Performance Analysis of Bidirectional Traffic WDM Passive Optical Network with Arrayed Waveguide Grating Filters

Asst. Lecturer Muhannad Yousif Muhsin
muhannad.yousif@yahoo.com
University of Technology - Electrical Engineering Department

Abstract: *The objective of this paper is to highlight the possibility of solving problems corresponding to "the concept of a flexible optical access network." The entire network architecture has been accomplished using the OPTISYSTEM development environment. The WDM-PON system architecture is based on two cascaded Array Waveguide grating (AWG). As compared with standard bidirectional WDM-PON, the system presented in this paper is low cost and more effective. Performance analysis of (NRZ, 0.6 RZ, and 0.8 RZ) modulation formats for both downstream and upstream and the effect of fiber length in them has been investigated. Two different filtering types of AWGs (Gaussian and rectangular) have been evaluated and their effect on the performance of the signal has been compared. Downstream and upstream signals performance was evaluated and optimized with respect to the bandwidth of AWG and the extinction ratio of the downstream signal.*

Keywords: WDM-PON, Array Waveguide Grating, Optical Access Network.

1. Introduction

The global internet explosive growth will access up to petabytes per minutes including video signals in the range of millions per minutes corresponding to CISCO forecast Project during 2011 to 2016 years. This tendency makes the Next Generation Access networks (NGAs) in demand. High bandwidth provision, less maintenance requirements and the low cost of the Passive Optical Network (PON) make it the most promising candidate of the Next Generation Access networks (NGAs). Passive Optical Networks (PONs) are very appealing according to the cost term because of the non-active components in the transmission line [1].

Wavelength Division Multiplexing Passive Optical Networks (WDM-PONs) with Arrayed Waveguide Gratings (AWGs) have more beneficial than Time Division Multiplexing Passive Optical Networks (TDM-PONs), where the WDM-PONs with Arrayed Waveguide Gratings (AWGs) allocate different wavelength channel to each user therefore high bandwidth is introduced in addition to that they have more security and possibly less cost effective than TDM-PONs. On the other hand the TDM-PONs have limitations in transmission capacity as well as the number of users with splitters, however the TDM-PONs are small, easy installed and require no electricity [2] [3].

WDM-PON architecture that is shown in figure (1) below uses a separated wavelength channel from the Optical Line Terminal (OLT) to each Optical Network Units (ONU) for each downstream and upstream transmission. Each ONU in the WDM-PON system can be able to exploit the whole bit rate of the wavelength channel, and it can be divided with others ONUs, thus different services can be backed up over the same network[4]. In another meaning different wavelengths groups can be exploited to back up different independent Passive Optical Network (PON) sub networks, all this can be operated over the same optical fiber infrastructure [5].

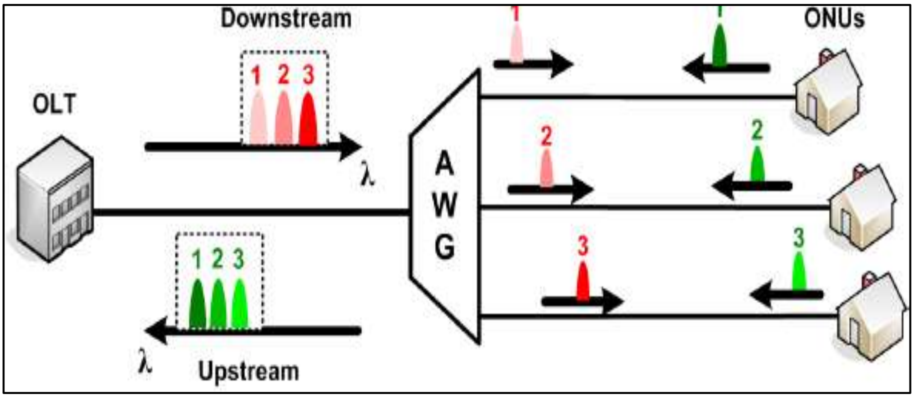


Figure (1) WDM-PON architecture

In terms of the physical network topology, the WDM-PON networks are point to multipoint passive topology because the use of the passive AWG couplers. However, WDM-PON networks are point to point in terms of the logical network topology, since the dedicated transmission channel is used to each user and the bandwidth is not shared with others as in the case of the classical PON networks [6].

In the downstream signal, the Arrayed Waveguide Grating (AWG) divides the coming signal to individual wavelengths, since each carrier propagates in separated channels to dedicated ONUs. The same principle is employed in the upstream signal, where the data is transmitted with dedicated wavelength at each ONU [7]. The advantages of the AWG are primarily the small loss insertion, high stability, less cost than the other conventional splitters, and the flexible selection of its channel number and channel spacing [8].

2. Modeling

The system architecture presented in this paper is shown in Figure (2). It is designed and simulated using (OPTISYSTEM 2013) as shown in appendix A. this network architecture consist of two cascaded of AWGs. The first AWG is an 8x1 input/output that connects the optical sources to the bidirectional fiber and then to the second 1x8 AWG which is connected to 8 ONUs. Each ONU has a receiver that contains simple photo detector and filter to select the chosen wavelength.

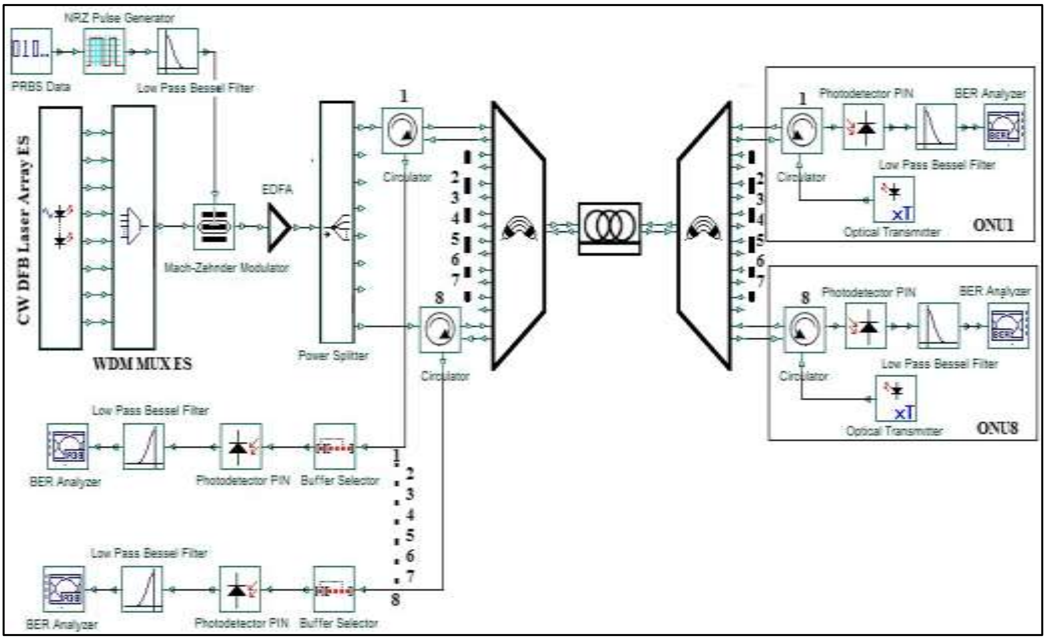


Figure (2) bidirectional WDM-PON system architecture

The upstream data can be modulated by any appropriate transmitter used for modulate the OLT carrier. Fixed laser stack is used as optical source of the OLT for downstream signals. It has 8 fixed lasers each one has wavelength that is compatible with routing table of the AWG. Single modulator is used for modulating the coupled optical sources. The modulated signal is then split using 1x8 splitter and became the inputs for 8x1 AWG with 3 dB insertion loss and 100 channel spacing. Return to Zero (RZ) and Non Return to Zero (NRZ) data format with 2.5 Gbit/s are used for modulating the driving amplitude. After the modulation signal amplification is needed.

After passing through the AWG and the two circulators the signal power endure -7 dBm losses before sending into the system fiber that have 0.5 dB/km loss and 16 ps/nm/km dispersion. Self phase Modulation (SPM), Rayleigh scattering and Cross Phase

Modulation (CPM) as Nonlinearity effects were also counted in the system fiber. The same AWG as in the OLT is used for demultiplexing the transmitted signals in order to deliver each one to the corresponding ONU with -14 dBm power. Receiving/ transmitting module are composed in each ONU. In the ONU a 3dB coupler is used for splitting the input signal. Finally at the PIN photodiode the received signal is about -17 dBm then it passed through a Bessel filter with (0.6×data bitrate) bandwidth. Bit error rate tester (BERT) is used for measuring the bit error rate of the converted electrical signal. The whole quality of the communication system is valued by the bit error rate (defined as the ratio of incorrectly received bits to the total number of bits received over time) [9]. BER measuring is presented in equation (1) as a function of the Q factor [10]:

$$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right) \approx \frac{exp\left(\frac{-Q^2}{2}\right)}{Q\sqrt{2\pi}} \qquad (1)$$

The Q factor provides an analog quality for the digital signal as shown in equation (2):

$$Q = \frac{I_1 - I_o}{\sigma_1 - \sigma_o} \qquad (2)$$

" where: I_1 - logic level '1', I_o - logic level '0', σ_1 – standard deviation of the logic level '1', σ_o - standard deviation of the logic level '0' "[10].

In each ONU an optical transmitter as the same as in the OLT is used for feeding the upstream signal. In order to get the same output power and modulation type of the downstream bias current and driving amplitude can be controlled. The power of the upstream signal about -2 dBm prior to passing through the system fiber. After passing through the fiber it is then demultiplexed using the AWG and fed in to the photodiode with -17 dBm power. As clarified, 22 dB is the power budget for both downstream and upstream signals.

3. Results and Discussion

In this section the designed system performance have been analyzed by the Q factor as a function of a fiber length, The BER to investigate the effects of the two different AWG filters (Gaussian and Rectangular types) and BER according to the extinction ratio for downstream and upstream signals as shown below.

3.1 Q factor for individual distances

From theoretical assumptions the quality of the optical communication system will reduce as the fiber distance increased. At the ONU side the power value have to be up -21 dBm which is the maximum sensitivity of the ONUs. Various factors can limit this value like dispersion, length of the fiber and purity of connectors. Q factor (The Q-factor gives us an analog quality of the digital signal with respect to the signal-to-noise ratio) has been chosen to find this quality simply. Bit error rate will be in lower level when the Q factor in higher level. , the results has no signs of degradation for distances up to 15 km so longer distances has been chosen in the simulation. As the distances increased up to 40 km there is a noticeable change where the Q value became 17 and the BER became $1.4*10^{-19}$. This results for downstream NRZ and RZ of duty cycle = 0.6 and 0.8. As the results shows RZ for this optical network is the better option.

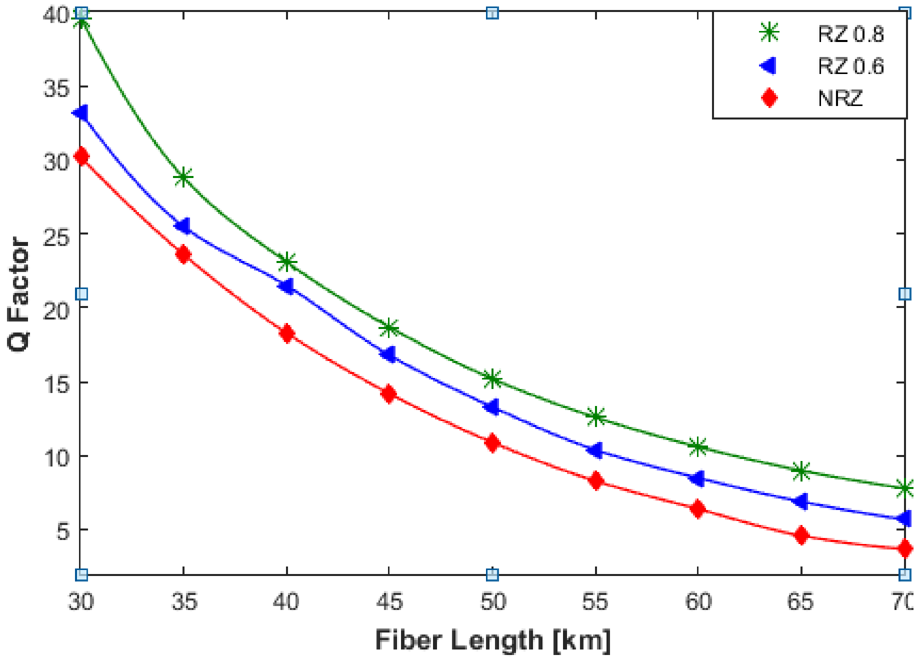


Figure (3) Q factor for number of fiber length of downstream (NRZ, 0.6 RZ and 0.8 RZ) signals

Figure (4) shows upstream signal of the NRZ and RZ of (0.6 and 0.8 duty cycle). For distance 40 km the Q values are 8, 11 and 12 of NRZ, 0.6 RZ and 0.8 RZ respectively. The BER is $4.7x10^{-6}$ and the Q factor value decreased to 5 when the distance is 60 km. although this BER value is very high the network still working. But with distance 65 km and upper such a network is not working as the effect of chromatic dispersion (CD) began to appear. Maximum chromatic dispersion value is 1000 ps/nm with 10 Gbps bit rate. Total chromatic dispersion will be 1020ps/nm if 60 km length and 17 ps/(nm·km) CD coefficient. Chromatic dispersion compensation is necessary for such a long distance. The goal of this paper is to obtain the maximum transmission parameters without any compensation.

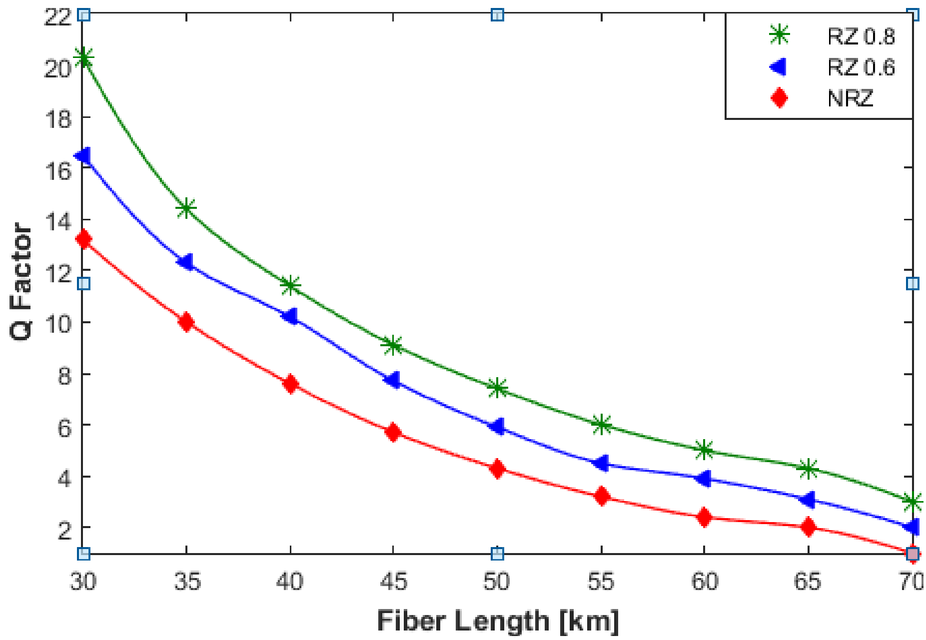


Figure (4) Q factor for number of fiber length of upstream (NRZ, 0.6 RZ and 0.8 RZ) signals

3.2 Performance of AWG

Two different transfer functions (Gaussian and Rectangular types) of AWG are investigated in the presented WDM PON system. The optical spectra of the two filters output signal is presented in figure (5) with 1 GHz resolution. The losses of two filters were normalized to the smallest value. A 3 dB bandwidth of 50 GHz is chosen for the Gaussian filter. 50 GHz flat pass bandwidth, stop bandwidth with 40 dB attenuation out of this bandwidth and least loss region are chosen for the rectangular filter. In order to analyze the effects of this two AWG filters BER is measured as shown in figure (6). The results present worst curve for the Gaussian type which is higher than 10^{-8} BER at −20 dBm received power. A saturation is appear at much higher received powers. Best curve is shown for the rectangular type where at −20 dBm received power the BER is 10^{-10}. Much better performance is achieved by the rectangular AWG because of relative intensity noise

(RIN) suppression so for practical consideration the rectangular AWG is the best.

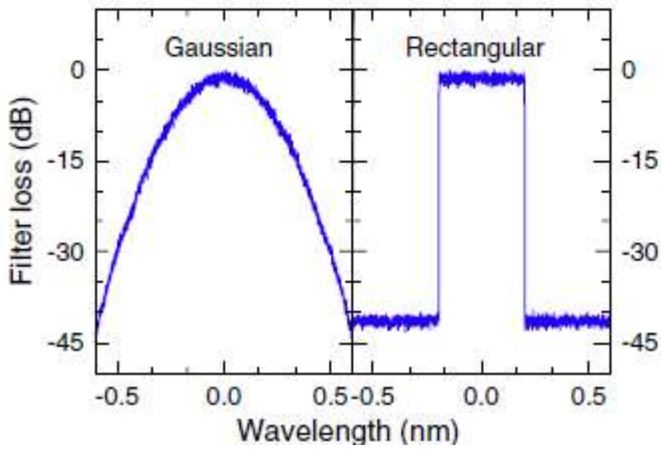


Figure (5) Optical output spectra of two AWG filters

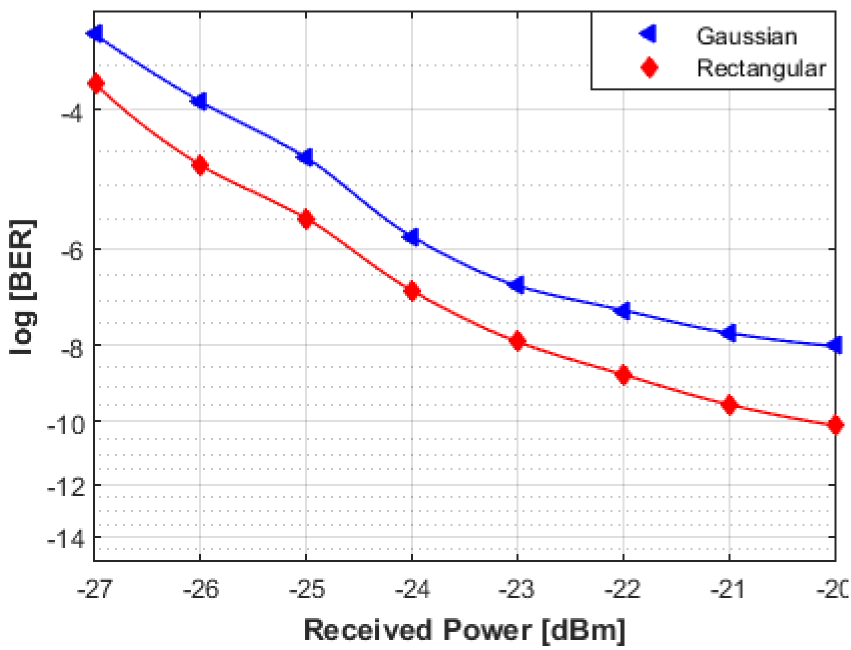


Figure (6) BER curves measurement of AWG filtering effect using Gaussian and rectangular transfer functions.

BER as a function of pass bandwidth for rectangular AWG is presented in figure (7) for the downstream and the upstream signals. The AWG pass bandwidth is varied from [10 -70] GHz with 20 GHz wider stop bandwidth. From the results as the bandwidth increased the BER is reduced because of relative intensity noise decline with bandwidth increasing. However increasing bandwidth not always guarantees better performance. For a bandwidth wider than 50 GHz the performance are not further improved for downstream and upstream signal that is because of cross phase modulation effect. For upstream signal, the intensity noise effect caused by the demodulation at lower AWG bandwidth reduces the intensity noise rise by AWG bandwidth decreasing this make upstream signal performance less make worse than that of downstream signal. As a result 50 GHz pass bandwidth of AWG is demanded for demodulation for both WDM signals.

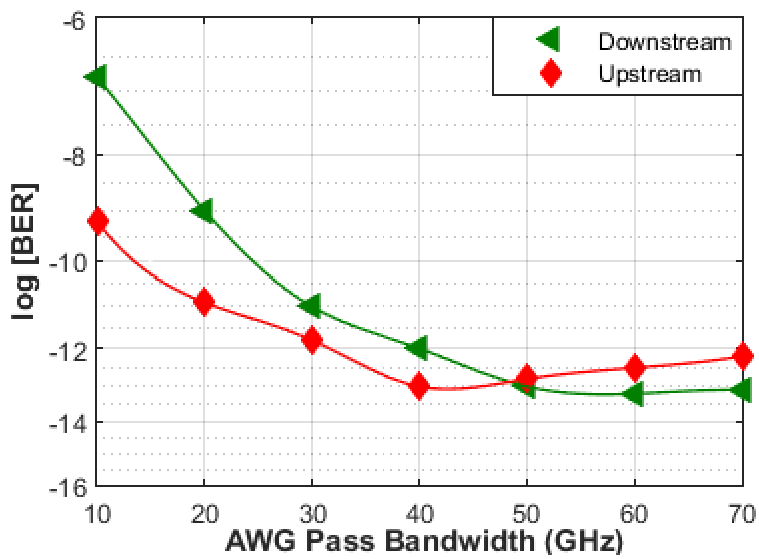


Figure (7) BER comparison at−17 dBm of downstream and upstream signals as a function of AWG pass bandwidth.

3.3 Extinction Ratio (ER)

The downstream and upstream signals performances are examined in order to show how an Extinction Ratio (ER (ER is the ratio of two optical power levels of a digital signal generated by an optical source) for downstream signal effects the signal demodulation at each ONU. Figure (8) shows the result of BERs as a function of ER varies between [4-8] dB. The output power was fixed at 5 dBm. The BERs were about 10^{-8} and 10^{-18} for the downstream signal and upstream signal respectively when a downstream signal ER is 4 dB. The BERs were opposite when the ER become 8 dB. Therefore as ER of the downstream signal increase BER of the downstream signal decrease but that of upstream signal increase. That is because of ER increasing means increasing in power change between 0 and 1 levels for the downstream signal.

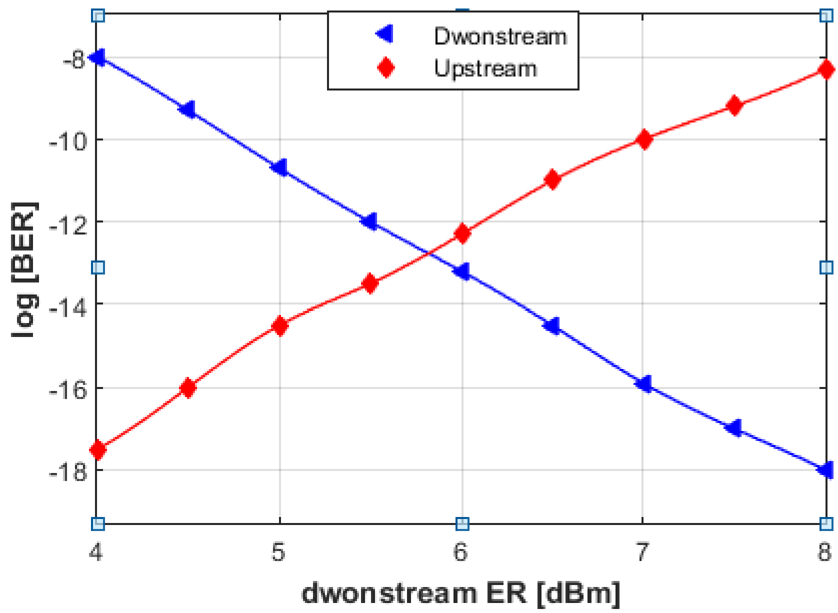


Figure (8) BER variations for downstream and upstream signals as a function of the extinction ratio.

The network will be limited to the downstream transmission if low values of ER is used so the Extinction Ratio must be optimized. Owing to the existence of downstream signal in the demodulated upstream signal there is a tradeoff between the maximum ER and the maximum BW provided by the WDM Transmitter in order to achieve best performance.

3.4 BER for downstream and upstream signals with received power

Figure (9) present BER curve to evaluate the performance of the upstream signal. The results show that power penalty to receive optical signal is 3.8 for 8 channel after 30 km transmission with desired BER < 10^{-12}.this power penalty due to dispersion and cross talk effects.

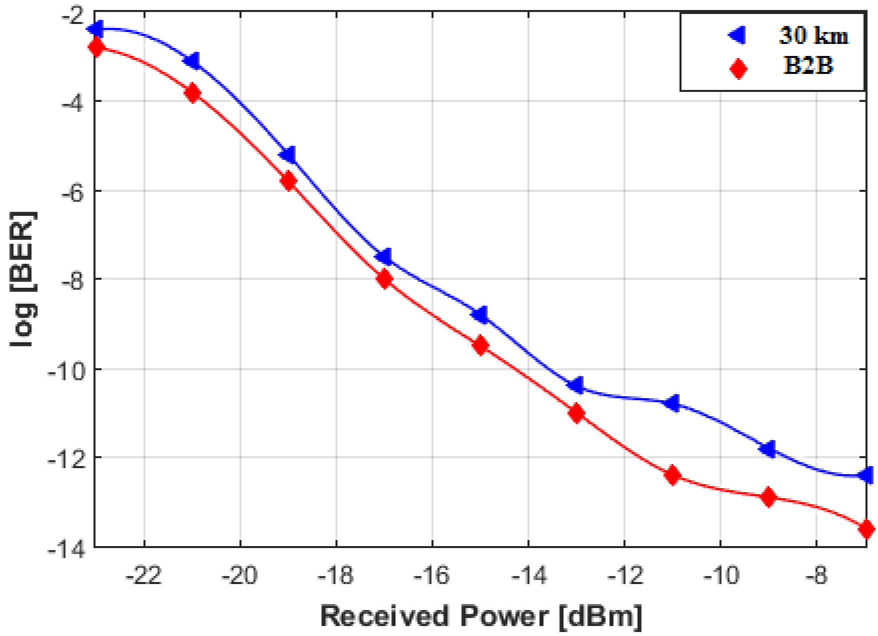


Figure (9) BER performance of upstream signals in B2B configuration and after 30 km transmission

For downstream signal in order to get BER < 10^{-12} minimal received power for B2B configuration have to be above -18.9 dBm and for 30 km SMF transmission above -17.6 dBm. The Power penalty for this downstream signal is 1.3 dB and this can be explained by the effect of chromatic dispersion. Figure (11) presents BER measurement as a function of received power using optimum ER value and rectangular AWG for balance the performance of both downstream and upstream signals. Under these conditions at 10^{-12} BER the upstream signal has 3dB better sensitivity and that is because there is no ER limitation where 15 dB ER value was used.

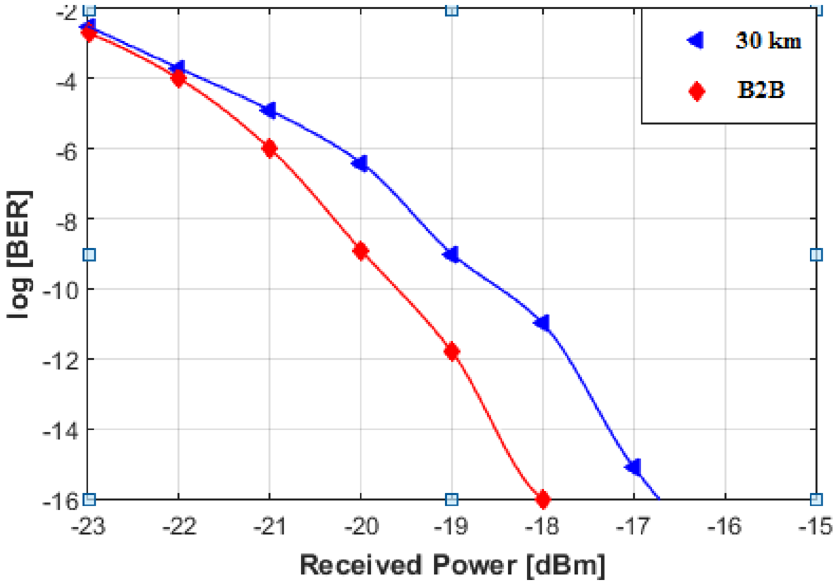


Figure (10) BER performance of downstream signals in B2B configuration and after 30 km transmission

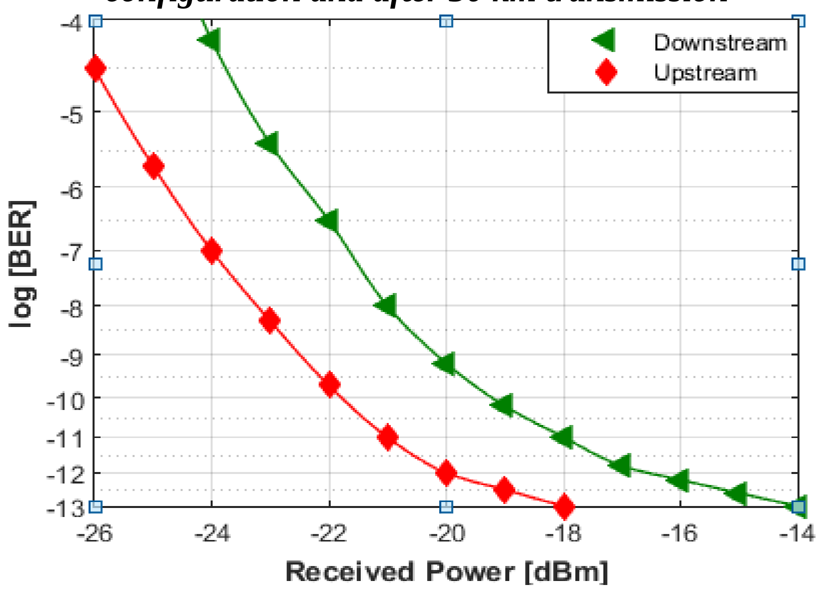


Figure (11) BER performance as a function of received power for both downstream and upstream signals.

4. Conclusion

The architecture of bidirectional WDM-PON system for data transmitting using two cascaded AWGs and low cost optical sources was investigated by computer simulation. The two AWGs used for increasing the ONU number, multiplexing, demultiplexing channels and supporting more security. For both downstream and upstream NRZ, 0.6 RZ and 0.8 RZ are used as the modulation format in this system. The RZ data modulation as concluded is superior to NRZ data modulation and that is because it's better immunity to fiber nonlinearities.

This paper focuses on the importance of AWG band shape in the WDM-PON system by framing the filtering effect which removes the upstream signal tails and decline the received signal. The simulation of the system with experimental analysis indicate that AWGs Gaussian type must not be used in such a system due to pattern dependent effects where a BER floor is not achievable. the performance of the network got better As the form of the filter became rectangular. For WDM-PON system it is essential to use flat band AWGs for reducing the filtering effects and extend acceptable BER.

An extinction ratio (ER) of 5.5 dB has been chosen as optimal value for the downstream signal in order to balance the performance between demodulated upstream and downstream signals. Pass bandwidth of a rectangular AWG effects on the signal performance is also investigated. While AWG pass bandwidth changed from [10-70] GHz with [20 GHz] stop bandwidth, the narrowest bandwidth that is keeping good performance was 50 GHz.

References

[1] Rajniti, A. Suman, A. Sheetal, Parveen, "Comparison of RZ and NRZ data formats for 2.5Gb/s bidirectional DM/TDM-PON using narrowband AWG", International Journal of VLSI and Signal Processing Applications, Vol. 1, Issue 2, May 2011.

[2] K. Sasi Kala Rani, A. Renuga Devi, J. Suganthi "Optimization of Disjoints Using WDM-PON in an Optical Network", Scientific Research Publishing, Hindusthan College of Engineering and Technology, Coimbatore, India, 2016.

[3] Kihwan Park, "OATM/WDM Optical Access Network Using Header Decoder-Based Router for Next-Generation Communications" Journal of the Optical Society of Korea Vol. 20, Issue 3, pp. 335-342, 2016.

[4] Liu D., Tang M., Fu S., Shum P.,"A long-reach WDM passive optical network enabling broadcasting service with centralized light source", Optics Communications, Volume 285, Issue 4, 15 February 2012.

[5] Sareh F. Harandi,"Integrated Optoelectronic Devices and System Limitations for WDM Passive Optical Networks", University of Waterloo, Canada, 2012.

[6] Choi B.H., Lee S.S. "The effect of AWG-filtering on a bidirectional WDM-PON link with spectrum-sliced signals and wavelength-reused signals", Optics Communications, vol. 284, issue 24, pp. 5692–5696, 2011.

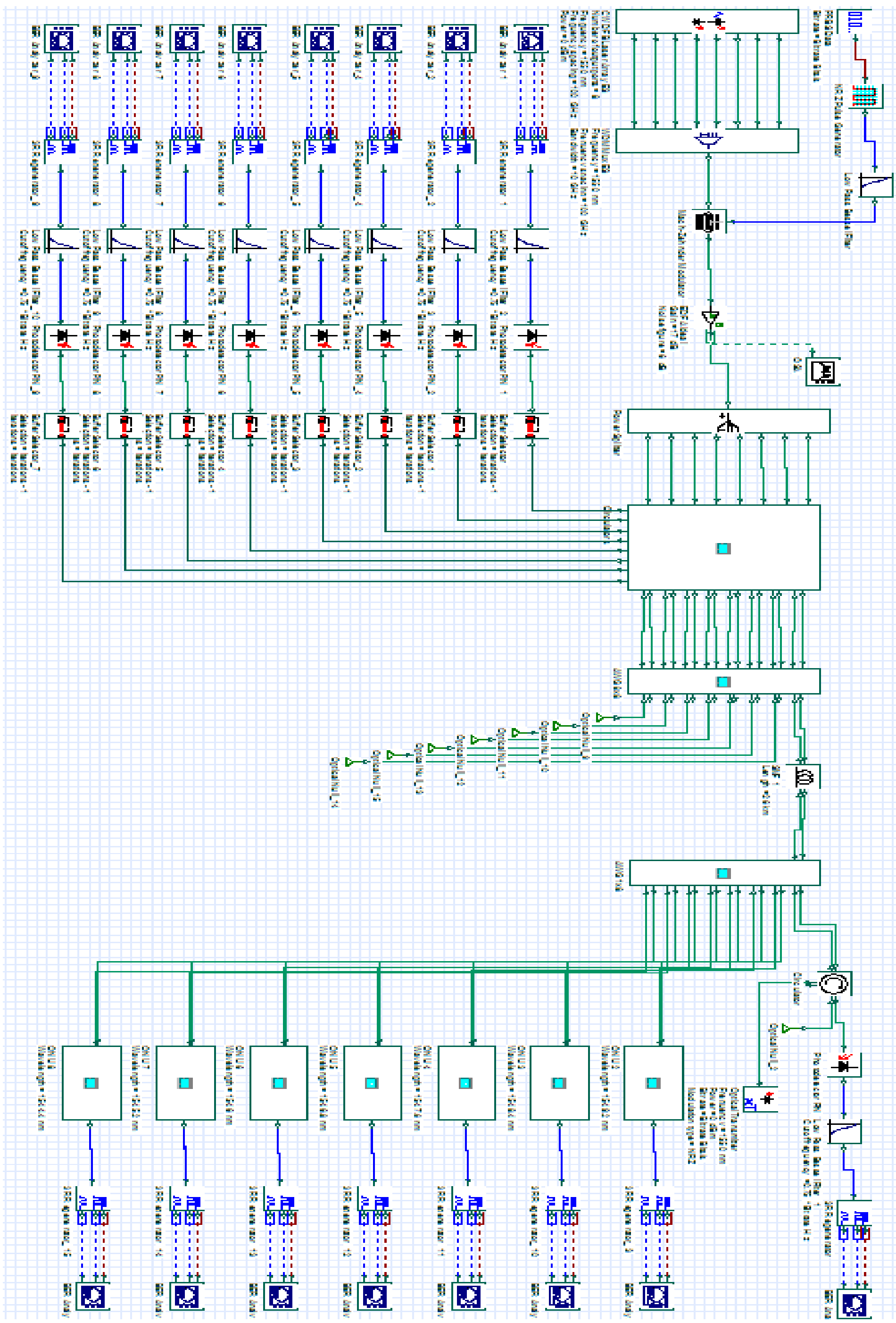
[7] Zhaowen Xu , Yang Jing Wen, Wen-De Zhong, "High-speed WDM-PON using CW injectionlocked Fabry-Pérot laser diodes" , Optical Society of America, 2007.

[8] Soo-Jin Park, Geun-Young Kim, Tae-Sang Park, “WDM-PON system based on the laser light injected reflective semiconductor optical amplifier,” Opt. Fiber Technol. 12, 162-169 (2006).

[9] Mohd S. Salleh, Zulkalnain M. Yusof,"Broadcasting and Multicasting in All Optical Packets Routing TWDM PON System Architecture", IJCNWC, Vol.2, No6, December, 2012.

[10] Kavita Awade, Rajkumar Biradar,"A Novel Design of Bidirectional WDM-PON by using Mode Locked Laser and RSOA", International Journal of Future Generation Communication and Networking, Vol. 8, No. 4, 2015.

Appendix-A



تحليل الاداء لشبكة مزج الارسال بتقسيم الطول الموجي الضوئية الثنائية الاتجاه الخاملة ذات مرشحات (AWG)

م.م. مهند يوسف محسن
muhannad.yousif@yahoo.com
الجامعة التكنولوجية - قسم الهندسة الكهربائية

المستخلص

الهدف من هذا البحث هو الاشارة الى امكانية حل المشاكل المتعلقة بمفهوم شبكات الوصول الضوئية المرنة. تم تحقيق البناء الكامل المصمم باستخدام بيئة التطوير (OPTISYSTEM).يوضح هذا العمل بنية النظام (WDM-PON) المستند على اثنين من Array Waveguide grating (AWG) المتتالية . من المتوقع ان يكون هذا البناء فعالا ومن حيث الكلفة اقل مقارنة مع نظام PON-WDM ثنائي الاتجاه العادي. تم تحقيق تحليل الاداء لتنسيق البيانات من نوع (NRZ, 0.6 RZ, and 0.8 RZ) كلا الاشارتين downstream وupstream وتأثير طول الليف الضوئي عليهما. وتم تحقيق تاثير الترشيح باستخدام AWG على الشبكة عن طريق استخدام نوعين من AWG وهي Gaussian وrectangular وتم مقارنة الاشارات الخاصة بهم مع الرابط لنقل لبيانات. تم تحليل والحصول على الامثل لتأثير الاداء لكلا الاتجاهين من نقل البيانات downstream و upstream وفقا لنسبة الاخماد التابعة لاشارة downstream وكذلك الحزمة الترددية للAWG .

الكلمات الرئيسية: شبكات الوصول الضوئية، نظام PON-WDM،AWG