DOI: 10.21917/ijct.2021.0357

LONG REACH DUAL POLARIZATION 128-QAM SYSTEM WITH DISPERSION/ NONLINEAR COMPENSATION USING OPTICAL BACK PROPAGATION

Kamalpreet Kaur and Baljeet Kaur
Department of Electronics and Communication Engineering, Guru Nanak Dev Engineering College, India

Abstract

Optical network systems with prolonged reach are required to cater the long distance located optical network units (subscribers). In this work, a DP-128 QAM based system is proposed with Optical Back Propagation (OBP) to cope up with nonlinear impairments in wavelength division multiplexed (WDM) systems. OBP module that consists of optical phase conjugator (OPC), Raman fiber amplifier (RFA) and erbium doped fiber amplifier (EDFA) is investigated in pre, post and symmetrical configuration. Ideal OBP conditions are simulated using Dispersion Compensation Fiber (DCF) as a RFA with dual directional pumping. Dual directional pumping shows better result than forward and backward pumping. Results revealed that system can cover 5100 km within acceptable BER (10-3) using symmetrical OBP with RFA dual bi-directional pumping. Proposed symmetrical OBP system provides enhanced performance as compared to other techniques such as single channel digital back propagation (DBP), wideband DBP, pre OBP with forward pumping, pre OBP with backward pumping, pre OBP with dual directional pumping, and post OBP with dual directional pumping.

Keywords:

Optical Back Propagation, DBP, Dispersion Compensation Fiber, DP-128-QAM

1. INTRODUCTION

Optical fiber communication (OFC) has wide bandwidth to cater high speed internet applications such as 4 K television, and high definition TV etc. In OFS, there are nonlinear effects which limit the performance of the system and divided into two types: dispersion and nonlinearity impairments (deterministic) [1], impairments arise from interplay between dispersion, nonlinearity and amplified spontaneous emission (ASE) [2]. Three types of impairment compensations are digital [3], optical [4] and optoelectronic [5]. Negative dispersion fibers, attenuation, nonlinear effects in digital domain realized with virtual fibers in DBP [6]. Only nonlinear impairments can compensate with DBP not stochastic nonlinear impairments. DBP effective in single channel system because it can compensate intra-channel nonlinearities and receiver have access to only single channel [7]. For inter-channel nonlinear distortion compensation, DBP is employed in WDM systems [8] but, it has not been used progressively because of limitation of accessing single channel. Both intra and inter channel impairments in WDM system can be compensated by optical back propagation (OBP) [9]. In OBP, real fibers replace virtual fibers and OPC act as negative nonlinear coefficients. Inline OBP compensates stochastic impairments in inline configuration and also has some issues such as low optical signal to noise ratio due optical amplifiers and difficulty in realization of dispersion-decreasing fiber (DDF)/dispersion-varying fiber (DVF) [10][11]. Dispersion compensation fiber can act as the DDF/DVF and replace it in optical network. Raman fiber (DCF) amplifier with pumps does the work of DDF/DVF [12]. Different researches have been reported in the compensation of intra-channel and inter-channel nonlinear impairments [13] [14] [15] however, the capacity of the reported works needs enhancements in terms of distance, data rate, no. of WDM channels [16].

In this work, DP-128 QAM based system is proposed with OBP to cope up with nonlinear impairments in WDM systems. OBP module that consists of OPC, RFA and EDFAs is investigated in pre, post and symmetrical configurations. Ideal OBP conditions are simulated using DCF as an RFA with dual directional pumping. Dual directional pumping shows better result than forward and backward pumping. Proposed symmetrical OBP system compared with single channel DBP, wideband DBP, pre OBP with forward pumping, pre OBP with backward pumping, pre OBP with dual directional pumping, and post OBP with dual directional pumping.

2. CONFIGURATIONS OF OBP

Symmetrical OBP configuration is used in this work and it is used to compensate the nonlinear effects, dispersion and other impairments by nullifying the phase change of input signal. In symmetrical configuration, OPC is placed in the middle of transmission fiber (TF) to provide opposite phase to first half TF phase change so as to give 0/null phase change. Power is launched from the WDM channels and coupled to first half TF/2, TF/2 then followed by OBP and second half TF/2. Length of the TF/2 is 50 km and total distance is 100 km.

OBP consisting of EDFA amplifiers, OPC and RFA with dual direction pumping. RFA (DCF=3.077 km) has two pumps in opposite sides such as co pump at 1450 nm (100mW) and counter pump at 1470 nm (100mW). Three amplifiers are employed in the OBP loop for the attenuation compensation. Signal launched in the TF experience dispersion, attenuation, nonlinear impairments. EDFA 1 boost the power of incoming signal and first half of TF/2 change phase of signal, then phase is reversed by OPC and loses in OPC are mitigated by again passing signal through EDFA2.

RFA with dual directional pumping performs the task of dispersion compensation due to DCF and is followed by second half TF/2 as well as EDFA 3. Proposed configuration is compared with the single channel DBP, wideband DBP, pre OBP with forward pumping, pre OBP with backward pumping, pre OBP with dual directional pumping, and post OBP with dual directional pumping.

2.1 SYSTEM SETUP

The Fig.1 represents the proposed symmetrical OBP system which consists of 6 channel WDM transmitters with DP-128 QAM having 25 Gsymbol/s symbol rate per channel and 50 GHz channel spacing. Simulation software Optisystem diagram of DP-128-QAM is shown in Fig.2.

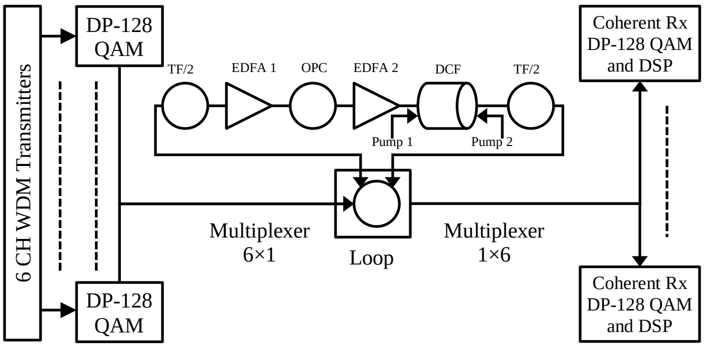


Fig.1. DP-128-QAM system employing OBP module

Table.1. System specifications of the proposed system

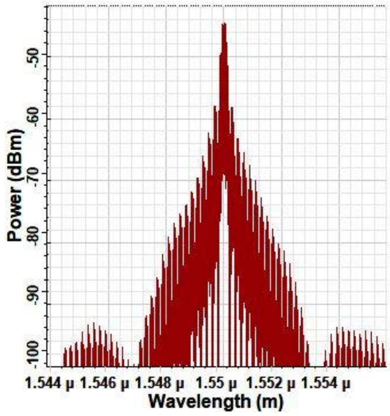
Parameter	Values
Data rate	350 Gbps/channel
WDM channels	6
Chanel spacing	50 GHz
Modulation	DP-128-QAM
EDFA 1 Gain/Noise figure	8.47 dB/4 dB
EDFA 2 Gain/Noise figure	8 dB/4 dB
EDFA 3 Gain/Noise figure	10 dB/4 dB
DCF Length	3.077 km
Co-Pump wavelengths	1450 nm
Counter pump wavelengths	1470 nm
TF/2	50 km

Total capacity of one channel is 350 Gbps (25 Gsymbol/s × 2 (dual polarization) × 7 (bits per symbol)) and total capacity of WDM system is 2100Gbps as there are 6 channels. TF has attenuation of 0.2dB/km, dispersion β_2 =8ps^2/km, and nonlinear coefficient γ=2.2W^{-1}km^{-1}. TF/2 length is 50km and for DCF, attenuation is 0.4dB/km, dispersion β_2 = 130ps^2/km, nonlinear coefficient γ=2.2W^{-1}km^{-1} and length 3.077km.

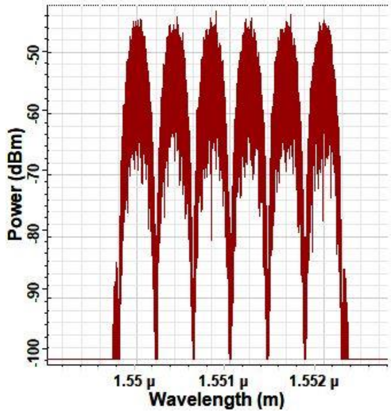
Simulation parameters are given in Table.1 for OBP loop. Each loop has total length of 100 km and therefore total 51 loops are required to get 5100 km. Gain is higher in the RFA when dual direction pumping is used. Receiver consists of coherent detection-based DP-128-QAM receiver followed by digital signal processing for frequency and carrier phase estimation. Constellation analyzer shows the error vector magnitude and BER tester gives the bit error rate.

3. RESULTS AND DISCUSSIONS

Performance analysis of the proposed system is performed at different input parameters. Optical spectrum analyzer (OSA) is representation of carrier spectrum with respect to power and center frequency.



(a)



(b)

Fig.2. OSA representation for (a) single (b) 6 WDM multiplexed DP-128-QAM

Single channel OSA depiction is given in the Fig.2(a) for the DP-128-QAM in proposed system. Further, OSA for 6 WDM channels is shown in the Fig.2(b).

Table.2. Performance values of different schemes in terms of Q factor (dB) at different input powers

I_P dB	$OBP_{S\text{-}Bi}$ Q.F.	DBP_{SC} Q.F.	DBP_{WB} Q.F.	$OBP_{P\text{-}Bi}$ Q.F.	$OBP_{P\text{-}Ba}$ Q.F.	$OBP_{P\text{-}FR}$ Q.F.	$OBP_{PO\text{-}Bi}$ Q.F.
-8	13.12	2	3.7	2.5	2.4	2.2	2.19
-6	13.12	2.1	3.8	3.9	3.7	2.5	2.48
-4	13.12	2.2	4.1	4.3	4.1	3	2.9
-2	13.12	2	4.8	5.9	5.6	2.1	2
0	13.12	1	4.5	6.2	6.2	1.8	1.78
2	17.25	0	0.4	8.1	7.9	1.5	1.49
4	17.24	0	0.3	8.7	8.5	1.2	1.18
6	17.25	0	0	9.6	9.4	0	0
8	17.25	0	0	9.5	9.2	0	0
10	17.25	0	0	7.1	7.1	0	0
12	13.12	0	0	6.2	6.2	0	0

where, I_P - input power, $OBP_{S\text{-}Bi}$ - symmetrical-bidirectional pumping, DBP_{SC} - single channel, DBP_{WB} - wideband, $OBP_{P\text{-}Bi}$ - pre configuration-bidirectional pumping, $OBP_{P\text{-}Ba}$ - pre configuration-backward pumping, $OBP_{P\text{-}FR}$ - pre-forward pumping, $OBP_{PO\text{-}Bi}$ - post configuration-bidirectional pumping

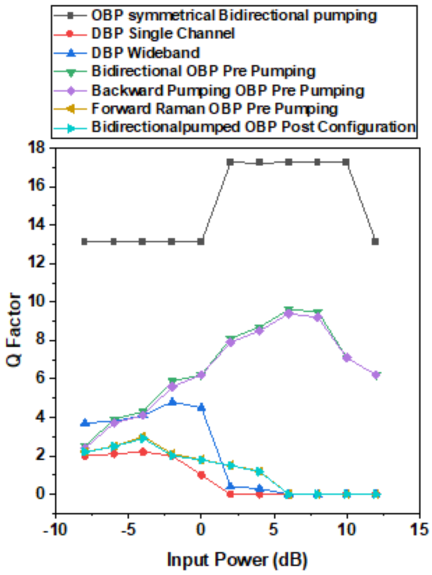


Fig.3. Performance of different schemes in terms of Q factor (dB) at different input powers

The performance of proposed symmetrical OBP system is compared with single channel DBP, wideband DBP, pre OBP with forward pumping, pre OBP with backward pumping, pre OBP with dual directional pumping, post OBP with dual directional pumping in Fig.3. *Q* factor is investigated at different input power levels and results revealed that OBP symmetrical bidirectional pumped (Q_{max} = 17.25) based system performed excellent and performance is followed by bidirectional pumped OBP pre configuration (Q_{max} = 9.6). Only backward pumping when OBP placed in pre configuration (Q_{max} = 2.48) has close performance to forward pumped OBP pre configuration (Q_{max} = 3) and next is wideband DBP (Q_{max} = 4.8). Bidirectional OBP post configuration (Q_{max} = 9.4) performs better than the wideband DBP (Q_{max} = 4.8) and least performing is single channel DBP (Q_{max} = 2.2).

The Fig.4 represents the BER performance of symmetrical OBP bidirectional pumped, single channel digital back propagation (DBP), wideband DBP, pre OBP with forward pumping, pre OBP with backward pumping, pre OBP with dual directional pumping, post OBP with dual directional pumping. Distance is varied from 500 km to 6000 km and it is observed that proposed symmetrical OBP bidirectional pumped scheme covered 5100 km successfully within acceptable range of BER (10^{-3}).

Table.3. BER performances values of different schemes at varied distances

D Km	$OBP_{S\text{-}Bi}$ BER	DBP_{SC} BER	DBP_{WB} BER	$OBP_{P\text{-}Bi}$ BER	$OBP_{P\text{-}Ba}$ BER	$OBP_{P\text{-}FR}$ BER	$OBP_{PO\text{-}Bi}$ BER
500	10^{-4}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
1000	10^{-4}	10^{-2}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
1500	10^{-4}	10^{-1}	10^{-3}	10^{-3}	10^{-2}	10^{-3}	10^{-3}
2000	10^{-4}	10^{0}	10^{-3}	10^{-3}	10^{-2}	10^{-2}	10^{-3}
2500	10^{-4}	10^{0}	10^{-2}	10^{-3}	10^{-2}	10^{-2}	10^{-3}
3000	10^{-4}	10^{0}	10^{-2}	10^{-3}	10^{-1}	10^{-2}	10^{-3}
3500	10^{-4}	10^{0}	10^{-2}	10^{-3}	10^{0}	10^{0}	10^{-3}
4000	10^{-4}	10^{0}	10^{-2}	10^{-3}	10^{0}	10^{0}	10^{-3}
4500	10^{-3}	10^{0}	10^{0}	10^{-3}	10^{0}	10^{0}	10^{-3}
5000	10^{-3}	10^{0}	10^{0}	10^{-2}	10^{0}	10^{0}	10^{-3}
5500	10^{-2}	10^{0}	10^{0}	10^{-1}	10^{0}	10^{0}	10^{-2}
6000	10^{-1}	10^{0}	10^{0}	10^{0}	10^{0}	10^{0}	10^{-1}

where, *D* - Distance, $OBP_{S\text{-}Bi}$ - Symmetrical-Bidirectional pumping, DBP_{SC} - Single Channel, DBP_{WB}-Wideband, $OBP_{P\text{-}Bi}$ - Pre configuration-bidirectional pumping, $OBP_{P\text{-}Ba}$ - Pre configuration -backward pumping, $OBP_{P\text{-}FR}$ - Pre-Forward Pumping, $OBP_{PO\text{-}Bi}$ - post configuration-bidirectional pumping.

Single channel DBP system can only able to cover 500 km, OBP pre based backward pumping scheme covered 1000 km, OBP pre forward pumping scheme covered 1500 km and Wideband DBP system covered 2000 km. OBP Pre based bidirectional pumped scheme and OBP Post based bidirectional pumped scheme covered 5000 km.

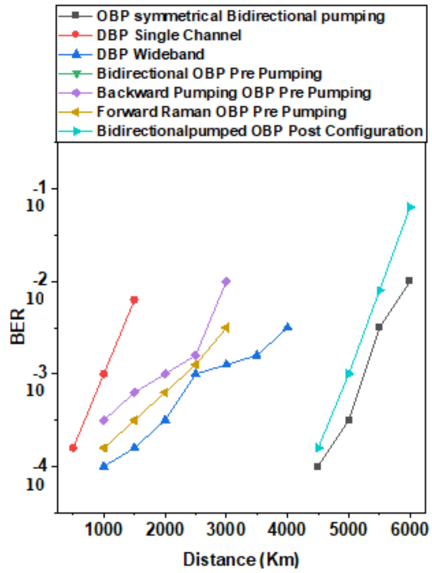


Fig.4. BER performances of different schemes at varied distances

4. CONCLUSION

We have investigated a symmetrical bidirectional pumped OBP technique to cope up with the dispersion and nonlinearity of the TF over 5100 km at 350 Gbps using DP-128-QAM and supported 6 WDM channels with channel frequency of 50 GHz (0.4 nm). OBP module that consists of OPC, bidirectional pumped RFA and three EDFAs is investigated to provide symmetrical configuration. Ideal OBP conditions are simulated using DCF as an RFA with dual directional pumping. Proposed symmetrical OBP system provides enhanced performance as compared to other techniques such as single channel DBP, wideband DBP, pre OBP with forward pumping, pre OBP with backward pumping, pre OBP with dual directional pumping, and post OBP with dual directional pumping. Distance is varied from 500 km to 6000 km and it is observed that proposed symmetrical OBP bidirectional pumped scheme covered 5100 km successfully within acceptable range of BER (10^{-3}). Single channel DBP system can only able to cover 500 km, OBP pre based backward pumping scheme covered 1000 km, OBP pre forward pumping scheme covered 1500 km and Wideband DBP system covered 2000 km. OBP Pre based bidirectional pumped scheme and OBP Post based bidirectional pumped scheme covered 5000 km. Q factor is investigated at different input power levels and results revealed that OBP symmetrical bidirectional pumped (Q_{max}=17.25) based system performed excellent and performance is followed by bidirectional pumped OBP pre configuration (Q_{max}=9.6). Only backward pumping when OBP placed in pre configuration (Q_{max}=2.48) has close performance to forward pumped OBP pre configuration (Q_{max}=3) and next is wideband DBP (Q_{max}=4.8). Bidirectional OBP post configuration (Q_{max}=9.4) performs better than the wideband DBP (Q_{max}=4.8) and least performing is single channel DBP (Q_{max}=2.2).

5. FUTURE SCOPE

OBP is investigated in different researches but some optimal parameters are yet to be explored and therefore future scope is given as:

- In proposed work, two pumps are used in the DCF to get high Gain and enhanced nonlinear compensation. However, in future, work should be done to use single pump because it lowers the cost of system.
- DP-128-QAM is used in the proposed work and this can further extend using DP-256-QAM.
- Data rate can be enhanced in future and channel spacing can be lowered in future.

REFERENCES

[1] G.P. Agrawal, "*Nonlinear Fiber Optics*", 5th Edition, Academic Press, 2012.

[2] J.P. Gordon and L.F. Mollenauer, "Phase Noise in Photonic Communications Systems using Linear Amplifiers", *Optics Letters*, Vol. 15, No. 23, pp. 1351-1353, 1990.

[3] K. Roberts, C. Li, L. Strawczynski, M. O'Sullivan and I. Hardcastle, "Electronic Precompensation of Optical Nonlinearity", *IEEE Photonics Technology Letters*, Vol. 18, No. 2, pp. 403-405, 2006.

[4] D. Pepper and A. Yariv, "Compensation for Phase Distortions in Nonlinear Media by Phase Conjugation", *Optics Letters*, Vol. 5, No. 2, pp. 59-60, 1980.

[5] B. Foo, B. Corcoran, C. Zhu and A.J. Lowery, "Distributed Nonlinear Compensation of Dual-Polarization Signals using Optoelectronics", *IEEE Photonics Technology Letters*, Vol. 28, No. 20, pp. 2141-2144, 2016.

[6] E. Mateo, L. Zhu and G. Li, "Impact of XPM and FWM on the Digital Implementation of Impairment Compensation for WDM Transmission using Backward Propagation", *Optics Letters*, Vol. 16, No. 20, pp. 16124-16137, 2008.

[7] X. Liang and S. Kumar, "Optical Back Propagation for Compensating Nonlinear Impairments in Fiber Optic Links with ROADMs", *Optics Letters*, Vol. 24, No. 20, pp. 22682-22692, 2016.

[8] X. Li, X. Chen, G. Goldfarb, E. Mateo, I. Kim, F. Yaman and G. Li, "Electronic Post-Compensation of WDM Transmission Impairments using Coherent Detection and Digital Signal Processing", *Optics Express*, Vol. 16, No. 2, pp. 880-888, 2008.

[9] X. Liang, S. Kumar and J. Shao, "Ideal Optical Backpropagation of Scalar NLSE using Dispersion-Decreasing Fibers for WDM Transmission", *Optics Express*, Vol. 21, No. 23, pp. 28668-28675, 2013.

[10] D. Pepper and A. Yariv, "Compensation for Phase Distortions in Nonlinear Media by Phase Conjugation", *Optics Letters*, Vol. 5, No. 2, pp. 59-60, 1980.

[11] S. Watanabe and M. Shirasaki, "Exact Compensation for both Chromatic Dispersion and Kerr Effect in a Transmission Fiber using Optical Phase Conjugation", *Journal of Lightwave Technology*, Vol. 14, No. 3, pp. 243-248, 1996.

[12] P. Minzioni, I. Cristiani, V. Degiorgio, L. Marazzi, M. Martinelli, C. Langrock and M.M. Fejer, "Experimental Demonstration of Nonlinearity and Dispersion Compensation in an Embedded Link by Optical Phase Conjugation", *IEEE Photonics Technology Letters*, Vol. 18, No. 9, pp. 995-997, 2006.

[13] T.J. Xia, G.A. Wellbrock, Ming-Fang Huang, Shaoliang Zhang, Yue-Kai Huang, Do-Il Chang, S. Burtsev, W. Pelouch, E. Zak, H. de Pedro, W. Szeto and H. Fevrier, "Transmission of 400g pm-16qam Channels over Long-Haul Distance with Commercial All-Distributed Raman Amplification System and Aged Standard Smf in Field", *Proceedings of International Conference on Optical Fiber Communication*, pp. 1-3, 2014.

[14] M. A. Iqbal, M. Tan and P. Harper, "On the Mitigation of RIN Transfer and Transmission Performance Improvement in Bidirectional Distributed Raman Amplifiers", *Journal of Lightwave Technology*, Vol. 36, No. 13, pp. 2611-2618, 2018.

[15] H.M. Wang, W.T. Shih and H. Taga, "Single Fiber Based 10.66 gb/s Bidirectional Long Reach WDM-PON Supported by Distributed Raman Amplifier", *Proceedings of Joint Conference on Opto-Electronics and Communications*, pp. 1-2, 2008.

[16] E. Bidaki and S. Kumar, "A Raman-Pumped Dispersion and Nonlinearity Compensating Fiber for Fiber Optic Communications", *IEEE Photonics Technology Letters*, Vol. 12, No. 1, pp. 1-17, 2019.