All Optical Bidirectional Wavelength Conversion Using Single Wide Band Traveling Wave Semiconductor Optical Amplifiers

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Abstract

Wavelength division multiplexing (WDM) is a very important technique to utilize the bandwidth of optical fiber. At different network nodes, it's requires to add or drop wavelength. The wavelength converter, responsible for converting the wavelength of signal, to another wavelength up or down from the original value. This paper presents a proposed model to generate inverted and non-inverted wavelength conversion by using single wide band traveling wave semiconductor optical amplifier (WBSOA), based on cross gain modulation (XGM). The investigation of conversion efficiency (η) and quality factor (Q) , versus pump power ranging from -30 dBm to 0 dBm, and input signal power of 0 dBm with data rate 25 Gb/s, studies for up and down wavelength conversion "co-propagation" and "counter-propagation" respectively, along c-band. All simulations in this study are performed by optisystem ver. 7.

Keywords: WDM, All optical wavelength conversion, (WBSOA), optical to electrical to optical (O/E/O), conversion efficiency, quality factor.

1. Introduction

WDM multiplexes a number of optical signals onto a single optical fiber by using different wavelengths, The capacity of WDM based optical communication networks is usually limited by the number of channels available and wavelength congestion. The construction in Fig.1 (a) is apart from network, only two wavelengths have been established in this network, the first wavelength between Node 1 and Node 2 is λ_1, and the second wavelength available between node 2 and node 3 is λ_2. Instant need to set up a light path from node 1 to node 3 directly, under previous condition the construction didn't have more than two wavelengths λ_1 and λ_2. It is impossible to establish a light path because the wavelengths available in two links are different, the network will be blocked. by using a wavelength converter, the data will sent from Node 1 to Node 2 on two different wavelengths λ_1 and λ_2, as in Fig. 1(b). Then at Node 2 we will create a wavelength converting, the data wavelength λ_2, should be change from wavelength λ_2 to λ_1. It is obviously clear, wavelength converter avoided, blocking and adds flexibility in optical network [1, 2].

The wavelength conversion process, can take two mechanisms. The O/E/O, where the signal originally in the optical domain, and converted to electrical domain, in electrical domain create all signal processing, then converted into the optical domain again. This mechanism has some limitation, such as system complexity, costly and power consumption. The other mechanism is all optical wavelength conversion, all signal processing done in the optical domain without need to enter the electrical domain. The advantage of this technique is simplest, fastest, and power efficient. The reason to choose SOA as a nonlinear device to create wavelength conversion is the dual functionality, the dual functionality of SOA is an enhanced nonlinear device and is also amplifying the optical signal.

The results from this configuration design are two wavelengths. The first one result from forward propagation "co-propagation", and the other signal result from backward propagation "counter-propagation". The Interaction between more than two signals in SOA medium take more than three types of phenomenon as indicate in [3, 4]. The three important phenomenons are Cross Gain Modulation (XGM), Cross Phase Modulation (XPM) and Four Wave Mixing (FWM). Each phenomenon required some conditions to be created [5].

2. Basic Concepts of XGM

The schematic for XGM wavelength converters is appears in Fig. 2. The important parameter required to create XGM is the power of the input signal must be greater than pump signal power, and SOA biased current must be enough to deplete the carrier concentration in the active region, hence saturate the SOA [6, 7]. The pumped signal parameters are, 3 dBm optical signal power and wavelength 1560 nm perform the desired wavelength, the pump signal will enter the SOA through pump coupler. The input data signal called probe signal has a 5 dBm optical power with wavelength 1565 nm, NRZ pesudo random bit sequence will enter the Mach Zehnder Modulator, the XGM WC is designed based on co-propagation configuration. AOWCs based XGM has simple configuration, a large dynamic range of the input optical signal power, high conversion efficiency, polarization immunity and wavelength insensitive. [8-10]. As shown in Fig. 2. The two signals pump and probe will enter the SOA through pump coupler co-propagation, during interaction of two signals in SOA block, the pump signal modulated by the input signal.

The result at the output is signal has the same information as input signal with new wavelength equal pumped wavelength.

3. Basic proposed Model simulation Architecture

The simulation schematic diagram Fig. 3(a) separately consists of four parts

i. **Transmitter section.**
ii. **Pumped power section**.
iii. **The nonlinear medium section** presented by "WBSOA".
iv. **Receiver and visualizes part**, for co-propagation and counter-propagation.

The transmitter consists of, pesedo-random bit sequence with bit rate equal 25 Gb/s of order 7**,** the bit sequence will modulate the output of non-returned to zero pulse generator. Non return to zero pulse generators are rectangle shape "Exponential", amplitude value is "1". Continuous wave laser diode with wavelength varied from 1530 nm to 1565 nm with optical power 0 dBm. Polarization control is seated to create more control on output polarization signal.

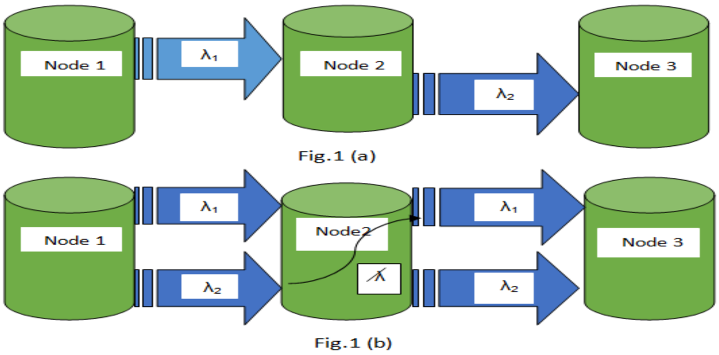

Fig.1 (a) Wavelength-continuity constraint in a wavelength-routed network without converter.
(b) Wavelength-continuity constraint in a wavelength-routed network with converter.

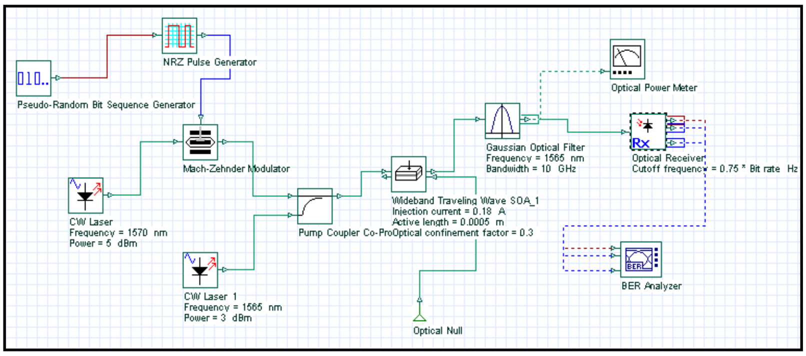

Fig. 2 Simulation schematic for XGM.

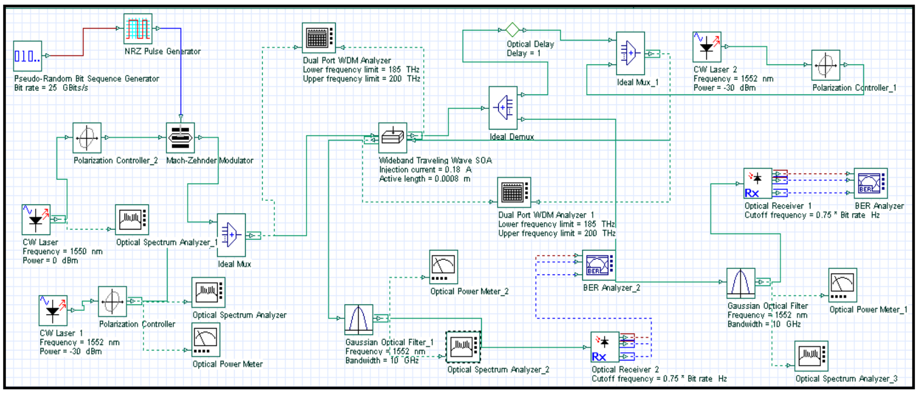

Fig. 3(a) Schematic diagram of circuit simulation.

The modulator is "Mach Zehander modulator", have extinction ratio 30 dB mix the non-returned to zero signals and continuous wave laser "CW Laser" signals. Will injecting the pump signal from CW laser_1 & CW laser_2 for co-propagation and Counter-propagation. The nonlinear medium, is WBSOA, the significant SOA parameter is, the inject current 180 mA [5, 6], the active length 800×10^{-6} m. At the output of WBSOA ideal Demux used to create two signals, each signal carry the same information and wavelength.

The outputs of WBSOA are two, the first one is co-propagation output and the second is counter-propagation output, the co-propagation output will enter the receiver part 1, the counter-propagation output will enter the receiver part 2. The curves Fig. 3(b, c) shows the relation between WBSOA gain (dB) versus input power (dBm) of the semiconductor optical amplifier for co-propagation Fig. 3 (b), and counter-propagation Fig. 3(c). In the Fig. 3(b). The amplifier gain is nearly constant from the input signal power -40 dBm to value below -25 dBm. On the other hand for counter-propagation gain curve the amplifier gain is of low value from input power -40 dBm to values near -25 dBm.

As the gain of forward direction "co-propagation" decreases the gain of backward "counter-propagation" is increasing, this obviously appears in the area around -20 dBm to the area around -10 dBm of input signal power. As will see in later, the area between -20 dBm to -10 dBm is the best choice to get maximum value for conversion efficiency, quality factor, and minimum bit error rate, and this area is the best choice to pushing up SOA in nonlinear region.
The main target in this paper is wavelength conversion, so loss in the gain as in Fig. 3(c) not significant in backward direction.

4. Simulation Results and Discussions

The start point for this paper comes from previous study of SOA non linearity in "co-propagation" and "counter-propagation" is obtained in [1, 2]. In paper reference [1] the generation of WC is done by using two wavelength shifters, for more amplification the designer uses erbium doped amplifier as a booster amplifier. In paper reference[2] the configuration design changed, the designer used two SOA, and injects signal opposite to each other and take the result in output arm of 2×2 coupler, the previous design is complex and power inefficiency.

Our design is minimized the circuit by using single WBSOA, as a main part to get the same result as in [1] and [2]. The availability of design can be measured as a function of conversion Efficiency η (dB) $=10\times\log (P(\lambda_{converted})/P(p_{umped}))$, and quality factor. The investigation of the proposed design is done for studying the system performance in up and down WC co-propagation and counter-propagation, for varying the pump signal from -30 dBm to 0 dBm and wavelength varying in C-band, with input bit rate 25 Gb/s and input signal power 0 dBm.

4.1 Up Wavelength Conversion Investigation.

Choose apart from C-band to create the up WC investigation and use configuration as in Fig. 3(a), the incoming signal wavelength is equal to 1550 nm, this signal will be converted up conversion until 1560 nm in ten steps each step vary 2 nm from the original signal and investigate at each wavelength shift the conversion efficiency and quality factor, to choice suitable wavelength shift "wavelength detuning" to get maximum performance and availability of the design.

4.1.1 Up wavelength conversion forward propagation "Co-propagation".

The conversion efficiency value is not big between each wavelength shifts "detuning", but still at 2 nm the conversion efficiency is greater than other wave length shift, the area between -20 dBm to -10 dBm the conversion efficiency for all wavelength shifts are nearly the same, as shown in Fig. 4(a). The greater value for all wavelength detuning is limited in area of pump power from -15 dBm to -5 dBm. The greater quality factor value is 4.3 done at pump power -10 dBm and wavelength shift 4 nm. The minimum BER value is 4.8×10^{-6} done at pump power -10 dBm and wavelength shift 4 nm, as shown in Fig. 4(b).

4.1.2 Up wavelength conversion backward propagation "Counter-propagation"

The conversion efficiency at wavelength shift 8 nm is better than other wavelength shift "detuning", the greater conversion efficiency value is 21.9 dB done at pump power -30 dBm and wavelength shift 8 nm. The conversion efficiency at the area from pump power -20 dBm to -10 dBm is nearly the same for all wavelength shifts, as shown in Fig. 5(a). The most significant value of the quality factor (Q) still limited around -10 dBm for all wavelength shifts "detuning". The greater value of quality factor is 4.3 done at pump power -10 dBm and wavelength shift 2 nm.

4.2 Down Wavelength Conversion Investigation

We choose apart in C-band to create the investigation, and use the configuration as in Fig. 3(a). The input wavelength equal to 1555 nm, will be converted down until 1545 nm, in ten steps, each step vary 2 nm from original signal. At each wavelength shifts, we will investigate the conversion efficiency and quality factor, to choice the perfect and suitable wavelength shift "detuning" to get maximum performance of the proposal design.

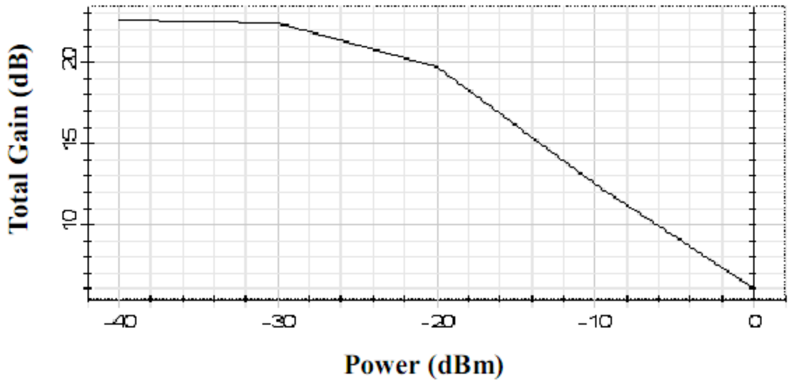

Fig. 3(b) The total gain (dB) variation due to "co-propagation" versus input power (dBm).

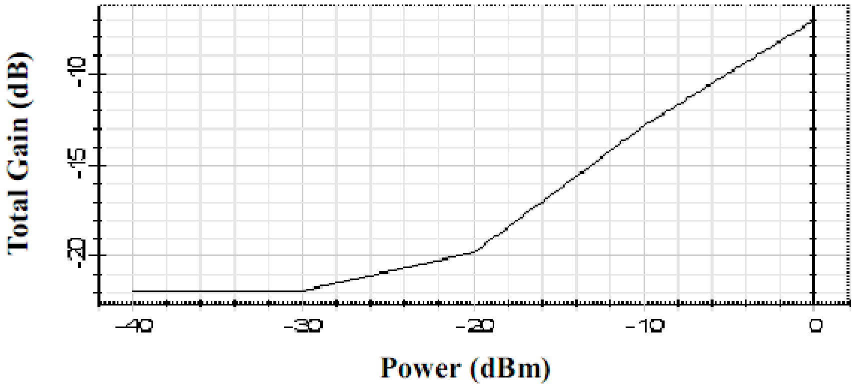

Fig. 3(c) The total gain (dB) variation due to "counter-propagation" versus input power (dBm).

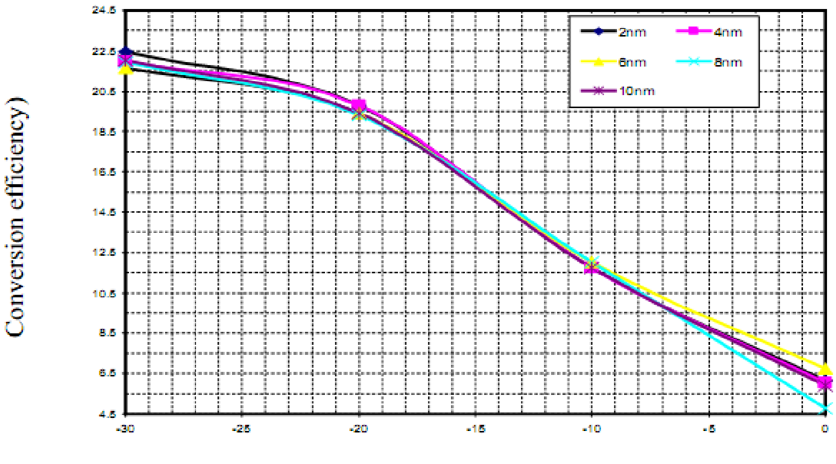

Fig. 4 (a). Conversion efficiency (dB) versus pump power (dBm) for up wavelength conversion "co-propagation" at different wavelength shifts.

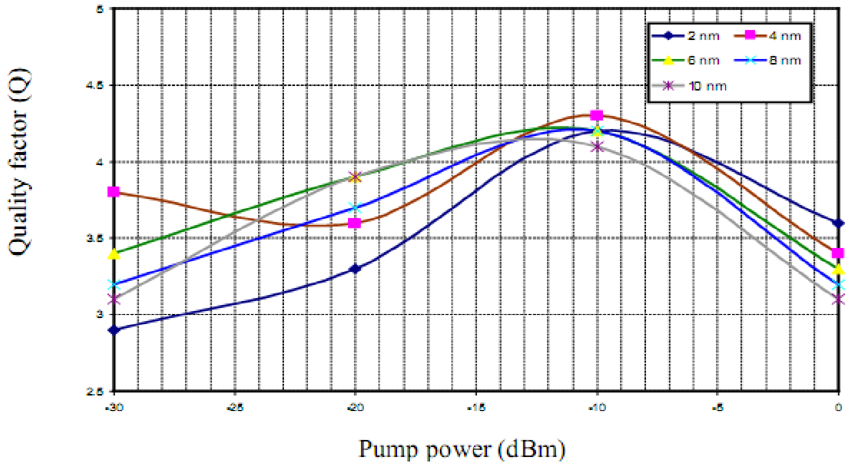

Fig. 4(b) The Quality factor (Q) versus pump power (dBm) for up wavelength conversion "co-propagation" at different wavelength shifts.

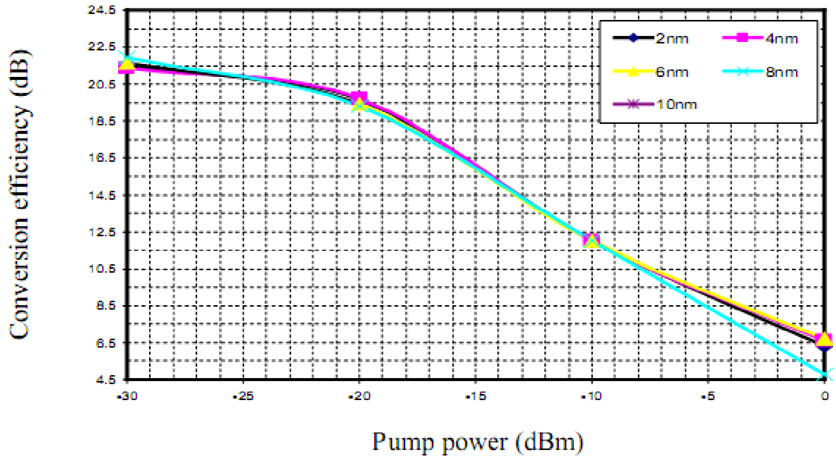

Fig. 5(a) Conversion efficiency (dB) versus pump power (dBm) for up wavelength conversion "counter-propagation" at different wavelength shifts.

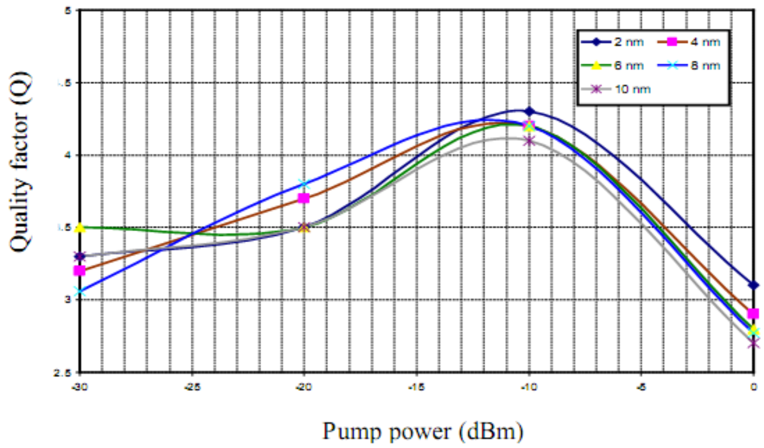

Fig. 5(b) The Quality factor (Q) versus pump power (dBm) for up wavelength conversion "counter-propagation" at different wavelength shifts.

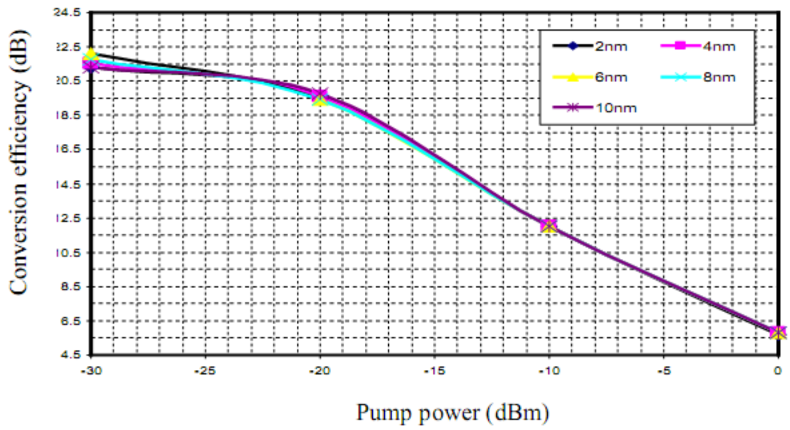

Fig. 6(a) The conversion efficiency (dB) versus pump power (dBm) for down wavelength conversion "co-propagation" at different wavelength shifts.

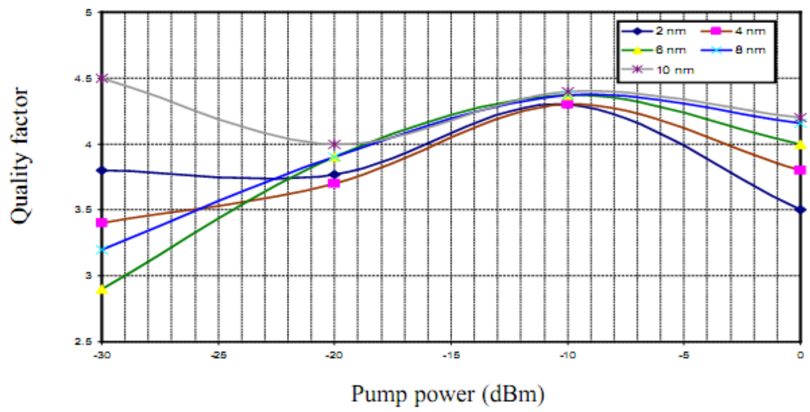

Fig. 6(b). Quality factor (Q) versus pump power (dBm) for down wavelength conversion "co-propagation" at different wavelength shifts.

4.2.1 Down wavelength conversion forward propagation "Co-propagation"

As shown in Fig. 6(a). The greater conversion efficiency value is 22.1 dB, done at pump power -30 dBm and wavelength shift 6 nm. The lowest conversion efficiency value 5.68 dB done at pump power 0 dBm, and wavelength shift 10 nm, the conversion efficiency result due to pump power from -20 dBm to -10 dBm for all wavelength shift nearly the same.

As shown in Fig. 6(b). The greater quality factor value 4.5 done at pumped power -30 dBm and wavelength shift 10 nm, and the lowest value is 2.9 done at pump power -30 dBm and wavelength shift 6 nm. At -10 dBm. The minimum BER value is 2.7×10^{-6}done at wavelength shift 10 nm and pump power -30 dBm and -10 dBm.

4.2.2 down wavelength conversion backward propagation "Counter-propagation"

The maximum conversion efficiency is 21.6 dB done at wavelength shift 6 nm and pump power -30 dBm, and lowest conversion efficiency value is 3.98 dB, done at wavelength shift 10 nm and pump power 0 dBm**.**
The graph Fig. 7(b) points to maximum quality factor is done at the pump power value from -15 dBm to -5 dBm for all wavelength shifts. The greater quality factor value 4.56 done at pump power -10 dBm and wavelength shift 10 nm, the lowest quality factor value is 2.9 done at pump power -30 dBm and wavelength shift 6 nm. The minimum BER value 1.5×10^{-6} done at pump power -10 dBm and wavelength shift 10 nm, as shown in Fig. 7(b).

5. Special Wavelength Conversion Investigation

We nominate intermediate value between -20 dBm and -10 dBm, as the best area for pump power, let this value is -15 dBm, the performances of designing will tested at this value. The results collected in Tables (1, 2).
Table 1. Performance of up wavelength conversion, where input power and wavelength of 0 dBm, 1550 nm Respectively and pump power is -15 dBm, at different wavelength shift "detuning".

6. Conclusion

All optical wavelength converters submit a plenty of advantages such as flexibility and simplicity. In this work, wavelength conversion based on XGM, is done by using single wide band traveling wave semiconductor optical amplifier, as performed design has given more advantages to generate inverted and noninverted signal from single WSOA and single source. The performance of the proposed design is tested for up and down wavelength conversion by adapting the variation of wavelength shifted from 2 nm to 10 nm, pump power from -30 dBm to 0 dBm, with input signal power fixed at 0 dBm with data rate up to 25 Gb/s. The conversion efficiency and quality factor, versus pump power in different propagation direction "co-propagation & counter-propagation" are shown at each wavelength shift. It is observed that, as the gain of forward direction decreases the gain of backward direction increases.

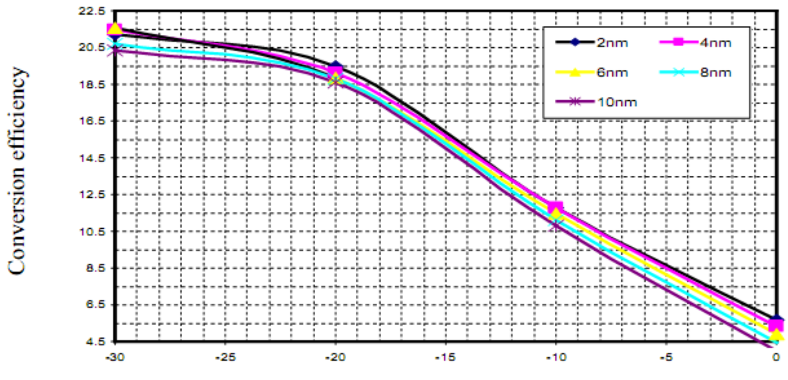

Fig. 7(a) Conversion efficiency (dB) versus pump power (dBm) for down wavelength conversion "counter-propagation" at different wavelength shifts.

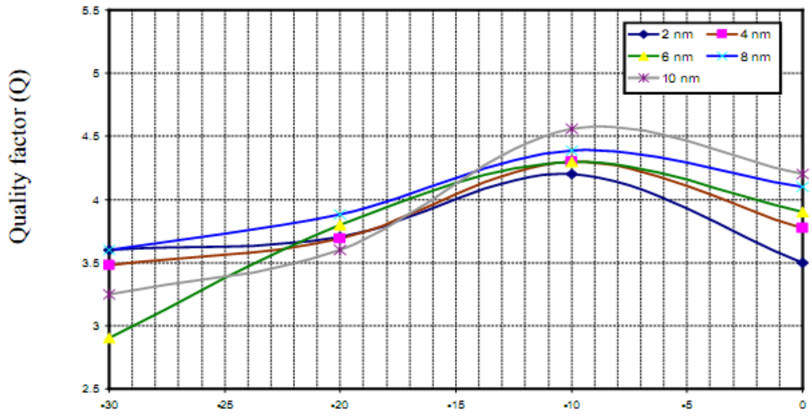

Fig. 7(b). Quality factor (Q) versus pump power (dBm) for down wavelength conversion "counter-propagation" at different wavelength shifts.

Table 1 Performance of up wavelength conversion, where input power and wavelength is 0 dBm, 1550 nm, and pump power is -15 dBm, at different wavelength shift "detuning”.

shifted wavelength nm	Up wavelength conversion						
	Forward "co-propagation"			Back ward "counter-propagation			converted Wavelenth nm
	η (dB)	Quality factor	BER	η (dB)	Quality factor	BER	
2	16.75	3.74	6x10^{-5}	16.5	3.86	3.9x10^{-5}	1552
4	16.7	3.89	3.40x10^{-5}	16.78	3.86	3.9x10^{-5}	1554
6	16.72	3.88	3.6x10^{-5}	16.9	3.68	7.5x10^{-5}	1556
8	16.75	3.88	3.6x10^{-5}	16.8	3.77	5.47x10^{-5}	1558
10	16.79	3.88	3.66x10^{-5}	16.6	3.74	6.05x10^{-5}	1560

Table 2 Performance of down wavelength conversion, at input power and wavelength of 0 dBm, 1555 nm respectively and pump power is -15 dBm, at different wavelength shift "detuning".

shifted wavelengh nm	Down wavelength conversion						
	Forward "co-propagation"			Back ward "counter-propagation			converted Wavelength nm
	η (dB)	Quality factor	BER	η (dB)	Quality factor	BER	
2	16.84	3.82	4.5x10^{-5}	15.6	3.8	5.05x10^{-5}	1553
4	16.96	3.89	3.4x10^{-5}	15.9	3.71	7.16x10^{-5}	1551
6	16.84	3.95	2.7x10^{-5}	16.22	3.9	3.1x10^{-5}	1549
8	16.7	3.96	2.67x10^{-5}	16.42	4.04	1.9x10^{-5}	1547
10	16.5	4	2.3x10^{-5}	16.51	3.88	3.6x10^{-5}	1545

Moreover it found that the area of gain variation is the best area to choose the pump power to get maximum conversion efficiency, maximum Quality factor and consequently minimum bit error rate. The area of gain variation is limited between pump power values from -20 dBm to -10 dBm. Special investigation is done at the pump power -15 dBm at a value intermediate between -20 dBm and -10 dBm. All simulations in this study are performed by optisystem ver. 7.

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