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Message from the Director

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

The Science develops the tools to solve the challenges posed by the utopias of the future. Without utopia, Science loses vision, is limited to the short term, becomes accustomed and accommodates in technology, and ends up being recurrent, incremental. Without the ability to identify the challenges of Science, it is meaningless. For this entire scientific ecosystem to work, it is necessary to combine the ideas of the utopian future of Humanity with a deep knowledge of basic technologies and sciences, with which to develop solutions to those scientific challenges.

Science in Spain has been integrated and developed mostly in the University. This essential link between University and Science is the basis of the feedback of scientific knowledge on university teaching, especially in masters and postgraduate degrees, quarry of future scientists, and incubator of ideas, sometimes utopian, almost always brilliant, of the future challenges of our Society. We do not imagine a separation from one and the other, we do not imagine a better bridge between science and teaching than the University, and we do not imagine a better teacher in our universities than the one that constantly renews and expands its knowledge through science and innovation projects.

That is why the Institute of Telecommunications and Multimedia Applications is not only a research centre on the campus of the Polytechnic University of Valencia, but also tries to be that quarry of excellence, scientific development, innovative projects, and source of knowledge feedback for our teachers and future students of the University.

iTEAM turns 15 years in 2020. During its trajectory, the Institute has not stopped growing in the number of people, projects, publications, patents, citations, and technology transfer; in short, in all the indicators that nowadays measure scientific production in public organizations. That puts us in a good position when measured with the usual indexes but the goal of iTEAM is not only focused to indexes but committed to scientific excellence.

Eva Antonino receives a world-class award for her contributions in the field of telecommunications

Dr. Eva Antonino, lecturer, researcher and Deputy Director of Research at the Institute of Telecommunications and Multimedia Applications (iTEAM) of the Universitat Politècnica de València, has been awarded by the **Institute of Electrical and Electronics Engineers (IEEE)**, the largest and most prestigious international association of engineers, for her contributions in the field of telecommunications.

Antonino has received the Lot Shafai Mid-Career Distinguished Achievement, a worldwide award that is given to very outstanding women in the middle of their professional career (they must be under 41 years old).

The jury distinguished the researcher from the iTEAM Institute of the UPV and professor at the College of Telecommunication Engineering (ETSIT) both for her contributions to the systematic design of antennas for practical applications and for promoting women's access to engineering.

Eva Antonino works on the design of antennas for applications in the microwave band: from VHF and UHF to mobile communications 4G and 5G and ultra-wideband (UWB), including antennas for WiFi, Bluetooth, Internet of things (IoT) devices and body environment sensors.

Currently, her research focuses on the design of high gain antennas for new applications of 5G systems, through a grant supported by the Ministry of Science, Innovation and Universities. "In these systems, antennas play a fundamental role, so it is necessary to propose new design strategies to meet their objectives," says Antonino.

Eva Antonino has just returned from a stage at the Georgia Institute of Technology (United States), learning about new materials and additive manufacturing technologies applied to antenna design, in one of the leading centers in this area.

Gonzalo Safont receives The IEEE SMCS Award for Outstanding phd thesis on Cybernetics

Dr. Gonzalo Safont, Postdoctoral Researcher at the Signal Processing Group of the iTEAM Research Institute has been awarded by the **IEEE Systems, Man, and Cybernetics Society (SMCS)** as part of their Outstanding Thesis Grant Initiative. This worldwide program aims to recognize the outstanding students and young professional members of SMCS who, early in their career, contributed to major advancements of theory or applications of systems science & engineering, human-machine systems, and cybernetics.

Dr. Safont's thesis, "New Insights in Prediction and Dynamic Modeling from Non-Gaussian Mixture Processing Methods," received the grant for Outstanding PhD Thesis Work on the field of Cybernetics. "This work is an essential contribution to develop integrated systems to process multimodal data in big data contexts," declared Dr. Addisson Salazar, senior researcher at iTeAM. Gonzalo's current work deals with the application of the methods proposed in his PhD thesis to the joint modeling of electroencephalographic data and functional magnetic resonance imaging. This is part of a joint work with Hospital Universitari i Politècnic La Fe and the ERESA Medical Group with the objective of exploring and diagnosing epileptic patients.

Professor José Capmany commissioned as IDEAS entrepreneurial ambassador

Professor José Capmany was commissioned last academic year as entrepreneurial ambassador by IDEAS UPV, the University body that provides entrepreneurship training and advice for spin-off company creation. This acknowledgment was awarded during the **12th IDEAS UPV Awards Ceremony** at the Polytechnic City of Innovation in December 2018.

According to the members of the jury, "not only is Prof. Capmany a worldwide renowned scientist in his research area (he was awarded King James I Prize on Novel Technologies in 2012), but he also is a great entrepreneur as evidenced by the spin-off companies he has founded over the years, spreading UPV excellence around the world."

MIGUEL FERRANDO ROCHER HAS BEEN AWARDED WITH THE COIT-AEIT AIRBUS SPACE AND DEFENCE AWARD

On June 14th, the awards ceremony of the **Telecommunication Engineers Awards COIT-AEIT** took place at the Academy of Arts and Cinematographic Sciences of Spain. These awards reflect a commitment to excellence in the training and development of Telecommunication Engineers.

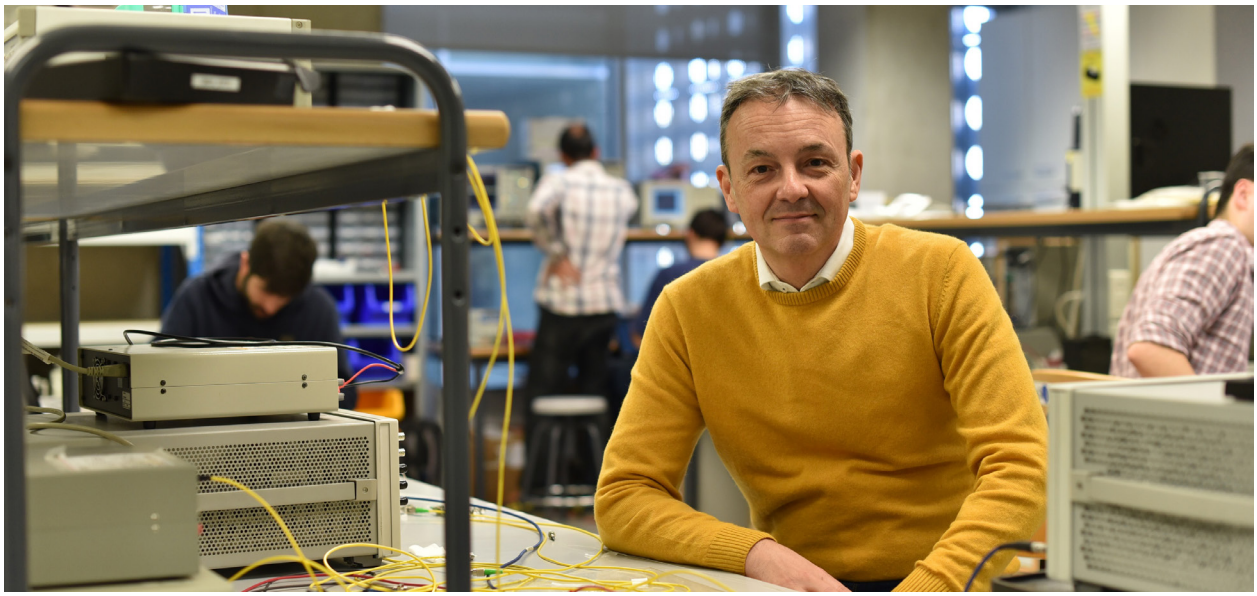
In this 39th edition, **Dr. Miguel Ferrando Rocher**, a researcher at the Electromagnetic Radiation Group of the iTEAM Research Institute, has been awarded with the **AIRBUS Space and Defence Award** for his doctoral thesis based on new antenna solutions in the millimeter wave-band for satellite communications. Dr. Miguel Ferrando Rocher received the award from Carlos Montesano, R&D Director of Airbus Spain.

21 VALENCIAN TELECOMMUNICATIONS NIGHT AND AWARDS 2019

Last July 11th, 2019, the **XXI edition of the Valencian Telecommunications Awards and Night**, organized by the Valencian College of Telecommunications Engineers (COITCV), the School of the Universitat Politècnica de València and Generalitat Valenciana took place in l'Hemisféric of the City of Arts and Sciences in Valencia. This event was sponsored by Cellnex/Adesal, HPE-Intel, Indra-Minsalt, Orange, Sothis, Telefónica and Vodafone.

Prof. Narcís Cardona, Director of the iTEAM Research Institute, received the Award as "Outstanding person in the field" for his important role in the dissemination and promotion of Telecommunications and ICTs.

Prof. José Capmany has obtained a Proof of Concept grant awarded by the European Research Council



Professor Capmany was awarded in 2016 with a prestigious **European Research Council** (ERC) Advanced Grant to design, manufacture and characterize a universal, multifunctional photonic chip. Now, in relation to that grant, he has obtained a **Proof of Concept** grant, where he and his team in the Photonics Research Labs of the iTEAM Research Institute will carry out the **Field Programmable Photonic Arrays** project (FPPA), whose objective is the technological development of an integrated photonic matrix with programmable gates, patented by UPV. With this type of grant, valued at €150,000, the ERC aims to foster transferring the results obtained in the Excellent Science ERC projects to the marketplace. The FPPA project kicked off in October and will last one year and a half.

Another of the aims of the project is the launching of a new UPV spin-off, whose activity will be focused on the development and commercialization of these new programmable photonic devices. They have a general purpose and they can be used, for example, in 5G digital communications, sensors, Internet of Things, artificial intelligence and quantum information systems, among other applications.

"The FPPA device," says Capmany, "shares similar features with FPGA, used in electronics, although it is also different in several significant aspects. FPGA means more than 50% global market of the complex electronic devices, and our aim is for FPPA to have a similar evolution and market share in parallel with the development of the embedded photonics. Since it is a programmable and highly versatile device, it can be used in almost any field of application, not only in systems that combine radio and optics."

iTEAM RECEIVES THE 2019 RESEARCH AWARD FROM THE SOCIAL COUNCIL OF THE UNIVERSITAT POLITÈCNICA DE VALÈNCIA

The **Social Council** of the **Universitat Politècnica de València** (UPV) has recognized the research excellence of the **iTEAM Research Institute** with the 2019 Research Award. The award was received by our director Narcís Cardona in the XVIII Award ceremony chaired by the highest authority of the Social Council of the UPV, Mónica Bragado, last May 9th, 2019.

The Social Council of the UPV is the body in charge of supervising the economic activities of the university and the performance of its services. In turn, it is responsible for promoting the collaboration of society in the financing of the university, as well as the relationship with its cultural, professional, economic and social environment.

A MATLAB-based ray launching simulation tool for VLC applications

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ABSTRACT

In this article we present a simulation tool for Visible Light Communications. This tool is based on MATLAB and uses the principles of ray launching methods for its calculations. The simulation tool uses a single LED as a transmitter and a single photodiode (PD) as a receiver. It allows for the assessment of different LED and PD characteristics and positions while considering both direct rays and first-order reflected rays. Subsequent versions of this program will focus on the study of VLC communications in an outdoor environment.

Keywords: VLC, ray tracing, ray launching, photodiode, LED.

1.- INTRODUCTION

Visible light communications (VLC) are a subset of optical wireless communications (OWC) technologies. Whereas OWC refers in a generic way to the communication in which light is used to carry a signal, VLC employs visible light that occupies the spectrum from 380 nm to 750 nm corresponding to a frequency spectrum of 430 THz to 790 THz [1].

Visible light communications' origins can be traced back to the ancient signal fires, followed by the Alexander Graham Bell's photophone in 1880. However, it was the emergence of solid state light sources that triggered the development of this novel technology [2]. At the beginning of the 21st century, a first approach to these applications can be found in the Nakagawa Laboratories. This ground-breaking research used white LEDs and different modulation schemes to conclude that it is feasible to use LED lights for wireless optical communications [3].

VLC offers multiple advantages compared to other technologies such as radio frequency (RF). Amongst these advantages, the most important ones are the possibility to use non-licensed channels, high bandwidth and low power consumption.

On the other side, some challenges that need to be overcome include the interference with the ambient light sources, the interference between VLC devices and the integration of the VLC with the existing technologies [1].

Just like any telecommunications system, a VLC system mainly consists of a transmitter, that utilizes the visible light source as a signal transmitter, air as a transmission medium (whether indoor or outdoor), and the appropriate photodiode as a signal receiving component [4]. There are several possible technologies to constitute each subsystem.

1.1 Transmitter

One of the key aspects of VLC is that it supports illumination and communication simultaneously. LEDs (Light Emitting Diodes) are the most extended option for the transmitter. Over the last decades, the development of LEDs has led to the gradual replacement of the incandescent and fluorescence light sources with solid state LEDs. The latter offer a bigger reliability, lifespan and efficiency. In addition to this, LEDs are capable of switching to different light intensities very fast, thus allowing the encoding of data.

There are several ways to generate white light from an inherently monochromatic device such as a LED. The main methods are based on a monochromatic LED utilizing yellow phosphor or a trichromatic approach (such as red, green and blue LEDs). Several advantages and disadvantages are bound to each method. Therefore, the appropriate transmitter type is selected based on the channel model.

The VLC data rate is dependent on the LED's modulation bandwidth. Although VLC systems have been demonstrated with both options, monochrome and trichrome, in [5] and [6], there are significant differences between them. While phosphorus-based white LEDs are less complex and less expensive compared to the RGB LEDs, they offer a lower modulation bandwidth, caused by the slow response of the phosphors (for a typical commercial LED, a bandwidth of 2MHz for the white component, and 10MHz for the blue component have been measured [7]). On the other side, RGB LEDs offer higher modulation bandwidths (around 180 MHz on the setup in [6]) at the expense of a bigger complexity.

There are several options to overcome the bandwidth limitations. Different methods, or a combination of them, that help to improve the data transmission rates are:

1) Digital signal processing (DSP), as in [8] and [9], where it is shown that the usage of DSP techniques can significantly enhance the performance of the VLC by improving the resilience to noise.

2) High-order modulations, such as a combination of DMT, multi-level modulation (QAM) as in [10].

3) Transmitter and receiver equalizations, as seen in [11], where blue-filtering and a post-equalization circuit achieves a better response.

4) Parallel transmissions like Single-Input-Single-Output (SISO) or Multiple-Input-Multiple-Output (MIMO), as in [12], which uses a combination of MIMO and OFDM techniques.

1.2 Receiver

There are mainly two types of VLC receivers: photodetectors (PD) or imaging sensors.

A photodetector (PD) is a semiconductor device that converts the received light into current. Commercial photodetectors with good responsivity are, for example, the silicon photodiode (Si PIN-PD) and the silicon avalanche photodiode (Si APD). Regarding the bandwidth, there are many photodiodes with bandwidths over 200 MHz (wider than the VLC LED transmitter) [4]. In [13] and [14], an analysis of the characteristics and performance of the different types of photodiodes is done.

Imaging sensors are basically multiple photodetectors arranged in a matrix on an integrated circuit. Already in [15] a 2-dimentional image sensor is proposed as a receiver, to overcome the limitations of an APD in terms of field of view (FOV). Other experiments have been carried out even by using the camera sensor of a smartphone [16].

One advantage of the CMOS image sensor usage is, due to the massive number of pixels available, its ability to spatially separate sources, like noise sources from LED transmission sources [17]. A downside of the commercially available imaging sensors is the frame rate, around 40 frames per second [18]. Higher rates would require high-speed cameras (e.g. 1000 fps as in [19]), thus increasing also the cost of the equipment.

1.3 Outdoor optical channel

VLC applications can be classified into two categories: indoor and outdoor.The outdoor optical channel has some characteristics that need to be considered, when considering VLC on the outdoor environment. Although VLC systems are preferably based on line-of-sight (LOS) configurations, in outdoor conditions there are many external light noise sources such as sun light or road and streets lights that may deteriorate the transmitted signal, and both natural and artificial ambient lights could induce shot noise on the receiver side. In addition, propagation characteristics of VLC drastically change with the atmospheric

conditions, which will condition the use of different modulation techniques. The work in [20] presented a VLC system suitable for outdoor applications, which allows a low data rate communication link ranging up to 40 m using commercially available LEDs and [21] used LED-based headlamps for V2V communication, reaching a distance of 20 m at a data rate of 2 Mbps. An experimental characterization of a traffic light to vehicle VLC link performance was carried out in [22].

To conclude this introduction, it should be pointed out that with respect to visible light communications, the outdoor applications are less explored when compared to those indoors. This is due to the fact that i) the dual use of LEDs (light and data) is not always practicable outdoors, ii) the level of interference and noise is considerably higher, iii) the alignment of transmitter and receiver is more complicated with high mobility, and iv) there are other technologies that adapt better to the outdoor environment, among others [23].

However, due to the great potential of VLC for vehicle applications it is important to understand and try to overcome these limitations. Current challenges regarding VLC usage in vehicular communications are:

i. increasing robustness to noise,

ii. increasing the communication range,

iii. enhancing mobility,

iv. increasing data range and

v. developing parallel visible light communications [24].

Most of the current and past investigations available have focused on indoor communications. However, the potential impact of VLC in outdoor environments, especially for vehicular communications, requires the extension of available models used in indoor for the outdoor case. The first phase into this direction consists in establishing a valid model with one or more LEDs as transmitter and one photodiode as receiver.

In this paper a MATLAB simulation tool for VLC modeling is presented. First, we introduce the ray launching method, which is the basis of our application, the modeling of the transmitter and the receiver elements and we explain the mathematical model of the LED-based VLC communications and how these models are applied in our program. Then, we show a block diagram of the whole application together with a description of the various subroutines, input and output data and internal structures. Lastly, we present the results of our simulations with different configurations and compare them with measurements done by other authors.

2.- SIMULATION TOOL

In this section, our simulation tool to reproduce the communication between an LED and a photodetector is presented. This tool is developed in MATLAB. In the first part, we present the two ray models that exist and the one chosen for our program. Then, we explain how the various elements of the VLC system are modeled and the block diagram or the program.

The main difference between our method and other researches that focus on MATLAB-based simulation tools for VLC applications like [25] is that the purpose of our tool is not to obtain results based on the direct application of mathematical models, but to take them as a base and apply the ray launching principles.

2.1 Ray launching

With wavelengths smaller than the surrounding obstacles, electromagnetic waves can be approximated by rays, applying the laws of optics. Mechanisms of reflection, diffraction and scattering have to be considered [26].

Ray models are usually based on one of the two ray construction techniques called ray tracing and ray launching. Whereas in ray tracing methods the paths are found by tracing a straight line joining the transmitter to the receiver, or to their respective image and checking if the reflection point lies within the limits of the considered reflector, in the ray launching method, a large set of rays is

launched from the source in 3D directions. Each ray represents a beam around its direction and the whole set of beams covers the 4 steradians solid angle of the sphere without holes or overlapping [27]. This simulation tool is based on the ray launching technique.

The identification of which rays eventually reach the receiver (and are considered for the received power calculations) is carried out through line-plane intersection methods. The straightforward option would be to check if any point of the line defined by an originating point and a direction is also a point of the plane that forms the receiver. However, this method would require a bigger effort compared to the algorithm that is used.

In [28], Möller and Trumbore describe an efficient algorithm for determining whether a ray intersects a triangle. In [29], Lagae and Dutré follow a similar approach but using quadrilaterals instead of triangles, which is, at least, as fast as the method with triangles. Although at first it can appear more logical to follow the second approach due to the geometry of the objects used by the simulation tool, our algorithm uses a tailored version of the method described in [28].

2.2 Modeling of the elements

2.2.1 Transmitter

As mentioned in the previous section, our simulation tool is based on the ray launching method. For this reason, the emitting LED is modeled as a large set of rays with a common origin. This origin is the position of the LED. For our purpose, the rays will not be launched in all directions of a sphere as stated before (4 steradians). Due to the shape and the emission pattern of an LED, only a hemisphere will be considered.

According to [30], the emitted light from an LED is assumed to have a Lambertian emission pattern, in which the radiant intensity depends on the angle of irradiance. The radiant intensity can be thus modeled using a generalized Lambertian radiant intensity

$$R_o(\theta) = \frac{m+1}{2\pi}\cos^{\mathrm{m}}(\theta),$$

where θ is the irradiance angle and m is order of Lambertian emission, which can be calculated

$$m = -\frac{\ln 2}{\ln\cos\Phi_{1/2}},$$

being $\Phi_{(1/2)}$ the semiangle at half power of a LED.

In addition to $\Phi_{(1/2)}$, our simulation tool uses the total optical power of the LED, P_{total}, for the calculations.

Having the total optical power of the LED, and considering that the LED will be represented by a number of individual rays, each of them must have a power that adds up to the power of the LED. The sum of the powers for every ray that reaches the receiver would result in the total power of the LED.

2.2.2 Receiver

At this stage of development, the receiver is modeled simply by a plane. The only purpose of the modeled receiver is to determine how many of the emitted rays or their corresponding reflections reach the receiver. The coordinates of the central point, the dimensions (width and length) and the normal vector of the receiver plane are part of the configuration parameters.

Other aspects that have to be considered in general according to Komine in [30] are the area of the receiver, A, the distance from the transmitter to the receiver, D_d, the angle of incidence, ψ, the gain of an optical filter, $T_s(\psi)$ and the gain of an optical concentrator, $g(\psi)$. If the incidence angle is bigger than the receiver's field of vision (FOV), Ψ_c, then the received power for that incidence angle is 0.

2.2.3 Optical link

Summing this up, Komine states that the received power, P_r, is derived from the transmitted optical power, P_t, as follows:

$$P_r = H(0)\cdot P_t,$$

where $H(0)$ is the channel DC gain of an optical link

$$H(0) = \begin{cases} \frac{(m+1)A_r}{2\pi D_d^2} \cos^m(\theta)\, T_s(\psi) g(\psi) \cos(\psi), & 0 \le \psi \le \Psi_c \\ 0 & \psi > \Psi_c \end{cases}.$$

For our simulator, we consider no gains at the moment so, $T_s(\psi)=1$ and $g(\psi)=1$. The area of the receiver, A_r, is also not important for our purpose, since our calculation of the received power is based on the count of incident rays and the sum of their corresponding optical powers. The distance from the transmitter to the receiver, D_d, is calculated by the triangle-ray intersection algorithms.

2.2.1 Direct and reflected rays

There is a significant difference between the way direct and reflected rays are handled.

For each direct ray that reaches the receiver ($0 \le \psi \le \Psi_c$), our simulation tool calculates its received power as

$$P_{rd}(\theta) = \frac{(m+1)}{2\pi D_d^2} \cos^m(\theta) \cos(\psi)\, P_t(\theta).$$

For reflected rays, other aspects like the reflection coefficient of the reflective surface, ρ, and the total distance traveled by the ray must be considered. Also, according to Komine in [15], it is acceptable to make the assumption that all reflectors are Lambertian, so the angles involved in the reflection should also be considered in the calculations [30]. In the following equation, α is the angle of irradiance to a reflective point and β is the angle of irradiance to the receiver

$$P_{rr}(\theta) = \frac{(m+1)}{2\pi^2 D_{d1}^2 D_{d2}^2} \rho \cos^m(\theta) \cos(\alpha) \cos(\beta) \cos(\psi)\, P_t(\theta).$$

At the end of the simulation we obtain the total received power as

$$P_r = \sum_{\forall\theta} P_{rd}(\theta) + \sum_{\forall\theta} P_{rr}(\theta).$$

2.3 Block diagram

In this section we describe the overall process of the simulation tool.

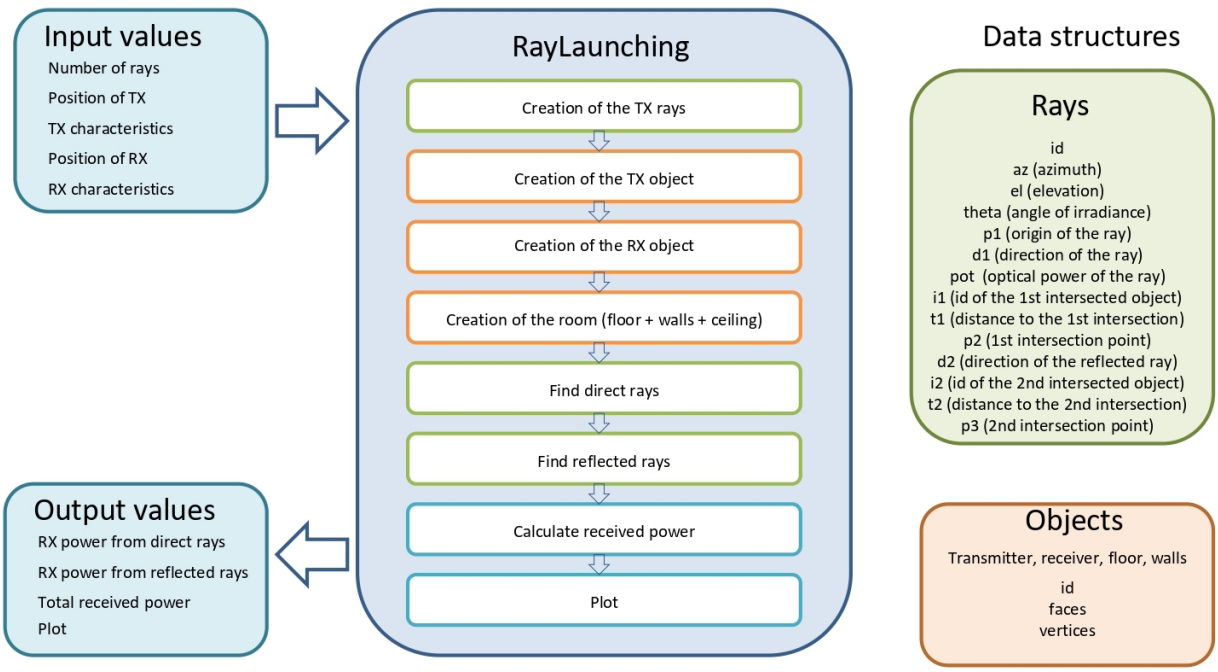

Figure 1: Block diagram of the simulation tool

On the left side of the figure we can see the input values that the program needs for the calculations:

- Number of rays: Configurable depending on the desired level of precision. This value determines how many rays will be launched.
- Position of TX: Cartesian coordinates of the position of the LED.
- TX characteristics: Values that describe the LED such as optical power and semiangle at half power.
- Position of RX: Cartesian coordinates of the position of the receiver plane (photodetector).
- RX characteristics: Values that describe the PD such as width, length and FOV.

The most important output values of the program are:

- RX power from direct rays: Total power received from the direct rays that reach the PD.
- RX power from reflected rays: Total power received from the reflected rays that reach the PD.
- Total received power: Sum of the two values mentioned above.
- Plot: A figure generated by MATLAB showing the scenario and the rays that reach the receiver.

On the right side of the picture we see the two structures that are used by the program: rays and objects. The rays structure contains all the data from the launched rays. The content of this structure is updated by several subroutines (depicted with a green border on the central part of the figure).

The objects structure contains the details of the different objects of the scenario: transmitter, receiver, walls and floor. Every object has a unique identifier and the list of faces and vertices (Cartesian coordinates) that form the object. This structure is updated by the subroutines depicted with an orange border on the central part of the figure.

The central part of the figure describes the different subroutines that are executed:

- Creation of the TX rays: This subroutine creates the set of rays that will be launched. All rays have a common origin given by the coordinates of the transmitter. The function that generates the rays does a linear spacing with the given "number of rays" value for the corresponding azimuth and elevation ranges. This ranges depend on the orientation of the LED. For instance, for a LED installed on the ceiling, azimuth $\in[0,2\pi]$, elevation: $\in[\pi,0]$. Then, each point of the mesh (currently in spherical coordinates) is converted to Cartesian coordinates. These points together with the center of the TX determine the direction of the ray. These values are stored in the rays structure.
- Creation of the TX object: An entry for the transmitter is stored in the objects structure.
- Creation of the RX object: With the given position, orientation, width and length of the receiver, the program generates the section of the plane that models the PD. This plane is split into two triangles and the corresponding coordinates of the vertices are stored in the objects structure.
- Creation of the room: Similar to the step above, given the position, orientation, width and length of the floor and walls, the program generates the corresponding planes and the vertices are stored in the objects structure.
- Find direct rays: Together with the following step, these two routines form the core of the program. For each ray in the rays structure, the triangle-ray intersection algorithm is run. The triangle-ray intersection function takes the ray origin and direction and returns the intersected object (i1), the intersection point (p2) and the distance from the origin of the ray to the intersection point (t1). These values are updated in the rays structure.

On this step the program calculates the corresponding received power of each ray, as described in section 2.2.4.

- Find reflected rays: For each ray in the rays structure that is not a direct ray (that means, that hasn't intersected with the receiver yet), the triangle-ray intersection algorithm is run.

Another loop runs through the rays structure and looks for the rays that have intersected a reflective surface (wall or floor). Given the intersection point and the direction of the ray, a function calculates the direction of the corresponding reflected ray. The program runs the triangle-ray intersection for this new ray and checks if it intersects the receiver. If that is the case, the intersection point (p3) and the distance from the origin of the reflected ray to the intersection point (t2) are updated in the rays structure.

The calculation of the corresponding received power, as described in section 2.2.4, is also done.

Calculate received power: For each received ray, the corresponding received power is added up and the received power (direct, reflected and total) is found.

- Plot: Finally, a plot with the transmitter, receiver, room and received rays (direct and reflected) is generated and shown.

3.- RESULTS AND DISCUSSION

In this section we present some results obtained with our simulation tool in order to prove the viability of using it for the simulation of real VLC scenarios.

We consider multipath environment in an empty room. The topology for the simulation is a cubic room (5 x 5 x 3 m) with plaster walls (ρ =0.83). The transmitter is a single LED source with $\Phi_{(1/2)}$=60° and P_{total}=1 W. The LED is located on the center of the ceiling (2.5, 2.5, 3). The receiver is a photodetector with FOV = 85° and area = 1 cm^2.

In order to validate that the simulation tool delivers correct results, a comparison between these results and calculations with the mathematical model is done. Two scenarios will be considered: a scenario where the photodetector is positioned right under the LED and a scenario where the PD is positioned in a different position. Simulations have been done with 250 000 launched rays.

As stated in section 2.2.4, the total power received by the PD is the sum of the contribution of the direct rays and the reflections in walls and other objects. In this case:

$$P_r = P_{rd} + P_{rr1} + P_{rr2} + P_{rr3} + P_{rr4},$$

where P_{rd} is the contribution of the direct rays and P_{rrk} is the contribution of the first-order reflections on each wall.

Scenario 1: Photodetector positioned right under the LED

In the first scenario, the photodetector is positioned right under the LED. That means, the PD is on the direction of maximum radiation of the LED. Due to the symmetry of the scenario, the individual contributions for the reflections on each wall will be the same.

Considering the direct rays' contribution and according to the mathematical model

$$P_{rd} = P_t \frac{(m+1)A_r}{2\pi D_d^2} \cos^{\mathrm{m}}(\theta)\cos(\psi) = 3.5368\ \mu W$$

where $P_t = 1\ W$, $m = -\frac{\ln 2}{\ln \cos 60} = 1$, $A_r = 1\ cm^2$, $D_d = 3\ m$, $\theta = 0$ and $\psi = 0$.

This contribution, according to the result of the simulation is 3.5359 μW.

Considering the reflected rays' contribution on any of the walls, according to the mathematical model

$$P_{rrk} = P_t \frac{(m+1)A_r}{2\pi^2 D_{d1}^2 D_{d2}^2} \rho \cos^{\mathrm{m}}(\theta)\cos(\alpha)\cos(\beta)\cos(\psi) = 0.022\ \mu W$$

where $P_t = 1\ W$, $m = -\frac{\ln 2}{\ln \cos 60} = 1$, $A_r = 1\ cm^2$, $\rho = 0.83$, $D_{d1} = 2.91\ m$, $D_{d2} = 2.91\ m$, $\theta = 59.03$, $\psi = 59.03$, $\alpha = 30.96$ and $\beta = 30.96$.

Due to the symmetry of the scenario, the total received power due to reflections is P_{rr}=0.089 μW. This contribution, according to the simulation is 0.0914 μW.

Table 1 shows the total received power in Scenario 1. From this outcome it can be seen that the results of the simulation are very close to the mathematical model. In addition, it is also evident that, in scenarios with Line-of-sight (LOS), the main contributors to the received power are the direct rays.

Table 1: Received power (direct and reflected) with the mathematical model and the simulation tool for Scenario 1.

	Model	Simulation
Direct rays	3.5368 μW	3.5359 μW
Reflected rays	0.089 μW	0.0914 μW
Total received power	3.6264 μW	3.6273 μW

Scenario 2: Photodetector positioned in a different position (0.5, 1, 0)

In the second scenario, the photodetector is positioned at a different position, in this case, at position (0.5, 1, 0), that is, away from the direction of maximum radiation of the LED. For the calculations, a similar approach as in the first scenario is followed, but considering that in this case there is no symmetry:

$$P_{rd} = P_t \frac{(m+1)A_r}{2\pi D_d^2} \cos^{\mathrm{m}}(\theta)\cos(\psi) = 1.232\ \mu W$$

where $P_t = 1\ W$, $m = -\frac{\ln 2}{\ln \cos 60} = 1$, $A_r = 1\ cm^2$, $D_d = 3.905\ m$, $\theta = 39.80$ and $\psi = 39.80$.

This contribution, according to the result of the simulation is 1.2341 μW.

The reflected rays' contributions can be calculated with the mathematical model knowing the angles of irradiance, incidence and reflection. For the following calculations, these angles have been obtained also with the simulation tool. Table 2 shows the parameters that have been used for the calculations and also the received power from reflected rays, obtained both with the model and the simulation.

Table 2: Received power and parameter values used for the calculations of the reflected rays

	Left wall	Back wall	Right wall	Front wall
Reflection point	(0, 1.25, 0.50)	(1.73, 5, 1.84)	(5, 1.96, 1.93)	(1.07, 0, 0.86)
Irradiance angle, θ	48.18°	77.69°	67.27°	53.34°
Angles on the reflecting point, α, β	41.82°	12.31°	22.73°	36.66°
Incidence angle, ψ	48.18°	77.69°	67.27°	53.34°
Received power, P_{rrk} (model)	0.2613 μW	0.0021 μW	0.0056 μW	0.0728 μW
Received power (simulation)	0.2101 μW	0.0061 μW	0.0053 μW	0.0548 μW

Table 3 shows the total received power obtained with the model and the simulation. It can be seen that, again, the contribution of the reflected rays is much lower than the contribution of the direct rays. In addition, by comparing the total received power of the two scenarios it can also be seen that the power received in scenario 1 is higher than in scenario 2. This is due to the fact that the LED's direction of maximum radiation is normal to its surface, that is, right below it.

Table 3: Received power (direct and reflected) with the mathematical model and the simulation tool for Scenario 2.

	Model	Simulation
Direct rays	1.232 μW	1.234 μW
Reflected rays	0.342 μW	0.276 μW
Total received power	1.574 μW	1.510 μW

The following drawings show the plotted outcome of the ray launching for the two scenarios. Only rays that eventually reach the receiver are shown. The walls and the ceiling of the room have not been plotted for the sake of clarity.

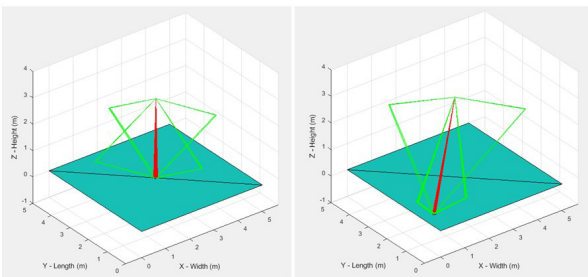

Figure 2: Results of the simulation. a) Photodetector positioned on the floor right under the LED (direction of maximum radiation) b) Photodetector positioned at a different position, in this case, at position (0.5, 1, 0)

To finalize this section, Figure 3 shows the received power distribution for the LOS path. As it can be seen, it has some symmetry and the peak power is observed at the center of the room (right below the LED). For this simulation, the receiver has been positioned in 1 024 different positions around the room. For each position, an individual simulation of the received power has been run. Lastly, the

total received power position (normalized) has been plotted.

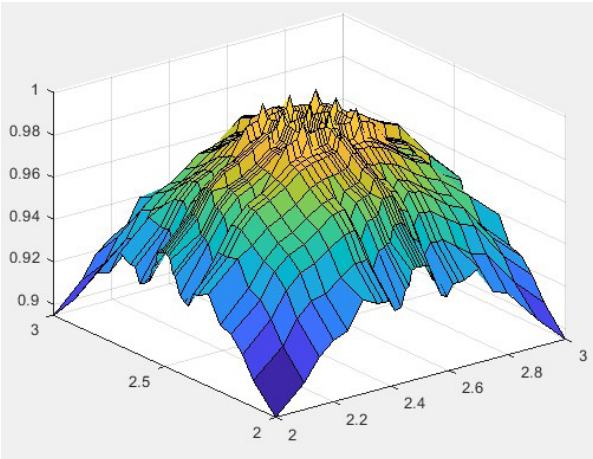

Figure 3: Spatial distribution of the received power (normalized)

4.- CONCLUSIONS

In this paper, we have reported the simulation program for visible light communication environment based on MATLAB. The program considers direct rays and first-order reflections at each wall. The results obtained by the simulations are accurate enough to conclude that this tool has a great potential in the study of VLC communications. Although the first results might indicate that the ray launching method is not as efficient as the mathematical models, it must be pointed out that the latter might face difficulties if the scenario gets more complex than a simple empty room. As the purpose of this tool is to be used for outdoor environments, which might not be easily covered by simple mathematical models, we think that it is worth continuing with this line of research.

However, to reach this purpose, some aspects need to be improved:

- Currently only a few part of the launched rays reaches the receiver. That means that most of the resources of the program are lost. The solution to this problem is to estimate which angle ranges (azimuth and elevation) should be used for the ray launching, so the most part of the launched rays reaches the receiver. This improvement is currently under development and will be included in next versions of the program.
- Although the results obtained with the simulation tool are close to the results of the mathematical model, it would be recommendable to calibrate the tool with real components. This leads us to the need for carrying out measurements in the lab, with a real hardware setup.
- The possibility to simulate MIMO configurations must be introduced, as it is a key aspect overcome the bandwidth limitations of the LED and increase the data transmission rate.

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6.- BIOGRAPHY

Rafael Zafrilla received his degree in Telecommunications engineering from the Universitat Politècnica de València (UPV) in 2013. Since then, he has developed his professional career in the field of mobile networks and GSM-R and he is a full-time maths high-school teacher. His research interests include optical wireless communications, free-space optics, and visible light communications.

Dr.-Ing. Jose F. Monserrat (H-index 23) received his MSc. degree with High Honors and Ph.D. degree in Telecommunications engineering from the Universitat Politècnica de València (UPV) in 2003 and 2007, respectively. He was the recipient of the First Regional Prize of Engineering Studies in 2003 for his outstanding student record receiving also the Best Thesis Prize from the UPV in 2008. In 2009 he was awarded with the best young researcher prize of Valencia. In 2016 he received the merit medal from the Spanish royal academy of engineering, in the young researcher category. He is currently full professor in the Communications Department of the UPV. His current research focuses on the design of future 5G wireless systems and their performance assessment. He has been involved in several European Projects, being especially significant his participation in NEWCOM, PROSIMOS, WINNER+, 5GXCAST and METIS/METIS-II where he led the simulation activities. He is currently Principal Investigator in two H2020 projects, 5G-CARMEN and 5G-SMART. He also participated in 2010 in one external evaluation group within ITU-R on the performance assessment of the candidates for the future family of standards IMT-Advanced. He co-edited two special issues in IEEE Communications Magazine on IMT-Advanced and 5G technologies and is co-editor of the Wiley book "Mobile and wireless communications for IMT-Advanced and beyond" and the Cambridge book "5G Mobile and Wireless Communications Technology". Jose Monserrat is senior member of the IEEE, manages around 0.5 M€ yearly budget, holds 6 patents and has published more than 50 journal papers. Currently the group headed by Prof. Jose F. Monserrat consists of 3 Postdoctoral fellows, 8 PhD students and 2 Master students.

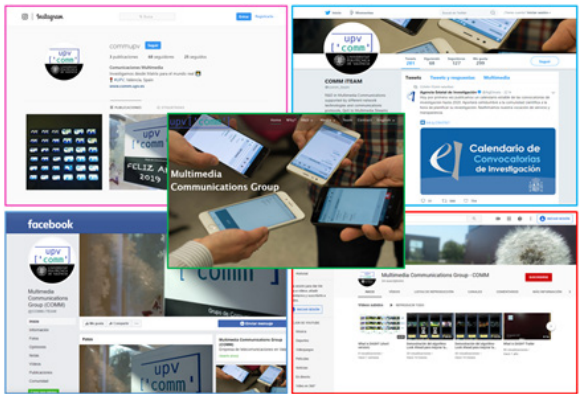
MULTIMEDIA COMMUNICATIONS GROUP (COMM) ANNUAL RESEARCH REPORT 2018/2019

HEAD OF THE GROUP RESEARCH REPORT

Multimedia Communications Group (COMM) started its activities in 2004, and nowadays is composed of a group of 6 researchers, focusing its research lines on multimedia systems and Quality of Experience (QoE). During the last year 2018/2019 the group has continued with its work lines focused on the distribution of multimedia content using protocols like Dynamic Adaptive Streaming over HTTP (DASH); carrying out more in-depth studies into the Internet of Things (IoT) trend; analysing and proposing new metrics for estimating the QoE; developing new functionalities for multimedia systems based on DRM and cross-layer techniques; and continuing studying new trendy lines such as the integration of protocols for broadcast distribution.

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

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



Website and social networks of the COMM

1.- PROJECT ACTIVITIES

The COMM has continued during the last year with its main research lines. Also, new emerging activities have appeared. A short summary of the main advances carried out is presented below:

Adaptive video through MPEG-DASH

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

Measure of the Quality of Experience

Another important research line this year has been the analysis of different metrics that help to calculate the quality perceived by users when consuming video contents. We have deeply analyzed the recommendation P.1203 proposed by the International Telecommunications Union (ITU). This recommendation describes a set of objective parametric quality assessment modules that help to predict the impact of media encoding and observed IP network impairments on quality experienced by the end-user in multimedia streaming applications.

Also, we have proposed different QoE metrics for the evaluation of adaptive bitrate (ABR) algorithms. Specifically we have proposed a bitrate-based QoE metric, a QoE metric based on the PSNR (Peak Signal-to-Noise Ratio) and a metric based on VMAF (Video Multimethod Assessment Fusion). The different evaluations carried out have proved that the proposed QoE metrics results more accurate than other similar metrics proposed in the literature, including the ITU-T P.1203 recommendation.

Optimization of the multimedia content transmission with cross-layer

In this year we have deepened in the use of cross-layer mechanisms in order to improve the performance of the network when several users are consuming multimedia contents concurrently. Specifically, we have developed a system based on a cross-layer server which, depending on the reports received by the clients (which include parameters like estimated bandwidth or video representation displayed), force the clients to change their displayed video quality in order to minimize the stalls of the overall clients. To that extent, the cross-layer server is based on MPEG SAND (Server and Network Assisted DASH). This technology offers standardization messages and protocols in order to improve the user experience in the streaming service and to better use the bandwidth.

Proxy-based near real-time TV content transmission in mobility

In this line, the group has developed a multimedia system that provides users in mobility with TV and radio services in near real-time. To that end, the system uses advanced selective pre-storage strategies of content sent to the vehicles from transcoding servers located on the cloud. One of the key elements of the system is an on-board proxy in charge of creating and managing the buffers associated to each video flow offered in the platform. Thus, the proxy is designed to adjust the amount of segments in buffer with the aim of providing continuous playback in on-board clients.

During this year we have carried out several tests to ensure the reliability of the service when numerous users access simultaneously. To perform the tests we have used a panel of tablets, as shown in the figure.

Testbed of the TV transmission system in mobility

The developed system has been assessed and results have demonstrated that using the proposed advanced on-board proxy in mobility help reduce video interruptions and, therefore, the quality of experience perceived by final users is improved. The recommendation ITU-T P.1203 is also applied in order to estimate this QoE more precisely.

Adaptive streaming for 3D video

Considering the importance of replicating and assessing the results obtained in a research environment, during this year we have focused on developing an easily exportable, reproducible and scalable system that allows automation and systematization of the quality of experience assessment in adaptive video streaming scenarios. The proposed system is oriented to the automated execution of a DASH player, using the Google Chrome browser and, specifically, using Puppeteer, the new library developed by Google that allows the automation of functional tests in web environments. Puppeteer enables access to the Chrome Developer Tools, thus allowing the capture of metrics and records related to network statistics, state of the buffer, number of stops, duration of stops, playback time and transmitted representations of the video, among others.

This data can be obtained either parsing the output log or analyzing a generated JSON file that records the interaction between the client and the server. These files are then processed to extract the data required for the reconstruction of the video and their subsequent subjective assessment through the ITU-T P.1203 recommendation. The different components of the system (client-server), including the emulation of bandwidth conditions, can be executed on the same machine. Thus, the aim is to use a virtualization system or a container-based system, such as Docker, to be able to deploy each module of the system independently, even deploying the client and server in the same computer, which would allow the system to be easily exportable and replicable by the scientific community.

Internet of Things

The application of the potential of Internet of Things (IoT) to improve the life of citizens leads to what nowadays the Smart Cities represent. A Smart City can be seen as an instrumented, interconnected and intelligent urban ecosystem. Hence, IoT technologies are fundamental for Smart Cities, since sensors are responsible for collecting data on the state of the city and then disseminate them among citizens, often making use of an urban platform and its capabilities.

During this year, the group has been working 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. In addition, all these developments follow the same principles, ensuring that data is open and guaranteeing interoperability through open APIs. For this, the UPV collaborates closely with the City Council and the other partners of the Valencia demonstrator,

in order to design the new models and data sets that will be used for the new services and devices integrated into the urban platform, as well as the indicators and significant metrics to monitor the progress and improvements developed in the project, following the most relevant standards in IoT.

Reliable multicast transmission over communication networks

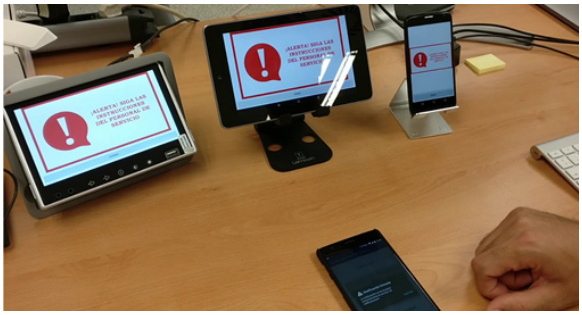
During this year we have carried out different comparative study between unicast, multicast and hybrid networks for live videos. In this sense, we have continued analysing a protocol named ROUTE (Real-Time Object Delivery over Unidirectional Transport), which is considered the evolution of FLUTE (File Delivery over Unidirectional Transport), a highly studied protocol by part of the research group. The ATSC (Advanced Television Systems Committee) published in 2016 a new candidate standard which proposes the jointly use of ROUTE and DASH. ROUTE, apart from the functionalities of the FLUTE protocol (such as multicast transmission of files), allows to provide video streaming services in multicast.

1.1.- ONGOING PROJECTS

Name of the project: *Desarrollo de nueva plataforma de entretenimiento multimedia para entornos náuticos (CDTI TIC-20170102)*

Summary of the project: *The overall objective of the project is the definition and implementation of a new platform capable of supporting and providing real-time content distribution services and Internet access in an environment of high user density and high mobility, taking into account the complexity of the reception and signal transmission in maritime environments, in which there are usually connectivity problems so Internet access is only possible by satellite. The project started in July 2017 and it has finished in 2019. During this last year, the COMM has developed different mechanisms for the improvement of the Quality of Experience of users, specifically a new adaptation algorithm for video adaptation as well as the use of cross-layer mechanisms to deal with several users connected at the same time. Also, it has been developed a notification service to inform clients about alerts and general information.*

Funding entity: *Ministerio de Economía, Industria y Competitividad. CDTI (Centro para el Desarrollo Tecnológico Industrial)*



Notification service within the CDTI TIC-20170102 project

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

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. During this year, first IoT sensors have been integrated into the Valencia urban platform (VLCi). Among the sensors, there are smart meters that measure energy and power consumption, and comfort parameters, such as temperature, humidity and luminosity. On the one hand, significant information is analysed and recommendations are provided to users regarding energy efficiency and ways to save expenses. On the other hand, anonymized data is published as open data sets on the city Open Data Portal so that citizens, entrepreneurs and third parties could build applications based on this data. New dashboards have been built to manage and control relevant KPI (Key Performance Indicators).*

Funding entity: *European Union's Horizon 2020 Research and Innovation Programme*

Meeting of the MAtchUP project in Valencia (Spain)

Name of the project: SSPressing - Smart Sound Processing for the digital living (TEC2015-67387-C4-4-R)

Webpage of the project: http://sspressing.upv.es

Summary of the project: The project performs systems for analysis and synthesis of environments and sound scenes in an "intelligent" and computationally efficient way

through network acoustic nodes. Specifically, the following objectives/developments are addressed: conformation of interactive virtual sound environments with distributed multinode control systems, creation of interactive virtual sound scenes and analysis of sound scenes for detection, location and classification of events and scenes, and development of systems to aid hearing and improve intelligibility. The tasks of the third and last year of the project have been focused on improving the acoustic classifier of the ad-hoc network. Specifically, different classes from an urban sound 8K dataset with different outdoor noises have been selected: siren, car horn and gun shot. The feature extraction is processed by each acoustic sensor where the classification process is carried out by the server using a multi-layer neural network.

Funding entity: Ministerio de Economía, Industria y Competitividad (Programa Estatal de I+D+i orientada a los Retos de la Sociedad)

2.- RESEARCH RESULTS

2.1.- FEATURED PUBLICATIONS

- ***Proxy-based near real-time TV content transmission in mobility over 4G with MPEG-DASH transcoding on the cloud***. *P. Arce, I. de Fez, R. Belda, J. C. Guerri, and S. Ferrairó, Multimedia Tools and Applications, vol. 78, no. 18, pp. 26399-26425, 2019.*

This paper presents and evaluates a system that provides TV and radio services in mobility using 4G communications. The system has mainly two blocks, one on the cloud and another on the mobile vehicle. On the cloud, a DVB (Digital Video Broadcasting) receiver obtains the TV/radio signal and prepares the contents to be sent through 4G. Specifically, contents are transcoded and packetized using the DASH (Dynamic Adaptive Streaming over HTTP) standard. Vehicles in mobility use their 4G connectivity to receive the flows transmitted by the cloud. The key element of the system is an on-board proxy that manages the received flows and offers them to the final users in the vehicle. The proxy contains a buffer that helps reduce the number of interruptions caused by hand over effects and lack of coverage. The paper presents a comparison between a live transmission using 4G connecting the clients directly with the cloud server and a near real-time transmission based on an on-board proxy. Results prove that the use of the proxy reduces the number of interruptions considerably and, thus, improves the Quality of Experience of users at the expense of slightly increasing the delay.

- ***Interoperability network for traffic forecast and full electric vehicles power supply management within the smart city.*** *V. Fernández, J. C. Guerri, and A. Roca, Ad Hoc Networks, vol. 93, article 101929, 2019.*

Information technologies and applied mathematics provide us with a comprehensive framework to search for solutions to problems derived from traffic management. It is relevant for the mobility in our future cities to integrate the Full Electric Vehicle (FEV) in an interoperability network which allows us to track the FEV autonomy and to forecast the traffic and the power supply demand in the city. The target is to optimize the energy consumption and to improve the mobility in the city. To achieve these goals we propose an infrastructure to efficiently manage the power supply availability in the network of charge stations in the city and an adaptive model to predict the traffic based on historic data and on time series obtained mathematically.

- ***Available bandwidth estimation for adaptive video streaming in mobile ad hoc.*** *W. Castellanos, J. C. Guerri, and P. Arce, International Journal of Wireless Information Networks, vol. 26, no. 3, pp. 218-229, 2019.*

We propose in this paper an algorithm for available bandwidth estimation in mobile ad hoc networks and its integration into a conventional routing protocol like AODV for improving the rate-adaptive video streaming. We have introduced in our approach a local estimation of the available bandwidth as well as a prediction of the consumed bandwidth. This information allows video application to adjust its transmission rate avoiding network congestion. We conducted a performance evaluation of our solution through simulation experiments using two network scenarios. In the simulation study, transmission of video streams encoded with the H.264/MPEG-4 advanced video coding standard was evaluated. The results reveal performance improvements in terms of packet loss, delay and PSNR.

- ***Algoritmo de adaptación DASH sensible al tamaño del segmento.*** *R. Belda, I. de Fez, P. Arce, and J. C. Guerri, in Proc. of the Simposium Nacional de la Unión Científica Internacional de Radio (URSI), Granada, Spain, Sep. 2018, article S7.1.3.*

Adaptation algorithms are one of the key elements regarding the performance of the Dynamic Adaptive Streaming over HTTP (DASH) video standard. Usually, adaptation algorithms use the average video bitrate to be compared with the estimated bandwidth as well as the playback buffer. This approach can cause stalls when there are peaks in the video segment sizes, since encoded videos have inherently variable bitrate, despite being encoded with a target bitrate. In this sense, this paper proposes an adaptation algorithm called Look Ahead which takes into account the bitrate variability of the videos in order to calculate in advance the appropriate representation that minimizes the number of stalls during the playback. The evaluation carried out proves that the

proposed algorithm outperforms other relevant adaptation algorithms both in number and duration of video playback stalls, but with hardly decreasing the average quality during playback.

- ***Mobility Network Model for Full Electric Vehicles to Interoperate with the Smart Grid and Efficiently Manage the Power Supply in the Smart City**. V. Fernández, J. C. Guerri, and A. Roca, in Proc. of the 5th ACM International Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks (PE-WASUN 2018), pp. 26-32, Montreal, QC, Canada, Nov. 2018.*

Never before have we seen such a wide range of opportunities for Full Electric Vehicle (FEV) to develop. The different choices to use computing to integrate FEV in our future European Smart City ecosystem are within our reach, here and now. This paper presents how to model the mobility in our future cities in order to make FEV interoperate with the smart grid and what an efficient way to control and manage the energy availability from a centralized information system would be.

MICROWAVE APPLICATIONS GROUP (GAM) ANNUAL RESEARCH REPORT 2018/2019

HEAD OF THE GROUP RESEARCH REPORT

Over the past year (September 2018 to July 2019), the group has continued working on one project awarded with national public funds, and it has successfully completed another project that was awarded with regional public funds. It is expected that at the end of this year, 2019 all the main objectives of the national project will be fully achieved.

In addition to this project, the group has also obtained national and regional public funding to hire some new researchers and PhD students, who are already collaborating with the group in its different research lines through formation grants and funds for hiring technical and support staff.

Furthermore, the group is also involved in two new European projects, to be developed in collaboration with other European universities and industries, for the training of young scientists and performing research activities in the space sector.

Apart from receiving public funding, the GAM activities were also funded through four technology transfer contracts agreed with industries and organizations, mainly subscribed with the European Space Agency (ESA) and space-sector companies.

Regarding the training capacity of the group, we should mention that one PhD doctoral thesis (in the area of remote sensing applications) has been successfully defended in the last year, and the group senior members are presently supervising others in different research areas.

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 more details about the group can be found at: http://gam.webs.upv.es/, or http://www.iteam.upv.es/group/gam/.

1.- PROJECT ACTIVITIES

The COMM has continued during the last year with its main research lines. Also, new emerging activities have appeared. A short summary of the main advances carried out is presented below:

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

- Analysis and design of high frequency (microwaves and millimetre-waves) 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 and multiplexers).
- Practical design of components (circuits and antennas) for high-frequency communication systems (e.g. wireless, space and mobile systems), including the modelling and experimental validation of high-power effects for satellite applications.

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

1.1.- ONGOING PROJECTS

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

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

As relevant players in the space sector have

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

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

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

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.

SELECTOR Project: SMT Compatible Electromechanical Relay for Compact Redundancy Ring

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.

This project has been funded by the H2020-RIA (Research and Innovation Action) Program

TESLA Project: Advanced Technologies for future European Satellite Applications

Figure 2. TESLA Network Logo

Space is key asset for Europe, which must continue to have a prominent role in this strategic sector. Since satellite payload RF components and systems are essential for delivering mission objectives and supporting ground equipment, new technologies and techniques are required to respond to emerging satellite applications and technology challenges.

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

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

This project has been funded by the H2020-MSCA-ITN-2018 (Marie Skłodowska-Curie Innovative Training Networks) Program.

2.- RESEARCH RESULTS

As a result of the joint research activity developed by this group in its research lines, during the last year of activity, more than 10 articles have been published in scientific journals with a high impact index (such as IEEE Transactions on Microwave Theory and Techniques, IEEE Microwave and Wireless Components Letters, IEEE Transactions on Antennas and Propagation, IET Proceedings on Microwave, Antennas and Propagation, IET Electronics Letters and Radio Science).

At the same time, the group has presented up to 19 communications in prestigious international conferences (such as IEEE-MTT Int. Microwave Symposium, IEEE-AP Int. Symposium on Antennas, European Microwave Conference on Numerical Electromagnetic Modeling and Optimization for RF, Microwave, and Terahertz Applications (NEMO), the 2018 European Microwave Week hold in Madrid, and the 2018 ESA Microwave Technology and Techniques Workshop), some of them as invited papers.

Finally, because of the research activity of the group developed in collaboration with companies and administrations of the aerospace sector, it has recently participated in the development of two new patents.

2.1.- FEATURED PUBLICATIONS

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

Controlled Out-of-Band Rejection of Filters based on SIW with Alternating Dielectric Line Sections, Juan Rafael Sánchez Marín; Maria Carmen Bachiller Martin; Vicente Nova Giménez; Vicente Enrique Boria Esbert. IEEE Microwave and Wireless Components Letters. Vol. 29, pp. 258 - 260. 2019. ISSN 1531-1309. DOI: 10.1109/LMWC.2019.2902034

A study for managing the out-of-band rejection in a new topology of filters based on substrate integrated waveguide with alternating dielectric line sections (ADLSs) is presented in this letter.

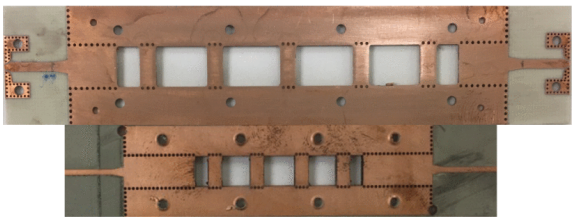


Figure 3. Manufactured filters. 13 GHz and five cavities filter with RO4003C (top) and 11 GHz and four cavities filter with TMM10i (bottom)

Compact Combline Filter Embedded in a Bed of Nails. Mariano Baquero Escudero; Alejandro Valero Nogueira; Miguel Ferrando Rocher; Bernardo Bernardo Clemente;Vicente Enrique Boria Esbert, IEEE Transactions on Microwave Theory and Techniques. Vol. 67, pp. 1461 - 1471. 2019. ISSN 0018-9480. DOI: 10.1109/TMTT.2019.2895576

In this paper, we propose a compact topology for high-frequency bandpass filters using coaxial cavities embedded in a bed of nails, including a complete design procedure combining equivalent circuit models and full-wave simulators.

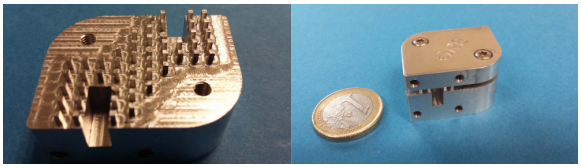


Figure 4. Filter base piece with periodic bed of nails, shortened cylindrical resonant nails, and input–output GGWs

Characterization of Nematic Liquid Crystal at Microwave Frequencies Using Split-Cylinder Resonator Method. Juan Rafael Sánchez Marín; Vicente Nova Giménez; Maria Carmen Bachiller Martin; Belén Villacampa; Alberto de la Rua; Rainer Kronberger; Felipe Laureano Peñaranda Foix; Vicente Enrique Boria Esbert. IEEE Transactions on Microwave Theory and Techniques. Vol. 67, pp. 2812 - 2820. 2019. ISSN 0018-9480. DOI: 10.1109/TMTT.2019.2916790

In this paper, a split-cylinder resonator method is used for the characterization of four different nematic LCs at two frequency points. This characterization includes the extraction of their complex dielectric permittivity values at these frequencies. The employed method allows to obtain the two extreme permittivity values without applying any external electric or magnetic field to polarize the LC molecules.

Figure 5. Measurement setup: VNA and split-cylinder resonator

Advanced Filtering Solutions in Coaxial SIW Technology Based on Singlets, Cascaded Singlets, and Doublets. Stefano Sirci; Miguel Ángel Sánchez Soriano; Jorge Daniel Martínez Pérez; Vicente Enrique Boria Esbert, IEEE Access. Vol. 7, pp. 29901 - 29915. 2019. ISSN 2169-3536. DOI: 10.1109/ACCESS.2019.2902956

The use of singlets, cascaded singlets, and doublets in a coaxial substrate integrated waveguide (SIW) technology is proposed in this paper, with the aim of implementing low-loss filters with very compact size and highly selective symmetric, asymmetric as well as dual-band responses.

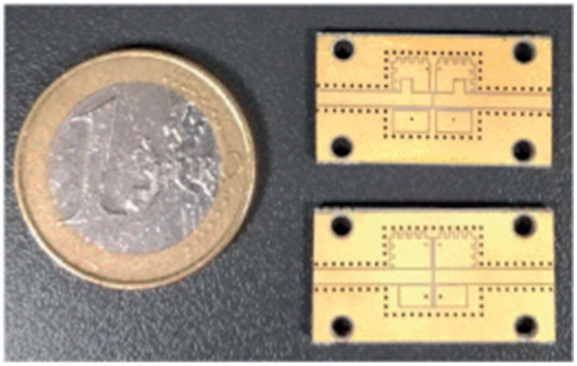
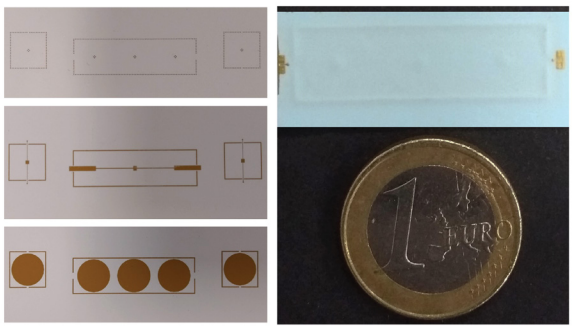


Figure 6. Photograph of filter prototypes: above filter DB2, and below filter DB1

A Novel Magnetic Coupling for Miniaturized Bandpass Filters in Embedded Coaxial SIW Stefano Sirci; Jorge Daniel Martínez Pérez; Vicente Enrique Boria Esbert. Applied Sciences (Basel). Vol. 9, pp. 1 - 14. 2019. ISSN 2076-3417. DOI: 10.3390/app9030394

In this paper, embedded coaxial substrate integrated waveguide (CSIW) filters with innovative magnetic couplings are presented and studied.



(a) (b)

Figure 7. (a) Some layers of the LTCC stack-up and (b) Three-pole BPF prototype

Empty SIW Technologies: A Major Step Toward Realizing Low-Cost and Low-Loss Microwave Circuits, Ángel Belenguer Martínez; Héctor Esteban González; Alejandro Lucas Borja; Vicente Enrique Boria Esbert. IEEE Microwave Magazine. Vol. 20, pp. 22 - 45. 2019. ISSN 1527-3342. DOI: 10.1109/MMM.2018.2885630

This review article summarizes much of the published material regarding Empty Substrate Integrated Waveguide (SIW) technologies, highlighting the main characteristics of each one of them.

Figure 8. Manufactured prototype of the back to back transition from microstrip to ESIW

2.2.- PATENTS

In the last year, the processing of the next two patents has been advanced:

José Manuel Merello Giménez; Maria Carmen Bachiller Martin; Vicente Enrique Boria Esbert; Mª Luisa Marín García; Vicente Nova Giménez; Juan Rafael Sánchez Marín

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

Pub. No.: P201830647

Pub. Date: 28/06/2018

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

DISPOSITIVO DE FILTRADO Y CONMUTACIÓN DE MICROONDAS

Pub. No.: P201830514

Pub. Date: 30/05/2018

ELECTROMAGNETIC RADIATION GROUP (GRE) ANNUAL RESEARCH REPORT 2018/2019

HEAD OF THE GROUP RESEARCH REPORT

The research areas of the Electromagnetic Radiation Group (GRE) are focused on the analysis and design of antennas at frequency bands ranging from UHF to V band. These frequency bands cover a wide range of applications, e.g. mobile and satellite communications, Wi-Fi, Bluetooth or on-body applications. GRE researchers are also investigating on realistic propagation environments for mobile applications.

GRE participates in many projects with public funding in collaboration with other Spanish universities, such as University Carlos III of Madrid, the Technical University of Barcelona or the Technical University of Cartagena. In addition, GRE collaborates with many foreign universities, such as Chalmers University of Technology, the Courant Institute of Mathematical Sciences or the University of Oulu. From the industrial point of view, GRE works with different technological companies and public entities, such as the European Space Agency (ESA), Thales Alenia Space, Huawei or Airbus. Moreover, GRE supports the local technological development through long-lasting links with regional companies like CELESTICA or MYSHERA.

The evolution of the national research programs in which GRE is involved has led GRE to be in the final year of two national projects, initiated in 2017, and in the second year of a third project granted in 2018. The work in all of them has been carried out in agreement with the proposed schedule, with significantly good results.

In 2019, GRE has released a renewed webpage of the research group: www.gre.upv.es. This web page aims to offer detailed information about GRE research lines, group members and activities. This web page also informs about the services offered by the group to third-party companies.

1.- PROJECT ACTIVITIES

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

- Application of the Theory of Characteristic Modes for antenna design in different applications (MIMO, UWB, RFID, mobile communications, UHF, 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 and channel modelling.

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

1.1.- ONGOING PROJECTS

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

Period: 2017-2019

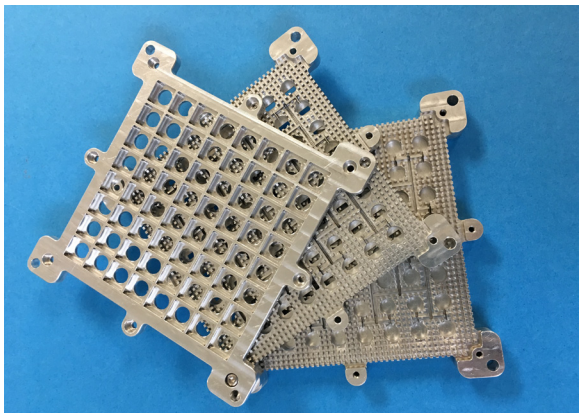
This project was initiated in 2017 within the framework of the Spanish national research program, funded by the Ministry of Economics, Industry and Competitiveness. The scope of this project is focused on the design of ground terminals for the new generation of high-throughput satellites operating in the Ka-band (from 19 to 31 GHz). These satellites have been conceived to provide high-data-rate services in areas not covered by terrestrial networks, such as remote areas, war or natural disasters zones, ships or aircrafts. This increment of the data rate with respect to previous systems is achieved by incrementing the operating frequency band, from the Ku-band to the Ka-band, and implementing a re-use frequency and polarization scheme in a multi-spot beam architecture. The increment of the operating frequency band widens the available bandwidth and, consequently, produces an increment of the data rate. This upscaling, however, does not simply implies an upscaling of the existing terminals in the Ku-band. The re-use scheme of the available resources imposes a set of specifications to the ground terminals that render the design a technological challenge that has not yet found a proper solution.

The SATCOM-KA project has explored new antenna concepts and topologies for Ka-band mobile satellite terminals, paying special attention to the reduction of the terminal volume and weight, a fundamental characteristic for on-the-move applications. With this in mind, during the first two years of the project, solutions based on metallized plastics, capable of reducing considerably the weight of the antenna, were

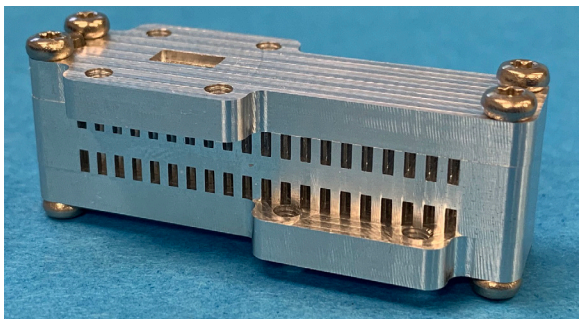
investigated. The comparison of this technology with the traditional direct-metal 3D printing proved the suitability of the new manufacturing technique for the fabrication of Ka-band ground terminals for on-the-move systems.

However, main research efforts have been focused on sharing the same antenna panel for both polarizations and/or both frequency bands, capable of switching the polarization or the operating frequency band during handover from one spot-beam to another. In particular, two solutions in gap waveguide technology have been proposed. Measured results of manufactured prototypes have shown excellent results in terms of return loss and radiation pattern. The attached image shows a picture of a dual-polarized antenna with two layers, each of them in charge of one polarization. A similar structure for the dual-band solution has also been presented. Alternative single-layer dual-band configurations have been explored. Attached picture shows a double-sided groove-gap waveguide used in this alternative configuration. The performance of a diplexer in gap waveguide technology to split, or combine, the K and Ka bands signals into a single waveguide in the dual-band solution has been also studied during the last year of the project.

Additionally, other topologies and devices are being studied. A frequency selective surface working as a microwave planar lens antenna capable of eliminating the grating lobes of the dual-polarized antenna has been designed and fabricated with excellent measured results. Also, new beam pointing mechanisms are being studied to facilitate the tracking of the satellite in ground terminals.



Dual-polarized slot-array antenna in gap-waveguide technology



Double-sided groove-gap waveguide.

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

Period: 2017-2019

This project, funded by the Spanish Ministry of Economics, Industry and Competitiveness (MINECO), was granted in 2017. The main goal of this activity was the design of new types of antennas for the upcoming 5G generation of mobile communications. One of the key features of this new generation will be the possibility of attending the future demands of massive connectivity of users. These demands are being reported in numerous studies, consequence of the future explosion of wireless data transmissions, when users will demand connectivity to everything everywhere. Current forecasts indicate that, in a decade, the number of connected devices could reach hundreds of billions, driven by many novel applications beyond personal communications. To deal with this traffic, the development of new technologies, not yet implemented, is required. One of the key aspects of these technologies will be the antenna systems under study in this project.

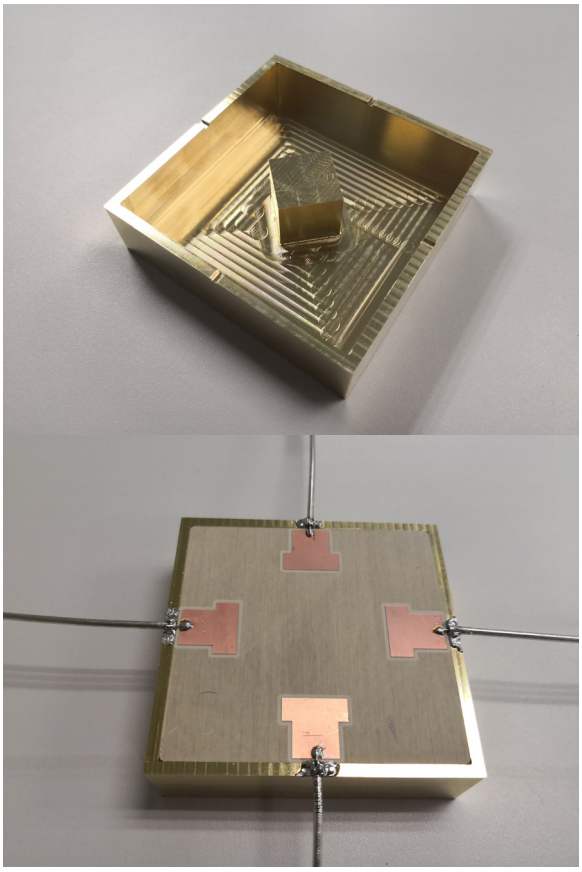
The range of applications and possibilities of the next generation of mobile communications is huge. This project has been focused on three specific areas in the microwave (below 6 GHz) and mm-wave bands:

1. On-body sensing applications: A computational modelling of the human body has been developed in the band 1 to 6 GHz using an integral equation approach. Also, within the framework of this project, several multimode antennas for on-body sensing applications have been analyzed and designed. These antennas have been specially conceived to radiate towards the human body and account for the attenuation produced by human tissues in the propagation of RF waves.

2. Reconfigurable mm-wave antenna design for mobile devices: the next 5G technology will demand for antennas with a reconfigurable radiation pattern capable of pointing the pattern towards the users dynamically. In this second area of the project, phased-array antennas with a reconfigurable beam-forming network have been studied in the mm-wave band. These antennas have been designed considering the LTCC (Low Temperature Co-fired Ceramics) fabrication technology. At GRE premises, there is available an antenna laboratory that implements this fabrication process, especially appropriate for the fabrication of mm-wave devices.

3. Reconfigurable multibeam mm-wave 5G indoor base station design: Two types of antennas have been considered for this area. Firstly, metallic planar lens antennas based on non-periodic frequency selective surfaces have been designed for the frequency range of 20-30 GHz. A prototype has been fabricated and tested at GRE premises.

Secondly, a cavity-backed antenna fed at four different points has been proposed for 5G femto-cells. The prototype of this antenna has shown measured results with an excellent performance for indoor environments.



Four-port cavity-backed antenna for indoor 5G femto-cells.

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

Period: 2018-2020

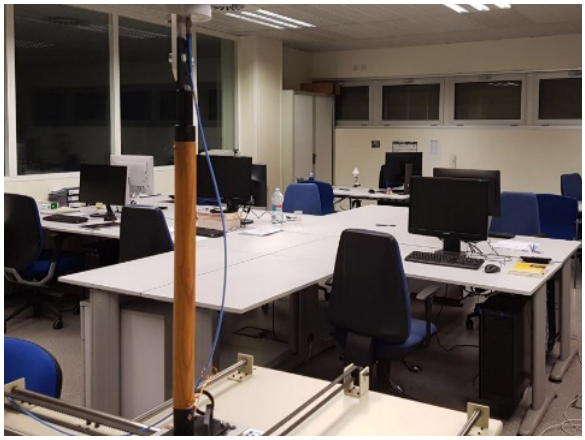
There is a widespread agreement among the scientific community, industry and mobile operators that future traffic demands, much higher than the current ones, will require the deployment of new systems with faster as well as more efficient and reliable connections. In the early 2012, ITU-R kicked off the program to develop IMT-2020 systems, thus initiating the definition and research activities of the fifth generation (5G) systems. These new systems will represent a significant improvement over 4G systems, increasing the speed of LTE-Advanced by 1000. 5G represents the possibility of implementing new business models, making the most of new applications and services by allowing the devices to connect anytime and anywhere. Among the different applications or services expected of 5G technology is to make the concept of Internet of Things (IoT) become a reality. The concepts of smart home, smart office, smart city, among others, along with health-related applications, vehicular communications, high-quality 4K-8K UHD video transmissions, virtual and augmented reality, just to name a few of them, are expected to emerge in the 5G era.

Of all the requirements set out in 5G, those that are most closely related to the capacity increase are the ones drawing the most attention. In this regard, the distribution of ultra-dense networks of base stations to improve the capacity per unit area, the use of new frequency bands, such as millimeter-wave (mmWave), and the combination of beamforming techniques and advanced MIMO systems arise as a requirement in order to increase the capacity. In this scenario, the knowledge of the radio channel holds the key to define the standard, select new frequency bands, and optimize the deployment of the network infrastructure.

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

Extensive channel measurements in underground and indoor office environments have been collected using a channel sounder implemented in the frequency domain. From the channel measurements, realistic channel models have been analyzed and developed in the potential frequency bands to deploy the future 5G systems, with special attention to mmWave, e.g., 26, 28, 38 and 60 GHz. The performance of advanced MIMO techniques, that can be introduced into 5G systems, are been investigated in these particular environments from the channel models.

(b)



(a)

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

2. RESEARCH RESULTS

2.1. FEATURED PUBLICATIONS

1. **An Augmented Regularized Combined Source Integral Equation for Nonconforming Meshes**, F. Vico, L. Greengard, M. Ferrando-Bataller and E. Antonino-Daviu, *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 4, pp. 2513-2521, April 2019.

DOI: 10.1109/TAP.2019.2891399

Abstract: We present a new version of the regularized combined source integral equation (CSIE-AR) for the solution of electromagnetic scattering problems in the presence of perfectly conducting bodies. The integral equation is of the second kind and has no spurious resonances. It is well conditioned at all frequencies for simply connected geometries. Reconstruction of the magnetic field, however, is subject to catastrophic cancelation due to the need for computing a scalar potential from magnetic currents. Here, we show that by solving an auxiliary (scalar) integral equation, we can avoid this form of low-frequency breakdown. The auxiliary scalar equation is used to solve a Neumann-type boundary value problem using data corresponding to the normal component of the magnetic field. This scalar equation is also of the second kind, nonresonant, and well conditioned at all frequencies. A principal advantage of our approach, by contrast with the hypersingular electric field integral equation, the combined field integral equation, or CSIE formulations, is that the standard loop-star and related basis function constructions are not needed, and preconditioners are not required. This permits an easy coupling to fast algorithms such as the fast multipole method. Furthermore, the formalism is compatible with nonconformal mesh discretization and works well with singular (sharp) boundaries.

2. **Designing Slot Antennas in Finite Platforms Using Characteristic Modes** N. Mohamed Mohamed-Hicho, E. Antonino-Daviu, M. Cabedo-Fabrés and M. Ferrando-Bataller, I*EEE Access*, vol. 6, pp. 41346-41355, 2018.

DOI: 10.1109/ACCESS.2018.2847726

Abstract: In this paper, the application of the Theory of Characteristic Modes for the design of narrow-in-width open slot antennas embedded in finite platforms is investigated. Purely magnetic and electric characteristic modes (CM) of a slot etched in both an infinite and a finite ground plane are analyzed, with the aim to provide a physical understanding of the slot behavior and its interaction with the metallic ground plane. Instead of traditional CM analysis, an alternative approach is proposed, which consists in dividing the design procedure into the separate and complementary analysis of purely magnetic and electric CM. Based on this analysis, some guidelines for the design of open slot antennas are provided, and a simple and compact narrow-in-width wideband open slot antenna is designed. Simulations and measurements are presented for the optimized slot antenna, showing an impedance bandwidth of 47.48% with a very stable radiation pattern.

3. **Dual-polarized planar lens antenna designed with a quad-ridged frequency selective surface**, H H. C. Moy-Li, D. Sánchez-Escuderos, E. Antonino-Daviu, M. Ferrando-Bataller, *Microwave and Optical Technology Letters*. 2019; 61: 479– 484.

DOI: 10.1002/MOP.31583

Abstract: This letter presents a microwave planar lens illuminated by a radially corrugated horn antenna. The lens is formed by a set of 5×5 multilevel unit cells working as a frequency selective surface. Each layer of the unit cells is formed by a square metallic ring with two sets of orthogonal stubs. The length of each set of stubs controls the transmission phase shift for each polarization, so that the lens can be configured independently for two orthogonal polarizations. The lens presented in this letter makes use of this operation to compensate the phase profile of the radiation pattern generated by the feeder. A

prototype, with the lens located at 0.59 λ from the feeder, has been fabricated. Measured results show a maximum gain above 14.44 dBi within the operating frequency band (12.55-13.10 GHz), and a crosspolar level below –32 dB within the HPBW.

4. **The Folded Normal Distribution: A New Model for the Small-Scale Fading in Line-of-Sight (LOS) Condition** J. Reig, V. M. Rodrigo Peñarrocha, L. Rubio, M. T. Martínez-Inglés and J. M. Molina-García-Pardo, *IEEE Access*, vol. 7, pp. 77328-77339, 2019.

DOI: 10.1109/ACCESS.2019.2921340

Abstract: In this paper, a novel form of the folded normal (FN) distribution has been proposed to model the small-scale fading in wireless communications. From a multiple-input multiple-output (MIMO) measurement campaign conducted in a lab environment with the line-of-sight (LOS) conditions at both the 60 and the 94 GHz bands, the authors obtain the parameters of the Rician, FN, and k-μ distributions. These parameters have been calculated by using the least square (LS) approximation and with techniques of statistical inference. The FN distribution provides the best fitting to the experimental results using the Kolmogorov-Smirnov (K-S) test for the inferred estimators with values of the fulfillment of 100% and 69.82% at the 60 and 94 GHz bands, respectively, for a significance level of 1%.

5. **Empirical characterization of the indoor multi-user MIMO channel in the 3.5 GHz band**. R. P. Torres, J. R. Pérez, J. Basterrechea, M. Domingo, L. Valle, J. González, L. Rubio, V. M. Rodrigo-Peñarrocha and J. Reig, *IET Microwaves, Antennas & Propagation*, in press, 2019.

DOI: 10.1049/iet-map.2018.6215

Abstract: This study presents an analysis of the capabilities of using multi-user multiple input multiple output (MU-MIMO) in indoor environments at the 3–4 GHz band through an empirical characterisation of the MU-MIMO channel, obtaining a statistical description of the degree to which this specific multi-user channel verifies the condition of 'favourable propagation'. Different metrics have been considered to measure the degree of orthogonality between the channels, such as the orthogonality coefficient or the condition number. In addition, in order to obtain a direct measure of the goodness of the channel in terms of the achievable spectral efficiency, the capacity of the channel has been calculated for different numbers of users and base station antennas and compared with theoretical i.i.d. Rayleigh channels.

6. **Full-Metal K-Ka Dual-Band Shared-Aperture Array Antenna Fed by Combined Ridge-Groove Gap Waveguide** M. Ferrando-Rocher, J. I. Herranz-Herruzo, A. Valero-Nogueira and B. Bernardo-Clemente, *IEEE Antennas and Wireless Propagation Letters*, vol. 18, no. 7, pp. 1463-1467, July 2019.

DOI: 10.1109/LAWP.2019.2919928

Abstract: This letter presents an 8 × 8 dual-band shared-aperture array antenna operating in K-(19.5–21.5 GHz) and Ka-band (29–31 GHz) using gap waveguide technology. Radiating elements consist of circular apertures located on the top plate of the antenna and excited by two stacked cavities with different diameters for dual-frequency operation. A waffle grid is used on top to increase the effective area of apertures and reduce grating lobes. Each stacked cavity is fed by its appropriate corporate-feeding network: The upper feeding layer operates at 20 GHz band, and the lower one at 30 GHz band. As a result, the antenna presents two ports, one for each band, which radiate a directive far-field pattern with linear polarization, orthogonal to each other. Experimental results show impedance and radiation pattern bandwidths larger than 1.5 GHz in both bands.

7. **Performance Assessment of Gap-Waveguide Array Antennas: CNC Milling Versus Three-Dimensional Printing** M. Ferrando-Rocher, J. I. Herranz-Herruzo, A. Valero-Nogueira and B. Bernardo-Clemente, *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 11, pp. 2056-2060, Nov. 2018.

DOI: 10.1109/LAWP.2018.2833740

Abstract: This letter focuses on comparing manufacturing features of three-dimensional (3-D) printing techniques versus conventional computer numerical control (CNC) milling in the context of gap waveguide technology. To this end, a single-layer array antenna has been designed as a demonstrator. The antenna under test, intended for Ka-band, is composed of 8 × 8 radiators fed by a gap-waveguide (GW) corporate network. Two identical prototypes have been manufactured, but each applying a different fabrication technique, i.e., 3-D printing and CNC milling. The experimental results of both antennas are presented, under the same conditions and measurement facilities. The conclusions drawn in this letter provide a valuable assessment of 3-D-printing viability for GW arrays against the conventional milling technique.

Here, some aspects in the interpretation of the solutions of a PEC infinite circular cylinder with the Theory of Characteristic Modes are presented. First, natural resonances and characteristic mode resonances (CMRs) are introduced and compared. Second, characteristic eigenvalues are used to find those natural resonances considering complex ka values. Furthermore, by linking the standard and the generalized eigenvalue problems, a relation between natural resonances and characteristic mode eigenvalues is shown. Finally, the thesis stating that external CMR does not imply maximum field scattering is also demonstrated.

8. **60 GHz Single-Layer Slot-Array Antenna Fed by Groove Gap Waveguide** M. Ferrando-

Rocher, A. Valero-Nogueira, J. I. Herranz-Herruzo and J. Teniente, *IEEE Antennas and Wireless Propagation Letters*, vol. 18, no. 5, pp. 846-850, May 2019.

DOI: 10.1109/LAWP.2019.2903475

Abstract: A V-band single-layer low-loss slot-array antenna is presented in this letter. Radiating slots are backed by coaxial cavities, which are fed through a groove gap waveguide E-plane corporate feed network. Cavity resonances are created by shortening nails with respect to the surrounding ones. This fact enables a compact single-layer architecture since coaxial cavities and feeding network can share the same bed of nails. A 16 × 16 array is designed, constructed, and measured to demonstrate the viability of this concept for high-gain single-layer slot-array antennas. In addition, this solution can be extended to circular polarization by seamlessly adding a polarizer above the slots without changing the feeding network piece. Measurements show a relative bandwidth of 10% with input reflection coefficient better than -10 dB and a mean antenna efficiency above 70% within the operating frequency band (57-66 GHz).

9. **8x8 Ka-Band Dual-Polarized Array Antenna Based on Gap Waveguide Technology** M. Ferrando-Rocher, J. I. Herranz-Herruzo, A. Valero-Nogueira, B. Bernardo-Clemente, A. U. Zaman and J. Yang, *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 7, pp. 4579-4588, July 2019.

DOI: 10.1109/TAP.2019.2908109

Abstract: This paper describes an 8×8 fully metallic high-efficiency dual-polarized array antenna working at the Ka-band, based on the gap waveguide (GW) concept. The radiating element is a circular aperture backed by two stacked cylindrical cavities, which are orthogonally fed to achieve a dual-polarized performance. Both feeding layers consist of a GW corporate network to reach all the cavities backing each radiating element. Cavities are naturally integrated within the bed of nails hosting grooves and ridges for the guiding electromagnetic (EM) field, leading to a low-profile dual-polarized array in the Ka -band. The experimental results present good agreement with simulations.

The measured radiation patterns agree well with the simulation and the antenna provides an average gain over 27 dBi within its operating bandwidth (29.5–31 GHz).

10. **Single-Layer Circularly-Polarized Ka -Band Antenna Using Gap Waveguide Technology** M. Ferrando-Rocher, J. I. Herranz-Herruzo, A. Valero-Nogueira and A. Vila-Jiménez, *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 8, pp. 3837-3845, Aug. 2018.

DOI: 10.1109/TAP.2018.2835639

Abstract: A single-layer circularly polarized array antenna is proposed in the context of the so-called gap waveguide (GW) technology. This ultracompact antenna combines the corporate-feeding network and the radiating apertures over one single layer, standing out among other solutions proposed so far in this technology. Apertures are backed by chamfered cylindrical cavities and are fed through a corporate feeding network, which combines both groove and ridge GWs. Cavities are naturally integrated within the bed of nails hosting grooves and ridges, leading to a very low-profile 4×4 array. Experimental results are presented to confirm the good radiation performance obtained by simulations. The proposed array architecture may be seamlessly enlarged to any size thanks to the scalability of the gap-based corporate feeding network, making this solution very attractive for medium to high-gain applications.

11. **Compact Combline Filter Embedded in a Bed of Nails**, M. Baquero-Escudero, A. Valero-Nogueira, M. Ferrando-Rocher, B. Bernardo-Clemente and V. E. Boria-Esbert, *IEEE Transactions on Microwave Theory and Techniques*, vol. 67, no. 4, pp. 1461-1471, April 2019.

DOI: 10.1109/TMTT.2019.2895576

Abstract: In this paper, we propose a compact topology for high-frequency bandpass filters using coaxial cavities embedded in a bed of nails, including a complete design procedure combining equivalent circuit models and full-wave simulators. The resonance generated around a shortened cylindrical nail of the bed hosting structure is used as the basic element of the proposed filter, which is fed through groove gap waveguides. For design purposes, an equivalent circuit model of the considered resonance is first obtained, and then the coupling levels between resonators are recovered with the distance between adjacent shortened nails. In order to validate the proposed structure and its design procedure, a filter prototype with a bandpass response (centered at 30 GHz and with relative bandwidth of 1.7%) has been designed, manufactured, and measured. Good experimental results, in terms of insertion losses (with a minimum value of 1.6 dB) and return losses (greater than 16.6 dB in the whole passband), have been achieved.

2.3. AWARDS

1. Prof. Eva Antonino-Daviu has been awarded by the IEEE Antennas and Propagation Society with the 2019 Lot Shafai Mid-Career Distinguished Achievement for her contribution to the systematic design of antenna systems for practical applications using characteristic modes and promoting access of women to engineering.

2. Miguel Ferrando-Rocher has been awarded by the Spanish Association of Telecommunications Engineers (COIT) with the 2019 Airbus Defense and Space award to the best PhD dissertation in satellite communications.

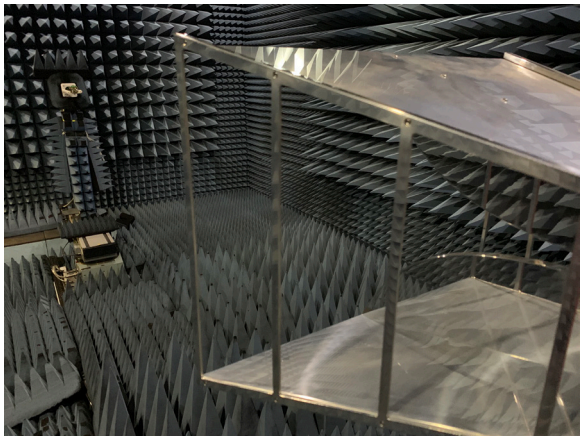
Prof. Eva Antonino-Daviu receiving the 2019 Lot Shafai Mid-Career Distinguished Achievement award.

3.- FACILITIES

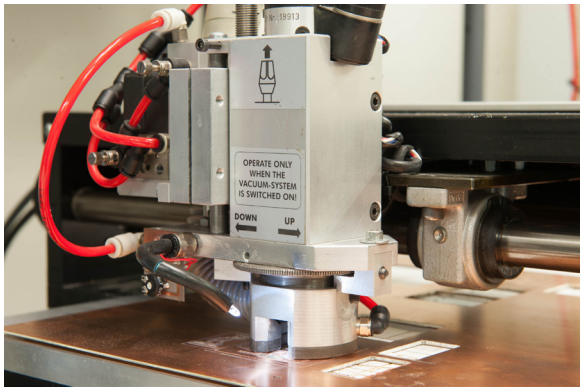
The laboratory of the GRE is hosted in the iTEAM premises. With an about 1 million euro in infrastructure investment, the facilities are intended to fabricate and measure antennas and microwave devices with high precision (some of them are shown in the ongoing projects figures). The main fabrication equipment is a 3-axes CNC milling machine with an accuracy of 5 microns. The highest frequency microwave device fabricated with this equipment has been a filter operating in the 60 GHz, with posts of 0.25 mm width and 2 mm high. The good measured results of this prototype validated the equipment for the fabrication of V-band antennas and devices. Alternatively, a micro milling machine and a chemical etching line are also available in the laboratory for the fabrication of planar microwave circuits and antennas.

The testing equipment of the GRE is able to characterize the fabricated antennas and microwave devices up to 67 GHz. These measurements are done by means of two Vector Network Analyzers that allow measurements of different parameters in frequency and time domain. Also, the GRE laboratory includes an anechoic chamber with roll over azimuth spherical system for measurement of antenna radiation patterns up to 40GHz. In addition, a signal (spectrum) analyzer up to 26 GHz is available at GRE premises. These capabilities, together with the expertise of the technical staff, form a perfect combination capable of detecting deviations between simulated and manufactured designs.

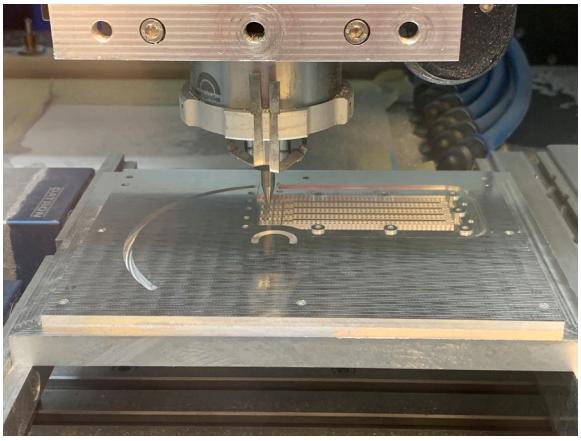
The GRE manages, together with the GAM (Microwave Applications Group), the laboratory of High Frequency Circuits (LCAF) in LTCC Technology. This laboratory is focused on the fabrication of high frequency components on multi-layer modules in Low Temperature Co-fired Ceramics (LTCC) technology. LTCC enables the miniaturization of RF components, the packaging of millimeter-wave devices, and the fabrication of Multi-Chip-Module (MCM) and System-in-Package (SiP) designs. Furthermore, this technology is also of great interest in other applications, not strictly related to information and communication technologies, such as ceramic packaging, highly integrated electronics, microfluidics or sensors.



Standard gain horn ready for measurements in the anechoic chamber.



Planar circuits milling machine.



CNC milling machine.

GTAC ANNUAL RESEARCH REPORT 2018-2019

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 2018-19 mainly on active noise control, spatial audio perception and rendering, and sound quality improvement for multi-channel audio systems. GTAC has carried out several research projects and has published their most relevant results in several scientific journals and conference proceedings. In particular, the European project "Distributed Network of Active Noise Equalizers for Multi-User Sound Control" has finished on October 2018 with great success, achieving their objectives by creating a laboratory prototype of a distributed active noise equalizer system for two independent car seats. Moreover, the whole system has been filed as a patent in the United States. On the other hand, the national project "Smart Sound Processing for the Digital Living" has also finished on December 2019 achieving several applications as: (1) Design of personal sound zones with spatial smoothness (2) Measurement and monitoring of noise conditions in industrial environments to detect high sound pressure levels (SPL), and (3) recording, monitoring and classification of sound events.

Regarding the GTAC facilities, a new laboratory for perceptual spatial sound (see Fig. 1) has been built within the iTEAM place. The purpose of the new audio lab is to measure the Head-Related Transfer Function (HRTF) of many people with a very high precision, in order to improve the way spatial sound is rendered to a particular person. The HRTF is in somehow a personal acoustic fingerprint that changes from one person to another. This new set-up 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.

As said before, GTAC current research includes the design optimization of personal audio zones. Personal audio systems aim to create listening (or bright) and quiet (or dark) zones in a room using an array of loudspeakers (see Fig. 2). It allows rendering a target soundfield in the bright zone while having control over the mean acoustic

Fig. 1. Perceptual spatial acoustic laboratory including a render system of 72 + 16 loudspeakers.

energy in the quiet zone. Moreover, it can create different listening sounds in different audio zones in the same room. For this purpose, a new array of 24 loudspeakers in blocks of 8 speakers each has been built to control mid-range frequencies. The new array is formed by small tweeters that allow for a separation of 4.5 cm between the center points. Fig. 3 shows in the first plane the array of microphones that has been used to control and validate the acoustic zones, and in second place two blocks of the new array (16 tweeters inserted in two wooden boxes) can be seen. This research line has been granted with the iTEAM Science Pills Video Award 2018 (link to the video: https://youtu.be/tSfrVNdAvEI).

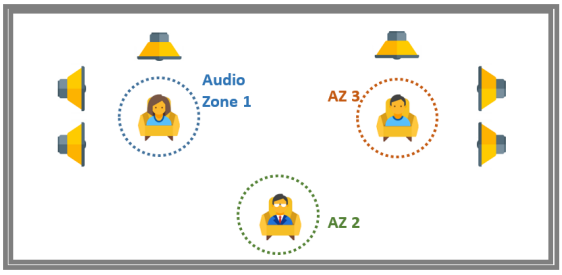


Fig. 2. Personal audio zones using loudspeakers.

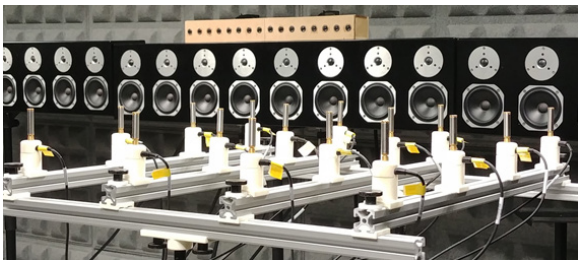


Fig. 3. Rendering and measurement of personal sound zones.

Moreover, three new projects have started during 2019. They are summarized in the following.

1.- ONGOING PROJECTS

1.1 *DYNAMIC ACOUSTIC NETWORKS FOR CHANGING ENVIRONMENTS (DANCE)*

Webpage: *www.dance.upv.es*

Summary

The ``Dynamic Acoustic Networks for Changing Environments'' (DANCE) is a coordinated project that intends to demonstrate the usefulness and applicability of Dynamic Acoustic Sensor Networks by the development of distributed algorithms and systems to different audio applications, such as, self-localization of nodes, dynamic room impulse responses (RIR) and inverse RIR estimation, dynamic characterization and control of acoustic wave fields, adaptation of communication and processing to changes of network topology and/or objective. Furthermore, go forward to real-time implementation by using emerging computing tools.

DANCE proposal will carry out research in the field of acoustic sensor networks, when dynamism, in the sensor network or in the environment, is considered. Dynamism is here referred to movement of the nodes in the sensor network, changes in the network configuration, movement of the sound sources or obstacles in the considered environment, or time-variant characteristics of any of them.

The project considers different complementary applications: control and generation (user selected) of time-variant sound scenes (in the audible band), monitoring of acoustic scenes for detecting and tracking acoustic threats in security applications (such as unmanned aerial vehicles-UAV in critical infrastructure protection or impulsive sound sources like electric sparks that could be the origin of fires), indoor human behaviour characterization using acoustic sensors, etc.

These applications will be based on the usage and development of innovative signal processing methods, such as space-time adaptive signal processing techniques (STAP), time-frequency signal models, algorithms for self-determination of sensor network topology, dynamic array signal processing, tracking algorithms based on Kalman and particles filters, detection algorithms based on machine learning tools, emerging pattern recognition tools such as Deep Learning, etc.

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

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

Summary

The sound industry has been experiencing profound changes in recent years under the perspective of 3 complementary approaches: the individual, the group and the contents.

On the one hand, the irruption of mobile devices has modified the way people listen to music, play and interact with machines and other people. The use of headphones has spread enormously, and the need to reproduce highly realistic spatial sound through them is a great opportunity for the industry. For a very immersive experience, the sound must be customized for each individual based on their anatomy, in particular the head and pinna shape, which define their particular Head-Related Transfer Function (HRTF). Measuring a subject's HRTF is still a costly process that requires specialized facilities and its indirect estimation remains an unresolved problem. By employing Deep Learning techniques and photographs of the ear/head, we aim to achieve a personalization of HRTF of better quality than other proposed methods. This will in turn allow mobile devices to incorporate personalized responses for their direct application in 3D sound, virtual and augmented reality, video games, etc.

On the other hand, the sound and entertainment industry has been redirected during the recent years to big live shows, where the spatialization of sound is still a challenge and an opportunity for using sound field synthesis algorithms and others for recreating virtual spaces. Array processing techniques should be developed aimed at allowing the control of sound in different listening areas while synthesizing the different live sound objects (musicians, actors, presenters, effects, etc.), adapting the synthesis of each object to its own movement (which must be captured and monitored), and achieving greater realism over the audience. In addition, there are other scenarios, such as museums, exhibitions, restaurants or smart homes, which would also benefit from the creation of independent audio zones or with different needs, using similar techniques employing loudspeaker and sensor arrays.

Finally, from the contents point of view, the viewer demands more and more a complete and interactive audiovisual experience. Within this line, this subproject will work on creating new methods for the analysis of audio and music based on Machine Learning, with application to synchronized audiovisual effects and live enriched events. The aim is to develop Machine Learning algorithms that extract features from music that allow the synchronization of audiovisual material such as 3D animations, lights or lasers. In addition to the improvement in rhythm extraction algorithms with low latency, it is necessary to work on the segmentation of songs into their different parts to link different animations. Thus, Machine Learning techniques trained from labeled songs are profiled as a solution for real-time song segmentation in a causal way, allowing for their application in live scenarios.

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

1.3. SMART SOCIAL COMPUTING AND COMMUNICATION (IN SPANISH: COMUNICACIÓN Y COMPUTACIÓN INTELIGENTES Y SOCIALES - COMTACTS)

Summary

The advances made in the field of distributed computing and the hardware-software available right now make possible to develop increasingly powerful information processing and exchange systems, which can 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 environment and the physical environment in which living beings, particularly humans, work and live.

At the same time, we can observe the boom in applications arising from computing and communication devices for personal use, and their massive use with the advance of communications; we can highlight some applications such as: 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.

Moreover, an insightful consideration is given in this project regarding the physical aspects of computing, signal processing, energy consumption, technology, communication, etc., particularly in distributed, collaborative scenarios and provided with massive and heterogeneous data. In this way, the research group of the present proposal 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.

Funded by: Regional Government – Generalitat Valenciana.

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

- ***Combined precoding for multiuser Multiple-Input Multiple-Output satellite communications.*** *M.A. Simarro-Haro, Beatriz Puig, Francisco José Martínez Zaldívar, Alberto Gonzalez, Computers & Electrical Engineering, vol. 71, pp. 704-713, 2018.*

DOI: 10.1016/j.compeleceng.2018.08.006.

Abstract: *Applying Multiple-Input Multiple-Output (MIMO) techniques in satellite communications can increase data rates. However, new signal processing elements have to be taken into account to fully exploit the expected advantages of MIMO communications. In this paper, we evaluate different precoding techniques over the satellite channel. A performance comparison between several precoders in terms of Bit Error Rate (BER) and complexity is given for different channel realizations. Furthermore, a novel hybrid scheme for signal precoding is proposed that optimizes the computation for a required BER. The new scheme is based on the matrix condition number of the satellite MIMO channel.*

- ***Perception of nonlinear distortion on emulation of frequency responses of headphones.*** *Pablo Gutierrez-Parera, José Javier López Monfort, The Journal of the Acoustical Society of America, vol. 143, nª 4, pp. 2085- 2088, 2018.*

DOI: 10.1121/1.5031030.

Abstract: *The equalization of headphones can force transducers to work in a non-linear condition, producing non-linear distortion. Depending on the headphone model and the reproduction level, that distortion can be audible. In this study, headphones of diverse quality and price were compelled to emulate the same target frequency response and the non-linear distortion was measured. A Diagonal Volterra model was used to simulate the different headphones with and without distortion. A perceptual test was carried out to determine the level of reproduction above which non-linear distortion is perceived for each headphone model. High correlation has been found between the level of detected distortion and retail prices of headphones.*

- ***Parallel SUMIS Soft Detector for Large MIMO Systems on Multicore and GPU.*** *Carla Ramiro Sánchez, M.A. Simarro-Haro, Alberto Gonzalez, Antonio Manuel Vidal Maciá, The Journal of Supercomputing, vol. 75, nª 3, pp. 1256-1267, 2019.*

DOI: 10.1007/s11227-018-2403-9.

Abstract: *The number of transmit and receiver antennas is an important factor that affects the performance and complexity of a MIMO system. A MIMO system with very large number of antennas is a promising candidate*

technology for next generations of wireless systems. However, the vast majority of the methods proposed for conventional MIMO system are not suitable for large dimensions. In this context, the use of high-performance computing systems, such us multicore CPUs and graphics processing units has become attractive for efficient implementation of parallel signal processing algorithms with high computational requirements. In the present work, two practical parallel approaches of the Subspace Marginalization with Interference Suppression detector for large MIMO systems have been proposed. Both approaches have been evaluated and compared in terms of performance and complexity with other detectors for different system parameters.

- ***Fast block QR update in digital signal processing.*** *Fran J. Alventosa, Pedro Alonso-Jordá, Antonio Manuel Vidal Maciá, Gema Piñero, Enrique S. Quintana-Ortí, The Journal of Supercomputing, vol. 75, nª 3, pp. 1051-1064, 2019.*

DOI: 10.1007/s11227-018-2298-5.

Abstract: *The processing of digital sound signals often requires the computation of the QR factorization of a rectangular system matrix. However, sometimes, only a given (and probably small) part of the system matrix varies from the current sample to the next one. We exploit this fact to reuse some computations carried out to process the former sample in order to save execution time in the processing of the current sample. These savings can be critical for real-time applications running on low power consumption devices with high mobility. In addition, we propose a simple out-of-order task-parallel algorithm for the QR factorization using OpenMP that exploits the multicore capability of modern processors. Furthermore, in the presence of a Graphics Processing Unit (GPU) in the system, our algorithm is able to off-load some tasks to the GPU to accelerate the computation on these hardware devices.*

2.2.- FEATURED CONFERENCE PROCEEDINGS

- ***On Perceptual Audio Equalization for Multiple Users in Presence of Ambient Noise.*** *Juan Estreder-Campos, Gema Piñero, Fabián Aguirre-Martín, María de Diego Antón, Alberto Gonzalez, 10th IEEE Sensor Array and Multichannel Signal Processing Workshop (SAM), Sheffield, UK, 2018.*
- ***Low cost algorithm for online segmentation of Electronic Dance Music.*** *Emanuel Aguilera Martí, José Javier López Monfort, Pablo Gutiérrez-Parera, Carlos Alberto Hernandez Franco, 144th International Audio Engineering Society Convention (AES 2018), Milan, Italy, 2018.*
- ***Binaural room impulse responses interpolation for multimedia real-time applications.*** *Victor García-Gómez, José Javier López Monfort, 144th International Audio Engineering Society Convention (AES 2018), Milan, Italy, 2018.*
- ***Array processing for echo cancellation in the measurement of Head-Related Transfer Functions.*** *José Javier López Monfort, Sergio Martínez-Sánchez, Pablo Gutiérrez-Parera, 11th European Congress and Exposition on Noise Control Engineering (EuroNoise 2018), Crete Island, Greece, 2017.*
- ***Optimization of line array wave guides.*** *Javier Redondo, Juan Vicente Sánchez Pérez, José Javier López Monfort, 25th International Congress on Sound and Vibration, Hiroshima, Japan, 2018.*
- ***On the performance of noise barriers based on sonic crystals.*** *Javier Redondo, Juan Vicente Sánchez Pérez, José Javier López Monfort, 25th International Congress on Sound and Vibration, Hiroshima, Japan, 2018.*
- ***Perception of noise annoyance reduction associated with acoustic screens.*** *Javier Redondo, M. Pilar Peiró-Torres, José Javier López Monfort, A..Pereira, P. Amado-Mendes, Luis Godinho, 48th International Congress and Exposition on Noise Control Engineering (Inter-noise 2019), Madrid, Spain, 2019.*

Group photo of the GTS team.

SIGNAL PROCESSING GROUP (GTS)

HEAD OF THE GROUP RESEARCH REPORT

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

Within these areas the GTS mainly focuses in some research lines in which the group has proven professional experience. Some of them are: signal processing applied to ultrasonic and impact-echo methods, signal processing techniques applied to bioacoustics and passive acoustics monitoring, signal processing algorithms for surrogate data generation and signal modality, image and video processing for biomedical applications, and technology for the arts. A complete list of research activities can be found at http://www.iteam.upv.es/group/gts/.

Among others, the GTS has been granted this year with a DG Environment European Research Project.

1.- PROJECT ACTIVITIES

The GTS has continued researching in the already stablished research lines as well as in some other emerging activities. A short summary of the main activities being accomplished in the group is given below:

Signal processing techniques applied to ultrasonic and impact-echo methods for the characterization of cementitious materials in the construction industry

Among the most consolidated research lines, the GTS advances in the use of signal processing for non-destructive testing, both for the detection and for the characterization of damage in construction 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 useful in the characterization of both natural and artificial stones.

The GTS collaborates, among some others, with the ICITECH (Institute of Science and Technology of the Concrete) and the Department of Civil & Environmental Engineering (University of Illinois) for the characterization of different types of global damage in cementitious materials using sonic and ultrasonic signals, and with the University College Cork and the Centro Superior de Investigaciones Científicas (CSIC) for the development of non-contact airborne ultrasounds.

Passive acoustics monitoring

The research line is focused on the use of Passive Acoustic Monitoring (PAM) to study marine mammals and anthropogenic noise. This is achieved by developing new acoustic instrumentation, such as the new SAMARUC acoustic recorder, as well as by sophisticated signal processing algorithms to detect and classify underwater acoustic events. Our goal is to improve the understanding of how

anthropogenic sounds impacts on the marine biodiversity, learn about animal bioacoustics and study the population abundance, seasonality and behavior of marine mammals in our seas and oceans. We combine traditional PAM techniques with recent advances in signal processing algorithms and representation techniques such as Big Data representations and deep learning. The group collaborates with the Instituto Español de Oceanografia (IEO) for the Spanish approach to the Marine Strategy Framework Directive (D11).

New version of the SAMARUC acoustic recorder with 2 TB of memory and enhanced bandwidth of 96 kHz.

Applications of biomedicine

We collaborate with the Clinical Area of Medical Image of the Hospital Universitario and Politécnico La Fe (GIBI230) in the processing and analysis of medical images. We provide a long experience in many fields of signal processing for the extraction of relevant information, detection of novelty, fusion of decisions when applied to image processing. During the last year, we have focused in extracting image biomarkers for the quantification of changes associated with the disease. We have also excelled in using the available tools to adapt the huge amount of information available in the image environment (DICOM, PACS, RIS) to the effective and real-time control of all quality aspects relevant to service excellence such as: radiation dose, number of procedures per process, temporary adjustment of demand, analysis of large consumers, costs, technological evaluation, etc. Finally, a recent research line consists in the use of automatic segmentation methodologies applied to Magnetic Resonance Images based on artificial intelligence and deep learning.

Graph Signal Processing

Graph Signal Processing (GSP) combines concepts emanating from two largely consolidated areas: signal processing and graph theory. From the perspective of signal processing it leads to a more general definition of a signal by assigning every sample value to the vertex of a graph. From the graph theory perspective, new graph transformations can be defined that extend classical signal processing concepts like filtering, prediction and spectral analysis. Signal processing on graphs is finding progressively new application in the areas of detection and classification due to its flexibility to model general dependencies between variables. Thus, GTS is currently developing new methods of classification, fusion of classifiers and signal surrogates based on GSP, which are applied to a variety of practical problems.

Emerging Signal Processing Techniques for Big Data Health Applications

GTS is currently working in the context of Big Data Health Applications. The proposed approach consists of multimodal fusion for biosignal analysis methods that include monitoring of the very variant dynamics of physiological phenomena sensed at high velocity on real time from several sources. We apply those methods in neurology and neurophysiology areas for the study and diagnosis of epilepsy, Alzheimer, and sleep disorders, collaborating in an interdisciplinary framework with physicians of the Hospital La Fe of Valencia. A multimodal analysis approach is considered in three specific scenarios: bimodal analysis of simultaneous recordings of fMRI (functional Magnetic Resonance Imaging) and EEG (electroencephalographic) recordings, analysis of EEG in combination with DTI (Diffusion Tensor Imaging) and ECoG (electrocorticographic) recordings for the case of epilepsy patients.

Technologies for the Arts (Soundcool)

Soundcool is an innovative system for collaborative Audiovisual creation using smartphones, tablets, Augmented Reality, computers, Open Sound Control (OSC), see Soundcool Introduction at https://youtu.be/zoZaVK7ysRM. The system started in 2013 being applied in education applications for primary, secondary and music schools, and in functional diversity. With the introduction of Soundcool control with Augmented reality in 2018 it was also proposed for professional applications, and we signed an agreement with Musikene Higher Center for Music Studies of the Basque Country for professional testing purposes. Soundcool is also being introduced at the New York University, and the collaboration with the Valencian Community Education Council continues with Soundcool courses at https://courses.edx.org and several Soundcool education proposals at http://soundcool.org/en/funding-soundcool/

1.1.- ONGOING PROJECTS

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

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

Summary of the project: *The RAGES project follows with the study of how human activities that take place at sea have an impact to the marine environment. However, in this new project a Risk-based approach is employed. The RAGES project is comprised of a consortium made up of competent authorities from Ireland, France, Spain and Portugal responsible for the implementation of the Marine Strategy*

Framework Directive in the North East Atlantic region (Celtic Seas, Bay of Biscay and Iberian) as well as Macronesian sub-regions. Our researchers study and propose methods to integrate the Risk-based approach in the acoustic modelling of the noise as well as in the Passive Acoustic monitoring of the different cetacean species. This innovative approach will help to establish anthropogenic noise levels that do not affect marine biota.

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

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

Lisbon coordination meeting of the EU- RAGES project.

Summary of the project: *The IEO-UPV has been commissioned by the Ministry of Ecological Transition for the Spanish implementation of European Directive 11 (D11), within the Marine Strategy Framework Directive (MSFD). This new project has just started and all the new technological developments the group has made in passive acoustic monitoring will be employed. Particularly, our SAMARUC devices as well as our software will be employed to obtain ambient noise levels indicators used for validation of the acoustic models (according to D11.2).*

Funding entity: *Ministry of Ecological Transition.*

Name of the project: *BreakingBad: Predictive maintenance of tunneling machines*

SAMARUC retrieved from its mooring in the Bay of Biscay.

Summary of the project: *The goal of this project was to perform a prospective analysis of sensor data from tunneling machines to predict critical situations. As a result of this project, it was found how to detect temperature offsets in the motors from their current variables. This finding could prevent production breaks with high associated costs.*

Name of the project: *Study of possible improvements for the CAV assessment system.*

Summary of the project: *In the context of car damage repair by insurance companies there is a negotiation phase in which the car repair shops propose a budget and a human expert accepts or rejects the proposal. The goal of this project was to provide an automatic tool that could analyse the budget proposal and make a decision based on data from many previous cases. The developed system has proven to be very valuable and helpful since it can now recommend aspects to the car repair shops to adapt their initial budget proposals with objective arguments.*

Name of the project: *Advanced Fruit Inspection using multi-view techniques*

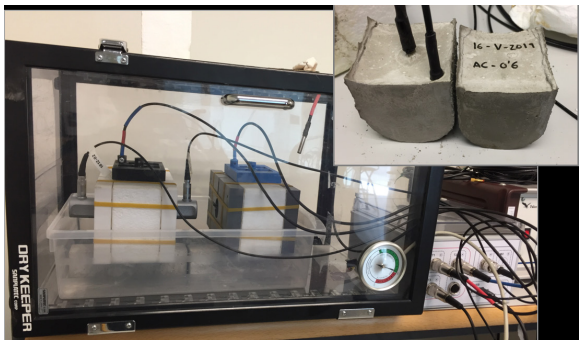
Summary of the project: *Sorting fruits is an application of computer vision. In order to be able to explore the whole surface of a fruit, several views are captured while the fruit is rotated. Analysing the different views independently is not optimum, since the degree of overlap between views is unknown. So in order to determine the degree of maturity or the number of defects, methods that consider all the views as a whole are needed. In this activity an ellipsoidal 3D model of the fruit is constructed from the collection of views. The different views are mapped onto the 3D model. Apart from the accuracy of the model, speed is a major concern in order to be able to translate the method into industrial inspection machines. Currently mode than 50 fruits per second (with about 10 views per fruit) can be analysed. The method has been successfully tested on tomatoes and oranges.*

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

Summary of the project: *The project aims to develop new methods for non-destructive evaluation of fresh pastes, mortars and concrete (rheological characterization), and damaged systems (cracking) in which a regeneration or self-healing process takes place. During this year, we have established ultrasonic based methods to evaluate the basic rheological properties, such as viscosity and yield stress. We also have*

evaluated the self-healing due to autogenous healing properties (by the own nature of hydrated cement). For this last case, monitoring is done using ultrasonic techniques and non-linear acoustic resonance impact spectroscopy. Additionally, non-contact techniques have been also applied and avoid any touching with the specimens.

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



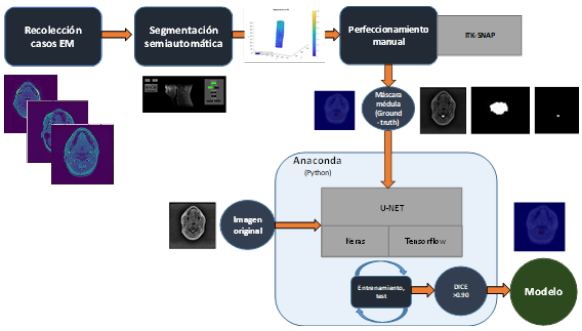
Ultrasonic monitoring of rheological properties

Name of the project: *Deep Learning for cervical cord segmentation in Multiple Sclerosis (DeepMedul)*

Summary of the project: The project aims to develop a new methodology of automated segmentation of the cervical spinal cord from MRI images. Using deep learning artificial intelligence techniques, it allows generating and storing massive data in Multiple Sclerosis patients, to increase knowledge about focal and diffuse alterations of demyelinating character in the cervical spinal cord, which currently leads to a high degree of disability and dependence in patients.

It aims to create a final product very close to the market, once its usability has been validated in a real environment such as the Clinical Area of Medical Imaging of the Hospital Universitario y Politécnico La Fe. With the design of a new type of structured report (implemented by the spin-off of the IIS La Fe, QUIBIM SL) that will integrate the most relevant information for the clinician, since the company has previous experience in the analysis service of LCR and will also contribute its know-how to the project.

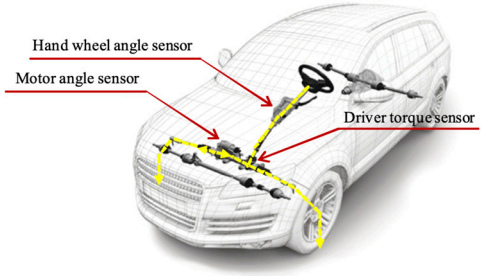
Funding entity: *Instituto de Investigación Sanitaria La Fé.*



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

Automatic signal classification systems require a large enough training base to achieve a proper performance. In many applications there is no possibility of a sufficient number of labelled signals due to several reasons: a shortage of real signals in one or more of the classes, complexity, slowness and cost of measurement recording, complexity of manual labelling. This project addresses the synthesis of signals to increase the training base through advanced methods that enable to directly incorporate information from experts in the application domain or from some colateral sources. In this way, the synthetic signals could adequately reproduce the characteristics and properties of the actual signals that are essential in the training and validation of automatic classifiers. The proposed methodology is based on three advanced concepts. The first concept is a Generative Adversarial Networks type structure, in which two blocks compete with each other. The first block, based on the concept of Conditional Random Field, is discriminatory and must decide whether the signal at its input is valid or not. The second block, based on the concept of Surrogate Signal, is generative and supplies synthetic signals to the first one for its validation. In the first block as well as in the second, it is possible to define (inform) on the part of an expert or from other sources about the relevant properties of the involved signals. Thus, in the discriminative block design, it can be defined signal segments and interdependences between them. These later must be translated to sample interdependences in the generative block. The project considers two applications, one industrial and another of the medical field, for experimentation with the new methodology and its comparison with other reference methods of signal synthesis. The industrial application is relative to the design of Advanced Driver Assistance Systems that are progressively incorporated into the automotive industry. The medical application is devoted to the diagnosis support from functional magnetic resonance imaging synchronized with electroencephalography. The project also contemplates a more theoretical study on the influence of the training base size on the quality of the classifier design.

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



Location of some of the EPS sensors (figure from NEXTEER AUTOMOTIVE).

Name of the project: Soundcool: *Collaborative Music and Video Creation*

Webpage of the project: *http://soundcool.org.*

Summary of the project: *Soundcool is active this year with the grant to improve the training and employability of technical and management personnel of R&D&I through their employment by public research entities, within the framework of the National System of "Youth Guarantee" (Garantía Juvenil) and co-financed by the European Social Fund, Generalitat Valenciana and the Youth Employment Initiative (Iniciativa de Empleo Juvenil). An extension of the project Soundcool: Mobile and Digital Tools for Musical and Audiovisual Art Education 16-AC-2016 from Daniel and Nina Carasso Foundation has been also granted.*

Soundcool performance with a new Augmented Reality visualization app.

2.- RESEARCH RESULTS

2.1.- FEATURED PUBLICATIONS

· ***Multi-class Alpha Integration of Scores from Multiple Classifiers.*** *G. Safont, A. Salazar, L. Vergara. Neural Computation, 31, 806-825, 2019.*

Alpha integration methods have been previously used for integrating stochastic models and fusion in the context of detection (binary classification). This work proposes two new methods based on alpha integration to perform soft fusion of scores in multi class classification problems, one of the most common problems in automatic classification: separated score integration (SSI) and vector score integration (VSI). Equations are presented to optimize the parameters of these methods to achieve the least mean squared error (LMSE) or the minimum probability of error (MPE). The proposed alpha integration methods were tested on several sets of simulated and real data. The simulated experiments replicated a case of automatic detection and classification of three types of ultrasonic pulses buried in noise (4-class classification). For the experiments on real data, we performed automatic staging of two sets polysomnographic data from subjects with sleep disorders in three classes: wake, rapid eye movement (REM) sleep, and non-REM sleep. In all cases, the proposed methods performed better than the considered single classifiers and classical fusion techniques.

DOI: *10.1162/neco_a_01169*

· ***Multichannel Dynamic Modeling of Non-Gaussian Mixtures.*** *G. Safont, A. Salazar, L. Vergara, E. Gómez, V. Villanueva. Pattern Recognition, 93, 312-323, 2019.*

This paper presents a novel method that combines coupled hidden Markov models (HMM) and non-Gaussian mixture models based on independent component analyzer mixture models (ICAMM). The proposed method models the joint behavior of a number of synchronized sequential independent component analyzer mixture models (SICAMM), thus we have named it generalized SICAMM (G-SICAMM). The generalization allows for flexible estimation of complex data densities, subspace classification, blind source separation, and accurate modeling of both local and global dynamic interactions. In this work, the structured result obtained by G-SICAMM was used in two ways: classification and interpretation. Classification performance was tested on an extensive number of simulations and a set of real electroencephalograms (EEG) from epileptic patients performing neuropsychological tests. G-SICAMM outperformed the following competitive methods: Gaussian mixture models, HMM, Coupled HMM, ICAMM, SICAMM, and a long short-term memory (LSTM) recurrent neural network. As for interpretation, the structured result returned by G-SICAMM on EEGs was mapped back onto the scalp, providing a set of brain activations. These activations were consistent with the physiological areas activated during the tests, thus proving the ability of the method to deal with different kind of data densities and changing non-stationary and non-linear brain dynamics.

DOI:*10.1016/j.patcog.2019.04.022*

· ***A new surrogating method by the Complex Graph Fourier Transform.*** *J. Belda, L. Vergara, G. Safont, A. Salazar, Z. Parcheta. Entropy, 21-759, 1-18, 2019.*

The essential step of surrogating algorithms is phase randomizing the Fourier transform while preserving the original spectrum amplitude before computing the inverse Fourier transform. In this paper, we propose a new method which considers the Graph Fourier transform. In this manner, much more flexibility is gained to define properties of the original graph signal which are to be preserved in the surrogates. The complex case is considered to allow unconstrained phase randomization in the transformed domain, hence we define a Hermitian Laplacian matrix that models the graph topology, whose eigenvectors form the basis of a Complex Graph Fourier Transform. We have shown that the Hermitian Laplacian matrix may have negative eigenvalues. We also show in the paper that preserving the Graph Spectrum Amplitude implies several invariances that can be controlled by the selected Hermitian Laplacian matrix. The interest of surrogating graph signals

has been illustrated in the context of scarcity of instances in classifier training.

DOI: *10.3390/e21080759*

· ***Nonlinear Acoustic Spectroscopy and Frequency Sweep Ultrasonics: Case on Thermal Damage Assessment in Mortar****, V. Genovés, A. Carrión, D. Escobar, J. Gosálbez, J. Monzó, M.V. Borrachero, J. Payá, Journal of Nondestructive Evaluation, 38-61, 2019.*

An exhaustive study on thermal damage of Portland cement-based materials is addressed. Damage carried out at different temperatures on concrete between 40 and 525 C were assessed by means of microstructural, physical and nondestructive tests. Microstructural analysis (thermogravimetry and scanning electron microscopy) showed the principal changes of the Portland cement hydrated products for the different analysed temperatures. Compressive and flexural strengths remained constant or even increased at a low heating temperature range, while the mass loss increases. Dilatometry analysis revealed important information about deformation incompatibilities between the paste and the aggregate. These results have been correlated with nondestructive tests: nonlinear impact resonance acoustic spectroscopy (NIRAS) and ultrasonic measures. The dynamic modulus and ultrasonic pulse velocity have closely predicted the linear stiffness decay of the specimens. However, hysteretic parameter from NIRAS analysis exhibited a different trend from stiffness-related parameters, keeping constant until 250 C and suffering a huge increasing for 400 and 525□C. Ultrasonic attenuation computed with a broadband ultrasonic signal (chirp) revealed interesting information about scattering components inside the material, and is sensitive to interfacial transition zone between aggregate and paste in a large range of frequencies. The correlation between microstructural, mechanical and nondestructive techniques were carried out successfully. Nonlinear vibration and ultrasonic attenuation are non-conventional parameters that gave specific information about a complex damage process, such as a thermal attack in highly heterogeneous materials (e.g. Portland cement composites).

DOI: *10.1007/s10921-019-0599-0*

· ***Flipped Accumulative Non-Linear Single Impact Resonance Acoustic Spectroscopy (FANSIRAS): A novel feature extraction algorithm for global damage assessment.*** *A. Carrión, V. Genovés, G. Pérez, J. Payá, J. Gosálbez, Journal of Sound and Vibration, 432, 454-469, 2018.*

High amplitude non-linear acoustic methods have shown great potential for the identification of micro-damage in inhomogeneous materials such as concrete. Usually, these methods evaluate non-linearity parameters related to the hysteretic behaviour from the dependence of the shifts in both frequency and damping on the amplitude of the strain. A deep understanding of the reverberation phenomena has been obtained in order to introduce a novel signal processing approach called FANSIRAS (Flipped Accumulative Non-linear Single Impact Resonance Acoustic Spectroscopy). Traditional acoustic spectroscopy techniques, NIRAS (Non-linear Impact Resonance Acoustic Spectroscopy) and NSIRAS (Non-linear Single Impact Acoustic Spectroscopy), have been analyzed and compared with the brand new approach when providing quantitative information related to the degree of micro-cracking in thermal damaged concrete based materials. The new resonance-based algorithm demonstrates that the non-linear non-classical parameters can be determined through a single resonance frequency measurement, obtaining the expected sensitivity to internal damage. Its simplicity and robustness may be important in industrial applications.

DOI: *10.1016/j.jsv.2018.06.031*

· ***Improved visualization of large temporal series for the evaluation of good environmental status****, R. Miralles, G. Lara, J. Gosálbez, I. Bosch, A. León, Applied Acoustics, 148, 55-61, 2019.*

Passive acoustic monitoring of underwater sounds is an emerging discipline that can be used to guarantee that anthropogenic noise meets acceptable limits, to detect the presence of cetacean species, and to ensure sustainable exploitation of our oceans and seas. In this scenario, graphical representation techniques play a key role in helping to reveal seasonal structures of human made noises. Nevertheless, for very long temporal series, it might be challenging to find a graphic visualization technique that allows representing a time range that is long enough to capture these seasonal events, while at the same time preserving short isolated events. We propose a framework for the creation of such visualization techniques and analyze the different stages involved: data reduction, color encoding, and signal processing on graphs. All of this is applied to data from deployments in two marine protected areas in order to provide an acoustic panorama and identify seasonal events.

DOI: *10.1016/j.apacoust.2018.12.009*

· ***Comparative Study of Coupling Techniques in Lamb Wave Testing of Metallic and Cementitious Plates,*** *S. Vázquez, J. Gosálbez, I. Bosch, A. Carrión, C. Gallardo and J. Payá, Sensors, 19, 4068, 2019.*

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

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

DOI: *10.3390/s19194068*

- ***Workshop Soundcool: Smartphones, Tablets and Kinect for Colaborative Creation,***

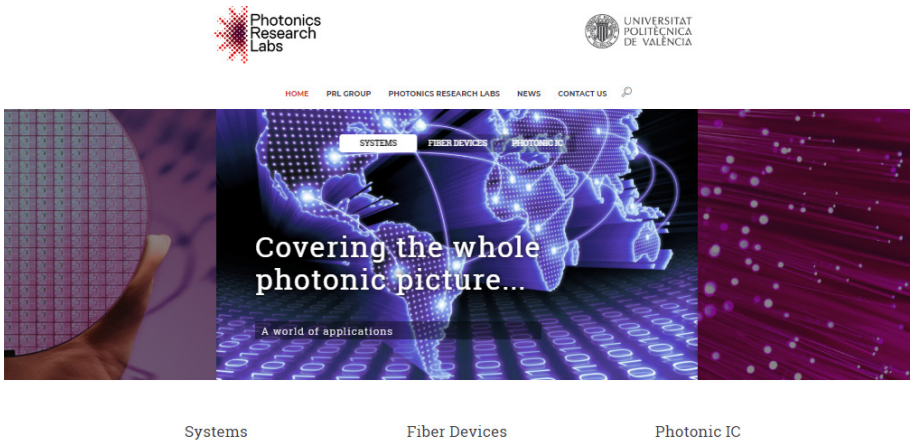
Jorge Sastre, Roger Dannenberg at the International Computer Music Conference, ICMC2018, Daegu (Korea), 5-10 Aug., 2018.

In this Workshop Soundcool was introduced to the international computer music research community and a jam session with Soundcool was produced by the participants, see https://bit.ly/2kameUd. The conference was co-organized by Prof. Tae Hong Park from the New York University (NYU), and with his approval the program NoiseGate-Soundcool "Seeing Music | Hearing Images" for kids https://nycemf.org/noisegate-soundcool/ was introduced at the ICMC2019 held at NYU https://bit.ly/2k8d2zy, New York, June 6-23, 2019.

2.2.- AWARDS.

In early 2019, our Soundcool engineers created the new 3.1 application that integrates control surfaces for both audio and video modules into a single platform and the functionalities of some modules have been improved. This has expanded Soundcool to be able to carry out more complex audiovisual projects. Moreover, an Augmented Reality app that allows to visualize the Soundcool virtual controls in smartphones and project them has been developed. This app has been used at the World Science Festival, where Soundcool had a workshop, a stand https://youtu.be/79Q_uGijp3k, and several performances, see https://youtu.be/l34X-qxln0Y

The multimedia opera La Mare dels Peixos (The Mother of Fishes) was performed on May 9 and 10 at the Palau de les Arts from Valencia (Spain) with a new Soundcool production. New performances are programmed in Mexico City with the Monterrey Institute of Technology and Higher Education in 2019, and in Pittsburgh (USA) in 2020. Other professional works have been presented such as Floating in the Deep Blue for percussion and Soundcool live electronics https://youtu.be/KPSiPHTfvzo, Chapitres for Symphonic Band, Soundcool live electronics and narrator https://youtu.be/f_Wt3fKi82E, Hope https://youtu.be/SFseQG5Mr-0, etc. Soundcool has been presented at the Spanish education community at the Con Euterpe Conference 2019. In this conference several workshops were given to teachers https://youtu.be/MggbjKwddGU and a Telegram help group was created to share experiences. The Soundcool team is giving support to that group. Install the Telegram app at your smartphone or tablet and click on https://t.me/soundcool for joining the Soundcool help group. It is organized with hashtags and many questions have been already answered. We have new web design http://soundcool.org in English and Spanish languages with an interesting FAQs link http://soundcool.org/en/faqs-doubts/. Moreover, the KA1 Erasmus+ project Collaborative creation and creativity through Music has adopted Soundcool. (2017-1-ES01-KA101-036693)



PRL web site

PHOTONICS RESEARCH LABS

PROF. DR. DR. JOSÉ CAPMANY – GROUP LEADER – PHOTONICS RESEARCH LABS

The Photonics Research Labs (PRL) are currently formed by more than 40 telecom engineers and physicists. The 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. The PRL research activity is focused on several applications of photonics, mainly on optical communications of analog and digital signals, radio-over-fiber systems and photonic integrated circuits. Part of the research is also performed in the field of fiber optic sensor and industrial photonics. Among others, PRL has been granted two Excellent Projects by the European Research Council (ERC).

PRL Twitter

MAIN ACTIVITIES

Microwave Photonics

Among the most productive research lines, PRL is considered a world-leading group in Microwave Photonics (MWP), principally due to its contributions to the field of microwave photonic signal processing, a fundamental technology for the convergence of fixed and wireless telecommunication networks. The research is focused in tunable and reconfigurable microwave filters based in fiber gratings and delay lines for the processing of radiofrequency, microwave and millimetric signals, directly in the optical domain, Remote antenna array feeders by means of optical delay lines (beamforming and beam steering), Signal processing and distribution over space-division multiplexing (SDM) optical fibers, Slow and Fast Light (SFL) Effects applied to Microwave Photonics. Implementation of tunable broadband microwave phase shifting and true time delay functionalities by means of different SFL technologies as Coherent Population Oscillations in Semiconductor Optical Amplifiers and stimulated Brillouin scattering in optical fibers, RADAR and Ultra-Wide Band (UWB) applications and Optical Frequency Division Multiplexing (OFDM) techniques.

Photonic integrated circuits

Design of integrated photonic devices for multiple applications (optical telecom, optical signal processing, sensing, bio-photonics): Silica or PLC (SiO_2), Silicon-on-Insulator (SOI), Silicon Nitride (Si_3N_4), active devices in InP.

Cryptography and quantum information

The research line is focused on the applications of Quantum Mechanic principles to information processing in optical telecommunication systems (Entanglement, Quantum state teleportation and Encryption).

Fibre Bragg Gratings

Design and fabrication of Fibre Bragg Gratings for communication networks (Dispersion compensation and optical filters) and Sensing applications (high temperature, stress, pressure, chemical, bio).

Optical Networks

Optical links conform a large part of the current global communication network, and the trend is growing with the latest deployments of Fiber-to-the-Home networks and fiber backhauling of mobile and radio networks. PRL currently develops an active line on the development of novel architectures and technologies as well as providing reasonable cost solutions for access networks with high capacity and upgraded reconfigurable features towards the convergence with 5G upcoming standards.

Photonic Instrumentation and Advanced Techniques for Metrology

Research and development of innovative photonic instrumentation focuses on photons or optical fields and the light-matter interaction for a wide range of scientific and industrial applications. Our main target is to design, implement and demonstrate the feasibility of photonic instruments with advanced functionalities featuring unique properties beyond the current state of the art.

FLAGSHIP PROJECTS

ERC Advanced Grant awarded to Prof. José Capmany – UMWP-Chip: Universal microwave photonics programmable processor for seamlessly interfacing wireless and optical ICT systems.

ERC Consolidator Grant awarded to Dr. Ivana Gasulla – InnoSpace: Revolutionizing fibre-wireless communications through space-division multiplexed photonics.

ERC Proof of Concept awarded to Prof. José Capmany – FPPAs: Field Programmable Photonic Arrays.

H2020-ICT project led by Prof. José Capmany – NEoteRIC: NEuromorphic Reconfigurable Integrated Photonic Circuits as artificial image processor.

SPIN-OFF COMPANIES

VLC Photonics (2011)

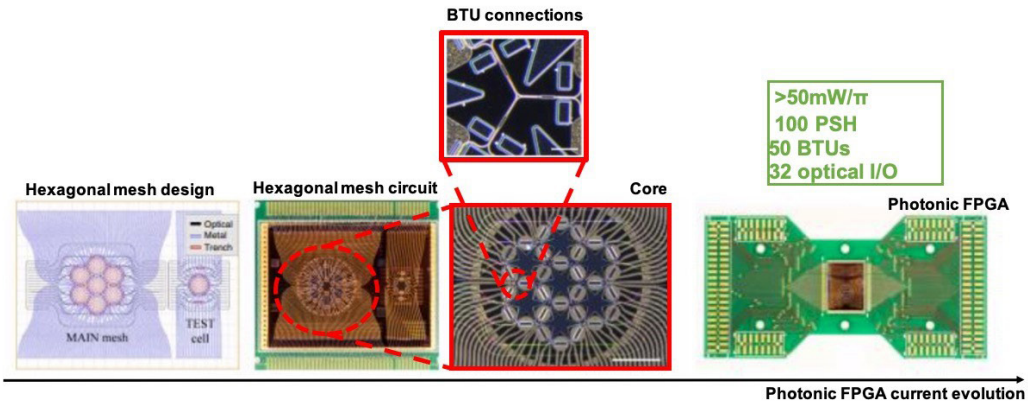
VLC Photonics' mission is to provide engineering solutions that allow our customers to harness the benefits of photonic integration, as well as to build up on our providers technologies. The mission spans from the initial work of drafting high-level optical system architectures to the final part of specifying its deepest technical details, all the while under a customized approach to the specific application domain at hand.

CalSENS (2013)

Cálculo y Estructuras Sensadas, CALSENS S.L., offers services of monitoring of processes and structures, of advice in the evaluation of its security and of decision making to guarantee its correct operation. It was born from the union of telecommunications engineering professionals and of roads, channels and ports that collaborate since 2004 in photonic technology research projects applied to the monitoring of processes and structures. This allows us to offer the customer an optimal solution adapted to their needs in the fields of civil engineering, aerospace, transportation and energy.

ePHOOX Engineering (2016)

EPHOOX Technology S.L. (founded in 2016) continues its activities towards the development of novel solutions based on Microwave Photonics technology for specific environments such as 5G.



ERC Proof of Concept Grant: Field Programmable Photonic Arrays

The module OVNA-P100X has been designed and manufactured as an advanced instrumentation for characterization and monitorization of photonic devices and hybrid RoF systems. Ongoing activities will provide soon an upgraded version with improved performance and new functionalities.

iPRONICS (2019)

The recently created company iPRONICS Programmable Photonics S.L. aims to turn programmable integrated photonic chips development into a commercial valuable proposition.

1. PROJECT ACTIVITIES

1.1. ONGOING PROJECTS

ERC Proof of Concept Grant: Field Programmable Photonic Arrays

***IP**: José Capmany Francoy*

2019-2021. European Funding - European Research Council (ERC).

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

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

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

ERC Advanced Grant: Universal microwave photonics programmable processor for seamlessly interfacing wireless and optical ICT systems (UMWP-Chip)

***IP:** José Capmany Francoy*

2017-2022. European Funding - European Research Council (ERC)

***Summary:** 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 a processor based on the novel concept of photonic waveguide mesh optical core and its integration in a Silicon Photonics chip.*

ERC Consolidator Grant: Revolutionizing fibrewireless communications through spacedivision multiplexed photonics (InnoSpace)

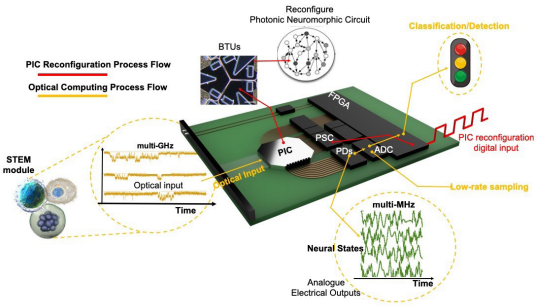
***IP:** Ivana Gasulla Mestre*

2017-2022. European Funding - European Research Council (ERC)

***Summary:** InnoSpace aims to revolutionize next generation fiber-wireless communication paradigms, such as 5G systems and Internet of Things, by pioneering the use of the photonic Space dimension. The present fiber-wireless landscape is characterized by radio-over-fiber distribution architectures that are static and inefficient, (with a replication of bundles of optical fibers) as well as by radiofrequency signal processing systems, such as antenna beam-steering or signal generation, which are nowadays bulky, heavy and power consuming. To overcome these limitations, we propose the*

application of Space-Division multiplexing to fiber-wireless scenarios where we provide "simultaneously" in a single optical fiber, a compact approach for both distribution and processing functionalities. This leads to the novel concept of "fiber distributed signal processing".

H2020 NEoteRIC: NEuromorphic Reconfigurable Integrated Photonic Circuits as artificial image processor



H2020-ICT: NEuromorphic Reconfigurable Integrated Photonic Circuits as artificial image processor

IP: *José Capmany Francoy*

2020-2022. European Funding - European Commission.

Summary: *NEoteRIC's primary objective is the generation of holistic photonic machine learning paradigms that will address demanding imaging applications in an unconventional approach providing paramount frame rate increase, classification performance enhancement and orders of magnitude lower power consumption compared to the state-of-the-art machine learning approaches. NEoteRIC's implementation stratagem incorporates multiple innovations spanning from the photonic "transistor" level and extending up to the system architectural level, thus paving new, unconventional routes to neuromorphic performance enhancement. The technological cornerstone of NEoteRIC relies on the development and upscaling of a highspeed reconfigurable photonic FPGA-like circuit that will incorporate highly dense and fully reconfigurable key silicon photonic components (ring resonators, MZIs, etc.). High-speed reconfigurability will unlock the ability to restructure the photonic components and rewire inter-component connections. Through NEoteRIC the integrated photonic FPGAs will be strengthened by the incorporation of novel marginal-power consuming non-volatile high-speed phase shifters that will push the boundaries of energy consumption. NEoteRIC's "unconventional" chips will be utilized as a proliferating neuromorphic computational platform that will merge the merits of photonic and electronic technology and will allow the all-optical implementation of powerful non-von Neumann architectures such as Reservoir Computing, Recurrent Neural Networks, Deep Neural Networks and Convolutional Neural Networks simultaneously by the same photonic chip. The in-project excellence will be tested through demanding high impact application such as high frame-rate image analysis and in particular single-pixel time-stretch modalities thus pushing the boundaries of state-of-the-art; exhibiting simultaneous high spatial resolution and Gframe/sec processing rate.*

H2020 BlueSPACE: Building on the Use of Spatial Multiplexing 5G Networks Infrastructures and Showcasing Advanced technologies and Networking Capabilities

IP: *Salvador Sales Maicas*

2017 - 2020. European Funding – H2020

Summary: *The core concept of BLUESPACE is to exploit the added value of Spatial Division Multiplexing (SDM) in the Radio Access Network (RAN) with efficient optical beamforming interface for the pragmatic Ka wireless transmission band. Both being seamlessly integrable in next generation optical access networks infrastructures with massive beam steering capabilities and with flexible network management control. The main objectives targeted by the BLUESPACE project are: to develop a truly viable and efficient path for 5G wireless communications with a 1000-fold increase in capacity, connectivity for over 1 billion users, strict latency control, and network software programming. BlueSPACE targets a disruptive yet pragmatic approach for the deployment of scalable, reconfigurable and future-proof fronthaul solutions for 5G communications, offering unrivalled characteristics that include: a) increased bandwidth provision by naturally enabling and supporting massive multiple Input Multiple Output (MIMO) transmission starting/ending in the fiber medium by enabling space diversity in the RF domain by supporting RF beam steering in the photonic domain, b) compact infrastructure that is reconfigurable by means of Software Defined (SDN) and Network Function Virtualization (NFV) paradigms and c) the possibility of providing full integration with other existing approaches for the implementation of access networks, such as Passive Optical Networks (PONs). This approach relies on the core concept of this project, which is the introduction of Spatial Division Multiplexing (SDM) in the fronthaul of the mobile access network.*

COST Action EUIMWP: European Network for High Performance Integrated Microwave Photonics

IP: *José Capmany Francoy*

2017 - 2020. European Funding – H2020

Summary: *This Action aims to shape and bring the relevant integrated Microwave Photonics community, supporting coordination and networking actions to consolidate this new ecosystem. EUIMWP is providing exchange of knowledge, ideas and, equally important, delivering a portfolio of technological benchmarkings to establish performance*

indicators and define future technological requirements in high-performance scenarios, mainly radar, 5G, Internet of Things, automotive and aerospace technologies. Over 40 partners from academia, industry and public organizations are founding members of the Action.

MSCA-ITN MICROCOMB: Applications and Fundamentals of Microresonator Frequency Combs (MSCA-ITN- 2018-ETN)

IP: *Pascual Muñoz Muñoz*

2019-2022. European Funding - European Commission.

Summary: *MICROCOMB is a collaborative research and training network, gathering together 17 European universities, research centers and industrial partners with complementary expertise on microresonator technology and the observation and exploitation of the microresonator frequency combs. Microcombs are emerging as a disruptive technology for realizing precision metrology, frequency and waveform synthesis and optical processing of information on a chip-scale platform. A typical microcomb setting is a microring resonator evanescently coupled with a waveguide mode, which is pumped by a continuous wave laser by means of a non-linear process like four-wave mixing (Kerr nonlinearity). Applications of microcombs for processing information with terabit rates, take advantage of the smaller resonator length and therefore being compatible with higher data transmission rates and also of the broad spectral coverage extending over C, L and U optical transmission bands. Other applications are: astronomical research, molecular spectroscopy, arbitrary wave form generators and RF and THz signal processing and generation.*

Website: https://www.microcomb-eu.org/

MSCA-ITN FINESSE: Fibre Nervous Sensing Systems (MSCA-ITN- 2016-ETN)

IP: *Salvador Sales Maicas*

2016-2020. European Funding - European Commission.

Summary: *FINESSE (FIbre NErvous Sensing SystEms) is a collaborative research and training network, gathering together 26 European universities, research centers and industrial partners with complementary expertise with the ultimate vision of a widespread implementation of distributed optical fibre sensor systems for a safer society.*

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

H2020 PICS4ALL: Photonic integrated circuits accessible to everyone

IP: *Pascual Muñoz Muñoz*

2016 - 2019. Public Funding - European Commission

Summary: *The aim of the PICs4All CSA is to establish a European network of Application Support Centres (ASC's) in the field of Photonic Integrated Circuits (PICs) technology. The main task of these ASC's is to lower the barrier to Researchers and SMEs for applying advanced Photonic IC technology, in particular InP and TriPleX based, and thus to increase the awareness of the existence of this worldwide unique facility. Website: http://pics4all.jeppix.eu/*

FOCAL: Energy eFficient hybrid Optical networks for indoor Communications And Lighting (RTI2018-101658-B-I00-AR)

IP: *Beatriz Ortega Tamarit, Vicenç Almenar Terre*

2019 - 2021. Public Funding - Ministerio de Ciencia, Innovación y Universidades (MICINN)

Summary: *The Project consists on the definition of the architecture of an indoor hybrid wired and wireless optical network based on VLC communications (Fi2VLC) to provide coverage and 5G services in residences and offices. Full characterization of hybrid POF and VLC links with improved capacity and flexibility, also including different multiplexing techniques will be addressed. Electro-optical transceivers based on low cost commercially available LEDs will be designed to transmit digital modulation formats such as OFDM, QPSK, CAP, 16QAM, etc. and adaptive modulations to adjust the transmission capacity to the actual demand in a multiuser scenario. The Project also includes the experimental characterization of the networks (QoS, BER, SNR) using the developed technologies (multiplexing, adaptive modulations and multiuser access) for service transmission and the implementation of software-defined Fi2VLC networks for energy efficient operation. Finally the techno-economical evaluation of the implemented solutions will assess their viability in short term 5G networks.*

CARÁCTER: Desarrollo de sistemas de caracterización y monitorizacion basados en fotonica de microondas de aplicacion en el mercado emergente de redes 5G (RTC-2016-5343-7)

IP: *José Mora Almerich*

2017 - 2019. Public Funding - Ministerio de Economía y Competitividad (MINECO)

Summary: *The main objective of the project is to develop a family of characterization systems based*

on the advanced control of high-performance microwave photonic components and a competitive price determinant for the implementation of new generation networks. The interest of the consortium in the present project is to analyze the feasibility of the Microwave Photonic technology for the development and implementation of an advanced performance analyzer for the characterization of devices and monitoring of hybrid radio-fiber systems that is capable of operating until the 70 GHz.

Silicon Nitride Spectrometers (TEC2016-80385-P)

***IPs**: Pascual Muñoz, Daniel Pastor*

2017 - 2020. Public Funding - Ministerio de Economía y Competitividad (MINECO)

***Summary:** Spectrometric devices are employed in multitude of disciplines, as information technologies, analytical chemistry, bio/life sciences and safety & security. The wavelength range spanning the upper part of the Near Infra-Red (NIR), wavelengths in the range of 1.5-4.0 µm, has recently raised considerable interest both for telecom due to the fiber capacity crunch, and non-telecom applications, since inorganic and organic molecules of fluids, and gases, exhibit fingerprint vibrations in this part of the spectrum. Compact integrated optics spectrometers on photonic integrated circuits (PICs) are comparatively smaller, but to the date they have not achieved the reconfiguration capabilities of the conventional bulk instruments. Among the different PIC technologies, Silicon Nitride on Silicon Oxide waveguiding platforms have received considerable interest in the recent years, due to their broad wavelength range of operation, from visible to the lower part of the mid infrared (400-4000 nm), serving to photonic applications in multiple disciplines (physics, engineering, bio/life sciences, safety & security, to name a few).*

FITNESS: Multicore fibers for next-generation fiberwireless applications (TEC2016-80150-R)

***IP:** Ivana Gasulla Mestre*

2017 - 2020. Public Funding - Ministerio de Economía y Competitividad (MINECO)

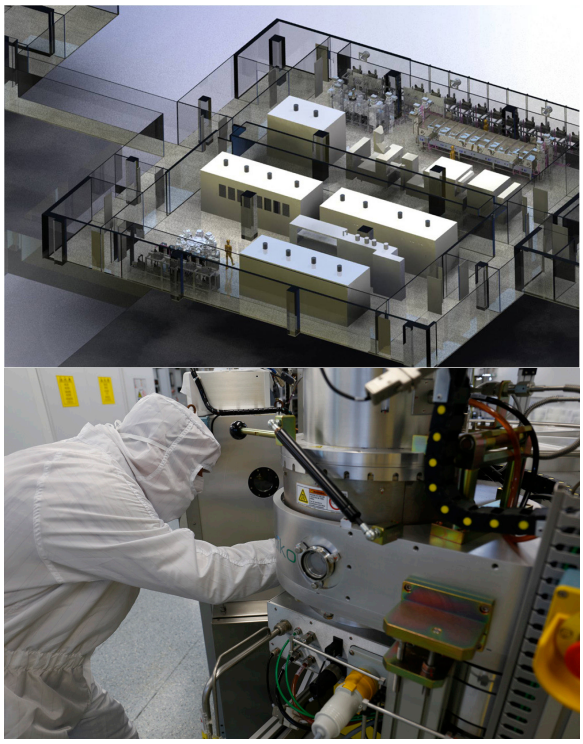
***Summary:** The pioneering idea of FITNESS is to develop a novel area of application for Space-Division Multiplexing by exploiting, for the first time, the inherent parallelism of multicore fibers to implement broadband delay lines for radiofrequency signals, which is the basis of multiple Microwave Photonics functionalities. More specifically, this project works on designing and fabricating group index variable delay line built upon the heterogeneous multicore fibers, where each one of the different cores that comprise it will feature an independent group delay.*

UPVFab: Micro-Fabricación para Fotónica, Electrónica y Química

***IP:** Pascual Muñoz Muñoz*

2017 - 2020. Public Funding - Generalitat Valenciana

***Summary:** Infrastructure acquisition project to upgrade and retrofit equipment at the class 100/10000 (ISO 5/7) 500 m² micro-fabrication pilot line / clean room www.fab.upv.es*



UPVfab

2. RESEARCH RESULTS

2.1. HIGHLIGHTED PUBLICATIONS

D. Pérez, I. Gasulla, J. Capmany, "Programmable multifunctional integrated nanophotonics" Nanophotonics 7 (8), 1351-1371, (2018)

Programmable multifunctional integrated nanophotonics (PMIN) is a new paradigm that aims at designing common integrated optical hardware configurations, which by suitable programming can implement a variety of functionalities that can be elaborated for basic or more complex operations in many application fields. The interest in PMIN is driven by the surge of a considerable number of emerging applications in the fields of telecommunications, quantum information processing, sensing and neurophotonics that will be calling for flexible, reconfigurable, low-cost, compact and low-power-consuming devices, much in the same way as how field programmable gate array (FPGA) devices operate in electronics. The success of PMIN relies on the research into suitable interconnection hardware architectures that can offer a very high spatial regularity as well as the possibility of independently setting (with a very low power consumption) the interconnection state of each connecting element. Integrated waveguide meshes provide regular and periodic geometries, formed by replicating a unit cell, which can take the

form of a square, hexagon or triangle, among other configurations. Each side of the cell is formed by two integrated waveguides connected by means of a Mach-Zehnder interferometer (MZI) or a tunable directional coupler that can be operated by means of an output control signal as a crossbar switch or as a variable coupler with independent power division ratio and phase shift. In this paper, we review the recent advances reported in the field of PMIN and, especially, in those based on integrated photonic waveguide meshes, both from the theoretical as well as from the experimental point of view. We pay special attention to outlining the design principles, material platforms, synthesis algorithms and practical constraints of these structures and discuss their applicability to different fields.

D. Barrera, J. Madrigal, S. Delepine-Lesoille, and S. Sales, "Multicore optical fiber shape sensors suitable for use under gamma radiation," Opt. Express 27, 29026-29033, (2019)

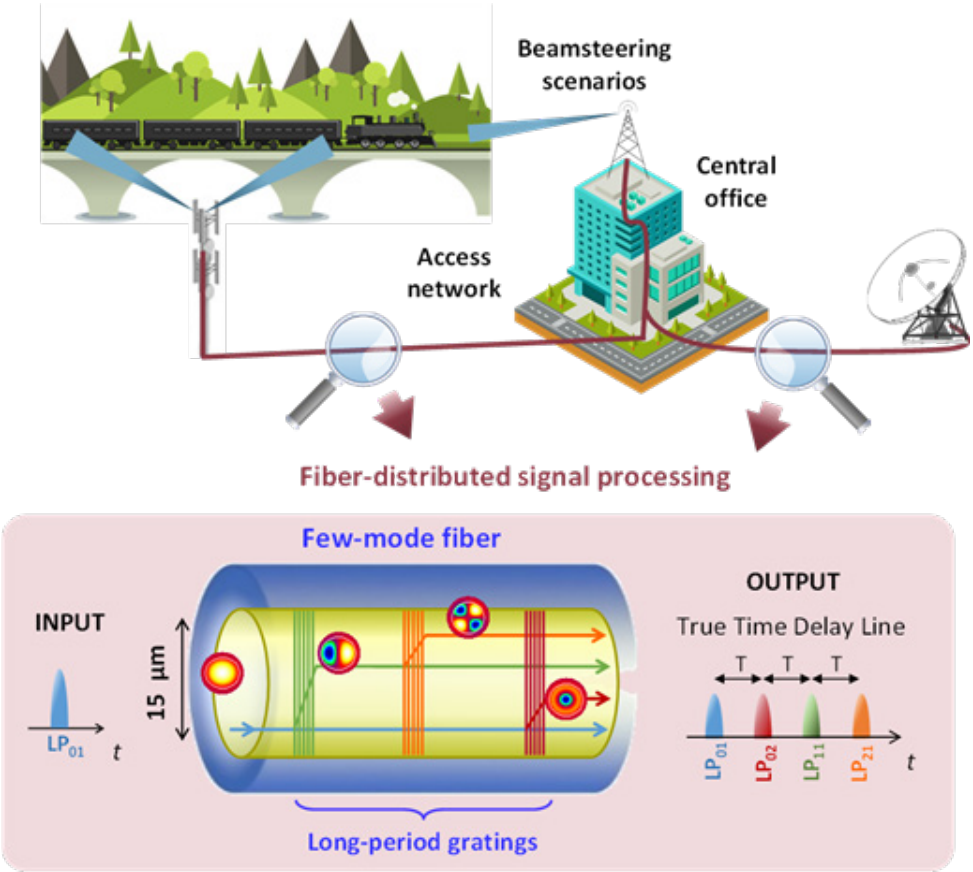
We have designed and implemented the first fiber optic shape sensor for nuclear radiation environments based on multicore optical fibers. We inscribed two fiber Bragg gratings arrays in a seven-core optical fiber. The radiation-induced Bragg wavelength shift (RI-BWS) produces errors. However, the use of the multiple cores permits to make these sensors immune to RI-BWS obtaining without modifying the composition of the fiber, pre-irradiation or thermal treatment.

D. Pérez, I. Gasulla, J. Capmany, "Field-programmable photonic arrays" Optics Express 26 (21), 27265-27278, (2018)

We propose a new programmable integrated photonic device, the Field Programmable Photonic Array, which follows a similar rationale as that of Field Programmable Gate Arrays and Field Programmable Analog Arrays in electronics. This high-level concept, basic photonic building blocks, design principles, and technology and physical implementation are discussed. Experimental evidence of its feasibility is also provided.

S. García, R. Guillem, J. Madrigal, D. Barrera, S. Sales and I. Gasulla, "Sampled true time delay line operation by inscription of long period gratings in few-mode fibers" Optics Express 27(16), 27(16), 27(15), 22787-22793, (2019).

We propose and experimentally demonstrate distributed microwave photonics signal processing over a few-mode fiber link by implementing 4-sample true time delay line operation. The inscription of a set of long period gratings at specific locations along the few-mode fiber allows the excitation of the higher-order modes while adjusting the individual sample group delays and amplitudes that are required for sampled true time delay line behavior.



Sampled true time delay line operation by inscription of long period gratings in few-mode fibers

We experimentally validate the performance of the implemented true time delay line when applied a typical signal processing system in fiber-wireless communications scenarios: radiofrequency signal filtering.

R. Min, B. Ortega, C. Broadway, C. Caucheteur, G. Woyessa, O. Bang, P. Antunes, C. Marques, "Hot water-assisted fabrication of chirped polymer optical fiber Bragg gratings", Optics Express, 26, 34655 – 34664, (2018)

We obtained chirped gratings by performing hot water gradient thermal annealing of uniform poly (methylmethacrylate) (PMMA) microstructured polymer optical fiber Bragg gratings (POFBGs). The proposed method's simplicity is one of its main advantages because no special phase mask or additional etching are needed. It not only enables easy control tuning of the central wavelength and chirp characteristics, but it also leads to obtain flexible grating response, compared with tapered chirped POFBGs. Therefore, a flexible and low-cost chirped POFBG devices fabrication technique has been presented by using a single uniform phase mask.

P. Muñoz et al. "Foundry developments towards silicon nitride photonics from visible to the mid-infrared" IEEE J. of Selected Topics in Quantum Electronics, 25 (5), 1-13, (2019).

Photonic integration technologies have spread in the past decade by means of foundry models that mirror the electronic-integrated circuit industry developments of the past century. Several monolithic technologies exist, based on silicon and III-V semiconductors. In this paper, we discuss the current state and forthcoming developments of open access photonic foundries whose technology platforms are based on silicon nitride material. The paper presents various silicon nitride technologies and foundries, alongside with access models supported by generic integration and process design kits. Technical features, enabled by different micro-fabrication processes and tools are summarized. Application examples and developments of forthcoming incorporation into these platforms are outlined.

2.2. PATENTS

J. Capmany, I. Gasulla y D. Pérez, "Método de configuración y optimización de dispositivos fotonicos programables basados en estructuras malladas de guiaondas opticas integradas", Application no. P201831118, Publication date: 2018. Priority country: Spain.

J. Capmany, I. Gasulla y D. Pérez, "Acoplador direccional fotofónico con sintonización independiente de factor de acoplo y desfase" Application no. P201831055, Publication date: 2018. Priority country: Spain.

J. Capmany, I. Gasulla y D. Pérez, "Photonic chip, Field Programmable Photonic Array and Programmable Circuit", Application no. 6/235,056, Publication date: 2018. Priority country: United States of America.

J. Capmany, I. Gasulla y D. Pérez, "Photonic chip, Field Programmable Photonic Array and Programmable Circuit," Application no. JP1598.79 Publication date: 2019. Priority country: Japan.

D. Pastor, P. Muñoz; et. al, "Dispositivo difractivo de análisis químico y biológico," Application no. P201930661. Publication date: 2019. Priority country: Spain.

D. Pastor, P. Muñoz; et. al, "Dispositivo difractivo de análisis químico y biológico," Application no. P201930661. Publication date: 2019. Priority country: Spain.

MOBILE COMMUNICATIONS GROUP (MCG) ANNUAL RESEARCH REPORT 2018/2019

The 2019 has been a successful year for the Mobile Communications Group. Apart from the important number of European projects reached, the quantity and quality of thesis defended, and the number of relevant publications, the organization of the EuCNC 2019 and the Global 5G Event has been the most important event that has put the MCG/ITEAM in the spotlight of the field of wireless communications. In the called Valencia 5G Week, the more relevant experts in 5G offered presentations and demonstrations of this technology. During the months of preparation of these demonstrations, the MCG worked together with important companies such as Orange, ZTE or RTVE and all this hard work is giving rise to new collaborations and future projects.

1.- PROJECT ACTIVITIES

5G-Xcast

5G-Xcast has developed broadcast and multicast Point to Multipoint (PTM) capabilities for 5G New Radio (NR) and the Core Network as built-in features integrated in the overall 5G system architecture considering Media & Entertainment (M&E), Automotive (Auto), Internet of Things (IoT) and Public Warning (PW) use cases. 5G-Xcast has also designed a dynamically adaptable network architecture with layer independent network interfaces to dynamically and seamlessly switch between unicast, multicast and broadcast modes, or use them in parallel. The results of the project are the starting point for the definition of 5G multicast/broadcast in Release-17.

The project has been coordinated by Prof. David Gomez-Barquero, member of the iTEAM. The project has 8 M€ budget, and 19 partners from 9 countries, including Nokia, Telecom Italia, Bristish Telecom, BBC and the EBU. iTEAM has also led the definition of the 5G-Xcast air interface.

5G-CARMEN

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

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

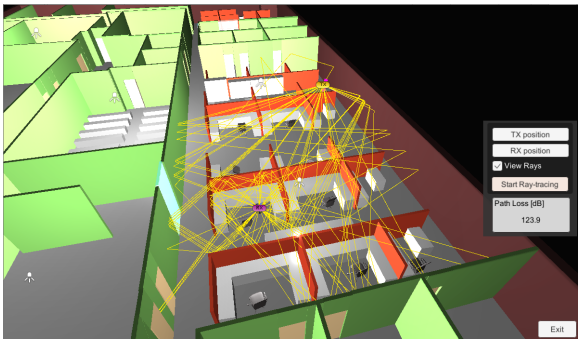


Figure 1: Channel Modelling Tool based on Ray Tracing Techniques

5G-SMART

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.

5G-TOURS

The goal of 5G-TOURS is to get the European 5G Vision of "5G empowering vertical industries" closer to commercial deployment with highly innovative use cases involving cross-industry partnerships, and to demonstrate the ability of 5G to support multiple vertical use cases concurrently on the same infrastructure. 5G-TOURS vision is to improve the life in the city for the citizens and tourists, making cities more attractive to visit,

more efficient in terms of mobility and safer for everybody. 5G-TOURS builds on three themes: the touristic city (Turin), the mobility efficient city (Athens), and the safe city (Rennes). iTEAM is involved in the touristic city, where visitors of museums and outdoor attractions are provided with 5G-based applications to enhance their experience while visiting the city. This includes VR/AR applications to complement the physical visit with additional content, involving interactive tactile communications. The experience of the visitors is also enhanced with robot-assisted services, telepresence to allow for remote visits, as well as live events enabled by mobile communications such as multi-party concerts.

5G-TOURS has almost 15M€ budget and a consortium of 27 partners. The project is led by Ericsson Italy. UPV is the leader of the broadcast use case, and will be involved in all the media distribution and production trials in Turin.

VLC-CAMPUS-5G

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

The deployment of the VLC-CAMPUS-5G test-bed is based on the expansion of the current communications' infrastructures of the UPV, by the acquisition of the necessary equipment for the emission and experimental tests of 5th generation mobile services. The objective is to cover all the use cases that occur in a closed and controlled environment such as the campus of the UPV, in which more than 50 thousand people move daily. The VLC-CAMPUS-5G project is an initiative that covers the entire University, being endorsed and supported by research groups from different Institutes and Departments, and with the particular support of the Infrastructure Service and the Calculation Center.

Millimetre Wave Communications in Built Environments (WaveComBE)

WaveComBE (www.wavecombe.eu) is an Industrial and Training Network dealing with the ultra-dense deployment of millimetre-wave (mmW) small-cells (SCs) in conjunction with massive multiple-input multiple output (MIMO) in 5G and beyond 5G (B5G) wireless networks. In WaveComBE the MCG is developing the simulation tools to analyse the human body blocking to millimetre wavelength radio frequencies, as well as efficient planning tools to deploy future access points in bands around and above 30GHz, as well as researching on beamforming techniques for the physical layer of mm-wave mobile communications. Two people are hired by the UPV in the framework of the project. Currently, both are enjoying their secondments in other beneficiary's facilities, one in UK and the other in Sweden. During the second year of the project, they have published two papers in international conferences and have attended the training events organized by the consortium. Narcís Cardona is the project coordinator and it is funded by the European Commission under the Marie Sklodovska-Curie programme.

Wireless In-Body Environment Communications (WIBEC)

This project is an Innovative Training Network that aims to train excellent researchers in the field of wireless communications inside the body. In particular, the two main application areas are Wireless Capsule Endoscopy (WCE) and pacemakers. WIBEC project will have a duration of 4 years during which 16 researchers will be trained in 8 European institutions, among them. WIBEC consortium is coordinated by Oslo University Hospital from Norway and is composed of 3 universities (Norges Tekninsk-Naturvitenskapelige Universitet, Norway; Universitat Politècnica de València, Spain; and Technische Universität Dresden, Germany); 3 companies (Sorin CRM, France; Ovesco AG, Germany; and ValoTec, France); and 2 university hospitals (Hospital Universitario y Politécnico La Fe, Spain; and Oslo University Hospital, Norway). This project has been funded by the European Commission

ElectroMagnetic prObe for early Tumour dEtection (EMOTE)

This is a joint collaborative project with Hospital La Fe, jointly funded by both public institutions. This project is devoted to the measurement of the dielectric properties of in vivo healthy and malignant colon tissues by using animal models (rats). In this way, it would be possible to evaluate whether the differences previously found for humans are also repeated at in in-vivo conditions. Furthermore, these tests will be used for verify and refine the methodology for the diagnosis of malignant body tissues based on the dielectric properties of both kind of tissues. This project has been funded by the Hospital Universitario y Politécnico La Fe and the Universitat Politècnica de València.

Sonda Colorrectal para la Detección Electromagnética de Tumores (COLODEM)

COLODEM project is based on the development of ta toold for colorectal cancer detection based on the reported difference in the electromagnetic properties of healthy and malignant colon tissues. Such tool will consist of three main parts: flexible probe to be integrated in the colonoscope, a software algorithm for measuring and identifying the malignant tissues, and a laboratory platform for testing. This platform will be based on the

electromagnetic reproduction of a human colon with presence of malignant tissues and it will be used for both the development of the probe and the detection algorithm as well as the training of the physicians. In this manner, the time needed for developing the tool will be dramatically shortened since it will be no need of animal testing. This project has been funded by the Universitat Politècnica de València.

2.- FEATURED PUBLICATIONS

Jordi Joan Gimenez, Jose Luis Carcel, Manuel Fuentes, Eduardo Garro, Simon Elliott, David Vargas, Christian Menzel, David Gomez-Barquero:

5G New Radio for Terrestrial Broadcast: A Forward-Looking Approach for NR-MBMS. IEEE Transactions on Broadcasting 65(2): 356-368 (2019) DOI: 10.1109/TBC.2019.2912117

3GPP LTE eMBMS release (Rel-) 14, also referred to as further evolved multimedia broadcast multicast service (FeMBMS) or enhanced TV (EnTV), is the first mobile broadband technology standard to incorporate a transmission mode designed to deliver terrestrial broadcast services from conventional high power high tower (HPHT) broadcast infrastructure. With respect to the physical layer, the main improvements in FeMBMS are the support of larger inter-site distance for single frequency networks (SFNs) and the ability to allocate 100% of a carrier's resources to the broadcast payload, with self-contained signaling in the downlink. From the system architecture perspective, a receive-only mode enables free-to-air (FTA) reception with no need for an uplink or SIM card, thus receiving content without user equipment registration with a network. These functionalities are only available in the LTE advanced pro specifications as 5G new radio (NR), standardized in 3GPP from Rel-15, has so far focused entirely on unicast. This paper outlines a physical layer design for NR-MBMS, a system derived, with minor modifications, from the 5G-NR specifications, and suitable for the transmission of linear TV and radio services in either single-cell or SFN operation. This paper evaluates the NR-MBMS proposition and compares it to LTE-based FeMBMS in terms of flexibility, performance, capacity, and coverage.

M. Barbi, C. Garcia-Pardo, A. Nevárez, V. Pons Beltrán and N. Cardona, "UWB RSS-Based Localization for Capsule Endoscopy Using a Multilayer Phantom and In Vivo Measurements" in IEEE Transactions on Antennas and Propagation, vol. 67, no. 8, pp. 5035-5043, Aug. 2019. doi: 10.1109/TAP.2019.2916629

Abstract: In recent years, the localization for capsule endoscopy applications using ultrawideband (UWB) technology has become an attractive field of investigation due to its potential benefits for patients. The literature concerning performance analysis of radio frequency-based localization techniques for in-body applications at UWB frequencies is very limited. Available studies mainly rely on finite-difference time-domain simulations, using digital human models and on experimental measurements by means of homogeneous phantoms. Nevertheless, no realistic analysis based on multilayer phantom measurements or through in vivo experiment has been reported yet. This paper investigates the performance of the received signal strength-based approach for 2-D and 3-D localizations in the UWB frequency band. For 2-D localization, experimental laboratory measurements using a two-layer phantom-based setup have been conducted. For 3-D localization, data from a recently conducted in vivo experiment have been used. Localization accuracy using path loss models, under ideal and non-ideal channel estimation assumptions, is compared. Results show that, under nonideal channel assumption, the relative localization error slightly increases for the 2-D case but not for the in vivo 3-D case. Impact of receivers selection on the localization accuracy has also been investigated for both 2-D and 3-D cases.

A. Fornes-Leal et al., "Dielectric Characterization of In Vivo Abdominal and Thoracic Tissues in the 0.5–26.5 GHz Frequency Band for Wireless Body Area Networks" in IEEE Access, vol. 7, pp. 31854-31864, 2019. doi: 10.1109/ACCESS.2019.2903481

Abstract: The dielectric properties of biological tissues are of utmost importance in the development of wireless body area networks (WBANs), especially for implanted devices. The early design stages of medical devices like capsule endoscopy, pacemakers, or physiological sensors rely on precise knowledge of the dielectric properties of the tissues present in their surrounding medium. Many of these applications make use of electromagnetic phantoms, which are software or physical models that imitate the shape and the electromagnetic properties of the tissues. They are used for designing devices in software simulations and for testing them in laboratory trials, aiding in both the development of WBAN antennas or in communication link evaluations. The existing reports about dielectric in vivo properties are limited and have drawbacks like: low variety of characterized tissues, lacking some relevant ones, and limitations and inhomogeneity in the measured frequency range. This paper aims at filling that gap by providing a new database of dielectric properties of biological tissues measured in vivo. In particular, it is focused on the tissues of the thoracic and the abdominal regions, measured at the same wide frequency band, on the same animal specimen, and under the same conditions. The properties have been obtained by measuring porcine tissues in the 0.5-26.5 GHz band with the open-ended coaxial technique. In this paper, we focus on those tissues that have been scarcely characterized so far in the literature, like heart, esophagus, stomach, and pancreas. The Cole-Cole fitting parameters of the measured tissues and their uncertainties are provided.

S. Perez-Simbor, C. Andreu, C. Garcia-Pardo, M. Frasson and N. Cardona, "UWB Path Loss Models for Ingestible Devices" in IEEE Transactions on Antennas and Propagation, vol. 67, no. 8, pp. 5025-5034, Aug. 2019. doi: 10.1109/TAP.2019.2891717

Abstract: Currently, medical devices such as the wireless capsule endoscopy (WCE) are used for data transmission from inside to outside the body. However, for certain applications such as WCE, the data rates offered by the current medical frequency bands can be insufficient. Ultrawideband (UWB) frequency band has become an interesting solution for this. However, to date, there is no formal channel path loss (PL) model for the UWB frequency band in the gastrointestinal (GI) scenario due to the huge differences between the proposed studies. There are three main methodologies to characterize the propagation channel, software simulations, and experimental measurements either in phantom or in in vivo animals. Previous works do not compare all the methodologies or present some disagreements with the literature. In this paper, a dedicated study of the PL using the three aforementioned methodologies (simulations, phantoms, and in vivo measurements) and a comparison with previous studies in the literature is performed. Moreover, numerical values for a PL model which agrees with the three methodologies and the literature are proposed. This paper aims at being the starting point for a formal PL model in the UWB frequency band for wireless body area networks in the GI scenario.

S. Castelló-Palacios, C. Garcia-Pardo, M. Alloza-Pascual, A. Fornes-Leal, N. Cardona and A. Vallés-Lluch, "Gel Phantoms for Body Microwave Propagation in the (2 to 26.5) GHz Frequency Band" in IEEE Transactions on Antennas and Propagation, vol. 67, no. 10, pp. 6564-6573, Oct. 2019. doi: 10.1109/TAP.2019.2920293

Abstract: Tissue phantoms are widely used for assessing the interaction between the electromagnetic waves and the human body. These are especially key in body area networks, where the body itself acts as the propagation medium since transmission is highly influenced by its diverse dielectric properties. Gels are suitable materials because of their high water content, which is required to mimic the dielectric properties of most tissues. In this paper, PHEA gels are suggested for achieving those properties due to their synthetic nature, which gives them the possibility to be swollen reversibly in more types of mixtures, in addition to water. These gels can be tailored to control the amount of liquid they embed so that they can imitate different body tissues in a wide bandwidth (2-26.5 GHz), which includes most of the current mobile communication and medical bands. This versatility offers the chance to create heterogeneous models of particular regions of the body, and thus improve the test realism. In addition, they own better mechanical and stability properties than the widely used agar or gelatin.

Muhammad Faheem Awan, Sofia Perez-Simbor, Concepcion Garcia-Pardo, Kimmo Kansanen and Narcis Cardona, "Experimental Phantom-Based Security Analysis for Next-Generation Leadless Cardiac Pacemakers", in Sensors 2018, 18(12), 4327. doi: 10.3390/s18124327

Abstract: With technological advancement, implanted medical devices can treat a wide range of chronic diseases such as cardiac arrhythmia, deafness, diabetes, etc. Cardiac pacemakers are used to maintain normal heart rhythms. The next generation of these pacemakers is expected to be completely wireless, providing new security threats. Thus, it is critical to secure pacemaker transmissions between legitimate nodes from a third party or an eavesdropper. This work estimates the eavesdropping risk and explores the potential of securing transmissions between leadless capsules inside the heart and the subcutaneous implant under the skin against external eavesdroppers by using physical-layer security methods. In this work, we perform phantom experiments to replicate the dielectric properties of the human heart, blood, and fat for channel modeling between in-body-to-in-body devices and from in-body-to-off-body scenario. These scenarios reflect the channel between legitimate nodes and that between a legitimate node and an eavesdropper. In our case, a legitimate node is a leadless cardiac pacemaker implanted in the right ventricle of a human heart transmitting to a legitimate receiver, which is a subcutaneous implant beneath the collar bone under the skin. In addition, a third party outside the body is trying to eavesdrop the communication. The measurements are performed for ultrawide band (UWB) and industrial, scientific, and medical (ISM) frequency bands. By using these channel models, we analyzed the risk of using the concept of outage probability and determine the eavesdropping range in the case of using UWB and ISM frequency bands. Furthermore, the probability of positive secrecy capacity is also determined, along with outage probability of a secrecy rate, which are the fundamental parameters in depicting the physical-layer security methods. Here, we show that path loss follows a log-normal distribution. In addition, for the ISM frequency band, the probability of successful eavesdropping for a data rate of 600 kbps (Electromyogram (EMG)) is about 97.68% at an eavesdropper distance of 1.3 m and approaches 28.13% at an eavesdropper distance of 4.2 m, whereas for UWB frequency band the eavesdropping risk approaches 0.2847% at an eavesdropper distance of 0.22 m. Furthermore, the probability of positive secrecy capacity is about 44.88% at eavesdropper distance of 0.12 m and approaches approximately 97% at an eavesdropper distance of 0.4 m for ISM frequency band, whereas for UWB, the same statistics are 96.84% at 0.12 m and 100% at 0.4 m. Moreover, the outage probability of secrecy capacity is also determined by using a fixed secrecy rate.

3.- AWARDS

5G-CARMEN got the recognition as best booth in the EuCNC event organized by the European Commission in Valencia in June 2019.

4.- EUCNC AND G5GE

Last June from 17th to 21th, the Mobile Communications Group organized two of the most important events in the field of Communications: the European Conference on Networks and Communications (EuCNC 2019) and the Global 5G Event. Both events were held in the Valencia Conference Centre, that gathered more than 800 international experts from both the scientific community and the world's leading telecommunications companies, to address the present and future of mobile telecommunications and the 5G technology industry. During that week, there were different demonstrations of practical applications and use cases of 5G technology, including the first global holographic videoconference 5G SA, a remote car driving system, an industrial robot controlled with 5G and an immersive reality cave. The world's first live transmission was also carried out using a directly connected HD camera, thanks to the collaboration of RTVE and the UPV. All this was possible thanks to the independent technology 5G SA developed by the multinationals ZTE and Orange. All these applications were evaluated during the weeks prior to the event at the Universitat Politècnica de València, in the framework of the VLC-5G project. In these tests, in addition to the institute iTEAM also participated the Institute ai2 (in cases of automobiles and remotely controlled robots) and the Institute I3B, which collaborated in the development of the cave of immersive reality. There was also a demonstration of rapid deployment of 5G emergencies in La Marina de València: A helicopter, drones and ambulances connected to its network and coordinated with each other, allowed a rapid response to the simulated emergency situation.

Figure 2: Local Organizing Committee

Figure 3: Robotic arm demonstration

Figure 4: General view of the Valencia Conference Centre

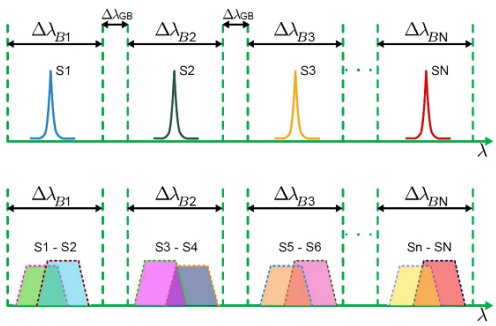
THESIS SUMMARY

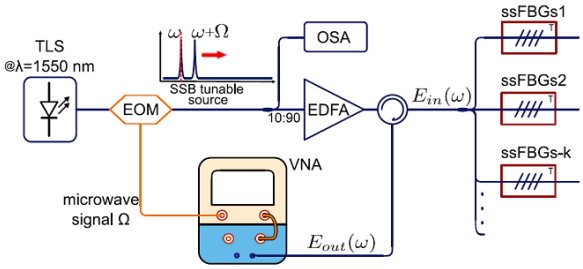
Encoding optical FBG sensors to enhance the capacity of optical sensing systems

Cristian Andrés Triana Infante
Supervisors: Dr. Daniel Pastor Abellán,
Dr. Gloria Margarita Varón Durán
Defended on October 11th, 2018

This thesis investigates the application of coding concepts to the design of optical sensors based on Fiber Bragg Gratings (FBG). Specifically, the design, characterization and experimental validation of custom coded devices that can be designed and manufactured as Super Structured FBG devices (SSFBG) is presented. The objective of this thesis is to improve the overall capacity and performance of the classical optical sensor networks based on conventional FBG devices. The constrains in classical optical sensors networks multiplexed in wavelength are the limitation in the number of sensors supported by spectral bandwidth unit and by the fact that eventual spectral overlapping between spectrally adjacent sensors leads to situations of uncertainty or indeterminacy of the measured magnitude.

For this purpose, three coding methodologies of SSFBG devices have been proposed, with the aim of providing each sensor with additional information useful for the identification of each sensor even in spectral overlapping conditions. An encoded sensor based on FBGs is an FBG structure whose shape has been adapted to an orthogonal code-word, so that its central wavelength can be unequivocally distinguished from other signals in the spectrum. The design of the encoded SSFBG sensors is carried out by modifying the reflection spectrum of multiband FBG devices, and this is achieved by translating the orthogonal code-words into the terms of amplitude and phase of the FBG sensors. The amplitude coding of the SSFBG sensors consists of translating the code words "Optical Orthogonal Code-words "(OOC), developed for multiple-access communications systems by optical code division (OCDMA), in the reflection pattern of the devices. The amplitude and optical phase coding has been proposed also following two different approaches: in the first one, custom amplitude and phase codewords were specifically designed to exhibit orthogonal behaviour, and then a new interrogation technique based on a dual wavelength tunable source was specifically modelled and implemented in the lab to retrieve the differential optical phase codes imprinted on the SSFBG sensor devices. The second approach uses the "Discrete Prolate Spheroidal Sequences" (DPSS) sequences, which are mutually orthogonal sequences developed for communication systems. The use of these structures as orthogonal detection elements with specific phase and amplitude patterns was also proposed and demonstrated. The different designed and simulated devices were fabricated at the PRL's silica fibre Bragg Gratings fabrication facility and tested under spectral overlap conditions. The central wavelength of the sensors was successfully recovered in the three methodologies, and the detection system error and sensitivity was characterized in terms of the design parameters for all the en/decoding configurations.





Waves - 2019 - year 11/ISSN 1889-8297

THESIS SUMMARY

Distributed and Collaborative Processing of Audio Signals: Algorithms, Tools and Applications

Christian Antoñanzas Manuel
Supervisors: Dr. Miguel Ferrer Contreras, Dr. Alberto González Salvador
Defended on September 30th, 2019

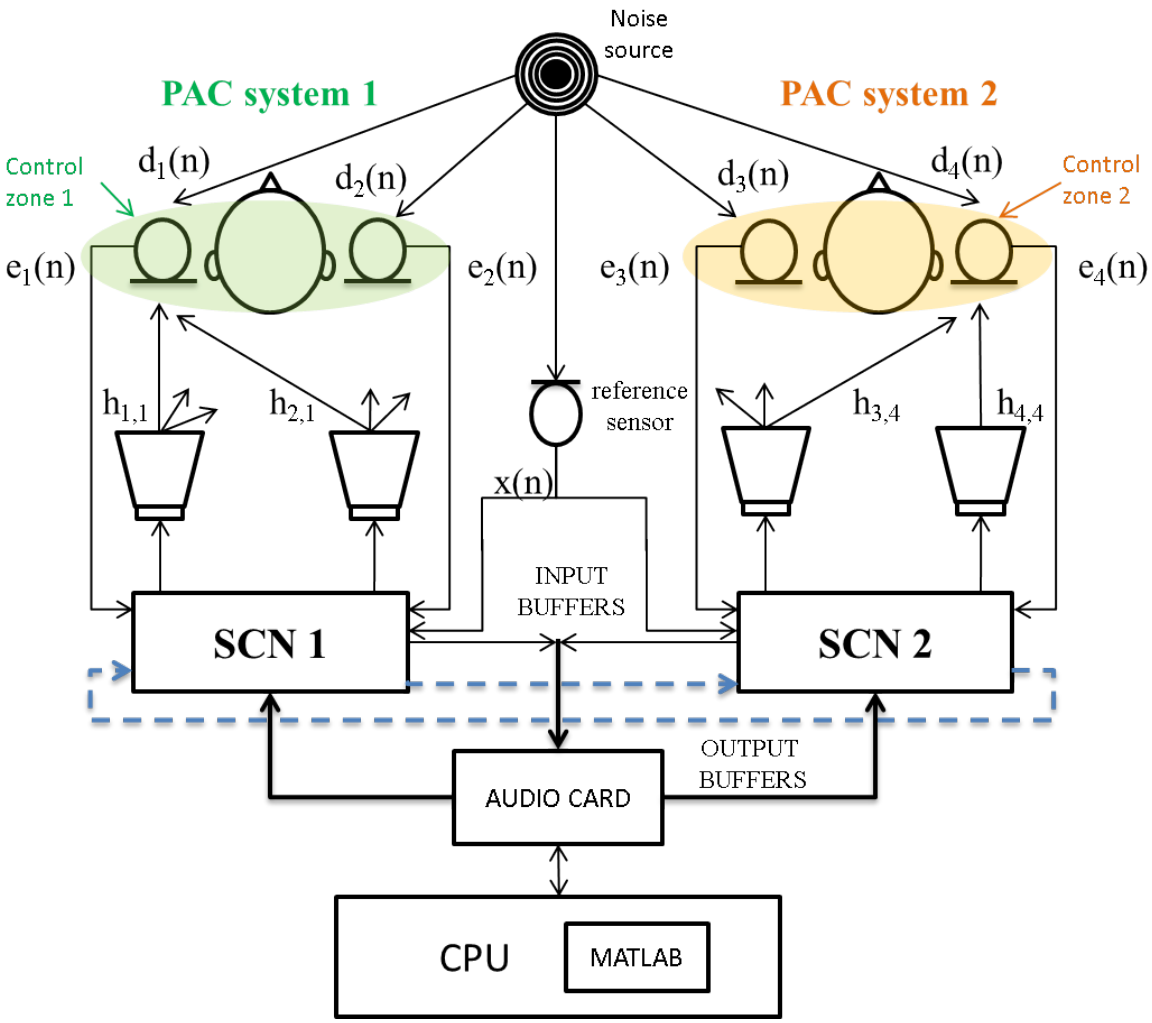
This thesis fits into the field of Information and Communications Technology (ICT), especially in the area of digital signal processing. Nowadays and due in part to the rise of the Internet of Things (IoT), there is a growing interest in wireless sensor net works (WSN), that is, networks composed of different types of devices specifically distributed in some area to perform different signal processing tasks. These devices, also referred to as nodes, are usually equipped with electroacoustic transducers, such as sensors or actuators, as well as powerful and efficient processors with communication capability. In the particular case of acoustic sensor networks (ASN), nodes are dedicated to solving different acoustic signal processing tasks, such as environmental sound monitoring, immersive audio, binaural hearing aids, noise-cancelling systems as well as audio teleconferencing. These audio signal processing applications have been undergone a major development in recent years due in part to the advances made in computer hardware and software. This has led to the development of powerful centralized processing systems that allow the number of audio channels to be increased, the control area to be extended or more complex algorithms to be implemented, thereby improving audio quality or creating independent control over several personal sound zones. In most cases, a distributed ASN topology can be desirable due to several factors such as the limited number of channels used by the sound acquisition and reproduction devices, the convenience of a scalable system or the high computational demands of a centralized fashion. All these aspects may lead to the use of novel distributed signal processing techniques with the aim to be applied over ASNs. To this end, one of the main contributions of this dissertation is the development of adaptive filtering algorithms for multichannel sound systems over distributed networks.

Note that, for sound field control (SFC) applications, such as active noise control (ANC) or active noise equalization (ANE), acoustic nodes must be not only equipped with sensors but also with actuators in order to control and modify the sound field. However, most of the adaptive distributed networks approaches used to solve soundfield control problems do not take into account that the nodes may interfere or modify the behaviour of the rest. This is an important issue which is tackled throughout this thesis. Therefore, other important contribution of this thesis is focused on analyzing how the acoustic system affects the behavior of the nodes within an ASN.

In cases where the acoustic environment adversely affects the system stability, several distributed strategies have been proposed for solving the acoustic interference problem with the aim to stabilize ANC control systems. These strategies are based on both collaborative and non-collaborative approaches. Implementation aspects such as hardware constraints, sensor locations, convergence rate or computational and communication burden, have been also considered on the design of the distributed algorithms. Moreover and with the aim to create independent-zone equalization profiles in the presence of multi-tonal noises, distributed narrowband and broadband ANE algorithms over an ASN with a collaborative learning and composed of acoustic nodes have been presented.

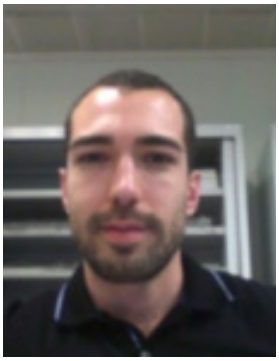
Experimental results are presented to validate the use of the distributed algorithms proposed in the work for practical applications. For this purpose, an acoustic simulation software has been specifically designed to analyze the performance of the developed algorithms. In this way, this simulation tool allows the transition between the initial formulation of any algorithm and its final programming on any digital signal processing platform.

Finally, the performance of the proposed distributed algorithms for multichannel SFC applications has been evaluated by means of a real practical implementation. To this end, a real-time prototype that controls both ANC and ANE applications by using collaborative acoustic nodes has been developed. The prototype consists of two personal audio control (PAC) systems composed of a car seat and an acoustic node, which is equipped with two loudspeakers, two microphones and a processor with communications capability. In this way, it is possible to create two independent noise control zones improving the acoustic comfort of the user without the use of headphones.



THESIS SUMMARY

Design of photonic sensors based on cavities and new interrogation techniques

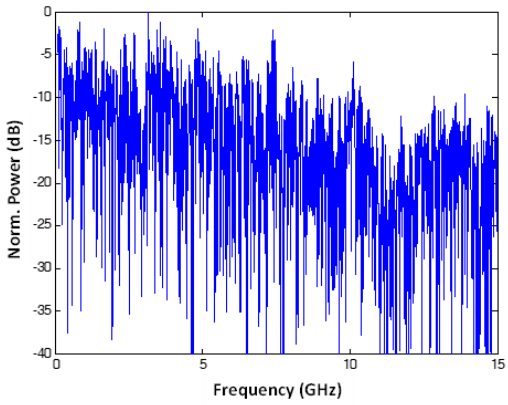


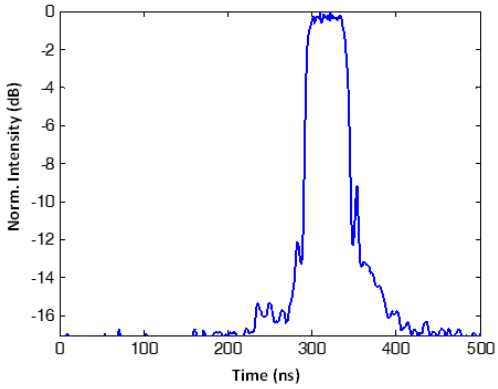
Javier Hervás Peralta
Supervisor: Salvador Sales Maicas
Defended on March 22nd, 2019

Optical sensors are photonic devices sensitive to different magnitudes that are used precisely to measure, in an absolute or a relative way, these magnitudes. These optical sensors are nowadays used to measure temperature, pressure, strain, humidity or the presence of a particular gas. In the past few decades a multitude of photonic sensors and different interrogation techniques have been developed, which had a great impact in dozens of different fields. One of the best examples is civil architecture, in which photonic sensors play a fundamental role in order to monitor the condition of the structures.

Despite of the good results showed by photonic sensors, the interrogation techniques used show different drawbacks. A large measurement time, low resolution or great complexity are some of them. In this doctoral thesis the design and characterization of a set of different photonic sensors based on the already known fiber Bragg gratings, along with the implementation of new interrogation techniques, are used in order to eliminate or at least reduce these problems. The interrogation techniques developed in this work are based on Microwave Photonics techniques, in which the interaction between optical and electrical signals is used to detect in this case the changes in a particular magnitude.

The techniques showed in this work have been designed in order to be as versatile and scalable as possible to have the opportunity to adapt to any requirement in different scenarios. In this work techniques that are able to interrogate hundreds or even thousands of sensors with great sensitivity and resolution can be found in addition to techniques that are developed to interrogate individual sensors with an enormous sensitivity. The work carried out in collaboration with the Swedish research institute RISE, based on the development of an electric field sensor based on poled fibers together with FBGs is also present.





Waves - 2019 - year 11/ISSN 1889-8297

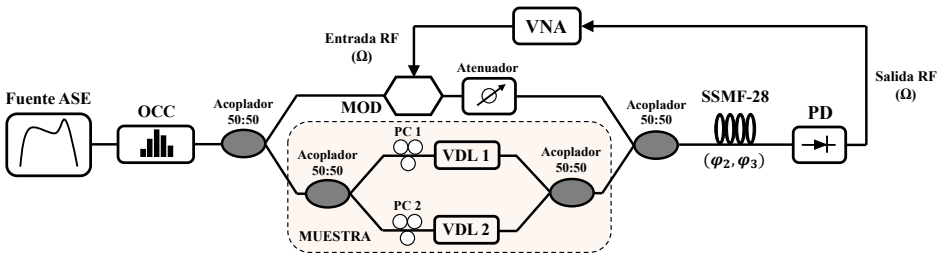
Microwave Photonics applied to Low Coherence Interferometry

Jesús Benítez González
Supervisors: Dr. José Mora Almerich, Dr. José Campany Francoy
Defended on May 21st, 2019

(Text in Spanish: Fotónica de microondas aplicada a la interferometría de baja coherencia)

Low Coherence Interferometry (LCI) is an optical technique for distance measurements, able to reach the micron scale of resolution in the axial direction of the sample. Its physical principle is based on the generation of an interference pattern which, after processing, can reveal the structural information of the sample studied. Among all the LCI applications, the medical field arises as one of the most relevant, mainly due to the non-invasive nature of the technique. In this sense, the Optical Coherence Tomography (OCT) is one of the most recognizable applications, where the acquisition of 2D and 3D images by using LCI enables the analysis and diagnosis of different biological tissues. Among other fields of application of this technique, we can highlight sensing and the optical components characterization. Nevertheless, LCI systems also suffer from some limitations related to compactness and cost-effectiveness, mainly when it is applied to the medical field where more complex structures are required. Furthermore, it also exists a strong limitation related to the interference pattern mostly due to its acquisition in the optical domain, where it is highly sensitive to vibrations and temperature variations.

On this basis, the main objective of this Ph.D. is focused in the study of the LCI technique and its combination with the field of Microwave Photonics (MWP). The benefits that MWP can offer to LCI are numerous, among which we can highlight the analysis of the interference pattern in the electrical domain instead of in the optical domain, or the possibility to make use of a more mature technology as the field of MWP is. The principle of operation of this technique, labelled as MWP-LCI, is based on the analysis of the interference pattern of the system when a certain sample is considered. The structural features of that sample generate different RF resonances where their position and width in the electrical spectrum are directly related to the different layers that compose the sample. In this way, the current Ph.D. is focused, firstly, in the demonstration of the existing analogy between the LCI and MWP-LCI techniques. Afterwards, several upgrade proposals are made to develop the most basic MWP-LCI structure. By the corresponding theoretical analysis of those proposals, it is demonstrated that the use of the MWP field allows the possibility to improve the limitations related to the first demonstrations carried out in MWP-LCI. Moreover, the experimental demonstrations associated to all the proposals are included, showing an excellent agreement with the theoretical results. Finally, the analysis is focused in the key elements that compose these structures: the sample, the optical source and the dispersive element. Through the different improvements applied to the MWP-LCI technique, we have been able to experimentally demonstrate a sensitivity level of 60 dB with resolutions of 27 μm in a working range that can easily exceed 1 cm.



THESIS SUMMARY

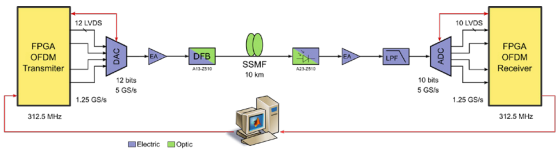
Algorithms and hardware architectures for OFDM implementation in optical communications system

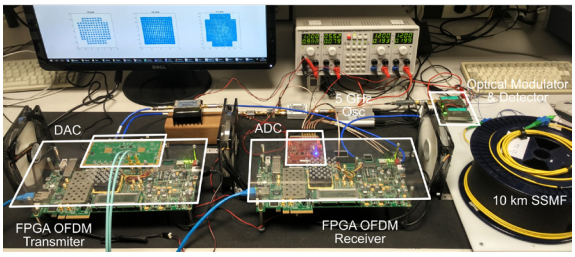
Julián Santiago Bruno
Supervisors: Dr. Vicenç Almenar Terré, Dr. Javier Valls Coquillat
Defended on March 14th, 2019
Text in Spanish: Algoritmos y arquitecturas hardware para la implementación de OFDM en sistemas de comunicaciones ópticos)

This doctoral thesis presents an in-depth exploration of the technical feasibility and achievable performance of a low-cost and high-speed optical communication system based on orthogonal frequency division multiplexing (OFDM) through the implementation of real-time digital signal processing algorithms over programmable logic devices (FPGA). Optical transmission systems based on intensity modulation and direct detection (IM/DD) is considered as one of the most interesting solutions for the deployment of the low-cost passive optical networks (PONs) that will be needed to cover the high traffic demand in the coming years. This demand is fueled, among others, by the significant increase of connected devices to the Internet, services and programs in the cloud, high definition video, etc.

The main objective of this thesis is to achieve the maximum bitrate and spectral efficiency of an IM/DD PON OFDM system (using a single band and a single wavelength). To this end, the hardware architecture of a high-speed real-time OFDM receiver, including all the necessary algorithms to perform the detection and demodulation of the OFDM symbols, has been implemented in a Virtex-7 FPGA device at a clock frequency of 312.5 MHz using a digital analog converter with a sampling rate of 5 GS/s. To reach the best possible performance, all the system bandwidth has been employed and the OFDM subcarriers have been loaded according to the characteristics of the electro-optical channel. An experimental platform for optical transmission through standard single-mode fiber (SSMF) has been developed to evaluate in real-time the performance of the implemented receiver. The main result of this thesis is the experimental validation of the proposed system that has achieved a bit rate of 19.63 GS/s and a spectral efficiency of 8.07 bit/s/Hz over 20 km SSMF. These results almost double the best performance published to date.

The receiver implementation included the design and development of several algorithms. First, it was designed a time synchronization algorithm (TSA) based on the cross-correlation between a known preamble and the received OFDM signal. This TSA has a good performance in low-SNR scenarios and its optimized design requires fewer resources than other synchronizers published in the literature. Second, a variable length parallel pipelined FFT processor has been implemented in a Virtex-7 device, it reaches a throughput of 10 GS/s with an efficiency (area/speed) higher than that of other published works. And finally, a channel equalizer working in the frequency domain to estimate and compensate channel distortions, which uses a known preamble to decrease the hardware complexity and increase the accuracy of the estimation, has been implemented. All the algorithms in this thesis have been developed to process 16 samples in parallel, thus reducing the required clock frequency (5 GHz/16) to acceptable values for the FPGA devices.





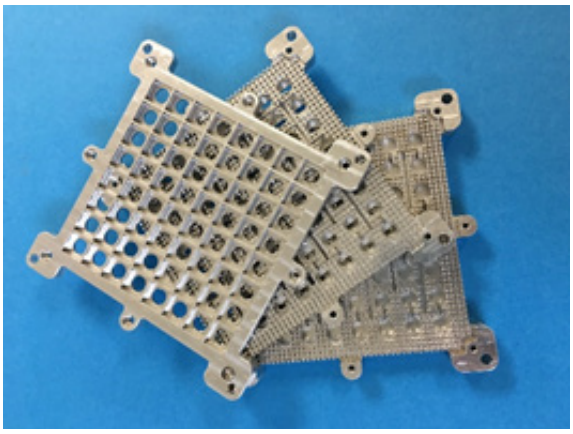
Gap Waveguide Array Antennas and Corporate-Feed Networks for mm-Wave band Applications

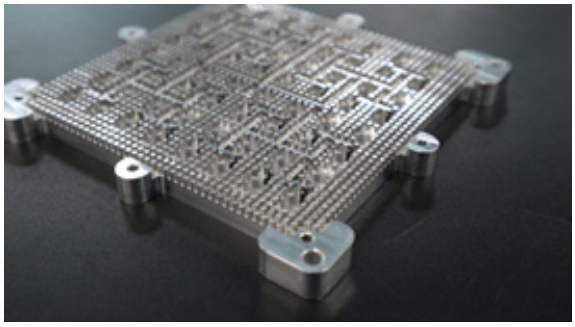
Miguel Ferrando Rocher
Supervisors: Dr. Alejandro Valero Nogueira,
Dr. Jose Ignacio Herranz Herruzo
Defended on December 18th, 2018

This thesis deals with topics of special interest regarding the design of antennas at the mm-wave band. Today, implementing passive components that operate in the mm-wave band and to ensure the appropriate metallic contact is challenging. Commonly, conventional planar transmission lines and hollow metallic waveguides are the usual solutions but they present high losses or they do not ensure a good metallic contact. So, new concepts must be explored.

Gap Waveguides (GWs), result suitably since they do not require metallic contact for shielding. Antenna arrays in Gap Waveguide Technology (GW) emerges as one promising candidate to naturally meet some of the mentioned needs. GW technology has demonstrated to be effective for mm-wave band devices because it enables full-metal distribution networks in a much simpler way than conventional waveguides. Very low distribution losses can be achieved preserving at the same time the assembly simplicity of multilayer microstrip feeding networks. This unique feature is a consequence of gap waveguides ability to safely confine the electromagnetic wave propagation through a contactless structure. During the last decade, there have been important advances in GW technology and a good number of gap waveguide-based arrays can be found in the literature.

This thesis goes a step further in the contribution to mm-wave gap waveguide antennas. Here, antennas with linear polarization as well as circular or dual polarization are proposed. Dual band antennas has also been explored. These contributions have been carried out with a focus on satellite communications on-the-move. In addition, new distribution networks have also been explored to obtain more compact, low-profile and lighter antennas.





THESIS SUMMARY

Polymer optical fiber gratings for microwave photonics and communications applications

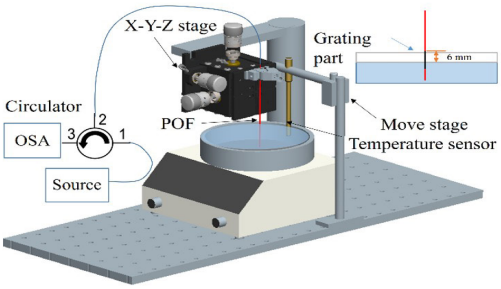
Rui Min
Supervisors: Dr. Beatriz Ortega Tamarit, Dr. Carlos Alberto Ferreira Marques
Defended on July 25th, 2019

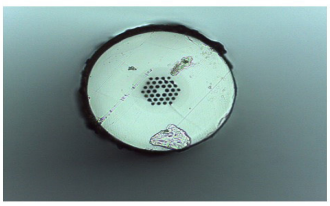
Polymer optical fibers (POFs) are optical fibers made of polymer materials with attractive characteristics compared with silica fibers, such as low Young's modulus, high failure strain, high flexibility and bio-compatibility.

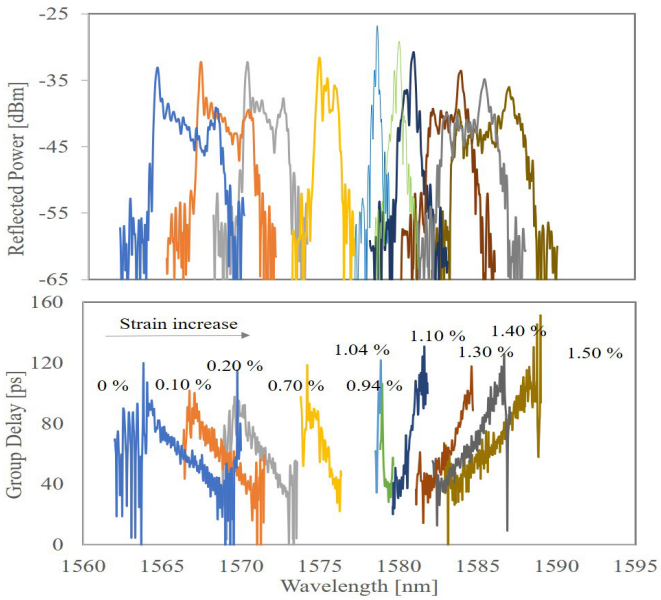
The present PhD thesis focus on the study, design, fabrication of fiber Bragg grating (FBGs) and long period gratings (LPGs) in POFs with the aim for microwave photonics, optical communication and bio sensing applications.

In this context, we fabricated uniform fiber Bragg gratings using different polymer materials, either in step index or microstructured fibers. Optimization of the FBG and LPG fabrication process was done by reducing the optical power, pulse duration and inscription time among other critical parameters and also the fabrication of polymer fiber gratings with different structures was demonstrated. We characterized stability, thermal, strain and humidity response of the fabricated gratings and finally demonstrated a variety of potential applications such as strain measurements, thermal detection and variable dispersion devices.

Although the advantages and characteristics of polymers have been successfully proved as promising for strain, temperature and humidity sensors and also for filters or variable delay lines in communications networks, several aspects require further research to make these devices real "off the shelf" sensors and filters in the next future.







THESIS SUMMARY

Change detection techniques through remote sensing for sustainable development and desertification

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Defended on February 6th, 2019

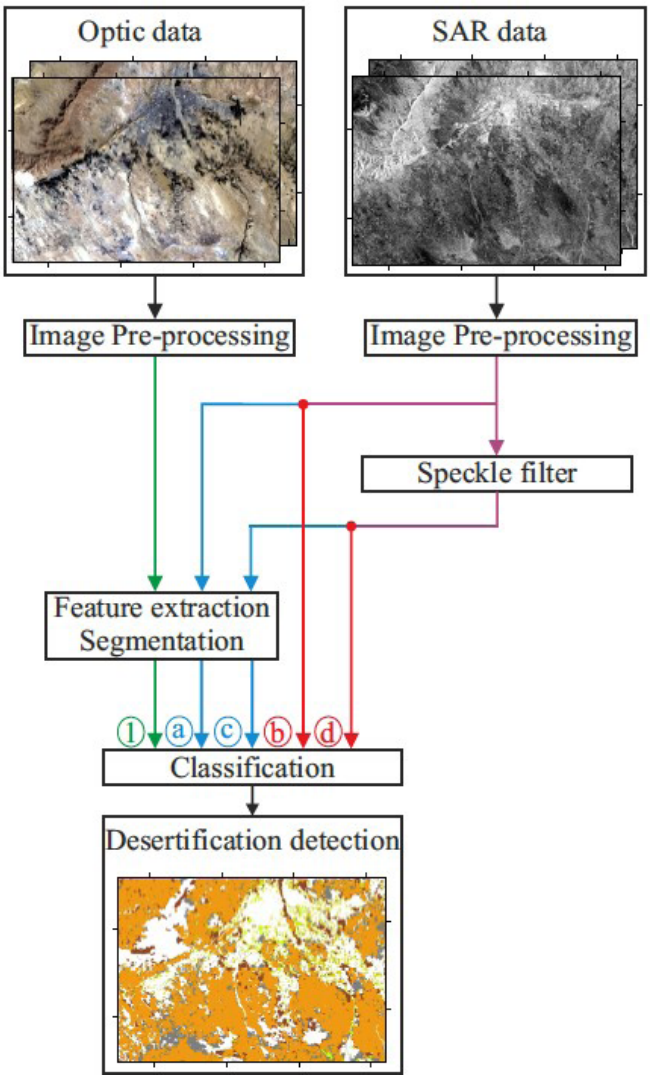
Over the last few years, the interest on the use of land use, land cover and its change in the time has grown. With the appearance of satellite images and Remote Sensing techniques, this type of Earth information can be obtained in a systematic way. In addition, the development of sensor technologies increases the availability of high and medium resolution images in the optical and microwave spectrum. On the other hand, the issue of desertification in arid zones is growing joined to the global awareness for climate change. For the last decades, the Algerian government has managed initiatives and programs to combat desertification in agricultural areas and cities located in the north of the country, near Sahara desert. Recently, they have started exploiting new sources of land cover information for this purpose. In general, land use and land cover monitoring methodologies require a high degree of human intervention for training and validation steps. The main focus of this Thesis is to develop change detection techniques through semiautomatic analysis of freely available optical and microwave images, with special emphasis on the detection of desertification in the north of Algeria.

Firstly, Change Vector Analysis is studied in two different zones in order to validate this change detection technique. For that purpose, supervised classification per pixel is employed with the selection of the appropriate classes for each scene information. In this step, comparison among different types of classifiers is done and Maximum Likelihood Classifier provides the better accuracy equal to 90,71 %. Quality evaluation is given by matrices of confusion and its derived parameters, such as global accuracy and kappa coefficient. A critical point in change detection methodology is optimal threshold selection. One possibility for it is given by the classical method Double-Window Flexible Pace Search. The results of change detection are given by transition matrices, change indexes and change maps.

Secondly, change detection applied to the issue of desertification in Algeria is studied using optical data. A methodology based on post classification comparison is developed to monitor the degradation of the Earth in a simple way. This method of change detection provides the best results with a value of 95,15 % in overall accuracy, after the comparison with Change Vector Analysis and considering different processing parameters in both methods. In this case, the Support Vector Machine classifier based on objects is the one that provides the best results with a remarkable global accuracy of 92,91 % and kappa coefficient equal to 0,91, after comparing the confusion matrices and their derived products. Consequently, a change detection method is designed and evaluated in the city of Biskra (Algeria) during a period of twenty-five years. The results are available in statistical format (transition matrices and change indexes) and in graphical format using change distribution maps. The excellent results are obtained with low human operator time.

Finally, taking into account the increasing availability of microwave images, the addition of radar images to the optical data in the previously selected desertification detection methodology is carried out. After evaluating different configurations, the integration of the radar image in vertical-vertical polarization without Speckle filtering after the segmentation step is chosen. This new strategy

employing optical and radar images provides a significant improvement over previous results (with a value of 97,05 % in global accuracy and 0,96 in kappa coefficient), since the properties of dry sand in the radar image make it more easily identifiable. This new semiautomatic method integrating different types of images reduces the analyst's work and produces an easily interpretable change detection report. The usefulness of this type of report lies in helping the Algerian government authorities to take appropriate actions to fight against land degradation.



The flowchart describes the algorithms used for the step of classification, where 1) is the standard classification, a) and c) fusion of the SAR and optical data before the process of segmentation, b) and d) fusion of the SAR and optical data after the segmentation step. And for each method you can apply the speckle filter or not. The approach achieves Land Use Land Cover change detection using Support Vector Machine and segmentation. The most useful change indices are obtained for the best methodology product. The simple improved methodology including radar images provides excellent results and it clearly outperforms the standard technique

Interoperability for the future European SmartCity ecosystem

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Defended on June 26th, 2018.

Sustainable development of urban areas is a challenge of highest interest at global level. Never before could anyone have thought of the information as an asset of our society. The advent of the new technologies has provided us with a huge amount of unthinkable resources to manage the data generated by the city and it is leading to an imminent evolution of urban areas behavior.

Nowadays a proper management of the city is vital and depends on the continent, the amount and nature of the data to be treated and/or shared and the resources and infrastructures to be taken into consideration. The necessary model of the city we will face is due to a higher connectivity and interaction, without human intervention, among all the services that determine an urban center. This is what is making the current concept of city change towards the intelligent city or Smart City.

This new model of the city is characterized by a higher connectivity and interaction among all the services that determine an urban center. A feature of paramount importance is the mobility of the components of the city, as it is what supports the daily routine in the urban model. A very relevant element in this context is the Full Electric Vehicle (FEV), for all the reasons we have analyzed in our work. For a proper launching of the FEV it is needed to integrate it with the rest of infrastructures that influence the mobility in the city.

Our work has consisted of researching and designing an interoperability system to integrate the FEV in the Smart City. The first of our goals in this work has been to put the FEV in place into the SmartCity along with to optimize the energy supply to the FEVs. It has required to model the mobility of the FEVs in an area, to analyze the power consumption of the vehicles and control it from a centralized proactive information system center, to forecast the power demand in the city and to study the power supply availability in the network of charge stations. It has led us to the design of a model for the estimation of power supply availability in the network of Charging Stations (CS). So the system designed is able to manage, in a proactive way, the needs of the network in order to optimize costs and improve efficiency.

On the other hand, the second of our objectives has been to study how the factors involved in the mobility within the SmartCity can ensure that FEV mobility is carried out as planned and, with it, conveniently integrate the FEV in the urban mobility system. In other words, our goal has been to integrate the FEV management landscape, studied in the first part, with the other agents of mobility into the SmartCity, thus providing a comprehensive solution to the problem of integration of the FEV in the new European cities ecosystem. This requires optimizing the interaction between the FEV and the meteorological information, traffic and mobility services in the city such as public transport, parking and e-sharing, in addition to a necessary traffic forecasting strategy for the early decision-making.