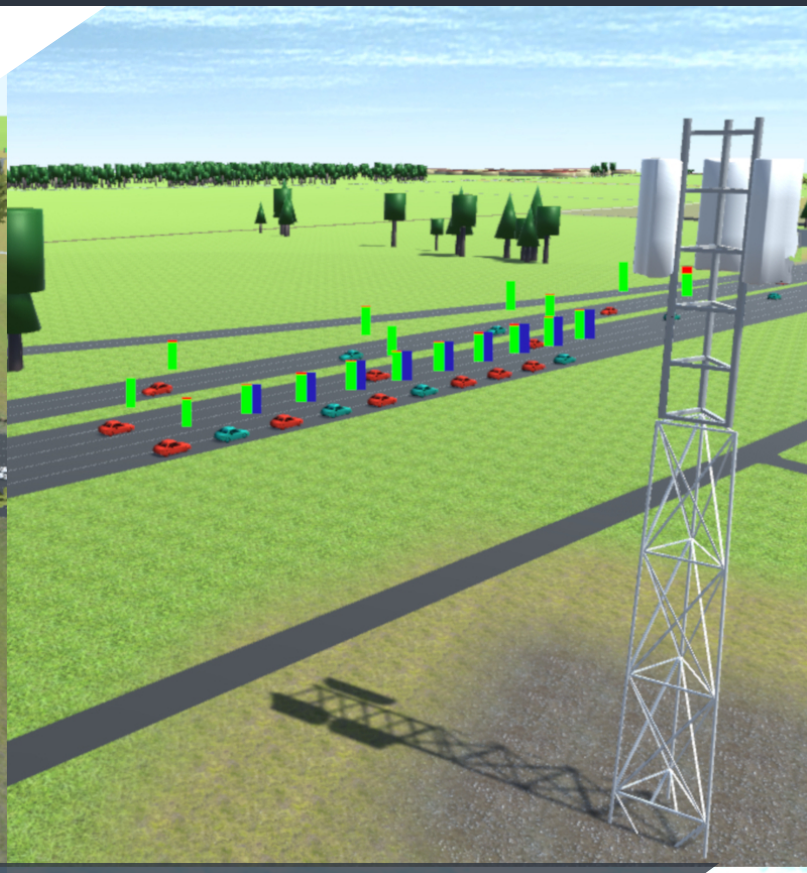
2018
year 10



[Waves]

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

iTEAM Instituto de Telecomunicaciones y Aplicaciones Multimedia

[Waves]

2018
year 10

Cover
System level simulator for autonomous car emulation.
Currently used in the 5G-CARMEN H2020 project

ISSN: *1889-8297*

INDEX

Annual Research Report 2018/2019

Theses Summary

INDEX

Message from the Director

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

Dear reader,

What you have in your hands, or screen, is a brief summary of the scientific production of the year 2018 of the iTEAM Research Institute. As you can realise from the next pages, iTEAM has consolidated as a centre of excellence in several disciplines of Telecommunications. Our researchers lead and participate in more than 20 projects of the European framework programme H2020, demonstrating their capabilities to generate new knowledge, and their tireless commitment to the constant search of new scientific and technological challenges, and of funding opportunities to keep growing.

I am particularly proud to say that, thanks to that, iTEAM is nowadays employing more than 110 researchers, quite over the numbers of many private research centres, which corresponds to more than two thirds of the iTEAM's total staff, and that is quite above the percentages of any other Spanish public R&D institutions.

Where's the magic? Sociologists state that while small groups can be self-organised and work without a clear leadership, and mid-size groups require a leader and an organisation structure to run, big groups over one hundred persons can only remain stable and progress if all their members feel being part of a common imaginary, which they recognise as their own brand, and to which they dedicate all their efforts. This is the case of iTEAM, which already counts with 170 people at the end of 2018, and which works, progresses, and keeps growing in productivity and excellence because all our researchers keep caring about the common brand of the Institute.

It's not about magic, it's about the Brand!

Open Standards for the Internet of Things

M. Ángeles Simarro, Paola Guzmán, M. Ángeles Rodríguez,
Pau Arce, Gema Piñero, Alberto Gonzalez, Juan Carlos Guerri
Institute of Telecommunications and Multimedia Applications,
Universitat Politècnica de València,
8G Building, access D - Camino de Vera s/n - 46022 Valencia (Spain)
Corresponding author: mdesiha@iteam.upv.es

ABSTRACT

The Internet of Things, commonly abbreviated as IoT is a novel paradigm that describes the idea of everyday physical objects being connected to the internet. This includes everything from mobiles, vehicles, air conditioners, headphones, wearable devices and almost anything. Unquestionably, the IoT idea has a high impact on several aspects of everyday life and behavior of potential users. Consequently, companies have started to introduce numerous IoT based products and services and several consortiums have been formed to define protocols and standards for the IoT. This article aims to provide a brief revision of the state of the arte in the IoT field. On the other hand, the Audio and Communications Signal Processing Group and the Multimedia Communications Group of the ITEAM are currently involved in different research projects related to the IoT concept. These projects are also briefly summarized in this article.

Keywords: Internet of Things, NB-IoT, LTE-M, FIWARE, MAtchUP project, SSEnCe project.

1.- INTRODUCTION

The Internet of Things (IoT) paradigm refers to a global network of interconnected things, that is, devices such as sensors equipped with a telecommunication interface, processing and storage units [1]. This communication paradigm also called the Internet of Everything is a new technology paradigm that should enable integration of potentially any object with the Internet, thus allowing new forms of interactions with each other. The interconnected objects are able to communicate, exchange information, take decision, invoke actions and provide amazing services.

The IoT is an extremely challenging topic, it is one of the most important areas of future technology and the debate on how to put it into practice is still open. The IoT provides connectivity for anyone at any time and place to anything, moving towards a society where everything and everyone will be connected [2]. In fact, 50 to 100 billion things expected to be connected to the Internet by 2020 [3]. IoT is building a worldwide infrastructure that will influence a lot of aspects of our daily life, a few examples of applications scenarios are for example domotics, assisted living, e-health and enhanced learning.

With the advancement of the IoT technology, smart devices are nowadays equipped with different types of sensors and are able to connect and communicate over the Internet. For instance, cellular networks standards need to add new techniques to improve the network performance to address traffic patterns generated by an increasing number of IoT devices [4]. No single technology or solution is ideally suited to all the different potential massive IoT applications. As a result, the mobile industry is standardizing several technologies, including Long Term Evolution for Machine (LTE-M) and Narrow Band IoT (NB-IoT) [5].

The wide heterogeneity of devices, operating systems, platforms and services available make it necessary to solve some of the essential problems of applications developers. Several industrial, standardization and researches are currently involved in the activity of development of solutions to fulfill the technological requirements. The usual battle is between proprietary platforms, which allow the interoperability only of devices that have been certified by the manufacturer of the IoT system, and open source platforms that offers open standards that everyone can share and adopt. Open source platforms are considered more promising when compared with proprietary alternatives mainly due to their faster integration. The open standard may include open specifications and assures the interconnectivity and interoperability across IoT. Some examples are the oneM2M2 [6] which is a global partnership developing standards for machine to machine communications and the IoT; Wi-SUN alliance[7] is a global association to promote certified standards that coordinate various wireless system and standardize power levels, data rates, modulations among others and Open Connectivity Foundation (OCF) [8] is dedicated to ensuring secure interoperability for consumers, businesses and industries.

Thereby, the IoT consists of smart devices equipped with different type of sensors and actuators. These devices can sense, perform computation, take intelligent decision and transmit useful information over the Internet. The information is the sensed data about, temperature, orientation, humidity, noise, etc.. depending on the type of sensors. In the context of audio related task, Acoustic Sensor Networks (ASNs) are especially important for communication. Each node in the network makes its own noisy measurement of the sound field and communicates with other nodes by sending and receiving information. Regarding to IoT acoustic based application we can mention for example the detection of traffic, crowd areas or emergency situations between others, some of these applications can be viewed in Figure 1.

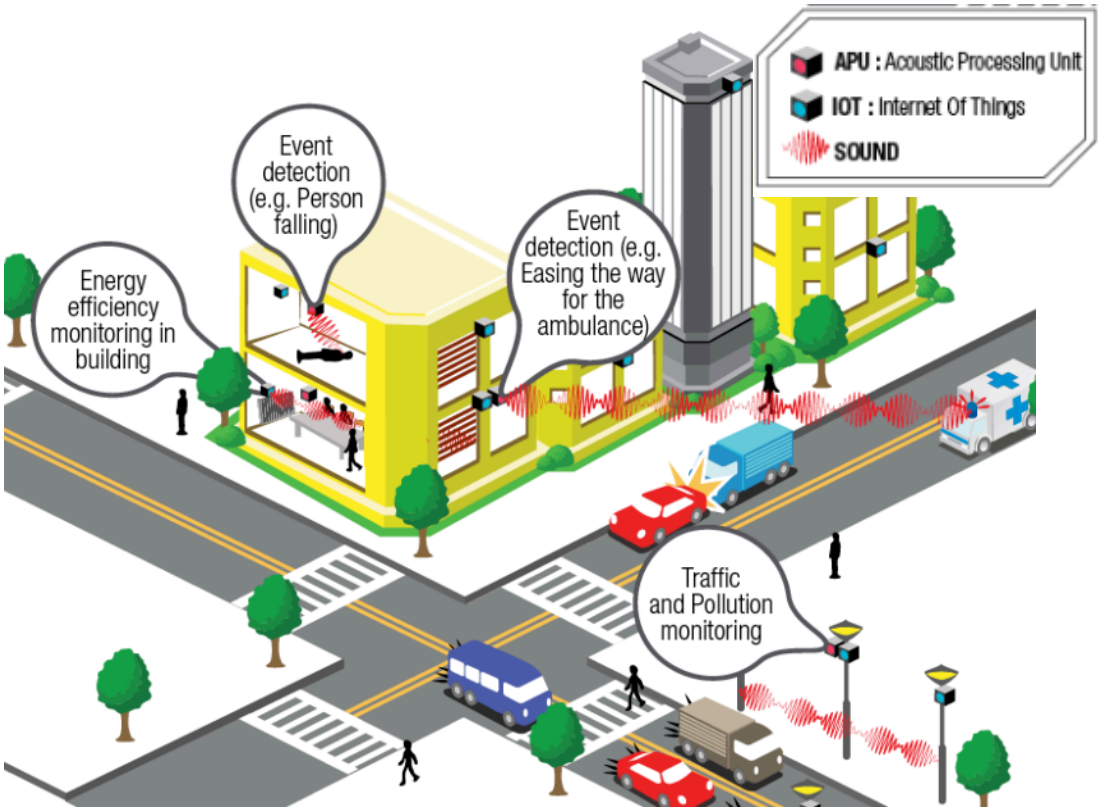


Figure 1. IoT acoustic based applications in smart environments. (IoT Accoustic Sensing Ressacs 2013, UBO).

In this way, research activities and projects already exist on acoustic monitoring of an environment. For example, in [10] the water quality and fish behavior in aquaculture tanks during the feeding process is monitored, [11] describes how to monitor and geo-reference noise in urban environments and [12] proposes how to infer hazardous situations via environmental sound identification. Thus, sound is an important source of information about urban and environmental life. This implies a great potential on intelligent audio based solutions to support a myriad set of applications.

2.- 5G IOT STANDARDS

Recent cellular standards like Long-Term Evolution (LTE) have been introduced for mobile devices but are not well suited for the requirements of the IoT devices. Basic requirements such as high throughput, low latency, high scalability to enable massive number of devices and efficient consumption are required. Thereby, next-generation networks and standards will need to solve complex challenge of combining communications and computing together. To address this, there is a number of emerging IoT standards.

Fifth generation (5G) is expected to play a vital role in the development of smart city applications addressing the limitations of previous cellular standards and be a potential key for future IoT [13]. One of the major advantages of 5G with respect to 4G are the increased data rate, reduced latency and the improved coverage supporting a large amount of devices. In this way, 5G allows the vision of a truly global IoT. To address the challenges, the standardization group 3rd Generation Partnership Project (3GPP), which is responsible for cellular telecommunications network standards, has been working to make sure that the communications are efficiently evolved in future and promising 5G New Radio systems be a reality for IoT application. The 5G air interface is planned to be standardized by 2020. The standardization is divided by 3GPP in phases: early commercial deployments and a subset of the 5G requirements is set up by 2018, first commercial launch is to be by 2020 and full 5G will be available once the standardization process is completed by 2022 and onwards [14].

No single technology or solution is ideally suited to all the different potential massive IoT applications, market situations and spectrum availability. As a result, the mobile industry is standardizing several technologies, including Long Term Evolution for Machines (LTE-M) and Narrow Band IoT (NB-IoT) which appears as promising solutions that will be included as 5G mobile standards [14]. Both are protocols with a low bandwidth that connect devices to the internet which need to transmit small amounts of data, at low cost and with high battery life.

LTE-M, also known as CAT-M1, is the industry term for the Long-Term Evolution (LTE) machine-type communications that was introduced by 3GPP in Release 13. Core specifications were completed in June 2016. Further work to enhance the technology has been ongoing in 3GPP. Release 14 enhancements were completed in June 2017, while Release 15 enhancements has been completed by June 2018 [15]. LTE-M supports IoT through lower device complexity and provides extended coverage, while allowing the reuse of the LTE

The other 3GPP technology is NB-IoT, also called Cat-M2, which has a similar goal as LTE-M. It was also standardized in Release 13 and is set to be completed in Release 15 [16]. NB-IoT uses Direct-Sequence Spread Spectrum (DSS) technology, which is a different technology to the LTE radios. Therefore, NB-IoT does not operate in the LTE band, meaning that providers have a higher upfront cost to deploy. However, NB-IoT would even support lower data rates and lower power consumption with a reduced bandwidth allocation than LTE-M.

The number of LTE-M and NB-IoT use cases are increasing and at the end of April 2018 there were a total of 48 commercial networks

launched [17]. In [18], a list of all Mobile IoT commercial Network can be bound, where the country in which it is developed and the used technology are specified.

3.- FIWARE STANDARD

Implementing IoT enabled smart applications requires gathering context information coming from "Things" (sensor networks, systems, end users, etc.). This current and historic context information, needs to be processed, visualized, and analyzed at large scale, in order to produce the expected smart behavior. FIWARE is an initiative to provide a platform and a set of standardized APIs to support the creation of Smart Applications in various fields. It initially started in 2011 as an EU's Seventh Framework Programme (FP7) project with the goal of "introducing an innovative infrastructure for cost-effective creation and delivery of services, providing high QoS and security guarantees" [19]. Since then it has got significant attention resulting in various follow-up projects [20][21][22]. Besides this, the so called FIWARE Foundation [23], was recently founded with the goal of building a sustainable community around the project. FIWARE mission, is: "to build an open sustainable ecosystem around public, royalty-free and implementation-driven software platform standards that will ease the development of new smart applications in multiple sectors" [24].

FIWARE architecture is very extensive and is divided into seven technical chapters [25], based on components known as Generic Enablers (GEs) [26], which are general-purpose functions, offered through well-defined, standard and open APIs, easing development of smart applications in multiple sectors. FIWARE also provides GE Open Specifications (that are public and royalty-free) and their implementations (GEi). There might be multiple compliant GEis of each GE Open Specification and at least one open source reference implementation of each FIWARE GE (FIWARE GEri). Available FIWARE GEis, GEris and incubated enablers are published on the FIWARE Catalogue [27]. The advantage of using FIWARE is that software architects can rely on a consolidated set of open source general-purpose platform functions that are supported by a worldwide community.

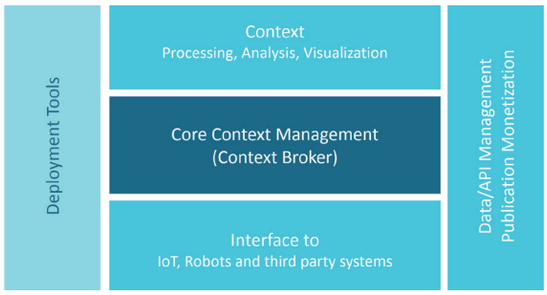


Figure 2. FIWARE architecture. (www.fiware.org)

Figure 2 shows the FIWARE Context Broker component that is the core component of any platform based on FIWARE. Around the FIWARE Context Broker, a rich suite of complementary FIWARE components are available for facilitating tasks such as the integration of the Internet of Things devices (Internet of Things, IoT), to analyze and process data at medium and large scale (Big Data), or to incorporate advanced interfaces to interact with users. Nevertheless, FIWARE is not about take it all or nothing. Developers are not forced to use all the complementary components (GEs), but they can use other components to design hybrid platforms. As long as it uses the FIWARE Context Broker technology to manage context information, our own platform can be labeled as "Powered by FIWARE" and solutions can be built on top as well.

Current deployment status

FIWARE provides an enhanced OpenStack-based cloud environment plus a rich set of open standard APIs that make it easy to connect to the Internet of Things, process and analyze Big data and real-time media or incorporate advanced features for user interaction. If the application has to be "smart", first of all we have to make it "aware". FIWARE provides us with means to produce, gather, publish and consume context information at large scale and exploit it to turn our application into a truly smart application.

Context information is represented through values assigned to attributes that characterize those entities relevant to the application. The Context Broker GE (open source reference implementation: Orion [28]) is the core and mandatory component of any platform or solution based on FIWARE. It enables to manage context information in a highly decentralized and large-scale manner. It provides the FIWARE NGSIv2 API which is a simple but powerful restful API enabling to perform updates, queries or subscribe to changes on context information. The Orion Context Broker holds information about the current context, and considering that the context information evolves over time, it creates a context history. the STH Comet Generic Enabler [29] is part of the Core Context Management Chapter and complements the Orion Context Broker component. The STH Comet Generic Enabler provides the means to store a short-term history of context data (typically months) on MongoDB whereas the Cygnus Generic Enabler [30] provides the means to manage the history of context. This last one is created as a stream of data which can be injected into multiple data sinks, including some popular databases like PostgreSQL, MySQL, MongoDB or AWS DynamoDB, as well as BigData platforms like Hadoop, Storm, Spark or Flink.

Likewise, a number of Generic Enablers are available making it easier to interface with the IoT, Robots and Third-party systems for the purpose of gathering valuable context information or trigger actuations in response to context updates. The IDAS Generic Enabler [31] is an implementation of the Backend Device Management GE, according to the FIWARE reference architecture. IDAS offers you a wide range of IoT Agents, making easier to interface with devices using the most widely used IoT protocols (LWM2M over CoaP, JSON or UltraLight over HTTP/MQTT or OPC-UA) as well as develop your own IoT Agent.

In order to implement the expected "smart behavior", the context information must be processed, analyzed or virtualized. To facilitate these tasks, a number of Generic Enablers are available: Wirecloud [32] that provides a powerful web mashup platform to develop operational dashboards highly customizable by end users, Knowage [33] that is a powerful Business Intelligence platform to perform business analytics over traditional sources and big data systems, and Kurento [34] and Cosmos [35], which enables real-time processing of media streams and tools for easyly performing Bigdata analysis respectively.

As mentioned above, to implement secured access to components in the architecture of any "Powered by FIWARE" solution, and the publication and monetization of context data resources, available through the core Orion Context Broker component, another set of Generic Enablers are available in the FIWARE platform. The Keyrock Identity Management Generic Enabler [36], which brings support to secure and private OAuth2-based authentication of users and devices, user profile management, privacy-preserving disposition of personal data, Single Sign-On (SSO) and Identity Federation across multiple administration domains. The Wilma proxy Generic Enabler [37] which brings support of proxy functions within OAuth2-based authentication schemas. It also implements PEP functions within an XACML-based access control schema and the AuthZForce PDP/PAP Generic Enabler [38], which brings support to PDP/PAP functions within an access control schema based on the XACML standard.

On the other hand, this chapter also brings Generic Enablers for the publication and monetization of context data resources, available through the core Orion Context Broker component of the developed platform. We highlight in first place the CKAN extensions Generic Enabler [39], which provides a number of add-ons able to extend current capabilities of the world-leading CKAN Open Data publication platform. It allows the publication of datasets matching right-time context data, the assignment of

access terms and policies to those datasets and the assignment of pricing and pay-per-use schemas to datasets. In second place, we consider the Biz Framework Generic Enabler that brings backend support to Context API/ Data monetization based on open TM Forum Business APIs.

Current cases of use

FIWARE is an Open Platform for a better Internet, an Open Environment, available for everyone willing to build smart solutions. FIWARE has given rise an Open Community around Open Standards for a data-driven world, making open data and applications available for everyone. FIWARE has accomplished to be empowered by lead Industry big players, but being guide by the needs, challenges and ideas of the users in each application sector. Being this joint work what has turned innovation and research into real products.

FIWARE cases of use cover several sectors like Smart Health, Smart Logistics, Smart Energy, Smart Cities, Smart Industry and Smart Agrifood among others. Within the sectors of greatest impact, we can find the Smart Industry, where FIWARE is creating a smart manufacturing platform based on industry standards and open source components that helps developing smart applications for all production processes. Smart Agrifood or Smart Farming whose aims are to optimize the production in farms by using the most modern means in a sustainable way, thereby increasing the production and delivering the best products in terms of quality while maximizing the return. It makes use of a wide range of technologies including IoT sensors, wearables, GPS services, UAVs, robots and drones operating in the field, which provide real-time data to systems helping to monitor the production line and support decisions. This enables less waste and maximum efficiency in operations.

Taking as a reference the number of applications developed, we can see that although FIWARE is a generic platform, it is especially useful to enable the concept of Smart Cities, and more than 100 cities have already published open data and developed prototypes using FIWARE, while several Spanish cities have adopted it in their systems. In accordance with this global trend, the Universitat Politècnica de València is currently participating in different European projects related to the field of IoT applications.

4.- PROJECTS RELATED TO IOT IN ITEAM

MAtchUP Project on Smart Cities

MAtchUP [40] is an EU-funded Smart City project involving three lighthouse cities (Valencia-Spain, Dresden-Germany and Antalya-Turkey) and four follower cities (Ostend-Belgium, Herzliya-Israel, Skopje-FYROM and Kerava-Finland). It started on September 2018 and will finish on September 2023. During this period, MAtchUP partners will create and adopt solutions that can turn urban problems into smart opportunities to improve the citizens' quality of life and boost the local economies, mainly in the areas of energy, mobility and ICT (information and Communications Technologies). The final aim is to create a prosperous and more liveable urban environment for communities.

MAtchUP cities will join forces to reshape their social, economic and environmental models and to promote social inclusion, liveability and prosperity for their citizens.

MAtchUP will design and implement a palette of innovative solutions in the energy, mobility and ICT sectors that will serve as a model of urban transformation for other cities in Europe and beyond.

In the context of this project, the existing VLCi smart city platform in Valencia (Figure 3) already offers a set of IoT adaptors also known as IoT agents. These agents allow the platform to directly connect devices supporting certain IoT device semantic languages (UL 2.0, Sensor ML), making use of different transport protocols (OMA LWM2M, COAP, MQTT, HTTP). The IoT agents are also in charge of adapting the IoT

device semantics to the open APIs exposed by the VLCi platform (based on FIWARE NGSI).

The city interventions planned by MAtchUP in Valencia will require the integration of additional IoT devices and data acquisition systems, and iTEAM is the partner in charge of providing the IoT devices integration in the platform, directly or through development of special IoT Agents. This will be done with the help of the VLCi platform SDK and APIs, and the main tasks will consist in adapting them to the specific city devices used as part of the interventions, beyond the standard protocols supported by the VLCi platform off-the-shelf.

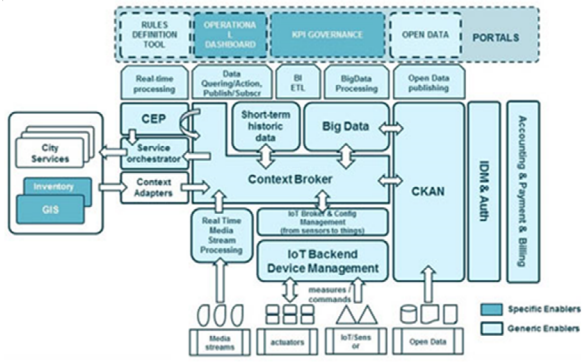


Figure 3. FIWARE architecture for Smart Cities. (www.fiware.org)

The action will include the development of a set of common basic data analysis blocks (both for batch historic files and real time data analysis) to be used for the design of the required complex analysis processes for the city of Valencia. It will be possible to reuse the common basic data analysis blocks in other cities, in order to build their specific complex analysis processes on top of them, therefore ensuring the replicability of the solution also in other cities. The implemented IoT & Big Data analysis processes will help the integration of new services into the VLCi platform, creating an innovative ecosystem. Additionally, they will help to evaluate and validate the effect of the applied city policies and the executed interventions, and will be a key input for the City Management Dashboard, where the output of these processes will be visualized and monitored.

Within the VLCi existing platform, new data resources will be integrated coming from the different data collection systems. Therefore, it will be necessary to publish non-sensible and anonymized data (privacy and security aspects) to be accessed and explored by citizens and developers willing to use them to create innovative services for the city. By collecting the data generated and exposed by the IoT devices used in the city interventions from the VLCi platform, new data insights will be generated and visualized in the City Dashboard. This action will cover the data analysis activities for the calculation of the new required KPIs (based on ISO 37120) associated to the planned interventions in the city of Valencia and also the generation of valuable data insights based on the combination of real time and historic context information gathered from the executed interventions in the areas of energy optimization, sustainable mobility, high performance buildings and environment.

SSEnCe Project on Acoustic-aided IoT

In general, the scope of the IoT technology is diverse, although the most important effort is being carried out in the field of health (e-health), transport and Smart Cities. The "Sound-Aided Smart Environments for the City, Home and Nature" (SSEnCe) project aims to encourage the dissemination and develop of real and practical prototypes focused on the Global concept of Intelligence in the IoT, particularly the applications are based mainly on the acoustic information of the environment. The main objectives of this project are the creation of an Observatory and the development of three technological demonstrators of immediate practical application.

The IoT observatory can be found at http://sound-aided-IOT.upv.es . The observatory will address issues related with the IoT projects carried out at iTEAM by publishing the most relevant information on the progress of the projects. Furthermore, the observatory will collect relevant information on the IoT field as news, new applications and products, prototypes, etc...

On the other hand, the demonstrators have the following specific objectives:

- In the home environment, it is intended to detect the acoustic events that indicate danger or emergency situation, especially for people with reduced mobility (sick people, elderly people, etc..). This application is related to IoT application in e-health.
- In the Smart Cities field, the project aims to develop applications which detect violence situations and disturbance of social coexistence (concerts, unauthorized manifestation, etc.) and to monitor the noise pollution.
- In natural parks is intended to detect any alteration of the natural environment produced by people.

In this sense, for the development of the three demonstrators the project presents three main axes of action, as shown Figure 4:

- Acoustic Sensor Networks (ASN) technology capable of "listening" the environment, processing the sound information and make decisions, that is, with computing capacity in the data source or near to it (edge computing).
- The IoT technology that allows to process additional information of the environment and to perform a much more complex processing (cloud computing).
- The applications, which are focused on the welfare of the citizen and the care of the environment.

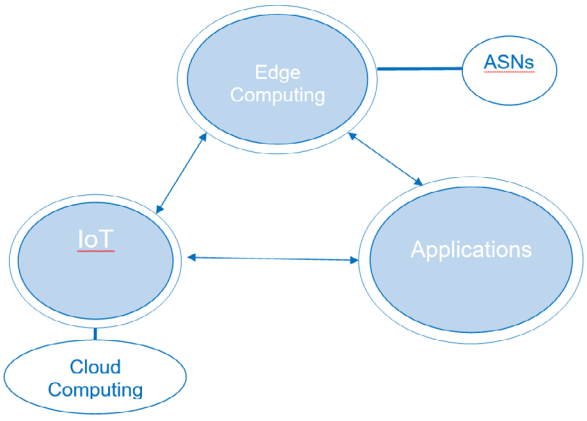


Figure 4. Basic elements for intelligence in the IoT.

The new paradigm called edge computing aims to move the border of the computing applications, data and services from the central nodes to the ends of the network. Thereby edge computing allows the analysis and generation of knowledge at the source of the data or near to it [41] [42]. The term edge computing covers a wide range of technologies, including: wireless sensor networks, networks and hoc cooperatives, node processing, storage and recovery of distributed data, self-configuring networks, etc.

On the other hand, acoustic sensors networks allow us to address new scenarios that traditional systems of digital sound processing have not been raised, many of them related to the mobility and versatility associated with these networks [43]. The use of several acoustic nodes instead of a single central system is justified when it is impossible to assume the computational cost of a centralized system; when the nodes have no physical possibility to access all the control information of the system and when a scalable system is needed.

For these reasons, in the SSEnCe project the proposal of the different applications implies a decision making from the acoustic information extracted from the ASN, both for the detection and for the classification of acoustic events. On the other hand, the needs of the end users are considered in the applications, as well as their integration. Likewise, notifications alarms and results reach to the end users in an easily way through various interfaces and devices (mobile devices, augmented reality, etc.).

Acknowledgment

This work has been partially supported by EU through H2020-SCC-2016-2017 / H2020-SCC-2017 MAtchUP project, EC Grant 774477, , and by Cátedra Telefónica UPV "Tecnologías para la Innovación Social y Ambiental" through SSEnCe Project on Acoustic-aided IoT.

References

[1] P. M. Madhura, B. Namrata, J. Palash, and J. Ranjith, "A Survey on Internet of Things: Security and Privacy Issues," Int. J. Innov. Technol. Res., vol. 3, no. 3, pp. 2069–2074, 2015.

[2] F. Javed, M. K. Afzal, M. Sharif, and B.-S. Kim, "Internet of Things (IoTs) Operating Systems Support, Networking Technologies, Applications, and Challenges: A Comparative Review," IEEE Commun. Surv. Tutorials, 2018.

[3] M. A. Feki, F. Kawsar, M. Boussard, and L. Trappeniers, "The Internet of Things: The Next Technological Revolution," Computer (Long. Beach. Calif)., vol. 46, no. 2, pp. 24–25, 2013.

[4] Y. Andreev, Sergey and Galinina, Olga and Pyattaev, Alexander and Gerasimenko, Mikhail and Tirronen, Tuomas and Torsner, Johan and Sachs, Joachim and Dohler, Mischa and Koucheryavy, "Understanding the IoT connectivity landscape: a contemporary M2M radio technology roadmap," IEEE Commun. Mag., vol. 53, no. September, pp. 32–40, 2015.

[5] S. Persia and L. Rea, "Next generation M2M Cellular Networks: LTE-MTC and NB-IoT capacity analysis for Smart Grids applications," AEIT 2016 - Int. Annu. Conf. Sustain. Dev. Mediterr. Area, Energy ICT Networks Futur., 2017.

[6] "ONE M2M." [Online]. Available: http://www.onem2m.org/. [Accessed: 26-Jun-2018].

[7] "WiSUN Alliance." [Online]. Available: https://www.wi-sun.org/. [Accessed: 26-Jun-2018].

[8] "Open Connectivity Foundation." [Online]. Available: https://openconnectivity.org/. [Accessed: 26-Jun-2018].

[9] S. T. Julien Mineraud, Oleksiy Mazhelis, Xiang Su, "A gap analysis of Internet-of-Things platforms. Computer Communications," Comput. Commun., vol. 89, pp. 5–16, 2016.

[10] L. Parra, S. Sendra, L. García, and J. Lloret, "Design and deployment of low-cost sensors for monitoring the water quality and fish behavior in aquaculture tanks during the feeding process," Sensors (Switzerland), vol. 18, no. 3, 2018.

[11] J. A. Gómez et al., "A Case Study on Monitoring and Geolocation of Noise in Urban Environments Using the Internet of Things," Proc. Second Int. Conf. Internet Things, Data Cloud Comput., p. 177:1–177:6, 2017.

[12] M. Quintana-Suárez, D. Sánchez-Rodríguez, I. Alonso-González, and J. Alonso-Hernández, "A Low Cost Wireless Acoustic Sensor for Ambient Assisted Living Systems," Appl. Sci., vol. 7, no. 9, p. 877, 2017.

[13] A. Orsino, G. Araniti, L. Militano, J. Alonso-Zarate, A. Molinaro, and A. Iera, "Energy efficient IoT data collection in smart cities exploiting D2D communications," Sensors (Switzerland), vol. 16, no. 6, pp. 1–19, 2016.

[14] S. Li, L. Da Xu, and S. Zhao, "5G Internet of Things: A survey," J. Ind. Inf. Integr., vol. 10, no. February, pp. 1–9, 2018.

[15] R. Ratasuk, N. Mangalvedhe, D. Bhatoolaul, and A. Ghosh, "LTE-M Evolution Towards 5G Massive MTC," 2017 IEEE Globecom Work. (GC Wkshps), pp. 1–6, 2017.

[16] R. Ratasuk, N. Mangalvedhe, Z. Xiong, M. Robert, and D. Bhatoolaul, "Enhancements of narrowband IoT in 3GPP Rel-14 and Rel-15," 2017 IEEE Conf. Stand. Commun. Networking, CSCN 2017, pp. 60–65, 2017.

[17] R. by GSMA, "Mobile IoT in the 5G FUTURE," no. JanUarY, 2018.

[18] "Commercial Launches." [Online]. Available: https://www.gsma.com/iot/mobile-iot-commercial-launches/. [Accessed: 15-Jun-2018].

[19] Publications Office of the European Union, "FI-WARE: Future Internet Core Platform," EU, Brussels, Belgium, 2011.

[20] Publications Office of the European Union, "FIGLOBAL: Building and supporting a global open community of FIWARE innovators and users," EU, Brussels, Belgium, 2016.

[21] Publications Office of the European Union, "A FIWARE-based SDK for developing Smart Applications," EU, Brussels, Belgium, 2017.

[22] Publications Office of the European Union, "Bringing FIWARE to the NEXT step," EU, Brussels, Belgium, 2017.

[23] "Fiware Foundation," 2017. [Online]. Available: https://www.fiware.org/foundation/.

[24] "FIWARE," FIWARE: THE OPEN SOURCE PLATFORM FOR OUR SMART DIGITAL FUTURE.

[25] FI-WARE Consortium, "FI-WARE

Architecture," FIWARE Architecture. [Online]. Available: https://forge.fiware.org/plugins/mediawiki/wiki/fiware/index.php/FIWARE_Architecture. [Accessed: 13-Jun-2018].

[26] FIWARE Catalogue, "Fiware Catalogue." 2017.

[2 7] "FIWARE Catalogue." [Online]. Available: https://catalogue-server.fiware.org/.

[28] "Orion Context Broker." [Online]. Available: https://catalogue-server.fiware.org/enablers/publishsubscribe-context-broker-orion-context-broker.

[29] "STH comet Fiware Catalogue." [Online]. Available: https://catalogue-server.fiware.org/enablers/sth-comet.

[30] "Cygnus Fiware Catalogue." [Online]. Available: https://catalogueserver.fiware.org/enablers/cygnus.

[31] "IDAS Fiware Catalogue." [Online]. Available: https://catalogue-server.fiware.org/enablers/backend-device-management-idas.

[32] "Wirecloud - Fiware Catalogue." [Online]. Available: https://catalogue-server.fiware.org/enablers/application-mashup-wirecloud.

[33] "Knowage Fiware Catalogue." [Online]. Available: https://catalogue-server.fiware.org/enablers/data-visualization-knowage.

[34] "Stream-oriented - Kurento - Fiware Catalogue." [Online]. Available: https://catalogue-server.fiware.org/enablers/application-mashup-wirecloud.

[35] "Cosmos Fiware Catalogue." [Online]. Available: https://catalogue-server.fiware.org/enablers/bigdata-analysis-cosmos.

[36] "Identity Management - KeyRock Fiware Catalogue." [Online]. Available: https://catalogue-server.fiware.org/enablers/identity-management-keyrock.

[37] "PEP Proxy - Wilma Fiware Catalogue." [Online]. Available: https://catalogue-server.fiware.org/enablers/pep-proxy-wilma.

[38] "Authorization PDP - AuthZForce Fiware Catalogue." [Online]. Available: https://catalogue-server.fiware.org/enablers/authorization-pdp-authzforce.

[39] "CKAN Extensions Fiware Catalogue" [Online]. Available: https://catalogue-server.fiware.org/enablers/fiware-ckan-extensions.

[40] MatchUP Project. [Online]. Available: https://www.matchup-project.eu/project/

[41] T. X. Tran, A. Hajisami, P. Pandey, and D. Pompili, "Collaborative mobile edge computing in 5G networks: New paradigms, scenarios, and challenges," IEEE Commun. Mag., vol. 55, no. 4, pp. 54–61, 2017.

[42] Y. C. Hu, M. Patel, D. Sabella, N. Sprecher, and V. Young, "Mobile Edge Computing A key technology towards 5G," no. 11, pp. 1–16, 2015.

[43] A. Bertrand, "Applications and trends in wireless acoustic sensor networks: A signal processing perspective," 2011 18th IEEE Symp. Commun. Veh. Technol. Benelux, SCVT 2011, 2011.

5G New Radio Numerologies and their Impact on V2X Communications

Josue Flores de Valgas, David Martín-Sacristán and Jose F. Monserrat

Universitat Politècnica de València
iTEAM - Instituto de Telecomunicaciones y Aplicaciones Multimedia
Camino de Vera s/n - 46022 Valencia (Spain)
Corresponding author: joflode1@iteam.upv.es

ABSTRACT

The 3GPP adopted Cyclic Prefix (CP)-OFDM as the only waveform for both uplink and downlink communications in 5G New Radio (NR). However, due to the variety of proposed deployment options and scenarios, a single numerology will not be enough to fulfil all performance requirements. A scalable OFDM numerology is required to enable diverse services on a wide range of frequencies and deployments, and finding the right numerology for each scenario is of special relevance for the proper functioning of 5G NR. Using a 3GPP calibrated simulator, this paper presents the performance evaluation of NR in a V2X scenario for different numerologies and device speeds. Results show that increasing subcarrier spacing boosts the protection of the system against Inter Carrier Interference (ICI) but makes Inter Symbol Interference (ISI) have a more predominant effect. This result allows concluding that each frequency operation has a different optimum numerology depending also on the deployment scenario.

Keywords: 5G, waveform, OFDM, NR, numerology, V2X, 802.11p, C-V2X.

1.- INTRODUCTION

The 3rd Generation Partnership Project (3GPP) has been working since 2016 on the standardization of the 5G New Radio (NR) [1], the global standard for 5G that will ensure the quality, performance, and interoperability of 5G devices and networks, as the next generation radio technology [2]. 5G NR will make services like automated intelligence, the Internet of Things (IoT) [3], autonomous vehicles, and virtual/augmented reality, come true. These technologies are based on more prompt, even faster, and more reliable inter-connectivity of everything, resulting in the need for the next generation of mobile communication systems.

5G is designed to provide a wide variety of services, and that is why there are three main challenges that 5G NR must solve in order to enable a truly networked society, these are: a higher traffic volume, massive growth in the number of devices, and a more reliable and low latency transmissions. These challenges result in three broad use cases [4]: Enhanced Mobile Broadband (eMBB), which requires very high data rates and large bandwidths, e.g., highly mobile UE connected to macrocells; Massive Machine Type Communications (mMTC), which requires low bandwidth, low energy consumption at the UE, and high connection density, e.g., collection of the measurements from a massive number of sensors; and Ultra Reliable Low Latency Communications (uRLLC) which requires very low latency, and very high reliability and availability, e.g., factory process, and power system automation.

Even before the formal beginning of the 5G NR standardization process, there have been different waveforms presented as candidates for this new specification [5]-[7]. Most of these candidates are multi-carrier waveforms, like Cyclic Prefix OFDM (CP-OFDM), Windowed-OFDM (W-OFDM), Universally Filtered-OFDM,

also known as universal filtered multi-carrier (UFMC), Pulse Shaped OFDM (P-OFDM) and Filter-Bank Multi-Carrier (FBMC). However, in August 2016, after a long process of evaluation and deliberation, 3GPP agreed to adopt only CP-OFDM for both uplink and downlink in NR. This gives 5G NR an advantage, since being built upon OFDM (which is used on LTE and Wi-Fi) allows devices to keep low complexity and, consequently, low hardware costs. Nevertheless, a single OFDM numerology, i.e. subcarrier spacing and cyclic prefix length, cannot fulfil the performance constraints across the desired frequency range and all proposed deployment options and scenarios. This is why the OFDM numerology must be adapted to fit the specific requirements of services, operation frequencies and deployment scenarios [8]. Currently 3GPP is working on the calibration of a number of different OFDM numerologies.

This paper is framed on V2X [9] communications, which can be mapped as a type of ultra-reliable Machine-Type Communication (uMTC), that in turn is a use case that shares some characteristics of mMTC and uRLLC. V2X is currently covered with two main standards: 802.11p [10], and C-V2X (Cellular-V2X) [11]. Although there are some studies related to the V2X standards with regards to new 5G technologies [12]-[14] and other studies regarding OFDM numerology itself [15]-[17], there is currently no evaluation of the impact of numerology changes on V2X services performance, or any other service for that matter. This paper's main contribution is to provide performance results on the use of the different OFDM numerologies within a V2X scenario in order to draw the optimum configuration for each operation point.

The remaining sections of the paper are structured as follows. Section 2 describes current V2X most popular standards and their main features. Section 3 explains the configuration of the different 5G OFDM numerologies and the new frame structure. Section 4 presents the measurement results. Finally, Section 5 draws the main conclusions of this work.

2.- V2X STANDARDS

The Vehicle to Everything (V2X) communication is based on vehicles exchanging data with each other and the network infrastructure. V2X is attracting significant attention as it promises to reduce road fatalities, increase traffic efficiency, improve mobility, enable a high-level of vehicle automation, and even reduce environmental impacts and provide additional traveler services. V2X communications as defined in 3GPP consist of four types: V2V, V2I, V2N and V2P. V2V being the communication among vehicles; V2I the communication between vehicles and nearby infrastructure as traffic control devices, such as in the vicinity of road work; V2N the communication from vehicles to Internet-based networks such as for traffic operations; and V2P the exchange of information between vehicles and pedestrians. Figure 1 shows some examples. We can see how these communications are bidirectional, i.e., V2I and V2N also involve the infrastructure sending messages to the vehicles.

V2V and V2P transmissions primarily

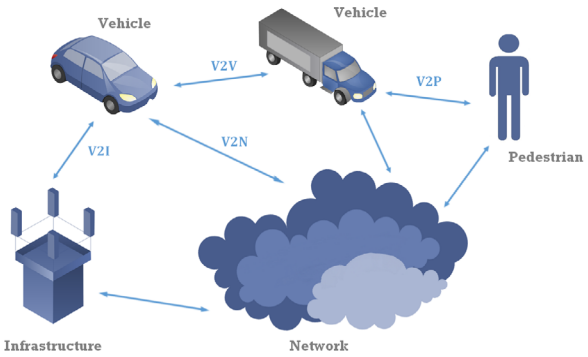


Figure 1: V2X Types

broadcast capability messages among vehicles, or between vehicles and vulnerable road users (e.g., pedestrian, cyclist), in order to provide information about direction, location and velocity to avoid accidents whenever the vehicle could take proactive actions in driving, in which it is known as autonomous driving. To accomplish this, autonomous vehicles require a variety of reliably-functioning sensors like camera, radar, and ultrasound,

in order to detect and avoid obstacles or compute and follow optimum trajectories. That is why autonomous vehicles will depend on the fast processing of these sensors data, and processing delays and ambiguities could result in serious problems of safety. Here V2X can offer a better environmental perception by enabling sharing of sensor-data between vehicles and infrastructure, providing the system greater benefits to achieve the automated driving control function.

There are two key sets of specifications for V2X direct communications, both technologies operating on the 5.9 GHz spectrum. These are: 802.11p and C-V2X standards.

2.1.- 802.11p

IEEE 802.11p is a modification of the IEEE 802.11 standard that extends its applicability to V2V and V2I communications. IEEE 802.11p is supported as the lower layers of Wireless Acces in the Vehicular Environment (WAVE), which is a standard for V2V defined in USA, also known as Dedicated Short Range Communications (DSRC). It is also supported as the lower layers of the ITS-G5 standard defined in Europe.

With the purpose of supporting vehicular radio environments, the IEEE 802.11 community decided to adapt the 802.11a Wi-Fi technology. 802.11p is based on OFDM as it happens in all modern 802.11 standard, and which is also the case of Long Term Evolution (LTE) 4G technology. However, it has some changes introduced to enable communication among fast moving vehicles. Among the main advantages of the 802.11p specification is the fact that it uses a half-clocked version of 802.11a, making it capable of handling fast-changing multi-path reflections and Doppler shifts generated by relative speeds as high as 500 km/h.

In spite of the fact that 802.11p was innovative at its time, recent studies [18][19] have shown that vehicular communications based on IEEE 802.11p face several challenges due to some legacy features that are not well-suited for vehicular communications. First, 802.11 inherits a sub-optimal synchronization and channel estimation approach which is for non-highly time-variant radio channels. Besides, due to its physical and Medium Access Control (MAC) layer designs that have been originally optimized for Wireless Local Area Networks (WLAN) with low mobility, it lacks of Quality-of-Service (QoS) guarantee. On the other hand, since vehicles now have a number of active sensors like radar, lidar, and cameras, it forces the V2X system to deliver additional values, including longer range and reliability especially in Non-Line-of-Sight (NLoS) scenarios, where other vehicles and buildings obstruct the vehicle's vision systems. This is where 802.11p shows that its limited range and undetermined performance when scaling up the number of units transmitting, limits the usefulness and overall application-set that it can serve, certainly putting into question its ability to ensure safety.

2.2.- C-V2X

Initially, the 3GPP global cellular specifications evolved LTE Direct technology and optimized it for automotive applications, defining it as LTE V2X in 3GPP Release 14. However, the evolution of this concept into a solution allowing improvements in future releases (Release 15 and beyond) for LTE and for the 5G NR, is lately commonly referred to as C-V2X direct communications and called technically as PC5 or sidelink communications. C-V2X supports direct V2V, V2I and V2P communication links not being routed via an eNodeB; and at the same time it uses network-based communications, being able to communicate with the elements of the network (V2N).

One of the main advantages of C-V2X is the fact that it is based on a technology originally intended for high-speed mobile applications, which has been improved specifically for automotive use cases, paying special attention to the shortcomings observed in 802.11p over several years of research. The need to support data-intensive and

low-latency new automotive applications to support improvements in safety and autonomous driving, along with essential enhancements in wireless communications, have also been key points for C-V2X. Modulation and coding enhancement, as well as better user equipment and overall advances in LTE technology can allow C-V2X to work with a better communication range, higher reliability (lower packet error rate), greater capacity, superior NLoS performance, and better congestion control in denser environments compared to 802.11p.

C-V2X is designed to deliver an evolution path to 5G NR-based C-V2X, taking advantage of the latest advances in wireless communications, while at the same time it accomplishes backward/forward compatibility to the previous releases of the same generation, enabling interoperability between generations and releases, guaranteeing that devices from different releases can communicate with each other. Backward compatibility also means that even after the 3GPP network is updated to a new release, all the devices working in earlier releases have to work properly and perform as expected, which is a very important feature, considering that vehicles typically remain in service for at least a decade. All this means that necessarily a 5G and an LTE device must be able to communicate with each other using V2V direct communication.

Finally, the conclusion reached after several considerations regarding how to map each V2V service to different 3GPP technologies, is that LTE will be only used for basic safety communications between vehicles, while 5G NR-based C-V2X will be used for advanced vehicular use cases for autonomous driving, so that LTE functionality is not duplicated or replaced. Therefore, in a first phase of deployment of cellular-based V2X, only LTE-V2X devices are expected to communicate. In a later phase, 5G UEs supporting C-V2X services will be dually supporting LTE and 5G.

3.- 5G NR NUMEROLOGY

As already mentioned, OFDM has a key role in 5G NR, although a single fixed OFDM numerology is not enough to meet all the requirements presented in the new 5G landscape. So far, LTE supports carrier bandwidths up to 20 MHz with a fixed OFDM numerology regarding cyclic prefix (CP) duration (TCP) and subcarrier spacing (Δf), which is a 15 kHz spacing between OFDM subcarriers, and 4.69 μs of CP. The idea for 5G NR is to introduce scalable OFDM numerology in order to support a wide range of frequencies, diverse scenarios and deployment models. One of the most critical requirements is that the OFDM subcarrier spacing must be able to scale with the channel bandwidth, so the processing complexity does not increase exponentially for wider bandwidths, as the FFT size scales.

Therefore, the main difference between LTE numerology (subcarrier spacing and CP length) and 5G NR numerology, is that the latter can support different types of subcarrier spacing. This subcarrier spacing is scalable according to the following factor: 15×2n kHz, where n is an integer and 15 kHz is the subcarrier spacing used in LTE. By using this 2n factor, 5G NR ensures that slots and symbols of different numerologies are aligned in the time domain, which is important to efficiently enable TDD networks.

Other features that change within the frame structure when 5G NR numerology is modified are slot duration, the symbol duration, and the number of slots per subframe, which are inevitably modified by changing the separation of carriers, with a general tendency to get shorter OFDM symbols as subcarrier spacing gets wider. This tendency comes from the nature of OFDM.

Finally, we have the number of OFDM symbols within a slot, which, despite not changing intrinsically when changing the numerology, it is necessarily adjusted so that the time alignment is not lost. For any numerology it will always be 14, unlike LTE that had two slots with 7 symbols each. The summary of

Δf = 15×2n (kHz)	Symbol duration (μs)	TCP (μs)	Slot Duration (ms)	Number of slots/ subframe	Number of symbols/slot
15	66.67	4.69	1	1	14
30	33.33	2.34	0.5	2	14
60	16.67	1.17	0.25	4	14

Table 1: Numerology Structures for 5G NR

5G NR numerology can be seen in Table 1.

The choice of a particular numerology depends on various factors including carrier frequency, mobility, type of deployment, service requirements (latency, reliability and throughput), and implementation complexity. For example, wider subcarrier spacing can be better suited for latency-critical uRLLC services, small coverage areas and higher carrier frequencies, which could be the case of a V2X scenario. A graphic explanation of the different channel widths and different scalable deployment types can be seen in the Figure 2.

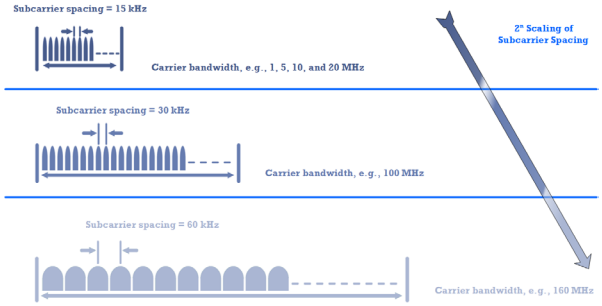


Figure 2: Example channel bandwidths, and subcarrier spacing

4.- PERFORMANCE RESULTS

The performance comparison of the different 5G NR numerologies at various speeds was made with 10000 Transmission Time Intervals (TTI) per numerology, using the PHY layer parameters of LTE, the parameters of the numerologies shown in Table I, a 64-QAM modulation, and a frequency of operation of 2 GHz. Based on a 3GPP calibrated simulator of the LTE PHY layer, changes were made to the CP and subcarrier spacing in order to set the V2X scenario.

The first result, shown in Figure 3, is the Block Error Rate (BLER) that was obtained from the 3GPP calibrated simulator, assuming a SISO case and a speed of 3 km/h. The purpose of presenting these results is to show how numerology affects the performance of the system. In this case, we can see how increasing the subcarrier spacing has an effect on the BLER. Indeed, when increasing the subcarrier spacing from 15 kHz to 30 kHz, the system undergoes a small improvement. This is because, the further apart the subcarriers are from each other, the less likely is that a frequency shift –produced by Doppler Effect– on any subcarrier will interfere with the contiguous subcarriers. For this reason, the system is more robust against the Doppler Effect and, therefore, it is better shielded against Inter-Carrier Interference (ICI).

By increasing the subcarrier spacing from 30 kHz to 60 kHz, one might think that the expected outcome is also an improvement in BLER performance since, obviously, the protection against ICI is even better. Although this is true, here it must be taken into account the effect that occurs in the time domain by increasing the subcarrier spacing, which is to decrease the OFDM symbol duration and, therefore, also the slot duration and the CP. Since the symbol duration and the cyclic prefix are four times shorter when the subcarrier spacing is 60 kHz compared to when it is 15 kHz, this system is less protected against multipath echoes that are produced by the topology of the scenario, which is independent on the numerologies. Hence, the system is more exposed to Inter-Symbol Interference (ISI), as the CP is not large enough to protect the signal from the echoes.

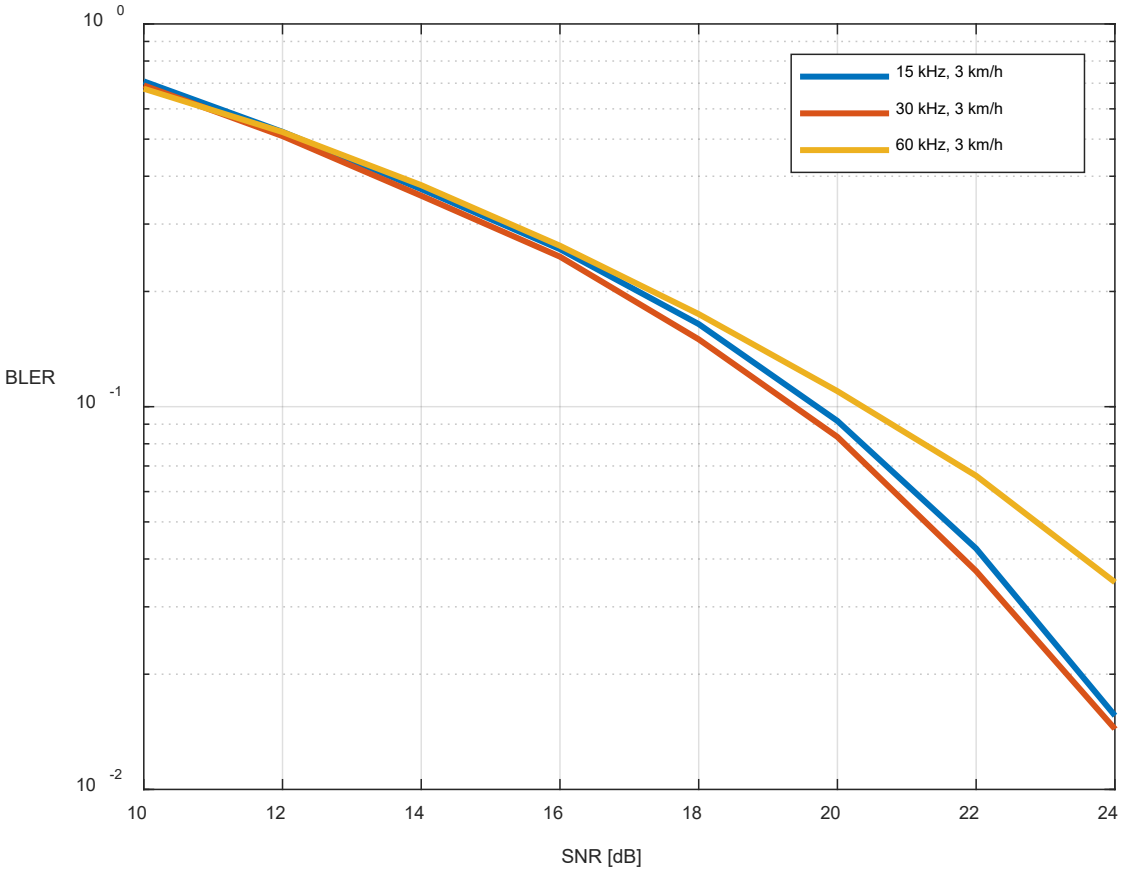


Figure 3: BLER with different numerologies at 3 km/h

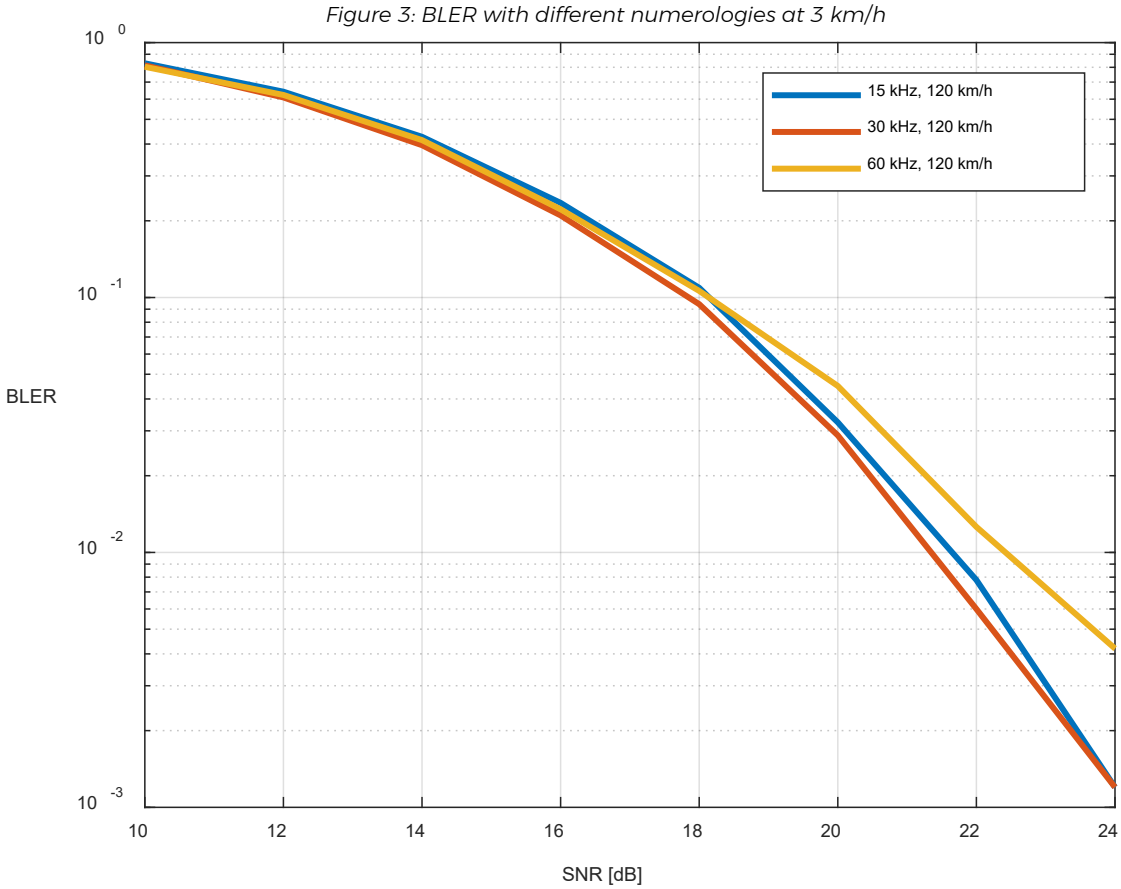


Figure 4: BLER with different numerologies at 120 km/h

Figure 4 shows the results of the same scenario detailed above, but at a speed of 120 km/h, in order to simulate the communication between vehicles moving at the highway speed limit. At first glance, it seems that the results are not what expected by increasing the speed, since it gives the impression that the behavior is the same as the 3 km/h scenario. However, by detailing the figure it can be seen that the values of the BLER are lower in this scenario with respect to the previous scenario since the Doppler effect is more significant and there is more ICI. As a consequence, it can be appreciated how the ISI effect has less influence over the BLER performance in this scenario. This is because increasing the system speed also increases the Doppler effect on the signal; therefore, if the subcarrier spacing is higher, the signal will be more protected against this effect.

5.- CONCLUSIONS

Changes in 5G NR numerology have a significant effect on the BLER performance within a V2X scenario. This has been verified according to the results obtained and the analysis thereof with respect to the presence of ICI, ISI and Doppler effect. However, as explained in the results section, increasing subcarrier spacing involves a trade-off between the ICI effect and the ISI effect over the performance of the system. Therefore, it is important to quantify the compromise that must be reached between both factors, in order to determine the best numerology for each V2X scenario. This trade-off quantification could be applied to any deployment type within the landscape of 5G.

Future work includes a deeper analysis and detailed calculation of the Doppler effect on the signal at different numerologies, so that it be possible to determine, according to the performance requirements of the diverse deployments, whether it is more convenient to be protected against ICI or against ISI.

It is worth noting that the Doppler effect depends on the operation band. Therefore, the optimum configuration of the CP and subcarrier spacing will depend on the frequency, being more subcarrier spacing needed whenever with increase the operation frequency.

REFERENCES

[1] 3GPP RP-160671, "Study on NR new radio access technology", 2016.

[2] A. Osseiran, J. Monserrat, P. Marsch (Eds.), 5G Mobile and Wireless Communications Technology, Cambridge University Press, 2016.

[3] 3GPP TR 45.820 "Cellular system support for ultra-low complexity and low throughput Internet of Things (CIoT)", 2015.

[4] P. Marsch, I. Da Silva, S. E. El Ayoubi, O.M. Boldi, Ö. Bulakci, P. Spapis, M. Schellmann, J. F. Monserrat, T. Rosowski, G. Zimmermann, et al., "5G RAN architecture and functional design", METIS II White Paper, 2016.

[5] F. Schaich and T. Wild, "Waveform contenders for 5G-OFDM vs. FBMC vs. UFMC," in Proc. Int. Symp. Commun. Control, Signal Process. (ISCCSP), pp. 457–460, May 2014.

[6] A. Aminjavaheri, A. Farhang, A. RezazadehReyhani, and B. Farhang-Boroujeny, "Impact of timing and frequency offsets on multicarrier waveform candidates for 5G," in Proc. Signal Process. Workshop Edu., pp. 178–183, Aug. 2015.

[7] R. Gerzaguet et al., "The 5G candidate waveform race: A comparison of complexity and performance," EURASIP J. Wireless Com. Network., vol. 2017, no. 1, p. 13, Jan. 2017.

[8] 3GPP TS 38.211, "NR; Physical channels and modulation", 2018.

[9] 3GPP TR 22.886, "Study on enhancement of 3GPP support for 5G V2X services", 2017.

[10] "Part 11: wireless LAN medium access control (MAC) and physical layer (PHY) specifications amendment 6: wireless access in vehicular environments", IEEE 802.11p published standard. IEEE. July 15, 2010. Retrieved August 10, 2011.

[11] 3GPP TR 36.885, "Study on LTE-based V2X Services (Release 14)", 2016.

[12] D. Garcia-Roger, J. F. de Valgas, J. F. Monserrat, N. Cardona, N. Incardona, "Hardware testbed for sidelink transmission of 5G waveforms without synchronization", in Proc. IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), 2016.

[13] H. Cao, S. Gangakhedkar, A. R. Ali, M. Gharba, and J. Eichinger, "A 5G V2X testbed

for cooperative automated driving," in Proc. IEEE Veh. Netw. Conf. (VNC), pp. 1–4, Dec. 2016.

[14] L. Liang, H. Peng, G. Li, and X. Shen, "Vehicular communications: A physical layer perspective," IEEE Trans. Veh. Technol., vol. 66, no. 12, pp. 10 647–10 659, Dec. 2017.

[15] J. Vihrial et al., "Numerology and frame structure for 5G radio access," in Proc. IEEE Symp. Pers. Indoor Mobile Radio Commun. (PIMRC), pp. 1–5, Sep. 2016.

[16] A. A. Zaidi et al., "Waveform and numerology to support 5g services and requirements," IEEE Commun. Mag., vol. 54, no. 11, pp. 90–98, Nov. 2016.

[17] A. Yazar B. Peköz, H. Arslan, "Flexible Multi-Numerology Systems for 5G New Radio" arXiv preprint arXiv:1805.02842, 2018.

[18] Z. H. Mir and F. Filali, "LTE and IEEE 802.11p for vehicular networking: A performance evaluation," EURASIP J. Wireless Commun. Netw., vol. 11, no. 89, pp. 1–15, May 2014.

[19] V. Vukadinovic, K. Bakowski, P. Marsch et al., "3GPP C-V2X and IEEE 802.11p for vehicle-to-vehicle communications in highway platooning scenarios," Ad Hoc Networks, vol. 74, pp. 17–29, 2018.

6.- BIOGRAPHIES

Josue Flores de Valgas was born and raised in Ecuador. He received the B.E. degree in Electronics and Telecommunications engineering from the Escuela Superior Politécnica del Litoral (ESPOL) in 2013, and the M.Sc. in Telecommunication Technologies, Systems and Networks from the Universitat Politècnica de València (UPV) in 2015. He is currently a Ph.D. student as a member of the Mobile Communication Group (MCG) at UPV, and a Grant Holder of the Ecuadorian Secretariat of Higher Education, Science, Technology and Innovation. His current research interests are mainly related to waveform design and harmonization. Before moving to Spain, he worked for three years on different Ecuadorian Telecommunications companies and a government project.

David Martín-Sacristán received the M.Sc. degree and the Ph.D. degree in telecommunications engineering from the Universitat Politècnica de València (UPV), in 2006 and 2016, respectively. He is currently a researcher with the iTEAM Research Institute, UPV. He has been involved in several European projects as a simulation expert, such as WINNER+ that was an External Evaluator of the IMT-Advanced Technologies for the ITU. He has also been involved in METIS and METIS-II, which lead the development of the 5G, and has contributed to two books about 5G design. He has participated in several contracts related to the automotive industry focused on vehicular communications. His research interests are focused on the modeling and simulation of communication networks, radio resource management, and vehicular communications.

Dr.-Ing. Jose F. Monserrat (H-index 21) received his MSc. degree with High Honors and Ph.D. degree in Telecommunications engineering from the Universitat Politècnica de València (UPV) in 2003 and 2007, respectively. He was the recipient of the First Regional Prize of Engineering Studies in 2003 for his outstanding student record receiving also the Best Thesis Prize from the UPV in 2008. In 2009 he was awarded with the best young researcher prize of Valencia. In 2016 he received the merit medal from the Spanish royal academy of engineering, in the young researcher category. He is currently an associate professor in the Communications Department of the UPV. His current research focuses on the design of future 5G wireless systems and their performance assessment. He has been involved in several European Projects, being especially significant his participation in NEWCOM, PROSIMOS, WINNER+, 5GXCAST and METIS/METIS-II where he led the simulation activities. He also participated in 2010 in one external evaluation group within ITU-R on the performance assessment of the candidates for the future family of standards IMT-Advanced. He co-edited two special issues in IEEE Communications Magazine on IMT-Advanced and 5G technologies and is co-editor of the Wiley book "Mobile and wireless communications for IMT-Advanced and beyond" and the Cambridge book "5G Mobile and Wireless Communications Technology". Jose Monserrat is senior member of the IEEE, manages around 0.5 M€ yearly budget, holds 6 patents and has published more than 50 journal papers. Currently the group headed by Prof. Jose F. Monserrat consists of 5 Postdoctoral fellows, 8 PhD students and 2 Master students.

Electronic Dance Music Analysis for Real-Time Synchronization of 3D Video Animations in Live Events

Emanuel Aguilera, Jose J. Lopez, Pablo Gutierrez-Parera and Carlos Hernandez

Instituto de Telecomunicaciones y Aplicaciones Multimedia,
Universitat Politècnica de València,
8G Building - access D - Camino de Vera s/n - 46022 Valencia (Spain)
Corresponding author: emagmar@iteam.upv.es

ABSTRACT

Video effects for Electronic Dance Music (EDM) events is an emerging and demanded but costly service for the industry. In this paper, a set of adapted and novel algorithms for automatic EDM feature extraction and segmentation are presented, suitable for the automation of video and 3D animation synchronized to the audio content. Features like frequency balance, color representation of the music, beat tracking and music segmentation have been specifically developed and tuned to EDM, taking into account a low computational cost. The segmentation algorithm has been trained with a database of 100 songs obtaining accurate event detection about 98% with low false alarm rate. It has been implemented in C performing in real-time and has been successfully integrated into a real-time commercial 3D graphics engine.

Keywords: Music analysis, beat detection, music segmentation, machine learning, electronic dance music.

1.- INTRODUCTION

Clubs, discos and music festivals are an important part of today's high income entertainment industry. Electronic dance music (EDM) is one of the most important styles according to number of venues and festivals dedicated to it. This audience expects a complete experience, so the music is always improved with lights and video projections as shown in Figure 1. The emerging work of video DJs does not yet have a mature software ecosystem for their work as the music DJ does, so there is still much room for improvement in this area.

Nowadays, the ability to provide compelling visual animation presentations during musical events in clubs, concert halls and other such venues, is restricted to large scale events promoters, artists, and mega-clubs. The main reason is that such visual animation must be designed in advance and specifically tailored for the music that will be played, increasing the budget. This work is focused on removing existing entry barriers and extending the use of this technology by developing affordable musical segmentation software to be used with a Real-Time 3D Motion Graphics for the Electronic Dance Music (EDM) industry.

One way of decreasing costs is to automate the visual animation presentations in real-time as the musical event is in session. That implies developing computational music analysis to extract the most relevant information needed for the visual content. This kind of analysis software has been employed to automatic classification of broadcast material [1] or musical databases [2], some of them also preserving real-time behavior [3, 4] and others are more difficult to implement in real-time [5, 6]. Apart from working in real-time, the software and its related algorithms developed in this work should employ low computational cost to meet the usage requirements of the EDM industry.

In this work we have identified three groups of music analysis features that are useful for

synchronizing video effects: those related to the fast evolution of signal energy, those related to the spectral composition of the signal, and those related to the song structure. The first group is in connection with the rhythm of the music and allows to link fast movements. The second group is related to slow changes in the signal as instruments change along the song. Finally, the third group of features appears only a few times during the song, when there are audible changes in the structure of the song and are more suitable to be linked with large changes in the video animation, such as topic, scene or camera view change. All of these groups of features, once linked with the visual animations have a powerful effect on the audience.

The rhythm of the music is also known as beat. In the literature many beat tracking algorithms have been proposed. Great advances have been reached and applied to different kinds of music with variable success. However, even state-of-the-art algorithms experience failures analyzing EDM music in real-time. For this reason, a specific algorithm tailored for EDM music has been developed in this work and is explained in section 2.

To follow slow changes in the composition of the music, different frequency balance and statistical parameters can be employed. Some statistical parameters as flatness, skewness or the kurtosis of the spectrum have been employed in the literature. However, in this work the effort has been put only in frequency balance parameters. After a thorough test, we found that they provide a better correlation with the perceptual sensation experienced by the listener and are therefore more suitable for video synchronization. Frequency band energy analysis has been employed in this work and it is explained in section 3 and 4.

Finally, regarding the structure of the song we have focused our efforts on the development of a segmentation system aimed at detecting changes in the song related to the different sections that it is composed by. Before going into segmentation details, a previous detailed study of the structure of EDM music is presented.

As commented before, section 2 describes the beat tracking algorithm developed for this work. Section 3 gives the mathematical details related to the frequency analysis of the signal in order to calculate energy level features by frequency bands. Section 4 describes the process of calculating a color representation of the music derived from previous parameters. A specific algorithm for EDM segmentation is described in section 5. Finally, section 6 summarizes the conclusions.

Figure 1: Lights and video projections in a club.

2.- BEAT ANALYSIS

Beat in musical language can be defined as a sequence of instants that might correspond to the taps that a human listener would do with his foot when listening to music. Many musical signal analysis applications require the accurate detection of the beat. In the current application, a stable and accurate detection of beat is mandatory, so that the video animation can be synchronized with the music.

The beat analysis usually consists of two parts: tempo estimation and onset determination of each individual beat pulse. The tempo is usually referred in EDM as beats per minute (BPM). In EDM and some other modern music genres, the tempo is likely to stay the same throughout the whole song, but sometimes can change, especially when the DJ mix two songs, a specific case that must be taken into account.

In general, beat tracking algorithms can be classified as offline [7] and online [8, 9]. The

first group has access to the whole song to label the beat instants, whereas the second group should work online, providing the beat instant in a causal way at the same time the song is reproduced. Obviously, the first group of algorithms usually obtain better results than the second group. Sometimes, algorithms prepared to work offline can be modified to work online with small changes, tricks or adding some latency. In this work the focus has been put in pure online algorithms that also exhibit low latency.

There are various difficulties when tracking the beats in real musical acoustic signals. The simple technique of peak-finding with a threshold is not enough, since there are many energy peaks that are not directly related to beats. The best way to discriminate the real beat from other peaks is to obtain the BPM in a first stage.

Convolution techniques have been successfully used to obtain BPM [9]. To implement that in a practical way, convolution is not applied directly to the sound samples. Instead, the signal is windowed and the energy of each window is computed. Then, the resulting vector of energies is used for convolution and BPM calculation. Better results can be obtained if the energy is calculated for different bands, for example Mel bands [7], then converted to dB scale and the first-order difference along time calculated in each band. The remaining positive differences are then summed up across all frequency bands. This technique has proven to be robust for any kind of music. In our work we follow this strategy, but instead of computing many different Mel bands, that usually require FFT computation, we employed only 3 bands, the same audio bands used for the frequency features described in section 3, greatly reducing the computational power required for this stage. These 3 bands strategy has been proven enough for EDM music, where percussion is present most of the time and always produces detectable changes in any of the 3 bands.

One problem that usually arises in BPM computation is that, depending on the type of rhythm, the maximums in the convolution may appear in the human-identifiable BPM or at twice this value. To solve this problem, we have limited the BPM to a range where most of the EDM song is found, thus avoiding the problem of double BPM, or even the half BPM if it appears.

The BPM is identified at the beginning of the song in a setup stage and is tracked throughout the whole playback. Different circumstances may arise during the song:

1. The BPM slightly and progressively changes during the song.
2. The BPM suddenly changes during the song.
3. The BPM cannot be calculated in some part of the song.

A finite state machine controls the calculation of the BPM during the song and acts depending on the circumstances discussed above. In the case 1, the algorithm verifies that the change in BPM is progressively increasing or decreasing and is different from noise or the precision related. In case 2, the algorithm checks that the change has been maintained for at least N frames to confirm it. In case 3, the algorithm continues with the same previous and stable BPM until a new valid BPM (the same or one included in case 1 or 2) is detected.

The second part of beat tracking, the onset estimation, has also been discussed in depth in the literature. Complex algorithms have been shown to be valid for different types of music with a high success rate. However, 100% of accuracy is still not reached because of the complexity of the problem. We have tested generic state-of-the-art algorithms [7] in EDM obtaining poor results, discarding them for this application. If the problem is restricted to a specific kind of music, performance can be improved. That is the reason why we have developed our own specific onset algorithm.

In EDM music, the patterns and musical phrases are quite constant, they do not change during the song at all. This means that

if an onset is determined with a high degree of confidence, it can usually be maintained throughout the song without changes. Even if the main drums that follow the beat disappears in some moments of the song, just extrapolating the position of the next beat from the tempo can be enough to follow the onset. Later in the song, when a clear beat is present, usually related to percussion, the algorithm can re-link the onset to this beat.

The resulting onset algorithm is implemented as a finite-state machine with an initial set-up state where a high confidence onset is obtained. In each window the algorithm checks the beat using a beat monitoring function similar to [9]. If the function provides the higher value for the current onset, the algorithm continues with the same onset synchronization. If the value is not the highest but it is high enough, nothing is changed; that situation can cope with temporary changes in the percussion composition. Only in the case that a different onset persists during a long period of time, a decision on onset changing is performed by the state machine. The different level thresholds, time thresholds, and other fine-tuning parameters have been adjusted by testing with a database of more than 100 EDM songs. Details of this procedure are out of the scope of this paper.

3.- FREQUENCY BALANCE ANALYSIS

Music experiences progressive changes in its frequency composition along its duration. The frequency balance at each moment is generally well perceived by the listener. In this way, a moment in the song can be described as bassy, trebly, voiced, etc. These changes are generally slow compared with the beat, so they describe the song softly. Attending to this criterion, we have defined some frequency balance parameters that are computations of the energy in some frequency bands. They provide a high correlation with the perceptual sensation experienced by the listener and therefore suitable for video synchronization. Moreover, low computational cost and simplicity of interpretation have been taking into account.

The frequency balance analysis is mainly based on a 3 bands filtering decomposition of the audio signal. Figure 2 describes the workflow of the feature extraction process. There is a common block of the music analysis, containing the bands decomposition, energy computation and softening. The resulting parameters of this stage would not only represent directly usable information for video synchronization (Bass/Mid/Treble), but they also constitute the feed for other stages: color representation (RGB, HSV) and segmentation (events), that will be explained in next sections.

The Common Audio Analysis Block comprises the next stages:

Windowing: As this algorithm is related with video signal, the processing window rate employed is linked with the frame rate of the video signal, typically 50 or 60 Hz, corresponding to windows of 20 or 16.6 ms. Smaller windows do not provide any advantage in latency and larger windows would increase it. Hamming windowing is employed.

Filters: The signal is divided into three bands using 4th order IIR filters. Filter 1 comprises frequencies up to 250 Hz, filter 2 comprised frequencies between 250 Hz and 4000 Hz and finally filter 3 is for frequencies over 4000 Hz.

Energy computation: The energy for the three frequency bands (low, mid & high) for each window is computed and converted to a logarithmic scale.

Features filtering: To smooth out the energy features with minimum latency penalty, an algorithm from the image processing field called bilateral filtering [10] has been adapted to audio. When a feature changes rapidly during the time, in order to adapt it for visualization (animation), smoothing is the common solution. A standard Kalman filter can be employed, but is not the best solution, because the output does not react to sudden changes of the music volume. Using bilateral filtering the outputs of the previous stages can be smoothed while preserving edges.

The bilateral filtering represented by f(x) in Eq. 1 can be summarized as a combination of a range s(f(**ξ**),f(x)) and a domain filtering c(**ξ**,x) as

$$\mathbf{h}(\mathbf{x}) = k^{-1}(\mathbf{x}) \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \mathbf{f}(\xi) c(\xi, \mathbf{x}) s(\mathbf{f}(\xi), \mathbf{f}(\mathbf{x})) \, d\xi \quad (1)$$

where k(x) is the normalization factor.

$$k(\mathbf{x}) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} c(\xi, \mathbf{x}) s(\mathbf{f}(\xi), \mathbf{f}(\mathbf{x})) \, d\xi \quad (2)$$

The bilateral filtering has been applied to the 3 frequency bands and employed in a causal way successfully.

Different weights are applied to each frequency band with a gain transformation matrix M1, because high frequencies usually need to compensate their lower energy to achieve similar variations than the lower bands. As a result, the energy features Bass, Mid and Treble are obtained.

An example of application of these features to video effects or animations is the association of the size of 3D objects with them, for example the width to Bass, height with Mid and depth with Treble.

Figure 3 shows the evolution of the three parameters during a full song. A pseudo-color track has been also added for visualization of the parts at a glance.

4.- COLOR REPRESENTATION

It is powerful to show visual color effects synchronized with the songs. There have been many studies on the synaesthesia between audio and colors, some very interesting ones study the association of colors to musical notes [11]. In this article they postulate as convenient to use the chromatic scale from red to green to blue in an orderly manner with the musical scale from DO to SI, that is, increasing with frequency. In our case, we have also adopted a de facto standard in commercial DJ software where the low frequency is associated with red, mid frequencies with green and high frequencies with blue.

To this end, based on the calculation of the energy in bands with their corresponding stabilization, a color transformation matrix M2 is applied to obtain 3 values, R, G and B. The tone is clearly associated to R with low frequency, G with medium frequency and B with high frequency. In addition, brightness and saturation are set to maximum to allow the colors to be as eye-catching as possible. Another color transformation matrix M3 is also applied to obtain HSV values for these colors and to facilitate their use.

A common application of the obtained values for colors is to apply them to the visual background or 3D object materials so that viewers naturally relate them to the different parts of the songs they are listening to.

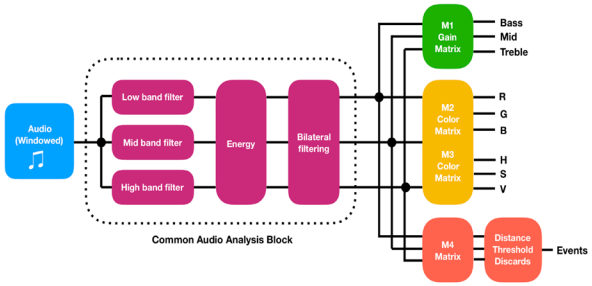


Figure 2: Block diagram of features extraction.

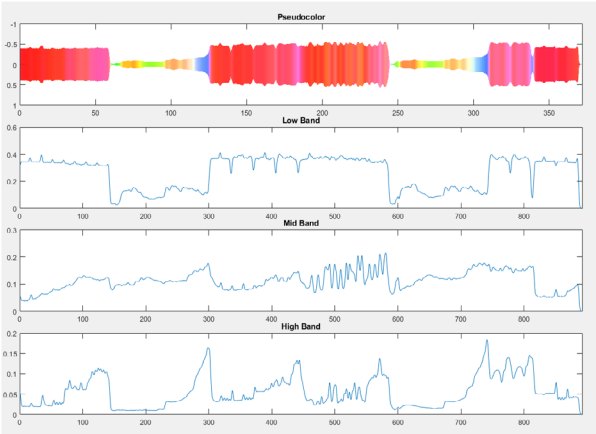


Figure 3: Evolution of the three values at the output of the common block during a full EDM song. A pseudo-color track has been created for visualization of the different parts at a glance

5.- MUSIC SEGMENTATION

5.1.- Electronic Dance Music Structure

When it comes to characterizing music, the genre particular features and the intention of the analysis will influence the choices of the recognition and segmentation system. In general, contemporary and pop music usually have a structure based on parts typically

named as: Intro, Verse, Chorus, Solo, Bridge, Outro, that are interleaved during the song.

- **Intro:** It is optional and is reproduced only once at the beginning of the song. In pop music should last 16 or 32 bars.
- **Verse:** This is the first main part of an arrangement. It is repeated a few times before moving on to the chorus. It usually contains lyrics.
- **Chorus:** The main part of the song. It's the hook, what the audience remembers and the most powerful passage. It will be usually repeated interleaved with the Verse.
- **Solo:** It can appear at any time to add a jam effect. It can create cool sections in music. They are very common in live performances.
- **Bridge:** It is used to break up what the listener has paid attention to. In electronic music the drums usually produce an ascending sound that is added to the next part. A bridge can be more powerful by adding new instruments or changing the key.
- **Outro:** It is used to resolve the song and go towards a soft landing.

However, the EDM structure works differently:

1. Quite frequently there are no lyrics or at least they are not as important as in pop music, so the concept of verse does not apply here.
2. Instead of a chorus, it is more common a single powerful loop which acts as the hook of the song.
3. Then the EDM song is built up adding and subtracting different instrument layers over the beat structure and driving the emotions of the listener by means of different tricks.
4. In EDM, the different parts are not necessarily repeated again. On the contrary, the parts are usually an evolution or modification of previous parts.

The most common structure in EDM is composed by:

- **Intro:** This is usually either a kick of some percussion and melodic elements which introduce the feeling of the track or a fade in of a melodic layer.
- **Breakdown:** It is the mellowest part of a track, where the melody is introduced and the atmosphere use to be calm.
- **Build-up:** All the melody layers in the breakdown are taken and some of the layers that are going to be used in the drop are added, establishing the most energetic part of the song.
- **Drop:** It changes according to the subgenre, but in general it is a passage in a dance track in which the tension is released and the beat kicks in. In some dance styles, it is known as a climax.

Moreover, the identification of this structure is more complex and less predictable when working with live DJ music. Songs do not start and end clearly because the DJ removes intros and outros to mix continuous music, making detection and segmentation more difficult.

On the other hand, within EDM music, different subgenres can be classified: house, techno, trance, dubstep, drum & bass, minimal and others. Each of these sub-genres has its own rules that can be adapted differently to the structure of the EDM music discussed above. This significantly complicates the development of universal software that can solve the segmentation challenge, even more if we consider that human listeners have no consensus in this field either; two different people would probably label segments differently.

Therefore, from a practical point of view, when asking what a segment is and what utterance it determines, we can focus our attention on the final application in order to narrow the problem. With the aim of giving a visual output that complements the visual effects, each segment can be considered as a part of the song with a minimum and maximum duration that can be noticed by the EDM audience. It includes detection of breaks and the main layers added to or subtracted from the music, among others events.

5.2.- Segmentation algorithm

In this work, a simple low-latency algorithm has been employed for the extraction of the important events in the structure of EDM music. It employs low computational cost and is efficient for extraction EDM features. Although FFT is used in other works in order to segment and classify the parts of a song with great detail [4], in this work an algorithm that does not use FFT have been developed instead, saving computational cost and reducing latency but obtaining enough information for the final purpose.

For practical reasons in this work, we have focused our efforts on detecting events that capture the attention of the listener during playback. In this way, these moments can be associated with a major change in the video animation. Four easily audible key events have been considered in the course of a song:

1. The beginning and the ending of the breaks that alternate between high and low energy moments of the music.
2. The different layers that are added or removed from the main base that build-up the song.
3. The moments when a new passage begins in crescendo or decrescendo.
4. Attractive punctual sounds, something very common in EDM.

The source for the segmentation algorithm is the features vector consisting of the three instantaneous values of the smoothed energy per band as explained in section 3. As commented in that section, the rate of the features matches the video frame rate (typically 50 or 60 Hz) and low latency should be desirable in the segmentation algorithm as well as in the features extraction. The proposed segmentation process consists of the following stages:

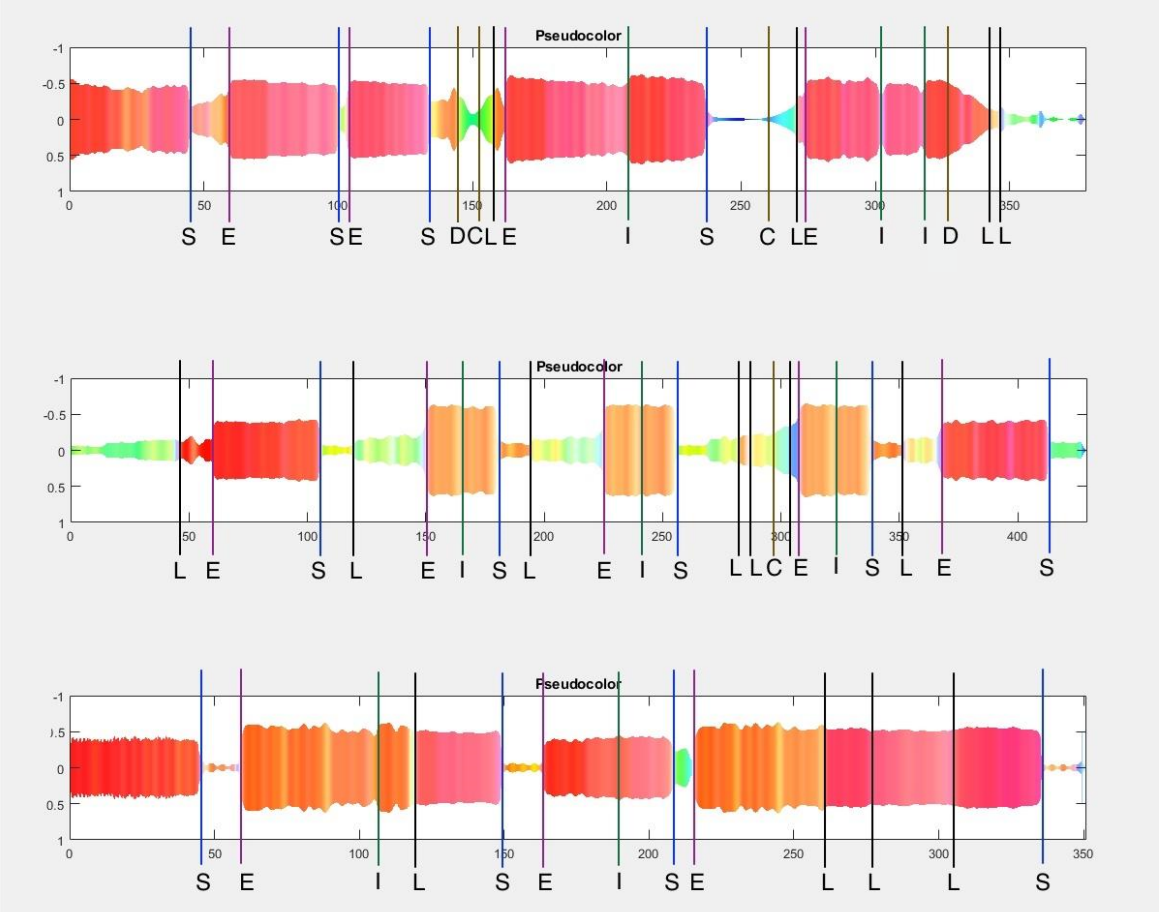


Figure 4: Resulting of labelling for three songs (S = Break Start, E = Break End, L = Layer Change, I = Instant Event, C = Crescendo, D = Decrescendo)

1) A transformation matrix M4 is applied to the three energy values to properly weight them and provide better detection of changing sections in the song.

2) The Euclidean distance between the actual and the previous feature vector is computed. The bilateral filtering applied in the previous stages guarantees some immunity to small changes but preserving big ones, which improves the detection.

3) Distance is compared to a threshold set in the training process which is described later.

4) If one of the previous thresholds is triggered, a mechanism to eliminate false positives is also implemented by attending to a minimum distance between events.

5.3.- Training of the algorithm

To adjust the different weights, threshold and minimum distance between events of our algorithm, it is necessary to fine-tune its values. This adjustment should be made using samples of the music style of interest.

A training set consisting of 100 songs of different EDM styles has been compiled. A balance between the different subgenres commented in section 2 has been taken into account. Next, a musical expert has hand-labeled the events in all the songs creating a database of time events.

The same expert labeled all songs because, due to the special characteristics of EDM music, sometimes two experts may have different criteria. Figure 4 shows an example of labeling for three different songs. The following events have been labelled: S = Break Start, E = Break End, L = Layer Change, I = Instant Event, C = Crescendo, D = Decrescendo.

Four parameters have been selected for the training process: two weight factors for mid and high frequency bands with respect to the low band, the features-vector distance threshold and the minimum time between events.

A simple optimization algorithm consisting of these steps is then started:

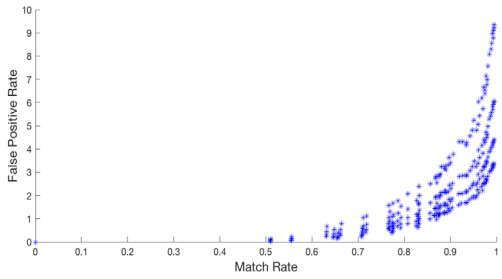


Figure 5: Match Rate vs False Positive Rate cloud of results for the first training iteration

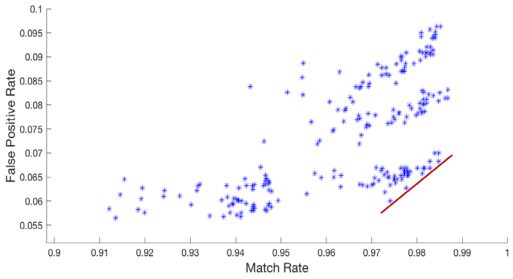


Figure 6: Match Rate vs False Positive Rate cloud of results of the last training iteration. Optimal solutions are along the red line.

1) The entire database is automatically labeled with a 4D grid of four equispaced values for each parameter, totaling 256 combinations

2) The match rate (matches / labeled events) and false alarm rate (false positives / labeled events) are calculated and plotted for each combination. This analysis gives us the information needed for step 3. Figure 5 shows the first iteration of this training with a very poor false alarm rate of almost 1000%.

3) Around the best combination, the grid is refined and step 2 is repeated. In the case that the best result of any variable is in the border of the grid, instead of refining it, the grid is extended in this direction and step 2 is repeated.

4) The iteration stops when there is no improvement in various iterations or a number of iterations are reached. In Figure 6 we can see the last iteration with the best results, all below 10% false alarm rate.

Since a perfect result with 100% match and 0% false positives cannot always be obtained on a large database, a trade-off was explored between the two values. Thus, it was necessary to choose which values of the four variables

produce the best solution. Figure 6 shows a line of optimal solutions marked in red. The solution selected for our purpose, which belongs to that line, has a 98.48% match rate and 6.82% false positives rate. This solution corresponds to the 4 specific values combination that we were looking for.

These results are quite good considering that the false alarm rate is not of prevalence importance in our case. In practice, finding more subtle changes in the song (than those a human would label) would not cause visual disturbances in the video animation.

5.4.- Results

The segmentation algorithm has been validated with a different set of songs, obtaining a matching detection rate of about 96%, which is similar to the results of the training set. The false alarm rate is constrained in an acceptable rate of 10-20%, depending on the set of songs saved for the validation test. Anyway, considering what was commented in the previous section, this quantity of false alarms does not represent a major problem.

A typical application for video effects of the detected segmentation events would be to change into a different animation scene or to move camera viewpoints synchronized with song section changes.

6.- CONCLUSIONS

In this work, different adapted and novel algorithms to extract easily audible musical features from Electronic Dance Music (EDM) have been presented. The focus has been put on its application for the automation of video and 3D animation synchronized with the audio content.

The algorithms implement low-cost time-frequency features, some of them smoothed with the novel application of a known image filtering algorithm to audio, resulting in a low latency output. The segmentation stage is based on a simple energy band distance threshold algorithm specifically tuned for EDM. Through a database of songs, a training stage has been carried out for the fine tune of weights, threshold, and minimum events separation. The balance between match rate and false alarm rate has been heuristically fixed according to the practical application.

The final algorithms have been implemented in C performing in real-time and have been successfully integrated into a real-time commercial 3D graphics engine called “Visual Music” that is under development, as it can be seen in figure 7. This piece of software is now being tested by video artists who are applying it to real scenarios. The feedback from these early users will be employed to improve the algorithm and to add new features.

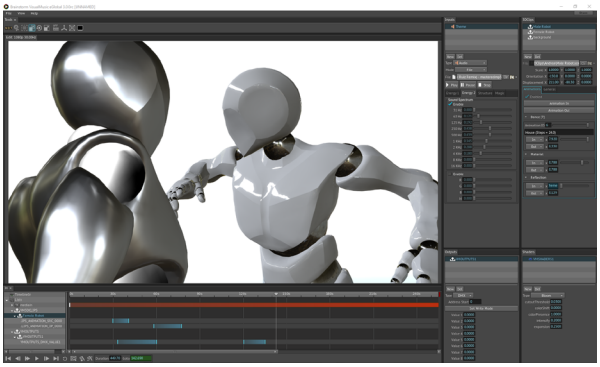


Figure 7: Visual Music software with audio module included.

7.- ACKNOWLEDGMENTS

This work has been supported by the European Commission under the H2020 program, project VISUALMUSIC, ID# 731986

8.- REFERENCES

[1] H. Meinedo and J. Neto, “Audio segmentation, classification and clustering in a broadcast news task.”, in IEEE International Conference on Acoustics, Speech, and Signal Processing, 2003. (ICASSP ’03). vol. 2, pp. 2–5. Hong Kong, China, 2003.

[2] G. Xia, D. Liang, R. B. Dannenberg and M. J. Harvilla, “Segmentation, clustering and display in a personal audio database for musicians.”, in 12th International Society for Music Information Retrieval Conference (ISMIR 2011) pp. 139–144. Miami, Florida, USA, 2011.

[3] A. Bietti, “Online learning for audio clustering and segmentation”, École Normale Supérieure de Cachan, Inria IRCAM. 2014.

[4] A. Dessein and A. Cont, "An information-geometric approach to real-time audio segmentation.", in IEEE Signal Processing Letters, 20(4), pp. 331–334, 2013.

[5] M. A. Siegler, U. Jain, B. Raj and R. M. Stern, "Automatic Segmentation, Classification and Clustering of Broadcast News Audio.", in Proc. DARPA Speech Recognition Workshop pp. 97–99, 1997.

[6] M. Levy and M. Sandler, "Structural Segmentation of Musical Audio by Constrained Clustering.", in IEEE Transactions on Audio, Speech and Language Processing, 16(2), pp. 318–326, 2008.

[7] D. Ellis, "Beat Tracking by Dynamic Programming", in Journal of New Music Research, Special Issue on Beat and Tempo Extraction, vol. 36 no. 1, pp. 51-60, 2007.

[8] Y. Shiu and J. Kuo, "Musical Beat Tracking via Kalman Filtering and Noisy Measurements Selection", in ISCAS 2008. IEEE Int. Symposium on Circuits and System, pp. 3250-3253, May 2008.

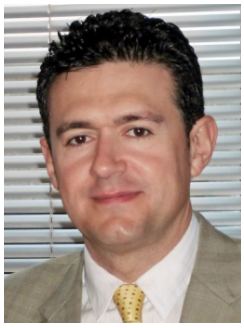
[9] Y. Shiu and J. Kuo, "On-Line Musical Beat Tracking with Phase-Locked-Loop (PLL) Technique", in IEEE Int. Conference on Consumer Electronics, April 2007.

[10] C. Tomasi and R. Manduchi, "Bilateral filtering for gray and color images", in Sixth International Conference on Computer Vision (IEEE Cat. No.98CH36271) pp. 839–846. Bombay, India, 1998.

[11] K. Itoh, H. Sakata, I. L. Kwee, and T. Nakada, "Musical pitch classes have rainbow hues in pitch class-color synesthesia," in Sci. Rep., vol. 7, no. 1, p. 17781, Dec. 2017.

9.- BIOGRAPHIES

Emanuel Aguilera received a telecommunications engineering degree in 2004 and a M.S. degree in Artificial Intelligence, Pattern Recognition and Digital Image in 2011, both from the Universitat Politècnica de València, Spain. He is a researcher and senior programmer at the Institute of Telecommunications and Multimedia Applications (iTEAM), where he has been working since 2006 on the area of digital signal processing for audio, multimedia, virtual reality and mobile devices applications. He is interested in wave-field synthesis, image processing, real-time multimedia processing for telecommunications and audio applications for mobile platforms.



Jose Javier Lopez was born in Valencia, Spain, in 1969. He received the telecommunications engineer degree and the Ph.D. degree, both from the Universitat Politècnica de València, Valencia, Spain, in 1992 and 1999, respectively. Since 1993, he has been involved in education and research at the Communications Department, Universitat Politècnica de València, where he is currently a Full Professor. His research activity is centered on digital audio processing in the areas of spatial audio, wave field synthesis, physical modeling of acoustic spaces, efficient filtering structures for loudspeaker correction, sound source separation, and development of multimedia software in real time. He has published more than 160 papers in international technical journals and at renowned conferences in the fields of audio and acoustics and has led more than 25 research projects. Dr. Lopez was workshop co-chair at the 118th Convention of the Audio Engineering Society in Barcelona and has been serving on the committee of the AES Spanish Section for nine years, currently as secretary of the Section. He is a full ASA member, AES member and IEEE senior member.

Pablo Gutierrez-Parera was born in Córdoba, Spain in 1982. He received a telecommunications engineer degree in 2008 from the Universidad Politécnica de Madrid. In 2010 and 2013 he obtained a M.S. degree in digital postproduction and a European graduate in telecommunication systems, sound and image engineering, both from the Universitat Politècnica de Valencia. Currently, he is a PhD grant holder from the Spanish Ministry of Economy and Competitiveness under the FPI program and is pursuing his PhD degree in telecommunications at the Institute of Telecommunications and Multimedia Applications (iTEAM) working in the field of spatial audio.

Carlos Hernandez is a Telecommunications Engineer from the Higher Polytechnic Institute "José Antonio Echeverría" (ISPJAE), Havana, Cuba, in 1989 and Ph.D. in Telecommunications Engineering from the Polytechnic University of Valencia (UPV), Spain, in 1998. He is teacher at the Communications Department of The UPV since 2001 and its current lines of research are related to the processing of signals and their application in the field of sound. He develops educational projects and teaches courses and workshops for teachers in order to improve educational methods and the quality of teaching in the university, as well as the study of the social impact of technologies as dynamic elements of sustainable human development and cooperation. He is a teacher at the UPV SENIOR University where he has been teaching courses since 2009 on the use of Internet and its services by elder people. He also develops musical applications based on Smartphones and Tablets for being used by people with intellectual and sensory disabilities.

Development of Substrate Integrated Passive Microwave Circuits

Carmen Bachiller, Juan R. Sánchez, Vicente Nova, José M. Merello, Vicente E. Boria

Instituto de Telecomunicaciones y Aplicaciones Multimedia,
Universitat Politècnica de València,
8G Building - access D - Camino de Vera s/n - 46022 Valencia (Spain)
Corresponding author: mabacmar@dcom.upv.es

ABSTRACT

In this work, the authors have developed a set of communication devices implemented in three different types of Substrate Integrated Circuit (SIC) technology: Decoupled Empty Substrate Integrated Waveguide (DESIW), Alternating Dielectric Substrate Integrated Waveguide (ADSIW) and Empty Substrate Integrated Coaxial Line (ESICL). The three are mixed technologies, waveguide-printed circuit, which perfectly solve the deficiencies associated with traditional technologies, integrating a rectangular waveguide or coaxial line into a planar substrate. With these novel hybrid technologies, traditional circuits can be implemented on a waveguide or coaxial guide but inheriting the advantages of the planar technologies, in terms of easy integration and low cost, as well as the advantages of waveguides and coaxial guides, in terms of low radiation losses. In addition, the practical implementation of these SIC lines and components has led to the efficient realization of broadband transitions with planar circuits, in order to get the integration with the same substrate and to use low cost planar production techniques.

The developed devices allow the use of substrate sections with different permittivity, even susceptible to being variable due to the use of a material whose dielectric permittivity varies with a polarization voltage, such as the liquid crystal. This provides a simple mechanism for the tuning of the device response after its manufacture. In this way, the same device can be used for a wide range of applications at different frequencies.

Keywords: liquid crystal, substrate-integrated circuits, reconfiguration, high-frequency communication, passive microwave devices.

1.- INTRODUCTION

The growing expansion of multimedia applications, satellite communication systems and wireless communication systems have prompted the electronics industry to operate in new frequency bands with a sufficient spectrum [1]. In addition, they have promoted the need to have low-cost technologies, with high performance, and that are adequately fitted to the requirements of mass production, while also allowing a significant reduction in the volume, weight and consumption of telecommunications equipment. Moreover, it is increasingly required that the communication devices are reconfigurable, that is to say that the same device can work dynamically in different frequency bands, adapting its response to the conditions of the environment, by means of mechanical, electronic or electromagnetic processes [2]. To achieve this, systems must incorporate devices or materials that allow varying some of their physical characteristics depending on: voltage, magnetic field, temperature and/or applied pressure.

Some examples of elements with this kind of dynamic behavior are ferrites [3], [4], [5], PIN diode [6], varactors [7], RF MEMS [8] and ferrolectric materials such as Barium-Strontium-titanate (BST) [9], KTa0.45Nb0.55O3 (KTN) [10] and liquid crystal [11].

The characterization of the electromagnetic properties of the liquid crystal is a field of study of high interest for the industry. These materials present different permittivities and losses depending on their polarization states, so their measurement is not trivial. There are previous works about characterization of liquid crystals at high frequency (upper K-band) and of course in the optical spectrum, but there are hardly any studies in lower bands, C-band or X-band, which are of great interest in current communications [12]-[17].

This type of materials are used to implement numerous devices, such as phase shifters, resonators and filters. These devices are implemented on transmission lines, which allow to guide the electromagnetic wave. Despite the fact that there are several implementation technologies, its commercial success demands a great efficiency in terms of cost and mass production along with the electromagnetic guidance features. Waveguide is the classical technology, which provides excellent performance: total electromagnetic shielding (it eliminates radiation loss totally), reduced insertion loss, ability to carry high power signals and high quality factor. Nevertheless this technology does not lend itself to mass production, since it requires a great deal of assembly and operation effort. In addition, this solution is, in general, bulky, heavy and difficult to integrate with other high-frequency integrated circuits, which are manufactured today in planar technology.

The intrinsic advantages of planar devices are numerous: low cost, reduced weight, compact size and relatively simple, economical and precise manufacturing processes. However, planar circuits present high losses and a reduced quality factor. In order to overcome the deficiencies and limitations of current manufacturing technologies, a whole new generation of high-frequency integrated circuits, known as Substrate Integrated Circuits (SICs), has recently been developed. The foundation of the SIC circuits is to synthesize non-planar structures on a flat dielectric substrate.

Substrate Integrated Waveguide (SIW) [18] technology is a mixed technology, waveguide-printed circuit board, that integrates a rectangular waveguide on a flat substrate. This is an "artificial" waveguide, which is synthesized by means of two parallel rows of metallized step holes that unite two planar conductors separated by a dielectric substrate (that has a certain permittivity value and related losses).

The Empty Substrate Integrated Waveguide, or ESIW [19], is another step in the improvement initiated by the SIW technology. In this case, the sidewalls of the synthetized waveguide are continuous metal walls, and the dielectric substrate is removed from the waveguide propagation region. This allows to reduce the associated losses and increase the quality factor of the devices, but maintaining the advantages of low cost, easy manufacturing, and integration with planar circuits.

Finally, the Empty Substrate Integrated Coaxial Line Transition (ESICL) [20] enables the construction of an empty coaxial line within a substrate. This type of structure presents the advantage of having two conductors (a very attractive property when it is used for reconfiguration applications) on which a completely confined TEM mode is propagated, and therefore it is immune to external electromagnetic interference.

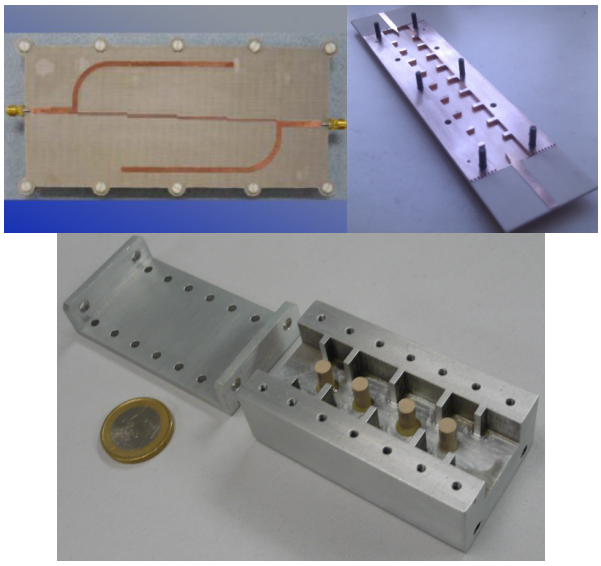


Figure 1. Microwave filters in microstrip (planar) technology, Empty Substrate Integrated Waveguide technology and waveguide technology.

2.- RESEARCH OBJECTIVE

The main objective of the research was the design and implementation of several microwave passive devices on substrate-integrated lines. The idea was to use SIC transmission lines, specifically the DESIW line, to implement a resonator, a filter and a phase shifter; moreover, the Alternating Dielectric SIW line was used to implement a filter, and the ESICL to implement a resonator, a phase shifter, a power divider and a directional coupler. Another aim was to study the potential variation of the response of these lines based on an external signal. In principle, and if the viability analysis enabled it, liquid crystals were used which, filling the interior of the device, allow their response to vary by changing their relative permittivity.

Since the considered transmission medium and the guided structures were slightly studied, the work had phases in which they had to be analyzed more deeply, as well as the problem of using these materials in the selected guided structure. On the other hand, any real process has a certain random behavior, so the effects of manufacturing tolerances on the final devices were also studied. This can help on the selection of one or other structure for future jobs.

3.- PROCEDURES AND TECHNIQUES

To achieve these high-level objectives, the following procedures and techniques were followed:

- **Study and analysis of ferroelectric materials.**

A detailed study of ferroelectric materials in general, and of liquid crystal in particular, was needed to know and characterize their properties and the necessary techniques for their implementation.

Since the electrical permittivity of the liquid crystals is proportional to the polarization of their particles with respect to the electromagnetic field that is applied to them, it was necessary to study the methods that exist for their polarization. This polarization field is applied to achieve a resting state (anchoring the liquid crystal in one of its limit states) and to serve as an actuator that allows to rotate its molecules.

On the other hand, the current research on the liquid crystal at microwave frequencies has increased the number of liquid crystal commercial mixtures, which require a study of their permittivity and loss in different polarization states.

For this study, a bibliographic collection and a research work on the measurement methods of these parameters was required. The measurements must be done at certain particular frequencies by using resonant cavities, as well as in a bandwidth by using waveguides and/or transmission lines.

This analysis was carried out in collaboration with two research groups of other Universities: the Department of Physics of Condensed Matter of the University of Zaragoza, and the High Frequency Laboratory of the Technical University of Cologne (THK).

- **Study of SIC guided structures.**

A study of the SIC structures in general, and of the structures DESIW, ADSIW and ESICL in particular, was required. This study began with the theoretical characterization of these structures, and the analysis and design of broadband transitions that enabled the easy implementation and measurement of devices. The study of the manufacturing techniques, necessary for their implementation, was also carried out, where it was necessary to employ simulation models that were faithful to reality.

- **Compatibility study.**

Once the guiding structure and filling material were studied, it was necessary to perform a compatibility study among them in order to ensure the correct development of the project. This compatibility was considered both theoretically and in practice, thus a relatively simple device (e.g. a resonator) was designed and manufactured to analyze it in an intuitive way.

This compatibility study had two main

objectives: the feasibility study of the project and its redesign in case of finding incompatibilities, as well as the election of the type and number of equipment that could be designed and manufactured.

On the other hand, it was necessary to study and design the polarization networks that allowed the RF signal and the polarization voltage to be properly uncoupled. Moreover, the study also considered the orientation of the liquid crystal particles by using alignment layers and/or an electric or magnetic field.

- **Device design**

Some devices were designed on DESIW: a resonator, a filter and a phase shifter; a filter on ADSIW and some others on ESICL: a resonator, a phase shifter, a power divider and a directional coupler. The designs were made for both reconfigurable and fixed devices, and the rest of the necessary elements for the correct functioning of the devices was also designed, such as alignment elements, polarization networks, etc. These designs were developed with in-house produced specific simulation and optimization software, and with commercial electromagnetic simulation software, such as CST Studio Suite.

- **Manufacture of designed devices.**

For manufacturing the prototypes of the designed devices, authors used the techniques and experience developed by the Group of Microwave Applications (GAM) of the iTEAM research institute of the Universitat Politècnica de València (UPV), and the Group of Applied Electromagnetism of the Universidad de Castilla la Mancha (UCLM). It was necessary to use a precision milling machine with numerical mechanical control and a laser milling machine for the fabrication of the devices. The reconfigurable components were filled with liquid crystal. For this reason, precise techniques were necessary for welding the structure, as well as the use of the pins of the polarization voltage and the necessary elements to isolate it of the high frequency signal. In Figures 2 and 3 we can see images of some of the manufacturing processes employed in this work.

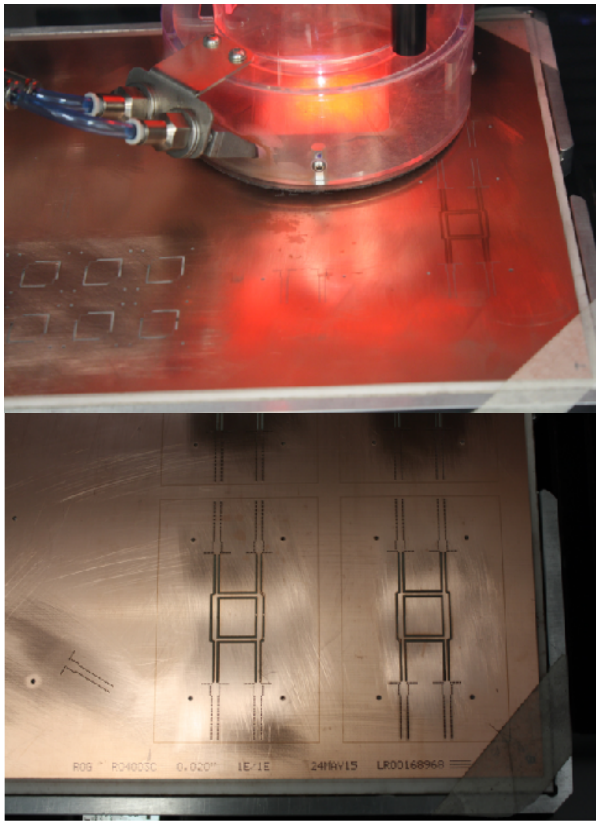


Figure 2. Manufacturing process by laser milling.

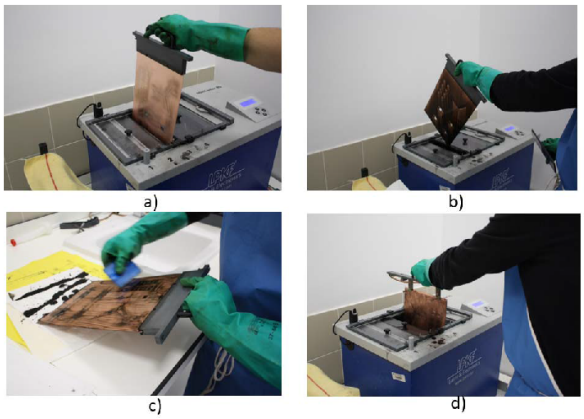


Figure 3. Galvanic plating of the device, a) immersion in the reactive solution, b) extraction, c) cleaning d) immersion in the acid solution.

ESICL and DESIW lines and transitions were designed, manufactured and measured. These lines were optimized to be filled with liquid crystal and therefore to have a reconfigurable response. These basic lines were used to manufacture other devices, such as filters, resonators, power dividers, phase shifters and hybrid couplers.

The liquid crystal was used to fill some of these devices. The process (see details in figures 4 and 5) was not so simple, and there were many considerations to take into account, because the liquid crystal needs to be perfectly confined and, additionally, it has to be possible to polarize it afterwards.

Figure 4. Filling of a glass cell and a microwave device with liquid crystal

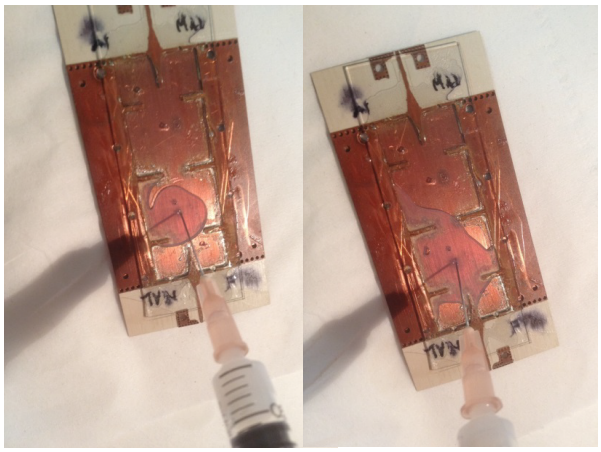


Figure 5. Detail of the filling process of a microwave filter with liquid crystal.

- **Reconfiguration and measurement**

Since there were some devices that were filled and some others that were not, the viability of implementing both kinds of responses (fixed and reconfigurable) was proven. The frequency responses were measured and compared to simulated results. The measurements were carried out with a vector network analyzer, obtaining the behavior of the device in a certain range of frequencies. The measurements required a calibration that considered the effects of the wires, but also of the connectors and the line sections that carry the signal to the device. For this purpose, specific TRL calibration kits were manufactured, for each technology and frequency range.

Moreover, the characterization of new liquid crystal mixtures was performed at microwave frequencies. Three cylindrical resonator cavities (at 5 GHz, 9 GHz and 11 GHz) were manufactured, and the electromagnetic responses of glass cells filled with the different mixtures of liquid crystal were measured. With these electromagnetic responses, it was possible to extract the permittivity and loss tangent of the considered mixtures. Some images of all these practical procedures are shown in Figures 6 and 7.

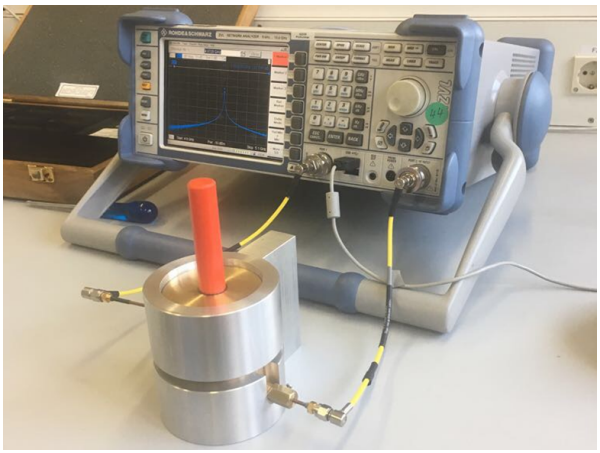


Figure 6. Electromagnetic characterization of liquid crystal mixtures.

Figure 7. Measurement of the frequency response of the devices. Calibration kit and measurement setup. Detail of the measurement process.

4.- RESULTS

The first developed device was an ADSIW filter at 11 GHz. This device is based on the ESIW technology, alternating sections of waveguide with and without dielectric. The structure combines resonant cavities and impedance inverters, which produces a directly coupled cavities H-plane filter. The filter is a single conductor structure, thus a polarization voltage cannot be applied for reconfiguration. Figure 8 presents the active layer and a detailed view of the sections of the manufactured ADSIW filter. The detailed view shows the discontinuity between SIW-ESIW sections and the sidewall conductors: metallized via holes for SIW and substrate metallization for ESIW. Figure 9 shows that the filter pass-band is 3% and the insertion loss is below 2.7 dB. Moreover, the out of band behaviour of the filter, i.e. the stopband, with attenuation higher than 35 dB, can reach values up to 20 GHz, which is around $2f_o$.

Figure 8. Filter built on Alternating Dielectric Substrate Integrated Waveguide (ADSIW) technology.

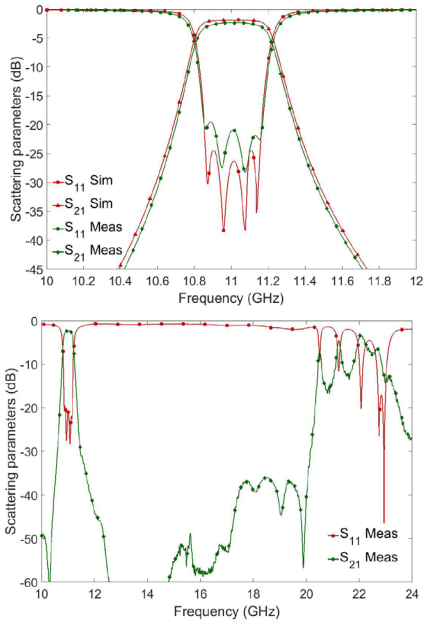


Figure 9. Comparison of measured and simulated frequency responses of ADSIW filter.

The natural improvement of ESIW structure, that enables reconfiguration, consists on the AC/DC decoupling of this line thanks to two conductors, i.e. the Decoupled Empty Substrate Integrated Waveguide (DESIW). As can be seen in Figures 10 and 11, this structure is based on a grid of small squares in the bottom of the top cover, and each square has a polarization via to access from outside the structure when it is welded. In the top of this cover, a big square is milled to isolate the vias from the rest of the device. A line in X-band and a filter centered at 10.8 GHz have been designed and manufactured with this technology. The manufactured device and the frequency responses of the line and the filter are shown in Figures 10 and 11, respectively. The frequency response of the line presents low attenuation in transmission (S_{21}), and reflection (S_{11}) below 15 dB in the pass-band, thus making it adequate for applications with low requirements. The frequency response of the filter presents an important attenuation in the pass band, so further research in order to improve the electromagnetic results is required.

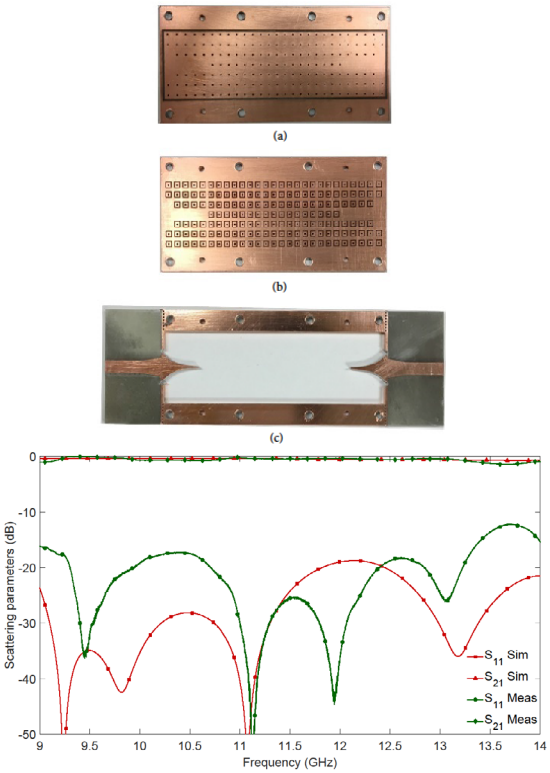
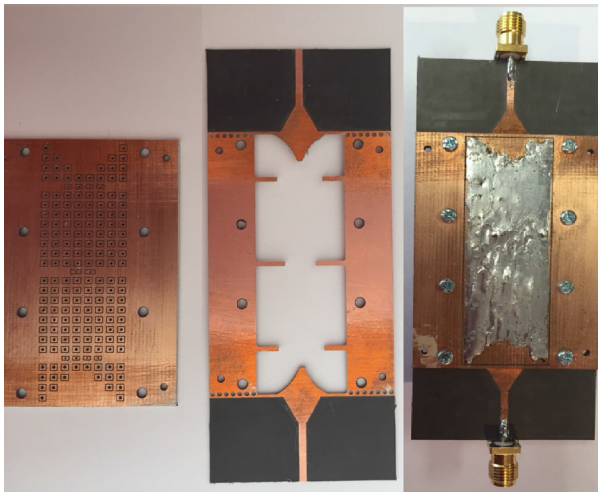


Figure 10. Decoupled Empty Substrate Integrated Waveguide (DESIW) line, detail of the different layers. Comparison of simulated and measured frequency responses.



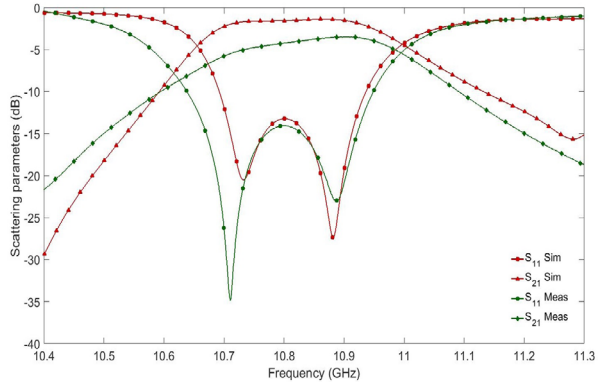


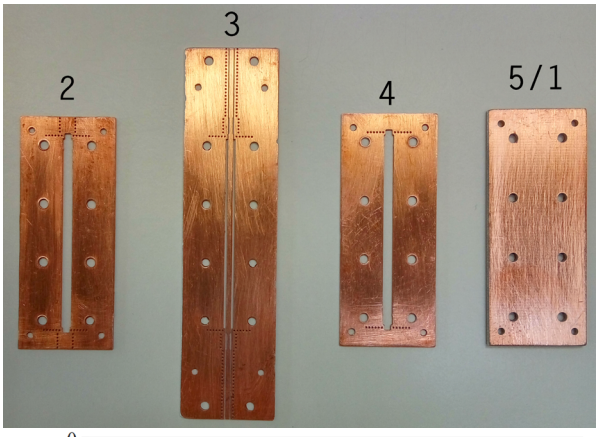
Figure 11. Decoupled Empty Substrate Integrated Waveguide (DESIW) filter, detail of the layers and assembled filter with connectors. Comparison of simulated and measured frequency responses.

The ESICL technology was used to design and manufacture a line, a power divider and a hybrid coupler. ESICL is a square coaxial line integrated in a bulk of metalized substrates, the structure has two conductors and the fundamental propagation mode is TEM.

Figure 12 shows the manufactured line and its frequency response. The transmission parameters are very close to the ideal ones (0 dB) and the reflection parameters are below -20 dB in the frequency range.

Figure 13 shows the direct hybrid coupler of 90° and Figure 14 its frequency response. In this realization the two branches divide the power equally (-3 dB in S_{31} and S_{41}), the input isolation is very high (S11 below -20 dB around the central frequency 5 GHz) as well as the isolation of the decoupled branch S_{21}.

Figure 15 presents the Y power divider and its frequency response in Figure 16. This realization divides the power equally between the two branches (-3 dB in S_{21} and S_{31}), and the input isolation is very high (S_{11} below -20 dB around the central frequency 5 GHz).



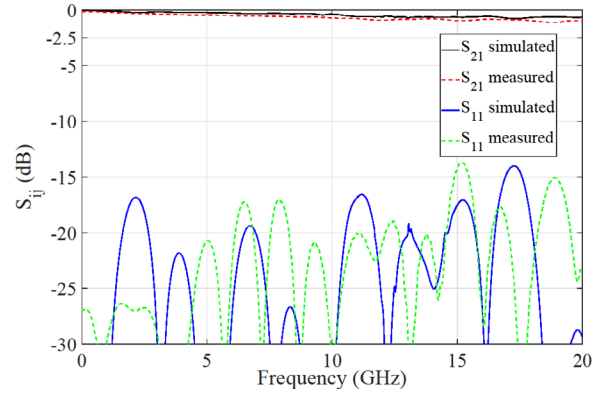


Figure 12. Empty Substrate Integrated Coaxial Line, detail of the different layers that compose the lines. Comparison of the simulated and measured frequency responses.

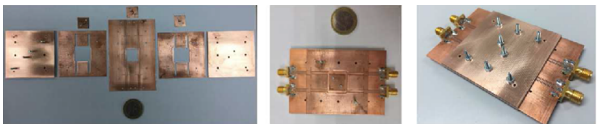


Figure 13. ESICL direct hybrid coupler of 90°, detail of the layers, the assembled prototype and the final result with connectors.

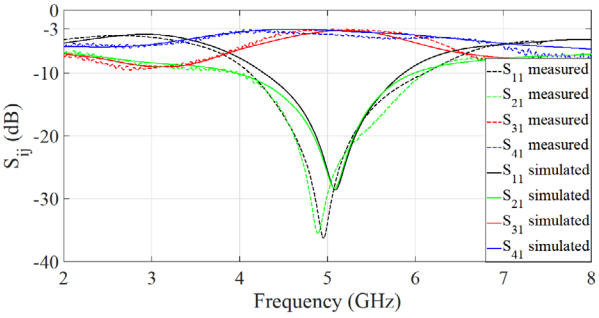


Figure 14. Comparison of simulated and measured frequency responses of direct hybrid coupler of 90°.

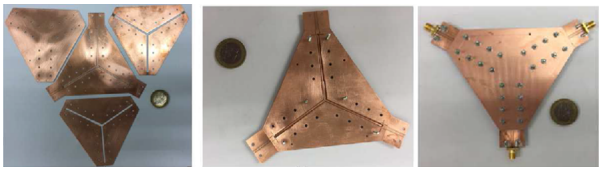


Figure 15. ESICL Y power divider, detail of the layers, the assembled prototype and the final result with connectors

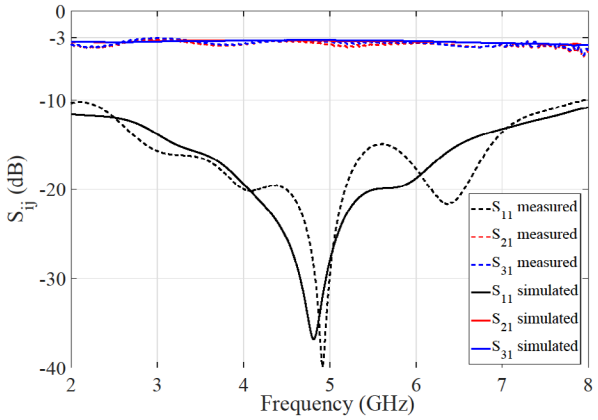


Figure 16. Comparison of simulated and measured frequency responses of the Y power divider.

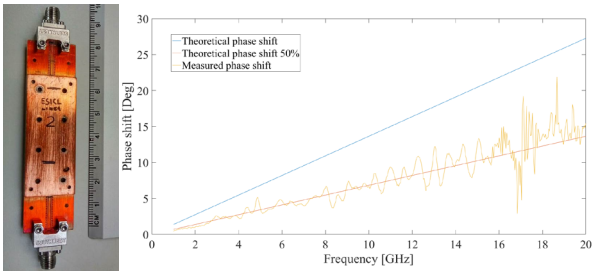


Figure 17: Phase shifter in ESICL technology. Comparison of theoretical and measured phase shift.

Finally, a phase shifter was designed and manufactured in ESICL technology as shown in Figure 17. To perform the phase shifter an ESICL line has been filled with liquid crystal, by applying a bias voltage to the active conductor of the coaxial line, the electric permittivity of the liquid crystal varies thus modifying the phase of the line response. The graph in Figure 17 shows the theoretical and measured differential phase between the two boundary polarization states. The insertion loss of the phase shifter is lower than 3 dB in the 1-20 GHz range, and the maximum phase shift is 21° at 17 GHz. These variables were obtained by applying a low frequency bias voltage of 200 Vpp at 1 kHz. Defining the Figure-of-Merit (FoM) as the maximum ratio of the phase shift and the insertion loss, the device performs a FoM of 8°/dB.

5.- CONCLUSIONS

In summary, it has been proven that passive microwave devices using novel hybrid SIC technologies are viable, easy to design and manufacture, and provide excellent performance. In addition, some strategies for the AC/DC decoupling of these lines have been developed to allow the introduction of reconfiguration elements. The electromagnetic performance of one of these elements with reconfiguration capability, the liquid crystal, has been studied in depth.

The results can be used in base stations of mobile communication systems, both in the input and output stages. The devices can also be used in feeding systems of arrays of beamforming antennas, in payload of satellites or in terrestrial equipment. All of them are, therefore, technical sectors with a great social and economic impact on our current and future Knowledge Society.

6.- REFERENCES

[1] K. Koufos et al., "Deliverable D5. 4 Future spectrum system concept." [Online]. Available: https://www.metis2020.com/wp-content/uploads/deliverables/METIS_D5.4_v1.pdf. [Accessed: 07-Jun-2017].

[2] J. Mitola and G. Q. Maguire, "Cognitive radio: making software radios more personal," IEEE Personal Communications, vol. 6, no. 4, pp. 13–18, Aug. 1999.

[3] S. Gevorgian, Ferroelectrics in microwave devices, circuits and systems: physics, modelling, fabrication and measurements. London: Springer, 2009.

[4] M. Almalkawi, L. Zhu, and V. Devabhaktuni, "Magnetically tunable substrate integrated waveguide bandpass filters employing ferrites," in 2011 International Conference on Infrared, Millimeter, and Terahertz Waves, 2011, pp. 1–2.

[5] S. Adhikari, Y. J. Ban, and K. Wu, "Magnetically Tunable Ferrite Loaded Substrate Integrated Waveguide Cavity Resonator," IEEE Microwave and Wireless Components Letters, vol. 21, no. 3, pp. 139–141, Mar. 2011.

[6] M. Armendariz, V. Sekar, and K. Entesari, "Tunable SIW bandpass filters with PIN diodes," in The 40th European Microwave Conference, 2010, pp. 830–833.

[7] F. He, K. Wu, and H. Wei, "Electrically tunable half mode substrate integrated waveguide resonator," in Asia-Pacific Microwave Conference 2011, 2011, pp. 1166–1169.

[8] V. K. Varadan, RF MEMS and their applications. Chichester, England Hoboken, NJ: John Wiley, 2003.

[9] V. Lee, S. Lee, S. A. Sis, and A. Mortazawi, "Intrinsically Switchable Frequency Reconfigurable Barium Strontium Titanate Resonators and Filters," IEEE Transactions on Microwave Theory and Techniques, vol. PP, no. 99, pp. 1–9, 2017.

[10] V. Laur et al., "Reconfigurable circuits for wireless applications using KTN ferroelectrics," in 2007 European Microwave Conference, 2007, pp. 102–105.

[11] J. F. Bernigaud, V. Laur, P. Laurent, N. Martin, G. Tanne, and F. Huret, "Ferroelectrics- and Liquid Crystal-based Microwave Agile Devices," in German Microwave Conference, 2008, pp. 1–4.

[12] Felix Gölden, "Liquid Crystal Based Microwave Components with Fast Response Times: Material, Technology, Power Handling Capability," Dissertation, Technische Universität Darmstadt, Darmstadt, 2010.

[13] Carlos Carrasco Vela and Patxi Xabier Quintana Arregui, "Diseño y fabricación de dispositivos basados en cristal líquido polimérico," Universidad politécnica de Madrid, 2012.

[14] L. Cai, H. Xu, J. Li, and D. Chu, "High FoM liquid crystal based microstrip phase shifter for phased array antennas," in 2016 International Symposium on Antennas and Propagation (ISAP), 2016, pp. 402–403.

[15] T. Yang, M. Zhan, and D. Jiang, "A novel tunable inverted microstrip phase shifter based on liquid crystal," in 2015 IEEE International Conference on Communication Problem-Solving (ICCP), 2015, pp. 575–577.

[16] S. Strunck, O. H. Karabey, C. Weickhmann, A. Gaebler, and R. Jakoby, "Continuously tunable phase shifters for phased arrays based on liquid crystal technology," in 2013 IEEE International Symposium on Phased Array Systems and Technology, 2013, pp. 82–88.

[17] Javier Torrecilla, E. Avila-Navarro, Carlos Marcos, Virginia Urruchi, Jose M. Sanchez-Pena, Julia Arias, and Maria M. Sanchez-Lopez "Microwave tunable notch filter based on liquid crystal using spiral spurline technology" in Microwave and Optical Technology Letters, Vol. 55, No. 10, pp 2420-2423. DOI 10.1002/mop. October 2013.

[18] D. Deslandes and K. Wu, "Integrated microstrip and rectangular waveguide in planar form," IEEE Microwave and Wireless Components Letters, vol. 11, no. 2, pp. 68–70, February 2001.

[19] Angel Belenguer, Hector Esteban, and Vicente E. Boria, "Novel empty substrate integrated waveguide for high performance microwave integrated circuits", IEEE Transactions on Microwave Theory and Techniques, vol. 62, no 4, 2014, pp: 832 – 839.

[20] A. Belenguer, H. Esteban, and V. E. Boria, "Novel Empty Substrate Integrated Waveguide for High-Performance Microwave Integrated Circuits," IEEE Transactions on Microwave Theory and Techniques, vol. 62, no. 4, pp. 832–839, Apr. 2014.

7.- BIOGRAPHIES

Carmen Bachiller received her MSc degree in Telecommunication Engineering in 1996 and her PhD in Telecommunication in 2010 from the Universitat Politècnica de València. She worked from 1997 to 2001 in the ETRA I+D company as a project engineer in research and development on automatic traffic control, public transport management and public information systems using telecommunication technology. In 2001, she joined the Communication Department of the Universitat Politècnica de València as an assistant lecturer; she is an Associated Professor since 2011. She is teaching electromagnetism theory. She has participated in several teaching innovation projects and technological heritage studies. Her current research activities include modal methods for electromagnetic analysis, optimization and design of passive microwave structures, analysis and design of substrate integrated transmission lines and circuits and power effects in passive waveguide systems.

Juan R. Sánchez received his MSc degree in Telecommunication Engineering from the Universitat Politècnica de València in 2014 (with first-class honours). In 2015 he received an MSc degree, "Master Program in Electronics and Telecommunications" from Högskolan i Gävle, Sweden. In 2015 he gained a grant under the Fellowship Program for Training University Professors FPU14/00150 to get the PhD degree in Telecommunication, he is now working in the Microwave Application Group of the Institute of Telecommunications and Multimedia Applications of the Universitat Politècnica de València. His current research interests include analysis methods, computer aided design of passive microwave devices in waveguide, and substrate integrated waveguide technologies.

Vicente Nova received his MSc degree in Telecommunication Engineering from the Universitat Politècnica de València in 2016. He made his master's degree project on ESICL broadband transitions. His current research includes optimization and design of substrate integrated microwave devices, design and manufacture of SICs lines and design of reconfigurable devices using anisotropic materials.

José M. Merello received his BSc degree in Telecommunication Eengineering from the Universitat Politècnica de València in 2017. He made his final degree project on analysis and design of passive devices on ESICL. Currently, he is studying in order to get an MSc degree in Telecommunication Engineering.

Vicente E. Boria was born in Valencia, Spain, on May 18, 1970. He received his Ingeniero de Telecomunicación degree (with first-class honours) and the Doctor Ingeniero de Telecomunicación degree from the Universidad Politècnica de València, Valencia, Spain, in 1993 and 1997, respectively. In 1993, he joined the Departamento de Comunicaciones, Universidad Politècnica de València, where he has been Full Professor since 2003. In 1995 and 1996, he was holding a Spanish Trainee position with the European Space Research and Technology Centre, European Space Agency (ESTEC-ESA), Noordwijk, The Netherlands, where he was involved in the area of EM analysis and design of passive waveguide devices. He has authored or co-authored 10 chapters in technical textbooks, 160 papers in refereed international technical journals, and over 200 papers in international conference proceedings. His current research interests are focused on the analysis and automated design of passive components, left-handed and periodic structures, as well as on the simulation and measurement of high power effects in passive waveguide systems. Dr. Boria has been a member of the IEEE Microwave Theory and Techniques Society (IEEE MTT-S) and the IEEE Antennas and Propagation Society (IEEE AP-S) since 1992. He is member of the Editorial Boards of the IEEE Transactions on Microwave Theory and Techniques, IEEE Microwave and Wireless Components Letters, Proceeding of the IET (Microwaves, Antennas and Propagation), IET Electronics Letters and Radio Science. Presently, he serves as Associate Editor of IEEE Microwave and Wireless Components Letters and IET Electronics Letters. He is also a member of the Technical Committees of the IEEE-MTT International Microwave Symposium and of the European Microwave Conference.

MULTIMEDIA COMMUNICATIONS GROUP

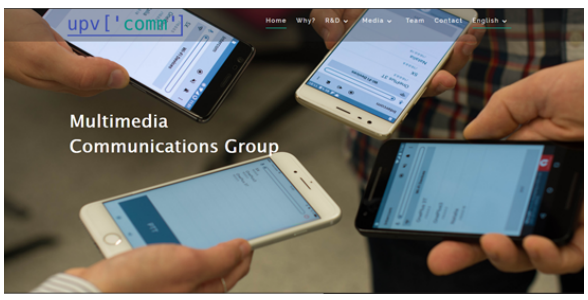
HEAD OF THE GROUP RESEARCH REPORT

Multimedia Communications Group (COMM) started its activities in 2004, and nowadays is composed of a group of 7 researchers, focusing its research lines on multimedia systems and Quality of Experience (QoE). During the last year 2017/2018 the group has continued with its work lines focused on the distribution of multimedia content using protocols like Dynamic Adaptive Streaming over HTTP (DASH); carrying out more in-depth studies into the Internet of Things (IoT) trend; developing new functionalities for multimedia systems based on DRM and cross-layer techniques; and continuing studying new trendy lines such as the integration of protocols for broadcast distribution.

These lines of action have been articulated through the execution of different research and development projects, as well as scientific publications. Among the new projects, we highlight the participation into the European project MAtchUP, in which COMM participates together with the GTAC group and other 27 partners.

In addition, in order to promote the main activities of the group, we have been continuously updating the webpage and we continue being very active in social networks (Facebook, Twitter and Youtube). Also, we have participated actively in initiatives carried out by iTEAM, such as scientific coffees and the first iTEAM Pills Contest, in which COMM was awarded by its video about DASH. Moreover, during the last year the head of the COMM, Juan Carlos Guerri, became a professor.

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



Home page of the COMM website

1.- PROJECT ACTIVITIES

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

Adaptive video through MPEG-DASH

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

In this sense, another important research line in this year has been the analysis of metrics that help to calculate the quality perceived by users when consuming video contents. In this regard, we have proposed a new QoE metric based on the PSNR (Peak Signal-to-Noise Ratio) for the evaluation of adaptive bitrate (ABR) algorithms. The different evaluations carried out have proved that this PSNR-based QoE metric results more accurate than other similar metrics proposed in the literature.

Test for the evaluation of the Quality of Experience

Adaptive streaming for 3D video

During this year, different tests were performed to evaluate the behavior of an adaptive streaming system over HTTP and how it affects the quality of 3D video. For this purpose, different channels of transmission with variable bandwidth have been emulated using the NetEm tool, which allows to modify and restrict the server output bandwidth (also the delay or packet loss).

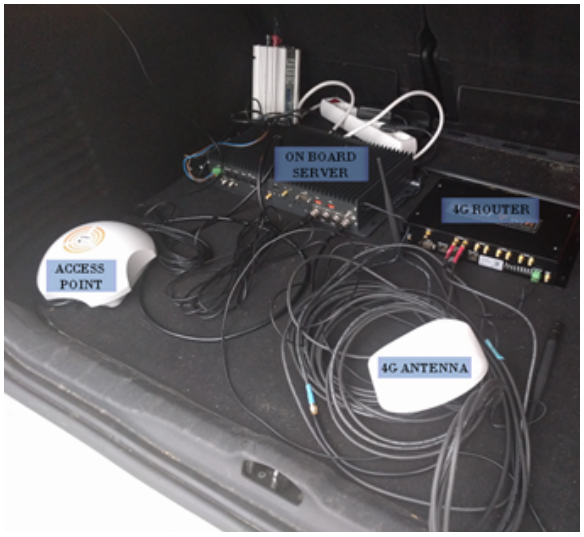
Understanding that objective evaluation techniques may not be sufficient to characterize a 3D video transmission system, in this year the work has focused on the design and implementation of subjective tests that allow assessing the performance of coding systems and 3D adaptive streaming video. The subjective tests also allow to validate the comparison between encoders (which was carried out previously) using objective quality parameters such as PSNR and Structural Similarity (SSIM). Currently, different subjective tests are being carried out. Also, we are working on a proposal that allows to establish automatically a relationship between the objective parameters of Quality of Service (QoS) and the QoE in adaptive 3D video streaming systems.

Video streaming over mobile wireless ad hoc networks

During this year we have kept on analysing and testing new routing algorithms in order to improve the QoE of the users. These routing algorithms work in a cross-layer manner, meaning that they can obtain relevant parameters from network and transport layers and take advantage of them in order to improve the quality of video flows. This is achieved by means of the adaptation of the video bitrate, either using scalable video coding or simply pre-encoded variants of the same video. In this line, we have started studying the MPEG SAND (Server and Network Assisted DASH) technology, which offers standardization messages and protocols in order to improve the user experience in the streaming service and to better use the bandwidth.

TV content transmission in mobility

This year we have implemented and evaluated a multimedia transmission system that sends TV/radio contents to vehicles in mobility. The system has mainly two blocks, one on the cloud and another on the mobile vehicle. On the cloud, a DVB (Digital Video Broadcasting) receiver obtains the TV/radio signal and prepares the contents to be sent through 4G. Specifically, contents are transcoded and packetized using the DASH standard. Vehicles in mobility use their 4G connectivity to receive the flows transmitted by the cloud. The key element of the system is an on-board proxy that manages the received flows and offers them to the final users in the vehicle. The proxy contains a buffer that helps reduce the number of interruptions caused by handover effects and lack of coverage.



Assembly of the TV content transmission in mobility over 4G system in a car

Internet of Things

During this year, the group has deepened in the field of Internet of Things, specifically in Smart Cities. The National Smart Cities Plan, within the Digital Agenda for Spain, is committed to helping local Spanish entities in the transformation processes towards smart urban areas. To this purpose, it is necessary the use of a package of tools designed to facilitate the transformation process as well as a catalog of ICT solutions. In this line of solutions we find FIWARE, an open software platform promoted by the European Union for the development and deployment of IoT services.

In our research group, during this year we have studied the components that allow the acquisition, the processing, the storage and the distribution of data within the framework of FIWARE, with the purpose of creating a pilot platform based on the FIWARE standards. This will allow the students of the IoT Classroom to develop their applications and simulate a connected city. In addition, this platform is useful for the research group to specialize in the integration of different devices to the platform, in the publication of open data and indicators, etc. In short, to be able to work as IoT integrators.

Reliable multicast transmission over communication networks

We have continued studying a protocol named ROUTE (Real-Time Object Delivery over Unidirectional Transport), which is considered the evolution of FLUTE (File Delivery over

Unidirectional Transport), a highly studied protocol by part of the research group. The ATSC (Advanced Television Systems Committee) published in 2016 a new candidate standard which proposes the jointly use of ROUTE and DASH. ROUTE, apart from the functionalities of the FLUTE protocol (such as multicast transmission of files), allows to provide video streaming services in multicast.

1.1.- ONGOING PROJECTS

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

Summary of the project: The overall objective of the project is the definition and implementation of a new platform capable of supporting and providing real-time content distribution services and Internet access in an environment of high user density and high mobility, taking into account the complexity of the reception and signal transmission in maritime environments, in which there are usually connectivity problems so Internet access is only possible by satellite. The project started in July 2017. Since then, COMM has been responsible for the design of the architecture and the specifications. Also, COMM has implemented a DRM (Digital Rights Management) offline module that allows to play video contents without the need of having a permanent connectivity to Internet. Moreover, COMM has developed a system for the improvement of the Quality of Experience of users based on the transmission of video contents.

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

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

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

Summary of the project: The project aims at strengthening the planning processes for urban transformation, consolidating the benefits of deploying large scale demonstration projects of innovative technologies in the energy, mobility and ICT sectors, by means of substantially improved models for replication and upscaling, based on impacts evaluation, and ensuring the bankability of the solutions by means of innovative business models, which lead to achieve real deployment further than the pilots carried out in the lighthouse cities. With this, it is sought a high penetration of the validated technologies in those cities less prepared to adopt very innovative solutions and formalize it in a standard commitment, accompanied by capacity building strategies, to guarantee at least medium term implementation. The project started in October 2017, with an expected duration of five years. COMM focuses on actions related to ICT. During this year, the detailed design of the interventions to be implemented in Valencia is being prepared. The design includes technical descriptions, financial plans (including the structure of business models of each individual action), social strategies and citizens' engagement.

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

Meeting of the MAtchUP project in Antalya (Turkey)

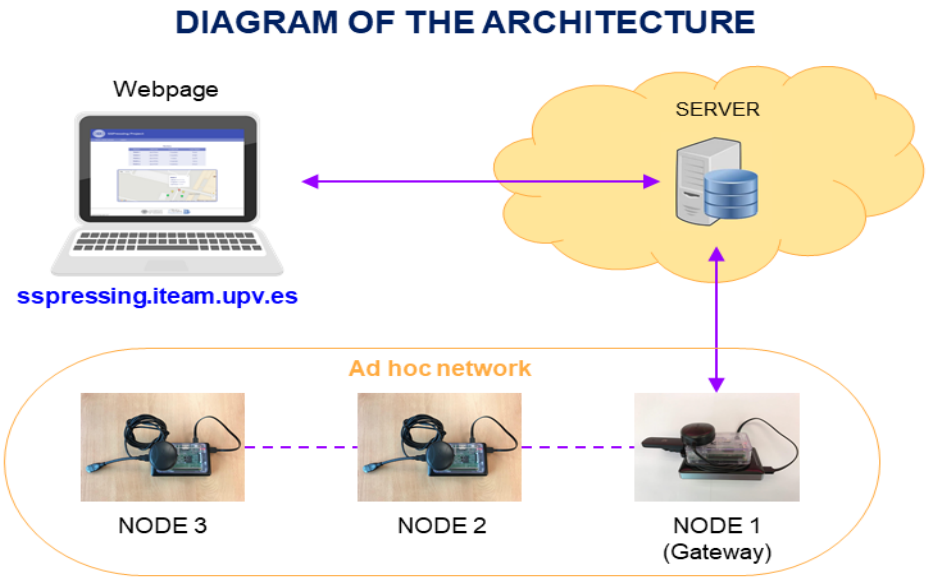
Name of the project: SSPressing - Smart Sound Processing for the digital living (TEC2015-67387-C4-4-R)

Webpage of the project:

http://sspressing.upv.es

Summary of the project: The project performs systems for analysis and synthesis of environments and sound scenes in an "intelligent" and computationally efficient way through network acoustic nodes. Specifically, the following objectives/developments are addressed: conformation of interactive virtual sound environments with distributed multinode control systems, creation of interactive virtual sound scenes and analysis of sound scenes for detection, location and classification of events and scenes, and development of systems to aid hearing and improve intelligibility. In the second year of the project, regarding the management of the communication network, the functionality of the ad-hoc network has been improved. Specifically, now sensors are able to record audio, doing the feature extraction and transmitting this value to the server throughout the ad hoc network. The server then receives the feature extraction from the sensors and runs the classifier, showing the classification results for each interval of time and sensor at the project webpage: https://sspressing.iteam.upv.es.

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



2.- RESEARCH RESULTS

2.1.- FEATURED PUBLICATIONS

- *Distributed sensor network for noise monitoring in industrial environment with Raspberry Pi.* N. Blasco, M. de Diego, R. Belda, I. de Fez, P. Arce, F. J. Martínez-Zaldívar, A. González, and J. C. Guerri, in Proc. of the Int. Conf. on Intelligent Systems and Applications (INTELLI-IAP), Nice (France), Jul. 2017, pp. 51-55.

Monitoring the noise in working places is essential to protect the health of workers. Two main factors must be taken into account, and thus controlled, when considering noise exposition during the working hours: level of perceived noise and time exposed to that noise level. In industrial environments, these factors represent a high priority due to the quantity of equipment inside the factory. We present a low cost system to measure and monitor noise conditions in an industrial environment. The proposed solution is based on ad hoc wireless probes and a server in the cloud, which acts as a centralized data sink. The proposed system helps to detect critical levels of noise for workers sending warning messages to predefined contacts by means of a text message or email when hazardous situations occur.

- *Evaluación de un sistema DASH para el streaming de vídeo 3D.* P. Guzmán, P. Arce, and J. C. Guerri, in Proc. of Jornadas de Ingeniería Telemática (JITEL), Valencia (Spain), Sep. 2017, pp. 224-228.

With the consumption of high definition content that becomes the main trend, we can once again observe an increase in the consumption of 3D content. This has made the topics related to content production, coding, transmission, Quality of Service (QoS) and Quality of Experience (QoE) perceived by users of 3D video distribution systems a subject of research with numerous contributions in recent years. As part of this work, a comparison of the performance of the most popular video coding standards H.264, H.265 and their corresponding extensions for 3D video has been made in the first place. On the other hand, an experimental evaluation of the video quality received in an HTTP adaptive streaming (DASH) 3D video scene has been carried out.

- *Look Ahead: A DASH Adaptation Algorithm.* R. Belda, I. de Fez, P. Arce, J. C. Guerri, presented at the IEEE International Symposium on Broadband Multimedia Systems and Broadcasting, Valencia, Spain, Jun. 2018.

This paper proposes a video quality adaptation algorithm based on the Dynamic Adaptive Streaming over HTTP (DASH) standard for on-demand video services. When a video is encoded with constant quality, the resulting bitstream has variable bitrate due to the inherent nature of the video encoding process. The proposed algorithm, called Look Ahead, takes into account this bitrate variability in order to calculate, on the fly, the appropriate quality level that minimizes the number of interruptions during the playback. Moreover, the Look Ahead algorithm has been implemented and integrated into ExoPlayer v2. The proposed algorithm is compared to the Müller and Segment Aware Rate Adaptation (SARA) algorithms as well as to the adaptive algorithm integrated into ExoPlayer. The comparison reflects that Look Ahead outperforms the Müller, SARA and the ExoPlayer adaptive algorithms in terms of number and duration of video playback stalls, with hardly decreasing the average video quality.

MICROWAVE APPLICATIONS GROUP

HEAD OF THE GROUP RESEARCH REPORT

Over the past year (June 2017 to May 2018), the group has continued working on its two projects awarded with national and regional public funds, respectively. It is expected that at the end of this year, 2018, when it ends the execution of the regional project, all its main objectives will be achieved.

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

Apart from receiving public funding, the GAM activities were also funded through at least five technology transfer contracts with industries and organizations, mainly subscribed with the European Space Agency (ESA).

Regarding the training capacity of the group, we should mention that one PhD doctoral thesis has been publicly defended in the last year -receiving the maximum degree of "Cum Laude"-, and the senior group members are presently supervising another ten more in different research areas.

It is fair to say, from the facts described above, that the quality of the group is growing year by year, therefore becoming a reference in the framework of their research areas and the space sector. More details about the group can be found at: http://gam.webs.upv.es/, or http://www.iteam.upv.es/group/gam/.

1. - PROJECT ACTIVITIES

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

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

In all these research lines and activities, the group has obtained relevant public funding, through both national and regional projects, making feasible to keep on producing new and relevant results in these R&D topics.

1.1. - ONGOING PROJECTS

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

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

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

To meet these emerging applications, future satellites will incorporate new and advanced

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

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

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

FUTUR-SAT Project: Advances in Microwave and Millimetre Wave Components (Circuits and Antennas) for Future Space Communication Systems

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.

All these future spectral requirements lead to the possibility of using higher frequency bands, such as Q- and V-band (40-60 GHz), which are currently being explored. However, the correct operation of these new services involves many technological challenges in the design of satellite payloads

At these frequencies, losses are high and require transmitting signals with power levels up to 500 W per channel. In addition, new space platforms must handle a large number of channels with very high bandwidths. The reduction of the physical dimensions of the components that integrate these satellites should be also considered, which will have implications in the managing of power levels, and in the precision of the manufacturing processes. Furthermore, the future space communications systems must provide reconfiguration capability of their parameters such as operating carrier frequencies, bandwidths and coverage, as well as to provide adaptive gain controls for atmospheric and environmental conditions changes.

This project aims to offer innovative solutions to all of these technological challenges that future space communications systems must face, more specifically in the area of advances in the development of components (passive circuits and antennas) in the microwave and millimetre wave bands that integrate the payloads and communication modules of the satellites.

This project has been funded by the Programa PROMETEO FASE II para grupos de Investigación de Excelencia, Consellería de Educación, Investigación, Cultura y Deporte, Generalitat Valenciana.

2.- RESEARCH RESULTS

As a result of the joint research activity developed by this group in all these research lines, during the last year of activity, more than 15 articles have been published in scientific journals with a high impact index (such as IEEE Transactions on Microwave Theory and Techniques, IEEE Microwave and Wireless Components Letters, IEEE Transactions on Antennas and Propagation, IET Proceedings on Microwave, Antennas and Propagation, IET Electronics Letters and Radio Science).

At the same time, the group has presented more than 20 communications in prestigious international conferences (such as IEEE-MTT Int. Microwave Symposium, IEEE-AP Int. Symposium on Antennas, European Microwave Conference on Numerical Electromagnetic Modeling and Optimization for RF, Microwave, and Terahertz Applications (NEMO), the 9th International Workshop on Multipactor, Corona and Passive Intermodulation (MULCOPIM'17), the European Microwave Week 2017, and the 2017 ESA Microwave Technology and Techniques Workshop, some of them as invited papers.

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

Some of the most outstanding results are described below:

The Microwave Application Group (MAG), in collaboration with the Universidad de

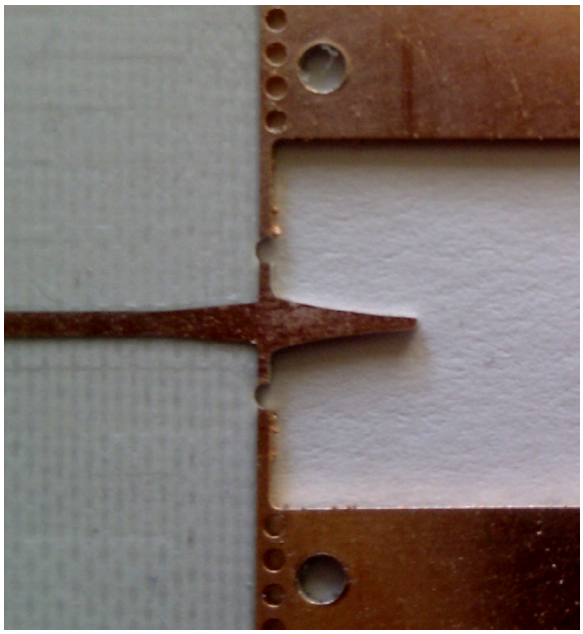


Figure 1: Transition detail from microstrip to ESIW

Castilla-La-Mancha, has developed new empty transmission lines integrated in a planar circuit board. These are the empty substrate integrated waveguide (ESIW), and the empty substrate integrated coaxial line (ESICL). Both lines are low profile, and low cost, and can be manufactured with standard planar circuit machinery. At the same time, they outperform the substrate Integrated waveguide in terms of losses and quality factor in resonators, due to the absence of dielectric. In order to validate the two transmission lines for high performance and high frequency communication systems, in the last year some communication devices have been successfully implemented, such as a narrow-band high-Q filter in ESICL [1], a folded filter in ESIW [2], and a Moreno cross guide coupler [3] in ESIW. Besides, new empty transmission lines have been developed: an E-plane ESIW [4] for implementing traditional E-plane devices, and a decoupled ESIW [5] that allows the polarization of liquid crystal inside the ESIW. Finally, the transition from microstrip to ESIW has been improved (see Figure 1) [6] so that now the insertion losses and reflection levels have both been decreased.

[1] Borja, A. L., Belenguer, A., Esteban, H., and Boria, V. E. (2017). Design and Performance of a High-Q Narrow Bandwidth Bandpass Filter in Empty Substrate Integrated Coaxial Line at $ K_ {u} $-Band. IEEE Microwave and Wireless Components Letters, 27(11), 977-979.

[2] Ballesteros, J. A., Diaz-Caballero, E., Fernandez, M. D., Esteban, H., Belenguer, A., and Boria, V. (2017, October). Performance comparison of a four-pole folded filter realized with standard and empty substrate integrated waveguide technologies. In European Microwave Conference (EuMC), 2017 47th (pp. 412-415). IEEE.

[3] Miralles, E., Belenguer, A., Esteban, H., and Boria, V. (2017). Cross-guide Moreno directional coupler in empty substrate integrated waveguide. Radio Science, 52(5), 597 603.

[4] Belenguer, A., Cano, J. L., Esteban, H., Artal, E., and Boria, V. E. (2017). Empty substrate integrated waveguide technology for E plane high-frequency and high-performance circuits. Radio Science, 52(1), 49-69.

[5] Sánchez, J. R., Bachiller, C., Esteban, H., Belenguer, A., Nova, V., and Boria, V. (2017). New decoupled empty substrate integrated waveguide realisation. Electronics Letters, 53(17), 1203-1205.

[6] Esteban, H., Belenguer, A., Sánchez, J. R., Bachiller, C., and Boria, V. E. (2017). Improved low reflection transition from microstrip line to empty substrate-integrated waveguide. IEEE Microwave and Wireless Components Letters, 27(8), 685-687.

The Microwave Application Group (GAM) and Aurora Software and Testing, S.L (AURORASAT),

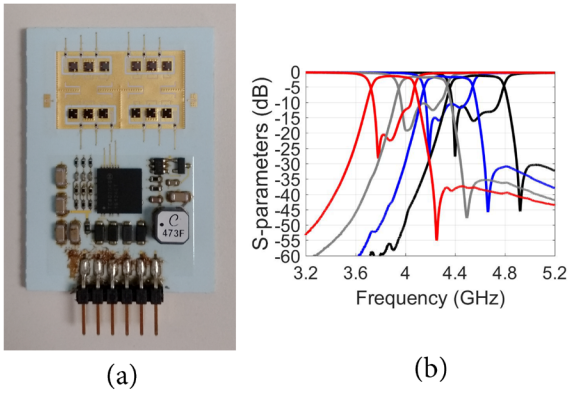


Figure 2: (a) RF MEMS reconfigurable coaxial SIW filter and (b) measured results.

in the framework of the ESA project RFQ/3-14301/15/NL/PA, have demonstrated the possibility of designing high selectivity RF MEMS reconfigurable coaxial SIW filters with wide tuning range and improved Q-factor. They can be used in a great variety of applications in order to increase flexibility and miniaturization, while reducing manufacturing costs. Thus, a discretely tunable 4-pole bandpass filter, which can be switched between four different frequencies has been designed, manufactured and tested. Specifically, the filter must cover the C-band between 3.7 GHz and 4.5 GHz with four equally spaced frequency responses showing constant FBW while providing more than 15% of tuning range. A potential application for such tunable components would be the implementation of flexible wideband receivers, especially for the uplink C-band for satellite applications. The basic building block of the proposed tunable filter is based on a coaxial

topology implemented in SIW technology [1]. The use of the multi-layer LTCC technology enables us to implement a monolithic integration of the tuning element control unit and the reconfigurable filter, as shown in Figure 2. This solution helps the designers to improve the overall EM performance of the component while achieving a remarkable miniaturization degree. In order to allow for digital frequency tuning of the filter, embedded loading capacitive patches are introduced by inserting electrically isolated bit capacitances at the top metal layer of the filter layout, as proposed in [2]. These bit capacitances are connected and disconnected from the remaining filter metallization, thus performing the filter frequency tunability, by using RF MEMS resistive switches from AirMems [3]. In this context, the RF MEMS switch AIM-OS100310 is fabricated on a high resistivity silicon substrate. The device is wafer-level packaged, and hermetically sealed with a temperature resistant material, which provides a great easiness of integration into RF circuits. It is a single pole, single throw MEMS resistive switch. Due to its high linearity level and very low power consumption, this switch represents a good solution for many wireless infrastructure applications.

[1] S. Sirci, J.D. Martínez, M. Taroncher, and V.E. Boria, "Varactor-loaded continuously tunable SIW resonator for reconfigurable filter design", 41st EuMW 2011, Manchester (UK), Oct. 2011, pp. 436–439.

[2] S. Sirci, J.D. Martínez, R. Stefanini, P. Blondy and V.E. Boria, "Compact SMD packaged tunable filter based on substrate integrated coaxial resonators", in Proc. IMS IEEE MTT-S, Jun. 2014.

[3] AirMems AIM-OS100314SPST RF MEMS Switch Data Sheet, Limoges (France).

2.1.- FEATURED PUBLICATIONS

Some of the most recent and relevant publications of the R&D group in the last year are briefly summarized next.

New Decoupled Empty Substrate Integrated Waveguide Realisation, J.R. Sánchez, C. Bachiller, H. Esteban, A. Belenguer, V. Nova, V.E. Boria, Electronics Letters, vol. 53, pp. 1203-1205, Aug. 2017.

DOI: 10.1049/el.2017.1240

A novel decoupled empty substrate integrated waveguide (DESIW), which enables AC/DC decoupling in any device that is integrated in it is presented. The decoupling strategy is performed throughout a micro-milling square pattern of easy implementation that increases the insertion losses compared with the standard ESIW. However, the DESIW related losses are still tolerable, allowing the employment of the new periodic structure in many practical applications. In particular, it can be used for the design and manufacturing of reconfigurable devices which need a bias voltage on the whole device, or just on some of its particular areas. A broadband transition from DESIW to microstrip planar lines has been also successfully designed. The new line has been manufactured and measured.

Advanced Compact Setups for Passive Intermodulation Measurements of Satellite Hardware, D. Smacchia, P. Soto, V.E. Boria, M. Guglielmi, C. Carceller, J. Ruiz-Garnica, J. Galdeano, D. Raboso, IEEE Transactions on Microwave Theory and Techniques, vol. 66, pp 700-710, Feb. 2018.

DOI: 10.1109/TMTT.2017.2783383

Guideline for the practical development of novel advanced test beds for passive intermodulation (PIM) measurements. The proposed test beds show high performance and are flexible, allowing for the measurement of several PIM signals of different orders, with two or more input carriers. In contrast to classic test beds for satellite hardware an integrated solution involving the minimum number of hardware pieces is proposed. The result is a lower number of flanged interconnections, thus reducing residual PIM level and insertion losses. In addition, return loss degradation and harmful spurious generation in the interconnections are also avoided. Measurement test beds for conducted and radiated PIM are discussed, highlighting the benefits and drawbacks of each configuration. Design guidelines for the key components are fully discussed. Finally, excellent experimental results obtained from low-PIM measurement setups, working from C-band to Ka-band, are shown, thus fully confirming the validity of the proposed configurations.

Novel Planar and Waveguide Implementations of Impedance Matching Networks Based on Tapered Lines Using Generalized Superellipse, S. Cogollos, J.J. Vague, V.E. Boria, J.D. Martínez, IEEE Transactions on Microwave Theory and Techniques, vol. 66, pp. 1874-1874, April 2018.

DOI: 10.1109/TMTT.2018.2791952

For the practical implementation of RF and microwave impedance matching networks, a widely employed solution is based on tapered lines. This paper shows a simple method to design smooth tapers that take into account the dispersion of the line and the required design bandwidth simultaneously. A planar taper has been designed in microstrip technology with the same length of classical ones but improving their performances. A waveguide prototype has also been designed with similar

performance to a commercial one but with one third of its length. Both tapered structures have been obtained through the optimization of very few parameters using the same design strategy. As a result, the reflection coefficient of the tapers can be optimally adapted to a given specific mask using the prescribed value of physical length. Experimental results for both tapers are included for the validation of the proposed topologies and the related design method.

Exploring the Tuning Range of Channel Filters for Satellite Applications Using Electromagnetic-Based Computer Aided Design Tools, J. Ossorio, J.J. Vague, V.E. Boria, M. Guglielmi, IEEE Transactions on Microwave Theory and Techniques, vol. 66, pp. 717-725, Feb. 2018.

DOI: 10.1109/TMTT.2017.2769083

The objective of this paper is to use electromagnetic-based computer-aided design (CAD) tools to investigate the maximum tuning range of channel filters, typically used in satellite payloads. Both circular and rectangular waveguide technologies are investigated. The results of the investigation show that single-mode rectangular waveguide implementations offer substantially wider tuning range, as opposed to classical dual-mode circular waveguide implementations. In addition to simulations, measurements are also presented indicating very good agreement with theory, thereby fully validating the CAD procedure.

Compact Wideband Balanced Bandpass Filters With Very Broad Common-Mode and Differential-Mode Stopbands, M. Sans, J.Selga, P.Vélez, J. Bonache, A.M. Rodriguez, V.E. Boria, F. Martín, IEEE Transactions on Microwave Theory and Techniques, vol. 66, pp 737-750, Feb. 2018.

DOI: 10.1109/TMTT.2017.2785246

Compact balanced bandpass filters based on a combination of multisection mirrored stepped-impedance resonators and interdigital capacitors are presented in this paper. The considered filter topology is useful to achieve wide bandwidths for the differential mode as well as very efficient common-mode suppression. By conveniently adjusting the transmission zeros for both operation modes can be extended up to significantly high frequencies. Filter size and this performance are the main relevant characteristics of the proposed balanced filters. The potential of the approach is illustrated by the design of a prototype order-5 balanced bandpass filter, with central frequency f_0 = 1.8 GHz, 48% fractional bandwidth (corresponding to 55.4% -3-dB bandwidth), and 0.04-dB ripple level. The designed filter is as small as 0.48λg x 0.51λg, where λg is the guided wavelength at the central filter frequency, and the differential-mode stopband extends up to at least 6.5 GHz with more than 22-dB rejection.

2.2.- PATENTS

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

M. Guglielmi, V.E. Boria, M. Baquero, G. Toso, P. Angeletti

BELOW CUTOFF ARRAYS

Pub. No.: P201730838

Pub. Date: 26/06/2017

International Patent Extension Application 09/01/2018

V.E. Boria, M. Baquero, D. Sánchez-Escuderos, M. Guglielmi

THE WAVEGUIDE CROSSOVER FILTER

Pub. No.: P201830106

Pub. Date: 07/02/2018

2.3.- AWARDS

Elevation to Fellow of the IEEE is an honor reserved for a select group of engineers each year. The number of Fellows elevated in any year cannot exceed one-tenth of 1% of the total voting membership. This highest grade of membership in the IEEE is conferred by the IEEE Board of Directors in recognition of an individual's outstanding record of accomplishments in any IEEE field of interest. And this year, with the IEEE Microwave Theory and Techniques Society (MTT-S) as the evaluating Society, 1 of the honorees awarded the status of member of the IEEE has been the head of or group, Vicente E. Boria Esbert, for his contributions to high-power microwave filters and multiplexers

ELECTROMAGNETIC RADIATION GROUP

HEAD OF THE GROUP RESEARCH REPORT

The Electromagnetic Radiation Group (GRE) focuses its research activities on various areas related to the analysis and design of antennas, as well as to the analysis of different propagation environments. The operating frequency bands under study range from UHF to the V band, thereby covering a wide range of applications, from mobile terminals to satellite antennas.

The GRE collaborates extensively with many academic and industrial partners, such as Chalmers University of Technology, the Courant Institute of Mathematical Sciences, the University of Oulu, the European Space Agency (ESA), Thales Alenia Space, or Huawei. The support to the local technological development becomes apparent in long-lasting links with regional companies. In 2017, GRE continued the work initiated within the framework of two national projects in 2016, and started a new national project 2017 related to propagation issues. All three projects are currently underway.

GRE research interests cover theory, numerical methods, design and measurement of antennas and propagation. A complete list of research activities can be found at http://www.iteam.upv.es/group/gre.html

1. - PROJECT ACTIVITIES

The group is involved in the following research lines:

- Slot-array antenna design for high-gain applications.
- Waveguide structures for millimeter and sub-millimeter wave bands.
- On-body antennas.
- Application of the Theory of Characteristic Modes for antenna design in different applications (MIMO, UWB, RFID, mobile communications, UHF, etc).
- Development of efficient methods for the electromagnetic analysis of complex structures.
- Diagnosis and antenna measurement.
- Propagation and channel modelling.

The ongoing projects within which the aforementioned research lines are being developed, as well as the main results obtained and the related publications, are described hereunder.

1.1. - ONGOING PROJECTS

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

Period: 2017-2019

Mobile satellite terminals are aimed at providing high data rate services in areas not covered by terrestrial networks, such as remote areas, war zones, natural disasters, ships or aircrafts. These terminals make use of the multi-spot beam coverage given by a new generation of satellites operating in Ka band (from 19 to 31 GHz). The increment of the operating frequency, from the Ku band (in systems implemented so far) to the Ka band, widens the available bandwidth and, consequently, increments the data rate. However, the new mobile terminals in Ka band cannot be simply designed by just upscaling the existing terminals (in the Ku band) to the new band. The specifications set to the new Ka-band terminals render the design a technological challenge that has not yet found a proper solution.

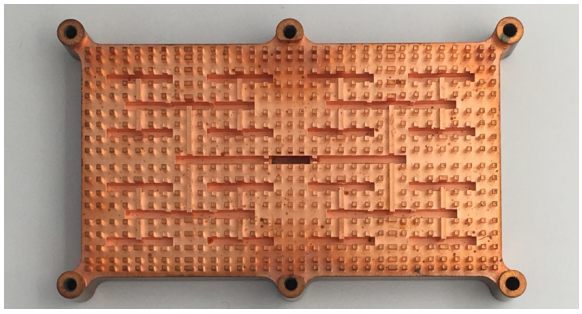
Within the framework of the SATCOM-KA project, new antenna concepts and topologies are being explored for Ka-band mobile satellite terminals, paying special attention to the reduction of the terminal volume and weight, a fundamental characteristic for on-the-move applications. In this context, during the second year of the project, the fabrication of the proposed solutions with metallized plastics, capable of reducing considerably the weight of the antenna, has been investigated. The comparison of the results obtained with this technology, and with the traditional direct-metal 3D printing, has shown the suitability of the new manufacturing technique for the implementation of Ka-band mobile satellite terminals for on-the-move systems.

Additionally, the project addresses the design of dual antennas sharing the same panel for both polarizations and/or both frequency bands, capable of switching polarization during handover from one spot-beam to another. Several solutions have been proposed in this

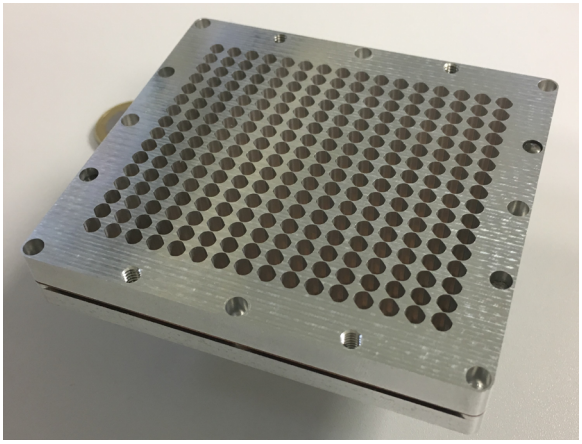
area during the second year of the project, reaching the manufacturing stage a circularly-polarized antenna in the V-band.

Collateral issues are also being considered within the framework of the SATCOM-KA project. On the one hand, new beam pointing mechanisms are being studied to facilitate the tracking of the satellite in ground terminals. On the other hand, the use of Frequency Selective Surfaces to maximize the aperture efficiency of the dual-polarized antennas proposed, and to convert linearly-polarized fields into circularly-polarized fields are also being explored.

This project has been funded by the *Ministerio de Economia Industria y Competitividad (MINECO).*



Corporate feeding network of a slot-array antenna fabricated with metallized plastics



Proof of concept of single-layer circularly-polarized aperture array antenna in the V-band.

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

Period: 2017-2019

The future explosion of wireless data transmissions in 5G systems will lead every user to demand connectivity to everything everywhere. Consequently, innovative smart and efficient technologies must be developed, starting from the antenna system. In this project, new efficient radiating elements are being developed for applications in the microwave (below 6 GHz) and mm-wave band.

The project focuses on various areas:

1. On-body sensing applications: Numerical methods for the computational modelling of the human body up to 6 GHz will be developed for applications related with on-body sensing systems. Multimode antennas will be also developed for these applications, which will be specifically conceived to radiate inside the human body.

2. Reconfigurable mm-wave antenna design for mobile devices: A phased-array antenna with a reconfigurable beam-forming network is going to be implemented for 5G mobile devices in the mm-wave band. Reconfigurable beams will be generated with the aid of LTCC (Low Temperature Co-fired Ceramics) technology, since the required facilities are already available at the GRE-GAM antenna laboratory at iTEAM.

3. Reconfigurable multibeam mm-wave 5G indoor base station design: Metallic planar lenses based on non-periodic Frequency Selective Surfaces (FSS) are being designed for a base station in the 20-30 GHz band. An efficient formulation of an integral equation approach for the analysis of metamaterial lenses in the mm-wave band is being developed. A prototype will be fabricated and characterized at UPV and channel measurement will be performed.

This project has been funded by the *Ministerio de Economia Industria y Competitividad (MINECO).*

Prototype of a metamaterial lens antenna designed at 10 GHz.

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

Period: 2018-2020

There is a widespread agreement among the scientific community, industry and mobile operators that future traffic demands, much higher than the current ones, will require the deployment of new systems with faster as well as more efficient and reliable connections. In the early 2012, ITU-R kicked off the program to develop IMT-2020 systems, thus initiating the definition and research activities of the fifth generation (5G) systems. These new systems will represent a significant improvement over 4G systems, increasing the speed of LTE-Advanced by 1000. 5G represents the possibility of

implementing new business models, making the most of new applications and services by allowing the devices to connect anytime and anywhere. Among the different applications or services expected of 5G technology is to make the concept of Internet of Things (IoT) become a reality. The concepts of smart home, smart office, smart city, among others, along with health-related applications, vehicular communications, high-quality 4K-8K UHD video transmissions, virtual and augmented reality, just to name a few of them, are expected to emerge in the 5G era.

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

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

This project has been funded by the *Ministerio de Economia Industria y Competitividad (MINECO).*

A measurement campaign has been developed in a typical underground environment in order to evaluate the propagation characteristics of some of the proposed 5G bands

2. RESEARCH RESULTS

2.1. FEATURED PUBLICATIONS

1. Low-Cost Ka-band Switchable RHCP/LHCP Antenna Array for Mobile SATCOM Terminal, J. I. Herranz-Herruzo, A. Valero-Nogueira, M. Ferrando-Rocher, B. Bernardo, A. Vila and R. Lenormand, IEEE Transactions on Antennas and Propagation, vol. 66, no. 5, pp. 2661-2666, May 2018.

*DOI:*10.1109/TAP.2018.2806421

Abstract: Achieving a functional antenna for mobile satellite communications terminals in Ka-band is probably one of the most challenging tasks in current antenna engineering, particularly bearing in mind they need to be low profile and "affordable." This quest is involving many companies in the field. Our contribution represents one of such efforts. The antenna is based on a slotted waveguide array technology to maximize efficiency and it features a number of novel solutions, going from its robust polarization switching mechanism, to the use of a thin wideband polarizer and the utilization of groove gap waveguides. This communication reports the measured data of a fully functional prototype to validate its novel contributions.

2. Low-Profile Radially Corrugated Horn Antenna, H. C. Moy-Li, D. Sánchez-Escuderos, E. Antonino-Daviu and M. Ferrando-Bataller, IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 3180-3183, 2017.

DOI: 10.1109/LAWP.2017.2767182

Abstract: This letter proposes a low-profile horn antenna with radial corrugations. The depth and width of the corrugations are suitably chosen to excite the mode HE11 in the corrugated section. This mode spreads uniformly across the whole aperture, thereby maximizing the radiating area and the aperture efficiency. The good polarization purity of mode HE11 provides a good cross-polar level and a low side-lobe level. The structure is fed by a circular waveguide with two matching elements on the feeding plane that minimize the return loss level. A prototype has been fabricated and measured to operate in the Ku band. The prototype, with a height of just 6.9 mm, provides a maximum gain above 12.2 dBi and an aperture efficiency better than 72 % within the operating frequency band.

3. On Multimode Equivalent Network Representation of Finite Arrays of Open-Ended Waveguides, D. Sánchez-Escuderos, M. Baquero-Escudero, P. Soto, V. E. Boria and M. Guglielmi, IEEE Transactions on Antennas and Propagation, vol. 65, no. 8, pp. 4334-4339, Aug. 2017.

DOI: 10.1109/TAP.2017.2710267

Abstract: This paper describes a multimode equivalent network (MEN) representation of a finite array of open-ended lossless waveguides on an infinite ground plane. The derivation is

based on an integral equation formulated at the interface between the waveguides and the free-space region. The MEN is formulated using the concept of accessible and localized modes, and includes ports for the free-space plane waves. The MEN derived can be easily combined with the MENs of other microwave components, thus allowing for the accurate analysis and design of more complex systems composed of waveguide elements and radiating apertures. Both simulated and experimental results are presented showing very good agreement, thereby fully validating the proposed equivalent network representation.

4. Analysis and Design of a Metamaterial Lens Antenna Using the Theory of Characteristic Modes D. Santillán-Haro, E. Antonino-Daviu, D. Sánchez-Escuderos, and M. Ferrando-Bataller, International Journal of Antennas and Propagation, 2018.

DOI: 10.1155/2018/6329531

Abstract: A new single-layer metamaterial lens antenna aimed to operate at 10 GHz is proposed in this paper. The lens antenna consists of twelve capacitively coupled unit cells distributed along a ring and illuminated by an open-ended circular waveguide with a metallic resonant ring. The theory of characteristic modes is used to analyze the metamaterial lens, in order to provide an insight into the radiation characteristics of the antenna. The proposed antenna has been optimized, obtaining a large bandwidth and a maximum directivity of 12.88 dBi at 10 GHz.

5. On the Contribution to the Field of the Nonphysical Characteristic Modes in Infinite Dielectric Circular Cylinders Under Normal Excitation T. Bernabéu-Jiménez, A. Valero-Nogueira, F. Vico-Bondia and A. A. Kishk, IEEE Transactions on Antennas and Propagation, vol. 66, no. 1, pp. 505-510, Jan. 2018.

DOI: 10.1109/TAP.2017.2768581

Abstract: Here, a detailed analysis of characteristic modes and fields of an infinite dielectric circular cylinder when computed through the Poggio-Miller-Chang-Harrington-Wu-Tsai formulation is carried out. The purpose is to determine their contribution to the total field, inside and outside the dielectric body and under two possible excitations: incident plane wave or electric line source within the cylinder. The study has been done analytically to provide necessary physical insight of the results obtained. New details about the so-called nonphysical modes are provided. It is found that these modes, that can be neglected outside the dielectric body, do have a significant contribution to the inner field when the excitation source is within the dielectric body. It is concluded that the terms physical and nonphysical characteristic modes should be replaced for radiating and nonradiating characteristic modes.

6. A Comparison Between Natural Resonances and Characteristic Mode Resonances of an Infinite Circular Cylinder T. Bernabéu-Jiménez, A. Valero-Nogueira, F. Vico-Bondia and A. A. Kishk, IEEE Transactions on Antennas and Propagation, vol. 65, no. 5, pp. 2759-2763, May 2017.

DOI: 10.1109/TAP.2017.2670368

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

7. Small-scale distributions in an indoor environment at 94GHz J. Reig, M.T. Martinez-Ingles, J.M. Molina-Garcia-Pardo, L. Rubio Arjona, V. M. Rodrigo Peñarrocha, Radio Science, vol. 52, no. 7, pp. 852-861, 2017.

DOI: 10.1002/2017RS006335

Abstract: In this paper, an extensive multiple-input multiple-output measurement campaign in a lab environment has been conducted at the 94 GHz band. Using a vector network analyzer, updown converters, and omnidirectional antennas displaced in virtual arrays, we have obtained an estimation of the distribution parameters for the most usual distributions employed in the small-scale fading modeling, i.e., Rayleigh, Rice, Nakagami-m and □-μ, by using statistical inference techniques. Moreover, in this scenario the best fit distribution to the experimental data is the Weibull distribution, using the Kolmogorov-Smirnov test. However, the □-μ distribution provides the best fitting to the experimental results in terms of the lower tails of the distributions.

2.2. PATENTS

1. Antena de frecuencia dual. Miguel Ferrando Rocher, Jose Ignacio Herranz Herruzo, Alejandro Valero Nogueira, Ref.: P201731194, Publication date: 10/10/2017

2. Dispositivo de cruce de microondas. Daniel Sánchez-Escuderos; Vicente E. Boria Esbert; Mariano Baquero Escudero, Marco Guglielmi, Ref.: P201830106, Publication date: 7/2/2018

GRE team

2.3. AWARDS

Best Student Paper Award at the National URSI Conference in 2017, "Single-Layer Circularly-Polarized Ka-Band Antenna using Gap Waveguide technology", Miguel Ferrando-Rocher, Jose I. Herranz-Herruzo, Alejandro Valero-Nogueira, Antonio Vila-Jiménez.

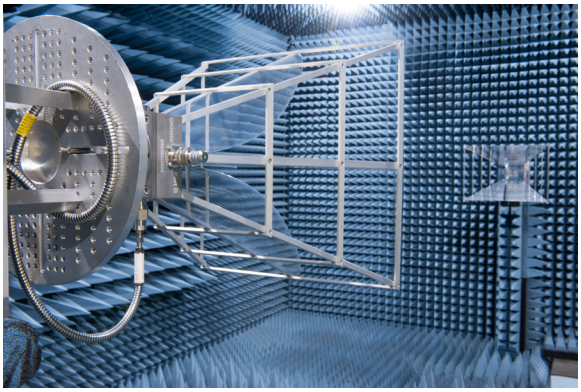
3.- FACILITIES

The GRE has a comprehensive antenna laboratory hosted in the iTEAM premises, with about 1 million euro in infrastructure investment. The facilities are intended to fabricate and measure the antennas and circuits designed by the researchers within the framework of the different ongoing projects. Prototypes (some of them are shown in the ongoing projects figures) are mainly fabricated in a 3-axes CNC milling machine with 5 microns of accuracy. The smallest prototypes developed in the GRE's premises are formed by pillars of 0.25 mm by side and 2 mm high, working perfectly at 60 GHz. Alternatively, a micro milling machine and a chemical etching line are also available in the GRE's laboratory for the fabrication of microwave circuits and antennas on planar substrates.

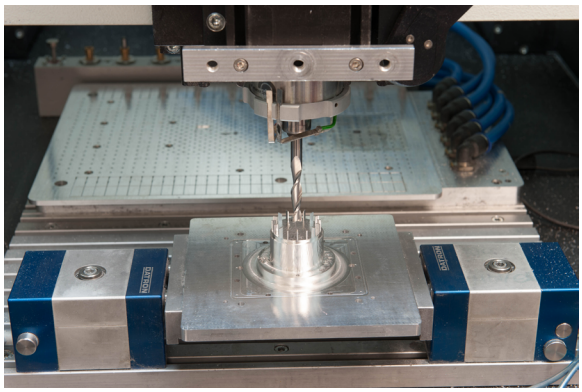
The GRE antenna laboratory is able to characterize and measure (up to 50GHz) antennas and microwave devices. The main equipment includes an anechoic chamber with roll over azimuth spherical system for measurement of antenna radiation patterns (up to 40GHz) and two Vector Network Analyzers that allow measurements of different parameters of antennas and microwave devices in frequency (up to 67 GHz) and time domain. In addition, a signal (spectrum) analyzer up to 26 GHz is available at GRE premises. These capabilities, together with the expertise of the technical staff, form a perfect combination capable of detecting any deviation from the simulated designs in the manufactured prototypes and, proposing solutions for their correction.

The GRE, together with the GAM (Microwave Applications Group), also has the laboratory of High Frequency Circuits (LCAF) in LTCC Technology focused on the fabrication of high frequency components and particularly on multi-layer modules in Low Temperature Co-fired Ceramics (LTCC) technology.

LTCC is a key enabling technology for RF/microwave component miniaturization, millimeter-wave packaging, Multi-Chip-Module (MCM) and System-in-Package (SiP) designs. Furthermore, it is also of great interest in a huge number of applications not strictly related to information and communication technologies as ceramic packaging, highly integrated electronics, microfluidics or sensors.



Standard gain horn ready for measurements in the anechoic chamber



CNC milling

Prototyping

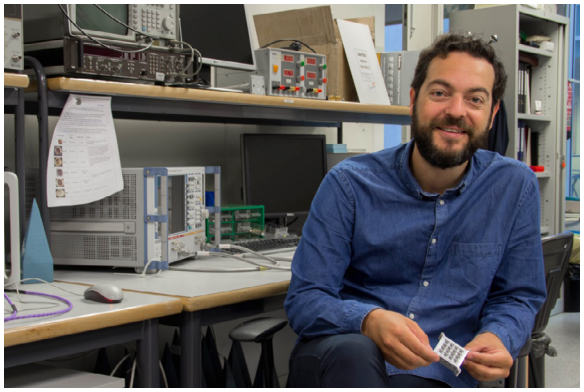
MIGUEL FERRANDO ROCHER RECEIVES THE "YOUNG SCIENTISTS URSI 2017" AWARD

Miguel Ferrando Rocher, researcher at the Institute of Telecommunications and Multimedia Applications (iTEAM) of the Universitat Politècnica de València has achieved the "Young Scientists URSI 2017" award by the International Union of Radio Science (URSI) to the best paper presented during the XXXII national symposium of URSI, held in Cartagena (Spain) in September 2017.

The award was granted for his work on the development of a new antenna concept that contributes to reduce the profile and weight of current antennas and could be applied to offer high-speed Wifi on trains or airplanes. In addition, it could be integrated into rescue teams in order to provide satellite coverage in uninhabited areas or affected by some catastrophe with devastated infrastructure.

The prototype has been manufactured and validated entirely in the laboratories of the iTEAM research institute of the Universitat Politècnica de València. The high gain and large bandwidth stand out as the main advantages of the antenna. "Moreover, its performance in terms of gain is up to what the market demands and therefore is a very attractive candidate to meet the huge market of satellite communications in Ka-band."

The research group is collaborating with companies working in similar applications and interested in such solutions as Thales Alenia Space and the European Space Agency (ESA). "The antenna, provided timely financing, could be on the market within 2 years," says Miguel Ferrando Rocher.



AUDIO AND COMMUNICATIONS SIGNAL PROCESSING GROUP

HEAD OF THE GROUP RESEARCH REPORT

The Audio and Communications Signal Processing Group (GTAC) reaches 20 years of research. GTAC research focuses in signal processing algorithms for sound and wireless communication applications, in particular related to active noise control systems, sound quality perception, spatial audio rendering and multi-channel audio filtering in the area of sound processing, and related to efficient MIMO receivers, multi-user communications and coordinated multi-point systems in the area of wireless communications. Fig. 1-3 show some of the equipment available at the GTAC facilities of the iTEAM used to develop the previous research lines.

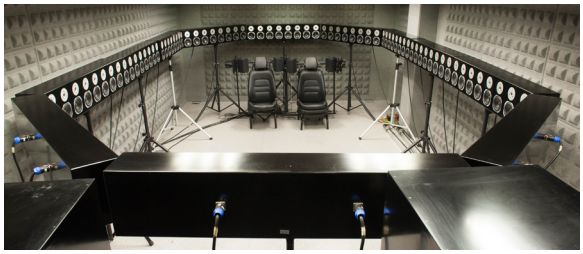


Fig. 1. Acoustic listening room including a render system of 96 loudspeakers.

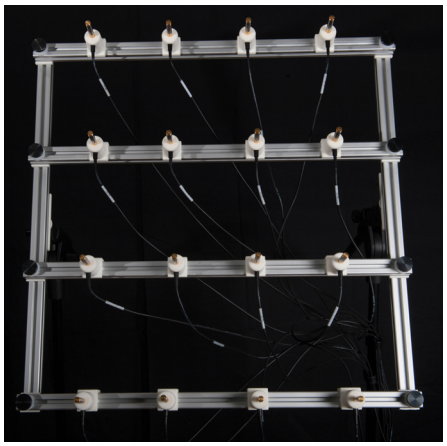


Fig. 2. Microphone array, flexible configurations

Fig. 3. Laboratory prototype of a system implementing multiple personal sound zones with two real car seats.

During 2017/2018 the group has continued its work on the development of sound control applications over different types of acoustic networks. The GTAC main lines of research have been developed within the framework of several research projects, the publication of relevant results in scientific journals and conference proceedings and the presentation of one PhD thesis.

The most important results of the GTAC research production 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.

1.- PROJECT ACTIVITIES

The GTAC research activities during 2017/2018 have been focused on developing and implementing sound processing applications on wireless acoustic sensor networks (WASN).

In particular, as the final period of the project "Smart Sound Processing for the Digital Living", a distributed low cost ad hoc sensor network based on Raspberry Pi 3 have been implemented (see Fig.4). One of the nodes acts as the main node (gateway) to communicate with the rest of nodes and the server located in the cloud. In an ad hoc network, each node is part of the routing by forwarding data to other nodes until finding the main node, which will upload the data to the server. Two main applications have been developed: (1) Measuring and monitoring noise conditions

in an industrial environment to detect high sound pressure levels (SPL), and (2) recording, monitoring and classification of sound events.

Fig. 4. Node formed by a Raspberry Pi, one microphone and one solar panel.

Furthermore, the project ***"Distributed Network of Active Noise Equalizers for Multi-User Sound Control"*** has been mainly developed through this period. A laboratory prototype of a multi-ambient sound-field control system consisting of two car seats (see Fig. 3) has been built, where active noise equalization (ANE) can be independently applied to each headrest or user. To allow this, every user controls his local system through an application running in his mobile device. This system formed by multiple ANEs, which act as a node in a WASN-type set up, cooperate to simultaneously solve their node-specific noise equalization problems.

Moreover, two new projects have started in this period. They are summarized below.

1.1.- ONGOING PROJECTS

Title of the project: *MAXIMIZING THE UPSCALING AND REPLICATION POTENTIAL OF HIGH LEVEL URBAN TRANSFORMATION STRATEGIES (MATCHUP)*

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

Summary of the project: *MAtchUP is an EU-funded Smart City project involving three lighthouse cities and four follower cities. MAtchUP cities will join forces to reshape their social, economic and environmental models and to promote social inclusion, liveability and prosperity for their citizens.*

MAtchUP will design and implement a palette of innovative solutions in the energy, mobility and ICT sectors that will serve as a model of urban transformation for other cities in Europe and beyond. MAtchUP's objective is to create and adopt solutions that can turn urban problems into smart opportunities to improve the citizens' quality of life and boost the local economies. The final aim is to create a prosperous and more liveable urban environment for communities.

MAtchUP approach is built on three main axes:

- *Planning of sustainable urban transformation, which means to get rid of old and inefficient technologies to seize new efficient solutions in the energy, mobility and ICT fields*
- *Effective replication and upscaling of smart city solutions by ensuring the convergence of the demand and supply sides*
- *Implementation of these upscaling and replication plans to successfully reshape and repaint cities and their communities*

The MAtchUP consortium is made of 28 organizations from 8 different countries. Three lighthouse cities and four follower cities are supported by the expertise of universities and research institutions, SMEs, industrial and non-profit partners. They include research experts, policy makers, industrial partners, investors and dissemination and exploitation experts which basically represent all the targets of MAtchUP.

Fig. 5. Valencia is one of the three cities where the MatchUp project will be developed.

Funding entity: *European Union's Horizon 2020 research and Innovation programme.*

Title of the project: *SOUND-AIDED SMART ENVIRONMENTS FOR THE CITY, HOME AND NATURE (SSENCE)*

Webpage of the project: *www.sound-aided-IOT.upv.es*

Summary of the project: *The ``Sound-Aided Smart Enviroments for the City, Home and Nature'' (SSEnCe) project aims to encourage the dissemination and development of real and practical prototypes focused on the Global concept of Intelligence in the Internet of Things (IoT). Particularly, their applications are based mainly on the acoustic information of the environment. Thus, the main objectives of this project are the creation of an observatory and the development of three technological demonstrators of immediate practical application.*

The demonstrators have the following specific objectives:

- *In the home environment, it is intended to detect the acoustic events that indicate danger or emergency situation, especially for people with reduced mobility (sick people, elderly people, etc..). This application is related to IoT application in eHealth.*
- *In the Smart Cities field, the project aims to develop applications which detect violent situations and disturbance of social coexistence (concerts, unauthorized manifestation, etc) and to monitor noise pollution.*
- *In natural parks is intended to detect any alteration of the natural environment produced by people.*

Funding entity: *Cátedra Telefónica-UPV.*

2.- RESEARCH RESULTS

The main publications in scientific journals and conference proceedings of this period are summarized in the following.

2.1.- FEATURED JOURNAL PUBLICATIONS

- ***Soft MIMO detection through sphere decoding and box optimization.*** *M. Ángeles Simarro, Víctor M. Garcia-Mollá, Antonio Vidal, F.J. Martínez-Zaldívar, Alberto Gonzalez, Signal Processing, vol. 145, pp. 48-58, 2018.*

DOI: *10.1016/j.sigpro.2017.11.010.*

Abstract: *Achieving optimal detection performance with low complexity is one of the major challenges, mainly in multiple-input multiple-output (MIMO) detection. This paper presents three low-complexity Soft-Output MIMO detection algorithms that are based mainly on Box Optimization (BO) techniques. The proposed methods provide good performance with low computational cost using continuous constrained optimization techniques. The first proposed algorithm is a non-optimal Soft-Output detector of reduced complexity. This algorithm has been compared with the Soft-Output Fixed Complexity (SFSD) algorithm, obtaining lower complexity and similar performance. The two remaining algorithms are employed in a turbo receiver, achieving the max-log Maximum a Posteriori (MAP) performance. The two Soft-Input Soft-Output (SISO) algorithms were proposed in a previous work for soft-output MIMO detection. This work presents its extension for iterative decoding. The SISO algorithms presented are developed and compared with the SISO Single Tree Search algorithm (STS), in terms of efficiency and computational cost. The results show that the proposed algorithms are more efficient for high order constellation than the STS algorithm.*

- ***Control Effort Strategies for Acoustically Coupled Distributed Acoustic Nodes.*** *Christian Antoñanzas, Miguel Ferrer, Maria de Diego, Alberto Gonzalez, Wireless Communications and Mobile Computing , 2017.*

DOI: *10.1016/j.sigpro.2017.11.010.*

Abstract: *This paper considers the effect of effort constraints on the behavior of an active noise control (ANC) system over a distributed network composed of acoustic nodes. A distributed implementation can be desirable in order to provide more flexible, versatile, and scalable ANC systems. In this regard, the distributed version of the multiple error filtered-x least mean square (DMEFxLMS) algorithm that allows collaboration between nodes has shown excellent properties. However, practical constraints need to be considered since, in real scenarios, the acoustic nodes are equipped with power constrained actuators. If these constraints are not considered within the adaptive algorithm, the control signals may increase and saturate the hardware devices, causing system instability. To avoid this drawback, a control effort weighting can be considered in the cost function of the distributed algorithm at each node. Therefore, a control effort strategy over the output signals at each node is used to keep them under a given threshold and ensuring the distributed ANC system stability. Experimental results show that, assuming ideal network communications, the proposed distributed algorithm achieves the same performance as the leaky centralized ANC system. A performance evaluation of several versions of the leaky DMEFxLMS algorithm in realistic scenarios is also included.*

- ***Optimized Fundamental Signal Processing Operations for Energy Minimization on Heterogeneous Mobile Devices.*** *Jose A. Belloch, José M. Badía, Francisco D. Igual, Alberto Gonzalez, Enrique S. Quintana-Ortí, IEEE Transactions on Circuits and Systems I: Regular Papers, vol. 65, no. 5, pp. 1614-1627, 2017.*

DOI: *10.1109/TCSI.2017.2761909.*

Abstract: *Numerous signal processing applications are emerging on both mobile and high-performance computing systems. These applications are subject to responsiveness constraints for user interactivity and, at the same time, must be optimized for energy efficiency. The increasingly heterogeneous power-versus-performance profile of modern hardware introduces new opportunities for energy savings as well as challenges. In this line, recent systems-on-chip (SoC) composed of low-power multicore processors, combined with a small graphics accelerator (or GPU), yield a notable increment of the*

computational capacity while partially retaining the appealing low power consumption of embedded systems. This paper analyzes the potential of these new hardware systems to accelerate applications that involve a large number of floating-point arithmetic operations mainly in the form of convolutions. To assess the performance, a headphone-based spatial audio application for mobile devices based on a Samsung Exynos 5422 SoC has been developed. We discuss different implementations and analyze the tradeoffs between performance and energy efficiency for different scenarios and configurations. Our experimental results reveal that we can extend the battery lifetime of a device featuring such an architecture by a 238% by properly configuring and leveraging the computational resources.

2.2.- FEATURED CONFERENCE PROCEEDINGS

- ***Personal active control over coupled networks.*** *Christian Antoñanzas, Miguel Ferrer, Maria de Diego, Alberto Gonzalez, 24th International Congress on Sound and Vibration (ICSV), London, UK, 2017.*
- ***Improved least-mean-square algorithm using a block-based strategy for active noise control.*** *Maria de Diego, Laura Fuster, Miguel Ferrer, Christian Antoñanzas, 24th International Congress on Sound and Vibration (ICSV), London, UK, 2017.*
- ***Distributed Sensor Network for Noise Monitoring in Industrial Environment with Raspberry Pi.*** *Natalia Blasco, Maria de Diego, Román Belda, Ismael de Fez, Pau Arce, Francisco J. Martinez, Alberto Gonzalez, Juan Carlos Guerri, INTELLI 2017: The Sixth International Conference on Intelligent Systems and Applications , Niza, Francia, 2017.*
- ***Block diagonalization aided precoding algorithm for large MU-MIMO systems.*** *Maria A. Simarro, Fernando Domene, Francisco J. Martinez, Alberto Gonzalez, 13th International Wireless Communications and Mobile Computing Conference , Valencia, Spain, 2017.*
- ***Parallel SUMIS soft detector for MIMO systems on multicore.*** *Carla Ramiro, Maria A. Simarro, Alberto Gonzalez, Antonio M. Vidal, 17th International Conference on Computational and Mathematical Methods in Science and Engineering (CMMSE 17) , Rota, Spain, 2017.*

SIGNAL PROCESSING GROUP

HEAD OF THE GROUP RESEARCH REPORT

During the academic year 2017/2018 the Signal Processing Group (GTS) of the iTEAM, has continued researching in the development of solutions for theoretical Signal Processing problems and the application of these algorithms in various fields of the industry, medicine, biology and fine arts.

The research of the group is mostly aimed towards signal processing techniques applied to ultrasonic and impact-echo methods, signal processing techniques applied to bioacoustics and passive acoustics monitoring, signal processing algorithms for surrogate data generation and signal modality, image and video processing for biomedical applications, and technology for the arts. A complete list of research activities can be found at http://www.iteam.upv.es/group/gts/.

The leadership of the group in several work packages of the interdisciplinary QUIETMED European Project has produced some interesting results for the scientific community, such as new techniques for Big Data representations of the ambient noise acoustic indicators that will help biologists to advance in the study of how anthropogenic sounds impact on some marine species.

1.- PROJECT ACTIVITIES

The GTS has continued researching in the already stablished research lines as well as in some other emerging activities. Thanks to some research programmes, the group has been able to consolidate many research lines, of which the group is particularly satisfied. In addition, the group has been able to expand beyond their boundaries into other areas or new research activities. A short summary of the main activities being accomplished in the group is given below:

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

We have advanced in the use of signal processing for non-destructive testing, both for the detection and for the characterization of damage in cementitious materials. For these materials, we have developed, among some others, algorithms that allow: material characterization, damage location and tomography reconstruction. As a novel application, GTS and the University College Cork have worked in together applying non-contact airborne ultrasound and signal processing for cement characterization. This advances have been recently published in Ultrasounds.

The GTS collaborates with the ICITECH (Institute of Science and Technology of the Concrete) for the characterization of different types of global damage in cementitious materials using sonic and ultrasonic signals.

Bioacoustics and passive acoustics monitoring for the characterization of cetacean calls and anthropogenic noises.

We employ Passive Acoustic Monitoring (PAM) techniques to advance in the study of marine mammals and anthropogenic sounds. This is achieved by developing new acoustic instrumentation and signal processing algorithms to detect and characterize underwater acoustic events. Our goal is to improve the understanding of how anthropogenic sounds impacts on the marine biodiversity as well as to study the population abundance, seasonality and behavior of marine mammals. We combine traditional PAM techniques with recent advances in signal processing algorithms and representation techniques such as Big Data representations and deep learning.

Signal processing algorithms for surrogate data generation and Recurrence Quantification analysis.

Surrogate generation has become a widespread tool for the statistical analysis in many fields. However, classical surrogate generation algorithms fail to generate valid data in many specific situations such as: detecting complexity in short oscillatory signals, nonlinear detection in non-stationary signals, etc. During the last year, the GTS has devised new surrogate generation techniques that, alongside with Recurrence Quantification analysis, have allowed to face complex problems such us: measuring the stress on financial markets, detecting irregular animal

vocalizations, and distinguishing explosions from impact pile drivers from Fin Whale pulses.

Applications of biomedicine:

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

Graph Signal Processing

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

Emerging Signal Processing Techniques for Big Data Health Applications

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

Technologies for the Arts (Soundcool)

Soundcool is an innovative system for collaborative creation of music and video using smartphones, tablets, Kinect, computers, Open Sound Control (OSC) and, recently, the Microsoft Hololens (https://bit.ly/2pxig5x). A Soundcool teaser is available at https://youtu.be/VV6bg3HIM4o. Soundcool has recently started a new direction towards an entrepreneurship endeavor. We aim at achieving a sustainable model based on a business solution. We are optimistic about this approach since the Soundcool user community has a growing tendency. In this regard we have recently been shortlisted as semifinalist for the Everis awards that promote innovation. We will compete within the category of "new business models in the digital economy".

1.1.- ONGOING PROJECTS

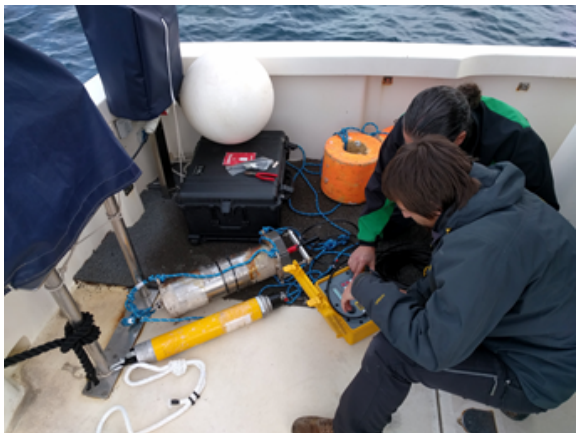
Name of the project: *Joint programme on noise (D11) for the implementation of the Second Cycle of the MSFD in the Mediterranean Sea (QUIETMED)*

Webpage of the project: *http://www.quietmed-project.eu/*

Summary of the project: *Human activities that take place at sea bring many benefits to society and economy but also many impacts to the marine environment. Among these impacts, the most widespread and pervasive is underwater noise. Marine Strategy Framework Directive (MSFD) represents a huge progress to preserve marine environment as it aims to achieve Good Environmental Status (GES) by 2020. It highlights the need to establish anthropogenic noise levels that do not affect marine Biota.*

During the second year of the QUIETMED project we have performed a Pilot project experiment in the Cabrera Archipelago Maritime-Terrestrial National Park (Spain). This is a Category A monitoring that will be used to stablish information on the ambient noise level in the location, and to give guidance on methodologies such as hardware calibration, signal processing, Big Data representations, etc.

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



Testing the surface unit of the acoustic releaser before the QUIETMED Cabrera pilot project deployment.

Name of the project: *Underwater ambient noise levels assessment and modelling of the noise probably due to the increase of marine traffic in the area of "El Gorguel".*

Summary of the project: *This is a joint collaborative project with the Universidad de Alcalá de Henares (Instituto Franklin), L'Oceanogràfic from Valencia and the iTEAM-UPV. The main purpose of the project is to assess the ambient noise levels and to model the underwater noise which might be due to the increase of marine traffic in the area of "El Gorguel", Cartagena, Spain.*

Funding entity: Port authority of Cartagena.

One of our SAMARUC systems deployed in "El Gorguel" for the assessment of ambient noise levels.

Name of the project: *Underwater ambient noise levels assessment of the installation of an undersea cable.*

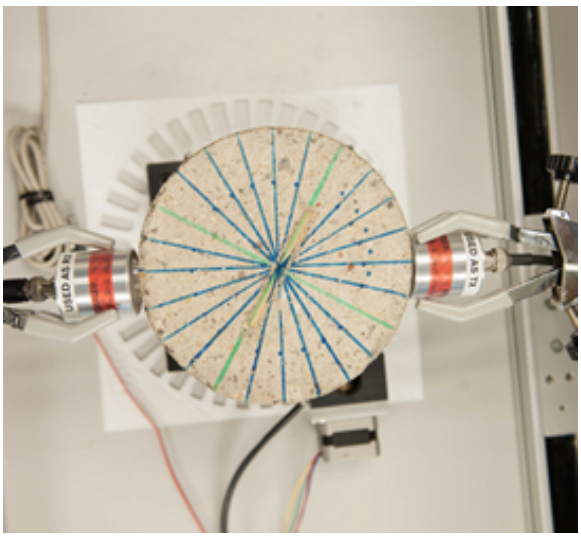
Summary of the project: *In this project we are collaborating with ELITTORAL for the evaluation of the ambient noise levels produced during the installation of an undersea cable.*

Funding entity: *elittoral S.L. Estudios de ingeniería costera y oceanográfica*

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

Summary of the project: *The project aims to develop new methods for non-destructive evaluation of fresh pastes, mortars and concrete (rheological characterization), and damaged systems (cracking) in which a regeneration or self-healing process takes place. We intend to establish ultrasonic based methods to evaluate the basic rheological properties, such as viscosity and yield stress. We analyze self-healing due to autogenous healing properties (by the own nature of hydrated cement) as well as due to autonomous processes (by addition of commercial products based on bacteria and reagent capsules). Monitoring is done using ultrasonic techniques and non-linear acoustic resonance impact spectroscopy. Regarding the ultrasonic techniques, we employ contact techniques (velocity, attenuation, signal modality, lamb waves, reflection...), tomography techniques (based on neural network) and non-contact techniques (airborne ultrasound).*

Funding entity: *Spanish Government.*



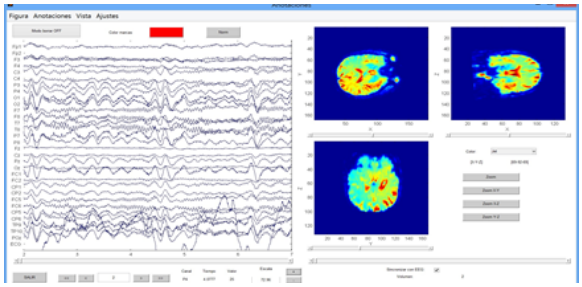
Characterization of a cylindrical cement specimen by means of airborne ultrasound sensors.

Name of the project: Signal Processing on Graphs for Classifier Systems

Summary of the project: *GTS keeps working on this topic in different areas of application. In particular Graph Signal Processing (GSP) is being applied to multimodal biomedical signals in neurology and neurophysiology areas for the study and diagnosis of epilepsy, Alzheimer, and sleep disorders, collaborating in an interdisciplinary framework with*

physicians of the Hospital La Fe of Valencia. A multimodal analysis approach is considered in three specific scenarios: bimodal analysis of simultaneous recordings of fMRI (functional Magnetic Resonance Imaging) and EEG (electroencephalographic) recordings, analysis of EEG in combination with DTI (Diffusion Tensor Imaging) and ECoG (electrocorticographic) recordings for the case of epilepsy patients. An "ad hoc" interface is being developed to facilitate the visualization of signals and images, and to ease the interaction with the physicians.

Funding entity: *Spanish Government, TEC2014-58438-R*



Name of the project: *Soundcool*

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

Summary of the project: Soundcool is active this year with the grant from Daniel and Nina Carasso Foundation, Project 16-AC-2016 (9/2016-8/2019): focused on the development of interactive video art systems, new OSC apps, new developments for functional diversity students, and increasing national and international dissemination.

The achievements of 17-18 year are summarized in the following lines. Firstly, we began incorporating Soundcool into the music education system in the Valencian Community (population of over 5 million people) with the support of the Valencian education council. With them, we are conducting a pilot test in 28 educational centers and have released a MOOC on the basics of collaborative music and sound creation with Soundcool (https://bit.ly/2yQRZrK). All the videos of the MOOC have English Subtitles and are also at https://bit.ly/2lJUi6S. A new MOOC Soundcool 2 about video modules and creative proposals was released on October 2018 (see https://bit.ly/2JTfqCO). Additionally, The Act I of the opera "The Mother of Fishes" involving Soundcool and composed by Jorge Sastre and Roger Dannenberg, has been performed in different times (https://bit.ly/2KztwsJ), in México at the Monterrey Institute of Technology and Higher Education (ITESM), and twice more in Spain. IIn October 30th 2018 the full opera was premiered in Mexico at the ITESM Puebla, see https://bit.ly/2PN5YX6, and then it is planned to perform the opera at the main campuses of the ITESM, and the best version at a main theatre in Mexico City. The experience has been so satisfactory that we reach an agreement with the ITESM for the premiere of a new opera with Soundcool in 2020 composed again by Sastre and Dannenberg.

Preview of the opera The Mother of Fishes at the ITESM. For the creation of the Mother of Fishes' voice in real-time with Soundcool see http://youtu.be/oyLDUMZgPX4?t=334

2.- RESEARCH RESULTS

2.1.- FEATURED PUBLICATIONS

• ***Ultrasonic signal modality: A novel approach for concrete damage evaluation****, A. Carrión, V. Genovés, J. Gosálbez, R. Miralles, J. Payá, Cement and Concrete Research 101 (2017) 25–32.*

In this paper, a new approach for characterizing material damage, using ultrasonic waves, is proposed. Two concrete series with two types of cement with different C3A content and similar mechanical properties were subjected to external sulphate attack (ESA) and evaluated using a novel Recurrence Plot Quantification Analysis (RQA) method. This brand new technique was compared with several methods, such as mechanical tests (compressive and flexural strength determination), dynamic test (dynamic modulus) measurements, and traditional ultrasonic measurements (propagation velocity and ultrasonic wave attenuation). In these experiments, RQA showed a high sensitivity to damage in spoiled series, improving the reliability of damage detection with ultrasonics in non-homogeneous materials compared to other non-destructive techniques. Interesting advantages of this new non-destructive technique are: a) the RQA parameter is normalized (range of 0 to 1); b) a calibration process is not required; c) the values of its standard deviation show the dispersion of the damage.

DOI: *10.1016/j.cemconres.2017.08.011*

• ***Ultrasonic and impact spectroscopy monitoring on internal sulphate attack of cement-based materials,*** *V. Genovés, F. Vargas, J. Gosálbez, A. Carrión, M.V. Borrachero, J. Payá, Materials and Design 125 (2017) 46–54*

An exhaustive monitoring of an internal sulphate attack of Portland cement-based materials is addressed. Four series of Portland cement mortars with different amounts of gypsum (0%–2% SO3 respect to the cement by mass) were monitored by means of physical, microstructural and non-destructive tests, studying specimens with a low expansion rate to examine the sensitivity of the applied techniques. Mechanical analysis has been correlated with non-destructive tests: impact resonance acoustic spectroscopy and ultrasonic measures. The dynamic modulus and ultrasonic pulse velocity have closely predicted the stiffness of the specimens. The total material attenuation (absorbed energy of the chirp signal ultrasonic wave) presented different trends, showing clear differences for the most damaged series (2% SO3). Attenuation supplied interesting information about the hardening process and the microcracking effect due to a mortar expansion higher than 0.04%. The novelties of this study are the exhaustive monitoring of an internal sulphate attack, as well as the examination of the sensitivity of brand new NDT techniques when this damage process overlaps with the curing process.

DOI: *10.1016/j.matdes.2017.03.068*

• ***Airborne non-contact and contact broadband ultrasounds for frequency attenuation profile estimation of cementitious materials,*** *J. Gosálbez, W.M.D. Wright, W. Jiang, A. Carrión, V. Genovés, I. Bosch, Ultrasonics 88 (2018) 148–156-*

The study of frequency-dependent ultrasonic attenuation in strongly heterogeneous cementitious materials is addressed. To accurately determine the attenuation over a wide frequency range, it is necessary to have suitable excitation techniques. We have analysed two kinds of ultrasound techniques: contact ultrasound and airborne non-contact ultrasound. The mathematical formulation for frequency-dependent attenuation has been established and it has been revealed that each technique may achieve similar results but requires specific different calibration processes. In particular, the airborne non-contact technique suffers high attenuation due to energy losses at the air-material interfaces. Thus, its bandwidth is limited to low frequencies but it does not require physical contact between transducer and specimen. In contrast, the classical contact technique can manage higher frequencies but the measurement depends on the pressure between the transducer and the specimen.

Cement specimens have been tested with both techniques and frequency attenuation dependence has been estimated. Similar results were achieved and it has been demonstrated that the air- borne non-contact ultrasound technique could be a viable alternative to the classical contact technique.

DOI: *10.1016/j.ultras.2018.03.011*

• ***Fusion Methods for Biosignal Analysis: Theory and Applications****, A. Salazar, V. Zarzoso, M. Rosa-Zurera, L. Vergara: Computational Intelligence and Neuroscience, 2017.*

Recent advances in data acquisition and biosignal processing are paving the way for the optimal integration or fusion of complementary data modalities in a wide variety of clinical settings. Data modalities include electrocardiography (ECG), electroencephalography (EEG), electrocorticography (ECoG), magnetic resonance imaging (MRI), functionalMRI (fMRI), positron emission tomography (PET), and diffusion tensor imaging (DTI). Integration can be performed by exploiting the analyses sequentially or simultaneously, depending on issues related to synchronization, physical compatibilities, and standard clinical procedures. Fusion approaches aim at integrating analyses of data from different modalities, establishing synergic relationships for improved clinical hypothesis testing and medical diagnosis.

DOI: *10.1155/2017/7152546*

• ***On the Detection of Impulsive and Tonal Events in Passive Acoustics Monitoring****, R. Miralles, G. Lara, A. Carrión, J. Gosalbez, I. Bosch, 22nd IEEE International Conference on Digital Signal Processing (DSP 2017).*

Anthropogenic underwater sound is now recognized as a world-wide problem. Shipping, seismic surveys and pile driving, among some other human activities, have shown a broad range of negative effects in a variety of species. It is thus important to control, register and characterize these activities in order to establish policies that mitigate its effects. For this purpose, automatic detectors of the major anthropogenic sound categories (impulsive and tonal sounds) are needed. An efficient algorithm capable of detecting impulsive and tonal sound categories is proposed. The detection algorithm is based on the Pulsed to Tonal Ratio (PTR) and, in this work, we show not only its simplicity but also how well it performs in a variety of situations. In contrast to what happens with some other techniques,

the proposed detector generally succeeds in detecting pulsed and tonal events with additive white and pink noise. This makes the PTR detector particularly appropriate for passive acoustic monitoring.

DOI: *10.1109/ICDSP.2017.8096125*

• ***Effect of exploitation and exploration on the innovative as outcomes in entrepreneurial firms.*** *N. Vargas, M.B. Lloria, A. Salazar, L.Vergara, International Entrepreneurship and Management Journal, 2018.*

The main aim of this study is to establish the effect of the Exploitation and Exploration; and the influence of these learning flows on the Innovative Outcome (IO). The Innovative Outcome refers to new products, services, processes (or improvements) that the organization has obtained as a result of an innovative process. For this purpose, a relationship model is defined, which is empirically contrasted, and can explains and predicts the cyclical dynamization of learning flows on innovative outcome in knowledge intensive firms. The quantitative test for this model use the data from entrepreneurial firms biotechnology sector. The statistical analysis applies a method based on variance using Partial Least Squares (PLS). Research results confirm the hypotheses, that is, they show a positive dynamic effect between the Exploration and the Innovative as outcomes. In the same vein, they results confirm the presence of the cyclic movement of innovative outcome with the Exploitation.

DOI: *10.1007/s11365-018-0496-5*

• ***Estimating the Laplacian matrix of Gaussian mixtures for signal processing on graphs Signal Processing,*** *J. Belda, L.Vergara, A. Salazar, G. Safont, Signal Processing, vol 148, pp. 241-249, 2018.*

Recent works in signal processing on graphs have been driven to estimate the precision matrix and to use it as the graph Laplacian matrix. The normalized elements of the precision matrix are the partial correlation coefficients which measure the pairwise conditional linear dependencies of the graph. However, the non-linear dependencies inherent in any non-Gaussian model cannot be captured. We propose in this paper a generalized partial correlation coefficient which is derived by assuming an underlying multivariate Gaussian Mixture Model of the observations. Exact and approximate methods are proposed to estimate the generalized partial correlation coefficients from estimates of the Gaussian Mixture Model parameters. Thus it may find application in any non-Gaussian scenario where the Laplacian matrix is to be learned from training signals.

DOI:*10.1016/j.sigpro.2018.02.017*

• ***New Perspectives of Pattern Recognition for Automatic Credit Card Fraud Detection,*** *A. Salazar, G. Safont, A. Rodriguez, L. Vergara, Encyclopedia of Information Science and Technology, IGI Global, 2017.*

We have presented a new application having unquestionable interest for the signal processing community. Some similarities and differences with classical detection problems in the signal processing area have been emphasized. Then it has been considered the use of fusion as a powerful technique to derive algorithms having reasonable performance to solve this very complex problem. Experimental results using large real and surrogate datasets have been showed, where the improvements of using fusion of scores have been illustrated. Different well-known methods were compared with the new approaches. The detection results obtained for different mixtures of real and surrogate data were comparable under real requirements of very low false alarm.

• ***Soundcool Project: Collaborative Music Creation,*** *Elena Robles Mateo, Jaime Serquera, Nuria Lloret Romero, Jorge Sastre Martínez, Springer International Publishing, 2018*

This paper addresses four criteria that the Soundcool project meets: to "be sustainable", "be future-oriented", "be transformative" and "be innovative". Soundcool is a pedagogical and technological project. A brief description of the technology behind Soundcool will be useful for the reader before addressing the four criteria. Soundcool is like a "Lego" for sound; Soundcool is composed of a series of software modules that run on a central computer, or host computer. Each module is sort of a musical instrument; it could be a synthesizer, a sampler, a sound effect processor, etc. these modules can be interconnected in different ways allowing the users, i.e. the students, to create their own arrangements, as we call the module creations and interconnections. Then, each module can be controlled either with the mouse or, what is more interesting, with a mobile device through WiFi. This way, every student can control one or several modules of the whole arrangement from their mobile device contributing to a collaborative and participative experience.

• ***Sound Creation and Artistic Language Hybridization Through the Use of the Collaborative Creation System:*** *Soundcool, Noemy Berbel-Gómez, Adolf Murillo-Ribes, Jorge Sastre-Martínez, María Elena Riaño-*

Galán, 2017. Turkish Online Journal of Educational Technology.

We submit the development of a collaborative sound creation proposal made reality using the Soundcool system from its initial design phase to the scenic performance at the International Festival of Contemporary Music ENSEMS, Valencia (Spain). The "interstellar machine", a transdisciplinary piece whose linking thread is a story, is characterized by hybridization of languages and artistic fusion. It's a piece made possible by the joint work between students of Primary and Secondary Education, a group of experts and musical educators. From a qualitative approach, all the participants were interviewed and the analysis of an audiovisual recorded during the work process of the artistic proposal was carried out. From using data triangulation, the results obtained show indicators related to the hybridization of contemporary art languages, the use of a collaborative didactic methodology and the strategies developed for innovation and creation. The conclusions we came to just confirm a horizontal and participative way of working throughout the proposal, the success of the system used, the interconnection of artistic languages, the promotion of bridges in and outside the classroom or the approach of contemporary music to young people, among others. In addition, it focuses on some aspects of improving teaching technique and the need to continue working on this line.

2.2.- AWARDS.

In May 2018 we beat a Guinness World Record of the Largest Music Lesson with 4130 students (https://bit.ly/2MAH1Zp); the title of the class was "Introduction to Soundcool" given by Jorge Sastre, Soundcool director, Adolf Murillo and Pere Vicalet. Soundcool also won the Art & Design Competition of NEM (New European Media) Summit 2017; more information is available at https://bit.ly/2H9OEYT. NEM is a European Technology Platform, fostering the convergence among Media, Content, Creative industries, Social Media, Broadcasting and Telecom sectors (https://nem-initiative.org/). Also, in 2017 we won two Bankia awards to musical talent to, (A) best researcher, Jorge Sastre and (B) the best educative group using technologies to ExperimentArts for our work with Soundcool (https://bit.ly/2tPUiWf).

SPECIAL EVENTS

Soundcool innovation has been showcased at different technological festivals, since our engineers have recently taken the project to the next level. They incorporated a new set of modules for live processing of images/videos and control using Hololens. With these new features Soundcool becomes a complete audiovisual system. To introduce videos the Video Sampler can be used which also can reproduce a video from specific time or reproduce specific loops from the video. Several modules can be used to edit the content: for example up to 8 inputs can be switched easily with the Switcher module and the Blending module allows the user to apply visual effects in real time.

The above mentioned festivals include the Marketlab of Sonar+D and Kikk Festivals, in Barcelona and Belgium respectively, in 2017. More recently, for the 2018 edition we repeated in Barcelona again with the stand, and the organization has selected us to make a presentation and concert in Sonar itself. We presented the audiovisual work HoloSound, where Soundcool is controlled by the Hololens of augmented reality, see https://youtu.be/Ql_J5KQIII0. The piece was also performed at the 50 anniversary of the UPV https://youtu.be/V-B1gE448tw and MEVArt Festival https://youtu.be/hLwjBvbpqgg. This is an exceptional showcase with artists and creatives from all around the world for the professional use of Soundcool.

Group photo of PRL staff

PHOTONICS RESEARCH LABS

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

The Photonics Research Labs (PRL) are currently formed by more than 40 telecom engineers and physicists. The PRL mission is to produce high-quality scientific knowledge in the field of optics, quantum optics and photonics, through research projects, R&D contracts and collaboration agreements with the private sector. The PRL research activity is focused on several applications of photonics, mainly on optical communications of analog and digital signals, radio-over-fiber systems and photonic integrated circuits. Part of the research is also performed in the field of fiber optic sensor and industrial photonics. Among others, PRL has been granted two Excellent Projects by the European Research Council (ERC).

Web site: www.prl.upv.es

Twitter: @PRL_UPV

LinkedIn: www.linkedin.com/in/photonicsresearchlabs

MAIN ACTIVITIES

Microwave Photonics

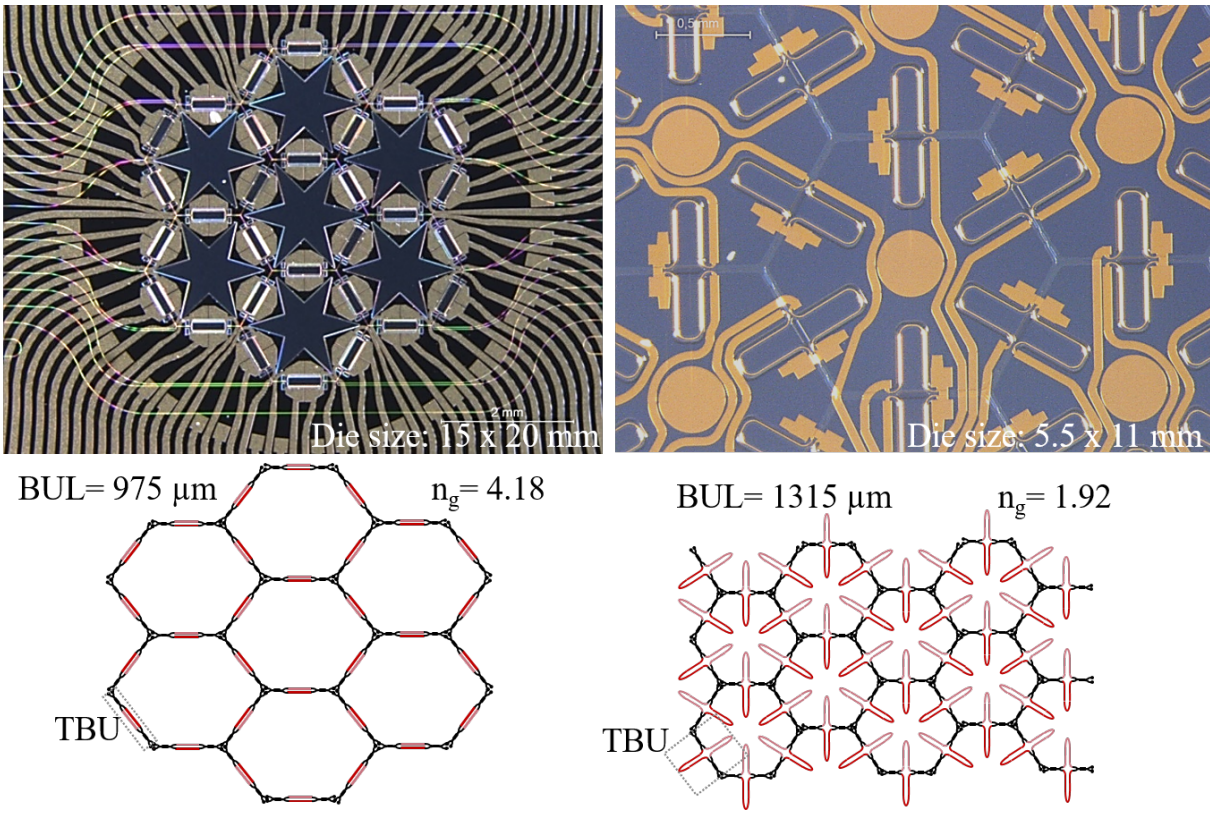
Among the most productive research lines, PRL is considered a world-leading group in Microwave Photonics (MWP), principally due to its contributions to the field of microwave photonic signal processing, a fundamental technology for the convergence of fixed and wireless telecommunication networks. The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

Photonic integrated circuits

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

Cryptography and quantum information

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



Reconfigurable photonic integrated processor

Fibre Bragg Gratings

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

Optical Networks

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

Photonic Instrumentation and Advanced Techniques for Metrology

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

FLAGSHIP PROJECTS

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

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

RESEARCH HIGHLIGHTS

1. J. Capmany, J. Yao, W. Li and S. Pan, "Editorial for focus issue on microwave photonics", **Chinese Optics Letters**, 15, 010001, 2017.
2. M. Rius, M. Bolea, J. Mora and J. Capmany, "Incoherent Photonic Processing for Chirped Microwave Pulse Generation," in **IEEE Photonics Technology Letters**, vol. 29, no. 1, pp. 7-10, Jan.1, 1 2017.
3. J. Hervas, A.L. Ricchiuti, W. Li, N.H. Zhu, C.R. Fernandez-Pousa, S. Sales, M. Li, and J. Capmany, "Microwave Photonics for Optical Sensors," in **IEEE Journal of Selected Topics in Quantum Electronics**, doi: 10.1109/JSTQE.2017.2651117.
4. J. Hervás, D. Tosi, H. García-Miquel, D. Barrera, C. R. Fernández-Pousa, and S. Sales, "KLT-Based Interrogation technique for FBG multiplexed sensor tracking," **Journal of Lightwave Technology**, vol. 35, no. 16, pp. 3387–3392, 2017.

5. J. Benítez, M. Bolea, and J. Mora, "High-performance low coherence interferometry using SSB modulation," **IEEE Photon. Technol. Lett**., vol. 29, no. 1, pp. 90–93, 2017.

6. J. Capmany, "Single-shot incoherent optical processing of microwave signals: opening the path to low cost high performance analog photonics," **Science Bulletin**, vol. 62, no. 9, pp. 652–653, 2017.

7. J. Benítez, J. Mora, and M. Bolea, "SCM Adaptation to Improve Scanning Rate in RF Interferometry Applications," **IEEE Photonics Technology Letters**, vol. 29, no. 12, pp. 999–1002, 2017.

8. D. Pérez, I. Gasulla, L. Crudgington, D. J. Thomson, A. Z. Khokhar, K. Li, W. Cao, G. Z. Mashanovich and J. Capmany, "Multipurpose silicon photonics signal processor core," **Nature communications**, vol. 8, p. 636, 2017.

9. D. Zheng, J. Madrigal, D. Barrera, S. Sales, and J. Capmany, "Microwave Photonic Filtering for Interrogating FBG-Based Multicore Fiber Curvature Sensor," **IEEE Photonics Technology Letters**, vol. 29, no. 20, pp. 1707–1710, 2017.

10. J. Benítez and J. Mora, "Sensitivity Enhancement for Low-Coherence Interferometry," **IEEE Photonics Technology Letters**, vol. 29, no. 20, pp. 1735–1738, 2017.

11. P. Muñoz et al., "Silicon Nitride Photonic Integration Platforms for Visible, Near-Infrared and Mid-Infrared Applications," **Sensors**, vol. 17, no. 9, p. 2088, 2017.

12. D. Zheng, J. Madrigal, H. Chen, D. Barrera, and S. Sales, "Multicore fiber-Bragg-grating-based directional curvature sensor interrogated by a broadband source with a sinusoidal spectrum," **Optics letters**, vol. 42, no. 18, pp. 3710–3713, 2017.

13. D. Barrera, J. Madrigal, and S. Sales, "Tilted fiber Bragg gratings in multicore optical fibers for optical sensing," **Opt. Lett**, vol. 42, pp. 1460-146, 2017.

14. J. Madrigal, F. J. Fraile-Peláez, D. Zheng, D. Barrera, and S. Sales, "Characterization of a FBG sensor interrogation system based on a mode-locked laser scheme," **Optics express**, vol. 25, no. 20, pp. 24650–24657, 2017.

15. A. Triana, D. Pastor, and M. Varón, "A Code Division Design Strategy for Multiplexing Fiber Bragg Grating Sensing Networks," **Sensors**, vol. 17, no. 11, pp. 2508, 2017.

16. D. Perez, I. Gasulla, F. J. Fraile, L. Crudgington, D. J. Thomson, A. Z. Khokhar, Ke Li, Wei Cao, Goran Z. Mashanovich, Jose Capmany, "Silicon photonics rectangular universal interferometer," **Laser & Photonics Reviews**, vol. 11, no. 6, 2017.

17. S. García, D. Barrera, J. Hervás, S. Sales and I. Gasulla, "Microwave Signal Processing over Multicore Fiber," **Photonics,** vol. 4, no. 4, pp. 4, 2017.

18. D. Sartiano and S. Sales, "Low Cost Plastic Optical Fiber Pressure Sensor Embedded in Mattress for Vital Signal Monitoring", **Sensors,** vol. 17, no. 12, 2017

19. J. Tang, T. Hao, W.Li, D. Domenech, R.Baños, P. Muñoz, N. Zhu, J. Capmany, and M. Li, "Integrated optoelectronic oscillator," **Opt. Express** 26, 12257-12265, 2018.

20. D. Pérez, I. Gasulla and J. Capmany "Towards Programmable Microwave Photonics Processors," **Journal of Lightwave Technology,** vol. 36, no. 2, pp. 519 – 532, 2018.

21. D. Barrera, J. Madrigal, S. Sales, "Long period gratings in multicore optical fibers for directional curvature sensor implementation", **Journal of Lightwave Technology,** vol. 36, no. 4, 1063-1068, 2018

22. J. Hervás, D. Barrera, J. Madrigal, S. Sales, "Microwave Photonics filtering interrogation technique under coherent regime for hot spot detection on a weak FBGs array", **Journal of Lightwave Technology**, vol. 36, no. 4, 1039 – 1045, 2018

23. J. C. Bellido et. al., "Fast Incoherent OFDR Interrogation of FBG Arrays Using Sparse Radio-Frequency Responses", **Journal of Lightwave Technology**, 2018, 10.1109/JLT.2018.2821199.

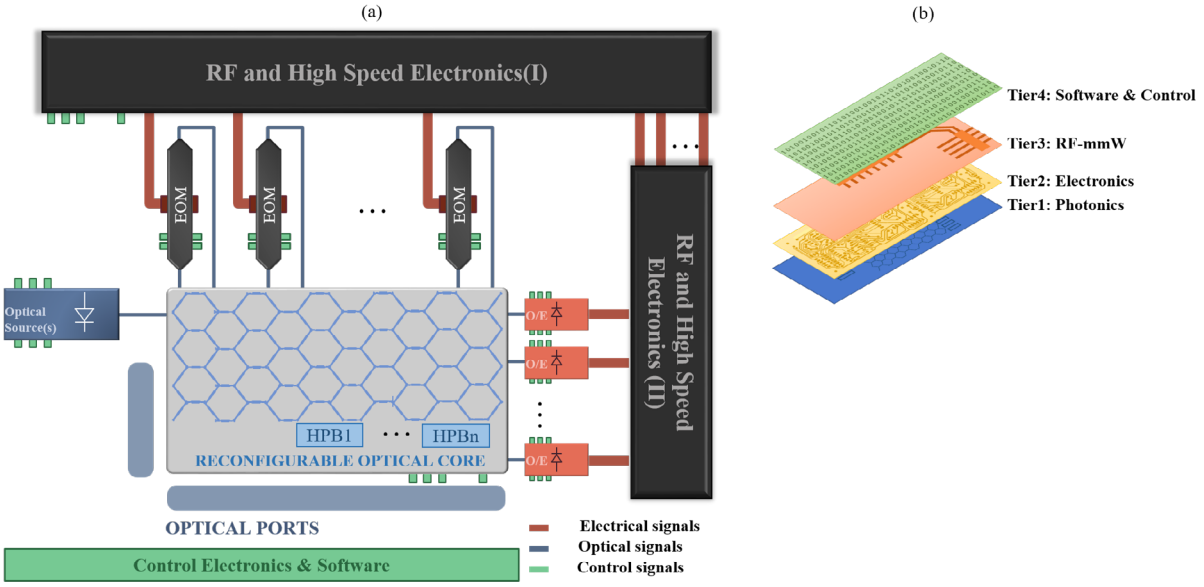
24. R. Min, B. Ortega, and C. Marques, "Fabrication of tunable chirped mPOF Bragg gratings using a uniform phase mask", **Optics Express** vol. 26, no. 4, pp. 4411-4420, 2018.

25. R. Min, C. Marques, K. Nielsen, O. Bang, and B. Ortega, "Fast inscription of long period gratings in microstructured polymer optical fibers", **IEEE Sensors Journal,** vol. 18, no. 5, 2018.

26. R. Min, B. Ortega, K. Nielsen, O. Bang and C. Marques, "Bragg grating inscription with low pulse energy in doped microstructured polymer optical fibers", **IEEE Sensors Letters**. vol. 3. 2018.

27. C. Marques et al., "Fast and stable gratings inscription in POFs made of different materials with pulsed 248 nm KrF laser", **Optics Express** vol. 26, no. 2, pp. 2013-2022, 2018.

28. L.P. Pereira, R. Min, Xuehao Hu, B. Ortega, C. Marques, C. Caucheteur, P. A. Joao Pinto, "Polymer optical fiber Bragg grating inscription with a single Nd:YAG laser pulse," **Optics Express**, vol. 26, no. 10, 2018.



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

SPIN-OFF COMPANIES

VLC Photonics (2011)

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

CalSENS (2013)

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

ePHOOX Engineering (2016)

EPHOOX Technology S.L. (founded in 2016) continues its activities towards the development of novel solutions based on Microwave Photonics technology for specific environments such as 5G. The module OVNA-P100X has been designed and manufactured as an advanced instrumentation for characterization and monitorization of photonic devices and hybrid RoF systems. Ongoing activities will provide soon an upgraded version with improved performance and new functionalities.

1.- PROJECT ACTIVITIES

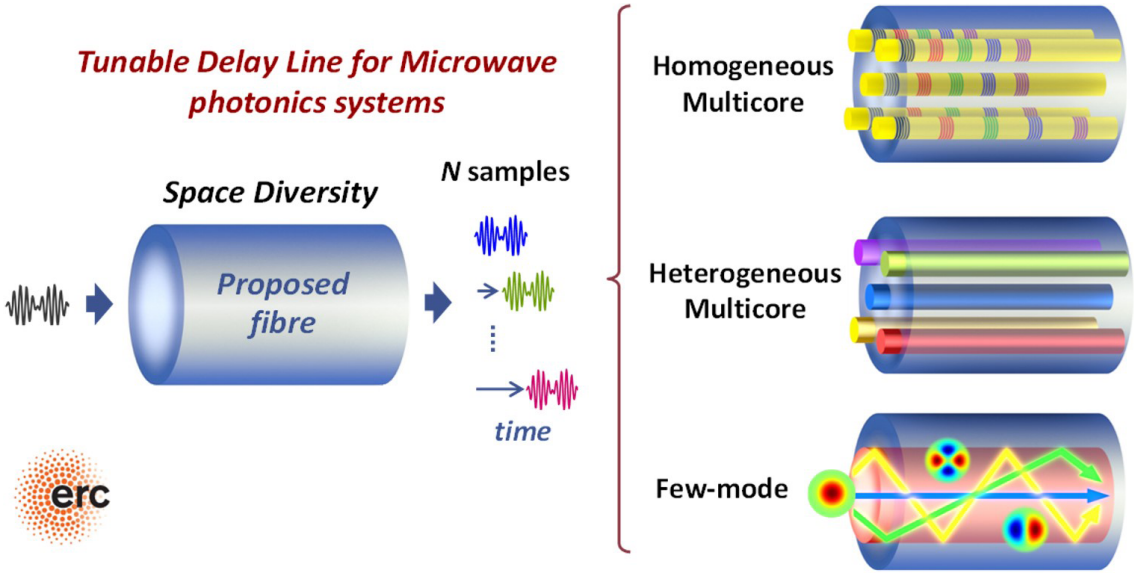
1.1.- ONGOING PROJECTS

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

IP: *José Capmany Francoy*

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

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



ERC Consolidator Grant: INNOSPACE
Revolutionizing fibre-wireless communications through space-division multiplexed photonics

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

ERC Consolidator Grant: Revolutionizing fibre-wireless communications through space-division multiplexed photonics (InnoSpace)

IP: Ivana Gasulla Mestre

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

Summary: *InnoSpace aims to revolutionize next generation fibre-wireless communication paradigms, such as 5G systems and Internet of Things, by pioneering the use of the photonic Space dimension. The present fiber-wireless landscape is characterized by radio-over-fiber distribution architectures that are static and inefficient, (with a replication of bundles of optical fibers) as well as by radiofrequency signal processing systems, such as antenna beamsteering or signal generation, which are nowadays bulky, heavy and power consuming. To overcome these limitations, we propose the application of Space-Division multiplexing to fiber-wireless scenarios where we provide "simultaneously" in a single optical fiber, a compact approach for both distribution and processing functionalities. This leads to the novel concept of "fiber distributed signal processing".*

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

IP: Salvador Sales Maicas

2017 - 2020. European Funding – H2020

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

network.

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

IP: José Capmany Francoy

2017 - 2020. European Funding – H2020

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

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

IP: Salvador Sales Maicas

2016 - 2020. European Funding - European Commission

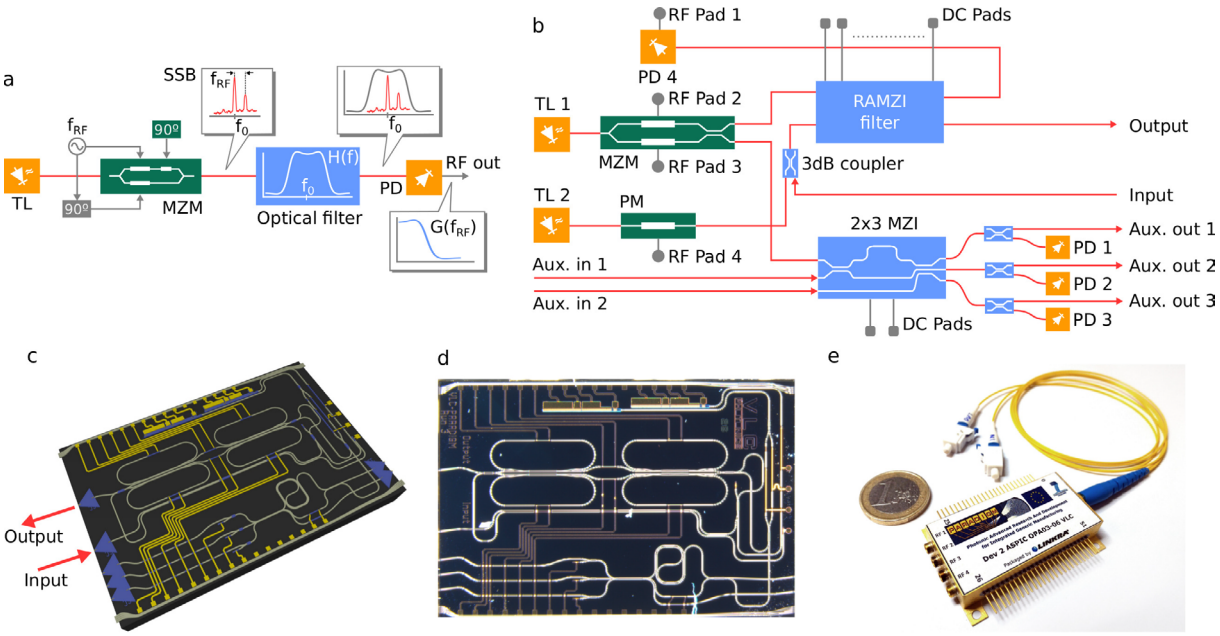
Summary: *FINESSE (FIbre NErvous Sensing SystEms) is a collaborative research and training network, gathering together 26 European universities, research centers and industrial partners with complementary expertise with the ultimate vision of a widespread implementation of distributed optical fibre sensor systems for a safer society. The objective behind FINESSE (FIbre NErvous Sensing SystEms) is to mimic the nervous system of living bodies by turning man-made and natural structures into objects that are sensitive to external stimuli owing to advanced distributed fibre-optic sensor technology, with the objective to either give early warning in case of possible danger or occurrence of damage, or to optimise the operation of the structure to allow for a sustainable use of natural resources and assets. Enabling such functionalities will greatly contribute to realizing a safe, secure and energy efficient Europe, which is an identified societal concern. Website: http://itn-finesse.eu/*

Photonic integrated circuits accessible to everyone

IP: Pascual Muñoz Muñoz

2016 - 2019. Public Funding - European Commission

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



Monolithic Integrated Microwave Photonics Filter

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

IP: José Mora Almerich

2017 - 2019. Public Funding - Ministerio de Economía y Competitividad

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

Silicon Nitride Spectrometers (TEC2016-80385-P)

IPs: *Pascual Muñoz Muñoz, Daniel Pastor Abellán*

2017 - 2020. Public Funding - Ministerio de Economía y Competitividad

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

Multicore fibers for next-generation fiber-wireless applications (TEC2016-80150-R)

IP: *Ivana Gasulla Mestre*

2017 - 2020. Public Funding - Ministerio de Economía y Competitividad

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

Desarrollo de láseres de pulsos ultracortos con prestaciones avanzadas y bajo coste para su aplicación en la nueva industria (ULTRALASER) RTC-2015-3631-5

IP: *José Mora Almerich*

2016 - 2018. Public Funding - Ministerio de Economía y Competitividad

Summary: *This project is focused on the development of high-efficiency pulses and femtoseconds based on modular technology with a competitive price adapted to the advanced applications of the small industry. The family of lasers obtained in the project will be composed of an ultra-short pulse laser of moderate energy, essentially in the range of the picoseconds whose compression to the range of the hundreds of femtoseconds will be studied throughout the project. A solid-state ultra-short pulse laser (up to 50 fs) and a laser system (laser plus modules for pulse processing) combining fiber technology and compression and amplification technology by free space propagation for very high performance.*

2.- RESEARCH RESULTS

2.1.- FEATURED PUBLICATIONS

D. Pérez, I. Gasulla, L. Crudgington, D. J. Thomson, A. Z. Khokhar, K. Li, W. Cao, G. Z. Mashanovich and J. Capmany, "Multipurpose silicon photonics signal processor core," **Nature communications**, vol. 8, p. 636, 2017.

This paper is a joint collaboration between ITEAM-PRL and ORC University of Southampton and reports the design, fabrication and experimental demonstration of a silicon photonics multipurpose processor core based on an integrated hexagonal waveguide mesh. The mesh is composed of 7 hexagonal MZI waveguide cells. We demonstrated the implementation of over 20 different configurations of photonic circuits ranging from simple single-input/single-output FIR filters, optical ring resonators (ORRs), coupled resonator waveguides (CROWs), side-coupled integrated spaced sequences of optical

resonators (SCISSORs) and ring loaded MZIs to multiple-input/multiple-output linear optic 2×2, 3×3 and 4×4 transformations including Pauli Matrices and a C-NOT gate. The experimental demonstration of this multifunctional integrated waveguide mesh photonic processor core included both classical FIR and IIR signal processing functions as well as multiport linear optics operations.

D. Perez, I. Gasulla, F. J. Fraile, L. Crudgington, D. J. Thomson, A. Z. Khokhar, K. Li, W. Cao, G. Z. Mashanovich and J. Capmany, "Silicon photonics rectangular universal interferometer," **Laser & Photonics Reviews**, vol. 11, no. 6, 2017.

This paper is a joint collaboration between ITEAM-PRL, the University of Vigo and ORC University of Southampton and reports the implementation of a fixed rectangular universal interferometer using a reconfigurable hexagonal waveguide mesh circuit. A suitable adaptation synthesis algorithm tailored to this mesh configuration was provided and the experimental demonstration of a rectangular multiport interferometer by means of a fabricated silicon photonics chip was reported. The 7-hexagonal cell chip can implement 2×2, 3×3 and 4×4 arbitrary unitary transformations. The proposed hexagonal waveguide mesh operates in a similar way as a Field Programmable Gate Array (FPGA) in electronics. This work represents an important step-forward towards fully programmable and integrable multiport interferometers

2.2.- PATENTS

J. Capmany, I. Gasulla, D. Pérez and S. Sales, "Compact broadband tunable photonic dispersive delay line," Application no. P201730990. Publication date: July 28, 2017.

Priority country: Spain.

2.3.- AWARDS.

1. **Daniel Pérez López,** Postdoctoral Researcher at the PRL has been awarded by COIT (the Spanish official association of telecommunication engineers) the prize to the best Spanish PhD thesis on Information and Communication Fundamentals and Basic Technologies, and their Applications.

Title: "Integrated Microwave Photonic Processors using Waveguide Mesh Cores"

Supervisors: Prof. Dr. Dr. José Capmany Francoy and Dr. Ivana Gasulla Mestre.

3.- SPECIAL EVENTS

20th European Conference on Integrated Optics – Valencia – 2018

Co-chairs: Pascual Muñoz and Pablo Sanchis

The 2018 European Conference on Integrated Optics (ECIO 2018, www.ecio-2018.org) celebrated its 20th anniversary in Valencia from the 30th May to the 1st June 2018. The conference focused on leading edge research on integrated optics, optoelectronics and nano-photonics and gathers experts from academia and industry to show their latest technical results, and showcase their products and services. The application scope was broad and it ranged from tele/datacom communications, optical interconnects, and (bio) optical sensing applications to more disruptive areas as quantum computing and mid-IR photonics. The conference featured more than two hundred attendees, and the 2019 edition will take place in Ghent University, Belgium. Conference topics covered waveguide technology and platforms, devices and materials, integrated circuits and applications of photonics integrated circuits (PICs). The most recent advances in photonic integration technologies, such as silicon photonics and III-V optoelectronics, was one of the main features of the conference. Assembly, packaging and hybrid integration techniques was also present, as well as novel concepts on materials, 2D materials or phase change materials.

Special events
20th European Conference on Integrated Optics – Valencia - 2018

MOBILE COMMUNICATIONS GROUP

The Mobile Communications Group (MCG) is aimed at developing new technologies for future standards in Mobile and Wireless Communications. The current activities of MCG are focused on four areas:

- 5G New Radio (5G-NR), with a frenetic activity in the definition of 5G for the next releases of NR standard.
- Multicast and Broadcast Services (MBMS) over 3GPP Networks, focused mainly in the research on new functionalities for the future releases of 5G (R.16 and following) to include Broadcast functions and native modes.
- Vehicular Communications, in which the MCG is working on cellular-assisted vehicular to anything (C-V2X) communications, in particular in topics of signalling for opportunistic usage of the different interfaces and advanced multi-antenna schemes. The final aim is guaranteeing the optimum operation of each vehicle and its interconnection in a 5G technology use scenario for increased levels of road safety.
- Body Area Communications (BAN), a relatively new domain in which the MCG is getting novel results on accurate characterization of UWB in-body propagation channels, design of in-body antennas for implanted and ingested devices, development of algorithms for the localization and tracking of in-body medical devices, human tissues measurement and modelling for research and diagnosis, and development of new full-spectrum phantom formulas tissues EM emulation. These tasks are currently undertaken with the support of the Hospital Universitario y Politécnico La Fe of Valencia, and the Centre for Biomaterials and Tissue Engineering at the UPV.

1.- PROJECT ACTIVITIES

1.1.- ONGOING PROJECTS

1. 5G-CARMEN

This project deals with the design and development of a 5G digital corridor for the connected and automated mobility of the future on European roads. Security, advanced management of emergencies, traffic sustainability, environment protection aspects: there are many challenges that await to be faced thanks to the most innovative technologies that will allow cars to be connected to each other and to land structures for a better management of vehicle traffic.

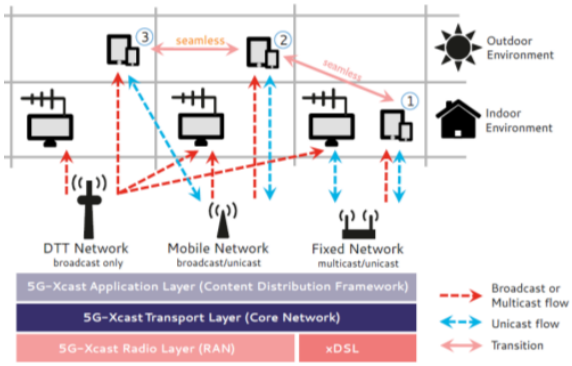
The "Munich-Bologna corridor", which covers 600 km of roads across three countries (Italy, Austria and Germany), is one of the most important corridors identified by the European Union for an initiative to improve the mobility of people and goods throughout Europe. As part of the 5G-CARMEN project, 5G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

This project has been funded by the European Commission.

2. Broadcast and Multicast Communication Enablers for the Fifth Generation of Wireless Systems (5G-Xcast)

5G-Xcast is a second phase 5G-PPP project focussed on devising, assessing and demonstrating a conceptually novel and forward-looking 5G network architecture for large scale immersive media delivery. The project objectives are to: (i) Develop broadcast and multicast point to multipoint (PTM) capabilities for 5G considering media, automotive, IoT and public warning use cases. (ii) Design a dynamically adaptable 5G network architecture with layer independent network interfaces to dynamically and seamlessly switch between unicast, multicast and broadcast modes or use them in parallel (iii) Develop proof-of-concept prototypes at Radio Access Network (RAN), core and content distribution level and experimentally demonstrate key innovations developed in the project for the

media and public warning verticals. Dr. David Gomez-Barquero from MCG is the Project Manager. The MCG is also leading the 5G-Xcast radio air-interface task which is developing PTM capabilities for the standalone 5G New Radio, and participating in the 5G PPP IMT-2020 Evaluation Working Group that is one of the External Evaluations Group within ITU-R for the performance assessment of the 5G radio interface technology.



This project is funded by the European Commission.

3. LDM with MIMO and 3GPP NOMA techniques

This project is a collaboration with the Electronics and Communications Research Institute (ETRI) from Korea in the disruptive Non-Orthogonal Multiple Access (NOMA), known as Layered Division Multiplexing (LDM), adopted on the new U.S. DTT standard, ATSC 3.0. The project continues the studies initiated in regarding the joint transmission of LDM with co-located MIMO schemes. It also analyses the new NOMA technologies that are being considered in 3GPP.

This project is funded by ETRI Korea

4. Wireless In-Body Environment Communications (WIBEC)

https://www.ntnu.edu/wibec

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

This project is funded by the European Commission

5. ElectroMagnetic prObe for early Tumour dEtection (EMOTE)

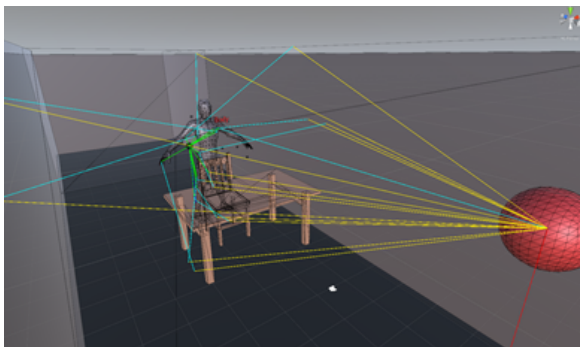
This is a joint collaborative project with Hospital La Fe, jointly funded by both public institutions. This project is devoted to the measurement of the dielectric properties of in vivo healthy and malignant colon tissues by using animal models (rats). In this way, it would be possible to evaluate whether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

This project is funded by the Hospital Universitario y Politécnico La Fe and the Universitat Politècnica de València.

6. Millimetre Wave Communications in Built Environments (WaveComBE)

WaveComBE (www.wavecombe.eu) is an Industrial and Training Network of the Marie Sklodovska-Curie Action, dealing with the ultra-dense deployment of millimetre-wave (mmW) small-cells (SCs) in conjunction with massive multiple-input multiple output (MIMO) in 5G and beyond 5G (B5G) wireless networks. In WaveComBE the MCG is developing the simulation tools to analyse the human body blocking to millimetre wavelength radio frequencies, as well as efficient planning tools to deploy future access points in bands around and above 30GHz, as well as researching on beamforming techniques for the physical layer of mm-wave mobile communications.

This project is funded by the European Commission



2.1.- FEATURED PUBLICATIONS

1. Ultrawideband Technology for Medical In-Body Sensor Networks. An overview of the human body as a propagation medium, phantoms, and approaches for propagation

analysis. Concepción García-Pardo, Carlos Andreu, Alejandro Fornés-Leal, Sergio Castelló-Palacios, Sofia Perez-Simbor, Martina Barbi, Ana Vallés-Lluch, and Narcís Cardona. IEEE Antennas and Propagation Magazine, pp 19-32, 2018.

DOI: 10.1109/MAP.2018.2818458

An in-body sensor network is that in which at least one of the sensors is located inside the human body. Such wireless in-body sensors are used mainly in medical applications, collecting and monitoring important parameters for health and disease treatment. IEEE Standard 802.15.6-2012 for wireless body area networks (WBANs) considers in-body communications in the Medical Implant Communications Service (MICS) band. Nevertheless, high-data-rate communications are not feasible at the MICS band because of its narrow occupied bandwidth. In this framework, ultrawideband (UWB) systems have emerged as a potential solution for in-body highdata-rate communications because of their miniaturization capabilities and low power consumption. In recent years, various open issues have guided the research on in-body propagation. First, the propagation medium, i.e., human body tissues, is frequency dependent and exhibits a large attenuation at UWB frequencies. Second, the behavior of in-body antennas is strongly dominated by the surrounding tissues. Thus, the in-body channel characterization in UWB depends not only on the channel behavior itself but also on the characterization methodology. This article outlines the research performed in the field of UWB in-body radio-channel characterization, considering the propagation medium and the analysis methodology: software simulations, phantom measurements, and in vivo measurements. We provide an overall perspective on the current state of the art, the limitations of in-body propagation analysis, and future perspectives on UWB in-body channel analysis.

2. Frequency Dependence of UWB In-Body Radio Channel Characteristics. Carlos Andreu, Concepción García-Pardo, Sergio Castelló-Palacios, Ana Vallés-Lluch, and Narcís Cardona. IEEE Antennas and Propagation Magazine, pp 359-361, 2018.

DOI: 10.1109/LMWC.2018.2808427

In this letter, a research of ultra-wideband in-body channel by using a high accurate phantom is performed in order to evaluate the impact of frequency dependence of human tissues on the channel characteristics. Hence, a phantom-based measurement campaign from 3.1 to 5.1 GHz has been conducted. From postprocessing data, the path loss is assessed considering subbands of 500 MHz as well as the entire frequency range under test. In addition, the correlation in transmission is computed and discussed.

3. Experimental Assessment of Time Reversal for In-Body to In-Body UWB Communications. Carlos Andreu, Concepcion Garcia-Pardo, Sergio Castelló-Palacios, and Narcís Cardona. Wireless Communications and Mobile Computing, 12 pages, 2018.

DOI: 10.1155/2018/8927107

The standard of in-body communications is limited to the use of narrowband systems. These systems are far from the high data rate connections achieved by other wireless telecommunication services today in force. The UWB frequency band has been proposed as a possible candidate for future in-body networks. However, the attenuation of body tissues at gigahertz frequencies could be a serious drawback. Experimental measurements for channel modeling are not easy to carry out, while the use of humans is practically forbidden. Sophisticated simulation tools could provide inaccurate results since they are not able to reproduce all the in-body channel conditions. Chemical solutions known as phantoms could provide a fair approximation of body tissues' behavior. In this work, the Time Reversal technique is assessed to increase the channel performance of in-body communications. For this task, a large volume of experimental measurements is performed at the low part of UWB spectrum (3.1-5.1 GHz) by using a highly accurate phantom-based measurement setup. This experimental setup emulates an in-body to in-body scenario, where all the nodes are implanted inside the body. Moreover, the in-body channel characteristics such as the path loss, the correlation in transmission and reception, and the reciprocity of the channel are assessed and discussed.

4. Point-to-Multipoint Communication Enablers for the Fifth-Generation of Wireless Systems. David Gomez-Barquero, David Navratil, Steve Appleby, Matt Stagg. IEEE Communications Standards Magazine, special issue on ENABLING 5G VERTICALS & SERVICES THROUGH NETWORK SOFTWARIZATION AND SLICING, 2018.

DOI: 10.1109/MCOMSTD.2018.1700069

3GPP has enhanced the point-to-multipoint (PTM) communication capabilities of 4G LTE in all releases since the adoption of eMBMS (enhanced Multimedia Broadcast Multicast Service) in Release 9. Recent enhancements cover not only television services, but also critical, machine-type and vehicular communications, following the backwards-compatibility design philosophy of LTE. This paper discusses the opportunity in the design and standardization of 5G to break with the existing paradigm for PTM transmissions in 4G LTE, where broadcast PTM transmissions were initially conceived as

an add-on and pre-positioned service. 5G brings the opportunity to incorporate PTM capabilities as built-in delivery features from the outset, integrating point-to-point (PTP) and PTM modes under one common framework and enabling a dynamic use of PTM to maximize network and spectrum efficiency. This approach will open a door to completely new levels of network management and delivery cost-efficiency. The paper also discusses the implications of PTM for network slicing, to customize and optimize network resources on a common 5G infrastructure to accommodate different use cases and services taking into account the user density.

5. Point-to-Multipoint Communication Enablers for the Fifth-Generation of Wireless Systems. Jordi J. Gimenez, David Gomez-Barquero, Javier Mogarde, Erik Stare, IEEE Communications Magazine, 2018.

DOI: 10.1109/MCOM.2018.1700675

Efficient and flexible use of spectrum will be inherent characteristics of 5G communication technologies with native support of wideband operation with frequency reuse 1 (i.e., all transmit sites use all available frequency resources). Although not in the very first 5G release of 3GPP, it is expected that broadcast/multicast technology components will later be added and fully integrated in the 5G system. The combination of both wideband and frequency reuse 1 may provide significant gains for broadcast transmissions in terms of energy efficiency, since it is more efficient to increase capacity by extending the bandwidth rather than increasing the transmit power over a given bandwidth. This breaks with the traditional concept of terrestrial broadcast frequency planning, and paves the way to new potential uses of UHF spectrum bands for 5G broadcasting. This article provides insight into the fundamental advantages in terms of capacity, coverage, as well as power saving of wideband broadcast operation. The role of network deployment, linked to frequency reuse in the UHF band, and its influence on the performance of a wideband broadcasting system are discussed. The technical requirements and features that would enable such a power-efficient solution are also addressed.

6. Study on the Optimum Co-Located MIMO Scheme for LDM in ATSC 3.0: Use Cases and Core Layer Performance. Eduardo Garro, Carlos Barjau, David Gomez-Barquero, Jeongchang Kim, Sung-Ik Park, Namho Hur, Proc. IEEE BMSB 2018.

DOI: 10.1109/BMSB.2018.8436920

In this paper, the joint transmission of ATSC 3.0 Layered Division Multiplexing (LDM) with co-located Multi-Antenna schemes (MIMO) is investigated for the mobile or Core Layer (CL). Previous works have already assessed the ergodic capacity of LDM plus MIMO, but the performance over realistic channels has not been performed yet. Four potential system models for the CL are compared, depending on the number of mobile receiving antennas and the use of Transmit Diversity Code Filter Sets (TDCFS). Mobile layer performance is evaluated by means of physical layer simulations. The main results obtained show that system models with one antenna receivers provide similar performance as more-complex implementations with two receiving antennas. The use of TDCFS is also recommended for mobile channels.

7. Distribution of Road Hazard Warning Messages to Distant Vehicles in Intelligent Transport Systems. Daniel Calabuig, David Martín-Sacristán, Jose F. Monserrat, Mladen Botsov, David Gozálvez. IEEE Transactions on Intelligent Transportation Systems (Volume: 19, Issue: 4 , April 2018).

DOI: 10.1109/TITS.2017.2718103

The efficient distribution of intelligent transport system (ITS) messages is fundamental for the deployment and acceptance of ITS applications by mobile network operators and the automotive industry. In particular, the distribution of road hazard warning (RHW) messages to distant vehicles requires special mechanisms. In this case, the combination of direct communication between vehicles and the wide area coverage provided by cellular networks might be crucial not only for reducing the data transmission costs but also for improving the timeliness of ITS information. Moreover, the application of clustering and cluster head selection mechanisms among vehicles can increase the efficiency of hybrid vehicular and cellular communication networks. This paper introduces a novel cluster head selection technique for the distribution of RHW messages, and proposes an implementation of another legacy technique that was originally intended for mobile ad-hoc networks (MANETs). This paper evaluates the performance of these techniques by the means of computer simulations in two scenarios with distinct congestion and propagation conditions. The simulation results show the potential benefit of hybrid networks compared with pure cellular transmissions, especially, if the novel cluster head selection technique is used.

2.3. AWARDS

1. Best Conference Paper award at the IEEE Conference on Standards for Communication and Networking (IEEE CSCN 2018) (Sofia Perez Simbor).

2. Best Student Paper award at the IEEE Broadband Multimedia Systems and Broadcasting (IEEE BMSB 2018) (Eduardo Garro)

Signal Modality Characterization: from Phase Space Reconstruction to Real Applications

Alicia Carrión García
Supervisor: Ramón Miralles Ricós
Defended on June 27th, 2018

The characterization of the modality of a signal is a new concept, which has been the subject of recent research. Its main purpose is to identify any changes in the nature of a real signal. The term "nature of a signal" refers to the underlying model that generates the signal from the point of view of two main characteristics: determinism and linearity. In this thesis, the modality of a signal is used for the advanced processing of acoustic signals, and in particular, in non-destructive tests of non-homogeneous materials, such as concrete.

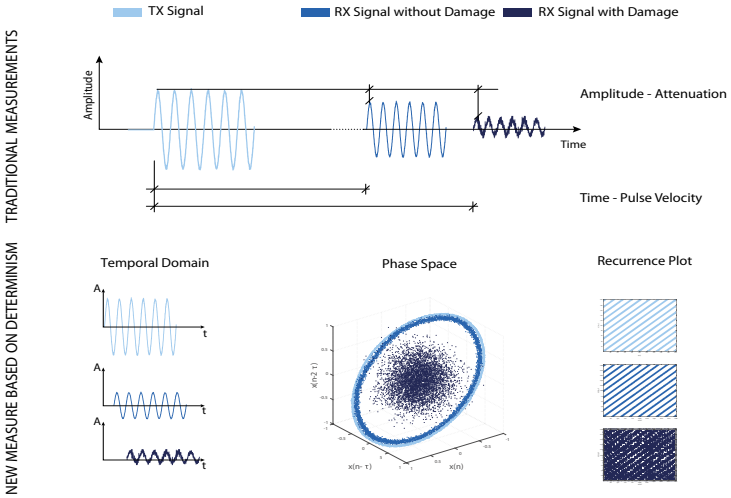
The problem of the characterization of the modality begins with the correct reconstruction of the phase space. This new domain allows identifying the different states of a signal, as to whether they are recurrent or not, depending on whether they are deterministic, respectively, random. In the field of non-destructive testing based on ultrasound, the material is excited with a purely deterministic signal. However, the nature of the received signal depends on the internal structure of the material. This working hypothesis allows us to propose measuring the degree of determinism as a complementary alternative to the usual ultrasound parameters such, as attenuation and speed. The level of determinism has been found to be proportional to the level of porosity in cementitious materials. It also allows characterizing the level of damage of mortar test pieces subjected to different kinds of damaging processes: external attack by sulphates, and loading processes.

The study of the non-linearity or complexity of a time series is initially presented blindly (without having information about the input signal) through hypothesis tests: generating surrogate data and applying a statistical test. Significant progress has been made in adapting this approach to nonstationary data, a common feature of real non-linear signals. The main results in this regard have been achieved in the characterization of the complexity of oscillatory signals of limited duration.

The concept of signal modality has also been used to perform a detailed study of the non-linear phenomenon of acoustic impact spectroscopy. This analysis has allowed understanding the variables involved, and thus, proposing a mathematical model that characterizes the phenomenon. The understanding of the phenomenon and the model have allowed proposing a new processing algorithm equivalent to the usual NIRAS technique, but optimal in its application. This processing alternative may mean significant advances, especially in industrial applications where time and effort are variables to be optimized.

This thesis demonstrates that the characterization of the modality of a signal presents an alternative to the characterization of complicated real phenomena. The measure of determinism and the FANSIRAS algorithm have shown that the modality of a signal is an interesting tool for future research into the characterization of cementitious materials.

Keywords: Signal Modality, Determinism, Non-linearity, Recurrence Plots, surrogates, Non-Destructive Testing, concrete, FANSIRAS



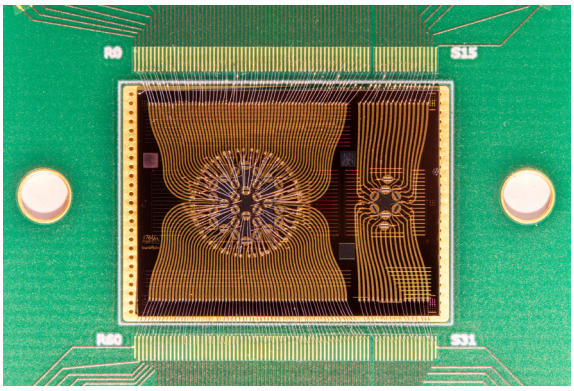
Graphical description of the ultrasonic measurements: traditional ones, velocity and attenuation, and the alternative approach based on the concept of the level determinism

Integrated Microwave Photonic Processors using Waveguide Mesh Cores

Daniel Pérez López
Supervisor: José Capmany Francoy, Ivana Gasulla Mestre
Defended on October 17th, 2017

Integrated microwave photonics changes the scaling laws of information and communication systems offering architectural choices that combine photonics with electronics to optimize performance, power, footprint and cost. Application Specific Photonic Integrated Circuits, where particular circuits/chips are designed to optimally perform particular functionalities, require a considerable number of design and fabrication iterations leading to long-development times and costly implementations.

A different approach inspired by electronic Field Programmable Gate Arrays is the programmable Microwave Photonic processor, where a common hardware implemented by the combination of microwave, photonic and electronic subsystems, realizes different functionalities through programming. Here, we propose the first-ever generic-purpose Microwave Photonic processor concept and architecture. This versatile processor requires a powerful end-to-end field-based analytical model to optimally configure all their subsystems as well as to evaluate their performance in terms of the radiofrequency gain, noise and dynamic range. Therefore, we develop a generic model for integrated Microwave Photonics systems. The key element of the processor is the reconfigurable optical core. It requires high flexibility and versatility to enable reconfigurable interconnections between subsystems as well as the synthesis of photonic integrated circuits. For this element, we focus on a 2-dimensional photonic waveguide mesh based on the interconnection of tunable couplers. Within the framework of this Thesis, we have proposed two novel interconnection schemes, aiming for a mesh design with a high level of versatility. Focusing on the hexagonal waveguide mesh, we explore the synthesis of a high variety of photonic integrated circuits and particular Microwave Photonics applications that can potentially be performed on a single hardware. In addition, we report the first-ever demonstration of such reconfigurable waveguide mesh in silicon. We demonstrate a world-record number of functionalities on a single photonic integrated circuit enabling over 30 different functionalities from the 100 that could be potentially obtained with a simple seven hexagonal cell structure. The resulting device can be applied to different fields including communications, chemical and biomedical sensing, signal processing, multiprocessor networks as well as quantum information systems. Our work is an important step towards this paradigm and sets the base for a new era of generic-purpose photonic integrated systems.



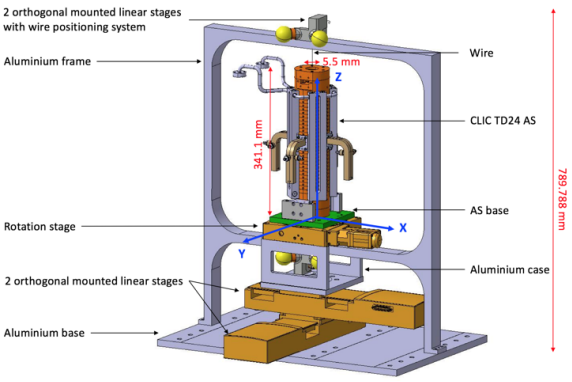
Development of direct measurement techniques for the in-situ internal alignment of accelerating structures

Natalia Galindo Munoz
Supervisors:Vicente E. Boria Esbert; Ángeles Faus Golfe
Defended on March 13th, 2018

In the next generation of linear particle accelerators, challenging alignment tolerances are required in the positioning of the components focusing, accelerating and detecting the beam over the accelerator length in order to achieve the maximum machine performance. In the case of the Compact Linear Collider (CLIC), accelerating structures (AS), beam position monitors and quadrupole magnets need to be aligned in their support with respect to their reference axes with an accuracy of 10 um. To reach such objective, the PACMAN (Particle Accelerator Components Metrology and Alignment to the Nanometer Scale) project strives for the improvement of the current alignment accuracy by developing new methods and tools, whose feasibility should be validated using the major CLIC components.

This Ph.D. thesis concerns the investigation, development and implementation of a new non-destructive intracavity technique, referenced here as the perturbative method, to determine the electromagnetic axes of ASs by means of a stretched wire, acting as a reference of alignment. Of particular importance is the experimental validation of the method through the 5.5 mm iris-mean aperture CLIC prototype known as TD24, with complex mechanical features and difficult accessibility, in a dedicated test bench.

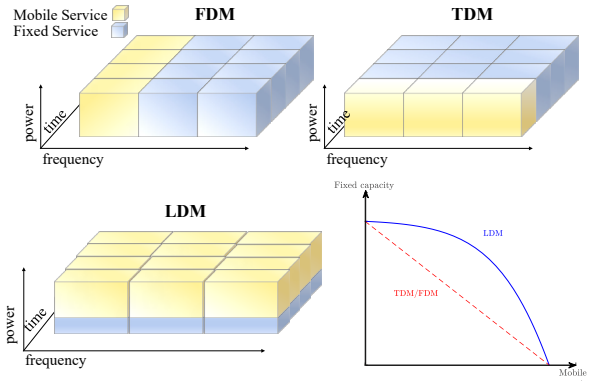
In the first chapter of this thesis, the alignment techniques in particle accelerators and the novel proposals to be implemented in the future linear colliders are introduced, and a detailed description of the PACMAN project is provided. The feasibility study of the method, carried out with extensive electromagnetic fields simulations, is described in chapter 2, giving as a result, the knowledge of the theoretical accuracy expected in the measurement of the electromagnetic axes and facilitating the development of a measurement algorithm. The conceptual design, manufacturing and calibration of the automated experimental set-up, integrating the solution developed to measure the electromagnetic axes of the TD24, are covered in chapter 3. The future lines of research and developments of the perturbative method are also explored. In chapter 4, the most significant results obtained from an extensive experimental work are presented, analysed and compared with simulations. The proof-of-principle is completed, the measurement algorithm is optimised and the electromagnetic centre is measured in the TD24 with a precision less than 1 um and an estimated error less than ±8.5 um. Finally, in chapter 5, the developments undertaken along this research work are summarised, the innovative achievements accomplished within the PACMAN project are listed and its impact is analysed.



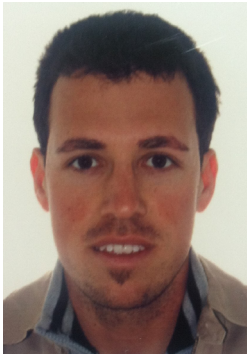
Advanced Layered Division Multiplexing Technologies for Next-Gen Broadcast

Eduardo Garro Crevillén
Supervisors: David Gómez Barquero, Narcís Cardona Marcet
Defended on June 4th, 2018

Since the beginning of the 21st century, terrestrial broadcasting systems have been blamed of an inefficient use of the allocated spectrum. To increase the spectral efficiency, Digital Terrestrial Television (DTT) Standards Developing Organizations settled to develop the technical evolution of the first-generation DTT systems. Among others, a primary goal of next-generation DTT systems (DVB-T2 and ATSC 3.0) is to simultaneously provide TV services to mobile and fixed devices. The major drawback of this simultaneous delivery is the different requirement of each reception condition. To address these constraints, different multiplexing techniques have been considered. While DVB-T2 fulfilled the simultaneous delivery of the two services by TDM, ATSC 3.0 adopted the Layered Division Multiplexing (LDM) technology. LDM can outperform Time Division Multiplexing (TDM) and FDM by taking advantage of the unequal error protection ratio, as both services, namely layers, utilize all the frequency and time resources with different power levels. At receiver side, two implementations are distinguished, according to the intended layer. Mobile receivers are only intended to obtain the upper layer, known as CL. In order not to increase their complexity compared to single layer receivers, the lower layer, known as EL is treated as an additional noise on the CL decoding. Fixed receivers, increase their complexity, as they should performed a successive interference cancellation process on the CL for getting the EL. To limit the additional complexity of fixed receivers, the LDM layers in ATSC 3.0 are configured with different error correction capabilities, but share the rest of waveform parameters, including the interleaving, the pilot pattern, the FFT size and the guard interval. This dissertation investigates advanced technologies to optimize the LDM performance. A demapping optimization for the two LDM layers is first proposed. A capacity increase is achieved by the proposed algorithm, which takes into account the underlying layer shape in the demapping process. Nevertheless, the number of Euclidean distances to be computed can be significantly increased, contributing to not only more complex fixed receivers, but also more complex mobile receivers. Next, the most suitable ATSC 3.0 pilot configuration for LDM is determined. Considering the two layers share the same PP a trade-off between pilot density (CL) and data overhead (EL) arises. From the performance results, it is recommended the use of a not very dense PP, as they have been already designed to cope with long echoes and high speeds. The optimum pilot amplitude depends on the channel estimator at receivers (e.g. the minimum amplitude is recommended for a Wiener implementation, while the maximum for a FFT implementation). The potential combination of LDM with three advanced technologies that have been adopted in ATSC 3.0 is also investigated: MultiRF technologies, distributed MISO schemes, and co-located MIMO schemes. The potential use cases, the transmitter and receiver implementations, and the performance gains of the joint configurations are studied for the two LDM layers. The additional constraints of combining LDM with the advanced technologies is considered admissible, as the greatest demands (e.g. a second receiving chain) are already contemplated in ATSC 3.0. Significant gains are found for the mobile layer at pedestrian reception conditions thanks to the frequency diversity provided by MultiRF technologies. The conjunction of LDM with distributed MISO schemes provides significant performance gains on SFNs for the fixed layer with Alamouti scheme. Last, considering the complexity in the mobile receivers and the CL performance, the recommended joint configuration is MISO in the CL and MIMO in the EL.



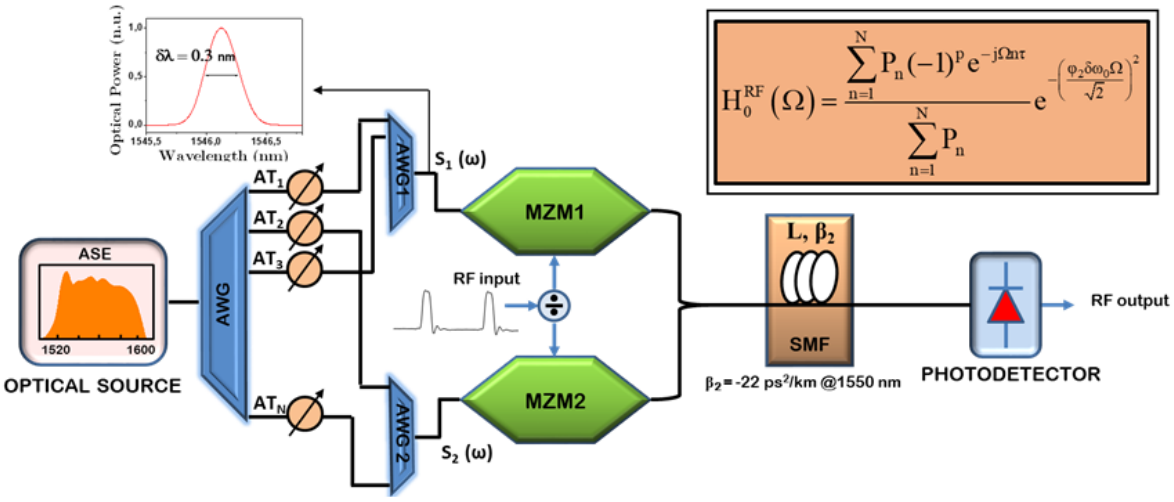
Radiofrequency signal generation systems based on Microwave Photonics



Manuel Rius Mercado
Supervisors: José Mora Almerich, Mario Bolea Boluda
Defended on 17th July 2018

The use of Photonics technology for the generation of arbitrary microwave signals permits to overcome the limitations of electrical systems and its direct integration in radio over fibre systems. The photonic technique based on microwave photonic filters presents ease of reconfiguration and frequency tuning of the generated waveform, as well as robustness and simplicity of the different structures.

In this thesis, the study and implementation of arbitrary microwave signal generators with optical processors based on microwave photonic filters is introduced. Firstly, a theoretical development of the general transfer function is found for the photonic systems based on microwave photonic filters with optical processors composed by delay lines or dispersive devices. This theoretical development has permitted to evaluate the harmonic distortion generated in these systems, which has revealed its relevance when a design of these systems is carried out. Secondly, arbitrary microwave signal generators based on microwave photonic filters have been proposed and specific waveforms have been generated for Ultra-Wideband technology as well as chirped signals, specifically, electrical chirped pulses. Moreover, capabilities of reconfiguration and tuning of the generated signal have been demonstrated for the proposed systems. Regarding theoretical response in relation to experimental measurements, a good concordance has been found and, consequently, the theoretical development has been validated. In this way, this theoretical development has been proved as a suitable tool to design photonic generators of arbitrary microwave signals.



THESIS SUMMARY

New broadband, low cost and compact MIMO radar frontends

Enric Miralles Navarro
Supervisors: Héctor Esteban, Ángel Belenguer, Volker Ziegler
Defended on July 2nd, 2018

This doctoral thesis deals with the design of new radiofrequency circuits for MIMO-type radars. The MIMO algorithms applied to radars are capable of increasing the virtual size of an antenna array in each dimension, provided that the radiant elements are properly placed. This artificial elongation of the effective area of the cluster provides improved radar resolution. MIMO radars do not only improve the performance of conventional radars, but they also reduce their cost. By reducing the number of antennas, all the radio frequency circuitry associated with the antenna (filters, amplifiers, switches...) is also reduced.

The first chapter makes a brief introduction to the history of radar until the present day and presents the objectives, methodology and structure of this work.

The second chapter introduces the basic radar concepts necessary for the development of this thesis.

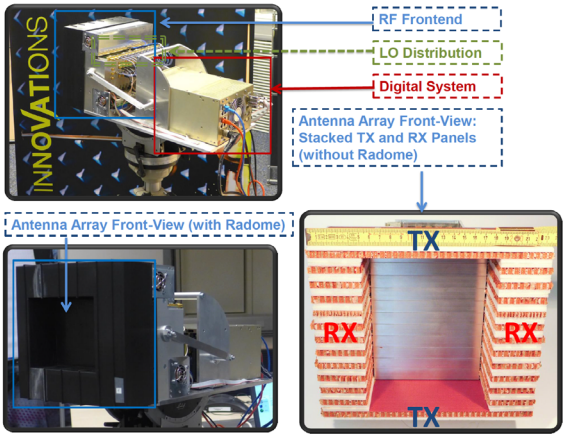
The third chapter presents the first prototype of MIMO radar developed at Airbus. This radar uses a stacked printed circuit board structure to achieve a two-dimensional antenna array. The design and performance of each one of the radiofrequency circuit devices are presented and discussed in detail, and the final performance of the whole system are also briefly described.

The fourth chapter describes a second prototype of MIMO radar. To make the radar more compact, the antennas have been replaced by printed antennas. In this way it is possible to create a two-dimensional cluster with only one printed circuit. The MIMO antenna configurations used have an unoccupied space in the centre. This space has been used to place spiral antennas for communication, and a camera with a servomotor.

The fifth chapter emphasizes the design of passive components with a large bandwidth (from 4 to 40 GHz). A Wilkinson splitter integrated in a printed circuit board in microstrip technology and a 3D printed antenna, achieve the proposed bandwidth. These devices integrated in a MIMO radar type would increase its performance. For example, they would enable algorithms of "frequency hopping". Thus, a single hardware could be used in different areas, with different frequency regulations, or modulations, with a higher bandwidth and in turn with higher resolution.

The sixth chapter presents an antenna and a coupler manufactured in a novel technology (ESIW). ESIW is a waveguide integrated in a substrate in which the inner dielectric has been emptied. This guide is compact, low cost and very low loss. These qualities make ESIW an ideal technology for radars.

The seventh and final chapter sets out the conclusions and future lines of research.



Advanced Optical Techniques of Transmission for OOFDM-WDM Networks

Francisco Israel Chicharro López
Supervisors: Beatriz Ortega Tamarit and José Mora Almerich
Defended on July 23rd, 2018

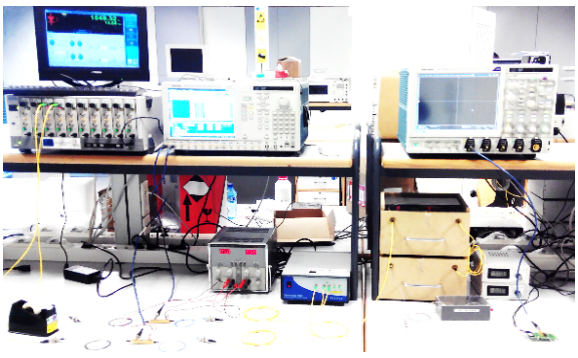
The increasing demand of bandwidth per end-user required by current Internet services, high-definition video, multimedia applications or on-line gaming drives the advanced modulations to play a significant role in optical networks. OOFDM (Optical Orthogonal Frequency Division Multiplexing) has been widely employed as a solution for network communications due to its advantages, such as overcoming chromatic and polarization dispersion impairments, its adaptability to channel variations and its high spectral efficiency.

The generation of OFDM signals, intensity modulated and directly detected, from double sideband modulations results in an inefficient use of the spectrum, adding the power fading related to the chromatic dispersion. Alternatively, the single band modulations avoid this drawback. In this work, we are introducing an original scheme of transmission of optical OFDM signals based on the single band modulation that makes a better use of the spectrum. It consists of the definition of paired channels. Each one includes two optical carriers with a narrow spectral separation, and the external single sideband.

Furthermore, this Thesis provides a low-cost solution for the implementation of WDM-OFDM transmitters based on the use of broadband sources. Despite the chromatic dispersion avoids the use of this kind of optical sources, the inclusion of some structures before the detection enable the transmission of OFDM signals in optical links. The use of a Mach-Zehnder interferometer, properly designed, enables the use of broadband sources in a dispersion tolerant scheme, as will be experimentally demonstrated. Moreover, every parameter that concerns the transmission of the signals is studied, with the goal of defining the optimal operation of these systems.

As an example of the flexibility of the introduced systems, the transmission of multiband OFDM signals is also demonstrated. Different OFDM bands form these signals, increasing the electric spectrum efficiency. Once again, the proper design of the Mach-Zehnder interferometer will result in an adaptive solution regarding the end-user requirements in each moment, as the experimental results will confirm.

Therefore, this Doctoral Thesis proposes and demonstrates advanced, novel and efficient solutions for the transmission of OFDM signals in optical networks. They are also validated along the Thesis in the context of the DWDM technology, for exploring their potential as a candidate for implementation in future networks.



Note: Fill out only the text/images between brackets []

OTHER THESES

Other PhD dissertations held in iTEAM between August 2017 and October 2018:

Title: Técnicas de transmisión sobre fibra óptica con dispersión modal (in Spanish)

Author: Medina Sevila, Pau

Supervisors: Juan Luis Corral González, Vicenç Almenar Terré

Defended on September 14th, 2017.

http://hdl.handle.net/10251/90414

Title: UWB radio channel and diversity characterization for wireless implanted devices

Author: Andreu Estellés, Carlos

Supervisors: Concepción García Pardo, José Francisco Monserrat Del Río, Narciso Cardona Marcet

Defended on September 26th, 2018.

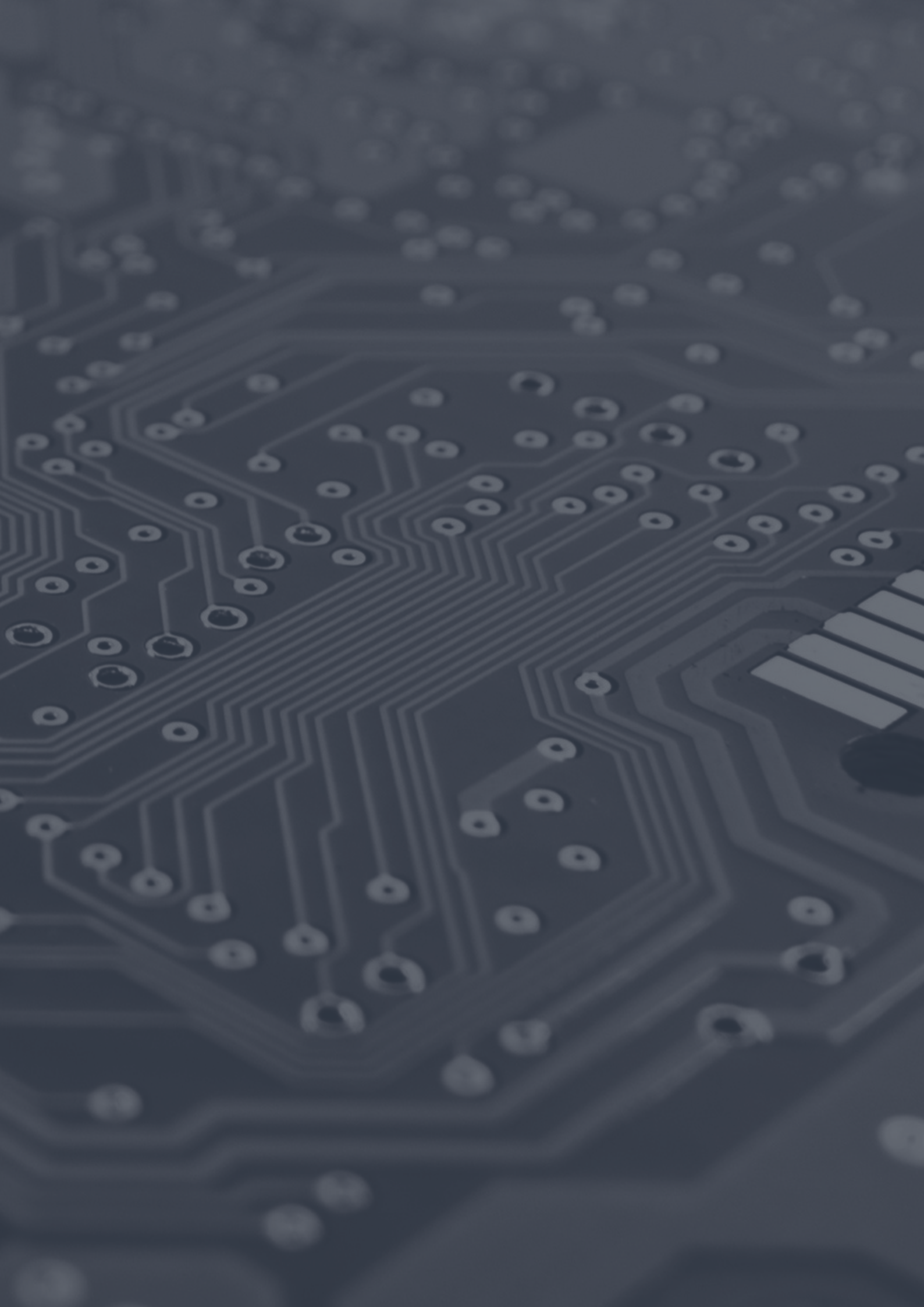
http://hdl.handle.net/10251/111836

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

Author: Triana Infante, Cristian Andrés

Supervisors: Daniel Pastor Abellán, Gloria Margarita Varón Durán

Defended on October 11th, 2018.



[Waves] 2018 year 10