Design of integrated photonic devices for high-speed coherent receivers

A. Ortega-Moñux[1], D. Pérez-Galacho[1], C. Alonso-Ramos[1], P. J. Reyes-Iglesias[1], R. Halir[1], R. Godoy-Rubio[1], J. G. Wangüemert-Pérez[1], Í. Molina-Fernández[1], R. Zhang[2], P. Runge[2]

[1] *Dpto. Ingeniería de Comunicaciones, ETSI Telecomunicación, Universidad de Málaga, Spain,* *aom@ic.uma.es*

[2] *Fraunhofer Inst. for Telecommun., Heinrich-Hertz-Inst., Berlin, Germany*

Abstract: In this tutorial we will discuss the most relevant aspects of the design of high performance Photonic Integrated Circuits for Dual Polarization Coherent Receivers suitable for 100GbE applications. Specifically, we will focus our attention on two hot topics: polarization diversity management and colorless operation. Practical issues such as technological constraints and tolerance to fabrication errors will also be covered.

As it is well known, the success of new services such as high definition video streaming or cloud computing and storage require an exponentially increase of available bandwidth. At the same time, these services are affected by severe cost constraints (end-user prices must be kept low), so the existing data communication infrastructure must be maintained with minimum changes.

In order to simultaneously satisfy these two requirements (high bandwidth and low cost), a significant increase of the spectral efficiency of existing long-haul fiber optic communication networks is required, since conventional schemes based on OOK intensity modulation with direct detection are limited to 10-40Gbps per optical carrier and the installation of new fiber links is not an option for economic reasons. The widespread solution to improve the spectral efficiency combines the use of coherent multilevel modulations (e.g. QPSK or 16-QAM) with polarization multiplexing to achieve 100Gbps (or even 400Gbps) per optical carrier in 50GHz grid DWDM systems. Fig. 1.a) schematizes the generation of a Dual Polarization QPSK 100Gbps data stream from four 25Gbps data channels.

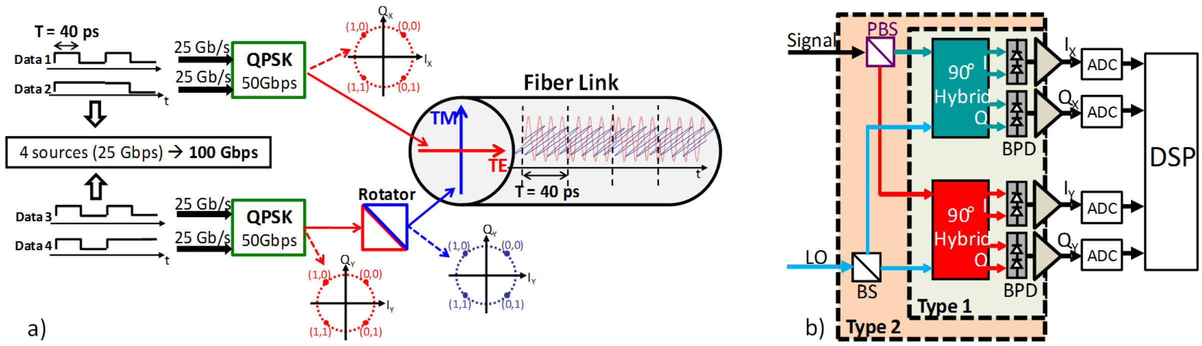

Fig. 1: a) Generation of a DP-QPSK 100Gbps data stream. b) Schematic of an integrated DP coherent receiver.

The first commercially available optical coherent receivers were based on bulk solutions, since the technology of photonic integrated circuits (PIC) was not mature enough. Nevertheless, during the last years a considerable effort has been dedicated to improve integrated solutions and nowadays, commercial products that integrate in a single PIC many of the components of a coherent receiver (e.g. 90º hybrids, Polarization Beam Splitters (PBS), photodetectors, etc.) can be found. Fig. 1.b) shows the functional diagram of an integrated Dual Polarization Coherent Receiver, where two integration levels (Type 1 and Type 2 respectively) have been considered[1]. The most usual approach in commercial products is Type 1, where all the components except the polarization management circuitry are integrated in a single PIC. The PBS is included in the package, but it is implemented in bulk technology and micro-assembled to the chip. On the contrary, receivers of Type 2 are fully integrated solutions where the polarization management circuitry is included, together with the other receiver components, in a single photonic circuit. The fully integrated solution is obviously preferred but it is not widely used in commercial products, since the reduced tolerance to fabrication errors of integrated polarization management devices may decrease the fabrication yield.

In this tutorial we will discuss the most relevant aspects of the design of high performance Photonic Integrated Circuits for Dual Polarization Coherent Receivers suitable for 100GbE applications. Specifically, we will focus our attention on two hot topics: polarization diversity management and colorless operation. Practical issues such as technological constraints and tolerance to fabrication errors will also be covered. For the sake of brevity, we will mainly show results of devices fabricated in InP technology, although the most relevant conclusions of this work can be also applied to other platforms.

Fig. 2.a) shows the widespread implementation of a 90º hybrid in integrated technology. It is composed of a 4x4 multimode interference coupler (MMI 4x4), an optimized output section (four monomode waveguides & two low loss crossings), and two pairs of high speed balanced photodiodes[2]. It must be noticed that the behavior of the 90º hybrid in terms of amplitude and phase imbalance over the complete operation band directly determine the colorless operation of the receiver, so it is worth to spent some time improving the MMI performance.

The design of robust (i.e. highly tolerant to fabrication errors) integrated PBS is a problem that has not yet been fully solved. Fig. 2.b) shows a Mach-Zehnder Interferometer (MZI) PBS fabricated in InP technology[3]. This device is composed of two polarization-independent MMIs and two waveguides with different widths (MZI arms) which exhibit highly dissimilar birefringent behaviors. In this device, active thermal tuning is necessary to compensate the effects of waveguide width fabrication errors. To overcome the drawback of active tuning, a fully passive and highly robust PBS has been recently proposed[4]. In this device, one of the MZI arms is substituted by the waveguide with engineered birefringence drawn in Fig. 2.c). The Si-SiO_2 multilayer structure placed around the core acts as an artificial birefringent material, so the field distributions of TE and TM guided modes (and therefore their propagation constants) are pretty different.

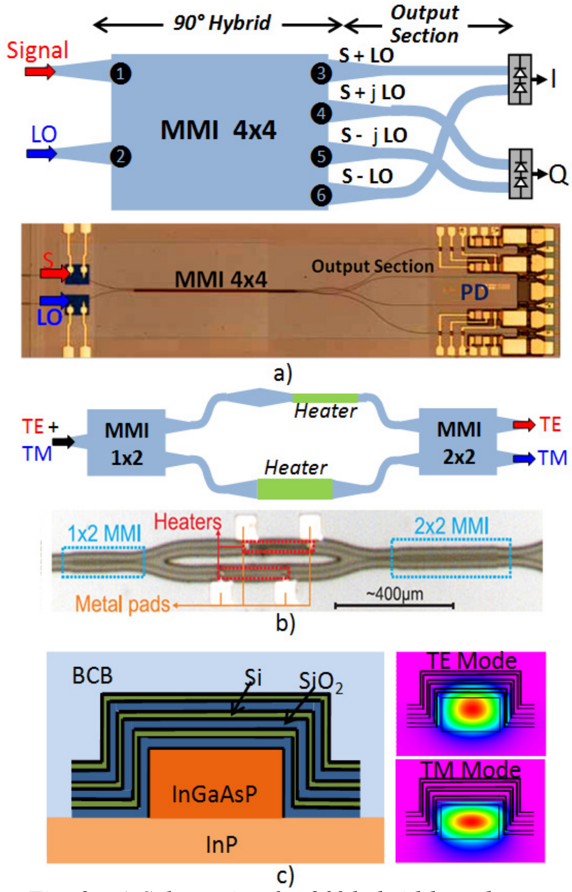

Fig. 2: a) Schematic of a 90º hybrid based on a MMI 4x4 and photograph of a fully integrated coherent receiver fabricated in InP technology[2]. b) Block diagram of a MZI -PBS with thermal tuning and photograph of a fabricated device[3]. c) Geometry of a waveguide with engineered birefringence and mode field profiles[4].

The aforementioned 90º hybrid and the thermally tuned MZI-PBS are the basic components of a fully integrated DP-coherent receiver that fulfill OIF requirements over the complete C-band and allows for reception of data streams up to 224Gbps, which is the highest reported bandwidth for a monolithic coherent receiver[5].

We will finish this tutorial presenting two innovative ideas: a highly tolerant fully passive PBS-less DP-coherent receiver[6] and a broadband colorless receiver based on an integrated 120º hybrid[7].

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D. Pérez-Galacho is currently at Université Paris-Sud.

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