Low Penalty 80Gb/s Non-Inverted Wavelength Conversion Using a Broad Rectangular Shaped Optical Filter

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Abstract

We demonstrate non-inverted wavelength conversion at 80Gb/s based on cross-phase modulation in a SOA. Using a flat-top 6nm broad filter with sharp roll-off we achieve a penalty of only 0.5dB

Introduction

All-optical wavelength converters (AOWCs) are likely to become essential building blocks for future dynamic high-capacity optical networks [1]. Semiconductor optical amplifiers (SOAs) have attracted considerable research interest for wavelength conversion due to their integration potential and power efficiency. Error-free wavelength conversion based on cross-gain and cross-phase modulation in a single SOA has been demonstrated at 320 Gb/s at the expense of a large penalty mainly caused by the excessive losses by a polarity inverter required for realizing non-inverted wavelength conversion [2]. It has been previously suggested [3] and demonstrated [4] that 80Gb/s direct non-inverted wavelength conversion can be achieved by filtering of only blue components out of the inverted probe signal coming out of an SOA based Wavelength Conversion (WC). However, limitation due to spectral shape of filters applied resulted in high penalties as the moderate roll-off and limited bandwidth of the filter resulted in poor Optical Signal to Noise Ratio (OSNR) [4]. Since the process of WC can be repeated many times during the flight of the optical signal in an all optical network, it is imperative that power penalty incurred after each WC is minimized.

In this paper we re-visit the concept of filtering the blue component of an inverted wavelength converted signal, but take advantage of an optical filter with very broad bandwidth (6nm) as well as very sharp roll off (>60dB/nm). In this way the all important 1st order side-band of the wavelength converted signal can be filtered with minimal insertion loss while the unwanted Continuous Wave (CW) is strongly suppressed. This stronger and broader signal, obtained from the SOA, results in reduced distortion to the optical eye and an improved OSNR leading to a low power conversion penalty of only 0.5dB.

Theory of Operation

Two optical signals, a CW probe and an Return to Zero (RZ) modulated pump, are launched into an SOA. Through cross gain and phase modulations (XGM, XPM) the probe signal is imprinted with an inverted pattern of the pump [5], dominated by the strong CW component. By filtering only the blue portion, while eliminating the CW component, of the signal's spectrum one can obtain a regenerated replica of the original signal [5]. The final shape of the time domain pulse is dominated by the duration of the blue chirp induced frequency change and the total bandwidth of the filter. In order to preserve the original pulse shape one needs the filter's optical bandwidth to be in the order of the spectral width of the original RZ pulses (~5nm). Another crucial aspect for this kind of regeneration scheme is the eventual OSNR obtainable as it will determine the penalty incurred. For that purposes it is desired to filter out the CW components without affecting the 1st blue modulation side-band as it contains most of the regenerated pulse energy. In order to fulfil both of the above requirements a special flat top, broad filter with sharp roll off is required [2].

Experimental Set-up and Results

The experimental set-up is shown in Fig. 1

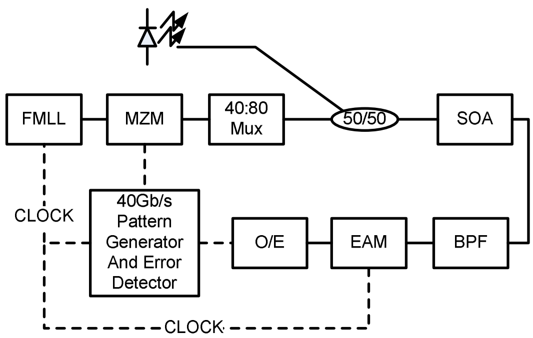

Figure 1: Experimental set-up

The 40GHz Fiber Mode Locked Laser (FMLL) RZ pulse source, with 2psec Full Width Hall Maximum (FWHM), is modulated at 40Gb/s by a 2^{31}-1 Pseudo Random Bit Sequence (PRBS) and then time multiplexed to reach a repetition rate of 80GHz. The pump signal entering the SOA is centered around 1560nm and has a power of 0.7dBm. The CW probe signal was at 1548.1nm with a power of 6.7dBm. An SOA similar to the one used in [2] was also used for this experiment. The SOA has a measured total recovery time of 56psec when biased at 400mA, dominated by a slow blue component. At the output of the SOA a sharp flat top 6.15nm wide Band Pass Filter (BPF) was place, centered around 1544.63nm. The filter has a roll-off of >60dB/nm and an insertion loss of 4.5dB. After filtering the 80Gb/s signal is time demultiplexed to the 40Gb/s original PRBS bit rate using Electro Absorption Modulator (EAM) gating, converted back to the electrical domain and tested for errors. In Fig. 2, the inverted (before filter) and non-inverted spectra are both shown. Notice the strong attenuation incurred by the CW signal (>35dB) compared to the 9dB (extra 4.5dB due to detuning) attenuation of the 1st side band and no extra attenuation on higher order modulation side-bands. Also visible is the SOA noise floor at around -45dBm, around the higher order side-bands. This noise together with the minimal impact on the 1st order side-band (-18dBm) give an OSNR >25dB, sufficiently good for the low penalty measured.

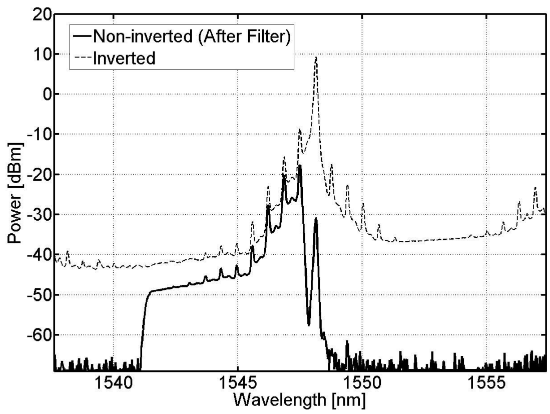

Figure 2: Spectra of the converted signal at the output of the SOA before and after the filter

In Fig. 3 the Bit Error Rates (BERs) for the two 40Gb/s tributaries are shown (dashed lines) compared to their back to back counterparts (bold line). Also shown for comparison are the pump and probe eye patterns. The measured penalty is 0.5dB and the eye is broadened from a 2psec FWHM to about 4.5psec.

Discussion and Conclusions

The use of smart optical filtering in order to improve and simplify AOWC is attractive since such filters can be designed also into integrated devices as Arrayed Waveguide Gratings (AWGs). Thus a chip size wavelength converter with low penalty, as little as 0.5dB, can be realized at speeds of 80Gb/s. As shown in this paper, it is possible to reduce penalty to as little as 0.5dB in the case where the optical filter is sharp enough to both block the CW components as well as have minimal effect on the 1st modulation side-band (which are only 0.6nm apart). Ultimately, the speed is limited by carrier dynamics in the SOA and the noise generated by the SOA. For the current device poor OSNR is obtained for higher bit rates (160GB/s and beyond) due to the strong dependence of modulation sideband power on the modulation speed. It is thus possible that improved performance and even faster operation can be accomplished with the aid of higher output power bulk SOAs, which will improve signal power at the SOAs output or alternatively Quantum Dot amplifiers which will reduce the noise floor.

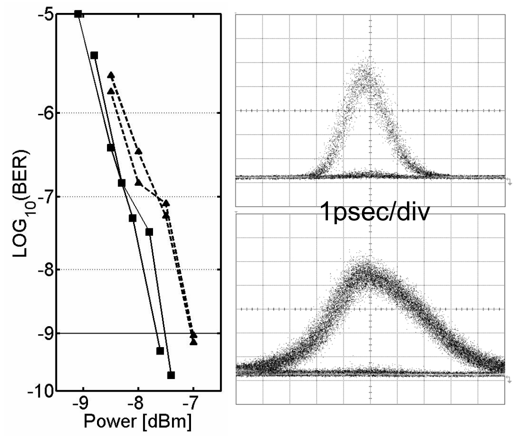

Figure 3: BER (left) and eye patterns for B2B (solid, top right) and Wavelength converted signal (dashed, bottom right) respectively

Acknowledgement

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References

1. S.J. Ben Yoo, "Optical packet and burst switching technologies for the future photonic internet", J. Lightwave Technol., Vol. 24, No. 12, 4468 (2006)
2. Y. Liu. *et al*, " Error-Free 320-Gb/s All-Optical Wavelength Conversion Using a Single Semiconductor Optical Amplifier", J. Lightwave Technol., Vol. 25, No. 1, 103 (2007)
3. J. Leuthold *et al*, "All-Optical Wavelength Conversion Using a Pulse Reformatting Optical Filter", J. Lightwave Technol., Vol. 22, No. 1, 186 (2004)
4. L. Bramerie *et al*, "Investigation of SOA-based wavelength conversion at 80 Gb/s using bandpass filtering", Proceeding of CLEO 2006, CMT7 (2006)
5. J. Mork *et al*, "Theory of the ultrafast optical response of active semiconductor waveguides", JOSA 13,(8), 1803-1815 (1996)