A Novel Microwave Photonic Link employing Cascaded Ring Resonators as Balanced Optical Discriminators

D.A.I. Marpaung,[1] C.G.H. Roeloffzen,[1] A. Leinse,[2] and M. Hoekman[2]

[1] Telecommunication Engineering group , University of Twente, PO Box 217, Enschede.7500 AE, the Netherlands

[2] LioniX BV, PO Box 456, Enschede, 7500 AL, the Netherlands

We report the design, fabrication and characterization of a balanced optical discriminator for a high performance phase modulation-direct detection microwave photonic link (MPL). The discriminator is an integrated optical filter consisting of five ring resonators which are fully tunable using thermo-optical tuning. The discriminator is configured to yield a desired transfer where the intensity transmission ramps linearly with the frequency. The performance of an MPL employing this discriminator is investigated. Measurement results on the MPL noise, linearity and spurious-free dynamic range are presented and discussed.

Introduction

Microwave photonics (MWP) has become a reliable technology for the distribution and processing of high frequency signals with applications in wireless communication, radar and radio astronomy systems to name a few. Some of the functionalities offered by MWP systems include signal remoting, filtering, time delay and instantaneous frequency measurements. A backbone of an MWP system to perform these functionalities is a microwave photonic link (MPL), where the E/O and O/E conversions take place. The MPL needs to fulfill several performance criteria namely high link gain, low noise figure and high spurious-free dynamic range (SFDR). High SFDR dictates high linearity and low noise in the MPLs.

A type of MPL that gains significant interest recently is the phase-modulated direct detection (PM-DD) link. In such a link, a phase modulated signal is converted to intensity modulation (PM-IM conversion) using an optical discriminator, thereby allowing a simple direct detection scheme instead of the complicated coherent detection. Such an MPL takes advantage of the linearity of a phase modulator and an additional degree of freedom in tailoring the characteristic of the discriminator to enhance its linearity and noise performance. In previous investigations, different filter types have been proposed as the photonic discriminator such as Mach-Zehnder interferometers and fiber-Bragg gratings [1]. In this paper, we report a fully tunable and programmable photonic chip as the photonic discriminator. The chip consists of five optical ring-resonators, all in an add-drop configuration, fully tunable with thermo-optical tuning.

The Photonic Chip Discriminator

The desired transfer function of the photonic discriminator consists of a pair of linear positive and negative slopes intersecting at the angular frequency of the optical carrier (ω_c), as shown in the inset of Fig. 1. Ideally, at the upper branch, for frequencies below ω_c the magnitude filter response is zero while above the ω_c it is linear up to a maximum frequency. This also applies to the other output for frequencies below ω_c. An MPL employing a discriminator with this characteristic will benefit from shot noise and RIN reduction leading to an SFDR enhancement [2].

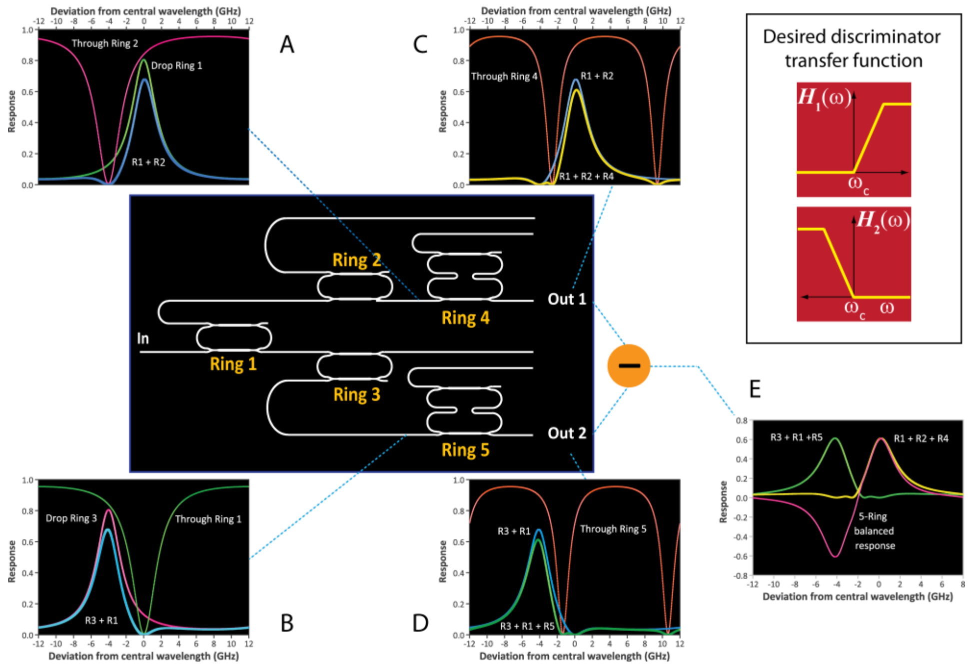

Fig. 1. Schematic and the principle of operation of the photonic discriminator chip. The frequency discriminator chip consists of five fully-tunable optical ring resonators. Simulation results of the filter responses in A-E illustrate the principle to obtain the desired discriminator response. A cascade of responses from through ports of ORRs is used to linearize and to increase the suppression of a response from drop port of another ORR. Here the optical waveguide propagation loss of 0.2 dB/cm is used in the simulation. Inset: the ideal discriminator response.

To obtain the desired filter response we use on-chip photonic discriminator consisting of five optical ring resonators (ORRs) all in an add-drop configuration. The ORRs considered are racetrack structures connected with a pair of tunable couplers to two straight optical waveguides, as depicted in Fig. 1. Using heaters placed on top of the ORRs the resonance frequency and the coupling coefficients (and subsequently the Q-factor) of all ORRs can be tuned via thermo-optics effects. The principle of operation of the photonic chip is illustrated with the simulation results depicted in Fig. 1A-E. A cascade of responses from the through ports of ORRs is used to linearize and to increase the suppression of a response from a drop port of another ORR. In this way, one obtains a linear slope for a PM-IM conversion. The detailed explanation of the chip operation is described in [3]. In this paper, we focus on the fabrication of the photonic discriminator and the performance of an MPL employing discriminator.

Photonic chip Fabrication and Packaging

The designed filter is fabricated in the CMOS compatible TriPleX™ waveguide technology with a high contrast box shaped waveguide structure. The fabricated ring resonators have a round trip length of 8 mm (16 mm for rings 4 and 5) and the bend radius of the curved part of the ORR is 150 µm. It can be calculated that the ORRs have a free spectral range of 21.5 GHz (for Rings 1 to 3 and 10.7 GHz for Rings 4 and 5).

The total footprint of the fabricated discriminator chip is 9 x 7 mm. The optical waveguide layout of the optical chip is depicted in Fig. 2a. For tuning the ORRs characteristics, chromium heaters are deposited on the chip. For the ease of measurements, the fabricated photonic chip is packaged. The bond pads for the heaters are wire bonded to a pair of PCBs. An array of 8 polarization maintaining fibers (PMFs) is aligned and glued to the inputs of the optical chip while at the output the chip is pigtailed with an array of standard single-mode fibers. The photograph of the packaged FM discriminator is shown in Fig 2b.

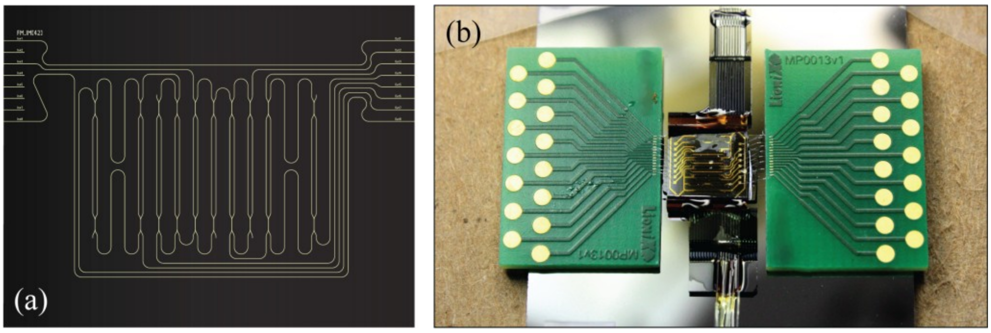

Fig. 2. Realization of the photonic chip discriminator. (a) Optical waveguide layout of the discriminator. (b) The packaged photonic chip with fiber array units and wirebonded PCBs

Photonic Link Characterizations

In this section, the two tone characterization of the MPL is described. The schematic of the measurement setup is shown in Fig. 3. The light from a high power DFB laser (EM4 inc.) is phase modulated in a phase modulator (Covega Mach-10) with two RF tones centered at the frequency of 2 GHz with a 10 MHz tone frequency separation. The power of the RF tones is set at +4 dBm. The phase modulated signal is then transferred into intensity modulation in the photonic discriminator chip. To overcome the loss in the optical chip a pair of EDFAs is used at the outputs of the discriminator prior to the balanced photodetector (BPD).

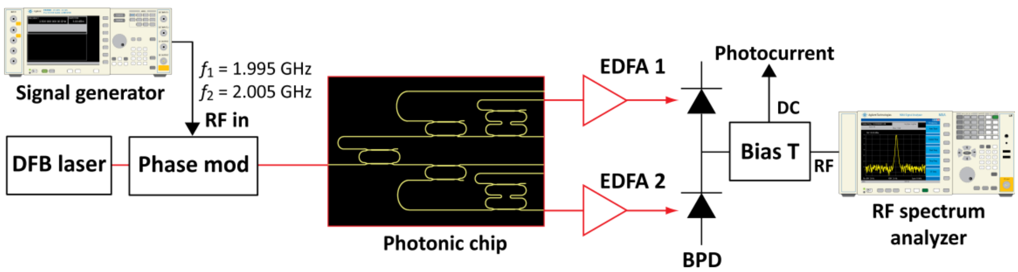

Fig. 3. The measurement setup used to characterize the MPL. A two tone test frequencies of 1.995 GHz and 2.005 GHz are carried out. To overcome the fiber-to-chip coupling loss a pair of EDFAs is placed at the chip output

To characterize the discriminator transfer function, the laser bias current is changed every 0.2 mA to change the laser central wavelength. The change in the central frequency of the laser is measured to be 0.75 GHz/mA. Then for every bias current, the power of the signal, second-order (IMD2) and third order (IMD3) intermodulation products at the frequency of 2.005 GHz, 4.0 GHz and 2.015 GHz, respectively, are measured in the RF spectrum analyzer.

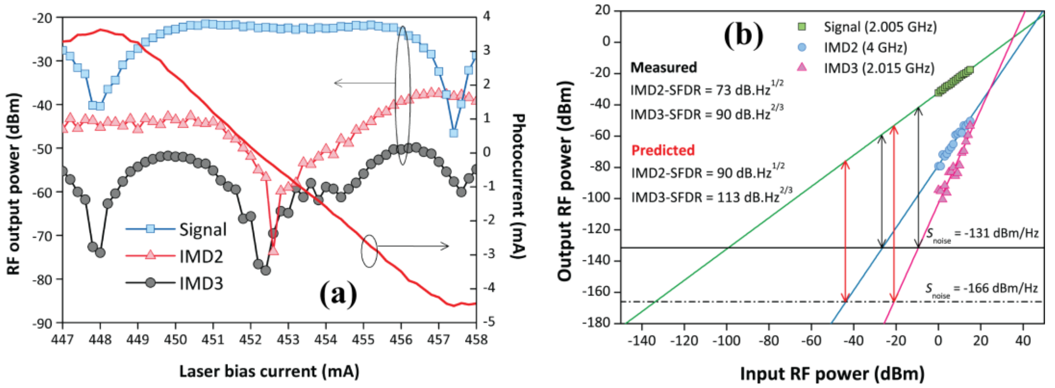

Fig. 4. Two tone test measurement results on the balanced MPL. (a) The detected photocurrent, signal, IMD2 and IMD3 powers as functions of the laser bias current. (b) The measured SFDR for the balanced MPL biased at 452.6 mA.

To yield the balanced discriminator, the photonic chip is tuned such that the through port response of Ring 1 (Fig. 1) is used to linearized the drop response of Ring 3 at Out 2 of the chip. At the same time, the through response of Ring 2 is used to linearize the drop response of Ring 1. The optical power at the desired outputs are equalized and subsequently detected and subtracted in the balanced detector. This subtracted photocurrent as well as the signal power and the IMD products are depicted in Fig. 4a. As evident from this figure, the bias region where both IMD2 and IMD3 products are suppressed coincides at approximately 452.6 mA. Thus, there is a single optimized bias point where both IMD products are suppressed and the SFDR is maximized. The measured second-order and third order dynamic range (IMD2-SFDR and IMD3-SFDR, respectively) is shown in Fig. 4b. Using the measured noise floor of -133 dBm/Hz, the measured IMD2-SFDR and IMD3-SFDR amount to 73 dB·Hz$^{1/2}$ and 90 dB·Hz$^{2/3}$, respectively. However, the measured noise floor is dominated by the noise from the EDFAs. If the optical loss in the chip is reduced, the EDFAs are not required anymore. In this case, the MPL noise can be designed to be limited by shot noise, which amounts to -166 dBm/Hz and the IMD2-SFDR and IMD3-SFDR will be enhanced to 90 dB·Hz$^{1/2}$ and 113 dB·Hz$^{2/3}$, respectively.

Conclusions

A phase-modulated direct detection MPL employing a fully programmable photonic discriminator chip has been reported. The MPL exhibit enhanced IMD2-SFDR and IMD3-SFDR simultaneously at a single bias operation.

References

[1] J. Wyrwas and M. Wu, “Dynamic range of frequency modulated direct-detection analog fiber optic link,” J. Lightwave Technol., **27**, 5552–5562, 2009.

[2] T. E. Darcie, et al., “Class-B microwave- photonic link using optical frequency modulation and linear frequency discriminators,” J. Lightwave. Technol., **25**(1), pp. 157–164, 2007.

[3] D. Marpaung, et al., “Design and realization of an integrated optical frequency modulation discriminator for a high performance microwave photonic link,” Proc. IEEE MWP 2010.

The research described in this paper is partly funded by the European Commission in the 7th Framework Program. The SANDRA project is a Large Scale Integrating Project for the FP7 Topic AAT.2008.4.4.2 (Integrated approach to network centric aircraft communications for global aircraft operations).