R_L under different conditions.

One of the main observations of this work is the huge potential that random field magnets (RFM) have as microwave absorbers. Our experimental results support the previous theoretical predictions [1, 2] about their performance.

On the other hand, we also report experimental evidence on the increase of absorption in existing absorbing materials by combining them with a second layer of dispersed RFM. These combinations show the capacity to double (in dB scale) the absorption peak compared to the former material.

Overall, here we highlight the exceptional capacities that composite materials containing RFM have to attenuate radiation when then are used in multilayered systems. Experiments and theory are combined to extract full knowledge about the necessary conditions that these systems require to maximize their performance.

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Use of graphene-based materials in electromagnetic shielding applications.

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Graphene-based materials (GBMs) are increasingly recognized as electromagnetic shielding materials (ESMs) due to their superior reflection loss properties and versatility. Defect engineering, mesoporous structuring and hybridizing GBMs with magnetic materials can optimize their electromagnetic shielding performance [1].

In our study, we follow-up the research on few-layered mesoporous graphene (FLMG), a novel GMB obtained through ball-milling [2], with amorphous magnetic microwires (MW) [3]. Results showed that the addition of FLMG generates a significant frequency shift and absorption bandwidth broadening, highlighting FLMG's potential as a performance tuner for electromagnetic shielding materials (Figure 1).

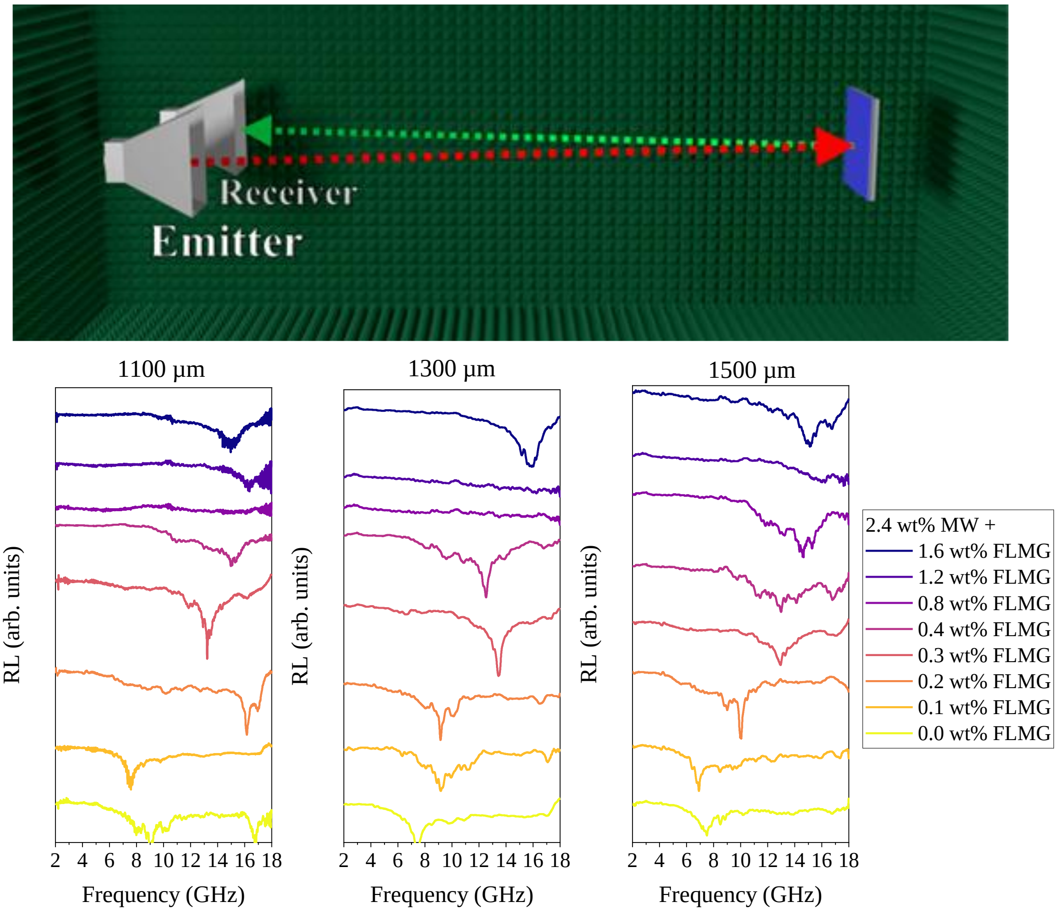

Figure 1: (Top) Free-space measurement setup representation and (bottom) RL spectra of an ESM containing 2.4 wt% of MW and increasing wt% of FLMG.

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[3] J. López-Sánchez, et al. ACS Appl Mater Interfaces, 15, 2, 3507–3521 (2023).

Spin injection and spin-charge conversion processes in all-oxide heterostructures

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The use of the electronic spin as a control variable would allow progress in the development of high-performance and low-power electronic devices compared to classic semiconductor-based devices. The development of this new technology requires strict control of the processes of generation, transmission and detection of pure spin currents. Fundamental in the generation and detection of spin currents are the spin-charge interconversion processes through spin Hall effect (SHE) and inverse spin Hall effect (ISHE). In these processes the spin-orbit interaction (SOI) plays a fundamental role since it enables direct charge-spin coupling and therefore, mediates spin-charge interconversion processes.
In this talk a study of spin injection and spin-charge conversion processes in all-oxide heterostructures will be presented. Ferromagnetic resonance (FMR) technique will be used to generate pure spin currents by spin pumping (SP) in ferromagnetic (FM) transition metal oxides (TMOs) materials, such as $La_{2/3}Sr_{1/3}MnO_3$ (LSMO), and the detection of these pure spin currents will be acomplished by measuring the ISHE transversal voltage signal in FM/normal metal (NM) bilayers. These studies will be performed in all-oxide heterostructures using $SrIrO_3$ (SIO) as spin detector. The role of microstructure, interfacial features and SIO layer thickness in these processes will be analyzed. Microstructure of the samples and interfaces were fully characterized by advanced X-ray diffraction and High-Resolution Electron Microscopy (HR-STEM).

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Novel approaches for RF testing of HTS coated-conductors for the FCC-hh

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The use of high-temperature superconductor-coated conductors (HTS-CCs) in combination with normal metals for coating the beam screen of the Future Circular Hadron Collider (FCC-hh) has the potential to significantly reduce the impedance presented by the beam screen to the particle beam. However, experimental verification of these benefits is necessary, including measuring the HTS-CC surface impedance under specific conditions such as synchrotron radiation, strong magnetic fields (16 T), and cryogenic temperatures.

To measure HTS-CC under FCC-hh conditions, microwave HTS testing techniques, devices, and systems needed to be adapted. These adaptations included accommodating sample formats different from those typically used in microwave HTS applications.

We will describe the innovative testing devices and systems developed to meet these requirements, including miniaturized Hakki-Coleman resonators, various versions of parallel plate resonators, and cavity resonators featuring different types of beam screen prototypes.

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GHz control of solid-state spins using acoustic fields

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Acoustic fields with GHz frequencies have proven to be a versatile tool for manipulating and controlling magnetic excitations in semiconductor structures. These fields can be conveniently excited in semiconductor chips using piezoelectric transducers with fabrication processes compatible with semiconductor technology. Furthermore, the μm-sized SAW wavelengths allow confinement with dimensions much smaller than those achievable with electromagnetic fields.

In this contribution, we present two recent applications of acoustic fields for advanced spin control. We first demonstrate the on-the-flight dynamic control of moving spin vectors in semiconductor nanostructures using surface acoustic waves (SAWs), which provides a method for the manipulation and exchange of quantum information between remote locations on a chip. The moving SAW fields have been shown to efficiently transport spins along 100's of μm along a quantum well (QW) structure. Typically, gates based on electric or magnetic fields along the SAW path can create the necessary perturbation for the control of the electron spin vector. Here, we demonstrate that the SAW field themselves also generate a pseudomagnetic field moving with the spins – a spin-orbit field – which acts as a contactless gate to control the spin precession frequency during transport [1]. The degree of spin precession exceeds previously reported results by an order of magnitude and is well accounted for by a theoretical model of the strain contribution to the spin-orbit interaction. This flying spin gate enables the realization of an acoustically driven optical polarization modulator based on electron spin transport, a key element for on-chip spin information processing with a photonic interface.

The second example addresses the acoustic manipulation of atom-like spin color centers in SiC. These spin centers are attractive for applications in quantum technologies due to their long coherence times, sensitivity to microwave and acoustic fields, as well as optical read-out. Specifically, we use the dynamic SAW strain field to selectively excite the room-temperature spin transitions with magnetic quantum number differences of ±1 and ±2 in the absence of external microwave fields [2]. We show that, compared to the ground states, the spin levels in the optically accessible excited states exhibit even stronger interactions with acoustic vibrations, thus leading to novel and, so far, largely unexplored physical phenomena. A remarkable example is the acoustically induced coherent spin trapping [3], which consists in the quenching of the optically detected spin resonance due to the precession of the spin around the same axis in both ground and excited states. Our results open new possibilities for the coherent control of spin qubits with dynamic strain fields, which may lead to the realization of future spin-acoustic quantum devices. Finally, we discuss the prospects of extending the acoustic control to the tens of GHz range using specially designed acoustic structures.

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Photo-assisted spin transport in double quantum dots with spin-orbit interaction

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Spin qubits in semiconductor quantum dots (QDs) have emerged as a promising platform for scalable and high-fidelity quantum computing [1-3]. These qubits encode information in the particle's spin state, which can be manipulated using microwave (MW) electrical pulses. To maximize the potential of this platform, a thorough understanding of the underlying processes is required, including the effects of spin-orbit coupling (SOC) that lead to spin rotations and novel spin transport features.

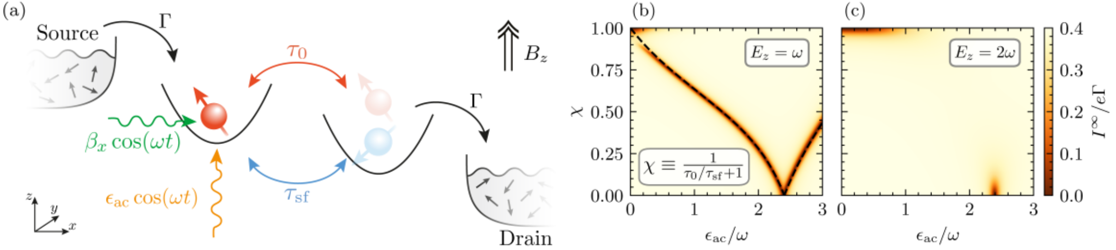

Figure 1: Panel (a) depicts a schematic of a double quantum dot system coupled to source and drain leads, with both spin-conserving and spin-flip tunneling rates connecting the dots. The system is subjected to periodic driving using a microwave pulse in the detuning, and an out-of-plane magnetic field is applied. Panels (b) and (c) present the current intensity as a function of the driving amplitude and the strength of spin-orbit coupling. In panel (b), the Zeeman splitting is in resonance with the one-photon transition, while in panel (c), it is in resonance with the two-photon transition.

This study focuses on a double quantum dot (DQD) system under a MW electric field and strong SOC, as shown in Fig. 1(a). We explore the interplay between SOC-induced spin-flip tunneling and electric-dipole spin resonances caused by the AC field, which can result in current suppression due to a dark state (DS) formation. The appearance of DSs depends on the number of photons involved in the transition, known as the even-odd effect.

By tuning the MW pulse, we demonstrate the use of DSs for characterizing the SOC in the system, as shown in Fig. 1(b-c), and for storing quantum information. We also show that the spin qubit dynamics can be fully controlled by tuning the MW pulse. Additionally, we obtain highly polarized spin currents through the DQD, even in the presence of weak SOC. Finally, we explore the implementation of a flopping-mode qubit [4], where an effective magnetic field in the x-direction emerges from virtual transitions to the other QD. The present configuration allows for full control of quantum gates applied to the qubit by adjusting the parameters of the applied MW pulse [5].

In summary, this study provides a comprehensive understanding of the interplay between SOC, MW electric fields, and electric-dipole spin resonances in DQD systems, and demonstrates their potential for implementing qubits for quantum computing applications.

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Topology detection in cavity QED

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Cavity Quantum Electro-Dynamics (c-QED) studies the interaction between light and matter at the most elementary level, either with real atoms or solid-state devices, like mesoscopic circuits. These hybrid systems have revealed themselves as an important tool for the control and manipulation of quantum systems, and in particular, for the development of quantum technologies [1]. The efficient transfer of information between light and matter is possible when the strong-coupling condition is fulfilled, that is, when their interaction strength is larger than the losses in the system. Therefore, there is an implicit quest for reducing the loss rates to consolidate the strong-coupling condition, but also for increasing the coupling strength to make it comparable to the bare frequencies of the system. This leads to new regimes of interaction, known as ultrastrong and deep-strong coupling, that have also been recently measured [2].

In this context, a step further can be taken through the combination of quantum light and complex quantum materials with emergent properties, such as topological. In this work [3], we investigate the physics of fermionic topological systems in c-QED architectures and explore the cavity transmission for arbitrary coupling strength. Typical experiments probe the cavity through its transmitted signal, and it is usually employed for readout and control of the state of the system [4]. Our aim is to study the use of the cavity transmission as a topological marker, identifying the experimental signatures of non-trivial topology, and characterize the physics of the hybrid system.

Specifically, we consider the case of a single-mode cavity interacting with a one-dimensional chain described by the SSH model a canonical example of one dimensional topological insulators [5]. We find that the transmission can be used to detect non-trivial topology in a fermionic system, with an appropriate state preparation depending on the regime considered.

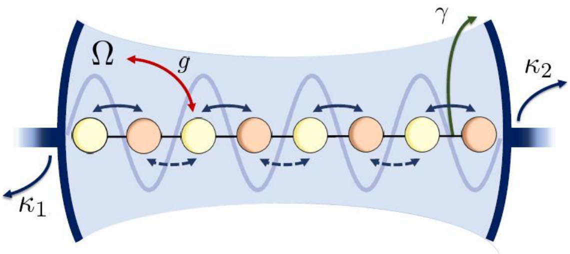

Figure 1. Schematic picture of a SSH chain interacting the photons in a cavity, with frequency Ω The cavity is connected to the input and output ports with factors κ. The coupling strength is *g* and γ represents the spectral broadening of the fermionic system.

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Spin-based direct-CNOT via virtual photons in a superconducting microwave resonator

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Quantum chips with fully connected architectures are predicted to operate at higher fidelity than those with only nearest-neighbor coupling[1]. Scaling connectivity beyond nearest neighbor interactions requires the implementation of a mediating interaction (e.g. cavity photons) often termed a “quantum bus”. It has been demonstrated that spin-based qubits in double quantum dots can reach the strong coupling regime[2,3] and exhibit spin-spin interactions via real or virtual photons[4,5]. Two-qubit entanglement beyond nearest-neighbors in these systems is essential for fully connected universal quantum computation. Here we explore the potential for driving entanglement between non-local flopping-mode spin qubits dispersively coupled to a common photonic mode of a superconducting microwave resonator. We propose a scheme for synchronizing a single-qubit rotation with a cross-resonance drive to realize a spin-based direct-CNOT[6]. This simultaneous evolution yields a gate-time within the entanglement time of the cross-resonance gate. The average gate fidelity (>90%) is calculated in the presence of cavity loss, electron-phonon interaction, and general spin-dephasing.

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Designing scalable robust optimal control for superconducting qubits

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Fault tolerant as well as Noisy Intermediate Scale Quantum (NISQ) quantum computing require quantum gates with very high fidelity, across large scale quantum processors. This is challenging given the limitations on the coherence time of qubits as well as uncertainties about the parameters of the system and its controls. Optimal control techniques can be used to achieve high-fidelity gates by shaping microwave control signals. Interestingly, these pulses can accommodate several constraints such as signal amplitude, bandwidth, and parameter uncertainties while maintaining high performance. They do, however require a very good model of the system and high level of calibration of the experiment. Here we will discuss the recent experimental and theoretical developments in the field and then discuss how we approach the design of such ‘smart’ control pulses in the microwave regime for single and two qubit gates. We will discuss recent results obtained on the IBM qubit and what can be learnt about the control landscape. The use of microwave pulses and optimal control may also find use in hybrid superconducting-semiconducting systems, and we discuss how it could be used for designing a gate for a qubit that is based on quasi-particles in the topological phase of the system. Finally, we will show how optimal control can help us achieve scalability in the design of quantum processors based fixed couplings, a strategy that can lead us to efficient hardware as well as efficient in operation.

Exploring the synergy of GHz acoustic waves and spin waves at the nano scale

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Spin waves in magnetic materials are coherent dispersive waves, typically in the low GHz frequency regime and with wavelengths of hundreds of nanometers. Interest in spin waves is motivated by the possibility of its integration into nano-scale devices for high-speed and low-power signal processing. However, generation of spin waves with high amplitudes—and their detection—is challenging due to the mismatch of wavelengths with electromagnetic waves in free space, which is of the order of several centimeters.

Surface acoustic waves are strain waves propagating at the surface of a material and can be generated at the GHz regime with electrical microwave excitation in piezoelectric materials. The resulting strain and electric propagating wave could couple to material's magnetization and thus be used to either modify magnetic states or sense the existence materials magnetic cofnfiguration. I will review some recent experiments on the coupling of strain waves and spin waves using X-ray Photo-Emission Electron Microscope (XPEEM). The main observations are: *i)* the sound waves generate up to 3 GHz large amplitude spin waves over large distances [1], *ii)* it is possible to control sound waves interference patterns and so it is the control of spin wave [2] *iii)* the possibility of generating non-resonance spin waves and its difference with resonance excitations [3] and *iv)* the possibility of moving magnetic domains at the SAW velocity [4,5].

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Microwave excitation with surface acoustic waves (SAWs) in magnetic thin films

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Microwave excitations with Surface Acoustic Waves (SAWs) in magnetic thin films are gaining interest due to the well-established fabrication of compact SAW devices together with the well-defined magnetic resonances in thin films as a mechanism to excite and manipulate magnetization dynamics efficiently.

The coupling between SAWs and magnetization in thin films is possible due to the magnetoelastic effect, which uses magnetostriction – change in magnetization due to a mechanical deformation – to transform strain into a change in the magnetization direction.

In recent experiments, we used a hybrid set-up consisting of a piezoelectric and magnetic thin film (see Fig. 1) along with X-ray Photoemission Electron Microscopy (XPEEM) to study the coupling between SAW and spin waves in the GHz range in several materials, including Nickel, Cobalt [2] and a Heusler Alloy (Fe_3Si). This technique combined with micromagnetic simulations allowed us to quantify the SAW strain [1] and the coupling strength between SAWs and spin waves. Additionally, the Heusler Alloy was used to investigate the coupling of SAW with out-of-resonance and in-resonance magnetization [3] and found spin waves in a large range of magnetic fields, which other spectroscopic techniques, such as Ferromagnetic Resonance (FMR), might not have enough sensitivity to detect them.

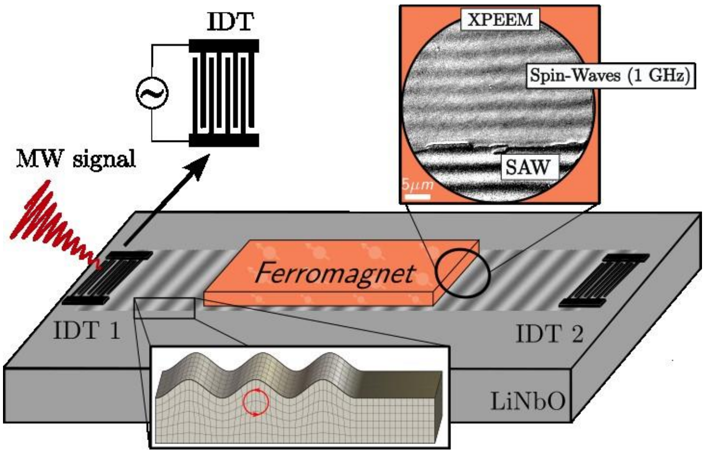

Figure 1. Schematic of a hybrid set-up of a piezoelectric ($LiNbO_3$) and a Ferromagnetic thin film. The IDTs are used to excite SAW on the piezoelectric that generate spin waves in the ferromagnetic film. The inset displays an XPEEM image with both SAW and spin waves at 1 GHz frequency.

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Building quantum computers for disruptive industry applications

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Trapped ions are arguably the most mature technology capable of constructing practical large scale quantum computers. We are now moving away from fundamental physics studies towards tackling the required engineering tasks in order build such machines.

By inventing a new method where voltages applied to a quantum computer microchip are used to implement entanglement operations, we have managed to remove one of the biggest barriers traditionally faced to build a large-scale quantum computer using trapped ions, namely having to precisely align millions of lasers to execute quantum gate operations. This new approach, quantum computing with global radiation fields, is based on the use of well-developed microwave technology [1].

Incorporating these two inventions, we unveiled the first industrial blueprint [2] on how to build a large-scale quantum computer which I will discuss in this talk. I will show progress in constructing a quantum computer prototype featuring this technology using modern silicon microchip technology [3]. I will provide an introduction to the development of microwave trapped ion quantum computing and discuss where microwave engineering may help accelerate overall progress.

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Towards High-Fidelity Entanglement Gates on Microfabricated Ion-Trap Chips

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Radio-frequency (RF) and microwave (MW) technologies are at the heart of developing practical utility scale quantum computers according the industrial blueprint we have developed [1, 2]. (For more details, see preceding presentation 'Building quantum computers for disruptive industry applications' by Winfried Hensinger). Hence, we seek a comprehensive understanding of our signal delivery chain and its noise characteristics, to ensure optimal utilisation and performance.

A vital step in developing and operating our quantum computer prototype is the demonstration of high-fidelity logic gate operations making use of microfabricated ion-trap chips [3], which serve as the modules of a practical quantum computer. A great obstacle for achieving high-fidelity gates is qubit decoherence, or loss of information, during the entanglement process. We work on accurately modelling the relevant error terms, so that we can use our simulations to optimise the experimental parameters for maximising two-qubit entangling fidelity.

Parameters such as MW power, amplitude, and phase stability are crucial in ensuring high fidelity gates. Therefore, we extensively examine our hardware (VSG, AWG) along with relevant amplifiers to identify potential bottlenecks and plan redesigns of our electronics, with the aim of minimising gate infidelities and enhancing the overall performance and reliability of our system. We present comparisons between various methods of MW delivery, including the use of a horn or patch antennas, with or without the inclusion of amplifiers and in-vacuum PCBs. Additionally, we investigate the performance of our boards under cryogenic temperatures, close to 50 K, which are representative of the operating conditions during experiments. We are interested to explore active stabilisation of multi-tone rf and microwave fields as well as antenna designs for the provision of homogenous rf and microwave fields inside the vacuum system.

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Terahertz Nondestructive Evaluation: From Art to Industry

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Terahertz electromagnetic radiation (100 GHz-5 THz) penetrates many electrical insulators enabling three-dimensional imaging and nondestructive evaluation (NDE) of various objects down to resolution of a few microns. In this presentation, we illustrate examples of THz NDE applied to art and archeological objects [1] as well as to industrial materials [2] using similar techniques. We emphasize the role of signal processing, image processing, and increasingly machine learning to extract information from the data in some cases providing super-resolution capability.

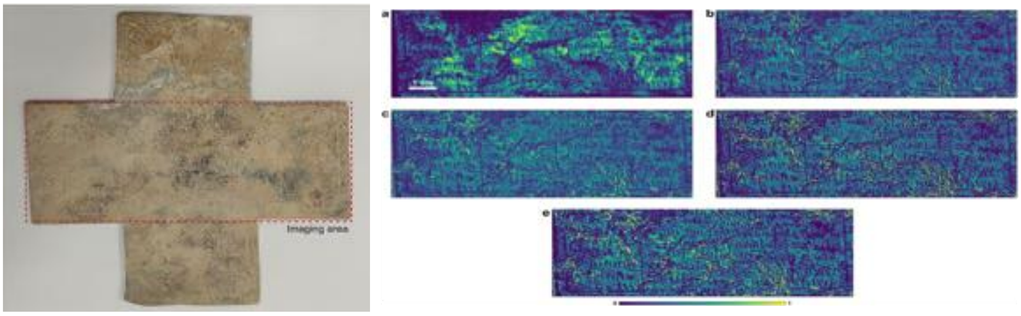

Fig. 1: Extracting an inscription obscured by a corrosion layer text (right) from an early modern lead funerary cross (left). The text is the *Pater Noster* [1].

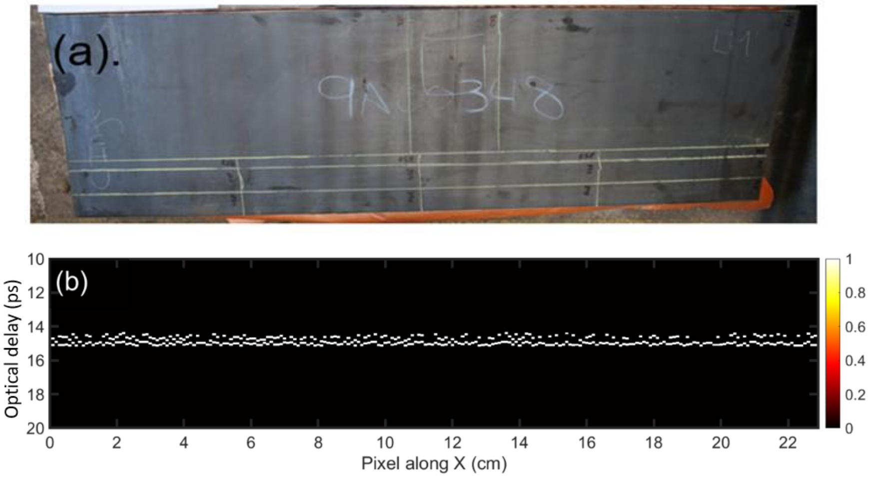

Fig. 2: (a) Photograph of hot-rolled steel strip. Samples studied are approx. 40 cm x 10 cm as seen in white rectangular regions at bottom of figure. (b) Binary B-scan of stratigraphic mill-scale reconstruction. Mill-scale thickness is ~12 mm [2].

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Characterization of 3D printing dielectric materials for RF and Microwave applications

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Nowadays, 3D printing techniques are those best identified with the implementation of the additive manufacturing (AM) concept. As an alternative or complement to traditional subtractive manufacturing processes, 3D printing is being adopted by a growing number of productive sectors. Aerospace, biomedical, automotive, and consumer goods industries are some representative examples [1]. Thus, 3D printing is no longer just a prototyping tool, its economic and social impact is considerable, and it is becoming a production tool able to replace or complement traditional manufacturing processes. In the areas of radiofrequency (RF) and microwave components production, 3D printing technology has not penetrated to the extend it has in other areas. Nonetheless, the full potential of applying AM to produce RF and Microwave components has been reported [2],[3].

Despite its potential, a major challenge limiting the use of 3D printing in the design of RF and microwave components is the need for reliable dielectric materials. Here, dielectric materials are no longer just a mechanical support, they play an important role in the operation of the entire system from an electromagnetic (EM) point of view. The EM properties of the 3D printing material must be known to assure an accurate modeling of the RF and microwave components. The availability of a wide range of 3D printing materials and the possibility of printing structures with different densities and textures complicates the development of databases of EM properties. However, the possibility of printing test structures with the most appropriate shape for each characterization technique greatly facilitates the task.

In this work, we present results of the EM characterization of a set of 3D printing materials corresponding to three printing techniques: material Jetting (M-Jet), stereolithography (SLA) and fused deposition modelling (FDM). We compare and discuss results obtained using the Nicolson-Ross-Weir method [4],[5], and the resonant cavity method [6].

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Influence of physical particle size and dielectric host selection for the designs of carbon-based microwave absorbers.

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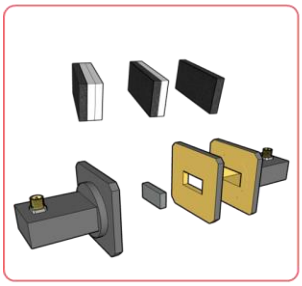
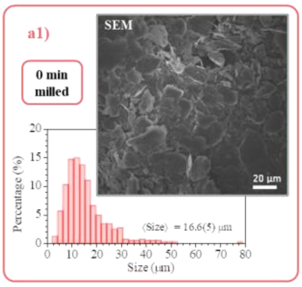
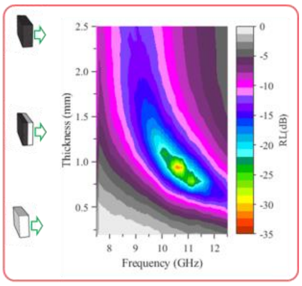
Immersed from a couple of decades at the height of the telecommunications era, much attention has been paid to the study of electromagnetic pollution generated by the coexistence of numerous electronic devices in operation, as well as to the demand for military radar-invisibility applications. Nowadays, there are multiple proposals on how to design shielding materials in the microwave radiofrequency domain, being the micro or nanosized material-composites the most promising base materials for that purpose [1]. But certain basic aspects are sometimes overlooked, not given the importance they should be and/or not being systematically studied. Generally, for the powder-dielectric matrix composites these are mainly: the physical particle size effect for the same material loaded into the matrix, the reproducibility of the samples, and the importance of the choice of a dielectric that gives a correct interaction with the powder loaded (in terms of solubility and homogeneity of powder grains dispersion).

In this work, we compare the shielding efficiency by calculating the reflection loss of three different samples of micro-nanosized graphite-paraffin composite materials. Each composite is based on the use of one of the three different physical-particle-size of the micro/nano-graphite/graphene flake-powders obtained by a high energy milling process (by different milling times: 0, 100 and 240 min). Furthermore, the effect of other dielectric selection for the composites is investigated. The characterization of the composite samples is carried out by obtaining the scattering matrix for each composite prepared by a Network Vector Analyzer using a wave guide (WR90) in the X-band (8.2-12.4 GHz). The intrinsic complex parameters, electric permittivity (and magnetic permeability), as a function of frequency of the thin microwave absorbent samples are intensively studied applying the NRW conversion [2]. A variety of slabbed carbon-composites samples are studied varying concentrations, thickness, and combinations of composite materials to determine the optimal conditions for the absorber.

These results could easily extend to: other materials or radiofrequency bands, magnetic nanosized materials or even towards the study of multi-slabbed absorber system materials.







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Computer Vision-Based Estimation of 3D Microwave Microscopy Probe Position

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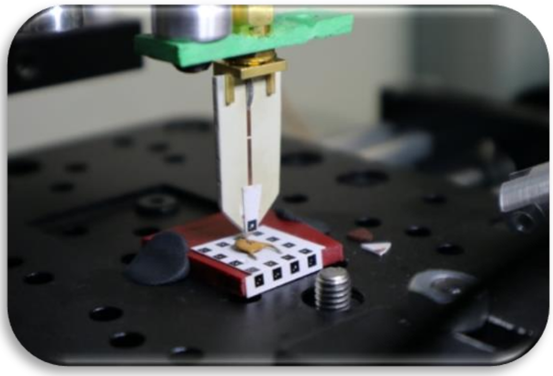
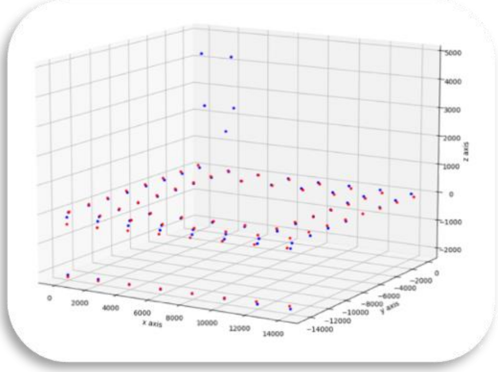
Microwave microscopy has been positioned as a powerful technique for acquiring high-resolution images and characterizing samples non-destructively. Importantly, in certain types of materials, microwave microscopy enables the visualization of subsurface features, allowing the examination beneath the surface of the sample. Precise control of the microwave probe's location in relation to the sample surface is crucial for achieving accurate measurements. In this work, we propose a methodology that utilizes computer vision techniques and stereoscopic vision to estimate the 3D location of the microwave probe.

Building upon the microwave microscopy model proposed in 1993 by Tabib-Azar, Shoemaker, and Harris [1], which utilized a microstrip probe positioned on an XYZ platform, we have developed a methodology that incorporates focus and camera calibration techniques, computer vision algorithms, stereoscopic vision principles [2], ARTags for feature matching, and digital image processing. This comprehensive approach enables the precise identification and triangulation of the 3D coordinates of the microwave probe, allowing for the analysis of non-planar samples and extraction of subsurface features.

Experimental validation of this methodology was performed using several samples with known shapes and dimensions. The results strongly support the effectiveness of the method in accurately estimating the 3D location of the microwave probe with exceptional precision. This approach offers a promising solution to enhance the capabilities of microwave microscopy, enabling confident and quantitative measurements.





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High Anisotropy Magnetic Oxides with mm-Wave Natural Ferromagnetic Resonances

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The forthcoming IoT (Internet of Things) era places millimetre wave frequencies in the focus for a variety of applications including sensors, imaging, wireless communications, radars and advanced driver assistance systems. Particularly, the 95-300 GHz range will become important in the next generation of wireless transmission applications 6G and beyond [1],[2]. Ferrites are used as functional materials in non-reciprocal devices such as circulators, commonly used in telecommunications. Saturation magnetization and the anisotropy field of the ferrite determine the ferromagnetic resonance frequency in an external applied field, and thus the operation frequency. Magnetic oxides with very high anisotropy like Sr-Ca-Al hexaferrite ($Sr_{0.67}Ca_{0.33}Al_4Fe_8O_{19}$) with magnetoplumbite structure [4] and epsilon iron oxide (ε-Fe_2O_3)[4] present natural ferromagnetic resonances (NFMR) at millimetre wave frequencies, making these materials appealing for implementing 6G non-reciprocal devices without use of external magnetic fields. Therefore, we prepared sub-micron sized powder samples by chemical methods of these two high magnetic anisotropy ferrites. We detail briefly the structural features and then compare magnetic properties and millimetre wave absorption of both compounds. The samples were analysed with a quasi-optical measurement system, using a Vector network analyser, to determine the absorption and permittivity at frequencies up to 220 GHz. Due to the strong magnetic anisotropy of these ferrites they show a natural zero field resonance around 180 GHz while ε-Fe_2O_3 nanoparticles show a narrow FMR resonance around 175 GHz. $Sr_{0.67}Ca_{0.33}Al_4Fe_8O_{19}$ hexaferrite shows a broader resonance compared with ε-Fe_2O_3 nanoparticles. We conclude that ε-Fe_2O_3 may yield advantages due to a much stronger absorption and sharper absorption line than the hexaferrite. This in turn may make this iron oxide a suitable candidate for ultra-fast electronic devices with high efficiency spin pumping at the resonance frequency without need of external magnetic field [5].

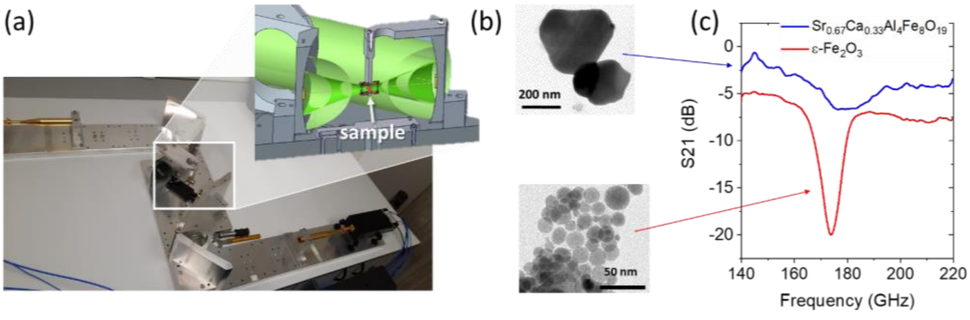

Figure: (a) Photograph and inset indicating the sample position of the used schematic quasi optical measurement setup [©Thomas Keating Ltd.] (b) TEM images for the measured sub-micron particles with corresponding millimetre wave absorption (natural ferromagnetic resonance, NFMR) shown in (c) hexaferrite (blue line) and ε-Fe_2O_3 (red line).

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