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Enhancement of traveling wave semiconductor optical amplifier approach for DWDM communication system

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ABSTRACT

In this study, the high performance of dense wavelength division multiplexing (DWDM) by using a traveling wave semiconductor optical amplifier (TW-SOA) at a channel spacing of 100 GHz is investigated, in terms of (Q-factor, injected current, transmitted power, gain). The Optisystem software is employed to send the different range of input power over the different ranges of the TW-SOA injected current with optimized TW-SOA parameters. The data rate of transmission optical signal up to 300 Gb/s at -35 dB input signal power have been investigated. The better results have been measured of the information signal with high quality and gain, when the range of input power is corresponding to the optimized range of injected current for the signal to be transmitted effectively. The present communication also supports various numbers of users with the same data rate of 5 Gb/s which is used to check the high quality of the signal in the receiver.

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1. INTRODUCTION

Future communication structures are supposed to give higher bit rate and wider bandwidth services to serve the subscriber's fast growing data use [1], [2]. Optical networks were expanded to maintain such high bandwidth and low-cost deployment in the distribution system.The dense wavelength division multiplexing (DWDM) network is a hopeful approach to meet the end user requirements with high efficiency, flexibility, and competitive pricing, since it can hold multiple wavelengths and may be clear to the channel bit rate [3], [4]. Despite the unique specifications and significant benefits of the optical communication network, it suffers from linear and non-linear losses because of the physical properties of the optical fiber [5], [6]. Traveling wave Semiconductor optical amplifiers a can be implemented in most optical systems to add distinct improvements [7], [8]. Recently, traveling wave semiconductor optical amplifier (TW-SOAs) were widely used as a sensible alternative to the erbium-doped fiber amplifier to substitute the attenuation in optical fibers [9], [10]. As well as, TW-SOAs are going into the fiber-optic domain, not as a substitute for the erbium-doped fiber amplifier, but as an empowering technology in various application fields [11]. TW-SOA technology offers low cost, compact size, with a reasonable energy consumption. In addition, rapid switching and working at wavelengths outside of the 1550 nm line are available [12]. These advantages are opening the road towards the adoption of TW-SOAs in modern and existing studies [13], [14]. Many researchers have studied the properties of SOAs in optical communication networks and their impact on performing these networks [15]. SOAs contribute to increasing the length of the transmission line in optical networks, improving network performance and raising the level of the quality factor, as they work to reduce the level of expected bit error rate (BER) in the signals sent through optical networks [16], [17]. Ivaniga *et al.* [18], studied and showed the four–channel using the DWDM system and using SOA amplifier, they got performance results of injected current (0.05, 0.1, and 0.2) A and the maximum data rate transmission was 40 Gb/s. Swetha *et al.* [19], studied and estimated the optimization of parameter values for the SOA amplifier. The maximum data rate transmission was 100 Gb/s at the range of got gain between (8-12) db. Miglani *et al.* [20] studied and showed the extended reach performances utilizing a 40 Gbps 100-channel DWDM system with SOA, erbium-doped fiber amplifier (EDFA), and Raman hybrid optical amplifier for a 100-km long fiber link. However, this system is more complex and expensive compared to other systems. In this paper, we focus on the parameters of TW-SOA amplifier that provide extending in bandwidth, which reaches 5 Gb/s × 60 channels of DWDM system. It achieved the optimum range injected current with input power to get the high gain and performance. Moreover, an intensive study of the TW-SOA behavior in DWDM systems has been presented. Network performance is investigated by changing the launch power. injected current and the number of channels. The rest of this paper includes the method which introduces the DWDM system and the theory of TW-SOA. The results and discussion are presented in section 3, and the paper is concluded in section 4. The high capacity in the DWDM system is more efficient when using TW-SOA amplifiers. The satisfied Q-Factor is achieved in this system designed with only one optical amplifier, as shown in Table 1.

Table 1. performance comparison of various DWDM communication systems based on data rate in a different number of channels

Ref.	Max. no. of channels	Spacing of wavelength (nm)	Data rate	Net capacity	Transmission distance	Amplification scheme technique
[20]	100	$\lambda = 0.1nm$	40 Gbps	4 Tbps	100 Km	Hybrid optical amplification
[21]	100	$\lambda = 0.2nm$	10 Gbps	1 Tbps	200 Km	Hybrid optical amplification
[22]	16	$\lambda = 0.8nm$	10 Gbps	160 Gbps	84 Km	SOA
[23]	4	$\lambda = 1.6nm$	2.5 Gbps	10 Gbps	125 Km	SOA
Proposed work	60	$\lambda = 0.8nm$	5 Gbps	300 Gbps	40 Km	SOA

2. METHOD

Figure 1 illustrates the optical fiber communication system components that have (transmitter, Mux, Demux, receiver, optical fiber, and TW-SOA amplifier), which have been simulated. The transmitter part is composed of a different number of channels which have a 5 Gbps data rate with 0.8 nm wavelength spacing. Each of them operates at a different frequency in a range of (193.1–199) THz. Each transmitter branch includes a virtual random binary sequence of five Gbps for the data rate source. The signal format is a non-return to zero (NRZ), which is generated by the data source. The laser source is used to send the data from an optical carrier wave. Each light signal will be combined based on a carrier signal in a DWDM mux. The dingle mode fiber (SMF) is used at a fixed distance of 40 km. The SOA amplifier has been covered successfully at a 0.4 coefficient factor, which is used for amplifying an optical signal in part two. In the receiver part, an avalanche photodiode receives the optical signal (APD) as a signal detector and the bandwidth value is 80 GHz of band pass filter with a 100 GHz channel spacing frequency. The operating properties of the (APD) photodiode that has a value of 10 nA of dark current, the quantum efficiency of 0.78, and the responsivity of 0.7 A/W parameters are set to investigate a high performance for the proposed system.

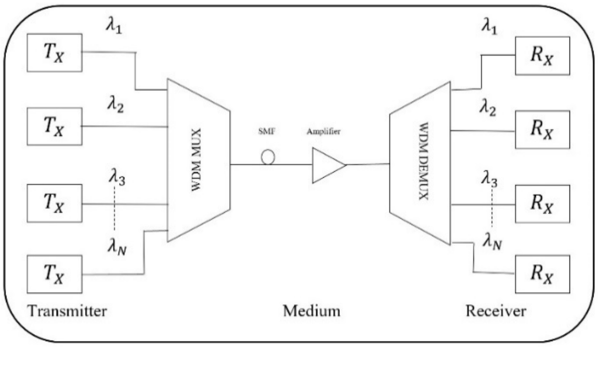

Figure 1. Generalized block diagram of DWDM communication system

2.1. DWDM SYSTEM

In the modern day, the optical fiber communications flourished owing to the rapid improvement in the world of communication due to many advancements producing high capacity, lightweight, low maintenance technologies that provide longer optical signal transmission. There are many applications utilized by DWDM technology as a telecommunication system, computer network, military and space applications, and internet services. The major limitations of optical communication are attenuation and dispersion [24]. The TW-SOA amplifier is providing a solution for many efficient systems at a low cost.

2.2. THEORY OF TW-SOA

One of the most important requirements for achieving all-optical processing operations is the presence of optical material with non-linear properties so that it constitutes a suitable environment to achieve the required interaction between the different light beams on the one hand, and between those light beams and the nonlinear optical material on the other hand. These materials constitute the main building block for manufacturing the TW-SOAs. TW-SOA is made from semiconductor materials with special optical properties, for example GaAs, AlAs, GaSb, HgTe, InAs, InP, and CdTe. TW-SOAs are pumped from an external electrical source in order to create a population inversion and, consequently, an optical gain is generated by stimulated emission [7], [25]. The performance quality and frequency band of the TW-SOA with which it works depend on many physical parameters. On the other hand, the dimensions of the TW-SOA (length, width, and height) depend on the optical properties of the material that constructs the TW-SOA, such as differential gain (G), loss (α), optical confinement factor, initial carrier density, line width enhancement factor, recombination coefficient (A), recombination coefficient (B), and recombination coefficient (C). The value of the optical gain (G) of the TW-SOA depends on many parameters. Some of these parameters are related to the properties of the material constituting the TW-SOA, such as the material gain that can be calculated through the (1).

$$g = a(n - n_0) \tag{1}$$

Where a is a gain constant, n is an injection current density, and n_0 is an injection carrier density. On the other hand, G depends on TW-SOA electrical pumping parameters, which is the injected current (I), and it can be calculated through the (2).

$$I = eWdL(Bn^2 + Cn^3) \tag{2}$$

Where e is the charge of the electron, W, d, L are the dimensions (width, thickness and length) of the gain medium, B is the radiative constant, and C is Auger recombination constant. Also, G depends on the power of amplified spontaneous emission (P), which can be calculated from the (3).

$$p = hvfWdBn^2(G - 1)/(\Gamma g - \alpha) \tag{3}$$

Where is photon energy, Γ is the confinement factor, and α is optical absorption. Therefore, G is given by (4).

$$G = exp[(\hat{A}g - \alpha)L] \tag{4}$$

The performance of the TW-SOA in optical communication systems can be improved by optimizing one or more of these parameters [19]. There are many parameters through which it is possible to evaluate the performance development in different optical communication systems, for example, studying the variation of gain and Q-Factor with the TW-SOA injected current, as well as with the number of users in DWDM systems.

3. RESULTS AND DISCUSSION

3.1. Parameters optimization

The optimization of parameters is shown in Table 2. By assigning a main parameter of injected current to (In GaAs), with all related physical parameters considered, the optimum values and typical range for the TW-SOA amplifier are obtained. The number of channels varies between (10 - 60). The DWDM system is used with the TW-SOA amplifier, which includes the listed value of TW-SOA parameters in Table 2. The amplification gain is calculated by changing the input power from -35 dBm to 35 dBm. Also, the measured output power is used to calculate the amplification gain at a data rate 5 Gb/s and is tabulated in Table 3. Figure 2 illustrates a plotted graph according to the values in Table 3, which is obtained at a saturation power value of 8.125 dBm in the receiver part by plotting gain saturation against input power.

Table 2. TW-SOA parameters of normal values

Parameter [symbols]	Normal value [Range]
Injection current [I]	0.14 A [0–1]
Length [L]	0.0008 m [0, 1e-003]
Width [W]	3e-006 m [0, 500e-006]
Height [H]	8e-008 m [0, 10e-006]
Differential gain [G]	3.5e-020 M^2 [0, 50e-020]
Loss [α]	2500 $\frac{1}{M}$ [0, 10e-004]
Optical confinement [Γ]	0.3 [0–1]
Initial carrier density [N_i]	1e+024 M^{-3}
Line width enhancement [β]	5 [-30 to 30]
Recombination coefficient [A]	1.43e+009 $\frac{1}{S}$ [0.1 to 4.5e+009]
Recombination coefficient [B]	3e-016 $\frac{M^3}{S}$ [1 to 9e-016]
Recombination coefficient [C]	3e-040 $\frac{M^6}{S}$ [1.97e–040]

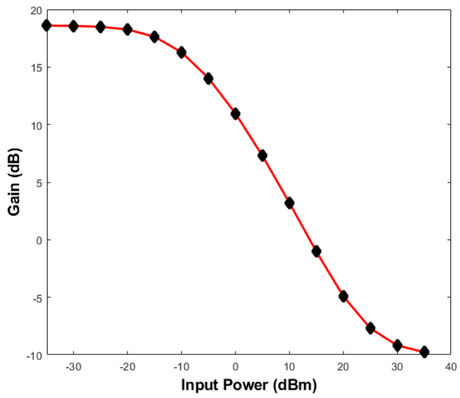

Figure 2. Gain vs send power

Table 3. The optimization of measured power

Send power (dBm)	Received power (dBm)	Amplification gain (dB)
-35	-16.40	18.596
-30	-11.43	18.569
-25	-6.51	18.489
-20	-1.75	18.252
-15	2.63	17.626
-10	6.28	16.277
-5	9.03	14.025
0	10.96	10.962
5	12.29	7.288
10	13.20	3.201
15	13.97	-1.034
20	15.10	-4.902
25	17.30	-7.699
30	20.83	-9.175
35	25.23	-9.77

3.2. DWDM system with TW-SOA gain (for multi users)

3.2.1. Impact of number of channels

The simulation is done at a data rate 5 Gb/s for the DWDM transmission scheme. The input signal power is 0 dBm and this signal passes through a single-mode optical fiber. The TW-SOA amplifier with optimized parameters is used to improve the quality of the signal. When the number of channels is increased with different injection currents, as shown in Figure 3, it can be seen that the system performance (Q factor) is decreased due to high interference between transmission data bits. Therefore, the received data becomes bad.

3.2.2. Impact of injected current (A)

The second scenario achieves the maximum Q factor when the number of channels (N) and the injected current (A) are changed, as shown in Figure 4. The input power of the CW laser diode is 5 dBm and the fiber link between transmitter and receiver is fixed at 40 Km. When the results are analyzed of Q factor and injection current (A), we can notice the Q factor increased when the injected current increases while the number of channels (N) decreases. This is due to extending the link capacity by the number of channels and the increased injected current, which leads to an increase in (ASE) noise and makes a distortion in information pulse. Hence, the range value of Q factor changes from 5.5 to 8.5 when the injected current (A) range value changes from (0.12 to 0.3) ampere satisfying the optimum system Q-factor > 6.

3.2.3. Impact of CW laser input power (dBm)

To evaluate the effect of input power on the CW laser diode, this is changed between -10 to 5 dBm to optimize injected current at a suitable range, as shown in Table 3. Besides increasing the gain value from 8 to 22 dB, our injected current value increased from 150 to 260 mA. The optimum gain can be decreased by approximately 2 dB besides increasing the number of channels for the DWDM system, as shown in Figure 5. This figure also shows the increased value of the gain and how it decreased to 1 dB when the injected current is increased above 260 mA. These optimization values of input power and injected current in Table 4 can be inferred by Figure 5 as plotted. This technique can be used to support a high data rate of up to 5 Gb/s for sixty users, as implemented in our designed model.

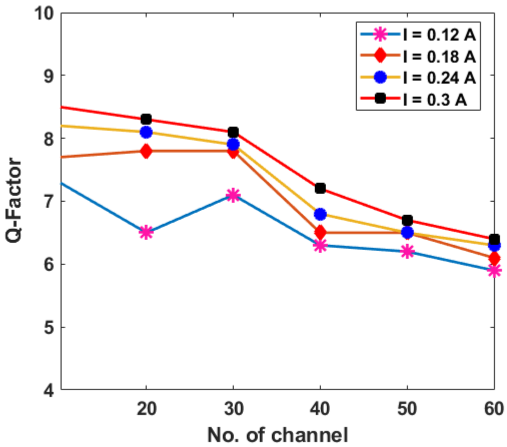

Figure 3. Q–factor vs no. of channel for different values of injected current

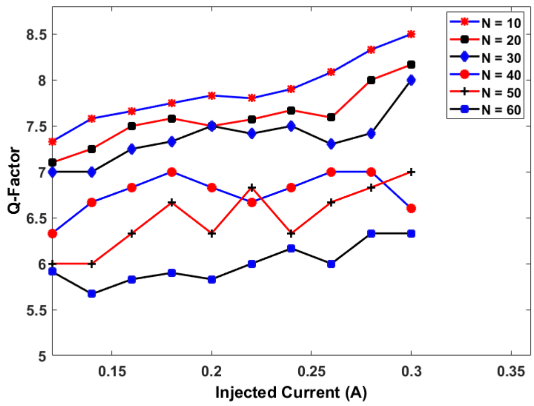

Figure 4. Q–factor vs injected current for different no. of channels

Table 4. The optimized range of injected current

Input power (dBm)	Injected current (mA)
-10	150–108
-5	180–200
0	200–220
5	220–250

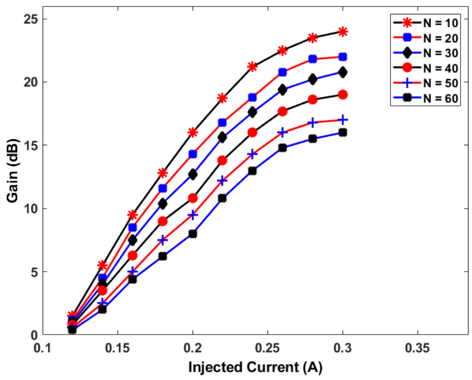

Figure 5. Gain vs injected current for different no. of channels

4. CONCLUSION

In this paper, a WDM system model designed by utilizing (60 channels × 5 Gb/s) (300 Gb/s) channels has been successfully achieved. The performance of DWDM systems has been evaluated to obtain results by analyzing the impact of optical power, active gain, quality of signal, injected current, and the number of users who utilized the TW-SOA amplifier after optimization of parameters. The data rate with proper fiber length is 5 Gb/s and 40 Km, respectively. The obtained results show that the TW-SOA amplifier provided numerous benefits, and the active gain with performance was developed as the injected current increased and the number of users N decreased. Then, the input power with injected current range is optimized to give a high data rate of 300 Gb/s to enhance the future transmission systems for long haul applications.

REFERENCES

[1] S. H. Chang, "Analyses of the key technologies and development trends of optical networks from the perspective of standard essential patents," *Applied Sciences (Switzerland)*, vol. 11, no. 4, pp. 1-10, 2021, doi: 10.3390/app11041583.

[2] Nivedita, S. Kaur, and R. Goyal, "All-optical decoder/demultiplexer with Enable Using SOA Based Mach-Zehnder interferometers," *2019 6th International Conference on Signal Processing and Integrated Networks, SPIN 2019*, 2019, pp. 780-784, doi: 10.1109/SPIN.2019.8711670.

[3] H. Ishio, J. Minowa, and K. Nosu, "Review and status of wavelength-division-multiplexing technology and its application (invited overview)," *Journal of Lightwave Technology*, vol. 2, no. 4, pp. 448-463, 1984, doi: 10.1109/JLT.1984.1073653.

[4] M. K. Dutta, "Design and performance analysis of EDFA and SOA for optical WDM networks: a comparative study," *2017 14th IEEE India Council International Conference, INDICON 2017*, 2017, pp. 1-6, doi: 10.1109/INDICON.2017.8487827.

[5] M. M. E. Adnan A. Abbas and R. S. Fyath, "Fiber nonlinearity compensation of WDM-PDM 16-QAM signaling using multiple optical phase conjugations over a distributed Raman-amplified link," *Photonic Network Communications*, vol. 35, pp. 342-352, 2018, doi: 10.1007/s11107-017-0748-2.

[6] I. Sackey *et al*., "Kerr nonlinearity mitigation in 5 × 28-GBd PDM 16-QAM signal transmission over a dispersion-uncompensated link with backward-pumped distributed Raman amplification," *Optics Express*, vol. 22, no. 22, pp. 27381-27391, 2014, doi: 10.1364/OE.22.027381.

[7] A. Rani and S. Dewra, "Investigation of semiconductor optical amplifier for DWDM system with 50 GHz channel spacing," *Proceedings of the International Conference on Recent Cognizance in Wireless Communication Image Processing*, 2016, pp. 209-215, doi: 10.1007/978-81-322-2638-3_24.

[8] D. K. Tripathi, "Evaluating RSOA performance with optical logic gates at 100 Gbps data rate," *Journal of Optical Communications*, vol. 43, no. 1, pp. 9-17, 2022, doi: 10.1515/joc-2018-0171.

[9] S. J. Anderson, A. C. As, and P. Amplifier, "Comparative study of EDFA and SOA in WDM optical network placed at different position," *Advances in Optical Technologies*, vol. 1, no. 1, pp. 4–6, 2015.

[10] A. K. A. Atieh and M. S. Bhamrah, "Simulations and optimizations of optical amplifiers," *2020 Photonics North (PN) IEEE*, 2020, pp. 1-1, doi: 10.1109/PN50013.2020.9166933.

[11] R. P. Webb, J. M. Dailey, and R. J. Manning, "Applications of semiconductor optical amplifiers," *2012 17th Opto-Electronics and Communications Conference*, 2012, pp. 825-826, doi: 10.1109/OECC.2012.6276649.

[12] M. Fujiwara and R. Koma, "Long-reach and high-splitting-ratio WDM/TDM-PON systems using burst-mode automatic gain controlled SOAs," *Journal of Lightwave Technology*, vol. 34, no. 3, pp. 901-909, 2016, doi: 10.1109/JLT.2015.2501432.

[13] A. Arnould *et al*., "Ultra-wideband transmission systems based on semiconductor optical amplifiers," *2019 21st International Conference on Transparent Optical Networks (ICTON)*, 2019, pp. 1-4, doi: 10.1109/ICTON.2019.8840464.

[14] V. K. Singh, A. K. Singh Yadav, A. Kumar, and A. Tyagi, "Semiconductor-optical-amplifier Mach-Zehnder interferometer based optical networks," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 11, no. 1, pp. 525-535, 2013, doi: 10.11591/telkomnika.v11i1.1926.

[15] M. M. A. Eid and A. N. Z. Rashed, "Hybrid NRZ/RZ line coding scheme based hybrid FSO/FO dual channel communication systems," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 22, no. 2, pp. 866-873, 2021, doi: 10.11591/ijeecs.v22.i2.pp866-873, 2021.

[16] A. Kumari and P. Srivastava, "Performance analysis of 16-channel CWDM system with EDFA and SOA amplifiers," *2018 3rd International Conference on Microwave and Photonics, ICMAP 2018*, 2018, pp. 1-2, doi: 10.1109/ICMAP.2018.8354601, 2018.

[17] H. Singh and S. Singh, "Performance analysis of hybrid optical amplifiers in 120 x 10 Gbps WDM optical network with channel spacing of 50 GHz," *Second International Conference on Advances in Computing, Communication and Information Technology CCIT-2014*, 2014, pp. 55-58, doi: 10.15224/978-1-63248-051-4-27.

[18] T. Ivaniga, L. Ovseník, and J. Turán, "The four-channel WDM system using semiconductor optical amplifier," *2016 26th International Conference Radioelektronika (RADIOELEKTRONIKA)*, 2016, pp. 354-357, doi: 10.1109/RADIOELEK.2016.7477350.

[19] K. Swetha, R. Manohari, and S. Prince, "SOA parameters optimization for high data rate operation," in *2Optical And Microwave Technologies*, Singapore: Springer , 2018.

[20] R. Miglani, G. Singh, G. Singh, and D. P. Agrwal, "Gain optimization of 100 × 40 Gbps high capacity DWDM fiber optical link using hybrid amplification techniques," *Journal of Optics (India)*, vol. 49, no. 3, pp. 323–331, 2020. doi: 10.1007/s12596-020-00620-8.

[21] K. Kaur and H. Sadawarti, "Gain analysis of hybrid optical amplifier for 100 channels DWDM system at bit rate of 10 Gbps," *2015 2nd International Conference on Recent Advances in Engineering and Computational Sciences, RAECS 2015*, 2015, pp. 1-5, doi: 10.1109/RAECS.2015.7453387.

[22] B. Ahuja, M. L. Meena, and R. S. Meena, "Design and performance analysis of shemiconductor optical amplifier for 16×10Gbps DWDM transmission systems," *ICTACT Journal on Communication Technology*, vol. 10, no. 2, pp. 1971-1978, 2019.

[23] F. Saliou, *et al*., "125-km long cavity based on self-seeded RSOAs colorless sources for 2.5-Gb/s DWDM networks," *Journal of Lightwave Technology*, vol. 33, no. 8, pp. 1602-1607, 2015, doi: 10.1109/JLT.2014.2384397.

[24] H. Hu, R. M. Jopson, A. H. Gnauck, S. Randel, and S. Chandrasekhar , "Fiber nonlinearity mitigation of WDM-PDM QPSK / 16-QAM signals using fiber-optic parametric amplifiers based multiple optical phase conjugations," *Optics Express*, vol. 25, no. 3, pp. 1618-1628, 2017, doi: 10.1364/OE.25.001618.

[25] D. F. Bendimerad and Y. Frignac, "Numerical investigation of SOA nonlinear impairments for coherent transmission systems based on SOA amplification," *Journal of Lightwave Technology*, vol. 35, no. 24, pp. 5286-5295, 15 Dec.15, 2017, doi: 10.1109/JLT.2017.2772223.

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