Tunable All-Optical WDM Channel Selection using Raman Assisted Cascaded Parametric Amplification

F. Alishahi[1], Y. Cao[1], M. Ziyadi[1], A. Mohajerin-Ariaei[1], A. Fallahpour[1], A. Almaiman[1], C. Bao[1], P. Liao[1], A. J. Willner[1], B. Shamee[1], Y. Akasaka[2], T. Ikeuchi[2], S. Takasaka[3], R. Sugizaki[3], J. D. Touch[1], M. Tur[4], A. E. Willner[1]

1) University of Southern California, 3740 McClintock Ave, Los Angeles, CA 90089, USA
2) Fujitsu Laboratories of America, 2801 Telecom Parkway, Richardson, TX 75082, USA
3) Furukawa Electric Co., Ltd., 6 Yawatakaigandori, Ichihara, Chiba, 290-8555 Japan
3) School of Electrical Engineering, Tel Aviv University, Ramat Aviv 69978, Israel
falishah@usc.edu

Abstract: A cascaded configuration of Parametric Amplifiers (PA) using distributed Raman amplification is proposed to selectively extract either of QPSK channels in a WDM system. Wavelength selectivity is obtained by changing PA pump wavelength and phase.

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1. Introduction

Tunable optical filtering plays an essential part in optical links due to the ever increasing demand for channel selection of wavelength division multiplexing (WDM) of multi-level amplitude and phase encoded data [1]. An optimum tunable optical filter strives to keep certain potential advantages such as wavelength tunability, bandwidth tunability, high extinction ratio and favorably optical gain. However, though the filtering takes place in optical domain, the majority of available technology for tuning relies on mechanical rather optical techniques [2]. Aside from the fact that mechanical tuning is prone to noise, it also dramatically decreases the speed of filter reconfigurability. Also, as a passive element, optical filters are lossy elements and unable to provide gain.

The ability to combine all the potential advantages of optical tunable filter using nonlinear interactions is intriguing enough, since the nonlinearity has been known to have low additive noise and potential higher speeds[3]. Hence, utilizing nonlinear interactions, high speed reconfigurable optical filters are promising. Phase-sensitive fiber optic parametric amplifiers (PS-FOPA) with their unique phase-sensitive amplification ability and ultralow noise figure, are among the most efficient nonlinear interactions which can potentially provide high speed reconfigurability [4].

To date, there are quite few works on PS-FOPA performance as wavelength selective elements [5-6]. In this paper, we experimentally demonstrate PS-FOPA in a special configuration to realize tunable optical filters. The filter is not only wavelength tunable but is also bandwidth using the pump wavelength and pump phase as the optical knob. Using PS-FOPA amplification, the filter can also provide optical amplification for the selected channels. The extinction ratio between 13dB to16dB has been achieved and the system shows the net gain of around 6dB and almost zero OSNR penalty.

2. Concept

The conceptual schematic in Fig. 1(a) describes the fundamentals of our PSA based filtering. Multiple channels of WDM are at the input. At the output either of WDM channels of input data stream can be selected by amplifying that channel while de-amplifying the others. The selection process takes place all-optically by tuning the wavelength and the phase of the pump of a PS-FOPA. The conceptual diagram in Fig. 1(b) shows the interaction inside a cascaded PS-FOPA configuration [5-6]. PS-FOPAs are based on the Kerr-induced four-wave mixing (FWM) process occurring between one or two pump wave(s) (P), a signal (S) and an idler (I) wave. The phase mismatch between pump(s), signal and idler dictates the efficiency and direction of the energy transfer between pump(s) and signal/idler. In the cascaded structure shown in Fig. 1(b) the phase mismatch can be controlled by the wavelength detuning of pump and signal/idler due to the strong dispersion of the connecting single mode fiber (SMF) between two highly nonlinear fibers (HNLF)s.

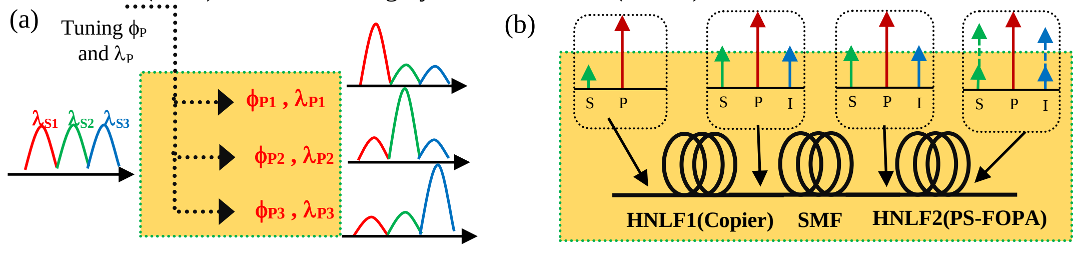

Fig. 1: (a) Conceptual Schematics of the PSA filter, λp and ϕp are the pump wavelength and phase. (b): Schematic of cascaded PS-FOPA

3. Experimental Setup and Results

The Experimental setup is shown in Fig.2. Three WDM channels at wavelengths 1562.83nm, 1563.5nm and 1564.12nm, carrying QPSK modulation are combined with a phased modulated cw pump. All the waves are made aligned and launched to the 500m-long HNLF1 which acts as a copier to generate idler waves as depicted in the spectrum observed from 1% tap at point A. The waves are then injected into an optical processor which is basically a phase shifter for the pump. Optical processor also equalizes the three channels before entering 500m of HNLF2 (see the spectrum at point B). Before entering the HNLF2, pump is strongly amplified by a 700m-long Raman amplifier. The output spectrum at point C shows the quasi periodic trend of PSA that mainly takes place inside HNLF2. After passing through an arrayed waveguide grating (AWG) pump is filtered out and three channels are routed to a coherent receiver locked to a Local Oscillator (LO).

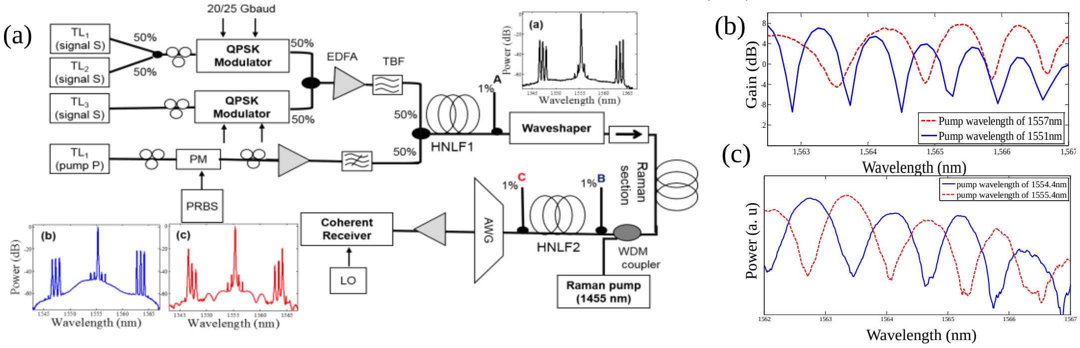

Fig. 2 (a): Experimental setup. (b): Bandwidth tunability. (c): wavelength tunability of output spectra of PS-FOPA.

Fig.2(b) and (c) show the output spectra for different pump wavelengths. As shown, PS-FOPA have acute wavelength dependent output spectra [5]. Instructive or destructive interferences between pump signals and generated idlers leave quasi periodic peaks and nulls-typically narrower than 1nm- in the output spectra [5-6]. The position/repetition frequency of these peaks and nulls can be changed by changing the pump wavelength. For instance, Fig. 2(b) shows the period reduction by almost 50% around 1564.5nm when pump wavelength is 6nm larger. Also, Fig. 2(c) demonstrates the interchange of peaks and nulls around 1563.5nm having the pump wavelength changed by 1nm. For the pump wavelength of 1555.4nm, the middle channel modulated at 20Gbaud rate, is positioned at the center of a peak as depicted in Fig. 2(c) while the two sideband channels are placed at the adjacent nulls. The middle channel is selected from the others with an extinction ratio of nearly 13dB (see Fig. 4(a)). However, the selection of channels at 1562.85nm or 1564.12nm needs a different procedure since they are symmetrically positioned either at nulls or peaks. Here, the pump wavelength is first tuned at 1554.4nm so the two channels are equally placed at two peaks and the middle channel is in a null (Fig. 2(c)). To cancel out either wavelengths of 1562.85nm or 1564.12nm the pump phase is adjusted to a specific value by optical processor. At s specific phase, the channel at 1564,12nm is suppressed by 16dB lower than channel at 1562.85nm (see Fig. 3(b)). Interestingly enough by changing the pump phase by almost 90^{o} from its previous value it is possible to have the opposite situation and select the channel at 1564.12nm and suppress the one at 1562.85nm (see Fig. 3(c)). This time the extinction ratio is around 13dB.

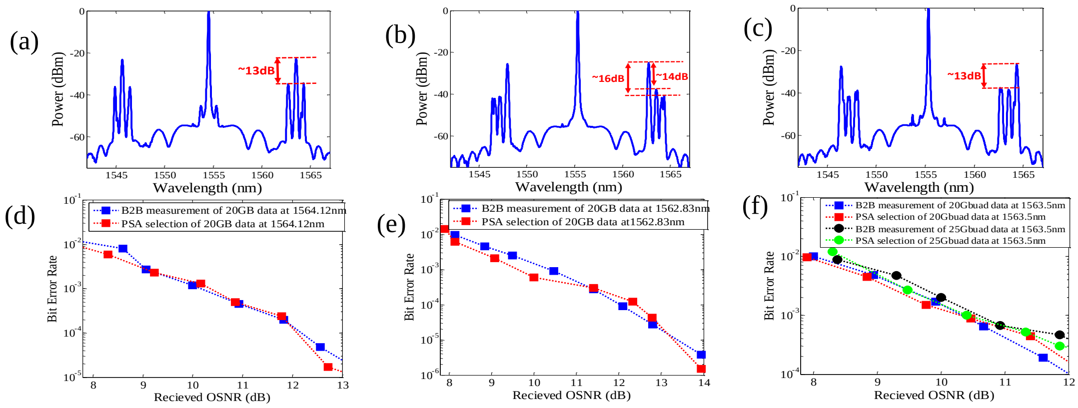

Fig. 3 : (a) : Output power spectra for the selection of middle channel, (b): Left channel, (c): right channel. System performance for the selection of (d): right channel (e): Left channel (f): middle channel.

Also, two different symbol rates of 20GB/s and 25GB/s are considered and the BERs are captured in the coherent receiver. These results are compared against the Back-to-Back (B2B) results when the LO is tightly locked to the desired channel of the transmitter. Almost no OSNR penalty is observed. It is important to mention that our proposed scheme produces 6dB overall gain for each channel. The gain can be increased if high power EDFAs and pulsed pump are used [6]. Also, the filtering scheme used here can be extended to larger number of channels when farther channels are killed out by tuning their phases.

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4. Reference

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