Photonics-based dual-use Transceiver based on a single dual-band Antenna Array

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***Abstract*— The first dual use radio system for communication and radar operations based on photonics and exploiting a single dual-band slotted waveguide antenna array is presented. The sharing-structure allows reducing size, weight, cost and powering consumption. The results obtained in an indoor environment confirm the effectiveness of the dual use and demonstrate that no penalty is introduced due to the simultaneous operation of the communication and radar functionalities.**

Keywords— dual-band antenna; dual-use system; microwave photonics; photonics-based radio transceiver.

I. INTRODUÇÃO

The increasingly demand in world data traffic [1] is pushing towards new solutions in systems design, capacity and protocols, capable of working in a multitask environment to reduce size, weight a power consumption of already existing communications systems. Among these solutions, improved standards and protocols, and the reduction of cell dimensions in order to increase the frequency reuse can be addressed. Concepts of pico- and femtocells with the capability of dealing with a large number of communication protocols are likely to be the next future generation in wireless communications. In this scenario, base stations will be equipped with several different protocol-specific hardware components leading to an increase of size, weight and power consumption (SWaP).

On the other side, the urge for radar systems with several different functionalities has been topic of great interest since the Second World War in order to provide a complete cognition of complex scenarios. All the functionalities, e.g., detection, tracking, imaging and so on, are performed by distinct hardware elements due to lack of a multi-band transceiver approach. In this direction, the gathering of several different functions in a single hardware could greatly increase performance. In both situations, i.e., in the communication and in the radar point of view, a concept of software-defined radio (SDR) [2,3] can be the solution for an enhancement of system performance and cost reduction.

Photonic technologies have been recently introduced for the development of RF systems ranging from few MHz to several tens of GHz [4], thus overcoming limitations of electronic systems which alone could not provide the desired frequency flexibility for nowadays desired operations. Moreover, the capability of operating in more than one band is a fundamental feature towards versatility of next generation systems. With this aim, our group has been focusing in the introduction of photonics for microwave signals generation and detection for wireless communications [5] and radar purposes [6]. Recently, a fully photonics based coherent radar system has been developed and a dual-band usage was demonstrated for the first time [7,8].

Envisioning a further enhancement of the system SWaP in a dual-use scenario, the antenna element is also an important topic to be considered [9]. It would be desirable to have the radiating element operating in more than one frequency band in order to obtain a complete multi-functional system. For instance, slotted waveguide antenna arrays (SWAAs) are suitable for radar purposes due to its characteristics of weight, volume and radiation [10].

To take fully advantage of these characteristics, in this paper we propose a brand-new concept: the use of photonics for enabling a dual-use radio system. It consists in a wireless communication system with radar capabilities that exploits a single photonic-based dual band transceiver and a single dual-band slotted-waveguide antenna array. The system works simultaneously and independently in the C- and S-band for communication and coherent radar purposes respectively with a fully software defined approach. The next sections, II and III present respectively the description of the system and architecture, and the experimental results confirming that radar operation does not affect the communication functionality.

II. PRINCIPLE OF OPERATION

The idea is to exploit photonics for implementing a multiband (dual band in this case) transceiver able to independently and simultaneously handle bidirectional communication and radar signals that can be transmitted and received by a single dual band antenna. The key element of the photonics-based transceiver is a mode locked laser (MLL) capable of generating extremely precise optical modes phase locked to each other that are used for ultra-stable photonics-based up- and down- conversion of the radio signals [8], this way the coherence of the radar system is guaranteed. With reference to Fig. 1A, the dual use photonic-based transceiver directly generates a communication signal in C-band and a radar signal in S- band which are going to be transmitted through the SWAA.

The generation of the RF signals through the photonic transceiver can be explained, in details, as follows (Fig. 1B): The MLL generates the optical modes with repetition rate F_{MLL} (Fig. 1B-1). A direct digital synthesizer (DDS) generates the two signals (radar and communication signals) at their

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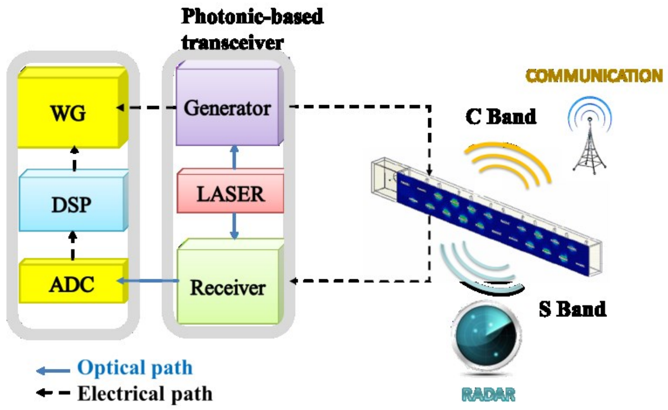
intermediate frequency (IF_1 and IF_2) (Fig. 1B-2), which are used to modulate the precise optical modes of the MLL. In this way, the IF signals are transferred in the optical domain as sidebands of each laser optical mode (Fig. 1B-3). At this point, at the photodetector the heterodyning of the modulated optical modes produces several RF replicas at the carrier frequency $CF = kF_{MLL} \pm IF_{1,2}$ (Fig. 1B-4), thus performing optoelectronic conversion. This process is known as the up-conversion of the signal. At the photodetector output, an RF band-pass filter will select the desired RF replicas to be transmitted (Fig. 1B-5) through the dual-band antenna.

At the receiver side, the same antenna is used to collect and combine both communication and radar echo signals which properly filtered and amplified feed the photonics-based receiver that performs the ultra-stable downconversion of the RF signals. Following the same process of the signal generation, the optical laser modes are modulated by the collected RF signal. Then, as a result of the photodetection process, several IF components are generated $IF = RF_{1,2} \pm kF_{MLL}$. At this point, a low-pass filter will select the down-converted replica of interest (Fig. 1B-6). Finally, a high resolution low-bandwidth analog-to-digital converter (ADC) is used to digitize the photodetected signals, at their respective intermediate frequencies, which then are going to be processed [8].



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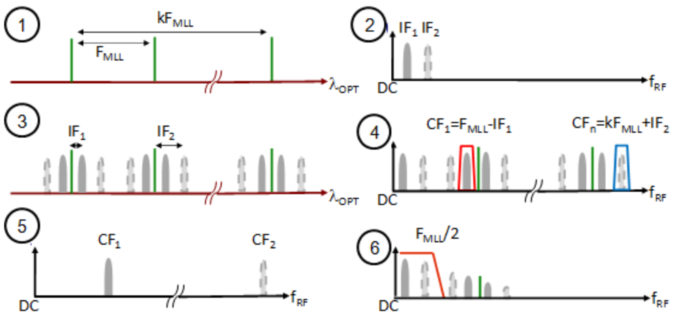

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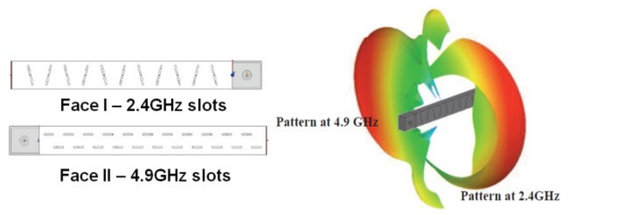
Fig. 1 - A) Scheme of the principle of operation (W.G. – Waveform Generator, DSP – Digital Signal Processing, ADC – Analog-to-Digital converter), B) (1) optical spectrum of the mode-locked laser; (2) electrical spectrum of the intermediate signals; (3) optical spectrum of the modulated signal after the modulator; (4) electrical spectrum at the photodiode's output, with the desired carrier frequencies highlighted; (5) electrical spectrum of the filtered RF (6) electrical spectrum of the received signals after the photodiode, with the desired signals highlighted (after the low-pass filter).

The used slotted waveguide antenna array, fabricated at Inatel (*Instituto Nacional de Telecomunicações*), enables operations over two different (S and C) frequency bands; more details can be found in [11]. To this purpose, the design of the antenna is based on two different slots groups, one for each operation frequency band and milled on each broad side face of the waveguide (opposite sides), as shown in Fig. 2A (Left). The face I enables operation in the S band, while the face II allows operation over the C band. The gain was measured in both bands and it resulted in 11.12 and 18.92 dBi (obtained gain with respect to the isotropic antenna) for the 2.475 and 4.9 GHz bands respectively. As shown by the radiation pattern (Fig. 2A (Right)), the structure radiates, simultaneously, orthogonal polarized signals over two different frequency bands maintaining high gain and high front-back ratio, allowing different systems to be managed simultaneously and independently.



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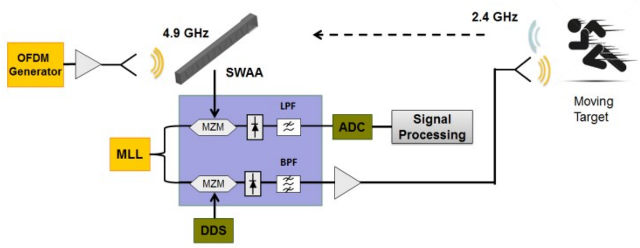


B

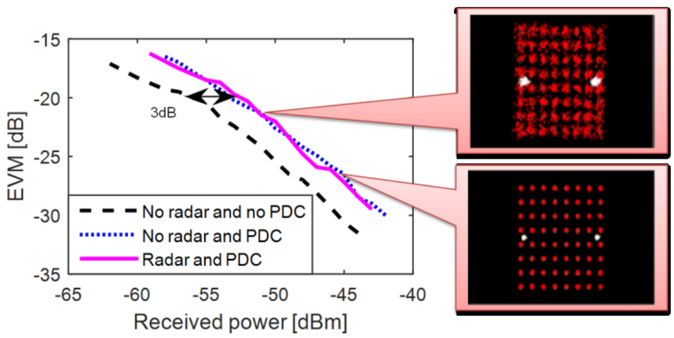
Fig. 2 – A) (Left) Slotted waveguide antenna array (SWAA) used in the experiments during a preliminary field trial (Right) Pattern radiation for the bands of interest: 2.475 and 4.9 GHz. B) Scheme of the experimental setup. OFDM – Orthogonal frequency division multiplex, MLL – mode locked laser, MZM – Mach- Zehnder modulator, DDS – Direct digital synthesizer, SWAA – Slotted waveguide antenna array, LPF – Low-pass filter, BPF – Band-pass filter, ADC – analog-to-digital converter

III. Experimental Results

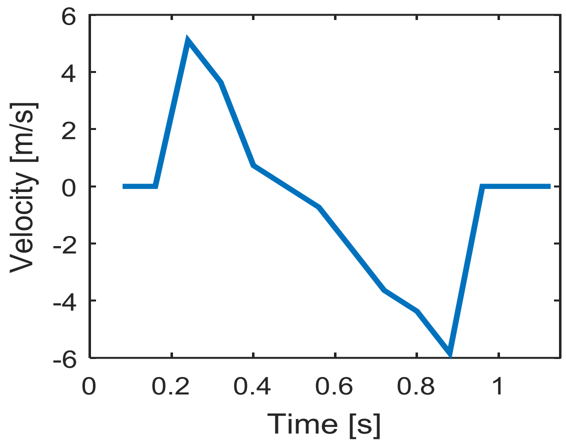
The tests of the photonic dual band system were performed in an indoor environment. Due to the unavailability of a dual band circulator, we tested the communication operation of the dual use transceiver just in the case of receiving external data. In this configuration, the SWAA antenna was used only to receive both communication and radar signals. We expect the same performance in case of transmitting communication data due to the similar features of transmitter and receiver, which was tested by the authors in [5]. The transmission of the radar signal from the photonic-based transceiver and the communication signal from the remote OFDM generator were performed through two commercial horn antennas with about 7 dBi of gain each. Fig. 2B presents the experimental setup. The communication experiment was performed by employing an OFDM generator which directly produces a 64-QAM signal, 54Mbit/s (IEEE 802.11g) at 4.9 GHz. At the same time, aiming to verify the proper operation of the dual use system, a continuous wave (CW) signal was generated for radar functionality through the photonics-based transceiver.

At the receiver, a single SWAA antenna is used to collect the signals and deliver them to the dual-band receiver. The received waveform containing the two signals is optically downconverted at the intermediate frequencies 75 MHz and 100 MHz (for 2.475 and 4.9 GHz respectively) due to the fact that replicas of the signals are going to be created every 400 MHz which is the frequency of the MLL. A low-pass filter is then used to filter out the photodetected signals which can finally be digitized by a 400Msample/s 12-bit ADC. After this point, the signals are going to be post-processed by proper algorithms.

The obtained results or the communication data link are presented in Fig. 3. In Fig. 3-A we can observe a graph of the error vector magnitude (EVM) versus received power for three cases. First we compared the communication system without radar capability with (blue dotted curve) and without (black dashed curve) the photonic downconversion (PDC) to evaluate the penalty introduced by photonics. Then we added the radar functionality (red curve) to verify the penalty due to the dual use. From the graph it can be noticed a penalty of about 3 dB at -20 dB of EVM due to the presence of PDC, raised mainly due to electro-optical conversion losses. Moreover, we can observe no penalty due to the presence of radar signal thus, indicating a negligible cross-talk between radar and communication system, which allows us to verify the proper behavior of the dual use approach.



A)



B)

Fig. 3 - Communication and radar performance: A) Graphic of error vector magnitude (EVM) versus received power for the OFDM transmission (PDC – photonic downconversion), B) Graphic of velocity versus time generated through the Doppler measurements of the radar signal at 2.475 GHz.

The radar functionality has been tested by Doppler measurement of a cooperative moving target. The detected signal processed by properly designed algorithms, presents the velocity profile as shown in Fig. 3-B. In accordance with the actual trajectory, the graph shows the Doppler profile of the target that first moves toward the SWAA and after reaching a speed of almost 6 m/s slows down and starts moving away from the antenna. The results are correctly measured by the system, within the velocity resolution of 0.76 m/s given by 80 ms integration time, thus demonstrating proper operation of the radar functionality in a dual use context.

IV. Conclusions

We have demonstrated the first photonics-based dual use radio system, including a 54 Mb/s wireless communication transmission with the detection of 64-QAM signals and a Doppler coherent radar detection exploiting a single dual band photonic-based transceiver and a single slotted waveguide antenna array. The demonstrator is able to independently and simultaneously manage the two different kinds of waveforms in two different frequency bands. It was demonstrated that both signals can coexist and work at the same time without penalties or measurements deviations. This paper proves that photonics can be used in software-defined radio systems working for multitask operations. Moreover, the sharing of the photonic hardware and the use of a single antenna element for the two different functionalities allow achieving a great cost-effective, power, weight and reduced-footprint solution.

Acknowledgments

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References

[1] White Paper, “Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012-2017,” February, 2013.

[2] A. Kaul, “Software defined radio: the transition from defense to commercial markets,” in SDR Technical Conference, 2007.

[3] P. Van Dorp, R. Ebeling, and A. G. Huizing, “High resolution radar imaging using coherent multiband processing techniques,” in IEEE Radar Conference, Washington DC, 2010, pp. 981-986.

[4] J. Yao, “Microwave photonics,” J. Lightw. Technol. **27**, 314-335 (2009).

[5] F. Laghezza, F. Scotti, P. Ghelfi, and A. Bogoni, “Photonics-Assisted Multiband RF Transceiver for Wireless Communications,” J. Lightw. Technol. **32**, 2896-2904 (2014).

[6] F. Scotti, et al., “In-field experiments of the first photonics-based software-defined coherent radar,” J. Lightw. Technol., vol.32, no.20, pp. 3365–3372, Oct. 2014.

[7] P. Ghelfi, et al., “A fully photonics-based coherent radar system,” Nature **507**, 341-345 (2014).

[8] F. Scotti, F. Laghezza, P. Ghelfi, and A. Bogoni, “Multi-Band Software-Defined Coherent Radar Based on a Single Photonic Transceiver,” in Microwave Theory and Techniques, IEEE Transactions on, **63**(2), 546-552 (2015).

[9] Y. P. Chien, T. S. Horng, W. S. Chen, and H. H. Chien, “Dual wideband printed monopole antenna for WLAN/WiMAX applications,” IEEE Antennas Wireless Propag. Lett., vol. 6, pp. 149–151, 2007.

[10] I. F. da Costa, D. H. Spadoti, and Arismar Cerqueira S. Jr., “Dual-band Slotted Waveguide Antenna Array for Communication, Maritime Navigation and Surveillance Radar,” in IEEE International Workshop on Telecommunications (IWT), 2015.

[11] I. F. da Costa, et al., “A Dual-band Slotted Waveguide Antenna Array for Radars Applications,” in Microwave and Optoelectronics Conference (IMOC), Porto de Galinhas, Brazil, 2015.