Propagation analysis of an 80-Gb/s wavelength-converted signal utilizing XPM

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Abstract: We model the propagation of an 80-Gb/s wavelength-converted signal generated by utilizing XPM in a highly nonlinear fiber. After propagation over 1280 km or less, wavelength conversion adds no signal degradation in terms of BER.

OCIS codes: (230.7405) Wavelength conversion devices; (060.5060) Phase modulation

1. Introduction

For robust operation of high speed networks, new optical signal processing and coding techniques are important. All-optical wavelength conversion techniques play an important role in enhancing the performance of future high speed and high capacity optical networks. The techniques demonstrated to date include four wave mixing (FWM) in a semiconductor optical amplifier (SOA) [1], cross phase modulation (XPM) in a non-linear optical loop mirror [2], and symmetric Mach-Zehnder switches [3].

The use of XPM in glass fibers for wavelength conversion has been successfully demonstrated in laboratory experiments [4]. This method has been shown to be scalable for data rates up to 160-Gb/s [5]. The method used in [4] is to combine an incoming data-modulated signal at one wavelength with a continuous wave (CW) signal at the desired output wavelength, and to propagate this combined signal through a short highly nonlinear dispersion-shifted fiber (HNL-DSF). The XPM in the HNL-DSF then imposes a phase modulation onto the CW signal from the incoming data-modulated signal, generating optical sidebands. When the original CW carrier is suppressed by an optical filter, the phase modulation is converted to amplitude modulation, thereby generating the wavelength-converted data-modulated signal. Numerical simulations based on a small-signal analysis have shown that the technique has a high conversion efficiency [6], and large wavelength shifts have been acheived in experiments [5]. However a study of the tolerance of the wavelength-converted signal to long-haul propagation in an optical communications system has yet to be reported. In this paper, we simulate the propagation of an 80-Gb/s wavelength-converted signal over 1280 km. We find that the bit error ratio (BER) is comparable to that of a signal generated at the same wavelength by a standard transmitter.

2. Simulation setup

The setup used for the simulation of wavelength conversion is shown in Fig. 1. The 80-Gb/s transmitter operates at a wavelength of 1556.4 nm and generates a return-to-zero (RZ) Gaussian format with a 16 bit pseudo-random binary data sequence. The pulses have an optical extinction ratio of 20 dB and full-width half maximum (FWHM) of 3 ps. This signal is similar to one obtained by time-domain multiplexing eight 10-Gb/s signals using a passive multiplexer [5]. This data stream is combined with a CW pump at 1548.6 nm before being launched into 1-km of HNL-DSF. The CW power is 3 dBm and the average signal power is set to 20 dBm. The HNL-DSF has a zero dispersion wavelength of 1550 nm, a dispersion slope of 0.03 ps/nm^2-km, and a nonlinear coefficient of 16.9 W^{-1} km^{-1}. The short length of this highly nonlinear fiber reduces the dispersive walk-off. The data-modulated signal imposes phase modulation on the CW signal and generates sidebands. A super-gaussian band-pass filter (BPF) with bandwidth of 2.56 nm and whose center is offset from the CW signal by 240 GHz is used to suppress the CW signal.

We compare the performance of the wavelength-converted signal to that of a signal centered at a wavelength of 1548.6 nm that is generated by the same 80-Gb/s transmitter described above. We will refer to this signal as the standard signal.

The standard and wavelength-converted signals are individually propagated through a transmission system consisting of alternating spans of 80 km of single mode fiber (SMF) followed by dispersion

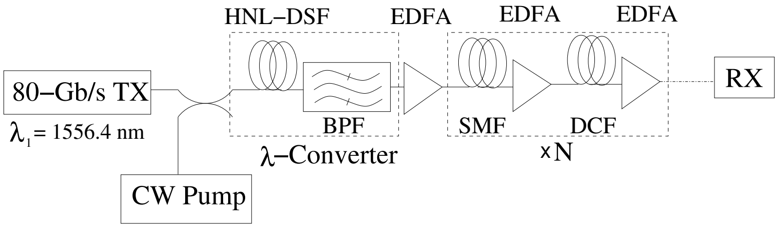

Fig. 1. System setup of the XPM wavelength converter and its propagation. TX:Transmitter; EDFA: Erbium-doped fiber amplifier; SMF: Single mode fiber; DCF: Dispersion compensating fiber; HNL-DSF: High non-linearity dispersion shifted fiber; BPF: Band-pass filter; RX: Receiver sub-system

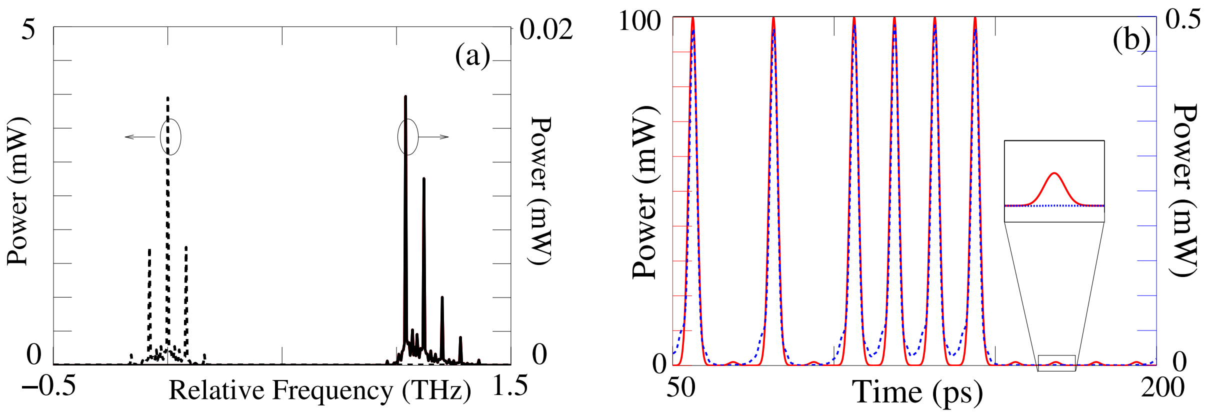

Fig. 2. (a) Frequency spectra before propagation through the transmission system. The spectrum of the original signal is shown with a dashed line and that of the wavelength-converted signal is show with a solid line. (b) The time sequence after wavelength conversion. The solid curve is from the standard transmitter and the dashed curve is that of the wavelength-converted signal. The inset shows an isolated space.

compensating fiber (DCF) that fully compensates for the dispersion of the SMF. Since the converted signal is at a very low power, it is first pre-amplified to 3 dBm. The average power of the standard signal was also set to 3 dBm. Erbium-doped fiber amplifiers (EDFAs) which compensate for the fiber loss, are positioned after each fiber span. The peak power after each EDFA is maintained at 2 mW. The signal is then passed through a receiver consisting of an optical filter, a square law photodetector and an electrical filter. We use a third order supergaussian filter with 320 GHz bandwidth, centered with an optimal frequency offset of 160 GHz compared to the original CW signal. The electrical filter is a fifth-order Bessel filter with a bandwidth of 80 GHz. The optical and electrical filter bandwidths have been optimized to minimize the BER.

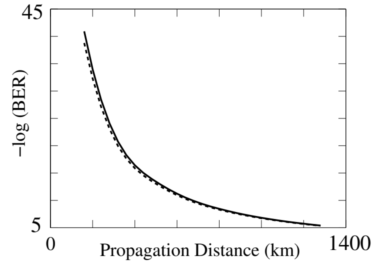

Fig. 3. The BER as a function of propagation distance. The solid line shows the BER for the wavelength-converted signal and the dashed line shows the BER for the standard 80-Gb/s signal.

3. Results and analysis

We now compare the transmission performance of the wavelength-converted signal to that of the standard signal. In Fig. 2(a), we show the frequency spectrum of the original 80-Gb/s signal before wavelength conversion with a dashed line and that of the wavelength-converted signal before the pre-amplifier with a solid line. The power scale for the standard signal is given on the left side of the plot, while that of the frequency-converted signal is shown on the right side. In particular, the power of the wavelength-converted signal is about two orders of magnitude smaller than that of the original signal. We observe that the original CW signal together with the low-frequency half of the wavelength-converted signal have been filtered out by the band-pass filter. The side tones generated by XPM can be clearly seen. In Fig. 2(b) the dashed curve shows a portion of the time sequence of the wavelength-converted signal and the solid curve shows the standard signal, both after the pre-amplifier. Figure 2(b) shows that the full-width half maximum (FWHM) pulsewidth of the wavelength-converted signal at 1548.6 nm is maintained at 3 ps.

The two signals are then propagated through the transmission system. We compute the BER from the average probability density functions (pdfs) of marks and spaces which are obtained by averaging the Gaussian approximations to the pdfs in each of the marks and spaces [7, 8]. We compare the BER of the wavelength-converted signal to that of the standard signal. In Fig. 3 we show the BER as a function of propagation distance. We show the BER of the wavelength-converted signal with a solid line and that of the standard signal with a dashed line. The BER of the wavelength-converted signal is slightly less than that of the standard signal. The reason is that the optical extinction ratio in the spaces of the standard signal is 20 dB, whereas that of the wavelength-converted signal is 30 dB, which can be clearly seen in the inset in Fig. 2(b). As a result, the variance due to sigal-noise beating in the spaces is somewhat smaller for the wavelength-converted signal than for the standard signal. This improvement of the performance in the spaces more than compensates for a slight degradation in the shape of the pulse in the marks that occurs during wavelength-conversion. After 1000 km propagation through the system both signals have a BER of about 10^{-7}.

4. Conclusion

We showed that wavelength conversion of an 80-Gb/s RZ signal based on XPM and optical filtering preserves the pulsewidth of the pulses in the marks and increases the optical extinction ratio in the spaces. As a consequence, the BER of the wavelength-converted signal is almost the same as that of a standard 80-Gb/s signal after both signals have propagated through a 1000 km long transmission system. We conclude that wavelength conversion by XPM has no degradation on a noise limited system.

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