

An Innovative Photonic Integrated Channelizer Design for Hyperspectral Microwave Sounding

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Abstract: A photonic integrated channelizer is designed for hyperspectral and ultra-high band coverage remote sensing applications. The tunable delay lines maximize the transmission performance and the device demonstrates 4.5 GHz of optical bandwidth and channel separation.

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1. Introduction

Microwave (MW) sounder measurements have provided tremendous progress in numerical weather prediction, climate modelling and societal applications with high impact for human health and the economy. Current MW sounders however suffer from limited spectral resolution and coverage due to size, weight, power consumption, and cost (SWaP-C) constraints. Our innovative photonic integrated channelizer can simultaneously boost the spectral resolution (< 1 GHz) and band coverage (20 – 250 GHz), enabling significant improvements in the vertical sounding resolution and accuracy of the retrieved atmospheric water vapor and temperature profiles [1]. The up-conversion of a MW signal to an optical carrier allows photonic signal processing techniques with a drastic SWaP-C reduction over the entire bandwidth. Photonic devices have recently been proposed and applied to innovative MW photonic spectrometer architectures [2, 3]. In this scenario, photonic integrated circuits (PIC) are characterized by several benefits, such as the reduction in system footprint, low power consumption, broad operation bandwidth, and immune to radio frequency interference [4]. In this work, we present a photonic integrated channelizer based on a modified arrayed guided grating (AWG) design with optical and electrical interfaces and a minimized footprint. The single device has the potential to operate up to a 100 GHz frequency range. Each channel will target a bandwidth and a spectral channel separation of 4.5 GHz. The minimized SWaP-C allows the use of multiple PICs enabling a band coverage above 250 GHz. The spectral power in a single channel band can be directly measured or it can be digitized for hyperspectral (< 1 GHz) resolution applications.

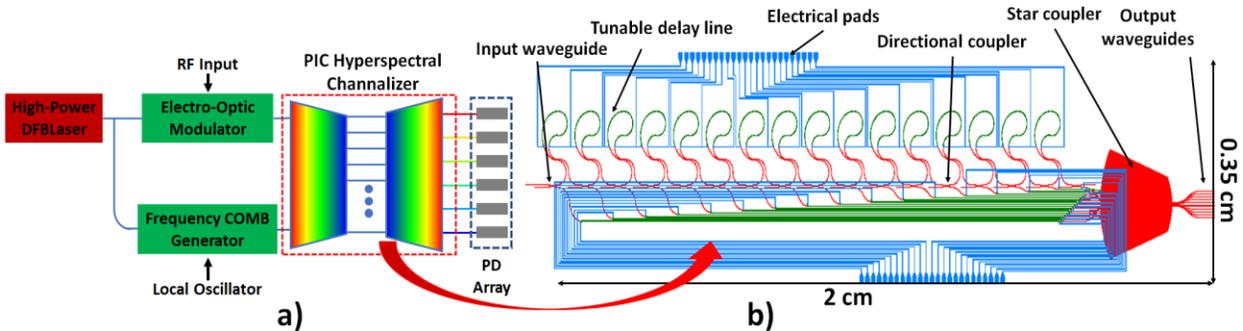


Figure 1. a) Microwave based spectrometer architecture for remote gas sensing and b) photonic integrated hyperspectral channelizer layout.

2. Spectrometer architecture and channelizer design

The MW photonic link architecture is reported in Figure 1 a). The high-power DFB laser is modulated by the input MW signal spectrum received by the antenna, with an electro-optic modulator. Once in the optical domain, the integrated hyper-spectral channelizing receiver, based on the novel proposed AWG design, provides the filtering technology to separate the broadened optical spectral signal into several 4.5-GHz bandwidth channels. Each channel can be down-converted to an intermediate frequency by beating it with the appropriate frequency component from an optical comb source or it can be directly detected. The result is multiple parallel channels, each spanning 0-4.5 GHz. This is the key technology that enables wider spectral coverage, narrower resolution and a smaller footprint. The design of the photonic integrated channelizer is shown in Figure 1 b). The time delays and the splitting ratios of

the directional couplers (DC) have been calculated in order to obtain a bandwidth and a channel spacing equal to 4.5 GHz. In order to thermally tune the optical delay lines (ODL), an integrated conducting path was designed above each line. This design minimizes the thermal crosstalk between the waveguide in the array, allowing a precise and independent control of the output spectra. The device consists of 16 ODL, 17 DC and a star coupler (SC). The input signal is split in two optical paths: the first one reaches the SC while the second one is delayed. The delayed signal is then split again: part of the signal feeds the second input port of the SC while the other part is delayed. The filtering performance of the device is obtained by optimizing the DC and ODL configurations. The heaters on top of the device enable the control of the delay lines. The footprint of the device is 2.0 cm x 0.35 cm. The insertion loss of the circuit can be decreased below 1 dB thanks to the improved design which does not require low-radius waveguide bends. The device was manufactured by ULL Technologies in a silicon nitride multi-project wafer run.

3. Simulation and experimental results

The PIC is tested using the setup reported in Figure 2 a). An external cavity tunable laser (TL) emits light in the range between 1549 nm and 1551 nm. A polarization controller (PC) maximizes the coupling efficiency between the optical fiber and the device under test while a current source, through a DC probe array, provides the electrical current to independently tune each ODL. A second optical fiber collects the light at the output ports of the device and a power meter controlled by a synchronization software reconstruct the frequency response.

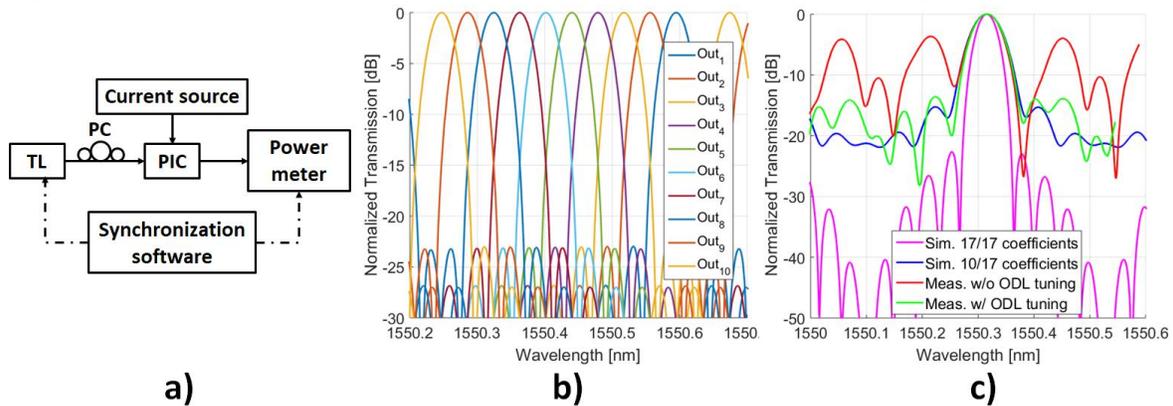


Figure 2. a) Experimental setup, b) simulated results and c) comparison between simulated and experimental results.

Figure 2 b) shows the simulated transmission response of the proposed AWG for 10 output channels with 4.5 GHz of bandwidth and 4.5 GHz of channel spacing. The optimization of the splitting ratio of the DC and the time delays change the intensity and phase of the light in the different paths, varying the shape of the spectral response with an improvement of the crosstalk and channel rejection. Figure 2 c) reports an example of the measured spectrum at one of the output ports (red line) obtained without tuning the ODLs. The result indicates a mismatch in the performance if compared to the simulated result (pink line). The difference is due to the fabrication inaccuracies that strongly affected the DC's splitting ratio of the device. However, the shape of the spectrum obtained by tuning the ODL (green line) is very similar to the simulation spectrum obtained with the new DC configuration (blue line).

4. Conclusions

This work demonstrates the feasibility of a photonic integrated channelizer, and the improvement added by the innovative design with tunable delay lines. The DC and the ODL are the key parameter of the device in order to maximize the transmission performance. The proposed design exhibits a high resolution and a limited crosstalk, with a bandwidth and channel separation of 4.5 GHz. The use of multiple PIC devices in the same system and channel digitalization will enable an unprecedented spectral coverage and resolution.

5. References

- [1] S. Boukabara and K. Garrett, "Benefits of a hyperspectral microwave sensor," in *SENSORS*, (IEEE, Limerick, Ireland), pp. 1881-1884 (2011)
- [2] B. B. Yang et al., "Photonic Integrated Circuits for Simultaneous Channelization and Downconversion," in *Avionics and Vehicle Fiber-Optics and Photonics Conference* (IEEE, Arlington, VA, USA), pp. 1-2 (2019)
- [3] K. Davis, et al., "Photonic Design Parameters for AWG-Based RF Channelized Receivers," in *Optical Fiber Communications Conference and Exposition* (San Diego, CA, USA) (2018)
- [4] T. Pett, et al., "Photonics-based Microwave Radiometer for Hyperspectral Earth Remote Sensing," in *International Topical Meeting on Microwave Photonics* (Toulouse, France), pp. 1-4 (2018)