Architecture for Compact Photonic Downconversion of Broadband RF Signals

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Abstract: We demonstrate the use of a dual comb photonic system for downconversion and disambiguation of RF signals ranging from 4.3 GHz to 17.3 GHz. Our system has future potential for miniaturization, a key for deployment in real-world applications.

In recent years, photonics-based RF downconversion has enabled exciting developments in technologies such as analog-to-digital converters. [1] These techniques leverage the timing stability of pulsed optical sources to sample broadband signals and surpass limitations in traditional electronics. For practical use, photonic downconversion should be compact - ideally even chip scale - yet some of the required components (e.g., mode-locked lasers) have kept some implementations on the bulky side.

Advancements in on-chip Kerr solitons have provided a convenient platform for micro-scale pulsed sources, and so have naturally been considered for use in downconverters for photonically-assisted ADCs, as in [2]. These microring sources typically have large repetition rates not suitable for direct detection (>10 - 100+ GHz), and so a dual comb system has been shown to be useful. In this construction, a signal of interest is modulated onto one comb, and the second comb is used to sample the signal comb, analogous to dual comb spectroscopy or optical cross-correlation. While these microring sources have tremendous benefit in terms of form factor, they suffer from fundamentally poor power efficiency and typically possess low power per comb line. In one recent effort [3], a similar dual-comb approach was demonstrated using EO combs rather than solitons, thereby providing potential for significantly higher power per comb line (and thus higher SNR).

In this work, we report a hybrid approach to dual-comb photonic signal channelization designed to leverage the portability of microcombs in conjunction with the larger SNR and flexibility of EO combs. Recent advances in thin-film lithium niobate modulators [4] could enable compact EO combs, making the entire photonic downconversion apparatus compatible with integrated photonic platforms.

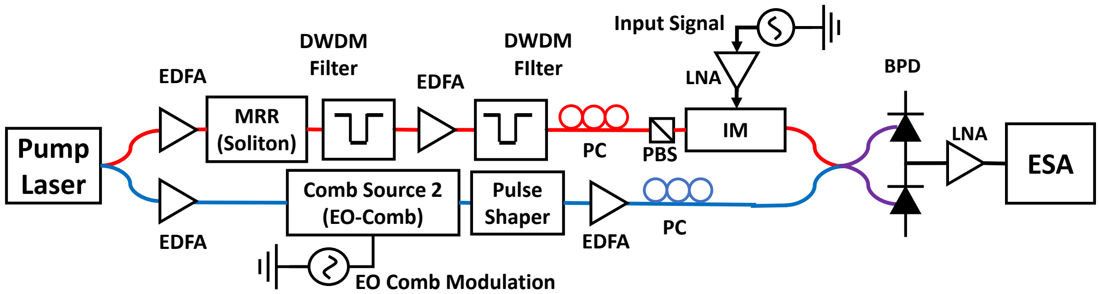

Fig. 1. Experimental setup diagram. MRR - Microring resonator, EO - Electro-optic, PC - Polarization controller, PBS - Polarizing beamsplitter, LNA - Low noise amplifier, IM - Intensity modulator, BPD - Balanced photodetector, ESA - Electrical spectrum analyzer

Our experimental setup is shown in figure 1. A single CW laser is split into two paths and amplified in two high-power EDFAs. One arm is coupled into a high-Q silicon nitride microring fabricated using the photonic Damascene reflow process. [5] A multisoliton is generated by tuning the pump laser from low to high wavelength across a ring resonance. The laser is backdetuned to land in a single soliton state with a repetition rate of ∼40.4 GHz. The resultant frequency comb is coupled off chip and amplified with an EDFA, and DWDM filters are used to remove the pump laser. The electrical signal to be downconverted is sent through a low-noise amplifier and modulated onto the soliton comb via a null-biased intensity modulator.

In the other arm of the setup, the amplified pump laser is passed through a series of electro-optic modulators, generating an EO comb spanning more than a THz with a repetition rate of ∼14.267 GHz. [6] The pulse shaper

(Finisar Waveshaper) following the EO comb generation passes every third EO comb line, thus effectively tripling the EO comb rep rate to ∼42.8 GHz. This yields a difference in repetition rates between the soliton and EO combs of δf_{rep} = 2.4 GHz. The EO comb functions as a bank of local oscillators which "sample" the modulated signal comb, folding the wideband electrical input down to a single band from DC to $\delta f_{rep}/2 = 1.2$ GHz. (See figure 2a) We further tune the pulse shaper in our setup to select out particular EO comb lines, allowing us to demodulate only specific bands of interest. The modulated soliton and filtered EO comb are combined with a 50/50 coupler and the RF output is recovered with a balanced detector which suppresses common-mode noise in the system. The bandwidth of our system is limited to 18 GHz on the high side by the pre-modulator LNA. On the low end, the passband of the DWDM filters attenuates the signal comb lines from which DC to 3.6 GHz would be demodulated.

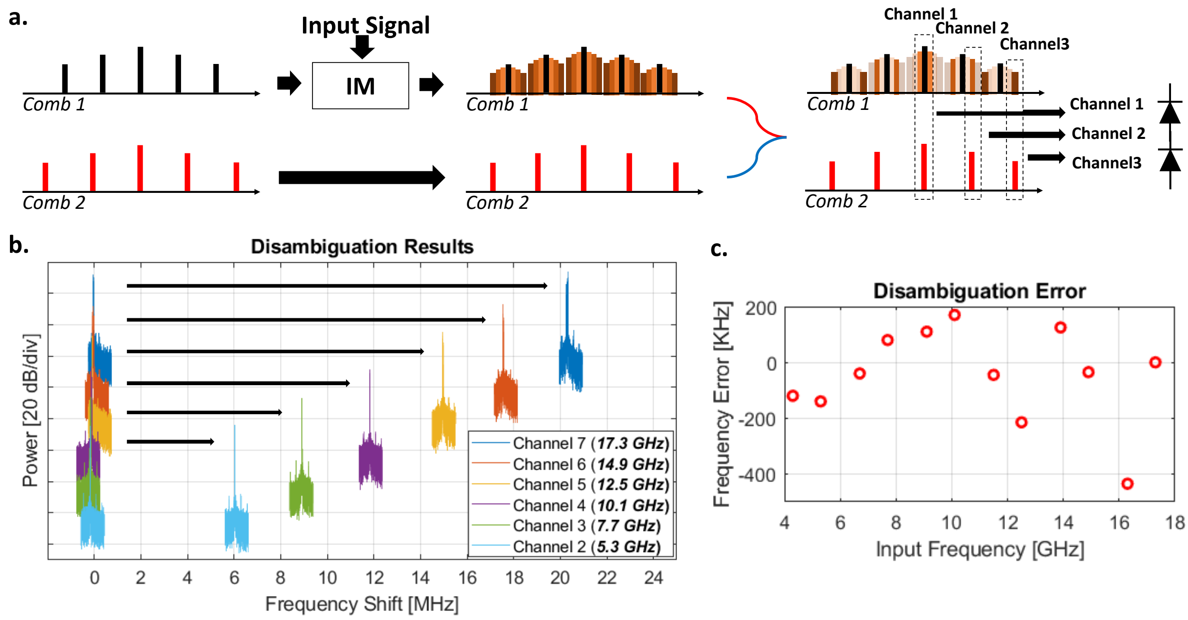

Fig. 2. **a.** Illustration of dual comb sampling approach. **b.** Example disambiguation results. As the EO comb repetition rate is changed by 3 MHz, the output frequency shifts by an amount corresponding to the channel at which the signal was input, thus allowing disambiguation. **c.** Experimental frequency error in signal disambiguation.

We note that the dual comb sampling causes a well-known ambiguity effect as input signals are folded down into a single Nyquist zone. [7] We leverage one of the advantages of our EO comb by tuning its driving frequency, thereby shifting the comb repetition rate. This allows us to disambiguate downmixed signals and recover the actual input signal frequency with a high accuracy. [8] Figure 2b illustrates this point visually; input signals at widely different frequencies (5.3 GHz - 17.3 GHz, corresponding to channels 2-7 in the figure) are sent into our link one at a time, and are folded down to similar intermediate frequencies (IFs) in the link output. By altering the EO comb repetition rate the signal's original frequency band becomes immediately clear - when the repetition rate is tuned, the IF shifts by an amount determined by the input frequency / δf_{rep} multiplied by the change in repetition rate (here, +3 MHz). Figure 2c illustrates the low error between actual input frequency and recovered input frequency using this technique. We believe this error could be further improved by stabilizing our free running soliton's repetition rate. Note, however, that the frequency error is well below the Nyquist bandwidth, signifying the correct input Nyquist band can be recovered accurately in all cases.

In summary, we have demonstrated a photonic link for downconversion of broadband electrical signals possessing potential for chip-scale integration. We note that while our EO comb system has been implemented with bulk components, recent advances in thin film lithium niobate modulators may allow the demonstration of similar systems on-chip in the coming years.

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