Broadband Uniform Wavelength Conversion and Time Compression of WDM Channels

Mohammad Amin Shoaie, Armand Vedadi, Camille-Sophie Brès
Ecole Polytechnique Fédérale de Lausanne (EPFL), Photonic Systems Laboratory, CH-1015 Lausanne Switzerland
Email: amin.shoaie@epfl.ch

Abstract: A scheme based on 2-pump OPA is proposed for uniform wavelength conversion and optimized compression. We show 4.7-fold compression over 32 nm range resulting in Gaussian pulses from sinusoidal modulation and enabling simultaneous compression of WDM channels for granularity adaptation.
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1. Introduction

Optical parametric amplifiers (OPA) has attracted a great interest due to their multi-functionality in optical signal processing area. Wavelength conversion (WC) is one attractive functionality in optical networks which prevents electrical regeneration in reconfigurable optical add-drop multiplexers (ROADM). It has been shown that 2-pump OPAs fulfill key requirements of WC devices by achieving broadband operating range, controlled inter-channel cross-talk and acceptable conversion efficiency. More importantly they are transparent to advanced modulation formats and can operate in polarization insensitive mode [1-4]. In all previous WC studies, continuous wave (CW) OPA pump seeds were used. However, employing a pulsed pump scheme provides new flexibility in terms of pulse compression, adaption to various network speeds/granularity and de-multiplexing capabilities.

In this paper we demonstrate a broadband uniform wavelength convertor based on 2-pump OPA with sinusoidal modulated pumps. By optimizing pumps modulation and compensating the inherent chirp of the converted wave, more than 4.7-fold time compression can be achieved for individual WDM channels. Leveraging the high compression and uniform wavelength response of the amplifier, we show that simultaneous compression of wavelength division multiplexed (WDM) channels for granularity adaptation is possible. This could be a key enabling tool in future multi-granular networks where the ability to change the bitrate transparently between network is essential.

2. Principal, experiment and results

In a 2-pump OPA the conversion gain profile depends on total pump peak power P_0, nonlinear medium specification (length L, nonlinear coefficient γ) and total phase mismatch $\kappa = \Delta\beta + \gamma P_0$ where $\Delta\beta$ is a function of pump and signal detuning from zero dispersion wavelength (ZDW), λ_0 as well as dispersion parameters of the medium. With proper pump powers and wavelengths, uniform conversion efficiency is obtained over a wide wavelength range, enabling efficient and uniform WC. However, once the pumps are modulated in intensity, the signal/idler will be gated by a time window centered at the pumps peak position [5]. The converted wave in this case is multiplied by the time window which shape is determined by normalized phase mismatch term, $\Delta\beta/\gamma P_0$. In this study we choose $\Delta\beta/\gamma P_0$ = -1, corresponding to the highest conversion gain. With sinusoidal modulated pumps at frequency f_R and signal initial amplitude $A_S(0)$, the idler amplitude field has a Gaussian chirped profile given by:

$$A_I(L) = A_S(0)\exp\left(\gamma P_0 L\right)/2 \times \exp\left(-\gamma P_0 L\left(\pi f_R t\right)^2\right) \times \exp\left(j\frac{3}{2}\gamma P(t) L\right) \quad (1)$$

Due to the nonlinear interaction, the idler in Eq.1 is compressed compared to the modulated pumps. Yet, to perform TDM of the converted waves, the time window can be further compressed following two adjustments. First by changing the bias voltage of intensity modulators, the initial sinusoidal modulation on each pump is modified by producing sidebands which amplitude is equal to the pump DC component. In fact the pump shape is modified from $P(t) = P_0 cos^2(2\pi f_R t)$ to $P(t) = P_0/9 \times sin^2(3\pi f_R t)/sin^2(\pi f_R t)$ leading to 60% decrease of FWHM of the pump pulses. Intuitively, this latter pump shape is in optimum trade-off between pulse width and peak to first side lobe ratio, such that the side lobes do not induce parametric gain. Second the chirp of generated Gaussian pulses is compensated using a dispersive element to obtain transform-limited pulses. We approximate the chirp factor C = +3/2 which roughly leads to 40% decrease of the Gaussian time window.

To investigate the uniform compression scheme the experimental setup in Fig.1 is realized. Two CW lasers (TL_1 at 1548.9 nm and TL_2 at 1612.7 nm) are used as pumps and are intensity modulated by a 10 GHz sinusoidal wave. A phase shifter synchronizes the peaks of two pumps. Next a PRBS phase modulation at 2.5 Gb/s is done to increase the Brillouin threshold. The pumps are then amplified by EDFA, filtered by 1 nm filters and combined by a WDM coupler. The signal is sent though a 90/10 coupler into a HNLF with L = 250 m, γ = 12 $W^{-1}km^{-1}$ and λ_0 = 1580.1 nm. Multiple signals at different wavelength (ch_n) can also be coupled. The total pump peak power at HNLF input is P_0 = 0.68 W. The converted pulses are finally de-chirped by a wavelength selective switch.

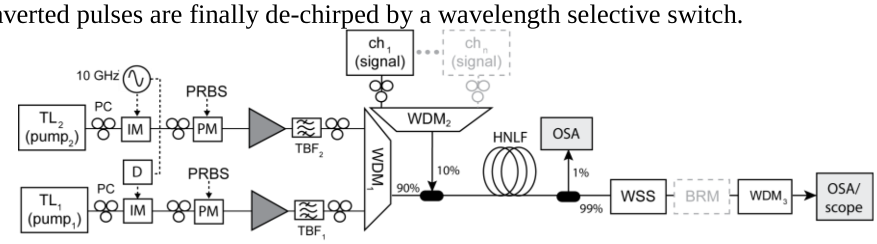

Fig.1 Experimental setup. TL: tunable laser; IM: intensity modulator; PM: phase modulator; TBF: tunable bandpass filter; WDM: wavelength division multiplexer; OSA: optical spectrum analyzer; WSS: wavelength selective switch, BRM bit rate multiplier.

The setup is first characterized for a single wavelength WDM channel. Figure 2(a) shows the experimental and theoretical gain spectrum along with the normalized phase mismatch term derived from theory showing that $\Delta\beta/\gamma P_0$ is indeed bound to -1 in the 1564 - 1596 nm range. Figure 2(b)-(c) show the experimental time window from sinusoidal pumps and equalized sideband pumps before and after de-chirping along with Gaussian fitting. The pump shape is also included as an inset. From fig.2(a),(c) it is shown that for optimized compression, the converted idler has uniform 6.6 ps Gaussian pulse shape (4.7 fold compression) over 32 nm wavelength range.

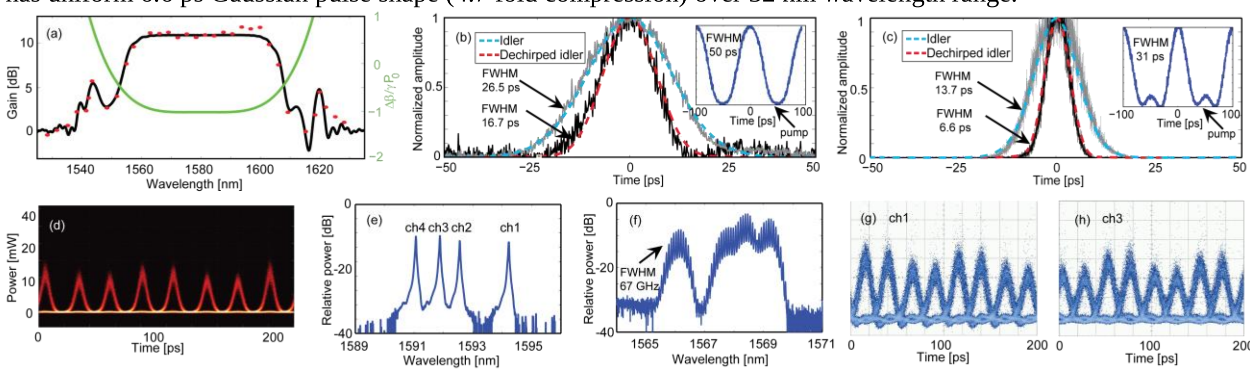

Fig.2 (a) Experimental (dot) and theoretical (line) OPA gain spectrum and $\Delta\beta/\gamma P_0$ term. Experimental (solid line) and theoretical (dash) time window before & after de-chirping with (b) normal sinusoidal pump, (c) equalized sideband pump. (d) Single wavelength OTDM stream observed on 500 GHz optical sampling scope. Spectrum of modulated WDM channels (e) before and (f) after FOPA. (g)-(h) OTDM ch_1 and ch_3 observed on 10 GHz bandwidth oscilloscope.

Owing to the high compression factor, the converted 10 GHz pulse sequence can be time multiplexed up to 4 times using a bit rate multiplier (see figure 2(d)). To exploit this functionality, 4 WDM channels (ch_1 – ch_4) are modulated with 10 Gb/s PRBS data and simultaneously sent to the FOPA. The spectrum is shown in Fig. 2(e): due to limited equipment three channels are spaced by 100 GHz and the last by 200 GHz. The four channels undergo simultaneous wavelength conversion and uniform compression to Gaussian shape (Fig, 2(f)). They are then sent through a bit rate multiplier to prove that they can be time multiplexed to 40 Gb/s, thus adapting the granularity of the channel. A 0.8 nm filter is finally used to separate individual converted WDM channels and monitor the corresponding eye-diagram on the oscilloscope. Since the wavelengths of converted ch_2-ch_4 were out of range for the optical sampling oscilloscope, the waveforms of all channels are observed on a 10 GHz bandwidth oscilloscope. Fig.2(g)-(h) shows sample eye-diagram of ch1 and ch3, respectively. The slightly unequal amplitude of different OTDM streams is due to the BRM. From this figure we estimate a Q^2-factor of 10 dB leading to error free operation of each 40 Gb/s RZ channel.

3. Conclusion

We demonstrate simultaneous wavelength conversion and uniform time compression for 10 Gb/s WDM channels. The 4.7-fold time compression allows for ×4-TDM of each WDM channel. The uniform compression capability is a key enabling feature in multi-granularity networks for transparent connection of dissimilar-rate WDM networks.

4. References

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