Experimental investigation of the cascadability of a cross-gain modulation wavelength converter

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Experimental Investigation of the Cascadability of a Cross-Gain Modulation Wavelength Converter

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Abstract—The cascading characteristics of a wavelength converter based on cross-gain modulation (XGM) are studied experimentally using a recirculating loop at 10 Gb/s. The maximum cascaded number of the wavelength converter converting the signal to the same wavelength is improved from five to eight by adding a fiber grating-based optical add–drop multiplexer after the semiconductor optical amplifier (SOA) to enhance the high-frequency response of the wavelength converter. However, the low-frequency degradation of the signal together with amplified spontaneous emission (ASE) noise and jitter accumulation finally limits the wavelength converter to be cascaded for more times.

Index Terms—Cascadability, cross-gain modulation (XGM), semiconductor optical amplifier (SOA), wavelength conversion.

I. INTRODUCTION

All-optical wavelength converters (AOWC’s) will be key components in future broadband wavelength-division-multiplexed (WDM) optical networks. Among several AOWC’s already demonstrated, the AOWC based on cross-gain modulation (XGM) in a semiconductor optical amplifier (SOA) is the simplest to realize and capable of converting the input signal to the same wavelength, which is favorable in all-optical networks [1], [2]. An important issue for the AOWC to be used in the WDM networks is its cascadability. However, up to now, only a few theoretical results have been reported, which do not consider the pattern effect [3], [4]. Actually, in practical systems, the cascadability of this kind of AOWC is limited seriously by the insufficient high-frequency response of the AOWC, which is caused by the slow gain recovery time of the SOA when it works at high bit rate. Recently, it has been reported that the frequency response of the AOWC can be improved by adding a fiber grating after the SOA, which reshapes the chirped converted signal [5].

In this paper, for the first time, the cascadability of the XGM-AOWC is studied experimentally using a recirculating loop setup at 10 Gb/s. The experiment shows that the maximum number of cascaded AOWC’s converting the signal to the same wavelength is 5 mainly due to the degradation of the high-frequency components of the signal. By adding a Mach–Zehnder optical add–drop multiplexer (OADM) based on fiber gratings after the SOA, the maximum cascading round-trips in the loop is increased to eight due to the improved high-frequency response in the AOWC. However, the inherent low-frequency degradation in the cascaded signal together with the accumulation of ASE noise and jitter limits the AOWC to be cascaded for more times.

II. EXPERIMENTAL SETUP

In the experiment, the AOWC performs the conversion to the same wavelength. The structure of the counterpropagating AOWC is shown in Fig. 1(a). The CW light is provided by an external cavity laser (ECL) and the power into the SOA is −1 dBm after a polarization controller and an attenuator. The input signal with a power of 8 dBm is launched into the SOA through an optical circulator (OC). The converted signal from the SOA comes into the OADM from the input port and comes out from the drop port. The OADM with a center wavelength of 1555.6 nm and a 3-dB bandwidth of 1 nm is used to reshape the converted signal when the wavelength of the converted signal is at the red side of the in-drop transfer function [6], which is 1556.0 nm in the experiment. The in-drop transfer function of
Fig. 2. Loop experimental setup. PC: Polarization controller. Att: Tunable attenuator. DSF: Dispersion-shifted fiber.

Fig. 3. Small signal bandwidths of the AOWC without and with the OADM. The cascadabilities of the AOWC both with and without the OADM are measured in the loop experiment. The AOWC without the OADM actually means that the wavelength of the continuous-wave (CW) light is located at the center of the OADM in order to keep the same ASE level as when the OADM is used to reshape the converted signal. The SOA used in the experiment has a chip length of 1250 μm, and the fiber-to-fiber gain is 20 dB at a bias current of 250 mA, which is used in our experiment. The reflection from the facets of the SOA is smaller than -26 dB. The loop setup used in the experiment is shown in Fig. 2. An externally modulated 10 Gb/s [pseudorandom binary signal (PRBS) 2^23 − 1] tunable transmitter provides the input signal to the AOWC in the loop, as shown in Fig. 2. The power of input signal and the CW light to the AOWC are kept constant for every round-trip. The polarization controllers in the setup are used to keep the interference between the converted signal and the reflected signal be minimum, so, the impact of crosstalk from the reflection can be neglected. Only 20 km of dispersion shifted fiber is used in the loop, so the dispersion can be neglected. The signal is coupled out via a 10-dB coupler and launched into a 10-Gb/s receiver.

III. RESULTS AND DISCUSSIONS

Fig. 3 shows the relative responses of the AOWC versus the modulation frequency at 1556 nm with and without the OADM. Fig. 4. The eye diagrams of the converted signal (a), (c) without and (b), (d) with the OADM after the second and fifth round-trips in the loop experiment, respectively.

Fig. 5. The eye diagrams of the converted signal after the tenth round-trips.

The cascadability can be improved from five to eight round-trips without an error floor at a bit-error rate (BER) of 10⁻⁹.
Fig. 6. Power penalty of the converted signal versus the cascading round-trips in the loop.

by adding the OADM after the SOA. Fig. 6 shows the power penalty of the converted signal with and without the OADM, respectively, as a function of different round-trips in the loop. It should be pointed out that there is a tradeoff among the parameters, like extinction ratio (ER), pattern effect, jitter and noise accumulation, all the parameters are optimized in our experiment. The power ratio between the signal and CW light used in the experiment corresponds to the theoretical prediction in [4], which assures a small amount of jitter and a high extinction ratio (ER). However, the maximum number of cascaded AOWC’s in the experiment is less than the theoretical prediction in [4]. This is because the SOA used in the experiment is shorter than that in [4], the ER degradation is more severe. Furthermore, the ASE noise is not considered in [4]. It should also be stressed that using a loop configuration to test cascadability of the XGM-AOWC prevents any individual adjustments of the operation conditions for the cascaded AOWC’s. So it is expected that the cascadability of the AOWC with the OADM can be improved further if a straight-line transmission or a longer SOA is used.

IV. CONCLUSION

The cascadability of the XGM-AOWC converting the signal to the same wavelength is studied experimentally at 10 Gb/s using a loop setup. The poor high-frequency response of the AOWC limits it to be cascaded only five times in the loop experiment. By adding an OADM after the SOA, the maximum number of cascaded AOWC reaches eight due to the improved high-frequency response. However, the degradation of low-frequency components in the converted signal together with the accumulation of ASE and jitter become the most important limiting factors in the cascading experiment. It is expected that the cascadability of the AOWC with the OADM can be improved further if a straight-line transmission or a longer SOA is used.

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