



Analysis of GPON Downstream with 128 Users using EDFA In-Line Amplifier for Extended Reach To 80 km

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Abstract: In this paper, we study different characterizations of EDFA in-line amplifier used for GPON Downstream, which depend essentially on the opt-geometric parameters (ions erbium density, length of the fiber doped erbium, core radius and numerical aperture...) and the effect of those parameters to optimize the gain G and quality factor Q for extending the reach to 80 km of GPON with 1:128 split ratio. Also the performance of this system has been evaluated in terms of Max Q factor, eye diagram, Min BER with various simulations by sweeping different parameter such splitter loss, signal input power and fiber length and format modulation etc.

Keywords: Amplification optic; Access network; GPON; Erbium Doped Fiber Amplifier; Reach of passive

I. Introduction

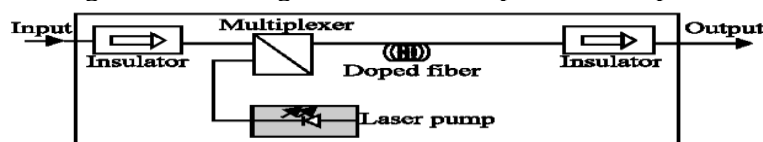
Recently, because of demand from high data rate triple-play services, the deployment of fiber to the home (FTTH) in the broadband access network also known as last mile network (connects central office to each end user) and the related standardizations are becoming increasingly important [1]. The interconnection between the end subscriber and the distribution node which is going to provide the services can be done through various architectures; one of the most attractive optical access network architectures is the Passive Optical Network (PON), the GPON is popular version of passive optical networks (PONs), it is an all-optical transmission based network which aims at providing a high speed network connection. The characteristics of GPON technology has been standardized by International Telecommunication Union-T (ITU-T) in recommendation G.984 series [3]. The downstream and upstream traffics are transmitted at 1490 nm and 1310 nm while 1550 nm wavelength is allocated for video. The physical configurations can be seen by the splitting ratio and the distance of OLT-ONT. Theoretically, the splits can be up to 64 but due to the current hardware limitations, the development so far can only reach 32 and the maximum physical length from the OLT to ONT is 20 km [2].

To cover a wider area and get more power margin in order to decrease the number of OLTs, an amplification scheme adapted to PON systems is required [4]. Various optical amplifiers, such as erbium-doped fiber amplifier (EDFA), semiconductor optical amplifier (SOA) and Raman amplifier, could provide an extended reach and/or a high split-ratio for the cost-effective implementation of PONs. Development of other types of DFAs for amplification in the remaining optical bands has been actively investigated. Praseodymium-doped fiber amplifiers (PDFAs for upstream) and thulium-doped fiber amplifiers (TDFAs for downstream) were developed to amplify signals around 1300 and 1490 nm, respectively [5].

II. EDFA for reach extension GPON

Erbium Doped Fiber Amplifiers (EDFAs) provide optical amplification to compensate power loss in optical signal transmission and are attractive candidates for GPON reach extension. They can be designed to provide low noise figure (NF), and fast gain dynamics in the 1550 nm (C-band) and 1490 nm (S-band) windows [6]. EDFA is an optical amplifier that uses a erbium doped optical fiber as gain medium to amplify an optical signal. The signal which is to be amplified and a pump laser are coupled into the doped fiber and the signal is amplified through stimulated emission. EDFA is the best known and most frequently used optical amplifier suited to low loss optical window of silica based fiber [7].

Figure 1: Block diagram of Erbium Doped Fiber Amplifier.



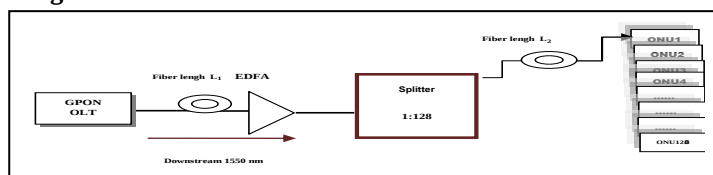
A particular attraction of EDFAs is their large gain bandwidth, which is typically tens of nanometers and thus actually it is more than enough to amplify data channels with the highest data rates without introducing any

effects of gain narrowing [8]. A single EDFA may be used for simultaneously amplifying many data channels at different wavelengths within the gain region [9].

III. The simulated chain and results

A diagram of the downstream GPON structure which can be implemented with a splitting ratio of 128 is shown in Figure 2. A schematic diagram of simulation, illustrating an OLT which is connected to the remote node by optical fiber (SMF) with an attenuation coefficient of 0.2 dB/km and length of 80 km for all wavelengths. For the OLT (optical Line Terminal) of the system GPON we employed a directly modulated distributed feedback laser (DFB) at 1550 nm as the transmitter for the downstream signal, the output power from both the OLT was set at 10 dBm. The ONU (optical Network Unit) receiver uses the avalanche photodiodes (APD). The procedure for data transmission in GPON downstream (from the OLT to the ONUs) with 2.5 Gbits/s employs TDM (Time Division Multiplexing) to broadcast the signal to all the ONTs sharing the same fiber, ONUs filter the received data and extract only their own traffic. Erbium doped optical amplifiers (EDFA) have been chosen for the simulation for amplify wavelength around 1550 nm for position in line-amplification burst mode, requiring optical amplifier to have fast transient control capabilities [10].

Figure2: Architecture of GPON downstream with EDFA in-line.



A. EDFA Characterization Parameters

The gain of the EDFA depends on a number of device parameters: erbium ion density, amplifier length, core radius and pump power. In this part, the effects of these quantities on the action and performance of erbium amplifiers such as amplifier gain, noise figure and quality factor Q are investigated. The following parameters values were used table (1):

Table (1) represents the typical EDFA parameters

Parameter	Value	Symbol
Signal input power	0 to 10 dBm	P_{in}
Signal wavelength	980 -1480 nm	λ
Pump power	50 to 350 mw	P_p
Amplifier length	0 to 30 m	L_{edfa}
Core radius	1 to 9 μm	D
Erbium ion density	$1e+24/m^3$ to $1e+25/m^3$	C
Numerical aperture	0.1 to 0.9	NA

• Effect of erbium ions density (C)

First part of the simulation considers the optimization of Q factor by sweeping erbium ion density $1e+24/m^3$ to $1e+25/m^3$ for two different amplifier length (L_{edfa}) at the pump wavelength ($\lambda = 980nm$). For this, the following parameters are used: $P_p = 200$ mw, $NA = 0.24$, $D = 2.2 \mu m$ and $P_{in} = 10$ dBm. The fig 3a show that the Q factor increases with increasing in the concentration of erbium ions for the lower values of $1e+25/m^3$ and up of this value the Q factor decreases. We can found at $C = 1e+25/m^3$ and $L_{edfa} = 10$ m a optimum Q factor of 8.55, however Q factor of 8 when $L_{edfa} = 15$ m. So in terms of actual amplifier performance, it has been reported that for optimum performance, erbium ions density should be less than about 1000 ppm or $1e+25/m^3$ [11].

Figure 3: a) - Q factor as a function of erbium ions density. b) - Gain and noise figure NF as a function of erbium ions density.

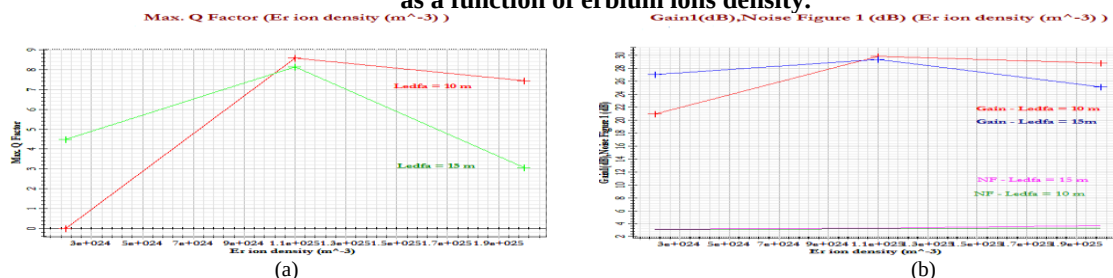


Figure 3.b shows the variation of gain and NF as a function of density erbium ions in EDFA in-line amplifier for two values of the amplifier length L_{edfa} (10 and 15m). So it is cleared from graphs that the gain increases with increasing of erbium ion concentration and with decreasing of amplifier length, however for amplifier length of

10m, the gains begins to be moderately saturated when ion concentration exceeds $1e+25/m^{-3}$ and after this value gains becomes saturated, while for higher density erbium ion of $1.5e+25/m^{-3}$ the gain decreased. Also the simulation results show, the optimal value which the gain is maximum (of 30dB) and noise figure is lower (of 3.28dB) is obtained at $L_{edfa} = 10$ m, however we provide a lower gain of 24.5dB and NF of 3.80 dB when $L_{edfa} = 15$ m.

• Effect of amplifier length (L_{edfa})

The effect of the amplifier length (L_{edfa}) in the Q factor, EDFA gain and its noise figure is study for two erbium ion density ($C = 1e+25/m^{-3}$ and $C = 2e+25/m^{-3}$), varied the amplifier length (0 to 30 m) and fixed other parameter: $P_p = 200$ mw, $NA = 0.24$, $D = 2.2 \mu m$, $P_{in} = 10$ dBm. According to the figure 4.a we can see that the quality factor Q increase linearly with the amplifier length for L_{edfa} lower of 10 m, however Q factor decreases linearly up of this value. Also we can notice for amplifier length ($L_{edfa} = 10$ m) and when density erbium ions $C = 1e+25/m^{-3}$ a high Q factor of 8.55 is obtained, however for $C = 2e+25/m^{-3}$ we provide the Q factor of 7.35

Figure 4 : a) - Q factor as a function as amplifier length, b) - Gain and noise figure NF as a function of amplifier length

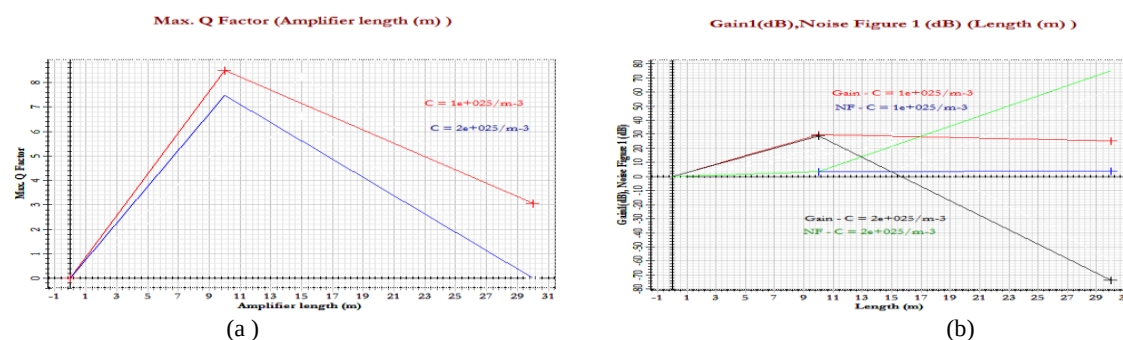


Figure 4.b shows Gain and its noise figure NF as a function of the amplifier length L_{edfa} for two value of density erbium ions, we can see that the gain increase linearly with L_{edfa} for short values (0 to 10 m) with no significant difference between the $C = 1e+25/m^{-3}$ and $C = 2e+25/m^{-3}$, however for higher L_{edfa} (10 to 30 m) Q decrease and this difference become more remarkable. At $L_{edfa} = 30$ m we find higher gain 26.5 dB and lower NF of 3.71dB when $C = 1e+25/m^{-3}$ and very lower negative Gain of -60dB and higher NF of 60 dB at $C = 2e+25/m^{-3}$. We can notice our result show that at erbium ions density of $1e+25/m^{-3}$ and for maximum gain, the optimal fiber length must be between 10 and 15 m are approximately nearly of reference [12].

• Effect of wavelength pump power (λ)

Efficient EDFA pumping is possible using semiconductor lasers operating near 980nm and 1480nm wavelengths pump. To estimate the performance, we have compared two wavelength pump (1480 and 980nm) by sweeping signal input power (0 to 10 dBm). The length of EDFA, density erbium ions and pump power are fixed at 10 m, $1e+25/m^{-3}$ and 200mw respectively. Figure 5.a shows the graphical representation of Q value. It is cleared from graphs the performance of 1480 nm improved and gives better system performance in term Q factor as compared to 980 nm. We can obtain the Q factor of 13.25 and 8.55 for 1480 nm, 980 nm respectively.

Figure 5: a) - Q factor as a function as signal input power for two wavelength power, b) - Gain and NF as a function as signal input power for two wavelength power.

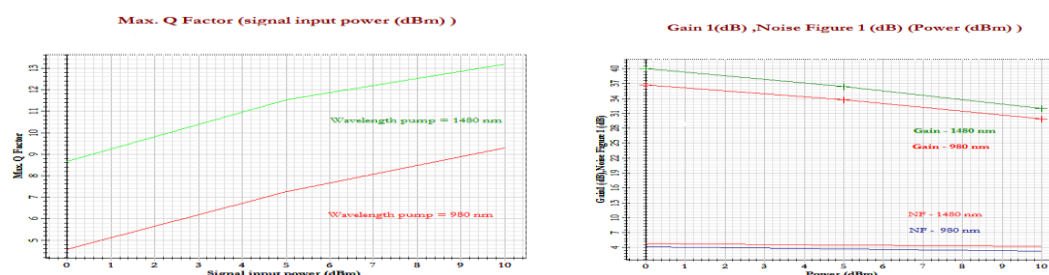


Figure 5.b shown in two different graphs the dependence of the gain and noise figure on the signal input power, that it is important to note that pumping with 1480 nm light is more efficient and gives higher gain (of 32 dB) but high noise figure (of 4.29 dB). On the other hand, pumping with 980 nm light produces a less noisy amplifier (minimum of noise of 3.27) but lower gain of 29.89 dB

Effect of amplifier core radium (D)

The progress of the factor Q as a function as changing core radium (1 to 9 μm) for two different density of erbium ion and the parameter in this case are: $P_p = 200$ mw, $NA = 0.24$, $P_{in} = 10$ dB and $L_{edfa} = 10$ m. The graphs

shows that when $C = 1e+025/m^{-3}$ and core radius lower of $2.2 \mu m$, the fixed and maximum Q factor around of 8.55 is found, however up of $2.2 \mu m$ the Q factor decrease rapidly with core radius. Whereas a high Q factor of 9.8 is found when concentrations of erbium ions $C = 2e+025/m^{-3}$. So the optimum core radius must be lower than $3 \mu m$, which is approximately equal at theoretical value found in reference [13].

Figure 6 : a) Q factor as a function as core radius, b)- Gain and noise figure NF as core radius.

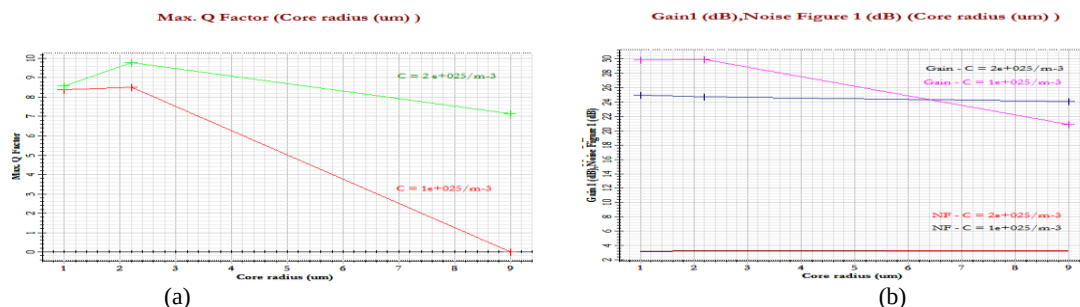
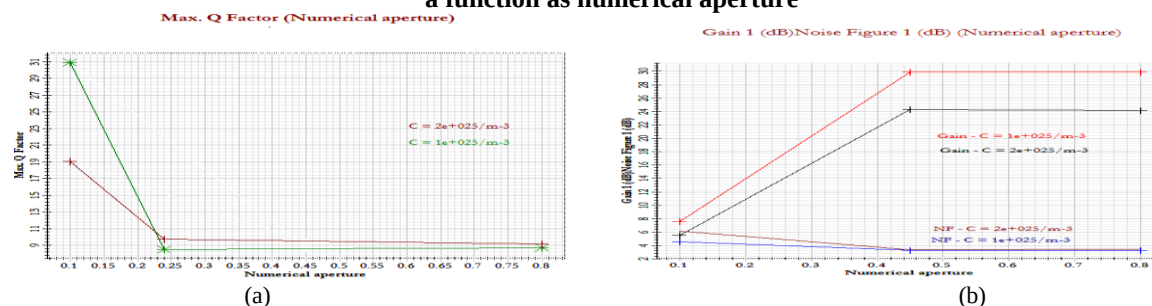


Figure 6.b show the effect of the radius core in the EDFA gain for two values of concentration, where for $C = 1e+025/m^{-3}$ we find a high gain of 30 dB and low NF of 3.5dB for a diameter between 1 and $2.2 \mu m$ and higher this value the gain decreased till obtained 20.7 dB at $9 \mu m$. By cons, we see that the gain remains constant (of 25 dB) whatever the value of the radius when $C = 2e+025/m^{-3}$.

• Effect of numerical aperture (NA)

This part of the study considers the optimization of numerical aperture (NA) for optimum fiber length ($L_{edfa} = 10m$) and two different erbium ion density, we used the following parameters: $P_p = 200 mw$, $D = 2.2 \mu m$, $P_{in} = 10 dB$ and $L_{edfa} = 10m$. The curves shows for numerical aperture lowers of 0.24 the Q factor decreases and high value of Q factor (over 30) is found when $C = 1e+025/m^{-3}$, however up of this value, the Q factor remains constant whatever the value of numerical aperture and a high value is obtained (over 9.5) when $C = 2e+025/m^{-3}$.

Figure7: a) - Q factor as a function as numerical aperture, b) - Gain and noise figure NF as a function as numerical aperture



It is seen that the gain increases with increasing NA and remains constant (saturate) after certain level for numerical aperture, the reason for this is that the amplifier reaches the population inversion. It is clear that the gain increases when NA increases because increasing NA proves the overlap between optical mode field and erbium ions.

• Effect of pump power (Pp)

the effect of sweeping the pump power (50 to 350 mw) for the optimum Q factor of EDFA in position in-line amplifier with fixed length amplifier at 10 m and varied concentration of erbium ions (erbium ion density) is shown in the graphs (figure 8.a), we can see that more the pump power increase more the Q factor increases, however the $C = 1e+025/m^{-3}$ offer good performance and provide a higher Q factor (over 15) for $P_p = 350 mw$, whereas the concentration $C = 2e+025/m^{-3}$ and at 350 mw of pump power provide a Q factor of 13.2

Figure 8: a) - Q factor as a function as pump power, b) - Gain and noise figure NF as a function as pump power

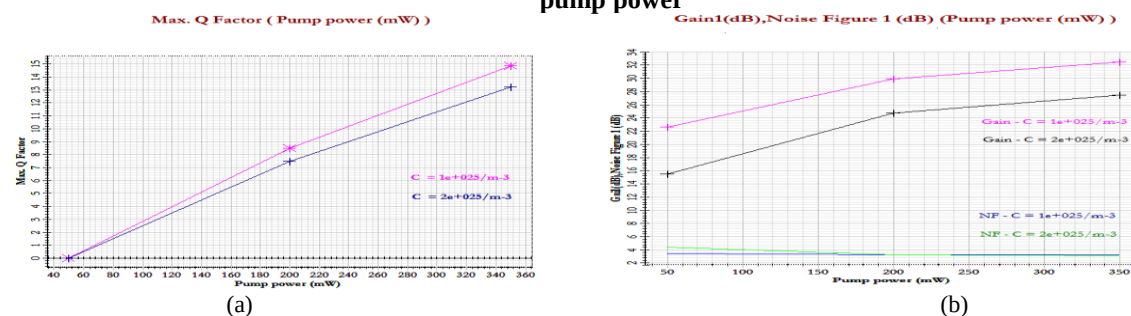


Figure 8.b shows the fast increase of gain with sweeping pump power (50 to 350 mw) and a decrease with increasing density erbium ions. Beyond for C of $1e+25/m^{-3}$ and at pump power 350 mw the gain can be achieve the optimal value of 32.2 dB and low noise figure of 3.7 dB, while at $C= 2e+25/m^{-3}$ an accepted amplifier gain around 27 dB and noise figure around 3.6 dB can be obtained in this simulation.

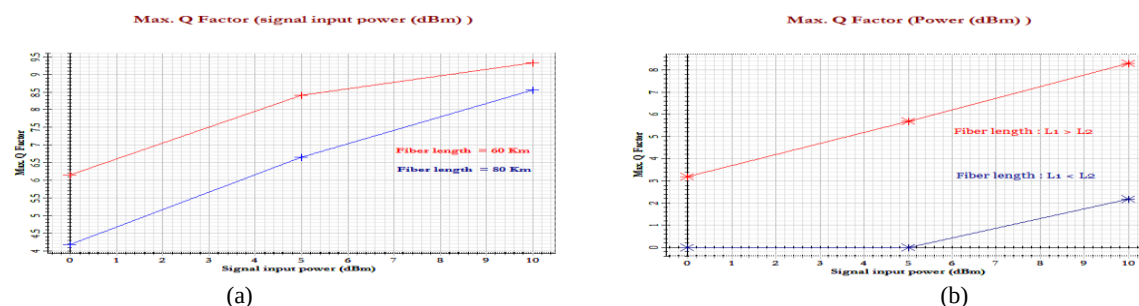
B. The performances of GPON

In this section we will evaluated the performances of GPON with EDFA in the function of an in-line amplifier characterized by these parameters opt-geometric ($D = 2.2 \mu m$, $L_{edfa} = 10 m$, $C = 1e+25/m^{-3}$, $P_p = 200 mw$, $NA = 0.24$, $\lambda = 980 nm$). The proposed simulation has been analyzed by changing number of users (ONU), data rate, loss splitter, modulation format, fiber length and signal input power.

• Performances as a function of fiber length

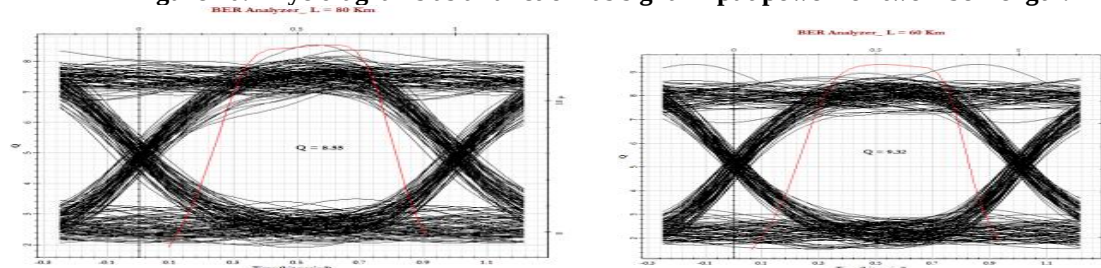
The following simulation showed the possibility of extending the distance of 60 to 80 Km where the dependence of Q factor on distance for the downstream traffic can be seen in figure 9.a , so for EDFA amplifier placed in front of the splitter works in the function of an in-line amplifier after passing through the optical fiber length of 60 km ($L_1 = 50$, $L_2 = 10$ km) and after the division in the 1:128 splitter, the received power at the detector has the signal power level of -70.23 dBm with the Q factor of 9,32 . The length of the fiber can be extended to 80 km ($L_1 = 70$, $L_2 = 10$ km) with a Q factor of 8.55 and a received power of -71.07 dBm.

Figure 9: a) - Q as a function as signal input power for two fiber length, b) - Q as a function as signal input power for 80 km for two position of EDFA in-line.



Other we can notice the dependence of the Q on position of the EDFA for both the downstream traffic, so the GPON employ EDFA near of the splitter ($L_1 > L_2$) provides the best Q factor , however when EDFA is far of the splitter ($L_1 < L_2$) we can notice for signal input power lower of 5 dBm the Q factor is null and up of this value this later increase and gives the lower performance (Q factor = 2.7) figure 9.b

Figure 10: Eye diagrams as a function as signal input power for two fiber length.

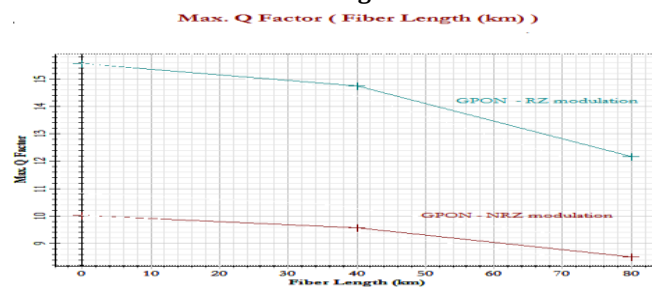


Analysis	L = 60 Km	L = 80 Km
Max Q factor	9.32	8.55
Min BER	5.41069e-021	8.99721e-034
Eye Height	8.349752e-006	7.30467e-005
Decision	0.53	0.5

• Performances as a function of modulation format

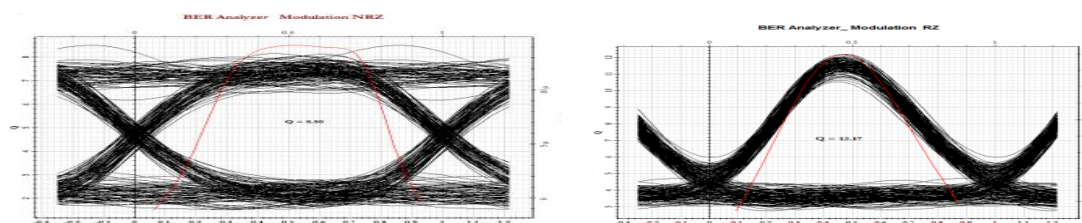
We have investigated and compared the performance of different modulation formats like Non Return to Zero (NRZ) and Return to Zero (RZ) for downstream data of GPON by varying the length of the fiber (0 to 80 km). Two graphs have been shown to verify the results at Optical Network Unit (ONU).

Figure 11: Q factor as a function as fiber length for RZ and NRZ format of modulation.



It is clearly indicated from graphs as the decrease the Q quality factor and an abrupt change have been seen in system performance. It has been observed that with increase in higher length fiber the Q factor decrease and RZ gives the better performance as compared to NRZ. For EDFA in-line amplifier and at 10 dBm, the 2.5 Gb/s data is successfully transmitted to 128 ONUs with best Q-factor around to 12.17 for RZ and Q factor of 8.55 with NRZ.

Figure 12: Eye diagrams as a function as fiber length for RZ and NRZ formats of modulation.



Analysis	RZ	NRZ
Max Q factor	12.17	8.55
Min BER	2.07011e-034	8.99721e-034
Eye Height	1.2721e-005	7.30467e-005
Decision	0.46	0.5

• Performances as a function of loss splitter

The optical budget is comprised of attenuation from splices, connectors, the transmission fiber and the optical splitters. The optical splitter is by far the most demanding component in terms of losses (a typical 1x32 optical splitter insertion loss could range between 17 dB and 18 dB). The evolution of quality factor Q as a function of the fiber length and splitter loss is illustrated in Figure.13, the Q factor is measured for EDFA in-line amplifier; we can see that Q factor decreases linearly as the fiber length and when the loss splitter increases.

Figure 13: Q factor as a function as fiber length for two splitter loss.

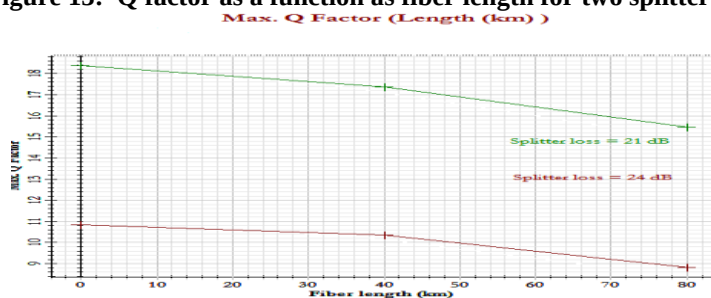
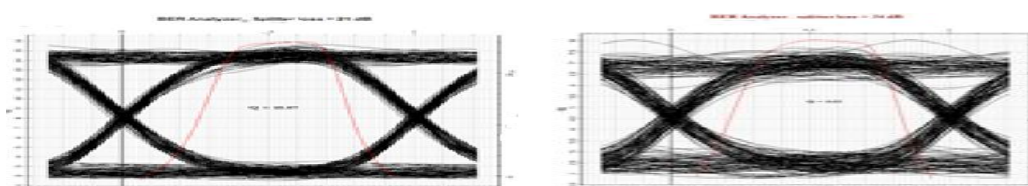


Figure14: Eye diagrams as a function as fiber length for two splitter loss.



Analysis	Loss = 21 dB	Loss = 24dB
Max Q factor	15.87	8.55
Min BER	4.49245e-057	8.99721e-034

Eye Height	1.84069e-005	7.30467e-005
Decision	0.625	0.5

- Performances as a function of number of the users**

From figure15, we can be seen for EDFA in-line as the distance (fiber length) and the number of users by splitting increases the Q factor is also degrade. For example at 80 km , the lowest Q =8.55 factor is achieved for using 1:128 splitter however the highest Q factor of 15.48 is by using 1:64 splitter with best eye diagram .

Figure 15: Q factor as a function as fiber length for two user numbers.

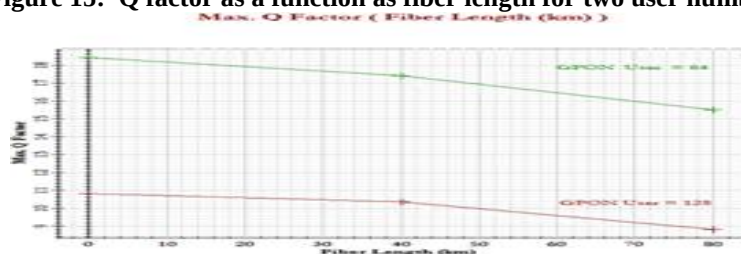
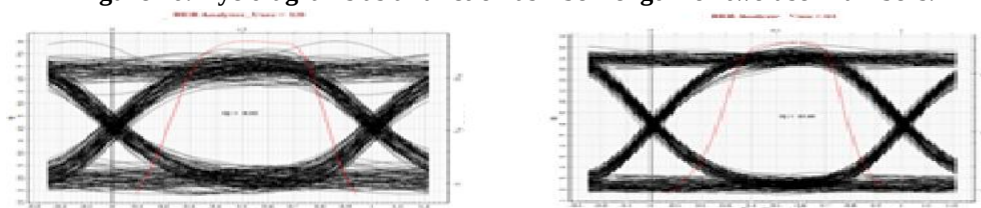


Figure 16: Eye diagrams as a function as fiber length for two user numbers.



Analysis	User = 64	User = 128
Max Q factor	15.48	8.55
Min BER	5.93465e-056	8.99721e-034
Eye Height	1.64035e-005	7.30467e-005
Decision	0.625	0.5

- Performances as a function of bits rates:**

Performance of EDFA in-line amplifiers is compared at different bits rate. The Q factor and diagram eyes versus transmission distance graph for two different bits rate at 80 km are shown, we can be seen that the Q factor decrease with increasing in the bits rates, were the max Q factor is 5.52 for Db = 5 Gbits/s and lower Q factor of 2.44 for Db = 10Gbits/s .

Figure 17: Q factor as a function as fiber length for two bits rate.

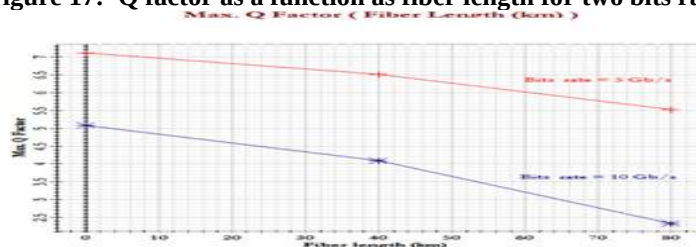
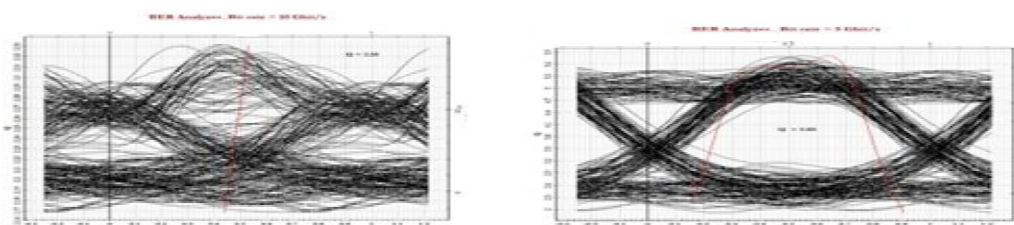


Figure 18: Eye diagrams as a function as fiber length for two bits rate.



Analysis	Bite rate = 10G/bits	Bite rate= 5G/bits
Max Q factor	2.44	5.52
Min BER	0.00712867	1.66866e-008
Eye Height	-1.7358e-006	5.01894e-006
Decision	0.57	0.62

III. Conclusion

This work has shown the different variations of the characteristics of the optical fiber amplifier doped with erbium. They give an overview on the adequate choice of opt-geometric parameters such erbium ions density , core radius and pump power for the optimization of EDFA used for a standard GPON with 128 users and 80 km of reach. So the knowledge of optimal values of the erbium doped fiber amplifier parameters (L_{edfa} , C , D , P_p , NA ...) is necessary to estimate the optimum Q factor. For this, we must choose the parameters of the amplifier that enable both high gain and low noise figure. Our analysis shows that for the optimum EDFA used in position in-line with maximum Q factor over 8.55 we need the following parameters : $C = 1e+25/m^{-3}$, $L_{edfa} = 10$ m , $D = 2.2$ μm , $NA = 0.24$, $P_p = 200$ mw and $\lambda = 980nm$.

Other, the performance analysis of GPON using for EDFA in-line amplifier are compared an terms of output parameters like Q factor, eye diagrams for various parameter (splitter loss, signal input power and fiber length...). From the simulation results, it is found that the Q factor decreases with increasing of the fiber length , loss splitter , bit rates , user numbers and gives the better performance with RZ format of modulation . Finally, the future research is to study the performances of EDFA amplifier for WDM-PON network and evaluation of quality factor of an erbium doped fiber Post-, Pre- and in-line amplifier for GPON with 128 users and 80 km of reach.

VI. References

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