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INFLUENCE OF PUMPING VARIABILITY ON NOISE FIGURE ANALYSIS OF EDFA-DWDM TRANSMISSION SYSTEM

A.A. Amer [1]   H.A. Wahab [1]   A. Abdulelah [1]

Department of Electrical Engineering, College of Engineering, University of Kufa, Najaf, Iraq
ahmeda.alsamiri@uokufa.edu.iq, husama.adujaili@uokufa.edu.iq, ahmeda.ahmed@uokufa.edu.iq

Abstract- This paper achieved good performance of Erbium doped fiber amplifier (EDFA) which has inline positioning with dense wavelength division multiplexing (DWDM) system 10 Gb/s x 16 channels. The NRZ–OOK modulation format is used at transmission scheme with channel spacing of 50 GHz. The pumping affects the noise figure of an EDFA by controlling the amount of amplification and the efficiency of the amplification process. By optimizing the pump power and wavelength, it is possible to achieve lower noise figures and higher-quality amplified signals. The configurations of (EDFA) were varied to obtain the optimized settings with low noise factor for both co-propagation and counter propagation at (980 nm) and (1480 nm) respectively. The obtained results for pumping wavelength (980 nm) show fixed values of noise factor at a range of 5.4-5.6 dB, for fibers of various lengths. While at pumping wavelength (1480 nm) the noise figure levels were up to 9-14 dB.

Keywords: DWDM, EDFA, Pump Power, Optical Fiber.

1. INTRODUCTION

The optical fiber technology has many advantages over transmission by copper wire as it yields lower attenuation, higher data rate, and better zero cross-talk. It supports data rate thousands of times more than copper wire [1-3]. The characteristics of the transmitted signal is dependent on the wavelength of the optical light beam which is subject to attenuation when transmitted through the optical [1], [3-5]. To reduce attenuation, certain wavelength regions of the transmission window should be [3, 4, 6]. There are three wavelength regions at optical communication systems, namely, 850 nm, 1310 nm, and 1550 nm, that provide acceptable attenuation levels [7-9]. To overcome the high attenuation levels at optical transmission signals, optical amplifiers play crucial role in modern transmission communication [9, 10]. The erbium doped fiber amplifier (EDFA) is the most [7, 10]. The normal operation of EDFA optical amplifier is dependent on erbium ions which have several places of energy states that can exist. The energy levels of erbium atom consist of three excited states for electrons to transition in-between [8, 10]. There are two wavelength lambdas, 980 nm and 1480 nm, that can be used for utilizing laser pumping to excite the electrons into upper levels of erbium atomic [11]. Some of the Er3+ ions that are excited by pump light to higher energy states, retain longer lifetime for their lower excitation levels as pumping continues. Hence, allowing for fixed population inversion under influence of pumping light. When the electrons get excited to an upper level, they rapidly decay non-radio-actively to next level at meta-stable state utilizing the emission light at band range values of (1525-1565) [12, 13]. The input signal of light-wave is in coherence with the stimulated photons, and that produces the signal [14, 15]. The transition process between different energy levels is shown by the simple scheme of Figure 1 [16]. In this study, major topics are examined. We specifically perform nonlinear modeling and analysis, controller design, and theoretical result validation [1].

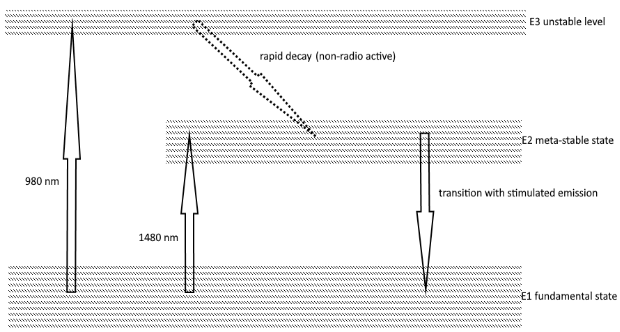


Figure 1. Energy level diagram of Er doped silica fiber [1]

The amplified spontaneous emission (ASE) in (EDFA) amplifiers represents the principal source of effective noise [17, 18]. The ASE origin is created by the spontaneous recombination of electrons and holes in the amplifier's medium. This process of the second photon emission has similar properties of wavelength as phase, polarization and the most important factor, direction [19]. If the process of ions transitioning from the upper level (excited state) to the lower level (fundamental state) does not occur, not all of the excited Er3+ ions will contribute to the amplification process. Some of these ions will naturally decay to their ground state through a process known as spontaneous emission, releasing photons at specific wavelengths without being stimulated by the injected signal. Therefore, properties of emission photons are random in phase as well as direction [20]. Figure 2 shows the relationship between the spectral density of ASE noise and output [21].

Various EDFA optical amplifier schemes have been suggested to fulfill large bandwidth requirements and low noise factor. Reference [11] demonstrated the high performance of inline erbium-doped fiber amplifier (EDFA) achieving 2.5 Gb/s x 32 WDM system with channel spacing of 50 GHz. Moreover, the pumping wavelength of 980 nm for 1546 nm to 1568 nm group of wavelengths, in long fibers, provides lower than 14 dB noise figure, in addition to the varying pump power. Reference [22] studied and presented the impact that pump power induces at a gain optimized at 980 nm for the wavelength range of 1548 nm to 1556 nm, at Data rate 40 Gbit/s, using specially designed fiber, such as FBG (Fiber Bragg grating) with channel spacing of 0.5 nm and optical fiber length 2Km, the EDFA-DWDM network operated at combined Raman dissipating and five EDFA's amplifier. For an 8 m long fiber, the noise level was roughly 7 dB.

The extended reach performances using a 5 Gb/s x 16 DWDM system with an EDFA optical amplifier were examined and demonstrated by the authors in reference [1]. For laser pumping at 980 nm, this system offers a noise figure of approximately 4.3-4.58 dB by varying the fiber length from 10 to 30, and for laser pumping at 1480 nm, it offers a noise figure of around 7.8-14.3 dB by varying the fiber length from 20 to 30.

This paper investigates the amplified signal of 980 nm and 1480 nm pumps of inline configuration EDFAs. The impact of signal power, length of fiber and 50 GHz channel spacing for 10 Gb/s x 16 DWDM system on noise figure parameters are utilized to determine the maximum amplified signal power. Finally, it is observed that our work proposed a simulation model that provides EDFA-DWDM at a big data rate of 160 Gbit/s with a noise figure of around 5.4-5.6 dB by variation of fiber length from 15 to 25 for laser pumping at 980 nm, and also provides a noise figure of around 8.5-13.5 dB by variation of fiber length from 10 to 25 for laser pumping at 1480 nm. However, we proposed a system with a high data rate, which offered one solution to numerous problems that are actually encountered in optical transmission.

Table 1. Comparing the proposed system to earlier work

Parameter		Proposed system	[11]	[22]	[1]
No. of Channel		16	32	8	16
Data rate Gbit/s		10	2.5	5	5
Net Capacity Gbps		160	80	40	80
Noise Figure (dB)	980 nm	5.4-5.6	6-17	7	4.3-4.58
	1480 nm	8.5-13.5	-	-	7.8-14.3
Pumping power range (mw)		100-300	50	250	200-500
Fiber length(m)	980 nm	15-25	5-9	8	10-30
	1480 nm	10-25	-	-	20-30

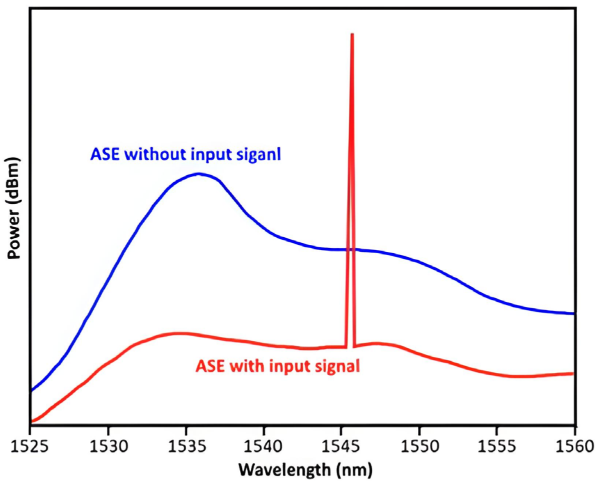


Figure 2. Spectrum of the EDFA output with ASE noise density [1]

2. ANALYSIS METHODOLOGY

The noise figure (NF) for an EDFA amplifier whose signal-to-noise ratio (SNR) has degraded as a result of transmitting optical signals via the amplifier and the output of the SNR, is lower than the input SNR. The equation defines the [1]:

$$NF = 10\log\left[\left(\frac{P_{ASE}}{hv.\Delta v}+1\right)\left(\frac{P_{input\_signal}}{P_{output\_power}}\right)\right]\ [\text{dB}] \quad (1)$$

where, P_{ASE} is the power of the spontaneous emission that is amplified, Δv (Delta v) refers to the spectral bandwidth of an ASE (Amplified Spontaneous Emission) wave (the range of optical frequencies or wavelengths that are emitted by the amplifier due to spontaneous emission), v (nu) is frequency of the signal and the relevant *ASE* noise, P_{input_signal} is signal input power, and P_{output_power} is signal output power. The lowest amount of *NF* is 3 dB, while 5 dB is the usual amount for EDFA.

As the optical wave generated by the laser source pass through the optical fiber and into the EDFA, the ASE noise of the EDFA gets increased due to the amplification of source spontaneous emission (SSE), that produce an error to noise figure measurement, as in Equation (2) [1]:

$$NF = 10\log\left(\frac{P_{ASE}}{GhvB_o}+\frac{1}{G}-\frac{P_{SSE}}{hvB_o}\right)\ [\text{dB}] \quad (2)$$

The EDFA parameters were optimized in this paper. Various doped fiber lengths (10, 15, 20, and 25) m and excitation levels of the source power (100, 150, 200, 250, and 300) mW were utilized to achieve lowest noise factor as optimum length is changed based on doping level concentration and power level pumping. The designed model of EDFA amplifier was simulated by using OptiSystem 13 software. Both EDFA saturation and wavelength are gain dependent in the proposed implementation model.

There are three parts of the modelled telecommunication system. The first include the transmitter part which is composed of signal generator, coder, CW Laser source, and (EOMZ) electro-optic Mach-Zander modulator. The transmitted data has a (NRZ) signal form with (OOK) modulation.

The second part is the transmission link, which consists of an amplifier in between two optical fiber links (single mode fiber). The last part at the receiving end includes a photo detector (avalanche photodiode) utilized to convert the optical signal to electrical signal. All parameters are evaluated depending on measured values of elements on both sides of the amplifier.

The simulation was done for the effect of 980 nm and 1480 nm for both co-propagation mode and counter propagation mode of EDFA configuration with 50 GHz channel spacing width. At all the different channels of DWDM system, the noise factor values were measured at realistic values of doped fiber lengths and pumping powers. Block diagram in Figure 3 shows aforementioned scheme used for investigated DWDM system.

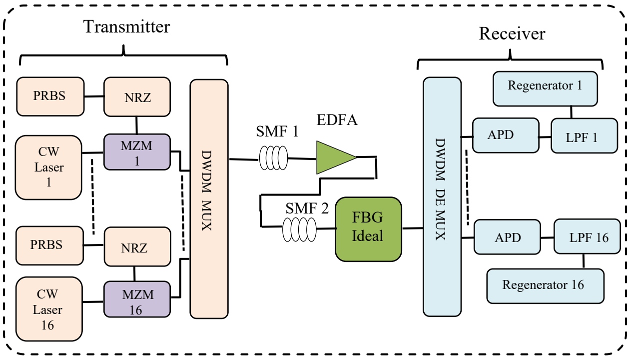


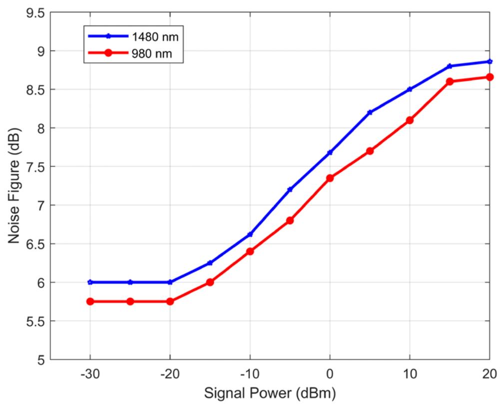
Figure 3. Block diagram of the EDFA configuration for DWDM transmission system

3. RESULTS AND DISCUSSION

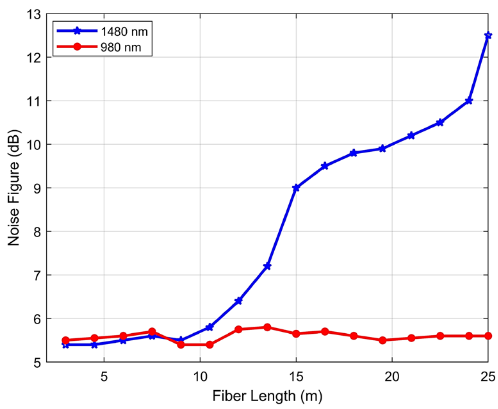
The main significant indicator in displaying and evaluating amplifier performance is noise figure. An effective amplifier is one that reduces the noise figure of the amplifier. At this part, effects of signal power, pumping power, and EDFA system fiber length on noise figure factor are explored and compared at transmission link with inline configuration. Figure 4 shows the noise figure graphs of EDFA amplifier at inline configuration. In general, an amplifier's noise figure will change depending on the signal and pumping power. At low signal power levels, the amplifier's inherent noise, which is unrelated to the signal power, will dominate the noise figure. Due to nonlinear effects in the amplifier, when the signal power rises, the noise figure will start to rely on the signal power. As other nonlinear effects begin to become apparent at high pumping power levels, the noise figure also begins to rise. Figure 4a shows the variations in noise figure against signal power at pumping power of 200 mW for a 10 m fiber length, as this length is widely used in the literature. The graphic is ascending due to the growing value of signal power. The noise figure gradually climbs as the amplification gets too higher. As a result of the gain saturation caused by spontaneous emission, the noise figure rises.

The energy of the 980 nm pump is exhausted earlier as the fiber became longer, generating slightly higher noise than the 1480 nm pump, as shown in Figure 4b. This figure represents the noise figure changes against fiber length at -20 dBm signal power amplification at pumping power of 200 mW. At length of 9 m, almost equal noise figure values were generated for 1480 nm and 980 nm pumps. The fiber length can impact the amplifier's noise figure in addition to the pumping power. Longer fibres have the potential to introduce more loss, which lowers the amplifier's gain, as well as greater dispersion, which raises the noise figure.

To enhance the noise figure at high pumping power levels, longer fibres can help lessen the impact of nonlinear effects. However, the 1480 nm pump generated higher values of noise figure at longer fiber lengths, due to the accumulation of noise over the length of the fiber.



(a)



(b)

Figure 4. Variation of noise figure with (980 nm and 1480 nm) pumps against (a) signal power (b) fiber length

3.1. Impact of the Co-Propagation Pumping at Wavelength 980 nm

The results were obtained after simulating a scheme of 10 Gb/s data rate transmission with EDFA amplifier. The designed system is studying the effect on long doped optical fibres with the usage of 5 m and 10 m lengths, which appear as the most widely used for [25]. At fiber length 10 m, Figure 5a shows that the value of noise figure is fixed almost on (5.4 dB). The slight variations are still apparent at pumping power values 100 mW, 150 mW and 200 mW. However, when pumping power values is increased to 250 mW and 300 mW, the variation of noise figure becomes almost non-existent. This is quite reasonable as the DWDM communication system have equal amplification for all channels. The short wavelength range shows higher value of noise due to greater transition cross section which cause high level of spontaneous emission (ASE). For fiber length of 25 m, the highest values of noise factor were recorded. It can be seen that the value of noise figure is decreased down to lower than 5.5 dB when the pump power is increased from 100 mW and 150 mW to 200 mW, 250 mW and 300 mW due to increasing the level of populations inverses.

It is observed that the wave length of 1552 at pump power value 250 mW exhibit a significant increase to noise figure value. At 300 mW pump power, the amplified spontaneous emission (ASE) with noise figure of an EDFA amplifier changes linearly and inversely proportional with the wavelength. Generally, at pumping powers lower than 300 mW, the noise figure ranges within (5.4-5.5) dB, and is remaining at the same range complying with the theoretical information about co-propagation of EDFA amplifier configuration.

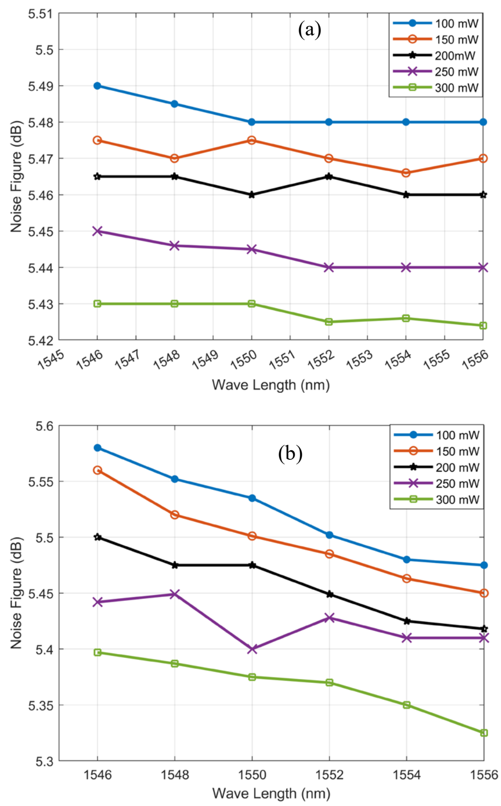


Figure 5. The noise figure of EDFA amplifier based on the pumps power to (980nm) with (a) 10 m fiber length (b) 25 m fiber length

3.2. Impact of the Centre-Propagation Pumping at Wavelength 1480 nm

The influence of counter-propagation on EDFA configuration when simulated with 1480 nm pump, lead to the measured results to show the highest noise figure values. For lengths of 15 m and 25 m fibers, the measured values of noise figure were without significant variations in correspondence to pump power. However, the highest recorded noise figure leapt up to 8 dB when the fiber length was increased above the 5-10 m range. Therefore, results are shown for fiber lengths of 15 m and 25 m fibers, as noise figure have more pronounced values at these lengths. Regarding Figure 6a, it can be observed that noise figure factor has reached (9-9.8) dB for fiber length of 15 m when the pump power is within a range of (100, 150, and 200) mW. This shows that at short wavelengths (lambda), ASE maintains relatively higher values.

Figure 6b indicates noise figure values when the fiber length used is 25 m. It can be observed that noise figure for short wavelengths kept a relatively stable value, that ranged between 12.5 dB and 13.5 dB. At the other end of the graph, with longer wavelengths, noise figure fell below 12 dB with very low observed variations. These results show high noise factor values at 1480 nm, due to pump level and excitation level occurring at identical bands, which leads to a situation where population inversion is hard to be completed.

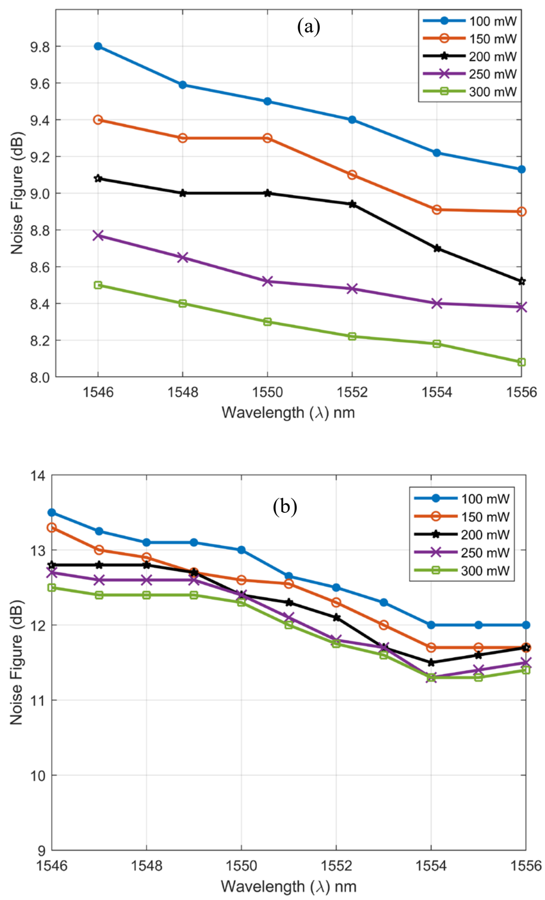


Figure 6. The noise figure of EDFA amplifier based on the pumps power at (1480 nm) with (a) 15 m fiber length (b) 25 m fiber length

6. CONCLUSIONS

This paper has investigated the DWDM transmission system that has 16 channels with inline positioning scenario of EDFA amplifier, under the influence of both co-propagation and counter propagation at (980 nm) and (1480 nm) respectively for each EDFA configuration. From the results it can be observed that at pumping lambda (980 nm), stable values of noise factor were within a range of (5.4-5.5) dB for fiber length of 10 m, which corresponds to the theoretical information for this configuration. The noise figure values were within range (5.4-5.6) dB at pumping (980 nm) wavelength, for 25 m fiber length. Noise figure was found to be much higher, within range (9-14) dB, at pumping λ (1480 nm) even with increased pump power. For both fiber lengths, 15 m and 25 m, the amplified spontaneous emission (ASE) is constraining transmission data in terms of gain, noise, and pumping efficiency. Also, increasing the input power of transmitting signal produces an increased noise figure and reduces the gain for both pumps. The 1480 nm pump gave higher noise figure compared to 980 nm for EDFA at lengths longer than 10 m. Generally, it can be concluded from the obtained results that noise figure at pump (980 nm) for fibers of any length has lower values than 1480 nm. Finally, the choice of pump wavelength is dependent on the noise figure, signal power, and bandwidth. The optimal pump wavelength depends on the specific requirements of the application and the comparison between these parameters.

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BIOGRAPHIES

Name: **Ahmed**
Middle Name: **Abdulhussein**
Surname: **Amer**
Birthday: 14.02.1977
Birthplace: Basra, Iraq
Bachelor: Electronics and Communications, Electrical Engineering Department, University of Technology, Baghdad, Iraq, 2005
Master: Electronic and Communications, FKE, Electrical Engineering Faculty, University Technology Malaysia, Johor Baharo, Malaysia, 2014
The Last Scientific Position: Lecturer, Electrical Engineering Department, Faculty of Engineering, University of Kufa, Kufa, Iraq, Since 2016
Research Interests: Communications, Electronics, Optical Fiber
Scientific Publications: 4 Papers, 10 Projects, 1 Theses

Name: **Husam**
Middle Name: **Abdulhussein**
Surname: **Wahab**
Birthday: 13.01.1981
Birthplace: Najaf, Iraq
Bachelor: Electronics, Electrical Engineering Department, University of Technology, Baghdad, Iraq, 2004
Master: Electronic, Electrical Engineering Faculty, University oF Technology, Baghdad, Iraq, 2013
The Last Scientific Position: Lecturer, Electrical Engineering Department, Faculty of Engineering, University of Kufa, Kufa, Iraq, Since 2014
Research Interests: Control, Electronics, Power
Scientific Publications: 4 Papers, 14 Projects, 1 Theses

Name: **Ahmed**
Middle Name: **Abdulelah**
Surname: **Ahmed**
Birthday: 09.06.1983
Birthplace: Najaf, Iraq
Bachelor: Control, Control Engineering Department, University of Technology, Baghdad, Iraq, 2004
Master: Control, Control Engineering Faculty, University Putra Malaysia, Kuala lumpur, Malaysia, 2014
The Last Scientific Position: Lecturer, Electrical Engineering Department, Faculty of Engineering, University of Kufa, Kufa, Iraq, Since 2014
Research Interests: Control, Electronics, Power
Scientific Publications: 1 Paper, 13 Projects, 1 Theses