EPhoox Technology S.L.: Microwave Photonics for characterization and monitorization of photonic devices and hybrid RoF systems

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Abstract

EPhoox is a spin-off of the Universitat Politècnica de València which offers innovative solutions based on Microwave Photonics technology combining the worlds of radiofrequency engineering and optoelectronics. Its main focus is the design and manufacture of advanced instrumentation for characterization and monitorization of photonic devices and hybrid RoF systems. In particular, EPhoox adapts and develops solutions for specific environments such as 5G, taking into consideration its emerging deployment. This manuscript describes the first optical solution OVNA-P100X developed by EPhoox. The OVNA-P100X permits the measurements of both passive and active photonic, opto-electronic and electro-optic devices by means of a complete combined solution composed of a radiofrequency (RF) Vector Network Analyzer (VNA) and an advanced photonic module. This module is compatible with any RF VNA in the market. The optical solution OVNA-P100X from EPhoox presents an added value which makes it the best solution of its kind. This added value comprises four aspects: adaptability, advanced functionalities, technical improvements and philosophy.

Keywords: microwave photonics, characterization, monitorization, vector network analyzer.

1. Scope and Overview

There are different instrument solutions in the market that are necessary for the deployment of the latest generation services for voice, data and videos for millions of homes by means of fiber or hybrid infrastructures with a reliable network architecture without failures [1]. Obtaining high quality networks requires the help of intelligent and automated test solutions. However, with regard to these conventional solutions well established in the telecommunications sector, the development of characterization systems with advanced component control using Microwave Photonics (MWP) technology is a scientific-technical challenge which opens the door to new business opportunities in the telecommunications sector at international level.

Whereas the MWP applications were initially focused on the defense sector, they have been recently expanded to other sectors such as the civil sector, including mobile and wireless networks, satellite communications, cable television, distributed antenna systems (DAS) and optical signal processing. In this context, MWP technology presents a promising solution for a near future and, more precisely, for the convergence of wireless-fibre networks. These applications require increasing values of speed on demand, greater bandwidth and wide dynamic range. Besides, it is necessary to minimize size, weight and power consumption of the devices, exhibiting a high tunability and immunity to electromagnetic interference [2-4].

Wireless services available today, based on technologies and standards such as Wi-Fi, GSM and 3G-UMTS, make use of the lower microwave bands, below 6 GHz. The new standards, such as 4G-LTE (Long Term Evolution), intend to improve performance and wireless transmission speeds of the previous standards to reach rates close to one hundred megabits per second at the expense of overloading the wireless spectrum, already congested, in this region. To download the RF spectrum of current wireless systems, the fifth generation of mobile communications systems (5G) intends to use all the radio frequency spectrum available in a much more efficient way to provide

Microwave Photonics technology constitutes a scientific-technical challenge that opens doors to new business opportunities.

mobile access at a much higher speed (greater than gigabit per second) and allow transport (backhaul) with high capacity between base stations and between base stations and the core network of mobile networks. In this context, the main research challenge currently facing the scientific community and industry is the definition of the operating bands of 5G technology, starting at 700 MHz and up to 60 GHz or even more, with and without license [5]. One of the main challenges of 5G is to permit the use of new bands of the RF spectrum (called millimeter waves, above 30 GHz and up to 60 GHz or more), so that future 5G networks allow high antenna density, better and more efficient interference management, facilitate mass communication between all types of devices, allow massive connectivity and deployment of all types of devices connected to the network, and are optimal for deployment of smaller cells (pico and / or micro cells) to increase efficiency and network coverage [6, 7].

The development of 5G technology in other radio frequency bands such as millimeters, is a major paradigm for manufacturers of equipment for analysis and monitorization of such networks. All the equipment in the market for analysis and diagnosis of access networks are designed for analysis and monitorization of fixed networks or radio networks in isolation, but not for hybrid radio-fibre networks, much less to operate at 60 GHz frequencies in the millimeter band. Operators will soon require new analysis equipment, currently nonexistent in the market, capable of operating in the millimeter frequency band (up to at least 64 GHz) which will characterize their convergent radio-fibre 5G networks, analyze their state and diagnose potential network problems anywhere on the link.

In short, the current market for optical test and measurement instrumentation potentially supports the EPhoox solution developed for component characterization. The evolution of characterization systems using MWP technology constitutes a scientific-technical challenge that opens doors to new business opportunities in the telecommunications sector at international level [4].

In this context, EPhoox is born as the most recent spin-off of the Universitat Politècnica de València. It has the aim to design and manufacture advanced instrumentation based on photonics technology. The company is composed of an interdisciplinary team of people specialized in the MWP field. EPhoox solutions enable complex functionalities to be carried out in an easier way than in other equipment that can be found in the market. The deep knowledge in the field of MWP enables EPhoox to develop products that facilitate the realization of functionalities in other devices in the market which are complex or simply cannot be carried out. In this context, based on MWP technology, EPhoox produces the most advanced and competitive Optical Vector Network Analyzer (OVNA) both in specifications and price.

In this manuscript, a compact solution for measurement and characterization of the S-parameters in this type of devices is presented. The combination of a VNA and an advanced photonic instrument, which performs different opto-electronic and electro-optical conversions, permits to carry out this type of measurements. Featuring a modulation bandwidth of up to 67 GHz and ready for using either fixed or tunable optical sources centered @ 1550 and 1310 nm, this external optical instrument upgrades the functionality of the VNA to carry out measurements and characterization of the S-parameters of a variety of components and systems.

2. System description

The EPhoox OVNA P100-X upgrades the functionality of a RF vector network analyzer (VNA), enabling it to carry out measurements and characterization of the S-parameters of a variety of components and devices. For instance, electro-optic modulators (EOMs), optical amplifiers, radio over fiber subsystems (RoF subsystems) and any other passive or active, photonic, opto-electronic or electro-optical devices and systems.

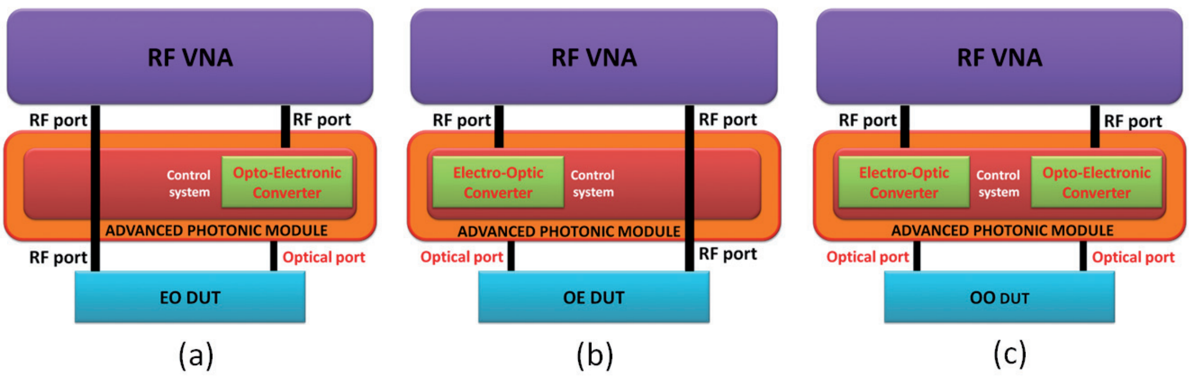


Figure 1. Block diagram of the complete system for carrying out the (a) electro-optical, (b) opto-electronic and (c) optical-optical configuration for S-parameters measurement of a DUT.

The proposed solution is composed of an advanced photonic module which controls a given VNA. The advanced photonic module acts as an interface between DUT's optical domain and VNA's electronic domain.

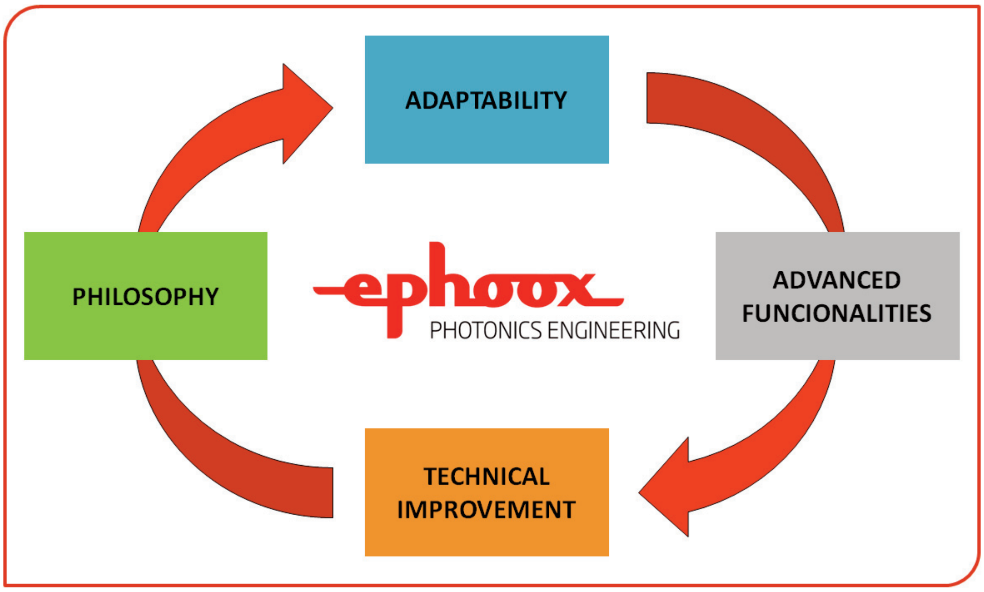
The proposed solution is composed of an advanced photonic module which controls a given VNA. Fig. 1 shows the block diagram of the complete system featuring different configurations for the S-parameter measurements of a general DUT. The advanced photonic module acts as an interface between DUT's optical domain and VNA's electronic domain. In the first stage, an electro-optic converter modulates an optical signal with the electronic signal from the VNA. The optical signal can be introduced from either the internal source or the external source through the external optical input. In the second stage, the opto-electronic converter returns the electronic signal to the VNA. Regarding electrical and optical paths, these are implemented by RF cables and optical patch-cords respectively. Note that the final user can select different RF and optical combinations for the input and output ports in order to implement available working modes: electro-optical (E/O), opto-electrical (O/E) and optical-optical (E/O) configurations.

The communication between the VNA and the optical instrument is performed using LAN connection employing the respective ports, without penalizing the performance of the VNA. Moreover, the modularity of the prototype will allow the realization of both hardware updates, to increase the frequency of the equipment, and software, to introduce new functionalities. In this way, users have the opportunity to make a long-term investment that enables the possibility of updating the solution according to their needs. The prototype can work with various peripherals from any manufacturer, such as vector network analyzers or optical sources so that the end user can take advantage of the existing infrastructure at its disposal. In addition, the solution will incorporate an innovative protection system for optical components that allows significant reduction in maintenance costs.

Fig. 2 shows the advanced photonic module developed by EPhoox. This corresponds to an external instrument which is compatible with VNAs from any manufacturer. It features a modulation bandwidth of 30/50/67 GHz and is ready for using either fixed (centered @ 1550 and 1310 nm) or tunable optical sources.

The EPhoox optical solution OVNA-P100X presents an added value which makes it the best solution of this kind in the market. This added value comprises its aspects as shown in Fig. 3. Firstly, one of the main characteristics is related to adaptability. This solution is compatible with VNAs from any manufacturer and allows both HW and SW upgrading. This upgrading enables the customer to increase the frequency of the solution and to include more advanced functionalities in the future, allowing the possibility of investing in a long-term solution. Secondly, the proposal includes advanced functionalities apart from time-domain measurements, which are already present in the market. EPhoox introduces different novel functionalities such as reduction of uncertainty and amplitude and delay characterization of optical components. In addition, different technical improvements have been considered. The current solution offers improved specifications for relative uncertainty and noise floor. The range for operation wavelength has also been extended. Besides, it includes a unique protection system both for electronic and optical components. Finally, EPhoox solutions inherit the company's philosophy, which is focused on customer satisfaction. In this way, EPhoox accompanies the final users during pre and post sale process with an exceptional client care. The company provides high quality products to be worthy of confidence and fidelity. Excellent calibration and first rate repair services support the guarantee of the products. In order to ensure a correct calibration regardless of the optical expertise of the user, EPhoox has been pioneer in designing an intuitive GUI that will provide guidance to obtain quality measurements.

■ **Figure 2.** Front panel of the advanced photonic module.



■ **Figure 3.** Added value of the OVNA offered by EPhoox.

3. Experimental measurements for different types of configurations.

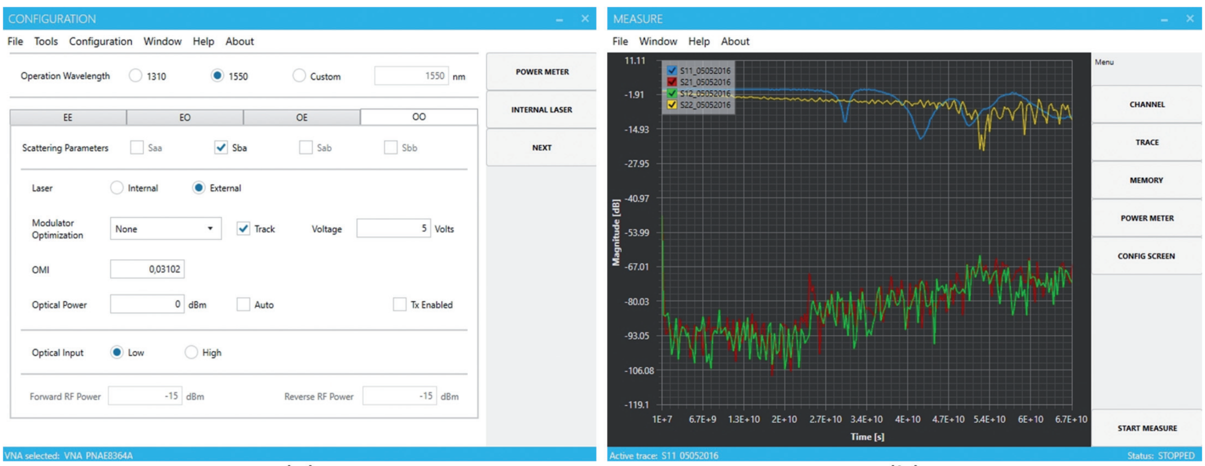
3.1 Calibration Process

As it is known, calibration should be performed regularly according to the desired measurement accuracy. The calibration process of the OVNA requires firstly an electrical calibration performed on the VNA in order to remove unwanted effects such as cables and other components in the measurement of the RF path. A calibration kit should be used to ensure the specifications of the OVNA.

The optical module contains the corresponding factory calibration to facilitate the use of the equipment in EO, OE and OO measurements, fully satisfying the technical specifications. Note that E/O/E measurements imply a double calibration since a general E/O/E DUT depends on the RF frequency and the optical wavelength. Besides, users can perform an optical path deembedding in case of connecting additional optical elements (adapters, patchcords, etc) to DUT. Furthermore, since the measurement accuracy depends on the temperature stability of the environment in which measurements are performed, a user calibration is automatically introduced in the system to improve the signal/noise ratio of the measurement if required.

3.1 O/E/O measures

Interfacing the optical and electronic domains allows four types of measurements that can be distinguished in terms of the DUT subject to measurement. A traditional VNA carries out electronic-electronic (EE) measurements. However, by means of combining the advanced photonic module with a VNA, this range is extended to allow EO, OE and OO measurements as well. Fig. 4 shows the typical configuration (Fig. 4a) and measurement (Fig. 4b) windows of the system user application.



(a) (b)

■ **Figure 4.** (a) Configuration window and (b) measurement window of the user application.

The solution includes a developed application that permits a configuration for each component in the desired way, depending on the type of component analysis or system to be analyzed. The ergonomic concept has been used for software development, as well as the requirement of functionality. The purpose has been to design an application that suits the different tasks and skills of each user. Ergonomic concepts related to software focus their study on the physical and mental aspects of the interfaces between the user and programs. They try to design dialogue procedures and formats that are effective and easy to use. They also seek that applications are easy to understand and learn, and that they enhance the knowledge of those who use them.

The OVNA P100-X solution can be used, for instance, for magnitude and phase response of electro-optic (Fig. 3a), acousto-optic and electro-absorption modulators, laser modulation transfer functions, RoF links and systems, etc. Fig. 5(a) shows an example of an electro-optical (EO) measurement corresponding to a magnitude frequency response of an electro-optical intensity modulator. Furthermore, optoelectronic (OE) measurements can be obtained. This option is useful, for instance, in the characterization of the responsivity of photodetectors such as PIN Diodes or APD's, etc. Fig. 5(b) shows a magnitude frequency response of a photodetector which corresponds to an example of an OE measurement as illustrated in Fig. 3(b). Finally, the OVNA P100-X allows optical-optical (OO) measurements according to Fig. 3(c) for the S-Parameter characterization of photonic components, such as optical attenuators, delay lines, dispersive fiber links, couplers, WDM multiplexers and demultiplexers and optical amplifiers as EDFAs and SOAs among other optical devices. In Fig. 5(c), the reader can observe an example of an optical-optical measurement corresponding to the magnitude response of a 20 km fiber link.

The optical module contains the corresponding factory calibration to facilitate the use of the equipment in EO, OE and OO measurements, fully satisfying the technical specifications.

3.3 OVNA-P100-X highlighted features

In Fig. 6, the most important features of the OVNA-P100X are located. The OVNA-P100-X must be integrated with a VNA to provide the OVNA solution. The software in the photonic module will control the whole system and therefore this integration must be carried out by EPhoox, being possible to integrate more than just one VNA. The VNA model(s) that will be used must be detailed to EPhoox in order to consider the optimum type of integration that should be made. EPhoox includes a one-year warranty in all of its products. Besides, it is possible to extend this warranty up to 3 or 5 years.

In order to guarantee the safety of internal devices and subsystems of the instrument, a protection system is implemented in the instrument. Warnings and messages are shown in the visual user interface that will help the user to proceed correctly in the configuration process of a measurement in case of a wrong procedure.

The OVNA-P100X allows complex S-parameters to be transformed into the time domain, making it possible to display discontinuities versus the time delay or the electrical/mechanical length of the device under test.

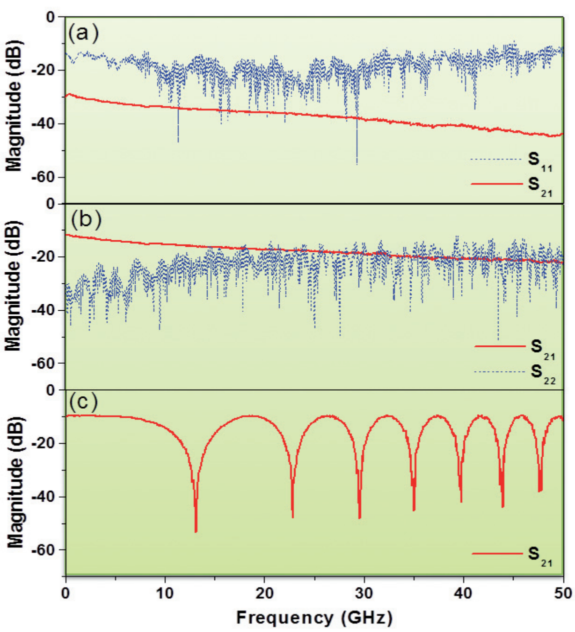


Figure 5. Magnitude frequency response of (a) an electro-optical intensity modulator, (b) a photodetector with a bandwidth @-3 dB = 50GHz and (c) 20 km long analog dispersive fiber link, where carrier suppression effect and fiber transparency properties are shown.

- Operation frequency up to 67 GHz
- Available for 1550 and 1310 nm
- Internal optical source and external optical input
- High OMI efficiency
- Two receivers for low and high power optical inputs
- Protection system for electronic and optical internal components
- Uncertainty reduction in measurements of linear DUTs
- Amplitude and delay characterization as a function of wavelength (using a tunable optical source)
- Proper addressing of measurements for non-linear DUTs

Figure 6. Most important features for OVNA-P100X.

On the other hand, measurement uncertainty is a parameter that shows the quality of a measurement instrument. In case of linear DUT characterizations, if the "Reduction uncertainty function" of the external optical system is enabled, a decrease of the measurement uncertainty is achieved. Using an external tunable laser, amplitude and delay measurements and characterizations of DUTs as a function of the optical wavelength can be performed. The equipment is provided with sweep function synchronized with a wavelength tunable laser source. These types of measurements are enabled by the user through interface.

4. Conclusions

In this manuscript, EPhoox has been presented as the latest spin-off of the Universitat Politècnica de València. EPhoox has the objective of offering products and services that improve or make up for the shortages in the offer available in the market as a guarantee of an added value for the customer by means of MWP technology. The principle of excellence is followed in the realization of all of its activities as part of its procedure towards customer satisfaction.

The first optical solution developed by EPhoox has been introduced, which consists of an advanced solution for characterization and monitorization of photonic devices and hybrid RoF systems. The added value of the proposed solution involves several concepts as adaptability, advanced functionalities, technical improvements and philosophy. In this context, EPhoox provides the best solution of its kind in the market in terms of both competitive specifications and excellent cost effectiveness for the final user.

For additional information, comments or questions, please contact at the email address info@ephoox.com. Besides, you can visit www.ephoox.com.

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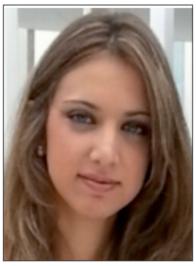
Biographies

José Mora was born in Torrent, Valencia, Spain, in 1976. He received the M.Sc. degree in Physical Sciences from the Universitat de València (Spain) in 1999. From 1999 to 2004, he worked in the Department of Applied Physics from the Universitat de València. He obtained a PhD. Degree in Physics from the Universitat de València in 2005 and he received the Extraordinary Doctorate Prize of the Universitat de València in 2006. In 2004, he joined as a researcher at the Optical and Quantum Communications Group in the Institute of Telecomunications and Multimedia Applications (ITEAM) from the Universitat Politècnica de València. He has been involved in the EU funded projects IST-LABELS, IST-GLAMOROUS, IST-OFFSOHO, IST-NEFERTITI and ICT-ALPHA. With an H-factor of 20, he has published more than 150 papers and conference contributions covering a wide range of fields related to fibre bragg gratings for sensing applications, optical signal processing, microwave photonics, reconfigurable and convergent optical for wired/wireless services and quantum cryptography using photonic technology. In 2016, he co-founded the UPV spin-off company EPhoox Technology S.L. from his expertise and research in Microwave Photonics.



Susana Fayos graduated in Civil Engineering at the Universitat Politècnica de València (UPV) in 2010 and holds a Master in Business and Administration from the same university. In 2014 she joined the Optical and Quantum Communications Group in the Institute of Telecommunications and Multimedia Applications (ITEAM) from the UPV, where she has been involved in several projects related to next generation Microwave Photonics technologies and optical networking. Her current interests are focused on optical instrumentation, measurement and metrology. She is currently responsible for Marketing and Business Development at EPhoox.

Mario Bolea was born in Albalat dels Sorells, Valencia, Spain, in 1981. He received the M. Sc. degree in Telecommunications by the Universitat Politécnica de València in 2008. In 2009 he obtained the Master in Networks, Systems and Technologies of Communications by the Polytechnic University of Valencia. From 2009 to 2012, he worked in the Institute of Telecommunications and Multimedia Applications (ITEAM) in the Optical and Quantum Communications Group. He holds a PhD. Degree in Telecommunications from the Universitat Politécnica de València in 2012 and he received the Extraordinary Doctorate Prize of the Universitat Politécnica de València in 2013. In 2012, he joined the Communications Research Group in Bangor University (Wales). Nowadays, he is working as the Project Manager at EPhoox Technology S.L. He has been involved in the EU funded projects ICT-ALPHA and OCEAN. With an H-factor of 6 (19/04/2016), he has published more than 60 papers and conference contributions in different fields such as: microwave photonic filtering, optical arbitrary waveform generation, optical signal processing and optical orthogonal frequency division multiplexing (OOFDM).

Juan Antonio Diaz is the Lead Software Engineer at Ephoox. He received the Telecommunications Engineering degree from the Universitat Politècnica de València in July 2005. Later he received the Mobile Communication Specialist degree from the Universitat Politècnica de València in 2007, as well as other training related to his activity. He has been involved in several IT projects, mainly in development of analysis and optimization tools for major companies like Motorola, Teltronic or Vossloh, mobile applications, web, NFC/RFID technologies or software as a service system. He is currently responsible of the software development area at Ephoox, focused on developing control and measurement tools for OVNA product.

Manuel Rius was born in Valencia, Spain, in 1981. He obtained the B.Sc. in Elctronics systems from Universidad de Valencia (UV) in 2003 and M.Sc. in Telecom Engineering from Universidad Politécnica de Valencia (UPV) in 2009. He joined as technical staff at Optical and Quantum Communications Group in 2009. His current interests include signal generation and distribution in Microwave Photonics technology.

Beatriz Ortega was born in Valencia, Spain, in 1972. She received the M.Sc. degree in Physics in 1995 from the Universidad de Valencia, and the Ph.D. in Telecommunications Engineering in 1999 from the Universidad Politécnica de Valencia (UPVLC). She joined the Departamento de Comunicaciones at the Universidad Politécnica de Valencia in 1996, where she was engaged to the Optical Communications Group and her research was mainly done in the field of fibre gratings. From 1997 to 1998, she joined the Optoelectronics Research Centre, at the University of Southampton (United Kingdom), where she was involved in several projects developing new add-drop filters or twin-core fibre-based filters. In 1999 she got an Associate Lectureship at the Telecommunications Engineering Faculty in the Universidad Politécnica de Valencia and she is a Full Professor since 2009. She has published more than 200 papers and conference contributions in fibre Bragg gratings, microwave photonics and optical networks and according to SCOPUS database, her H factor is 23. She has got three patents, and she is also a co-founder of EPHOOX company, which is recently funded as an UPVLC spinoff. She has participated in the European Networks of Excellence IST-NEFERTITI, IST-EPIXNET, and IST-EPHOTON/ONE and she has also been involved in several EU funded projects such as IST-LABELS, IST-GLAMOROUS, IST-OFFSOHO and IST-ALPHA project, apart from a large number of national and regional projects. Her main research is currently focused on optical devices, optical networks and microwave photonic systems and applications.

José Capmany was born in Madrid, Spain, on December 15 1962. He received the Ingeniero de Telecomunicacion degree from the Universidad Politécnica de Madrid (UPM) in 1987 and the Licenciado en Ciencias Físicas in 2009 from UNED. He holds a PhD in Electrical Engineering from UPM and a PhD in Quantum Physics from the Universidad de Vigo. Since 1991 he is with the Departamento de Comunicaciones, Universidad Politecnica de Valencia (UPV), where he started the activities on optical communications and photonics, founding the Optical Communications Group. He has been an Associate Professor from 1992 to 1996, and Full Professor in optical communications, systems, and networks since 1996. In parallel, he has been Telecommunications Engineering Faculty Vice-Dean from 1991 to 1996, and Deputy Head of the Communications Department since 1996. Since 2002, he is the Director of the ITEAM Research Institute, Universidad Politécnica de Valencia. His research activities and interests cover a wide range of subjects related to optical communications including optical signal processing, ring resonators, fiber gratings, RF filters, SCM, WDM, and CDMA transmission, wavelength conversion, optical bistability and more recently quantum cryptography and quantum information processing using photonics. He has published over 470 papers in international refereed journals and conferences and has been a member of the Technical Program Committees of the European Conference on Optical Communications (ECOC), the Optical Fiber Conference (OFC). Professor Capmany has also carried out activities related to professional bodies and is the Founder and current Chairman of the PS Spanish Chapter, member of IEEE PS BoG (2010-2012), and a Fellow of the Optical Society of America (OSA). Professor Capmany is the recipient of King James I Prize on Novel Technologies, the highest scientific distinction in Spain, in recognition to his outstanding contributions to the field of microwave photonics, the Extraordinary Engineering Doctorate Prize of the Universidad Politécnica de Madrid and the Extraordinary Physics Laurea Prize from UNED. He is an associate Editor of IEEE Photonics Technology Letters.