Design analysis of multi-wavelength conversion based on XAM effect of EAM for high speed optical transmission

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In this work, cross absorption modulation (XAM) or high-speed optical transmission in electroabsorption modulator (EAM) has been utilized to investigate all-optical multi-wavelength converter. 40-Gbps data signal with NRZ format is considered to analyze the impact of various input parameters of EAM. The input power (launched power) of the signal and bias voltage on multi-wavelength conversion is validated in optical signal-to-noise ratio (OSNR), Q factor, and received power. The main highlight of this investigation is to find the optimal operating parameters of EAM for designing the perfect wavelength converter. The range of input power of the signal tuned from 15 to 21 dBm and a bias voltage of EAM tuned from 0 to -3 V are utilized to investigate the Q factor and converted signal power of multi-wavelength converter and found the best possible bias voltage is -2.0 V and input signal power at 15 dBm. The optimal converted signal quality is obtained at 1548 nm and 1550 nm with reverse bias voltage at 1.5 V and 2 V.

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Keywords: Bias voltage, EAM, NRZ format, Wavelength, Q factor, Conversion

1. Introduction

Nowadays, Wavelength conversion is becoming one of the best technologies for upcoming optical network. Lots of efforts have been suggested to understand its functionality by using semiconductor lasers, amplifiers, optical fibers, $LiNbO_3$/semiconductor waveguides [1, 10]. All-optical wavelength conversion based on non-linearities in electroabsorption modulator is an attractive approach due to its fast recovery time compared to semiconductor optical amplifiers (SOA) [2-5]. Carrier recovery time of SOA is very high so SOA- based wavelength converter constantly used interferometric pattern and moreover, the intricate control method must be used for the practical purpose [6].

EAMs are becoming fascinated device due to its various advantages, such as low driving voltage, high bandwidth, simple structure, polarization independence and integrated with DFB. In ref. [2], clear picture of cross absorption modulation effect in EAM for wavelength conversion is demonstrated. In [7], 2R regeneration is achieved by using RZ format modulated signal at a bit rate of 20 Gbit/s. 100 Gbit/s data rate using DI structure in electroabsorption modulator-based wavelength converter has been reported [8]. In [9], the impact of input factors on NRZ format performance for single wavelength conversion has been investigated. N. El Dahdah *et al*. [11] demonstrated the efficient 40 Gb/s RZ format based wavelength conversion at low switching data pulse energy (500 fJ) and the small bias voltage (1.75 V). Li Huo *et al.* in [12] demonstrated the numerical model of XAM effect of EAM and calculated the absorption recovery time as well as investigated the performance of 40 Gbps wavelength converter with 3R regenerators. They have concluded that bias voltage should be high to get better conversion performance. Also suggested that for the best result of 3R regenerator, pulse width of clock signal should be narrow, extinction ratio should be high and timing jitter should be low.

Here, XAM effect of EAM at 40 Gbps NRZ format signal for all-optical wavelength converter is considered for arbitrary input signal power and arbitrary bias voltage to examine the performance of multi-wavelength converter through monitoring eye diagrams and measuring the OSNR and Q-value of converted signals. Section 2 describes the system setup and working principle. Section 3 covers the impact of input power and variable bias voltage on the consequence of wavelength converted signal and concluded in section 4.

2. System setup and principle

The experimental setup of EAM based wavelength converter is shown in Fig. 1. It comprises three parts; the transmitter section, non – linear device and the receiver section. The transmitter's foremost job is to transform the input signal (electrical domain) into the output signal (optical domain) and send the converted signal into the system. The transmitter section consists of a CW laser source that provides an optical signal at a wavelength of 1549 nm and is further followed by a Mach-Zehnder modulator (MZM). The MZM modulator is controlled by an electrical signal coming out from the electrical signal generator. The electrical signal generator gives the NRZ formatted electrical signal at 40-Gbps bit-rate.

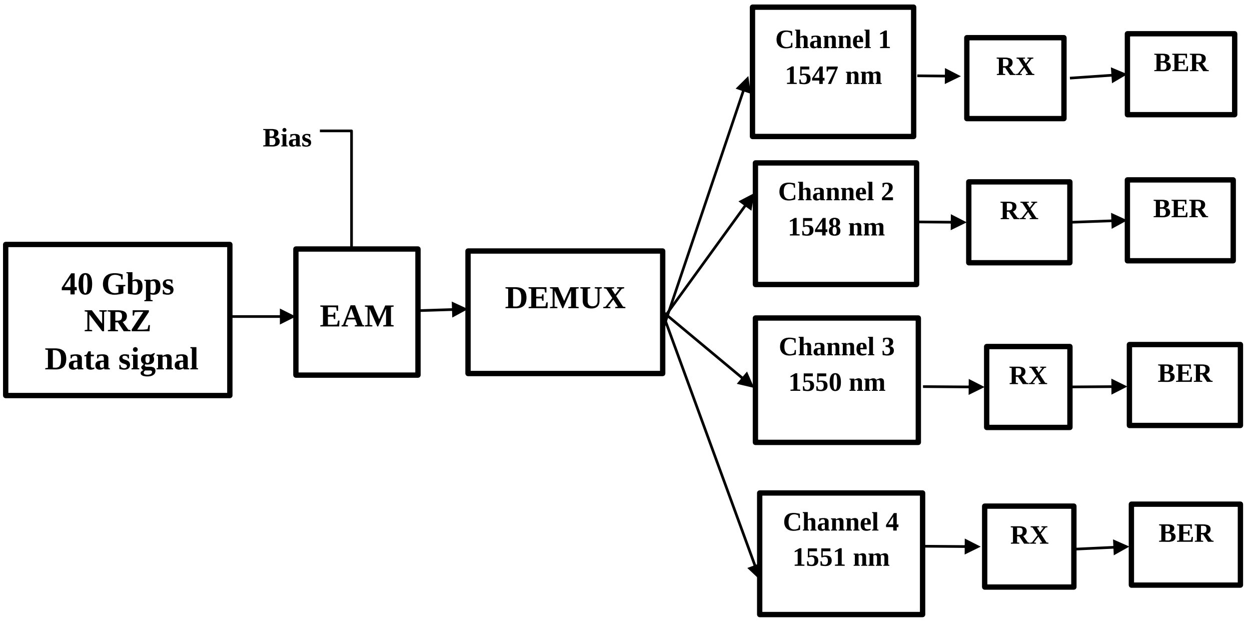
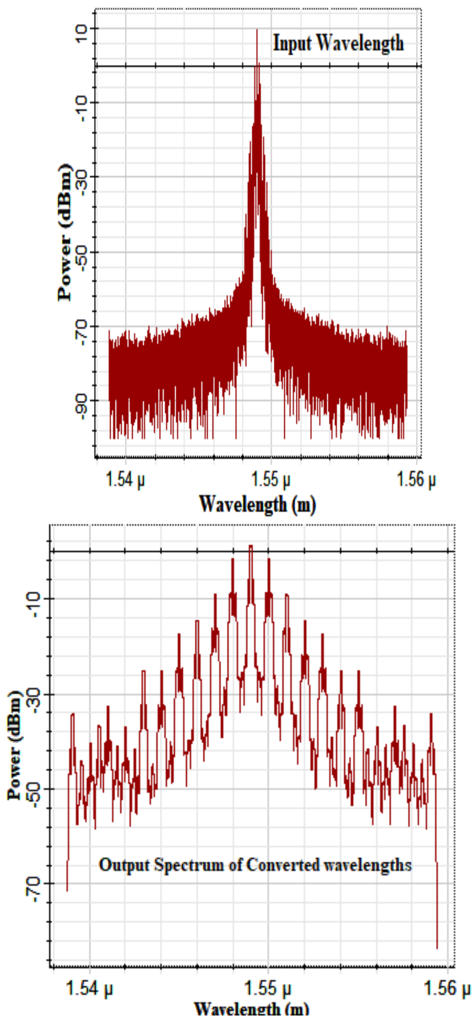


Fig. 1. Schematic of NRZ format EAM based multi-wavelength converter; EAM: electro absorber modulator, DEMUX: demultiplexer, RX: NRZ data receiver, BER: bit error rate analyzer

The MZM modulator gives the input optical signal. The output of MZM is further followed by a multi-wavelength converter which consists of an EAM modulator controlled by a bias voltage and 125 GHz periodic sinusoidal signal and followed by a wavelength selective demultiplexer. When the high-intensity NRZ data signal has a time slot for logic 1, applied to reverse biased EAM, large number of photo engendered charge carriers are formed. Because of the transition of these carriers, contort and screening effect are formed, which drops the absorption coefficient. Hence XAM effect get saturated at high optical power. On the other side at the time slot for logic 0, XAM effect is not saturated because of low optical power. Hence absorption coefficient rapidly mends to an original value. When the input data signal at 1549 nm and electrical deriving signal at 125 GHz are applied to EAM, cross absorption induced in the EAM. Therefore the power of the converted signal turns out to be the same as that of input data and hence wavelength converted signal achieved at 1547 nm, 1548 nm, 1550 nm and 1551 nm. The detected optical spectrum of an input signal and multi-wavelength converted signals is shown in Fig. 2. Due to the non-linearities of EAM modulator, various signals at different wavelengths have been generated. The spectrum of the converted signal can be observed with the help of an optical spectrum analyzer at the output of EAM. Further, the optical signal is followed by a wavelength-selective 1×4 demultiplexer with individual channel's bandwidth of 75 GHz. The demultiplexer filtered out the optical signal at 1549 nm, 1548 nm, 1550 nm and 1551 nm. Further, the optical signal from the demultiplexer is followed by PIN diode and low pass Bessel filter with a cut-off frequency of 30 GHz.



(a)

(b)

Fig. 2. Detected Optical spectrum (a) At input of EAM 2 (b) At output of EAM (color online)

3. Results and discussions

For wavelength conversion; launched power and EAM's reverse bias voltage play a key role in the performance evaluation of NRZ format wavelength converter. Here the dependence of both parameters on each other to achieve best wavelength converter is discussed. In the first case dependence of bias voltage at preset input power signal and in second case dependence of bias voltage at variable input power signal and in third case dependence of the input power signal on preset bias voltage is investigated to achieve the wavelength converted signal.

Case I : Variable reverse bias voltage of EAM at fixed input power signal

In this case system performance has been investigated for variable reverse bias voltage of EAM at fixed input power signal. The preset input power signal is 15 dBm and the reverse bias voltage is fixed commencing from 0.0 to 3.0 V is considered first for wavelength converted signal and the corresponding converted signal quality is shown in Fig. 3. Here the performance of converted wavelength at 1547 nm, 1548 nm, 1549 nm and 1550 nm is considered and reject the rest of converted wavelength due to degraded quality.

Fig. 3 shows the variations in the quality of converted signal with respect to reverse bias voltage (0.0 to 3.0 V) at 15 dBm input power. The quality factor of the converted signal performed a superior result at the converted wavelength of 1548 nm and 1550 nm among the other converted wavelength signals. At fixed reverse bias voltage 0.5 to 3.0 V the quality of the converted wavelength *i.e.* 1548 nm and 1550 nm, increases. In case of 1551 nm the quality of converted signal increases up to 1.5 V reverse bias voltage and as we further increases the reverse bias voltage from 1.5 to 2.5 V the quality of converted signal slightly varies from last value but further as we increase the reverse bias voltage to 3.0 V the quality is slightly decreased because of the cross absorption saturation effect. In case of 1547 nm the quality of converted signal increases up to 1.0 V reverse bias voltage. Further, quality of converted signal gradually decreased at 1.5 V and after that converted signal quality increases as we raise the bias voltage of EAM from -2.0 V to -3 V.

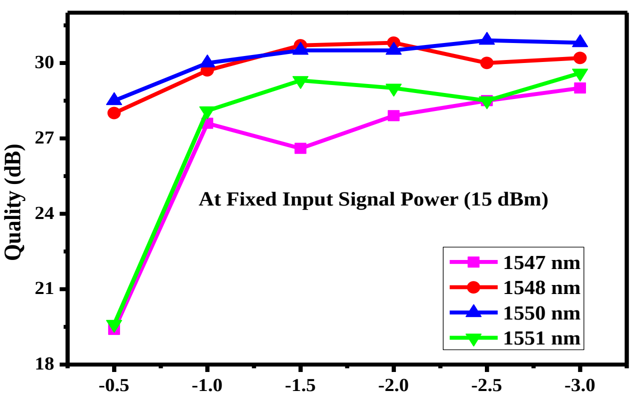


Fig. 3. Converted signal quality as a function of variable reverse bias voltage (color online)

Case II: Fixed bias voltage at variable input power signal

Here the range of launched power is tuned from 15 dBm to - 21 dBm respectively and bias voltage dependence at variable input power of the signal is investigated as well as measured the converted signal quality. Here the converted signal quality increases with the rises of input power signal at different reverse bias voltages. The main reason is that, with the increase in the signal's input power, the cross absorption saturation effect within the EAM becomes stronger. Fig. 4 to Fig. 9 concluded that the maximum quality of converted signal, i.e. 1547 nm, 1548 nm, 1550 nm and 1551 nm, is attained at high value of launched power. The best-converted signal quality is attained at 1548 nm and 1550 nm with respective voltage of -1.5 V and -2.0 V. Hence, it is clear that the pattern effect induced by high input signal power can be balanced by use of low reverse bias voltage [9]. Therefore the pattern effect is successfully obscured at fixed reverse bias voltage at 2.0 V.

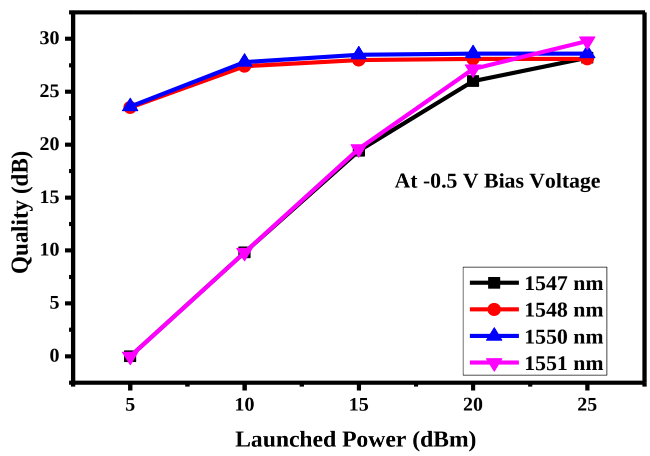


Fig. 4. Converted signal quality under fixed reverse bias voltage (color online)

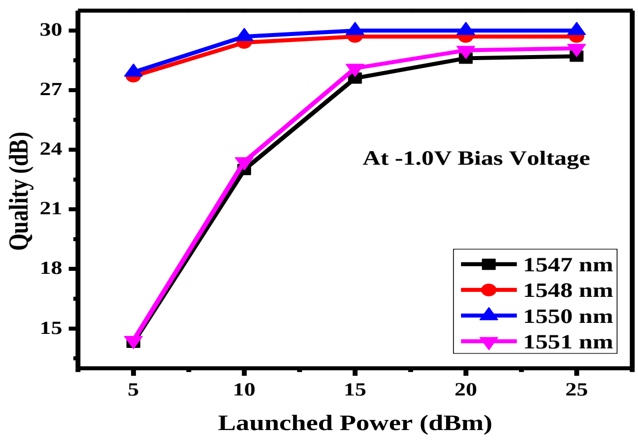


Fig. 5. Converted signal quality under fixed reverse bias voltage (color online)

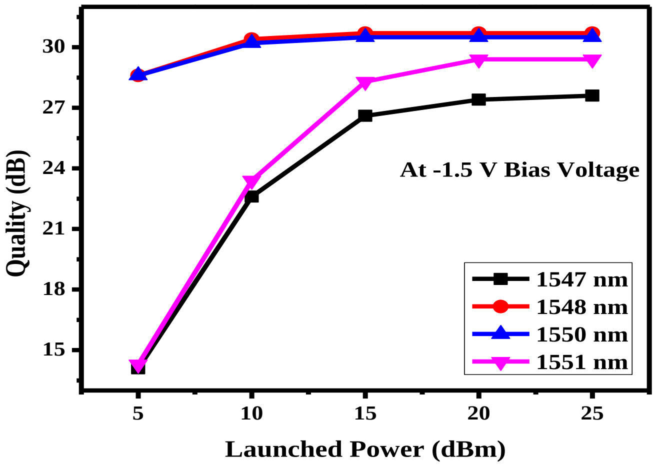


Fig. 6. Converted signal quality under fixed reverse bias voltage (color online)

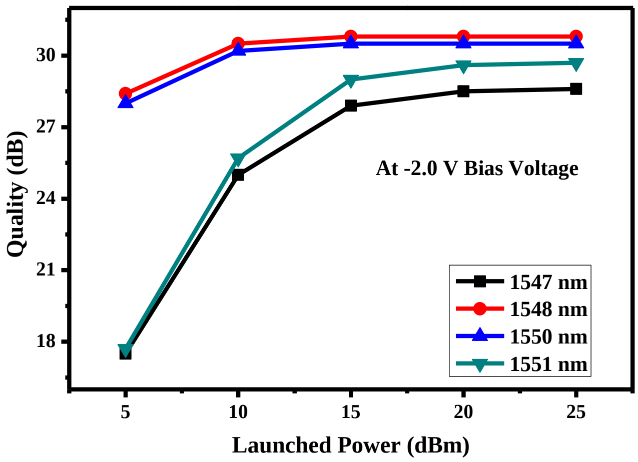


Fig. 7. Converted signal quality signal under fixed reverse bias voltage (color online)

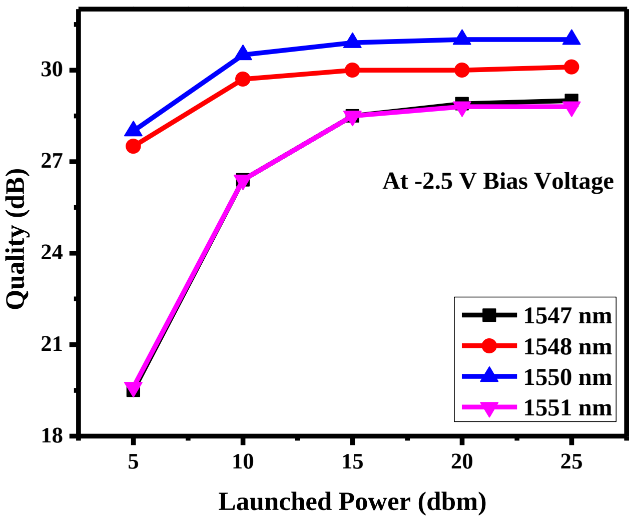


Fig. 8. Converted signal quality under fixed reverse bias voltage (color online)

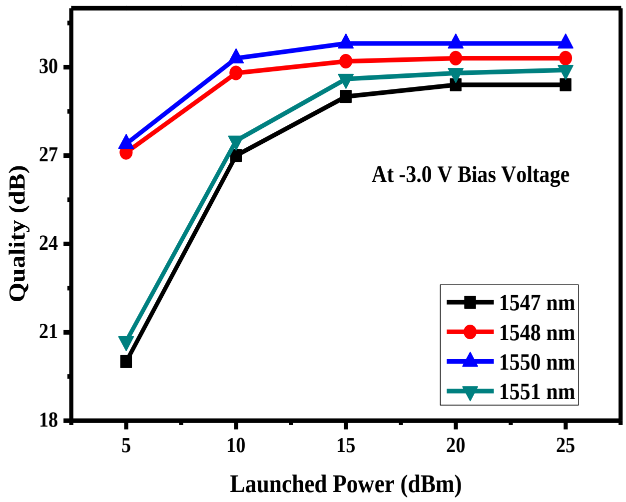


Fig. 9. Converted signal quality under fixed reverse bias voltage (color online)

It has been concluded that the wavelength converted signal quality is enhanced as the input power signal rise from 15 to 21 dBm, although the present result indicates the higher input power to be beneficial to achieve high quality of converted signals. But due to excessive use of input signal power; photogenerated charge carriers increases. Which increases the carrier recovery time, therefore the excessive field screening preventing the carrier sweep-out. This problem can be resolved using a higher reverse bias. However, the insertion loss of the device increases. Beyond this, the consistency of an EAM under such circumstances also needs consideration, so to avoid the input signal power 15 dBm and - 2.0 V, EAM bias voltage is considered for wavelength converted signals.

Case III: Launched power versus fixed (-2.0 V) biased voltage

Here bias voltage value is set to -2.0 V and the input power of the signal range is as of 15 to 21 dBm consider for wavelength conversion and the corresponding converted signal power shown in Fig. 10 and output OSNR shown in Fig. 11 respectively. The power of input signal raises the corresponding power of converted signal and OSNR of converted signal also increases due to XAM effect of EAM. Eye diagram of converted signal shown in Fig. 12 and related timing diagram of converted signal shown in Fig. 13 at 1547 nm, 1548 nm, 1550 nm and 1551 nm with input power signal at 15 dBm and bias Voltage at -2 V. Results shown in Fig. 12 and Fig. 13, validated the faithful performance of converted wavelength at -2.0 V bias voltage and 15 dBm input signal power.

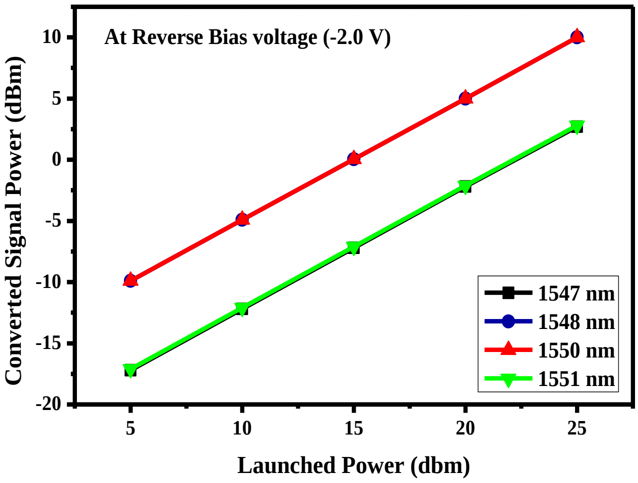


Fig. 10. Received power of converted signal under different input signal power (color online)

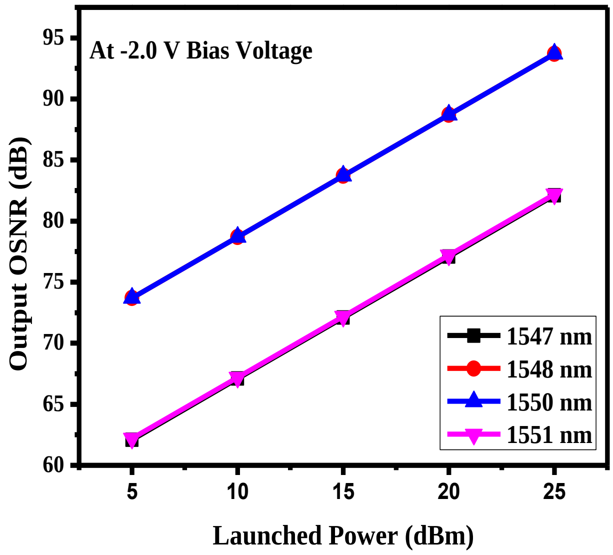
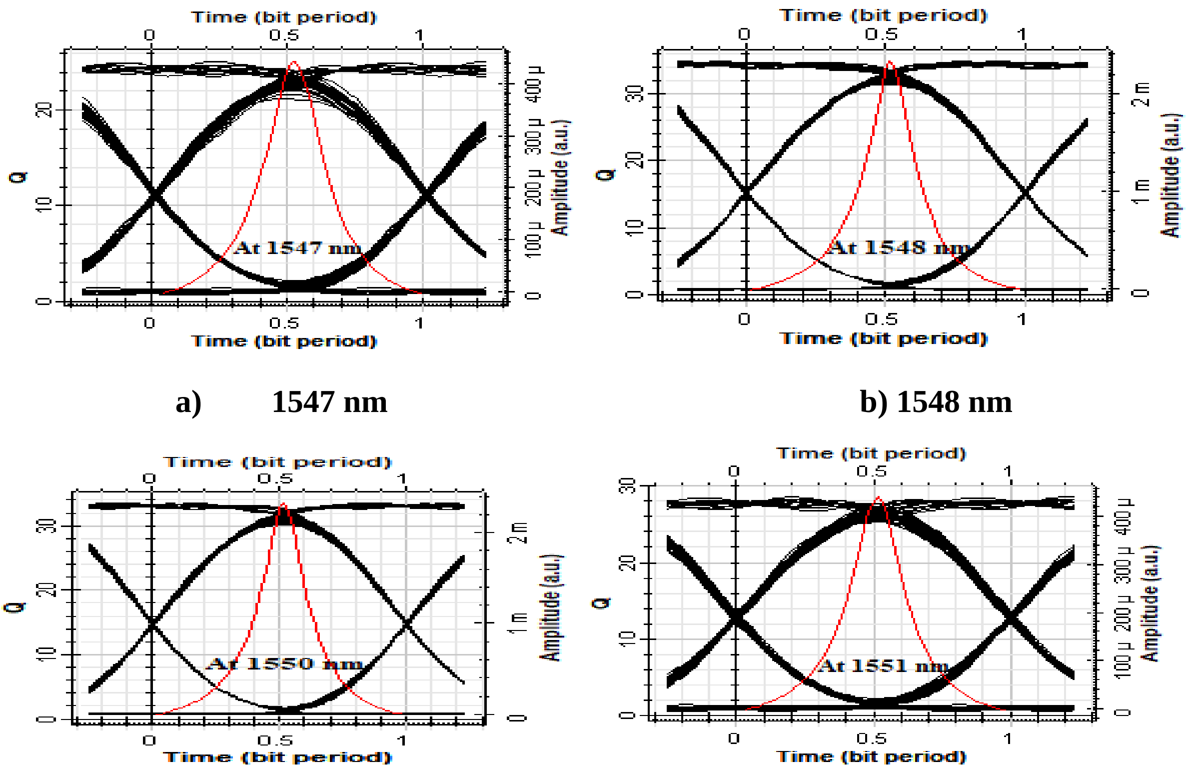


Fig. 11. OSNR versus different input signal power at fixed reverse bias voltage (color online)



a) 1547 nm **b) 1548 nm**

c) 1550 nm **d) 1551 nm**

Fig. 12. Eye diagram of converted signal at a) 1547 nm b) 1548 nm, c) 1550 nm and d) 1551 nm with Launched power at 15 dBm and bias Voltage at -2 V

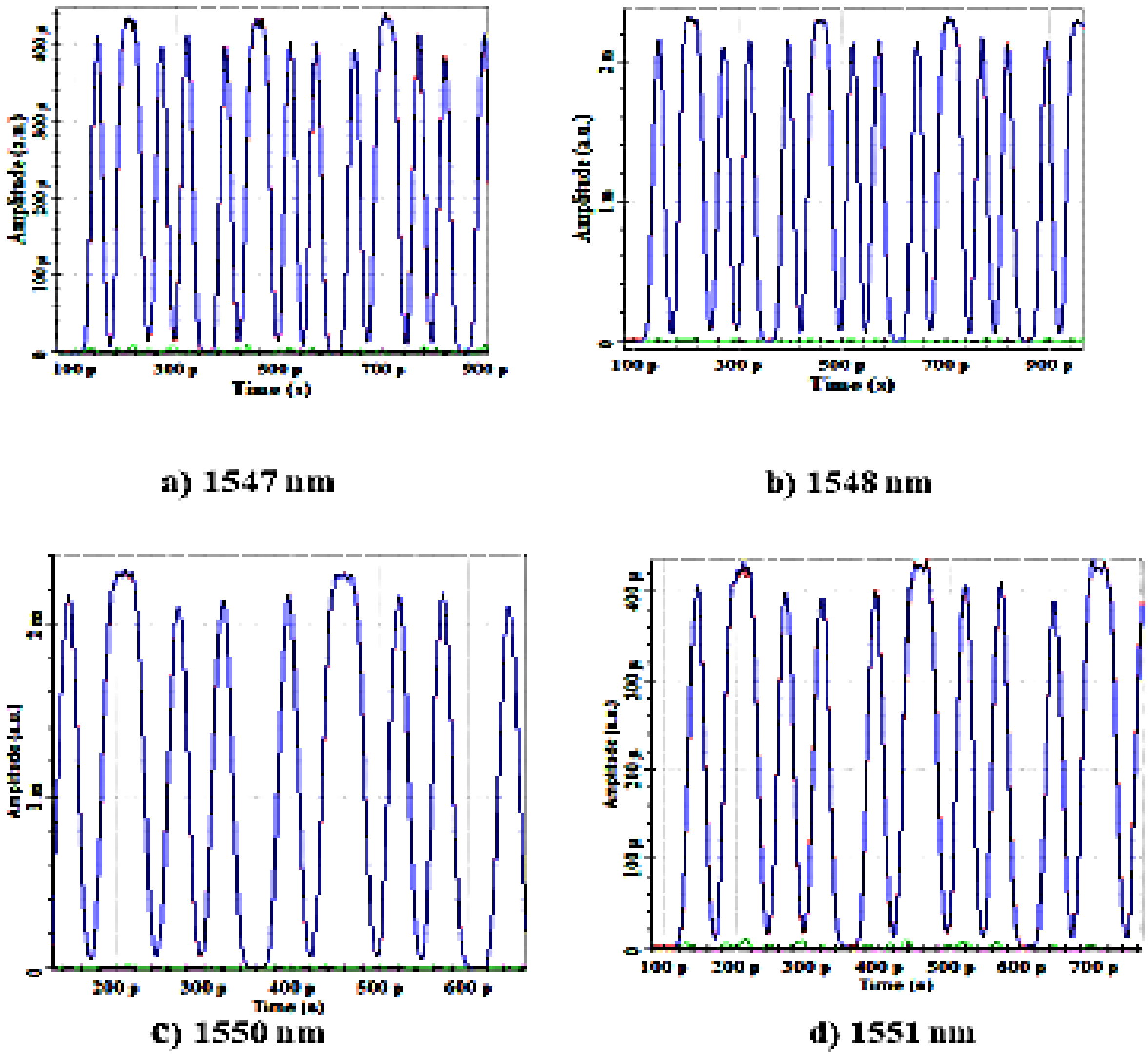


Fig. 13. Timing diagram of converted signal at a) 1547 nm b) 1548 nm, c) 1550 nm and d) 1551 nm with launched power at 15 dBm and bias Voltage at -2 V

4. Conclusions

Here cross absorption modulation (XAM) in electroabsorption modulator (EAM) at 40 Gbps, NRZ format is exploit for conversion of one wavelength to another wavelength is examined. To achieve the best possible wavelength converter, the impact of input power signal and reverse bias voltage of EAM play a significant role**.** In the first case the maximum quality of converted signal achieved at different bias voltage *i.e.* in 1547 nm (29.4 dB) at -3.0 V, 1548 nm (30.8 dB) at -2.0 V, 1550 nm (30.8dB) at -3 V and 1551 nm (29.8 dB) at -3.0 V. The results suggest that at higher reverse bias voltage the maximum quality of converted signal is achieved; but this lead to more losses so 2.0 reversed bias voltage is considered. In the second case where bias voltage dependence at Variable input power of the signal; converted signal quality at preset -2 V, increases as we raise the launched power. The best converted signal quality has been attained at 1548 nm and 1550 nm with reverse bias voltage of 1.5 V as well as 2.0 V respectively. Finally the special case of reverse bias voltage 2.0 V with respect to input power signal 15 dBm is investigated. With the increase in input power signal; the corresponding received power and OSNR of converted signal also increase due XAM effect of EAM. These results suggest that this configuration is a strong approach for practical applications in all – optical network systems.

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