All-optical wavelength conversion and multicasting by cross-gain modulation in a single-stage fiber optical parametric amplifier

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Abstract: We have demonstrated an all-optical wavelength conversion and multicasting for a 10Gb/s NRZ system with 100GHz channel spacing by using a single-stage two-pump fiber optical parametric amplifier (OPA) with the conversion gain of at least 15dB.

OCIS codes: (060.2320) Fiber optics amplifiers and oscillators; (060.2330) Fiber optics communications; (190.4370) Nonlinear optics, fibers

1. Introduction

It is perceived that optical wavelength conversion is anticipated to be an essential function for the emerging bandwidth-intensive applications (video conferencing, video-on-demand services etc.) of high-speed wavelength division multiplexing (WDM) optical networks by enabling rapid resolution of output-port contention and wavelength reuse [1].

On the other hand, multicasting is another potentially useful networking function. It involves routing the same data stream from a single node to several destinations, commonly implemented via IP digital routers in electrical domain. Network effectiveness will be boosted when the multicasting can be performed all-optically, i.e. the optical routers will be able to multicast an input signal to different wavelengths. In theory, although one may use a 1:N power splitter and N-1 wavelength converters, it is desirable to achieve all N-1 wavelength conversions simultaneously in a single device.

Existing techniques for wavelength conversion and multicasting include: (1) nonlinear SOA-based interferometer [1]; (2) injection locking of a Fabry-Perot laser [3]; (3) cross-phase modulation in a dispersion-shifted fiber (DSF) [4]; (4) four-wave mixing in either DSF [4] or highly-nonlinear dispersion-shifted fiber (HNL-DSF) [5]. These techniques are limited from one or more of the following constraints: limited speed due to long carrier lifetime, moderate noise performance compared with fiber-based devices, and low conversion efficiency.

Previously we have proposed a scheme of using cross-gain modulation (XGM) in one-pump OPA for the tunable wavelength conversion [7]. However, the phase dithering of one-pump OPA will inevitably broaden the spectrum of the idler. Therefore, we propose another scheme here, using a two-pump OPA, which has the potential to avoid this problem. Furthermore, we will be able to obtain both wavelength conversion and multicasting at the same time by a single-stage two-pump OPA configuration, with conversion efficiency greater than unity. Note that Ref. [8] also uses two-pump OPA to achieve wavelength multicasting but relies on different principle from our technique here.

2. Principle and Experiment

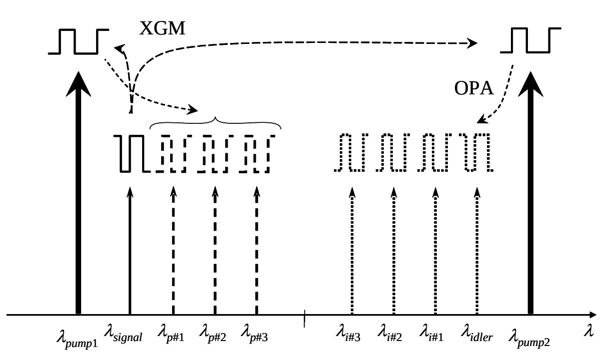

Fig. 1. Illustration of the wavelength conversion and multicasting due to XGM effect in a 2P-OPA configuration.

The mechanism of XGM-based wavelength conversion in an OPA is similar to that in an SOA [9]. An amplitude-modulated signal is fed into the OPA, and modulates the OPA gain through pump depletion. Efficient gain modulation can be expected, since large pump depletion can be achieved in OPA. The probes ($\lambda_{p\#1}$ to $\lambda_{p\#3}$), simultaneously fed into the OPA, are modulated by the gain modulation, and become converted ($\lambda_{i\#1}$ to $\lambda_{i\#3}$, respectively) and multicasted signals whose amplitude modulation are inverted with respect to the original signal as shown in Fig. 1.

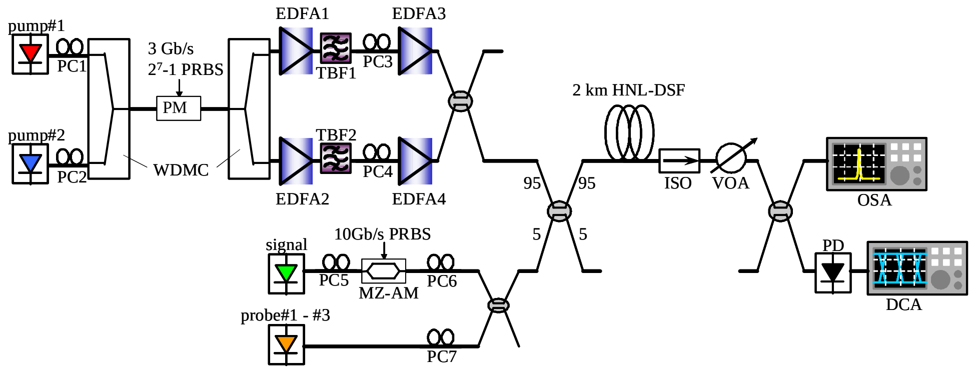

Fig. 2. Wavelength conversion and multicasting using 2-pump OPA configuration. Refer to the text for details.

The experimental configuration is shown in Fig. 2. The parametric gain medium consists of 2 km of HNL-DSF (OFS Ltd.) with a nominal zero-dispersion wavelength λ_0 of 1543.4 nm, dispersion slope of 0.019 ps/nm^{2}km and nonlinear coefficient γ of 10.4 W^{-1}km^{-1}. Two tunable laser sources, TLS1 and TLS2, set at 1529.45 nm and 1556.8 nm, respectively, serve as the pump sources. The pump wavelengths are selected to flatten the ASE gain spectrum, with the average wavelength approximately equal to λ_0. The CW pumps are combined by a WDM coupler (WDMC) and then phase-modulated (PM) by a 3 Gb/s 2^7-1 pseudo-random bit sequence (PRBS) to suppress stimulated Brillouin scattering (SBS). The polarization controllers, PC1 and PC2, align the pump SOP's with PM, which helps to reduce the insertion loss. The two pumps are then separated by another WDMC, amplified by two C-band EDFA's (EDFA1 & 2), and followed by tunable bandpass filters (TBF) with 0.84 nm (TBF1) and 1.96 nm (TBF2) bandwidth, respectively. Each pump is amplified by second EDFA with a maximum output power of 21 dBm. Polarization controllers (PC3 and PC4) are used to ensure that the two pumps incident on the HNL-DSF are parallel. This is achieved by maximizing the ASE noise level at the optical spectrum analyzer (OSA). The signal is amplitude-modulated by a 10 Gb/s PRBS. The input signal power is -1.9 dBm while the power of each probe is about -7 dBm. The signal gain is about 14 dB, so that the signal output power is about 12 dBm; while the conversion gain is about 15 dB. The signal and probes are combined with the output of EDFA3 & 4 by a 95/5 coupler. The polarization states of pump, signal and probe were optimized with polarization controllers (PC6 and PC7) to maximize the wavelength conversion efficiency. The power of each pump at the input of HNL-DSF is about 20 dBm. The output spectrum of HNL-DSF, followed by an isolator (ISO) which prevents any reflection from the variable optical attenuator (VOA), is observed at the OSA. The modulated probes derived from the OPA are filtered by a tunable bandpass filter whose full width at half maximum was 0.22 nm. It is connected to either a digital communication analyzer (DCA) for eye diagram measurement, or to a pin-PD receiver for bit error rate (BER) measurement.

3. Results and Discussion

Fig. 3 show the eye diagrams of output signal at 1551nm (a) and three probes at 1552.7nm, 1553.5nm and 1554.3nm, respectively, (b-d). They all show clear eye-opening, except that the locations of the crosspoint for the output signal and the probes. While the increase of the crosspoint (above the mid-point between the mark and space levels) in the output signal is due to the OPA gain saturation. We take advantage of it to suppress the noise in the mark level. On the contrary, the crosspoint locations of the probes are different from that of the output signal. It can also be explained by the XGM nature of this technique. In other words, the probes are inverted comparing with the output signal. Note that the probe#3 shows a slight signal degradation compared with probe#1 and #2, which is due to the lower parametric gain at that wavelength. Also note that noisy mark level of the probes may due to the FWM amongst different WDM channels since the channel spacing is only 100GHz in this configuration.

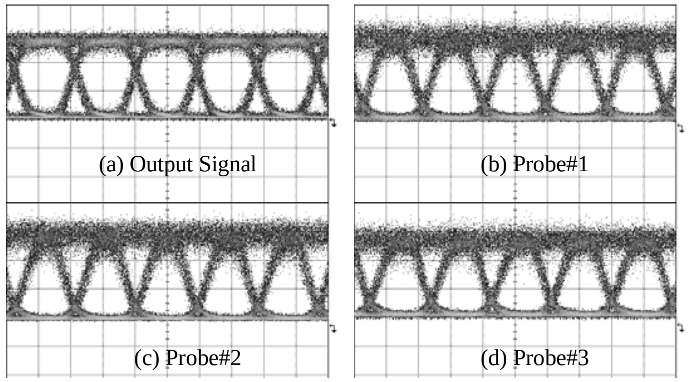

Fig. 3 Eye diagrams for (a) output signal at 1551nm; (b) probe#1 at 1552.7nm; (c) probe#2 at 1553.5nm; (d) probe#3 at 1554.3nm.

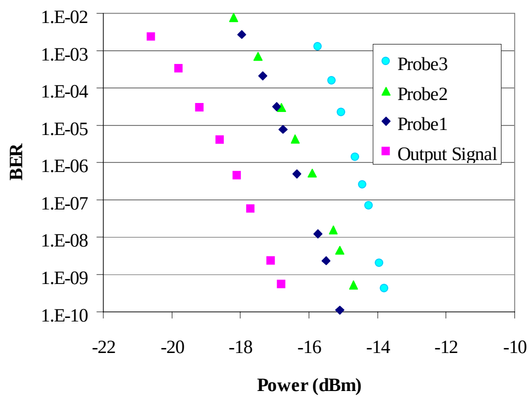

Fig. 4 Bit error rate of the multicasted signals.

We measured the BER performance to evaluate the quality of the multicasted signals, as shown in Fig. 4. The measurements are performed for the input signal, output signal (with wavelength at 1551 nm), three other probes at 1552.7nm, 1553.5nm, and 1554.3nm, respectively. The results show that the probes are successfully modulated with a power penalty of less than 3 dB compared with the output signal when the BER is 10^{-9}, consistent with the eye diagrams as shown in Fig. 3.

4. Conclusion

We have demonstrated simultaneous all-optical wavelength conversion and multicasting for a 10Gb/s NRZ system with 100GHz channel spacing by using a single-stage two-pump fiber optical parametric amplifier, with the conversion gain of at least 15 dB.

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