Analysis of filter-assisted 160 Gb/s wavelength converter using a single semiconductor optical amplifier

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Abstract: We present for the first time a systematic analysis of the Q-factor and eye opening for wavelength conversion based on a single semiconductor optical amplifier and a detuned filter at 160 Gb/s.

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Extensive research has been dedicated to semiconductor optical amplifier (SOA) based wavelength converters due to their large nonlinearity and integration potential. SOA-based wavelength converters, however, suffer from long carrier lifetime (typically several tens to hundreds of ps), which limits the maximum operating speed of the device. Recently, through combining a detuned optical filter and an delay interferometer, 160 Gb/s and 320 Gb/s non-inverted wavelength conversion have been demonstrated [1, 2]. However, despite the experimental success, little attention has been paid to better understanding of filter-assisted wavelength conversion. For example, the dependence of the output signal quality on the operating conditions remains unclear and deserves investigation. In this paper, we systematically analyze the wavelength converter behaviour. Fig. 1(a) shows a schematic setup of the wavelength converter under investigation. A modulated return-to-zero pump signal and a continuous wave probe are injected into an SOA, followed by an optical bandpass filter (OBF). At the exit of the OBF, both inverted and non-inverted wavelength conversion can be achieved depending on the OBF detuning from the probe wavelength.

The analysis is based on a comprehensive numerical model, which takes into account the inter- and intra-band carrier dynamics in the SOA [3]. To the best of our knowledge, this model is the first to include gain dispersion and group velocity dispersion, while taking into account the intra-band carrier dynamics explicitly. We extended the modified nonlinear Schrödinger equation in [4] to take into account the influence of two photon absorption and free carrier absorption. The model has been applied to simulate the gain recovery dynamics with good agreement with experiments [1]. Fig. 1(b) shows the SOA amplification gain as a function of the input pulse energy for different pulse widths, showing pulse-width dependent saturation energy. The OBF is modeled in the frequency domain and the transfer function of the OBF is assumed to have Gaussian amplitude and linear phase[5] In the simulations the full-width at half maximum bandwidth of the OBF is 200 GHz.

Fig. 2 shows the Q-factor as a function of the OBF detuning and typical eye diagrams for different OBF detuning are also presented. One can see that the output signal from the OBF is inverted when the detuning is small (in this case, -200 GHz to 280 GHz) and the output becomes non-inverted for larger detuning. One can also see that the eye diagram is almost closed when the filter is not detuned [Fig. 2 (a)]. This is due to the slow gain recovery of the SOA, resulting in strong pattern effects. One can also notice that for the inverted signal, the Q-factor dependence on the OBF detuning is asymmetric. This asymmetry is caused by non-zero linewidth enhancement factor induced asymmetric chirp for the probe signal at the output of the SOA.

It is interesting to investigate the dependence of the output signal quality on the operating conditions. For non-inverted wavelength conversion, the dependences of the maximum Q-factor and the maximum eye opening on the pump pulse energy, probe power, linewidth enhancement factor and injection current are plotted in Fig. 3. The maximum Q-factor and eye opening are obtained by tuning the filter center frequency while keeping the bandwidth the same. As shown in Fig. 3(a), the Q-factor drops continuously from > 30 dB to < 10 dB with increasing pump pulse energy from 2 fJ to 1 pJ.
The maximum eye opening has a maximum value for a pump pulse energy around 10 fJ. Although the Q-factor is larger for small pump pulse energy, the eye opening becomes too small for too weak pump pulses and this smallest eye opening is limited by the ASE noise, which is not treated in our analysis. It can be seen from Fig. 3(b) that the maximum eye opening reaches a peak value when the probe power is around 3 mW while the maximum Q-factor increases logarithmically with increasing probe power. Larger linewidth enhancement factor leads to larger maximum Q-factor and maximum eye opening, as is shown in Fig. 3(c), although it is also seen that the improvement due to larger $\alpha$ is small (<0.8 dB for Q-factor and about 2.3 dB for eye opening). Fig. 3(d) shows the dependence on the injection current. While larger current leads to larger maximum eye opening, the Q-factor decreases due to larger nonlinear pattern effect [6].

Inverted and non-inverted wavelength conversion at 160 Gb/s based on an SOA and a Gaussian OBF are numerically investigated for the first time. Q factor higher than 24 dB eye opening of about 20 dB can be achieved through OBF detuning. The Q-factor dependence on the OBF detuning is asymmetric for inverted output. Similar Q-factors can be obtained for both detuning to higher and lower frequencies than the probe. Larger linewidth enhancement factors, larger CW power, lower current and lower pump pulse energy lead to a higher Q-factor. Hence, one can tune these parameters to optimize the wavelength conversion and, therefore, the output signal’s quality.

References