PERFORMANCE OPTIMIZATION OF MULTICHANNEL LONG-HAUL DWDM OADM RING NETWORK

Preet Kanwal
Lecturer, Mehr Chand Polytechnic College, Jalandhar, Punjab, India

Abstract

Wavelength-division multiplexing (WDM) is a method of combining multiple signals. WDM increases the carrying capacity of the physical fiber. But, DWDM carries a greater overall capacity. Such a capacity demand has been driving the service providers to upgrade their network from conventional 10 Gbit/s per wavelength based DWDM systems to more spectrally-efficient 40/100 Gbit/s and beyond based DWDM systems due to the economic advantage of high spectral efficiency. In this paper, we designed a 16 channel long haul DWDM OADM ring network and experienced that PMQPSK is the best modulation format among the used formats. Also, it is proved that the cross saturation effects can be minimised with the help of ring laser mitigation technique. The effect of PMD has also been displayed here and results are declared to show how much it effects the system as its value increases. OptSim simulation tool is utilised for the simulation of the designed network.

Keywords: WDM, DWDM, EDFA, PMQPSK, DFRA.

1. INTRODUCTION

Huge transmission capacity is provided by numerous installed point-to-point links, making use of wavelength division multiplexing (WDM). In an attempt to improve reliability and efficiency of the transmission, significant efforts are undertaken to integrate these links in optical networks [26]. Although normal channel add/drop can be managed to be relatively slow, accidental channel ‘add/drop’ such as a fiber cut or in-line component failure can be potentially very fast [13]. Amplification of light-waves by means of erbium doped fiber amplifiers (EDFAs) has become the preferred solution to mitigate reach limitations imposed by fiber attenuation and losses in optical networks based on wavelength division multiplexing (WDM). Network reconfiguration, component failures, fiber breaks or protection switching can cause abrupt changes in optical power of wavelength channels, known as transients. These changes can be transferred to other wavelengths due to the non-ideal dynamic properties of optical amplifiers and stimulated Raman scattering in transmission and dispersion-compensating fibers. Thus, even channels that are not directly affected by the switching operations or failures can suffer from some performance degradation at the receivers. In addition, gain variations can accumulate in a cascade of amplifiers. For this reason, even small gain variations can result in significant power changes at the receivers. But also the speed of the transients increases along the chain. Therefore, efficient amplifier control techniques are required that allow us to keep the gain profile of an amplifier or an amplifier stage relatively constant even if the input power changes [11]. Hybrid amplifiers, composed of erbium doped fiber amplifiers (EDFAs) and Distributed Fiber Raman Amplifiers (DFRAs), have emerged as a promising solution in extending the span and transmission capacity of dense wavelength division multiplexed (DWDM) optical networks that already utilize EDFAs [9]. The capacity offered by the today’s DWDM networks using 10Gb/s and 40Gb/s modulated wavelengths with 50GHz spacing is considered insufficient to meet the rapidly growing bandwidth requirement. In response to this market demand, WDM systems are being developed for 100Gb/s transmission [23] per wavelength operating on the 50GHz grid, using polarization multiplexed quadrature phase shift keying (PM-QPSK) modulation format. This modulation format has been proven to offer the optimum combination of features: highest bandwidth density with commercially available components [12]. Dense-Wavelength-Division-Multiplexing (DWDM) technologies are being employed widely by network integrators for the next-generation network implementations. The recent trend in the optical transport layer technology migrates from simple point-to-point DWDM links to optical-ring networks with optical add–drop multiplexers (OADMs) located at large traffic aggregation points in the network. The DWDM channels in such topology can be dropped at each OADM node but they can also transparently bypass the node without expensive optoelectronic conversions [7].

2. SYSTEM DESIGN

The designed OADM DWDM long-haul ring network architecture is based on a single unidirectional fiber ring topology having data rates of 60Gbps. It consists of six OADM nodes as shown in fig. 1 connected by non linear single mode fiber and the dispersion compensated fiber. Each node is converting the electrical data into the optical signal and transmitting the optical link of DWDM ring. Each node is also equipped with tuneable transmitters operating in multiband environment and compound receivers with multiple filters. Here, each receiver takes care of a particular data channel which owns a unique wavelength [26].

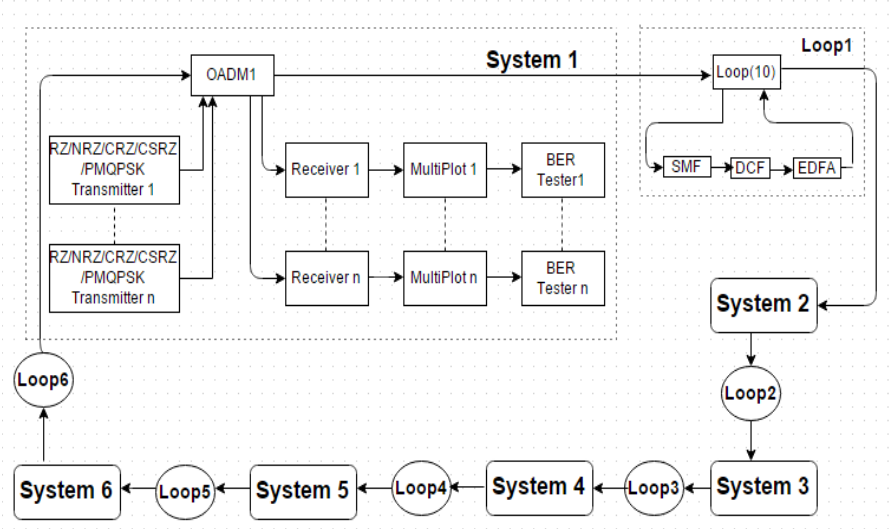


Fig. 1. Six node, 16 Channel DWDM OADM Ring Network

Each node has the ability to add/drop any wavelength of each data channel. EDFA has been employed to compensate for the fiber attenuation. SMF of 80 Km is used along with 20 Km of DCF in each loop of 100 Km and each loop iterated 10 times to realize effective transmission distance of 1000 Km in each loop. The power per channel of -9 dBm was used at the transmitter side. The value of crosstalk was fixed at -15dB.We used 16 wavelengths at 50 GHz (0.4nm) spacing ranging from 1547.2nm to 1553.2 nm wavelength. Time delay block was inserted to connect the signal from the last node back to the first node for performing simulation [26]. Performance of the designed system is optimized by using various modulation formats viz. RZ, NRZ, CRZ, CSRZ and PMQPSK.

3. RESULTS AND DISCUSSIONS

Performance of the modelled optical communication link is gauged on the basis of Eye opening, BER and Q^2(dB). The output has been obtained on the sample basis from higher wavelength channel, central wavelength channel and lower wavelength channel in order to ensure the optimal functioning of the system over entire wavelength range.

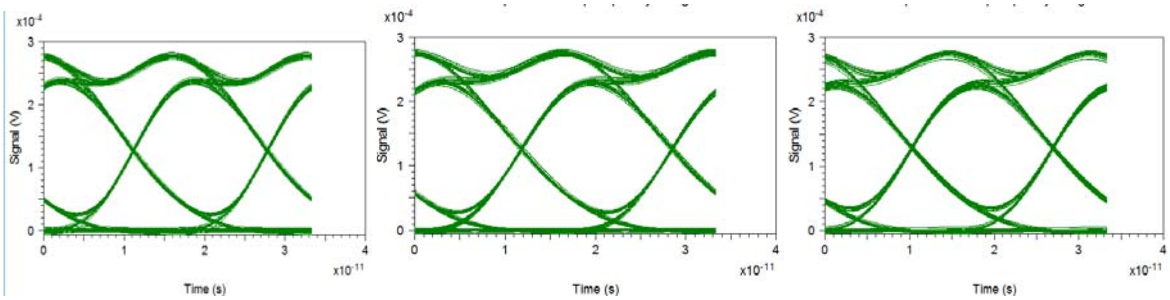
3.1. Performance evaluation of Modulation Formats

The BER and Q^2(dB) values of received signal for $\lambda 1$=1547.20 nm, $\lambda 2$=1550 nm and $\lambda 3$=1553.20 nm are tabulated in Table 1 and the corresponding eye patterns of the received signal for various modulation formats are shown in Fig. 2(a–e).

Table 1 Modulation formats comparison

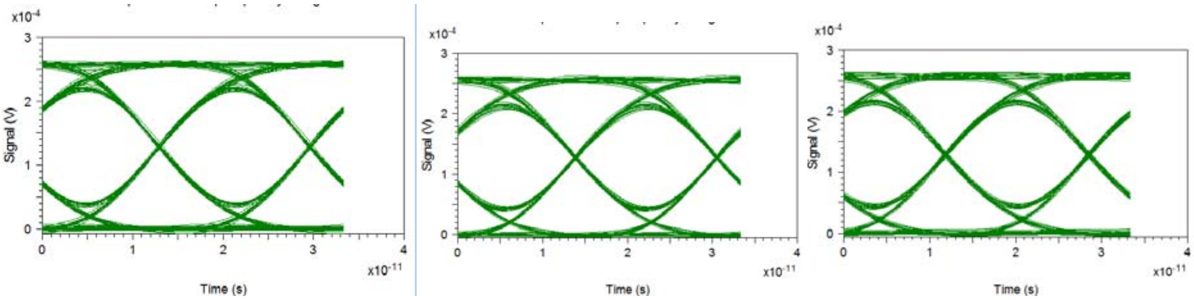
Modulation Formats	**RZ**		**NRZ**		**CRZ**		**CSRZ**		**PMQPSK**	
	BER	**Q^2**	**BER**	**Q^2**	**BER**	**Q^2**	**BER**	**Q^2**	**BER**	**Q^2**
λ_1	10^{-17}	18.5	10^{-16}	18.2	10^{-20}	19.2	10^{-17}	18.4	10^{-23}	19.9
λ_8	10^{-17}	18.6	10^{-16}	18.0	10^{-20}	19.2	10^{-17}	18.4	10^{-22}	19.7
λ_{16}	10^{-15}	18.2	10^{-15}	17.8	10^{-19}	18.9	10^{-17}	18.3	10^{-20}	19.2

It is observed from table 1 that PMQPSK modulation format yielded better performance as compared to oter considered formats.



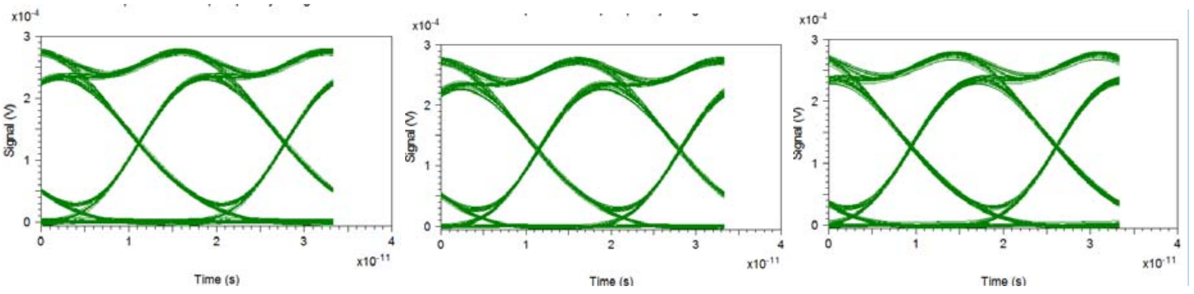
(i) (ii) (iii)

Fig. 2(a) Eye Diagram response of RZ modulation format for λ_1, λ_8 and λ_{16} respectively



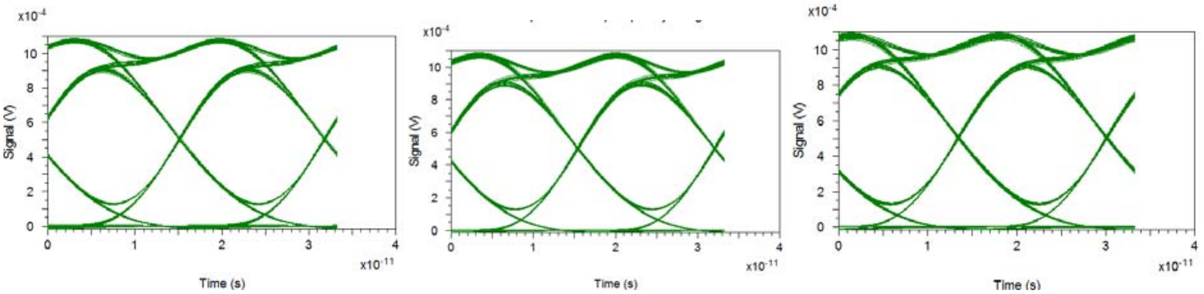
(i) (ii) (iii)

Fig. 2(b) Eye Diagram response of NRZ modulation format for λ_1, λ_8 and λ_{16} respectively



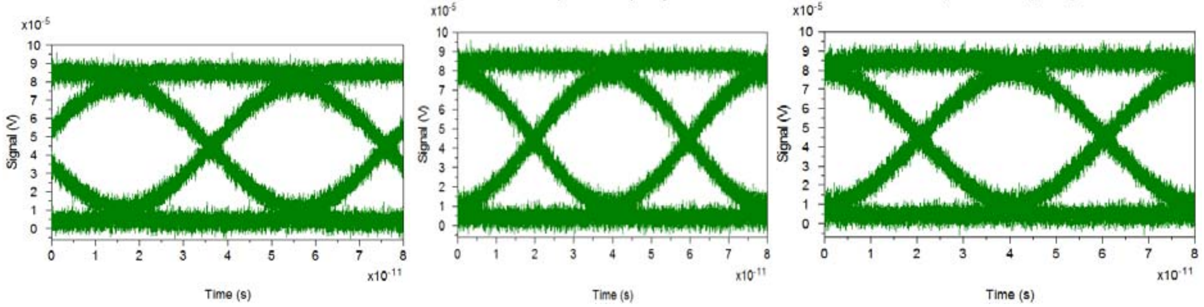
(i) (ii) (iii)

Fig. 2(c) Eye Diagram response of CRZ modulation format for λ_1, λ_8 and λ_{16} respectively



(i) (ii) (iii)

Fig. 2(d) Eye Diagram response of CSRZ modulation format for λ_1, λ_8 and λ_{16} respectively



(i) (ii) (iii)

Fig. 2(e) Eye Diagram response of PMQPSK modulation format for λ_1, λ_8 and λ_{16} respectively

3.2. PMD Estimation

The system is also designed to check the effect of PMD on the different modulation formats in the system. Polarization Mode Dispersion (PMD) is a very severe problem and it limits the distance and data rate in the optical communication system. It is a time varying quantity that degrades the performance of the system. Its impact becomes more severe and serious if we move towards multi-channel systems and high data rates. The PMD coefficient is used to ensure the reliability of the system. In this system, pmd_seed value was varied from 0–50 at pmd_coefficient of 0.1 and 1.0 and the corresponding effect on BER and Q^2dB was recorded as shown in fig. 3(a–e) [1].

(i) (ii)

Fig. 3(a) pmd_seed v/s BER and pmd_seed v/s Q^2 dB response of RZ modulation format for λ_8

(i) (ii)

Fig. 3(b) pmd_seed v/s BER and pmd_seed v/s Q^2 dB response of NRZ modulation format for λ_8

(i) (ii)

Fig. 3(c) pmd_seed v/s BER and pmd_seed v/s Q^2 dB response of CRZ modulation format for λ_8

(i) (ii)

Fig. 3(d) pmd_seed v/s BER and pmd_seed v/s Q^2 dB response of CSRZ modulation format for λ_8

(i) (ii)

Fig. 3(e) pmd_seed v/s BER and pmd_seed v/s Q^2 dB response of PMQPSK modulation format for λ_8

3.3. Mitigation of Cross-Saturation Transients

The system model designed to plot the transient response is given below in fig. 4. It consists of the DWDM OADM ring network. Only one node is considered here for observing the result after 1st EDFA. Two wavelengths 1547.2nm and 1553.2nm are used at this node. Here, 1547.2nm is added or dropped in the system but 1553.2nm has been kept as the surviving channel. A pump laser of 980nm is employed to pump the signal into the system.

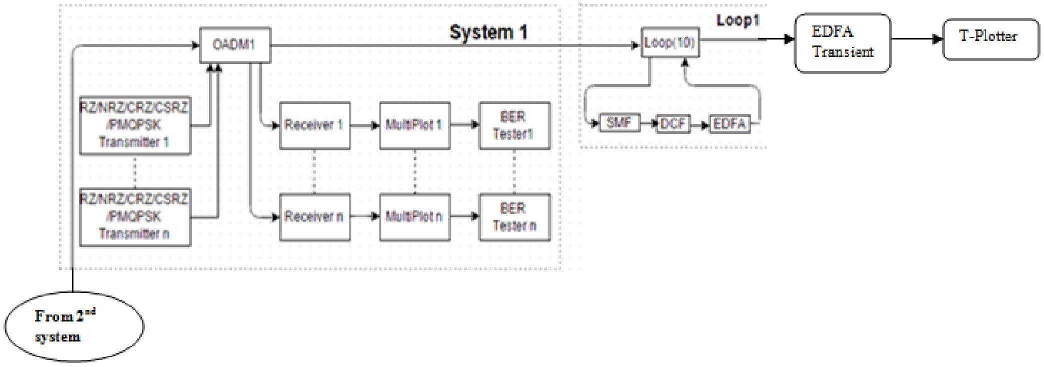


Fig. 4 Block diagram of system model to plot transients after EDFA

The transient response of the system is checked and the results are collected. The main objective is to mitigate the cross saturation in the proposed system. For the mitigation of the transients, ring laser technique is utilised. In this technique, an optical filter along with the delay system is implemented and the transients are mitigated. The block diagram of system is designed to mitigate the cross saturation effect in the system and this is shown in fig. 5. However, these small power excursions (transients) are much smaller than those that would be realized without the gain control mechanism. The lasing signal evolves from the ASE noise of the EDFA. The lasing wavelength is selected by the filter in the feedback path. By controlling the amount of loss in the feedback path, we can trade gain stability for EDFA gain. Fig. 5 shows the system model designed to mitigate the cross-saturation (transient) effect.

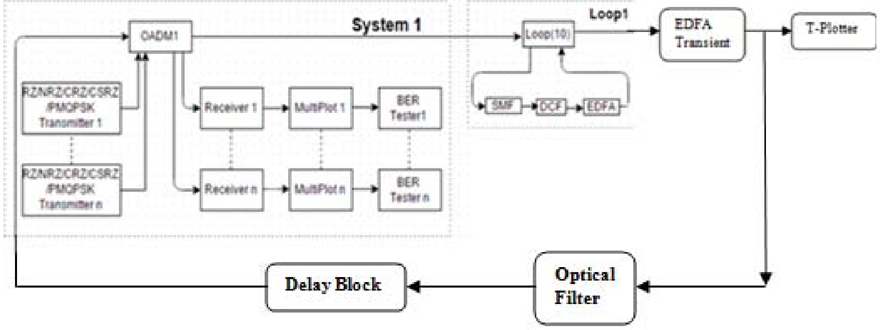
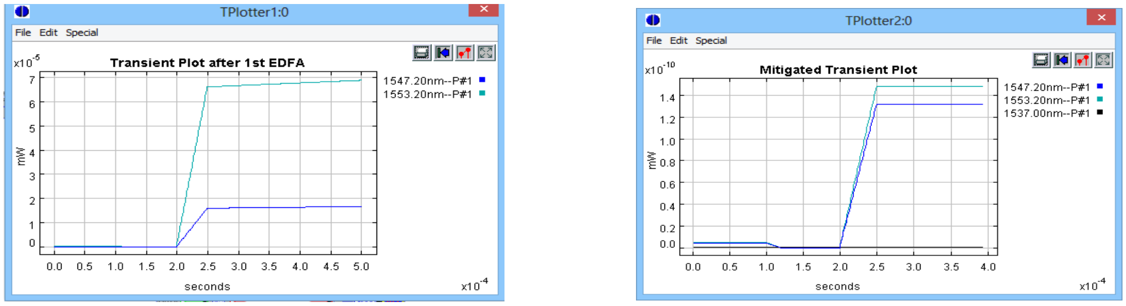


Fig. 5 Block diagram of system model to mitigate the cross saturation effect (Ring Laser Technique)

The ring laser technique is working effectively and the transients are mitigated with the help of this technique. In this method, two wavelengths are utilised i.e., lambda1 and lambda16. The lasing wavelength used here is 1537nm. The response of the transients without using control method was up to 6.6x10^{-5} mW and after using the control method, it switched to 1.4x10^{-10} mW. The response of the system before and after the mitigation is shown in fig. 6.



(a) (b)

Fig. 6 (a) Transient plot before mitigation, (b) Mitigated cross saturation effect with transient plot

Table 2 shows the comparison of transient response before and after employing the mitigation (ring laser) technique.

Table 2 Comparison of Transient Response before and after mitigation

Time ↓ (Sec)	**Response of transients after 1st EDFA (mW)**		**Response of transients after 2nd EDFA (mW)**			**Response of transients after mitigation (mW)**	
	λ 1	**λ 16**	**λ 1**	**λ 8**	**λ 16**	**λ 1**	**λ 16**
2.0	0 x 10^{-5}	0 x 10^{-5}	0 x 10^{-5}	0 x 10^{-5}	0 x 10^{-5}	0 x 10^{-10}	0 x 10^{-10}
2.5	1.7 x 10^{-5}	6.6 x 10^{-5}	1.7 x 10^{-5}	3.0 x 10^{-5}	6.6 x 10^{-5}	1.3x10^{-10}	1.5 x 10^{-10}
3.0	1.8 x 10^{-5}	6.7 x 10^{-5}	1.8 x 10^{-5}	3.0 x 10^{-5}	6.7 x 10^{-5}	1.3x10^{-10}	1.5 x 10^{-10}
3.5	1.8 x 10^{-5}	6.8 x 10^{-5}	1.8 x 10^{-5}	3.0 x 10^{-5}	6.8 x 10^{-5}	1.3x10^{-10}	1.5 x 10^{-10}

IV. CONCLUSION

The DWDM system with OADM, 16 channels, 1000Km fiber and with 5 different modulation formats has been designed and is working successfully. The simulation has been performed and the results are obtained. This proves that the PMQPSK modulation format is best among the 5 given modulation formats. The cross saturation transients have also been successfully reduced with the help of the mitigation technique i.e., the ring laser technique. Further, the response of different system was recorded in terms of BER and Q^2 dB in accordance with the values of PMD i.e., pmd_seed and pmd_coefficient. The best system was decided who tolerates/handles the effect of PMD better than any other system i.e., PMQPSK is found to be the best system for PMD tolerance.

REFERENCES

[1] Jagjit Singh Malhotra, Manoj Kumar and Ajay K. Sharma," Performance Evaluation and PMD Tolerance of PM-QPSK at 100 Gbit/s in Dispersion Managed 64 Channel Long Haul DWDM Optical Communication Link", 2013.

[2] Radisavljevic Gajic, "Non-linear integral control of photon power transients in optical communication networks with erbium-doped fibre amplifiers", Circuits, Devices & Systems, IET (Volume:8 , Issue: 5) pp :412 - 420 , 2014.

[3] Yunfeng Shen, Xiumin Liu, Shan Zhong, Lei Zong, John Veselka, Peter Kim, Joseph Ferment, and Harshad P. Sardesai, " *Design of Polarization De-Multiplexer and PMD Compensator for 112 Gb/s Direct-Detect PDM RZ-DQPSK Systems*", JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 28, NO. 22, NOVEMBER 15, 2010.

[4] Ghoniemy, S., MTC, Cairo, George, K.F. ,MacEachern, L., "Performance Evaluation and Enhancements of 42.7 Gb/s DWDM Transmission System Using Different Modulation Formats", 2011

[5] Chaouch, H.,Tucson, AZ, Kuppers, F.,Vorbeck, S., Schneiders, M., " Simulation and optimization of 100 Gbit/s single channel modulation formats", 2010

[6] Jeffrey T. Rahn, Han Sun, Kuang-Tsan W and Bert E. Basch," *Real-Time PMD Tolerance Measurements of a PIC-Based 500 Gb/s Coherent Optical Modem*", JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 30, NO. 17, SEPTEMBER 1, 2012

[7] Annika Dochhan, Helmut Griesser, Nicklas Eiselt, "*Solutions for 80 km DWDM Systems*", JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 34, Issue: 2, Jan 15, 2016

[8] Vivek Kachhatiya, Shanthi Prince, "*Wavelength division multiplexing-dense wavelength division multiplexed passive optical network (WDM-DWDM-PON) for long reach terrain connectivity*", Communication and Signal Processing (ICCSP), 2016 International Conference

[9] Bárbara Dumas and Ricardo Olivares, "*Transient Link Control Technique Applied to Optical Hybrid Amplifier (EDFAÅDFRA)*

Cascades", J. OPT. COMMUN. NETW./VOL. 4, NO. 11/NOVEMBER 2012

[10] A. Richter, H. Louchet, I. Koltchanov, N. Karelin, J. Farina," Dynamic Events in Optical Networks – Emulation and Performance Impact Analysis", The Military Communications Conference - Unclassified Program - Networking Protocols and Performance Track, 2010

[11] Lutz Rapp and João Ferreira, "*Dynamics of Spectral Hole Burning in EDFAs: Dependency on Pump Wavelength and Pump Power*", IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 22, NO. 16, AUGUST 15, 2010

[12] M. Filer and S. Tibuleac," DWDM transmission at 10Gb/s and 40Gb/s using 25GHz grid and flexible-bandwidth ROADM", 2011

[13] Xiang Zhou, Mark Feuer and Martin Birk, "Fast control of inter-channel SRS and residual EDFA transients using a multiple-wavelength forward-pumped discrete Raman amplifier", 2007

[14] Hyeon-Min Bae, Jonathan Ashbrook, Naresh Shanbhag, Fellow, IEEE, and Andrew Singer, "*Fast Power Transient Management for OC-192 WDM Add/Drop Networks*", IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 43, NO. 12, DECEMBER 2008

[15] Pavel Skoda , Jan Radil, Josef Vojtech, "*Time transfer over 1900 km of DWDM network*", Telecommunications and Signal Processing (TSP), 2017 40th International Conference

[16] D. Chiaroni, C. Simonneau, M. Salsi, G. Buforn, S. Etienne, H. Mardoyan, J. E. Simsarian, J-C. Antona," Optical Packet Ring Network Offering Bit Rate and Modulation Formats Transparency", 2010

[17] Diego E. Crivelli, Mario R. Hueda, Hugo S. Carrer, Martín del Barco, Ramiro R. López, Pablo Gianni, Jorge Finochietto, Norman Swenson, Paul Voois, and Oscar E. Agazzi," *Architecture of a Single-Chip 50 Gb/s DP-QPSK/BPSK Transceiver With Electronic Dispersion Compensation for Coherent Optical Channels*", IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS—I: REGULAR PAPERS, VOL. 61, NO. 4, APRIL 2014

[18] Samael Sarmiento, Jose A. Altabas, David Izquierdo,"*Cost-effective DWDM ROADM design for flexible sustainable optical metro–access networks*", IEEE/OSA Journal of Optical Communications and Networking (Volume: 9, Issue: 12, Dec. 2017)

[19] Emma Lazzeri, An Truong Nguyen, Nobuyuki Kataoka, Naoya Wada, Antonella Bogoni, and Luca Potì, "*All Optical Add and Drop Multiplexing Node for Hybrid Topology Networks*", JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 29, NO. 24, DECEMBER 15, 2011

[20] Hongjie Wang, Leonid V. Kotov, Dmitry A. Gaponov, Am´elie Cabasse, Mikhail V. Yashkov, Denis S. Lipatov, Mikhail E. Likhachev, Jean-Louis Oudar, Gilles Martel, S´ebastien F´evrier, and Ammar Hideur, "*Dissipative Soliton Generation and Amplification in Erbium-Doped Fibers Operating at 1.55 μm*", IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL. 20, NO. 5, SEPTEMBER/OCTOBER 2014

[21] D. A. Fishman, J. Ying, X. Liu2, S. Chandrasekhar, and A. H. Gnauck, "Optical Add/Drop Multiplexer with Asymmetric Bandwidth Allocation and Dispersion Compensation for Hybrid 10-Gb/s and 40-Gb/s DWDM Transmission", 2006

[22] Lutz Rapp, "*Transient Behavior of EDFA Stages Using Pump Power Splitting or Pump Bypass Technique*", JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 25, NO. 3, MARCH 2007

[23] João M. Ferreira, Daniel Fonseca, Paulo Monteiro, Armando N. Pinto, and Lutz Rapp, "Site Dependent Pumping Effect on Two–level EDFAs", 2013

[24] Vikrant Sharma, Anurag Sharma, Dalveer Kaur, "*Observation and Mitigation of Power Transients in 160Gbps Optical Backhaul Networks*", European Scientific Journal, vol. 9, no. 18, June 2013

[25] Zhaoxin Wang, Chinlon Lin, and Chun-Kit Chan, "*Demonstration of a Single-Fiber Self-Healing CWDM Metro Access Ring Network With Unidirectional OADM*", IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 18, NO. 1, JANUARY 1, 2006

[26] Optsim Application Notes and Examples, *www.rsoftdesign.com,* *http://optics.synopsys.com/rsoft/application-gallery/optsim-dwdm-ring.html*

[27] Wavelength Division Multiplexing, *http://en.wikipedia.org/wiki/Wavelength-division_multiplexing*