Integrated Microwave Photonics for Radar Applications

Giovanni Serafino[1], Salvatore Maresca[2], Manuel Reza[1], Claudio Porzi[1], Antonio Malacarne[3], Filippo Scotti[3], Paolo Ghelfi[3], Antonella Bogoni[1,3]

[1]Sant'Anna School of Advanced Studies, TeCIP Institute, via G. Moruzzi 1, Pisa, Italy
[2]Institute of Electronics, Information Engineering and Telecommunications (IEIIT), CNR. Pisa, Italy
[3]Consorzio Nazionale Interuniversitario per le Telecomunicazioni, PNTLab, via G. Moruzzi 1, Pisa, Italy
g.serafino@santannapisa.it

Abstract: Integrated microwave photonics enables high-performance, compact, and rugged radar systems for applications in diverse domains. This paper provides a brief overview of promising photonic integrated solutions for maritime surveillance and Earth observation. © 2022 The Author(s)

2022 Conference on Lasers and Electro-Optics Pacific Rim (CLEO-PR) | 979-8-3503-5001-2/22/$31.00 ©2022 IEEE | DOI: 10.1109/CLEO-PR62338.2022.10432218

1. Introduction

Microwave photonics (MWP) is a discipline merging the domains of photonics and electronics for radiofrequency (RF) applications [1]. Although electronics is one of the most mature existing technological fields, photonics is demonstrating its capabilities of enabling electronic systems with high performance and unprecedented flexibility, thanks to frequency-agnostic operation, waveform agility, superior signal stability, immunity to electromagnetic interference (EMI), low losses in signal distribution [2]. In the RF domain, such features are particularly attractive for radar applications, and photonics-assisted radars are now an active field of research [3].

The first realised MWP systems were built with bulk, discrete photonic devices, connected with optical fibers. Today, thanks to the impressive advances of integrated photonic technologies, miniaturised, rugged, and even fiber-less MWP systems with reduced size, weight, and power consumption are now a reality [4], [5]. The integration platforms that have emerged in the last years are based on Silicon [6], or on III-V compounds [7]. Si photonic integrated circuits (PICs) are more compact, exhibit lower propagation losses, and are CMOS-compatible; yet, this platform employs indirect-gap materials, which make impossible on-chip amplification and lasing. With III-V compounds, active devices can be obtained, but losses are higher, non-linear effects are non-negligible, and circuits size usually larger. For this reason, hybrid PICs can be realised merging Silicon and similar materials, like Si_3N_4, with III-V compounds, as InP or InGaAs, to obtain the advantages of both platforms, trying to mitigate their downsides. In this paper, we report a brief overview of some of the most interesting microwave systems for remote sensing applications in diverse domains like maritime surveillance [4] and satellite Earth observation [5], completely realised in, or taking advantage of, photonic integrated technologies.

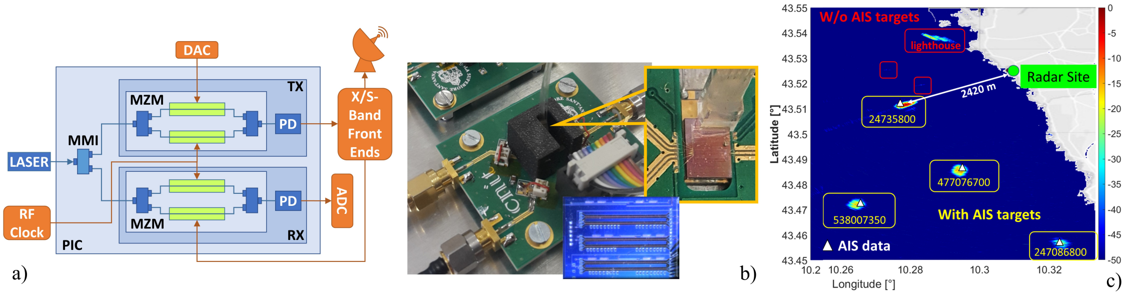

Fig. 1: a) Block scheme of the dual-band radar on PIC; b) Picture of the packaged PIC (insets: microscope image of the PIC and zoom-in view of the PIC on printed circuit board); c) Example of a latitude-longitude map resulting from the system field trial [4].

2. Integrated Photonics in Microwave Sensing

Microwave signals can be treated in the photonic domain, implementing filtering, beamforming, frequency up- and down-conversion, and sampling [2]. A paramount advantage of photonics is the high coherence, intended as high signal stability, as well as the possibility of generating multiple mutually coherent signals. These features have been recently exploited in several applications, as reported in the following two use cases.

The block scheme of a radar for maritime surveillance, completely realised in Si [4] is reported in Fig. 1 a). A laser is coupled to the PIC by a grating coupler and equally split by a multi-mode interference (MMI) coupler to the transmitter (TX) and receiver (RX) arms. These both include a Mach-Zehnder modulator (MZM) on whose arms independently driven *p-n* junctions realise phase modulation. On one arm of the MZMs, the laser is modulated by an RF clock at 2.5 GHz, generating a frequency comb. In the TX, the other arm is employed for electro-optical (E/O) conversion of the radar waveform generated at intermediate frequency (IF) by a digital-to-analog converter (DAC). The two optical signals are again coupled by an MMI block and heterodyned in a photodiode (PD). The frequency up-converted signals obtained at 2.575 GHz (S band) and 9.875 GHz (X band) are filtered, amplified, and transmitted by the RF front-ends. The received echoes are instead E/O converted by modulating the lower arm in the RX, coupled with the optical comb and heterodyned in a PD, obtaining RF signals downconversion to IF before analog-to-digital conversion (ADC). A picture of the bare and of the packaged PIC is shown in Fig. 1 b) and its insets. The system has been characterised in X and S band showing, respectively, a spurious-free dynamic range of 81 and 83 dB·Hz$^{2/3}$, a conversion gain of 11 and 17 dB, and a sensitivity of -110 and -100 dBm. It has been tested in a maritime environment, showing capabilities of detecting boats in a 2.5 km range. Detections have been validated by comparison with automatic identification system (AIS) data, as shown in Fig. 1 c).

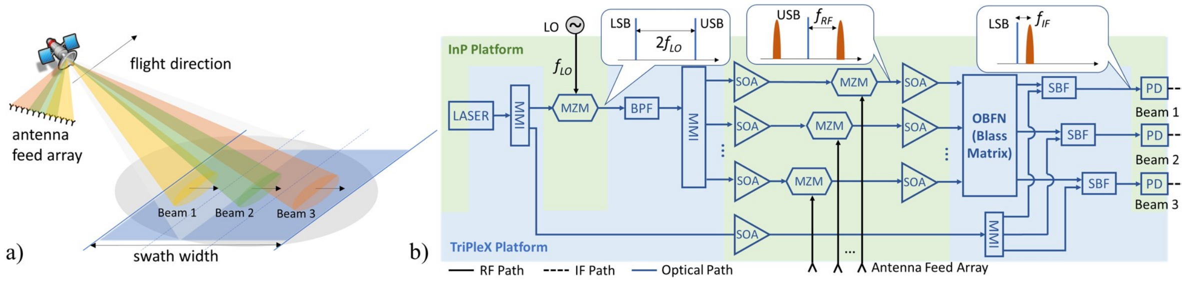

Fig. 2: a) Concept of spaceborne SCORE-SAR; b) Architecture of the photonics-assisted RX including OBFN for SCORE-SAR applications [5].

Fig. 2 reports an architecture proposed for scan-on-receive (SCORE) synthetic aperture radar (SAR) [5]. As depicted in Fig. 2 a), in SCORE-SAR an antenna illuminates the ground with a single large beam, then receives the echoes synthesizing multiple narrow, high-gain beams, allowing decoupling swath width and ground resolution. The photonics-assisted SCORE-SAR RX architecture is sketched in Fig. 2 b), highlighting the passives realised in TriPleX^{TM} and the opto-electronic (MZMs, PDs) and active blocks (Semiconductor Optical Amplifiers, SOA) in InP. A continuous-wave (CW) laser is split, modulated in carrier suppression by a tone generated by an electrical local oscillator (LO) at $f_{LO} = 8.3$ GHz, obtaining an upper and a lower sideband (USB and LSB). A band-pass filter (BPF) selects the USB, which is split over 12 arms (one for each antenna feed array element), where it is E/O modulated by the received RF echoes at $f_{RF} = 9.6$ GHz with 390 MHz bandwidth. These optical signals are fed into an optical beamforming network (OBFN), implemented by a 12 input x 3 output Blass matrix. Each OBFN output is then coupled thanks to a side-band filter (SBF) to the replica of the seed CW, obtaining a coherent beating in the PDs, generating the frequency downconversion of received echoes optical replica at $f_{IF} = f_{RF} - f_{LO} = 1.3$ GHz. This way, the RX realises simultaneously the received signals downconversion and the synthesization of three beams with beamforming capabilities. The development of this architecture is underway, and the PICs functionality characterization is currently ongoing. Afterwards, packaging in a gold-box will be realised, followed by environmental tests to verify its space-compliance in agreement with European Cooperation for Space Standardization (ECSS). Expected performance estimation analyses revealed that this photonics-assisted RX can realise frequency-agnostic operation, guaranteeing a 55 dB dynamic range, against the mission requirement of 32.5 dB, and a sensitivity of -90 dBm, observing a 50 km-wide swath with a ground resolution of 1.5×1.5 m^2.

This work has been partially supported by the projects H2020 SPACEBEAM #870421 and by the NATO SPS Program under grant G5888.

References

1. J. Capmany and D. Novak, *Nat. Photon.* 1, pp. 319–330, 2007.
2. G. Serafino *et al.*, *IEEE Journ. Lightw. Techn.* 38 (19), pp. 5339-5355, 2020.
3. S. Pan and Y. Zhang, *IEEE Journ. Lightw. Techn.* 38 (19), pp. 5450-5484, 2020.
4. G. Serafino *et al.*, "Maritime Field Trial of a Dual-Band Silicon Integrated Photonics-Based Radar" (Submitted to *IEEE Journ. Sel. Topics in Quant. Electr.*)
5. M. Reza *et al.*, *IEEE Journ. Lightw. Techn.* 39 (24), pp. 7588-7599, 2021.
6. R. Maram, S. Kaushal, J. Azaña, L. Chen, *MDPI Photon.* 6 (1), p. 13, 2019.
7. M. Smit, K. Williams, J. van der Tol, *AIP APL Photon.* 4 (5), 2019.