# Experimental Demonstration of a Variable Bandwidth, Shape and Center-Frequency RF Photonics Filter using a Continuously Tunable Optical Tapped-Delay-Line and Having an Optical Output

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**Abstract:** We experimentally demonstrate the RF photonics filter using optical tapped delay line based on an optical frequency comb and a PPLN waveguide as the multiplexer. RF filters with variable bandwidth, shape and center-frequency are implemented.

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## 1. Introduction

RF and microwave photonics has many applications, and these areas generally require accurate signal filtering and processing.[1,2] As is true for any non-static and dynamic analog system, there is value in the ability to tune such a filter in terms of its bandwidth, shape, and center frequency. In general, optical approaches tend to employ a tapped-delay-line, which is a key building block for data signal processing.[2-4] Previous reports have shown tunable RF filters, for which the complex tap coefficients can be varied.[1,5, 6] These demonstrations have typically multiplexed the tapped signals in the electrical domain following photodetectors.[1-3] Although these approaches produce tunable RF filter characteristics, they do not allow for further signal processing or transmission while still in the optical domain, which might provide for additional overall system value.

In this paper, we experimentally demonstrate a variable bandwidth, shape and center-frequency RF photonics filter using a continuously tunable optical tapped-delay-line (OTDL) and having an optical output. We modulate the RF signal on the frequency lines of an optical frequency comb as the taps of the OTDL following by a dispersive element to achieve the delay. Utilizing a periodically poled lithium niobate (PPLN) crystal, we multiplex the tapped delay lines in the optical domain. RF filters with bandwidths of 480 MHz and 340 MHz are implemented. Moreover, tunablity over the center frequency and different shapes, i.e., Sinc and Gaussian, are shown.

## 2. Concept

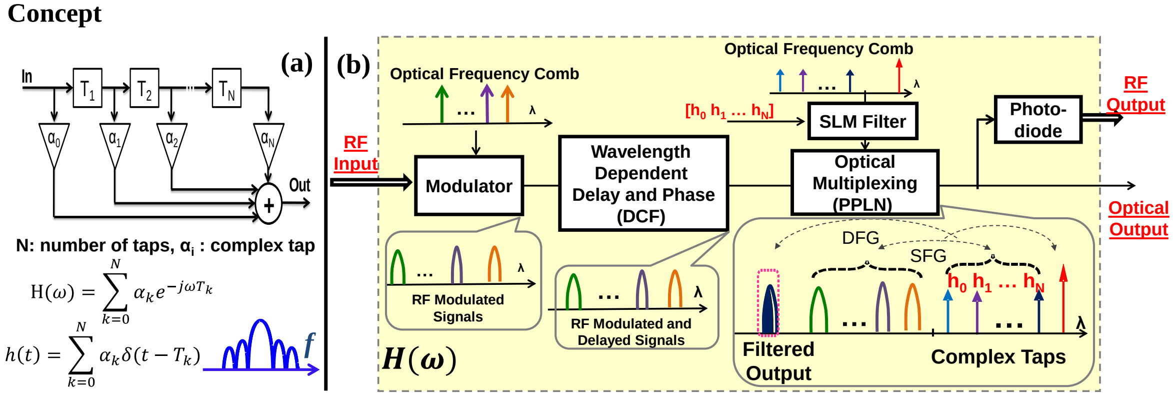


**Fig. 1.** (a) Concept of RF FIR filter. (b) Concept of microwave photonics FIR filter generation using comb based OTDL (using optical comb as the taps of the FIR filter and utilizing DCF to delay the tapped RF modulated signals and multiplexing the signals in a PPLN waveguide).

The concept of the RF FIR filter using a TDL structure is shown in Fig. 1(a). Figure 1(b) depicts the concept of microwave photonic filter using a frequency comb based OTDL. The frequency comb fingers are modulated with the RF signal (generated by a vector network analyzer (VNA)) such that the number of taps equals to the number of fingers. The modulated fingers are sent through a dispersion compensating fiber (DCF) to induce delays on the signals with the relative delay of $\Delta T = D\times\Delta\lambda$, where D is the dispersion parameter and $\Delta\lambda$ is the wavelength separation between frequency fingers. These delayed signals are equivalent to OTDL taps that need to be coherently combined. Tap weights are tuned using a spatial light modulator (SLM) to introduce arbitrary phase and amplitude on the fingers. The taps are multiplexed in a PPLN waveguide with quasi-phase matching (QPM) frequency of $f_{QPM}$. Delayed signals are mixed with another set of coherent pumps through the sum-frequency-generation (SFG) process and this creates a signal at $2\times f_{QPM}$. All the signals, pumps, and another pump laser are injected into the PPLN waveguide for the difference-frequency generation (DFG) process to convert the output of the FIR filter to the desired $f_{out}$. To achieve the desired filter shape at the output, we adjust the phase and amplitude of coherent pumps to the tap weights of the FIR filter. The output of the designed FIR filter can be either (a) kept in optical domain or (b) transferred to RF domain using through a photodiode and then be analyzed in the VNA. Keeping the singal in the optical domain saves the feasibility of further processing in the optical domain on the RF signal.

## 3. Experimental Setup

The experimental setup for the RF photonics filter is shown in Fig. 2. A mode-locked laser with a 10GHz repetition rate generates a coherent frequency comb which passes through a DLI with a free spectral range (FSR) of 20-GHz to increase the frequency spacing. The resulting 20-GHz frequency comb is sent through an EDFA and a highly nonlinear fiber (HNLF) to generate a flat and broad spectrum. The programmable SLM filter selects and writes complex weights on the comb fingers, and separates signals and coherent pumps into two separate paths at the output ports. For each path, we select up to 13 comb fingers with a spacing of 0.64 nm. Using an intensity modulator, RF signal generated by a VNA is modulated on the comb fingers. After enough amplification, the signals and pumps travel through a ~400 ps/nm DCF to introduce relative delays on the signals. With another amplified CW laser pump at ~1564 nm, all the signals and pumps are sent to a 4-cm-long PPLN waveguide to create the photonic RF FIR filter with the optical spectrum shown in Fig. 3(a). The output signal is filtered and sent to a photo-diode to be analyzed in the VNA.

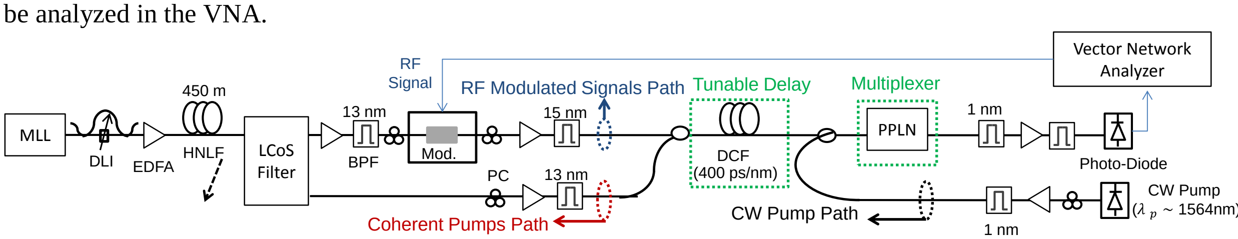


**Fig. 2.** Experimental setup. MLL: Mode Lock Laser, DLI: Delay Lin Interferometer, BPF: Band Pass Filter, PC: Polarization Controller.

## 4. Results and Discussion

The experimental results of the RF photonics filter are shown in Fig. 3. Figure 3(b) shows the experimental result which matches the simulation of the RF Gaussian filter with 13-tap. To change the bandwidth (BW) of the filter, we change the tap coefficients weight to get the desired BW (shown in Fig. 3(c)). Moreover, we could implement different shapes of the filter using 9-taps photonics FIR filter (see Fig. 3(d)). Furthermore, tunablity over the center-frequency (CF) is shown in Fig. 3(e). We could also implement filters with different number of taps (Fig. 3(f)). As shown in the experimental results, different RF filters with complex coefficients can be achieved in this method.

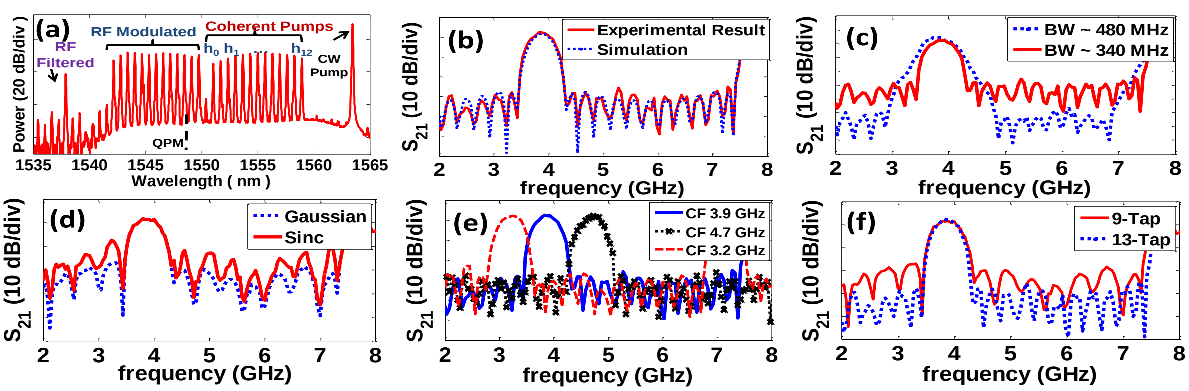


Fig. 2. Experimental Results. (a) Optical spectrum of the PPLN output. (b) 13-tap FIR Gaussian RF photonics filter. (b) Tunabity over the bandwidth (BW). (c) Tunablity over the shape. (d) Tunablity over the center-frequency (CF). (b) Tunablity over the number of taps.


## Acknowledgements

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## 5. References


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