Monolithically Integrated Quadrature EAM Structure for 28 GHz Full Duplex Radio over Fiber

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We discuss a quadrature modulator for remote radio heads allowing full duplex operation when used in combination with a 90 degree radio-frequency (RF) hybrid coupler. The same circuit can also be used as an optical single-sideband (OSSB) modulator by feeding the two electro-absorption modulators (EAMs) with identical signals and tuning the heaters such that the arms show 90 degree optical phase difference. This essentially omits the required external RF phase shifter used in traditional OSSB modulators. The device was constructed on the iSiPP50G silicon photonics platform for operation in the 28 GHz band.

1. Introduction

The ever increasing demand for higher wireless data rates requires fundamental changes in current network architectures. Key enablers include miniaturization of communication cells and migration to millimeter-wave (mmWave) frequencies [1]. These trends, however, increase the complexity and cost of the network significantly. To keep the deployment cost sustainable, a centralized approach is preferred. A prime example of such an approach relies on radio over fiber technologies where the remote radio head (RRH) complexity is largely reduced by aggregating more functionality at the central office (CO) [2]. The RRH complexity can be further diminished by reusing the downlink laser light for the uplink. To enable this, we propose parallel electro-absorption modulator (EAM) devices embedded in a Mach Zehnder Interferometer (MZI) with a quarter period delay between the EAMs.

The design of this quadrature EAM device will be covered in section 2 and two potential use cases will be introduced in the subsequent sections. Section 3 first shows the optical single-sideband (OSSB) generation. Secondly, it will be shown in section 4 how this topology can be used to discriminate uplink and downlink in a full duplex radio over fiber RRH.

2. Design

The design of the quadrature EAM is depicted in Figure 1. The core of the design is the migration of the 90 degree phase shifter from the RF domain to the optical domain. This is enabled by separating the EAMs by the distance L described in equation (1), where the constant c denotes the speed of light and n_g is the group index: 4.26 for 450 nm wide strip waveguides in C-band on the iSiPP50G silicon photonics platform [3]. The design is custom-made for the targeted radio frequency. In this paper, we present a 28 GHz variant resulting in an EAM separation of approximately 629 µm. The two EAMs are placed in a MZI topology with one heater on each arm to tune the bias point of the MZI. It should be noted that the EAM structure can be used simultaneously for both modulation and detection [4].

$$L = \frac{1}{4f_{RF}}\frac{c}{n_g} \Rightarrow L_{28\,GHz} \approx 629\ \mu m \tag{1}$$

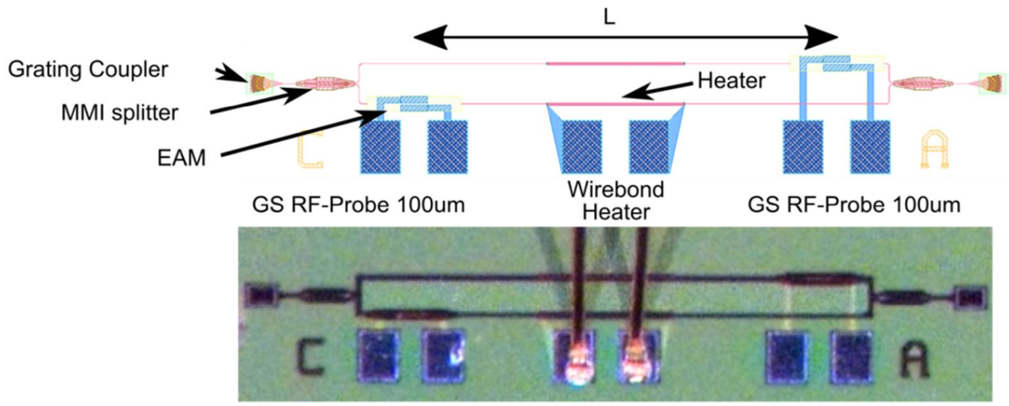

Figure 1: Layout and implementation of the quadrature EAM structure. (MMI: multi-mode interferometer; GS: ground signal.)

3. Optical Single-Sideband Generation

Optical single-sideband (OSSB) modulation has an enhanced spectral efficiency and the ability to overcome dispersion-induced distortion prevalent in optical double-sideband (ODSB) links. An OSSB signal is created by a coherent transmitter, where the in-phase light is modulated with a real-valued information signal and the quadrature light is modulated with the Hilbert transform of this information signal. The use of narrowband signals simplifies the Hilbert transformation into a $\pi/2$ phase delay [5]. The proposed architecture can be used to directly generate the OSSB variant by tuning the heater such that a $\pi/2$ optical phase shift is present between the two branches, and by the inherent $\pi/2$ electrical phase shift due to the delay (L) between the two EAMs.

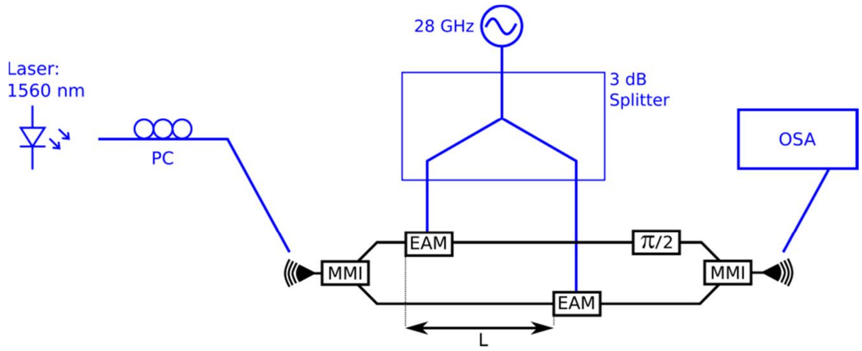

Figure 2: Setup optical single-sideband generation with the quadrature EAM structure
(PC: polarization controller; OSA: optical spectrum analyzer; MMI: multi-mode interferometer.)

In Figure 2, a schematic overview of the setup is given. It consists of a 1560 nm continuous wave laser, followed by a polarization controller (PC) to get efficient coupling to the photonic integrated circuit via the grating coupler. A 28 GHz sinewave generator is used to mimic a narrowband RF signal. A splitter is used to drive the two EAMs with the same RF-phase. The OSSB is verified by the optical spectrum analyzer (OSA).
Figure 3 shows the optical spectrum after the quadrature EAM structure. It clearly shows correct OSSB generation and indicates that one can easily change between upper and lower sideband by adjusting the optical phase shift through the heater from $\pi/2$ to $3\pi/2$. With the quadrature EAM, sideband suppression of 13 dB is obtained. The imperfect sideband suppression can be caused by discrepancies on optical 50:50 splitting by the multi-mode interferometer (MMI).

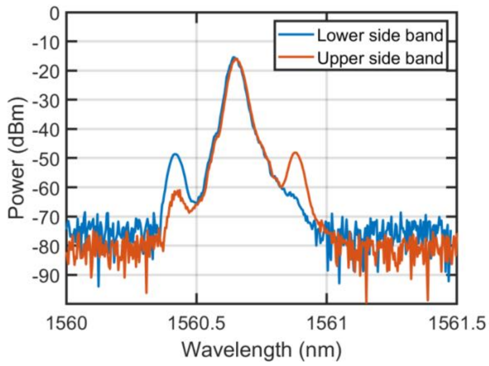

Figure 3: Optical spectrum after the optical single-sideband generator.

4. Full Duplex Operation

To simultaneously achieve modulator and receiver operation with good isolation and unidirectional light-passage, an electrical quadrature coupler is connected to the quadrature EAM **s**tructure as depicted in Figure 4. This electrical quadrature coupler is a 4-port device splitting an input signal equally between two output ports with a π/2 phase difference between them.

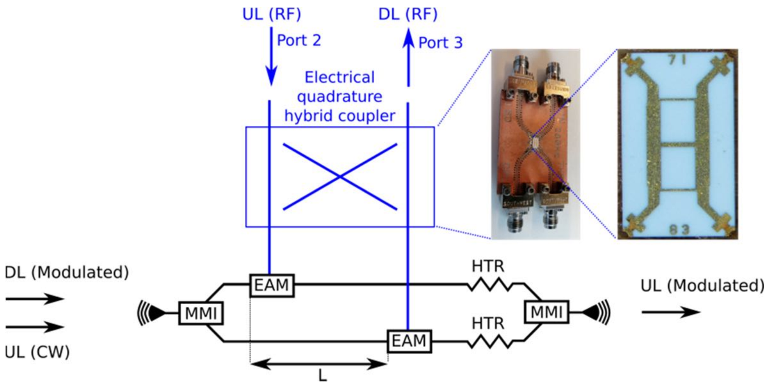

Figure 4: Quadrature modulator. (DL: downlink; UL: uplink; CW: continuous wave; HTR: heater; MMI: multi-mode interferometer..)

The optically modulated downlink (DL) signal arrives at the quadrature EAM **s**tructure. The two EAMs receive the DL signal and the generated electrical signals are constructively combined at port 3 of the electrical quadrature coupler. At port 2 of the electrical quadrature coupler, the DL signals are destructively combined. Similarly, the uplink (UL) signal will only be modulated by the signal applied at port 2 and not by the signal present at port 3. This results in perfect isolation between the DL and UL.

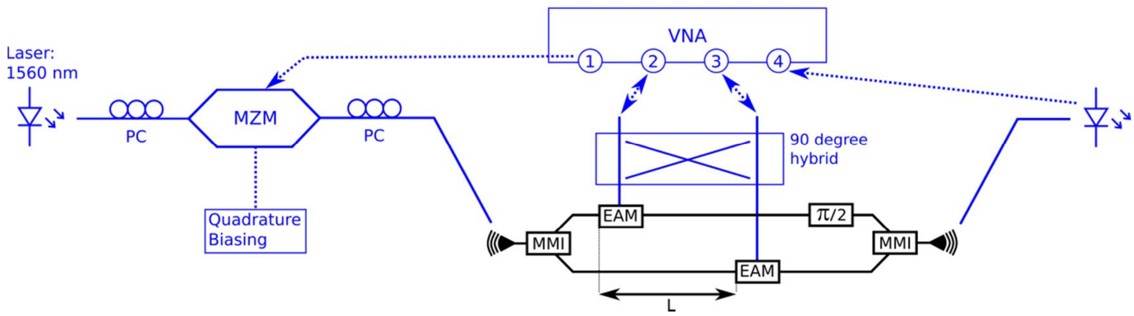

Figure 5: Full duplex measurement setup. (PC: polarization controller; MZM: Mach Zehnder modulator; VNA: vector network analyzer; MMI: multi-mode interferometer.)

Figure 5 is the experimental setup and Figure 6 presents the corresponding results. Electrical isolation levels of 15dB and 14dB are achieved for the DL and UL respectively. Due to the approximately 7° phase mismatch in the hand-soldered electrical quadrature coupler, the optimum frequency (with most isolation) is shifted to 25.6 GHz in the DL path. In the UL path, the optimum frequency for best isolation is found at 30.5 GHz.

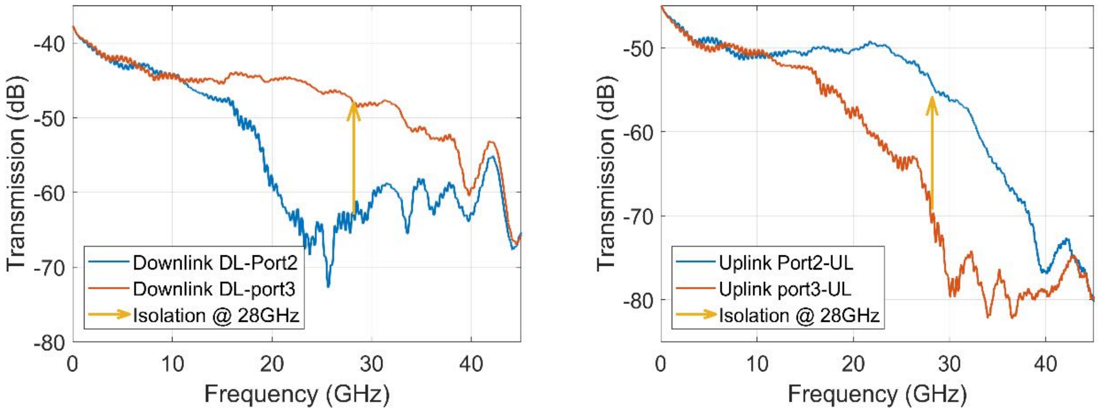

Figure 6: Transmission between the optical downlink/uplink to the respective electrical port and to the isolated port. The isolations at 28GHz are indicated with the arrows.

5. Conclusion and future work

This work explores the capabilities of the quadrature parallel EAM structure. It can be used for optical single-sideband generation as well as unidirectional modulation and/or reception, with only the loss of a single EAM and without using an optical circulator. The electrical quadrature coupler required for this can be monolithically integrated on the photonic integrated circuit [6].

Acknowledgements

This work was supported by the Ghent University Special Research Fund (BOF14/GOA/034), and the European Research Council Grant ATTO (695495).

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