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UNIVERSITAT POLITÈCNICA DE VALÈNCIA

iTEAM
Instituto de Telecomunicaciones
y Aplicaciones Multimedia

[Waves]

Cover

"3D-printed resonators"

Carmen Bachiller Martín.

Álvaro Ferrer Claver.

Vicente Nova Giménez.

Index

Message from the director

Prof. Narcís Cardona Marcet

Prof. Narcís Cardona Marcet
Director of ITEAM
Universitat Politècnica de València

2022 was called to be the year of the consolidation of technology, of the revolution in the way of accessing and using information, and of the definitive digitization of the industry. The slowdown caused in world progress by the waves of pandemic, recent events -the war- in Europe, and the global supply crisis, however, have not affected our research activity so significantly. The drive and initiative that all of us who are part of iTEAM continue to have, aided by the support for research and development that has begun to arrive strongly from European funds, reinforce our activity, and even overwhelm our management capacities. iTEAM continues to grow in quality, in productivity, in incomes, and in the number of projects, and for a few years it has remained the number 1 of the University Institutes at the Polytechnic of Valencia, and the largest in Spain in our field. The reader will be able to see in these pages the summary of all those projects and results that iTEAM has achieved along the recent months. The challenge for 2023 continues to be maintaining the level of quality and productivity that we have achieved, and continuing to excite new generations of researchers for science and technology. Enjoy reading.

IN MEMORY OF
ANA MARÍA RODRÍGUEZ PÉREZ

On Monday, November 7th, 2022, our great friend Ana passed away, suddenly, with great sorrow for all her family, José Vicente and Pelayo, her parents Ángeles and Jesús, her sister Susana, parents-in-law, brothers-in-law, and nephews, and for those of us who treated her personally, such as all her colleagues from the GAM research group, and from the iTEAM R&D institute.

After completing her studies of Telecommunication Engineering at the University of Vigo, Ana arrives in Valencia in 2008, where she studies the Official Master in Technologies, Systems and Communications Networks, offered by Departamento de Comunicaciones (DCOM) of Universitat Politècnica de València (UPV). Soon she gets a scholarship in the Microwave Applications Group (GAM), and she receives the Master's degree after defending her work on "Synthesis of Metamaterial Transmission Lines with Aggressive Space Mapping" in September 2010.

Then, thanks to a grant for the training of research staff from Generalitat Valenciana (Regional Government) programme "Gerónimo Forteza", she continues her work with the GAM at the Institute of Telecommunications and Multimedia Applications (iTEAM). She follows the PhD programme on "Telecommunications" from DCOM-UPV, and she receives the Doctoral degree on December 11th 2014 after defending her thesis titled "Synthesis of Planar Microwave Circuits based on Metamaterial Concepts through Aggressive Space Mapping".

Her doctoral thesis, that received the highest grade of "Sobresaliente cum Laude", paved the way for a new R&D line of the GAM group, developed under collaboration with CIMITEC, a research and technology transfer centre focused on "metamaterials" technology. In addition to working hard and intensively, Ana established a very good personal relationship with Prof. Ferran Martí and Dr. Jordi Selga, founder and researcher, respectively, of CIMITEC. This created a very pleasant and productive joint team and work environment, which we keep remembering and yearning. From this so rewarding cooperation, Ana published 14 research papers in relevant scientific journals, and 20 communications in well-known international conferences. She also collaborated with several well-renowned industries, such as Agilent and Ansys, that were interested in the transfer of her results to their commercial products.

Since 2015 Ana continued to work as a research staff member with a doctoral degree of iTEAM, being actively involved in several R&D contracts and projects of the GAM group, always with great dedication, thoroughness, and excellent results, offering her everlasting smile, as well as giving full support to all those around her. From this period, I highlight her high-level technical contributions in new projects with other research centres (AIMPLAS), companies (Aurora Software and Testing, now with Dassault Systèmes) and international organizations (European Space Agency). She also acted as a reviewer of most relevant scientific journals, and provided a very active support to the GAM group (e.g. with our facility for fabricating high-frequency circuits). She was always a model of dedication, effort, professionalism, and good spirit, leaving an indelible mark on everyone she works with.

I cannot conclude this Ana's obituary without explicitly mentioning my excellent personal relationship with her, as well as with all her family, and particularly their parents, that I have met personally and received their kind heartedness. Ana's naturalness, together with her perseverance and kindness, with everyone, won me since I first met her. We developed a very nice friendship, plenty of family gatherings with our children, that went beyond the university environment. At work, Ana always found spare time to come and see me, together with José Vicente, and even with Pelayo (as it was on some Friday evenings of this year), where all of them showed calm, joy and human warmth. I am also well aware of Ana's willingness to listen and help anyone close to her who might need it.

I am fully sure that we will all remember Ana with great affection, we will see her reflected through their loved ones, and she will be always in our hearts.

Vicente Boria (on behalf of GAM and iTEAM)

iTEAM ⊕ NEWS

2022

THE ALFREC3D PROJECT COMES TO AN END WITH OPTIMUM RESULTS

High frequency devices for wireless communication made by additive manufacturing have been developed and tested in this project.

A multidisciplinary team integrated by members of UPV and CSIC has developed a new manufacturing method based on 3D printing, metallization and integration of the high frequency devices which are used in terrestrial and space communication systems.

As a result of the project activities, a complete set of filters, antennas, resonators and transmission lines have been developed, in integrated technology in substrate and waveguide, perfectly functional. The manufactured prototypes have a high dimensional and surface precision, which makes this technology optimal for the manufacture of high-frequency devices.

In addition, dimensional, temperature, power and vibration control tests have been carried out, which certify the manufacturing tolerances of the process, the response to changes in temperature, to mechanical waves and the power handling of the manufactured devices.

These devices provide a fundamental advantage, which is their flexibility and modularity thanks to a new integration system in planer technology systems.

UPV AT MOBILE WORLD CONGRESS

The attendees to the Mobile World Congress 2022 in Barcelona were able to live an immersive experience while controlling in real time and with gestures a robot submerged in the shark aquarium of the Oceanogràfic de València. Thanks to the joint work between the iTEAM Institute of the Universitat Politècnica de València, Orange, the Oceanogràfic, Huawei and Ender Ocean, it has been possible to enjoy this experience 400 km away.

5G technology makes this experience possible thanks to its huge bandwith and ultra-low latency, which transmits mo-

vement control commands in real time, while receiving the images captured by the two cameras located in Valencia and allows an immediate response.

This use case has potential applications in the exploration, research, monitoring, dissemination and conservation of the underwater ecosystem and aims to raise awareness of the importance of preserving marine biodiversity through 5G technology.

TELECOMMUNICATIONS FOR SOCIETY – SMART CITIES SEMINAR

Representatives of the public administrations, sector companies, telecommunication professionals, researchers and professors met at the "Telecommunications for society – Smart Cities" seminar which took place at the Gandia Campus of the UPV.

The seminar was addressed to students, research and public administration staff and persons concerned about information and communication technologies.

Prof. David Gómez-Barquero from iTEAM took part of the round table "5G: The forefront of telecommunications" as an expert in Wireless Communications and 5G Systems.

BEST DEGREE FINAL PROJECT AWARDED BY COITT

The Official School and Spanish Association of Graduated and Technical Engineers in Telecommunication celebrated the XV Future of Telecommunications Awards.

It was conceded the 1st award in the Telecommunication Systems to Sergio Martorell Ortega for his Degree Final Project "Colorectal Cancer Diagnosis Using Electromagnetic Tissue Characterization and Video Endoscopic Analysis", which was conducted at iTEAM in collaboration with CVLab and La Fe Hospital in Valencia.

ITEAM (UPV) RESEARCHERS DEVELOP THE FIRST 5G BROADCAST TRANSMISSOR

A group of iTEAM researchers formed by Aarón Montilla, Álvaro Ibáñez and Jaime Sánchez worked together with ORS Group to push the implementation of various components of the 5G-MAG Reference Tools.

Workshop took place between 21st to 24th February and helped to develop a SDR prototype based on a 5G Broadcast transmitter. In addition, efforts were carried out to implement RaptorQ with the Media Delivery BitRipple solution to improve broadcast transmissions. SDR prototype will be tested in the 5G TOURS European project.

The radio equipment defined by software that was used for the tryouts was acquired thanks to VLC-CAMPUS-5G II project, supported by European Union through the operative programme of European Regional Development Fund (FEDER).

DGT IS COMMITTED TO 5G TECHNOLOGY

À Punt's A la Ventura program connected live with iTEAM researcher Danaisy Prado to learn more about the DGT 3.0 proposal to improve road safety.

This proposal aims to minimize accidents and emissions, relying on the digitization and electrification of vehicles. The iTEAM Mobile Communications Group is working on both technological part and regulatory part associated with connected car industry, making these proposals a reality.

iTEAM News 22

VALENCIA, CAPITAL OF 5G TECHNOLOGY – V5G DAYS 2022

More than 60 companies met at the second edition of the V5G Days, which took place on May 30th and 31st at the Oceanogràfic of Valencia. The event brought together professionals from the telecommunications sector and leaders in 5G with the aim of discussing the latest developments, achievements and challenges in the application of this technology in the industrial field.

The director of iTEAM and coordinator of the V5G Days explained: "5G opens up an infinite field for us; It is the first mobile communications network faster than the human senses and that means that machines can react faster, communicate faster and therefore act sooner than we would."

The conference emphasized the leadership of Valencia and Spain in 5G research and development and attendees were able to interact with connected robotics applications, virtual and immersive reality and immersive telepresence, among others.

SCIENTIFIC COFFEE ON THE DIGITAL UNIVERSITY WITH DAVID ROLDÁN

In the first face-to-face iTEAM scientific coffee after the CO-VID-19 pandemic, we were able to count on David Roldán, Solutions Architect at Sensedia, who spoke about the Digital University and the digital transformation applied to the University.

The Digital Transformation is based on a change in technology, culture and processes and opens the door to many opportunities for teaching and research staff. In addition to this, David Roldán also gave advice on how to gain visibility for our research and position ourselves on networks like LinkedIn.

David Roldán Martínez is a Doctor in Telecommunications Engineering from the UPV, associate professor in the Department of Applied Mathematics, affiliated researcher at VRAIN and solutions Architect at Sensedia. He has worked as an Applications Analyst and has published more than 20 books and numerous articles related to the dissemination of science and technology.

JOINT WORKSHOP COST INTERACTIVE + 6G JIC HUAWEI-ITEAM

iTEAM and Huawei organised the COST INTERACT + 6G JIC Huawei-iTEAM Workshop on "Enabling Technologies for 6G" held at the UPV Campus on 19th September 2022.

Prof. Narcís Cardona introduced the event to the attendees in person and online after the welcome coffee. Among the speakers from Huawei and Universities such as Bologna or Twente, it is worth mentioning the participation of iTEAM members, Professors Jose Monserrat and Jose Capmany and Dr. Conchi García-Pardo.

LIVE ELECTRONICS AND INTERACTIVE VIDEO CREATION WITH THE PARTICIPATION OF SOUNDCOOL

The Palau de les Arts with the Municipal Band of Valencia received on September 2022 the work CHAPITRES, a composition which harmonized a symphonic band with live electronics and interactive video.

Stefano Scarani and Roser Domingo were in charge of live electronics and interactive video creation, both made with the Soundcool system of the Universitat Politècnica de València (UPV), and performed by Stefano Scarani, Marcel Estornell and Jorge Sastre.

FIRST EXPERIMENTAL DEMONSTRATION OF DISPERSION-DIVERSITY MULTICORE FIBER OPTICAL BEAMFORMING

A joint work from APL and PRL groups about dispersion-diversity multicore fiber optical beamforming has been published in Optics Express journal.

As a compact and efficient solution to provide tunable beam steering simultaneously to parallel antenna distribution and connectivity, researchers demonstrate, for the first time to their knowledge, tunable optical beamforming implemented on a dispersion-diversity multicore optical fiber.

Dispersion-diversity MCFs open the door towards the implementation of compact and versatile fiber-distributed signal processing, where both distribution and processing functionalities are provided within the same fiber medium.

MICROWAVE APPLICATIONS GROUP (GAM) AND ELECTROMAGNETIC RADIATION GROUP (GRE) OF ITEAM COORDINATE THE CAFTAM PROJECT FOR THE DEVELOPMENT OF NOVEL DEVICES FOR WIRELESS COMMUNICATIONS THROUGH ADDITIVE MANUFACTURING

Saturation of the electromagnetic spectrum of today's telecommunication systems requires efficient communication devices and further integration of radiation, guidance, filtering, etc. equipment.

Additive manufacturing technologies enable a very wide spectrum of volumetric topologies, as well as reducing manufacturing time, weight and cost compared to traditional metal milling processes.

The main objective of the CAFTAM project is therefore to develop experimental procedures and technologies that enable the additive manufacturing and plating of radio frequency communications devices for terrestrial, maritime and space applications.

The GAM and GRE groups of iTEAM are already working together with the companies DISMUNTEL and AIJU, and with the Institute of Chemical Technology (ITQ) of CSIC for the implementation of this project funded by the Agència Valenciana de la Innovació (AVI) within the Strategic Projects in Cooperation Programme. Ref. INNEST/2022/138.

SCIENTIFIC COFFEES

Scientific coffees were created as a way to disseminate the different studies that are carried out in iTEAM and share knowledge with all researchers. Numerous voices of scientific research have participated in them since their creation, providing an intangible and essential value. With the advent of the pandemic caused by COVID-19, these meetings ceased to be face to face, giving way to seeing and listening to each other through video calls.

The beginning of this year 2022 was marked by a first coffee in January, focused on junior professors, and another in February, this one dedicated to doctoral students.

The first scientific coffee with alumni took place in April and we were able to count on luxury guests who had completed their PhD at iTEAM: PhD David Vargas (BBC R&D, UK), PhD Jose Escolano (Hudson Data, USA) and PhD Enric Miralles (Qorvo, Germany).

May was marked by three different scientific coffees, each of them focused on a different research profile, which served to resolve many doubts from the attendees and listen to experienced voices from iTEAM research.

We finally had the chance to meet again in person. On June 20th, the first face-to-face scientific coffee after the Covid pandemic was held, in which we had David Roldán, PhD in Telecommunications Engineering from the UPV, associate professor in the Department of Applied Mathematics, researcher attached to VRAIN and Solutions Architect at Sensedia. The coffee was focused on Digital Transformation and how it can open the door to numerous opportunities for teaching and

research staff, derived not only from Open Science and the sharing of information but also from the ability to add value to the results of the research.

In the month of July, we were fortunate to have the presence of Prof. Navin Kumar from the Amrita School of Engineering in India. In the coffee, the topics "5G Architecture and Call processing" and "LiFi Network Design and Challenges" were

discussed, which were of great interest for the work carried out by the attendees.

Finally, to close the calendar year of scientific coffees, but also to start the coffees for the 2022-2023 academic year, on November 3rd Dr. Addisson Salazar visited us and all the attendees could enjoy his talk entitled "Learning from Small Data".

With this last coffee we concluded 2022, a year that has been full of new experiences and in which we have been lucky to have fantastic professionals in the field of telecommunications to learn from in each scientific coffee. There is no doubt that 2023 will be even more exciting and we are looking forward to launching ourselves into new challenges in iTEAM.

PADDLE TENNIS AND TABLE TENNIS ITEAM TOURNAMENTS

Since not everything was going to be work, this year we have had time to practice a bit of sport and we have done it in a big way... With two tournaments!

The paddle tennis tournament was very disputed in each round in which we experienced some vibrant and emotion-filled matches where the opposing couples were very even. Other couples... well, let's just say they had a good time and enjoyed being involved, but this will only improve. The best game came with the final match played between the couples formed by Aarón Montilla and Borja Iñesta against Andrés Macho and Luis Torrijos, who ended up prevailing and winning the tournament.

In the table tennis tournament, Pablo Picazo did not give any rival a chance and prevailed with solvency throughout the competition until he won the iTEAM champion trophy.

This initiative was very well received by all the people who make up iTEAM, so we are convinced that this is just the beginning of this type of event and we hope that the 2023 championships will be even more exciting.

Deployment and Trial of 5G for media content production in 5G-RECORDS

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ABSTRACT

The fifth generation (5G) of mobile communications has revolutionized the telecommunications industry, allowing to explore the opportunities that this new technology brings to different verticals. 5G-RECORDS explores the possibilities that 5G may bring to the professional audio-visual (AV) content production sector. This work describes, in the context of the 5G-RECORDS project, three different use cases that target the integration and validation of 5G and media technologies in end-to-end infrastructures to meet the requirements of the emerging market players in Europe for professional content production. 5G-RECORDS use cases focus on live audio production, multiple camera wireless studio and live immersive media production. Special emphasis is placed on the deployment of 5G Non-Public Networks (NPNs), which give the content producers control over the network in terms of performance, privacy, data security and compliance.

Keywords: *5G, professional content production, technology enablers, components, end-to-end infrastructure, non-public networks, mmWaves, audio-visual requirements.*

1. INTRODUCTION

5G-RECORDS is a European H2020 project that aims to explore the opportunities that new 5G technology brings to the professional audio-visual (AV) content production sector. The 5G specifications allow for the deployment of specialist networks based on the same technologies as those operated by Mobile Network Operators (MNO). This offers the opportunity for content producers to build and operate their own networks to support their business requirements. 5G Non-Public Networks (NPNs) have been deployed and demonstrated to broaden the opportunities that MNOs provide in terms of performance, privacy, data security and compliance. They aim to provide improved performance in terms of bandwidth, latency, accurate timing support, quality of service (QoS) assurance and scenario flexibility.

The capabilities provided by 5G networks have opened ways to new use cases. 5G-RECORDS has considered three use cases to deploy three challenging scenarios in professional content production: live audio production, multiple camera wireless studio and live immersive media production.

2. OVERVIEW

To ensure the successful demonstration of the 5G-RECORDS use cases, the project gathered a set of experienced partners whose expertise covers both 5G and content production value chains. Together, they have designed the main components and the architecture for each use case, also identifying the benefits for users, requirements, and technical enablers. Scenarios and workflows have been defined to understand the nature of each use case, identifying the specific Key Performance Indicators (KPIs) required to measure the performance of the proposed solutions. After the development and integration process, trials have been successfully deployed and demonstrated to validate the three use cases.

2.1. Consortium

The 5G-RECORDS consortium consists of two

5G infrastructure manufacturers (Ericsson and Nokia), four partners that provide 5G core technologies (Cumucore, RED Technologies and Accelleran) and a major telecom operator (Telefonica). The content production sector is represented by four major European public broadcasters (EBU, RAI, BBC and TV2) and three leading media technology companies (Sennheiser, LiveU, and Bisect). The consortium also includes two universities (Universidad Politécnica de Valencia and Universidad Politécnica de Madrid) and one research center (Eurecom).

In addition, the project has a strong Advisory Board to monitor, evaluate and propose improvements to the work in progress and respond to the results achieved. It is composed of seven companies belonging to both 5G mobile communications and content production sectors: Amarisoft, BT Sports, SWR, RTVE, NEP Group, Nevion, ZDF and ATEME.

2.2. Objectives

The main objectives of the project were: (i) to design and develop 5G components based on 3GPP Rel-15 and 16, (ii) to integrate the developed 5G components into end-to-end (E2E) 5G infrastructures, (iii) to validate the 5G components in the context of the considered use cases, (iv) to demonstrate the potential value that 5G brings to the content production sector, and (v) to maximize the impact of project results and influence standardization and technical solutions.

These objectives were fulfilled via the execution and validation of the three use cases that cover different aspects of the media industry, i.e., live audio production, live wireless studio production and contribution, and immersive experience.

2.3. Challenges

The 5G-RECORDS project dealt with several technical and management challenges related to:

(a) IP network configuration: one major challenge in initially setting up the E2E application was the IP network configuration of several 5G system (5GS) components. This is related to the fact that mobile networks today include significant restrictions on IP traffic e.g., due to security considerations in public networks. Furthermore, Network Address Translation (NAT) is typically an inherent function in today's mobile networks, which is not required in local networks.

(b) Spectrum licenses not available for trials and test-beds. Harmonising the spectrum used by Programme Making and Special Events (PMSE) equipment would contribute to allow economies of scale, foster cross-border portability of equipment and interoperability, improve the quality and efficiency of spectrum use, and providing legal certainty for access to relevant spectrum bands. Stakeholders must be conscious of the existing rules that may affect the use cases, and business aspects of 5G-based content production.

(c) 5G RAN functional splits: 5G-RECORDS deployed a disaggregated radio access network (RAN) for the live audio production use case. The interoperability between the gNodeB (gNB) distributed unit (DU) and centralized unit (CU) using the standardised 3GPP F1 interface posed a major challenge towards the overall integration process. This was due, in part, to the incompatibility issue related to Eurecom's cluster (deployed on OpenShift) and ACC cluster (deployed on Vanilla Kubernetes). The integration of this split involved the implementation of specific protocols and procedures.

(d) Integration of components given the high number and complexity of 5G-RECORDS components development, the integration of the 5G and media disaggregated components took more time than expected. For example, compatibility issues arose between the video streams generated and the decoder on the Media Gateway in the multiple camera wireless studio use case.

(e) Lack of availability of a 5G network with NEF/PCF (Network Exposure Function / Policy Control Function) APIs to provide QoS prioritization features. Because 5G Release 15 is significantly more basic in this respect, joint efforts between the use cases were needed for a possible interim REST API to access QoS flow functionality.

(a) Maturity of available technology and unavailability of equipment: The readiness of 5G ecosystem is not yet on-par with the demanded use case requirements. For instance, mmW solutions are limited to band configurations strongly focused on downlink capacity, and NSA only. Also, latency for live audio production use cases is still a major constraint for the success of live audio production performances. Ultra-Reliable Low Latency Communication (URLLC) features need to be further investigated and applied to this use case to attain the requested level of user experience. For the multiple camera wireless studio, only 1080p25 video material was available while Tektronix Prism network analyzer was able to receive but not decode this format. Moreover, IP/SDI converters were temporarily unavailable.

(b) Compliance with the use-case KPIs and desired system functionalities: for instance, the

live audio production requires a mouth-to-ear latency lower than 4 milliseconds. The latency of the audio signal from the microphone to the IEM system is the most critical parameter and, if it exceeds a certain threshold, the artist will not be able to perform. Also, another challenge is to accurately synchronize all audio sources over the network to produce a combined audio mix. Finally, an additional challenge is the interconnection and transmission issues associated with the stringent latency and data rate requirements of Free ViewPoint Video (FVV) systems in the live immersive media production use case.

2.4. Achievements

The project achieved the objectives listed in section 2.2 and demonstrated significant outcomes in the different work categories. The project was highly focused on both 5G and media components design, development, testing and validation on E2E infrastructures. The general performance of all involved components was evaluated and optimized regarding the specific use-case KPIs and requirements. The main achievements of the project are summarized below:

- Proof-of-concept of remote live audio production, multiple camera wireless studio and immersive live production.

- Implementation, integration, and optimization of disaggregated 5G components.

- Optimization of 5G disaggregated testbed to reduce the end-to-end latency within the live audio production use case (latency reduction by factor of 10).

- Capturing the state-of-the-art of current 5G ecosystem and benchmarking towards use case requirements.

- Identification of remaining gaps and bottlenecks in 5G ecosystem.

- Cross-collaboration between the projects use cases to test the audio for local 5G TV production, serving as a proof-of-concept of audio and video transmission over the same private 5G network in TV production scenarios

- Fully remote-controlled trials and measurements

- Proof-of-concept of shared access to spectrum for a private 5G network

- Analysis of Precision Time Protocol (PTP) performances on 5G networks Release 15 and URLLC testbed Release 16.

- Development of an FVV system that work on live and offline content, adapted for 5G and cloud production.

- Design and validation of a 5G+MEC compact deployment that can be used in immersive media workloads.

- Deployment and testing of E2E transport slicing over a software-defined network (SDN), including automatic slice change.

- Pioneer tests on immersive content production over millimeter wave (mmW) 5G RAN.

- Analysis of the system performance and their inherent limitations.

- Analysis of how the systems will perform over the next generation of infrastructure elements.

3. KEY TECHNOLOGY ENABLERS

Traditional public mobile networks may not be able to fulfil the requirements of certain type of applications that rely on low latency, high bandwidth, reliability, service prioritization or business-critical data privacy. Conversely, **5G Non-Public Networks (NPNs)** are tailored to satisfy the needs of a specific industry, such as media organizations, allowing them to deploy fixed and nomadic networks with coverage ranging from small areas to entire premises. NPNs benefits include the deployment of 5G systems for private use. The project put special emphasis on the deployment of NPNs to exploit the opportunities they provide in terms of performance, privacy, data security and compliance. They are useful for content producers as they allow dedicated 5G connectivity for a restricted number of users in a more secure environment. Dedicated resources allow users to tune the network based on their own requirements.

For media production, this enables the deployment of networks in a production environment to connect various devices such as microphones, monitors and cameras. NPNs provide dedicated connectivity to support the characteristics required such as low latency for audio equipment or high throughput for video transmission. Also, given the 5G duplex nature, it is possible to send audio and video in both directions, thus removing the need to have multiple radio connections for a single device. The deployment of NPNs goes hand in hand with the use of **network slicing for guaranteed Quality of Service (QoS)**, i.e., the virtual partition of the network that serves a specific purpose for an application or entity, usually with a set of guaranteed Key Performance Indicators (KPIs)

and Quality of Service (QoS). A paramount connectivity requirement is to ensure that service level agreements (SLAs) for a given QoS are met for all services running in a slice, taking into consideration available network resources and capabilities. In this project, different network slices are tailored to specific use cases and allocated to the different users of the network to ensure the required Quality of Experience (QoE).

Further, **Multi-access Edge Computing (MEC)** is a great asset to seize new opportunities with applications for stadiums or localized events. MEC allows the deployment of computing power closer to the network endpoints in order to improve real-time processing capabilities and guarantee specific KPIs such as response time and latency. In this project, the implementation of new Virtual Network Functions (VNF) instantiated very near to the radio provides very low latency and enhanced performance video capabilities.

However, none of the previous advantages nor technologies would be useful without proper time synchronization and timing. Professional content production requires specific QoS and timing parameters. Live media content needs precision when sending information to enable production workflows. As transmission speed is considerably high, time synchronization is crucial. In 5G-RECORDS, the time synchronization of devices over the 5G network was tested in both non-optimized networks and Time Sensitive Networks (TSN).

Another key aspect of 5G-RECORDS was the implementation of solutions based on open-source software running on general-purpose processors. Live audio production disaggregated 5G tested relied on Software-Defined Radio (SDR) to deploy the gNB DU, providing developers and users with a great set of tools to (i) support a multi-vendor ecosystem, (ii) simplify network access, (iii) reduce cost, (iv) increase flexibility, and (v) accelerate the introduction of new services into the market. The use of Software Defined Networking (SDN) within live immersive media production has also been a cornerstone.

Dynamic Spectrum Access (DSA) was also demonstrated within the project to provide increased spectrum efficiency and network capacity within the live audio production. The deployment of a dynamic spectrum access server and client allowed the real-time adjustment of radio resources.

Finally, the use of mmW antennas and devices allowed the live immersive media production to explore the capabilities of the 5G new bands between 30- 300 GHz, based on Line-Of-Sight (LOS) paths, with larger bandwidth availability

aimed at providing extreme capacity for the busiest locations.

4. 5G USE CASES FOR REAL MEDIA CONTENT PRODUCTION APPLICATIONS

4.1. Use Case 1: Live audio production

Today's typical professional live audio production combines several wireless and wired technologies to capture, produce, playback and distribute audio content. In a typical production setup, performers are equipped with PMSE equipment such as wireless microphones and in-ear monitoring (IEM) systems. 5G-RECORDS use case 1 (UC1) aimed to deploy a local 5G disaggregated testbed to provide a high-quality and low-latency audio production network based on open-source software solutions and a multivendor ecosystem.
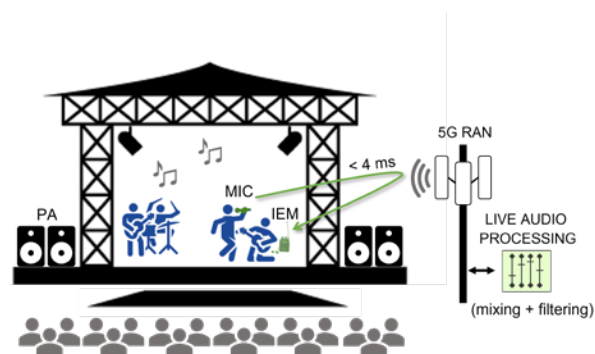

Fig. 1. Live audio production.

This use case allowed to capture and evaluate the state-of-the-art of available 5G components in the context of live audio production scenarios. The integration of 5G and audio components into the network was successfully demonstrated, allowing to study the performance of the E2E system when using a single UE, to measure deterministic audio streams through multiple 5G modems, and to conduct mobility tests to better understand the use-case KPIs in a more realistic environment.

5G-RECORDS has also shown that it was possible to integrate live audio production on network layer into multiple 5G testbeds. In a joint effort between UC1 and UC2, it was possible to demonstrate the delivery of audio and video over the same private 5G network in some TV production scenarios.

The main live audio production requirements within this project are reliability, latency and synchronicity.

◆ **Network latency:** UC1 efforts concentrated on extensive optimizations on the 5G components, interfaces and deployments

to reduce the latency in a state-of-the-art 5GS. Network latency describes the latency of a continuous stream of audio data packets from the application layer on the User Equipment (UE) side to the application layer on the Local Audio Processing (LAP) side for uplink direction and the other way around for downlink direction. This use case requires a one-way network latency of below 1 millisecond (ms).

After multiple iterations, UC1 partners were able to reduce the one-way E2E network latency in the disaggregated 5G testbed to about 10 ms for a single audio UE and about 20 ms for up to three audio UEs. Those results are still far from the 1ms target, thus the availability and maturity of URLLC components are key to meet UC1 requirements. On the other hand, test results for the delivery of audio and video over the same 5G network for a local TV production showed that packets were faster than 75 ms.

- **Synchronicity:** needed to ensure low latency and high-quality audio transmission of all audio devices, that need to be synchronized to a common clock with a maximum deviation of 500 nanoseconds (ns). In the wired part of the production network, this can be achieved by using PTP over wired IP networks. For wireless devices it is required to synchronize with a similar accurate clock like the wired. Since no 5G components with PTP support were available until the end of the project, it was not possible to perform measurements that would show the needed performance.

- **Packet error ratio:** This use case requires a packet error ratio <10-6 to ensure a high-quality audio production. Furthermore, the distribution of the errors plays a role when it comes to the effect on audio quality. Short measurements with stationary

devices in a controlled lab environment showed that the system can work without any packet errors at this point in time. However, it remains difficult to conclude about PER of a current 5GS in live stage environment since it is a parameter that is tightly bundled to latency.

4.2. Use Case 2: Multiple camera wireless studio

Live or pre-recorded media content production usually requires deploying a large number of equipment and crew on the event location or studio, all connected to the production facilities. This use case is based on multi-camera audio and video production in a professional environment. It aimed to replicate existing technologies such as COFDM radio cameras in terms of performance and capabilities using 5G technology. Furthermore, UC2 focused on exploring multi-location scenarios with production facilities local to an event as well as remote and distributed production models. In some additional scenarios, 5G based contribution solutions were integrated using different types of network configuration to provide contribution links into production centers.

Efforts within this use case were devoted to the development of the 5G 2110 Gateway, which acts as a media translator between different networks and the definition of the Operational Control Gateway architecture, including camera controls, timing & synchronization and device registration. These processes will be based on specialized technologies, such as NMOS, PTP, NTP, MQTT and so forth.

Following, KPIs that have been considered to evaluate the success of the use case are listed:

- **Glass-to-Glass latency:** the measured glass-to-glass latency for the wireless studio scenario was around 200 ms which could be further improved using more performant low-latency encoders.
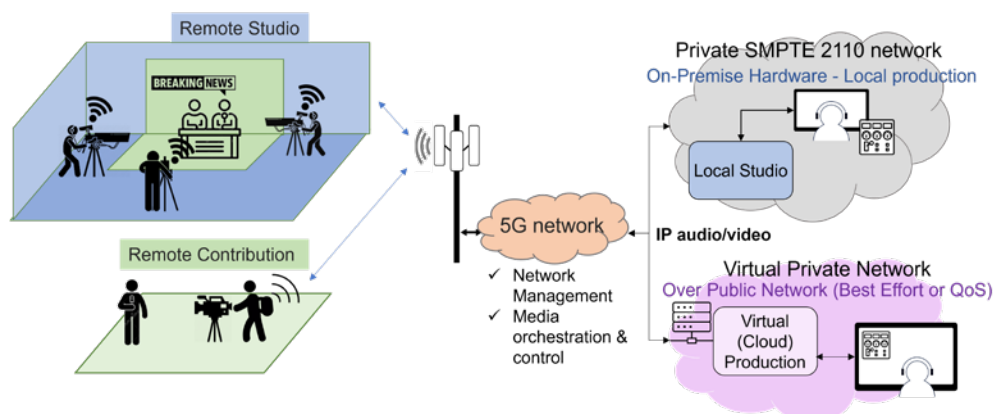

Fig. 2. Multiple camera wireless studio.

◆ **UL throughput, contribution latency and packet loss rate:** UL bandwidth for one audio/video/data stream over a single link reaching 50Mbps, and 4 simultaneous streams reaching a max of 60Mbps between all four for the contribution scenario. Contribution scenario UL latency was below 1 sec, tested at ~600 ms end-to-end, from image capture, through A/V encoding, to transmission over the 5G networks, through the public internet from one country to another (in the EU), to studio, to decoding, to output. Loss rate over this full end-to-end path was achieved by the network – at 0% or close to it.

◆ **Multi-camera contribution:** Multi-camera via specialized equipment was tested – up to 4 streams were measured.

◆ **Remote audio communication (remote contribution):** Remote audio communication was tested and achieved. Audio communications between remote producer/director and camera operator/reporter, in parallel to the UL video streams including when 4 streams were uplinked, was working from RAI studio all the way to the Aachen or TV2 labs over the labs 5G networks.

◆ **Cameras remote control (remote contribution):** Camera control was tested and passed. Camera control from RAI labs all the way over the full path to the Aachen labs and TV2 labs over their local 5G network was done using the LiveU IP-PIPE link via the Cyanview control boxes. Latency from sending the command from the RAI lab to receiving the visual feedback after the camera iris actually electro-mechanically responded and moved and the video captured, encoded, transmitted

over the 5G UL, the public internet, back into the Rai and decoded there, was about 800 milliseconds.

4.3. Use Case 3: Live immersive media services

This use case considers a real-time E2E Free ViewPoint View (FVV) system aiming to cover multitudinary events on theater or stadium-like venues, that includes: (i) video capture, (ii) 5G contribution using mmW, (iii) virtual view synthesis on an edge server thanks to several VNFs, (iv) 5G delivery through VNFs and (v) visualization on users' terminals using the mmW link on-premise or the core network for remote attendees. The system finally delivers a synthesized virtual video, offering customers a high level of immersivity and groundbreaking QoE.

In addition, network slicing contributes to delivering assured QoS streams. Each user can access a specific angle live, offering a unique QoE.

Following, key KPIs that have been considered to evaluate the success of the use case are listed:

◆ *Motion-to-photon latency:* the time needed in the system for a specific user movement to be reflected on a display screen should be 170 ms or less. In the 5G network deployed in Segovia (phase 1 of UC3 trials), 290 ± 80 ms was achieved. In the compact 5G deployment in Madrid (phase 2 of UC3 trials), 210 ± 20 ms was achieved. The target was not achieved with the existing FVV + 5G network configuration. However, the obtained result (210 ± 20 ms) is close enough. The next generation of 5G networks with higher uplink capacity will be able to achieve the target of 170 ms.

◆ **Uplink bitrate:** critical KPI for the deployment of FVV cameras in the field
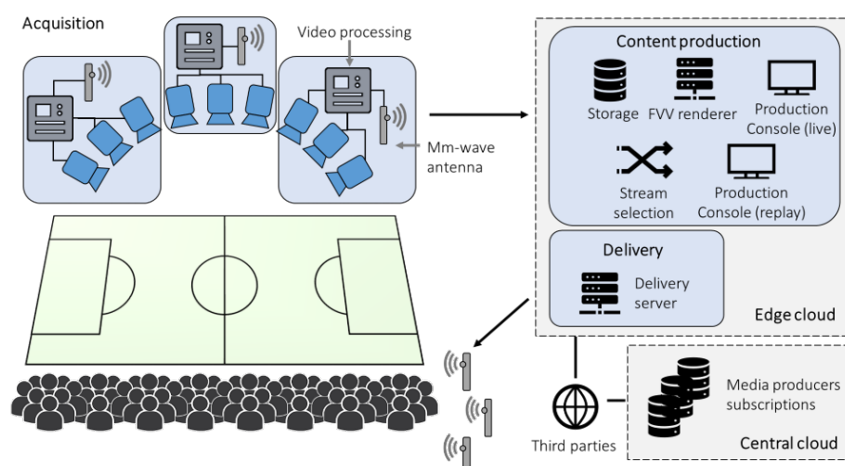

Fig. 3. Live immersive media production

that enables FVV production. Each camera stream (RGB+Depth) should be less than 100 Mbps, and ideally less than 50 Mbps. As proved in the final field trial, it is possible to obtain functional FVV production over a moderately complex scene using a configuration of 720p15. This results in 25 Mbps of average bitrate, which is clearly within the ideal target bitrate.

◆ **Round-trip Time (RTT):** defined as the time it takes for a packet to go from the sending endpoint (UE) to the receiving endpoint (MEC) and back. It is required a low delay to support interactivity and low motion-to-photon latency. The RTT between the UE and the MEC should be less than 40 ms, in this specific live immersive media production environment is about 12 ms in idle conditions, and 25 ms in load conditions.

5. 5G-RECORDS COMPONENTS

A key aspect of 5G-RECORDS was the development of both 5G and media components. Some of the components used in this project have been enhanced and adapted from previous commercial or research products to fit the use case, while others have been specifically developed from scratch.

The development of these components and their integration into the 5G network was the core of the 5G-RECORDS technical activities in order to provide the functionalities requested for the use cases validation.

Table 1, Table 2 and Table 3 present the list of components per use case and their role. [1]

Table 1. List of components for live audio production use case

Component	Partner	Role
Local Audio Processing*	SENNHEISER	Stationary device connected wired to the 5GS. Located on-site to allow low-latency interaction with the wireless audio equipment. Network audio streams from microphones are received, mixed, and sent to IEM receivers in the 5G network.
Audio User Terminal	SENNHEISER	5G-enabled microphones and IEMs. The audio part is based on a custom developed hardware. The audio- and the 5G-part are connected by a 1 Gbps Ethernet connection. IP audio streams can be received or transmitted, and the audio network device converts between analogue and IP domain.
Media Orchestration and Control Gateway*	SENNHEISER	It advertises the audio network devices capabilities. Based on the desired configuration, it sets up the audio network devices accordingly. It terminates audio data flows.
5G RAN (inc. Shared Access Client)	EURECOM, ACCELLERAN	Support of E2E SA setup based on a 5G CN and SA capable COTS UE devices. It consists of Eurecom's Radio Units (RU) and Distributed Unit (DU) based on OpenAirInterface (OAI) and Accelleran's Centralised Unit (CU). DU/CU communication over the F1 interface.
5G Core	CUMUCORE	3GPP Rel-15 compliant 5G Core including dynamic network features. It is capable to connect local data network directly to UPF, which enables local audio mixing. Support of Network Slice lifecycle functionality and PCF functionality to dynamically create data flows.
Shared Access Server	RED TECHNOLOGIES	It determines the maximum allowed transmission power of each device, determines the protection zone contour and identifies the most suitable frequencies.

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1 New 5G and media components fully developed during the project are marked with an asterisk (*).

Table 2. List of components for multiple camera wireless studio use case

Component	Partner	Role
Media devices	ALL	Media capturing and additional devices (cameras, microphones, RCPs, etc.)
Media gateway*	BISECT	Bridges the media devices, 5G network and production network & devices together by encoding/decoding and translating transport protocols
Media Orchestration and Control Gateway*	BBC, BISECT	Manages discovery, registration, authentication interconnection, configuration, control and monitoring of devices
Network slice management/NEF	ERICSSON	Manages the network slicing functionality based on QoS
5G network	ERICSSON	The backbone of all the communications of the use case
5G modem	FIVECOMM	Connects the cameras to the 5G network
5G camera interface unit*	FIVECOMM ERICSSON	Device that combines a video/audio encoder with the 5G modem, attached to the back of the camera
MCR	EBU	Virtual, cloud media production software
LU800	LIVEU	Encodes media from cameras and connects them to the 5G network for remote contribution scenarios
LU2000-SMPTE	LIVEU	Decodes the LU800 streams and outputs ST2110 for remote contribution scenarios

Table 3. List of components for live immersive media production use case

Component	Partner	Role
5G-Ready FVV Live	UNIVERSIDAD POLITÉCNICA DE MADRID	Immersive technology that allows the user to freely move around the scene. It is composed of cameras, capture servers, view renderer, virtual camera control system
Compact 5G Network & Multi-Access Edge Computing (MEC)	NOKIA	5G mmWave RAN provides service to the FVV System. By moving part of the processing to the MEC, makes it possible to distribute the computational load
Media Delivery*	NOKIA	Subsystem to delivery to third parties (content producers, broadcasters) in contribution quality and delivery to event attendees in streaming quality
Delivery cloud & End-to-End SDN*	TELEFONICA	Edge solution to ensure compute, storage and network capacity with SDN capabilities to handle the E2E transport slicing

6. TRIALS

Several tests and final trials were successfully deployed to assess and validate the 5G-RECORDS components and E2E solutions in the context of the three project use cases. These trials allowed project partners to study to which degree 5G fulfills the technical KPIs and requirements of the project use cases in the context of professional content production.

6.1 Use Case 1: Live Audio Production

UC1 disaggregated testbed was located in Sophia Antipolis, France, using Eurecom's infrastructure. It integrated the 5G-enabled microphones and IEM systems from Sennheiser, the COTS RUs and the open-source OAI gNB-DU from Eurecom, the CU from Accelleran, the compact 5GC from Cumucore and spectrum sharing management technologies from RED Technologies. After extensive interoperability optimizations, several tests were conducted to study the performance of the E2E system when using single and multiple UEs.

During the trials, UC1 partners identified that some components introduced significant latency jitter into the processing and forwarding of audio IP packets in the 5GS. Even if the UC1 network has evolved gradually during the project to reduce latency, the one-way network latency achieved was finally about 10 ms for a single audio UE and about 20 ms for up to three audio UEs. As introduced in Section 2.3, the availability and maturity of available 5G components remained a major constraint until the end of the project. For instance, the COTS 5G modems had a major influence on the support for specific features and achievable KPIs.
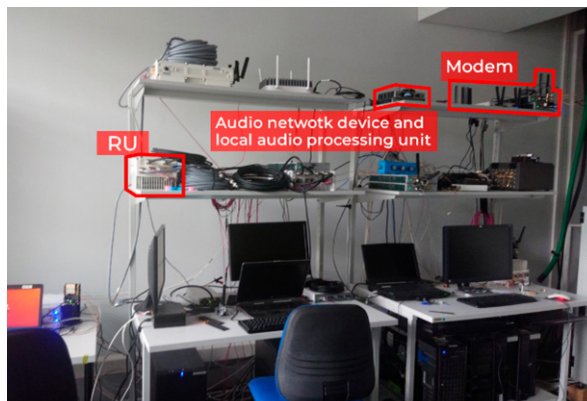

Figure 4. Lab room at Eurecom with radio unit, modem, audio network device and local audio processing unit.

In addition, UC1 partners were able to conduct mobility tests to better understand the use-case KPIs in a more realistic environment. For that one UE was connected to the 5G network and moved around in the lab premises (see Figure 3). Also, UC1 team was able to collaborate with UC2 partners during the trial in Tivoli Garden to demonstrate the delivery of audio and video over the same 5G network, and to conduct latency measurements as part of the evaluation of the state-of-the-art 5G components. Test results for the delivery of audio and video over the same 5G network for a local TV production during the Tivoli trial showed that packets were faster than 75 ms.

Figure 5 Mobile audio UE modem on a trolley; corridor for mobility trial.

6.2 Use Case 2: Multiple Camera Wireless Studio

Several tests were performed by UC2 towards the technology validation and execution of the final trial at Tivoli Garden, Copenhagen. Despite several setbacks due to development and integration delays and consortium amendments, it was possible to perform the desired tests and trials in the second phase of the project, which focused on PTP performance, remote production, local production, gateways, camera controls, glass-to-glass latency measurement, among other topics in Aachen, Turin, Copenhagen and Valencia. The PTP tests were successful in demonstrating that PTP over 5G is sufficient for frame-level synchronization. It was also demonstrated that the basic PTP performance can be greatly enhanced by client −−−−tweaking and using advanced TSN features (from about 117 μs to 3,6 μs median offset).

Regarding local and remote production, several tests have been performed to stress the complete production chain to prepare it for the trial in Tivoli.

In the last tests performed in Aachen, Germany,

UC2 team was able to integrate the media gateway into the infrastructure. The tests allowed the team to study the traffic behavior and extract different KPIs (frame delay, interarrival, packet latency, etc.). In summary, the most important KPIs such as E2E latency and uplink throughput have been measured and validated, with a glass-to-glass latency of around 200 ms and 50 Mbps per video stream.

Later, the final trial in Tivoli was performed, in which the E2E system was tested. The trial was a success, as professional content production could be carried out thanks to the developed components (such as the encoder-5G smart board, media gateway, MOCG, etc.) via 5G connection, both the local studio at Tivoli and the remote contribution from RAI lab.

Fig. 6. Overview of the Tivoli trial. Media gateway and cloud production (top) and video cameras with 5G interface units (bottom).

6.3. Use case 3: Live immersive media production

During the final UC3 field trial, the viability of a full E2E FVV live deployment to stream and record an event over a 5G network was demonstrated. The trial was chiefly intended to bring the use case into a real environment and validate each of the modules and components. This final trial was successful and provided relevant information

as a result of all the work carried out during the project. The event consisted in a live music performance by professional artists which was produced as a FVV service in real-time and streamed to the final user. The event took place in Nokia premises in Madrid (Spain), and the FVV content was also recorded to demonstrate the FVV playback functionality of the system. Furthermore, Grafana dashboards were shown and monitored during the whole session. The results collected provide useful insights on options to reduce, if necessary, the amount of data to deliver FVV providing the highest possible quality to the end users. Also, they can help define trajectories that can be appealing for the users. Regarding the delivery network, with the results obtained during the final trial for UC3, we can certify that the expected KPIs have been met for four different scenarios and the whole setup is working as expected with two QoS slices.
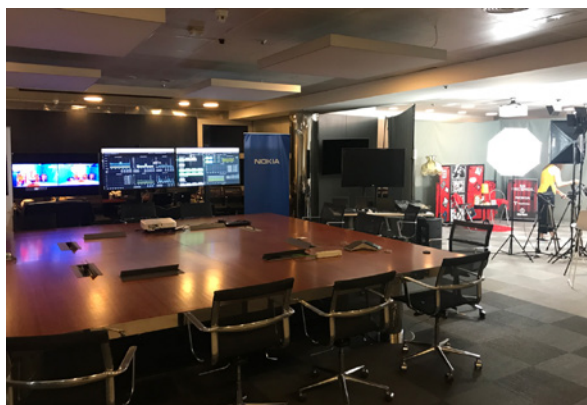

Fig.7. Trial music show.

Fig. 8. Trial Location.

7. CONCLUSIONS

5G-RECORDS aimed at exploring the opportunities that 5G technology components, integrated into NPNs, bring to professional audio-visual content production. 5G-RECORDS partners worked for 26 months to exploit the potential of 5G to greatly facilitate and possibly even revolutionize media content production. During this time, 5G-RECORDS proved that

5G components and NPNs can be used successfully within several content production scenarios, providing in most cases the required performance and functionalities expected from the network. However, some aspects of the technology are yet in a very early stage of maturity and, therefore, it is necessary to further work around these limitations by developing new, non-existing features or improving the current ones. This is the case of use cases like live audio production use cases since extensive effort and development of the ecosystem is still needed to make 5G technology feasible for such use cases. In any case, 5G-RECORDS consortium dedicated great efforts in developing and integrating components and features in the 5G infrastructures to meet the requirements of 5G-RECORDS use cases. All these technical efforts have culminated in several successful final trials which have demonstrated that 5G media content production is a reality, but of course not trivial yet.

Thus, this project could serve as a good starting and reference point for the professional media content production industry, opening doors to build future projects on the base of 5G-RECORDS.

8. REFERENCES

[1] D Gomez-Barquero, I Alepuz, C Avellan, S García, A Rodrigo, E Madejon, N Garcia, "5G Key Technology Enablers for Emerging Media Content Production Services (5G-RECORDS)," [Online]. Available: https://www.5grecords.eu/.

[2] 5G-RECORDS, "Deliverable D2.1 - Use cases, requirements and KPIs," 2021.

[3] 5G-RECORDS, "Deliverable D4.2 - Integration of 5G components (phase-2)," 2022.

[4] 5G-RECORDS, "Deliverable D5.3 - Final trials and technology validation," 2022.

Acknowledgments:

Antennas and Propagation Lab (APL)

HEAD OF THE GROUP RESEARCH REPORT

The Antennas and Propagation Lab (APL) is a research group 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 wireless systems, with special emphasis on potential mm-wave frequency bands. Antenna analysis and design carried out at APL cover a wide range of applications, e.g. mobile and satellite communications, Wi-Fi, Bluetooth, UWB, IoT or on-body applications.

APL 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, APL 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, MYSPHERA or AITEX.

1.- Project activities

The group activities are developed into four main research lines:

- ◆ Application of the Theory of Characteristic Modes for antenna design in different applications (IoT, MIMO, UWB, RFID, WPT, 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.

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

Name of the project: **MAOCOM-6G: Design of MAterials Optimized for an objective function and their application to 6G COMmunication systems.**

Funding entity and duration: Generalitat Valenciana, 2021-2025.

Summary of the project: The objective of the project is the design of artificial materials (metamaterials or metasurfaces) aimed to exhibit singular or unusual properties when interacting with electromagnetic waves (e.g., reflections, transmissions, and unusual dispersion of the waves). The materials will be designed to operate at the mm-Wave and sub-THz band and will be created using an in-house-developed advanced mathematical optimization code, which will be able to optimize the position of microscopic elements embedded in a macroscopic substrate. These novel materials will be fabricated and tested in the APL facilities at iTEAM. The materials will allow to gain a greater control of the environment of the radio signal propagation, being the objective to create a smart environment around the user for the 6G communication signal propagation.

Name of the project: **A6GMODEL-UPV: Measurement techniques and advanced channel models for the definition of future 6G systems (PID2020-119173RB-C21).**

Funding entity and duration: Agencia Estatal de Investigación. Ministerio de Ciencia e Innovación. MCIN/ AEI/10.13039/501100011033/, 2021-2023.

Summary of the project: The new application technologies envisioned for the next decade make that technical performance requirements of 6G must be higher than those currently achieved by 5G. Requirements of large bandwidths (to be defined, but higher than 400 MHz), high peak data rate (more than 1 Tbps), high user experience rate (on the order of 1 Gbps), density of connected devices (10^7 devices/km^2) and user plane latency (from 25 µs to 1 ms), to mention the most representative, require technical challenges at the PHY layer, but also new improvements in the core network. To overcome these technical challenges, 6G wireless channels need to be thoroughly studied, since the knowledge of the channel is the basis
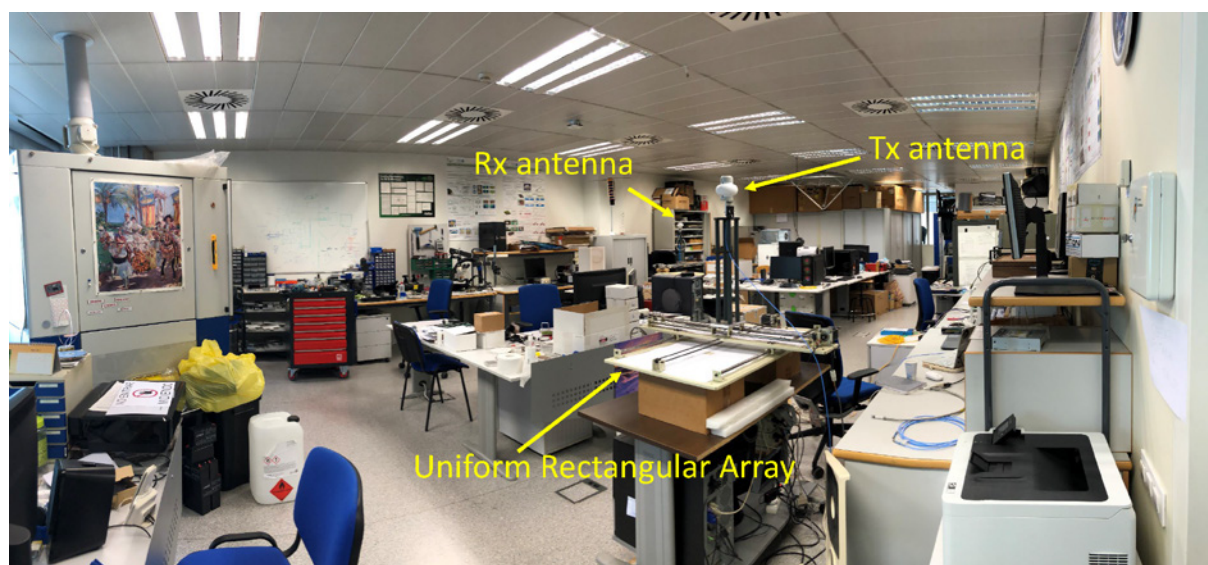
MmWave channel measurements in a rich scattering environment (A6GMODEL-UPV project).

for designing, optimizing and evaluating the performance of any wireless system. As in 5G, the definition of 6G once again represents a challenge in channel measurements and modelling. The introduction of new enabling technologies, e.g., very large arrays and distributed arrays, and large bandwidths require more complete and robust channel models.

Based on the starting hypothesis, the objective of the project is to develop wireless channel models and generate the channel knowledge required to the definition, standardization, and deployment of the future 6G systems. As indicated in the future vision of channel models in Section 1, important contributions are expected to be made in the three following challenges:

◆ Definition of a new taxonomy of radio channels.

◆ Inclusion of very large MIMO arrays and distributed MIMO arrays in the wireless channel model.

◆ Development of hybrid Quasi-Deterministic channel models.

To achieve the objective of the project, we define a methodology that combines channel measurements, channel simulations, and experimental and theoretical channel modelling.

Name of the project: **RECOMM: REconfigurable antennas for mm-wave broadband COMMunications**
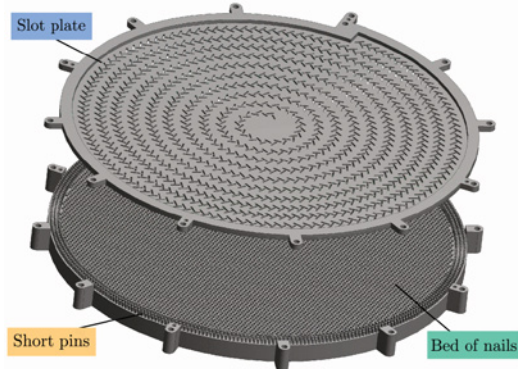
Funding entity and duration: Proyecto PID2019-107688RB-C22 de la Agencia Estatal de Investigación (MCIN/ AEI/10.13039/501100011033), 2020-2022.

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 beam pointing, 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.

RECOMM project: All-metal circularly-polarized radial-line slot-array antenna in Ka-band.
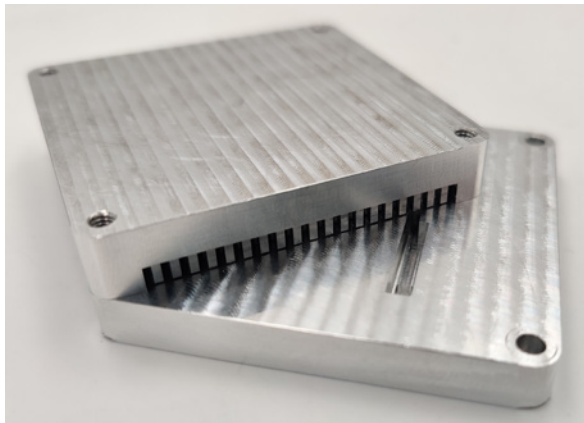
*RECOMM project: Novel half-mode groove-gap waveguide for mm-wave device design.*

Name of the project: **MUMSYS: MUltimode and Multibeam reconfigurable x-wave antennas for communication and sensing SYStems.**

Funding entity and duration: Proyecto PID2019-107885GB-C32 de la Agencia Estatal de Investigación del Ministerio de Ciencia e Innovación, 2020-2022.

Summary of the project: The main goal 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 focus on various areas:

- Development of an integral equation approach for computational modelling of dielectric mediums. The code presents high efficiency, and it has direct application to the study of dielectric lenses.

- Design of multibeam and mutimode antennas for the sub-6 GHz band, using the Theory of Characteristic Modes. Different antenna designs for 5G base stations with MIMO capability have been developed for the sub-6 GHz band, based on the combined use of multiple feed points and resonant cavities of arbitrary shape.

- Design of a time-multiplexed array, according to new standards for determining the angle of arrival of the waves. Antenna arrays have been developed for angle-of-arrival detection applications and digital beamforming at the LTE-A (1.8 GHz) and 5G (2.6 GHz) bands.

- Fabrication and measurement of a set of LTCC antennas with ceramic materials for the sub-6 GHz band.
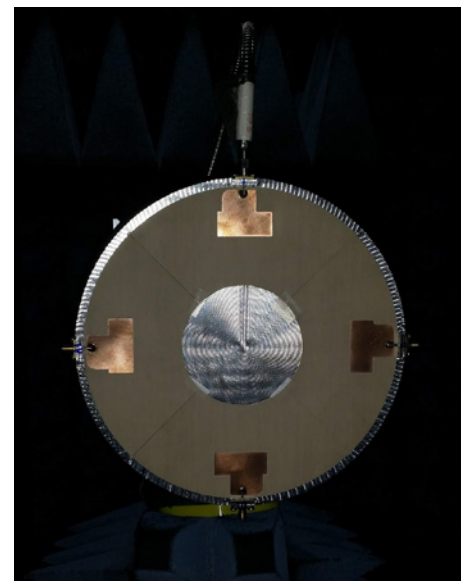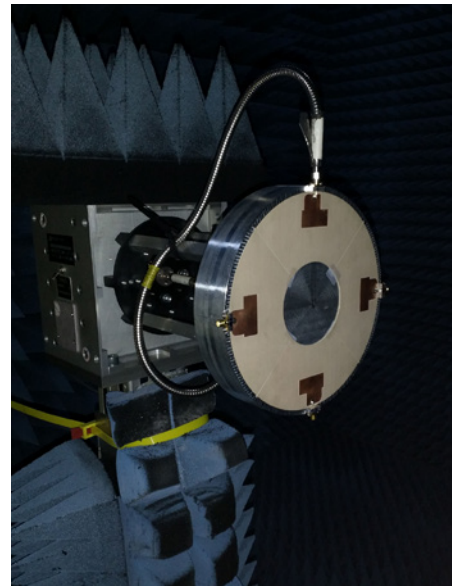
UWB cavity backed antenna for Massive MIMO Systems operating in vehicular environments.
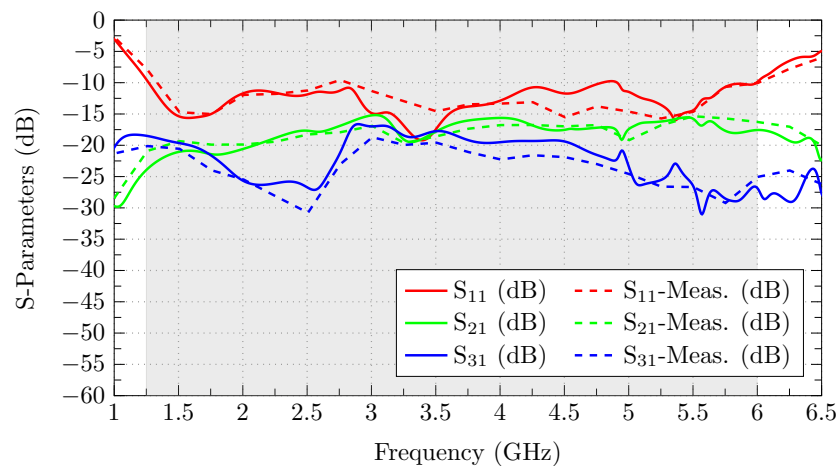
Measured S-parameters (MUMSYS project).

Different models of chip-type antennas have been manufactured with ceramic substrates using Low Temperature CoFired Ceramic (LTCC) technology. The new development features a compact size, good efficiency, does not require a "clearance" zone to be integrated into the PCB, and does not detune when installed on IoT devices and sensors of different sizes.

◆ Fabrication and measurements of a prototype of a reconfigurable multibeam mm-wave indoor low-cost for 5G and beyond base station, based on metallic planar lenses. A multi-beam multi-feed antenna prototype based on a low-cost flat metallic lens has been fabricated and characterized at UPV. In order to obtain a reconfigurable beam antenna for applications in the 5G millimeter wave band, the focal point is controlled by feeding the lens in different positions. Channel measurement are being performed at UPCT, yielding good results.
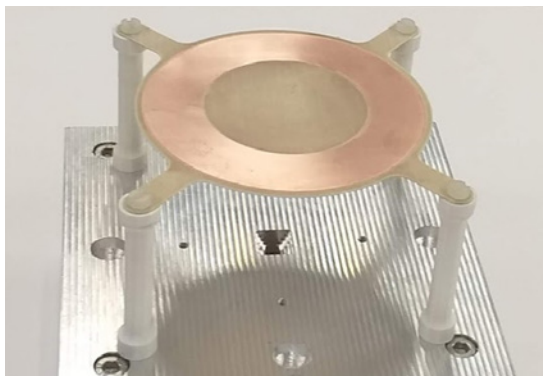
Ring shaped metallic lens prototype.
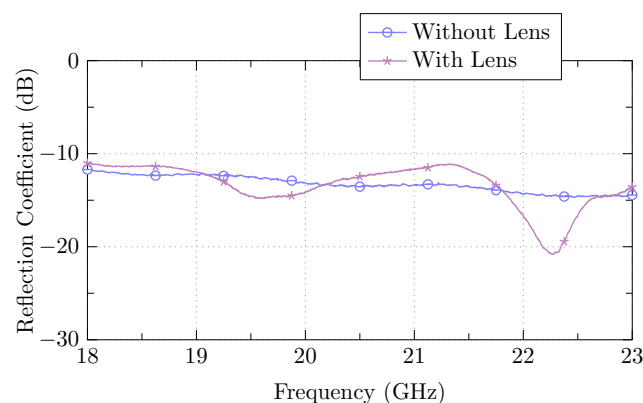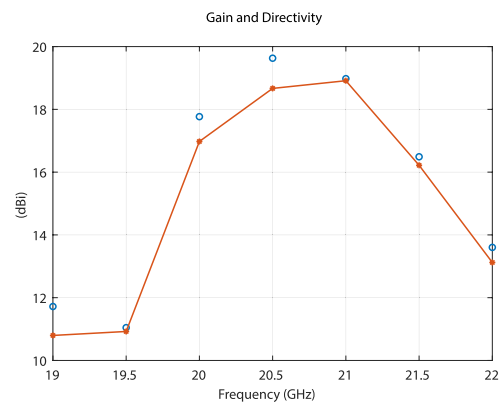
Measured results for the gain, directivity and S_{11} (dB) (MUMSYS project).

Name of the project: ***INNOdeAPI: Innovation and beekeeping development in the region of Murcia.***

Funding entity and duration: ASOCIACIÓN PARA LA INNOVACIÓN Y EL DESARROLLO APÍCOLA. 2022-2023.

Summary of the project: The aim of this project is to design a complete electromagnetic system for the location of queen bees inside honey combs using Radio Frequency Identification (RFID) at 868 MHz. Small RFID tags are commercially available, but none of them meet the specifications that are needed for this application, so it is necessary to make an specific tag design. The APL research team has designed an external antenna that will be integrated with a proper chip in an RFID tag. This tag will be placed on a queen bee and will allow determining its location in a honey comb. The APL team will also develop a flat planar antenna with circular polarization for the portable reader of the detection system.


RFID chip antenna used to detect queen bees in a honeycomb (INNOdeAPI project).

Name of the project: **BRODER: INVESTIGACIÓN Y DESARROLLO DE TEXTILES INTELIGENTES EMPLEANDO TECNOLOGÍA DE BORDADO.**

Funding entity and duration: Asociación de Investigación de la Industria Textil AITEX. 2021-2022.

Summary of the project: The objective of this project is to generate different coil designs on a textile substrate using an embroidery machine for the development of wireless energy transmission/reception systems. Specifically, the project contemplates carrying out the following developments: Design of textile loops with the capacity to charge batteries for robots, drones or even electric vehicles, development of smart textiles that obtain the energy necessary for their operation wirelessly, without the need for a battery and development of textile loops capable of feeding environmental sensors using NFC technology.
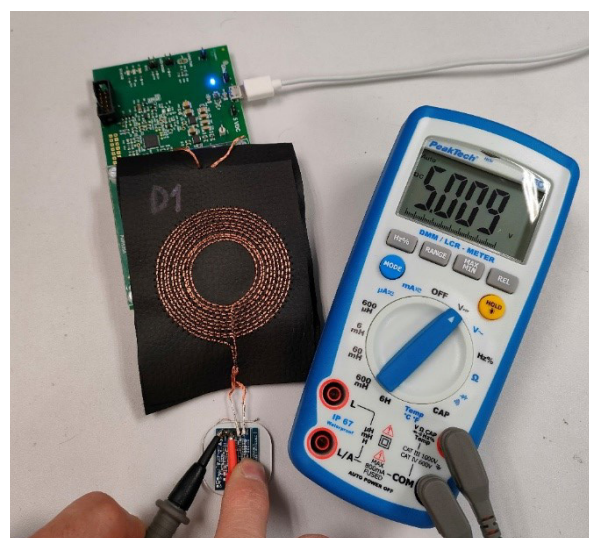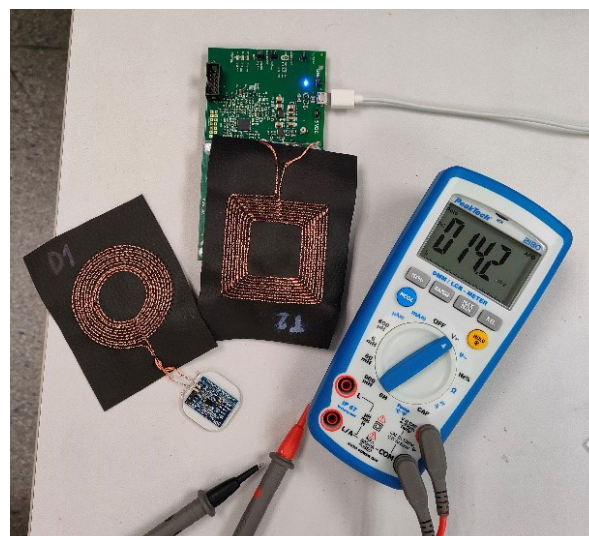
Set-up used to validate the correct operation of the textile antennas (BRODER project).

2.- Research results

Name of the project: ***FLAT PANEL ANTENNA***

Funding entity and duration: Tampa Microwaves, 8 months

Summary of the project (no more than 300 words per project): The project's purpose was to design two flat panel antennas for TX and RX, respectively, for satellite communications. The panels should provide fixed beam patterns with very good circular polarization (AR<1.5 dB) in the corresponding frequency bands of 19.2 to 21.2 GHz (RX) and 29-31 GHz (TX). Along with the full-size panels design, the project includes the design, fabrication, and measurement of two smaller size panels (16x16 elements array) as a prove of concept.

The project was successfully completed in May 2022. No images of the antennas are shown due to confidentiality.

2.1.- Featured publications

1. Sector Unit-Cell Methodology for the Design of Sub-6 GHz 5G MIMO Antennas, J. Molins-Benlliure, M. Cabedo-Fabrés, E. Antonino-Daviu and M. Ferrando-Bataller, *IEEE Access*, vol. 10, pp. 100824-100836, 2022, **DOI:** 10.1109/ACCESS.2022.3207163.

A novel methodology based on the sectorization of multiple-port cavities with azimuthal symmetry into sector unit cells is presented to design 5G multiple-input multiple-output (MIMO) sub-6 GHz antennas. The methodology divides an N-port cavity antenna into N unit cells and predicts the performance of the N-port design with the analysis of two adjacent cells. This approximation reduces the time and complexity of the simulation of cavity antennas with a high number of ports.

2. Half-Mode Waveguide Based on Gap Waveguide Technology for Rapid Prototyping, M. Ferrando-Rocher, J. I. Herranz-Herruzo, A. Valero-Nogueira and M. Baquero-Escudero, *IEEE Microwave and Wireless Components Letters*, vol. 32, no. 2, pp. 117-120, Feb. 2022, **DOI:** 10.1109/LMWC.2021.3119534.

A half-mode gap waveguide technology for rapid prototyping is explored for the first time. Two devices have been designed and measured for demonstration purposes, a power divider and a curved waveguide. Both devices are constructed from two non-contacting metal pieces: one with half horizontally-polarized groove and the other with a uniform pinned surface, acting as a high impedance surface. These devices stand out for their ease of fabrication and open a horizon for cheaper and more robust microwave designs.

3. High-Efficiency Ka-Band Circularly Polarized Radial-Line Slot Array Antenna on a Bed of Nails, J. I. Herranz-Herruzo, A. Valero-Nogueira, M. Ferrando-Rocher and B. Bernardo-Clemente, *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 5, pp. 3343-3353, May 2022, **DOI:** 10.1109/TAP.2021.3137376.

A half-mode gap waveguide technology for rapid prototyping is explored for the first time. Two devices have been designed and measured for demonstration purposes, a power divider and a curved waveguide. Both devices are constructed from two non-contacting metal pieces: one with half horizontally-polarized groove and the other with a uniform pinned surface, acting as a high impedance surface. These devices stand out for their ease of fabrication and open a horizon for cheaper and more robust microwave designs.

4. Single-Layer Sequential Rotation Network in Gap Waveguide for a Wideband Low-Profile Circularly Polarized Array Antenna, M. Ferrando-Rocher, J. I. Herranz-Herruzo, A. Valero-Nogueira and B. Bernardo-Clemente, *IEEE Access*, vol. 10, pp. 62157-62163, 2022, **DOI:** 10.1109/ACCESS.2022.3182336.

A low-profile circularly-polarized sequential rotation fed 4x4 array antenna working in Ka-band is presented. The particularity of the antenna lies in its single-layer sequential rotation feed network using a combination of groove and ridge gap waveguides. The basic radiating element is one slot loaded by a simple coffee-bean-shaped parasitic element on top. Experimental results show an antenna matching below –10 dB in a 13.6% bandwidth and a measured axial ratio below 1.3 dB in the desired band.

5. Antenna Element Design Using Characteristic Mode Analysis: Insights and research directions, J.J. Adams, S. Genovesi, B. Yang, E. Antonino-Daviu. *IEEE Antennas and Propagation Magazine*, vol. 64, no. 2, pp. 32-40, April 2022, **DOI**: 10.1109/MAP.2022.3145718.

This paper provides a comprehensive review of recent applications of characteristic mode analysis (CMA) to innovative antenna element designs, including multiport, circularly polarized, wideband, reconfigurable, and dielectric resonator antennas (DRAs). Emphasis is placed on the interpretation of the characteristic modes (CMs) for those unfamiliar with the method and physical insights gained from the characteristic eigenvalues and eigenvectors of an antenna. In addition, we review CMA-based design strategies and specific design examples that highlight the application of CMA to various types of antennas. Ultimately, this article seeks to demonstrate the value of CMA-based design insights for antenna engineering and look toward promising new research directions for CMA and antenna research.

6. Wireless Channel Analysis Between 25 and 40 GHz in an Intra-Wagon Environment for 5G Using a Ray-Tracing Tool, J. Pascual-Garcia; L. Rubio; V. M. Rodrigo Penarrocha; L. Juan-Llacer; J.M. Molina-Garcia-Pardo; C. Sanchis-Borras; J. Reig, *IEEE Transactions on Intelligent Transportation Systems,*

2022, **DOI:** 10.1109/TITS.2022.3199159.

In this work, the wireless channel in an intra-wagon environment is thoroughly analyzed using simulations performed with a ray-tracing tool calibrated and validated with wideband measurements. Thanks to the accurate ray-tracing tool the main replicas are identified in different typical user equipment-access point positions; the contribution of each propagation mechanism to the total power is extracted; and the angular spread in azimuth and elevation for the direction of arrival and departure are obtained. This analysis is performed in the frequency range from 25 to 40 GHz, where spectrum for several 5G bands has been already allocated.

7. A Comparison Between Concentrated and Distributed Massive MIMO Channels at 26 GHz in a Large Indoor Environment Using Ray-Tracing, J. R. Perez; L. Valle; O. Fernandez; R.P. Torres; L. Rubio; V.M. Rodrigo Peñarrocha; J. Reig, *IEEE Access,* vol. 10, pp.65623-65635, 2022, **DOI:** 10.1109/ACCESS.2022.3184450.

In this paper, a comparative analysis between concentrated and distributed massive multiple-input multiple-output channels (C-mMIMO and D-mMIMO respectively), in an indoor environment using ray-tracing (RT) in the 26 GHz band is presented. The comparison is carried out in a realistic scenario consisting of a floor of a large building. The simulations emulated the up-link channel in an indoor cell in the framework of a time division duplex (TDD) - orthogonal frequency division multiplexing (TDD-OFDM) system. The results show that the D-mMIMO channel outperforms the C-mMIMO one from the point of view of their behavior in broadband as well as in terms of the obtainable capacity.

8. Millimeter Wave MISO-OFDM Transmissions in an Intra-Wagon Environment, C. Sanchis Borras; J.M. Molina-Garcia-Pardo; L. Rubio; J. Pascual-Garcia; V.M. Rodrigo Peñarrocha; L. Juan Llacer; J. Reig, *IEEE Transactions on Intelligent Transportation Systems,* vol. 22, Issue: 8, 2021, **DOI:** 10.1109/TITS.2020.2983028.

In this paper, the maximum achievable throughput is analyzed in the intra-wagon channel when multiple-input single-output (MISO) and orthogonal frequency division multiplexing (OFDM), MISO-OFDM, techniques are used. This analysis is performed from real wideband propagation channel measurements at 28 and 37 GHz,

two potential frequency bands to deploy the future 5G wireless communications networks. Four different scenarios in terms of the access point (AP) and user equipment (UE) positions inside the wagon have been considered, using 4 and 8 antennas at the AP. These 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, where high-data-rates are expected to support different types of digital applications.

9. Fading Evaluation in Standardized 5G Millimeter-Wave Band, T.R. Rufino Marins; A.A. Dos Anjos; C. R. Nogueira Da Silva; V.M. Rodrigo Penarrocha; L. Rubio; J. Reig; R.A. Amaral De Souza; M. Daoud Yacoub, *IEEE Access,* vol. 9, pp. 67268 - 67280, 2021, **DOI:** 10.1109/ACCESS.2021.3076631.

This paper reports on a thorough measurement campaign conducted in an indoor environment characterized by rich-multipath scattering, a part of a modern building, with floor and ceiling constructed of reinforced concrete over steel plates with wood and plasterboard-paneled walls. Particularly, measurements have been performed in a variety of scenarios, under line-of-sight (LoS) and non-line-of-sight (nLoS) conditions, for a wide range of frequencies, namely from 25 to 40 GHz.

10. Novel Asymmetric T-Shaped Radiating Element for Circularly-Polarized Waveguide Slot Arrays, J. I. Herranz-Herruzo, M. Ferrando-Rocher, A. Valero-Nogueira, B. Bernardo-Clemente, *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 11, pp. 7452-7461, Nov. 2021, **DOI:** 10.1109/TAP.2021.3076277.

An all-metal T-shaped radiating element is conceived with the aim of replacing the usual rectangular slots and attaining all-metal circularly polarized arrays. The design of resonant shunt arrays has been addressed for validation purposes. The experimental results of two sample linear arrays at 30 GHz demonstrate the design accuracy and manufacturing reliability, reporting an axial ratio below 2 dB within a bandwidth of 1.9 GHz and a peak efficiency around 98%.

11. Switchable T-Slot for Dual-Circularly-Polarized Slot-Array Antennas in Ka-Band, M. Ferrando-Rocher, J. I. Herranz-Herruzo, A. Valero-Nogueira and B. Bernardo-Clemente, *IEEE Antennas and Wireless Propagation Letters*, vol. 20, no. 10, pp. 1953-1957, Oct. 2021, **DOI:** 10.1109/LAWP.2021.3101156.

Two slotted array antennas working in Ka-band with switchable circular polarization capability are presented. Radiating elements in both antennas are reconfigurable T-shaped slots, forming a linear 1x10 and a corporate-fed 2x2 array, respectively. Good polarization purity is achieved for both polarization senses and in both prototypes. The fundamental contribution of this letter is to propose a simple mechanism to switch the circular polarization sense in a low-cost, low-profile, and high-efficient antenna.

12. Low-profile UWB antenna with unidirectional radiation pattern analyzed with the theory of characteristic modes, C. R. Peñafiel-Ojeda, M. Cabedo-Fabrés, A. Llanga-Vargas, M. Ferrando-Bataller, *AEU - International Journal of Electronics and Communications*, vol. 142, 202.

This paper presents a low-profile Ultra Wide Band (UWB) antenna with polarization diversity for new 5G base stations. The antenna consists of a metallic ring capacitively fed with four circular monopoles and reinforced with a cylindrical cavity to generate a unidirectional radiation pattern. The Theory of Characteristic Modes is used to analyze and explain the behaviour of the proposed antenna excited with differential feeding configurations.

13. Responsivity enhancement of a strained silicon field-effect transistor detector at 0.3 THz using the terajet effect, I. V. Minin, O. V. Minin, J. Salvador-Sánchez, J. A. Delgado-Notario, J. Calvo-Gallego, M. Ferrando-Bataller, K. Fobelets, J. E. Velázquez-Perez and Y. M. Meziani, *Optics Letters*, vol. 46, n. 13, pp.3061-3064, 2021.

The enhancement of responsivity by more than one order of magnitude of a silicon-based sub-terahertz detector is reported when a mesoscopic dielectric particle is used to localize incident radiation to a sub-wavelength volume and focus it directly onto the detector. A strained-silicon modulation field-effect transistor is used as a direct detector on an incident terahertz beam at 0.3 THz. A systematic study in which Teflon cubes are placed in front of the detector to focus the terahertz beam is performed.

Multimedia Communications Group (COMM)

HEAD OF THE GROUP RESEARCH REPORT

During the last year 2021/2022, the main lines of research of the Multimedia Communications Group (COMM) have continued to be focused on multimedia systems and user Quality of Experience (QoE). The work carried out in multiple public funded projects has focused on the distribution of multimedia content using protocols like Dynamic Adaptive Streaming over HTTP (DASH) and studying low latency variants. In fact, new developments have been released as open source in this topic. Additionally, the monitoring tasks and improvements on the urban platform in MAtchUP project have continued this year, following the group trend inside the Smart City and IoT (Internet of Things) projects.

These lines of action have been articulated through the execution of different research and development projects, european, national and regional funded projects, as well as scientific publications in both international conferences and journals.

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

1.- Project activities

Internet of Things and Smart Cities

The use of sensors and application of Internet of Things (IoT) are key factors to improve the life of citizens in the increasingly popular Smart Cities. 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. At this point, an urban platform is important to gather, collect, process and store all this data. In this sense, in the recent years several technologies and standars have appeared proposing architectures, protocols and components for urban platform implementations, like FIWARE. FIWARE is a market-driving open source software, combining components and standard architectures to enable the connection to IoT with context information management and Big Data services that can be stored in the cloud, and it is the stantard which the Valencia urban platform is based on.

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
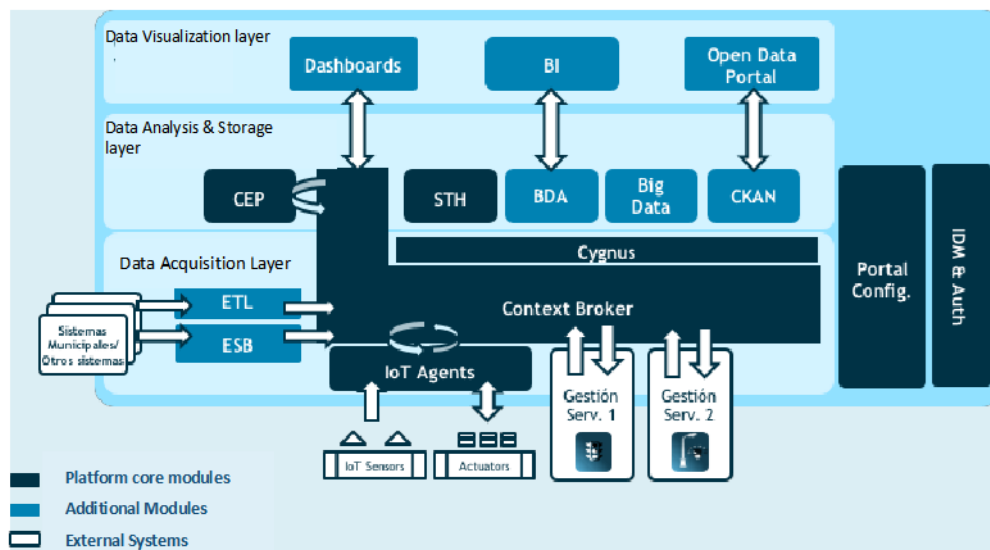
FIWARE building blocks and architecture in Valencia urban platform

for the new services and devices integrated into the urban platform based on FIWARE.

Audio and video synchronization in production systems

During the previous years, we developed an application to carry out an automatic realization of a recording in real-time and tested in real scenarios, such as city council plenary sessions, where the application detected the active microphones in each instant of time and decided which camera should be on air. After the successful tests, this year we have focused on the development of new improvements to the application, adding further compatibility to new microphone brands and systems and deploying a mobile app to manage the production system from a smartphone. Additionally, we worked on improving the scalability by implementing multi-bitrate adaptive encoding using Amazon Web Services (AWS) platform.

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. 2017-2023.*

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.*

In the Valencia demo pilot, sensors have been installed during the project, collecting data about four main pillars, Energy, with data from energy consumption, comfort, energy storage, energy generation, energy accumulation; Mobility, with data from electric and hybrid
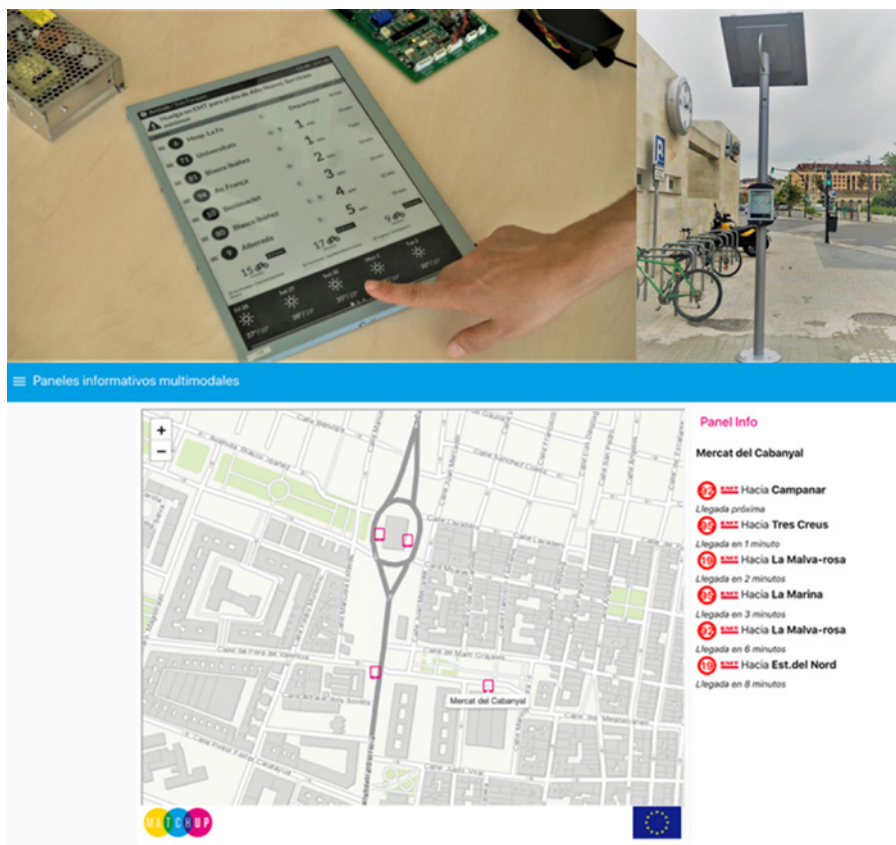
Multimodal hub info panel and dashboard.

buses and electric bikes and vehicles from the municipality; ICT, with data from the urban platform and connectivity; and Social, with data from the social interventions and improvements. As an example, one of the interventions within the project was to develop e-ink solar-powered panels showing information about transport lines and schedules in the city multimodal hubs. This information is also available through a dashboard on the web.

The project is in its final stage. Almost all interventions are deployed and data is being collected and monitored. Moreover, some tasks in this phase are devoted to the analysis of the data quality and avoid or correct the errors that can arise from the data collecting process. Last developments are foreseen to be deployed shortly.

In addition, the project has been extendend one more year (until september 2023). During this extra year it is intended to collect more data from sensors in order to obtain enough insights and extract conclusions on the impact that the project interventions have had on the city.

Name of the project: *Sistema de realización audiovisual automatizada y desatendida* (Automated and unattended audiovisual production system)

Webpage of the project: *https://esveu.es*

Funding entity and duration: *Generalitat Valenciana IVACE (Institut Valencià de Competitivitat Empresarial). 2020-2022.*

Summary of the project: *The main objective of the project is the design and development of a new multimedia system for automated and unattended audiovisual recording and production. At the same time, the recording is timestamped with the start and end of each participant in the meeting. The new solution is designed for environments in which the recording of a session or meeting involving several participants, such as a municipal plenary session of a city council, a conference or a meeting of the board of directors of a company, is carried out.*

The main novelty of this solution is that it allows an automated and unattended management of the production process, i.e., without requiring a dedicated person to carry out the realization of the different shots that make up the video. Also, by enabling the generation of timestamps of the video recording, it allows the identification of the person involved for subsequent location in a concrete and immediate way. The project

thus aims to implement a new application responsible for managing the entire process of making and recording a session.

Automatic video production system in a plenary session.

Name of the project: *Nueva plataforma a bordo basada en redes 5G y WI-FI 6 para medios de transporte terrestre.*

Webpage of the project: *https://www.azimutelectronics.com/*

Funding entity and duration: *Ministry of Science and Innovation. CDTI (Center for the Development of Industrial Technology). FEDER Funds. 2020-2022.*

Summary of the project: *The main objective of this project is the design and development of a new entertainment and communications platform for means of transport based on 5G and Wi-Fi 6 networks. Specifically, the platform is oriented to ground transportation (buses, trains). The generation of this new solution requires research on 5G and Wi-Fi 6 technology and its application to the transmission of multimedia content in mobility environments, as well as the software development of the management processes of this new communications technology and, ultimately, of a new entertainment platform capable of working on these new standards, thus making the most of the technological innovations and advantages it introduces, generating new services for the passenger.*

2.- Research results

2.1.- Featured publications

1. DASH Streaming traffic influence over energy efficient ethernet to improve energy savings. T. R. Vargas, J. C. Guerri, P. Arce. Ad Hoc Networks, vol. 136, article 102951, doi https://doi.org/10.1016/j.adhoc.2022.102951, 2022.

Dynamic Streaming over HTTP (DASH) is the main standard used in online video

streaming services, given that more than 1.2 billion pay subscribers around the world use this standard. This fact entails billions of streaming connections between video servers and client displays. These devices involved in the streaming connection use an Ethernet Interface Card that consumes energy. In order to reduce the energy consumption, IEEE proposed the 802.3az Energy Efficient Ethernet standard, with a mechanism to make the network card change to a low power consumption mode when it is not in transmission mode. This behavior will be beneficial for services where traffic is sent in bursts, for instance video packet bursts like in video streaming over Real Time Transport Protocol in IPTV or the widely used DASH standard. Therefore, in this study the Ethernet traffic pattern when transmitting online video content using DASH is characterized in order to analyze the efficiency of the IEEE 802.3az standard under this video streaming scenario, and to verify the convenience of activating this energy saving alternative at the network interface of billions of client devices. The experiments have been conducted using a test-bed consisting of a full DASH streaming architecture, comparing different video segment sizes and changing the available bandwidth during the experiments in different scenarios in order to analyze the effect of the DASH content segment size on the Ethernet traffic pattern to identify

the trade-off between energy efficiency, the energy savings, and the impact on the performance of the dynamic adaptation on the video streaming and reproduction.

2. Study on the Impact of DASH Streaming Services using Energy Efficient Ethernet. T. R. Vargas, J. C. Guerri, P. Arce. Proceedings of the 18th ACM Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks (PE-WASUN'21), November 22–26, 2021, Alicante, Spain. Pp 89-94, doi https://doi.org/10.1145/3479240.3488527, 2021.

Dynamic Streaming over HTTP is the main standard used for online video streaming, service that has about 1.1 billion subscribers around the world. That implies billions of streaming connections between video servers and client displays. These devices involved in the streaming connection use an Ethernet Interface Card that consumes energy. In order to reduce the energy consumption, the IEEE 802.3az Energy Efficient Ethernet has been proposed. In this study, the ethernet traffic pattern when transmitting online video content is characterized in order to analyze the efficiency of the IEEE 802.3az standard under video streaming scenarios, and to verify the convenience of activating this energy saving alternative at the network interface of billions of client devices.

Microwave Applications Group (GAM)

HEAD OF THE GROUP RESEARCH REPORT

Over the past year (September 2021 to July 2022), the group has continued working on two projects awarded with national and regional public funds, respectively. Both projects are in the final phase of their whole execution periods, and promising results are being obtained during their development.

In addition to these two R&D projects, the group has national and regional public funding to train new researchers and PhD students, who are already collaborating with the group in its different technology transfer activities and present research lines.

Furthermore, GAM continues involved in two European Union projects and grants, which are developed in collaboration with other European universities and industries, for the training of young scientists and performing research activities in the satellite communications 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 many other space-sector companies.

Regarding to the training capacity of the group, it is worth mentioning that two doctoral thesis 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 on topics related to their PhD thesis works. During the next years it is hoped that we can continue sending students to carry out the planned stays, and to host 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 European, 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

GUIDESAT Project: Advanced Design of New High Frequency Components in Compact Waveguide Technologies for Future Telecommunications Satellites

Retos Investigación: Proyectos I+D+i 2019

Programa Estatal de I+D+i Orientada a los Retos de la Sociedad, Ministerio de Economía y Competitividad, Gobierno de España. 01/06/2020 – 31/05/2023

The most relevant European satellite communication systems and applications are currently supporting a huge number of services of modern Digital Society. Among them, we highlight the global navigation system GALILEO, meteorological and Earth Observation programs like COPERNICUS, nanosatellites for scientific missions and big constellations of small satellites for implementing the upcoming "Internet of Satellites", as well as large Telecommunication satellites in geostationary orbit. Thanks to these satellite payloads, many civil and military applications and a wide variety of sectors are being benefitted globally.

With the aim of keeping the growing rate of such applications, all cited space programs are already deploying their future evolutions. Among them, one can find the Galileo second generation project, the next generations of meteorological (METEOSAT and METOP) satellites, the near future SENTINEL missions, the coming breed of small platforms for Starlink and OneWeb constellations, and the new large multi-beam space platforms operating in the millimetre wave (and sub-millimetre wave) frequency ranges (up to some terahertz). All these next-generation satellites will need more advanced communication payloads based on novel equipment with more stringent requirements.

The main aim of this coordinated project is to address all identified challenges by designing novel passive components and antennas for next-generation satellite communication systems, including their prototyping and experimental validation. For that purpose, the four sub-projects will closely work on all available high-frequency technologies: i.e. more classical ones based on planar circuits and waveguides, more recent integrated planar waveguides with/without dielectric substrate, and the promising concept of gap waveguides. Advanced materials (such as bioplastics, artificial materials, liquid crystals, and also gallium nitride and graphene for terahertz frequencies), as well as manufacturing techniques (classical milling, 3-D fabrication methods, LTCC and micromachining processes), will be also investigated.

This project has been funded by the Programa Estatal de I+D+i Orientada a los Retos de la Sociedad, Ministerio de Economía y Competitividad, Gobierno de España.

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

www.selectorspace.eu

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

Figure 1: SELECTOR Project Logo.

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 devises 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 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

https://tesla.unilim.fr/

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 set up collaborations 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, 12 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, and IEEE Journal of Microwaves).

At the same time the group has presented up to 7 scientific communications in prestigious international conferences (such as the 2021 IEEE MTT-S International Microwave Symposium -IMS-, 2021 IEEE MTT-S International Microwave Filter Workshop -IMFW-, 2021 51st European Microwave Conference -EuMC-, 2021 18th European Radar Conference -EuRAD-), some of them in on-line format.

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 one new patent (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:

High Power RF Discharge Detection Technique Based on the In-Phase and Quadrature Signals, Oscar Monerris-Belda, Raúl Cervera, Miguel Rodríguez, Elena Díaz-Caballero, Carlos Alacide, John Petit, Vicente E. Boria, Benito Gimeno, David Raboso, IEEE Transactions on Microwave
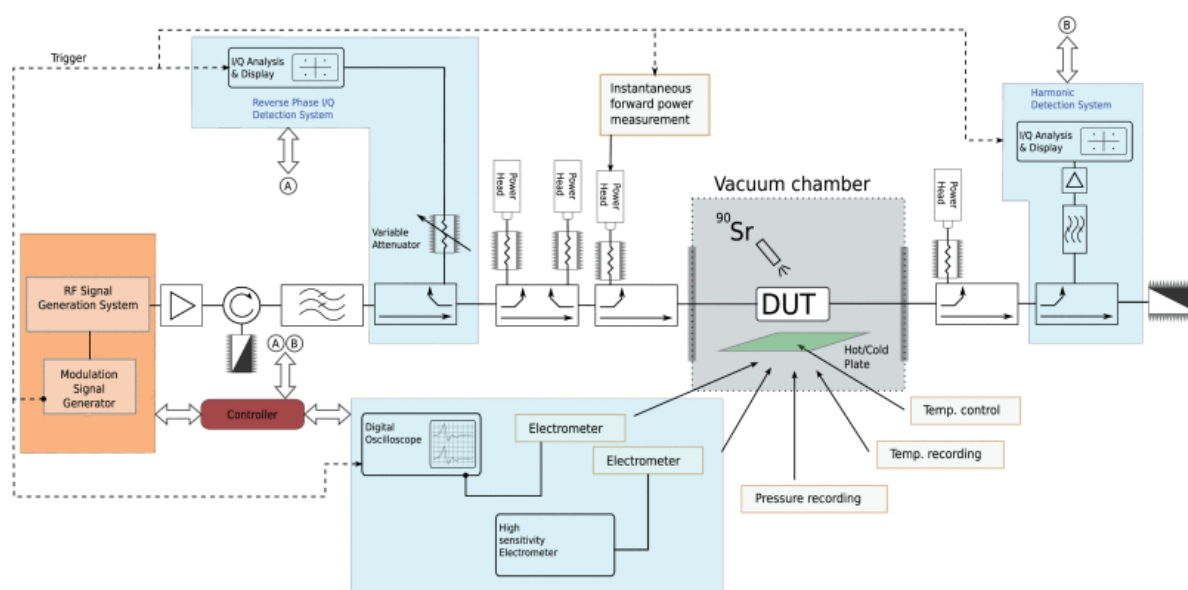
Figure 3: Schematic of the test bed used for the IQ validation test campaign.

Theory and Techniques, Vol. 69, no. 12, pp. 5429-5438, Dec. 2021, Q1

This work presents a novel RF breakdown detection system, which monitors the same parameters as the microwave nulling system but with several advantages. The proposed technique is broadband and uses a larger analysis bandwidth, thus reducing the cases in which a small response is difficult to be classified. It also represents a major step forward in high power testing as it runs without human intervention, warning the operator or decreasing the RF power automatically.

Hybrid Wideband Staircase Filters in Rectangular Waveguide With Enhanced Out-of-Band Response, Joaquin F. Valencia Sullca, Marco Guglielmi, Santiago Cogollos, Vicente E. Boria, IEEE Transactions on Microwave Theory and Techniques, pp. 3783 – 3796, Vol. 69, Issue 8, Aug. 2021, Q1

The objective of this article is to describe the design of a new family of wideband filters in a rectangular waveguide based on hybrid couplings and a staircase configuration. The design of several hybrid filter prototypes is discussed in detail, and finally, simulations and measurements for an eight-pole filter prototype are also compared, showing very good agreement, thereby fully validating both the design procedure and the new filter topology that we propose.

Inline Combline Filters of Order N With up to N + 1 Transmission Zeros, José Joaquín Vague, David Rubio, Miguel Angel Fuentes, Santiago Cogollos, Mariano Baquero, Vicente E. Boria, Marco Guglielmi, IEEE Transactions on Microwave Theory and Techniques, pp. 3287 – 3297, Vol. 69, Issue 7, July 2021, Q1

In this article, we describe several alternative inline implementations for combline filters with transmission zeros (TZs) located both below and above the passband. Good agreement between the measured and simulated results is demonstrated, thereby fully validating the new filter concepts.
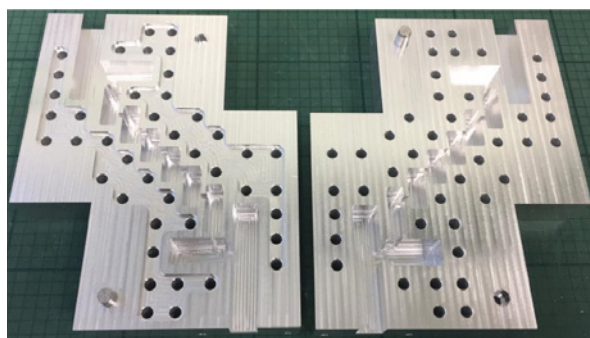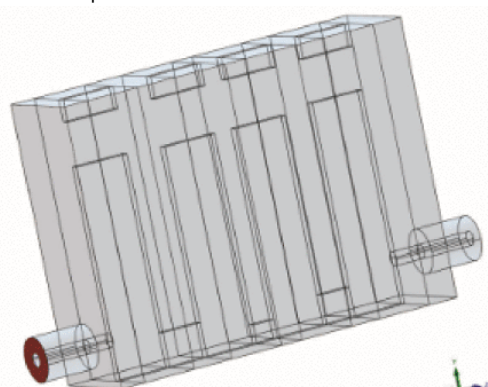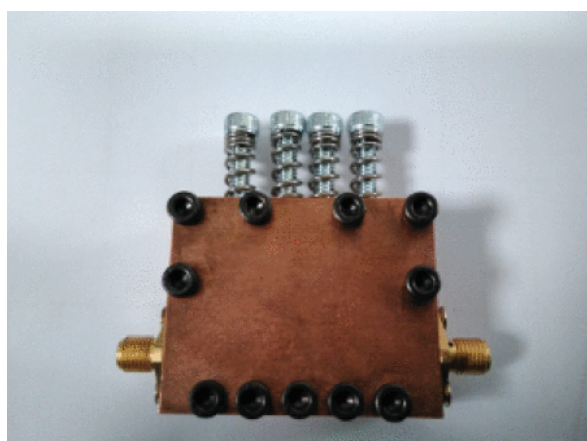

Figure 4: Manufactured prototype in aluminum (no silver plating).

(a)

(b)

Figure 5: Four-pole filter with TZs above the passband. (a) Inner view designed with FEST3D. (b) Photograph of the manufactured prototype.

Microstrip to Double Ridge Empty Substrate Integrated Waveguide Transitions Based on Exponential and Superelliptical Dielectric Taper, David Herraiz, Héctor Esteban, Darío Herraiz, Ana Vidal, Angel Belenguer, Vicente E. Boria, IEEE Access, vol. 9, pp. 165745-165753, Dec. 2021
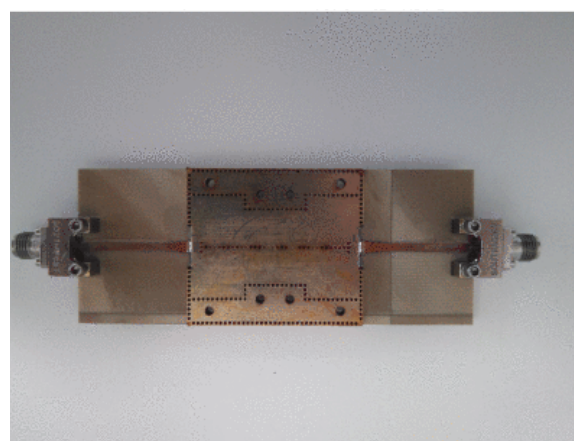
The operational (monomode) bandwidth of the ESIW can be increased with the Single Ridge ESIW (SRESIW). However, the bandwidth can be further increased with the Double Ridge ESIW (DRESIW). In this paper, a brief study of possible DRESIW geometries has been performed, and
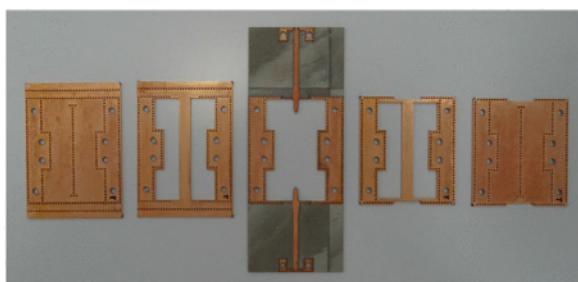
(a)
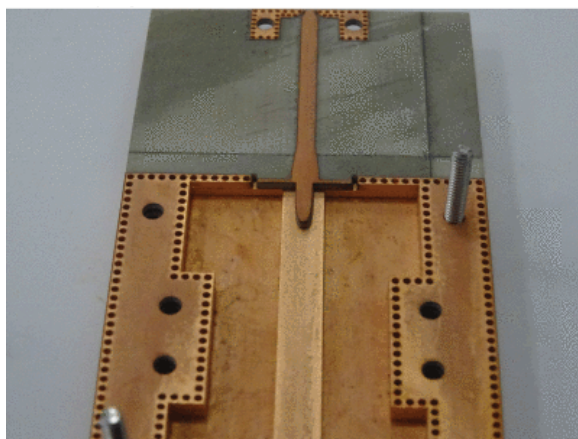
(b)

(c)

Figure 6: Back-to-back manufactured prototype of the superellipse microstrip to DRESIW transition.

two transitions from microstrip line (MS) to DRESIW with a dielectric taper geometry based on different equations are proposed.

Inductive Cascaded Quadruplet with Diagonal Cross-Coupling in Rectangular Waveguide, Santiago Cogollos, Richard J. Cameron, Marco Guglielmi, Juan Carlos Melgarejo, Vicente E. Boria, IEEE Access, vol. 10, pp. 45241-45255, April 2022

The objective of this paper is to show how inductive quadruplets with diagonal cross-couplings can be used as building blocks for filters in rectangular waveguide. The results show excellent agreement with simulations, thereby fully validating both the new family of filter structures and the related design procedures.
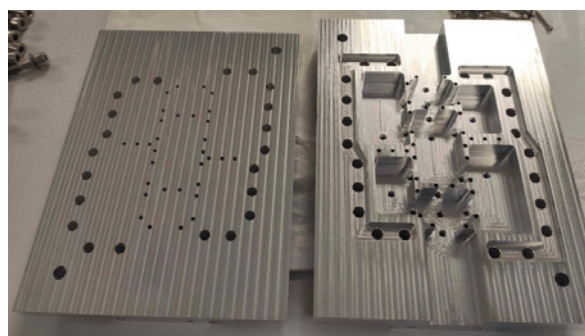

Figure 7: Manufactured 7-4 symmetric filter. Top cover (left) and body (right).

Multipactor Threshold Estimation Techniques Based on Circuit Models, Electromagnetic Fields, and Particle Simulators, Pablo González, Carlos Alcaide, Raúl Cervera, Miguel Rodríguez, Óscar Monerris, John Petit, Ana Rodríguez, Ana Vidal, Joaquín Vague, José V. Morro, Pablo Soto, Vicente E. Boria, IEEE Journal of Microwaves, vol. 2, no. 1, pp. 57-77, Jan. 2022

This paper describes the different techniques available to predict the multipactor threshold

power for radio frequency (RF) and microwave passive hardware under continuous wave (CW) excitation, from cumbersome particle simulations to fast approximate methods based on circuit models. The techniques are applied to both wideband and narrowband application examples. The predictions have been compared with measured thresholds of manufactured samples obtained with a novel multipactor test bed, thus allowing to highlight the advantages and limitations of each technique and particle simulator.

		Coaxial line	Combline filter	
Frequency (GHz)		1.575	1.548	1.575
Measured		220 W	12.0 W	17.9 W
Circuit Approach	Predicted	353.4 W	14.5 W	20.4 W
	Delta	2.06 dB	0.82 dB	0.57 dB
SPARK3D	Predicted	251.8 W	12.1 W	19.9 W
	Delta	0.59 dB	0.04 dB	0.46 dB
CST-PS	Predicted	238 W	9.5 W	14.1 W
	Delta	0.34 dB	-1.01 dB	-1.04 dB

Table 1: Comparison between Predicted and Measured Multipactor Thresholds for the Coaxial Transmission Line and the 3-Pole Combline Filter Samples.

Audio and Communications Signal Processing Group (GTAC)

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 2021-22 mainly on active sound field control, personal sound zones, 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. Two new national projects have begun this year, "Adaptive Sound-processing Technologies foR soundfIeld Deployment: algorithms, tools and test beds (ASTRID)." and "Characterization of dynamic acoustic environments using machine learning (DYNAMIC)". Whereas, the national project "Intelligent Spatial Audio Synthesis and Customization (ISLA-THESON)" and the regional project "Smart Social Computing and Communication (COMTACTS)" are in halfway through their completion. On the other hand, the national projects "Dynamic Acoustic Networks for Changing Environments (DANCE)" has ended with great success, achieving its main objectives by creating several demonstrators for indoor dynamic real-life scenes. For instance, personal audio system for indoor environments and massive multichannel noise reduction in open-plan offices. More details of the projects' achievements are shown at the "Ongoing Projects" section.
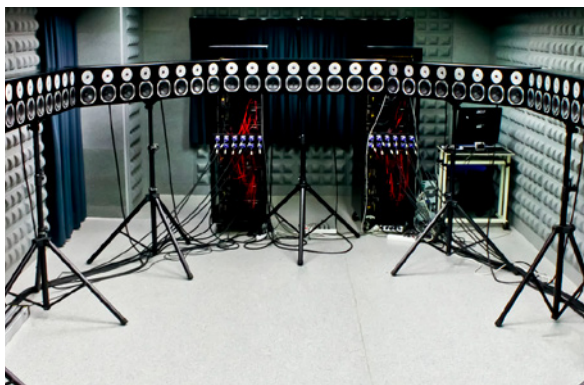

Figure 1. Listening room overview.

With regards to the GTAC audio facilities, a large listening room of 40 m2 is totally equipped with top-notch audiovisual and control instrumentation (see Fig. 1).

Moreover, car seats surrounded by sound transducers are placed in this room to measure both objectively and perceptually, local sound zones around listener heads in enclosures (such as a cabin of a public transport or a living room, Fig. 2). As singular equipment, a self-designed robotic X-Y-Azimuth platform (see Fig. 3), which can support and move any sound recording or emitting device, is available, i.e., arrays of microphones, loudspeaker or audio-head. This platform will be used to characterize and monitor dynamic acoustic zones in indoor environments, as well as experiment with moving sound sources.
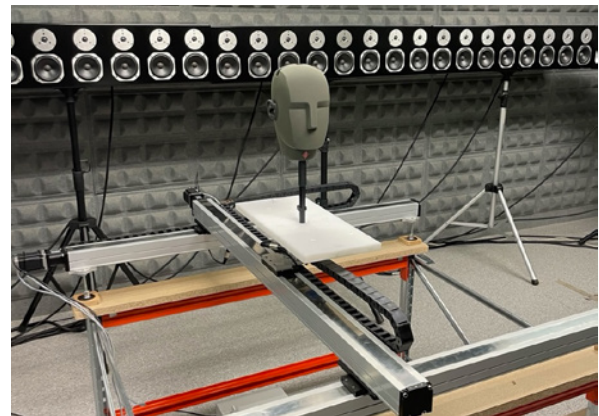

Figure 2. Car seats with transducers.

Figure 3. Robotic X-Y-Azimuth platform.

On the other hand, the laboratory for perceptual spatial sound of Fig. 4 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. The HRTF is 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. 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.

Figure 4. General view of the perceptual spatial sound laboratory.

1.- Project activities

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

***Title*: INTELLIGENT SPATIAL AUDIO: SYNTHESIS AND CUSTOMIZATION (ISLA-THESON)**

Funded by: Spanish Ministry of Science, Innovation and University. 2019-2022.

The sound industry has been experiencing profound changes in recent years under the perspective of three complementary approaches: the individual, the group and the contents. Due the advances in virtual reality, mobile devices, video games and innmersive 3D movies, the spatial audio is today a discipline that attracts the attention of the industry. In this context, spatial audio systems try to accurately recreate the acoustic sensations that a listener would perceive within a real listening environment. 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 finding an indirect way to get individualized HRTF is required. At ITEAM, we have built a new facility to measure HRTFs of real subjects in an efficient way (Fig.4).
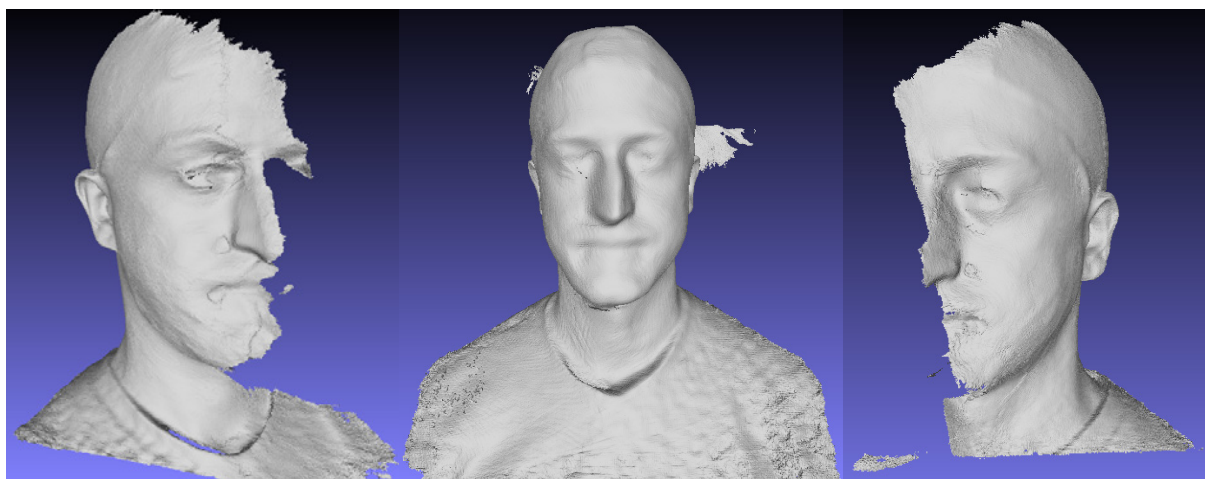

Fig. 5 Three different scans of the subject.

By employing Deep Learning techniques and photographs of the ear/head, we have achieved an HRTF personalization of better quality than previous methods. Previously, a new system has been constructed for the capture and extraction of individual anthropometric parameters from photographs. To this end, work is being done on the creation of 3D models through mobile devices that are equipped with depth cameras. 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. 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.

A smartphone with a 3D scan application was used to obtain these 3D models. The smartphone had a dot projector which could project more than 30000 infrared dots on the subject and a TrueDepth camera which could capture the images for the 3D reconstruction. Then, the 3D scan application could convert these images into a 3D model with a resolution range of 0.5 mm to 8.0 mm. Three different

Figure. 6 Final model of the subject.

scans were taken, one of the head and two of both ears (see Fig. 5). Finally, in post-processing unwanted parts of the model were removed, holes were filled, and the scans were merged (see Fig.6).

Title: SMART SOCIAL COMPUTING AND COMMUNICATION (in Spanish: COMUNICACIÓN Y COMPUTACIÓN INTELIGENTES Y SOCIALES - COMTACTS)

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.

COMTACTS 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, COMTACTS 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.

Title: DYNAMIC ACOUSTIC NETWORKS FOR CHANGING ENVIRONMENTS (DANCE)

Webpage: www.dance.upv.es

Funded by: Spanish Ministry of Science, Innovation and University. 2019-2022.

DANCE is a coordinated project that has developed distributed algorithms and systems to deal with different audio applications under the common frame of dynamic scenarios. Some of their tasks are: self-localization of nodes' positions, estimation of dynamic room impulse responses (RIRs) and inverse filters, fast adaptation and/or implementation over a distributed and heterogeneous network, characterization and control strategies adapted to the environments where control or listening points may vary with time, development of multiuser perceptual equalization methods to improve the listening experience in presence of undesired ambient noises. Additionally, emerging computing tools have been used to meet the real-time requirements of audio rendering and control in time-varying scenarios.

The DANCE project has included the development of four testbeds. The first one allows 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. Examples are: watching TV and simultaneously listening to different languages in different positions, improving the listening experience in any room, tracking the listener over the home. The second demonstrator consists of a network of acoustic nodes that work together and simultaneously for the classification of sounds in the city using a Raspberry as a computing device. The third testbed comprises a massive multichannel noise reduction system for open-plan offices. The goal is to reduce the annoyance caused by the ambient noise and speech produced by other workers in open working spaces through their masking with pleasant sounds. The four testbed includes the development of perceptual equalization methods to improve the listening experience in presence of undesired broadband noises with multiple listeners.

Title: CHARACTERIZATION OF DYNAMIC ACOUSTIC ENVIRONMENTS USING MACHINE LEARNING (DYNAMIC)

Funded entity and duration: Spanish Ministry of Science, Innovation and University. 2022-2025.

The overall user experience of media and entertainment is expanding in terms of the types of services, the environment where it is consumed, and the devices used to access them. However, the COVID-19 pandemic has abruptly changed our habits and most of the audiovisual content is consumed at homes instead of at theaters. Moreover, innovative entertainment experiences such as streaming music concerts have joined the traditional video (films and user-generated content) streaming and gaming services. At this point, it is necessary to develop intelligent sound reproduction systems that can provide in a natural way (without headphones) good-quality sound for a full immersive experience. The primary goal of the DYNAMIC project is to investigate on sound space control applications for real and dynamic environments using novel machine and deep learning techniques, aiming at maximum performance and feasibility.
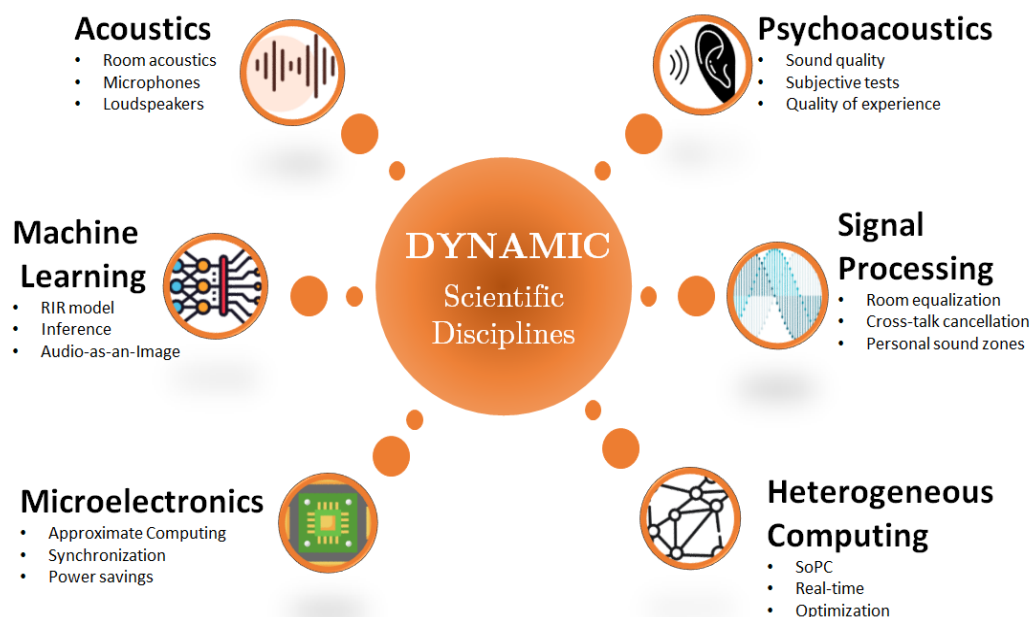

Figure 7. Multidisciplinary diagram of the coordinated DYNAMIC project.

The acoustic environment is the physical medium by which the sound propagates, and its physical characteristics have been studied for decades. Thanks to the digital approach to the physical modelling of sound propagation, the acoustic environment can be described by its room impulse response (RIR). To deal with dynamic acoustic environments where each time a listener moves a new RIR is generated, all the possible RIRs of the room should be known a priori. In this project, a new approach to the digital characterization of dynamic acoustic environments is proposed based on machine learning (ML) and, especially, deep Learning (DL) algorithms. DL has successfully addressed a wide range of applications in the audio field, as source separation, speech enhancement and acoustic echo cancellation. Most of the ML models that try to solve these problems have one thing in common: the input to the neural network is an image that represents the audio content, usually the short-term Fourier Transform (STFT). This will be the main approach to tackle the problem.

***Title*: ADAPTIVE SOUND-PROCESSING TECHNOLOGIES FOR SOUNDFIELD DEPLOYMENT: ALGORITHMS, TOOLS AND TEST BEDS (ASTRID).**

Webpage of the project: https://gtac-iteam-upv. github.io/Astrid/

Funding entity and duration: Spanish Ministry of Science, Innovation and University. 2022-2025.

ASTRID is proposed as a project that involves several PhD researchers in the field of signal processing and computing, with long-term, well-established collaboration between them and showed experience to confidently address a suitably selected range of scientific and technological challenges in the field of signal processing of sound signals and computing. Furthermore, this project exhibits a strong vocation for research excellence, internationalization, training and transfer. ASTRID Project promotes multidisciplinary research since it mobilizes complementary knowledge from various scientific fields, mainly: signal processing, telematics, computing, applied matematics and applied physics; to get its objectives, which are oriented to: research, dissemination, formation and transfer; towards finding solutions to society's problems, through publication of research results in forums with high scientific and technological impact, technology transfer and internationalization of activities.

The general objective of ASTRID is to contribute to sound-field deployment systems by the design and development of test beds, algorithms and computational kernels, that improve the performance, increase the resiliency, and reduce the energy consumption in order to transfer knowledge and tools to the productive sector. ASTRID will address complex sound deployment scenarios along three research fields: Fast multichannel adaptive algorithms, Distributed and collaborative systems and Psychoacoustic aspects of listening; focused on four related application target domains: Active sound field control, Personal sound zones and spaces, and Computational and mathematical tools for sound processing.

That can be settled down with the following ones: Improve the sound deployment systems in complex scenarios when listener or reproduction zones moves or change. Improve the sound deployment systems in distributed scenarios. Improve human perception of sound deployment systems. Develop and implement a Road Active Noise Control system.

The demand for a quieter and healthier human environment is growing rapidly and needs experts possessing a comprehensive knowledge and practical experience in sound and noise control technology. Currently, market-available solutions are not sufficient in many cases. Regulatory guidelines also favour demand in the noise control system market. But through the completion of ASTRID new feasible and comprehensive noise reducing systems will be developed and delivered, for both indoor environments and vehicle/aircraft cabins, boosting the advancement of European companies in this field and allowing them to take advantage of the growing noise control market.

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

◆ ***Transfer functions of FXLMS-based Multi-channel Multi-tone Active Noise Equalizers.*** *Miguel Ferrer, María de Diego, Gema Piñero, Amin Hassani, Marc Moonen, Alberto González, Electrical Engineering and Systems Science, Audio and Speech Processing, 2022. DOI:* *10.48550/arXiv.2207.01102*.

Abstract: Multi-channel Multi-tone Active Noise Equalizers can achieve different user-selected noise spectrum profiles even at different space positions. They can apply a different equalization factor at each noise frequency component and each control

point. Theoretically, the value of the transfer function at the frequencies where the noise signal has energy is determined by the equalizer configuration. In this work, we show how to calculate these transfer functions with a double aim: to verify that at the frequencies of interest the values imposed by the equalizer settings are obtained, and to characterize the behavior of these transfer functions in the rest of the spectrum, as well as to get clues to predict the convergence behaviour of the algorithm. The information provided thanks to these transfer functions serves as a practical alternative to the cumbersome statistical analysis of convergence, whose results are often of no practical use.

◆ ***Low-complexity soft ML detection for generalized spatial modulation.*** *M. Angeles Simarro, Víctor Manuel García Mollá, Francisco José Martínez Zaldívar, Alberto Gonzalez, Signal Processing, vol. 196, July 2022. DOI:* 10.1016/j.sigpro.2022.108509.

Abstract: Generalized Spatial Modulation (GSM) is a recent Multiple-Input Multiple-Output (MIMO) scheme, which achieves high spectral and energy efficiencies. Specifically, soft-output detectors have a key role in achieving the highest coding gain when an error-correcting code (ECC) is used. Nowadays, soft-output Maximum Likelihood (ML) detection in MIMO-GSM systems leads to a computational complexity that is unfeasible for real applications; however, it is important to develop low-complexity decoding algorithms that provide a reasonable computational simulation time in order to make a performance benchmark available in MIMO-GSM systems. This paper presents three algorithms that achieve ML performance. In the first algorithm, different strategies are implemented, such as a preprocessing sorting step in order to avoid an exhaustive search. In addition, clipping of the extrinsic log-likelihood ratios (LLRs) can be incorporating to this algorithm to give a lower cost version. The other two proposed algorithms can only be used with clipping and the results show a significant saving in computational cost. Furthermore clipping allows a wide-trade-off between performance and complexity by only adjusting the clipping parameter.

◆ ***Weighted pressure matching with windowed targets for personal sound zones.*** *Vicent Molés-Cases, Stephen J. Elliott, Jordan Cheer, Gema Piñero, Alberto Gonzalez, The Journal of the Acoustical Society of America,*

vol. 151, 2022. DOI: 10.1121/10.0009275.

Abstract: Personal sound zones (PSZ) systems use an array of loudspeakers to render independent audio signals to multiple listeners within a room. The performance of a PSZ system, designed using weighted pressure matching, depends on the selected target responses for the bright zone. In reverberant environments, the target responses are generally chosen to be the room impulse responses from one of the loudspeakers to the control points in the selected bright zone. This approach synthesizes the direct propagation component and all the reverberant components in the bright zone, while minimizing the energy in the dark zone. We present a theoretical analysis to show that high energy differences cannot be achieved for the diffuse reverberant components in the bright and dark zones, and so trying to synthesize these components in the bright zone does not lead to the best performance. It is then shown that the performance can be improved by using windowed versions of these measured impulse responses as target signals, in order to control which reverberant components are synthesized in the bright zone and which are not. This observation is supported by experimental measurements in two scenarios with different levels of reverberation.

◆ ***Parallel signal detection for generalized spatial modulation MIMO systems.*** *Victor M. Garcia-Molla, M. Angeles Simarro, F. J. Martínez-Zaldívar, Murilo Boratto, Pedro Alonso, Alberto Gonzalez, The Journal of Supercomputing, vol. 78, pp. 7059 – 7077, 2022. DOI:* 10.1007/s11227-021-04163-y.

Abstract: Generalized Spatial Modulation is a recently developed technique that is designed to enhance the efficiency of transmissions in MIMO Systems. However, the procedure for correctly retrieving the sent signal at the receiving end is quite demanding. Specifically, the computation of the maximum likelihood solution is computationally very expensive. In this paper, we propose a parallel method for the computation of the maximum likelihood solution using the parallel computing library OpenMP. The proposed parallel algorithm computes the maximum likelihood solution faster than the sequential version, and substantially reduces the worst-case computing times.

◆ ***Compensating first reflections in non-anechoic head-related transfer function measurements.*** *Jose J. Lopez,*

Abstract: Personalized Head-Related Transfer Functions (HRTFs) are needed as part of the binaural sound individualization process in order to provide a high-quality immersive experience for a specific user. Signal processing methods for performing HRTF measurements in non-anechoic conditions are of high interest to avoid the complex and inconvenient access to anechoic facilities. Non-anechoic HRTF measurements capture the effect of room reflections, which should be correctly identified and eliminated to obtain HRTFs estimates comparable to ones acquired in an anechoic setup. This paper proposes a sub-band frequency-dependent processing method for reflection suppression in non-anechoic HRTF signals. Array processing techniques based on Plane Wave Decomposition (PWD) are adopted as an essential part of the solution for low frequency ranges, whereas the higher frequencies are easily handled by means of time-crop windowing methods. The formulation of the model, extraction of parameters and evaluation of the method are described in detail. In addition, a validation case study is presented showing the suppression of reflections from an HRTF measured in a real system. The results confirm that the method allows to obtain processed HRTFs comparable to those acquired in anechoic conditions.

- ***Interaural time difference individualization in HRTF by scaling through anthropometric parameters.** Pablo Gutierrez-Parera, Jose J. Lopez, Javier M. Mora-Merchan, Diego F. Larios. EURASIP Journal on Audio, Speech, and Music Processing, Article number: 9, 2022. DOI: 10.1186/s13636-022-00241-y.*

Abstract: Head-related transfer function (HRTF) individualization can improve the perception of binaural sound. The interaural time difference (ITD) of the HRTF is a relevant cue for sound localization, especially in azimuth. Therefore, individualization of the ITD is likely to result in better sound spatial localization. A study of ITD has been conducted from a perceptual point of view using data from individual HRTF measurements and subjective perceptual tests. Two anthropometric dimensions have been demonstrated in relation to the ITD, predicting the subjective behavior of various subjects in a perceptual test. With this information, a method is proposed to individualize the ITD of a generic HRTF set by adapting it with a scale factor, which is obtained by a linear regression formula dependent on the two previous anthropometric dimensions. The method has been validated with both objective measures and another perceptual test. In addition, practical regression formula coefficients are provided for fitting the ITD of the generic HRTFs of the widely used Brüel & Kjær 4100 and Neumann KU100 binaural dummy heads.

2.2.- Featured Conference Proceedings

- ***Perceptual active noise equalization with virtual microphones.** Juan Estreder, Miguel Ferrer, Maria de Diego, Gema Piñero, Alberto Gonzalez, 28th International Congress on Sound and Vibration (ICSV28), Singapur, July 2022.*

- **Conditional Generative Adversarial Networks for Acoustic Echo Cancellation**, F. Pastor-Naranjo, R. del Amor, J. Silva-Rodríguez, M. Ferrer, G. Piñero, V. Naranjo (2022). *30th European Signal Processing Conference, EUSIPCO 2022.*
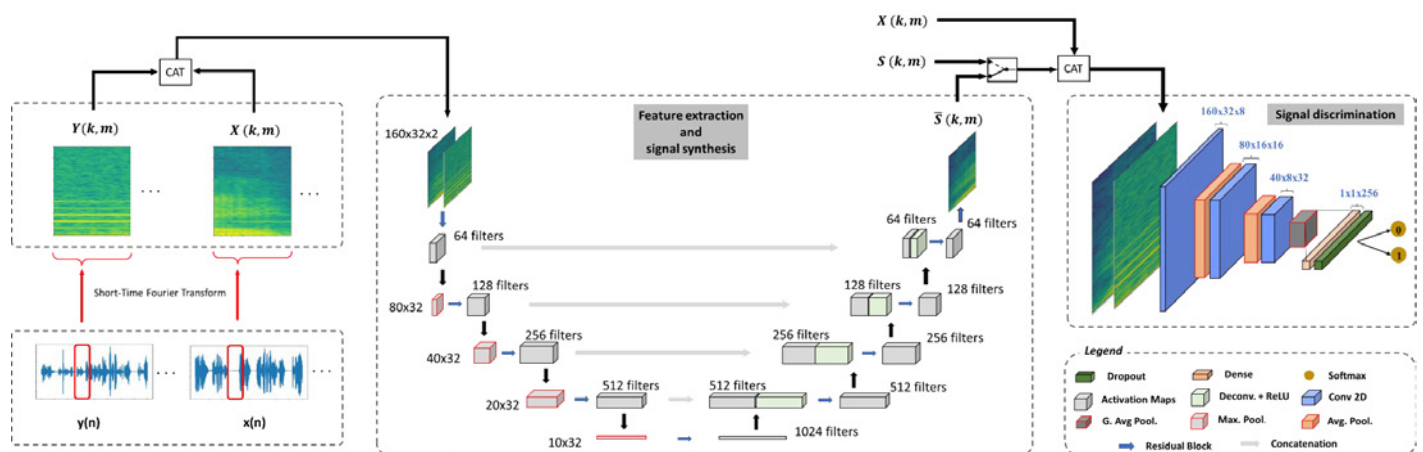
  https://eurasip.org/Proceedings/Eusipco/Eusipco2022/pdfs/0000085.pdf

Figure 8. Proposed framework to perform acoustic echo cancellation.

SIGNAL PROCESSING GROUP (GTS) GTS lab

HEAD OF THE GROUP RESEARCH REPORT

The Signal Processing Group (GTS) produces high-quality basic and applied interdisciplinary research in signal processing and data science. Currently formed by 19 researchers, the GTS faculty, students, and staff continue to work on national and international research projects. The application areas include medicine, industry, underwater acoustics, and technologies for the arts.

The GTS is currently involved in a LIFE European Green Deal project managed by the European Climate, Infrastructure and Environment Executive Agency (CINEA) "Reducing the impact of underwater noise on the marine environment of the Port of Cartagena" (LIFE PortSounds), and several Spanish government-funded projects such as the "Smart sensing of composite materials through non-linear mechanical wave signal processing algorithms" (SMARTSENSE) and the "Informed Methods for Signal Synthesis" (MISS)

A complete list of research activities can be found at http://www.iteam.upv.es/group/gts/

Also, follow us in:

Facebook: https://www.facebook.com/gts.iteam/

1.- Project activities

The GTS has continued researching the established research lines and other emerging activities. A summary of some of the main activities is listed below:

- Signal processing techniques applied to ultrasonic and impact-echo methods for the characterization of composite materials (including cementitious materials): 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 helpful 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), the Department of Civil & Environmental Engineering (University of Illinois), 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 the study of marine animal populations and the impact that anthropogenic sounds have on them. The aim is to help ensure marine biodiversity conservation and sustainable use. For this purpose, we design surveillance systems, create real-time noise maps, and evaluate the results using a risk-based approach. The group collaborates, among other institutions, with the Instituto Español de Oceanografia (IEO) for the Spanish approach to the Marine Strategy Framework Directive (D11), with the Oceanogràfic of Valencia, and with the Cartagena Harbor Authority.

- Applications of biomedicine: Advanced digital image processing through artificial intelligence (deep learning) for biomedical applications, in collaboration with the Clinical Medical Imaging Area of the Hospital Universitario y Politécnico La Fe in Valencia, and the global leader in whole-body medical imaging analysis Quibim.

- Graph Signal Processing (GSP): We continue developing new methods of classification, fusion of classifiers, and signal surrogates based on GSP, which are applied to various practical problems.

- Emerging Signal Processing Techniques for Big Data Health Applications.

- Technologies for the Arts (Soundcool): Last year, we opened a new line of research to use innovative audiovisual technologies derived from Soundcool for treating neurodegenerative diseases. The system is constantly evolving and has adapted to COVID social distancing to be able to work online with users in their own homes. Most of the groups affected by neurodegenerative diseases are the elderly and have been the hardest hit by the pandemic. Especially the group of patients with a mild-moderate impairment who maintained activity outside the home (day centers, etc.) has been those who have shown more significant deterioration with confinement due to the interruption of therapies. Providing them with new alternative therapies suitable for social distancing and working from their homes or centers is essential in the current situation.

1.1.- Ongoing projects

Name of the project: *Reducing the impact of underwater noise on the marine environment of the Port of Cartagena (LIFE PortSounds)*

Summary of the project: *In the first year of the LIFE PortSounds, we thoroughly studied the cetacean species in the Port of Cartagena area. We also defined where the project's impact and control zones will be located and did the first deployments of the PAM devices in these two areas. The towed array recordings are being analyzed, and shortly we will start creating the database of marine mammal sounds in the area.*

Funding entity: *LIFE20 ENV/ES/000387.*

The first deployment of the LIFE PortSounds PAM device and towed array recording campaign

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

Summary of the project: *We continue to work with the Spanish Institute of Oceanography (IEO), developing technology and analyzing data for noise assessment according to the Spanish implementation of European Directive 11 (D11). Specifically, they use our PAM system (named SAMARUC) and the software analysis SamLab. See https://samaruc.webs.upv.es for more details.*

**Funding entity:** *Ministry of Ecological Transition.*
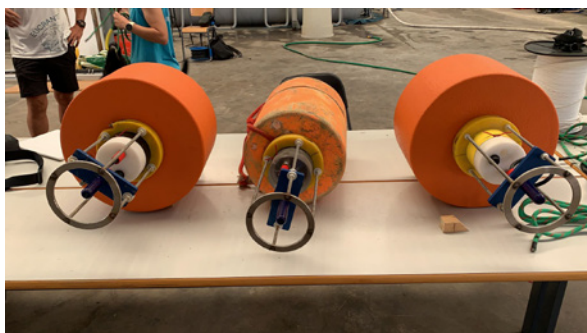
Several SAMARUC recording devices ready to be deployed.

Name of the project: *Cabo Fin Whale Project (CaboRorcual)*

Summary of the project: *The Cabo Rorcual project is a multidisciplinary project that aims to study the fin whale as it passes next to the coast of Dénia and Xàbia (Spain). The goal is to determine the population and route of these marine mammals. We are in the last year of the project, and we have achieved to collect an extensive catalog of fin-whale vocalizations to train automatic deep-learning detection & classification techniques. In addition to the well-known 20 Hz fin-whale notes, we have detected 60 Hz, 80 Hz, and down sweep fin-whale notes.*

Funding entity: *Fundación Biodiversidad*
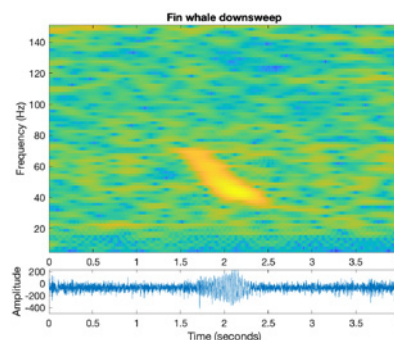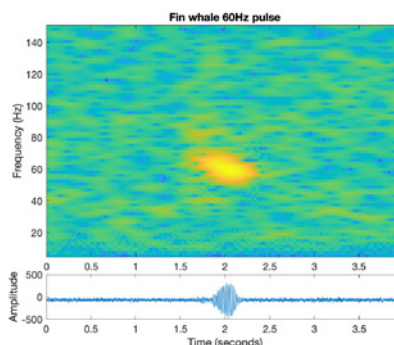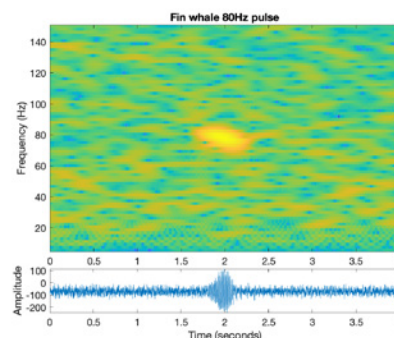
Fin-whale 60 Hz note, fin-whale 80 Hz note, and fin whale down sweep note.

Name of the project: *Non-destructive testing based on mechanical waves*

Summary of the project: *The UPV is studying the use of mechanical waves for the quality control of artificial marble stones. The final goal is to design a system that will be installed in the production line and inspect 100% of the production.*

Funding entity: *Cosentino*

Name of the project: *Smart sensing of composite materials through non-linear mechanical wave signal processing algorithms (SMARTSENSE)*

Summary of the project: *This year we have studied different non-destructive testing (NDT) techniques for quality control of different materials (including composite materials). For that purpose, we compared the mechanical waves obtained using traditional accelerometers and ultrasonic sensors, with those obtained with interferometric sensors, and fiber optic sensors embedded in the material itself. Two examples are Using an automatic shaker to control the impact energy achieving repeatability in NDT of artificial stones, and using an ultrasonic speaker and an automated laser to generate and sense mechanical waves in composite materials.*

Funding entity: *Spanish Government, PID2020-120262GB-I00.*

Automatic impact hammer system.

Monitoring a composite material through an automated scanning laser system and ultrasound parametric speaker.

Name of the project: *Modelos innovadores para la predicción de impagos*

Summary of the project: *This is a project carried out for CAIXABANK, whose objective is to predict defaults on both personal and legal entity loans. The greatest innovation is the implementation of optimal fusion techniques so that the complementarity of different classifiers can be used to achieve a better performance of the final classifier. It has been demonstrated the interest of the approach over thousands of real data provided by CAIXABANK.*

Funding entity: *CAIXABANK.*

2.- Research results

2.1.- Featured publications

- **On training road surface classifiers by data augmentation.** *A. Salazar, A. Rodríguez, N. Vargas, L. Vergara, Applied Sciences, Applied Sciences, Special Issue in Novel Methods and Technologies for Intelligent Vehicles 2022, 12 (7), 3423.*

  It is demonstrated that data augmentation is a promising approach to reduce the size of the captured dataset required for training automatic road surface classifiers. The context is on-board systems for autonomous or semi-autonomous driving assistance: automatic power assisted steering. Evidences are obtained by extensive experiments involving multiple captures from a 10-channel multisensor deployment: three channels from the accelerometer (acceleration in the X, Y and Z axes); three microphone channels; two speed channels; and the torque and position of the handwheel. Those captures were made under different settings: three worm-gear interface configuration; hands on or off the wheel; vehicle speed (constant speed of 10, 15, 20, 30 km/h, or accelerating from 0 to 30 km/h); and road surface (smooth flat asphalt, stripes or cobblestones). It has been demonstrated in the experiments that data augmentation allows a reduction by an ap-proximate factor of 1.5 in the size of the captured training dataset.

  DOI*: 10.3390/app12073423*

- **Automated Cervical Spinal Cord Segmentation in Real-World MRI of Multiple Sclerosis Patients by Optimized Hybrid Residual Attention-Aware Convolutional Neural Networks**. *Bueno, A., Bosch, I., Rodríguez, A. et al., J Digit Imaging, Jul 5, 2022.*

Magnetic resonance (MR) imaging is the most sensitive clinical tool in the diagnosis and monitoring of multiple sclerosis (MS) alterations. Spinal cord evaluation has gained interest in this clinical scenario in recent years, but, unlike the brain, there is a more limited choice of algorithms to assist spinal cord segmentation. Our goal was to investigate and develop an automatic MR cervical cord segmentation method, enabling automated and seamless spinal cord atrophy assessment and setting the stage for the development of an aggregated algorithm for the extraction of lesion-related imaging biomarkers. The algorithm was developed using a real-world MR imaging dataset of 121 MS patients (96 cases used as a training dataset and 25 cases as a validation dataset). Transversal, 3D T1-weighted gradient echo MR images (TE/TR/FA = 1.7-2.7 ms/5.6-8.2 ms/12°) were acquired in a 3 T system (Signa HD, GEHC) as standard of care in our clinical practice. Experienced radiologists supervised the manual labelling, which was considered the ground-truth. The 2D convolutional neural network consisted of a hybrid residual attention-aware segmentation method trained to delineate the cervical spinal cord. The training was conducted using a focal loss function, based on the Tversky index to address label imbalance, and an automatic optimal learning rate finder. Our automated model provided an accurate segmentation, achieving a validation DICE coefficient of 0.904 ± 0.101 compared with the manual delineation. An automatic method for cervical spinal cord segmentation on T1-weighted MR images was successfully implemented. It will have direct implications serving as the first step for accelerating the process for MS staging and follow-up through imaging biomarkers.

DOI: 10.1007/s10278-022-00637-4

◆ ***A Risk-Based Model Using Communication Distance Reduction for the Assessment of Underwater Continuous Noise: An Application to the Bottlenose Dolphin (Tursiops truncatus) Inhabiting the Spanish North Atlantic Marine Demarcation,*** Bou-Cabo, M.; Lara, G.; Gutiérrez-Muñoz, P.; Saavedra, C.; Miralles, R.; Espinosa, M., J. Mar. Sci. Eng., 10, 605, 2022.

Over the last decade, national authorities and European administrations have made great efforts to establish methodological standards for the assessment of underwater continuous noise. The evaluation of the Sound Pressure Level (SPL) at the local or regional scale for 1/3 octave band of 63 Hz and 125 Hz and the identification of long temporary trends were considered to be a priority due to the valuable information they can offer in relation to continuous low-frequency noise. Nevertheless, the methodology to determine threshold values from which to evaluate the Good Environmental Status (GES) has become difficult to define, and new approaches and considerations are currently being discussed by groups of experts. This work presents a methodology to perform the assessment of the GES of a given area by providing a risk index that is related to potential appearance of masking effect due to the underwater noise produced by marine traffic. The risk index is hinged on the calculation of area under curves defined by the density of animals and a variable related to underwater noise SPL, defined as the percentage of communication distance reduction. The methodology presented has been applied to the bottlenose dolphin (Tursiops truncatus) inhabiting the ABIES—NOR marine demarcation to illustrate the possible use of risk-based models to manage marine areas related to human pressures, such as marine traffic, with the potential adverse impact on a given species.

DOI: 10.3390/jmse10050605

◆ ***Impacts of underwater noise on non-mammal marine animals: first (2012-2018) and second cycle (2018-2024) of the marine strategies for the five Spanish marine subregions,*** José Antonio Esteban Simón; Paula Alonso Recarte; Ramón Miralles Ricós; Journal of Animal Law & Interdisciplinary Animal Welfare Studies, 9, 2022.

This paper aims to determine the legal context in which the control of harm to marine animals due to noise pollution does operate. It also describes the extent to which there is already sufficient scientific knowledge and technology to be able to set permissible underwater noise levels. Since the vast majority of studies generally focus on the welfare of marine mammals, particularly cetaceans, this paper focuses on the hearing and communication capacities of the rest of marine animals and advances in the identification of potential harm that may hypothetically result in direct injury - including death - or that may imply other types of mistreatment (increased stress, undesirable behavioral changes, etc.).

Available at: https://www.iustel.com

Mobile Communication Group (MCG)

HEAD OF THE GROUP RESEARCH REPORT

The Mobile Communications Group (MCG) highlighted the leadership of Spain, in general, and Valencia, in particular, in the field of research and development in 5G technology. The MCG has about 40 researchers, including three senior researchers with outstanding biographies and global impact, seven post-doc and twelve pre-doc researchers. It is led by the current Director of iTEAM, Prof. Narcis Cardona.

Researchers from MCG have a consolidated experience in 5G due to their involvement with several international projects related to 5G. The group is now coordinating 6 European projects, all on 5G verticals and the initial stages of 6G, while participating in 8 more competitive projects of the H2020 and FP7 programs.

In addition, the group has a long tradition of cooperation with international companies and established contracts with the major players in the Mobile Networks area, from the Tier-1 operators to the technology vendors. The MCG has contracted with Huawei to create the iTEAM – Huawei Joint Research Center, which involves 12 projects, where the MCG participates in 8 of them.

This last academic year, the MCG has also obtained €8,562,000 in grants within the framework of the call for aid from the Universalization of Digital Infrastructures for Cohesion UNICO -5G I+D 2021 Plan de Recuperación, Transformación y Resiliencia del Gobierno de España, for the development of 3 projects, 12 subprojects in total, and the Plan for the Promotion of Telecommunications Engineering Studies at the UPV.

The group also collaborates with companies in the sector to develop 5G technology, applicable to industry 4.0 and the transfer of knowledge referring to measures in 5G networks and their optimization. The MCG members are very active in dissemination activities.

The main three lines in which the MCG is active are:

◆ Mobile Network Technologies beyond 5G, led by Prof. J. Monserrat.

◆ Broadcast Technologies and standardization, led by Prof. D. Gomez-Barquero.

◆ Body Environment Communications, led by Dr. Concepción García and Prof. Narcis Cardona.

V5G Days 2022

The second edition of V5G Days was held on May 30 and 31, 2022, in the Red Sea Auditorium of the Oceanogràfic de València, in hybrid format, giving continuity to the success achieved in the first edition, the event was extended to two days of duration and was opened to the international public. On this occasion, the V5G Days 2022 event brought together professionals from the telecommunications sector, national and international leaders in the field of 5G, to discuss and present the latest developments, achievements, and challenges of the application of this technology to the industrial field. The theme chosen for this second edition is "5G as a driver of digitization", intending to expose, discuss and demonstrate how 5G technology is becoming a driving force for the modernization of our industry, presenting recent success stories of its implementation in Valencia and the rest of Spain. In total, more than 60 companies from the sector participated, making València the European capital of 5G. V5G Days 2022 was organized by the Mobile Communications Group of iTEAM of the UPV with the collaboration of Mobile World Capital, AMETIC and IEEE ComSoc Latam, and has the support of the València City Council and the Generalitat Valenciana (through the PROMETEO2020/040 project).

Also highlighted the leadership of Spain, in general, and Valencia, in particular, in the field of research and development in 5G technology. The demonstrations that stood out the most these days were those of connected robotics, virtual reality, autonomous driving... There were driving applications with Virtual Reality glasses, immersive mobile tourism experiences with 360° cameras and 5G, smart water meters equipped with 5G technology, and an immersive telepresence application, which allowed participants to feel as if they were teleported to another place (in this case nearby, in another part of the Oceanogràfic) and interact with people. At V5G Days, emphasis was placed on Valencian leadership in other disciplines, such as microelectronics.
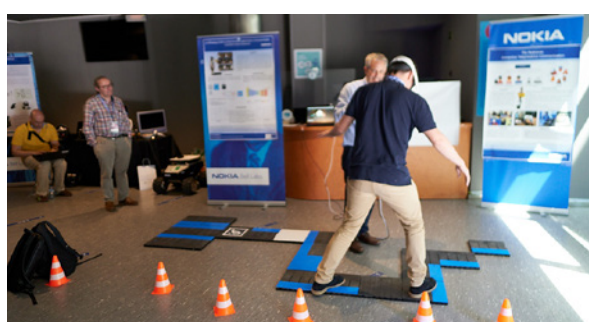
V5G Days 2022.

In addition, for the second consecutive year, the iTEAM's MCG participated in the Mobile World Congress 2022 in Barcelona presenting the "5G underwater drone" demonstration from the Orange stand, together with the Oceanogràfic de València Huawei and Ender Ocean and Content Lab. Those attending the congress could live this immersive experience by controlling in real-time and only with their gestures a submerged robot (ROV) in the shark's aquarium of the Oceanogràfic de València (400 kilometers underwater), all thanks to 5G technology.

5G underwater drone demo at the MWC 2022.

1.- Project activities

1.1.- Ongoing projects

VLC-CAMPUS-5G II (Pilot Test Campus, Development and Demonstration of 5G Mobile Technologies for the Internet of Things and Connected Machines Applied to Logistics)

VLC-CAMPUS-5G II is the project to deploy an experimental field of 5G Mobile Technologies for the Internet of Things and Connected Machines that extends the current VLC-CAMPUS-5G infrastructure (from Release-15 to Release-16 standard).

The new equipment will include the mMTC (massive-Machine-Type Communications) and URRLC (Ultra-Reliable-Low-Latency Communications) functionalities that are fundamental for the Internet of Things and the connection of machines. Those will allow pioneering tests of 5G-IoT connected machines related to the world of Logistics and Industry 4.0 in general, with practical use cases applied to process and safety improvements in the port of Valencia.

During this year, the recruitment calls were launched for the acquisition of required equipment for the construction of the 5G-IoT test campus: Equipment with different types of mobile robots for indoor and outdoor industrial applications consisting of a fleet of mobile robots and a manipulator arm (MY21/ITEAM/S/95), 5G-IoT Release-16 end-to-end connectivity equipment in the frequency band below 6 GHz (MY21/ITEAM/S/96); Core network, radio access network; and 5G-IoT Release-16 devices emulation equipment (MY21/ITEAM/S/115); and 5G-IoT Release-16 end-to-end connectivity equipment in the millimeter wave frequency band (26-28 GHz) (MY22/ITEAM/S/28).

The purchased equipment will be used in the context of the current projects (iNGENIOUS, FUDGE-5G, 5G-TOURS, 5G-RECORDS, CROFT (PROMETEO 2020), ITN-5VC, 5G-INDUCE, 5G-IANA, Red.es 5G Pilots), among others, in which ITEAM participates. **https://vlc-campus5g.com/**

COREMAT-6G (Smart Radio 6G Communications using REconfigurable MATerials)

COREMAT-6G aims at developing smart surfaces from an integral perspective, addressing from the design of the surface materials, their electromagnetic optimization, their influence on channel performance, their use for sensing and localization, as well as their management from the radio access network (RAN). The novelty of COREMAT-6G lays on the use of novel materials capable of changing their complex dielectric properties by adjusting their initial composition in combination with external control signals. These materials are in addition non-metallic, of lower cost and recyclable, so improving the

sustainability of the next generation networks deployment. All these concepts imply an interdisciplinary approach which accounts with highly specialized insight from different players, that will play a key role in the development, manufacturing and commercialization of these devices as 6G technology enablers.

Therefore, this project envisions involving the participation of both the scientific community in academia and research departments at companies, to succeed in the development of smart surfaces and their application.

Concretely, COREMAT 6G (Subproject A – RIS Implementation) will be focused on the research and development of both metallic and non-metallic RIS panels using novel dielectric materials to compare their performance. To achieve this goal, the engineering and design of both the materials of the panel as well as the design and optimization of the elements of the panel from the electromagnetic perspective will be also addressed. Besides, the physical implementation of the surface is also envisioned in the subproject, leading to a final manufactured prototype ready to be used in future applications in 6G networks (Subproject B - RIS Radio and Sensing) or to operate as an element of the network in future 6G systems (Subproject C - RIS Integration on 6G RAN).

Advancing-5G-Digital Twins (Real-time digital twin applications using advanced 5G and 6G technologies for industrial and logistics environments)

The overall objective of the project is to create a flagship 6G application laboratory for real-time digital twins for industrial environments, which impose new requirements on the telecommunication network infrastructure in these vertical industries, and to progress beyond the current state of the art on new promising technological trends to enable the implementation of real-time digital twins, such as 5G-Advanced Internet-of-Things (IoT), edge and cloud computing, and real-time AI/ML (Artificial Intelligence/Machine Learning) analytics.

This project is divided in three subprojects: Advancing-5G-Digital Twins. 5G-IoT platform with edge and cloud computing (ADV5G-TWINS-CLOUD), Advancing-5G-Digital Twins for Industry 4.0 (ADV5G-TWINS-INDUSTRY), Advancing-5G-Digital Twins for Industry 4.0 (ADV5G-TWINS-INDUSTRY).

> *Call for applications for grants PRO-GRAMME FOR UNIVERSALIZATION OF DIGITAL INFRASTRUCTURES FOR UNICO-5G COHESION R&D 2021 published in BOE, on November 24, 2021 belonging to the Plan/Programme Plan for Recovery, Transformation and Resilience of the Government of Spain. From 29/11/2021 to 31/12/2024.*

Advancing-5G-Immersive (Immersive and holographic advanced 5G laboratory)

Advancing-5G-Immersive aims to create a cutting-edge immersive laboratory which will serve as one of the main Spanish testbeds for stakeholders and companies willing to validate their emerging 6G applications. The project is formed by three innovative types of communications: Haptic/Tactile, Holographic, and Telepresence. For each one of them, a subproject has been assigned, since the requirements, capabilities, technology enablers and use cases are different. These credible research proposals are completely aligned to the strategic research agenda of Smart Network and Services (SNS). The three subprojects will foster the creation of a highly-competitive beyond 5G ecosystem in Spain, which will strength the position and participation of Spain in the upcoming SNS work program in Horizon Europe, and therefore increase the reimbursement funding of Spain in this program.

This project will be carried out through the three subprojects: Advancing-5G-Immersive-Holographic (ADV5G-IMM-HOLOGR), Advancing-5G-Immersive-Telepresence (ADV5G-IMM-TELEP), Advancing-5G-Immersive-Haptic (ADV5G-IMM-HAPTICS).

The overall objective of Advancing-5G-Immersive project is twofold. On one side, the project aims to create a flagship 6G application laboratory for three emerging type of communications that impose new requirements on the telecommunication network infrastructure that cannot be met with existing 5G networks: emerging human-centric immersive applications (i.e. holographic, telepresence and haptics communications),

that are expected to revolutionize the work and everyday life of citizens. The three subprojects will pioneer the design and development of advanced 6G applications in Spain, increasing the Spanish competitiveness and sovereignty in future 6G "killer apps". The laboratory will be also fundamental to define the Key Performance Indicators (KPI) and requirements for 5G-Advanced and 6G. On the other side, the three Advancing-5G-Immersive subprojects will research new promising technologies to optimize the delivery and implementation of the considered 6G applications, including: The combination of enhanced Mobile Broadband (eMBB) with the low-latency features of Ultra-Reliable Low Latency Communications (URLLC), 5G-Advanced broadcast with Non-Terrestrial Networks (NTN), and softwarized core and radio components for holographic, telepresence and haptic communications.

> *Call for applications for grants PRO-GRAMME FOR UNIVERSALIZATION OF DIGITAL INFRASTRUCTURES FOR UNICO-5G COHESION R&D 2021 published in BOE, on November 24, 2021 belonging to the Plan/Programme Plan for Recovery, Transformation and Resilience of the Government of Spain. From 29/11/2021 to 31/12/2024.*

EMERGE-5G (Electromagnetic Fields Metho-dologies for 5G Use Cases)

The Fifth Generation (5G) of mobile communication systems is expected to bring novel applications and business models. Its many enhanced capabilities are going to provide ultra-high speed, low latency and reliable communications never seen so far. These new features will be possible thanks to several innovations in their radio interface: massive MIMO (mMIMO) antennas and beamforming. These new features along with the intensive use of Time Division Duplexing multiplexing (TDD), will lead to a novel radio interface, called 5G New Radio (NR).

Exposure to electromagnetic (EM) fields have been a controversial issue during the last decades and years. The International Commission of Non-Ionizing Radiation Protection (ICNIPR) published in 1998 their guidelines for limiting exposure to EM fields, and in May 2020 has updated their recommendations in order to better adapt them to future 5G transmissions. The techniques for the assessment of human exposure to EM fields have been regulated y international organisms and can be performed by means of exposimeters and spectrum analysers. However, due to the

several novelties of the radio interface of 5G, it is not clear yet whether existing methodologies can evaluate properly the EMF in 5G.

The objective of EMERGE-5G project is the development of new methods and guidelines for the assessment of human exposure to the different novel used cases envisioned in 5G communication networks. To achieve this goal, firstly measurements in commercial and private 5G networks will be performed with different methodologies and equipment in order to compare them and obtain guidelines that can be translated to other use cases. Next, particular scenarios will be evaluated by means of software simulations or laboratory measurements with the aim of deducing recommendations for evaluating 5G exposure in such scenarios.

ITN-5VC (Integrated Telematics for Next Generation 5G Vehicular Communications)

ITN-5VC aims to investigate how multi-band multi-antenna communications, including mmWave, could be integrated with radar heads and other wireless sensors into the same telematics unit so that transmission chains and radiation systems were reused opportunistically using the same spectrum. This idea has important implications for the design of the vehicle and its communications that will also be addressed in the project. With this premise, the project aims to investigate the future C-V2X systems based on 5G NR and how to integrate them with autonomous driving sensor systems. In the last year, three different training activities have been held: General Skills Training School (UPV), Vehicular Automation Seminar (Volkswagen), and V2X Communications/Simulations Training School (Bosch). These activities have provided high-quality interdisciplinary and cross-sector research training for a new generation of scientists. https://itn5vc.eu/

5G-INDUCE (Open cooperative 5G experimentation platforms for the industrial sector NetApps)

The 5G-INDUCE project develops and open and cooperative 5G network platforms that will allow the showcasing and evaluation of advanced network applications, supporting emerging and innovative services related to the industry 4.0.

The goal is to provide an end-to-end orchestration platform over enabling experimentation infrastructures for advanced 5G network applications that can be applied for the realisation of extensive 5G UCs in the broader Industry 4.0 sector, leading to technological and business validation of 5G technologies by multiple collaborating tenants (e.g., manufacturing, logistics, maintenance power management, security/surveillance and more).

Focus is given on validation of the 5G-readiness of both telecom operators and applications providers. The 5G-INDUCE experimentation facilities (ExFas) are deployed with the goal to validate and showcase over a real industrial 5G environment the developed NetApps.

Three ExFas are envisioned Spain, Italy, and Greece, all linked with large industrial facilities (Ford, Whirlpool and PPC respectively) while being supported by advance 5G infrastructures.

The overall purpose of the adopted ExFa sites is to address actual Industry 4.0 needs in a diverse set of industrial environments, showcasing the beneficial use of 5G technology in terms of latency, optimized interoperability and management, security, and safety.

Following the evolution of Automated Guided Vehicles (AGVs) use in Ford three UCs will be tested to achieve a higher level of automation and increase human-machine iteration: Autonomous AGV fleet management, Smart operation of AGVs based on human gesture recognition and Virtual Reality (VR) immersion of AGVs control. https://www.5g-induce.eu/

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

iNGENIOUS aims to design and evaluate the Next-Generation IoT (NG-IoT) solution, with emphasis on 5G and the development of Edge and Cloud computing extensions for IoT, as well as providing smart networking and data management solutions with Artificial Intelligence and Machine Learning.

For this purpose, the project will exploit some of the most innovative and emerging technologies in line with the standardised trend, contributing to the NG-IoT and proposing technical and business enablers to build a complete platform towards the future fully digitized 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. Following these references, the project proposes a cross-layer architecture including 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. All this integrated under secure and trustworthy data management, thanks to 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.

Project outcomes are validated into 4 large-scale Proof of Concept demonstration, covering 1 factory in the North of Spain, 2 ports, the port of Valencia in Spain and the port of Livorno in Italy, and 1 ship traveling from Valencia in Spain to Piraeus in Greece, encompassing 6 uses cases.

iNGENIOUS consortium is formed by 21 partners from eight countries, including telecom vendors and manufacturers, network operators, logistics partners, universities, research institutes and seven high-tech Small Medium Enterprises (SMEs) www.ingenious-iot.eu

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 that can be deployed anywhere as micro-services (i.e., edge, on premises and cloud), while the access network is hosted over 5G, WiFi or wired Ethernet links. iTEAM is the coordinator of the project, and the leader of the Multimedia use case, divided into two sub-scenarios: an uplink focused Remote Production over 5G and a downlink intensive Media Showroom. iTEAM is also developing 5 Mobile Broadband System (5MBS) prototype to provide broadcast/multicast services over 5G. iTEAM also hosts one of the Interconnected NPN (Non Public Network) node, interworking with a Berlin and a London nodes. www.fudge-5g.eu

eSCOPE (Early Diagnosis of Colorectal Cancer by using an Electromagnetic Probe)

The project addresses clinical studies on patients with colorectal tumours who are going to undergo surgery, using both a commercial rigid probe already available to the research team and flexible probe prototypes that would form part of the final diagnostic device. This study will allow, on the one hand, to finally confirm that the differences in permittivity (dielectric constant and conductivity) between healthy and tumour tissue are as expected by our previous studies and that they can be used as a diagnostic criterion for colorectal cancer. On the other hand, measurements with the flexible probe prototype would allow further progress in the development of this device while comparing its performance and features with commercial rigid measuring

probes already available to the research team. At the same time, the project will improve the diagnostic algorithm to distinguish tumours from other types of pathologies, optimising its specificity and sensitivity.

HEPATOAXIAL (ElectroMagnetic prObe for early Tumour dEtection)

The specific objective of this project is to find out how permittivity correlates with hepatic steatosis under in vivo conditions. To this end, an extensive measurement campaign is to be carried out throughout the duration of the project, which will provide a sufficient sample size to determine this correlation and confirm whether a greater presence of steatosis translates into a lower value of the permittivity typical of a healthy organ. Once this relationship has been determined, the overall objective of the final project is to design, implement and validate a measurement and diagnostic system based on the open coaxial method to determine the degree of steatosis in livers. The potential advantage of this method will lie in the possibility of making the diagnosis in just a few minutes, which can have a great impact when performed in situ during transplants. In addition, unlike liver biopsy, this system will have the ability to analyse several points and segments of the organ, not just a single point as is currently the case with biopsy.

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

5G-RECORDS aims to explore the opportunities that new 5G technology components, including the core network (5GC), radio access network (RAN) and end devices (UEs), can 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 is using 5G key enabling technologies, such as NPNs, network slicing, millimeter waves, network function virtualization, among others, 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 work hand in hand with 5G.

5G-RECORDS is structured around three real-world content production use cases: live audio production, a multicamera wireless studio and live immersive media production. The 5G project use cases testbeds are located in Sophia Antipolis (France), Aachen (Germany) and Segovia (Spain), respectively.

The first use case focuses on deploying a 5G private local network using open-source software and general-purpose processors as part of the overall infrastructure. To meet the challenges of live audio production, i.e., stringent requirements in terms of latency, availability and synchronization, ultra-reliable low-latency communications (URLLC) is key.

The second use case aims to develop a complete production system that takes advantage of 5G technology. This use case will deploy a studio with wireless 5G-enabled cameras for operation under remote production scenarios. This wireless scenario involves video, audio, and auxiliary data processing with strict requirements in terms of quality, data rate, latency, reliability, and synchronization between devices. Its main goal is to equip media equipment with external codecs and 5G modems that feed the media signals into the 5G network. A project-developed media gateway on the other end translates the 5G-IP transport protocols to the desired ones suited for media production networks, such as SMPTE-2110. The media equipment is managed through an also project-developed control gateway through the 5G network via Networked Media Open Specifications (NMOS) protocols.

The third use case aims to enable real-time immersive capture of sporting and cultural events through cameras connected via 5G millimeter waves. The key to this use case is to develop a high-definition free-viewpoint-video (FVV) solution to provide a new kind of experience to viewers in the location of the live event, as well as to remote viewers. Thanks to

the enhanced bandwidth, it will be possible to broadcast content both live and in replays, with different perspectives and shots, so that the live program director can move the viewpoint of the image freely. www.5g-records.eu

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

5G-TOURS vision was 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 was 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 included VR/AR applications to complement the physical visit with additional content, involving interactive tactile communications. The experience of the visitors was 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 was the leader of the broadcast use case. In this use case, a novel 5G Broadcast network was used to send high-quality multimedia content using a High Power High Tower architecture to the visitors of Palazzo Madama. UPV contributed directly to the development of equipment compatible with 5G Broadcast specifications, based on Software Defined Radio (SDR), as well as the implementation of the multicast interfaces of the 5G Core. www.5gtours.eu

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.

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 multihop 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 infrastructures of VLC-CAMPUS-5G I and II are being exploited. In addition, this project aims to attract the talent of women to the new job opportunities that 5G will generate and increase the visibility of the group in the definition of 5G, for this this year the second edition of V5G Days 22 has been organized. https://vlc-croft5g.com/

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 operations. 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/

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 have been deployed along selected stretches of the motorway in the border regions. First demos were experienced in June 2021, being the fall 2021 a new opportunity for testing real autonomous cars along European motorways. Final results in June 2022 showcased vehicles performing semi-autonomously, and equipped with communication technologies developed in 5G-CARMEN, which were demonstrated in the Austria-Italy border. Moreover, a centralized connected and automated lane change demo was tested at the Germany-Austria border. https://5gcarmen.eu/

5G Valencia Pilots (5G Mobile Networks Pilot, Red.es Call 2019)

This is a Spanish national project, dedicated to study and experiment with 5G technology thanks to several real-world use cases performed in the city of Valencia, Spain. The main objective of the project is to deploy real-world use cases using 5G technology to extract knowledge about technical aspects and viability of 5G applied to different verticals. iTEAM has participated in several use cases out of the 15 use cases proposed by the project: (1) Robotic Remote diagnostic, (2) Disaster Recovery, (3) Fleet management: Robotics Remote control of AGVs, (4) Robotics-Remote inspection and maintenance, (5) 5G Digital Contents, and (6) Massive IoT for smart meters in supplies.

The Disaster Recovery use case aims to study if 5G Millimetre Waves (mmW) connectivity can provide high bandwidth, reliable communications which can substitute fiber in disaster scenarios. In this use case, a backup system has been designed and tested to provide educational media content to the Universitat Politècnica de València (UPV) students and teachers in case of internal network failure or disaster. Through a real-world demo, the use case was demonstrated and the 5G mmW technology was presented as a future viable solution for wireless, high bandwidth communications solution.

The use case of 5G Digital Contents aims to study 5G and traffic prioritization as a viable solution for remote media content production. In this case, a media production system has been designed and tested to evaluate if 5G-enabled devices (cameras and microphones) which are covering a live event located remotely from the production center can provide the necessary performance and reliability to carry out a media content production, through network traffic prioritization. Through a real-world demo, the use case was demonstrated and the 5G technology was presented as a future viable solution for remote content production scenarios.

Use Case Demonstration of 5G Valencia Pilots (Red.es)

Some of 5G use cases demos, specifically in the field of telemedicine, remote inspection, and fleet management, were shown in front of senior officials from the national and local government, as well as managerial staff from Orange Spain, during the Red.es 5G pilots presentation event hosted by Orange Spain at the UPV on June 2021.

In addition, the use case of remote inspection and maintenance of electrical and railway infrastructures using Orange Spain's 5G network was demonstrated at the Universitat Politècnica de València on May 2022, thanks to the 5GBROAD from Fivecomm that successfully provided 5G connectivity to a Robotnik Automation robot. https://5gpilotosvalencia.orange.es

5G Castilla La Mancha Pilots (5G Mobile Networks Pilot, Red.es Call 2019)

The national project of Red.es in Castilla-La Mancha is based on the first real time demo of a live production and distribution of TV content by means of a 5G network in the city of Toledo, Spain. The project is made up of two use cases, the first that encompasses the multimedia content production through the use of 5G and the second use case is based on the content distribution using a 5G broadcast network. The first use case is based on the live production in the cloud of multimedia content from a live event in the Cortes of Castilla-La Mancha located in the city of Toledo. This requires reporters from the Corporación Radiotelevisón Española (RTVE), a 5G network arranged by Telefónica, which will be in charge of collecting information, in high-quality audio and video format. The objective is to transfer it in real time to the capture servers in the cloud of the WATCHITY.

For the second use case, this output signal is required from a web browser with professional rendering quality. This content will be modulated and transmitted using the 5G Broadcast network, by means of the integration of the iTEAM software-defined radio (SDR)-based 5G Broadcast network together with the high-power RF equipment of BTESA, getting a 5G Broadcast transmitter with enough radio frequency power to cover the city of Toledo completely. TelecomCLM will provide the high power High Tower (HPHT) infrastructure, in which Digital Terrestrial Televisión (DTT, Cerro de los Palos broadcasting center) is currently being broadcast.

AUDERE (Advanced Urban Delivery and Refuse Recovery)

The AUDERE project aims to design and develop an intelligent automated system for urban waste collection as well as last-mile parcel delivery. The AUDERE platform coordinates robots (autonomous vehicles) and smart containers that are connected to a 5G network. The project has been included as a use case within the 5G Pilots project in the Comunitat Valenciana where Orange participates as an infrastructure provider. The system has been validated at the VLC-CAMPUS-5G of the Universitat Politècnica de València, a closed and controlled environment, which could be considered a small city due to its infrastructure, commercial and sports places, banks, parks, and where more than 20,000 people move daily. The second validation 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.

6G Evaluation Methodologies (SOW 1, SOW12)

In this project, work continues on an exploratory research towards the definition of the 6G developing the required models and making a specific proposal of scenarios, assumptions and KPI. Considering that the frequency range will exceed the 100 GHz limit, and the propagation will be highly dependent on the details, new channel models are required, while a more accurate characterization of the obstacles is a must. In this way, the project is focused on the set up of an advanced E2E simulation platform in which new channels models light-oriented will be integrated. Accurate modelling of the channels and the obstacles are being included, while a first set of scenarios for simulation are being analysed as a prospective analysis.

Quantum Machine Learning for the AI Integration in 6G (SOW2, SOW10)

The project was planned as exploratory and aimed to use the advantages of quantum information theory to improve classical machine learning. Quantum machine learning met high expectations of providing a solution to the analysis of large volumes of data using the power of quantum computing "parallelism". Specifically, aims at meeting the Grover algorithm for the identification of matches in an exploratory search among big data. A clear example is to identify a face image pattern through the cameras and thus be able to locate the person among millions of images captured instantly. This could be used in a subsequent phase of the project to elaborate in a collaborative manner the hologram of a person for the holographic moving call.

This project was funded by iTEAM – Huawei Joint Research Center and it's original duration of 12 months, from 01/04/2021 to 30/03/2022 has been extended until next April.

Customized materials for EM communications in the GHz and THz band (SOW6)

The project aims to develop full-spectrum phantoms, i.e., liquids and semisolids (gels) components with tailor-made electromagnetic properties fully adjustable in the range above 26GHz and up to 100MHz for a range of applications in 6G new devices and interfaces. This "custom EM materials" can be used in many areas like the physical interface between antennas and surfaces, the better impedance adaptation in wearables or implants, to develop "liquid" antennas, to build physical EM filters for certain bands, to improve human brain interfaces, and to explore the possibility of integrating these materials (in its gel configuration) in printed electronics or Reconfigurable Intelligent Surfarces (RIS). The scope of the project is to develop novel composite materials, on the basis of iTEAM's expertise, that can replicate the behavior of different human body tissues in an ultra-large frequency band.

Huawei as a part of our iTEAM – Huawei Joint Research Center funds this project. Duration: 18 months, from 01/04/2021 to 30/09/2022.

AI Video-Assisted Radio Communications (SOW7, SOW11)

The project combines Artificial Intelligence video tracking algorithms with reconfigurable radiating systems, to improve beamforming performance and vehicle's location. Current systems rely on the detection of sensing radio signals and their quality. These solutions are reactive, meaning that the system responds to the radio channel behaviour and changes accordingly. Many scenarios in which the future communication systems will be deployed, or are deployed nowadays, can be assisted by video information, to feed the reconfiguration algorithms of the radio systems and even to anticipate such configuration on the basis of predictive video analytics. The aim of this project is to develop a prototype of a video-assisted beamforming panel, as a first proof of concept of the AI applied to the Physical Layer of beyond 5G radio, as well as to explore the application to reinforce the location and tracking of moving objects in indoor (industrial) environments, to define a potential follow-up of the work on that direction.

Huawei as a part of our iTEAM – Huawei Joint Research Center funds this project. Original duration: 12 months, from 01/04/2021 to 31/03/2022. Extended until next April.

2.- Research results

2.1.- Featured publications

"5G key technology enablers for emerging media content production services" Universitat Politècnica de València, Nokia Spain S.A., Ericsson Gmbh., Telefonica Investigación y Desarrollo SA, Cumucore OY, RED Technologies, Image Matters, Radiotelevisione Italiana Spa, Accelleran, LiveU Ltd., 5G Communications for Future Industry Vertical S.L., Eurecom, Sennheiser Electronic Gmbh & Co. KG, Red Bee Media, Union Européenne de Radio Télévision, British Broadcasting Corporation, Universidad Politécnica de Madrid, TV 2 Denmark AS, doi: 10.3030/957102

This paper explores the possibilities that 5G technologies and innovations may bring to the content production industry. The project targets the integration and validation of 5G technologies as part of an overall infrastructure in order to meet the requirements of the emerging market players in Europe, especially in the context of

professional content production. Three use cases will be deployed in professional environments, enabling performance measurements and evaluation, aiming to explore and demonstrate the feasibility of using 5G in the context of professional content production, opening new horizons for the industry and generating new business models that will help to deliver value.

"A Disaggregated 5G Testbed for Professional Live Audio Production" J. Dürre, N. Werner, P. Matzakos, R. Knopp, A. Garcia and C. Avellan, "A Disaggregated 5G Testbed for Professional Live Audio Production," 2022 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), 2022, pp. 1-6, doi: 10.1109/BMSB55706.2022.9828613.

Professional wireless audio equipment such as microphones and in-ear-monitoring systems are popular among live musicians and performers due to their beneficial flexibility and mobility. At the same time, artists have very high technical requirements for these devices e.g., regarding transmission delay, reliability, and battery runtime. In addition, cost, efficient use of scarcely available spectrum, and related scaling factors play a major role in professional audio productions. As of today, the entirety of technical requirements under given constraints can only be met with highly optimized custom RF technology. The new generation of cellular technology 5G is targeted to deliver new ultra-reliable low latency communication (URLLC) use cases similar to fore mentioned audio scenarios. Within the H2020 project 5G-RECORDS, a consortium of relevant actors from the media and mobile industry are exploring and evaluating 5G technology and related eco systems in the context of professional audio productions. Key element of the consortiums holistic approach of answering the question if requirements can be met and understanding relevant economic trade-offs, is the setup and optimization of a disaggregated 5G testbed. This work describes the testbed in detail and presents first results of the technical evaluation.

"A Multiple Camera 5G Wireless Studio for Professional Content Production Scenarios" P. Sunna et al., 2022 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), 2022, pp. 1-6, doi: 10.1109/BMSB55706.2022.9828740.

In this paper, a detailed overview of the H2020 European 5G-RECORDS project Use Case 2 (UC2) is presented. Currently, the project is in its 20th month of 26 and it is in the final stages of integration, tests and trials. The project devised three use cases focused around exploring 5G technologies for content production scenarios.

Use Case 2 is "Multiple Camera Wireless Studio" and has two main objectives: exploring how 5G can help create an IP studio environment in which wired and wireless equipment can be used for media content production; and how 5G can help for remote contribution scenarios. The paper outlines the envisioned scenarios, describes the components of the use case (a detailed description of two of the components is given: the Media Gateway and the Media Orchestration and Control Gateway), the results obtained via a series of tests performed to demonstrate the validity of multiple production scenarios are presented and finally work remaining, expected outcomes and future beyond the project are discussed.

"5G Broadcast SDR Open Source Platforms", A. Ibanez, J. Sanchez, D. Gomez–Barquero, J. Mika, S. Babel and K. Kuehnhammer, *2022 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB)*, 2022, pp. 01-06, doi: 10.1109/BMSB55706.2022.9828570.

SDR stands for Software Defined Radio. This term encompasses programmable transceiver which supports various wireless technologies with low dependence of hardware. The main advantage of the SDR is the capability of the migration during prototypes developments from one standard based device to the other, support for many technologies (such as WiFi, LTE, 5G NR), the easy introduction of new releases with minimum hardware updates and also it deals with many software defined wireless communication protocols (e.g. PHY, MAC) rather than hardware based solutions. One of the technologies that have benefited from SDR is the mobile communications, being LTE and 5G NR technologies that are currently available, under Open Source solutions in SDR for a laboratory tests. The deployment of a SDR prototype could be key for the emerging 5G Broadcast solutions. In this article we will perform an analysis of the SDR open source platforms which offers 5G Broadcast solutions. For instance, the current OAI SDR broadcast solution and the 5G broadcast solution, recently developed by UPV and ORS, will be evaluated.

"Received power modelling in ultra-dense networks" D Prado-Alvarez, A Antón, D Calabuig, JF Monserrat, S Bazzi, W Xu. Electronics Letters 58 (11), 448-450

This paper studies the impact of accounting or not accounting for receiver antenna gain in ultra-dense indoor environments with ceiling-mounted antennas. A simple approach to account for this gain using the effective antenna area is provided. Finally, this approach is compared with that based on antenna radiation patterns.

"Effect of Breathing on UWB Propagation Characteristics for Ingestible and Implantable Devices". Concepcion Garcia-Pardo, Alejandro Fornes-Leal, Matteo Frasson, Vicente Pons-Beltrán, Narcis Cardona. IEEE Transactions on Antennas and Propagation, Pages 3118 - 3122, 14 October 2021. DOI: 10.1109/TAP.2021.3118724

Wireless in-body devices are those in which a medical sensor is introduced–implanted or ingested– inside the human body and communicates with a remote node. Some in-body applications demand high data rates, so ultrawideband (UWB) spectrum has been proposed as a good candidate because of its large bandwidth available. Besides, breathing can lead to internal movement of the torso and consequently, of devices installed in this area. Thus, the radio channel performance can be affected by such movement leading to a malfunction of the radio interface of the medical device. This work aims at analyzing the effect of breathing on the propagation channel by means of in vivo measurements in living animal models. Continuous wave (CW) measurements have been carried out for five different frequencies in the lower part of the UWB band, and the effects of breathing on the relative received power (module and phase) are analyzed and discussed.

2.2.- Awards.

◆ **Best Final Work of Degree award** at the Valencian Telecommunications Night (NTV) and 1st prize in the Telecommunication Systems category at the XV edition of the Future of Telecommunications Awards organized by the Official College and Spanish Association of Graduates and Technical Telecommunications Engineers. "Colorectal Cancer Diagnosis Using Electromagnetic Tissue Characterization and Video Endoscopic Analysis." (Sergio Morell)

◆ **Best Master's thesis award** at the Valencian Telecommunications Night (NTV). "5G mobile robotics: Implementation of a control platform for robotic systems." (Miriam Ortiz).

Photonics Research Labs (PRL)

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, programmable photonics and 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), "Applications and Fundamentals of Microresonator Frequency Combs" (MICROCOMB) and "European Network on Future Generation Optical Wireless Communication Technologies" (NEWFOCUS). Of particular interest regarding excellence are the two projects granted by the European Research Council (ERC): Consolidator Grant "Revolutionizing fibre-wireless communications through space-division multiplexed photonics" (InnoSpace) and Advanced Grant "Universal microwave photonics programmable processor for seamlessly interfacing wireless and optical ICT systems" (UMWP-Chip).

Continuous work to transfer research results to the market has led to the foundation of 4 successful spin-off companies: VLC-Photonics (acquired by Hitachi High-Tech Corporation in November 2020), Calsens, Ephoox engineering and iPronics programmable photonics (awarded with a EIC Transition grant by the European Innovation Council in January 2022).

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

Also, follow us in:

- *Twitter: @PRL_UPV*

- *LinkedIn: https://www.linkedin.com/in/photonicsresearchlabs/*

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), 66 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 in 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 same hardware architecture the main required functionalities. The aim of this project is the design, implementation and validation of such processor based on the novel concept of photonic waveguide mesh optical core and its integration in a Silicon Photonics chip. Its three specific objectives are: (1) The architecture design*

(a)   *(b)*   *(c)*
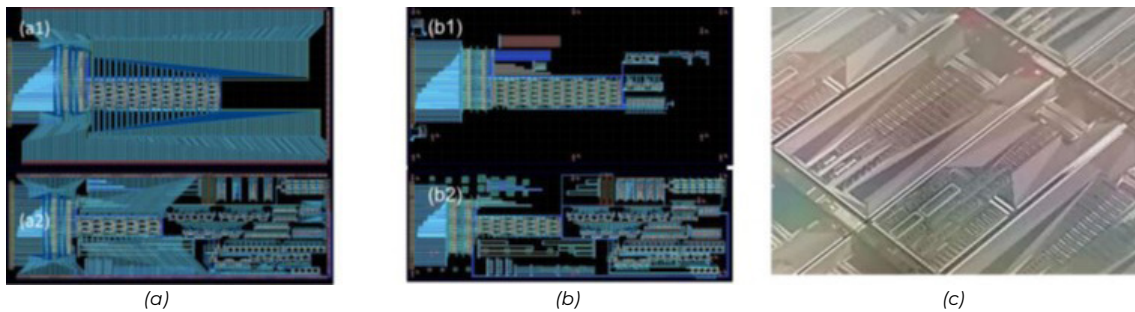
Generated layouts/designs of silicon programmable photonic processors chip incorporating the programmable mesh and external high-performance building blocks (a). 2 Chips to be wire-bonded (b). 2 Chips to be flip-chipped (c) fabricated from (a).

and optimization of a technology agnostic universal MWP programmable signal processor; (2) The chip mask design, fabrication, and testing of the processor; and (3) The experimental demonstration and validation of the processor. Targeting record values in bandwidth and footprint its potential impact will be very large by unlocking bandwidth bottlenecks and providing seamless interfacing of the fiber and wireless segments in future ICT systems.

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, 48 months*

Summary of the project: *The technological proposition of NEoteRIC aims to merge* cutting edge photonic technologies like reconfigurable silicon integrated structures and planar ferroelectric schemes so as to spawn a disruptive generation of general purpose neuromorphic photonic chips, having hundreds of nodes, exhibiting supreme processing speed and consuming negligible power. Low-power & high-speed chip reconfiguration will unleash the true potentials of NEoteRIC's arsenal providing for the first-time photonic implementation of cutting-edge neuromorphic paradigms, multi-task capabilities and on-chip. NEoteRIC's pave a clear technological roadmap to revolutionize high speed imaging applications through careful escalating steps that start from the realization of innovative reconfigurable integrated photonic building blocks, moving to their encapsulation to low-power high-bandwidth machine learning subsystems and finally reaching to application-bound integrated systems able to deliver unparalleled performance in terms of frame rate and marginal power. Through NEoteRIC's photonic-FPGA neuromorphic platform
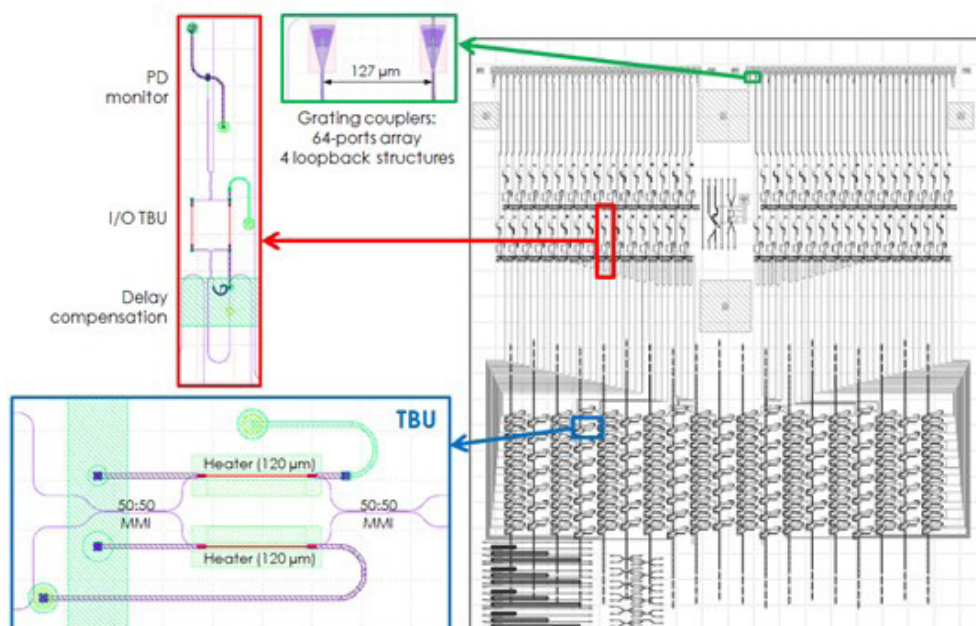
2nd Generation of the Photonic Processor (high node density with TO phase-shifters).

cytometric data analysis will be performed in the analogue-optical domain, alleviating the need for high-speed electronics, offering unparalleled speed, eliminating offline data storage and minimizing power consumption due to photonic passive processing. NEoteRIC's devices can be directly implemented in a vast pallet of applications ranging from laser manufacturing to cyber security applications.

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), 72 months*

Summary of the project: *Space-Division multiplexing (SDM) has been touted as a solution for the capacity bottleneck in digital communications by establishing independent light paths in a single fibre via multicore fibres (MCF) or few-mode fibres (FMF). This project envisions an unprecedented revolution in fibre-wireless communications through the powerful concept of SDM that lead to reconfigurable multifunctional architectures that will allow resource and functionality sharing by suitable software definition. The key challenge that is being faced in the project is to design, implement and demonstrate the feasibility of this new optical technology that offers the required parallelism for the implementation of a compact broadband tunable true time delay line (TTDL) using a single optical fibre, without the need to resort to bulky, heavy, power-consuming and expensive replication architectures, enabling important functionalities such as controlled signal distribution, signal filtering, antenna beam-steering, arbitrary waveform generation and multi-gigabit-per-second analogue-to-digital conversion. These functionalities, in turn, are required in a variety of Information Technology applications, such as broadband wireless and satellite communications, distributed antenna*

systems, signal processing, sensing, medical imaging and optical coherence tomography. This approach not only goes beyond the state-of-the-art properties of TTDLs, but it also leads to the novel concept of distributed signal processing than can be implemented in the link connecting a central office and a remote base station. The project outcomes will hence constitute a groundbreaking achievement in the next generation of fibre-wireless communications with dramatic scientific, technical, and economic impacts.

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

Webpage of the project: *https://www.cost.eu/actions/CA19111/#tabs|Name:overview*

Funding entity and duration: *European Union's Horizon 2020, 48 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 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 is carrying 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
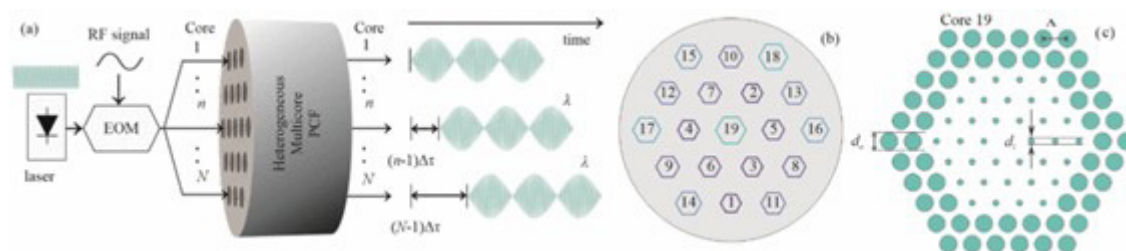
Schematic of (a) a sampled TTDL based on a heterogeneous multicore PCF exploiting the fiber spatial diversity; (b) cross-section of a heterogeneous 19-core PCF, individual cores represented by numbered hexagons with Λcore=36 μm, (c) core 19 in close-up for which di=0.87 μm, do=2.42 μm and Λ=3.08 μm.

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 serves 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 is training experts to accompany related European industries for the standardisation and commercialization of the OWC technology.

Name of the project: Applications and Fundamentals of Microresonator Frequency Combs (MICROCOMB)

Webpage of the project: https://www.microcomb-eu.org/

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

Summary of the project: This network establishes and supports cross-sectorial training and research programme bringing together leading European academic and industrial centers working in the area of optical frequency combs in microresonators (microcombs). The programme allows to combine and share some of the world leading experience and expertise in the microcombs and train a new generation of scientists in this actively developing area bordering physics and photonic engineering and having pronounced applied and fundamental dimensions. The frequency comb research itself is the Nobel prize winning area (T. Hänsch and J. Hall, 2005), while the microcombs can qualify as an emerging disruptive technology. Europe lacked before the start of this project a structured and comprehensive training programme in this area, while facing a growing competition with its global rivals. This programme will have a lasting impact increasing European innovation capacity through expanding knowledge base, new IP, trained personnel, better equipped laboratories, and future collaborations leading to product development. The project addresses research and technology problems with interdisciplinary importance from the areas of precision frequency metrology, ultrafast data processing, optical to RF signal conversion, astronomical measurements, and soliton physics.

Name of the project: Specialty fibers exploiting spatial multiplexing for signal processing, sensing and beyond (SYNERGY)

Webpage of the project:

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

Summary of the project: Firstly, SYNERGY seeks a novel Spatial Division Multiplexing (SDM) fiber solution for a better optical True-Time Delay Lines (TTDL) performance for microwave signal processing in terms of RF bandwidth, chromatic dispersion range, number of signal samples and robustness against fabrication errors, going beyond our preliminary demonstrations in the field. Furthermore, it will explore the implementation of different optical signal processing functionalities, such as optical sampling or parallel chromatic dispersion compensation.

Secondly, SYNERGY project aims at pioneering and developing innovative optical technologies based on specialty SDM fibers to revolutionize the future display of broadband fibers-wireless communication scenarios. More specifically, the general goal is to exploit the inherent parallelism of multicore fibers, few-mode fibers and combination of both to implement a variety of signal processing and multiparameter sensing applications featuring unique properties beyond the state of the art in terms of compactness, lightness, system stability, power efficiency, versatility and record bandwidth.

Finally, SYNERGY will bring the chance to develop sensors not only with commercially available fibers but also with specialty ones, improving the sensor sensibility and providing novel techniques of interrogation for better requirement benchmarking. We want to explore the incorporation of specially designed cavities not only to use the reflected light, but also to exploit the benefits of retrieving the phase of the signal, while providing a robust design against external interferences. We plan as well to develop structures that will enhance the interaction with the external medium and postprocess the fibers with different coatings and terminations.

Name of the project: Interrogación de Temperaturas Extremas con Sensores Ópticos (INTENSO)

Webpage of the project: https://intenso.itq.webs.upv.es/
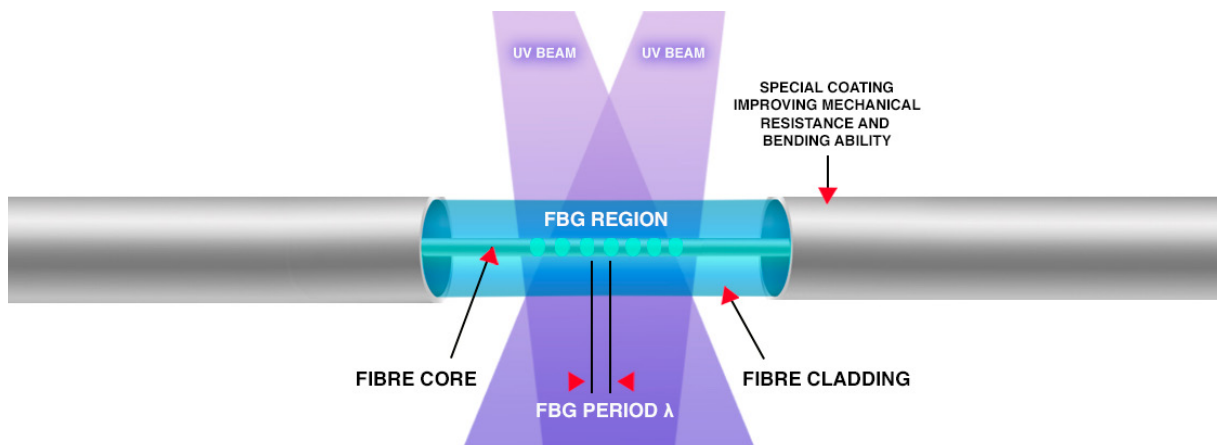
Fiber Bragg Grating.

Funding entity and duration: *Agencia Valenciana de la Innovación, 30 months*

Summary of the project: *The use of a new type of sensors based on optical fibers for the measurement of high temperatures in very hostile conditions is gaining a huge interest at industrial level. This application has been greatly favored by recent innovations in optoelectronics and in the different manufacturing technologies of both passive components and optical cables, and recent improvements in assembly and connectorization techniques. These sensors have proven, without any doubt, to possess high accuracy and reliability of measurements and are positioning themselves as a relevant technology due to the inherent properties of optical fibers. However, the optical fiber by itself is fragile and the sensors currently available on the market are usually coated by a layer of thermoplastic/metallic composite materials to give them mechanical strength while retaining the inherent flexibility of the fiber. Such coatings are not suitable and greatly limit the practical applicability of this technology at an industrial level in processes that operate in very extreme conditions. To overcome this limitation we propose to develop new coatings prepared for very high temperatures environments while preserving the inherent flexibility of the fiber, even under chemically aggressive conditions.*

Name of the project: *Energy efficient 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 in 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: *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: Embedded optical fiber sensors in composites for 3D structural Health monitoring in real time (EOS-3D)

Webpage of the project:

Funding entity and duration: Ministerio de Ciencia e Innovación, 24 months

Summary of the project: The EOS-3D project will deal with the development of a 3D Shape Sensing system in composite materials for transport applications. The main objective is the real-time structural health monitoring based on optical fiber sensors using SDM technologies, mainly MCF fibers and validate proof of concept by embedding the sensors in composites parts, similar to the ones used in aerospace applications, through an experimental setup in certified measurement equipment.

Name of the project: Inter-core crosstalk for future space division multiplexing networks and optical sensor devices (INSTILL)

Webpage of the project:

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

Summary of the project: In this project we intend to develop new and disruptive devices based on inter-core crosstalk produced by the inscription of fiber diffraction gratings in the cores of a Multicore Optical Fiber (MCF) to improve the performance of Space Division Multiplexing (SDM) amplifiers, Reconfigurable Add-Drop Optical Multiplexers and optical sensors. Tilted Fibre Bragg Gratings (TFBG) and Long Period Grating (LPG) in MCFs have shown that it is possible to deliberately and locally increase inter-core crosstalk in MCFs to transfer light from one core to another in a specific wavelength range. This project will study the optimization of the properties of these gratings

and the modification of the fiber structure to increase this effect and proposes novel schemes to use this phenomenon in the design of optical devices for SDM networks and optical sensors. In particular, we propose to use inter-core crosstalk to implement a new injection scheme of the pumping signal in a distributed way. This scheme can contribute to improve the performance of SDM amplifiers, avoid current limitations, and increase the maximum detection range of the distributed optical sensors. Another application of this technology that will be explored in this project is the use of inter-core crosstalk as a mechanism to implement distributed optical sensors that can simplify the current interrogation schemes.

Name of the project: Multi-level Microfabrication Technologies (IDIFEDER/2021/046)

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: The project addresses the acquisition and retrofit of capital
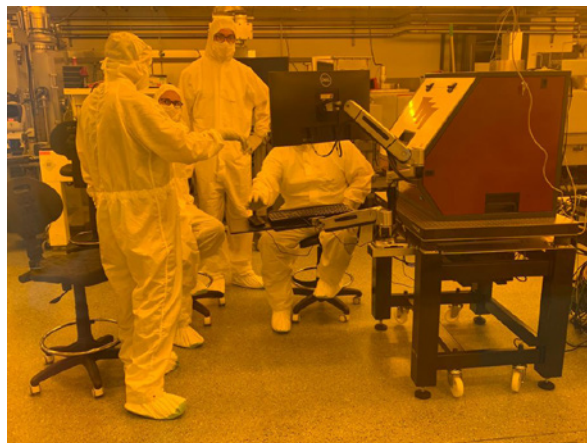
UPVFAB Technopole facilities.

semiconductor manufacturing equipment at UPVfab (www.fab.upv.es). This includes: a) retrofit of ther Tempress LPCVD Si3N4 tube for low stress silicon nitride process, b) incorporation of a sputter process module and a PECVD SiO2 module to the Nordiko 5000 cluster tool, c) acquisition of a chemical-mechanical polishing tool and d) direct laser writing lithography tool. All the equipment can process up to 8-inch wafers (currently configure for 6 inch).

Name of the project: Advanced Instrumentation for world class microwave and programmable photonics Research (IDIFEDER/2021/050)

Webpage of the project: https://www.prl.upv.es/advanced-instrumentation-for-world-class-microwave-and-programmable-photonics-research-2-2/

Funding entity and duration: Generalitat Valenciana and the European Regional Development Fund (ERDF), 24 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 the acquisition of i) photonic chip encapsulation capabilities through the incorporation of a multifunctional, modular and expandable machine designed for an R&D laboratory environment, capable of automatically carrying out the different tasks required for the assembly, preparation and optical, electrical, thermal and mechanical encapsulation of integrated photonic circuits of low and intermediate complexity; ii) the ability to write periodic and aperiodic variations in all types of circular guides (optical fibers) and flat guides by incorporating a femtosecond laser of high pulse energy that generates a two-photon process and allows the variation of the

Láser de femtosegundos de estado sólido y elevada energía de pulso

guide structure in nanometer sizes. For this, it was necessary to accompany the laser with an ultra-precision alignment system in the three axes with nanometer resolution, which has the flexibility to generate complex structures in the guides and to allow possible future extensions when necessary; iii) measurement and spectral characterization capabilities of optical networks using multiple channels in new and promising optical windows spanning from 350 to 2400 nm, either in terms of energy efficiency (visible) or low latency and high capacity (2-micron band).

Name of the project: Microwave Photonics IC Systemization and Development

Webpage of the project:

Funding entity and duration: HUAWEI TECHNOLOGIES CO., LTD., 36 months

Summary of the project: The goal of this project is to research and develop some of the key microwave-photonic technologies required for microwave-photonic radio base station architecture – more specifically these key technologies are modulator, true-time delay, and tunable filter with supporting required technologies such as semiconductor optical amplifier, photodetector, etc. The scope of the project includes systemization of the end-to-end microwave-photonic architecture to assess system performance, proposal of novel concepts/techniques, assessment of key technologies feasibility, maturity, performance, and limitation, and research/development of the key technologies

Name of the project: H2 safety – Fibre optics development for LH2 Gauging

Webpage of the project:

Funding entity and duration: Airbus Operations, S.L., 18 months
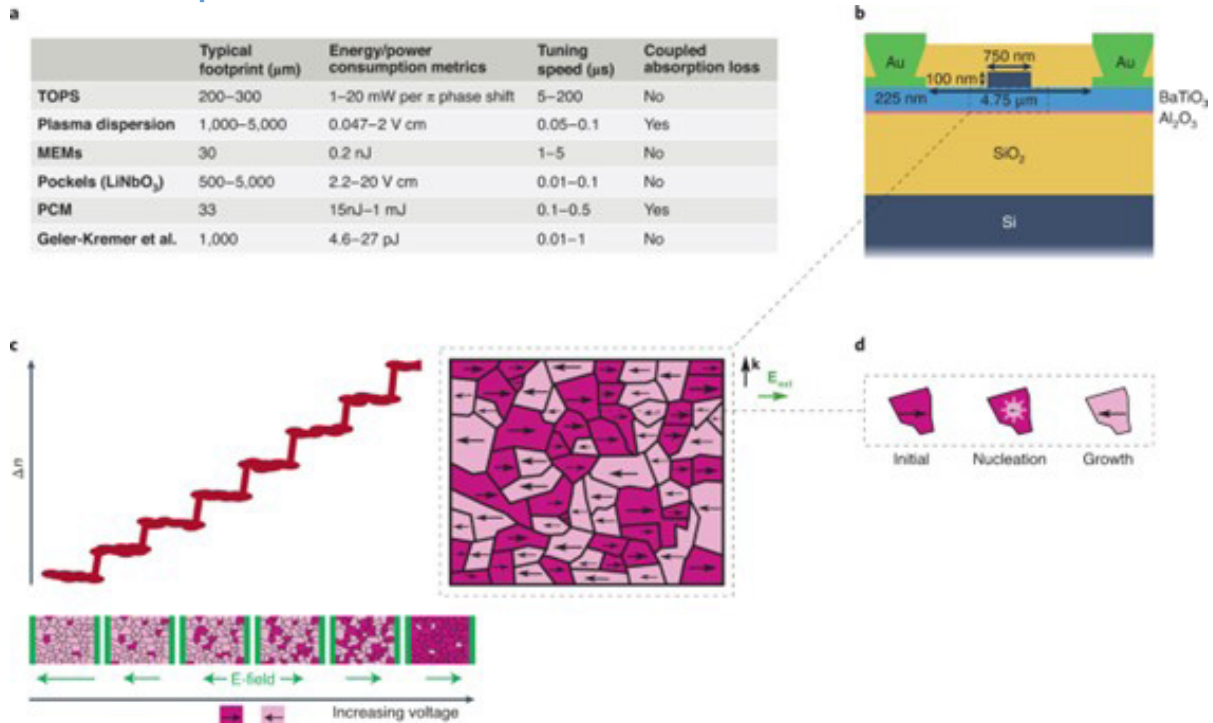
Summary of the project: Within the ZeroE program, we will perform research in the field of liquid hydrogen (LH2) characterization by developing and testing optical fibre sensors designed to operate as part of the equipment of the LH2 optical gauging system.

2.- Research results

2.1.- Featured publications

a, Comparison between different technologies for the implementation of OPS. b, BaTiO3 on silicon OPS structure reported by Geler-Kremer and colleagues10. c, Refractive index change by domain switching. d. Illustration of the internal process of a domain switching.
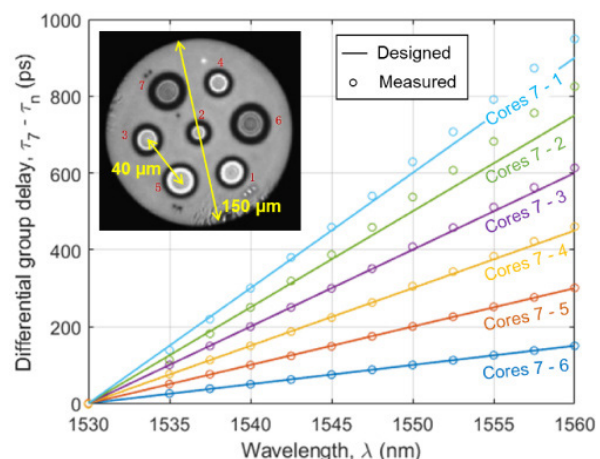
Title, Authors, Name of the publication, pages, year: *"A new change of phase", J. Capmany, D. Pérez-López, Nature Photonics 16, pp 479-480, 2022*

Brief summary of the paper: *Ferroelectric domain switching controlled by electrical pulses provides a controllable means to tune the refractive index of BaTiO3 thin films. Now, a device based on this material is presented that is capable of implementing low-power, high-speed and CMOS-compatible programmable phase shifters in silicon photonic chips.*

Title, Authors, Name of the publication, pages, year: *"Heterogeneous multicore fiber-based microwave frequency measurement", E. Nazemosadat, S. García, I. Gasulla, Optics Express 30, pp 26886-26895, 2022*

Brief summary of the paper: *A novel microwave frequency measurement scheme using a heterogeneous multicore fiber (MCF) is experimentally demonstrated. The inherently different relative group delays among the cores of a heterogeneous 7-core MCF are used to realize two individual 2-tap microwave filters with different free spectral ranges (FSRs). The ratio of the frequency response traces of these two filters is used to*

establish an amplitude comparison function (ACF). Furthermore, by varying the operational wavelength, the relative group delays between the cores and consequently the FSRs of the filters are tuned and different ACF curves are obtained. The complementary information provided by these different ACFs allows us to estimate the unknown frequency with an improved accuracy, over a broad measurement range. In our experiments, a measurement error of ±71 MHz is achieved over a frequency range of 0.5-40 GHz. The proposed scheme offers flexibility and compactness, thanks to the parallelism provided by MCF.

Differential group delays of the MCF cores with respect to core 7. The inset shows the SEM image of the fabricated MCF.
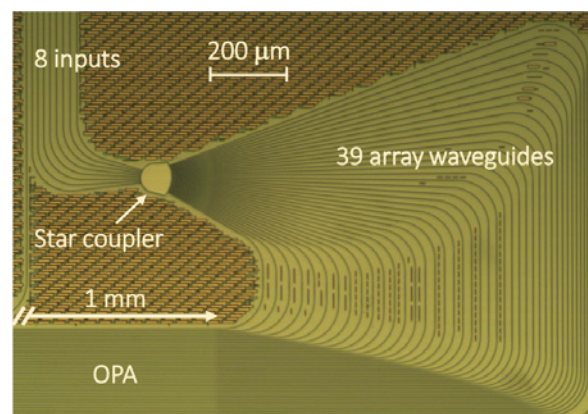
Title, Authors, Name of the publication, pages, year: *"Harmonic and Intermodulation Distortion Analysis in Directly Modulated Lasers over Local and Remote Photonically Generated Millimeter-Wave Signals", L. Vallejo, J. Mora, B. Ortega, Journal of Lightwave Technology, 2022*

Brief summary of the paper*: This paper presents a comprehensive analytical derivation and experimental evaluation of the impact of harmonic and intermodulation distortion on data transmission over local and remote photonically generated millimeter wave (mmW) signals over an optical fronthaul based on a directly modulated laser (DML) and carrier-suppressed (CS) external modulation for frequency up-conversion. Frequency response of different harmonic distortion (HD) and intermodulation (IMD) terms are measured for a 40 GHz signal under back-to-back, local and remote scenarios for the sake of comparison. Furthermore, measurements of error vector magnitude (EVM) of single and multiband QPSK signals are presented in good agreement with the frequency measurements for (2wk), (wk-w1) and (wk+w1)-type distortion terms. Wideband signals with in-band distortion and multiband signals with out-of-band distortion are examples that need to be transmitted over local generation mmW approach in cloud-radio access networks (C-RAN), in spite of the high performance achieved by remote generation approach due to the combined effect of fiber dispersion and laser chirp. Results will serve as valuable guidelines for 6G networks deployment in concrete application scenarios.*

Title, Authors, Name of the publication, pages, year: *"Scalable switched slab coupler based optical phased array on silicon nitride", P. Muñoz, D. Pastor, LA. Bru, GM. Cabanes, J. Benítez, D. Goodwill, E. Bernier, IEEE Journal of Selected Topics in Quantum Electronics 28, pp 1-16, 2022*

Brief summary of the paper*. Two-dimensional optical-phased array is demonstrated by using a multiple-input star coupler, compatible with FMCW LiDAR. Previous approach using a single-input design achieves two-dimensional beam-steering by relying on a tunable laser source, taking advantage of grating coupler radiation angle wavelength dependance and variation of the waveguide refractive index. While implementing a convenient way to distribute power in a single step, star coupler architecture is inefficient in terms of employed waveguide length and thus, optical loss and footprint. Multi-input approach partially alleviates this by condensing several single-input devices into one, permitting to reduce the footprint proportionally to the employed number of inputs. We fabricated*

in silicon nitride technology a proof-of-concept steerer with beam waist 0.36 ×0.175° addressing a field of view of 15° ×2.8°. A new design iteration is also reported with and 0.24° ×0.16° beam waist and 15° ×11.2° field of view. Implications of this optical-phased array chips from a LiDAR system perspective are also presented.


Multi-input star coupler fabricated device microscope picture.

Title, Authors, Name of the publication, pages, year: *"Modeling amplified arbitrary filtered heterodyne microwave photonic links", E. Sánchez, D. Pérez-López, D. Pérez-Galacho, D. Wessel, J. Capmany, Optics Express 30, pp 6519-6530, 2022*

Brief summary of the paper*: We report an end-to-end analytic model for the computation of the figures of merit (FOMs) of arbitrarily filtered and amplified heterodyne coherent microwave photonics (MWP) links. It is useful for evaluating the performance of complex systems where the final stage is employed for up/down converting the radio frequency (RF) signal. We apply the model to a specific case of complex system representing the front-haul segment in a 5G link between the central office and the base station. The model can be however applied to a wider range of cases combining fiber and photonic chip elements and thus is expected to provide a useful and fast tool to analyze them in the design stage.*

Title, Authors, Name of the publication, pages, year: *"Optical CS-DSB Schemes for 5G mmW Fronthaul Seamless Transmission", J. Bohata, L. Vallejo, B. Ortega, S. Zvánovec, IEEE Photonics Journal 15, pp 1-7, 2022.*

Brief summary of the paper*: This paper describes the experimental demonstration of the hybrid optical/millimeter wave signal generation and transmission over combined optical fiber and free space optics fronthaul network with a seamless antenna link. An electrical bandpass filter is used to filter out the spectrum after*
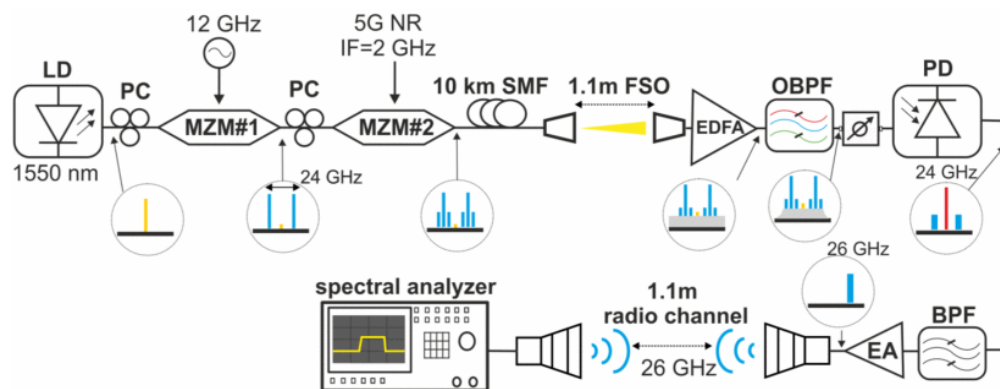
EM setup for optical mmW generation at 26 GHz with the seamless transmission, insets illustrate spectra at given points.

photodetection to realize the seamless antenna transmission. The successful transmission of 64/256-quadrature amplitude modulation (QAM) 5G signal with up to 200 MHz bandwidth is presented by using two different setups: one is based on two Mach-Zehnder modulators (MZM) and the other employs a directly modulated laser (DML) to provide more cost efficient fronthaul solution. The DML based approach reveals mildly better performance in comparison to the MZMs in terms of higher achieved signal-to-noise ratio and lower error vector magnitude (EVM). More specifically, the best signal-to-noise ratio and EVM achieved with the DML based setup has been 31.5 dB and 3. 3%, respectively, compared to 30.3 dB and 3.8% with the MZMs based setup while transmitting 256-QAM signal with 100 MHz bandwidth. However, both setups kept the EVM well below the given 9% and 4.5% limit for 64- and 256-QAM, respectively.

Title, Authors, Name of the publication, pages, year: "Sensing with coupled-core optical fiber Bragg gratings", JA. Flores-Bravo, J. Madrigal, J. Zubia, W. Margulis, S. Sales, J. Villatoro, Frontiers in Optics, FM2C. 2, 2021

Brief summary of the paper: Sensitive bending and vibration sensors based on a coupled-core optical fiber with Bragg gratings are proposed and demonstrated. The interrogation of such sensors is cost effective without comprising the sensors performance.

Title, Authors, Name of the publication, pages, year: "Coupled-core fiber Bragg gratings for low-cost sensing", JA. Flores-Bravo, J. Madrigal, J. Zubia, S. Sales, J. Villatoro, Scientific Reports 12, pp 1-9, 2021

Brief summary of the paper: overcome this issue, in this work, it is proposed and demonstrated the use of coupled-core optical fiber Bragg gratings. It was found that the

relative reflectivity from such gratings changed when the coupled-core fiber was subjected to point or periodic bending. This feature makes the interrogation of such gratings simple, fast, and cost-effective. The reflectivity changes of the gratings are attributed to the properties of the supermodes supported by the coupled-core fiber. As potential applications of the referred gratings, intensity-modulated vector bending, and vibration sensing are demonstrated. We believe that the results reported here can pave the way to the development of many inexpensive sensors. Besides, coupled-core fiber Bragg gratings may expand the use of grating technology in other areas.
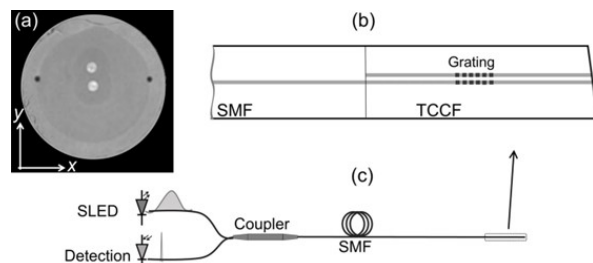
(a) Cross section of the twin coupled-core optical fiber (TCCF) used in the experiments. The coordinate system to orient the cores is indicated. (b) Schematic representation of a single mode fiber (SMF) spliced to the TCCF. (c) Sketch of the device interrogation; SLED is superluminescent light emitting diode. The input and reflected light are illustrated with a broad and narrow 'spectrum', respectively.

Title, Authors, Name of the publication, pages, year: "Photonic crystal fibers for microwave signal processing, S. Shaheen, I. Gris-Sánchez, I. Gasulla, IEEE Photonics Conference (IPC), 2021

Brief summary of the paper: We present a novel design of an optical True Time Delay Line based on a 19-core Photonic Crystal Fiber that operates in a broad radiofrequency signal processing range from 1 to 67 GHz on a 10-km link, thus enabling simultaneous microwave signal distribution and processing.

Title, Authors, Name of the publication, pages, year: "Advanced and versatile interferometric technique for the characterization of photonic integrated devices", LA Bru, D Pastor, P Muñoz, Optics Express 29, pp 36503-36515, 2021

Brief summary of the paper: Adaptable and complex optical characterization of photonic integrated devices, permitting to unearth possible design and fabrication errors in the different workflow steps are highly desired in the community. In this article, a technique was proposed capable of resolving full optical amplitude and phase response, in both frequency and time domains, of a photonic integrated device. It relies on optical frequency domain interferometry and makes use of a novel integrated architecture; a 3-way interferometer enabling single input and single output detection. We derive the test structure design rules and provide extensive experimental validation in silicon nitride and silicon on insulator technologies, by testing relevant devices such as arrayed waveguide grating, Mach-Zehnder interferometers, and ring resonators. Horizontal and vertical chip coupling, different external setup arrangements, and the optical dispersion de-embedding inherent to the technique are demonstrated. Finally, we discuss why this characterization approach might lay the groundwork of a standard testing tool for photonic integrated devices.

2.2.- Awards.

Sergi García awarded with the COIT/AEIT prize for best doctoral thesis.

On October 8, 2021, Dr. Sergi García Cortijo, Postdoctoral Researcher at the Photonic Research Labs, has been awarded by COIT (the Spanish official association of telecommunication engineers) the prize to the best 2020 Spanish Doctoral thesis on Technologies and Applications of Telecommunication Engineering.

The Jury of the XLI call for the Best Doctoral Thesis, Master's Thesis and Academic Trajectories in Telecommunications Engineering Awards, has awarded this distinction to Sergi García for his work "Distributed radiofrequency signal processing based on space-division multiplexing fibers", supervised by Dr. José Capmany and Dr. Ivana Gasulla.

This PhD thesis represents an important milestone 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, which is the main goal of my ERC Consolidator Grant project InnoSpace.

Furthermore, the true time delay lines that have been developed during his thesis 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.

Award Sergi Garcia

Advanced Techniques for the Characterization and Experimental Validation of Passive Inter-Modulation Effect (PIM) in Space Communications Systems

Author: Davide Smacchia
Supervisor: Dr. Vicente E. Boria Esbert and Dr. Pablo Soto Pacheco

Defended on March 23rd, 2022

SUMMARY

Modern satellite payloads operate in multicarrier scenarios, under a continuous demand for higher capacity links. This leads to an increase in the RF power levels, frequency of operation, and the number of transmitted channels, thus stimulating non-linear high-power effects, such as Multipactor, Corona, thermal issues and Passive Inter-Modulation (PIM). Among the above-mentioned phenomena, PIM is the less studied, or, at least, understood. This is due to its extreme non-linear nature and its close relation to workmanship, which make very difficult the development of models able to faithfully predict and explain PIM degradation. PIM terms, once ignited in the downlink, may interfere the weak signal to be detected in the uplink channel, thus threatening the payload throughput. Traditional PIM models are based on a two-carriers excitation. This is a simple and quite representative case, but has significant differences with the real multi- carrier scenario. This Ph.D. thesis work tries to diminish this gap by two novel contributions of relevance for real operation conditions. Firstly, the role of the carrier phases (neglected for two-carriers excitation) has been theoretically investigated. Secondly, a new model to account for the effect of non-contributing carriers for a given PIM term has been developed, which is based on a novel energy conservation assumption. The resulting models fit to experimental data. Due to the complexity of PIM modeling, PIM validation of RF components is conducted only by testing. The availability of low PIM test set-ups is therefore of great interest for the space industry. However, the design of low PIM test benches is challenging, as their intrinsic residual PIM has to be below the one requested to validate the test devices. For satellite hardware, the dynamic range between the RF power levels of the transmission carriers and the signal to be detected may be 185 dBc. During this Ph.D. thesis work, novel integrated test bed architectures in waveguide technology, both for conducted and radiated PIM scenarios, have been developed. These architectures consent a mitigation of the residual PIM of the test facility, being at the same time flexible, free from unwanted interactions and spurious resonances, and able to withstand considerable RF power levels for the transmission carriers. The key elements of these set-ups are the low PIM multiplexers, which may integrate two new families of waveguide filters able to provide a high number of transmission zeros, and therefore a high rejection, in the PIM reception channel. The test benches conceived for measuring conducted backward PIM, however, are normally unprotected from the PIM generated by the termination absorbing the high-power transmission carriers. To alleviate this situation, a new type of low PIM terminations in waveguide technology has been proposed and verified with PIM tests, showing a clear benefit in mitigating the residual PIM of the test facilities. Moreover, novel transitions able to improve the PIM performance of standard flanges have also been conceived. Finally, and with regard to radiated scenarios, a novel formulation able to convert payload PIM specifications to a practical PIM test is proposed. This formulation consents to link the power flux densities at the device under test (DUT) with the RF power levels measured by the test bench. Last, a large class of PIM measurements carried out with the novel test bed architectures have been reported. These measurements cover several frequency bands (C-, Ku-, K- and Ka) and different PIM scenarios, both conducted and radiated. The exceptional residual PIM noise floor of each test bed will be pointed out. In addition, PIM tests on an anechoic chamber facility, multi-layer insulation blankets (MLIs) and reflector mesh samples are presented, with interesting considerations about the geometry of the structure and the impact on the PIM performance of typical elements as sawing areas and rivets.
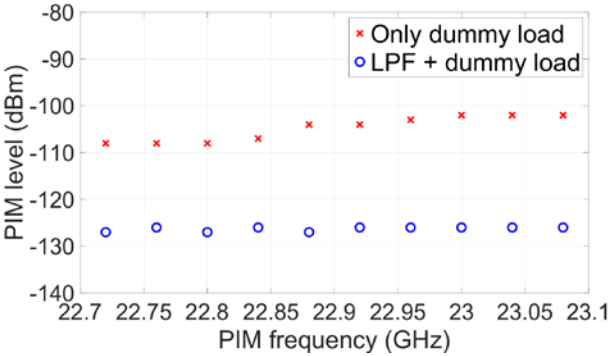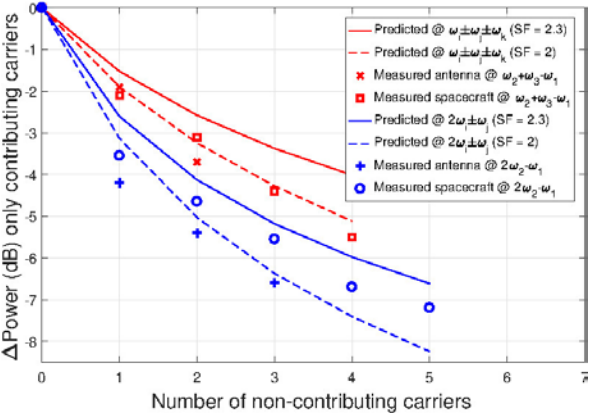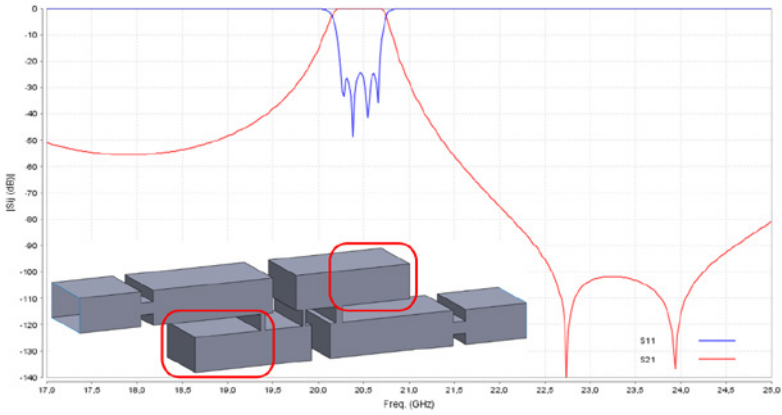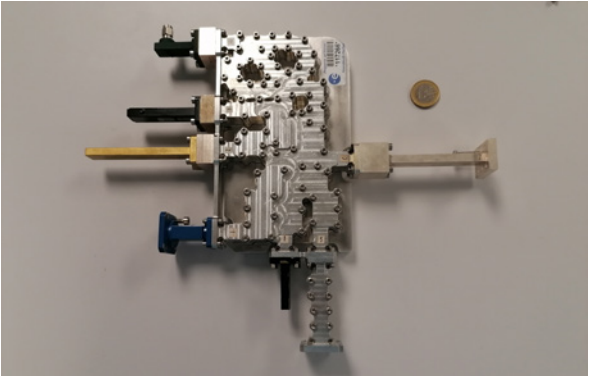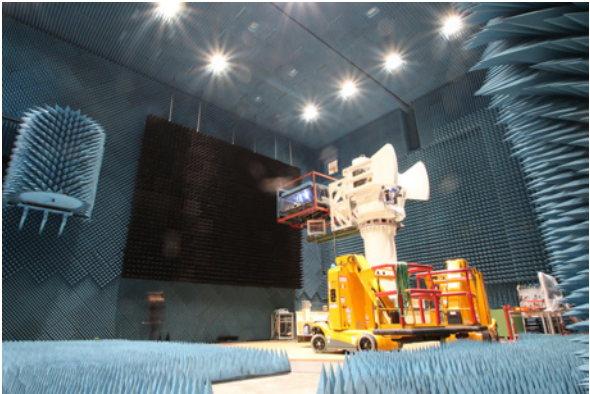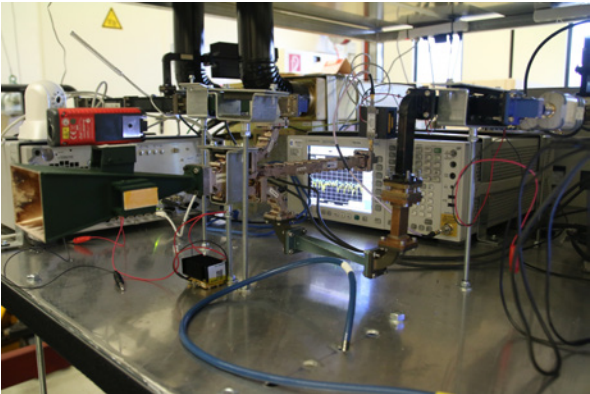
Smart sound control in acoustic sensor networks: a perceptual perspective

Author: Juan Estreder Campos

**Supervisor:** Dr. Gema Piñero Sipán and Dr. María de Diego Antón

Defended on February 24th, 2022

SUMMARY

Audio systems have been extensively developed in recent years thanks to the increase of devices with high-performance processors capable of performing more efficient audio processing. In addition, the expansion of wireless communications has given the possibility of implementing networks in which devices can be placed in different locations without physical limitations, unlike wired networks. The combination of these technologies has led to the emergence of Acoustic Sensor Networks (ASN). An ASN is composed of nodes equipped with audio transducers, such as microphones or speakers. In the case of acoustic field monitoring, only acoustic sensors (or microphones) need to be incorporated into the ASN nodes. However, in the case of control applications, the nodes must interact with the acoustic field through loudspeakers.

The ASN can be implemented through low-cost devices, such as Raspberry Pi or commercial mobile devices, capable of managing multiple microphones and loudspeakers and offering good computational capacity. In addition, these devices can communicate through wireless connections, such as Wi-Fi or Bluetooth. This ASN design provides high processing power and flexibility due to the processors and the wireless communications offered by the current mobile devices. Therefore, in this dissertation, an ASN composed of commercial mobile devices connected to wireless speakers through a Bluetooth link is proposed. Additionally, the problem of synchronization between the devices in an ASN is one of the main challenges
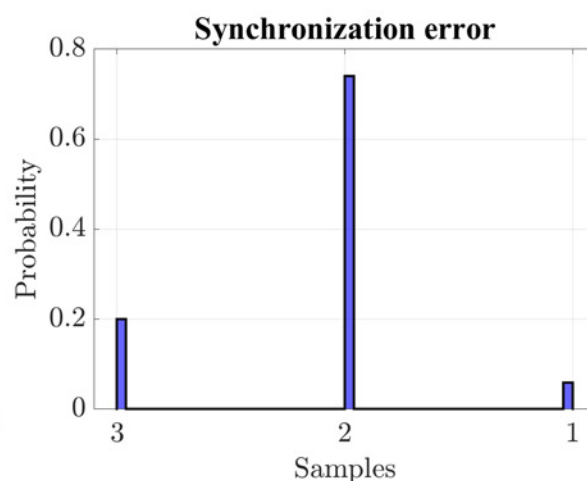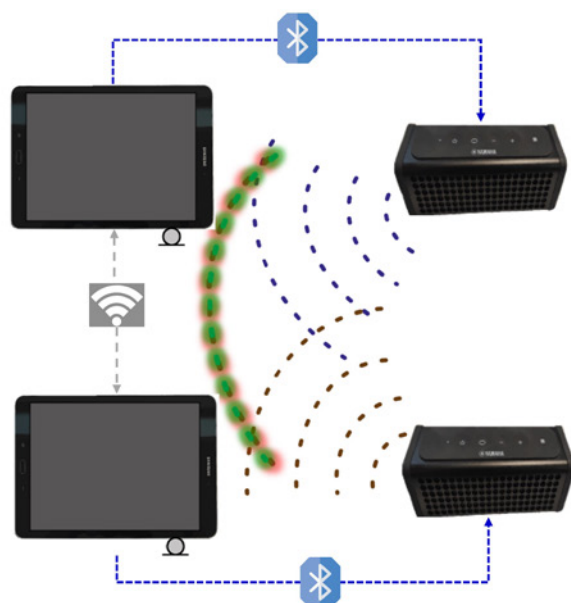
to be addressed since the audio processing performance is very sensitive to the lack of synchronism. Therefore, a deep analysis of the synchronization problem between commercial devices connected to wireless speakers in an ASN is also carried out. In this regard, one of the main contributions is the analysis of the audio latency of mobile devices when the acoustic nodes in the ASN are comprised of mobile devices communicating with the corresponding loudspeakers through Bluetooth links. A second significant contribution of this dissertation is the implementation of a method to synchronize the different devices of an ASN, together with a study of its limitations. Finally, the proposed method has been introduced in order to implement personal sound zones (PSZ) applications. Therefore, the implementation and analysis of the performance of different audio applications over an ASN composed of commercial mobile devices and wireless speakers is also a significant contribution in the area of ASN

In cases where the acoustic environment negatively affects the perception of the audio signal emitted by the ASN loudspeakers, equalization techniques are used with the objective of enhancing the perception threshold of the audio signal. For this purpose, a smart equalization system is defined and implemented in this dissertation. In this regard, psychoacoustic algorithms are employed in order to implement a smart processing based on the human hearing system capable of adapting to changes in the environment, and thus increase the perception threshold of the audio signal dynamically. Therefore, another important contribution of this thesis focuses on the analysis of the spectral masking between two complex sounds. This analysis will allow to calculate the masking threshold of one sound over the other in a more accurate way than the currently used methods. This method is used to implement a perceptual equalization application that aims to improve the perception threshold of the audio signal in presence of ambient noise. To this end, this thesis proposes two different equalization algorithms: 1) pre-equalizing the audio signal so that it is perceived above the ambient noise masking threshold and 2) designing a perceptual control of ambient noise in active noise equalization (ANE) systems, so that the perceived ambient noise level is below the masking threshold of the audio signal. Therefore, the last contribution of this dissertation is the implementation of a perceptual equalization application with the two different embedded equalization algorithms and the analysis of their performance through the testbed carried out in the GTAC-iTEAM laboratory.

The wind orchestra as a means of application and development of current compositive techniques. A performative proposal

Author: José Miguel Fayos Jordán
Supervisor: Dr. Carlos Fontcuberta Llavata and Dr. Jorge Sastre Martínez

Defended on May 4, 2022

SUMMARY

The aesthetic revolution that the twentieth century has seen, where a multitude of proposals arose, reached the different instrumental groups in a disparate way. While symphonic and chamber music lived a rebirth sponsored by new compositional techniques, the wind orchestra was stuck in an apparent context of tonality and modality that, far from evolving at the same time as the other formations, has experienced an apparent retreat towards postures more conservative aesthetics.

The present work arises from the need to evolve the current repertoire for wind orchestra, deepening its timbral possibilities and developing a repertoire that addresses composition for wind orchestra, from a current perspective that develops some of the main aesthetic currents of the avant-garde musical of the twentieth and twenty-first centuries, such as spectralism, algorithmic composition or the use of techniques derived from the scientific-mathematical field. Next, a detailed analysis of the compositional processes addressed in each of the works under study is elaborated, without losing the perspective of the fundamental objective; the composition of two works that develop the sound potential of the orchestral wind and percussion formation within a contemporary style.

Previously, some of the most important contributions to the genre made by different composers are exposed, which have meant a real and significant connection of the new compositional proposals of the 20th and 21st centuries with the formation of winds in their orchestral or large ensemble

Variables:	A, B, C, D
Axioms:	(A←B), (B←AB), (BB←CAA), (C←ADB), (D←ABC)
n = 0 :	A
n = 1 :	B
n = 2 :	AB
n = 3 :	BAB
n = 4 :	ABBAB
n = 5 :	BCAABAB
n = 6 :	AADBBBABBAB
n = 7 :	BBABCCAAABBCAABAB
n = 8 :	CAABABADBADBBBBCAAADBBBABBAB
n = 9 :	ADBBBABBABBABCABBABCCAACAA...

concretion. Especially noteworthy are those proposals by authors closely related to the wind repertoire, especially in its band aspect. At the same time, other works by significant authors within the orchestral and chamber repertoire are referenced, who have made sporadic contributions to the wind orchestra / ensemble. Contributions that for their originality or style framed in the aesthetic compositional currents of the XX and XXI, imply an outstanding fact for the wind and percussion genre.

New Wide-Band Capacitive Filter Structures in Rectangular Waveguide Technology With Enhanced Out-of-Band Response

Author: Joaquin Francisco Valencia Sullca

Supervisor: Dr. Vicente E. Boria Esbert, Dr. Santiago Cogollos Borrás and Dr. Marco Guglielmi

Defended on December, 16, 2021

SUMMARY

The main objective of this doctoral thesis is the development of new capacitive filtering structures in rectangular waveguide that are able to provide wide bandwidths in the passband and improve, at the same time, the out-of-band response. These new guided structures have been developed in order to offer new technological solutions for high-frequency microwave filters, with a variety of different transfer functions, addressing specifically the needs of future telecommunication systems for both ground and space applications.

In this context, therefore, we discuss in this document the study, design and manufacture of several types of microwave filter in rectangular waveguide that show a significant improvement with respect to the state-of-the-art. The new solutions that we propose are obtained by introducing simple modifications in the structure of classic microwave filters. Several techniques based on hybrid irises, stepped impedance resonators, staircase configuration and E-plane T-junctions with shorted stubs or manifold connections, are successfully used in order to meet the very demanding specifications of future systems for both ground and space applications. Furthermore, an additional current challenge faced by all designers of microwave components is the need to reduce both their physical size and mass (or weight). To address this issue, we discuss in this document the use of resonant apertures (RAs) in rectangular waveguide, introducing a new family of filters which can be used to implement complex single and dual-band transfer functions with significant size and mass reduction.

In this doctoral thesis, each subject is discussed in detail including the basic theoretical formulations, design procedures, the results of full-wave electromagnetic simulations, manufacturing considerations, and the measured performance of a number of prototypes. Excellent agreement is found in all cases between measurement and simulations, thereby fully validating both the novel structures discussed and their design procedures.
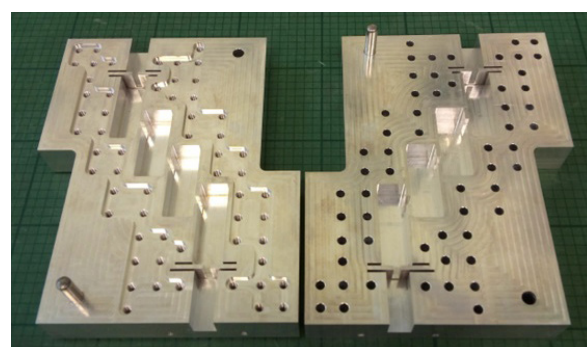
Manufactured extended bandpass RA prototype in aluminum (no silver plating)..
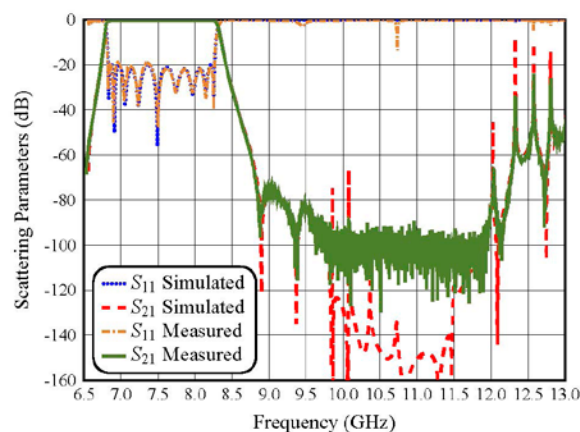
Measurement of the out-of-band performance of the extended bandpass RA filter compared with the EM simulation (CST).

Evaluation of QoE in a DASH-based 3D video adaptive streaming system

Author: Paola Guzmán Castillo

**Supervisor:** Dr. Juan Carlos Guerri Cebollada and Dr. Pau Arce Vila

Defended on July 21, 2022

SUMMARY

The distribution of multimedia content, and in particular video streaming, currently dominates global Internet traffic and will become even more important in the future. Thousands of titles are added monthly to major service providers such as Netflix, YouTube and Amazon. In addition to the consumption of high-definition content becoming the main trend, an increase in the consumption of 3D content can be observed again. This fact has caused that issues related to content production, encoding, transmission, Quality of Service (QoS) and Quality of Experience (QoE) perceived by users of 3D video distribution systems became a research topic with numerous contributions in recent years.

This thesis addresses the problem of providing 3D video streaming services under variable bandwidth network conditions. In this sense, it presents the results of the evaluation of the QoE perceived by the users of 3D video systems, analyzing mainly the impact of the effects introduced in two of the elements of the 3D video processing chain: the encoding stage and the transmission process.

To analyze the effects of the encoding process on the quality of 3D video, the first stage deals with the objective and subjective evaluation of video quality, comparing the performance of different encoding standards and methods, in order to
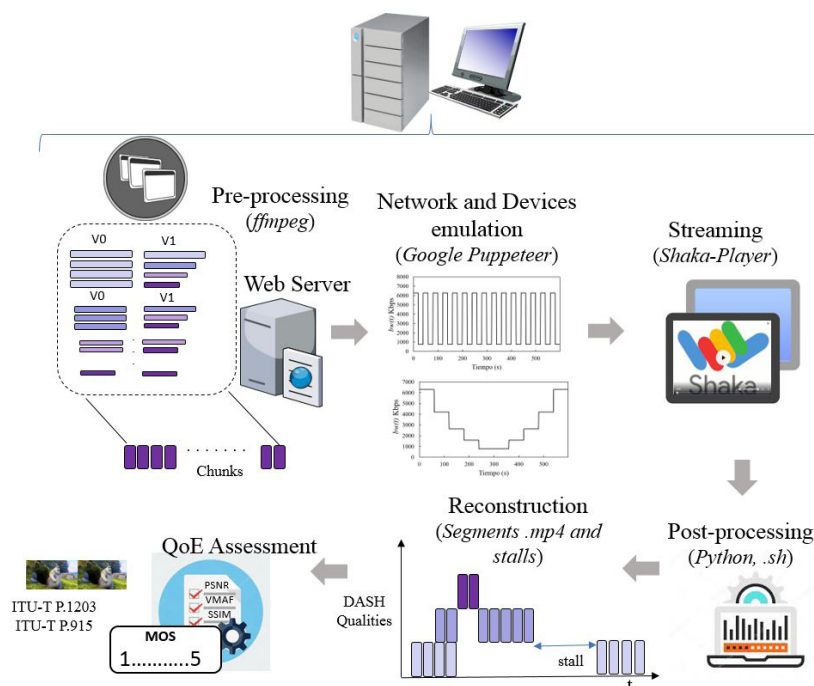
identify those that achieve the best ratio between quality, bit rate and encoding time. Also, in the context of transmission in a simulcast environment, the advantages of using asymmetric coding for 3D video transmission is evaluated as an alternative for bandwidth reduction while maintaining overall quality.

Secondly, for the study of the impact and performance of the transmission process, the work has been carried out on the basis of an adaptive dynamic over HTTP (DASH) transmission system in the context of both 2D and 3D video transmission, using different bandwidth variation scenarios. The aim has been to develop a framework for the evaluation of QoE in 3D adaptive video streaming scenarios, which allows analyzing the impact on the user's QoE against different bandwidth variation patterns, as well as the performance of the adaptation algorithm under these scenarios. The work focuses on identifying the impact on the user's

Quality of Experience in aspects such as: frequency, type, range and temporal location of bandwidth variation events.

The proposed system allows to perform performance measurements in an automated and systematic way for the evaluation of DASH systems in the 2D and 3D video distribution service. The tool Puppeteer, the Node.js library developed by Google, has been used, which provides a high-level API to automate actions in the Chrome Devtools protocol, such as starting playback, causing bandwidth changes and saving the results of the quality change processes, timestamps, stops, etc. From this data, a further processing is performed that allows the reconstruction of the displayed video, as well as the extraction of quality metrics and the evaluation of the QoE of the users using the ITU-T P.1203 recommendation.

Filter Optimization for Personal Sound Zones Systems
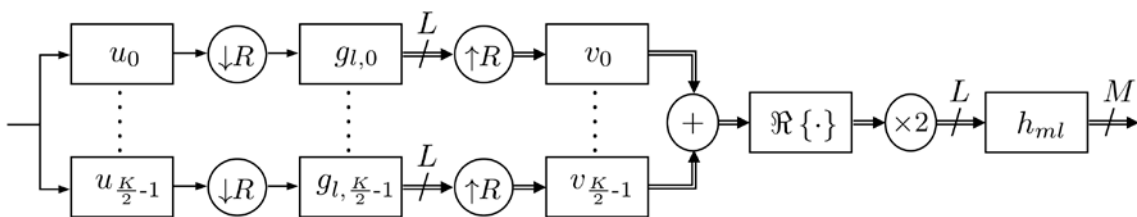
Author: Vicent Molés Cases
Supervisor: Dr. Gema Piñero Sipán and Dr. Alberto González Salvador

Defended on July 1st 2022

SUMMARY

Personal Sound Zones (PSZ) systems deliver different sounds to a number of listeners sharing an acoustic space through the use of loudspeakers together with signal processing techniques. These systems have attracted a lot of attention in recent years because of the wide range of applications that would benefit from the generation of individual listening zones, e.g., domestic or automotive audio applications. A key aspect of PSZ systems, at least for low and mid frequencies, is the optimization of the filters used to process the sound signals. Different algorithms have been proposed in the literature for computing those filters, each exhibiting some advantages and disadvantages. In this work, the state-of-the-art algorithms for PSZ systems are reviewed, and their performance in a reverberant environment is evaluated. Aspects such as the acoustic isolation between zones, the reproduction error, the energy of the filters, and the delay of the system are considered in the evaluations. Furthermore, computationally efficient strategies to obtain the filters are studied, and their computational complexity is compared too. The performance and computational evaluations reveal the main limitations of the state-of-the-art algorithms. In particular, the existing solutions can not offer low computational complexity and at the same time good performance for short system delays. Thus, a novel algorithm based on subband filtering that mitigates these limitations is proposed for PSZ systems. In addition, the proposed algorithm offers more versatility than the existing algorithms, since different system configurations, such as different filter lengths or sets of loudspeakers, can be used in each subband. The proposed algorithm is experimentally evaluated and tested in a reverberant environment, and its efficacy to mitigate the limitations of the existing solutions is demonstrated. Finally, the effect of the target responses in the optimization is discussed, and a novel approach that is based on windowing the target responses is proposed. The proposed approach is experimentally evaluated in two rooms with different reverberation levels. The evaluation results reveal that an appropriate windowing of the target responses can reduce the interference level between zones.

[Waves]

2022 | YEAR 14