EAM-based Microwave Mixer Implemented in Silicon Photonics

(Student Paper)

Kasper Van Gasse[1,2], Jochem Verbist[1,2,3], Haolin Li[3], Guy Torfs[3], Johan Bauwelinck[3], Gunther Roelkens[1,2]
[1] Ghent University-imec, Technologiepark 15, 9052 Ghent - Belgium
[2] Center for Nano- and Biophotonics, Ghent University, Belgium
[3]IDLab, Ghent University–Imec, Technologiepark 15, 9052 Ghent - Belgium
e-mail: kasper.vangasse @ugent.be

ABSTRACT

Analogue Radio-over-Fiber (ARoF) could play an enabling role in future small-cell Radio Access Networks (RANs). The use of high-frequency carriers in 5G requires wide-band and flexible frequency converter circuits. The use of ARoF allows performing the frequency conversion in the optical domain using wide-band and flexible microwave photonic up-conversion. A lot of research has been dedicated to the development of microwave photonic mixers using $LiNbO_3$ MZMs with promising results. However, using discrete bulky components is not a scalable solution and could be difficult to use in small-cell Radio Access Networks. In this work we present a silicon photonic up-converter and transmitter circuit. The photonic integrated circuit consists of two high-bandwidth waveguide-coupled EAMs in a MZI structure. One EAM is driven by the data on an IF carrier while the other EAM is driven by a high frequency LO. We present first simulation results of the structure and compare these results to an alternative mixer topology. The fabricated EAM-MZI mixer is then fully characterized and used to up-convert 16-QAM and 64-QAM data on a 1.5-3.5 GHz IF to 26-28 GHz carrier frequencies and transmit it over 2 km of single mode fiber.

Keywords: Silicon photonics, Radio-over-fiber, Microwave photonics.

1. INTRODUCTION

In next generation mobile networks (5G) new technologies will be needed to realize Radio Access Networks (RANs) capable of serving an ever-increasing amount of connected devices. One appealing approach to realize future RANs is the use of small-cell networks in combination with Analogue Radio-over-Fiber (ARoF) for antenna remoting. Using ARoF, complex wireless signals can be transported several kilometres with very low losses. It allows to centralize signal processing, which limits the deployment and maintenance cost of the remote antenna units. ARoF links not only offer the advantage of high-frequency antenna remoting, but also allow to perform signal up-conversion in the optical domain. Microwave photonic frequency conversion has been extensively studied using $LiNbO_3$ MZMs [1,2]. Although this approach has shown very promising results, the use of discrete components does not enable the scalability needed for deployment in future RANs. Integrating the optical system on a silicon photonic chip allows to strongly reduce the footprint and production cost while allowing for high-volume manufacturing. In this work we present a silicon photonic ARoF transmitter also capable of wide-band and flexible frequency conversion. The PIC is based on two waveguide-coupled GeSi EAMs placed in a MZI structure using silicon waveguides and splitters (see Fig. 1).

2. SIMULATION RESULTS

To make a detailed analysis of the optimal performance of the circuit we first performed a simulation using VPITransmissionmaker. Two possible silicon photonic mixer topologies are considered, first a serial EAM mixer where the LO and IF EAM are optically connected in series. This system was investigated using MZMs in [1]. The second topology is the parallel EAM mixer as shown in Fig. 1. This approach has also been extensively investigated using MZMs [2]. For the simulations we used previously measured transmission characteristics of the EAM (3dB bandwidth of 65 GHz, extinction ratio of 8 dB for a voltage swing of 2 V_{pp} and a dynamic insertion loss of 8 dB). We furthermore assumed that the grating couplers have an insertion loss of 5 dB and that passive components (waveguides, splitters) are lossless. Finally, an EDFA was inserted in the link simulation with a fixed output power of 2 dBm and a noise figure of 4 dB. The result of the generated RF signals for the serial and parallel mixer are shown in Fig. 2. From these results it is clear that the parallel up-converter has a better conversion efficiency when compared to the serial structure. This is thanks to the MZI structure in the parallel system that is used to supress the optical carrier. By removing the optical carrier only the relevant signal is amplified by the EDFA. A second interesting feature is that the LO throughput is much lower in the parallel system than in the serial mixer, which requires less filtering at the output. Finally, we note a conversion efficiency of -27 dB for the parallel EAM mixer, without a TIA at the photodiode output.

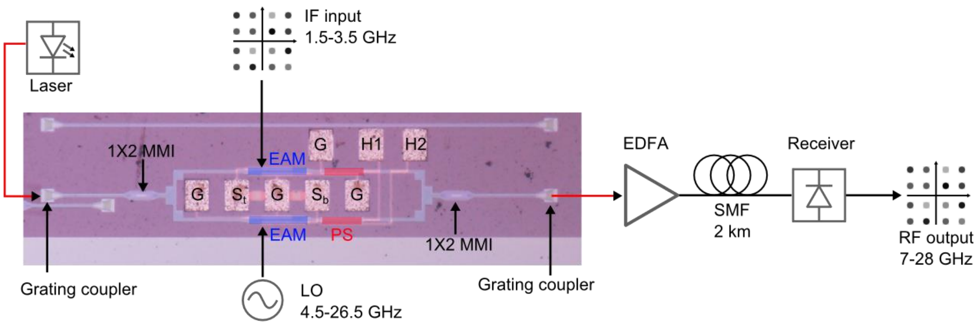

Figure 1. Overview of the parallel EAM up-conversion-transmitter link. The IF input is represented as a 16-QAM signal on a 1.5 GHz IF carrier. EAM: Electro Absorption Modulator; PS: Phase Shifter; MMI: Multi-Mode Interferometer; SMF: Single Mode Fiber.

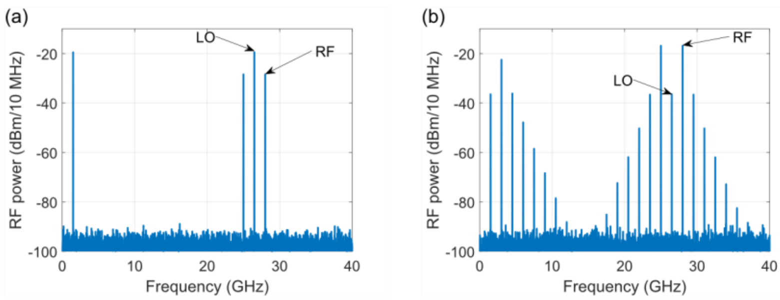

Figure 2. Simulated output from photodiode for (a) the serial EAM link and (b) the parallel link.

3. MEASUREMENT RESULTS

To characterize the up-converter/transmitter, the PIC shown in Fig. 1 was placed on a temperature-controlled stage and electrically contacted using a custom GSGSG RF probe with a 100 µm pitch. The PIC was optically interfaced with cleaved single mode fiber. A laser with an output at 1565 nm and 10 dBm output power was used as optical input.

3.1 Small-signal EAM characterization

To fully characterize the parallel EAM mixer we first measured the S21 and S11 parameters of the EAM. An on-chip parallel 70 Ohm resistor was used to have broadband matching. The result of the S21 measurement is shown in Fig. 3(a) and it shows a 3 dB modulation bandwidth exceeding 67 GHz. This very high modulation bandwidth makes the EAM an ideal candidate for the higher carrier frequencies envisioned in future mobile networks. In Fig. 3(a) the S11 of the EAM is shown, indicating a return loss better than 10 dB over the entire frequency range. Although the on-chip resistor is a straightforward and practical matching solution, the conversion efficiency could be further improved by a dedicated narrow band matching network.

3.2 System characterization

To assess the linearity of the mixer an IP3 measurement was performed as a function of the IF input power and a spurious free dynamic range of 82 $dBHz^{2/3}$ was found. This can be improved by increasing the link gain and lowering the noise floor. Using low-loss edge couplers would reduce the noise figure and a photodiode with higher saturation power would allow for a higher conversion gain. The conversion efficiency also depends on the extinction ratio of the MZI, as it determines the amount of carrier suppression achievable. Using the thermo-optic heater we can achieve a π-phase shift with 28 mW of power and an extinction ratio of 30 dB when EAMs are un-biased. This excellent extinction ratio means that the losses of the EAMs are almost identical.

3.3 Transmission experiment

Finally we performed transmission experiments where we up-convert 16-QAM and 64-QAM data on a 1.5 GHz IF to an RF carrier frequency up to 28 GHz. The carrier frequency was limited by the measurement equipment. The high 3 dB modulation bandwidth of the EAM indicates that the up-converter/transmitter could also be used for up-conversion to the 60 GHz frequency bands.

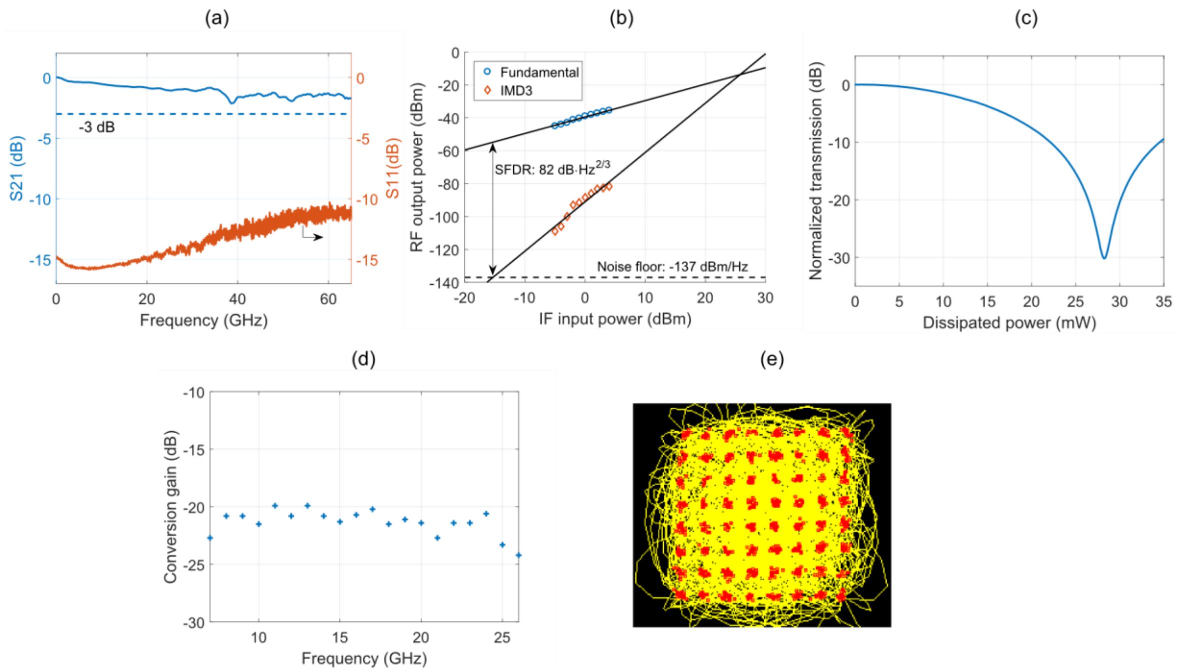

Figure 3. Measurement results of the EAM based up-converter/transmitter. (a) Small-signal measurement of a single EAM; (b) Result of a linearity (IP3) measurement. (c) Measured transmission as a function of the power dissipated in the thermo-optic phase shifter; (d) Conversion gain as function of RF output frequency for a fixed IF of 1.5 GHz. (e) Constellation diagram of 10 MBd 64-QAM data upconverted from 1.5 GHz IF to 26 GHz RF.

In a first transmission experiment we upconverted 10 MBd of 64-QAM data on a 1.5 GHz IF carrier to a 26 GHz RF carrier. The resulting (peak output power referred) rms EVM was 3.2 %, well below the 3GPP recommended maximum rms EVM for current LTE RANs of 8 % for 64-QAM signals. Both the baud rate and RF carrier frequency were limited by the bandwidth of the used equipment. Furthermore, we investigate the evolution of the EVM as a function of the LO frequency and found that the rms EVM remains between 2 and 4 % over a span of more than 20 GHz. This attest to the extremely flat response of the mixer, which is a strong advantage of this mixer. In a final transmission experiment we used an in-house programmed FPGA signal generator to create a 218 MBd 64-QAM signal on a 3.5 GHz carrier and up-converted it to a 28 GHz carrier. Given the limited bandwidth of the signal analyser, a real-time oscilloscope with native de-modulation software was used to analyse the up-converted signal. Again, the 28 GHz carrier frequency was limited by the real-time oscilloscope. For the 64-QAM signal an on-line rms EVM of 5.5 % was found, which is still well below the recommended 8 %. This degradation in signal is partially due to the bandwidth of the data, but also due to the lower quality of signal generation of the FPGA compared to the commercial signal generator.

4. CONCLUSIONS

In summary we have shown that a parallel EAM microwave photonic up-converter/transmitter is capable of transmitting 64-QAM data over 2 km of single mode fiber with rms EVM lower than 5.5 % for data rates up to 1.3 Gb/s. Given the extremely compact foot-print of the EAMs, multiple such mixers can be integrated on a single PIC and multiplexed in wavelength or space for transmission over optical fiber.

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