Experimental Demonstration of a 2-Stage Continuously Tunable Optical Tapped-Delay-Line in which N+M Pump Lasers Produce N×M Taps

A. Mohajerin-Ariaei[1], M. R. Chitgarha[1], M. Ziyadi[1], S. Khaleghi[1], A. Almaiman[1], J. Touch[2], M. Tur[3], L. Paraschis[4], C. Langrock[5], M. M. Fejer[5], and A. E. Willner[1]

1) Department of Electrical Engineering, University of Southern California, 3740 McClintock Ave, Los Angeles, CA 90089, USA
2) Information Sciences Institute, University of Southern California, 4676 Admiralty Way, Marina del Rey, CA, 90292, USA
3) School of Electrical Engineering, Tel Aviv University, Ramat Aviv 69978, Israel
4) Cisco Systems, 170 W. Tasman Drive, San Jose, CA 95134, USA
5) Edward L. Ginzton Laboratory, 348 Via Pueblo Mall, Stanford University, Stanford, CA 94305, USA
mohajera@usc.edu

Abstract: We experimentally demonstrate a 2-stage continuously tunable optical tapped-delay-line in which N+M pump lasers produce N×M number of taps. A 3×2-taps optical correlator is implemented to search multiple patterns among 20-Gbuad QPSK signals using nonlinearities and coherent comb source.

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1. Introduction

Tapped-delay-lines are a fundamental building block for many data signal processing functions, including correlation, equalization, filtering, and almost any element that provides a transfer function [1]. Moreover, it may be beneficial to enable an optical tapped-delay-line (OTDL) so that: (i) certain functions may be performed natively on optical data streams, and (ii) there exists the potential for optical functions to be performed at a very high rate [2].

There have been several reports on different ways to achieve an optical tapped-delay-line [2-5]. One technique to achieve a continuously tunable OTDL is the use of chromatic dispersion as well as wavelength conversion and mixing [3,5] In this approach, an input data stream experiences a transfer function, and a set of wavelength pumps is used such that each wavelength acts as one of the taps in the OTDL.

A key challenge of this OTDL approach is that the number of taps is limited to the number of pump wavelengths, and yet there are applications for which there might be a need for a fairly large number of taps. In such a scenario, the large number of needed pumps may make this approach impractical. Therefore, a laudable goal would be to enable a large number of taps with a fewer number of pump lasers.

In this paper, we experimentally demonstrate a 2-stage continuously tunable OTDL in which N+M pump lasers produce N×M number of taps. A 3×2-taps OTDL correlator is implemented to search multiple patterns among 20-Gbuad QPSK symbols using nonlinearities and coherent comb source.

2. Concept

Fig. 1(a) depicts the generic form of a proposed tunable $N \times M$-taps OTDL. The structure composed of two cascades OTDL with N and M number of taps respectively. For this structure, the relation between the input signal $x(t)$ and the output $z(t)$ is determined by $z(t) = \sum_{i=0}^{N-1} \sum_{j=0}^{M-1} c_{ij} x(t - iT - j\tau)$ where $c_{ij} = a_i b_j$, representing an OTDL with $N \times M$ number of taps. By choosing appropriate values for the delays, for instance, $T = T_s$ and $\tau = NTs$, the output function can be simplified as $z(t) = \sum_{k=1}^{N\times M} h_k x(t - kT_s)$ where Ts denotes one symbol time interval.

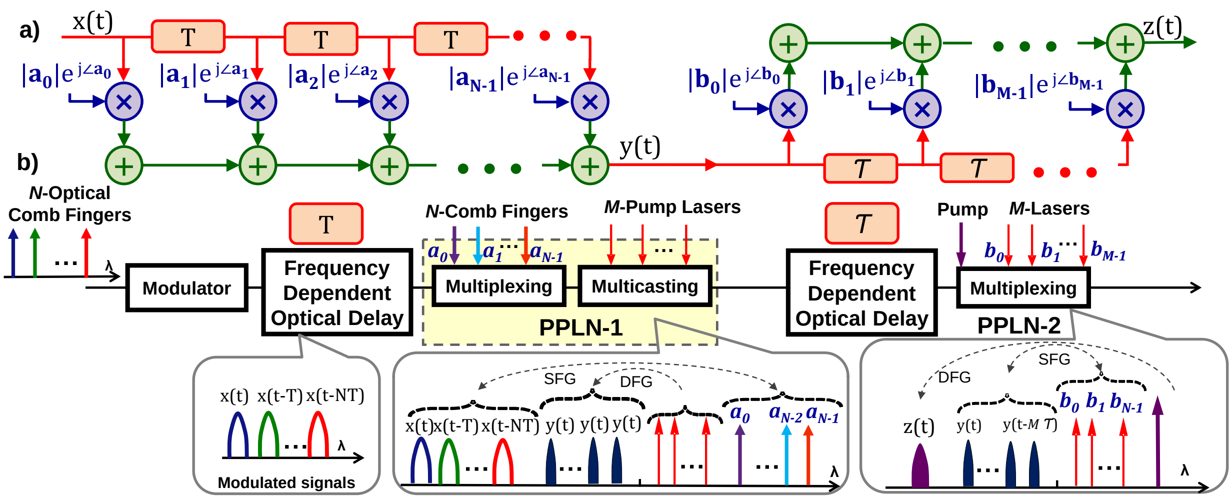

Fig. 1. (a) Generic block diagram of an OTDL with N×M number of taps. (b) The principle of operation of the proposed OTDL.

The principal of operation of our proposed OTDL is shown in Fig.1(b). N fingers from an optical comb source are selected and modulated using an I/Q modulator. These signals travel through a chromatic dispersive element at various speeds incurring a different time delay (T). The delayed signals with another set of fingers (a_i) which are passed through the phase/amplitude filter multiplexed together in a PPLN-1 waveguide and by injecting M pump lasers, M replicas are generated. The M replicas are delayed relatively (τ) and with the M lasers (b_j) which are passed through another phase/amplitude filter are multiplexed together in PPLN-2 to generate the output signal $z(t)$. The proposed method can be used to implement a N×M-taps optical correlator. To find the specific pattern on the stream, the values of stream{A, B, C, D} are mapped onto the four QPSK symbols. Then, the optical signal is multiplied with the conjugate of the target pattern to achieve the correlation output. For instance, to identify the appearance of a six-length pattern [BDCABD] in a long stream of optical QPSK symbols, a 3×2-taps OTDL might be used in which the correlator weights are set to the phase conjugate of the target pattern [B*D*C*A*B*D*].

3. Experimental Setup

The experimental setup for 3×2-taps OTDL is illustrated in Fig. 2. A flat and broad spectrum 20-GHz frequency comb can be produced using the method of [6]. A SLM phase/amplitude filter is used to select and write complex weights on comb fingers (a_i) and separate them into two paths. For each path, three comb fingers with a spacing of 1.92 nm are selected. A nested Mach-Zehnder modulator generates the 40-Gbit/s optical QPSK data on comb fingers. The signals sent through a ~650 m DCF to introduce one symbol-time relative delay between the two adjacent signals. The delayed signals with comb fingers are multiplexed together and with two injected pumps produce two replicas in PPLN-1. The two replicas and pumps are sent to another SLM to adjust appropriate phases on the pumps (b_j). They are all with another pump are injected to PPLN-2 to create the correlator output signal.

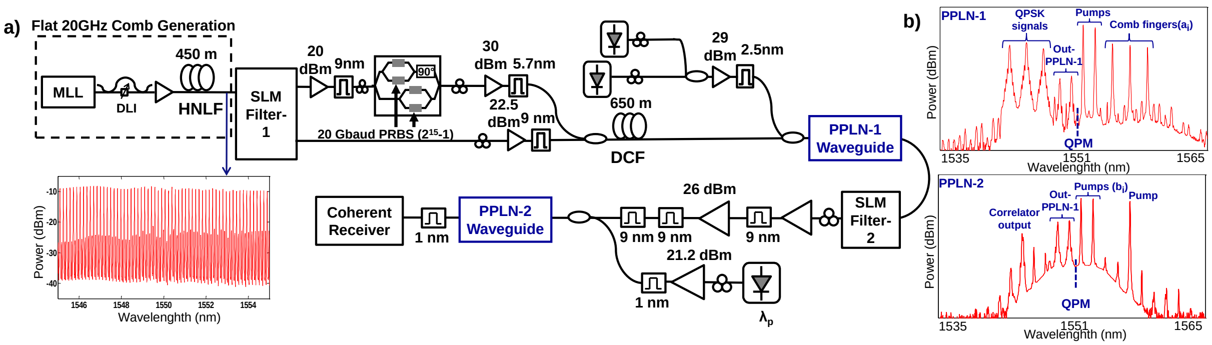

Fig. 2. (a) Experimental setup. DCF: Dispersion compensating fiber, SLM: Spatial light modulator, (b) Optical spectra of PPLN-1, PPLN-2.

4. Results and Discussion

Figure 3(a) shows the 3×2taps correlator result for the specific pattern of [BDCABD]. All output symbols in all four corner points of the IQ-plane can be detected as the target pattern with 0°, 90°, 180°, and 90° rotations, separately [6]. Analyzing the upper right corner of the constellation yields the location of the matched patterns in a 4096 QPSK symbol stream shown as the correlator peaks in Fig. 3(a). Figure 3(b) shows the similar results for [BCDAAB].

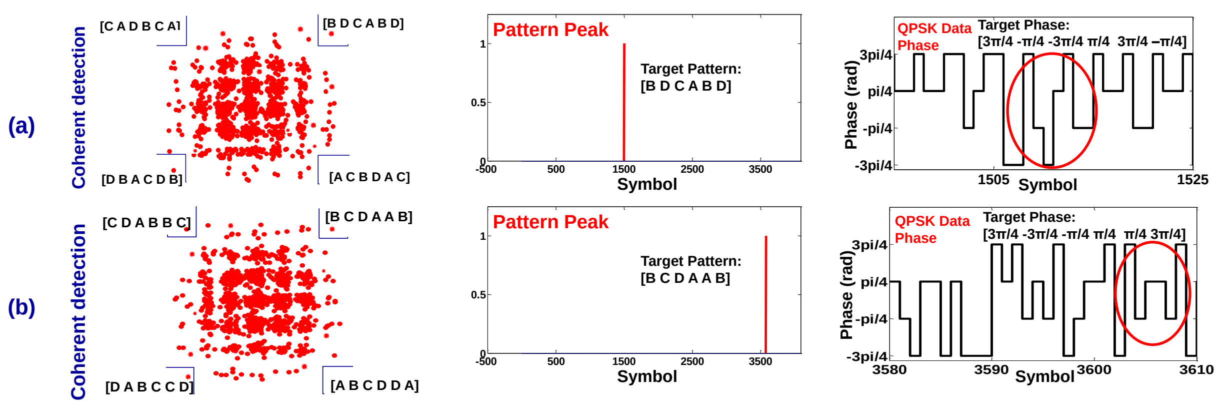

Fig. 3. Experimental results for 3×2-taps OTDL correlator. (a) Target pattern [B D C A B D]. (b) Target pattern [B C D A A B].

Acknowledgments

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4. References

[1] J. G. Proakis, Digital Communications. McGraw-Hill (2000).
[2] C. R. Doerr, JLT, vol. 22, no. 1, pp. 249–256, (2004).
[3] J. Sharping, Opt. Exp.,vol.13, no.20, (2005).
[4] M. S. Rasras, IEEE Photon. Lett., vol. 20, no. 9, (2008).
[5] S. Khaleghi, et al., IEEE Photonics Journal 4, 1220 (2012).
[6] M. Ziyadi, Opt. Exp., vol. 22, no. 1, pp. 84-89, (2014).