

2020
year 12

[Waves]



UNIVERSITAT
POLITÈCNICA
DE VALÈNCIA



iTEAM
Instituto de Telecomunicaciones
y Aplicaciones Multimedia

[Waves]

2020

year 12

Cover

*"Photonic Christmas!
(Reconfigurable photonic integrated processor)"
Daniel Pérez López*

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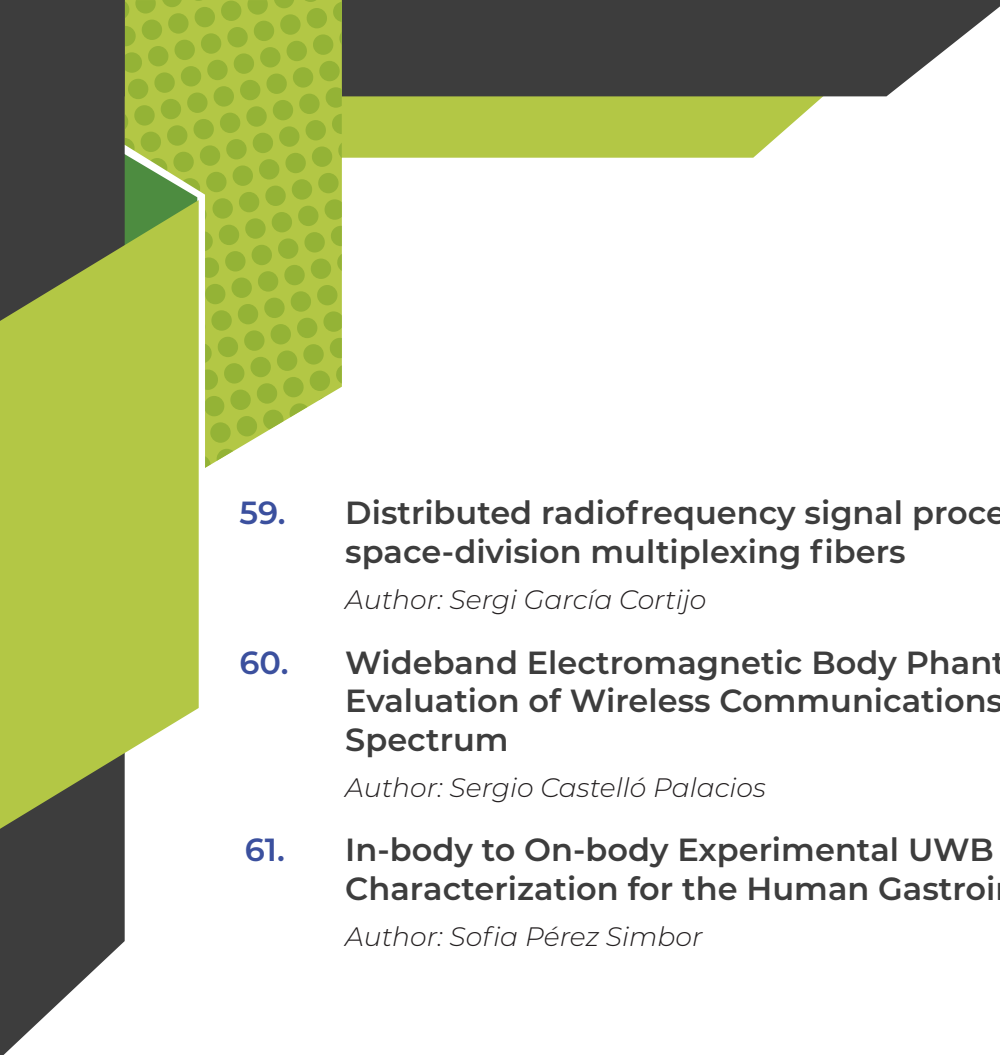
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Message from the Director



Prof. Narcís Cardona Marcet

Director of ITEAM

Universitat Politècnica de València

Nonetheless...

This has been a complicated year, in circumstances that have revealed the true potential of the Research and the Telecommunications in our Society. Thanks to Telecommunications, we have been able to maintain personal and work relationships that, otherwise, would have been blocked. Due to the pandemic, the term "Information Society" has been valued, with the resurgence of services that had a residual use and that have been essential this year, such as teleconferences and virtual connections to corporate networks, which have allowed online working and the ultimate push of the electronic administration. Our Institute has maintained, even increased, its activity in research projects, with great success in calls for international projects, prestigious awards for our researchers and important advances in some of the spin-offs arisen from ITEAM. Without direct contact between our staff for several months, we have got achievements that would not have been possible without the commitment of all the Institute staff. This year, as never before, the credit for keeping this ship on course goes to each and every one of its crew. May 2020 serve so that those who manage public science never forget the fundamental role it has played in this crisis, and we stop being the crazy-creative-subsidized of the productive system to become one of the engines of the economy and future well-being, as has been demonstrated.

MULTIMEDIA COMMUNICATIONS GROUP

HEAD OF THE GROUP RESEARCH REPORT

Multimedia Communications Group (COMM) started its activities in 2004, and nowadays is composed of a group of 6 researchers, focusing its research lines on multimedia systems and Quality of Experience (QoE). During the last year 2019/2020 the group has continued with its work lines focused on the distribution of multimedia content using protocols like Dynamic Adaptive Streaming over HTTP (DASH); carrying out more in-depth studies and developments related to the Internet of Things (IoT) trend; analysing and proposing new metrics for estimating the QoE; and developing new functionalities for multimedia systems based on DRM and cross-layer techniques.

These lines of action have been articulated through the execution of different research and development projects, as well as scientific publications. In addition, in order to promote the main activities of the group, we have been continuously updating the webpage and being very active in social networks (Facebook, Twitter, Youtube, LinkedIn and Instagram).

Following, the main results of the group are summarized, which are accessible through the COMM webpage (www.comm.upv.es).



Website and social networks of the COMM

1.- PROJECT ACTIVITIES

The COMM has continued during the last year with its main research and development lines.

Also, new emerging activities have appeared. A short summary of the main advances carried out is presented below:

Adaptive video through MPEG-DASH

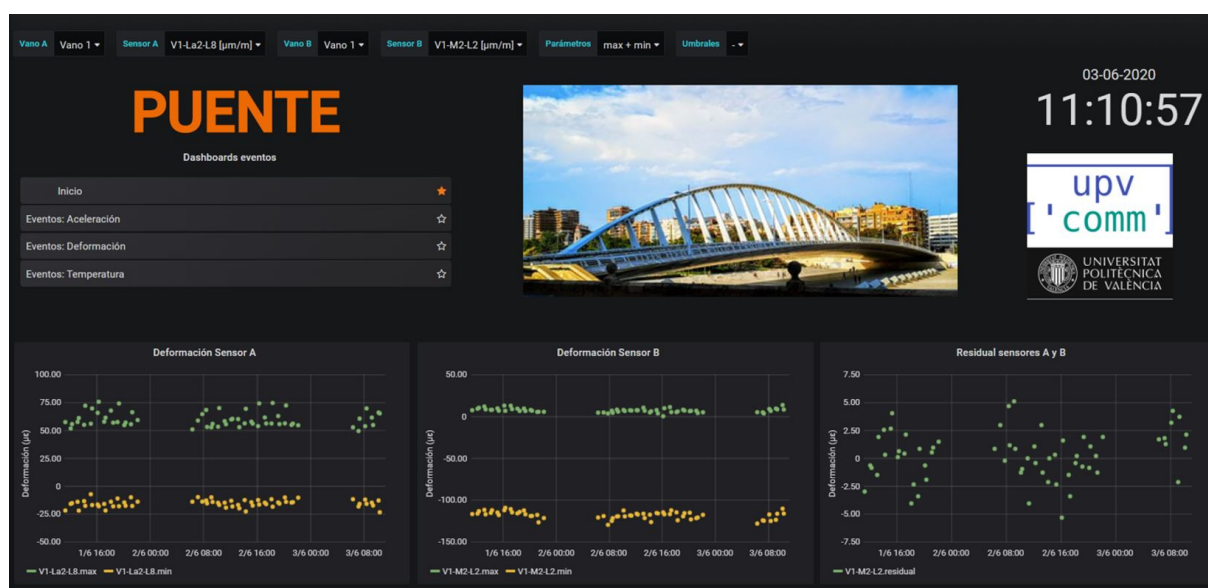
One of the main research lines of this year has been the study and development of DASH-based applications. In this sense, the proposed algorithm Look Ahead takes into account the information of the size of the forthcoming segments. With our proposal, there is no need to encode videos with constant bitrate because clients will have the tools to choose the best quality that fits in its available bandwidth. To test the algorithm, we have implemented Look Ahead for the ExoPlayer library, the video player behind the YouTube app in the Android platform. Also, the proposed algorithm is compared to relevant algorithms existing in the literature, specifically the Müller and Segment Aware Rate Adaptation (SARA) algorithms as well as to the adaptive algorithm integrated into ExoPlayer. The comparison is carried out by using the most relevant parameters that affect the Quality of Experience (QoE) in video playback services, that is, the number and duration of stalls, average quality of the video playback and number of representation switches. Also, during this year we carried out a subjective study with real users in order to prove the validity of the proposed algorithm.

Measure of the Quality of Experience

In this year we have deepened in the study and analysis of different objective models for estimating the quality perceived by users when consuming video contents. Taking the ITU recommendation P.1203 as a reference, we have proposed different QoE models, based on well-known parameters such as the PSNR (Peak Signal-to-Noise Ratio) and the VMAF (Video Multimethod Assessment Fusion), for the evaluation of the QoE in an objective way. The different evaluations carried out prove that the proposed QoE models are more realistic than other similar models proposed in the literature, including the ITU-T P.1203 recommendation.

Adaptive streaming for 2D and 3D video

During this year we have continued working on the development and improvement of a framework for the automatic assessment of the Quality of Experience in adaptive video streaming systems. The proposed framework, which can be used for both 2D and 3D video streaming services, allows the automated execution of different DASH players such as Bitmovin and Shaka Player and automatically emulates any bandwidth variation scenario by using Google Puppeteer.



Dashboard for sensors monitoring in real-time

The system outputs provide all the information required for the reconstruction of the played video. Reconstructed video is evaluated using objective metrics (PSNR, SSIM or VMAF) and in 2D video scenarios, automated QoE subjective assessment is carried out using ITU-T P.1203 recommendation. Currently, we are focus on how to predict the quality of stereoscopic 3D videos from objective and automatic subjective assessment of 2D single-view videos.

Optimization of the multimedia content transmission with cross-layer

We have continued our work on cross-layer mechanisms in order to improve the performance of video streaming in crowded scenarios where many people are streaming content at the same time. To improve the experience of users we have developed a cooperation service that uses the data reported by the players (measured bandwidth, buffer level and displayed quality among others) to create recommendations that players take into account for the common good. All communications are carried out using websockets to keep the same level of compatibility as MPEG-DASH. To that extent, the cross-layer server is based on MPEG SAND (Server and Network Assisted DASH). This technology offers standardization messages and protocols in order to improve the user experience in the streaming service and to better use the bandwidth.

Internet of Things and Smart Cities

Smart cities entail a combination of people, technology and strategies that makes the city more sustainable regarding strategic pillars, such as mobility, health or energy. For this to be feasible, the application of Internet of Things (IoT) is a key

factor to improve the life of citizens. IoT technologies comprise sensors to acquire data but are not limited to that. For a full comprehension of IoT applied to Smart Cities, a wider vision is needed, including data storage, analysis and presentation. Data can be collected with sensors, but this data must be processed and analysed in order to be transformed into information. Afterwards, citizens and city managers need an assortment of tools to manage this information to take advantage and transform it into knowledge. It is only with this full path when data can be transformed into knowledge and be fully profitable, and this should be the focus of a modern Smart City.

Following this approach, during this year, the group has been collaborating with Valencia City Council on tasks related to Valencia Urban Platform (VLCi). Within the context of MAtchUP project, we aim at improving the performance of the city, decision making or citizen participation, among others, guaranteeing interaction between the city of Valencia and its citizens, designing new data models, datasets and APIs for the new services and devices integrated into the urban platform.

Monitorization of information in real-time

Following the previous research line about IoT, this year we have delved into applications for monitoring information in real-time. The objective is to develop solutions that, apart from collecting and processing data in real-time, display information neatly in order to allow users to consult this data in a clear and simple way. Among the developments carried out, we highlight a dashboard for monitoring bridges or a mobile app for monitoring shots on a paddle racket.



App for monitoring shots on a paddle racket

Synchronization of audio and video devices

Following one of the main lines of the group, this year we have carried out tasks referred to media synchronization. Specifically, we have developed an application that allows to carry out an automatic realization of a recording in real-time. To that extent, the application detects the active microphones in each instant of time and, considering certain parameters as the number of cameras or the refreshing time, decides which camera should be on air.

1.1.- ONGOING PROJECTS

Name of the project: MAtchUP: MAXimizing the UPscaling and replication potential of high level urban transformation strategies (774477, Call H2020-SCC-2017)

Webpage of the project: <http://www.matchup-project.eu>

Funding entity and duration: European Union's Horizon 2020 Research and Innovation Programme. 2017-2022.

Summary of the project: The project aims at strengthening the planning processes for urban transformation, consolidating the benefits of deploying large scale demonstration projects of innovative technologies in the energy, mobility and ICT sectors, by means of substantially improved models for replication and upscaling, based on impacts evaluation, and ensuring the bankability of the solutions by means of innovative business models, which lead to achieve real deployment further than the pilots carried out in the lighthouse cities. With this, it is sought a high penetration of the validated technologies in those cities less prepared to adopt very innovative solutions and formalize it in a standard commitment, accompanied by capacity building strategies, to guarantee at least medium term implementation. The project started in October 2017, with an expected duration of five years. COMM focuses on actions related to ICT. As the project progresses and KPIs are going to be calculated for the interventions, new data models have been defined for these KPIs based on FIWARE data models. Regarding open APIs, the environment to develop and deploy new APIs has been defined and the first usable API have been developed, which enables the possibility of request predictions about sustainable mobility and bicycle availability, complementing current urban platform services. Moreover, the needed building blocks to analyse Big Data is ready for processing data collected from electric and hybrid buses when they are available. From this data measured on the vehicles, the platform can distinguish whether the driving pattern is eco-friendly and show an alert in real-time in case it is not.

Name of the project: Sistema de grabación y realización automatizada

Webpage of the project: <https://digiacta.com/>

Funding entity and duration: ESVEU Media Systems. 2019-2020.

Summary of the project: The main objective of the project is the design and development of a new automatic and unattended audiovisual recording and production multimedia system.



Meeting of the MAtchUP project in Skopje (North Macedonia)

The new solution is aimed at environments with several participants, such as the municipal plenary session of a city council, a conference or a meeting of a company's management board. Specifically, the objective is to develop a new application that manages, on the one hand, the communication with the microphone system, and on the other, the realization software in charge of managing the video cameras and the recording process. Thus, once the video cameras and the microphone system have been configured, the developed solution is in charge of carrying out the entire process of recording and audiovisual realization of a session as if it were an autopilot, without the need for human intervention.

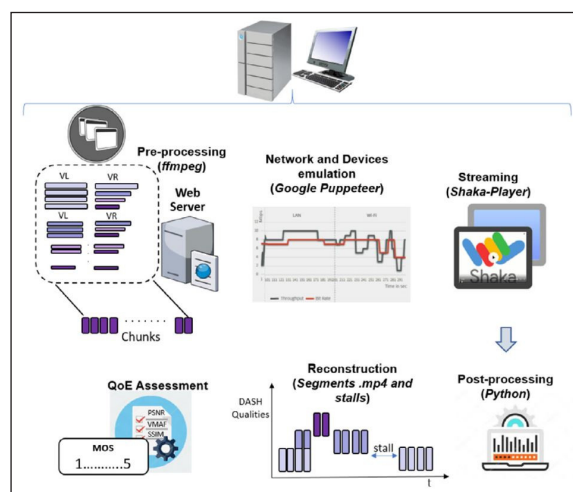
2.- RESEARCH RESULTS

2.1.- FEATURED PUBLICATIONS

New objective QoE models for evaluating ABR algorithms in DASH. I. de Fez, R. Belda, and J. C. Guerri, *Computer Communications*, vol. 158, pp. 126-140, doi: <https://doi.org/10.1016/j.comcom.2020.05.011>, 2020. This paper proposes three new models to measure the QoE analytically in DASH (Dynamic Adaptive Streaming over HTTP) video services. The first is based on the bitrate of the displayed video segments, whereas the second and the third are based on the PSNR and VMAF of each video segment, respectively. The proposed models are compared to the ITU-T standard P.1203 as well as the bitrate-based QoE model proposed by Yin et al.

Automatic QoE evaluation for asymmetric encoding of 3D videos for DASH streaming service. P. Guzmán, P. Arce, and J. C. Guerri, *Ad Hoc Networks*, vol. 106, article 102184, doi: <https://doi.org/10.1016/j.adhoc.2020.102184>, 2020. The paper is based on the study of the performance of a Dynamic Adaptive Streaming over HTTP (DASH) system for 3D video streaming. The proposed framework allows performance measurements to be carried out in an automated and systematic way. We have used Puppeteer, to automate actions such as starting playback, causing bandwidth changes and saving the network statistics. From this data the video played is reconstructed, quality metrics are extracted and users' QoE assessment are carried out.

Interoperability network for traffic forecast and full electric vehicles power supply management within the smart city. V. Fernández, J. C. Guerri, and A. Roca, *Ad Hoc Networks*, vol. 93, article 101929, doi: <https://doi.org/10.1016/j.adhoc.2019.101929>, 2019. It is relevant for the mobility in our future cities to integrate the Full Electric Vehicle (FEV) in an interoperability network. The target is to optimize energy consumption and to improve the mobility in the city. This paper proposes an infrastructure to



Proposed framework architecture of paper
“Automatic QoE evaluation for asymmetric encoding
of 3D videos for DASH streaming service”

efficiently manage the power supply availability in the network of charge stations in the city and an adaptive model to predict the traffic based on historic data and on time series obtained mathematically.

Automatic QoE Evaluation of DASH Streaming using ITU-T Standard P.1203 and Google Puppeteer. P. Guzmán, P. Arce, and J. C. Guerri, in *Proc. of Int. Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, & Ubiquitous Networks (PE-WASUN)*, pp. 79-86, Miami Beach, FL (USA), Nov. 2019. This document presents a framework for the automatic evaluation of DASH (Dynamic Adaptive Streaming over HTTP) system. We have used Google Puppeteer, the Node.js library developed by Google, which allows us to automate actions on Chrome Devtools Protocol. From this data, the reconstruction of the visualized video, as well as the extraction of objective quality metrics and the automated evaluation of the QoE (Quality of Experience) using the ITU-T P.1203 standard are carried out.

Evaluación automática de la QoE del streaming DASH utilizando el estándar ITU-T P.1203 y Google Puppeteer. P. Guzmán, P. Arce, and J. C. Guerri, in *Proc. of Jornadas de Ingeniería Telemática (JITEL)*, Zaragoza (Spain), Oct. 2019. This document presents a framework for the evaluation of DASH systems that allows performance measurements in an automated and systematic way. By using the high-level API provided by Google Puppeteer, that allows to automate actions on Chrome Devtools Protocol, such starting playback, making bandwidth changes and saving the results from the streaming processes. By processing this data, the reconstruction of the video is carried out and the subjective evaluation using the ITU-T P.1203 takes place.

MICROWAVE APPLICATIONS GROUP

HEAD OF THE GROUP RESEARCH REPORT

Over the past year (September 2019 to July 2020), the group has continued working on one project awarded with national public funds, whose main objectives are fully achieved, and it has just ended in March 2020.

In addition, another project granted with regional funds is now in progress. It is a four-year project and it officially started in January 2019. This project has allowed the recruitment of new researchers and PhD students with public funding, who are already collaborating with the group in different activities and research lines.

Furthermore, GAM continues involved in two European Union projects, that are developed in collaboration with other European universities and industries, for the training of young scientists and performing research activities in the space sector.

Apart from public funding, the GAM activities are also financed through several technology transfer agreements with different industries and organizations, mainly subscribed with the European Space Agency (ESA) and space-sector companies.

Regarding to the training capacity of the group, it is worth mentioning that three doctoral theses have been successfully defended during the last year. Meanwhile, other pre-doctoral students continue developing their investigation with the supervision of group senior members. In some cases, our doctorate students have performed short-term research stages in centers of excellence in topics related to their PhD topics. On the other hand, the GAM (iTEAM) has also hosted several foreign students doing part of their research work together with us.

It is fair to say, from the facts described above, that the quality of the group is growing year by year, therefore becoming a reference in the framework of their research areas (high-frequency components) and the space sector. A complete list of research activities and further details about the group can be found at the following links: <http://gam.webs.upv.es/>, or <http://www.iteam.upv.es/group/gam/>.

1.- PROJECT ACTIVITIES

The main research lines in which the GAM group is currently working are listed below:

- Analysis and design of high frequency (microwave and millimetre-wave) passive circuits implemented in guided, planar, and hybrid (waveguides integrated in dielectric and empty substrates, such as SIW, coaxial SIW, ESIW and ESICL) technologies, using micro-electro-mechanical systems (MEMs), as well as periodic materials (EBGs) and metamaterials.
- Electromagnetic study of dispersion/transmission problems in open space, in connection with the analysis and design of antennas and scattering (radar and remote-sensing) applications.
- Development of algorithms based on artificial intelligence techniques, for the automated synthesis and design of high frequency passive components (e.g. filters, diplexers and multiplexers).
- Practical design of components (circuits and antennas) for high-frequency communication systems (e.g. wireless, space and mobile systems), including the modelling and experimental validation of high-power effects for satellite applications.

In all these research lines and activities, the group has obtained relevant public and private funding, through national and regional projects as well as through research contracts with industries, making feasible to keep on producing new and relevant results in the R&D topics mentioned above.

1.1.- ONGOING PROJECTS

COMPASSES Project: Technological Demonstrators for Filters and Multiplexers with Selective and Reconfigurable Responses in New Compact Waveguides for Space Applications

Retos Investigación: Proyectos I+D+i 2016

Programa Estatal de I+D+i Orientada a los Retos de la Sociedad, Ministerio de Economía y Competitividad, Gobierno de España. 30/12/2016 – 29/03/2020

Nowadays, space communication systems provide many services to our modern Digital Society. For this purpose, on-board payloads operating at lower microwave bands have been used and, new satellites offering communication services in the Ka-band are available since 2006. Even all these satellites continue to be employed, recently, new emerging applications of space communications are forthcoming.

As relevant players in the space sector have

pointed out, future space communications must respond to the following new scenarios: data transmission from small platforms (pico- and nano-satellites with scientific and technological missions) in C-band (6 GHz), global Internet Access (from and to the entire planet) through mega-clusters of micro-satellites operating in the Ku-band (12-14 GHz), civil and military -security and defence- applications with variable demand of performance (through reconfigurable payloads operating in high frequency bands as Ka, Q, V and W), and new remote sensing services in the sub-millimetre wave range (between 100 GHz and 1 THz).

To meet these emerging applications, future satellites will incorporate new and advanced communication payloads, whose equipment and subsystems (passive components such as filters, diplexers and multiplexers, as well as antennas) are going to require specific technological solutions that best fit to each particular scenario. Therefore, small satellite platforms will need more compact devices and with low manufacturing costs, payloads of next telecommunication satellites (in Ka, Q and V bands) will have to incorporate flexibility (capacity of reconfiguration of operational frequencies and bandwidths, as well as of coverage), whereas components of future space communications operating at higher frequencies (between 100 GHz and 1 THz) will need of manufacturing techniques with higher accuracies.

This joint project aims to offer solutions (through the design, implementation and experimental validation of specific technology demonstrators) to these challenges for the high-frequency equipment (passive components and antennas) of future satellite applications.

SPACE – VLC Project: Advanced technological demonstrators for emerging and inclusive space applications in the microwave and millimeter wave bands

Prometeo – 2019

Subvenciones para la realización de proyectos de I+D+i para grupos de investigación de excelencia PROMETEO 2019, Conselleria de Innovación, Universidades, Ciencia y Sociedad Digital, Generalitat Valenciana. 01/01/2019 – 31/12/2022

Space communication systems, which currently operate in the lower microwave bands, provide key scientific, technological and social services, as well as critical security and defence applications. Since 2006, space communications offer broadband (10 Gbps), TV and video on demand, deep space communications and military applications. Today, the 2nd generation of Ka-band satellites, currently under development and with transmission rates greater than 100 Gbps, will be able to offer

advanced mobile communications services, navigation and Earth observation systems, with huge civil, security and defence purposes.

To meet all these emerging applications, future satellites will incorporate new and advanced communications payloads, whose equipment and subsystems (passive components such as filters, with various responses and functions, diplexers and multiplexers, as well as antennas) will require technological specific solutions, better adapted to each specific scenario. Thus, this R&D project aims to offer solutions (through the design, implementation and experimental validation of specific technological demonstrators) to these great challenges in new high-frequency equipment (passive components and antennas) for future space applications. In order to achieve this, the most appropriate technologies (more classic ones such as planar and waveguides, or more recent ones such as the hybrid guided-planar SIW and its novel embodiments without dielectric substrate -ESIW and ESICL-, or guides with corrugated walls also known as groove gap waveguide), the materials (dielectrics, ferrites and liquid crystal) and novel manufacturing techniques (LTCC and additive manufacturing) will be considered in each application.

SELECTOR Project: SMT Compatible Electromechanical Relay for Compact Redundancy Ring

H2020-RIA (Research and Innovation Action) Program. 01/01/2019 – 31/12/2021

SELECTOR project (funded as an H2020 Research and Innovation Action) is focused on the development of innovative passive components to increase the number of freely accessible space qualified passive components; thus, contributing to the European policy about “Reaching non-dependence in certain technologies that will open new markets to industries and will increase the overall competitiveness of the European Space sector”.

SELECTOR aims at developing Surface Mount Technology (SMT) compatible electromechanical switches for space sector high miniaturization. These devices called “Miniature Electro-Mechanical Relay” (MEMR), already exist for microwave industrial ground application like Automatic Test Equipment. SELECTOR will deliver MEMR as part of ESA portfolio European Preferred Part List (EPPL) so that this high integration, high performance passive component be available with non-restriction for the whole European



Figure 1: SELECTOR Project Logo

industry. SELECTOR will also demonstrate a whole new approach of self-redundant microwave equipment called “Meta-equipment” based on microwave specific SMT board level assembly and MEMR components to minimize cost and improve integration. This demonstrator will address Very High Throughput Satellites (VHTS) emerging applications, where the new paradigm is the introduction of digital technologies dealing with very high number of RF chains. New evolution toward RF high power and high frequency capability will be implemented to open-up new sector of application within Space satellites (Navigation, earth observation), but also non-space sectors.

In the framework of this project, the GAM group is directly involved in the (theoretical and practical) evaluation of the new developed passive components in terms of high-power and high-frequency space applications.

TESLA Project: Advanced Technologies for future European Satellite Applications

H2020-MSCA-ITN-2018 (Marie Skłodowska-Curie Innovative Training Networks) Program.
01/01/2019 – 31/12/2022



Figure 2: TESLA Network Logo

Space sector is key and strategical asset for Europe to face global challenges, which must continue to be developed to have a prominent role in the world, contributing to the independence security and prosperity of Europe. Since satellite payload RF components and systems are essential for delivering mission objectives and supporting ground equipment, new technologies and techniques are required to respond to emerging satellite applications and technology challenges.

To this end, TESLA ETN (European Training Network) will create a multidisciplinary research environment to develop the Advanced Technologies for future European Satellite Applications. It will collaborate with senior staff in academic and industrial sectors to conduct top research into new and enabling technologies for satellite flexible payloads, big constellation systems, satellite high-speed communications and remote sensing, as well as large satellite

platforms. TESLA will also implement a unique research program, with the objective to push the next generation of creative, entrepreneurial and innovative satellite communication developers, to enhance the European space economy and business through outreach activities for a wider economic and social impact.

2.- RESEARCH RESULTS

As a result of the joint research activity developed by this group in its research lines, during the last year of activity, more than 20 articles have been published in scientific journals with a high impact index (such as IEEE Transactions on Microwave Theory and Techniques, IEEE Access, IEEE Microwave and Wireless Components Letters, IEEE Transactions on Antennas and Propagation, IET Proceedings on Microwave, Antennas and Propagation, IET Electronics Letters and Radio Science).

At the same time, the group has presented up to 19 scientific communications in prestigious international conferences (such as IEEE-MTT Int. Microwave Symposium -IMS-, IEEE-AP Int. Symposium on Antennas, IEEE MTT-S Int. Conf. on Numerical Electromagnetic Modelling and Optimization for RF, Microwave, and Terahertz Applications -NEMO-, the 2019 European Microwave Week -EuMC-, and the 2019 ESA Microwave Technology and Techniques Workshop), some of them as invited papers.

Finally, due to the research activity of the group developed in collaboration with companies and administrations of the aerospace sector, it has recently participated in the development of two new patents (see more details in section 2.2. of this report).

2.1.- FEATURED PUBLICATIONS

Some of the most recent and relevant publications of the GAM group in the last year are briefly summarized next:

Compact Wideband Hybrid Filters in Rectangular Waveguide With Enhanced Out-of-Band Response, Joaquin Valencia, Vicente E. Boria, Marco Guglielmi, Santiago Cogollo, IEEE Transactions on Microwave Theory and Techniques, vol 68, issue 1, pp. 87 – 101, Jan. 2020 Q1.

This article describes the design procedure of a compact wideband waveguide filter, based on stepped impedance resonators (SIRs) and a combined usage of capacitive and inductive coupling irises, that provides a significant improvement in the out-of-band response of the filter with respect to the state-of-the-art.

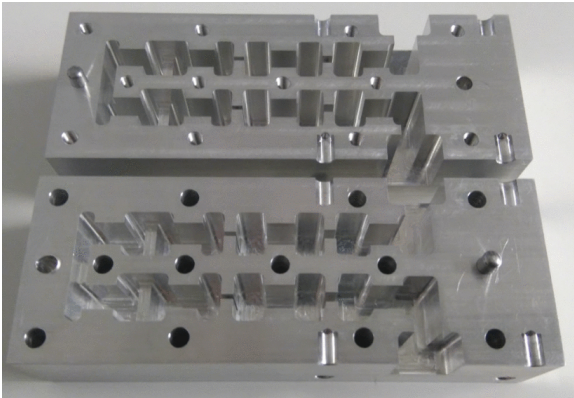


Figure 3: Manufactured prototype in aluminum (no silver plating)

On Space Mapping Techniques for Microwave Filter Tuning, Juan Carlos Melgarejo, Javier Ossorio, Santiago Cogollos, Marco Guglielmi, Vicente E. Boria, John W. Bandler, IEEE Transactions on Microwave Theory and Techniques, vol 67, issue 12, pp. 4860 – 4870, Dec. 2019 Q1

The objective of this article is to extend the state of the art of space mapping (SM) and aggressive SM (ASM) techniques, that are widely used in the synthesis and design of microwave filters, by discussing how they can also be used very effectively to tune microwave filters.

Implementation of Waveguide Terminations

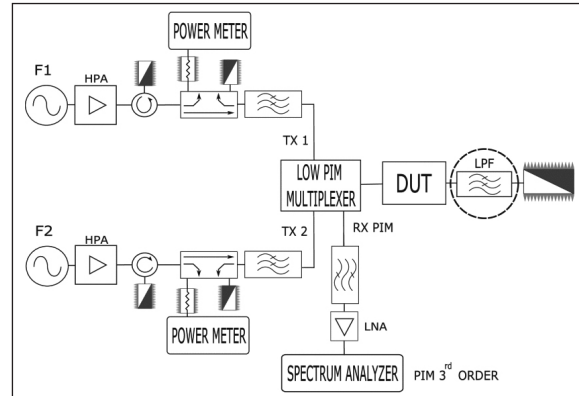


Figure 5: Low-PIM test bench in the backward configuration with the filter (circled block) placed before the waveguide dummy load

with Low-Passive Intermodulation for Conducted Test Beds in Backward Configuration, Davide Smachhia, Pablo Soto, Marco Guglielmi, José Vicente Morro, Vicente E. Boria, David Raboso, IEEE Microwave and Wireless Components Letters, vol 29, issue 10, pp. 659 - 661, Oct. 2019 Q1

This letter proposes a simple procedure to implement low-passive intermodulation (PIM) terminations in waveguide technology to measure conducted backward PIM. The procedure consists in inserting a filter before the waveguide termination of the test bench.

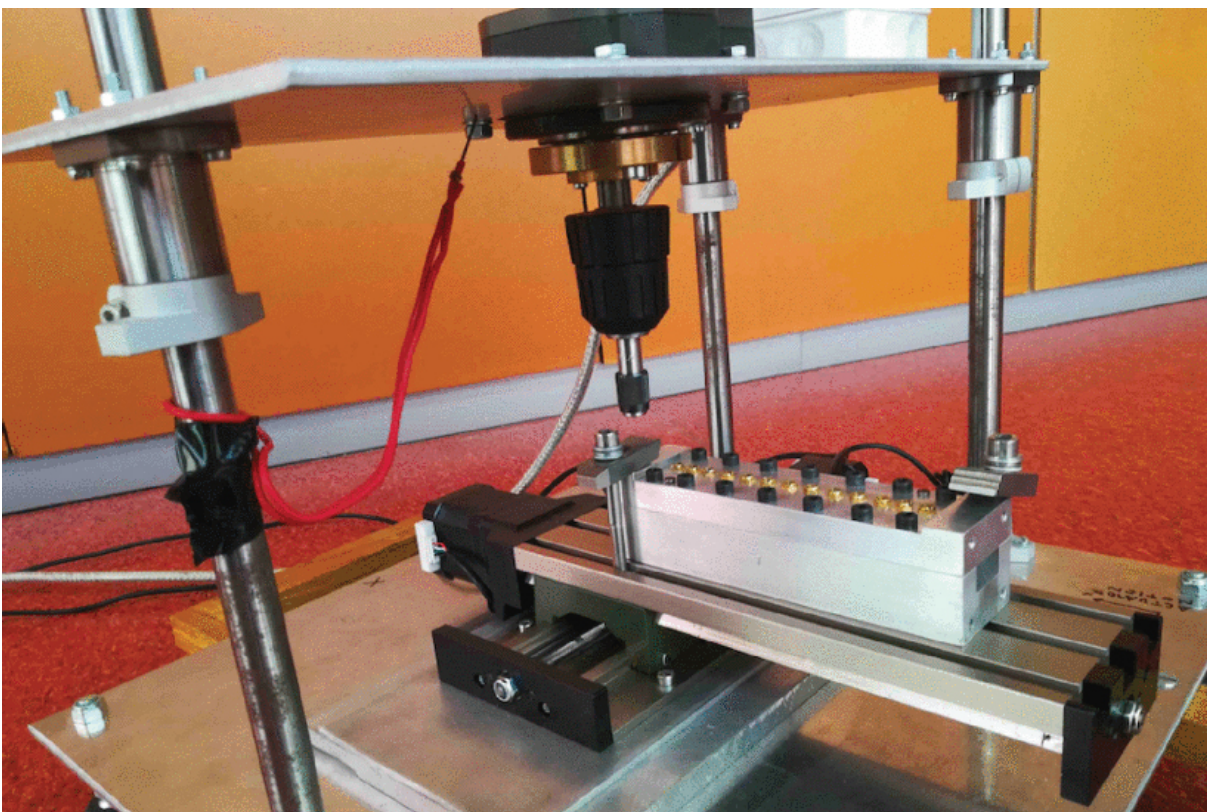


Figure 4: Robotic tuner for microwave filters

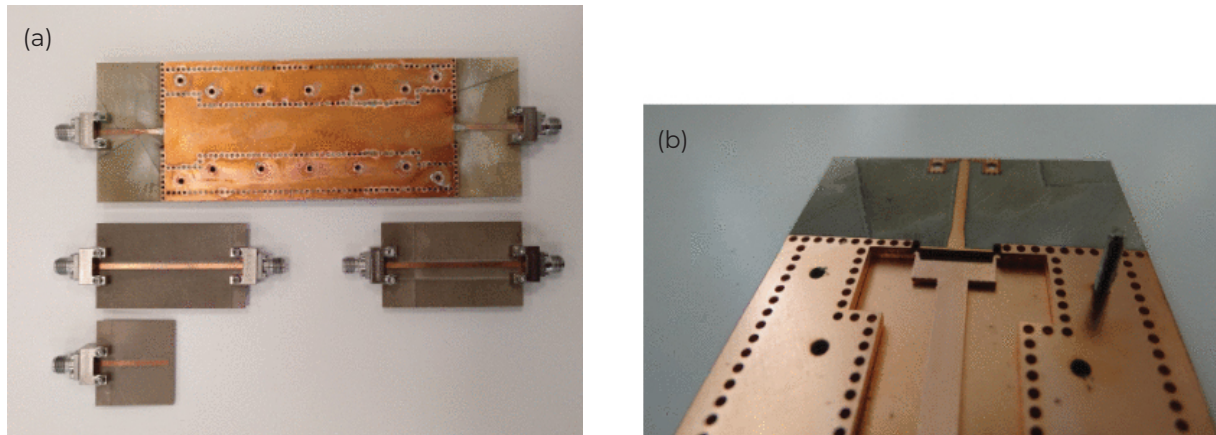


Figure 6: Back-to-back manufactured prototype. (a) TRL calibration kit and assembled prototype. (b) Detailed view of transition

Microstrip to Ridge Empty Substrate-Integrated Waveguide Transition for Broadband Microwave Applications, David Herraiz, Héctor Esteban, Juan A. Martínez, Angel Belenguer, Vicente E. Boria, IEEE Microwave and Wireless Components Letters, vol 30, issue 3, pp. 257 - 260, March 2020 Q1. A study of possible ridge ESIW (RESIW) geometries has been performed, and a novel transition from microstrip line to RESIW is proposed in this paper.

Experimental Validation of Multipactor Effect for Ferrite Materials Used in L- and S-Band Nonreciprocal Microwave Components, José J. Vague, Juan C. Melgarejo, Vicente E. Boria, Marco Guglielmi, Rocío Moreno, Marta Reglero, IEEE Transactions on Microwave Theory and Techniques, vol 67, issue 6, pp. 2151 - 2161, June 2019 Q1. This paper reports on the experimental measurement of power threshold levels for the multipactor effect between samples of ferrite material, which is typically used in the practical implementation of L- and S-band circulators and isolators.

2.2.- PATENTS

In the last year, two patents registered in 2018 have received the national concession:

José Manuel Merello Giménez; Maria Carmen Bachiller Martín; Vicente Enrique Boria Esbert; M^a Luisa Marín García; Vicente Nova Giménez; Juan Rafael Sánchez Marín

MÉTODO DE FABRICACIÓN DE DISPOSITIVO DE MICROONDAS BASADO EN GUÍA DE ONDA VACÍA INTEGRADA EN SUSTRATO

Pub. No.: P201830647

Pub. Date: 19/03/2019

Vicente Enrique Boria Esbert; Javier Ossorio Gracia; José Joaquín Vague Cardona; Marco Guglielmi

DISPOSITIVO DE FILTRADO Y CONMUTACIÓN DE MICROONDAS

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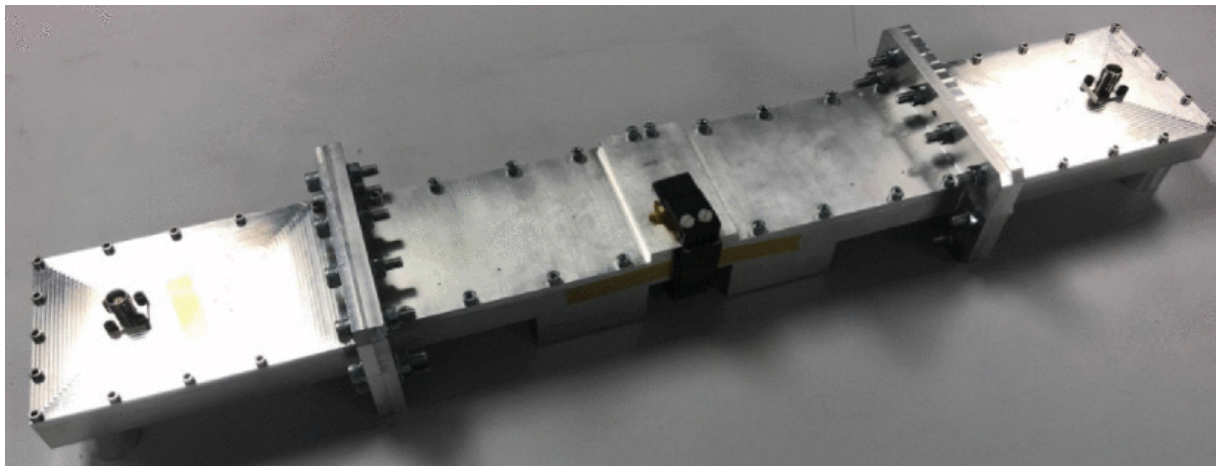


Figure 7: View of the manufactured prototype of the S-band ferrite test device (S-FTD), including the permanent magnets (PMs) and the "U" shaped magnetic circuit used to polarize the ferrites

ELECTROMAGNETIC RADIATION GROUP

HEAD OF THE GROUP RESEARCH REPORT

The research areas of the Electromagnetic Radiation Group (GRE, www.gre.upv.es) are focused on the analysis and design of antennas at frequency bands ranging from UHF to V band, and on propagation measurements and channel modeling for vehicular and 5G systems, with special emphasis on potential mmWave frequency bands. Antenna analysis and design carried out at GRE cover a wide range of applications, e.g. mobile and satellite communications, Wi-Fi, Bluetooth, UWB, IoT or on-body applications.

GRE participates in many projects with public funding in collaboration with other Spanish universities, and collaborates with other foreign universities (in Sweden, USA and Finland) as well. From the industrial point of view, GRE works with different technological companies and public entities, such as the European Space Agency (ESA), Thales Alenia Space, Huawei or Airbus, and also supports the local technological development through long-lasting links with regional companies like Celestica, MYSHERA or AITEX.

1.- PROJECT ACTIVITIES

The group activities can be classified into four main research lines:

- Application of the Theory of Characteristic Modes for antenna design in different applications (MIMO, UWB, RFID, mobile communications, UHF and on body antennas).
- Gap waveguide technology for the design of antennas and microwave devices in the mm-wave band.
- Development of efficient methods for the electromagnetic analysis of complex structures.
- Propagation measurements and channel modelling at mm-wave frequencies.

These research lines are being developed within the framework of different research projects. Next sections describe these projects and the main activities that have been performed during the last year.

1.1.- ONGOING PROJECTS

ICAR5G: Radio CHannel research for the deployment of 5G systems in a digital society multi-connected. (TEC2017-86779-C2-2-R).

Funding entity and duration: Ministerio de Economía, Industria y Competitividad, 2018-2020.

Summary of the project: The future traffic demands will require the deployment of new communication systems with faster as well as more efficient and reliable connections. The new 5G systems will represent a significant improvement over 4G systems, increasing the speed of LTE-Advanced by 1000. To increase channel capacity, the distribution of ultra-dense networks of base stations, the use of new frequency bands, such as millimeter-wave (mmWave), and the combination of beamforming techniques and advanced MIMO systems arise as a requirement. In this scenario, the knowledge of the radio channel holds the key to define the standard, select new frequency bands, and optimize the deployment of the network infrastructure.

With the aim of studying the radio channel properties for the new 5G scenarios, the project ICAR5G started in 2018. The objectives of this project are to generate new radio channel models based on extensive measurement campaigns, complementing the actions being already developed in other projects, to evaluate the different technologies to be implemented in the radio interface and to optimize the deployment of base stations. In addition, this knowledge is intended to assist decision-making in the process of reorganization and assignment of frequencies in future 5G systems by the standardization and radio spectrum management bodies.

Up to now, extensive channel measurements in underground and indoor office environments have been collected using a novel channel sounder implemented in the frequency domain and based on the use of radio over fiber (RoF) links with omnidirectional antennas. From the channel measurements, realistic channel models have been analyzed and developed in the potential frequency bands to deploy the future 5G systems, with special attention to mmWave, e.g., 26, 28, 38 and 60 GHz. These models have been compared with ray-tracing techniques to develop diffuse scattering models. The performance of multiuser MIMO techniques, that can be introduced into 5G systems, have also been investigated in these particular environments from the channel models.

Multimode and Multibeam reconfigurable x-wave antennas for communication and sensing SYStems (MUMSYS)

Funding entity and duration: Ministerio de Ciencia e Innovación, 2020-2022.



Extensive channel measurements have been collected in (a) underground and (b) indoor office environments in order to evaluate the propagation characteristics and develop new channel models in the potential 5G mmWave frequency bands.

Summary of the project: In order to comply with communication, radar and sensing needs, there is a growing demand for highly flexible and effective antenna systems able to operate in different modes, frequency bands (from microwave to millimeter waves and eventually the low part of the THz spectrum) and environments (indoor-outdoor, cellular to vehicular).

The objective of this project is to conceive and develop a new generation of reconfigurable antennas operating into the microwave and millimeter frequency (x-Wave) domains of the electromagnetic spectrum, to face the challenges and requirements of incoming applications. Specifically, the project will be focused on various areas:

1. Multibeam and multimode antennas for the sub-6 GHz band: Different models of antennas will be designed using the Theory of Characteristic Modes. The new antennas will exhibit reconfigurable capability and will be developed for Internet of Things (IoT), communications and human body sensing applications. New fabrication methods such as conductive inks, metal deposition on plastic 3D prototypes, or metal embroidery on fabrics will be explored as a low-cost alternative to classical microstrip technology. Low Temperature CoFired Ceramic (LTCC) technology, available at UPV facilities, will be also used for multi-sensor wireless systems and IoT applications.
2. Planar metallic lenses for reconfigurable multi-beam mm-wave indoor low-cost 5G base station: A planar lens with low cost single metallic layer will be designed. The reconfigurable beam characteristic of the base station will be obtained by switching the feeding in different positions. A prototype will be fabricated and characterized at UPV and channel measurement will be performed at Universidad Politècnica de Cartagena.
3. New beam-forming networks, antenna switching and control for multi-beam applications: Complete

systems will be developed to determine the angle of arrival of the waves to the base station. The antenna, that will be designed at UPV, will be an array of apertures, slots or notches with a specific beamforming network, designed using Universitat Politècnica de Catalunya designed planar transmission lines. The array will consist of multiple antennas, a time-multiplexed feeding network and electronics based on the new standards.

REconfigurable antennas for mm-wave broadband COMMunications (RECOMM)

Funding entity and duration: Ministerio de Ciencia e Innovación, 2020-2022.

Summary of the project: In the coming years, the implementation of broadband communications systems in the millimeter band with global coverage will acquire special relevance. It aims at a convergence of the fixed and mobile services to offer a universal quality of service similar to that of the already mature fiber optic networks. The imminent deployment of 5G networks promises to provide broadband service in sufficiently populated areas, the rest being covered by next-generation communications satellites. The latter allow uninterrupted connection in means of transport (trains, ships, planes) and serve as backup in areas affected by natural disasters or conflict and / or remote zones.

The development of antennas for satellite communications in Ka band, valid for trains or airplanes, represents a great technological challenge that has not yet been effectively solved by the industry. Very low profile antennas must meet very demanding specifications in terms of gain, secondary lobes, high purity circular polarization, and dual band operation. To these requirements must be added a high degree of reconfigurability, since they must be able to switch polarization in addition to pointing the beam dynamically towards the satellite to compensate for the movement. Also, the

deployment of the emerging 5G demands reconfigurable multibeam antennas capable of serving several users simultaneously.

This project addresses the development of new antenna concepts in the millimeter band capable of meeting the demanding needs of these communication systems. Special attention is paid to highly efficient antennas, dual in polarization and / or frequency and capable of reconfiguring their radiation pattern. The control of the aiming of the beam, maintaining the flat character of the antenna, is one of the main objectives of the project. The implementation of a low-cost alternative mechanism to electronic phase shifters opens the door to the development of competitive low-profile terminals. Innovative solutions capable of generating several simultaneous directing beams are also implemented, valid for multi-user and/or multi-path MIMO communications.

2.- RESEARCH RESULTS

Two National projects have ended in 2019:

Project SATCOM-KA: New Antennas for Satellite Mobile Communications in Ka-band (TEC2016-79700-C2-1-R).

Funded by Ministerio de Economía, Industria y Competitividad during period 2017-2019, new antenna concepts and topologies for Ka-band terminals (in the range from 19 to 31 GHz) for satellite communications were explored in this project, targeting at reducing terminal volume and weight so that they may be suitable for on-the-move applications. The proposal was focused on the antenna panel, probably the most complex part of the whole terminal: the mobile terminal comprises TX and an RX antennas operating at well-separated bands (30 GHz and 20 GHz, respectively).

Furthermore, being a cellular service, the mobile terminal must be capable of switching polarization during handover from one spotbeam to the next. Therefore, the project has faced the design of so-called dual antennas sharing the same panel for both polarizations and/or both frequency bands, so that overall surface reserved to the antenna is lower. In addition, the project has studied new

beam pointing mechanisms so that the antenna may remain static while the main beam moves tracking the satellite.

During the last year, main effort has been devoted to mechanically-scanned-beam antennas, giving rise to a new concept of mechanical phase shifter which has been experimentally verified. This concept has been subject to a patent and a journal paper.

Project MANCOM: Design of High-Gain Multibeam Antennas for Next Generation Communications Systems (TEC2016-78028-C3-3-P).

Funded by Ministerio de Economía, Industria y Competitividad during period 2017-2019, the main goal of this project was the design of new types of antennas for the 5G generation of mobile communications. This project has focused on three specific areas in the microwave (below 6 GHz) and mm-wave bands:

1. On-body sensing applications: A computational modelling of the human body has been developed in the band from 1 to 6 GHz using an integral equation approach and several multi-mode antennas for on-body sensing applications have been analyzed and designed.
2. Reconfigurable mm-wave antenna design for mobile devices: These antennas have been designed using LTCC (Low Temperature Co-fired Ceramics) fabrication technology available at GRE premises.
3. Reconfigurable multibeam mm-wave 5G indoor base station design: Different metallic planar lens antennas based on non-periodic frequency selective surfaces have been designed for the frequency range of 20-30 GHz, and a prototype has been fabricated and tested at GRE premises. Moreover, a cavity-backed antenna fed at four different points has been proposed for 5G femto-cells. The prototype of this antenna has shown measured results with an excellent performance for indoor environments.

Regarding the propagation and channel modeling research line, statistical channel models based on propagation measurements at mm-wave frequency bands have been developed. These models establish a path loss dependence on both distance and frequency and their parameters have been derived using regression and optimization techniques.

2.1.- FEATURED PUBLICATIONS

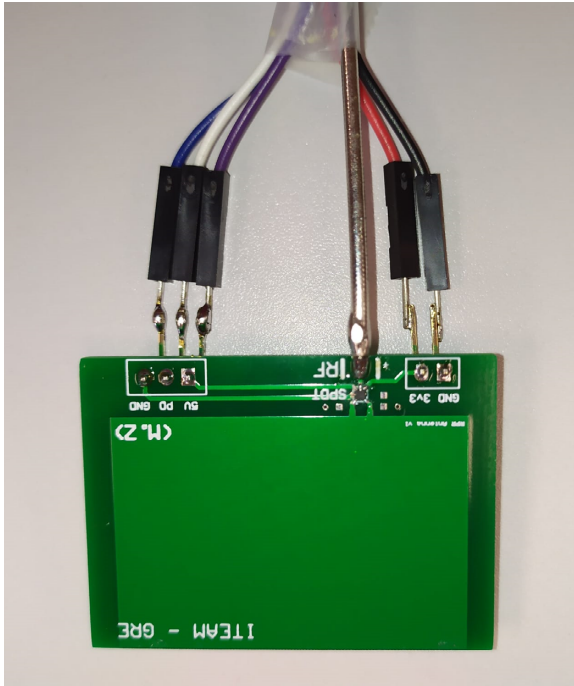
1. True-Time-Delay Mechanical Phase Shifter in GapWaveguide Technology for Slotted Waveguide Arrays in Ka band, D. Sánchez-Escuderos, J.I. Herranz-Herruzo, M. Ferrando-Rocher,

A. Valero-Nogueira, IEEE Trans. on Antennas and Propagation, under review, 2020.

A novel all-metal mechanical phase shifter in gap waveguide technology is proposed to provide



Mechanical Phase Shifter in GapWaveguide Technology for Slotted Waveguide Arrays in Ka band



Fabricated radiation-pattern reconfigurable antenna prototype.

beam scanning capabilities to conventional slot array antennas along the elevation plane. To validate experimentally the beam-steering functionality, a 4x8 slot-array antenna has been designed and fabricated, along with the phase-shifting mechanism.

2. Millimeter wave MISO-OFDM transmissions in an intra-wagon environment, C. Sanchís-Borras, J.-M. Molina-García-Pardo, L. Rubio, J. Pascual-García, V. M. Rodrigo-Peñarrocha, L. Juan-Llácer, and J. Reig, *IEEE Transactions on Intelligent Transportation Systems*, pp. 1-10, In Press (pre-print version available). DOI: 10.1109/TITS.2020.2983028

Abstract: The maximum achievable throughput is analyzed in the intra-wagon channel when MISO-OFDM techniques are used, by means of real wideband propagation channel measurements at 28 and 37 GHz. Results provide useful insight to better understand the intra-wagon channel properties and deploy the future 5G wireless networks in this particular scenario at mmWave frequencies.

3. Grating Lobes Reduction Using a Multilayer Frequency Selective Surface on a Dual-Polarized Aperture Array Antenna in Ka-Band, D. Sánchez-Escuderos, J.I. Herranz-Herruzo, M. Ferrando-Rocher, A. Valero-Nogueira, *IEEE Access*, vol. 8, pp. 104977-104984, May 2020. DOI: 10.1109/ACCESS.2020.3000069

This paper presents a multilayer frequency selective surface (FSS) for a dual-polarized aperture array antenna in Ka-band. The 8×8 elements of the array are cylindrical open cavities

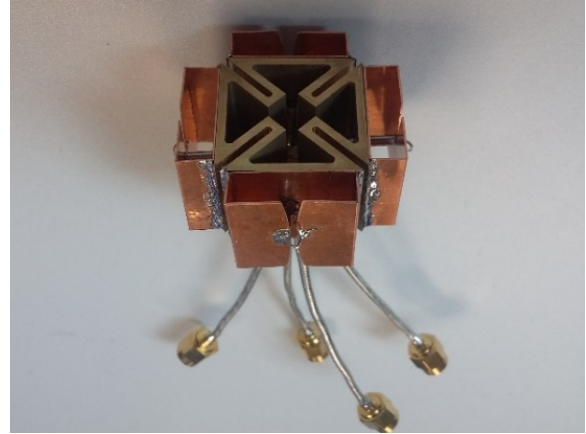
with a diameter of 0.6λ at 30 GHz, and spaced one wavelength. Due to this separation between elements, grating lobes appear. FSS can be a solution to this problem without modifying the feeder architecture nor the radiating elements.

4. Dual Circularly Polarized Aperture Array Antenna in Gap Waveguide for High-Efficiency Ka-Band Satellite Communications, M. Ferrando-Rocher, J.I. Herranz-Herruzo, A. Valero-Nogueira, B. Bernardo Clemente, *IEEE Open Journal on Antennas and Propag.* vol 1, pp 283-289, 2020. DOI: 10.1109/OJAP.2020.3001087

A fully metallic Ka-band dual circularly polarized antenna array is presented. It consists of 64 circular apertures (8×8) and it is implemented in gap waveguide technology. The antenna includes 4 layers, which are completely metallic, leading to a highly efficient performance. Experimental results confirm good performance in terms of axial ratio, reflection coefficient and efficiency from 29 GHz to 31 GHz.

5. Millimeter wave channel measurements in an intra-wagon environment, L. Rubio, V. M. Rodrigo-Peñarrocha, J.-M. Molina-García-Pardo, L. Juan-Llácer, J. Pascual, and J. Reig, *IEEE Transactions on Vehicular Technology*, vol. 68, no. 12, pp. 12427-12431, October 2019. DOI: 10.1109/TVT.2019.2947205

Useful measurement results of the propagation channel characteristics in an intra-wagon environment at mm-wave frequencies are presented. The measurements were collected inside an underground convoy from 25 to 40 GHz in the



Fabricated prototypes: (a) UWB antenna with cavity and dual polarization; (b) MIMO multibeam antenna.

frequency domain. These results allow us to have a better knowledge of the path loss and time dispersion characteristics of the propagation channel in this particular environment, characterized by rich-scattering with long delays.

6. Planar Lens Antenna for High Data Rate Applications, D.A. Santillán-Haro, E. Antonino-Daviu, D. Sánchez-Escuderos, M. Ferrando-Bataller, *Wireless Communications and Mobile Computing*, vol. 2019. DOI: 10.1155/2019/5125287.

A low-profile lens antenna formed by 2 metallic rings with strips short-circuiting both rings is presented. The theory of characteristic modes is used to facilitate the design, optimization, and analysis of the structure. Measured results show a large operating bandwidth (14.7% relative -14 dB impedance bandwidth) with a maximum directivity above 13.70 dBi and a return loss better than 14 dB.

7. Fading evaluation in the mm-Wave band, T. R. Rufino-Marins, A. Antônio dos Anjos, V. M. Rodrigo Peñarrocha, L. Rubio, J. Reig, R. A. Amaral de Souza, and M. D. Yacoub, *IEEE Transactions on Communications*, vol. 67, no. 12, pp. 8725-8738, September 2019. DOI: 10.1109/TCOMM.2019.2941493

A thorough mm-wave measurement campaign is carried out in an indoor environment to characterize the short-term fading channel behavior. The measurements are conducted in a variety of scenarios, with frequencies ranging from 55 GHz to 65 GHz, in line-of-sight and non-line-of-sight conditions, and combinations of horizontal and vertical polarizations at both transmitter and receiver. A number of fading models are tested and the statistics under analysis are those characterizing the fading amplitude and the frequency selectivity.

8. Design of a Dual-band Frequency Reconfigurable Patch Antenna based on Characteristic Modes, Z. Mahlaoui, E. Antonino-Daviu, A. Latif, M. Ferrando-Bataller, *International Journal on*

Antennas and Propagation, vol. 2019. DOI: 10.1155/2019/4512532.

A WLAN frequency reconfigurable patch antenna based on the characteristic mode analysis is proposed. The antenna presents a reconfigurable lower band (at 2.4GHz) and a steady band at higher frequencies (from 5.3GHz to 5.8GHz). Varactor diodes are used in the antenna in order to tune the lower band, while the second operating frequency keeps stable.

9. Integral equation methods for electrostatics, acoustics and electromagnetics in smoothly varying, anisotropic media, L.M. Imbert-Gerard, F. Vico, L. Greengard and M. Ferrando, *SIAM Journal on Numerical Analysis*, vol. 57, no. 3, pp. 1020-1035, 2019. DOI: 10.1137/18M1187039.

A collection of well-conditioned integral equation methods for the solution of electrostatic, acoustic, or electromagnetic scattering problems involving anisotropic, inhomogeneous media is presented. In the electromagnetic case, this approach involves a minor modification of a classical formulation. In the electrostatic or acoustic setting, we introduce a new vector partial differential equation, from which the desired solution is easily obtained. It is the vector equation for which we derive a well-conditioned integral equation.

2.2.- PATENTS

The mechanical phase shifter is currently under a patent process: DESFASADOR MECÁNICO, PCT/ES2020/070296.

2.3.- AWARDS

1. Miguel Ferrando-Rocher has been awarded by Universitat Politècnica de València with one Premio Extraordinario de Tesis Doctoral to the best PhD dissertation in ICT in 2020.

AUDIO AND COMMUNICATIONS SIGNAL PROCESSING GROUP

HEAD OF THE GROUP RESEARCH REPORT

The Audio and Communications Signal Processing Group (known by their acronym GTAC from its Spanish name Grupo de Tratamiento de señal en Audio y Comunicaciones) has developed its research during the scholar year 2019-20 mainly on active noise control, spatial audio perception and rendering, and sound quality improvement for multi-channel audio systems. GTAC has carried out several research projects and has published their most relevant results in several scientific journals and conference proceedings. In particular, the Cátedra Telefonica-UPV project "Sound-Aided Smart Environments for the City, Home and Nature (SSEnCe)" is reaching its final stage with great success, achieving their objectives by creating a demonstrator that allows detecting and classifying acoustic events, for home environments, Smart Cities and Natural parks. On the other hand, the national projects "Dynamic Acoustic Networks for Changing Environments (DANCE)" and "Intelligent Spatial Audio Synthesis and Customization (ISLA-THESON)" are in halfway through their completion. More details of their achievements are shown at the "Ongoing Projects" section, but in the following, we want to highlight the most novel developments of the GTAC during this last year.

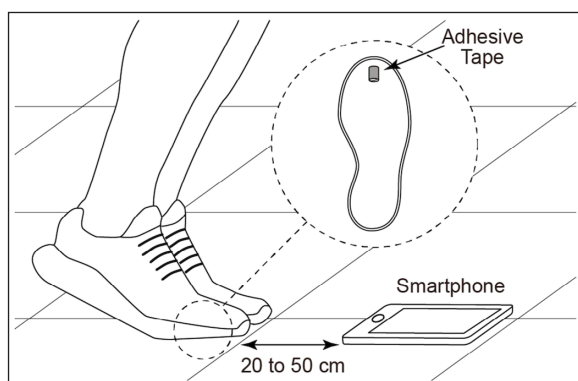


Figure 1. Experimental setup of jump recordings with the microphone of a smartphone.



Figure 2. Subjective test on 3D sound perception using individualized HRTFs.

A new audio application in Sports (see Fig. 1) has been developed with the collaboration of researchers from the University of Alicante. This is an audio-based system acting as a trustworthy instrument to accurately measure the height of a jump. It can be easily automated as a mobile app to facilitate its use both in laboratories and in the field.

With regards to the GTAC facilities, the new laboratory for perceptual spatial sound is finishing their equipment. It allows measuring Head-Related Transfer Functions (HRTF) of any person with very high precision, in such a way that spatial sound can be rendered to a that particular person with high fidelity (see Fig.2). The HRTF is in somehow a personal acoustic fingerprint that changes from one person to another. By using individualized HRTFs, we can generate a virtual sound that is indistinguishable from reality. As it can be seen from Fig. 2, the loudspeaker array is formed by a 4-meter-diameter circular array of 72 loudspeakers placed in the same horizontal plane, plus two sets of 8 loudspeakers, one placed in the ceiling and one on the floor.

1.- PROJECT ACTIVITIES

In the following we describe the main ongoing projects that are being developed by GTAC researchers.

ONGOING PROJECTS

Title: Sound-Aided Smart environments for the city, home and nature (SSEnCe)

Webpage of the project:

www.sound-aided-IOT.webs.upv.es

Funding entity and duration: Cátedra Telefónica UPV. 2017-2020

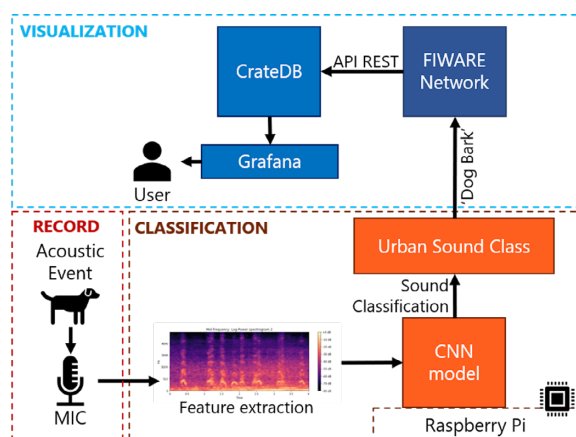


Figure 3. Scheme of the WASN used for cities' sound classification.

The SSENCE project aims to encourage the development and dissemination of real and practical prototypes focused on the concept of intelligence for the Internet of Things (IoT). Particularly, the project will develop applications mainly addressed to obtain acoustic information of the environment. A second main objective of this project is the creation of an observatory of technological demonstrators developed by national and international research groups related to the acoustic-aided IoT.

We have developed within the frame of the project a demonstrator of an environmental sound classifier (ESC) of city sounds based on a wireless acoustic sensor network (WASN)

whose nodes are low-cost devices, whose scheme is shown in Fig. 3. The WASN recognizes a set of sound events or classes from urban environments. Their nodes are formed by Raspberry Pi devices equipped with outdoor microphones, and they not only record the ambient sound, but can also process and recognize a sound event by means of deep learning (convolutional neural network (CNN) model in Fig. 3). To our knowledge, this is the first WASN running a CNN classifier at their own nodes and not using cloud or edge computing to get the record signals classified. In our WASN, the nodes send the resulting probability of every sound class to the server, so the data can be displayed in a map. Such WASNs have many advantages as monitoring system: they are cheap compared to other monitoring systems, they can be easily deployed and they can work day and night. An additional advantage of our WASN is that uses the open standard FIWARE in their communication network, so the whole system can be replicated without the need of proprietary software or hardware. Fig. 4 shows the system dashboard where the data are visualized, including the location of the nodes over the map of Valencia city.

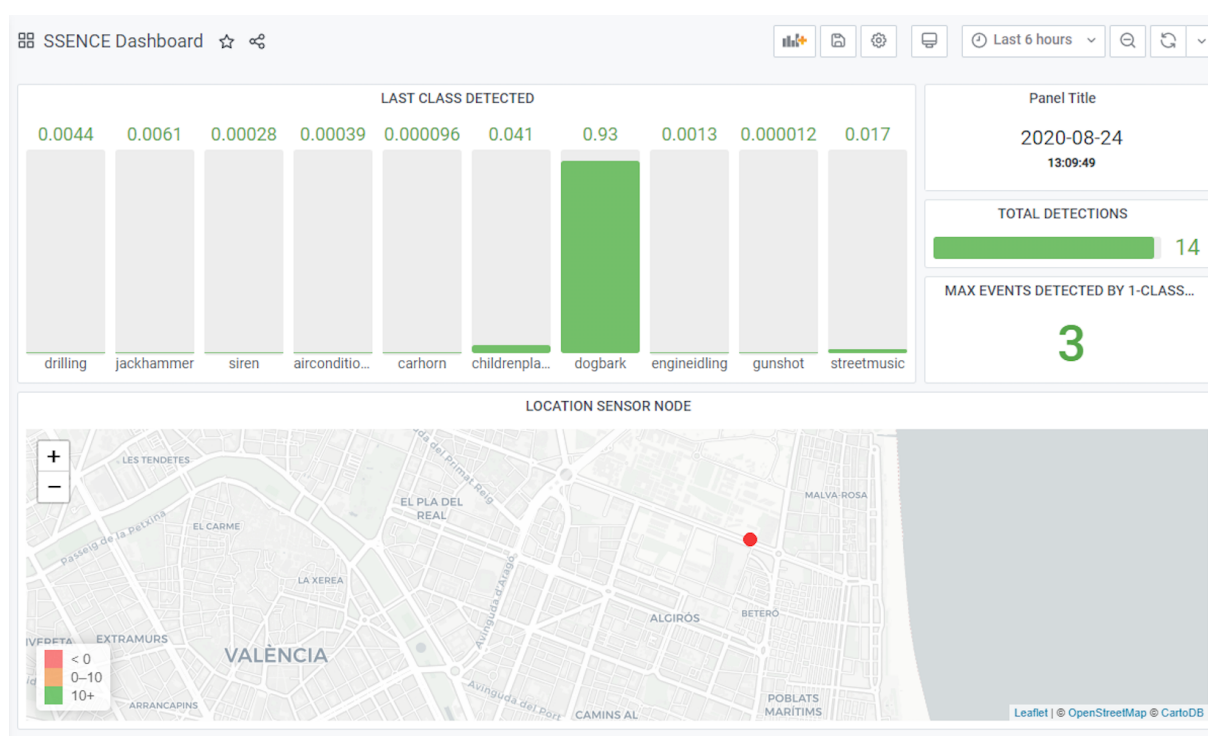


Figure 4. Dashboard of the WASN monitoring system in Valencia city.

Title: *Dynamic acoustic networks for changing environments (DANCE)*

Webpage: www.dance.upv.es

Funded by: Spanish Ministry of Science, Innovation and University. 2019-2021.

DANCE is a coordinated project that will develop distributed algorithms and systems to deal with different audio applications under the common frame of dynamic scenarios. Some of their tasks will be: self-localization of nodes' positions, estimation of dynamic room impulse responses (RIRs) and inverse filters, characterization and control of time-varying acoustic wave fields, etc. Additionally, emerging computing tools will be used to meet the real-time requirements of audio rendering and control in time-varying scenarios.

The DANCE project includes the development of two testbeds in the GTAC audio laboratory: (1) The first one employs sub-band filtering and optimized filter bank computation in the time domain for the design of personal sound zones (PSZ). The aim is to render a target soundfield in the "bright" zone while having control over the mean acoustic energy in the "dark" (quiet) zone. The PSZ system presents a great versatility since it can be adapted and optimized according to the frequency content of the audio signals, the

characteristics of the room and the typology and location of the transducers used. (2) The second testbed consists in a massive multichannel noise reduction for open-plan offices. The aim is to reduce the annoyance caused by the ambient noise and speech in open working spaces through their masking with pleasant sounds. These pleasant sounds (waterfall, birdsongs, pink noise,...) will make the annoying ambient sounds almost inaudible thanks to the masking properties of the human hearing system.

For this purpose, we have designed a robotic X-Y-Azimuth platform (see Fig. 5) able to support and move any recording or audio emitting device, i.e. arrays of microphones or audio-heads as shown in Fig. 5. The platform is controlled by its own software, but with it can also be controlled from Matlab. It can operate within an area of 1.3x1.3m (X-Y) and supports a whole azimuth range of 360°. This platform will be used to characterize dynamic acoustic zones in indoor environments.

Title: *Intelligent spatial audio: synthesis and customization (ISLA-THESON)*

Funded by: Spanish Ministry of Science, Innovation and University. 2019-2021.

The sound industry has been experiencing profound changes in recent years under the

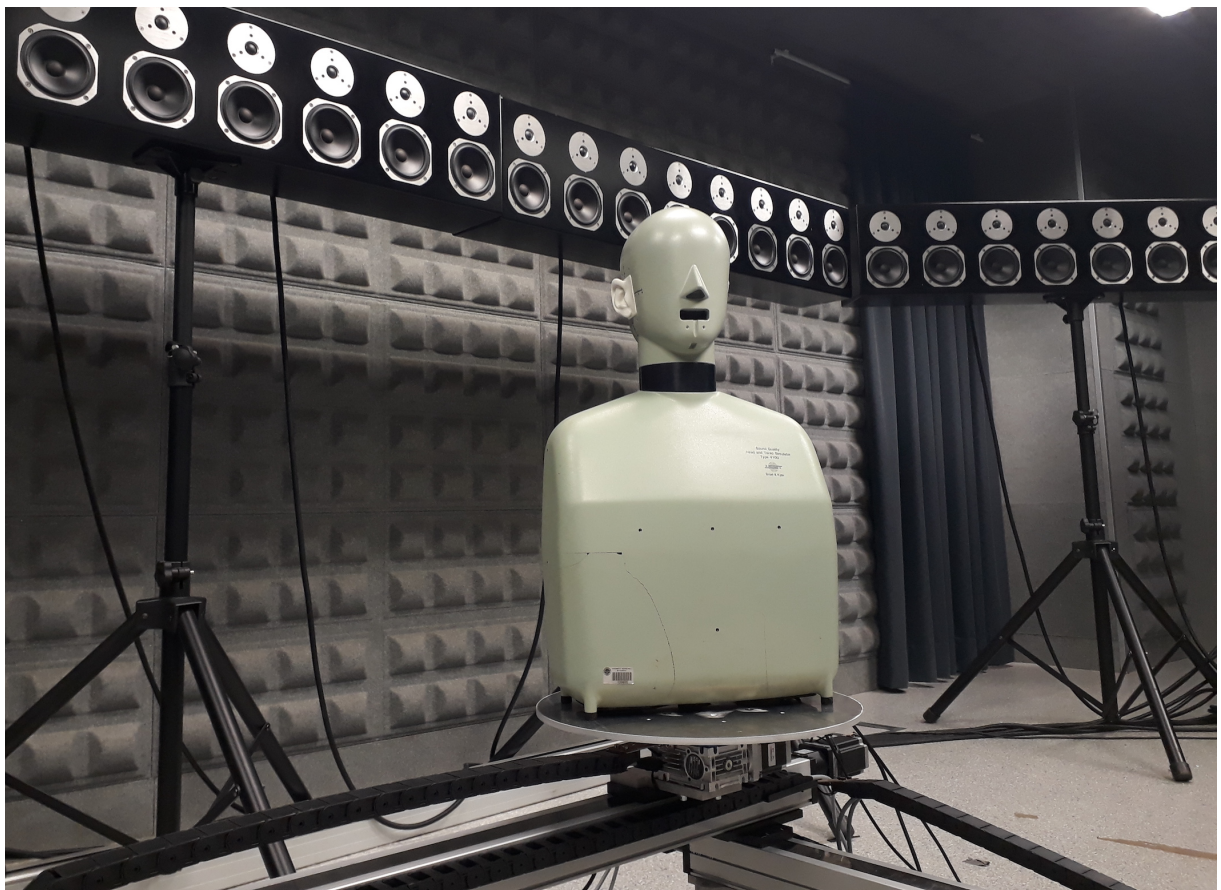


Figure 5. Robotic platform for the measurement of dynamic scenarios.



Figure 6. Objective measurements of the HRTF.

perspective of three complementary approaches: the individual, the group and the contents. Moreover, the use of headphones has spread enormously, and the need to reproduce highly realistic spatial sound through them is a great opportunity for the industry. For a very immersive experience, the sound must be customized for each individual based on their anatomy, in particular the head and pinna shape, which define their particular Head-Related Transfer Function

(HRTF). Measuring a subject's HRTF is still a costly process that requires specialized facilities and its indirect estimation remains an unresolved problem. At ITEAM, we have built a new facility to measure HRTFs of real subjects in an efficient way (Fig. 6). By employing Deep Learning techniques and photographs of the ear/head, we have achieved an HRTF personalization of better quality than previous methods. To this end, a new system has been constructed for the capture and extraction of individual anthropometric parameters from photographs (Fig. 7). The results obtained by combining both objective measurements (individual HRTF and anthropometric parameters) with deep learning techniques, can be evaluated by means of subjective perceptual tests as was shown in Fig. 2. By using an individualized HRTF, we can generate a virtual sound indistinguishable from reality. This will in turn allow mobile devices to incorporate personalized responses for their direct application in 3D sound, virtual and augmented reality, video games, etc.

On the other hand, the sound and entertainment industry has been redirected during the recent years to big live shows, where the spatialization of sound is still a challenge and an opportunity for using sound field synthesis algorithms to recreate virtual spaces. Array processing



Figure 7. Setup of the multi-camera system.

techniques should be developed to control the sound in different listening areas while synthesizing the different live sound objects (musicians, actors, presenters, effects, etc.), adapting the synthesis of each object to its own movement and achieving greater realism over the audience. Other scenarios such as museums, exhibitions, restaurants or smart homes would also benefit from the creation of independent audio zones, using similar techniques employing loudspeaker and sensor arrays.

Finally, from the contents point of view, this subproject will work on creating new methods for the analysis of audio and music based on Machine Learning, with application to synchronized audiovisual effects and live enriched events. The aim is to develop Machine Learning algorithms able to extract features from music and enable the synchronization of 3D animations, lights or lasers with the music.

Title: *Smart social computing and communication (in Spanish: Comunicación y computación inteligentes y sociales - CONTACTS)*

Webpage: www.comtacts.upv.es

Funded by: Prometeo Call. Regional Government – Generalitat Valenciana. 2019-2023.

The advances made in the field of distributed computing and the hardware-software available right now make possible to develop powerful systems to process and exchange information, and at the same time, able to interact with the environment through numerous sets of transducers. These transducers, in turn, provide an ever-increasing volume of signals and data, making possible a more precise knowledge of the social and physical environment of the human beings' daily life.

On the other hand, let us consider the boom in applications arising from computing and communication devices for personal use, and their massive use with the advance of communications; some highlighted applications are human-machine interaction, control systems, location and tracking systems, telepresence, automatic classification, high-speed communications, diagnostic assistance systems, etc. Within this framework, intelligent and social computing and communication is defined as the hybrid mix of the two disciplines in order to face challenges of high socio-economic interest. Science is used for the purpose of communications and computing, but taking into account ubiquity, versatility, scalability, efficiency and cooperative processing of heterogeneous computing and data acquisition device networks.

CONTACTS project considers the physical aspects of computing, signal processing, energy consumption, technology, communication, etc., particularly in distributed, collaborative scenarios

where massive and heterogeneous data are provided. In this way, CONTACTS addresses the design, development and implementation of products, systems, programs and algorithms for signal processing and communications, which make use of state-of-the-art architectures, advanced computing and efficient communications within the framework of intelligent computing and communication aimed at tackling social challenges.

2.- RESEARCH RESULTS

The most important results of the GTAC publications over the past year are summarized in the following. For a more detailed description, visit our webpage: www.gtac.upv.es where a complete list of projects and papers can be found.

2.1.- FEATURED JOURNAL PUBLICATIONS

Personal Sound Zones by Subband Filtering and Time Domain. Vicent Moles, Gema Piñero, Maria de Diego, Alberto Gonzalez, *IEEE/ACM Trans. on Audio, Speech and Language Processing*, vol. 28, pp. 2684 - 2696, 2020. DOI: 10.1109/TASLP.2020.3023628.

Abstract: Personal Sound Zones (PSZ) systems aim to render independent sound signals to multiple listeners within a room by using arrays of loudspeakers. One of the algorithms used to provide PSZ is Weighted Pressure Matching (wPM), which computes the filters required to render a desired response in the listening zones while reducing the acoustic energy arriving to the quiet zones. This algorithm can be formulated in time and frequency domains. In general, the time-domain formulation (wPM-TD) can obtain good performance with shorter filters and delays than the frequency-domain formulation (wPM-FD). However, wPM-TD requires higher computation for obtaining the optimal filters. In this article, we propose a novel approach to the wPM algorithm named Weighted Pressure Matching with Subband Decomposition (wPM-SD), which formulates an independent time-domain optimization problem for each of the subbands of a Generalized Discrete Fourier Transform (GDFT) filter bank. Solving the optimization independently for each subband has two main advantages: 1) lower computational complexity than wPM-TD to compute the optimal filters; 2) higher versatility than the classic wPM algorithms, as it allows different configurations (sets of loudspeakers, filter lengths, etc.) in each subband.

Effects and applications of spatial acuity in advanced spatial audio reproduction systems with loudspeakers. José Javier López Monfort, Pablo Gutiérrez-Parera, Lauri Savioja *Applied Acoustics*, vol. 161, 107179, 2020. DOI: 10.1016/j.apacoust.2019.107179

Abstract: Spatial audio reproduction systems using loudspeakers produce coloration effects at high frequencies due to spatial interference between loudspeakers, in both those based on panning and those based on field synthesis. As a response to this problem and in order to reduce coloration, this paper studies the feasibility of an alternative approach where high frequencies are reproduced from a single loudspeaker, with a different direction from that of its panned low-frequency counterpart. Listening tests are conducted to investigate the localization and quality of the source in the case that frequencies higher than 1.5 kHz are reproduced from a different direction than the low frequencies. In this context, the human ability to discriminate the spatial direction of low/high frequency bands and the error in the perceived direction of arrival for different separation angles is evaluated and quantified. The resulting data has been analyzed with ANOVA, providing significant results that allow us to establish a threshold in the angular separation of the high and low frequency parts where subjects do not perceive source location artifacts. The term just noticeable band splitting angle (JNBSA) is defined and introduced. It represents the minimum angle of separation between high and low frequencies from which the listener starts to perceive artifacts in the reproduction of a sound source using loudspeakers.

Audio-Based System for Automatic Measurement of Jump Height in Sports Science. Basilio Pueo, José Javier López Monfort, Jose M. Jimenez-Olmedo, *Sensors*, vol. 11, n° 19, pp. 2543- 2556, 2019. DOI: 10.3390/s19112543

Abstract: Jump height tests are employed to measure the lower-limb muscle power of athletic and non-athletic populations. The most popular instruments for this purpose are jump mats and, more recently, smartphone apps, which compute jump height through manual annotation of video recordings to extract flight time. This study developed a non-invasive instrument that automatically extracts take-off and landing events from audio recordings of jump executions. An audio signal processing algorithm, specifically developed for this purpose, accurately detects and discriminates the landing and take-off events in real time and computes jump height accordingly. Its temporal resolution theoretically outperforms that of flight-time-based mats (typically 1000 Hz) and high-speed video rates from smartphones (typically 240 fps). A validation study was carried out by comparing 215 jump heights from 43 active athletes, measured simultaneously with the audio-based system and with of a validated, commercial jump mat. The audio-based system produced nearly identical jump heights than the criterion with

low and proportional systematic bias and random errors. The developed audio-based system is a trustworthy instrument for accurately measuring jump height that can be readily automated as an app to facilitate its use both in laboratories and in the field.

On the use of many-core machines for the acceleration of a mesh truncation technique for FEM. Jose A. Belloch, A. Amor-Martin, D. García-Donoro, Francisco J. Martinez, L. E. Garcia-Castillo, *The Journal of Supercomputing*, vol. 75, n° 3, pp. 1686-1696, 2019. DOI: 10.1007/s11227-018-02739-9.

Abstract: Finite element method (FEM) has been used for years for radiation problems in the field of electromagnetism. To tackle problems of this kind, mesh truncation techniques are required, which may lead to the use of high computational resources. In fact, electrically large radiation problems can only be tackled using massively parallel computational resources. Different types of multi-core machines are commonly employed in diverse fields of science for accelerating a number of applications. However, properly managing their computational resources becomes a very challenging task. On the one hand, we present a hybrid message passing interface + OpenMP-based acceleration of a mesh truncation technique included in a FEM code for electromagnetism in a high-performance computing cluster equipped with 140 compute nodes. Results show that we obtain about 85% of the theoretical maximum speedup of the machine. On the other hand, a graphics processing unit has been used to accelerate one of the parts that presents high fine-grain parallelism.

2.2.- FEATURED CONFERENCE PROCEEDINGS

A Low-cost Wireless Acoustic Sensor Network for the Classification of Urban Sounds. David Salvo, Gema Piñero, Pau Arce, Alberto Gonzalez, *The Seventeenth ACM International Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor and Ubiquitous Networks, PEWASUN*, 2020.

Providing Spatial Control in Personal Sound Zones Using Graph Signal Processing. Vicent Moles, Gema Piñero, Alberto Gonzalez, Maria de Diego *27th European Signal Processing Conference (EUSIPCO 2019)*, A Coruña, Spain, 2019.

Towards low cost acoustic cameras for the Internet of Things. José Javier López Monfort, Maximilian Becker, Carlos Alberto Hernandez Franco, *23rd International Congress on Acoustics (ICA 2019)*. (3329-3336). Aachen, Germany: German Acoustical Society.

SIGNAL PROCESSING GROUP

HEAD OF THE GROUP RESEARCH REPORT

The Signal Processing Group (GTS) is devoted to produce quality research to advance in both the theoretical aspects of signal processing and its applications. The areas of application include medicine, industry, underwater acoustics, and arts.

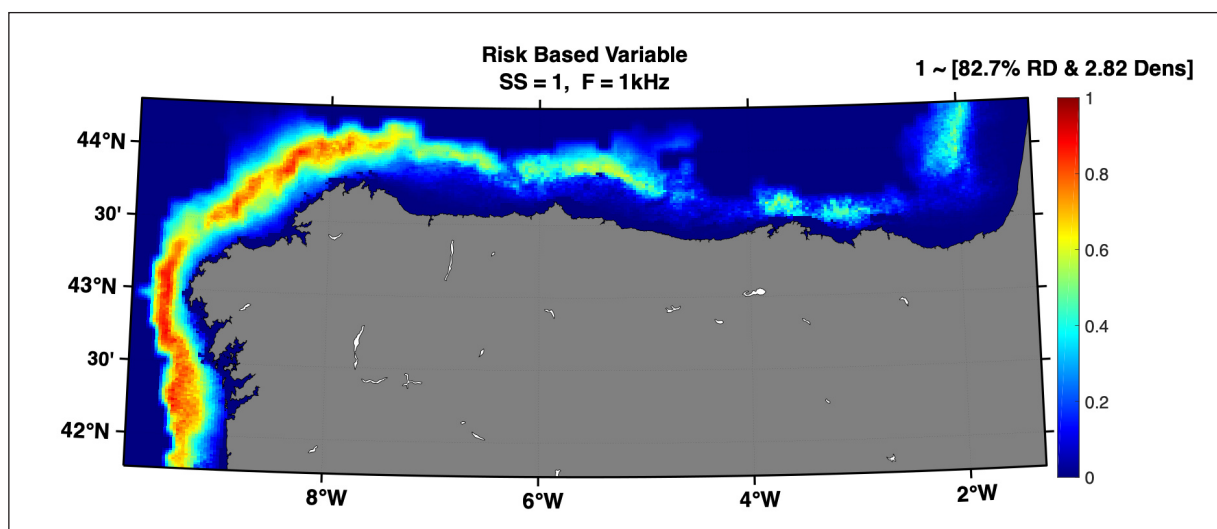
1.- PROJECT ACTIVITIES

The GTS has continued researching in the already established research lines as well as in some other emerging activities. A short summary of some of the main activities is listed below:

- Signal processing techniques applied to ultrasonic and impact-echo methods for the characterization of cementitious materials in the construction industry: The research has produced innovative techniques for material characterization, damage location and tomography reconstruction (FANSIRAS and non-contact airborne ultrasound techniques are clear examples). These techniques have proven to be useful in the characterization of both natural and artificial stones. The GTS collaborates, among others, with the ICITECH (Institute of Science

and Technology of the Concrete), with the Department of Civil & Environmental Engineering (University of Illinois), with the University College Cork, and with the Centro Superior de Investigaciones Científicas (CSIC).

- Passive acoustics monitoring: We develop acoustic sensors and signal processing algorithms to advance in the study of marine animal population and the impact that anthropogenic sounds have on them. The aim is to help to ensure the conservation and sustainable use of marine biodiversity. For this purpose, we design surveillance systems, create real time noise maps for harbours, and evaluate the results using a risk-based approach. The group collaborates with the Oceanogràfic of Valencia, and with the Instituto Español de Oceanografía (IEO) for the Spanish approach to the Marine Strategy Framework Directive (D11).
- Applications of biomedicine.
- Graph Signal Processing (GSP): We continue developing new methods of classification, fusion of classifiers and signal surrogates based on GSP, which are applied to a variety of practical problems.
- Emerging Signal Processing Techniques for Big Data Health Applications.
- Technologies for the Arts (Soundcool): The Group of Performing Arts and Technology (PerformingARTech) continues the developments on the Soundcool system. In its new version Soundcool 4.0 has further video processing capabilities. One of the main novelties this year is that Prof.



Risk map based on density of population and distance reduction from pristine ambient considering sea state 1 at 1kHz. In this case 'Risk index' value 1 is related with maximum values of distance reduction and density of bottlenose dolphins (82.7% & 2.82 respectively).

Roger Dannenberg, Director of the Computer Music Project at Carnegie Mellon University, is now a member of the board of directors of Soundcool (<http://soundcool.org/en/team/>).

1.1.- ONGOING PROJECTS

Name of the project: Risk-based Approaches to Good Environmental Status (RAGES)

Webpage of the project: <https://www.msfd.eu/rages/>

Summary of the project: The RAGES project continues with the study of how human activities that take place at sea have an impact to the marine environment. A risk-based approach for continuous noise is being studied and different alternatives are evaluated. Specifically, we are using the communication distance reduction from pristine ambient as a result of anthropogenic noise. Risk evaluation can be based on the possibility of a masking effect occurring in areas with presence of a given cetacean species. Combining the communication distance reduction with cetacean density (*T. truncatus* for example), we can identify risk areas with a potential threat of masking (see figure in page 27).

Funding entity: DG for Environment (ENV), European Commission.

Name of the project: Spanish implementation of the Marine Strategy Framework Directive.

Summary of the project: The IEO-UPV has been commissioned by the Ministry of Ecological Transition for the Spanish implementation of European Directive 11 (D11), within the Marine Strategy Framework Directive (MSFD). The project continues by doing the different deployments around the Spanish Marine Waters. New releases are been made in the PAM device SAMARUC obtaining more accurate acoustic data, complying with the regulations marked by de TGNoise (according to D11.2).

Funding entity: Ministry of Ecological Transition.



SAMARUCs ready to deploy

Name of the project: Influence of anthropogenic noise in cetacean populations

Summary of the project: The project aims to evaluate the possible acoustic conditions suffered by the cetacean populations living near of the bay of Cartagena, more specifically between Cabo Tiñoso and Escombreras. For this purpose, different deployments are being made using underwater acoustic devices that allow the monitoring of acoustic data (anthropogenic and animal sounds) to be later analysed by visual inspection techniques (in aerial and nautical visualisation campaigns). This will provide a sample of the diversity of cetacean populations in this area close to the Port of Cartagena and their possible affection due to the existing marine traffic.

Funding entity: Autoridad Portuaria de Cartagena



Aerial view of a pod of dolphins swimming through the Mediterranean Sea

Name of the project: Development and application of non-destructive testing based on mechanical waves for the assessment and monitoring of rheology and self-healing in cementing materials (WAVECON)

Summary of the project: The project aims to develop new techniques for non-destructive evaluation of fresh pastes, mortars and concrete (rheological characterization), and damaged systems (cracking) in which a regeneration or self-healing process takes place. During this year, we have determined the memory capability of the mortar specimens when they are assessed by acoustic spectroscopy. New neural network algorithms have been achieved for ultrasonic tomographic reconstruction and different techniques for lamb waves generation on cement specimens have been also developed.

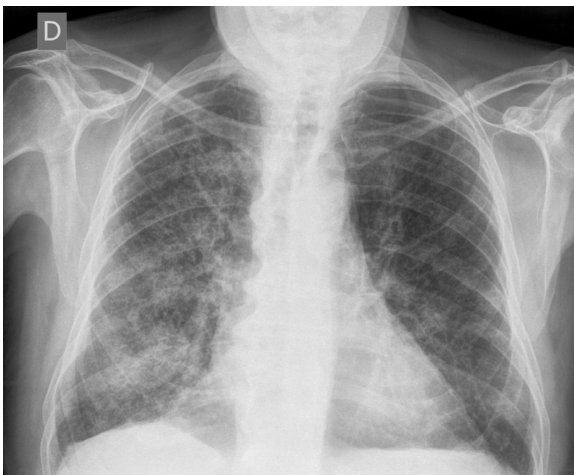
Funding entity: Spanish Government. BIA2017-87573-C2-2-P.



Mortar test probes (4x4x16cm³) with different damage level to be characterized with nondestructive techniques.

Name of the project: Screening covid-19 patients using chest x-ray images

Summary of the project: The goal of this project is to perform a retrospective study to evaluate the performance of deep learning algorithms to predict the presence of covid-19 pneumonia from chest x-ray images.



Chest x-ray from a covid-19 patient

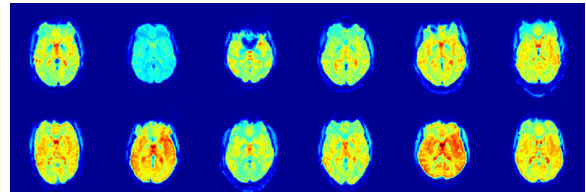
Name of the project: Carlos III Health Institute (Spain) in cooperation with Consejo Superior de Investigaciones Científicas.

Summary of the project: Informed Methods for Signal Synthesis (MISS)

The project has advanced in the expected way. It has been developed a new scheme for increasing the number of training samples in scenarios of extreme scarcity of original data. It is based in a Generative Adversarial Network, which combine a linear discriminant with a generator of synthetic samples based on the concept of surrogates and Markov Random Fields. It has been successfully applied in different types of diagnosis from EEG and fMRI signals. Thus, for

example, an automatic classifier to detect schizophrenia, has been trained with just 6 examples of every class (see figure)

Funding entity: Spanish Government, TEC-2017-84743-P.

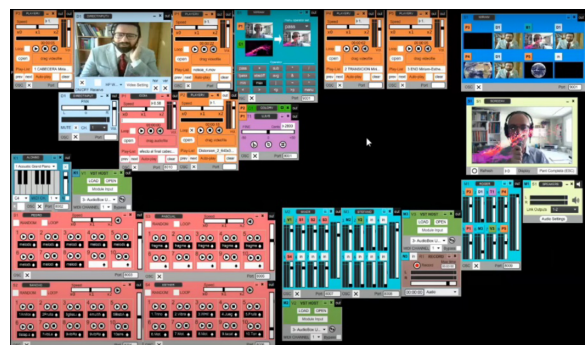


Axial view of fMRI slices from 12 subjects The top row corresponds to individuals with schizophrenia and the bottom row corresponds to healthy controls (subject database identification 11, 12, 15, 37, 46, 49, from left to right).

Name of the project: "Soundcool: Mobile Phones and Digital Tools for Music and Audiovisual Art Education" (16-AC-2016) and "Soundcool: Collaborative Music and Video Creation" (GJIDI/2018/A/169).

Webpage of the project: <http://soundcool.org>.

Summary of the project: The new version 4.0 of the Soundcool application adds new video modules such as video Delay, ChromaKey, or audio to artistic video conversion, new MIDI and OSC interface modules, and improvements on the existing modules. In addition, due to the current situation of social distancing due to COVID19, our team has taken a step further to carry out the connection of the Soundcool app for smartphones and tablets through internet controlling remotely the Soundcool application running in the central computer. This allows live collaborative sound, music and audiovisual remote creation even in confinement with the participants in their own homes. Two tests of remote audiovisual performances have been carried out with students and teachers at their homes in several



Soundcool patch for the Earth Chronicles show, performed remotely with participants in several cities in Spain and in Pittsburgh (USA), July 28th, 2020.

cities in Spain and the USA, and several workshops have been given.

Funding entity: Daniel and Nina Carasso Foundation and Generalitat Valenciana, European Social Fund, Garantía Juvenil.

2.- RESEARCH RESULTS

2.1.- FEATURED PUBLICATIONS

Evaluation of Combined Artificial Intelligence and Radiologist Assessment to Interpret Screening Mammograms. Thomas Schaffter, et al., JAMA network open 3 (3), 2020.

Mammography screening currently relies on subjective human interpretation. Artificial intelligence (AI) advances could be used to increase mammography screening accuracy by reducing missed cancers and false positives. In this paper, we evaluate whether AI can overcome human mammography interpretation limitations with a rigorous, unbiased evaluation of machine learning algorithms. Overall, 144 231 screening mammograms from 85 580 US women (952 cancer positive ≤ 12 months from screening) were used for algorithm training and validation. A second independent validation cohort included 166 578 examinations from 68 008 Swedish women (780 cancer positive). The top-performing algorithm achieved an area under the curve of 0.858 (United States) and 0.903 (Sweden) and 66.2% (United States) and 81.2% (Sweden) specificity at the radiologists' sensitivity, lower than community-practice radiologists' specificity of 90.5% (United States) and 98.5% (Sweden). Combining top-performing algorithms and US radiologist assessments resulted in a higher area under the curve of 0.942 and achieved a significantly improved specificity (92.0%) at the same sensitivity.

DOI:10.1001/jamanetworkopen.2020.0265

Densitometric radiographic imaging with contour sensors. Francisco Albiol, Alberto Corbi, Alberto Albiol. IEEE Access, 2019, Vol.7,

This paper presents the technical/physical foundations of a new imaging technique that combines ordinary radiographic information (generated by conventional X-ray settings) with the patient's volume to derive densitometric images. After measuring the patient's volume with contour recognition devices, the physical traversed lengths within it (as the Roentgen beam intersects the patient) are calculated and pixel-wise associated with the original radiograph (X). The patient's surface is also translated to the point-of-view of the X-ray beam and all its entrance/exit points are sought with the help of ray-casting methods. The derived L is applied to X as a physical operation (subtraction), obtaining soft tissue- (DS) or bone-enhanced (D0 B) figures. In the DS type, the contained

graphical information can be linearly mapped to the average electronic density (traversed by the X-ray beam). This leads to other advantages: improvement in the visibility of border/edge areas (high gradient), extended manual window level/width manipulations during screening, and immediate correction of underexposed X instances. In the D0 B type, high-density elements are highlighted and easier to discern. All these results can be achieved with low-energy beam exposures, saving costs and dose.

DOI: 10.1109/ACCESS.2019.2895925

New Insights into the Design and Application of a Passive Acoustic Monitoring System for the Assessment of the Good Environmental Status in Spanish Marine Waters, Guillermo Lara, Ramón Miralles, Manuel Bou-Cabo, José Antonio Esteban and Víctor Espinosa, Sensors, 20 (18), 2020.

Passive acoustic monitoring systems allow for non-invasive monitoring of underwater species and anthropogenic noise. One of these systems has been developed keeping in mind the need to create a user-friendly tool to obtain the ambient noise indicators, while at the same time providing a powerful tool for marine scientists and biologists to progress in studying the effect of human activities on species and ecosystems. The device is based on a low-power processor with ad-hoc electronics, ensuring that the system has efficient energy management, and that the storage capacity is large enough to allow deployments for long periods. An application is presented using data from an acoustic campaign done in 2018 at El Gorguel (Cartagena, Spain). The results show a good agreement between theoretical maps created using AIS data and the ambient noise level indicators measured in the frequency bands of 63 Hz and 125 Hz specified in the directive 11 of the EU Marine Strategy Framework Directive. Using a 2D representation, these ambient noise indicators have enabled repetitive events and daily variations in boat traffic to be identified. The ship noise registered can also be used to track ships by using the acoustic signatures of the engine propellers' noise.

DOI: 10.3390/s20185353

Comparative Study of Coupling Techniques in Lamb Wave Testing of Metallic and Cementitious Plates. Vazquez-Martinez, Santiago; Gosálbez Castillo, Jorge; Bosch Roig, Ignacio; Carrión García, Alicia; Gallardo-Llopis, Carles; Paya Bernabeu, Jorge Juan., Sensors, 19 (19), 1 - 30, 2019.

Lamb waves have emerged as a valuable tool to examine long plate-like structures in a faster way compared to conventional bulk wave techniques, which make them attractive in non-destructive testing. However, they present a

multimodal and dispersive nature, which hinders signal identification. Oblique incidence is one of the most known methods to generate and receive Lamb waves and it is applied in different experimental arrangements with different types of sensors. In this work, several setups were conducted and compared to determine the optimal ones to launch and detect ultrasonic Lamb waves, especially in non-homogeneous specimens. The chosen arrangements were contact with angle beam transducers, immersion in a water tank, localised water coupling using conical containers and air coupling. Plates of two different materials were used, stainless steel and Portland cement mortar. Theoretical and experimental dispersion curves were compared to verify the existence of Lamb modes and good correspondence was achieved.

DOI: 10.3390/s19194068

Effects of slow dynamics and conditioning on non-linear hysteretic material assessment using impact resonance acoustics spectroscopy,

A. Carrión, V. Genovés, G. Pérez, J. Bittner, J.S. Popovics, J. Payá, J. Gosálbez, *Mechanical Systems and Signal Processing* 150, 1-15, 2021.

The microstructural features of heterogeneous and porous materials give rise to unique non-linear dynamic behaviour. The purpose of this work is to investigate the dynamic response of thermally damaged concrete specimens measured by two different techniques: Non-linear Impact Resonance Acoustic Spectroscopy (NIRAS) and new Flipped Accumulative Non-linear Single Impact Acoustic Spectroscopy (FANSIRAS). Specimens were characterised in two different dynamic condition states of the material: relaxed and conditioned. The specimen's relaxed state indicates that no previous dynamic excitation event occurred. The conditioned state denotes that the specimen has been dynamically tested before. The NIRAS results show that the non-linear material parameters, and, are affected by their previous dynamic history (its conditioning). The recently proposed algorithm, FANSIRAS, extracts from a single resonant signal equivalent results to NIRAS when the specimen is conditioned. In this situation, both parameters were equivalent. The results suggest that new NDT parameters based on non-linear hysteretic parameters can quantify the damage level of thermally treated mortar specimens.

DOI: 10.1016/j.ymssp.2020.107273

LoRaWAN Network for Fire Monitoring in Rural Environments, Sendra, Sandra; García-García, Laura; Lloret, Jaime; Bosch Roig, Ignacio; Vega-Rodríguez, Roberto, *Electronics*, 3 (9), 1 - 29, 2020.

The number of forest fires that occurred in recent years in different parts of the world is causing

increased concern in the population, as the consequences of these fires expand beyond the destruction of the ecosystem. However, with the proliferation of the Internet of Things (IoT) industry, solutions for early fire detection should be developed. The assessment of the fire risk of an area and the communication of this fact to the population could reduce the number of fires originated by accident or due to the carelessness of the users. This paper presents a low-cost network based on Long Range (LoRa) technology to autonomously evaluate the level of fire risk and the presence of a forest fire in rural areas. The system is comprised of several LoRa nodes with sensors to measure the temperature, relative humidity, wind speed and CO₂ of the environment. The data from the nodes is stored and processed in a The Things Network (TTN) server that sends the data to a website for the graphic visualization of the collected data. The system is tested in a real environment and, the results show that it is possible to cover a circular area of a radius of 4 km with a single gateway.

DOI: 10.3390/electronics9030531

Computing the partial correlation of ICA models for non-Gaussian graph signal processing,

Belda, J., Vergara, L., Safont, G., Salazar, A., *Entropy*, Volume 21, Issue 1, 1 January 2019.

Conventional partial correlation coefficients (PCC) were extended to the non-Gaussian case, in particular to independent component analysis (ICA) models of the observed multivariate samples. Thus, the usual methods that define the pairwise connections of a graph from the precision matrix were correspondingly extended. The basic concept involved replacing the implicit linear estimation of conventional PCC with a nonlinear estimation (conditional mean) assuming ICA. Thus, it is better eliminated the correlation between a given pair of nodes induced by the rest of nodes, and hence the specific connectivity weights can be better estimated. Some synthetic and real data examples illustrate the approach in a graph signal processing context.

Nonlinear estimators from ICA mixture models

Safont, G. Salazar, A., Vergara, L., Rodríguez A., *Signal Processing*, Volume 155, February 2019, Pages 281-286.

Independent Component Analyzers Mixture Models (ICAMM) are versatile and general models for a large variety of probability density functions. In this paper we assume ICAMM to derive new MAP and LMSE estimators. The first one (MAP-ICAMM) is obtained by an iterative gradient algorithm, while the second (LMSE-ICAMM) admits a closed-form solution. Both estimators can be combined by using LMSE-

ICAMM to initialize the iterative computation of MAP-ICAMM. The new estimators are applied to the reconstruction of missed channels in EEG multichannel analysis. The experiments demonstrate the superiority of the new estimators with respect to: Spherical Splines, Hermite, Partial Least Squares, Support Vector Regression, and Random Forest Regression.

Pattern recognition techniques for provenance classification of archaeological ceramics using ultrasounds, Salazar, A., Safont, G., Vergara, L., Vidal, E., *Pattern Recognition Letters*, Volume 135, July 2020, Pages 441-450.

This paper presents a novel application of pattern recognition to the provenance classification of archaeological ceramics. This is a challenging problem for archaeologists, which involves assigning a making location to a fragment of archaeological pottery that was found along with other fragments of pieces made in different distant locations from the find. The pieces look very similar to each other and, often, other contextual information about the use of the pieces cannot be used due to the small size of the fragments. Current standard methods to solve this problem are limited since they are time consuming, require costly equipment, and can lead to the destruction of a part of the pieces. The proposed method overcome those limitations using non-destructive ultrasonic testing and incorporates versatile data analysis through advanced pattern recognition techniques. Those techniques include the following: feature ranking, sample augmentation, semi-supervision based on active learning; and optimal fusion. This latter is based in the concept of alpha integration, which allows optimal fitting of the fusion model parameters. Different provenance classification problems are showcased: provenance classification of terra sigillata ceramic pieces from Aretina, Northern Italy and Sud-Gaul origins; and provenance classification of Iberian ceramic pieces from archaeological sites of Paterna, and Les Jovaes in Valencia, Spain. We demonstrate that the proposed fusion-based method achieves the best results, in terms of balanced classification accuracy and F1 score, compared with competitive methods like linear discriminant analysis, random forest, and support vector machine. Experiments for simulating small sample sizes and uncertainty in labeling of the pieces are included. In addition, the paper provides a design of a practical specialized device that could be used in different applications of archaeological ceramic classification.

Vector score alpha integration for classifier late fusion, Safont, G., Salazar, A. Vergara, L., *Pattern Recognition Letters*, Volume 136, August 2020, Pages 48-55.

Alpha integration is a family of integrators that encompasses many classic fusion operators (e.g., mean, product, minimum, maximum) as particular cases. This paper proposes vector score integration (VSI), a new alpha integration method for late fusion of multiple classifiers considering the joint effect of all the classes of the multi-class problem. Theoretical derivations to optimize the parameters of VSI for achieving the minimum probability of error are provided. VSI was applied to two classification tasks using electroencephalographic signals. The first task was the automatic stage classification of a neuropsychological test performed by epileptic subjects and the second one was the classification of sleep stages from apnea patients. Four single classifiers (linear and quadratic discriminant analysis, naive Bayes, and random forest) and three competitive fusion methods were estimated for comparison: mean, majority voting, and separated score integration (SSI). SSI is based on alpha integration, but unlike the proposed method, it considers the scores from each class in isolation, not accounting for possible dependencies among scores corresponding to different classes. VSI was able to optimally combine the results from all the single classifiers, in terms of accuracy and kappa coefficient, and outperformed the results of the other fusion methods in both applications.

Software for Interactive and Collaborative Creation in the Classroom and Beyond: An Overview of the Soundcool Software, S. Scarani, A. Muñoz, J. Serquera, J. Sastre, R.B. Dannenberg, *Computer Music Journal*, MIT Press, Vol. 43, No. 4, 2019.

This article presents a free framework for collaborative creation of interactive and experimental computer music called Soundcool. It is designed to fill a gap between rigid ready-to-use applications and flexible programming languages. The system offers easy-to-use elements for generating and processing and sound, much like ready-made applications, but it enables flexible configuration and control, more like programming languages. The system runs on personal computers with an option for control via smartphones, tablets, and other devices using the Open Sound Control (OSC) protocol. Originally developed to support a new music curriculum, Soundcool is being used at different educational institutions in Spain, Portugal, Italy and Romania through EU-funded Erasmus+ projects. In this article we present our system and showcase three different scenarios as examples of how our system meets its objectives as an easy-to-use, versatile, and creative tool.

Soundcool: collaborative sound and visual creation, Sonic Ideas (CMMAS), J. Sastre & R.B. Dannenberg, *Ideas Sónicas* (ISSN 2317-9694), Vol. 12, No. 22, pp. 75-86, 2020.

This paper describes Soundcool from its inception up to the premiere of the Soundcool opera The Mother Fishes in the US in February 2020: educational applications, professional applications and applications for functional diversity, awards and latest news.

Available at: <https://bit.ly/301CtVd>

2.2.- AWARDS AND EXHIBITIONS.

Interactive audiovisual art applications of the Soundcool system in the Higher Conservatory of Dance from Valencia (CSDV) for a project based on the Yerma play from the Spanish Lorca poet have been carried out.

Face-to-face workshops were held with soundcool at the reformatory of Alicante (EDUSI youth group) and in the functional diversity center of the APSA association in Alicante funded by the Spanish Foundation for Science and Technology within the Atenea association (<http://atenea.in>) mentoring program.

The Mexico City Region of the Monterrey Institute of Technology and Higher Education and the



Soundcool Yerma project with CSDV students

National Center of the Arts (CENART) of Mexico premiered the Soundcool opera "La Mare dels Peixos" in Nov. 2019 (<https://bit.ly/32V0qzA>, see El Mundo newspaper <https://bit.ly/2CY8DJ8>), and the English version "The Mother of Fishes" of the opera was premiered in 2020 in the USA with the support of the Audacity team (<http://bit.ly/tmof-audacity>, <https://bit.ly/32V0RtI>).



American premiere of the opera La Mare dels Peixos at CENART (Mexico, 2019)

PHOTONICS RESEARCH LABS

HEAD OF THE GROUP RESEARCH REPORT

The Photonics Research Labs (PRL) brings together research lines or Labs focused on different technologies and fields of application within the area of photonics and optical communications. Currently formed by more than 40 researchers, PRL mission is to produce high-quality scientific knowledge in the field of optics, quantum optics and photonics, through research projects, R&D contracts and collaboration agreements with the private sector. Our research activity is focused on several applications of photonics, mainly on optical communications of analog and digital signals, radio-over-fiber systems, space-division multiplexing fibers, photonic integrated circuits, fiber optic sensing and industrial scenarios.

PRL is nowadays involved in different H2020 EU funded projects: "NEuromorphic Reconfigurable Integrated Photonic Circuits as artificial image processor" (NEoteRIC), "Building on the Use of Spatial Multiplexing 5G Networks Infrastructures and Showcasing Advanced technologies and Networking Capabilities" (BlueSpace), "European Network for High Performance Integrated Microwave Photonics" (EUIMWP), "Fibre Nervous Sensing Systems" (FINESSE), "European Network on Future Generation Optical Wireless Communication Technologies" (NEWFOCUS). Of particular interest regarding excellence are the three projects granted by the European Research Council (ERC): Consolidator Grant "Revolutionizing fibre-wireless communications through space-division multiplexed photonics" (InnoSpace), Advanced Grant "Universal microwave photonics programmable processor for seamlessly interfacing wireless and optical ICT systems" (UMWP-Chip), and Proof-of-Concept Grant "Field Programmable Photonic Arrays" (FPPAs).

A complete list of research activities can be found at <http://www.iteam.upv.es/group/photronics-research-labs-prl> and <http://www.prl.upv.es>

Also, follow us in:

- Twitter: @PRL_UPV
- LinkedIn: <https://www.linkedin.com/in/photonicresearchlabs/>

1.- PROJECT ACTIVITIES

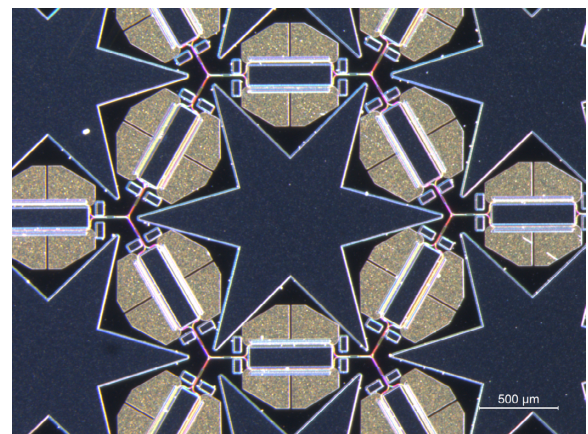
1.1.- ONGOING PROJECTS

Name of the project: Universal microwave photonics programmable processor for seamlessly interfacing wireless and optical ICT systems (UMWP-Chip)

Webpage of the project:
<https://cordis.europa.eu/project/id/741415>

Funding entity and duration: European Research Council (ERC), 60 months

Summary of the project: Information and communication technology (ICT) systems are expanding at an awesome pace in terms of capacity demand, number of connected end-users and required infrastructure. To cope with these rapidly increasing growth rates there is a need for a flexible, scalable and future-proof solution for seamlessly interfacing the wireless and photonic segments of communication networks. RF or Microwave photonics (MWP), is the best positioned technology to provide the required flexible, adaptive and future-proof physical layer with unrivalled characteristics. Its widespread use is however limited by the high-cost, non-compact and heavy nature of its systems. Integrated Microwave Photonics (IMWP) targets the incorporation of MWP functionalities in photonic chips to obtain cost-effective and reduced space, weight and power consumption systems. IMWP has demonstrated some functionalities through application specific photonic circuits (ASPICs), yielding almost as many technologies as applications and preventing cost-effective industrial manufacturing processes. A radically different approach is based on a universal or general-purpose programmable photonic integrated circuit (PIC) capable of performing with the



Reconfigurable photonic integrated processor

same hardware architecture the main required functionalities. The aim of this project is the design, implementation and validation of such a processor based on the novel concept of photonic waveguide mesh optical core and its integration in a Silicon Photonics chip.

Name of the project:

Field Programmable Photonic Arrays (FPPAs)

Webpage of the project:

<https://cordis.europa.eu/project/id/859927>

Funding entity and duration:

European Research Council (ERC), 18 months

Summary of the project: The main idea behind this ERC Proof of Concept project spins-off from the activity of the Advanced Grant ERC-ADG-2016-741415 UMWPCCHIP. The aim of that project is to develop a generic universal signal processor for microwave photonics applications. The central part of such processor is a reconfigurable waveguide mesh circuit.

The waveguide mesh circuit can enable a much more powerful concept with a considerable wider scope of applications. This new paradigm, which we call programmable photonics is radically different from the so-far dominant Application Specific Photonic Circuit paradigm. Furthermore, we expect that, as it happened in electronics, programmable circuits will play a key role in photonics.

In programmable electronics, the key device is the field Programmable Gate Array (FPGA). For photonics we have proposed a novel device, the

Field Programmable Photonic Array (FPPA). The FPPA has a similar rationale as the FPGA in electronics: A common hardware is designed to provide several resources that can be employed to implement different functionalities by means of programming. However, the FPPA is different from the FPGA in the sense that it does not carry digital logic operations but rather exploits optical interference to perform very high-speed analog operations acting over the phase and amplitudes of optical signals in a controlled environment provided by the chip's reduced footprint. Now that we have demonstrated the potential of developing FPPA, the challenge is to demonstrate its innovation potential, developing the first steps towards its technical and commercial viability and launching a spin-off company based on this concept.

Name of the project: Revolutionizing fibre-wireless communications through space-division multiplexed photonics (InnoSpace)

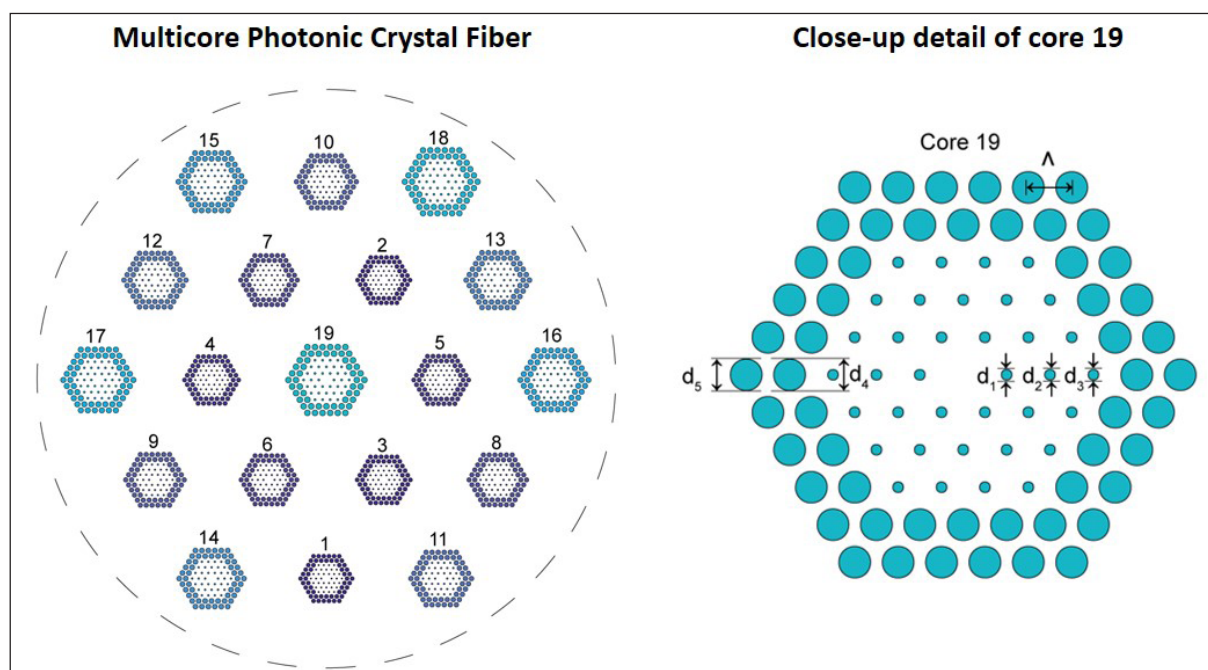
Webpage of the project:

<https://cordis.europa.eu/project/id/724663>

Funding entity and duration:

European Research Council (ERC), 66 months

Summary of the project: InnoSpace aims to revolutionize next generation fiber-wireless communication paradigms, such as 5G systems and Internet of Things, by pioneering the use of the photonic Space dimension. The present fiber-wireless landscape is characterized by radio-over-fiber distribution architectures that are static and inefficient, (with a replication of



Schematic cross-section view of the 19-core multicore photonic crystal fiber developed in the European project InnoSpace.

bundles of optical fibers) as well as by radiofrequency signal processing systems, such as antenna beam-steering or signal generation, which are nowadays bulky, heavy and power consuming. To overcome these limitations, we propose the application of Space-Division Multiplexing to fiber-wireless scenarios where we provide “simultaneously” in a single optical fiber, a compact approach for both distribution and processing functionalities. This leads to the novel concept of “fiber distributed signal processing”.

Name of the project: NEuromorphic Reconfigurable Integrated Photonic Circuits as artificial image processor (NEoteRIC)

Webpage of the project:
<https://neoterich2020.eu/>

Funding entity and duration: European Union's Horizon 2020, 36 months

Summary of the project: NEoteRIC's primary objective is the generation of holistic photonic machine learning paradigms that will address demanding imaging applications in an unconventional approach providing paramount frame rate increase, classification performance enhancement and orders of magnitude lower power consumption compared to the state-of-the-art machine learning approaches. NEoteRIC's implementation stratagem incorporates multiple innovations spanning from the photonic “transistor” level and extending up to the system architectural level, thus paving new, unconventional routes to neuromorphic performance enhancement. The technological cornerstone of NEoteRIC relies on the development and upscaling of a highspeed reconfigurable photonic FPGA-like circuit that will incorporate highly dense and fully reconfigurable key silicon photonic components (ring resonators, MZIs, etc.). High-speed reconfigurability will unlock the ability to restructure the photonic components and rewire inter-component connections. Through NEoteRIC the inte-

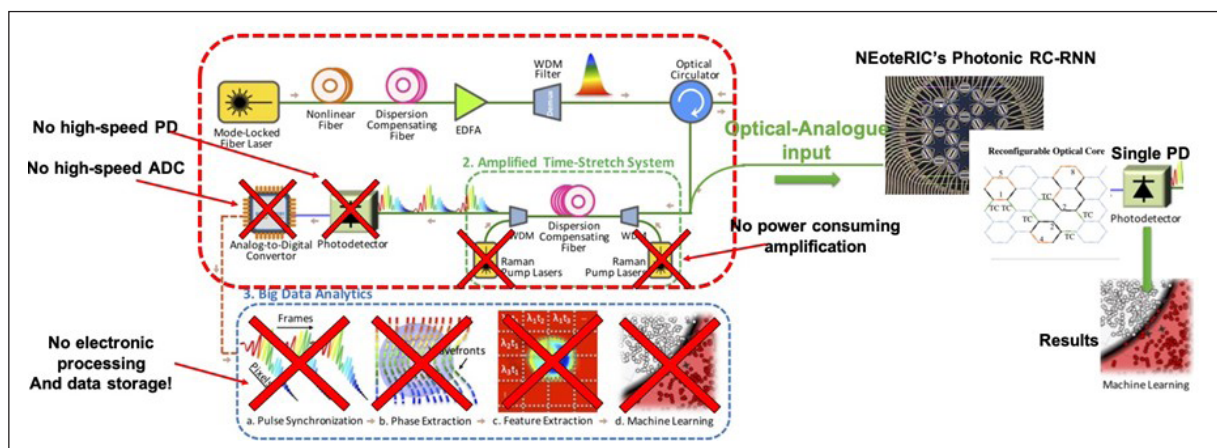
grated photonic FPGAs will be strengthened by the incorporation of novel marginal-power consuming non-volatile high-speed phase shifters that will push the boundaries of energy consumption. NEoteRIC's “unconventional” chips will be utilized as a proliferating neuromorphic computational platform that will merge the merits of photonic and electronic technology and will allow the all-optical implementation of powerful non-von Neumann architectures such as Reservoir Computing, Recurrent Neural Networks, Deep Neural Networks and Convolutional Neural Networks simultaneously by the same photonic chip. The in-project excellence will be tested through demanding high impact application such as high frame-rate image analysis and in particular single-pixel time-stretch modalities thus pushing the boundaries of state-of-the-art; exhibiting simultaneous high spatial resolution and Gframe/sec processing rate.

Name of the project: Building on the Use of Spatial Multiplexing 5G Networks Infrastructures and Showcasing Advanced technologies and Networking Capabilities (BlueSpace)

Webpage of the project:
<https://5g-ppp.eu/bluespace/>

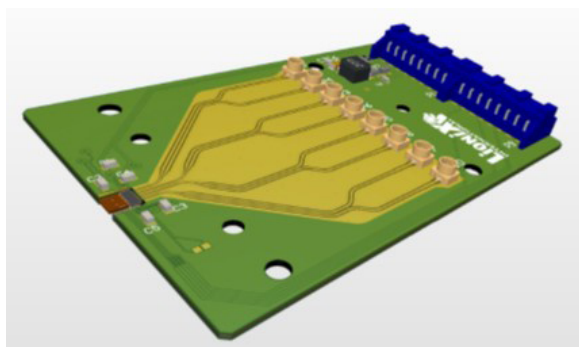
Funding entity and duration: European Union's Horizon 2020, 42 months

Summary of the project: The core concept of BlueSpace is to exploit the added value of Spatial Division Multiplexing (SDM) in the Radio Access Network (RAN) with efficient optical beamforming interface for the pragmatic Ka band wireless transmission band. Both being seamlessly integrable in next generation optical access networks infrastructures with massive beam steering capabilities and with flexible network management control. The main objectives targeted by the BlueSpace project are: to develop a truly viable and efficient path for 5G wireless communications with a 1000-fold



Conceptual depiction of STEM cytometry alongside NEoteRIC induced changes

increase in capacity, connectivity for over 1 billion users, strict latency control, and network software programming. BlueSpace targets a disruptive yet pragmatic approach for the deployment of scalable, reconfigurable and future-proof fronthaul solutions for 5G communications, offering unrivalled characteristics that include: a) increased bandwidth provision by naturally enabling and supporting massive multiple Input Multiple Output (MIMO) transmission starting/ending in the fiber medium by enabling space diversity in the RF domain by supporting RF beam steering in the photonic domain, b) compact infrastructure that is reconfigurable by means of Software Defined (SDN) and Network Function Virtualization (NFV) paradigms and c) the possibility of providing full integration with other existing approaches for the implementation of access networks, such as Passive Optical Networks (PONs). This approach relies on the core concept of this project, which is the introduction of Spatial Division Multiplexing (SDM) in the fronthaul of the mobile access network.



Optical beamformer developed by BlueSpace
H2020 project

Name of the project: European Network for High Performance Integrated Microwave Photonics (EUMWP)

Webpage of the project: <https://euimwp.eu/>

Funding entity and duration: European Union's Horizon 2020, 41 months

Summary of the project: This Action aims to shape and bring the relevant integrated Microwave Photonics community, supporting coordination and networking actions to consolidate this new ecosystem. EUMWP is providing exchange of knowledge, ideas and, equally important, delivering a portfolio of technological benchmarkings to establish performance indicators and define future technological requirements in high-performance scenarios, mainly radar, 5G, Internet of Things, automotive and aerospace technologies. Over 40 partners from academia, industry and public organizations are founding members of the Action.

Name of the project: European Network on Future Generation Optical Wireless Communication Technologies (NEWFOCUS)

Webpage of the project:

<https://www.cost.eu/actions/CA19111>

Funding entity and duration: European Union's Horizon 2020, 41 months

Summary of the project: The design of future wireless communication networks that cope with the ever-growing mobile data traffic as well as support varied and sophisticated services and applications in vertical sectors with a low environmental impact is recognized as a major technical challenge that European engineers face today. The COST Action NEWFOCUS will propose truly radical solutions with the potential to impact the design of future wireless networks. Particularly, NEWFOCUS aims to establish optical wireless communications (OWC) as an efficient technology that can satisfy the demanding requirements of backhaul and access network levels in beyond 5G networks. This also includes the use of hybrid links that associate OWC with radiofrequency or wired/fiber-based technologies.

Towards this vision, NEWFOCUS will carry out a comprehensive research programme under two major pillars. The first pillar is on the development of OWC-based solutions capable of delivering ubiquitous, ultra-high-speed, low-power consumption, highly secure, and low-cost wireless access in diverse application scenarios. The developed solutions will in particular support Internet-of-Things (IoT) for smart environments with applications in vertical sectors. The second pillar concerns the development of flexible and efficient backhaul/fronthaul OWC links with low latency and compatible with access traffic growth.

In addition to scientific and technological advances, NEWFOCUS will serve as a global networking platform through capacity building of all relevant stakeholders including universities, research institutions, major industry players, small medium enterprises, governmental bodies and non-governmental organisations. Within this rich consortium, NEWFOCUS will train experts to accompany related European industries for the standardisation and commercialisation of the OWC technology.

Name of the project: Fibre Nervous Sensing Systems (FINESSE)

Webpage of the project: <http://itn-finesse.eu/>

Funding entity and duration: European Union's Horizon 2020, 48 months

Summary of the project: FINESSE (Fibre Nervous Sensing SystEms) is a collaborative research and training network, gathering together 26 European universities, research centers and indus-

trial partners with complementary expertise with the ultimate vision of a widespread implementation of distributed optical fibre sensor systems for a safer society.

The objective behind FINESSE (Fibre Nervous Sensing SystEms) is to mimic the nervous system of living bodies by turning man-made and natural structures into objects that are sensitive to external stimuli owing to advanced distributed fibre-optic sensor technology, with the objective to either give early warning in case of possible danger or occurrence of damage, or to optimise the operation of the structure to allow for a sustainable use of natural resources and assets. Enabling such functionalities will greatly contribute to realizing a safe, secure and energy efficient Europe, which is an identified societal concern.

Name of the project: Devices in Multicore/modE Novel Selected fibres for Optical Networks and sensor applications (DIMENSION)

Webpage of the project:

Funding entity and duration: Ministerio de Ciencia e Innovación and the European Regional Development Fund (ERDF), 36 months

Summary of the project: The DIMENSION Project aims to develop novel devices and techniques based on multicore/multimode fibres and in-fibre gratings that can lead to systems with unprecedented performance, in order to meet the requirements of the ever increasing need of bandwidth and cost per bit reduction in optical networks and also for sensor applications. In doing so it addresses several challenges. In particular, it mainly targets the challenge Digital economy and society. Optical networks based on SDM techniques and advanced remote sensor systems are instrumental to sustain the concept of internet of things, which lies at the heart of future internet. Specifically, radio-over-fiber transmission and SDM fibres are a key enabler of 5G mobile systems and networks but also of the concept of smart cities where citizens are permanently connected to services via wireless devices. In this last context, the advanced metrology techniques combining fiber optics and wireless systems are also fundamental as they can provide a low-cost solution to continuous monitoring of civil structures and environmental monitoring. The main technical objectives are: to develop concepts and benefits of space multiplexing for processing of analog and digital photonic signals and to support networking and new technologies for 5G front-hauling; to show that SDM technology can bring benefits to traditional applications that can take advantage for the inherent parallelism SDM devices/fibres like in selected microwave applications including filtering, optical beamforming, generation of train of pulses and arbitrary waveform generation

to design and fabricate novel sensors using SDM technologies and to widen the range of application of optical fibre sensors; to implement novel fibre based spectroscopic measurement techniques for the characterization of sources that emit very weak signals.

Name of the project: Broadband HYbrid Silicon Nitride Photonic Integrated CircuitS (BHYSINPICS)

Webpage of the project:

Funding entity and duration: Ministerio de Ciencia e Innovación, 36 months

Summary of the project: Integrated photonics has experienced exponential growth in the last 10 years, thanks to the research, development and commercial exploitation of generic technologies, which allow complex photonic systems into a single micro-chip. These technologies cover different parts of the spectrum, depending on the properties of the materials used in manufacturing, for different applications, in the visible (VIS), near (NIR) and mid infrared (MIR) wavelength ranges. However, there is no broadband technology platform, that allows light guiding over VIS, NIR and MIR. Even if it existed, the problem of hybridization with other active technologies, to enable the incorporation of sources and light detectors, would not be solved either. Together with the two previous aspects, the increasing complexity of photonic integrated circuits (PICs) requires advanced characterization methods, beyond those traditionally used. This project aims at researching and developing technologies, manufacturing and design processes, alongside the associated characterization methods, to address these three challenges: i) a passive photonic integration platform covering VIS, NIR and MIR, ii) advanced characterization methods and iii) micro-fabrication processes for hybridization with active technologies.

Name of the project: Energy eEfficient hybrid Optical networks for indoor Communications And Lighting (FOCAL)

Webpage of the project:

Funding entity and duration: Ministerio de Ciencia e Innovación, 36 months

Summary of the project: The Project consists on the definition of the architecture of an indoor hybrid wired and wireless optical network based on VLC communications (Fi2VLC) to provide coverage and 5G services in residences and offices. Full characterization of hybrid POF and VLC links with improved capacity and flexibility, also including different multiplexing techniques will be addressed. Electro-optical transceivers based on low cost commercially available LEDs will be designed to transmit digital modulation

formats such as OFDM, QPSK, CAP, 16QAM, etc. and adaptive modulations to adjust the transmission capacity to the actual demand in a multiuser scenario. The Project also includes the experimental characterization of the networks (QoS, BER, SNR) using the developed technologies (multiplexing, adaptive modulations and multiuser access) for service transmission and the implementation of software-defined Fi2VLC networks for energy efficient operation. Finally, the techno-economical evaluation of the implemented solutions will assess their viability in short term 5G networks.

Name of the project: UPVFAB Technopole

Webpage of the project: <https://www.fab.upv.es/>

Funding entity and duration: Generalitat Valenciana and the European Regional Development Fund (ERDF), 24 months

Summary of the project: It's an infrastructure acquisition project to upgrade and retrofit. The new action continues the previous infrastructure project ("Micro-manufacturing for photonics, electronics and chemistry" GVA/IDIFEDER/2018/042, 2018-2020). The infrastructure is at the class 100/10000 (ISO 5 / 7) 500 m² micro-fabrication pilot line / clean room (www.fab.upv.es). More specifically, it is intended to complement the installation with the following equipment:

1) (Deposition) Sputter for cylindrical samples, 2) (Attack) Wet banks and attack tanks for samples and wafers up to 6 inches, 3) (Attack) Extraction and neutralization systems for wet banks and attack tanks, 4) (Metrology) FTIR equipment with microscope for sample analysis. 5) (Post-process) Microscopic transfer equipment by priming chips from 2-4 inches wafers to 6 inches wafers. The general objective is to develop new technological processes in the work areas of the proposing groups (ITEAM, ITQ, CI2B), specifically: I) integrated photonics, II) integrated catalytic membranes and III) electro-chemical devices.



UPVFAB Technopole facilities



mmWave Vector Network Analyser available at PRL laboratory thanks to the GVA and the ERDF funding

Name of the project: Advanced Instrumentation for World Class Microwave Photonics Research (IDIFEDER/2018/031)

Webpage of the project:

<https://www.prl.upv.es/services/advancedinstrumentation/>

Funding entity and duration: Generalitat Valenciana and the European Regional Development Fund (ERDF), 36 months

Summary of the project: The Photonics Research Labs (PRL) has thoroughly enlarged and improved through this project the equipment and instrumentation available in its facilities due to the procurement of a last generation infrastructure for i) 5G systems analysis and characterization, ii) comprehensive vector analysis of the radiofrequency response of optical devices, techniques and means of transmission used in MWP and modulated up to millimeter bands, iii) the phase characterization of the frequency response of different optical components such as integrated chips and short distance optical fiber devices, iv) the recoating of the optical fiber devices built by the Photonics Research labs, mainly based on cavities made by Bragg devices inscribed into the core. As a result, the PRL has consolidated its world reference position in the field of Microwave Photonics, which will be still strengthened and complemented by the specific objectives pursued by the ERDF infrastructure project "Instrumentation for World Class Microwave And Programmable Photonics Research" (IDIFEDER/2020/032) during the next two years.

2.- RESEARCH RESULTS

2.1.- FEATURED PUBLICATIONS

Title, Authors, Name of the publication, pages, year: "High-Capacity 5G Fronthaul Networks Based on Optical Space Division Multiplexing", S. Rommel, D. Perez-Galacho, J. M. Fabrega, R. Muñoz, S. Sales and I. Tafur Monroy, *IEEE Transactions on Broadcasting* 65 (2), pp. 434-443, 2019

Brief summary of the paper: This paper discusses the introduction of SDM with multi-core fibers in the fronthaul network as suggested by the blueSpace project, regarding both digitized and analog radio-over-fiber fronthaul transport as well as the introduction of optical beamforming for high-capacity millimeter-wave radio access. Analog and digitized radio-over-fiber are discussed in a scenario featuring parallel fronthaul for different radio access technologies, showcasing their differences and potential when combined with SDM.

Title, Authors, Name of the publication, pages, year: "Multi-Core Optical Fibers with Bragg Gratings as Shape Sensor for Flexible Medical Instruments", F. Khan, A. Denasi, D. Barrera, J. Madrigal, S. Sales and S. Misra, *IEEE Sensors Journal* 19 (14), pp. 5878-5884, 2019.

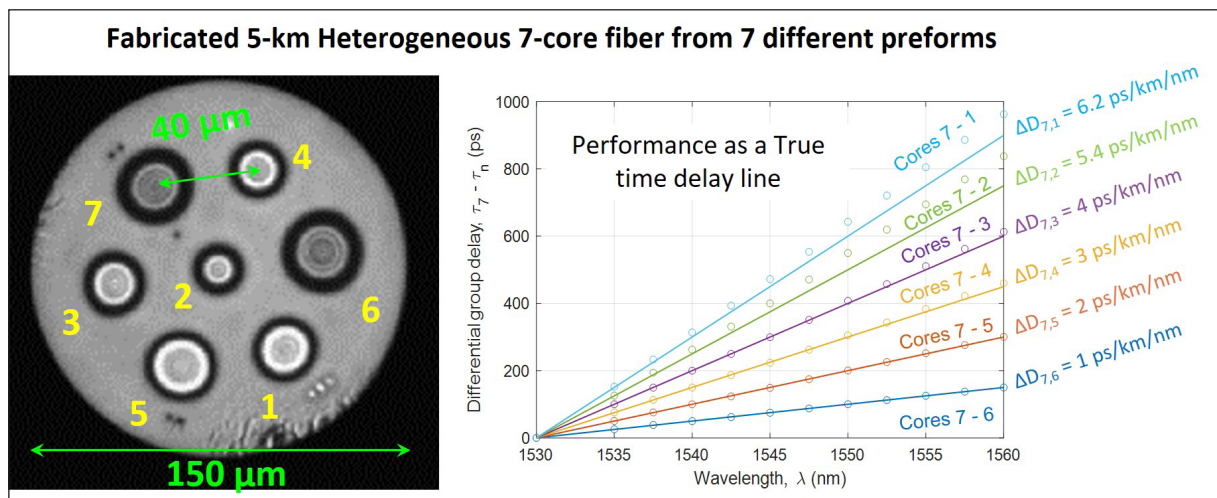
Brief summary of the paper: This paper presents a technique to reconstruct the shape of a flexible instrument in three-dimensional Euclidean space based on data from fiber Bragg gratings (FBGs) that are inscribed in multi-core fibers. Its main contributions are the application of several multi-core fibers with FBGs as shape sensor for medical instruments and a thorough presentation of the reconstruction technique.

Title, Authors, Name of the publication, pages, year: "Open-Access Silicon Photonics Platforms in Europe", A. Rahim, P. Muñoz, D. Domenech et al., *IEEE Journal of Selected Topics in Quantum Electronics* 25 (5), pp. 1-18, 2019

Brief summary of the paper: Fabless enterprises rely on the open-access silicon photonics-based technologies for their product development. In the last decade, a diverse set of open-access technologies with medium and high technology readiness levels have emerged. This paper provides a review of the open-access silicon and silicon nitride photonic IC technologies offered by the pilot lines of European research institutes and companies. The paper also highlights upcoming features of these platforms and discusses how they address the long-term market needs.

Title, Authors, Name of the publication, pages, year: "Si₃N₄ photonic integration platform at 1 μ m for optical interconnects", X. Hu, M. Girardi, Z. Ye, P. Muñoz, A. Larsson, and V. Torres-Company, *Optics Express* 28 (9), pp. 13019-13031, 2020.

Brief summary of the paper: In this work, we show the first passive Si₃N₄ platform in the 1- μ m band (1030-1075 nm) with an equivalent loss < 0.3 dB/cm, which is compatible with the system requirements of high-capacity interconnects. The waveguide structure is optimized to achieve simultaneously single-mode operation and low bending radius, and we demonstrate a wide range of high-performance building blocks, including arrayed waveguide gratings, Mach-Zehnder interferometers, splitters and low-loss fiber interfaces.



Viewgraph of the fabricated heterogeneous 7-core multicore fiber and corresponding performance as a True Time Delay Line, European Project InnoSpace.

Title, Authors, Name of the publication, pages, year: “True-Time Delay Line based on dispersion-flattened 19-core Photonic Crystal Fiber”, S. Shaheen, I. Gris Sánchez and I. Gasulla, *IEEE Journal of Lightwave Technology*, early access, 2020.

Brief summary of the paper: A novel design of a tunable True-Time delay line based on a multicore Photonic Crystal Fiber is proposed. It enables simultaneous transport and processing of microwave photonic signals over a broad radiofrequency processing range. Independent group delay behavior in 19 different cores characterized by a constant differential group delay between cores provides TTDL operation on 19 signal samples. The 19-core PCF structure allows tailoring the chromatic dispersion range between 1.5 and 31.2 ps/nm·km, which translates into a very broad microwave signal processing range from a few up to tens of GHz. This work advances the state-of-the-art of a TTDL based on SDM technology by increasing the number of samples and microwave processing range.

Title, Authors, Name of the publication, pages, year: “Demonstration of distributed radiofrequency signal processing on heterogeneous multicore fibres”, S. García, M. Ureña and I. Gasulla, 45th European Conference on Optical Communication (ECOC 2019), Dublin, Ireland, 2019.

Brief summary of the paper: We experimentally demonstrate for the first-time to our knowledge distributed radiofrequency signal processing performed by a heterogeneous multicore fibre link. A trench-assisted 7-core fibre, where each core presents a different chromatic dispersion behaviour, is custom-engineered to operate as a 2D sampled true time delay line.

Title, Authors, Name of the publication, pages, year: “M-QAM transmission over hybrid microwave photonic links at the K-band”, D. Nguyen, J. Bohata, J. Spacil, D. Dousek, M. Komanec, S. Zvanovec, Z. Ghassemlooy, B. Ortega, *Optics Express* 27 (23), pp. 33745-33756, 2019.

Brief summary of the paper: Two experimental configurations of a hybrid K-band (25 GHz) microwave photonic link (MPL) are investigated for seamless broadband wireless access networks. Experimental configurations consist of optical fiber, free-space optics (FSO) and radio frequency (RF) wireless channels.

Title, Authors, Name of the publication, pages, year: “Seamless 25 GHz transmission of LTE 4/16/64-QAM signals over hybrid SMF/FSO and wireless link”, D. Nguyen, J. Bohata, M. Komanec, S. Zvanovec, B. Ortega, Z. Ghassemlooy, *Journal*

of Lightwave Technology 37 (24), pp. 6040-6047, 2019.

Brief summary of the paper: The authors propose and experimentally demonstrate a photonics-assisted converged radio-over-fiber (RoF), radio-over-free-space optics (RoFSO) and millimeter-wave (MMW) wireless transmission system for use in broadband wireless access (BWA) networks.

Title, Authors, Name of the publication, pages, year: “Programmable Integrated Photonics”, J. Capmany and D. Pérez, Oxford University Press, 2020.

Brief summary of the paper: This book provides the first comprehensive, up-to-date and self-contained introduction to the emergent field of Programmable Integrated Photonics (PIP). It covers both theoretical and practical aspects, ranging from basic technologies and the building of photonic component blocks, to design alternatives and principles of complex programmable photonic circuits, their limiting factors, techniques for characterization and performance monitoring/control, and their salient applications both in the classical as well as in the quantum information fields.

Title, Authors, Name of the publication, pages, year: “Programmable Photonic Circuits”, W. Bogaerts, D. Pérez, J. Capmany et al., *Nature*, 586, pp. 207–216, 2020.

Brief summary of the paper: This paper covers possible applications of this emerging technology in linear matrix operations, quantum information processing and microwave photonics, and examine how these generic chips can accelerate the development of future photonic circuits by providing a higher-level platform for prototyping novel optical functionalities without the need for custom chip fabrication.

2.2.- PATENTS

Capmany Francoy, José; Pérez-López, Daniel; Dasmahapatra, Prometheus. “Methods, Systems, And Apparatus for Multipurpose Multicore Programmable Photonic Processor”, P202030736. 16 July 2020.

Capmany Francoy, José; Pérez-López, Daniel. “Dispositivo Fotónico Integrado de Matriz Cuántica de Puertas Fotónicas Programables en Campo, Dispositivo Cuántico y Circuitos Programables”, P201931123. 18 December 2019.

Capmany Francoy, José; Pérez-López, Daniel; Dasmahapatra, Prometheus. “Photonic Chip Equally-Oriented / Parallel Waveguide Mesh Arrangements and Programmable Circuits”, P201930410. 09 May 2019.



iPronics team received by UPV rector José Mora

2.3.- AWARDS.

iPRONICS, ITEAM-PRL deep-Tech company, among the pioneering spin-offs worldwide in 2020

iPronics Programmable Photonics, a spinoff from the Institute of Telecommunications and Multimedia Applications (ITEAM), has been selected as one of the spinoff companies to watch in the frame of the first edition of the Spinoff Prize, sponsored by Nature magazine and the German multinational Merck.

The company intends to make the computational power of photonics commercially affordable. Its processors share a common hardware platform that is reconfigurable by software. This cost-effective solution enables the same hardware to be applied to limitless commercial applications.

iPronics' approach combines the best of both worlds and is called to radically change the way in which information, communication and processing systems have been conceived until now, because it seeks to cooperate with electronic systems and not compete with them. On top of this it adds a disruptive nature by breaking the barriers of access and use of complex photonic chips. In words of its co-

founders, in a few years this product will be ready to be used by anyone, regardless of his/her technical background.

Nature and Merck have 44 selected spinoffs that translate original, high-quality scientific research into products and services that address market problems and are well positioned to make a positive impact on society. For *iPronics*, being on this list is a tremendous boost, even more so when the company has barely six months of existence, although the experience and professional career of the founding team comes from many years ago.

The company was founded as a spinoff of ITEAM Research Institute, Universitat Politècnica de València, in 2019 after multiple years of research. The founding team, José Capmany, Daniel Pérez López, Ivana Gasulla, Prometheus DasMahapatra, Eladio Crego, and Iñaki Berenguer, has pioneered the field of programmable photonics and developed the first general-purpose photonic processor capable of programming high-speed light signals on-chip with unprecedented flexibility.

The Spinoff Prize has been established by Nature Research in association with Merck, a leading German multinational in science and technology, to show and recognize global excellence in the commercialization of scientific research through the creation of spinoffs. Among the finalists, there are companies in sectors such as medicine, materials or digital technologies. (Source: *iPronics*)





Most distinguished Valencian woman researcher award ceremony.

Ivana Gasulla, researcher at the Photonics Research Labs, awarded as the best woman researcher in the Autonomous Community of Valencia.

Dr. **Ivana Gasulla**, researcher at the Institute of Telecommunications and Multimedia Applications (ITEAM) and a worldwide renowned scientist in the field of Microwave Photonics, was awarded the “Concepción Aleixandre” Prize as the most distinguished woman researcher in the Autonomous Community of Valencia. This acknowledgement was awarded during a ceremony in the city of Picanya last February.

The jury highlighted “her prolific career and the high impact of her research work in the design and development of new optical fibers that will increase transmission and processing capacity in fiber-wireless scenarios.”

“I am really honored to receive this scientific award, specially at a time when less and less girls and young women take up a STEM (science, technology, engineering and mathematics) career. It is our joint responsibility to encourage girls and young women by leading the way”, she said.

An extraordinary curriculum

Ivana Gasulla is a senior researcher (Ramon y Cajal Fellow) and deputy director for Dissemination and Promotion at the ITEAM

Research Institute of the Universitat Politècnica de València (UPV).

Ivana Gasulla received the M.Sc. and the Ph.D. degrees from UPV, respectively, in 2005 and 2008. Her PhD thesis, focused on broadband radio over multimode fiber transmission, was recognized with the IEEE/LEOS Graduate Student Fellowship Award.

In 2012 she was awarded a Fulbright Fellowship to carry out research on spatial division multiplexing at Stanford University. Back to ITEAM in 2014, her current research interests encompass the application of multimode and multicore fibers to Microwave Photonics systems. The results of her work have led to more than 120 international publications, highlighting contributions to Nature Communications and Nature Photonics. She is a member of the Technical Program Committee of the most prestigious conferences in the field: European Conference on Optical Communications (ECOC), Optical Fiber Communication Conference (OFC) and IEEE International Topical meeting on Microwave Photonics (MWP), among others.

In 2017, she was awarded a prestigious ERC Consolidator Grant to develop new Space-Division Multiplexing technologies for emergent fiber-wireless communications through the project InnoSpace.

MOBILE COMMUNICATIONS GROUP

HEAD OF THE GROUP RESEARCH REPORT

The Mobile Communications Group (MCG), led by Narcís Cardona, is composed of about 30 people between professors and researchers. The MCG is aimed at developing new technologies for future standards in Mobile and Wireless Communications. The current activities of MCG are focused on four areas: 5G New Radio (5G-NR), Multicast and Broadcast Services (MBMS) over 3GPP Networks, Vehicular Communications and Body Area Communications (BAN). The Mobile Communications research Group has worked on several international projects related to 5G, most notably the METIS and METIS-II projects. The group led the 5G-Xcast project and currently leads the European projects 5G-RECORDS, INGENIOUS, FUDGE-5G, and also participates in the 5G-CARMEN, 5G-SMART, 5G-TOURS, ORCA, and WAVECOMBE projects, all of them in the development of "vertical" 5G applications. Furthermore, it can be stated that the group of MCG researchers have a consolidated experience in 5G, as shown by the organization in 2019 of the 5G Global Event. In this event, some 5G end-to-end demonstrations were performed for the first time in history. In addition, the 5G Global Event brought together all European 5G projects and 5G industry associations around the world.

1.- PROJECT ACTIVITIES

1.1.- ONGOING PROJECTS

VLC-CAMPUS-5G (pilot testing field, development and demonstration of 5G mobile technologies)

VLC-CAMPUS-5G is the project to launch a 5G technology wireless communications platform on the campus of the Universitat Politècnica de València, which supports the testing of new 5G services and equipment and promotes Valencia as a 5G city. The VLC-CAMPUS-5G project is aligned with the evolution of mobile networks towards 5G, which will bring important developments and improvements not only in terms of capacity, latency, connection density, quality and user experience, but also in terms of flexibility, efficiency, scalability and openness of the networks, which will allow offering new services.

The deployment of the VLC-CAMPUS-5G testbed is based on the expansion of the current communications' infrastructures of the UPV, by the acquisition of the necessary equipment for the emission and experimental tests of 5th generation mobile services. There is currently an ultra-dense network of femtocells configured within a private operating network, a 5G network core emulator, as well as software-configured radio units and various equipment and software licenses that together configure a network 5G laboratory.
<https://vlc-campus5g.com/>

This project is co-financed by the European Union through the operational program of the European Regional Development Fund (FEDER) of the Comunitat Valenciana 2014-2020, duration (2018-2020)

Valencia 5G

Valencia 5G is a project to validate the capabilities of 5G technology in Valencia, Spain by testing 15 use cases that involve sectors of health, industry, energy, gaming, and tourism. Valencia 5G has a budget of 10,145,234 euros and involves Orange, Huawei, Arborea Intellbird, CFZ Cobots, Global Omnium Idrica, Etra Research and Development, Red Eléctrica y de Telecomunicaciones Innovación y Tecnología and Robotnik. The project aims to contribute from three approaches: support the deployment of the first 5G networks in Spain; experiment with the network management techniques; and testing the main capabilities of the technology: ultra-reliable and low-latency communications; massive machine-to-machine communications; and extremely high speed and capacity mobile broadband. The MCG of the iTEAM will be involved in 5 out of 15 uses cases, being these: (1) Robotic Remote diagnostic. (2) Fleet management: Robotics Remote control of AGVs. (3) Robotics-Remote inspection and maintenance. (4) 5G Digital Contents. (5) Massive IoT for smart meters in supplies. The use case of robotic remote diagnostic for the skin cancer diagnostic using the 5G mobile communications network, consisting of a specialist will scan the patient remotely using robotic arms that have built-in biometric sensors that capture and process the information. On the other hand, the VLC-CAMPUS-5G of the Universitat Politècnica de València, has been chosen as one of the testing scenarios.

This project has been funding by Red.es through European Regional Development Fund (FEDER), 18 months duration (July 2020 – December 2021)

AUDERE (Advanced Urban Delivery and Refuse Recovery)

AUDERE aims to design and develop an intelligent and innovative system for urban refuse collection and last mile delivery logistics. To fulfil this objective, a fleet of autonomous vehicles (autonomous mobile robots) are equipped with 5G connectivity to carry out last mile delivery and urban waste container recovery tasks. The AUDERE system will assess the technical, economic, social, and environmental viability in a range of use cases. Therefore, AUDERE will offer high-tech solutions to the growing forward and reverse logistics needs in our cities. Trials will be performed in two scenarios. The first one is the VLC-CAMPUS-5G of the Universitat Politècnica de València, which is equipped with the infrastructure of a private 5G mobile network that allows the validation of different use cases, such as logistics, automotive, industry, media, among others. In addition, among the main advantages of VLC-CAMPUS- 5G we can mention that it is a closed and controlled environment, which could be considered as a small city due to its infrastructure, commercial and sport places, banks, parks and where more than 20,000 people move daily. The second scenario is the La Pinada District, which is an eco-district, the first in Spain, that will integrate the principles of sustainable urban development, creating an attractive environment for family living, work, and enjoyment of nature. The results of this project will define new technological products that can be deployed in Smart Cities or Smart Quarters.

This project has been funded by The Valencian Innovation Agency (Agència Valenciana de la Innovació - AVI), 21 months duration (April 2020 – December 2021).

CROFT (Cloud Robotics and factories Of The FuTure)

This project addresses the research required for the development of mobile robotics in the cloud based on 5th generation mobile networks for the future IoT revolution. Low latency, high capacity demands, and a large number of mobile wireless entities connected to the Internet will require a continuous Ultra Dense Network (UDN) that is likely to use mmW bands to support future factory wireless connectivity. The connection network must be multi-hop, with connectivity nodes moving throughout the factory, even with drones, to ensure line of sight conditions for successful mmW communication. The nodes can cooperate in the transmission/reception of data in a centralized or distributed way. In addition, the design of the protocol, mainly speaking of the PHY and MAC procedures, will guarantee the minimum battery consumption of the communicating machines.

The objective of the project is to research and optimize the operation of RAN architectures for 5G standards beyond NR phase 2, and to design reliable and realistic PHY and MAC procedures adapted to this new communication model composed of mesh networks and mobile nodes. The ultimate goal is to achieve an improvement in the latency, reliability and capacity of the large number of robots, drones, droids and humans that will work together in the factory of the future. In this context, the new communication paradigm of mmW and continuous UDNs together with the use of multi-hop cellular communications play a transversal role. During the project, the performance of the systems will be evaluated, simulations, RF measurements, and experiments with a large number of devices will be performed to validate the design principles used. For this purpose, the VLC-CAMPUS-5G will be exploited. In addition, this project aims to attract the talent of women to the new job opportunities that 5G will generate.

This project has been funded by the Prometeo 2020 grant from the Generalitat Valenciana to carry out R & D & I projects for research groups of excellence, 36 months duration (01/01/2020 - 30/12/2022)

WaveComBE (Millimetre Wave Communications in Built Environments)

WaveComBE is an Industrial and Training Network dealing with the ultra-dense deployment of millimetre-wave (mmW) Small Cells (SCs) in conjunction with massive multiple-input multiple-output (MIMO) in 5G and beyond 5G (B5G) wireless networks. In WaveComBE the MCG is developing simulation tools to analyse the human body blocking at millimetre-wave band, as well as efficient planning tools to deploy future access points in bands around and above 30GHz. Besides beamforming techniques are being investigated for the physical layer of millimetre-wave mobile communications.

The UPV is in charge of coordinating this project, led by Narcís Cardona, in consortium with The University of Sheffield, University of Durham, University of Twente and companies Ranplan Wireless Network Design Ltd. and Televis Conference, Capwaves AB together with the partner organizations, Axió Infraestructuras de Telecomunicaciones S.A.U, Telenor Group and Nokia Bell Labs.

WaveComBE provides high quality interdisciplinary and cross-sector research training for a new generation of scientists. Specifically, 11 Early Stage Researchers are hired, two of them by the UPV. During the third year of the project, two training schools were held, one of them in Valencia which was attended by all ESRs and took ad-

vantage to celebrate the Project Management Committee Meeting. This last year 15 papers have been published by the ESRs.
<https://wavecombe.eu/>

This project is funded by the European Commission under the Marie Skłodowska-Curie programme. Duration: 01/10/2017 - 30/09/2021

EMOTE (ElectroMagnetic prObE for early Tumour dETection)

This is a joint collaborative project with Hospital La Fe, jointly funded by both public institutions. This project is devoted to the measurement of the dielectric properties of in vivo healthy and malignant tissues by using animal models (rats). In this way, it would be possible to evaluate whether the differences between healthy and tumor tissues found for humans are also repeated at in in-vivo conditions. During the first semester of 2020 preliminary tests in health rats were carried out. For the second semester, trials in rats with colon, ovary and prostate cancer are being performed.

This project has been funded by Ayudas para el Desarrollo de Proyectos de Innovación Coordinados entre la Universidad Politécnica de Valencia y el Hospital Universitario y Politécnico La Fe (call 2017). Duration: 01/01/2018 to 31/12/2020.

COLODEM (Sonda Colorrectal para la Detección Electromagnética de Tumores)

COLODEM project is based on the development of a tool for colorectal cancer detection based on the reported difference in the electromagnetic properties of healthy and malignant colon tissues. Such tool will consist of three main parts: a flexible probe to be integrated into the colonoscope, a software algorithm for measuring and identifying the malignant tissues, and a laboratory platform for testing. This platform will be based on the electromagnetic reproduction of a human colon with presence of malignant tissues and it will be used for both the development of the probe and the detection algorithm as well as the training of the physicians. During 2020, the activities of the project have been focused on the development of 3D synthetic gel phantoms for the laboratory platform.

This Project has been funded by Convocatoria de Ayudas a Primeros Proyectos de Investigación (PAID-06-18). Duration: 1/09/2019 to 28/02/2021

5G-TOURS (SmarT mObility, media and e-health for toURists and citizenS)

5G-TOURS vision is to improve the life in the city for the citizens and tourists, making cities more attractive to visit, more efficient in terms of mobility and safer for everybody. 5G-TOURS builds on three themes: the touristic city (Turin), the mobility efficient city (Athens), and the safe city (Rennes). iTEAM is involved in the touristic city,

where visitors of museums and outdoor attractions are provided with 5G-based applications to enhance their experience while visiting the city. This includes VR/AR applications to complement the physical visit with additional content, involving interactive tactile communications. The experience of the visitors is also enhanced with robot-assisted services, telepresence to allow for remote visits, as well as live events enabled by mobile communications such as multi-party concerts. iTEAM is the leader of the broadcast use case. www.5gtours.eu

This project has been funded by H2020, 36 months duration (June 2019 – May 2022)

5G-ROSE (5G bROadcast Software defined radio Experiment)

The 5G-ROSE project worked towards the transmission of 5G broadcast services over SFN virtualized networks, using opensource software. The project is very well aligned with the current trends in the world of 5G. On one side, the virtualisation of the 5G infrastructure, both core and RAN (Radio Access Network), allowing for different deployment architectures with maximum flexibility and scalability. On the other side, the adoption of so-called LTE-based 5G Terrestrial Broadcast mode, which is currently under standardization in 3GPP Release-16, and that will meet the requirements of broadcasters for the distribution of media content in 5G. 5G-ROSE has made use of the virtualised IRIS testbed at Trinity College Dublin. The project has used and contributed to the open source SDR LTE software suite srsLTE, offered by Software Radio Systems. The 5G-ROSE project consisted of three clearly differentiated, but related, broadcast experiments over a virtualised SDR (Software Defined Radio) access infrastructure. The first experiment was the development and testing of the first virtualized Multimedia Broadcast Multicast Service over Single Frequency Network (MBSFN) transmission. The second experiment dealt with the introduction of 5G physical layer Release (Rel)-16 specific components. The third part was about the combination of both unicast and broadcast transmissions by means of network slicing. <https://www.orca-project.eu/open-calls/3rd-open-call-for-experiments/>

This project has been funded by third Open Call for experiment of H2020 project Orchestration and Reconfiguration Control Architecture (ORCA), 6 months duration (December 2019 – May 2020)

5G-RECORDS (5G key technology enableRs for Emerging media CoNtent pRoDuction Services)

5G-RECORDS aims to explore the opportunities which new 5G technology components - these include the core network (5GC), radio access

network (RAN) and end devices - bring to the professional production of audiovisual content. The project targets the development, integration, validation and demonstration of 5G components for professional content production, as part of an overall ecosystem integrating a subset of 5G network functions. The project aims to use of 5G non-public networks (NPNs) as a way to bring these new 5G components to emerging markets and new market actors, while also addressing recent emerging remote and distributed production workflows where cloud technologies cooperate with 5G. 5G-RECORDS has considered 3 use cases to embrace some of the most challenging scenarios in the framework of professional content production: live audio production, a multi-camera wireless studio and live immersive media production. iTEAM is the coordinator of the project. www.5g-records.eu

This project has been funded by H2020, 24 months duration (September 2020 – August 2022)

FUDGE-5G (FULLY DisinteGrated private nEtworks for 5G verticals)

FUDGE-5G will make a leap forward in realizing the notion of cloud-native 5G private networks by developing a further enhanced Service-Based Architecture (eSBA) for both control plane and user plane with “decomposed” players of the ecosystem divided into: New Radio (NR) access network infrastructure provider, eSBA platform provider, mobile 5G Core (5GC) provider, vertical application orchestration provider and vertical service provider. The forward-looking FUDGE-5G architecture will also feature “all-Ethernet” 5GLAN (Local Area Network), 5G-TSN (Time- Sensitive Networking), 5G-Multicast and intelligent vertical application orchestration features. The proposed framework enables highly customized cloud-native deployment of private 5G networks. FUDGE-5G will accelerate the (inevitable) shift to a fully software-based 5G core network by offering a disintegrated environment where components, both in control and user plane, can be deployed anywhere as micro-services (i.e., edge, on premises and cloud), being agnostic to the underlying infrastructure. This softwarization exposing 5G NR HW to third parties will enable the usage of off-the-shelf commodity HW to deliver additional cost savings, faster deployments and ultimately greater adoption for private networks. iTEAM is the coordinator of the project, and the leader of the media use case. www.fudge-5g.eu

This project has been funded by H2020, 30 months duration (September 2020 – Feb. 2023)

INGENIOUS (Next-GENeration IoT sOlutions for the Universal Supply chain)

INGENIOUS will exploit some of the most innovative and emerging technologies in line with the

standardised trend, contributing to the Next-Generation IoT and proposing technical and business enablers to build a complete platform for supply chain management. iNGENIOUS embraces the 5G Infrastructure Association (5G IA) and Alliance for Internet of Things Innovation (AIOTI) vision for empowering smart manufacturing and smart mobility verticals. The iNGENIOUS network layer brings new smart 5G-based IoT functionalities, federated Multi-Access Edge Computing (MEC) nodes and smart orchestration, needed for enabling the projected real-time capable use cases of the supply chain. Security and data management are fully recognized as important features in the project. iNGENIOUS will create a holistic security architecture for next-generation IoT built on neuromorphic sensors with security governed by Artificial Intelligence (AI) algorithms and tile-based hardware architectures based on security by design and isolation by default. In the application layer, iNGENIOUS new AI mechanisms will allow more precise predictions than conventional systems. Project outcomes will be validated into 4 large-scale Proof of Concept demonstration, covering 1 factory, 2 ports, and 1 ship, encompassing 6 use cases. iTEAM is the coordinator of the project, and the leader of the media use case. www.ingenious-iot.eu

This project has been H2020, 30 months duration (October 2020 – March 2023)

5G-CARMEN (5G for Connected and Automated Road Mobility in the European union)

This project, funded by the European Commission, has progressed with relevant impact on research community, being declared the most active project on autonomous driving by the European Commission.

The “Munich-Bologna corridor”, which covers 600 km of roads across three countries (Italy, Austria and Germany), is one of the most important corridors identified by the European Union for an initiative to improve the mobility of people and goods throughout Europe. As part of the 5G-CARMEN project, 5G technologies will be deployed along selected stretches of the motorway in the border regions. <https://5gcarmen.eu/>

This project has received funding from the European Horizon 2020 Programme for research, technological development and demonstration under grant agreement n° 825012 – 5G CARMEN. Will last 36 months until November 2021.

5G-SMART (5G for smart manufacturing)

5G-SMART unlocks the value of 5G for smart manufacturing through demonstrating, validating and evaluating its potential in real manufacturing environments. 5G-SMART trials will test the most advanced 5G integrated manufacturing applications such as digital twin, industrial robotics and machine vision based remote oper-

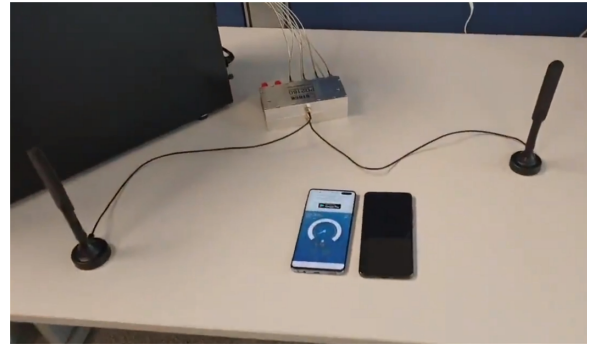
ations. 5G-SMART will undertake the first ever evaluation of ElectroMagnetic Compatibility (EMC), channel measurements and co-existence between public and private industrial networks in real manufacturing environments easing the integration of 5G. The new 5G features, developed in 5G-SMART such as time synchronisation and positioning for manufacturing use cases represent a technological leap.

5G-SMART lead by Ericsson brings together a strong consortium of partners involved in every aspect of the manufacturing ecosystem. Prof. Jose F. Monserrat, member of the iTEAM, is the Innovation Manager of the Project. This project is funded by the European Commission. <https://5gsmart.eu/>

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 857008. Will last 30 months until November 2021.

2.- RESEARCH RESULTS

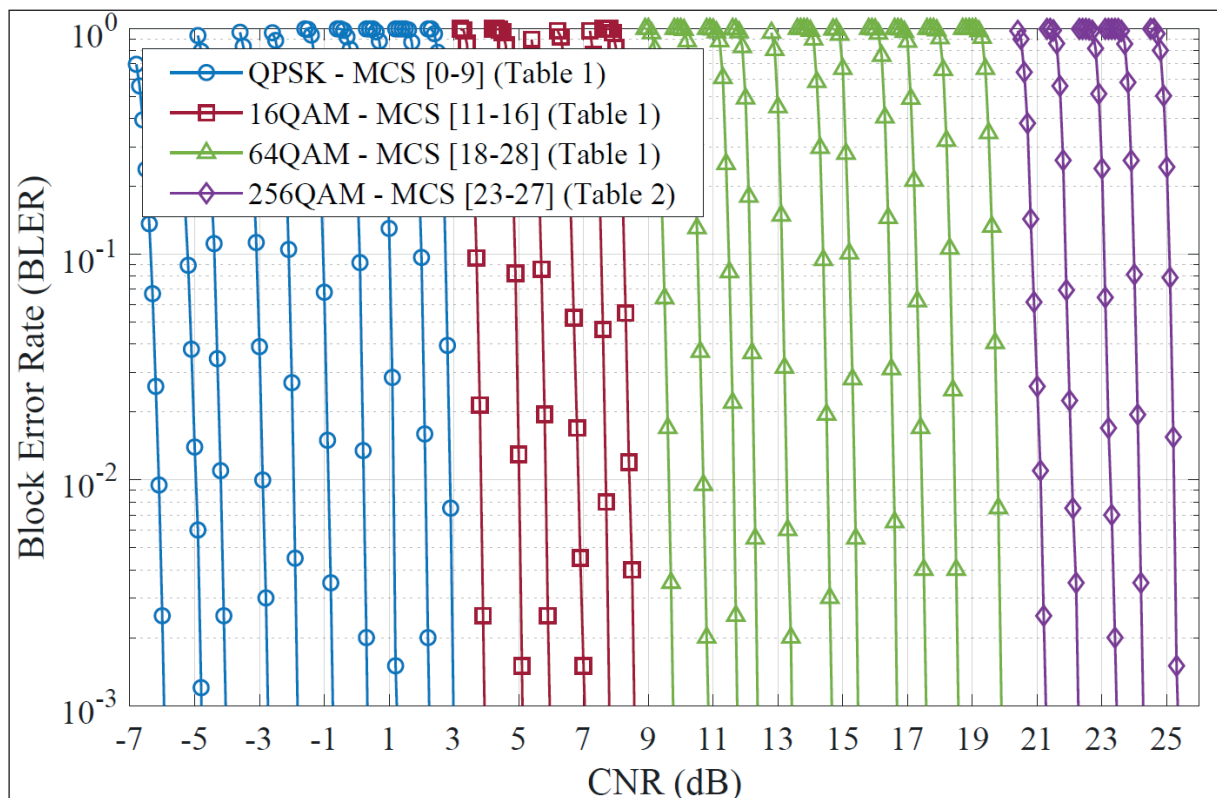
Throughout this year, the deployment of a private open source 5G network by the mobile communications group has been completed. With a bandwidth of 20 MHz, more than 300 Mbps are reached, which is an important performance milestone compared to 4G. It is also worth highlighting the participation of Prof. Jose



Mobile connected to the private 5G network based on open source "VLC-CAMPUS-5G"

F. Monserrat in the report prepared by the World Bank and entitled *Envisioning 5G Enabled Transport*. This report discusses if the development and rollout of fifth-generation (5G) mobile broadband has the potential to not only support, but accelerate these revolutionary changes as today's digital transport solutions evolve and entirely new opportunities become viable.

The Figure below shows the Simulated 5G New Radio (NR) physical layer performance for different Modulation and Coding Schemes (MCS) in AWGN channel. These results have been obtained by the Mobile Communications Group of the



Simulated 5G New Radio (NR) physical layer performance for different Modulation and Coding Schemes (MCS) in AWGN channel.

iTEAM with its own 5G NR physical layer simulator. The simulation results have been used within the 5G PPP IMT-2020 Evaluation Group to perform a detailed analysis and performance evaluation of 5G NR against a set of Key Performance Indicators (KPI), as defined in the International Mobile Telecommunications 2020 (IMT-2020) guidelines by the International Telecommunication Union (ITU), providing an independent evaluation of the Third Generation Partnership Project (3GPP) contribution. <https://5g-ppp.eu/5g-ppp-imt-2020-evaluation-group/>

2.1.- FEATURED PUBLICATIONS

"5G New Radio Evaluation Against IMT-2020 Key Performance Indicators". Manuel Fuentes, Jose Luis Carcel, Christiane Dietrich, Lang Yu, Eduardo Garro, Volker Pauli, Fotis I. Lazarakis, Ole Grøndalen, Ömer Bulakci, Jian Yu, Werner Mohr and David Gomez-Barquero. IEEE Access 8: 110880-110896 (2020), DOI: 10.1109/ACCESS.2020.3001641

This work provides a detailed analysis and performance evaluation of 5G New Radio (NR) against a set of Key Performance Indicators (KPI), as defined in the International Mobile Telecommunications 2020 (IMT-2020) guidelines, and provides an overview about the fulfillment of their associated requirements. The objective of this work is to provide an independent evaluation, complementing the Third Generation Partnership Project (3GPP) contribution. From the original group of sixteen KPIs, eleven of them have been carefully selected, paying special attention to eMBB services. Results show that 5G NR achieves all considered requirements, therefore fulfilling the specific market's needs for years to come.

"5G V2V Communication With Antenna Selection Based on Context Awareness: Signaling and Performance Study". Sandra Roger, David Martín-Sacristán, David Garcia-Roger, Jose F. Monserrat, Apostolos Kousaridas, Panagiotis Spapis and Serkan Ayaz. IEEE Transactions on Intelligent Transportation Systems, 14 pages, 09 September 2020.-DOI: 10.1109/TITS.2020.3019530

Enhanced vehicle-to-everything (eV2X) communications include ultra-high reliable fifth-generation (5G) fully-autonomous driving vehicular applications. Depending on the communication context, antenna subgroups at specialized positions may perform better. We propose a context-aware antenna selection procedure enhancing multi-antenna eV2X, extending current 5G radio resource control and radio resource management signaling. The context exchange signaling overhead is analyzed in comparison to the exchange of reference signals. Simulation results for a platooning use case show the ad-

vantages of antenna selection.

"V2X Support in 3GPP Specifications: from 4G to 5G and Beyond". David Garcia-Roger, Edgar E. González, David Martín-Sacristán and Jose F. Monserrat. IEEE Access, accepted 28 August 2020.

The connected car is gaining momentum as a research, standardization and industrial development concept. Vehicles may use many wireless connectivity options: conventional cellular technology, a base station or infrastructure element, but also directly to each other using different standards from the IEEE and 3GPP. This article reviews with detail and rigor the system architecture aspects involved in the support of vehicular communications by the 3GPP 5G standard, focusing on its most recent iteration: Release 16.

"Analysis of an open-ended coaxial method for detection of colorectal cancer obtained through colonoscopy biopsies. Preliminary results". A. Nevárez, A. Fornés-Leal, A. Parra-Escrig, C. García-Pardo, M. Frasson, N. Cardona and V. Pons-Beltrán. Endoscopy, Vol. 52. Issue S01, pp 122, April 2020.

Many technological advances have been made to optimize the detection of colorectal cancer (CRC) lesions. Research has shown that the electromagnetic properties of healthy and cancerous tissues differ in many biological samples. We aim to analyse differences in healthy and pathological colon tissues gathered from colonoscopy biopsies. Results have shown that measurements of electromagnetic properties could aid in the detection of colorectal pathologies. The variability of the results is quite large and hence the system should be improved prior to a potential implementation.

"Doppler Characterization in Ultra Wideband BAN Channels During Breathing". R. Garcia-Serna, C. Garcia-Pardo, J.M. Molina-Garcia-Pardo, L. Juan-Llácer, N. Cardona. IEEE Trans. On Antennas and Propagation, vol. 68, Issue 2, pp. 1066-1073, Nov. 2019, DOI: 10.1109/TAP.2019.2951849.

Monitoring the physical parameters from devices inside the body, using ultra wideband (UWB) technology, enables the development of high bandwidth demanding applications in real time. The relative movement of the nodes deployed in the body, due to breathing, can give rise to a frequency shifting effect, increasing the fading level in the propagation channel during transmissions. In this article, therefore, we present a study of the frequency effects on the propagation channel derived from the relative movement between two nodes of a wireless body area network (WBAN), at least one of them placed inside the human body, caused by breathing. The

study is performed on the basis of the Doppler spectrum characterization in terms of the shape fitting and frequency spread parameter derivation. Continuous wave (CW) signals have been used to cover the UWB range at four selected frequencies: 3.1, 4.8, 6, and 8.5 GHz, and a liquid phantom has been employed for emulating the dielectric properties of the high water content tissues at the considered UWB frequencies.

“UWB Channel Characterization for Wireless Capsule Endoscopy Localization”. C. Garcia-Pardo, M. Barbi, S. Pérez-Simbor, N. Cardona. 2020 IEEE International Conference on Communications Workshops, June 2020, DOI: 10.1109/ICCWorkshops49005.2020.9145270.

Wireless capsule endoscopy (WCE) is a medical device for the inspection of some parts of the gastrointestinal (GI) tract. Currently, WCE transmits to the outside low resolution video, although high quality images would be necessary for improving the detection of diseases. Ultra wideband (UWB) frequency band is a good candidate to achieve such requirement due to its large available bandwidth. Besides, the knowledge of the exact location of WCE would also help physicians to locate the suspicious tissue so diagnosis time could be shortened. Received Signal Strength (RSS) based localization is one of the simplest localization techniques. However, RSS localization requires a good knowledge of the path loss model, what is not easy for in-body communications. The objective of this paper is to provide a review of the problem of modelling the path loss for WCE in UWB as well as give implementation guidelines for WCE localization.

2.2.- PATENTS

Method for transeiving broadcast signal using combination of multiple antenna schemes with layered division multiplexing and apparatus for the same. Sung-Ik Park, LIM Bo-Mi, KWON Sun-Hyoung, Heung-Mook Kim, Jae-Hyun Seo, Jae-Young Lee, Nam-Ho Hur, JUNG Hoi-Yoon, David Gomez-Barquero and Eduardo Garro. Reference: US10454536. Entity: ETRI. Granted.

Methods, telematics server and base station for supporting vehicular communications in a cellular network. Calabuig Gaspar, Jordi; Calabuig Soler, Daniel; Monserrat del Río, Jose Francisco and Gozávez Serrano, David. Reference: US10455367. Entity: BMW AG. Granted.

Vehicle-based femtocell with prioritization of data packets on the basis of the required internet service quality. Monserrat del Río, Jose Francisco and Peter Fertl. Reference: US10277303. Entity: BMW AG. Granted

2.2.- AWARDS

Scott Helt Memorial Award to recognize the best paper published in the IEEE Transactions on Broadcasting 2019. Physical Layer Performance Evaluation of LTE-Advanced Pro Broadcast and ATSC 3.0 Systems. IEEE Trans. Broadcast. 65(3): 477-488 (2019). (Manuel Fuentes, De Mi, Hongzhi Chen, Eduardo Garro, Jose Luis Carcel, David Vargas, Belkacem Mouhouche and David Gomez-Barquero)

Extraordinary Doctoral Thesis Award of the Social Council of the UPV. Advanced Layered Division Multiplexing Technologies for Next-Gen Broadcast. (Eduardo Garro Crevillén)

Dielectric Characterization of Biological Tissues for Medical Applications

Author: Alejandro Fornés Leal

Supervisor: Dr. Narcís Cardona and Dr. Concepción García Pardo

Defended on October, 28, 2019



Nowadays, a careful knowledge of the electromagnetic properties of biological tissues is required for developing a great number of applications. The development of wireless medical devices, the design of in-body and on-body antennas, specific absorption rate evaluations, cancer treatment techniques such as hyperthermia and detection techniques like medical imaging are some examples of applications that rely on these data.

Since cancer causes modifications on the biological structure of cells that can lead in turn to changes in the electromagnetic properties of the tissues, it is possible to develop novel detection applications taking advantage of it. One potential target is colorectal cancer (CRC), as suspicious tissues can be accessed quite easily through colonoscopy procedures. This kind of cancer is one of the most spread kinds, being responsible of about 1 out of 10 new cancer cases and deaths. There are several risk factors currently related to the apprising of this cancer, although in essence the higher the age of the population, the higher the incidence of CRC.

Screening programs are key for detecting and diagnosing cancer: if found at early stages, the probability of survival increases greatly, and the cost of the treatment can be reduced as well. One of the major objectives of this thesis is proposing applications for detecting CRC that aid in the colonoscopy procedures by making use of the differences in electromagnetic properties. Aside from enhancement in the diagnosis of CRC, improving the colonoscopy procedure can lead to collateral benefits like a lowering of the burden of anatomical pathology unit.

With the aim at demonstrating the feasibility and the potential future development of these applications, in the framework of this thesis the dielectric properties of healthy, cancerous and pathological human colon tissues were measured and compared in order to find electromagnetic differences. Measurements were carried out by means of an open-ended coaxial system. Its principle of operation has been revisited with the aim at maximizing

the accuracy of the method, and the calibration procedure has been optimized serving the same purpose. Two main sources of colon tissue have been analyzed: samples from colonoscopy biopsies and samples from surgery resections. Given the variability that can appear among subjects, the electromagnetic properties of suspicious tissues from a particular patient have to be always compared with those of his healthy ones, not evaluated independently. Significant differences between the dielectric properties of healthy and malignant tissues were found for both sources, which can be exploited to develop novel CRC diagnostic applications.

The second major objective of this thesis involved the development of a new database of electromagnetic properties of biological tissues obtained at *in vivo* conditions. Nowadays, the available collections are limited either in the number of tissues or the measured frequencies, and hence researchers have to make use of more complete databases but that were performed *ex vivo*. The drawback of using these collections is that results can be compromised by factors such as lack of blood perfusion and tissue dehydration. This new database can facilitate the design of applications that needs of a careful knowledge of these properties.





Metallic lens antenna design using the Theory of Characteristic Modes

Author: Daniel Antonio Santillán Haro

Supervisor: Dr. Miguel Ferrando Bataller and Eva Antonino Daviu

Defended on March 3, 2020

In recent years, the worldwide data traffic is increasing significantly. Consequently, the new telecommunications systems seek to increase the data transmission rate with a wide coverage area. To cope with the current demand, the new communications systems move to new frequency bands of the radio spectrum, especially in the range of millimetre waves, because of the greater bandwidth available and less interference, what allows considerable size reduction of the antennas.

In these new systems, satellites that generate multiple beams are used with a frequency and polarization reuse scheme, increasing the capacity and the number of users. Moreover, to facilitate new user demands, the future telecommunications systems require the integration of advanced multimedia services through heterogeneous networks, such as fixed terrestrial and wireless networks.

To cope with these challenges, lens antennas and their variants are promising solutions.

Lenses have interesting properties because they have generally low losses and great directivity, which are the basic requirements that antennas must satisfy for these new communications systems.

The aim of this thesis has been to propose the use of the Theory of Characteristic Modes to facilitate the design, optimization, and analysis of metallic lenses with high gain in a large bandwidth, achieving a compact size for the structure.

The analysis with the Theory of Characteristic Modes has been used as a starting point to evaluate the modal behaviour and provide a physical insight of the radiation characteristics of the metallic structure in a certain frequency range. In this work, a study of the characteristic modes of the main regular geometric objects with sym-

metry of revolution was carried out to investigate its potential to be employed in the design of the metallic lenses.

Specifically, the modal significance and characteristic angle was investigated, along with the contribution of each mode to the total radiated power when illuminating the conducting body by a plane wave.

Using the information considered by the eigenvalues, the shape and size of the metallic structure was optimized and the optimal feeding was determined, which allowed to excite the desired mode in the structure. Then, an alternative method was proposed to calculate the focal point of the metallic structure.





Furthermore, in this thesis we have studied the most important lens feeders that have been developed in recent years, and two practical feeders with low cross polarization level have been proposed to operate in microwave and millimeter-wave frequencies.

When studying the lenses, we have begun to compare and describe the techniques most used in the design of these structures. Then, the Theory of Characteristic Modes has been applied to the metallic lenses design. First, the modal currents have been analysed in various metallic structures, and then this information has been used to design low profile lenses. The same approach has been then applied to antennas with single-layer structures, which have larger physical dimensions. Subsequently, a two-layer metallic lens has been studied and designed, and various combinations of the metallic structures have been analysed to achieve greater directivity.

In addition, a three-layer metallic lens and a single-layer antenna with double feeder have been designed. Finally, a lens has been proposed for a dual-polarization base station, with the possibility of obtaining up to four orthogonal radiation modes.

The last chapter of this thesis presents the prototypes and the performance of the following antennas: a single-layer lens formed by a central circular metallic ring surrounded by a set of eight metallic rings, an antenna formed by two metallic rings of different diameter distributed in two layers, a new low-profile metallic lens antenna formed by twelve metallic rings distributed in a single layer and arranged along a ring, and a low-profile lens antenna formed by two metallic rings with strips short-circuiting both rings.

In this part, the main measurements of gain, efficiency and cross polarization have been presented for the aforementioned lenses. The designs have been verified, obtaining good results in a wide bandwidth, thus validating the proposed technique.



Optical Multicore Fiber Shape Sensors. A numerical and experimental performance assessment

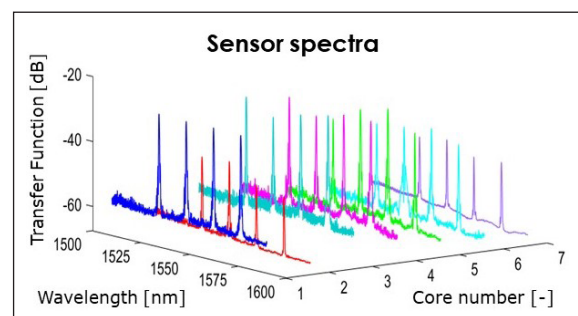
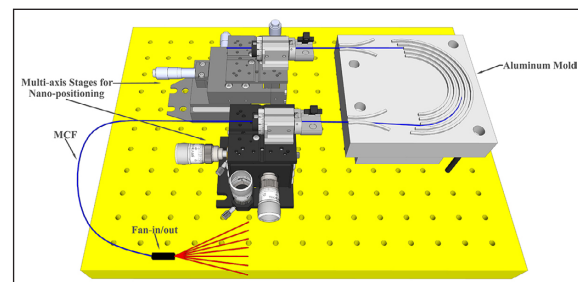
Author: Ignazio Floris

Supervisor: Dr. José Miguel Adam and Pedro Antonio Calderón García

Defended on June 25, 2020

Structural Health Monitoring (SHM) is a discipline that quantitatively assesses the integrity and performance of infrastructures, relying on sensors, and support the development of efficient Maintenance and Rehabilitation (M&R) plans. Optical Multicore Fiber (MCF) Shape Sensors offer an innovative alternative to traditional methods and enable the reconstruction of the deformed shape of structures directly and in real-time, with no need of computation models or visual contact and exploiting all the advantages of Optical Fiber Sensors (OFS) technology. Despite the intense research efforts centered on this topic by research groups worldwide, a comprehensive investigation on the parameters that influence the performance of these sensors has not been conducted yet. The first part of the thesis presents a numerical study that examines the effects of strain measurement accuracy and core position errors on the performance of optical multicore fiber shape sensors in sensing three-dimensional curvature, which is at the basis of shape reconstruction. The analysis reproduces the strain measurement process using Monte Carlo Method (MCM) and identifies several parameters which play a key role in the phenomenon, including core spacing (distance between outer cores and sensor axis), number of cores and curvature measured. Finally, a set of predictive models were calibrated, by fitting the results of the simulations, to predict the sensors performance. Afterward, an experimental study is proposed to evaluate the performance of optical multicore fiber in sensing shape, with particular focus on the influence of strain sensors length. Two shape sensors were fabricated, by inscribing long (8.0 mm) and short (1.5 mm) Fiber Bragg Gratings (FBG) into the cores of a multicore seven-core fiber. Thus, the performance of the two sensors was assessed and compared, at all the necessary phases for shape reconstruction: strain sensing, curvature calculation and shape reconstruction. To conclude, an innovative approach, based on the Saint-Venant's Torsion Theory, is presented to determine the twisting of multicore fiber and to compensate the errors due to twisting during shape reconstruction. The efficiency of the theoretical approach was then corroborated

performing a series of twisting tests on a shape sensor, fabricated by inscribing FBGs sensors into an optical spun multicore seven-core fiber. The investigation of the mechanical behavior of multicore optical shape sensors has synergically involved diverse disciplines: Solid Mechanics, Photonics, Statistics and Data Analysis. Such multidisciplinary research has arisen from the prolific cooperation between the Institutes of the Institute of Science and Technology of Concrete (ICITECH) and the Institute of Telecommunications and Multimedia Applications (ITEAM) - Photonics Research Labs (PRL) - of Universitat Politècnica de València (UPV), in addition to valuable collaboration with other members of the European ITN-FINESSE project, to which this work belongs. This research work aims to enhance the performance optical multicore fiber shape sensors and support the development of new sensor geometries, with great potential for structural health monitoring applications.



Location and Tracking for UWB In-Body Communications in Medical Applications

Author: Martina Barbi

Supervisor: Prof. Narcís Cardona Marcet and Dr. C. Garcia Pardo

Defended on November 28, 2019

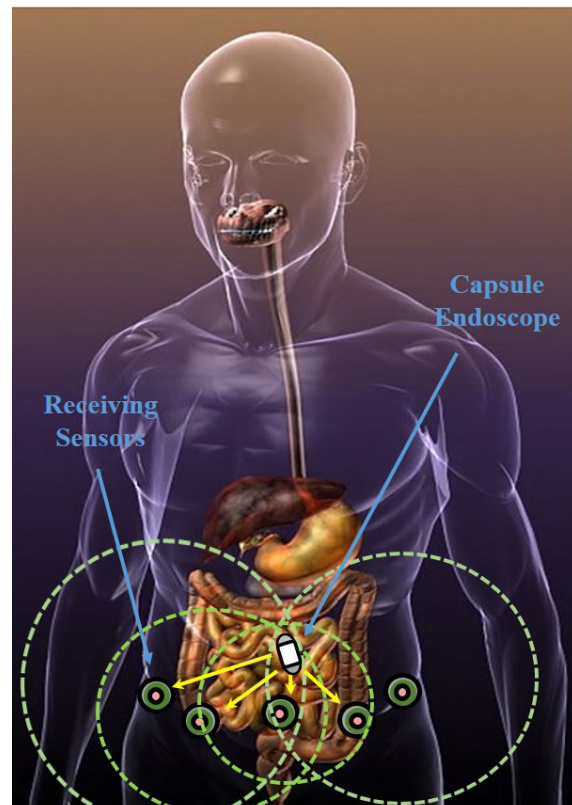


Wireless Capsule Endoscopy (WCE) is a remarkable and attractive technology adopted in the biomedical sector several years ago. It provides a non-invasive wireless imaging technology for the entire gastrointestinal (GI) tract. WCE allows specialists to recognize and diagnose diseases affecting the whole GI tract. Although physicians can receive clear pictures of abnormalities in the GI tract, they have no information about their exact location. Precise localization of the detected disorders is crucial for the subsequent removal procedure by surgery.

Currently, the frequency band allocated for capsule endoscopy applications is the MICS band (402-405 MHz). This band offers data rate up to 500 kbps, which is insufficient to transmit high quality images. Recently, Ultrawideband (UWB) technology has been attracting attention as potential candidate for next-generation WCE systems. The advantages of UWB include simple transceiver architectures enabling low power consumption, low interference to other systems and wide bandwidth resulting in communications at higher data rate.

In this dissertation, performance of WCE localization techniques based on Radio Frequency (RF) information are investigated through software simulations, experimental laboratory measurements involving homogeneous and heterogeneous phantom models and *in vivo* experiments which constitute the most realistic testing scenario. Ultra-Wideband technology (3.1-10.6 GHz) is considered as communication interface in Wireless Capsule Endoscopy. In such scenario, the wireless transmitter is located in the gastrointestinal track while one or more wireless receivers are located over the surface of the body. Received Signal Strength (RSS)-based approach is mainly explored due to its imple-

mentation simplicity and less sensitivity to bandwidth limitations. Impact of the position and the number of selected receivers on the localization accuracy is analyzed. Finally, a graphical user interface (GUI) is developed to visualize the three-dimensional (3D) localization results obtained through *in vivo* measurements.





Optimization and improvements in spatial sound reproduction systems through perceptual considerations

Author: Pablo Gutiérrez Parera

Supervisor: Dr. José Javier López Monfort

Defended on April 3rd, 2020

The reproduction of the spatial properties of sound is an increasingly important concern in many emerging immersive applications. Whether it is the reproduction of audiovisual content in home environments or in cinemas, immersive video conferencing systems or virtual or augmented reality systems, spatial sound is crucial for a realistic sense of immersion. Hearing, beyond the physics of sound, is a perceptual phenomenon influenced by cognitive processes. The objective of this thesis is to contribute with new methods and knowledge to the optimization and simplification of spatial sound systems, from a perceptual approach to the hearing experience. This dissertation deals in a first part with some particular aspects related to the binaural spatial reproduction of sound, such as listening with headphones and the customization of the Head-Related Transfer Function (HRTF). A study has been carried out on the influence of headphones on the perception of spatial impression and quality, with particular attention to the effects of equalization and subsequent non-linear distortion. With regard to the individualization of the HRTF a complete implementation of a HRTF measurement system is presented, and a new method for the measurement of HRTF in non-anechoic conditions is introduced. In addition, two different and complementary experiments have been carried out resulting in two tools that can be used in HRTF individualization processes, a parametric model of the HRTF magnitude and an Interaural Time Difference (ITD) scaling adjustment. In a second part concerning loudspeaker reproduction, different techniques such as Wave Field Synthesis (WFS) or amplitude panning have been evaluated. With perceptual experiments it has been studied the capacity of these systems to produce a sensation of distance, and the spatial

acuity with which we can perceive the sound sources if they are spectrally split and reproduced in different positions. The contributions of this research are intended to make these technologies more accessible to the general public, given the demand for audiovisual experiences and devices with increasing immersion.



New spatial audio and HRTF measurement facility built at ITEAM

Distributed radiofrequency signal processing based on space-division multiplexing fibers

Author: Sergi García Cortijo

Supervisors: Dr. Ivana Gasulla Mestre and Dr. J. Capmany Francoy

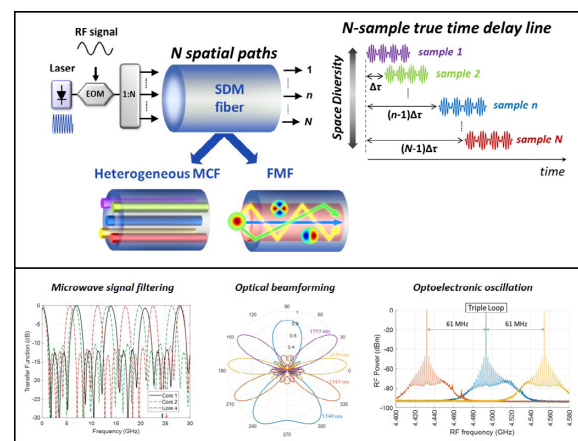
Defended on June 11th 2020



Space-division multiplexing fibers emerged as a promising solution to overcome the imminent capacity crunch of conventional singlemode fiber networks. Despite these fibers were initially conceived as distribution media for long-haul high-capacity digital communications, they can be applied to a wide variety of scenarios including centralized radio access networks for wireless communications, data-center interconnects, Microwave Photonics signal processing and fiber sensing. Particular interest is raised by emerging communications paradigms, such as 5G and The Internet of Things, which require a full integration between the optical fiber network and the wireless segments. Microwave Photonics, discipline that focuses on the generation, processing, control and distribution of radiofrequency signals by photonics means, is called to play a decisive role. One of the major challenges that Microwave Photonics has to overcome to satisfy next-generation communication demands relates to the reduction of size, weight and power consumption while assuring broadband seamless reconfigurability and stability. There is one revolutionary approach that has however been left untapped in finding innovative ways to address that challenge: exploiting space, the last available degree of freedom for optical multiplexing.

In this Thesis, we propose to exploit the inherent parallelism of multicore and few-mode fibers to implement sampled discrete true time delay lines, providing, in a single optical fiber, a compact and efficient approach for both Microwave Photonics signal distribution and processing. For the multicore fiber approach, we study the influence of the refractive index profile of each heterogeneous core on the propagation characteristics as to feature specific group delay and chromatic dispersion values. We designed and fabricated two different heterogeneous trench-assisted 7-core fibers that behave as sampled true time delay lines. While one of them was fabricated by using 7 different preforms to feature a plenary performance, the other one employed a single preform with the aim of

minimizing fabrication costs. In the case of few-mode fibers, we propose the implementation of a tunable true time delay line by means of a custom-designed fiber with a set of inscribed long period gratings that act as mode converters to properly tailor the sample group delays. We designed and fabricated a true time delay line on a 4-mode fiber by inscribing 3 long period gratings at specific positions along the fiber link. As a proof-of-concept validation, we experimentally demonstrated different Microwave Photonics signal processing functionalities implemented over both multicore and few-mode fiber approaches. This work opens the way towards the development of distributed signal processing for microwave and millimeter wave signals in a single optical fiber. These true time delay lines can be applied to a wide range of Information and Communication Technology paradigms besides fiber-wireless communications such as broadband satellite communications, distributed sensing, medical imaging, optical coherence tomography and quantum communications.





Wideband Electromagnetic Body Phantoms for the Evaluation of Wireless Communications in the Microwave Spectrum

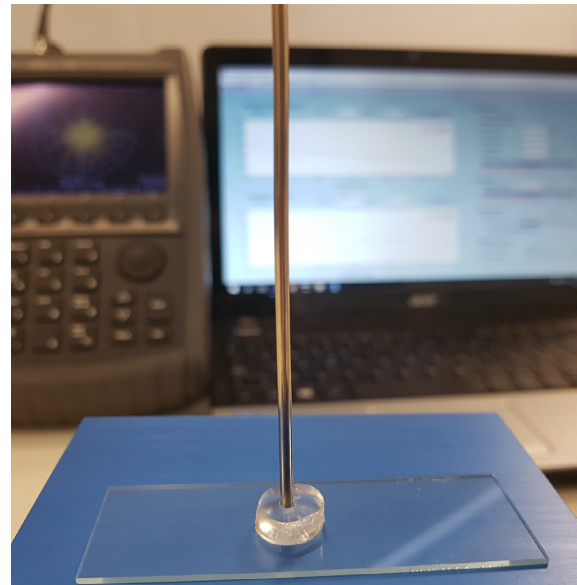
Author: Sergio Castelló Palacios

Supervisor: Dr. Narcís Cardona Marcet and Dr. Concepción García Pardo and Dr. Ana Vallés Lluch

Defended on October 28th, 2019]

The constant evolution of technology and the search for new applications that improve people's lives has led to the arrival of the incorporation of these technologies in the organism. Wireless body area networks (WBANs) are a good example of this, consisting of communications networks located in the body itself, both on the surface and implanted inside it through the use of wireless devices. These networks use the human body as the transmitting medium, so its influence over the propagation has to be assessed. Besides, new generations of mobile communications are moving towards the use of higher frequencies, as the millimetre waves, which are more sensitive to the presence of any object in the environment, including humans. The research and design of antennas and devices that take into account the human body requires testing in the environment where these are supposed to be used. Phantoms become a tool for evaluating the transmission of electromagnetic signals in a body-equivalent medium in order to avoid experimentation on humans or animals. In addition to that, the influence of these electromagnetic waves over the tissues themselves can be studied with regard to the specific absorption rate (SAR).

The objective of this thesis has been to obtain phantoms with the relative permittivity of the tissues from the human body. These were both in liquid and gel form, so that the appropriate medium can be chosen according to the type of experiment. Polymeric materials were used for the gel form, which are capable of providing mechanical consistency and own the possibility of being synthesized with the desired shape, i.e., that of the tissue in question. In the case of liquids, these were confined in containers with the shape of the tissues in order to adapt them to the type of test. For



that purpose, the main 3D printing materials were studied from the point of view of degradation in time with the presence of these liquid mixtures.

It was necessary to analyse the dielectric behaviour of different chemical compounds within the frequency band of interest. The selected bands were the main ones for biomedical use, as well as the new millimetre wave frequencies that will be used in the new 5G generation. Once the ideal compounds were chosen, a great number of tissues from the body were imitated, prioritising those of greatest relevance for the cases of use. Finally, these phantoms were used in different real tests, such as channel characterization or antenna matching, in order to obtain useful information for the design of future wireless communication devices.

In-body to On-body Experimental UWB Channel Characterization for the Human Gastrointestinal Area

Author: Sofia Pérez Simbor

Supervisor: Dr. Concepción García Pardo and Prof. Narcís Cardona

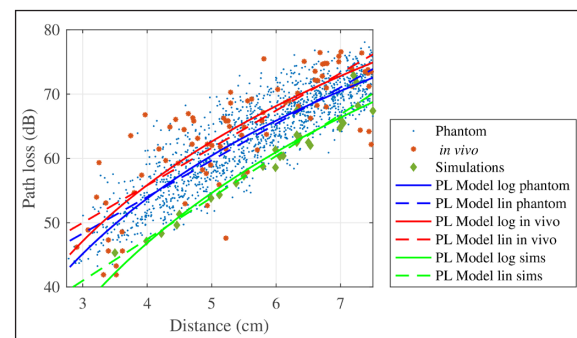
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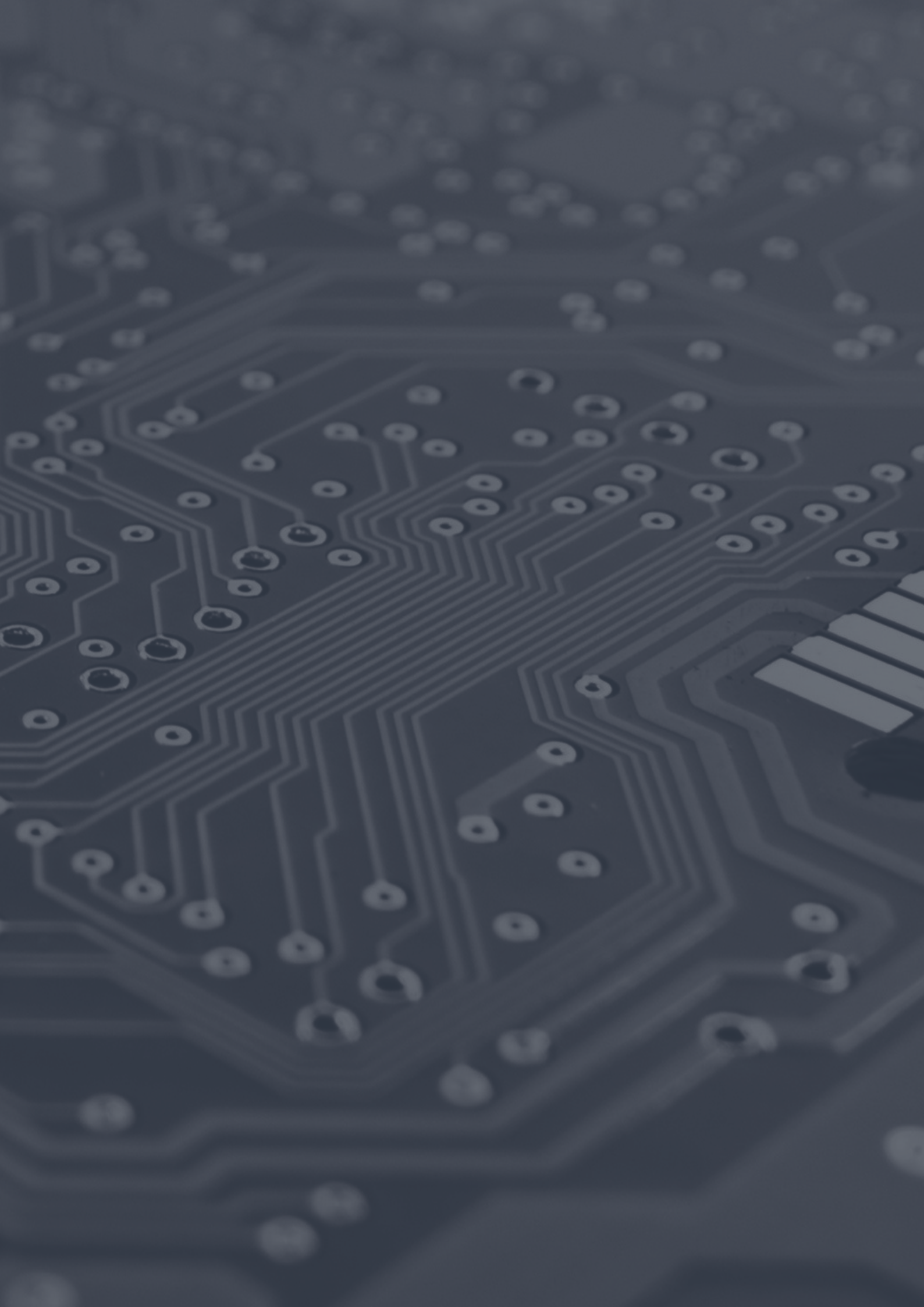


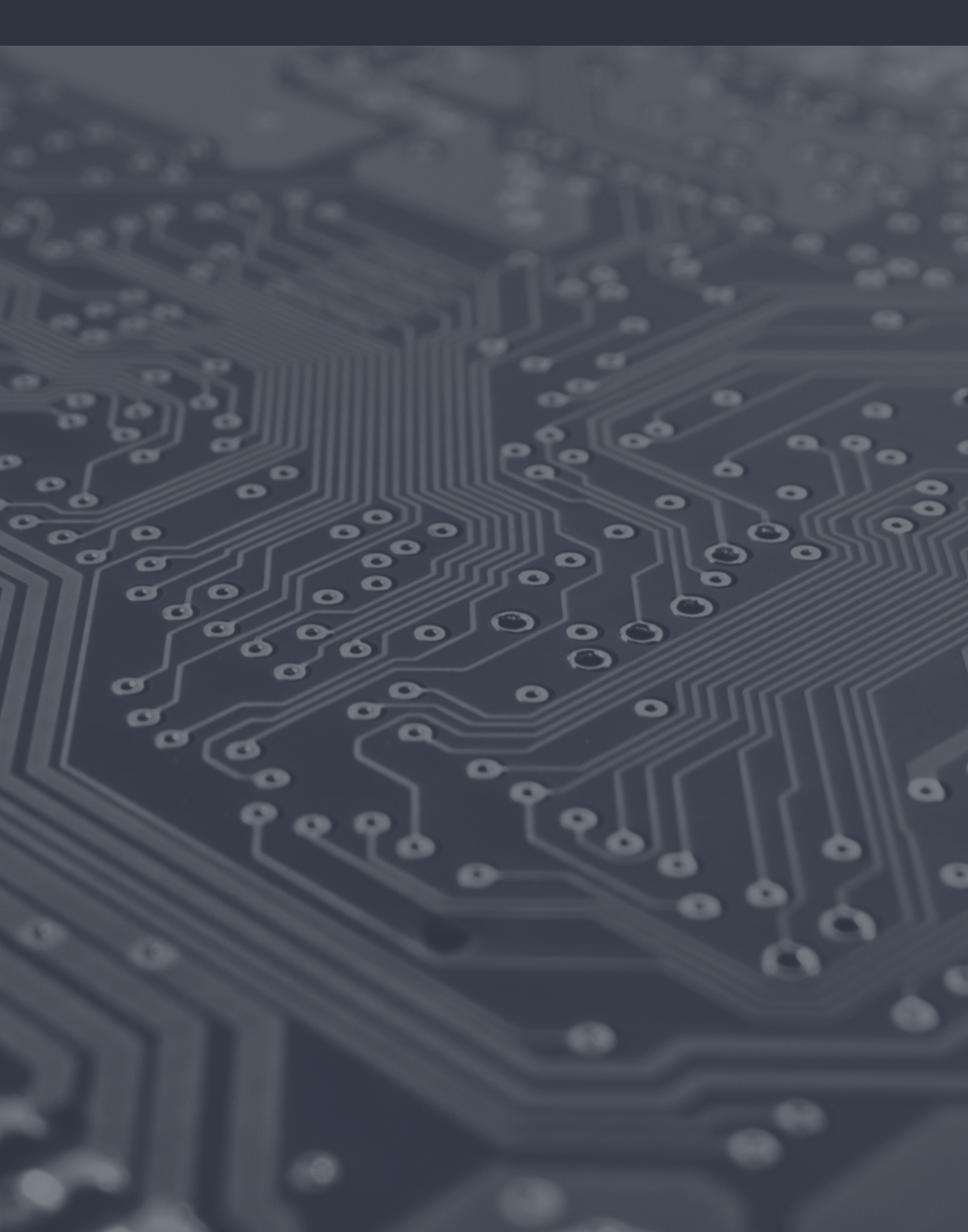
The current global population in developed countries is becoming older and facing an increase in diseases mainly caused by age. New medical technologies can help to detect, diagnose, and treat illness, saving money, time, and resources of physicians. Wireless in-body devices opened a new scenario for the next generation of medical devices. Frequencies like the Ultra Wide-band (UWB) frequency band (3.1 - 10.6 GHz) are being considered for the next generation of in-body wireless devices. The small size of the antennas, the low power transmission, and the higher data rate are desirable characteristics for in-body devices. However, the human body is frequency dependent, which means higher losses of the radio frequency (RF) signal from in-to out-side the body as the frequency increases. To overcome this, the propagation channel has to be understood and known as much possible to process the signal accordingly. This dissertation aims to characterize the (RF) channel for the future of in-body medical devices.

Three different methodologies have been used to characterize the channel: numerical simulations, phantom measurements, and living animal experiments. The phantom measurements were performed in a novel testbed designed for the purpose of in-body measurements at the UWB frequency band. Moreover, multi-layer high accurate phantoms mimicking the gastrointestinal (GI) area were employed. The animal experiments were conducted in living pigs, replicating in the fairest way as possible the phantom measurement campaigns. Lastly, the software simulations were designed to replicate the experimental measurements. An in-depth and detailed analysis of the channel was performed in both, frequency and time domain. Concretely, the performance of the receiving and transmitting antennas, the effect of the fat, the shape of

the phantom container, and the multipath components were evaluated. As a result, a novel path loss model was obtained for the low UWB frequency band (3.1 - 5.1 GHz) at GI scenarios. The model was validated using the three methodologies and compared with previous models in literature. In addition, from a practical case point of view, the channel was also evaluated for UWB signals at lower frequencies (60 MHz) for the GI area. Finally, for the next generation of leadless pacemakers the security link between the heart and an external device was also evaluated. The results obtained in this dissertation reaffirm the benefits of using the UWB frequency band for the next generation of wireless in-body medical devices.







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