2021 | YEAR 13

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UNIVERSITAT POLITÈCNICA DE VALÈNCIA

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Instituto de Telecomunicaciones y Aplicaciones Multimedia

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Cover

"Circular Array"

José Javier López Monfort

Editorial Board

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ANNUAL RESEARCH REPORT 2020/2021

THESES SUMMARY

Message from the director

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

Tienes en tus manos la revista anual de iTEAM, nuestro particular resumen de la actividad investigadora del Instituto. A las puertas de dejar atrás la pandemia, vemos como nuestra actividad no ha menguado en estos dos años, no hemos dejado de creer en nuestras posibilidades y de crecer en la dirección hacia la que siempre nos hemos enfocado, hacia la excelencia. Con mejores contribuciones científicas y un reconocimiento internacional que va aumentando en diversos frentes, iTEAM sigue liderando proyectos europeos, importantes proyectos nacionales y relevantes colaboraciones con empresas punteras de nuestro sector. La pandemia ha hecho cambiar muchas cosas, también a la propia Universidad, que no debería dejar de ser en nuestro país el pilar sobre el que se sustenta la investigación básica y aplicada, ya que, de otro modo, ambos, investigación y academia, perderían el potencial que han alcanzado juntas. Los fondos de restauración y resiliencia europeos, así como el nuevo programa marco Horizon Europe, están a punto de empezar a generar nuevos proyectos, nuevas oportunidades, a las que iTEAM por supuesto optará, y de las que iTEAM con mucha probabilidad conseguirá seguir financiando la investigación que realiza en la Universitat Politècnica de València, manteniendo conjuntamente su liderazgo. ¡Disfrutad de la lectura!

You have in your hands the annual magazine of iTEAM, our particular summary of the research activity of the Institute. On the eve of leaving the pandemic behind, we note how our activity has not diminished in these two years, we have not stopped believing in our possibilities and growing in the direction in which we have always focused, towards excellence. With better scientific contributions and international recognition that is increasing on various fronts, iTEAM continues to lead European projects, important national projects and relevant collaborations with leading companies in our area. The pandemic has changed many things, including the University itself, which should not cease to be the pillar on which basic and applied research are supported in our country, since, otherwise, both research and academia would lose the potential they have reached together. The European NextGeneration funds, as well as the new Horizon Europe framework program, are about to start generating new projects, new opportunities, for which iTEAM will of course bid, and from which iTEAM will very likely continue to finance the research carried out at the Polytechnic University of Valencia, jointly maintaining its leadership. Enjoy the reading!

SCIENTIFIC PAPER

5G-Enabled AGVS for industrial and logistics environments

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ABSTRACT

5G has changed the telecommunications industry, allowing a new generation of devices and applications to be connected. These provide a more friendly and efficient environment to operators, who manage systems and devices that require real-time connectivity as well as ultra-high reliability. One of the most exciting use cases that 5G brings is the remote driving of Automated Guided Vehicles (AGVs) in industrial and logistics environments. This work proposes, in the context of the 5G-INDUCE and iNGENIOUS projects, two different use cases that will be deployed in Valencia. The paper describes the early prototypes that have been analyzed and tested to explore the capabilities of such use cases.

Keywords: *5G, edge computing, artificial intelligence, AGV, gesture recognition, haptic gloves, tactile internet.*

1. Automated guided vehicles: impact on the Industry 4.0AGVs are highly flexible, intelligent, and versatile systems used to transport materials from different loading points of the facilities of an industrial environment [1]. The design of AGV environments needs some considerations, such as the design of trajectories, number of vehicles that comprise the system, requirements, type of materials to transport, and how, when and where the loading and unloading of materials will take place. In the same way, it is necessary to know where the batteries of the vehicles will be charged and what safety systems will be used to avoid possible collisions and damage to the system.

Nowadays, AGVs are gaining a foothold in hundreds of companies. In the industry and manufacturing areas, autonomous robots enable customization and optimization of the production lines. AGVs are more suited than humans for certain tasks, in particular for hazardous or repetitive situations given in industrial environments. AGVs used to work guided through black lines, but in the last years these guides have disappeared, allowing AGVs to freely move around the factory. For this reason, advanced AGVs are also known as Autonomous Mobile Robots (AMRs).

The migration from fixed to mobile paths is provided by two main key enablers. On the one hand, robots are in fact getting more autonomous thanks to Artificial Intelligence and Machine Learning (AI/ML), thus they can take decisions and create new paths in real time. On the other hand, 5G wireless technologies allow not only high data rates, but also with extremely low latency.

In general, the deployment of mobile robots is only possible increasing flexibility, which can be achieved by innovative network architectures such as Multi-Access Edge Computing (MEC). It consists in bringing cloud computing closer to the senders and receivers of the data, in such a way that the times in the transmission of the information are cut operating in real time. In combination with 5G, MEC will allow vehicles to talk to each other fluently, so that an external vehicle can unload in another interior without manual intervention, controlled by the network.

One of the applications of 5G in the industry is the use of collaborative robots (cobots), with hardly any human supervision. The synchrony must be almost absolute, a matter of milliseconds, and that is the reason why edge computing is a key element in the future of the industry. It is about bringing cloud computing closer to the senders and receivers of the data, in such a way that the times in the transmission of the information are cut operating in real time. In addition, 5G will allow vehicles to talk to each other fluently, so that an external vehicle can unload in another interior without manual intervention, controlled by the network.

2. The use of 5G for AGVs in manufacturing

Although being evolutionary in terms of technology, 5G is revolutionary in terms of connectivity. For the first time in a mobile system, the network adapts to the application to offer the maximum QoS. Thus, the real potential of 5G resides in the new use cases that it enables. Through the support for big game changers such as massive IoT, critical services and cloud computation, 5G NR goes far beyond LTE and targets many types of devices and applications.

The 5G system is expected to provide support for a variety of services, each of them characterized by different Key Performance Indicators (KPIs), combining reliability, latency, throughput, positioning, and availability. The 3rd Generation Partnership Project (3GPP) and the International Telecommunications Union (ITU) provide various examples of latency KPIs to support robotics use cases in logistics [2]. For remote vehicle control, an E2E latency between 10 and 30 ms is desired, combined with 99.9999% of reliability and 99.9999% of availability. The 5G URLLC use case family is expected to satisfy such requirements.

More data, transmitted with imperceptible latency will be a key enabler for digital experiences. The truth is that its impact on the industry is probably even greater. It offers speed but also productivity, and, probably most importantly, enormous flexibility and reliability.

Hence, 5G is the best resource to take advantage of robotization. So far, the best way to transmit data between machines was an industrial ethernet cable. Currently, 5G acts like an invisible cable that eliminates the stiffness of the factory. Thay way, managers can rethink the configuration of the factories with great agility.

3. 5G technology and Edge Computing

The telecommunications industry has been immersed on an incredible transition which will redefine its role in industry and society while it prospers. Although 5G often is represented as a tool for higher speeds or critical to the development of Industry 4.0. It illustrates a foundational shift for wireless communications that it is placed directly at the center of a fully digitized economy. The 5G architecture itself consists of two parts, i.e., the Next-Generation Radio Access Network (NGRAN) who supports 5G New Radio (NR), and 5G Core (5GC) [3].

5G is defined by a set of requirements that allow for a set of usage scenarios, 5G services. These 5G services are:

URLLC: Ultra-reliable low latency communications, requires very low latency services and high reliability, critical needs communications (autonomous car, industry automation...) where bandwidth is not quite as important as speed, end to end latency 1 ms or less [3].

mMTC: Massive Machine Type Communications, enables machine to machine (M2M) communications and Internet of things (IoT), connecting thousands of devices in a small area, small amounts of data are sporadically transmitted (smart cities) [3].

eMBB: Enhanced Mobile Broadband, high speed, and wide coverage area, which does not encompass either of the other two groups. The aim is to serve more densely populated metropolitan centers with downlink speeds approximately 1 Gbps indoors, and 300 Mbps outdoors [3].

Figure 1 compares the 5G KPIs (Key Performance Indicators) for each type of 5G service. Interpolating this to a real UC yields values that are very different from the theoretical ones.

3GPP offers a detailed overview of the areas of work that are being developed so that 5G is a tool of facing verticals. The growth rate in 5G deployments is faster than in previous technologies, especially

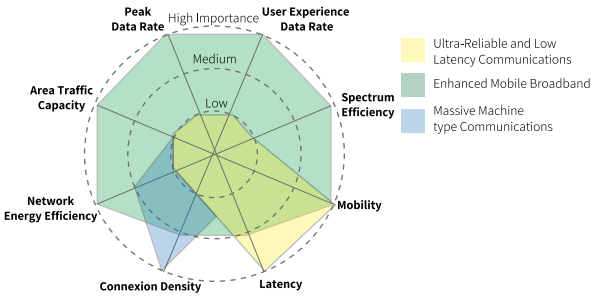

Figure 1. 5G KPIs

in relation to 4G. The improvements provided by each of the releases are brief explained below [4].

Release 15: It focus is Enhanced Mobile Broadband. It allows mMTC and IoT, Vehicle-to-Everything Communications (V2x), SBA, WLAN (Wireless

Local Area Network) and unlicensed spectrum, SlicingCurrently, there are products from this Release on market [5]

Release 16: It was completed in 2020. Its main focus is to enable ultra-reliable low latency for mission-critical applications. Some of the improvements it includes are slow latency, time synchronization for time-critical applications, resource management, pre-emption (URLLC data transmission can pre-empt ongoing non-URLLC transmissions), fast processing, reliability5G URLLC is a good match for standard defined for Time Sensitive Networking (TSN) which is a perfect candidate for industrial automation [6].

Release 17: It is mostly study items as NR MIMO (Multiple-Input and Multiple-Output), Industrial IoT, low complexity NR devices, power saving, NR coverage, Non-Public networks, RAN Slicing, Edge computing in 5G Core [7].

A critical factor of 5G is computing capacity. The edge places computing capabilities close to the traffic originates, at the edge of the network. This reduces latency and eliminates the need for all traffic to run across the entire transport network, optimizing the use of network resources. Edge resources will also enable new applications, such as virtual reality, augmented reality, and autonomous driving, that need to be run close to the data sources [8]. A variety of network functions will run at the edge. However, it is not feasible to simply move all workloads to the edge of the network. Instead, a balance of centralized and distributed compute resources in a layered architecture across the network between the core and edge will enable workloads to be placed where they can best support the required service and traffic profiles [9].

Modifying the location of the elements of the network allows to obtain different hybrid edge-cloud architectures in 5G networks as mentioned before. Figure 2 shows three different deployments of a 5G architecture. The first one, all in the factory (on-premise). The second one, a hybrid solution in which the control plane is remote and the UPF is decentralized at the edge, and the third with everything outside the factory (outdoor). In the second case, three types of edges are proposed: edge on-premise, far edge, a telecommunications tower such as the solution of Cellnex company or near edge, in an in-country data center as Telefonica company data centers.

In conclusion, this type of distribution will benefit all kind of sectors with different goals, either real-time performance of automated vehicles, high velocity response for interactive applications and video games, or the more sustainable and efficient industrial facilities. Besides, it has a narrow relationship with other key technologies

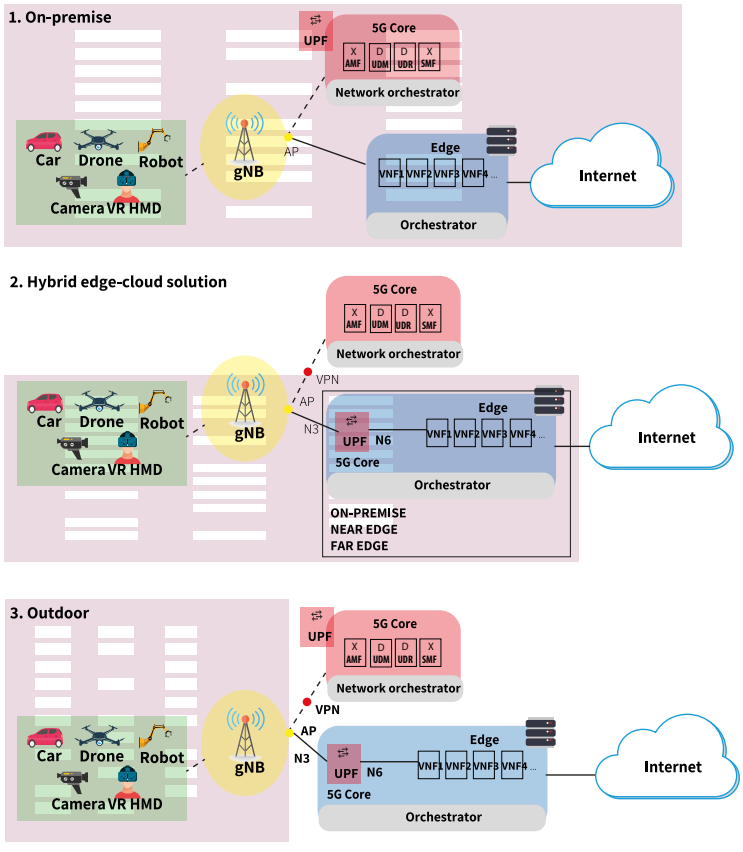

Figure 2. 5G architecture deployments

that mark this new digital revolution, as 5G, complex machine learning or big data.

4. 5G application to real use cases: iNGENIOUS and 5G-INDUCE

Among the numerous H2020 projects that tackle 5G-enabled AGVs for industrial and logistic environments, iNGENIOUS (NextGENeration IoT sOlutions for the Universal Supply chain) and 5G-INDUCE have chosen Valencia as their scenario for trials.

iNGENIOUS aims to design the next generation of Internet of Things (IoT) technology to add digital value to future supply chains, whereas 5G-INDUCE targets the development of an open 5G orchestration platform for the deployment of advanced 5G network applications.

a. iNGENIOUS testbed in the port of Valencia

Supply chains have become complex ecosystems where every process is critical and addresses a certain risk to individuals and/or resources. The way that products are made and delivered needs an evolution towards the Industry 4.0 principles, making the flow of goods and services as smart and monitored as possible. The decentralized approach of Industry 4.0 benefits the management of processes and H2M interaction within a supply chain, thus helping industries to improve efficiency and productivity.

In this context, the H2020 iNGENIOUS project aims at the digitalization and automation of the supply chain management, defining the Next-Generation IoT solution and creating new business models. It places a particular emphasis on 5G and the development of Edge and Cloud computing extensions for IoT, in addition to providing smart networking and data management solutions with AI/ML [10]. iNGENIOUS offers IoT and Tactile-IoT solutions, using both NR and 5GC to release the full potential of 5G capabilities.

One of the most exciting use cases envisioned by iNGENIOUS is the remote driving of AGVs using Head Mounted Displays (HMDs) and haptic gloves, which are key enablers for improving operation of Internet of Things (IoT) systems in industrial and logistic environments. The “Improved driver’s safety” use case aims to explore the remote transportation of goods with AGVs thanks to Tactile Internet, MEC, and immersive enablers. The final scenario is a terminal of the Valencia port that will be reserved for this use case. The idea is that an operator located in an indoor, safe environment can take control of an AGV when necessary (i.e., when automated routes cannot be followed) using MR and haptic solutions, which will be integrated in the remote indoor cockpit. The operator’s telepresence is provided by low latency video cameras and proximity sensors installed in the AGV, wirelessly connected to the cockpit via 5G and a compatible MEC infrastructure.

The use of haptic gloves and haptic sensors will improve the perception, quality and safety of the remote operators managing AGVs, which is required to guarantee the operation even in very exceptional situations where the autonomous robots cannot operate [10]. Haptic gloves will produce haptic feedback allowing operators to create a tactile experience in the shape of psychophysical stimulations including precise texture discrimination, pressure, or the sensation of holding objects. Haptic reactions and vibrations will be used as alarms for the remote driving experience in case of any detected risks. In a future prototype of the haptic gloves, biometric sensors will be implemented to monitor blood pulse, respiration frequency and body posture. This information will be processed to estimate fatigue or stress levels, detecting risk for the operator, and further avoiding accidents [11].

i. Proof-of-Concept implementation

Before the deployment in the final scenario, a Proof-of-Concept (PoC) has been developed in the Fivecomm office to test the viability of the final iNGENIOUS use case. This PoC consists of a Unity3D application that integrates the haptic gloves and the MR headset into the immersive cockpit and communicates with the AGV via 5G.

As Figure 3. (1) Varjo XR3, (2) Sensorial XR, (3) Windows PC, (4) Linux Server, (5)(6) 5G Modems. showsFigure 3. (1) Varjo XR3, (2) Sensorial XR, (3) Windows PC, (4) Linux Server, (5)(6) 5G Modems., the user is equipped with a pair of Varjo XR3 glasses and one Sensorial XR haptic glove. These are both cutting edge, premium devices despite being limited for a wired connection. The sensorial XR unique feature is the fact that the four conductive zones allow to carry out gestures, whereas the haptic capabilities are provided by ten vibrotactile actuators. On the other hand, the Varjo XR3 include passthrough cameras that enable the combination of VR and AR to create immersive MR environments.

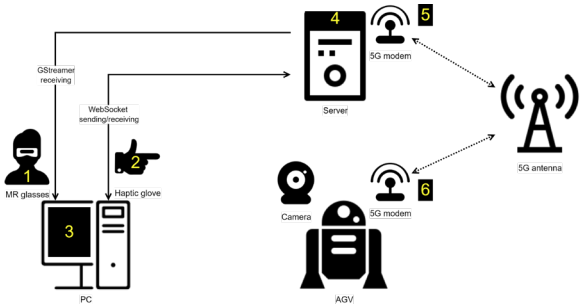

Figure 3. (1) Varjo XR3, (2) Sensorial XR, (3) Windows PC, (4) Linux Server, (5)(6) 5G Modems.

Both the glove and the HMD are controlled by a Unity3D application that communicates with the robot through an intermediary server. The aim of using two computers is that the second acts as the MEC in the near future, reducing the required computational power both in the user and in the AGV.

The UL communication only involves the specified gesture, whereas in DL the cockpit receives haptic and visual feedback from the AGV peripherals. The Unity3D application mixes a synthetic rendered scenario with real time video captured from the AGV camera which is streaming RTP H.264 video. The telemetry received from the AGV is handled by the same application for rendering visual information and creating haptic sensations. Depending on the minimum distance detected by the AGV laser, a haptic vibration is activated in the glove, the more intense the closer is the obstacle to the AGV.

The robot employed is the model RB1 Base manufactured by Robotnik. It is an AGV designed for autonomous logistics in indoors environments, but it is also used for testing or R&D applications due to its compact dimensions (515 mm of diameter and 303 mm of height). Up to 50 kg of cargo can be transported and a maximum speed of 1.5 m/s can be reached, supported by two motor wheels and three omni wheels. The motor wheels have a power of 250 W each, whereas the omni wheels are in charge of providing stability. The robot can detect obstacles from both a RGB-D sensor (depth sensing camera) and a laser sensor used for navigation and positioning. The 2D laser gives a 270° vision range and detects obstacles located at a height of 195 mm from the ground. When an obstacle is at a distance of 1 m, the robot looks for an alternative route if possible or otherwise stops. For smooth H2M interaction, Fivecomm has equipped the AGV with a humanoid torso that contains a display and two more RGB-D cameras. The display has not been used since it is not necessary for teleoperation, whereas the camera selected to be streamed has been the upper one due to a better placement, at a height similar to human head. RB1 Base is controlled by native ROS over an embedded Linux PC.

ii. Performance evaluation

A series of 4G and 5G measurements have been performed to test the current viability of the iNGENIOUS use case. The average network latency obtained has been 36.11 ms via 5G and 63.61 ms via 4G, whereas the average DL throughput measured has been 392.5 Mbps via 5G and 37.75 Mbps via 4G. On the other hand, the average E2E latency via 5G has been measured for both video streaming and gesture control, obtaining 240.71 ms and 880 ms respectively. These values far exceed the requirements due to a lack of optimization especially on the application since it represents half the E2E delay for both video and control.

b. 5G-INDUCE testbed in the Ford factory

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

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

The 5G-INDUCE experimentation facilities (ExFas) are deployed with the goal to validate and showcase over a real industrial 5G environment the developed NetApps. Three ExFas are envisioned Spain, Italy, and Greece, all linked with

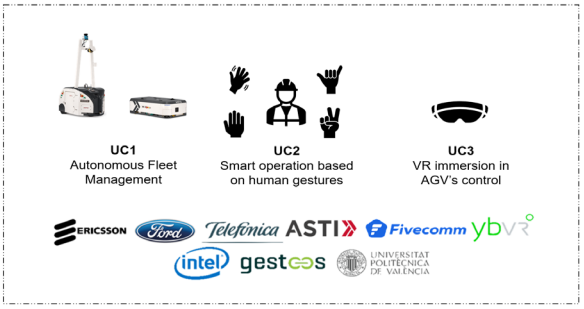

Figure 4. 5G-INDUCE Spain use cases

large industrial facilities (Ford, Whirlpool and PPC respectively) while being supported by advance 5G infrastructures, this document will focus on just in the Spain experimentation facility in Ford. The overall purpose of the adopted ExFa sites is to address actual Industry 4.0 needs in a diverse set of industrial environments, showcasing the beneficial use of 5G technology in terms of latency, optimized interoperability and management, security, and safety.Figure 4. 5G-INDUCE Spain use cases shows the three UCs that will be tested to achieve a higher level of automation and increase human-machine iteration.

The mobile communications group oversees the developing the second use case of the project, alongside with Fivecomm. The objective is the AGVs to recognize some defined human gestures and perform a specific action, improving the

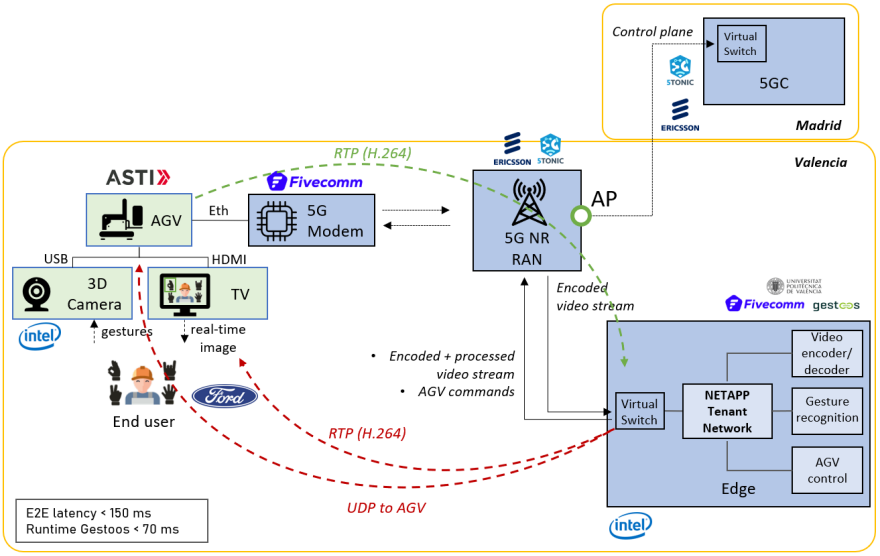

Figure 5. Second use case architecture

human machine interaction. The goal is to enable the transport robots to stop, continue or go to specific points of a route, apart from an ON/OFF listening mode.

This recognition is performed by the Gestoos software, that provides different tools to enable developers to capture several human gestures and work with them to execute different functions, depending on their applications. This is a powerful algorithm as it enables to communicate with machines with a zero-touch approach, making the communication intuitive, more secure, and easier. This tool works with a camera that receives the video stream from the user and runs its algorithm to detect some early predefined and trained gestures.

The Figure 3 shows the second use case architecture. The information will go from the industry operator to the Edge where the command will be sent back, Figure 16. The industry operator makes a gesture, this gesture is recognized by the camera. The AGV, located in the experimentation facility of Ford, receives the /depth and gesture info from the 3D (3 dimensional) camera placed in the AGV. The 5G modem, connected to the AGV will send the video stream encoded using H.264 and RTP (Real-time Transport Protocol) protocol to the edge. In the edge, the video will be decoded to process it (frame by frame). The algorithm detects the gesture and selects the different commands to be sent to the AGV. The raw processed video from the 3D camera will be encoded again using H.264 and RTP to be sent back to the AGV (UDP command). The AGV will move, stop, or change its direction depending on the worker's order.

ii. Proof-of-Concept implementation

Fivecomm, an SME created to implement 5G solutions into industry verticals to give a speed up to the 5G research and development projects, was a vital contributor to this work. An early prototype was developed before the final deployment in Ford, so the network functions and the software development kits were tested, along with the main components of the architecture to serve as a proof of concept.

The developed prototype in Figure 6 consisted of two main parts. The first involves the AGV equipped with an Intel Realsense camera to detect the user gestures. This AGV has also a screen to provide feedback to the user with the performed commands and the action that will perform the robot. The other part is the server, acting as an Edge in charge of all the computation power, including the encoders/decoders and the gesture software. Both AGV and server are connected to the network through CPEs, allowing the full E2E communication.

The video captured by the camera is sent from the AGV to the sever through an RTP protocol encoded in H264. Once the video is at the sever, it is decoded and processed by the gesture recognition algorithm, that modifies the video including a feedback interface for the user. The modified video is encoded again and sent back to the AGV together with the control command for the robot, ordering it to perform a specific action.

The developed integration scope consists of sending the AGV to specific points of a previously defined route, and the ability to stop/resume the route on its way. Besides, the AGV has a listening mode, so while it is in OFF, the AGV does not respond to any gesture made (the feedback screen shows in which mode is the AGV). This was thought as a security feature to avoid false

detections.

Some considerations about the integration are, for example, the fact that if the robot is waiting for a command and we send the stop command, even if we send the order to follow a route the robot will not move unless a continue command is sent to it.

5. Conclusions

5G has driven the industry's global economic growth. This mobile technology increases connection speed, minimizes latency, and exponentially multiplies the number of connected devices. Combining 5G with other technologies such as Edge, Cloud computing and virtual reality increases its advantages.

The Gestoos software, core of the use case, needs more optimization to reach the desired latencies and include critical factors like enabling perfect detections with any kind of gadgets like glasses or gloves. Nowadays this software is perfect for demos, prototypes, or single user purposes, but it has a long way to run to fully adapt it to industrial environments, that require a 100% reliability. The

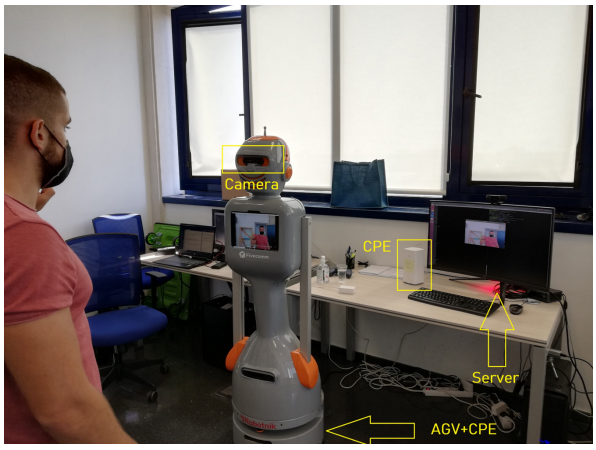

Figure 6. Second use case developed prototype

core code of the software is the critical factor in terms of E2E latency, so it needs to be optimized before entering other factors like the network, that has proven not to be the most critical factor in this integration.

As for the testbed in Valencia port, it has been demonstrated that current 5G eMBB networks improve the performance of 4G, but they do not get close to the strict latency requirements of Tactile Internet. It is expected that the installation of a mm-wave antenna compliant with URLLC will reduce network latency, but the target of 1 ms will be hard to met. Nevertheless, the network latency is negligible in comparison to the E2E latency. The obtained results show that the developed application needs further optimization specially in the AGV control, since a delay of 880 ms makes unfeasible the deployment in the Valencia port, where a real time response is needed. However, this is an innovative use case with a lot of work left, so future lines will focus on reducing latency and improving the functionalities, reaching higher levels of immersion.

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Antennas and Propagation Lab (APL)

HEAD OF THE GROUP RESEARCH REPORT

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

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

1.- Project activities

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

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

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

1.1.- Ongoing projects

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

Funding entity and duration: Ministerio de Economia, Industria y Competitividad, 2018-2021.

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

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

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

RECOMM: REconfigurable antennas for mm-wave broadband COMMunications

Funding entity and duration: Proyecto PID2019-107688RB-C22 de la Agencia Estatal de Investigación (MCIN/ AEI/10.13039/501100011033), 2020-2022.

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

(a)

(b)

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.

The development of antennas for satellite communications in Ka-band, valid for trains or airplanes, represents a great technological challenge that has not yet been effectively solved by the industry. Very low profile antennas must meet very demanding specifications in terms of gain, secondary lobes, high purity circular polarization, and dual band operation. To these requirements must be added a high degree of reconfigurability, since they must be able to switch polarization in addition to pointing the beam dynamically towards the satellite to compensate for the movement. Also, the deployment of the emerging 5G demands reconfigurable multibeam antennas capable of serving several users simultaneously.

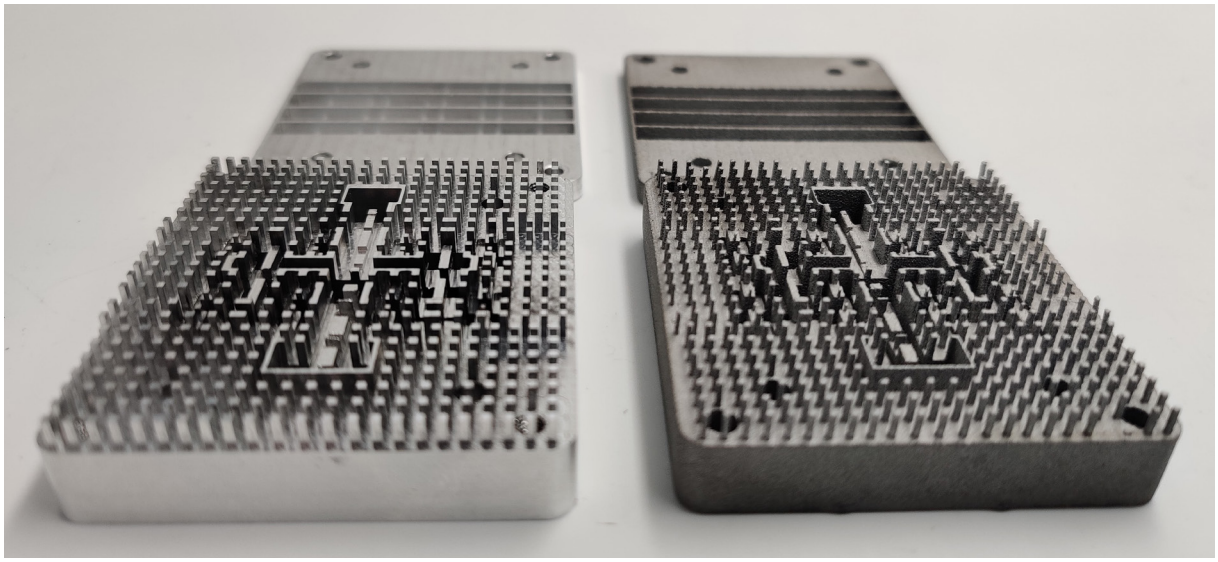
This project addresses the development of new antenna concepts in the millimeter band capable of meeting the demanding needs of these communication systems. Special attention is paid to highly efficient antennas, dual in polarization and / or frequency and capable of reconfiguring their radiation pattern.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

Project MUMSYS: MUltimode and Multibeam reconfigurable x-wave antennas for communication and sensing SYStems.

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

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

1. Multibeam and mutimode antennas for the sub-6 GHz band: Different models of antennas will be designed using the Theory of Characteristic Modes. The antennas will be integrated into devices such as bracelets, key chains, clothing or other small devices, with low ECC coefficient for the new 5G and ISM bands. The new antennas will exhibit reconfigurable capability and will

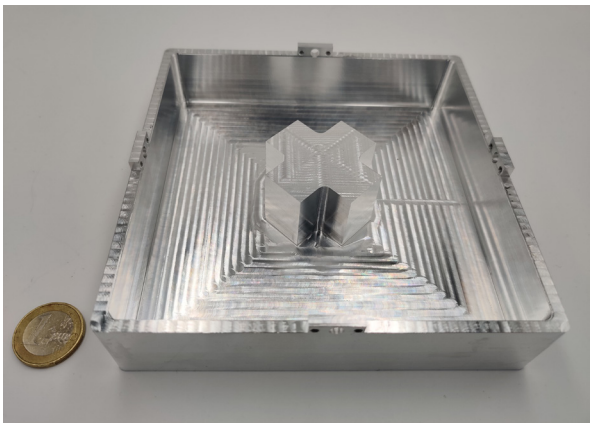


Layer of the manufactured prototype of a dual-band single-layer slot array antenna fed by K/Ka-band dual-mode resonators in Gap Waveguide Technology.

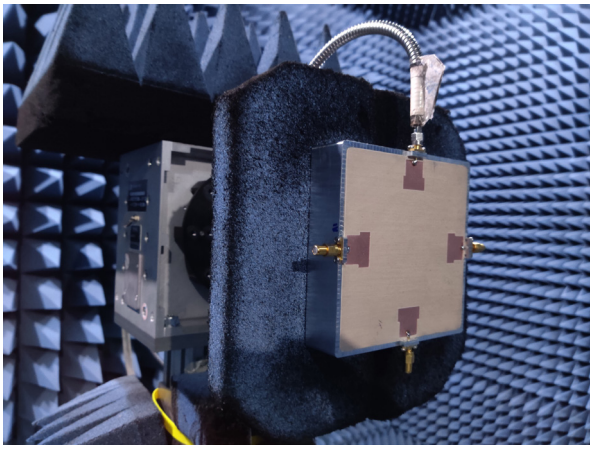
be developed for Internet of Things (IoT), communications and human body sensing applications. New fabrication methods such as conductive inks, metal deposition on plastic 3D prototypes, or metal embroidery on fabrics will be explored as a low-cost alternative to classical microstrip technology. Low Temperature CoFired Ceramic (LTCC) technology will be also used for multi-sensor wireless systems and IoT applications, where compact reconfigurable antennas of very small size that can be easily integrated into printed circuit boards are required. Equipment obtained through the Valencia International Campus of Excellence will be used for manufacturing LTCC circuits.

2. Planar metallic lenses for reconfigurable multibeam mm-wave indoor low-cost 5G base station: A planar lens with low cost single metallic layer will be designed. The reconfigurable beam characteristic of the base station will be obtained by switching the feeding in different positions. A prototype will be fabricated and characterized at UPV and channel measurement will be performed at UPCT. In addition, new reconfigurable antennas based on multiple coupled resonators will be proposed and analyzed using the Theory of Characteristic Modes.

3. New beam-forming networks, antenna switching and control for multi-beam applications: Complete systems will be developed to determine the angle of arrival of the waves to the base station. The antenna, that will be designed at UPV, will be an array of apertures, slots or notches with a specific beamforming network, designed using UPC designed planar transmission lines. The array will consist of multiple antennas, a time-multiplexed feeding network and electronics based on the new standards.



(a)



(b)

(a) Prototype of a four-port wide-band cavity-backed antenna for a sub-6 GHz 5G indoor base station measured in the anechoic chamber; (b) View of the isolating X-Shaped block in the square cavity.

2. Research results

2.1.- Featured publications

1. **True-Time-Delay Mechanical Phase Shifter in Gap Waveguide Technology for Slotted Waveguide Arrays in Ka band**, D. Sánchez-Escuderos, J.I. Herranz-Herruzo, M. Ferrando-Rocher, A. Valero-Nogueira, *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 5, pp. 2727-2740, May 2021, **DOI:** 10.1109/TAP.2020.3030993.

   A novel all-metal mechanical phase shifter in gap waveguide technology is proposed to provide beam-scanning capabilities to conventional slot array antennas along the elevation plane. To validate experimentally the beam-steering functionality, a 4x8 slot-array antenna has been designed and fabricated, along with the phase-shifting mechanism.

2. **Dual-Band Single-Layer Slot Array Antenna Fed by K/Ka-Band Dual-Mode Resonators in Gap Waveguide Technology,** M. Ferrando-Rocher, J.I. Herranz-Herruzo, A. Valero-Nogueira, M. Baquero-Escudero, *IEEE Antennas and Wireless Propagation Letters*, vol. 20, no. 3, pp. 416-420, March 2021, **DOI:** 10.1109/LAWP.2021.3054408.

   A 4 × 4 single-layer dual-band array antenna operating in the K- and Ka-band using gap waveguide (GW) technology is proposed. The antenna presents two ports, one for each band, and radiates a directive far field pattern with linear polarization. A diplexer is integrated as part of the network to separate both working bands.

3. **Selective Laser Sintering Manufacturing as a Low Cost Alternative for Flat-Panel Antennas in Millimeter-Wave Bands,** M. Ferrando-Rocher, J. I. Herranz-Herruzo, A. Valero-Nogueira and B. Bernardo-Clemente, *IEEE Access*, vol. 9, pp. 45721-45729, 2021, **DOI:** 10.1109/ACCESS.2021.3067637.

   In this paper, the capabilities of Selective Laser Sintering metal 3D-Printing technology to achieve a lightweight and cost-effective flat panel antenna in the millimeter wave band are studied. Measured performance of an SLS antenna prototype is benchmarked with the performance of the previously measured CNC antenna. Experimental results reveal the strengths and weaknesses of this particular low-cost additive manufacturing technique with respect to traditional subtractive manufacturing techniques.

4. **Four-Port Wide-Band Cavity-Backed Antenna With Isolating X-Shaped Block for Sub-6 GHz 5G Indoor Base Stations,** J. Molins-Benlliure, E. Antonino-Daviu, M. Cabedo-Fabrés and M. Ferrando-Bataller, *IEEE Access*, vol. 9, pp. 80535-80545, May 2021, **DOI:** 10.1109/ACCESS.2021.3084852.

   A four-port wideband cavity-backed antenna is presented for indoor base stations applications. The antenna is composed of a square open cavity with an X-shaped isolating block and 4 feeding monopoles symmetrically and orthogonally arranged in the aperture of the cavity. A novel methodology based on Characteristic Modes Analysis (CMA) is used for identifying the modes, which are contributing to the coupling. As a result of this analysis, an X-shaped isolating block placed at the center of the cavity is proposed for increasing the isolation between ports. A wide-band four-port antenna with unidirectional radiation patterns is obtained with a measured impedance bandwidth (S11<-10 dB) ranging from 1.55 to 6 GHz (118%), covering most of the sub-6 GHz 5G bands. The proposed antenna provides four independent radiation patterns, with 16 dB of measured minimum isolation between ports and an efficiency higher than 84%. Multiple-input multiple-output (MIMO) compatibility is confirmed with a 4x4 MIMO simulated system with an envelope correlation coefficient (ECC)<0.5 in different propagation conditions. The antenna is easy to fabricate and presents a compact size of 129.5 x 129.5 x 28.2 mm^3 (0.68λ x 0.68λ x 0.15λ, at a frequency $f=f_{min}$=1.55 GHz). Moreover, the antenna has the advantage of avoiding complex feeding structures with baluns or directional couplers.

5. **Radiation Pattern Reconfigurable Antenna for IoT Devices,** Z. Mahlaoui , E. Antonino-Daviu and M. Ferrando-Bataller, *International Journal of Antennas and Propagation*, vol. 2021. **DOI:** 10.1155/2021/5534063.

   This paper proposes a versatile radiation pattern reconfigurable antenna based on the characteristic mode theory. The analysis starts from two parallel metallic plates with the same and different dimensions. By means of two PIN diodes, the size of one of the parallel metallic plates can be modified and consequently the behavior of the radiation pattern can be switched between bidirectional and unidirectional radiation patterns. Moreover, a SPDT switch is used to adjust the frequency and match the input impedance. The reconfigurable antenna prototype has been assembled and tested, and a good agreement between simulated and measured results is obtained at 2.5 GHz band, which fits the IoT applications.

Multimedia Communications Group (COMM)

HEAD OF THE GROUP RESEARCH REPORT

The history of the Multimedia Communications Group (COMM) started in 2004, and nowadays 5 researchers belong to this group. The main research lines are always involving multimedia systems and Quality of Experience (QoE) topics. During the last year 2020/2021 the group has continued with its work lines focused on the distribution of multimedia content using protocols like Dynamic Adaptive Streaming over HTTP (DASH) and studying low latency variants; carrying out more in-depth studies and developments related to the Internet of Things (IoT), specifically about Smart Cities and other projects based on the collection of data from monitoring devices and developing specific dashboards for visualization; analysing and proposing new metrics for estimating the QoE; and developing new functionalities for multimedia systems based on DRM and cross-layer techniques.

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

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

1.- Project activities

Internet of Things and Smart Cities

Smart cities entail a combination of people, technology and strategies that makes the city more sustainable regarding strategic pillars, such as mobility, health or energy. For this to be feasible, the application of Internet of Things (IoT) is a key factor to improve the life of citizens. IoT technologies comprise sensors to acquire data but are not limited to that. For a full comprehension of IoT applied to Smart Cities, a wider vision is needed, including data storage, analysis and presentation. Data can be collected with sensors, but this data must be processed and analysed in order to be transformed into information. Afterwards, citizens and city managers need an assortment of tools to manage this information to take advantage and transform it into knowledge. It is only with this full path when data can be transformed into knowledge and be fully profitable, and this should be the focus of a modern Smart City.

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

Monitoring of information in real-time

Following the footsteps from previous years, we have delved into applications for monitoring in real-time information collected from sensors. The objective is to develop solutions that, apart from collecting and processing data in real-time, display information neatly in order to allow users to consult this data in a clear and simple way. For this purpose, we have joined forces with other groups in the iTEAM and other UPV spin-off.

Particularly, we have been working in a monitoring tool to collect, analyse and present data obtained from optical sensors installed in several railway bridges. All the gathered information serves as deep knowledge to understand the forces applied to the bridge when trains come over, and more important, this data is used to trigger alarms when a weakness is detected in any of these bridges.

Also related to monitoring activities, we have been working in a project with the aim of monitoring asphalt condition to determine the deterioration of the road. Optical sensors installed beneath the asphalt send signals to the monitoring device. These signals are analysed and presented in dashboards for the future study. All of this is very useful in the early detection of road faults.

Audio and video synchronization in production systems

Last year, we developed an application to carry out an automatic realization of a recording in real-time. This year, this tool has been tested in real scenarios, such as city council plenary sessions, where the application detected the active microphones in each instant of time and, considering certain parameters as the number of cameras or the refreshing time, decided which camera should be on air. The tests have been very successful and this year we focus on develop new improvements to the application, adding further

Dashboards for bridge sensor monitoring

compatibility to new microphone brands and systems and starting a mobile app development to manage the production system from a smartphone.

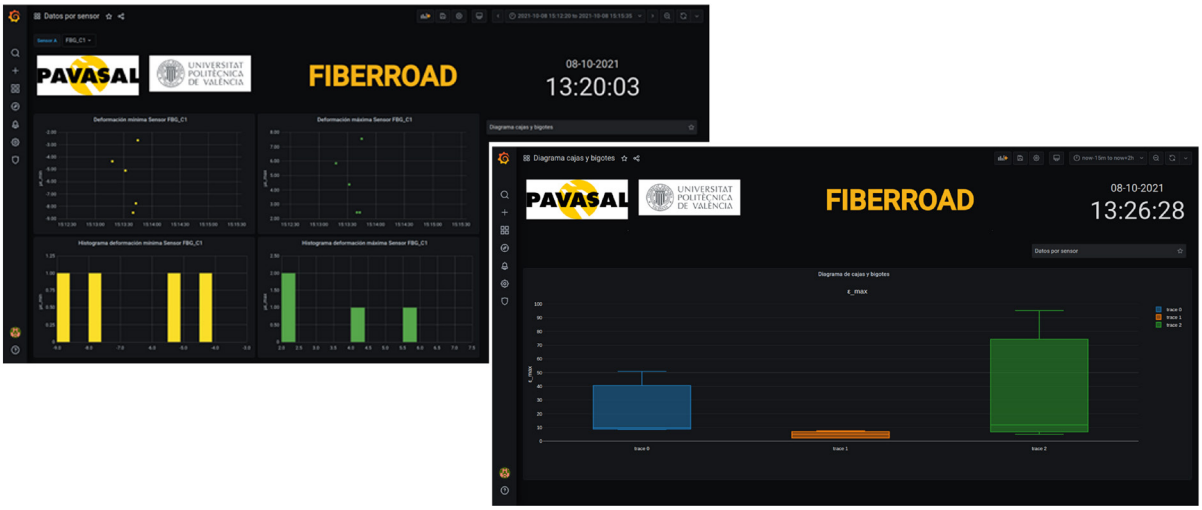
1.1.- Ongoing projects

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

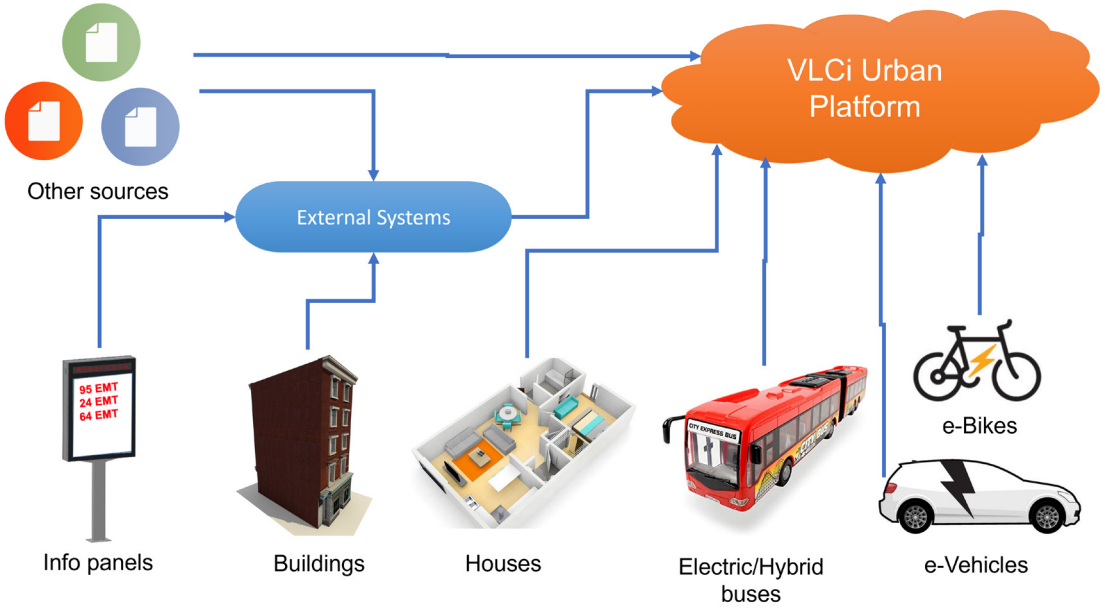
Webpage of the project: http://www.matchup-project.eu

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

Summary of the project: *The project aims at strengthening the planning processes for urban transformation, consolidating the benefits of deploying large scale demonstration projects of innovative technologies in the energy, mobility and ICT sectors, by means of substantially improved models for replication and upscaling, based on impacts evaluation, and ensuring the bankability of the solutions by means of innovative business models, which lead to achieve real deployment further than the pilots carried out in the lighthouse cities. With this, it is sought a high penetration of the validated technologies in those cities less prepared to adopt very innovative solutions and formalize it in a standard commitment, accompanied by capacity building strategies, to guarantee*



Fiber road sensors monitoring in real-time



MAtchUP architecture and data flow

at least medium-term implementation. The project started in October 2017, with an expected duration of five years. COMM focuses on actions related to ICT.

As sensor installation progresses, more and more types of sensors have been tested and included in the data flow of the urban city platform. New sensors and devices installed include energy consumption, comfort, energy storage, energy generation, energy accumulation, smart controller, electrical bus data, hybrid bus data, electric bike data and electric vehicle data. Data collected from the IoT devices in several project interventions is being stored in the urban platform database. Hence, additional devices and services have been monitored such as eBikes, electric and hybrid buses, and also from services such as modal information in multimodal hubs and status of the deployed charging stations.

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

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

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

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

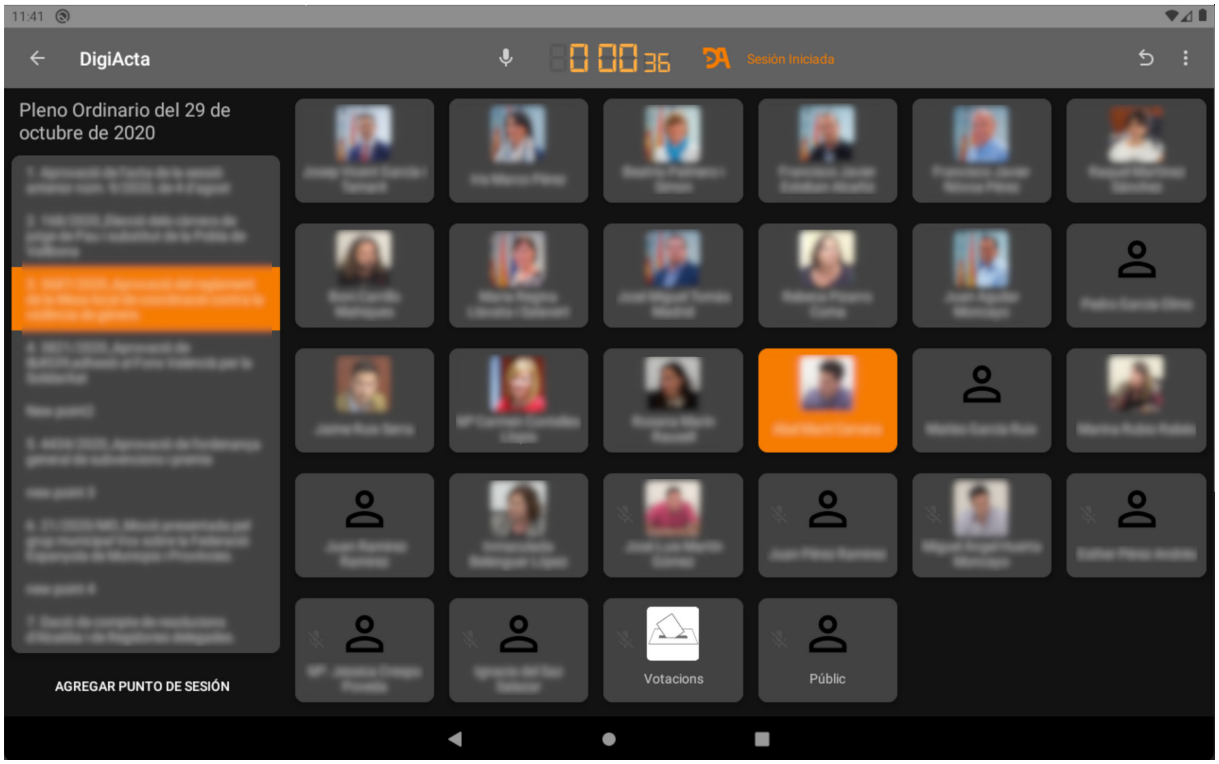
The main novelty of this solution is that it allows an automated and unattended management of the production process, i.e., without requiring a dedicated person to carry out the realization of the different shots that make up the video. Also, by enabling the generation of timestamps of the video recording,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

2.- Research results

2.1.- Featured publications

FIWARE based low-cost wireless acoustic sensor network for monitoring and classification of urban soundscape. P. Arce, D. Salvo, G. Piñero, A. Gonzalez. Computer Networks, vol. 196, article 108199, doi https://doi.org/10.1016/j.comnet.2021.108199, 2021.

This work presents a wireless acoustic sensor network (WASN) that monitors urban environments by recognizing a given set of sound events or classes. The nodes of the WASN are Raspberry Pi devices and the classification task is carried out by a convolutional neural network (CNN). Regarding the underlying WASN, it has



Automatic video production system

been designed according to the open standard FIWARE, which was developed to create a smart and open solution for sensor network. Therefore, the whole system can be deployed without the need of proprietary software.

A Low-cost Wireless Acoustic Sensor Network for the Classification of Urban Sounds. D. Salvo, G. Piñero, P. Arce, A. Gonzalez. Proceedings of the 17th ACM Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks (PE-WASUN'20), November 16–20, 2020, Alicante, Spain. Pp 49-55, doi https://doi.org/10.1145/3416011.3424759, 2020.

We present in this paper a wireless acoustic sensor network (WASN) that recognizes a set of sound events or classes from urban environments. The nodes of the WASN are Raspberry Pi devices that not only record the ambient sound, but they also process and recognize a sound event by means of a deep convolutional neural network (CNN). We propose to introduce a pre-detection stage prior to the CNN classification in order to save power consumption. Experimental results have been carried out in the city of Valencia, achieving a six-times reduction of the Raspberry Pi CPU's usage due to the pre-detection stage.

Look ahead to improve QoE in DASH streaming. R. Belda, I. de Fez, P. Arce, and J. C. Guerri, Multimedia Tools and Applications, vol. 79, pp. 25143-25170, 2020.

When a video is encoded with constant quality, the resulting bitstream will have variable bitrate due to the inherent nature of the video encoding process. This paper proposes a video Adaptive Bitrate Streaming (ABR) algorithm, called Look Ahead, which considers this bitrate variability in order to calculate, in real time, the appropriate quality level that minimizes the number of interruptions during the playback. The algorithm is based on the Dynamic Adaptive Streaming over HTTP (DASH) standard for on-demand video services. The evaluations presented in the paper reflect: first, that Look Ahead outperforms other ABR algorithms in terms of number and duration of video playback stalls, with hardly decreasing the average video quality; and second, that the two Quality of Experience (QoE) models proposed are more accurate than other similar models existing in the literature.

Microwave Applications Group (GAM)

HEAD OF THE GROUP RESEARCH REPORT

Over the past year (September 2020 to July 2021), the group has continued working on two projects awarded with national and regional public funds, respectively. Both projects are in the middle of their whole execution periods, and they are beginning to show promising results.

In addition to these two projects, the group has also obtained national and regional public funding to hire new researchers and PhD students, who are already collaborating with the group in its different activities and present research lines.

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

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

Regarding to the training capacity of the group, it is worth mentioning that two doctoral theses have been successfully defended during the last year. Meanwhile, other pre-doctoral students continue developing their investigation with the supervision of group senior members. In some cases, and despite the situation derived from COVID19, our doctorate students have performed short-term research stages in centers of excellence on topics related to their PhD thesis works. It is hoped that with the improved situation we can continue sending students to carry out the planned stays, and to host several foreign students doing part of their research work together with us.

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

1.- Project activities

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

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

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

1.1.- Ongoing projects

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

Retos Investigación: Proyectos I+D+i 2019

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

The most relevant European satellite communication systems and applications are currently supporting a huge number of services

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

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

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

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

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

Prometeo – 2019

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

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

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

SELECTOR Project: SMT Compatible Electromechanical Relay for Compact Redundancy Ring

www.selectorspace.eu

Figure 1: SELECTOR Project Logo

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

SELECTOR project (funded as an H2020 Research and Innovation Action) is focused on the development of innovative passive components to increase the number of freely accessible space qualified passive components; thus, contributing

to the European policy about "Reaching non-dependence in certain technologies that will open new markets to industries and will increase the overall competitiveness of the European Space sector".

SELECTOR aims at developing Surface Mount Technology (SMT) compatible electromechanical switches for space sector high miniaturization. These devises called "Miniature Electro-Mechanical Relay" (MEMR), already exist for microwave industrial ground application like Automatic Test Equipment. SELECTOR will deliver MEMR as part of ESA portfolio European Preferred Part List (EPPL) so that this high integration, high performance passive component be available with non-restriction for the whole European industry. SELECTOR will also demonstrate a whole new approach of self-redundant microwave equipment called "Meta-equipment" based on microwave specific SMT board level assembly and MEMR components to minimize cost and improve integration. This demonstrator will address Very High Throughput Satellites (VHTS) emerging applications, where the new paradigm is the introduction of digital technologies dealing with very high number of RF chains. New evolution toward RF high power and high frequency capability will be implemented to open-up new sector of application within Space satellites (Navigation, earth observation), but also non-space sectors.

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

TESLA Project: Advanced Technologies for future European Satellite Applications

https://tesla-itn.hw.ac.uk/

Figure 2: TESLA Network Logo

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

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

To this end, TESLA ETN (European Training Network) will create a multidisciplinary research environment to develop the Advanced Technologies for future European Satellite Applications. It will set up collaborations with senior staff in academic and industrial sectors to conduct top research into new and enabling technologies for satellite flexible payloads, big constellation systems, satellite high-speed communications and remote sensing, as well as large satellite platforms. TESLA will also implement a unique research program, with the objective to push the next generation of creative, entrepreneurial and innovative satellite communication developers, to enhance the European space economy and business through outreach activities for a wider economic and social impact.

2.- Research results

As a result of the joint research activity developed by this group in its research lines, during the last year of activity, 14 articles have been published in scientific journals with a high impact index (such as IEEE Transactions on Microwave Theory and Techniques, IEEE Access, IEEE Microwave and Wireless Components Letters, IEEE Transactions on Antennas and Propagation, IET Proceedings on Microwave, Antennas and Propagation, IET Electronics Letters and Radio Science).

At the same time, and despite restrictions due to the pandemic, the group has presented up to 6 scientific communications in prestigious international conferences (such as the 2020 European Microwave Conference -EuMC-, the 17th European Radar Conference and the XXXV Simposium Nacional de la Unión Científica Internacional de Radio -URSI-), most of them in on-line format.

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

2.1.- Featured publications

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

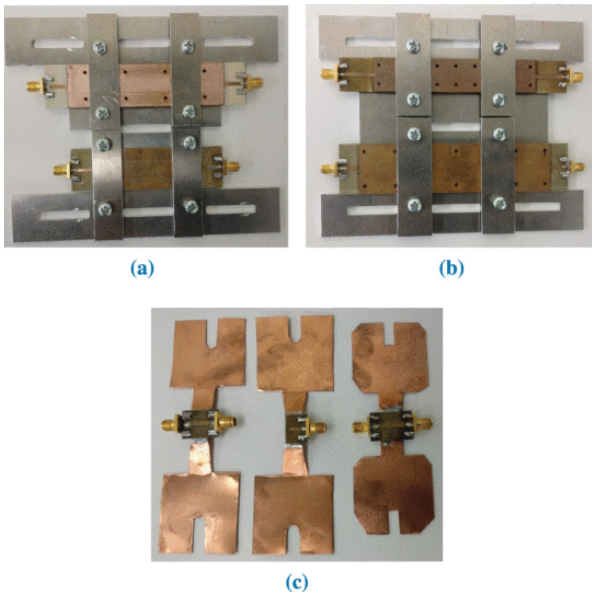


Figure 3: (a) ADLS and SIW filters on aluminium jigs, (b) ESIW and ESICL filters on aluminium jigs, and (c) TRL CalKit elements on copper thermal bridge

Thermal Stability Analysis of Filters in Substrate Integrated Technologies Under Atmospheric Pressure and Vacuum Conditions, Vicente Nova, Carmen Bachiller Martin, Juan Angel Martínez, Héctor Esteban González, José Manuel Merello, Ángel Belenguer Martínez, Oscar Monerris, Vicente E. Boria, IEEE Access, vol. 8, pp. 118072 - 118082, Jun. 2020 Q1

In this work the same filter is implemented on four different Substrate Integrated technologies (including completely and partially filled with dielectric, as well as empty - no dielectric - versions). The four filters are designed, manufactured, and measured at different temperatures according to the thermal testing standards for space applications. The thermal study is performed under atmospheric pressure conditions and, for the first time, under high vacuum conditions.

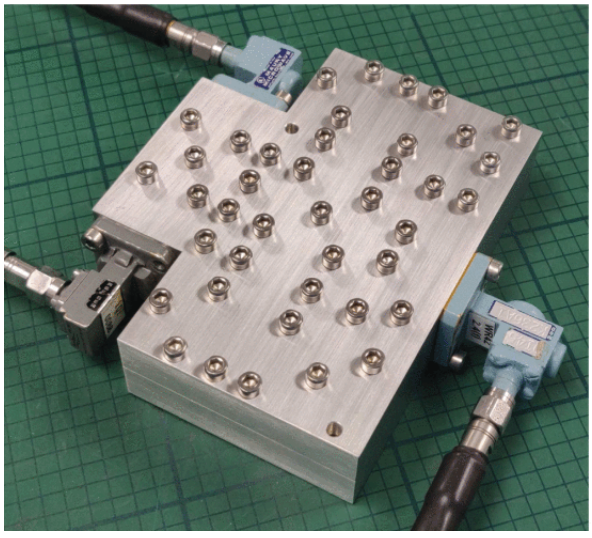


Figure 4: Diplexer breadboard

Waveguide Quadruplet Diplexer for Multi-Beam Satellite Applications, Javier Ossorio García, Juan Carlos Melgarejo Lermas, Santiago Cogollos, Vicente E. Boria, Marco Guglielmi, IEEE Access, vol. 8, pp. 110116 - 110128, Jun. 2020 Q1

The objective of this paper is to describe the design of an innovative low-cost diplexer for Ka-band multi-beam satellite applications. The device is based on the use of two quadruplets to implement several transmission zeros (TZs) thus obtaining high-selectivity quasi-elliptic transfer functions. The resulting diplexer is particularly flexible in terms of layout, does not require tuning and has an excellent high-power behaviour. We also compare the simulations with the measurements obtained with a manufactured breadboard.

A New Family of Multiband Waveguide Filters Based on a Folded Topology, Juan Carlos Melgarejo, Santiago Cogollos, Marco Guglielmi, Vicente E. Boria, IEEE Transactions on Microwave Theory and Techniques, vol. 68, issue 7, pp. 2590 - 2600, May 2020 Q1

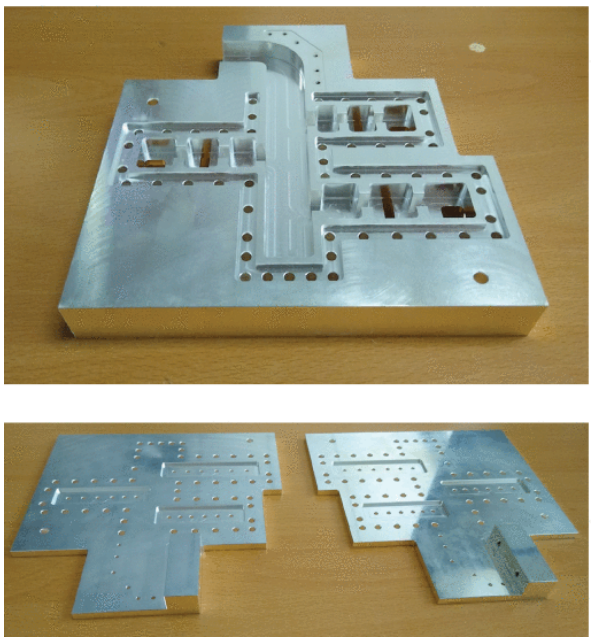


Figure 5: Top: body of the triband filter. Bottom: top and bottom covers of the filter

A new family of multiband waveguide filters based on a folded topology is described. The design of the multiband filter is based on the aggressive space mapping (ASM) technique and can consider manufacturing details, such as round corners and tuning elements. The structure is validated by designing, manufacturing, and measuring a triband filter. The agreement between simulations and measurements is shown to be excellent, thereby validating both the filter topology and the design process.

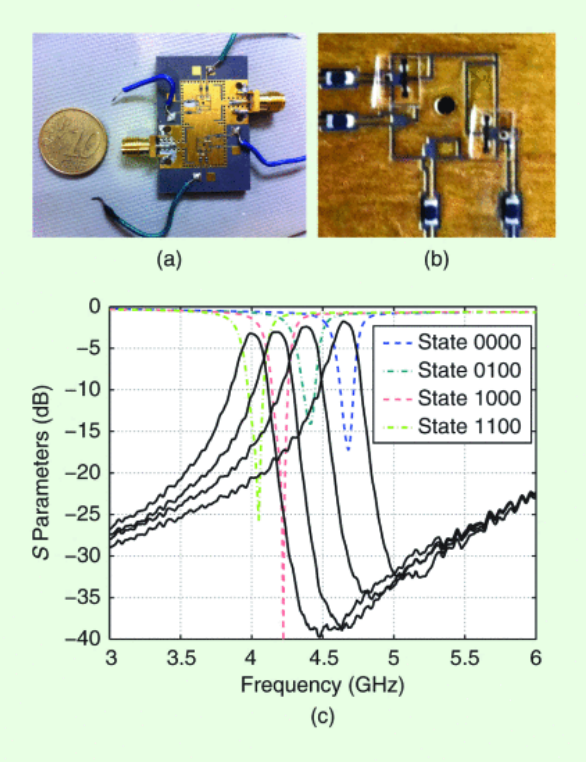


Figure 6: (a) The discretely tunable filter with four assembled RF MEMS resistive switches. (b) A close-up image of the MEMS assembly on one resonator. (c) The preliminary measurements for the four frequency states.

When Compactness Meets Flexibility: Basic Coaxial SIW Filter Topology for Device Miniaturization, Design Flexibility, Advanced Filtering Responses, and Implementation of Tunable Filters, Jorge Daniel Martinez, Stefano Sirci, Vicente E. Boria, Miguel Angel Sanchez-Soriano, IEEE Microwave Magazine, vol. 21, issue 6, pp. 58 - 78, May 2020 Q2

Optimized SIW filters can reach a Q factor of 200-800 using low-loss substrates and standard fabrication procedures. Furthermore, packaging and electromagnetic (EM) shielding, power-handling capabilities, and low-cost batch manufacturing are other broadly recognized strengths of this approach. However, SIW filters are still larger than most of their planar counterparts; in addition, advanced topologies are not always easy to accommodate, and filter reconfigurability usually leads to very complex implementation. In this work, a more compact solution based on the novel coaxial SIW topology is successfully used for the implementation of several filters.

Microstrip to Ridge Empty Substrate-Integrated Waveguide Transition for Broadband Microwave Applications, David Herraiz, Héctor Esteban, Juan Angel Martínez, Angel Belenguer, Vicente Boria, IEEE Microwave and Wireless Components Letters, vol 30, issue 3, pp. 257 - 260, Feb. 2020 Q1

The empty substrate-integrated waveguide (ESIW) is of low cost and low profile and can be integrated into a printed circuit board. To increase the operational (monomode) bandwidth of the rectangular waveguides, a metal ridge can be inserted (leading to the ridge waveguide). Extrapolating this idea to the ESIW, a study of possible ridge ESIW (RESIW) geometries has been performed, and a novel transition from microstrip line to RESIW is proposed.

2.2.- Patents

During this year the following patent has been registered:

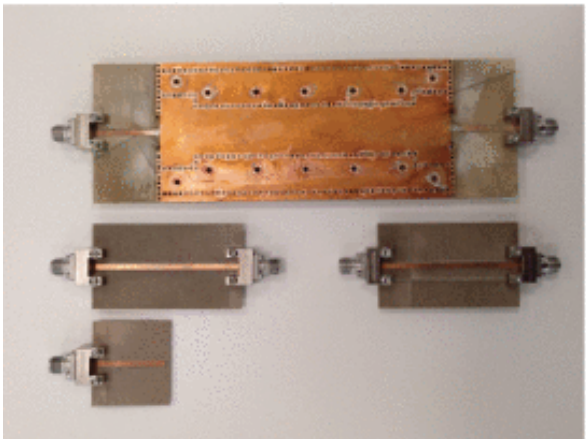
Marco Guglielmi, Vicente E. Boria

Dielectric Tuner

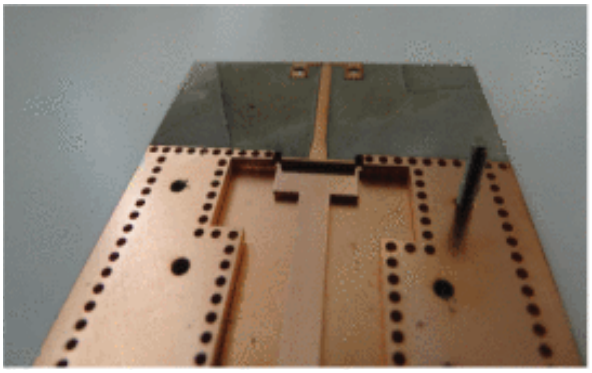
Pub. No.: P202030640

Pub. Date: 25/06/2020

National concession date: 02/02/2021



(a)



(b)

Figure 7: Back-to-back manufactured prototype. (a) TRL calibration kit and assembled prototype (b) Detailed view of transition

Audio and Communications Signal Processing Group

HEAD OF THE GROUP RESEARCH REPORT

The Audio and Communications Signal Processing Group (known by their acronym GTAC from its Spanish name Grupo de Tratamiento de señal en Audio y Comunicaciones) has developed its research during the scholar year 2020-21 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 relevant scientific journals and conference proceedings. In particular, the national projects "Dynamic Acoustic Networks for Changing Environments (DANCE)" and "Intelligent Spatial Audio Synthesis and Customization (ISLA-THESON)", which are in halfway through their completion,and the regional project "Smart Social Computing and Communication (COMTACTS)".

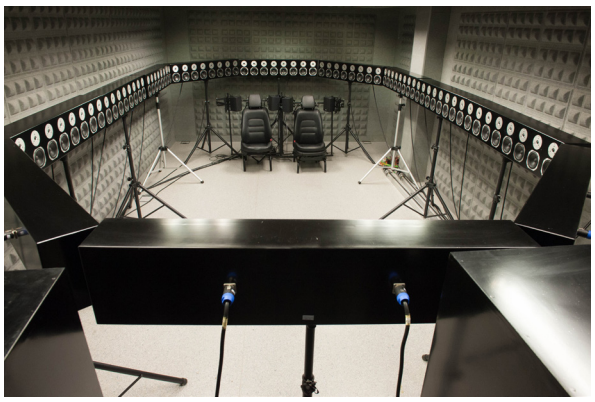


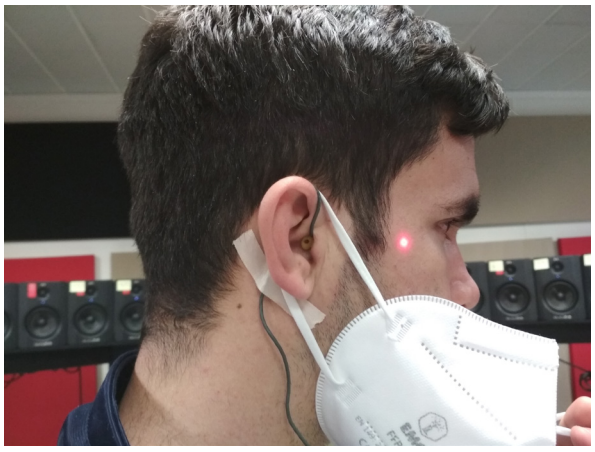
Figure 1. Listening room overview.

On the other hand, the Cátedra Telefonica-UPV project "Sound-Aided Smart Environments for the City, Home and Nature (SSEnCe)" has ended with great success, achieving their objectives by creating a demonstrator that allows detecting and classifying acoustic events, for home environments, Smart Cities and Natural parks. More details of the projects' achievements are shown at the "Ongoing Projects" section.

With regards to the GTAC audio facilities, it comprises two main audio laboratories. A large listening room of 40 m^2, totally equipped with audiovisual and control instrumentation (see Fig.1). This laboratory includes 96 loudspeakers to render an acoustic field over this large listening area. Moreover, car seats are placed in this room to create local quiet zones in enclosures (such as a cabin of a public transport) over a distributed network composed of acoustic nodes.

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

(a)



(b)

Figure 2. Acoustic measurements of the HRTF with miniature microphones inserted in the ears: a) General view of the perceptual spatial sound laboratory when an HRT is measured; b) Miniature microphone detail.

1.- Project activities

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

***Title*: DYNAMIC ACOUSTIC NETWORKS FOR CHANGING ENVIRONMENTS (DANCE)**

Webpage: www.dance.upv.es

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

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

The DANCE project includes the development of two testbeds in the GTAC audio laboratory. The first one employs sub-band filtering and optimized filter bank computation in the time domain for the design of personal sound zones (PSZ). The aim is to render a target soundfield in the "bright" zone while having control over the mean acoustic energy in the "dark" (quiet) zone (see Fig. 3). The PSZ system has been adapted and optimized according to the frequency content of the audio signals, the characteristics of the room and the typology and location of the transducers used. Examples are: watching TV and simultaneously listening to different languages

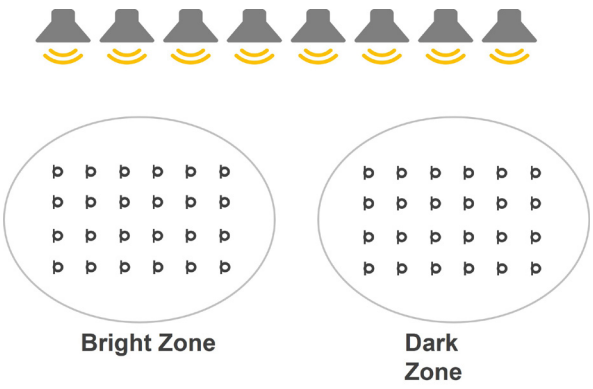


Figure 3. Layout of the PSZ system. Loudspeakers and microphone setup for the bright and dark zones.

in different positions, improving the listening experience in any room, tracking the listener over the home.

The second testbed consists in a massive multichannel noise reduction for open-plan offices. The aim is to reduce the annoyance caused by the ambient noise and speech produced by other workers in open working spaces through their masking with pleasant sounds. Masking implies directing a pleasant sound (such as waterfall, birdsongs, non-voiced music) to a certain zone, such that the pleasant sound makes the annoying noise almost inaudible in that area thanks to the masking properties of the human hearing system.

Figure 4. Masking system.

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

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

The sound industry has been experiencing profound changes in recent years under the perspective of three complementary approaches: the individual, the group and the contents. Due the advances in virtual reality, mobile devices, video games and innmersive 3D movies, the spatial audio is today a discipline that attracts the attention of the industry. In this context, spatial audio systems try to accurately recreate the acoustic sensations that a listener would perceive within a real listening environment. Moreover, the use of headphones has spread enormously, and the need to reproduce highly realistic spatial sound through them is a great opportunity for the industry. For a very immersive experience, the sound must be customized for each individual based on their anatomy, in particular the head and pinna shape, which define their particular Head-Related Transfer Function (HRTF). Measuring a subject's HRTF is still a costly process that requires specialized facilities and finding an indirect way to get individualized HRTF is required. At ITEAM, we have built a new facility to measure HRTFs of real subjects in an efficient way (Fig.2). By employing Deep Learning

techniques and photographs of the ear/head, we have achieved an HRTF personalization of better quality than previous methods. Previously, a new system has been constructed for the capture and extraction of individual anthropometric parameters from photographs. To this end, work is being done on the creation of 3D models through mobile devices that are equipped with depth cameras (see Fig. 5). The results obtained by combining both objective measurements (individual HRTF and anthropometric parameters) with deep learning techniques, can be evaluated by means of subjective perceptual tests. By using an individualized HRTF, we can generate a virtual sound indistinguishable from reality. This will in turn allow mobile devices to incorporate personalized responses for their direct application in 3D sound, virtual and augmented reality, video games, etc.

Figure 5. Creation of a 3D model for HRTF characterization.

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

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

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

Webpage: www.comtacts.upv.es

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

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

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

COMTACTS project considers the physical aspects of computing, signal processing, energy consumption, technology, communication, etc., particularly in distributed, collaborative scenarios where massive and heterogeneous data are provided. In this way, COMTACTS addresses the design, development and implementation of products, systems, programs and algorithms for signal processing and communications, which make use of state-of-the-art architectures, advanced computing and efficient communications within the framework of intelligent computing and communication aimed at tackling social challenges.

Title: SOUND-AIDED SMART ENVIRONMENTS FOR THE CITY, HOME AND NATURE (SSEnCe)

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

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

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

We have developed within the frame of the project a demonstrator of an environmental sound classificafier (ESC) of city sounds based on a wireless acoustic sensor network (WASN) whose nodes are low-cost devices and whose scheme is shown in Fig.6. The WASN recognizes a set of sound events or classes from urban environments. Their nodes are formed by Raspberry Pi devices equipped with outdoor microphones, and they not only record the ambient sound, but can also process and recognize a sound event by means of deep learning (convolutional neural network (CNN) model in Fig.3). In our WASN, the nodes send the resulting probability of every sound class to the server, so the data can be displayed in a map. Such WASNs have many advantages as monitoring system: they are cheap compared to other monitoring systems, they can be easily deployed, and they can work day and night. An additional advantage of our WASN is that uses the open standard FIWARE in their communication network, so the whole system can be replicated without the need of proprietary software or hardware. In order to obtain a classification model adjusted to the city of Valencia, a database that collects different clips related to traffic noise has been recorded in different locations of Valencia. This database called VLCSound, collects different audios that have been previously validated and labeled within the following classes: Traffic, Siren, Horn and Noisy. The goal is to continue increasing VLCSound database to have a robust classification model.

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

Affine Projection Algorithm Over Acoustic Sensor Networks for Active Noise Control. *Miguel Ferrer, Maria de Diego, Gema Piñero, Alberto Gonzalez, IEEE/ACM Trans. on Audio, Speech and Language Processing, vol. 29, pp. 448 - 461, 2020. DOI: 10.1109/TASLP.2020.3042590*

Abstract: Acoustic sensor networks (ASNs) are an effective solution to implement active noise control (ANC) systems by using distributed adaptive algorithms. On one hand, ASNs provide scalable systems where the signal processing load is distributed among the network nodes. On the other hand, their noise reduction performance is comparable to that of their respective centralized processing systems. In this sense, the distributed multiple error filtered-x least mean squares (DMEFxLMS) adaptive algorithm has shown to obtain the same performance than its centralized counterpart as long as there are no

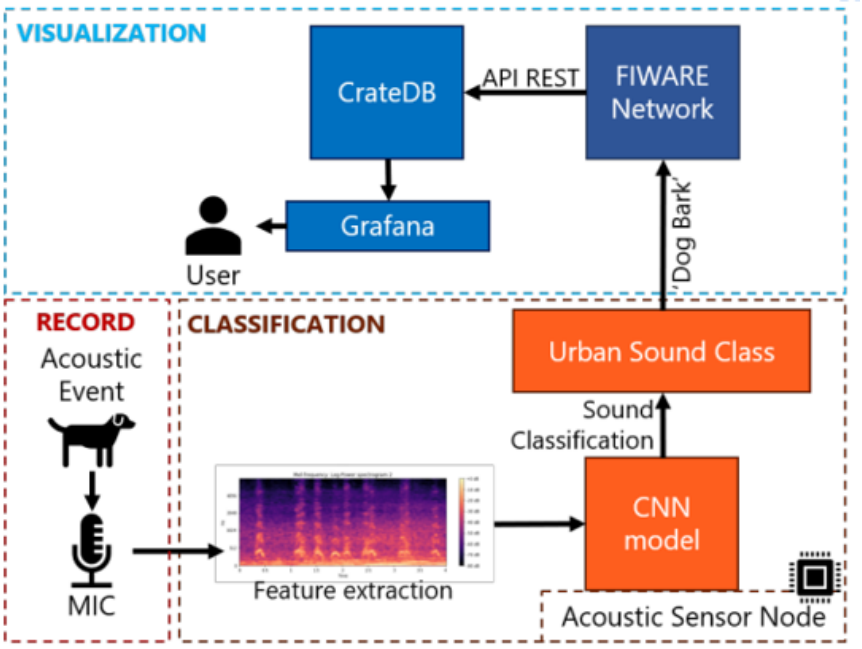


Figure 6. Scheme of the WASN used for cities' sound classification.

communications constraints in the underlying ASN. Regarding affine projection (AP) adaptive algorithms, some distributed approaches that are approximated versions of the multichannel filtered-x affine projection (MFxAP) algorithm have been previously proposed. These AP algorithms can efficiently share the processing load among the nodes, but at the expense of worsening their convergence properties. In this paper we develop the exact distributed multichannel filtered-x AP (EFxAP) algorithm, which obtains the same solution as that of the MFxAP algorithm as long as there are no communications constraints in the underlying ASN. In the EFxAP algorithm each node can compute a part or the entire inverse matrix needed by the centralized MFxAP algorithm. Thus, we propose three different strategies that obtain significant computational saving: 1) Gauss Elimination, 2) block LU factorization, and 3) matrix inversion lemma. As a result, each node computes only between 25% - 60% of the number of multiplications required by the direct inversion of the matrix. Regarding the performance in transient and steady states, the EFxAP exhibits the fastest convergence and the highest noise level reduction for any size of the acoustic network and any projection order of the AP algorithm compared to the DMEFxLMS and two previously reported distributed AP algorithms.

Video-Based System for Automatic Measurement of Barbell Velocity in Back Squat. *Basilio Pueo; José Javier López Monfort; José Manuel Mossi García; Adrián Colomer; Jose M. Jimenez-Olmedo. Sensors 2021, vol. 21 (3), 925. DOI: 10.3390/s21030925.*

Abstract: Velocity-based training is a contemporary method used by sports coaches to prescribe the optimal loading based on the velocity of movement of a load lifted. The most employed and accurate instruments to monitor velocity are linear position transducers. Alternatively, smartphone apps compute mean velocity after each execution by manual on-screen digitizing, introducing human error. In this paper, a video-based instrument delivering unattended, real-time measures of barbell velocity with a smartphone high-speed camera has been developed. A custom image-processing algorithm allows for the detection of reference points of a multipower machine to autocalibrate and automatically track barbell markers to give real-time kinematic-derived parameters. Validity and reliability were studied by comparing the simultaneous measurement of 160 repetitions of back squat lifts executed by 20 athletes with the proposed instrument and a validated linear position transducer, used as a criterion. The video system produced practically identical range, velocity, force, and power outcomes to the criterion with low and proportional systematic bias and random errors. Our results suggest that the developed video system is a valid, reliable, and trustworthy instrument for measuring velocity and derived variables accurately with practical implications for use by coaches and practitioners.

On the performance of a GPU-based SoC in a distributed spatial audio system. *Jose A. Belloch, José M. Badía, Diego F. Larios, Enrique Personal, Miguel Ferrer, Laura Fuster, Mihaita Lupoiu, Alberto Gonzalez, Carlos León, Antonio M. Vidal, Enrique S. Quintana-Ortí. The Journal of Supercomputing, vol. 77, 6920–6935, 2021. DOI: 10.1007/s11227-020-03577-4.*

Abstract: Many current system-on-chip (SoC) devices are composed of low-power multicore processors combined with a small graphics accelerator (or GPU) offering a trade-off between computational capacity and low-power consumption. In this context, spatial audio methods such as wave field synthesis (WFS) can benefit from a distributed system composed of several SoCs that collaborate to tackle the high computational cost of rendering virtual sound sources. This paper aims at evaluating important aspects dealing with a distributed WFS implementation that runs over a network of Jetson Nano boards composed of embedded GPU-based SoCs: computational performance, energy efficiency, and synchronization issues. Our results show that the maximum efficiency is obtained when the WFS system operates the GPU frequency at 691.2 MHz, achieving 11 sources-per-Watt. Synchronization experiments using the NTP protocol show that the maximum initial delay of 10 ms between nodes does not prevent us from achieving high spatial sound quality.

FIWARE based low-cost wireless acoustic sensor network for monitoring and classification of urban soundscape. *Pau Arce, David Salvo-Gutiérrez, Gema Piñero, Alberto Gonzalez, Computer Networks, vol. 9 (196), 2021. DOI: 10.1016/j.comnet.2021.108199.*

Abstract: This work presents a wireless acoustic sensor network (WASN) that monitors urban environments by recognizing a given set of sound events or classes. The nodes of the WASN are Raspberry Pi devices that not only record the ambient sound, but also detect and recognize different sound events. All the signal processing tasks, from the recording to the classification carried out by a convolutional neural network (CNN), are run on Raspberry Pi devices. Due to the low cost of the proposed acoustic nodes, the system exhibits a very high potential scalability. Regarding the underlying WASN, it has been designed according to the open standard FIWARE, thus the whole system can be deployed

without the need of proprietary software. Regarding the performance of the sound classifier, the proposed WASN achieves similar accuracy compared to other WASNs that make use of cloud computing. However, the proposed WASN significantly minimizes the network traffic since it does not exchange audio signals, but only contextual information in form of labels. On the other hand, most of the time the class reported by the WASN nodes is the "background" soundscape, which usually contains no event of interest. This is the case when monitoring the soundscape of big avenues, where four events have been identified: "traffic", "siren", "horn" and "noisy vehicles", being the "traffic" class associated to the background soundscape. In this paper, the use of a simple pre-detection stage prior to the CNN classification is proposed, with the aim of saving computation and power consumption at the nodes. The pre-detection stage is able to differentiate the other three relevant sounds from the "traffic" and activates the classifier only when some of these three events is likely occurring. The proposed pre-detection stage has been validated through data recorded in the city of Valencia (Spain), achieving a reduction of the Raspberry Pi CPU's usage by a factor of six.

Maximum likelihood low-complexity GSM detection for large MIMO systems. *Victor M.Garcia-Molla, F.J.Martínez-Zaldívar, M.Angeles Simarro, Alberto Gonzalez, Signal Processing, vol. 175, 2020. DOI: 10.1016/j.sigpro.2020.107661.*

Abstract: Hard-Output Maximum Likelihood (ML) detection for Generalized Spatial Modulation (GSM) systems involves obtaining the ML solution of a number of different MIMO subproblems, with as many possible antenna configurations as subproblems. Obtaining the ML solution of all of the subproblems has a large computational complexity, especially for large GSM MIMO systems. In this paper, we present two techniques for reducing the computational complexity of GSM ML detection. The first technique is based on computing a box optimization bound for each subproblem. This, together with sequential processing of the subproblems, allows fast discarding of many of these subproblems. The second technique is to use a Sphere Detector that is based on box optimization for the solution of the subproblems. This Sphere Detector reduces the number of partial solutions explored in each subproblem. The experiments show that these techniques are very effective in reducing the computational complexity in large MIMO setups.

An Efficient Implementation of Parallel Parametric HRTF Models for Binaural Sound Synthesis in Mobile Multimedia. *Jose A. Belloch, German Ramos, Jose M. Badia, Maximo Cobos, IEEE Access, vol. 8, 49562 - 49573, 2020. DOI: 10.1109/ACCESS.2020.2979489.*

Abstract: The extended use of mobile multimedia devices in applications like gaming, 3D video and audio reproduction, immersive teleconferencing, or virtual and augmented reality, is demanding efficient algorithms and methodologies. All these applications require real-time spatial audio engines with the capability of dealing with intensive signal processing operations while facing a number of constraints related to computational cost, latency and energy consumption. Most mobile multimedia devices include a Graphics Processing Unit (GPU) that is primarily used to accelerate video processing tasks, providing high computational capabilities due to its inherent parallel architecture. This paper describes a scalable parallel implementation of a real-time binaural audio engine for GPU-equipped mobile devices. The engine is based on a set of head-related transfer functions (HRTFs) modelled with a parametric parallel structure, allowing efficient synthesis and interpolation while reducing the size required for HRTF data storage. Several strategies to optimize the GPU implementation are evaluated over a well-known kind of processor present in a wide range of mobile devices. In this context, we analyze both the energy consumption and real-time capabilities of the system by exploring different GPU and CPU configuration alternatives. Moreover, the implementation has been conducted using the OpenCL framework, guarantying the portability of the code.

2.2.- Featured Conference Proceedings

- ***Perceptual Active Equalization of Multi-frequency Noise.*** *Juan Estreder, Gema Piñero, Miguel Ferrer, Maria de Diego, Alberto Gonzalez 18th International Conference on Signal Processing and Multimedia Applications (SIGMAP), Online, 2021.*

- ***Subjective analysis of speech privacy using speech masking in open-plan offices.*** *Laura Fuster, Maria de Diego, Gema Piñero, Alberto Gonzalez, Miguel Ferrer 27th International Congress on Sound and Vibration (ICSV27) , Online, 2021.*

- ***Low Complexity Near-ML Sphere Decoding based on a MMSE ordering for Generalized Spatial Modulation.*** *M. Angeles Simarro, Víctor M. García, Francisco J. Martínez-Zaldívar, Alberto Gonzalez, 31th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2020).*

SIGNAL PROCESSING GROUP (GTS) GTS lab

HEAD OF THE GROUP RESEARCH REPORT

The Signal Processing Group (GTS) is devoted to produce quality basic and applied interdisciplinary research in the field of signal processing and data science. Currently formed by 19 researchers, the GTS faculty, students, and staff have developed scientific knowledge and innovative technologies in national and international research projects. The areas of application include medicine, industry, underwater acoustics, and technologies for the arts.

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

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

Also, follow us in:

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

1.- Project activities

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

- Signal processing techniques applied to ultrasonic and impact-echo methods for the characterization of composite materials (including cementitious materials): The research has produced innovative techniques for material characterization, damage location and tomography reconstruction (FANSIRAS and non-contact airborne ultrasound techniques are clear examples). These techniques have proven to be useful in the characterization of both natural and artificial stones. The GTS collaborates, among others, with the ICITECH (Institute of Science and Technology of the Concrete), with the Department of Civil & Environmental Engineering (University of Illinois), with the University College Cork, and with the Centro Superior de Investigaciones Científicas (CSIC).

- Passive acoustics monitoring: We develop acoustic sensors and signal processing algorithms to advance in the study of marine animal population and the impact that anthropogenic sounds have on them. The aim is to help to ensure the conservation and sustainable use of marine biodiversity. For this purpose, we design surveillance systems, create real time noise maps for harbours, and evaluate the results using a risk-based approach. The group collaborates, among other institutions, with the Instituto Español de Oceanografia (IEO) for the Spanish approach to the Marine Strategy Framework Directive (D11), with the Oceanogràfic of Valencia, and with the Cartagena Harbor Authority.

- Applications of biomedicine: Advanced digital image processing through artificial intelligence (deep Learning) for biomedical applications, in collaboration with the Clinical Medical Imaging Area of the Hospital Universitario y Politécnico La Fe in Valencia.

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

- Emerging Signal Processing Techniques for Big Data Health Applications.

- Technologies for the Arts (Soundcool): Last year we have opened a new line of research for the use of creative audiovisual technologies derived from Soundcool for the treatment of neurodegenerative diseases. The system is constantly evolving and has adapted to COVID social distancing to be able to work online with users in their own homes. Most of the group affected by neurodegenerative diseases are elderly and have been the hardest hit by the pandemic. Especially the group of patients with mild-moderate impairment who maintained activity outside the home (day centers, etc.) have

Aerial view of the Cartagena harbor.

been those who have shown greater deterioration with confinement due to the interruption of therapies. Providing them with new alternative therapies suitable for social distancing and working from their homes or centers is essential in the current situation.

1.1.- Ongoing projects

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

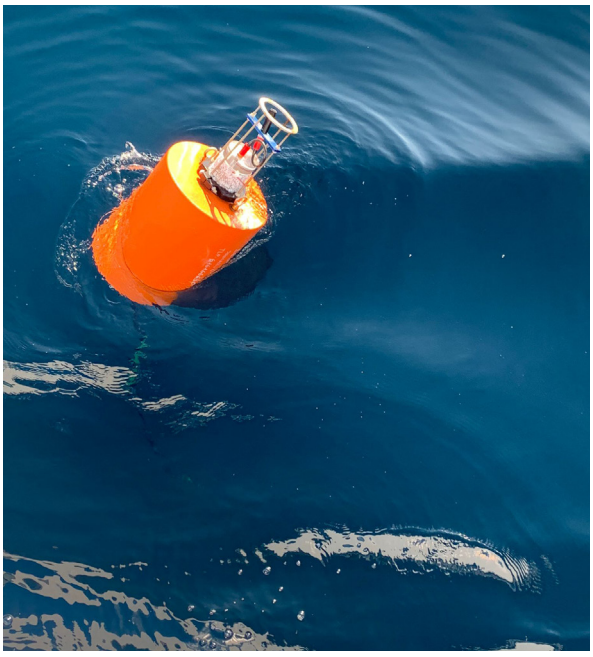
Summary of the project: The main objective of LIFE PortSounds is the characterization, monitoring and assessment of underwater noise levels in the Port of Cartagena area to reduce underwater noise pollution generated by maritime traffic and to avoid its pressure on the marine environment with the application of mitigation measures. We will measure and identify the anthropogenic and natural sounds while studying the noise impact on the abundance, distribution and physiological state of 3 cetaceans species of Community Interest: bottlenose dolphin, striped dolphin and long-finned pilot whale. Both, underwater sounds and cetaceans populations data, will be integrated in a new management tool which will allow to understand the local noise problems, to develop mitigation measures (MM) which will reduce the pressure on the marine environment, and so the impact on the Special Areas of Conservation (SAC) and to improve its state of conservation

Funding entity: LIFE20 ENV/ES/000387.

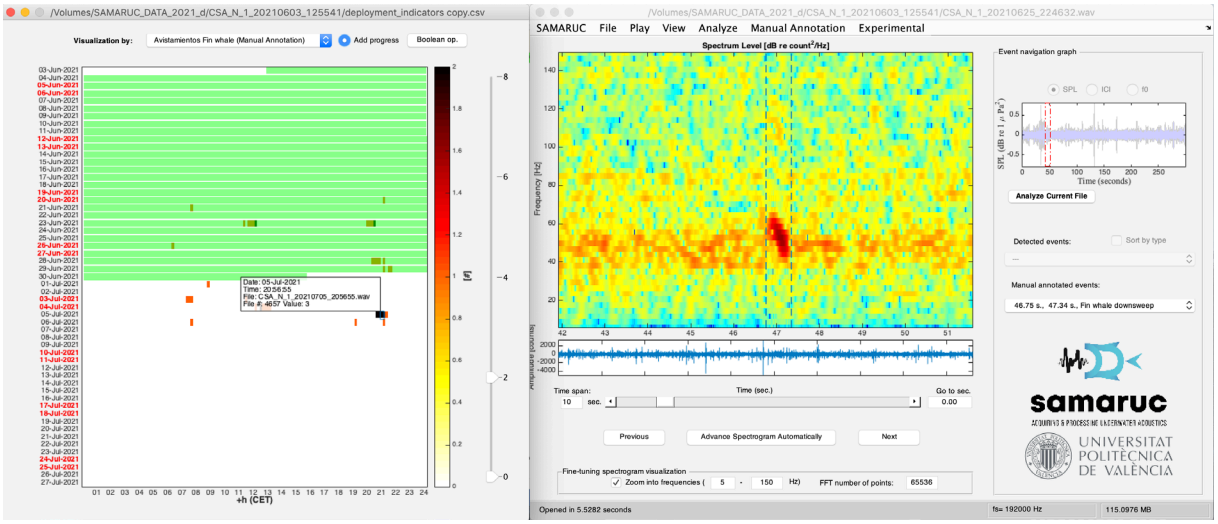
Name of the project: **Spanish implementation of the Marine Strategy Framework Directive.**

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

Funding entity: Ministry of Ecological Transition.



Recovery of one of the SAMARUC recording devices.



Fin whale downsweep detection using the SAMARUC software

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

Summary of the project: The Cabo Rorcual project is a multidisciplinary project that aims to study the fin whale with the aim of providing information on the movements and migratory routes of these animals.

The Cabo Rorcual project wants to determine which population of these whales belong to and why they pass so close to the coasts, as is the case of Dénia and Xàbia that presume to be areas where these sightings occur most. For this purpose, passive acoustic monitoring techniques will be combined, using signal processing and machine learning techniques, with satellite tracking and traditional visual surveys.

Funding entity: Fundación Biodiversidad

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

Summary of the project: The solution to many of the new challenges faced by society requires research and development into new composite materials with excellent properties as regards to corrosion, high resistance, a good weight/rigidity relationship and a high level of integration. The high cost and severely limited recycling possibilities for these materials make it advisable to develop new methods to enable the average life of composite materials to be monitored, evaluated and predicted depending on the environment surrounding them. The main objective of this project is to develop new NDTs based on mechanical waves for these materials. For this purpose, we develop different techniques that enable signals to be captured optimally and contactlessly, ranging from known direct contact technologies to sensors embedded in the material itself, as well as non-contact technologies such as air-coupled ultrasound and laser interferometry. We will also develop the underlying spectroscopic testing model and new signal processing algorithms that are sensitive and will enable these materials' mechanical parameters to be extracted.

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

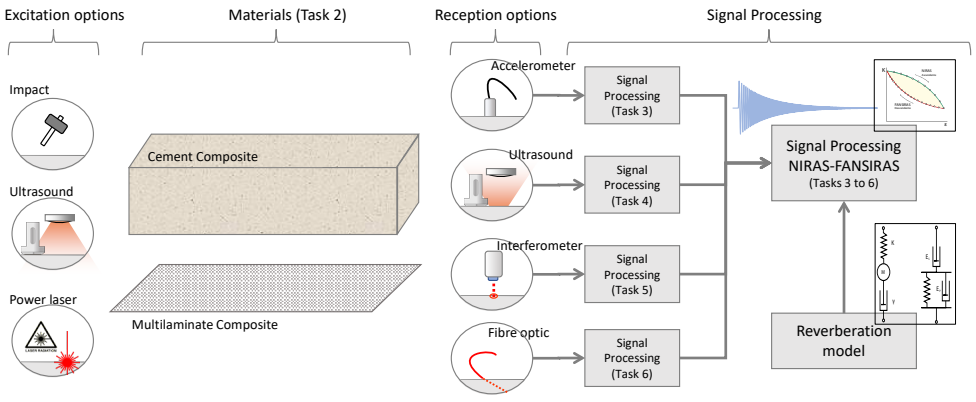
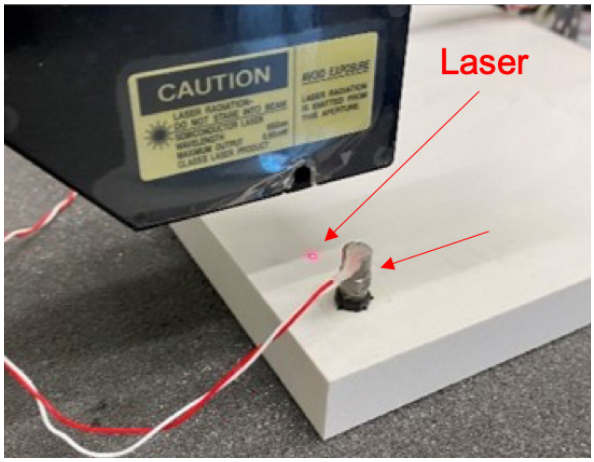
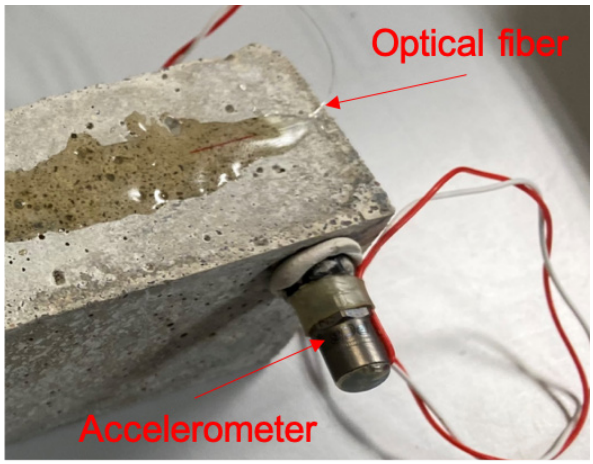


Diagram of the relationship of the technologies, materials and signal processing.



Monitoring a marble probe using accelerometers and laser sensors.



Monitoring a cement probe using accelerometers and optical fiber sensors.

Name of the project: **Development of transfer learning-based techniques for massive multi-groups segmentation**

Summary of the project: This project aims to establish an Artificial Intelligence (AI) methodology based on Transfer Learning (TL) for automatic multi-organ segmentation (liver, spleen, kidneys, perirenal fat, paravertebral muscle, etc.) from different modalities (CT, MRI) and potentiation's (T1, T2, DWI, etc.), which minimizes manually generated segmentations. Based on the following situations:

(a) When the target organ to be segmented is available, segmented in another modality or potentiation.

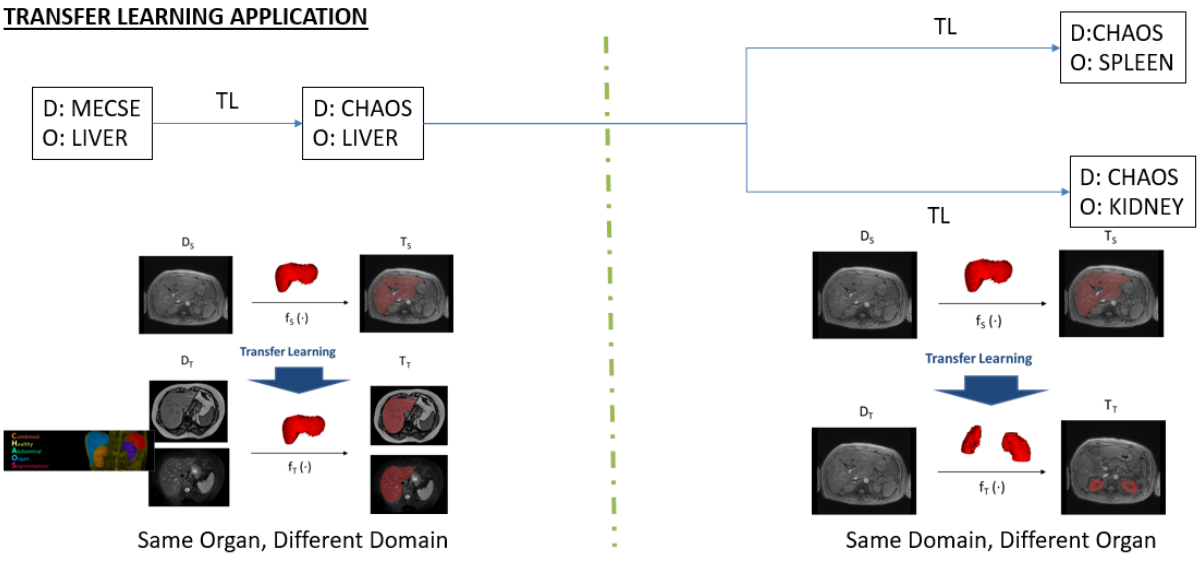
b) When there are other organs other than the one to be segmented in the same modality or potentiation.

This is performed in collaboration with the GIBI2^30 of the Clinical Medical Imaging Area of the Hospital Universitario y Politécnico La Fe in Valencia. It provides abdominal MRI studies in different potencies for the characterization of the liver by means of non-invasive imaging biomarkers, from the current Virtual Liver Biopsy (VHLB) project. The proposed methodology will be evaluated on the particular case of kidney segmentation using the studies of this project.

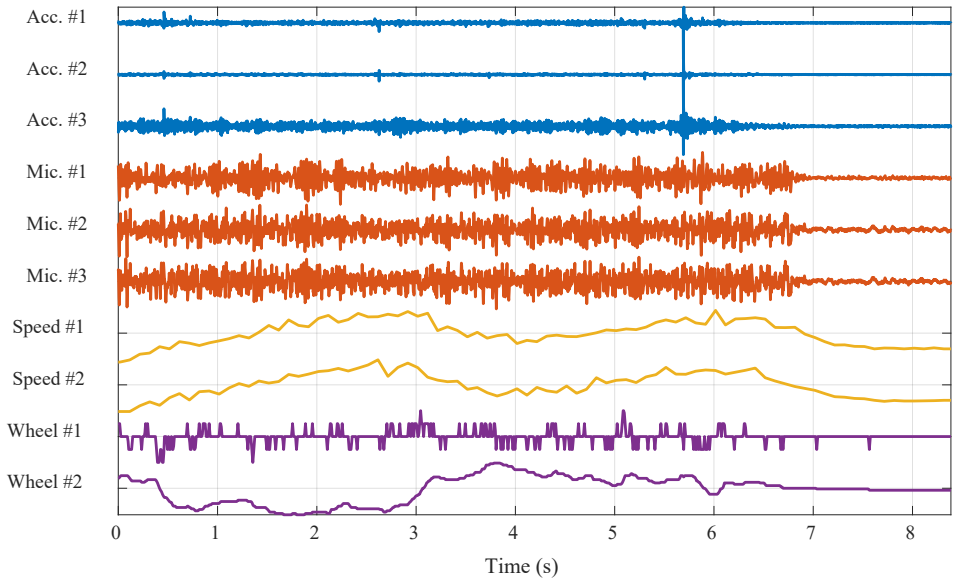
Funding entity: UPV- La Fe 2021 Preparatory Actions**.**

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

The project is in the final phase mainly focused on experimental verification of the new algorithms developed so far for signal synthesis. Two application domains were considered in the project: biomedical and automotive signal analysis. In this final phase, extensive work has been applied to the problem of training road



TIAbdSeg project summary block diagram



Example of the captured signals from four sensors: three accelerometers (Acc.), three microphones (Mic.), two speed channels (Speed), and two handwheel signals (Wheel).

surface classifiers by data augmentation. The context is on-board systems for autonomous or semi-autonomous driving assistance. Evidences are obtained by experiments involving 63 captures of a 10-channel multisensor deployment under different settings of the involved parameters. It has been demonstrated significant reductions of the overall capture time by data augmentation. (see figure)

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

Name of the projects: **Alternative Therapies based on New Audiovisual Technologies for Neurodegenerative Diseases in Social Distancing COVID-19 (TANTAENDSCovid)**

Summary of the projects: The TANTAENDSCovid project aimed to carry out a preliminary study for future research projects, including the AICO / 2020/151, which will generate cognitive stimulation therapies / activities for neurodegenerative diseases. These therapies are based on individual and collaborative musical, sound and image / video activities with tablets, smart phones and augmented reality using the Soundcool system created at the UPV, and systems derived from Soundcool. The TANTAENDSCovid project is studying the possibility of applying Soundcool's new audiovisual technologies in new therapies and collaborative activities in Alzheimer's, and a first therapy will be designed and tested for working even in the distance.

Funding entity: Polisabio program from the Foundation for the Promotion of Health and Biomedical Research of Valencia Region (FISABIO) and the UPV.

Name of the Project: **New Technologies for Music and Audiovisuals for the Treatment of Neurodegenerative Diseases (AICO/2020/151)**

Summary of the project: In the AICO / 2020/151 project, activities and therapies are being expanded, also applying to other neurodegenerative diseases. Currently the tests of these activities and therapies are being tested with the users of the center of the Association of Relatives and People with Alzheimer's and other dementias of Canals (AFA Canals) and the residence of La Saleta Campolivar of the Colisée group. Among the activities carried out is the Conference "New Therapies for Neurodegenerative Diseases" held in collaboration with FISABIO in March 2021.

Funding entity: Generalitat Valenciana (Spain)

2.- Research results

2.1.- Featured publications

Estimation of the number of endmembers in hyperspectral images using agglomerative clustering. J. Prades, G. Safont, A. Salazar, L. Vergara, Remote Sensing, vol. 12(21), pp.1-22, 2020.

We present an algorithm that estimates the number of materials in the scene using agglomerative clustering. The algorithm is based on the assumption that a valid clustering of the image has one cluster for each different material. After reducing the dimensionality of the hyperspectral image, the proposed method obtains an initial clustering using K-means. In this stage, cluster densities are estimated using

Independent Component Analysis. Based on the K-means result, a model-based agglomerative clustering is performed, which provides a hierarchy of clustering. Finally, a validation algorithm selects a clustering of the hierarchy; the number of clusters it contains is the estimated number of materials. Besides estimating the number of endmembers, the proposed method can approximately obtain the endmember (or spectrum) of each material by computing the centroid of its corresponding cluster.

DOI: 10.3390/RS12213585

Generative Adversarial Networks and Markov Random Fields for oversampling very small training sets. A. Salazar, L. Vergara, G. Safont, Expert Systems with Applications, vol. 163, pp.1-12, 2021.

We propose a new method for oversampling the training set of a classifier, in a scenario of extreme scarcity of training data. It is based on two concepts: Generative Adversarial Networks (GAN) and vector Markov Random Field (vMRF). Thus, the generative block of GAN uses the vMRF model to synthesize surrogates by the Graph Fourier Transform. Then, the discriminative block implements a linear discriminant on features measuring clique similarities between the synthesized and the original instances. Both blocks iterate until the linear discriminant cannot discriminate the synthetic from the original instances. We have assessed the new method, called Generative Adversarial Network Synthesis for Oversampling (GANSO), with both simulated and real data in experiments where the classifier is to be trained with just 3 or 5 instances. The applications consisted of classification of stages of neuropsychological tests using electroencephalographic (EEG) and functional magnetic resonance imaging (fMRI) data and classification of sleep stages using electrocardiographic (ECG) data.

DOI: 10.1016/J.ESWA.2020.113819

A Machine Learning SDN-Enabled Big Data Model for IoMT Systems, Haseeb, K.; Ahmad, I.; Awan, I.I.; Lloret, J.; Bosch, I. A***,*** Electronics 10, 2228, 2021.

This paper presents a machine-learning model with Software Define Network (SDN) enabled security to predict the consumption of network resources and improve the delivery of sensors data when using the Internet of Medical Things (IoMT). Additionally, it offers centralized-based SDN architecture to overcome the network threats among deployed sensors with nominal management cost. Firstly, it offers an unsupervised machine learning technique and decreases the communication overheads for IoT networks. Secondly, it predicts the link status using dynamic metrics and refines its strategies using SDN architecture. In the end, a security algorithm is utilized by the SDN controller that efficiently manages the consumption of the IoT nodes and protects it from unidentified occurrences.

DOI: 10.3390/electronics10182228

Klebsiella aerogenes and Comamonas testosteroni as bioremoval agents on graffiti-coated concrete and granite: Impact assessment through surface analysis. P. Sanmartín, P. Bosch-Roig, D. Gulotta, R. Fort, I. Bosch, F. Cappitelli, International Biodeterioration & Biodegradation, Volume 161, 2021.

We explore further the graffiti bioremoval capacity of Klebsiella aerogenes ATCC 13048 and Comamonas sp. ATCC 700440 (C. testosteroni), by means of an experiment that was carried out encompassing an improved assay protocol (protocol time was reduced from 20 to 14 days). The formation of pinholes - noticeably higher on concrete than on granite - was already observable by naked eye and further proved by digital image analysis, novel to this experiment, which showed holes greater in number due to K. aerogenes and greater in size due to C. testosteroni. Complementarily, surface microtopography - also novel for bioremoval studies with bacteria - offered detailed information on surface irregularities that allows better understanding of the performance of the bacteria. In contrast, non-mapping techniques, such as wetting by droplet, specular gloss and roughness measured in line transects provided less information for the study. Infrared (ATR-FTIR) spectroscopy and colour change assessment – mainly in the achromatic parameter L* – showed more intense changes by C. testosteroni.

DOI: 10.1016/j.ibiod.2021.105244

Assessment of Arrow-of-Time Metrics for the Characterization of Underwater Explosions, A. Miralles, R.; Lara, G.; Carrión, A.; Bou-Cabo, M., Sensors, 21, 5952, 2021.

Anthropogenic impulsive sound sources with high intensity are a threat to marine life and it is crucial to keep them under control to preserve the biodiversity of marine ecosystems. Underwater explosions are one of the representatives of these impulsive sound sources, and existing detection techniques are generally based on monitoring the pressure level as well as some frequency-related features. We propose a complementary approach to the underwater explosion detection problem through assessing the arrow of time. The arrow of time of the pressure waves

coming from underwater explosions conveys information about the complex characteristics of the nonlinear physical processes taking place as a consequence of the explosion to some extent. We present a thorough review of the characterization of arrows of time in time-series, and then provide specific details regarding their applications in passive acoustic monitoring.

DOI: 10.3390/s21175952

Application of a risk-based approach to continuous underwater noise at local and subregional scales for the Marine Strategy Framework Directive, E. Verling, R. Miralles, M. Bou-Cabo, G. Lara, M. Garagouni, JM. Brignon, T. O'Higgins, Marine Policy, Volume 134, 2021.

The Marine Strategy Framework Directive's (MSFD) goal of achieving Good Environmental Status (GES) in European waters presents Member States (MS) with a significant challenge in measurement and monitoring of a suite of descriptors of GES, some of which are poorly understood. To address the burden for MSs of monitoring and measuring environmental status and trends over vast areas, provisions have been made for the use of risk-based approaches to assessment and monitoring. Here, a standardised risk-based approach is described, aligned with the articles of the directive and with the DAPSI(W)R(M) conceptual frame. The parallel applications of the risk-based approach illustrate that it is a powerful tool that can provide useful outputs, even where significant data gaps and limitations in understanding exist.

DOI: 10.1016/j.marpol.2021.104786

Collaborative Creation with Soundcool for Socially Distanced Education, J. Sastre-Martínez, N. Lloret-Romero, S. Scarani, R.B. Dannenberg, J. Jara, Proceedings of Korean Electro-Acoustic Music Society's Annual Conference (KEAMSAC) 2020, Seoul, Korea, 30-31 Oct. 2020, pp. 47-51.

Soundcool is a flexible, modular computer music software system created for music education. Moreover, Soundcool is an educational approach that embraces collaboration and discovery in which the teacher serves as a mentor for project-based learning. To enable collaboration, Soundcool was designed from the beginning to allow individual modules to be controlled over WiFi using smartphone and tablet apps. This collaborative feature has enabled network-based performance over long distances. In particular, the recent demand for social distancing motivated further explorations to use Soundcool for distance education and to enable young musicians to perform together in a creative way. We describe the educational approach of Soundcool, experience with network performances with children, and future plans for a web-based social-network-inspired collaborative music creation system.

Available at: https://www.researchgate.net/publication/350688934_Collaborative_Creation_with_Soundcool_for_Socially_Distanced_Education

Soundcool: A Business Model for Cultural Industries Born Out of a Research Project, Lloret-Romero N., Sastre-Martínez J., Ospina-Gallego C., Scarani S., Music as Intangible Cultural Heritage pp 41-49, 2021

Soundcool is a system for musical, sound and visual collaborative creation through mobile phones, tablets and other interfaces. This paper describes the creation of the app from the outset, illustrating not only how the Soundcool® system has been developed from the initial idea to the current reality, but also the evolution that the app has had during this period and how it has become ready to use. The research group in the Universitat Politècnica de Valencia (UPV) has played a key role in the development of the app. We also explain the opportunities for Soundcool in different markets and economic sectors. Last but not least, we describe how the idea has been financed to make it a reality.

DOI: 10.1007/978-3-030-76882-9_4

Effects of slow dynamics and conditioning on non-linear hysteretic material assessment using impact resonance acoustic spectroscopy, A. Carrión, V. Genovés, G. Pérez, J. Bittner, J.S. Popovics, J. Payá, J. Gosálbez, Mechanical Systems and Signal Processing, Vol. 150, 2020

The purpose of this work is to investigate the dynamic response of thermally damaged concrete specimens measured by two different techniques: Non-linear Impact Resonance Acoustic Spectroscopy (NIRAS) and new Flipped Accumulative Non-linear Single Impact Acoustic Spectroscopy (FANSIRAS). Specimens were characterised in two different dynamic condition states of the material: relaxed and conditioned. The recently proposed algorithm, FANSIRAS, extracts from a single resonant signal equivalent results to NIRAS when the specimen is conditioned. The results suggest that new NDT parameters based on non-linear hysteretic parameters can quantify the damage level of thermally treated mortar specimens.

DOI: 10.1016/j.ymssp.2020.107273

2.2.- Awards and exhibitions.

Workshop and exhibition at the Korean Electro-Acoustic Music Society's Annual Conference 2020. Within this Conference the musical and audiovisual show "Autumn" was premiered. It was the first professional remote show taking advantage of the new Soundcool capability of working with the participants connected through the internet. The participants controlled a computer with Soundcool in Valencia from South Korea, Indonesia, the USA and Spain on Saturday October 31, 2020. Prior to the premiere, the Collaborative Creation with Soundcool for Socially Distanced workshop was held. The workshop and the show was streamed and it is available at https://youtu.be/kRp4SMfpL0Y.

The Soundcool team has been a finalist in the Creative Spain Cup with the project "Collaborative creation with Soundcool for multimedia opera on a traditional story", being the best-rated project in the category of universities and non-profit companies. The project teaser is available at https://youtu.be/fYnp1HF-bIs, and the presentation of the project is available at https://youtu.be/xQq68mn_TNs?t=9666. In addition, Soundcool was selected to participate in the VI meeting of Culture and Citizenship of the Ministry of Culture and Sports (https://youtu.be/_0_tWC5gBa4)

Soundcool has also been selected in the 3rd Collab de las Naves program, receiving training in the acceleration process for Startups. We continue with the education field extended to any subject thanks to the new video modules, including chroma, mixers, effects, etc...; This video shows a demo of the new Soundcool capabilities: https://youtu.be/z1SYV-Jw9es (English subtitles available). Advanced artistic examples of use even at a distance can be seen by composers (https://youtu.be/QyCYa71SGtc), PhD students (https://youtu.be/onAHkyMc9IU and https://youtu.be/maHRMXn92JE) and undergraduate students in Fine Arts (https://youtu.be/fqGxoDmW3oQ).

On Sept. 23rd, 2021, Soundcool was invited to participate in "Visiones sonoras, International Festival of Music and New Technologies, Creative Minds Come Together" with a Workshop with a new performance of the piece "Autumn" with performers in the distance (USA, Mexico and Spain) composed by the Soundcool PhD student Pedro Miguel Astasio Molina. The Workshop was presented by J. Sastre, R.B Dannenberg, S. Scarani and P. Astasio (https://en.cmmas.com/taller-soundcool).

Finally, the Soundcool team created and performed the audiovisual show "Africa" controlled by dance with augmented reality on June 28th, 2021. The show was commissioned for the Africa Table event for the digitization of the African continent organized by the Ministry of Foreign Affairs, European Union and Cooperation (Spain), chaired by the Secretary of State for Foreign Affairs and for Latin America and the Caribbean, Cristina Gallach. The event counted on the participation of the General Director of Smart Africa, Lacina Koné (https://youtu.be/0hbcscvlktw?t=5859)

Show "Africa" with Soundcool controlled by dance with augmented reality commissioned by the Ministry of Foreign Affairs, European Union and Cooperation (Spain)

Mobile Communications Group (MCG)

HEAD OF THE GROUP RESEARCH REPORT

The Mobile Communications Group (MCG), led by Narcís Cardona, is aimed at developing new technologies for future standards in Mobile and Wireless Communications. The current activities of MCG are focused on four areas: 5G New Radio (5GNR), Multicast and Broadcast Services (MBMS) over 3GPP Networks, Vehicular Communications, and Body Area Communications (BAN). Currently, the MCG is composed of about 40 people between professors and researchers. The MCG researchers have a consolidated experience in 5G due to their involvement with several international projects related to 5G, most notably the METIS, METIS-II, and 5G-Xcast projects. It leads the H2020 European projects 5G-RECORDS, INGENIOUS, FUDGE-5G, WaveComBE, ITN-5VC and also participates in the 5G-CARMEN, 5G-SMART, 5G-TOURS. These researchers participate in the development of "vertical" 5G applications and some of them being in phases 2 and 3 of the 5G-PPP program, in addition to being involved in other of the ministry and autonomic projects such as PROMETEO 2020 (FEDER), Red.es 5G Pilots, etc.

The MCG has also achieved a contract with Huawei to create the iTEAM – Huawei Joint Research Center, which involves 7 projects, where the MCG participates in 4 of them. Furthermore, the MCG collaborates with companies in the sector such as the spin-off Fivecomm, among others, with which the UPV has signed agreements for the development of 5G technology applicable to industry 4.0, and in the transfer of knowledge referring to measures in 5G networks and their optimization.

Valencia 5G

During this period, the MCG members have been very active in the dissemination of the group's activities and achievements. An example of this is the event to present the results of the Valencia 5G agreement, which was signed in 2018 by the UPV, the Valencia City Council, the *Generalitat Valenciana,* and the *Universitat de València*. Thanks to this agreement, milestones such as the

Laser 5G demo at the MWC 2021

celebration of the EuCNC2019 & Global 5G Event and the implantation of the VLC-CAMPUS-5G in the UPV were possible. This has led to the Base 5G, a new public laboratory for experimentation and demonstration on pioneering 5G technologies in Spain located in the surroundings of La Marina and managed by the UPV and the City Council. The objective of Base5G is to allow small and medium-sized companies to test or demonstrate applications of 5G technology in different sectors, not only in industry, and thus facilitate the experimentation of new ideas and prototypes that can later be transferred to the Valencian business community.

Fruit of this success, the Valencia 5G (V5G) brand and platform (https://v5g.es/) has been created, in which all the information on the achievements of all the participating entities will be collected. Within the framework of this brand, the first edition of the V5G Day was held as a seed of a family of events to be organized yearly in Valencia. The V5G Day event was held on July 7th 2021, at the Valencia Conference Center, with the slogan "5G and the digitization of the Industry", it was organized by the MCG of iTEAM in collaboration with the UPV, *Generalitat Valenciana*, and the Valencia City Council. In this edition, the event was hybrid, with a limited presence of attendees at the venue, where demonstrations of live 5G technology were also carried out, applied to real use cases, specifically Remote Driving, Touch Internet, and Social Robot. At the same time, the event was broadcast live via

high-quality streaming. Throughout the day discussions and demonstrations were held on how 5G technology can become a catalyst for the modernization of our industry, and therefore the focus of presentations, round tables, and demonstrations were placed on representatives of various industrial sectors. Here, industry representatives could discuss in three round table sessions the possibilities that the 5G technology may provide to the local industry.

In addition, this year, the MCG group from iTEAM, together with Orange and ZTE, participated in the Mobile World Congress 2021. They showed the pioneering project "Laser 5G", an unmanned remote-controlled boat equipped with 360 ° cameras that was driven from Barcelona while sailing at La Marina of Valencia, thanks to the 5G technology. The project also involved the company Fivecomm and a team from the *Universidad Politécnica de Cartagena* (UPCT).

Laser 5G

1.- Project activities

1.1.- Ongoing projects

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

VLC-CAMPUS-5G is the project to launch a 5G technology wireless communications platform on the campus of the Universitat Politècnica de València, which supports the testing of new 5G services and equipment and promotes Valencia as a 5G city. The VLC-CAMPUS-5G project is aligned with the evolution of mobile networks towards 5G, which will bring important developments and improvements not only in terms of capacity, latency, connection density, quality, and user experience, but also in terms of flexibility, efficiency, scalability, and openness of the networks, which will allow offering new services. There is currently a 5G network core emulator, as well as software-configured radio units, such as the Ettus USRPs B210 (3) and N321 (2) as well as various equipment and software licenses that together configure a network 5G laboratory. At this moment, it supports PROMETEO 2020 (FEDER), Red.es 5G Pilots, and H2020 projects, among others. Research projects and demonstrations of use cases of this technology are being carried out in the VLC-CAMPUS-5G, especially focused on the industry, and collaborates with companies in the energy and automotive sectors on projects for the sustainability and promotion of electric and connected vehicles.

This project is co-financed by the European Union through the operational program of the European regional (FEDER) development fund of the Comunitat Valenciana 2014-2020, with reference IDIFEDER/2018/030, duration 2018 - 2020 ext. to March 2021.

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

VLC-CAMPUS-5G II is the project to deploy an experimental field of 5G Mobile Technologies for the Internet of Things and Connected Machines that will use current infrastructure available by the Mobile Communications Group of the Institute of Telecommunications and Multimedia Applications (iTEAM) of the UPV, especially the equipment of the VLC-Campus-5G (pilot testing field, development and demonstration of 5G mobile technologies). The new equipment will be added that will allow pioneering tests of 5G-IoT connected machines related to the world of Logistics and Industry 4.0 in general, with practical use cases applied to process improvements in the port of Valencia. It should be noted that the VLC-Campus-5G has 5G Release-15 equipment (the first version of the standard), while the 5G equipment requested in this grant corresponds to the second version of the Release-16 standard,

which was completed in June 2020, and which includes the mMTC (massive-Machine-Type Communications) and URRLC (Ultra-Reliable-Low-Latency Communications) functionalities that are fundamental for the Internet of Things and the connection of machines. The construction of the 5G-IoT test campus requires different equipment that can be classified into the following categories:5G-IoT-mmW (5G-IoT Release-16 end-to-end connectivity equipment in the millimeter wave frequency band (26-28 GHz)); 5G-IoT-UHF (5G-IoT Release-16 end-to-end connectivity equipment in the frequency band below 6 GHz); 5G-IoT emulation (Core network, radio access network and 5G-IoT Release-16 devices emulation equipment.); and Automated mobile robotic system (Equipment with different types of mobile robots for indoor and outdoor industrial applications (mobile base, guided vehicle, collaborative robotic arm, automatic guided vehicle for warehouse transport and platform type)). https://vlc-campus5g.com/

This project is co-financed by the European Union through the operational program of the European Regional Development Fund (FEDER) of the Comunitat Valenciana 2021-2022, with reference IDIFEDER/2021/088, duration from January 2021 to December 2022.

WAVECOMBE (Millimetre Wave Communications in Built Environments)

WaveComBE is an Industrial and Training Network dealing with the ultra-dense deployment of millimetre-wave (mmW) Small Cells (SCs) in conjunction with massive multiple-input multiple-output (MIMO) in 5G and beyond 5G (B5G) wireless networks. This project is coordinated by UPV, in consortium with The University of Sheffield, University of Durham, University of Twente and companies Ranplan Wireless Network Design Ltd. and Televic Conference, Gapwaves AB together with the partner organizations, Axión Infraestructuras de Telecomunicaciones S.A.U, Telenor Group, and Nokia Bell Labs.

WaveComBE provides high-quality inter-disciplinary and cross-sector research training for a new generation of scientists. Specifically, 11 Early Stage Researchers have been involved in the project, two of them by the UPV. From the MCG has been developed simulation tools to analyse the human body blocking at millimetre-wave band, as well as efficient planning tools to deploy future access points in bands around and above 30GHz. Besides beamforming techniques have been investigated for the physical layer of millimetre-wave mobile communications.

This last year of the project, training, and dissemination activities have continued. In total, the project ends with 10 training activities organized by the consortium, up to 36 publications in conferences and journals, 5 contributions to the ITU, and 2 patent requests. The main outcome of WaveComBE MSCA-ITN-EID project is a group of excellent PhDs, with both technical and soft skills, that can lead future projects in the field of Telecommunications. https://wavecombe.eu/

This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Sklodovska-Curie agreement No. 766231. Duration: 01/10/2017 - 30/09/2021.

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

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

The "Munich-Bologna corridor", which covers 600 km of roads across three countries (Italy, Austria and Germany), is one of the most important corridors identified by the European Union for an initiative to improve the mobility of people and goods throughout Europe. As part of the 5G-CARMEN project, 5G technologies have been deployed along selected stretches of the motorway in the border regions. First demos were experienced in June 2021, being the fall 2021 a new opportunity for testing real autonomous cars along European motorways. https://5gcarmen.eu/

This project has received funding from the European Horizon 2020 Programme for research, technological development and demonstration under grant agreement no.: 825012. From November 2018 to July 2022.

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

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

outdoor attractions are provided with 5G-based applications to enhance their experience while visiting the city. This includes VR/AR applications to complement the physical visit with additional content, involving interactive tactile communications. The experience of the visitors is also enhanced with robot-assisted services, telepresence to allow for remote visits, as well as live events enabled by mobile communications such as multi-party concerts. iTEAM is the leader of the broadcast use case. In this case of use, a 5G Broadcast network will be used to send high-quality multimedia content, which will be received by the visitors of Palazzo Madama. The UPV will contribute directly to the development of equipment compatible with 5G Broadcast specifications, based on Software Defined Radio (SDR), as well as the implementation of the multicast interfaces of the 5G Core. www.5gtours.eu

This project has received funding from the European Horizon 2020 under grant agreement no.: 856950, 36 months duration (June 2019 – May 2022).

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

5G-RECORDS aims to explore the opportunities that new 5G technology components, including the core network (5GC), radio access network (RAN) and end devices, bring to the professional production of audiovisual content. The project targets the development, integration, validation, and demonstration of 5G components for professional content production, as part of an overall ecosystem integrating a subset of 5G network functions. The project is using 5G key enabling technologies, such as NPNs, network slicing, millimeter waves, network function virtualization, among others, to bring these new 5G components to emerging markets and new market actors, while also addressing recent emerging remote and distributed production workflows where cloud technologies work hand in hand with 5G. 5G-RECORDS is structured around three real-world content production use cases: live audio production, a multi-camera wireless studio and live immersive media production. The first use case focuses on deploying a 5G private local network using open-source software and general-purpose processors as part of the overall infrastructure. To meet the challenges of live audio production, i.e., stringent requirements in terms of latency, availability, and synchronization, ultra-reliable low-latency communications (URLLC) is key. The second use case aims to develop a complete production system that takes advantage of 5G technology to fit remote, distributed production and remote contribution scenarios. This use case involve video, audio, and auxiliary data processing with strict requirements in terms of quality, data rate, latency, reliability, and synchronization between devices. Its main goal is thus to equip media equipment with external codecs and 5G modems that feed the media signals into the 5G network. A project-developed media gateway on the other end translates the 5G-IP transport protocols to the desired ones in the final production network, such as SMPTE-2110. The media equipment is managed through an also project-developed control gateway through the 5G network via NMOS protocols. The third use case aims to enable real-time immersive capture of sporting and cultural events through cameras connected via 5G millimeter waves. Thanks to the enhanced bandwidth, it will be possible to broadcast content both live and in replays, with different perspectives and shots, so that the live program director can move the viewpoint of the image freely. www.5g-records.eu

iTEAM is leading this project, which has received funding from the European Union's Horizon 2020, under grant agreement no.: 957102, 24 months duration (September 2020 – August 2022).

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

FUDGE-5G will make a leap forward in realizing the notion of cloud-native 5G private networks by developing a further enhanced Service-Based Architecture (eSBA) for both control plane and user plane with "decomposed" players of the ecosystem divided into: New Radio (NR) access network infrastructure provider, eSBA platform provider, mobile 5G Core (5GC) provider, vertical application orchestration provider and vertical service provider. The forward-looking FUDGE-5G architecture will also feature "all- Ethernet" 5GLAN (Local Area Network), 5G-TSN (Time- Sensitive Networking), 5G-Multicast and intelligent vertical application orchestration features. The proposed framework enables highly customized cloud-native deployment of private 5G networks that can be deployed anywhere as micro-services (i.e., edge, on premises and cloud), while the access network is hosted over 5G, WiFi or wired Ethernet links. iTEAM is the coordinator of the project, and the leader of the Concurrent Media Delivery use case, divided into two sub-scenarios: an uplink focused Remote News Gathering over 5G and a downlink intensive Media Showroom. iTEAM is also developing 5G-Multicast functions and hosting a node of the interconnected

private networks trials; which seek to emulate EDUROAM functionality over 5G networks. www.fudge-5g.eu

iTEAM is leading this project, which has received funding from the European Union's Horizon 2020, under grant agreement no.: 957242., 30 months duration (September 2020 – Feb. 2023).

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

iNGENIOUS will exploit some of the most innovative and emerging technologies in line with the standardised trend, contributing to the Next-Generation IoT and proposing technical and business enablers to build a complete platform for supply chain management. iNGENIOUS embraces the 5G Infrastructure Association (5G IA) and Alliance for Internet of Things Innovation (AIOTI) vision for empowering smart manufacturing and smart mobility verticals. The iNGENIOUS network layer brings new smart 5G-based IoT functionalities, federated Multi-Access Edge Computing (MEC) nodes and smart orchestration, needed for enabling the projected real-time capable use cases of the supply chain. Security and data management are fully recognized as important features in the project. iNGENIOUS will create a holistic security architecture for next-generation IoT built on neuromorphic sensors with security governed by Artificial Intelligence (AI) algorithms and tilebased hardware architectures based on security by design and isolation by default. In the application layer, iNGENIOUS new AI mechanisms will allow more precise predictions than conventional systems. Project outcomes will be validated into 4 large-scale Proof of Concept demonstration, covering 1 factory, 2 ports, and 1 ship, encompassing 6 uses cases. iTEAM is the coordinator of the project, and it participates on three use cases. The first is Situational Understanding and Predictive Models in Smart Logistics Scenarios, where we work on the tracking of trucks inside the port and a dashboard to represent different sources of data. The second one is called Automated Robots with Heterogeneous Networks. Here we're deploying an open RAN network together with other partners to implement new capabilities and intelligence thanks to AI/ML. The last one is called Inter-modal Asset Tracking via IoT and Satellite, where we work on implementing new Non-Terrestrial Networks (NTN) channel models and link level simulations. www.ingenious-iot.eu

iTEAM is leading this project, which has received funding from the European Union's Horizon 2020, under grant agreement no.: 957216. 30 months duration (October 2020 – March 2023).

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

ITN-5VC aims to investigate how multi-band multi-antenna communications, including mmWave, could be integrated together with radar heads and other wireless sensors into the same telematics unit, so that transmission chains and radiation systems were reused using the same spectrum in an opportunistic manner. This idea has important implications in the design of the vehicle and its communications that will also be addressed in the project. With this premise, the project aims to investigate the future C-V2X systems based on 5G NR and how to integrate them with autonomous driving sensor systems. https://itn5vc.eu/

This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No. 955629 Duration: 01/10/2020 - 30/09/2024.

5G-SMART (5G for smart manufacturing)

5G-SMART unlocks the value of 5G for smart manufacturing through demonstrating, validating and evaluating its potential in real manufacturing environments. 5G-SMART trials will test the most advanced 5G integrated manufacturing applications such as digital twin, industrial robotics and machine vision based remote operations. 5G-SMART will undertake the first ever evaluation of ElectroMagnetic Compatibility (EMC), channel measurements and co-existence between public and private industrial networks in real manufacturing environments easing the integration of 5G. The new 5G features, developed in 5G-SMART such as time synchronisation and positioning for manufacturing use cases represent a technological leap.

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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no.: 857008. From June 2021 to May 2022.

COLODEM (Colorectal Probe for Electromagnetic Tumour Detection)

COLODEM project is based on the development of a tool for colorectal cancer detection based on the reported difference in the electromagnetic properties of healthy and malignant colon tissues. Such tool will consist of three main parts: flexible coaxial 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.

Regarding the platform, it was determined that artificial gels, specifically the PHEA hydrogel, was the most optimal gel for the requirements of the test platform to be developed. On the other hand, the most important limitations that can affect the three-dimensional production of the phantom to conform it to the size and shape of a real colon were determined, being especially relevant the polymerization initiator used.

Presentation Red.es 5G Pilots- Demo Robotics Remote control of AGVs.

Regarding the tests with the flexible probe and the detection algorithm, they have been performed both with the developed semi-solid phantoms and with data from other studies where measurements were already available. The results obtained showed that it is the cross section of the flexible probe is key to optimize the sensitivity of the measurement thus. In addition, calibration tests were performed taking into account the sterile conditions of the actual application environment. Finally, preliminary analyses of the difference in dielectric property values of healthy and tumor tissue showed that this methodology can provide good performance in the identification of colorectal cancer tissues, provided the realization of extensive clinical studies to refine the diagnostic algorithm.

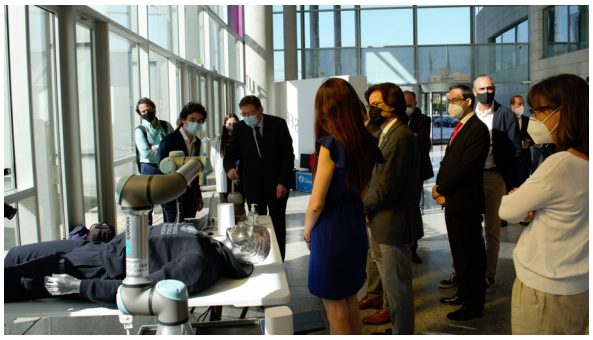
This Project has been funded by the Call for Grants for First Research Projects (PAID-06-18). Duration: 1/09/2019 to 28/02/2021.

CROFT (Cloud Robotics and factories Of The FuTure)

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

The objective of the project is to investigate and optimize the operation of RAN architectures for 5G standards beyond NR phase 2, and to design reliable and realistic PHY and MAC procedures adapted to this new communication model composed of mesh networks and mobile nodes. The ultimate goal is to achieve an improvement in the latency, reliability and capacity of the large number of robots, drones, droids and humans that will work together in the factory of the

V5G Day -Demo Social Robot



V5G Day -Demo Touch Internet

future. In this context, the new communication paradigm of mmW and continuous UDNs together with the use of multihop cellular communications play a transversal role. During the project, the performance of the systems will be evaluated: simulations, RF measurements, and experiments with a large number of devices will be performed to validate the design principles used. For this purpose, the VLC-CAMPUS-5G will be exploited. In addition, this project aims to attract the talent of women to the new job opportunities that 5G will generate.

During this first year of the project, the V5G Day event was held at the Conference Center, with the slogan "5G and the digitization of the industry". At the V5G Day event there were live demos, personalized information, collaboration, and co-working opportunities. Special emphasis was placed on the participation of female engineers specialized in 5G to promote the training and incorporation of women into the ICT sector, taking advantage of the great opportunity that opens with this technology. https://vlc-croft5g.com/

V5G Day Industry 5G round table

This project has been funded by the Prometeo 2020 grant (PROMETEO2020/040) from the Generalitat Valenciana to carry out R & D & I projects for research groups of excellence, 36 months duration (01/01/2020 - 30/12/2022).

AUDERE (Advanced Urban Delivery and Refuse Recovery)

AUDERE aims to design and develop an intelligent and innovative system for urban refuse collection and last mile delivery logistics. To fulfil this objective, a fleet of autonomous vehicles (autonomous mobile robots) are equipped with 5G connectivity to carry out last mile delivery and urban waste container recovery tasks. The AUDERE system will assess the technical, economic, social, and environmental viability in a range of use cases. Therefore, AUDERE will offer high-tech solutions to the growing forward and reverse logistics needs in our cities. Trials will be performed in two scenarios. The first one is the VLC-CAMPUS-5G of the Universitat Politècnica de València, which is equipped with the infrastructure of a private 5G mobile network that allows the validation of different use cases, such as logistics, automotive, industry, media, etc. In addition, among the main advantages of VLC-CAMPUS-5G we can mention that it is a closed and controlled environment, which could be considered as a small city due to its infrastructure, commercial and sports places, banks, parks and where more than 20,000 people move daily. The second scenario is the La Pinada District, which is an eco-district, the first in Spain, that will integrate the principles of sustainable urban development, creating an attractive environment for family living, work, and enjoyment of nature. The results of this project will define new technological products that can be deployed in Smart Cities or Smart Quarters. This year, the AUDERE project has been included as a use case within the 5G Pilots project in the Comunitat Valenciana where Orange participates as an infrastructure provider. The development of the AUDERE project is in its final stage of implementation, the intelligent system that automates the collection of urban waste, as well as the logistics in the delivery of goods and parcels through autonomous vehicles and 5G connectivity, were validated at the Universitat Politècnica de València at the end of November 2021.

The results of this project will define new technological products that can be deployed in Smart Cities or Smart Quarters. This project has been funded by The Agència Valenciana de la Innovació (AVI), 21 months duration (April 2020 – December 2021).

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

This is a project to validate the capabilities of 5G technology in Valencia, Spain, by testing 15 use cases that involve sectors of health, industry, energy, gaming, and tourism. In the 5G Valencia Pilots

participates Orange, Huawei, Arborea Intellbird, CFZ Cobots, Global Omnium Idrica, Etra Research and Development, Elewit (Grupo Red Eléctrica) and Robotnik. The project aims to contribute from three approaches: support the deployment of the first 5G networks in Spain; experiment with the network management techniques; and test the main capabilities of the technology: ultra-reliable and low-latency communications; mass machine-to-machine communications; and extremely high speed and capacity mobile broadband. ITEAM is involved in 5 out of 15 use cases, which are: (1) Robotic Remote diagnostic, (2) Fleet management: Robotics Remote control of AGVs, (3) Robotics-Remote inspection and maintenance, (4) 5G Digital Contents, and (5) Massive IoT for smart meters in supplies. The VLC-CAMPUS-5G of the Universitat Politècnica de València, has been chosen as one of the testing scenarios. Some of these 5G use cases demos, specifically in the field of telemedicine, remote inspection, and fleet management, were shown in front of senior officials from the national and local government, as well as managerial staff from Orange Spain, during the Red.es 5G pilots presentation event hosted by Orange Spain at the UPV on June 14th, 2021.

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

6G Evaluation Methodologies

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

This project is funded by Huawei as a part of our iTEAM – Huawei Joint Research Center, Duration 12 months, from 01/04/2021 to 30/03/2022.

Quantum Machine Learning for the AI Integration in 6G

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

This project is funded by iTEAM – Huawei Joint Research Center. Duration 12 months, from 01/04/2021 to 30/03/2022.

Customized materials for EM communications in the GHz and THz band

The project aims to develop full-spectrum phantoms, i.e., liquids and semisolids (gels) components with tailor-made electromagnetic properties fully adjustable in the range above 26GHz and up to 100MHz for a range of applications in 6G new devices and interfaces. This "custom EM materials" can be used in many areas like the physical interface between antennas and surfaces, the better impedance adaptation in wearables or implants, to develop "liquid" antennas, to build physical EM filters for certain bands, to improve human brain interfaces, and to explore the possibility of integrating these materials (in its gel configuration) in printed electronics or reconfigurable intelligent surfaces (RIS).

The scope of the project is to develop novel composite materials, on the basis of iTEAM's expertise, that can replicate the behavior of different human body tissues in an ultra-large frequency band.

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

AI Video-Assisted Radio Communications

The project combines Artificial Intelligence video tracking algorithms with reconfigurable radiating systems, to improve beamforming performance and vehicle's location. Current systems rely on the detection of sensing radio signals and their quality. These solutions are reactive, meaning that the system responds to the radio channel behaviour and changes accordingly. Many scenarios in which the future communication systems will be deployed, or are deployed nowadays, can be assisted by video information, to feed the reconfiguration algorithms of the radio systems and even to anticipate such configuration on the basis of predictive video analytics.

The aim of this project is to develop a prototype of a video-assisted beamforming panel, as a first proof of concept of the AI applied to the Physical Layer of beyond 5G radio, as well as to explore the application to reinforce the location and tracking of moving objects in indoor (industrial) environments, to define a potential follow-up of the work on that direction.

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

2.- Research results

2.1.- Featured publications

"Millimeter-wave Human Blockage Model Enhancements for Directional Antennas and Multiple Blocker."

D. Prado-Alvarez, Inca, D. Martín-Sacristán and J. F. Monserrat. IEEE Communications Letters, doi: 0.1109/LCOMM.2021.3095617

This manuscript targets a set of enhancement of the 3GPP body blockage model by proposing new criteria for: (i) the positioning of diffraction points over the body, (ii) the determination of the effective blockers from the set of potential blockers in a scenario taking into the account a blockage area determination concept, and (iii) the grouping of close blockers. Our approach is compared to real measurements at 30 GHz, showing a substantial decrease of the absolute error, while keeping the model simple.

"Limitations of ATSSS technology in ATSC 3.0 – 5G convergent systems" Carlos Barjau, David Gomez-Barquero, Hoiyoon Jung, Sung-Ik Park and Namho Hur. IEEE International Symposium on Broadband Multimedia Systems and Broadcasting 2021, doi: 10.1109/BMSB53066.2021.9547016

This paper explores the use of the 3GPP technology Access Traffic Steering, Switching and Splitting (ATSSS) to enable IP layer convergence between 5G and ATSC 3.0. ATSSS was first introduced in Release 16 and originally devised to integrate non-3GPP access networks such as WiFi and wireline into the 5G System; and is flexible enough to include IP-based broadcast standards like ATSC 3.0. The limitations of the ATSSS technology to enable this convergence are detailed in this paper. A proposal to overcome them with a high-level converged architecture between ATSC 3.0 and 5G, featuring ATSSS Release 17 characteristics, is additionally described. Presented at BMSB 2021, pending publication.

2.2.- Patents

"PROCEDIMIENTO DE ANÁLISIS DE LA COBERTURA EN ESPACIOS INTERIORES PARA REDES INALÁMBRICAS" (COVERAGE ANALYSIS PROCEDURE IN INTERIOR ENVIRONMENTS FOR WIRELESS NETWORKS)

Samuel Romero and Narcís Cardona. Ref. 202130290

"REFLECTOR PARA ONDAS MILIMÉTRICAS" (MILLIMITER WAVE REFLECTOR)

Samuel Romero and Narcís Cardona. Patent request P202130068

Photonics Research Labs

HEAD OF THE GROUP RESEARCH REPORT

The Photonics Research Labs (PRL) brings together research lines or Labs focused on different technologies and fields of application within the area of photonics and optical communications. Currently formed by nearly 50 researchers, PRL mission is to produce high-quality scientific knowledge in the field of optics, quantum optics and photonics, through research projects, R&D contracts and collaboration agreements with the private sector. Our research activity is focused on several applications of photonics, mainly on optical communications of analog and digital signals, radio-over-fiber systems, space-division multiplexing fibers, photonic integrated circuits, programmable photonics and fiber optic sensing and industrial scenarios.

PRL is nowadays involved in different H2020 EU funded projects: "NEuromorphic Reconfigurable Integrated Photonic Circuits as artificial image processor" (NEoteRIC), "European Network for High Performance Integrated Microwave Photonics" (EUIMWP), "Applications and Fundamentals of Microresonator Frequency Combs" (MICROCOMB) and "European Network on Future Generation Optical Wireless Communication Technologies" (NEWFOCUS). Of particular interest regarding excellence are the two projects granted by the European Research Council (ERC): Consolidator Grant "Revolutionizing fibre-wireless communications through space-division multiplexed photonics" InnoSpace and Advanced Grant "Universal microwave photonics programmable processor for seamlessly interfacing wireless and optical ICT systems" (UMWP-Chip).

Continuous work to transfer research results to the market has led to the foundation of 4 successful spin-off companies: VLC-Photonics (recently acquired by Hitachi High-Tech Corporation), Calsens, Ephoox engineering and iPronics programmable photonics (selected as one of the spinoff companies to watch in year 2020).

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

Also, follow us in:

- Twitter: @PRL_UPV
- LinkedIn: https://www.linkedin.com/in/photonicsresearchlabs/

1.- Project activities

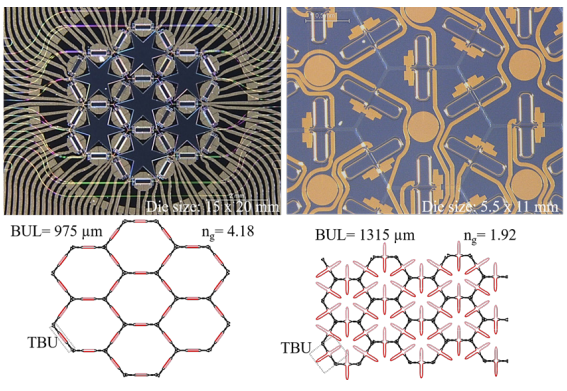
1.1.- Ongoing projects

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

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

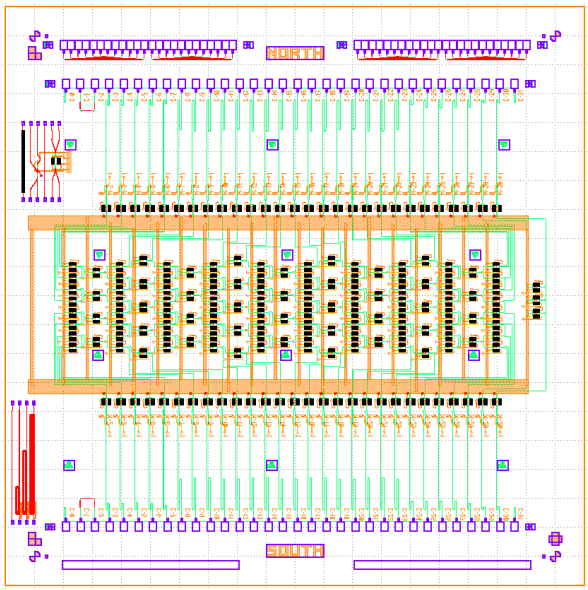
***Funding entity and duration**: European Research Council (ERC), 60 months*

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



Reconfigurable photonic integrated processor

integration in a Silicon Photonics chip. Its three specific objectives are: (1) The architecture design and optimization of a technology agnostic universal MWP programmable signal processor; (2) The chip mask design, fabrication and testing of the processor; and (3) The experimental demonstration and validation of the processor. Targeting record values in bandwidth and footprint its potential impact will be very large by unlocking bandwidth bottlenecks and providing seamless interfacing of the fiber and wireless segments in future ICT systems.



Design of a Photonic processor with a high node density

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

***Webpage of the project**: https://neoterich2020.eu/*

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

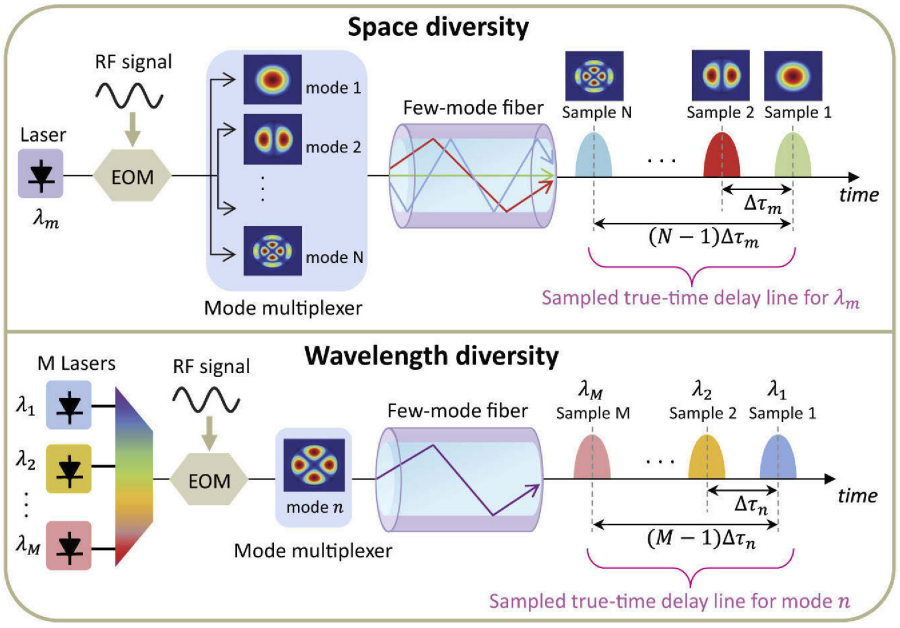
***Summary of the project**: The technological proposition of NEoteRIC aims to merge cutting edge photonic technologies like reconfigurable silicon integrated structures and planar ferroelectric schemes so as to spawn a disruptive generation of general purpose neuromorphic photonic chips, having hundreds of nodes, exhibiting supreme processing speed and consuming negligible power. Low-power & high-speed chip reconfiguration will unleash the true potentials of NEoteRIC's arsenal providing for the first-time photonic implementation of cutting-edge neuromorphic paradigms, multi-task capabilities and on-chip. NEoteRIC's pave a clear technological roadmap to revolutionize high speed imaging applications through careful escalating steps that start from the realization of innovative reconfigurable integrated photonic building blocks, moving to their encapsulation to low-power high-bandwidth machine learning subsystems and finally reaching to application-bound integrated systems able to deliver unparalleled performance in terms of frame rate and marginal power. Through NEoteRIC's photonic-FPGA neuromorphic platform cytometric data analysis will be performed in the analogue-optical domain, alleviating the need for high-speed electronics, offering unparalleled speed, eliminating offline data storage and minimizing power consumption due to photonic passive processing. NEoteRIC's devices can be directly implemented in a vast pallet of applications ranging from laser manufacturing to cyber security applications.*

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

***Webpage of the project**: https://cordis.europa.eu/project/id/724663*

***Funding entity and duration**: European Research Council (ERC), 66 months*

***Summary of the project**: Space-Division multiplexing (SDM) has been touted as a solution for the capacity bottleneck in digital communications by establishing independent light paths in a single fibre via multicore fibres (MCF) or few-mode fibres (FMF). This project envisions an unprecedented revolution in fibre-wireless communications through the powerful concept of SDM that lead to reconfigurable multifunctional architectures that will allow resource and functionality sharing by suitable software definition. The key challenge that is being faced in the project is to design, implement and demonstrate the feasibility of this new optical technology that offers the required parallelism for the implementation of a compact broadband tunable true time delay line (TTDL) using a single optical fibre, without the need to resort to bulky, heavy, power-consuming and expensive replication architectures, enabling important functionalities such as controlled signal distribution, signal filtering, antenna beam-steering, arbitrary waveform generation and multi-gigabit-per-second analogue-to-digital conversion. These functionalities, in turn, are required in a variety of Information Technology applications, such as broadband wireless and satellite communications, distributed antenna systems, signal processing, sensing, medical imaging and optical coherence tomography. This approach not only goes beyond the state-of-the-art properties of TTDLs, but it also leads to the novel concept of distributed signal processing than can be implemented in the link connecting*



Sampled true-time delay line realized by exploiting the spatial and wavelength diversities of an FMF.

a central office and a remote base station. The project outcomes will hence constitute a groundbreaking achievement in the next generation of fibre-wireless communications with dramatic scientific, technical, and economic impacts.

Sampled true-time delay line realized by exploiting the spatial and wavelength diversities of an FMF.

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

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

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

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

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

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

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

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

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

Summary of the project: *This network establishes and supports cross-sectorial*

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

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

Webpage of the project:

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

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

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

Webpage of the project:

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

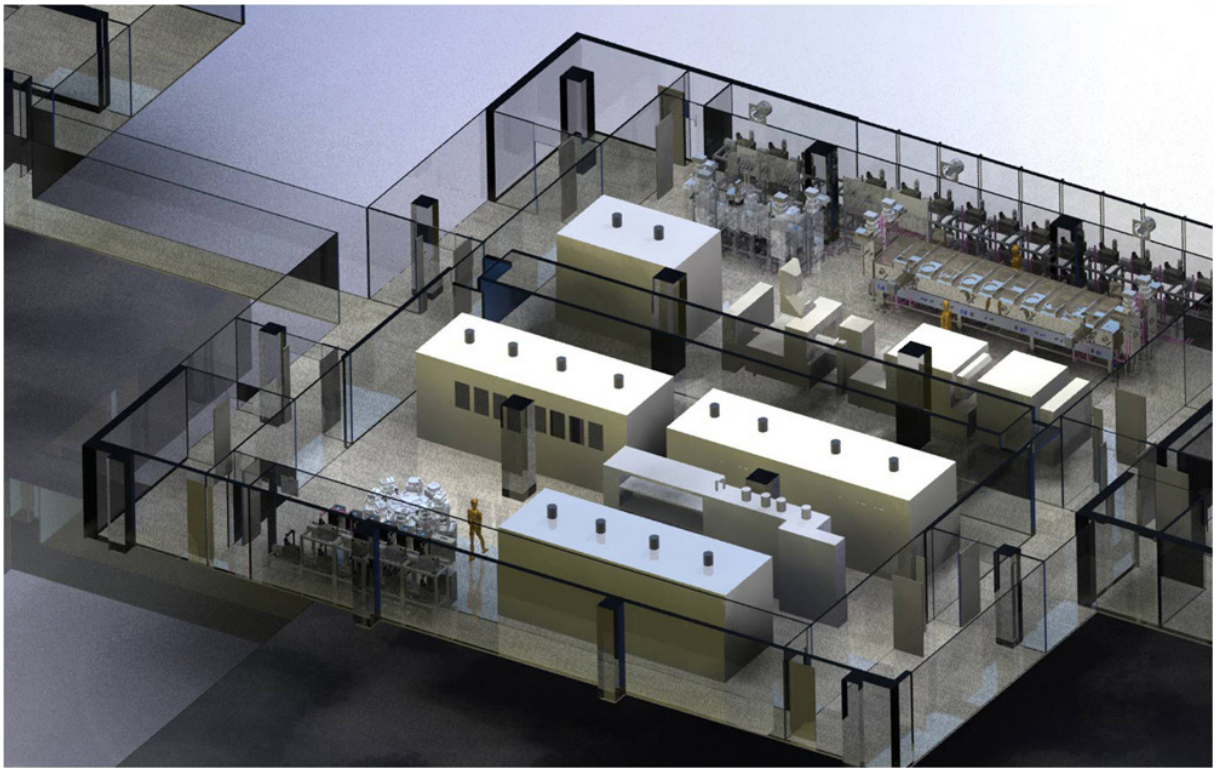
Summary of the project: *Integrated photonics has experienced exponential growth in the last 10 years, thanks to the research, development and commercial exploitation of generic technologies, which allow complex photonic systems into a single micro-chip. These technologies cover different parts of the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

Name of the project: UPVFAB Technopole (IDIFEDER/2020/028)

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

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

Summary of the project: *It's an infrastructure acquisition project to upgrade and retrofit. The infrastructure is at the class 100/10000 (ISO 5 / 7) 500 m2 micro-fabrication pilot line / clean room. More specifically, it is intended to complement the installation with the following equipment: 1) (Deposition) Sputter for cylindrical samples, 2) (Attack) Wet banks and attack tanks for samples and wafers up to 6 inches, 3) (Attack) Extraction and neutralization systems for wet banks and attack tanks, 4) (Metrology)*



UPVFAB Technopole facilities

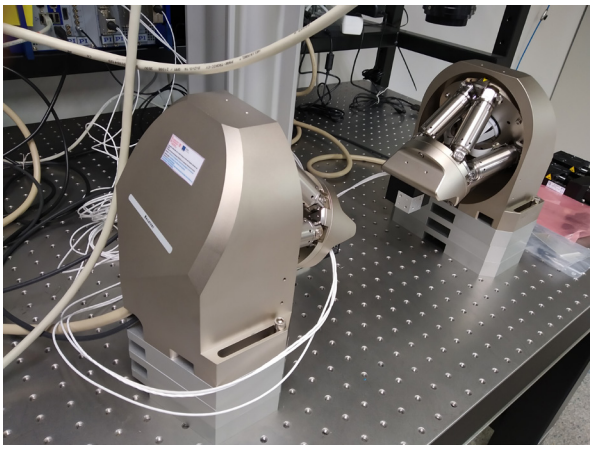
FTIR equipment with microscope for sample analysis. 5) (Post-process) Microscopic transfer equipment by priming chips from 2-4 inches wafers to 6 inches wafers. The general objective is to develop new technological processes in the work areas of the proposing groups (ITEAM, ITQ, CI2B), specifically: I) integrated photonics, II) integrated catalytic membranes and III) electro-chemical devices. A new 2-year ERDF action, "multi-level microfabrication technologies" (T-MFAB-MN, IDIFEDER/2021/046), will still strengthen and complement this key infrastructure.

Name of the project: Advanced Instrumentation for world class microwave and programmable photonics Research (IDIFEDER/2020/032)

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

Funding entity and duration: *Generalitat Valenciana and the European Regional Development Fund (ERDF), 27 months*

Summary of the project: *The Photonics Research Labs (PRL) has thoroughly enlarged and improved through this project the equipment and instrumentation available in its facilities due to the procurement of a last generation infrastructure to i) carry out measurements in the time domain of pulses and radio frequency signals up to 70GHz that will be used both in the temporal characterization of programmable photonic chips and the special MCF and FMF fiber-based components that process high-speed radio frequency and wireless input signals, ii) expand the measurement capabilities of the our programmable integrated photonics laboratory through the acquisition of programmable motorized nano-positioner equipment that allows six degrees of freedom (3 of position and 3 angular) for measuring individual chips. The objective is to complete the equipping of the silicon technology programmable chip measurement workstation, iii) provide fiber fusion and glass shaping functionalities that will allow to expand the capabilities of the PRL optical fiber laboratory, enabling the realization*



Six degrees of freedom nano-positioner

of splices between various types of optical fibers, considering both standard fibers and special fibers (multicore and few modes); the production of modal and geometric adaptation elements (Tapers) between different fiber cores; the writing of spherical lenses at the ends of the fibers and, in general, the realization of combiners (and splitters) of signals at the input (and output) of arbitrary optical fibers. As a result, the PRL has consolidated its world reference position in the field of Microwave Photonics, which will be still strengthened and complemented by the specific objectives pursued by the ERDF infrastructure project "Advanced Instrumentation for world class microwave and programmable photonics Research Phase 2" (IDIFEDER/2021/050) during the next two years.

Name of the project: Microwave Photonics IC Systemization and Development

Webpage of the project:

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

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

2.- Research results

2.1.- Featured publications

Title, Authors, Name of the publication, pages, year: "Broadband random optoelectronic oscillator", Z. Ge, T. Hao, J. Capmany, W. Li, N. Zhu & M. Li, Nature Communications 11, art. 5724, 2020

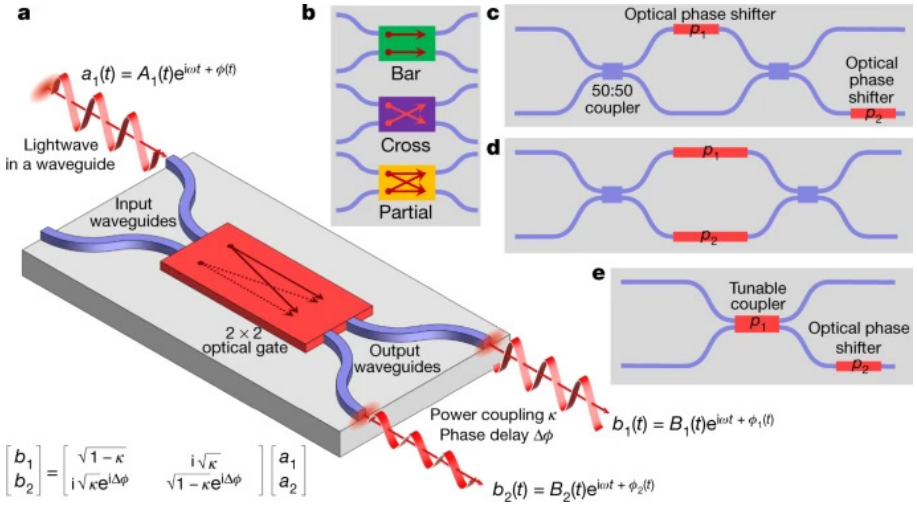
Brief summary of the paper*: Random scattering of light in transmission media has attracted a great deal of attention in the field of photonics over the past few decades. An optoelectronic oscillator (OEO) is a microwave photonic system offering unbeatable features for the generation of microwave oscillations with ultra-low phase noise. Here, we combine the unique features of random scattering and OEO technologies by proposing an OEO structure based on random distributed feedback. Thanks to the random distribution of Rayleigh scattering caused by inhomogeneities within the glass structure of the fiber, we demonstrate the generation of ultra-wideband (up to 40 GHz from DC) random microwave signals in an open cavity OEO. The generated signals enjoy random characteristics, and their frequencies are not limited by a fixed cavity length figure. The proposed device has potential in many fields such as random bit generation, radar systems, electronic interference and countermeasures, and telecommunications.*

Title, Authors, Name of the publication, pages, year: "Programmable photonic circuits", W. Bogaerts, D. Pérez, J. Capmany, DAB. Miller, J. Poon, D. Englund, F. Morichetti & A. Melloni, Nature, 586, pp 207-216, 2020

Brief summary of the paper*: The growing maturity of integrated photonic technology makes it possible to build increasingly large and complex photonic circuits on the surface of a chip. Today, most of these circuits are designed for a specific application, but the increase in complexity has introduced a generation of photonic circuits that can be programmed using software for a wide variety of functions through a mesh of on-chip waveguides, tunable beam couplers and optical phase shifters. Here we discuss the state of this emerging technology, including recent developments in photonic building blocks and circuit architectures, as well as electronic control and programming strategies. We cover possible applications in linear matrix operations, quantum information processing and microwave photonics, and examine how these generic chips can accelerate the development of future photonic circuits by providing a higher-level platform for prototyping novel optical functionalities without the need for custom chip fabrication.*

Title, Authors, Name of the publication, pages, year: "Dispersion-tailored few-mode fiber design for tunable microwave photonic signal processing ", E. Nazemosadat & I. Gasulla, Optics Express, 28, pp 37015-37025, 2020

Brief summary of the paper*: This paper presents a novel double-clad step-index few-mode fiber that operates as a five-sampled tunable true-time delay line. The unique feature of this design lies in its particular modal chromatic dispersion behavior, which varies in constant incremental steps among adjacent groups of modes. This property, which to the best of our knowledge has not been reported in any other few-mode fiber to date, is the key to tunable operation of radiofrequency signal processing functionalities implemented in few-mode fibers. The performance of the*



a, A 2 × 2 optical gate mixes the modulated optical waves a1 and a2 from two input waveguides, controlling both the power coupling κ and the phase delay Δϕ of the output waves b1 and b2. b, the gate can be tuned between 'bar' and 'cross' states. c–e, the gate can be implemented as a circuit with two degrees of freedom, p1 and p2, such as an MZI with two optical phase shifters, or a tunable coupler with an additional phase shifter.

designed true-time delay line is theoretically evaluated for two different microwave photonics applications, namely tunable signal filtering and optical beamforming networks for phased array antennas. In the 35-nm optical wavelength tuning range of the C-band, the free spectral range of the microwave filter and the beam-pointing angle in the phased array antenna can be continuously tuned from 12.4 up to 57 GHz and 12.6° up to 90°, respectively.

Title, Authors, Name of the publication, pages, year: " Mode-division multiplexing for microwave signal processing", E. Nazemosadat & I. Gasulla, IEEE Photonics Society Summer Topicals Meeting Series, 2021

***Brief summary of the paper**: This paper presents an overview of different mode-division multiplexing fiber technologies engineered to provide tunable microwave signal processing, including signal filtering and optical beamforming for phased-array antennas. The exploitation of both the space and wavelength dimensions brings advantages in terms of increased compactness, flexibility, and versatility.*

Title, Authors, Name of the publication, pages, year: "Fiber Optic Shape Sensors: A comprehensive review", I. Floris, J. M. Adam, P.A. Calderón & S. Sales, Optics and Lasers in Engineering, 139, pp 106508, 2021

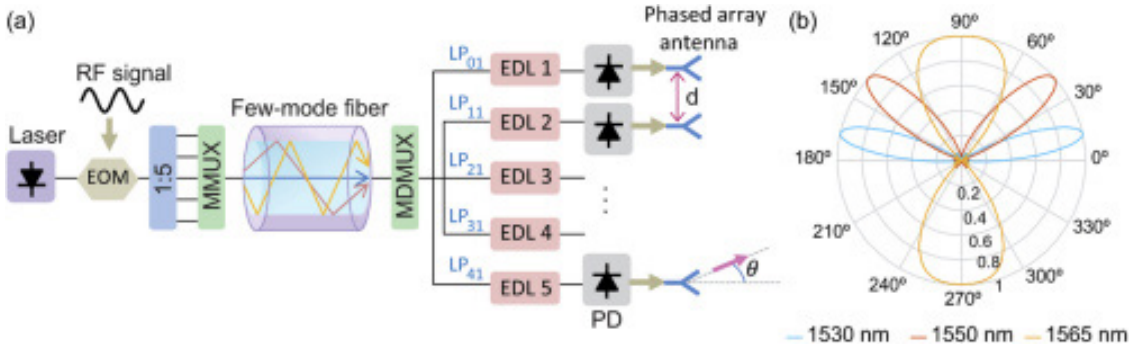
***Brief summary of the paper**: This paper presents an ambitious review of the current state of the art of Fiber Optic Shape Sensors (FOSS) based on Optical Multicore Fibers (MCF) or multiple optical single-core fibers with embedded strain sensors and provides a comprehensive analysis of a wide range of aspects, comprising: existing alternative technologies; an overview of optical fiber sensors; characteristics and advantages of fiber optic shape sensors; historical achievements; applications; performance and error analysis; and present and future perspectives.*

Title, Authors, Name of the publication, pages, year: " Fiber Bragg Gratings for Medical Applications and Future Challenges: A Review", D. Lo Presti, C. Massaroni, C. S. Jorge Leitao, M. F. Domingues, M. Sypabekova, D. Barrera, I. Floris, L. Massari, C. M. Oddo, S. Sales, I. I. Iordachita, D. Tosi & E. Schena, IEEE Access, 8, pp 156863 - 156888, 2020.

***Brief summary of the paper**: This paper reviews the FBG-based measuring systems, their principle of work, and their applications in medicine and healthcare. Particular attention is given to sensing solutions for biomechanics, minimally invasive surgery, physiological monitoring, and medical biosensing. Strengths, weaknesses, open challenges, and future trends are also discussed to highlight how FBGs can meet the demands of next-generation medical devices and healthcare system.*

Title, Authors, Name of the publication, pages, year: "Optical-phased array beam-steering using multi-input slab coupler in silicon nitride waveguides", P Muñoz, D Pastor, J Benítez, G Micó, LA Bru, DJ Goodwill & E Bernier, Optical Fiber Communication Conference, W1D. 4, 2021

***Brief summary of the paper**: A 2D beam-steering optical phased array is demonstrated in SiN. The multiple-input slab- coupler reduces OPA footprint 8x versus previous single-input*



Implementation of an optical beamforming network using the designed FMF in space diversity operation.

designs. Measured field of view is 15° x 2.8°. Gaussian beam full width is 0.36° x 0.175°.

Title, Authors, Name of the publication, pages, year: "On the 40 GHz Remote versus Local Photonic Generation for DML-based C-RAN Optical Fronthaul", L. Vallejo, J. Mora, D.-N. Nguyen, J. Bohata, V. Almenar, S. Zvanovec and B. Ortega, Journal of Lightwave Technology, 2021

***Brief summary of the paper**: The paper presents a full comprehensive formulation of the frequency response of a system based on a directly modulated laser transmitting data over 40 GHz signal generated by external carrier suppressed modulation and optical frequency multiplication. Theoretical and experimental characterization of the system response at baseband and mmW band for local and remote generation setups show very good agreement.*

Title, Authors, Name of the publication, pages, year: "Efficiency Analysis of a Truncated Flip-FBMC in Burst Optical Transmission", M. S. Bahaaelden, B. Ortega, R. Pérez-Jiménez & M. Renfors, IEEE Access, 9, pp. 100558-100569, 2021

***Brief summary of the paper**: A novel Flip-filter bank multicarrier (Flip-FBMC)-based transmultiplexer (TMUX) with offset quadrature amplitude modulation is proposed to enhance the transmission performance compared to a conventional Flip-OFDM system. Moreover, the possibility to reduce the TMUX response (latency) and increase spectral efficiency is investigated for the first time through a tail shortening method.*

2.2.- Patents

P. Muñoz, D. Pastor, G. Micó, L.A. Bru & J. Benítez. "OPTICAL-PHASED ARRAY BEAM-STEERER", 87246075US0. 2021.

J. Villatoro, S. Sales & J. Madrigal, "COUPLED-CORE OPTICAL FIBER WITH FIBER BRAGG GRATING AND SENSING DEVICE", EP21382402, 2021

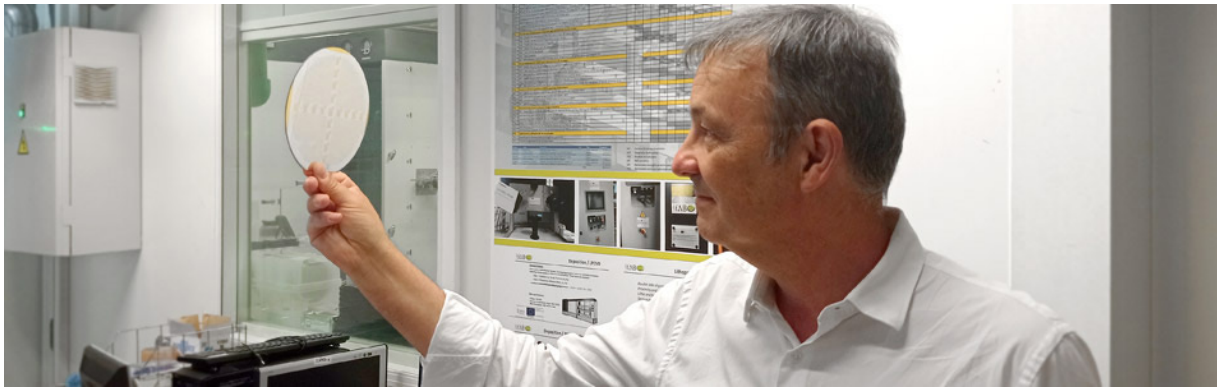
2.2.- Awards.

King Philip VI of Spain hands the National Research Award in the Engineering area to José Capmany.

The jury of the 2020 National Research Awards decided to grant **José Capmany Francoy**, lead researcher of the Photonics Research Labs (PRL), this award for his pioneering contribution to the field of photonic engineering and optical telecommunications, through a cutting-edge scientific activity with a significant international impact. In addition, he highlighted the exemplary nature of Capmany's professional career, his leadership capacity and his perseverance in developing the practical application of his research. "This award recognizes the top-level research and technology transfer work that has been carried out by my research group for the last 25 years. For me is an honor to work with the members of my team and learn from them in a daily basis, to jointly contribute to the development of the science and the competitiveness in Spain, what is especially important in difficult times like these", pointed out professor Capmany.

R&D and innovation, essential

José Capmany receiving the prize



José Capmany holding a wafer

The National Research Awards aim to recognize the merit of Spanish researchers who are carrying out an outstanding work in scientific fields of international relevance and their extraordinary contribution to the scientific progress, the transfer of technology and the progress of Humanity. These prizes grant 30.000€ per category.

National Research Awards ceremony has been chaired by the kings of Spain, **Philip VI and Letizia**, along with the minister of Science and Innovation, **Pedro Duque**, who highlighted the special relevance of the awards granted this year because "effective vaccines to stop coronavirus pandemic have been delivered in a surprisingly short time period thanks to science and innovation research". The minister said during his speech that R&D and innovation is "essential to improve competitiveness of Spain, what makes possible high quality and highly paid employment". Prof. Capmany and the rest of the excellent scientific researchers awarded this year "play a key role to achieve that objective".

José Capmany receives the Engineering Achievement Award from IEEE Photonics Society

José Capmany, Head of the Photonics Research Labs-iTEAM and Full Professor at the Escuela Técnica Superior de Ingeniería de Telecomunicación (ETSIT) of the Universitat Politècnica de València (UPV), has obtained a new international recognition for his scientific career.

This time, Professor Capmany has been honored by the IEEE Photonics Society, the most prestigious organization in the field of Photonics. This organization bestowed him the Engineering Achievement Award for his "pioneering and sustained contributions to integrated microwave and programmable photonics including the invention of Field Programmable Photonic Gate Arrays".

"I am really proud to receive this prize from the IEEE Photonics Society, that not only recognizes my work, but also the great effort made by my teammates, specially by the other co-founders of iPRONICS. What makes this award remarkable is that it recognizes excellent scientific research altogether with the engineering development and technological transfer of the scientific results", highlighted Prof. Capmany.

A technological revolution in telecommunications

Photonics is revolutionizing the field of telecommunications. It is a real breakthrough that will have a direct impact not only in the industrial sector but also in our daily life. Among the numerous applications of this technology, it is worth highlighting 5G communications and autonomous driving, as well as quantum and neuromorphic computing, which develops chips that imitate the neural network structure of the human brain.

According to José Capmany, "These applications need to process a huge amount of data at a high speed with extreme versatility, and this is just what both microwave and programmable photonics can provide. In fact, we are currently developing a programmable photonic circuit at the Photonics Research Labs to meet the highly demanding requirements of these new applications."

Design of optical fiber sensors and interrogation schemes

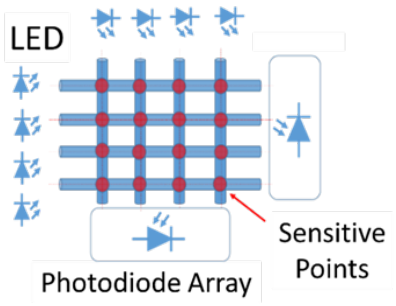
Author: Demetrio Sartiano
Supervisor: Dr. Salvador Sales Maicas and Dr. David Barrera Vilar

Defended on 01,14,2021

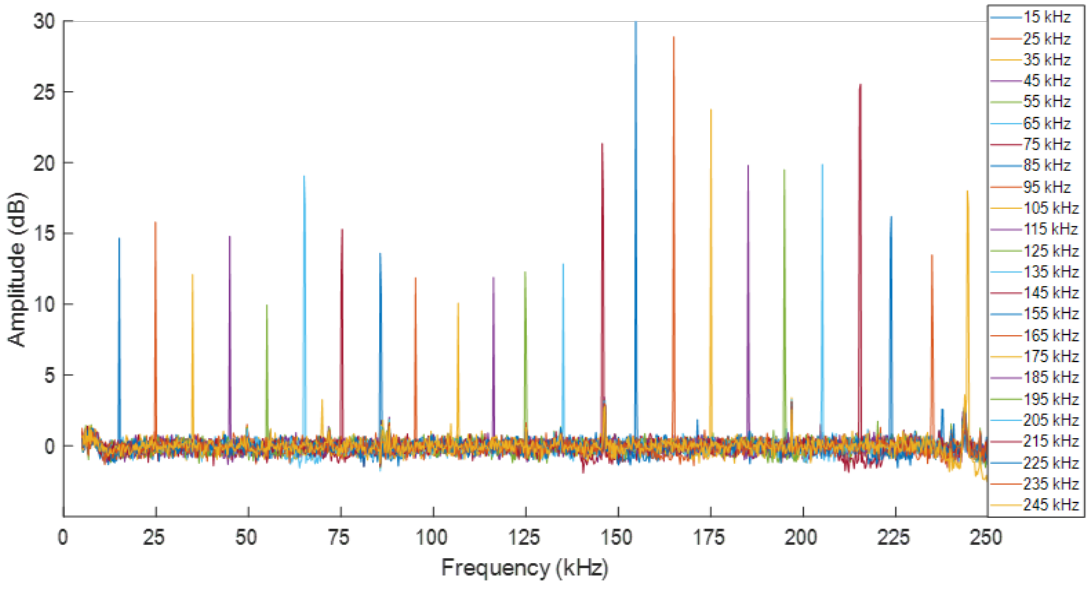
SUMMARY

Optical fibers are devices largely used in telecommunication field since their discovery. In the last decades, optical fibers started to be used as photonic sensors. The first works were focused on the measurement of physical dimensions to a specific point. Afterward, emerged the possibility to measure the optical fiber properties at different locations along the fiber. These kinds of sensors are defined as distributed sensors. The optoelectronic components were developed and investigated for telecommunications. The progress in telecommunication made possible the development of optical fiber sensors interrogation systems, growing in parallel with the advances of telecommunications.

Optical fiber interrogation systems were developed to use a single standard monomode optical fiber as a sensor that can monitor tens of thousands of sensing points at the same



Plastic optical fibers sensor matrix for 2D pressure sensing



Response for a wide range of vibration frequencies of the FBG-based vibration sensor

time. The methods that extract the sensing information from the backscattered signal in the optical fiber are widely employed because of the easiness of access to the sensor element and the flexibility of these systems. The most studied are the reflectometry in time and frequency domains. The optical time domain reflectometry (OTDR) was the first technique used to detect the position of the failures in the optical fiber communication networks. Using phase sensitive OTDR it is possible to sense strain and temperature at a specific position. In parallel, fiber Bragg gratings (FBGs) became the most widely used devices to implement discrete optical fiber sensors. Multiplexing techniques were developed to perform multi points sensing using these gratings. The reflectometry performed interrogating weak FBGs arrays demonstrate to improve the performance of the system employing a single mode fiber.

The interrogation systems nowadays have some drawbacks. Some of them are limited speed of interrogation, bulkiness, and high cost. New interrogation systems and optical fiber sensors were developed in this doctoral thesis to overcome some of these drawbacks. Plastic optical fiber sensors demonstrate to be an innovative platform to develop both new sensors and low cost, easy to implement interrogation systems for commercial plastic fibers. Reflectometry in time domain and microwave photonic techniques were investigated for the interrogation of weak gratings array allowed to simplify the interrogation system for the sensing of temperature and vibration.

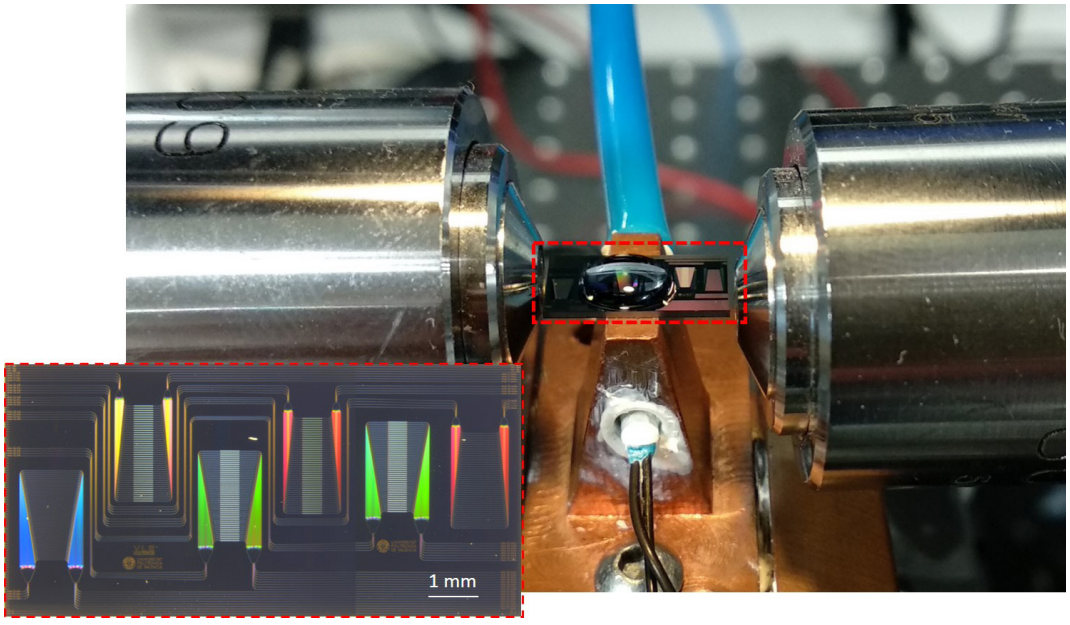
Integrated spectroscopic sensor fabricated in a novel Si3N4 platform

Author: Gloria Micó Cabanes
Supervisor: Dr. Pascual Muñoz Muñoz and Dr. Daniel Pastor Abellán

Defended on December, 16th, 2020

SUMMARY

This thesis is focused on the model, design and experimental demonstration of an integrated spectroscopic sensor based on a modified Arrayed Waveguide Grating (AWG). The device has been designed and fabricated in a new silicon nitride (Si3N4) on silicon oxide (SiO2) platform developed in Spain. The work performed for this thesis can be then divided into two main sections. In the first part, an overview of the existing Si3N4 platforms and their state of art is described, along with the report on the fabrication and characterization of our 300 nm guiding film height Si3N4 platform. On the second part, the device named Integrated Optical Spectroscopic Sensor (IOSS) is presented. The IOSS consists of an AWG which arrayed waveguides are divided into two sub-sets engineered to replicate the AWG channels. The waveguides of one of the sub-sets contain sensing windows, defined as waveguides sections which core is in contact with the surrounding media. Thus, the sensing is performed through evanescent field interaction with the sample deposited. The waveguides from the second sub-set remain isolated. Therefore, the device provides both sensing and reference spectra. The IOSS mathematical model, design procedure and proof of concept configured for absorption spectroscopy are reported in this thesis.



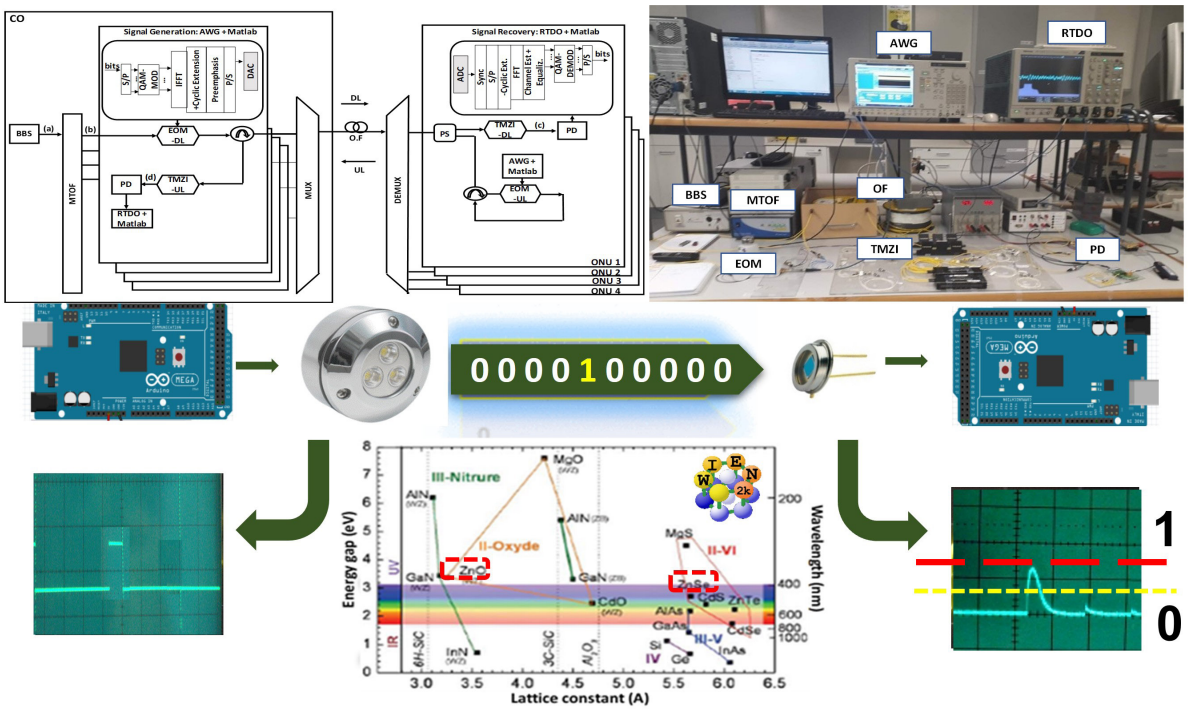
Design of communication systems based on broadband sources for fiber and free space optical links

Author: Imene Sekkiou
Supervisor: Dr. Beatriz Ortega and Dr. Benoudnine Hadjira

Defended on June, 28, 2021

SUMMARY

Optical wireless communication (OWC) is a very promising technology for future wireless communications developments. It has attracted increasing interest from researchers and several companies around the world are currently working on the development of very high-speed wireless networks. The scientific and industrial communities believe that OWC will be a complementary technology in its various forms: Free Space Optical communications (FSO), Visible Light Communications (VLC), Light Fidelity (Li-Fi). In fact, the optical spectrum has been considered for many years as a great opportunity for wireless communications especially due to the saturation of the radio frequency (RF) spectrum. This dissertation deals with the use of broadband sources in visible light transmission systems (VLC) as well as fiber optic systems. To carry out the research, three parts can be distinguished: In the first part, we consider the study and simulation of Light Emitting Diode (LED) components with the WIEN2k software by focusing on the optical and electrical properties of elements II-VI. The second part deals with the design, implementation and testing of different VLC communication prototypes for analogue and digital transmission in simplex and half-duplex mode. We have demonstrated that an OWC system using a broadband source (i.e., an LED)



can be used not only for data transmission, but also for wireless power transmission. Moreover, the synchronization problem and the detection of level “1” or “0” of a bit often arise in the optical wireless communication systems. This is a result of the attenuation nature of the light over the distance and the problem of Non-Line-Of-Sight (NLOS) between the emitter and the receiver. To deal with this problem, a communication protocol ensuring reliable digital data transmission with an adaptive bit level detection algorithm has been provided and its effectiveness has been demonstrated by the transmission of texts and images. In addition, this thesis provides a solution for the implementation of wavelength division multiplexed - orthogonal frequency division multiplexed (WDM-OFDM) transmitters based on the use of broadband sources in the infrared spectrum for centralized bidirectional fiber networks. Despite the chromatic dispersion that avoids the use of this type of optical sources, the inclusion of certain structures before detection allows the transmission of OFDM signals in optical links. Carrier reuse, dynamic bandwidth allocation and multiband OFDM signals transmission will be experimentally demonstrated by using optical broadband sources in WDM networks. The main results obtained during this thesis work demonstrate the study procedures, for each part, the effectiveness of the proposed solutions as well as the constraints encountered.

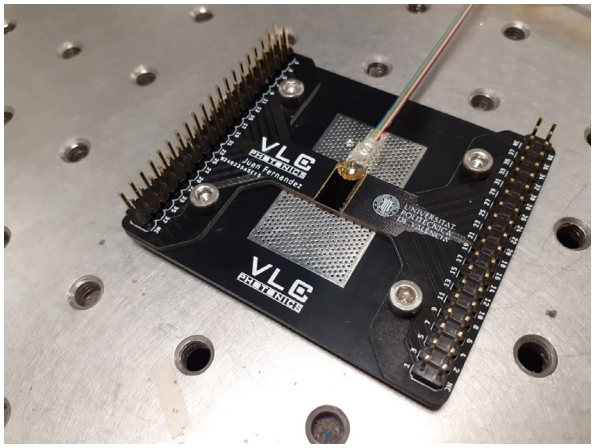
Reconfigurable reflective arrayed waveguide grating on silicon nitride

Author: Juan Fernández Vicente
Supervisor: Dr. Pascual Muñoz and Dr. José David Doménech

Defended on March, 26, 2021

SUMMARY

This thesis is focused on the modelling, design and experimental demonstration for the first time of Reconfigurable Reflective Arrayed Waveguide Grating (R-RAWG) device. In order to build this device, that can be employed in spectrometry, a silicon nitride platform termed CNM-VLC has been chosen since this material allows to operate in broad range of wavelengths. This platform has the necessary elements, but some limitations because the operation of this device had a low performance. Therefore, a methodology has been developed and validated, which has allowed to obtain better splitters. Also an inverted taper has been designed, which has considerably improved the coupling of light to the chip. This has been possible thanks to an exhaustive analysis of existing options in the literature, that has allowed choosing the best option to make a reconfigurable mirror on the platform without changing or adding new manufacturing steps. Reconfigurable mirrors have been demonstrated by using feedback splitters. Furthermore, codes have been developed to predict the behaviour of the actual device. With all the work done, a R-RAWG has been designed by using certain considerations so that it can operate over a broad wavelength range and the phase actuators are not in danger of being damaged. A code has also been developed for the modelling of the R-RAWG, which allows manufacturing imperfections to be considered, thanks to this, a method or algorithm called DPASTOR has been developed. DPASTOR resembles machine learning to optimise the response by just using the optical output power. Finally, a PCB and an assembly with the chip interconnected to it have been made and designed. Moreover, a measurement method has been developed, which has made it possible to have a stable response and to demonstrate a multitude of optical filter responses with the same device.



Improving DASH video streaming with variable bitrate encoding through the Look Ahead algorithm and playback coordination mechanisms, and proposal of new metrics for QoE assessment

Author: Román Belda Ortega
Supervisor: Dr. Juan Carlos Guerri Cebollada and Dr. Ismael de Fez Lava

Defended on 07,17,2021

SUMMARY

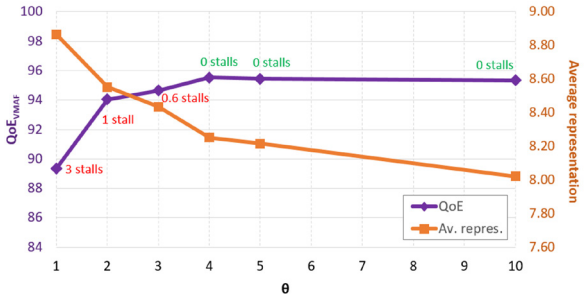
This thesis presents several proposals aimed at improving video transmission through the DASH (Dynamic Adaptive Streaming over HTTP) standard.

This research work studies the DASH transmission protocol and its characteristics. At the same time, this work proposes the use of encoding with constant quality and variable bitrate as the most suitable video content encoding mode for on-demand content transmission through the DASH standard.

Based on the proposal to use the constant quality encoding mode, the role played by adaptation algorithms in the user experience when consuming multimedia content becomes more important. In this sense, this thesis presents an adaptation algorithm called Look Ahead which, without modifying the standard, allows the use of the information on the sizes of the video segments included in the multimedia containers to avoid making adaptation decisions that lead to undesirable stalls during the playback of multimedia content.

Comparison of the VMAF value of each segment of the "Elephants Dream" video encoded at constant quality (CRF 45) and constant bitrate (1.13 Mbps)

In order to evaluate the improvements of the presented adaptation algorithm, three models of objective QoE evaluation are proposed. These models allow to predict in a simple way the QoE that users would have in an objective way, using well-known parameters such as the average bitrate, the PSNR (Peak Signal-to-Noise Ratio) and the VMAF (Video Multimethod Assessment Fusion). All of them applied to each segment.



Evolution of the number of stalls, average representation, and the QoE with the number of future segments considered by Look Ahead (Θ)

Finally, the DASH behavior in Wi-Fi environments with high user density is analyzed. In this context, there could be a high number of stalls in the playback because of a bad estimation of the available transfer rate due to the ON/OFF pattern of DASH download and to the variability of the access to the Wi-Fi environment. To relieve this situation, a coordination service based on SAND (MPEG's Server and Network Assisted DASH) is proposed, which provides an estimation of the transfer rate based on the information of the state of the clients' players.

Setup of 36 tablets used to evaluate the proposed SAND based coordination mechanism

Advanced Techniques for the Design and Optimization of Multi-Band and Reconfigurable Microwave Waveguide Filters

Author: Juan Carlos Melgarejo Lermas
Supervisor: Dr. Vicente E. Boria Esbert and Dr. Santiago Cogollos Borrás

Defended on: 07/30/2021

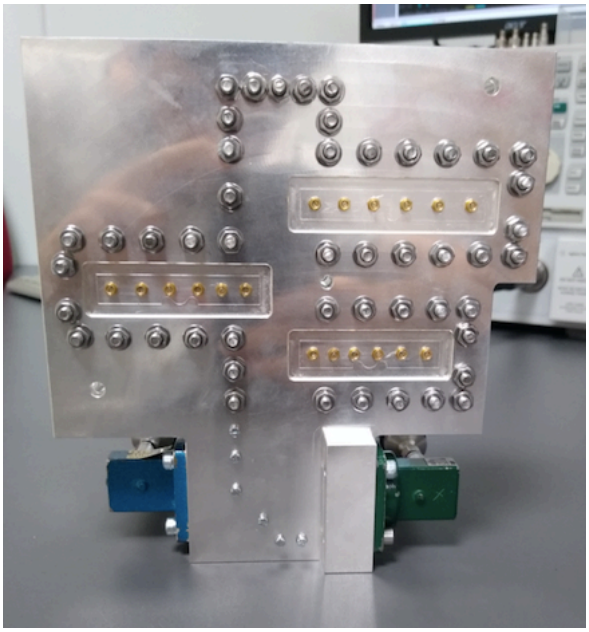
SUMMARY

The need for ever increasing data rate of modern communication systems has motivated companies in the space sector to exploit higher frequency bands, such as Ku, K and Ka, in order to offer wider bandwidths to their customers. However, as the frequency increases, the wavelength decreases, and all waveguide hardware becomes smaller and more sensitive to deviations from the ideal dimensions that normally occur when manufacturing the devices. In order to compensate for these deviations (or errors), tuning elements must then be added to the hardware and included in the design process.

In this context, therefore, we focus on the investigation of novel design strategies for filters and multiplexers with the objective of including all necessary non ideal factors in the design process.

It is important to note in this context that, once the filters are manufactured, the tuning elements are usually adjusted manually until the desired target performance has been achieved. However, successfully performing this task requires a considerable amount of time and very significant previous experience in tuning microwave filters. Consequently, an additional goal of our research work is to propose efficient and systematic tuning procedures so that anyone, regardless of their previous tuning experience, can successfully perform this difficult task.

In addition to the increasing data rates, another current challenge of advanced communication systems is the ability to be reconfigured remotely to adjust to changes in customer demands. The use of multi-function or reconfigurable devices is then an attractive possible solution. In this context, therefore, we also investigate new families of multi-band waveguide filters that can be used to accommodate several pass bands in the same filtering device. Furthermore, we also propose a new family of reconfigurable devices with several discrete states that can be easily controlled remotely.



Development of New Tunable Passive Microwave Components in Waveguide Technology

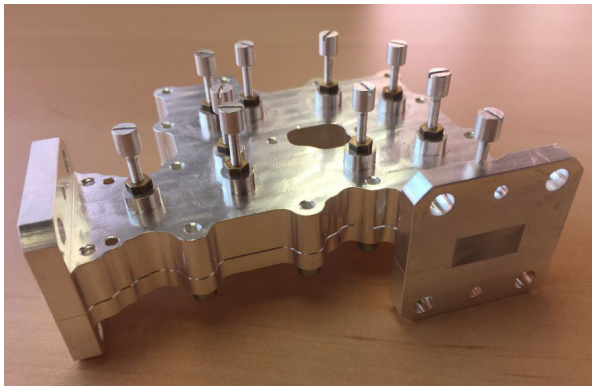
Author: Javier Ossorio García
Supervisor: Dr. Vicente E. Boria Esbert

Defended on April, 7, 2021

SUMMARY

The main objective of this doctoral thesis is the study, development, design and manufacture of new passive microwave components in waveguide technology, such as filters and multiplexers, that operate in the high frequency bands of current and future telecommunication satellite payloads between 12 and 40 GHz (Ku, K and Ka bands). The new solutions developed must offer both classic and advanced (elliptical) responses, as well as the possibility of being reconfigured both in terms of center frequency and bandwidth. The motivation for this research is to address the current and future needs of space communication systems which require a higher data transmission rate (that is larger bandwidths), as well as flexibility with respect to the operating frequency to dynamic adaptation to possible changes in user demands.

In this context, we propose in this thesis alternative microwave filter structures in metallic waveguide, as well as novel solutions. We explore different approaches to adjust the filter performance, using both traditional metallic tuning screws as well as tuning elements made with different dielectric materials. We also advance the state-of-the-art by developing higher performing Space Mapping procedures for the design, optimization and tuning of the



filter structures that we propose. The objective is to improve the response of the devices and reduce, at the same time, their manufacturing time and costs.

As a fundamental element of our work, in addition to theoretical developments, we also apply the findings of our research to the design, manufacture and measurement of a number of more complex components, such as diplexers and integrated switches and filters. They are practical devices to demonstrate the ability of the novel filters that we propose to satisfy the requirements of current and future advanced satellite payloads.

[Waves]

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