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Determination of the Optimal Length of the EDF Amplifier within the C-band for the Optical Communication System

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ABSTRACT

A computer simulation was used in the design of a multi-channel optical communication system within the band (1546-1552) nm to determine the optimum length of the Erbium Doped Fiber Amplifier EDFA by using of 1480nm pumping with 40mW.The quality factor QF , bit error rate BER for different EDFA ranged between 2-18m as well as the gain G, noise figure NF and optical signal to noise ratio OSNR were calculated for optimal conditions of operation. The results shown that the optimum length of the amplifier is 10 m in the C packet with the transmission power of 1 mW , bit rate of 10 Gbps and distance of 150 Km.

Key-words : Erbium-doped fiber amplifier EDFA. Gain, Optical signal to noise ratio OSNR, noise figure NF

HOW TO CITE THIS ARTICLE

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INTRODUCTION

Several designs and computer models of erbium doped fiber amplifiers EDFAs were developed by finding numerical solutions for propagation equations. These models included amplified spontaneous emission ASE, gain G, noise figure NF, effect of pumping power and fiber length on the amplifier work within C-band (1525 -1565) nm in the optical communication [1].

One of the most inherent difficulties of multichannel systems, wavelength division multiplexer WDM, using EDFAs is the reliability of G on: wavelength of transmitted signal λ_S , length of amplifier L_{EDF}, wavelength and power of pumping signal λ_P, P_P respectively. So, this effect results in optical signal to noise ratio OSNR differential between channels after passing through a cascade of EDFAs[2].Therefore, a number of practical techniques have been suggested to correct this gain non-uniformity such as using of , filters (external or internal) ,optical isolators , thermally decreasing the homogeneous line broadening of the amplifier; but these methods require either extra components or are complicated ; or by optimizing the EDFA itself by controlling the fiber length and pump power for a given input power and desired output power [2].

However , several studies was published for adoption of gain values and noise factor along the EDFAs .G= 47 dB , NF= 13 dB , λ_P =1480nm , L_{EDF} = 9 m , P_P = 40 mW, as well as far away less than P_P = 22mW because the noise figure is greater than gain [3]. While , other studies was indicated that the length of the amplifier under these specifications should be greater than 13 m to avoid oscillations in the signal power [4-7]. but all studies are numeric treatment and did not investigate accurately all of the practical results .

In this paper we present a detailed study to simulate a more realistic communication system , an eight-channel C-band WDM optical communication system was designed in the wavelength region of 5.6 nm (1546.92-1552.52nm) with 0.8 nm separation, power of each channel is 0dBm , 150 km transmission length , 10 Gb/s - NRZ rate with external Mach-Zehnder Modulator MZM , EDFAs with variable length in order to investigate the ideal practical parameter of L_{EDF} , G, NF, OSNR, Bit Error Rate BER, Quality Factor QF and Gain Flatness GF.

EDFA THEORY

The EDFAs is one of the most common devices in modern C-band communications systems. This technology has significantly improved in WDM requirements because it has high gain, low noise in wideband, high output power, polarization dependent, low interference between channels and ease of coupling with optical fiber [8].

Basic elements of an EDFA are shown schematically in Fig. 1. The gain medium in the amplifier is a specially fabricated optical fiber with its core doped with erbium (Er). The erbium-doped fiber is pumped by a semiconductor laser, which is couple by using a wavelength selective coupler, also known as a WDM coupler that combines the pump laser light with the signal light. The pump light propagates either in the same direction as the signal (co-propagation) or in the opposite direction (counter-propagation). Optical isolators are used to prevent oscillations and excess noise due to unwanted reflection in the assembly. More advanced architecture of an amplifier consists of multiple stages designed to optimize the output power and noise characteristics while incorporating additional loss elements in the mid-stage [1] .

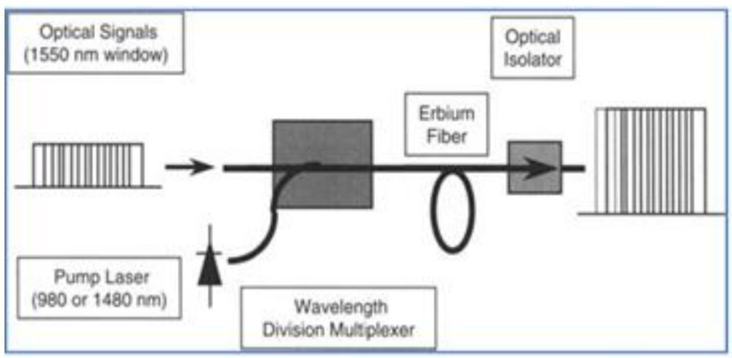


Fig. 1: Schematic diagram of an erbium-doped fiber amplifier

One of the most important considerations in the design of the optical amplifier is reducing the noise associated with the signal amplification process (the noise appears as a large spectral of the ASE amplifier) ,while maintaining high output power , low cost and high reliability [1]. The gain G in dB of the amplifier is defined as the ratio of the signal output and input powers according to the following relationship [1].

$$G = 10 \log \frac{Pout}{Pin} \quad \text{-------(1)}$$

The NF is a measure of the noise value ,degradation of the optical signal by ASE noise, added by the amplifier in dB for incoming signal according to the following equation [1].

$$N\,F = 10 \log \frac{SNR_{out}}{SNR_{in}} \quad \text{-------(2)}$$

The nominal OSNR for 1.55μm WDM system with N optical transmission spans can be given by the following formula [1]

$$OSNR_{nom} = 58 + P_{out} - 101og_{10}(N_{ch}) - L_{sp} - NF - 101og_{10}(N) \text{ ----- } (3)$$

P_{out} optical amplifier output power in dBm, N_{ch} is the number of WDM channels, L_{sp} is the fiber span loss in dB .

The first generation of these amplifiers is designed to compensate the lack of signal capacity for one stage ,as a booster ,while currently many are being used to cover the serial stages of long haul fiber communications .Application of EDFAs as repeaters in WDM systems is particularly important because they offer a cost – effective means of faithfully amplifying all the signal wavelengths within the amplifier band simultaneously. [1]

The EDFAs gain is practically ~ 20 – 40 dB depending on the Er^{3+} doping concentration , signal wavelength and pumping power. However, this is a major problem in multichannel networks covers a wide spectral regime 1500-1600 nm and when the amplifiers are cascaded. Passive optical filters can be employed to flatten the gain spectrum [9],[10].

It is important to note that both the pump intensity and the population inversion decrease along the fiber due to linear attenuation . At the same time, the signal-carrying beam is being amplified. This causes the signal intensity to continue to increase until the point where the pump beam is depleted by the combination of linear attenuation and stimulated emission. Beyond this point, the signal intensity starts to decrease with distance. Consequently, there is an optimal fiber length where the gain is maximized [9] .

The performance measures used are the Q-factor and BER. The voltage eye level (decision level) is sampled to obtain the means for a '1' and '0' signal (μ1 and μ0) as well as for their respective standard deviations (σ1 and σ0), assuming a Gaussian distribution for the noise fluctuations. The Q-factor is then determined and the BER is related to the Q-factor by equations [6] , [11] .

$$QF = \frac{\mu 1 - \mu 0}{\sigma 1 - \sigma 0} \quad \text{-----------------(4)}$$

$$BER = 0.5 \text{ erfc} \left[\frac{Q}{\sqrt{2}}\right] \approx \frac{e^{-Q2/2}}{Q\sqrt{2\pi}} \quad \text{- ---(5)}$$

Commonly the acceptable of BER for optical communication system is $\leq 10^{-9}$.On the other hand , eye diagram is a technique that provides an aggregation of signal measurement information and so helps us to evaluate the quality of the received signal [12] .

SIMULATION RESULTS AND DISCUSSION

A computer-based optical communication system is designed through the Optisystem 7 program as detailed in Fig. (2) . The system consists of the following parts:

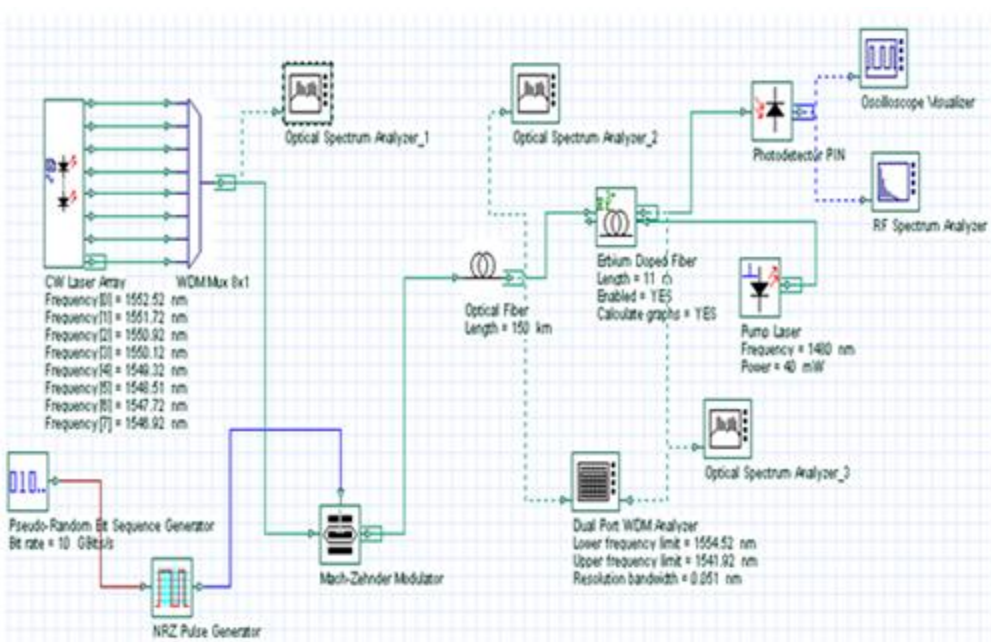


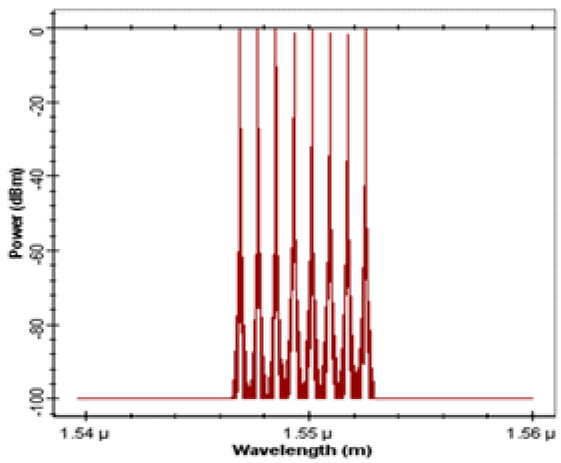
Fig. 2: Schematic diagram of an optical communication system, under modulation

*Transmitter : includes eight semiconductor lasers ,CW Laser Array, with power of each channel is1mw(0dBm) within the C band in the wavelength region of 5.6 nm (1546.92 -1552.52 nm) with 0.8 nm separations with WDM (8×1).
*Transmission medium : Standard Single-Mode Fiber (SSMF) with a length = 150 Km , attenuation = 0.2 dB / km and dispersion =16.75ps / nm / Km for wavelength =1550 nm .
*EDFAs with the specifications shown in Table (1) and Photo detector PIN.

Table 1: shows the specifications of the EDFAs

Length of Fiber L_{EDF}	Radius of the fiber r	Numerical Aperture NA	Pumping wavelength λ_p	Spontaneous emission time τ	Erbium ion density ρ	Pumping power P_P
2-18m	2.2 μm	0.24	1480 nm	10 ms	$1X10^{25}$ m^{-3}	40 mW

In order to assess the system performance, external modulation speed at 10 Gbps are included in the NRZ format using MZM technology, as shown in the diagram of



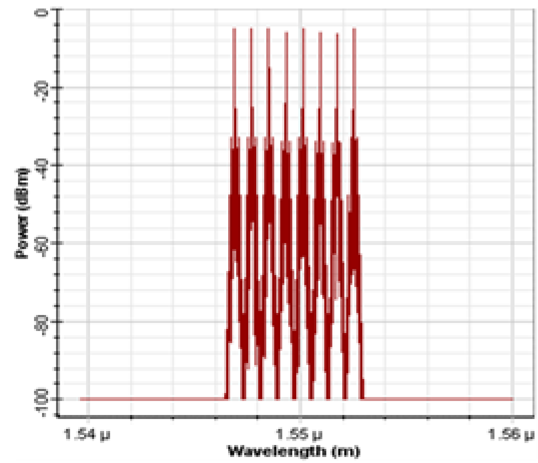
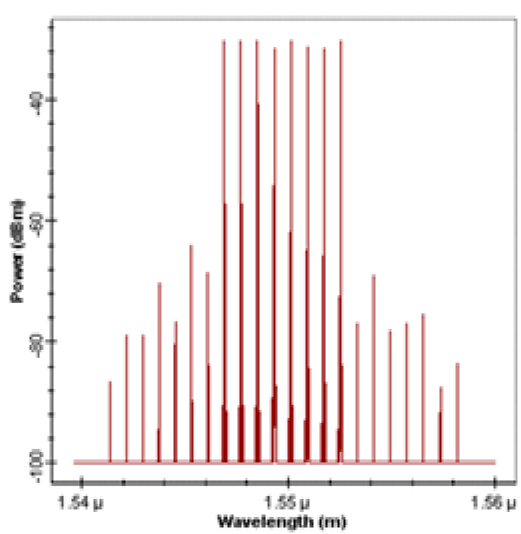


Fig. 3: Light signals spectrum at the multiplexer. Fig. 4: Light signals spectrum after modulation

Fig. (2). To follow the changes in the spectrum for all wavelengths during the transmission through the system phases, figures (3,4) are shown . Fig. (3) presents the spectrum of the eight wavelengths at the WDM and the optical power for all channels is 0 dBm , while the first decrease in the power about -5 dBm was indicated after the signal modulation process , Fig. (4).



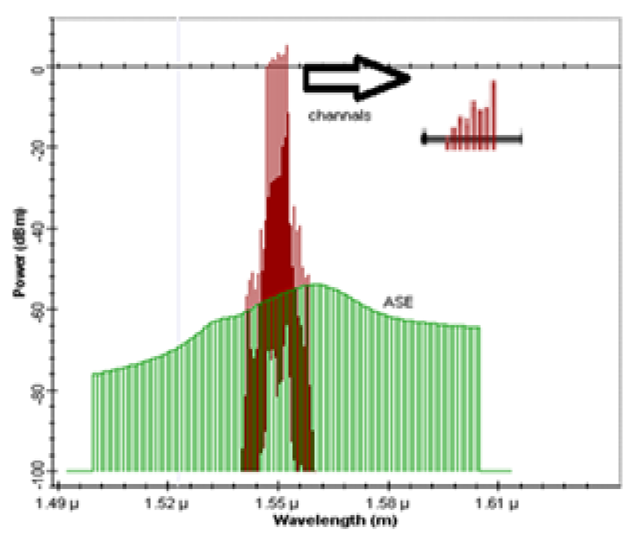


Fig. 5: Light signals spectrum after travel 150km Fig. 6: Signals and noise spectrum after amplification

To examine the changes in ASE as a function of wavelength along the amplifier's , for 11 m length , fig.(7) showing the exponential growth where identified especially at the beginning of 8 m. Fortunately ,these results seem that the EDFAs have a wide spectral range within C band , but it varies amplification response with the variation in the wavelength. These experimental validation are consistent with previous works [3-7] .

To investigate the Influences of the fiber length on the gain and noise values, the fiber length was scanned within the range (7-11) m. It is clear that there is a different gain in the signal for each length and for each wavelength.

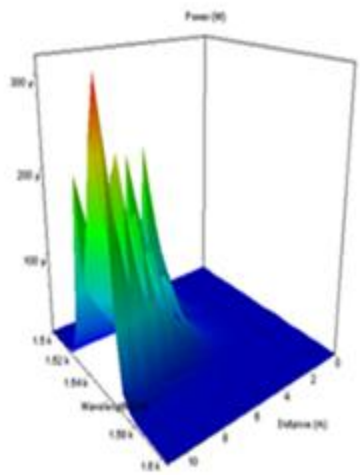


Fig. 7: Growth in the ASE spectrum along the Amplifier fiber length 11m

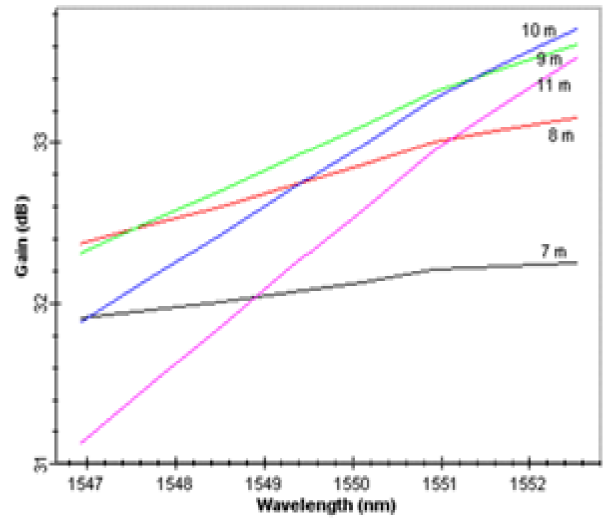


Fig. 8: Amplifier gain spectrum for different lengths of the fiber

Note Fig. (8,9) . G_{max} = 33.7 dB at λ_s= 1552.5 nm for L_{EDF} = 10m, blue color in Fig. 8, and the gain flatness GF is approximately equal in all lengths, GF = G_{max} / G_{min} [2]. While , Fig. (9) illustrates the output power of the amplifier as a function of a wavelength in three dimension. It also supports the progressive zoom along the fiber length. And thus, the amplifier noise factor associated with the signal is increased , note Fig. (10), NF = 8 dB at L_{EDF} =10 m for λ_s= 1552.52 nm.

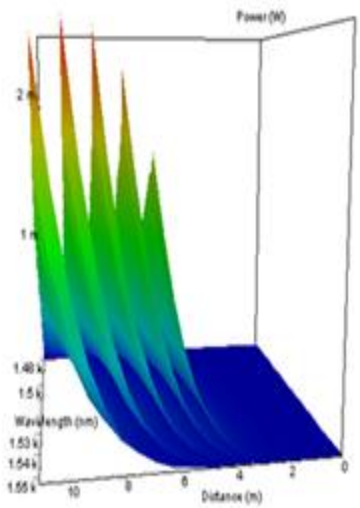


Figure (9) Amplifier output power level for different lengths of fiber

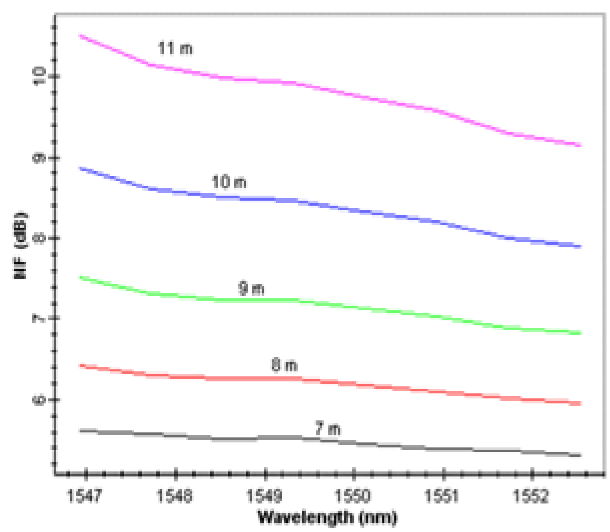


Figure (10) Noise figure spectrum level for different lengths of fiber

To evaluate the OSNR spectrum of the EDFA for all wavelengths and all fiber lengths referred to earlier, the results were analyzed and plotted by numerical simulation in Fig. (11), the figure showing that the highest ratio is 25 dB at 10 m.

To study the effect of lengths larger than 11 m, under the specifications in Table 1, many fiber lengths were scanned within range (2-18) m. As illustrated in figures (12,13) . Also ,figures are enhances the optimum work of the magnifier around L_{EDF}= 10 m and away from the lengths of less than 5 m and greater than 15m.

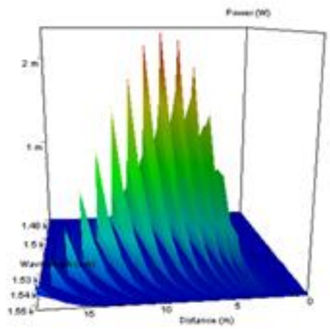


Figure (12) Amplifier output power spectrum as a function of fiber length and wavelength .

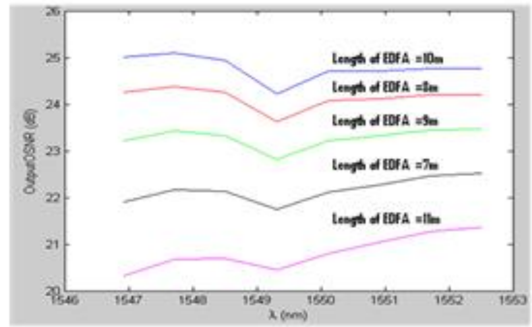


Figure (11) OSNR output spectrum for different fiber lengths

L_{EDF}= 10 m and away from the lengths of less than 5 m and greater than 15m. To check of the proposed system performance, for a distance of 150Km, the relationship between BER and QF values was plotted by numerical simulation after selecting the amplifier length range 2-14 m as shown in Fig. (14). It was found that the system has high reliability within universally recognized values For a bit rate of up to 4GBits / s especially at lengths greater than 8m.

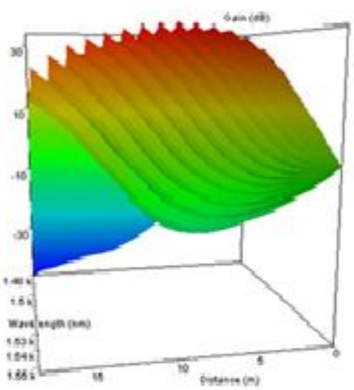


Figure (13) Amplifier gain spectrum as a function of fiber length and wavelength

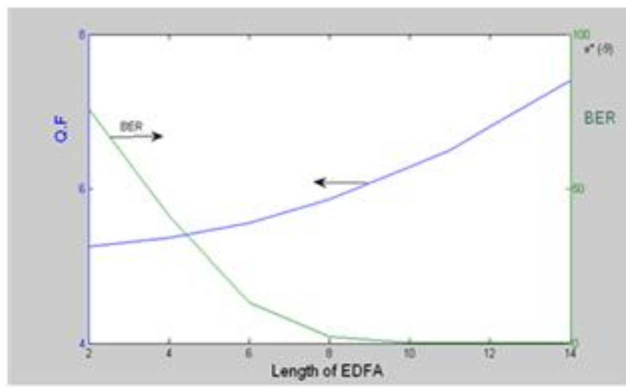


Figure (14) BER and QF evaluation for EDFAs system with fiber length range (2-14) m.

To illustrate the differentiation between these lengths, Fig. (15) illustrates the role of the ideal length of the amplifier, 10 m, the violet color. Finally, fig. (16) shows eye diagram , the method used to measure BER, QF values for λs=1552.52 nm by using 10m EDFAs.

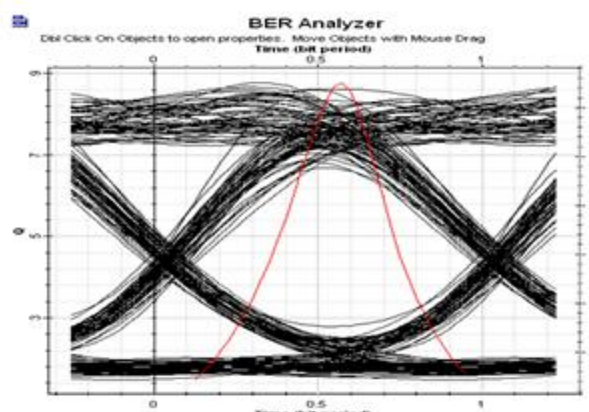


Figure (16) Eye diagram , to evaluate the values of BER and QF by using amplifier length of 10m

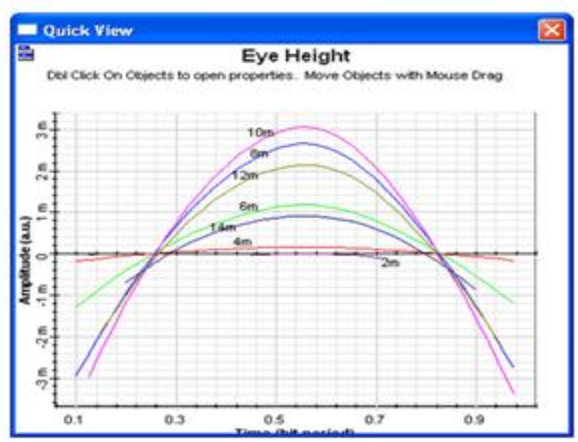


Figure (15) Effect of amplifier fiber length on the system performance evaluation

Summary of the above, Table 2 contains the most important simulation parameters results for selecting the optimum length of the amplifier. However, this is not enough to create a good and optimal optical communication system so that the gain (with a amplifier) must be high reliability and small values of noise figure . In the end, we find that there is a process of maturity and a balance between these values to determine the optimal length of the EDFA amplifier.

Table (2) Simulation Parameters for EDFAs with L_{EDF} =10 m

L_{EDF} m	λ_s nm	BER dB	QF dB	G dB	NF dB	OSNR dB
10	1552.52	8.87×10^{-19}	8.76	33.7	7.6	19.93
	1546.92	1.43×10^{-15}	7.89	32	8.5	19

CONCLUSION

This study concerned the design of an optimal communication system with an EDFA amplifier. This study came out with several conclusions summarized as follows:

- The optimal length of the EDFA amplifier is 10 m (within the specifications in Table 1) to make QF and BER reliable within the internationally accepted limits.
- The amplifier can also operate at a length greater than 10 m or slightly smaller, but there are increase in NF and decrease in G especially at lengths greater than 11m and less than 5m. Fiber dispersion, (16.75ps / nm / Km), limits the speed of transmission and restricts BER and QF to be universally accepted.
- The study of spectra gives more advantage for determining the basic parameters in the proposed optical communication system because it was more comprehensive and credible, taking into account study's of more than one parameter instantaneously.

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