Optically Powered WDM Signal Transmission System with Distributed Parametric Amplification

Xing Xu, Chi Zhang, Sigang Yang, T. I. Yuk and Kenneth K. Y. Wong*

Department of Electrical and Electronic Engineering, The University of Hong Kong, Hong Kong

*presently on leave at the Massachusetts Institute of Technology, Cambridge, MA, USA. Email: kywong@eee.hku.hk

Abstract—We report an optically-powered WDM communication system with distributed parametric amplification in dispersion-shifted fiber. The parametric pump also supplies power for the receiver. Power penalties less than 2-dB for each channel at the BER of 10^{-9} are demonstrated with 10-dB gain.

I. Introduction

Distributed parametric amplification (DPA), one of the most promising candidates for the distributed amplification of optical signal in long-haul transmission links, has been studied in recent research [1]. Different from the discrete optical parametric amplifier (OPA) in the specially fabricated highly-nonlinear dispersion-shifted fiber (HNL-DSF) [2]–[6], DPA adopts the widely available dispersion-shifted fiber (DSF) in which the transmission and amplification of the optical signal can be achieved simultaneously. In this paper, a 4-channel WDM signal transmission system with DPA has been achieved within a 10-km DSF. Additionally, in order to enhance the energy-efficiency of the whole system, the residual optical pump is utilized as the power supply for the receiver. In the mean time, the energy-efficiency is enabled by a commercially available InP-based concentrated photovoltaic (CPV) cell, which can provide up to 26% power conversion ratio at 1300-1550 nm illumination.
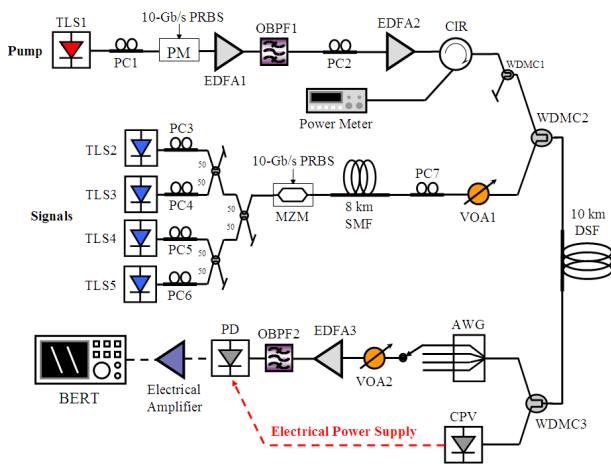
II. Experimental Setup

Fig. 1. Experimental setup for the optically powered WDM signal transmission system with DPA. WDMC: WDM coupler, AWG: arrayed-waveguide grating.

Fig. 1 shows the experimental setup of the proposed transmission system with DPA. The input 4-channel WDM signals, located over 1542.9 nm to 1545.45 nm, were generated by combining the output of four continuous-wave (CW) tunable laser sources (TLS2-5) with 3-dB couplers and intensity-modulating them together by a Mach-Zehnder modulator (MZM) driven by a 10-Gb/s 2^7-1 pseudorandom binary sequence (PRBS). The polarization controllers (PC3-6) after each laser source were used to minimize the insertion loss by aligning its state-of-polarization (SOP) with the transmission axis of the MZM. A spool of 8-km single-mode fiber (SMF) was then deployed to de-correlate different channels in time domain. On the other branch, the pump, sourced from TLS1 at 1548.8 nm, was first phase-dithered with a phase modulator (PM), driven by a 10-Gb/s 2^{23}-1 PRBS, to suppress the stimulated Brillouin scattering (SBS). A double-stage erbium-doped fiber amplifier (EDFA) scheme was applied to amplify the pump power upto 23 dBm. The optical band pass filter (OBPF1) between two EDFAs was used to reduce the amplified spontaneous emission (ASE) noise level from EDFA1. In order to avoid the reflection and to monitor the SBS level, a circulator (CIR) was inserted after EDFA2. A wavelength-division multiplexing coupler (WDMC1) with the passing band of 2-nm was applied to trim down the ASE noise of EDFA2. After combining with WDMC2, the pump and the signals were then launched together into the 10-km DSF with the nonlinear coefficient of $2\ W^{-1}km^{-1}$ and the zero-dispersion wavelength γ_0 of 1548 nm. By controlling the variable optical attenuator (VOA), the signal powers at the input of DSF were maintained at less than -19 dBm, while the pump power at the same point was 19.5 dBm. This ensured that the pump was not depleted and the generation of signal-related nonlinear effects, such as four-wave-mixing (FWM) and cross-gain modulation (XGM), would be insignificant. The SOP of the pump and the signals were aligned by polarization controllers (PC2 and PC7) to attain the maximum optical parametric gain.

The optical spectra at the output of DSF with and without pump are shown in Fig. 2. The power of four channels at the input of DSF was -20.35, -19.33, -20.05 and -19.56 dBm, respectively. The corresponding on-off gains were 10.03, 10.87, 11.02 and 10.36 dB. At the receiving end, after WDMC3, the residual pump power of 15.2-dBm was sent to the CPV cell to supply the electrical power for the signal receiving component. Fig. 3 shows the output curve of the CPV with different
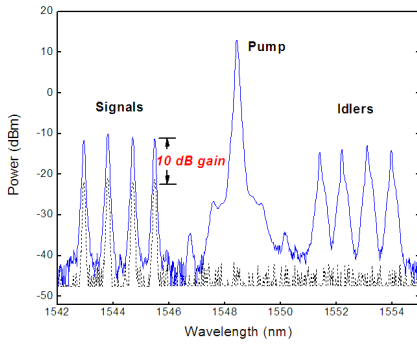
Fig. 2. Optical spectra at the output of DSF with (blue solid line) and without (black dotted line) parametric pump.
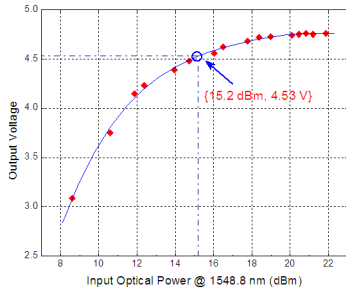

Fig. 3. The response curve of the CPV cell with the input pump light @ 1548.8 nm.
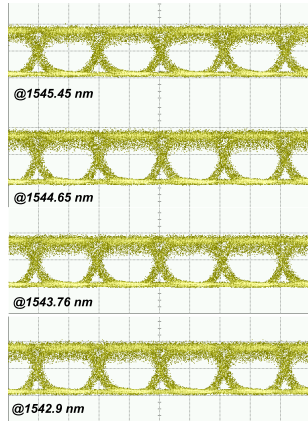

Fig. 4. The received eye-diagrams of four individual WDM channels with DPA in DSF.

input optical power at the pump wavelength. According to the curve, the corresponding output could reach 4.53 V which was enough for the bias voltage of 5-V photodiode (PD) used at the receiving end as the optical signal to electrical signal converter in our experiment. Finally, 4-channel 10-Gb/s WDM NRZ signals were de-multiplexed by an arrayed-waveguide grating (AWG) and the performance of each channel was then quantified by the bit-error rate tester (BERT).

III. EXPERIMENTAL RESULTS AND DISCUSSION

Fig. 4 lists the measured eye diagrams of all the received 10-Gb/s NRZ signals. Clear and widely open eye diagrams are observed for all four channels, which indicate the high
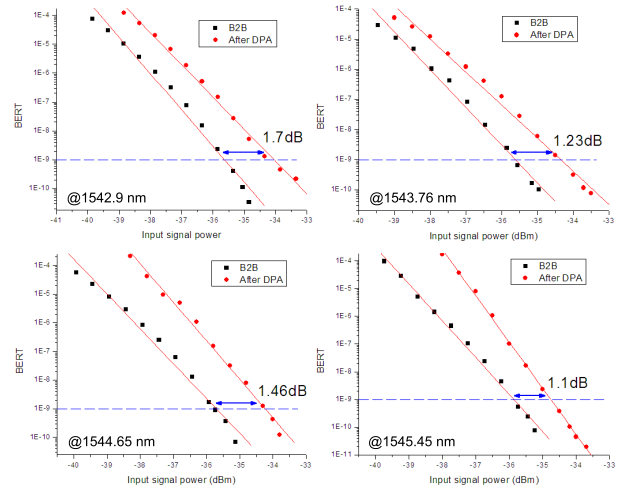

Fig. 5. BER plots for the back to back signals and the signals after DPA in the 10-km DSF.

quality of the receiving WDM signals. The noise observed on the mark level is mainly due to the conversion of pump phase modulation to signal intensity modulation along the DSF. The corresponding BER of each channel was measured and compared against the back-to-back (B2B) signals as shown in Fig. 5. Error-free operations are attained for all channels and the power penalties incurred range from 1.1 to 1.7 dB at the BER of 10^{-9}.

IV. CONCLUSION

We have demonstrated an optically powered WDM signal transmission system with DPA. Clear and widely open eye diagrams have been obtained for all WDM channels, with a less than or equal to 1.7-dB power penalty at 10^{-9} BER. By utilizing the remaining optical parametric pump as the power supply for the receiving end, the energy-efficiency of the whole system has been promoted.

ACKNOWLEDGMENT

REFERENCES

[1] G. Kalogerakis, M. E. Marhic, K. K. Y. Wong, L. G. Kazovsky, "Transmission of Optical Communication Signals by Distributed Parametric Amplification," *J. Lightwave Technol.*, vol. 23, pp. 2945-2953, 2005.
[2] M. E. Marhic, N. Kagi, T. K. Chiang, L. G. Kazovsky, "Broadband fiber optical parametric amplifiers," *Opt. Lett.*, vol. 21, pp. 573-575, 1996.
[3] M. E. Marhic, *Fiber Optical Parametric Amplifiers, Oscillators and Related Devices*: Cambridge University Press, 2007.
[4] M. E. Marhic, K. K. Y. Wong, G. Kalogerakis, L. G. Kazovsky, "Toward Practical Fiber Optical Parametric Amplifiers and Oscillators," *Opt. Photon. News*, vol. 15, no. 9, pp. 20-25, 2004.
[5] S. Radic, C. J. McKinstrie, "Two-pump fiber parametric amplifiers," *Opt. Fiber Technol.*, vol. 9, pp. 7-23, 2003.
[6] J. Hansryd, P. A. Andrekson, M. Westlund, J. Li, P. O. Hedekvist, "Fiber-based optical parametric amplifiers and their applications," *J. Sel. Topics in Quantum Electronics*, vol. 8, pp. 506-520, 2002.