Development of a Broadband Integrated Microwave Photonic Beamformer for 5G applications

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Introduction

Microwave photonics (MWP) is an emerging field in which radio frequency (RF) signals are generated, distributed, processed, and analyzed using the advantages of photonic techniques such as large RF frequency bandwidth capability and absence of cross-talk between integrated waveguides. Using this technology numerous functionalities become feasible in the microwave domain. In particular the use of photonic integrated circuit (PIC) technology in MWP to enhanced functionalities and increase the robustness as well as the reduction of size, weight, cost as well as power consumption [1]. For this reason, over the last few years, a tremendous amount of research and development was focused to our hybrid PIC platform to combine Si_3N_4-based TriPleX with InP [2, 3].

The need of hybrid integration is evident as the advantages of both platforms can be combined. Figure 1 and 2 show a schematic and photograph of a state-of-art microwave photonic beamformer, respectively. The laser light is generated in the hybrid InP-TriPleX laser then modulated by incoming RF signals in the InP chip with an array of 30 GHz modulators. The modulated signals are then processed in the beamforming network on TriPleX and finally converted back to the RF domain in an InP chip with an array of 40 GHz detectors. An additional fiber array is connected to the TriPleX chip for the sole purpose of testing and calibration or possible remoting of the signals. The processing (splitting, combining, filtering, beamforming, phase, and delay tuning) is performed on the ultra-low loss (<0.1 dB/cm) Si_3N_4 TriPleX optical waveguide chip. Such processing would be unfeasible using InP waveguides due to their higher waveguide losses (2 dB/cm). The three functionalities on InP have been separated on individual chips to maximize the performances of the InP chips and, furthermore, reduce the mutual disturbance. For example, a high power gain section will saturate the photodetectors when placed together on one InP chip. An additional advantage is the tremendous reduction of RF crosstalk by separating modulator and detector chips.

Measurements

The RF responses of a single path of the beamformer with ring resonator based tunable delays have been measured using a VNA and are shown in Fig. 3. The measured link gain varies from -39 to -44 dB from 1 to 18 GHz with a noise figure from 41 to 44 dB and a spurious-free dynamic range of 105 dB $Hz^{2/3}$. The generated optical power of the internal laser is 10 dBm and the average optical power on the detector was -3.5 dBm. The delay response was also measured for varying delay settings from 19.7 to 20.7 ns with a delay ripple smaller than 50 ps over the frequency range of 17.8 to 22 GHz. The delay has also been increased to 21.5 ns, with a ripple of 100 ps at the cost of a reduced bandwidth of 2.2 GHz.

5G projects

In this work we will present the various designs investigated in the two H2020 projects, 5G-PHOS and BlueSpace.

The optical system for the 5G-PHOS project is a binary-tree type OBFN, which is connected to an antenna array, and employed to provide beam forming (beam shaping and beam steering). The OBFN consists of three parts; active chips in InP, passive chips in TriPleX and packaging. The passive chips will provide tunable true-time delay and phase shifts, required for flexible beam forming. The TriPleX will be passively aligned and connected via end-facet-coupling to InP-based lasers, high-speed modulators, optical amplifiers and high-speed detectors. The combination of these passive and active chips provide a unique and very powerful microwave photonic processing engine to fully control antennas' emission patterns in a way that is very challenging to achieve using electronics only.

In the early stage of BlueSpace, we investigate two kinds of multi-beam optical beamformers to improve the performance of the 5G infrastructure. The optical beamformers will allow to spatially distribute the network capacity, where needed, making future 5G networks more efficient and flexible. The two beamformers investigated in this project are based a Blass-matrix [4] using a single laser (as in presented in Section I) and a multi-wavelength approach, where a specific delay is applied on lasers with channel spacing of 100 GHz and coming on a photodetector. The combining will be done by an a wavelength combiner with a spectral response as shown in Fig. 5.

Acknowledgements

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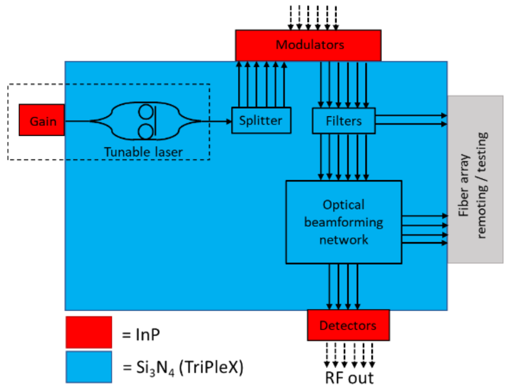

Fig. 1. Block diagram of an integrated optical beamformer

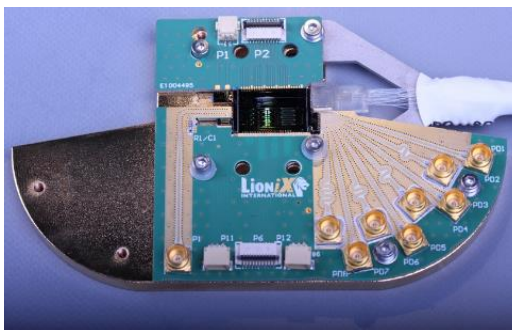

Fig. 2. Photograph of an state-of-the-art of an integrated optical 1x4 beamformer module.

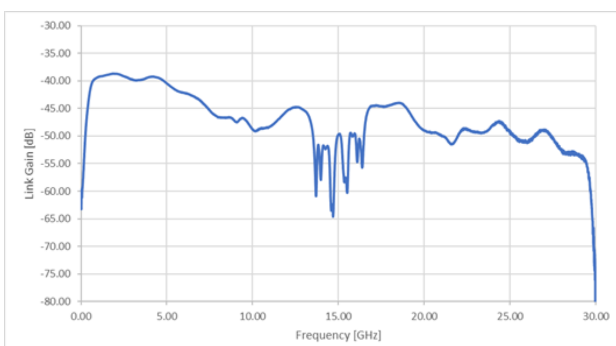

Fig. 3. Measured link gain of the integrated optical 1x4 beamformer.

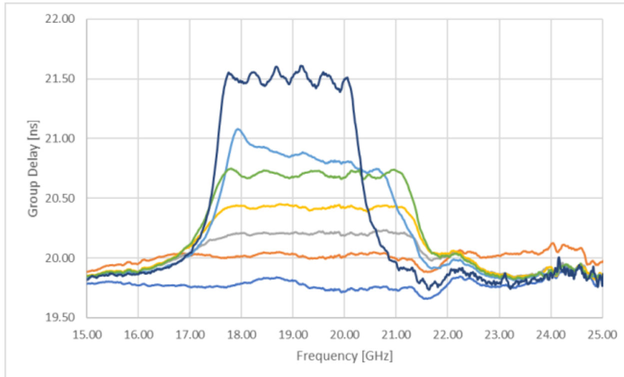

Fig. 4. Measured delay applied by the integrated optical 1x4 beamformer.