Design of a Frequency Modulation - Direct Detection Microwave Photonic Link receiver monolithically integrated in InP generic technology

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***Abstract*—The steps followed in the design of an InP photonic integrated circuit (PIC) working as a discriminating receiver for Frequency Modulation-Direct Detection (FM-DD) Microwave Photonic links (MPL) are presented, including filter synthesis values.**

I. Introduction

Because of its high bandwidth and long reach, microwave photonic links (MPL) are expected to play an important role in many telecommunication applications, including radio-over-fiber and antenna distribution systems. Even though traditional IM-DD-based MPL have already reached the commercial stage, it is well-known that nonlinearities arising from the modulator transfer function, along with shot and RIN noise produced by the detected optical carrier, put a limit to the maximum attainable spurious-free dynamic range (SFDR) . In order to mitigate these impairments, several techniques have been proposed in recent years, such as adaptative biasing of the modulator and direct optical filtering. More recently, ideal class-B operation has been devised and theoretically shown to allow for significant improvement in dynamic range [1]. Frequency modulation and optical filters acting as frequency discriminators, together with direct detection (FM-DD), have been explored as means to effectively achieve the desired intensity transfer function. Several experimental demonstrations have also been reported so far, including specially designed FBGs [2], ring-assisted fiber Sagnac filters [3], as well as photonic integrated circuits (PIC) using multiple ring resonator [4] and cascaded MZIs [5].

II. Filter synthesis and design

The structure of the device, which includes a tunable optical filter acting as a frequency discriminator and a high speed balanced photodetector integrated in the same chip, can be seen in Fig. 1. A pass-band input filter splits up the spectrum of the FM signal into its upper and lower sidebands, while reducing the power of the optical carrier. Each one of its complementary outputs is fed to another structure (Filter 1 & Filter 2) acting as a frequency discriminator, which modifies the amplitude of sideband harmonics and reduces even more the carrier power. Finally, both signals are detected in a balanced configuration.

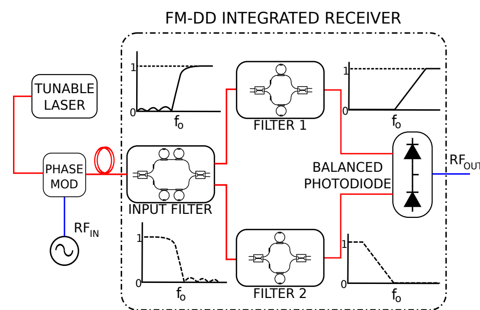

Fig. 1: Block diagram of the device. Optical power transfer functions at the output of each filter are shown.

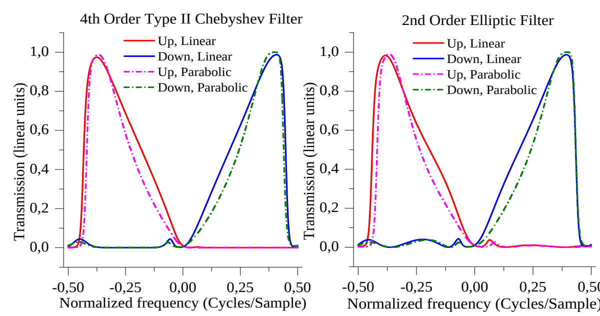

Fig. 2: Simulated transfer function of each input filter (Chebyshev & Elliptic), when combined with two different frequency discriminators (Linear & Parabolic).

All the aforementioned filters were chosen to be implemented by means of integrated ring-loaded Mach-Zehnder interferometers, where the power coupling constants (κ) and relative phases of each ring (ϕ) and each MZI (β) are designed so as to achieve the desired intensity transfer function. Since the response of this structure is intrinsically periodic, powerful digital IIR filter synthesis techniques can be exploited [6]. In principle, any transfer function can be sufficiently approximated if the order is high enough, at the expense of a higher sensitivity to manufacturing defects. Hence, two different designs which differ in the type and order of the

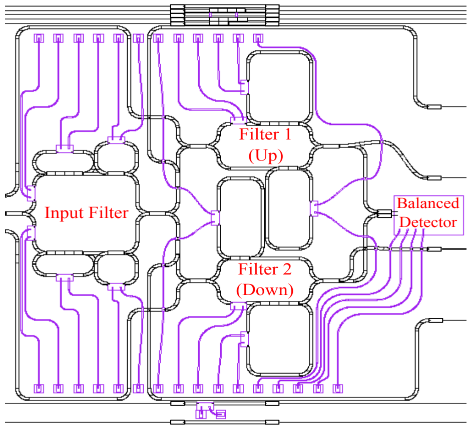

Fig. 3: Chip layout for the Chebyshev design.

input filter were submitted to fabrication: a second-order (N=2) elliptic filter and a fourth-order (N=4) type II Chebyshev filter. Synthesis values $\{(\kappa_i, \phi_i \text{ for } i = 1 \ldots N),(\beta)\}$ are: Chebyshev Type II = $\{$(0.5,1.376)(0.95,-1.351)(0.5,-1.376)(0.95,1.351),(-4.97)$\}$; Elliptic = $\{$(0.72,-1.374)(0.72,1.374),(1.236)$\}$.

In the literature, two main approaches can be found for the design of the discriminator, where variation of the optical intensity response is either linear or parabolic. While the former performs good in terms of harmonic distortion for large modulation index [2], the latter is intrinsically distortion free provided all the sidebands fall within the bandwidth of the filter [7]. In order to achieve both types of response, Filter 1 and Filter 2 were firstly chosen to be second-order (N=2) filters acting as linear frequency discriminators (i.e. they present an optical intensity transmission ramp which scales linearly with frequency). Synthesis values from [6] were employed. These values are: $\{$(0.91,0.009)(0.38,-0.01),(1.589)$\}$. The FSR of the structures is estimated to be around 47 GHz for the elliptic filter design, and 46 GHz for the Chebyshev filter. Combined responses (pass-band plus linear frequency discrimination) are shown in Fig. 2.

Secondly, silicon nitride thermo-optic heaters were laid out, so as to enable fine tuning of the optical phases. This allows to dynamically change the overall response of the device. Assuming fixed coupling constants, an optimization routine was run in order to find those phases which best approximated a parabolic response. Synthesis values are: Parabolic (Up) = $\{$(0.91,0.031)(0.38,-0.366),(0.994)$\}$; Parabolic (Down) = $\{$(0.91,-0.113)(0.38,0.337),(2.177)$\}$. Combined responses (pass-band plus parabolic frequency discrimination) are shown in Fig. 2.

III. Technology and Layout

A section of the layout can be seen in Fig. 3, which shows the device using a Chebyshev type II filter at its input. InP generic process technology developed under EuroPIC EU FP7 project was employed to design and manufacture the chip. Die chip area (6x6 mm^2) limitations lead to the use of deeply etched (1.7 μm) rib waveguides, enabling sharp bends (150 μm), with an InGaAsP core (n = 3.258 @ λ = 1.55 μm, height = 1 μm, width = 2 μm) over an InP substrate (n = 3.169 @ λ = 1.55 μm). Accordingly to design values, a suitable structure to implement 2x2 optical couplers with arbitrary splitting ratios needs to be chosen. Strong confinement of the mode in the deeply etched waveguide does not allow using directional couplers, owing the aforementioned die size limit. Instead, butterfly MMI couplers were used. All couplers were designed using the approximate analytical expressions provided in [8], and then optimized by means of BPM numerical simulations. MMI sections were designed to be 12 μm wide. Tapered transitions to shallow etch (0.2 μm) waveguides were performed in different areas, in order to maximize input/output coupling. Several metal pads (50x100 μm^2) with gold metallization (Fig. 3, magenta lines) allow to supply current to multiple SiN thermo-optic heaters, as well as to the 50 GHz 3dB bandwidth balanced photodiode. Unused inputs/outputs from the MZI 2x2 couplers were routed to left/right chip facets, in order to provide individual characterization and testing of each filter.

IV. Conclusions and Further Work

The steps followed in the design of a photonic integrated circuit acting as a MPL FM-DD receiver have been described. Further work will include a complete experimental characterization of the filters, in order to contrast design targets with real measurements, assessing the quality and reliability of the design and manufacturing process. Experimental work will also be conducted in order to contrast other studies about FM-DD receivers, so as to further understand their performance and practical limitations.

Acknowledgements

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