# 40 Gb/s NRZ-DQPSK Data All-Optical Wavelength Conversion Using Four Wave Mixing in a Bulk SOA

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***Abstract*— Differential quadrature phase shift keying (DQPSK) modulation has become particularly attractive in high-speed optical communications because of its resistance to fiber nonlinearities and its more efficient use of fiber bandwidth. Because of its wavelength conversion ability, semiconductor optical amplifier (SOA) four wave mixing effect has attracted much attention. We experimentally study the FWM wavelength conversion of 40 Gb/s (20 GBd) NRZ-DQPSK data. A bulk SOA with 21 dB gain and 10 dBm output saturation power is used. The $Q$-factors of the input and wavelength converted signal are measured. Some signal regeneration properties are shown. A $Q$-factor improvement up to 1.7 dB is observed.**

***Index Terms*— DQPSK, phase modulation, semiconductor optical amplifier, four wave mixing, all optical wavelength conversion.**

## I. Introduction

THE constantly increasing demand for data transmission speed is causing a need to improve the effectiveness of bandwidth use. The Differential Phase Shift Keying (DPSK) format, despite the potential disadvantage of higher complexity of the system, offers a number of advantages compared to On-Off Keying (OOK), such as requiring a 3 dB lower optical signal-to-noise ratio (OSNR) to reach a given bit error rate (BER) [1], [2] and improved resilience to fiber chromatic and polarization mode dispersion [3]. Furthermore, constant-intensity modulation formats like DPSK are resilient to semiconductor optical amplifier (SOA) pattern-induced crosstalk, which affects OOK signals. The Differential Quadrature Phase Shift Keying (DQPSK) format is even more attractive. While having a lower receiver sensitivity than DPSK [4], it offers the same advantages with the additional advantage of increasing the spectral effectiveness by transferring two bits per symbol. Its high spectral efficiency and relatively narrow signal spectrum are desired when it comes to increasing the capacity of WDM transmission systems.

The SOA has been of great interest for many years because of its attractive properties. Its lower size, lower power consumption and wider bandwidth makes it a potentially cheaper alternative for erbium-doped fiber amplifiers (EDFAs) as power boosters in transmitters, in-line amplifiers, and receiver preamplifiers [5]. Furthermore, besides performing as amplifiers, SOA nonlinearities make them very attractive for applications such as demultiplexing, wavelength conversion and signal regeneration [6]–[9]. For DQPSK transmission, four wave mixing is particularly interesting, because it preserves the phase of the input signal.

In this letter, for the first time to our knowledge, a 20 Gbaud (40 Gb/s) NRZ-DQPSK data FWM wavelength conversion experiment in a bulk SOA is demonstrated. Wavelength conversion was achieved without signal degradation for a positive detuning up to 2 nm. For a detuning of 1 nm the Q-factor was improved from 8.44 to 10.25 (1.7 dB) with eye diagram shape improvement.

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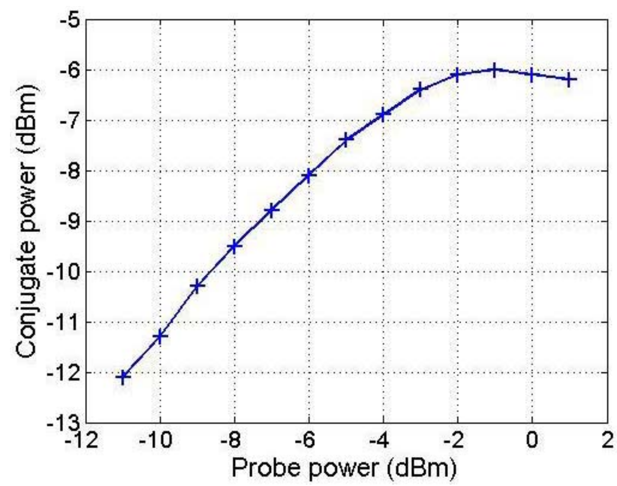


Fig. 1. CW conjugate power vs probe power for input pump power of −1.8 dBm for fixed pump-probe detuning of 1 nm.

## II. FWM Efficiency

Firstly, the FWM efficiency of the SOA was characterized. The FWM efficiency is defined as ratio of output conjugate power to the input probe power.

The SOA used is a tensile-strained bulk device (Amphotonix) operated with a 250 mA bias current, 21 dB unsaturated gain (with its maximum at 1480 nm) and a saturation output power of 10 dBm. The pump was a CW laser set at 1531.8 nm and its maximum power −1.8 dBm. The probe wavelength was set at 1532.8 nm. For the purpose of wavelength conversion, it was desired to have the conjugate at the highest possible power level. This was obtained by adjusting the probe power, as seen on Fig. 1.

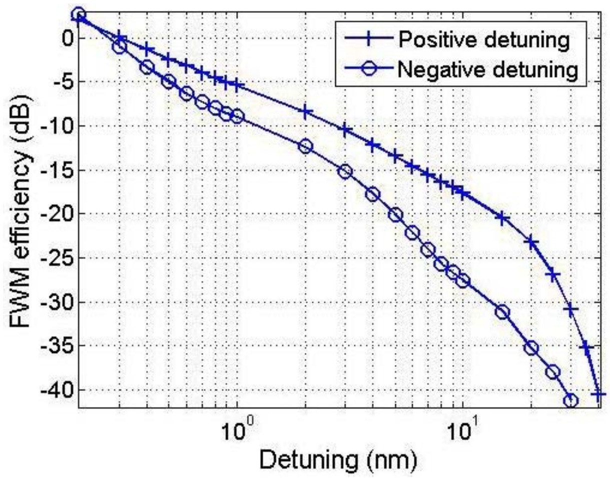


Fig. 2. CW FWM efficiency vs detuning for input probe power of −1 dBm and input pump power of −1.8 dBm.

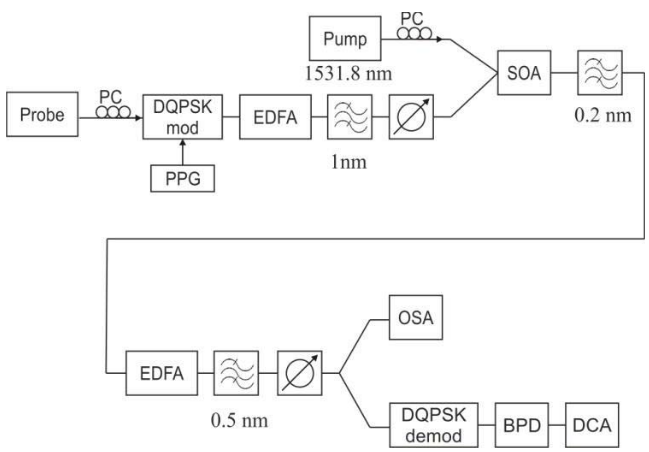


Fig. 3. DQPSK FWM experimental setup (PC - polarization controller, PPG - pulse pattern generator, OSA - optical spectrum analyzer, BPD - balanced photodetector, DCA - digital communications analyzer).

The FWM efficiency was measured for different detuning values. The probe, with power set to −1 dBm, was set to a range of different wavelengths with maximum detuning reaching up to 40 nm. As shown on Fig. 2, the FWM efficiency was much higher for positive detuning with a rapid decrease with increasing detuning range.

## III. DQPSK FWM Wavelength Conversion

The experimental setup is shown in Fig. 3. The input pump power is −1.8 dBm. The probe is a 20 Gbaud/s (40 Gb/s) NRZ-DQPSK $2^{15-1}$ pseudo random bit pattern. The DQPSK modulation was carried out using a commercial modulator (Photline-MODBOX). The signal is amplified by an EDFA and its ASE reduced by a 1 nm optical filter. The use of attenuator before SOA allows control of the SOA input probe power. The SOA was operating under the same conditions as before. In order to fully separate conjugate from the pump and input probe signal, a cascade of filters was used at the output of the SOA: a 0.2 nm FWHM fiber Bragg grating (FBG) and a 0.5 nm tunable filter. The conjugate signal was then

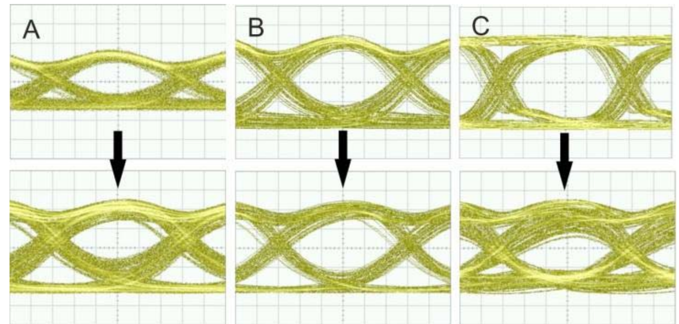


Fig. 4. Eye diagrams of input (top) and converted (bottom) signals for probe power of: A) −15 dBm ($Q_{in}$ = 6.75, $Q_{conv}$ = 6.11), B) −6 dBm ($Q_{in}$ = 8.44, $Q_{conv}$ = 8.2), C) 0 dBm ($Q_{in}$ = 10.86, $Q_{conv}$ = 5.15). The detuning is 1.5 nm, horizontal scale is 8.3 ps/div.

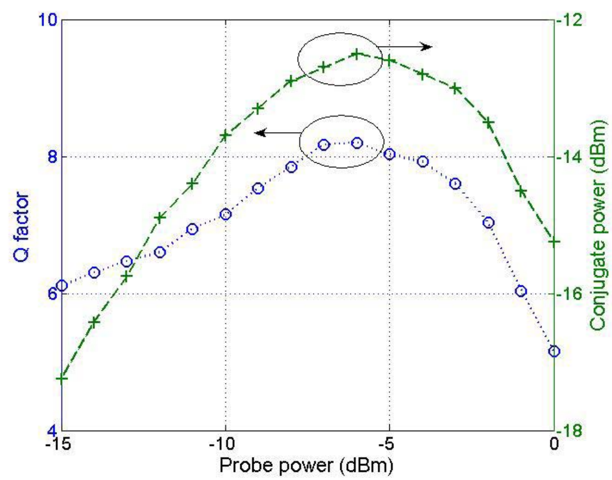


Fig. 5. Converted signal: Q-factor (−o) and conjugate power (−x) vs probe power for a detuning of 1.5 nm.

amplified by an EDFA and its ASE filtered out by a 0.5 nm filter. The DQPSK demodulator (OPTOPLEX) consists of two delay-line interferometers, which converts the I and Q components of the signal into intensity changes. The optical signals from the interferometer outputs are detected by a balanced photodiode receiver (Discovery Semiconductors Lab Buddy) with an 23 GHz bandwidth and an Agilent 86100C digital communication analyzer with an 80 GHz electrical bandwidth is used to obtain the balanced receiver output eye diagrams and to calculate the resulting Q-factor. Both the demodulated I and Q components show almost identical performances. To this effect we concentrate on the I-component for analysis purposes.

The dependence of probe power on the quality of wavelength converted signal was measured. The pump wavelength and power were set to 1534.6 nm and −1.8 dBm, respectively. The probe wavelength was set to 1536.1 nm. Fig. 4 shows the eye diagrams for different probe powers and the wavelength converted conjugate Q-factors. The input probe power of the SOA was adjusted by the EDFA/attenuator. The converted signal power level was kept fixed at −4.5 dBm at the input of the demodulator. The input Q-factor was increasing along with the probe power. The maximum Q-factor of the converted

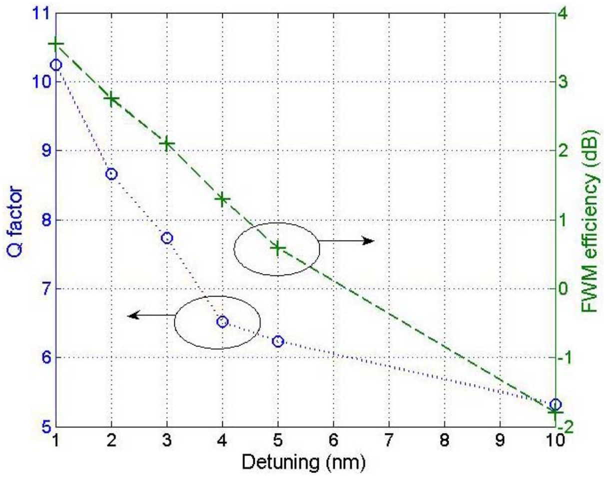


Fig. 6. Converted signal: Q-factor (−o) and FWM efficiency (−x) vs detuning range.

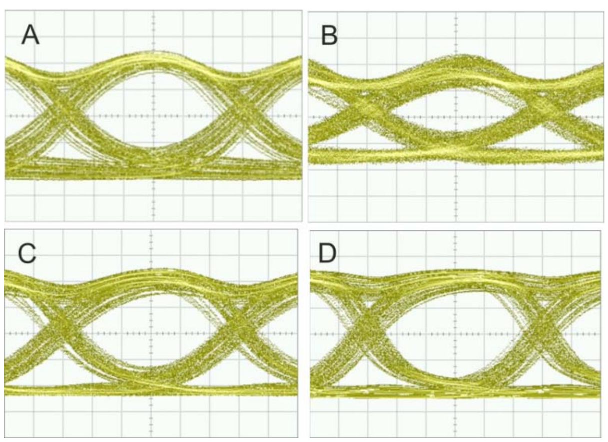


Fig. 7. Eye diagrams for: A) input probe ($Q_{in}$ = 8.44), B) 10 nm down conversion ($Q_{conv}$ = 5.32), C) 3 nm down conversion ($Q_{conv}$ = 7.73), D) 1 nm down conversion ($Q_{conv}$ = 10.25). The horizontal scale is 8.3 ps/div.

signal was reached for a probe power value of −6 dBm (from $Q_{in}$ = 8.44 to $Q_{conv}$ = 8.2). Patterning effects and degradation of the converted signal were observed for probe power values above that level.

Fig. 5 shows the dependence of the converted Q-factor on the input probe power. It's also shown that the Q-factor value is strongly connected to the conjugate power at the output of the SOA (before EDFA amplification).

We measured the quality of the converted signal for different detuning values. Because of a non-tunable filter used, both pump and probe wavelengths were adjusted in order to maintain the conjugate at 1533.04 nm. Pump and probe powers were kept at −1.8 dBm and −6 dBm, respectively. The input Q-factor was 8.4. The converted signal power was set to its maximum. The results are shown in Fig. 6.

The Q-factor depends strongly on the FWM efficiency, meaning that the maximum obtainable Q-factor value decreases with the detuning range. For detuning up to 2 nm the Q-factor was improved, reaching a maximum value of 10.25 for 1 nm down-conversion. By keeping the converted conjugate power constant at −7.8 dBm for different detuning values, which was the maximum for a detuning value of +10 nm, similar Q-factors of the conjugate signal (Q = 5.3) were obtained. Fig. 7 shows a comparison of the eye diagrams for the input and converted signal at different detuning. For a detuning of 1 nm, a clear improvement in the eye diagram shape is seen, which demonstrates signal regenerative properties.

## IV. CONCLUSION

40 Gb/s NRZ-DQPSK FWM wavelength conversion by a bulk SOA was demonstrated. Lossless wavelength conversion was achieved for positive detuning up to 2 nm, resulting with a maximum 1.7 dB improvement in Q-factor. Eye diagram analysis showed some signal regeneration properties. The converted Q-factor is strongly related to the four wave mixing efficiency parameter, resulting in a lower quality of conversion for higher detuning values.

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