Dual-use System Combining Simultaneous Active Radar & Communication, Based on a Single Photonics-Assisted Transceiver

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Abstract—**This paper report on the development and field trial of a dual-band and dual-use system based on a single photonics-based transceiver and a single radiating element, able to simultaneously carry out radar and communication functionalities. The coexistence of the two operations does not introduce any penalty on the system performance. The innovative sharing of both transceiver and antenna element allows for a reduction in terms of cost and Size Weight and Power consumption. The dual-use radar-communication system has been demonstrated in a outdoor field trial combining a radar experiment in S-band and C-band OFDM (Orthogonal Frequency Division Multiplexing) communication.**

Keywords—Microwave photonics, radar, dual-band, OFDM.

I. INTRODUCTION

The next generation of radar systems needs to fulfill new requirements as reconfigurability for addressing the cognitive radar concept, multifunctionality for providing a more complete surveillance system and the capability to provide high capacity networked sensors. This last feature means radars able to communicate among them for optimizing the sensor configuration and increase the situation awareness in security contexts, or able to merge in the same hardware independent sensing and communication operations. This can contribute to enhance the quality, the performance, the security and the interactivity of urban services, and at the same time to reduce costs and resource consumption, as required in the emerging concept of smart cities. Few transceivers for dual operations have been reported in the past years making use of two independent hardwares [1] and the most of the efforts have been spent for optimizing the spectral resource sharing [2]. Envisioning a multifunctional approach with a reduction of the system size, weight and power consumption (SWaP) it is desirable to have a unique transceiver hardware shared between the two operations.

Nowadays, the possibility of implementing a multifunctional unique transceiver is limited mainly due to the inability of current systems to generate more than one carrier radio frequencies (RFs) and the bandwidth constraints of actual electronic devices as direct digital synthesizers and analog-to-digital converters that present suitable performance up to a few GHz. Moreover, electrical highly stable local oscillators currently used for up- and down-conversion of the RF signals are not tunable. This is the reason why only few multi-band radio and radar transceivers have been reported [2][4] but their functionalities are limited and fixed, being suitable for only few specific applications.

With the purpose of enhance the frequency flexibility of radar and radio systems and obtain high stability up to several tens of GHz [5], photonic technologies have been proposed over the last years. The huge time-bandwidth product and great flexibility offered by photonics can be applied for different applications, as: generation [6] and detection [7] of microwave signals, for radar [8] and wireless communication [9] systems. The authors have recently developed a fully photonic-based RF transceiver demonstrated, singularly, both for radar [10] and communication [11] operations. They also demonstrate the capability of the photonics-based transceiver to simultaneously work on different bands and they reported a dual-band coherent radar system [11].

The antenna is another key issue, attracting a lot of research efforts [12],[13],[14], toward the complete sharing of the hardware in a dual-operation RF system. Among the possible solution, slotted waveguide antenna arrays are widely applied to radar systems due to its suitability in terms of weight, volume and radiation characteristics [13],[14].

In this paper, we propose for the first time to the best of our knowledge, a dual-use radar-communication system based on a single dual-band photonics-based transceiver and antenna. The system is completely software defined and allows to independently carry out surveillance and communication without penalty introduced by the two operation coexistence. While sharing of both transceiver and antenna element allows for a reduction in terms of system cost and SWaP.

An outdoor field trial in a smart city scenario allowed to confirm the effectiveness of the system.

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This paper is divided as follows: section II presents the description of the system and architecture, section III reports the experimental setup, experimental results and discussion and finally section IV presents the conclusions of our work.

II. Principle of Operation

The principle of operation of the dual-use system is depicted in Fig. 1.

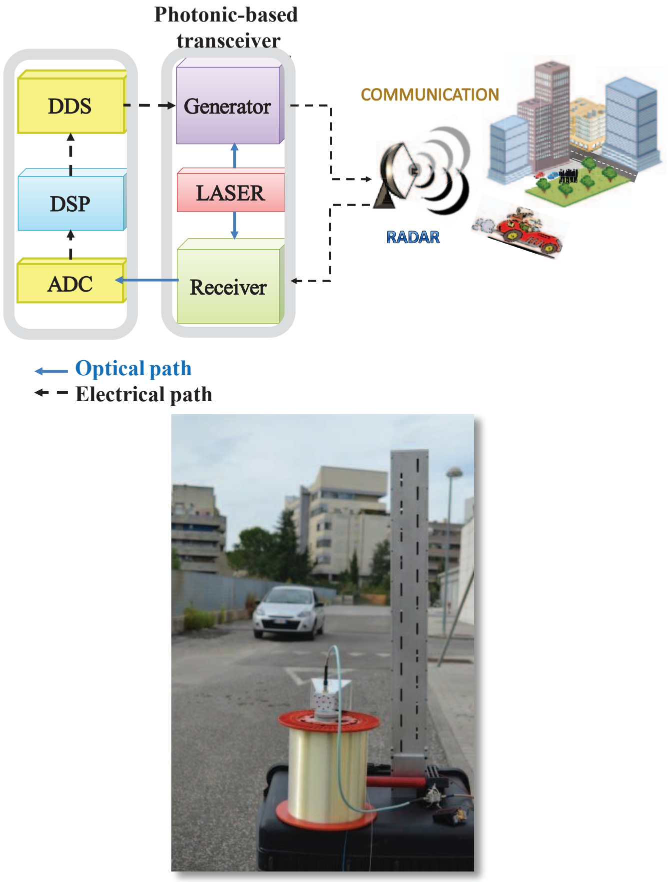


Fig. 1 top) reference scenario and photonic-based transceiver basic concept, DDS – direct digital synthesizer, DPS – digital signal processor, ADC – analog-to-digital converter, bottom) photo of the in-field experint with visible the dual-band slotted waveguide antenna array.

The idea is to take advantage of the capability of the photonic-based coherent transceiver [9] to simultaneously generate and receive independent multifrequency signals that can be exploited for a bidirectional radar/communication operation. The central element of the photonic-based transceiver is a laser source, acting as a highly stable local oscillator, which generates several optical modes precisely phase locked to each other to be exploited both in the photonic generator and receiver blocks, respectively, for the signal up- and down-conversion.

Going into details (Fig. 2), a mode locked laser (MLL) with repetition rate F_{MLL} generates several optical modes precisely phase locked to each other (Fig. 2A). At the transmitter, the radar and communication signals, generated at their intermediate frequency IF_1 and IF_2 (Fig. 2B) by a direct digital synthesizer (DDS), are used to modulate the optical modes of the MLL thus transferring the IF signals in the optical domain as sidebands of each laser optical mode (Fig. 2C). At this point the heterodyning of the modulated optical modes, occurring during the opto-electronic conversion in the photodiode produces several RF replicas at carrier frequency $CF=kF_{MLL}\pm IF_{1,2}$ (Fig. 2D), thus performing signal up-conversion. At the photodiode output, an RF band-pass filter will then select the proper RF replicas to be transmitted (Fig. 2E) through a dual-band antenna.

The same antenna is also responsible for collecting both radar echoes and communication signals which once properly filtered and amplified are sent to the photonics-based receiver.

Here, based on the same process of the signal generation, the optical laser modes are modulated by the collected RF signal. As a result of the photodetection process, several *IF* components $IF=RF_{1,2}\pm kF_{MLL}$ are generated, and a low pass filter will then select the down-converted replica (inset F). Now the signals, at their respective intermediate frequencies, are digitized by a high-resolution low-bandwidth analog-to-digital converter (ADC), which finally are going to be processed in the block of digital signal processing (DSP).

The use of the same highly stable MLL for both generation and reception of the RF signals guarantees the coherence of the system.

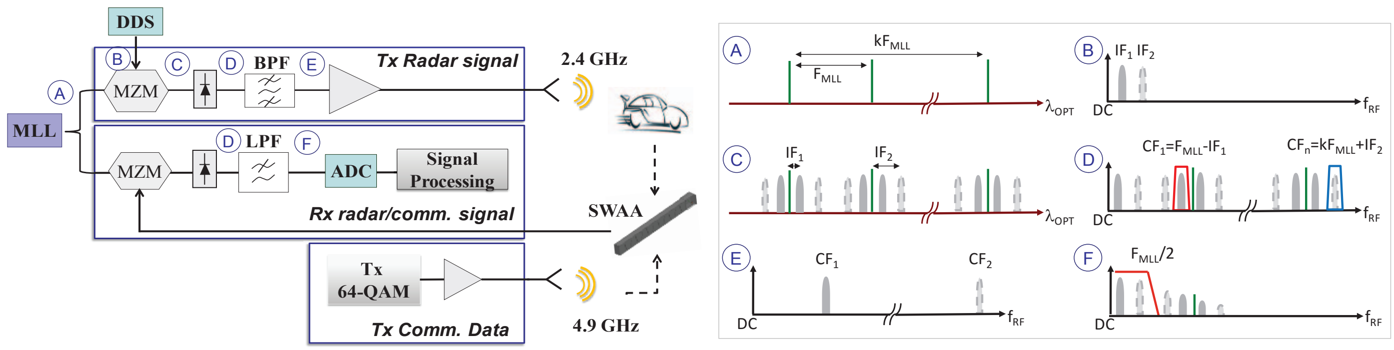


Fig. 2 left) Experimental setup (MLL – mode-locked laser, DDS – direct digital synthesizer, MZM – Mach-Zehnder modulator, BPF – band-pass filter, LPF – low pass filter, ADC – analog-to-digital converter, OFDM – orthogonal frequency division multiplexing, SWAA – slotted waveguide antenna array), (A) optical spectrum of the MLL; (B) electrical spectrum of the applied signals; (C) optical spectrum of the modulated signal after the MZM; (D) electrical spectrum at the photodiode's output, with the following RF filters highlighted; (E) electrical spectrum of the filtered RF signals before the wideband antenna; (F) electrical spectrum of the received signals after the receiver PD with the LPF highlighted.

III. EXPERIMENTAL SETUP AND RESULTS

Due to laboratory impairments, in our experiment both the transmission and reception of the radar signal was performed by the RF photonic-based transceiver, while the communication signal was generated by an independent signal generator and only received by the photonic system. In this configuration the dual-band antenna was used only for reception. Because of the similar features of transmitter and receiver, as already tested by the authors in [9], the performance of the transmission of communication data is expected to be the comparable with the receiver one.

The system exploited a MLL source with repetition rate F_{MLL} = 400 MHz to generate the phase locked optical modes. The radar waveform, generated by the DDS, is made by a pulse train of 1 us long chirped pulses with 20 MHz bandwidth and pulse repetition frequency (PRF) of 10 kHz, at intermediate frequency f_{IF} = 75 MHz. Such signal modulates via a Mach Zehnder modulator (MZM) the whole spectrum generated by the MLL. At this point, the radar signal transferred as lower- and upper-sidebands around each mode of the MLL is photodetected and properly filtered at RF frequency equal to 2.475 GHz (S-band, $CF=6F_{MLL}+f_{IF}$), in order to be boosted up and transmitted by a commercial horn antenna of about 7 dBi of gain.

The communication signal is generated from a remote orthogonal frequency division multiplexing (OFDM) generator which directly produces a 64-QAM (quadrature amplitude modulation) signal with a bitrate of 54Mbit/s at 4.9 GHz (C-Band, $CF=12F_{MLL}+100MHz$). The signal modulation format follows the IEEE 802.11g standard. As in the radar signal case, the communication signal is transmitted by a second commercial horn antenna with the same gain.

Both radar echoes and communication signals are collected by means of a dual-band antenna (shown in Fig. 2 left), a slotted waveguide antenna array (SWAA) designed and fabricated by the authors [12], with a gains of 11.12 and 18.92 dBi for S- and C- band, respectively. The received waveform, containing the radar and communication signals, modulates the MLL optical pulses by means of MZM, thus performing the optical sampling directly at the carrier frequencies, i.e. 2.475 GHz for the radar signal and 4.9 GHz for the communication one. This way signals are optically downconverted in the intermediate frequencies of 75 MHz and 100 MHz for S- and C-band respectively. As we can see in Fig. 3, where the power spectrum of the down-converted received signal, measured at the receiver output, is reported. It is clearly possible to notice the two 20MHz bandwidth signals with central frequency of 75 and 100MHz which are, respectively, the radar and communication signals.

Finally, a 400MSp/s 12-bit ADC digitizes the photodetected waveforms, which are then going to be post-processed with proper algorithms.

In order to demostrate the actual operation of the dual-use photonic-based coherent system, radar and communications experiments were conducted simultaneously in an outdoor environment (Fig. 1 bottom) where a car has been used as cohoperative target.

The combined signal received by the dual-band transceiver is then processed, by standard algorithms, to obtain the complete range-Doppler map of the target and to evaluate the performance of the communication link.

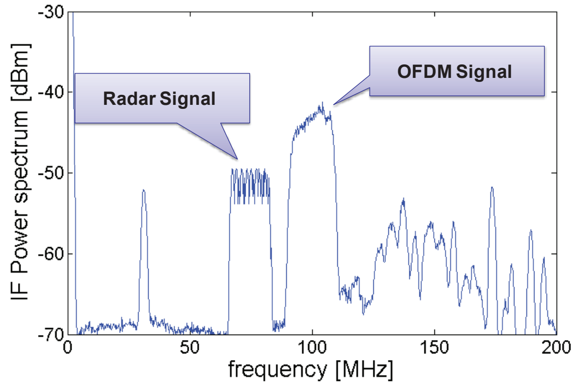
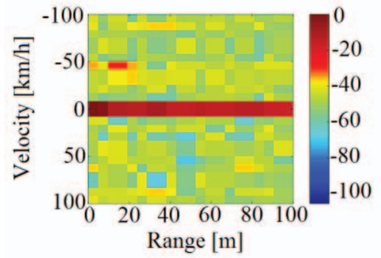


Fig. 3 Power spectrum of the down-converted received signal

From the range-Doppler map of the radar trace in Fig. 4a we can note a very strong component at zero Doppler which corresponds to the earth clutter, i.e., all fixed targets that the radar captures during its acquisition. Despite the clutter, we can clearly observe a signal echo in the third range bin, corresponding to 13.8 meters distance given from the target moving away with approximately 50km/h.



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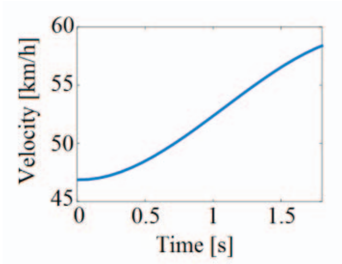

B

Fig. 4 a) Range Doppler map of a radar trace b) Velocity profile fitting of the target for 1.8 seconds of observation

In Fig. 4b is reported the curve fitting of the target velocity profile for 1.8 seconds of observation, computed with an integration time of 20ms. The analysis in accordance with the real measurements target velocity profile, show the target entering the radar field of view with a velocity above 45 km/h moving away from the system.

Simultaneously, the communication data link has been tested by measuring, as quality factor, the error vector magnitude (EVM) versus the received OFDM signal power, shown in Fig. 5. In order to verify the effects of the photonic down-conversion and of the radar signal on the communication link performance, we tested three cases. In the first one (red dotted curve) the communication signal is detected without the use of photonic down-conversion (PDC), the signal is then received, directly at carrier frequency, by a signal analyzer which carries out the measure of EVM. In the second case (black continuous curve), the received communication signal is passing through the photonics-based receiver therefore to be down-converted, but there is still no radar signal.

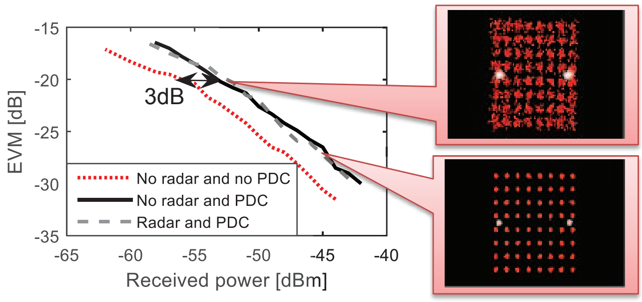

Fig. 5 Graph of the error vector magnitude (EVM) versus received power for the OFDM transmission (PDC – photonic downconversion). The insets show the constellation for different values of EVM for the gray dashed curve.

Finally, in the third case (gray dashed curve) the 64-QAM signal is being received exploiting photonic downconversion in presence of the radar signal. The insets show the 64-QAM constellations for two different values of received power for the gray dashed curve, where we have radar signal and photonic downconversion operating in the system.

Comparing the results we can observe a penalty of about 3 dB at -20 dB of EVM within the presence of PDC, penalty that can be reduced by reducing the electro-optical conversion losses. However, there is no penalty instead due to the presence of the radar signal, demonstrating a negligible cross-talk between radar and communication functionalities.

The absense of penalty in the system operation, due to the presence of the radar capability, demonstrates the effectiveness of the photonic-transceiver as dual-use simultaneous radar-communication system.

IV. Conclusions

In this paper we proposed for the first time, to the best of our knowledge, a photonic-based dual-use radar-communication system. Radar and communication operation in the S-band (2.475GHz) and C-band (4.9GHz), have been accomplished.

The photonic transceiver exploits a single highly stable mode-locked laser to perform both signal up- and down-conversion of the transmitted and received signals, respectively. Moreover the system is completely software defined and allows to independently carry out surveillance and communication without penalty introduced by the two operation coexistence.

The experimental results show the detection and velocity measurement of a moving target, and simultaneous reception of a 54Gbps 64-QAM OFDM signal with no penalty induced by the coexistence of the two operations, thus proving the effectiveness of the photonic-based transceiver as dual-use simultaneous radar-communication system. The innovative sharing of both transceiver and antenna allows for a reduction in terms of cost and SWaP.

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