optica

Programmable photonic signal processor chip for radiofrequency applications: supplementary material

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Published 25 September 2015

This document provides supplementary information to "Programmable photonic signal processor chip for radiofrequency applications," http://dx.doi.org/10.1364/optica.2.000854. It includes descriptions of chip fabrication, experiment setup, and the transfer function of the generated radiofrequency filters.

http://dx.doi.org/10.1364/optica.2.000854.s001

Processor chip fabrication. The demonstrator processor chip described in this paper was fabricated using a Si_3N_4/SiO_2 waveguide technology (TriPleX™ [1], proprietary to LioniX B.V., The Netherlands) in a CMOS-equipment-compatible process. This waveguide platform allows to modify the waveguide dispersion and polarization properties by changing the cross-section. The waveguides can be optimized to provide extremely low losses, around 0.01 dB/cm (which includes bending losses for a radius of 75 µm) at C-band wavelengths. Tapered facets can be provided to reduce fiber-chip coupling loss to lower than 1 dB/facet. Thermo-optical tuning elements were implemented using Chromium heaters and Gold leads, allowing for a tuning speed in the order of milliseconds.

Experiments. The microwave photonic system setup for the RF filter experiment consists of a CW laser with 1 MHz-linewidth (EM4 EM-253-80-557) driven by a high-resolution current source (ILX Lightwave LDX-3620), a dual-parallel MZ modulator (JDSU 10Gb/s DPMZ), the programmable processor chip, and a photodetector (Discovery semiconductor DSC30S). The RF filter frequency responses presented in Fig. 4 and 5 were obtained by means of the S_{21} network factor measurement using a vector network analyzer (Agilent NA5230A). The configuring of the processor chip was performed by monitoring its optical response, using a high-resolution optical vector analyzer. Programming and calibration of the tuning elements were performed via a dedicated 12-bit-resolution multi-channel voltage supply.

Filter transfer function. The RF filter described in this paper is subject to the principle of a microwave photonic link based on double-sideband modulation and direction detection [2]; however, with the fiber link replaced by a processor chip. The derivations of the overall transfer function of such microwave photonic systems can be found in several previous works [2—4]. Using the similar derivation steps and assuming small signal condition, the overall transfer function of our RF filter can be expressed as

$$\begin{aligned} H_{\mathrm{RF}}(f) = \sqrt{G(f)}\cdot\sqrt{P_{\mathrm{cl}}}\cdot\{C^{*}_{\mathrm{opt}}(-\Delta f_2,\Delta f_1)\cdot[H_{\mathrm{rr\_2}}(f-\Delta f_2) \\ +H_{\mathrm{rr\_1}}(f+\Delta f_1)]+\mathrm{e}^{-\mathrm{j}\Delta\theta}\cdot C_{\mathrm{opt}}(-\Delta f_2,\Delta f_1) \\ \cdot[H_{\mathrm{rr\_2}}(-f-\Delta f_2)+H_{\mathrm{rr\_1}}(-f+\Delta f_1)]^{*}\} \end{aligned} \quad \text{(S1)}$$

where $G(f)$ represents the link gain without the effect of the processor chip; P_{cl} is the optical insertion loss of the processor chip; Δf_n is the frequency spacing between the resonance of nth ring resonator and the optical carrier; $H_{\mathrm{rr\_}n}(f)$ is the complex transfer function of the nth ring resonator, $C_{\mathrm{opt}}(-\Delta f_2, \Delta f_1) = H_{\mathrm{rr\_2}}(-\Delta f_2) + H_{\mathrm{rr\_1}}(\Delta f_1)$ is a complex amplitude factor to the optical carrier, and $\Delta\theta$ is the differential phase between the two optical sidebands ($\Delta\theta$ = 0 for amplitude modulation and π for phase modulation). The transfer function of a ring resonator can be given by

$$H_{\mathrm{rr\_}n}(f)=\frac{\sqrt{1-\kappa_n}-\sqrt{L_{\mathrm{rt}}}\cdot e^{-\mathrm{j}(2\pi f/\Delta f_{\mathrm{FSR}}+\phi_n)}}{1-\sqrt{L_{\mathrm{rt}}}\cdot\sqrt{1-\kappa_n}e^{-\mathrm{j}(2\pi f/\Delta f_{\mathrm{FSR}}+\phi_n)}} \quad \textbf{(S2)}$$

where κ_n and ϕ_n are the coupling coefficient and additional roundtrip phase shift of the nth ring resonator, Δf_{FSR} the FSR, and L_{rt} the roundtrip loss.

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