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ORIGINAL ARTICLE

Increase of Transmission Distance Using Edfa and Module Design for Free Space Optics Applications

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ABSTRACT

Free-space optical (FSO) communications, also known as wireless optical communications, is a cost-effective and high bandwidth access technique and has compelling economic advantages. With the potential high-data-rate capacity, low cost and particularly wide bandwidth on unregulated spectrum, FSO communications is an attractive solution for the "last mile" problem to bridge the gap between the end user and the fiber-optic infrastructure already in place. However, also other structural conditions atmospheric losses fairly affect the signal gain communication due to the fact that communication medium is an air. In this study, a FSO component is designed using Matlab software for geometrical and atmospheric losses and integrated into OptSim 4.0 software to analyze the FSO system. Somewhat apart, signal attenuations due to the atmosphere conditions are eliminated using Erbium Doped Fiber Amplifier (EDFA). In this way, signal transmission distance is increased in comparison with the traditional FSO systems.

Key Words: *Free space optics, component design, EDFA, transmission distance*

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1. INTRODUCTION

FSO systems which are used in communication technologies without the necessity of official license, have low power consumption, high bandwidth, less weights and smaller dimensions provide regional communication between various corporations. In addition, they have many advantages like; fiber optic cables are not required, they compose simple network structures with receivers and transmitters, have high transmitting speeds. In addition, they could be installed in a few times in case of situations like natural disasters where the other communication devices do not response [1-10].

FSO systems use atmosphere as transmission medium while transmitting the light. Therefore, the weather conditions of the region that have an important role on the transmission quality of the signal. There are many losses taken into account in FSO systems; the attenuation of window when the light passes through the windows of the building in the receivers and transmitters, attenuation of positioning that is required for the transmitting the signal from the transmitter with a specific angle in order not to be affected from the movements of the building during the day, geometric losses that is caused by the spreading of light between the transmitter and the receiver, obstacles that can weaken or interrupt the communication between the receiver and the transmitter (birds, moving objects etc.), luminance effect; in which the light beams are deflected like a lens by the air saccules that is related with the index of refraction of air medium but most of the FSO system have the properties to avoid that effect, and finally the seasonal changes in the atmosphere that highly affect the performance of FSO systems (rain, snow, fog, storm, extreme cold and hot air). FSO systems operate in the regions at 780 nm and 1550 nm [3-6]. Especially 1550 nm region is very suitable that EDFA (Erbium Doped Fiber Amplifier) is operable [11-14]. Thus, it can be easily integrated to FSO systems for that bandwidth. In addition to that, EDFAs that have high gain, low noise, high bandwidth, small dimensions, and that is suitable for wideband applications like internet and teleconference [15-17] are compatible with FSO systems which create an important advantage.

In this study, a FSO component that is not included in OptSim 4.0 software is designed using Matlab program for geometrical and atmospheric losses. This component is used with other components that are present in OptSim 4.0 software [18] and FSO system is simulated in this way. Besides, in order to increase the transmitting length which seriously affected by the various atmospheric events (snow, fog, etc.) an EDFA that can operate in 1550 nm region is added and the analysis is performed.

2. MATHEMATICAL ANALYSIS AND DESIGN

The designed FSO system is shown in Figure 1. In transmitter part a PRBS (Pseudorandom Bit Sequence) generator that have 1.25 Gb/s ratio, NRZ (Non Return to Zero) modulator and a led that have 1550 nm wavelength and 1.3 dBm power is used. The signal of transmitter reaches the FSO Matlab component and transmitted to the atmosphere by FSO transmitter. The transmitting medium is an atmospheric medium as shown in Figure 1 and various atmosphere conditions may occur. The average attenuation and distance values are used in the simulation shown in Table 1 [19]. The optical signals transmitted from the atmosphere are received by FSO receiver. Then in order to amplify the received signal it is applied to EDFA. The amplified signal is received either by PIN (Positive Intrinsic Negative diode) or APD (Avalanche Photo Diode) receiver.

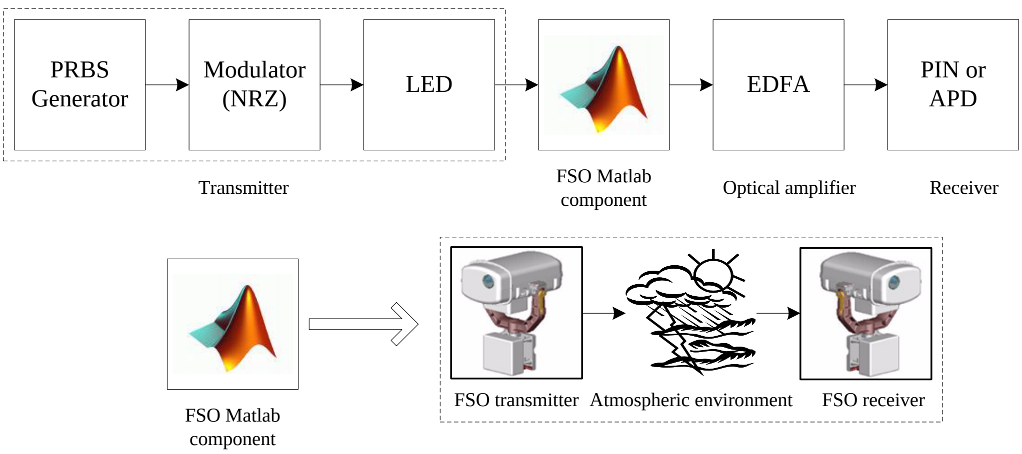

Figure 1. The block scheme of the designed FSO system.

Table 1. Maximum range and atmospheric loss for various weather conditions (All values are measured at the 1550 nm wavelength).

Weather Condition	**Attenuation (dB/km)**	**Maximum Range (km)**
Clear-air	<1.5	>6
Heavy rain	5	3.2
Extreme downpour, moderate snowfall; light fog	13	1.7
Heavy snow; light fog	20	1.25
Blizzard; heavy fog	30	0.92
Very dense fog	60-100	0.35-0.55

When designing the FSO component in Matlab, weak turbulence approach is used. This approach considers statistical states that can be viewed as large ensembles of weakly interacting waves and that can be described by a kinetic equation for the wave energy [20]. Therefore, during the design of the model, the diameter of the receiver and the effect of the distance of the transmitter to the optical power are taken in to consideration. In addition, the model involves the possible atmospheric losses [21].

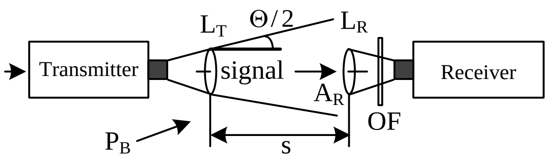

Figure 2. Transmission link via atmosphere.

Figure 2 shows in principle signal path from the light source via transmitter lens L_T and receiver lens L_R, background radiation P_B, and an optical filter OF to the light detector. If Θ is the divergence angle of the radiation, A_R the receiving area, and s the distance between transmitter and receiver, α_g is geometric attenuation for the optical signal and:

$$\alpha_g = 10\log\frac{\pi.\Theta^2.s^2}{4.A_E} \tag{1}$$

The geometric attenuation is constant for a given installation. In addition, it is necessary to consider an additional attenuation by aberration of the lenses, reflections at glass/air interfaces, and light filters. Due to scattering of the light at aerosols (fog, rain drops, snowflakes) an additional attenuation α_a dependent from the weather conditions is produced. In extreme cases, for instance dense fog, it is possible that the transmission is interrupted completely. There are statistical measurement results with the probability of certain average attenuations over the year available for the size of this additional attenuation in certain climatic zones.

Turbulences in the atmosphere cause short-term fluctuations of the additional attenuation. Because the fluctuations of the attenuation are normal distributed, the attenuation behavior can be characterized well by the parameters mean of the attenuation and variance of the attenuation. Fig. 2 shows the measurements of the attenuation behavior as an example. The daylight causes a background radiation that is added to the signal radiation and causes an additional receiver noise. Through an optical band pass filter for the signal radiation and a preferably small receiving angle, the background radiation can be mostly suppressed. There is a residual background radiation, however, which reduces the signal to noise ratio of the receiver.

In the model of the transmission link, the attenuation of the signal light is realized by a block diagram with controlled voltage source. The optical power P_R at the receiver can be obtained with the optical power of the transmitter multiplied by an attenuation factor (F) plus the optical power of the background radiation, e.g.

$$P_R = F.P_S + P_B \tag{2}$$

The size of F is determined with the parameters for the geometrical base attenuation and the weather dependable additional attenuation (in dB), that is [21]

$$F = 10^{-\frac{(\alpha_g+\alpha_a)}{10}} \tag{3}$$

While writing code for the FSO Matlab component, Equation 1-3 are used and to integrate OptSim 4.0 [19], input and output nodes of the program's signals are defined as arrays. The weakened signal from the FSO component's output is transmitted to EDFA and amplified. The gain in the output of the EDFA [22];

$$G(\lambda) = \frac{P_{out}(\lambda) - P_{ASE}(\lambda)}{P_{in}(\lambda)} \tag{4}$$

where $P_{in}(\lambda)$ and $P_{out}(\lambda)$ are optical powers within the signal wavelength and measured at the input and output of the EDFA, respectively. $P_{ASE}(\lambda)$ is the amplified spontaneous emission (ASE) power generated by the EDFA within the λ. Equation 3 becomes the following when ASE can be neglected.

$$G(\lambda)=\frac{P_{out}(\lambda)}{P_{in}(\lambda)} \tag{5}$$

3. RESULTS AND DISCUSSIONS

The designed FSO Matlab component is run with OptSim 4.0 program and FSO system is analyzed in the heavy rain, heavy shower, heavy snow fall or light fog, snow storm or heavy fog conditions.

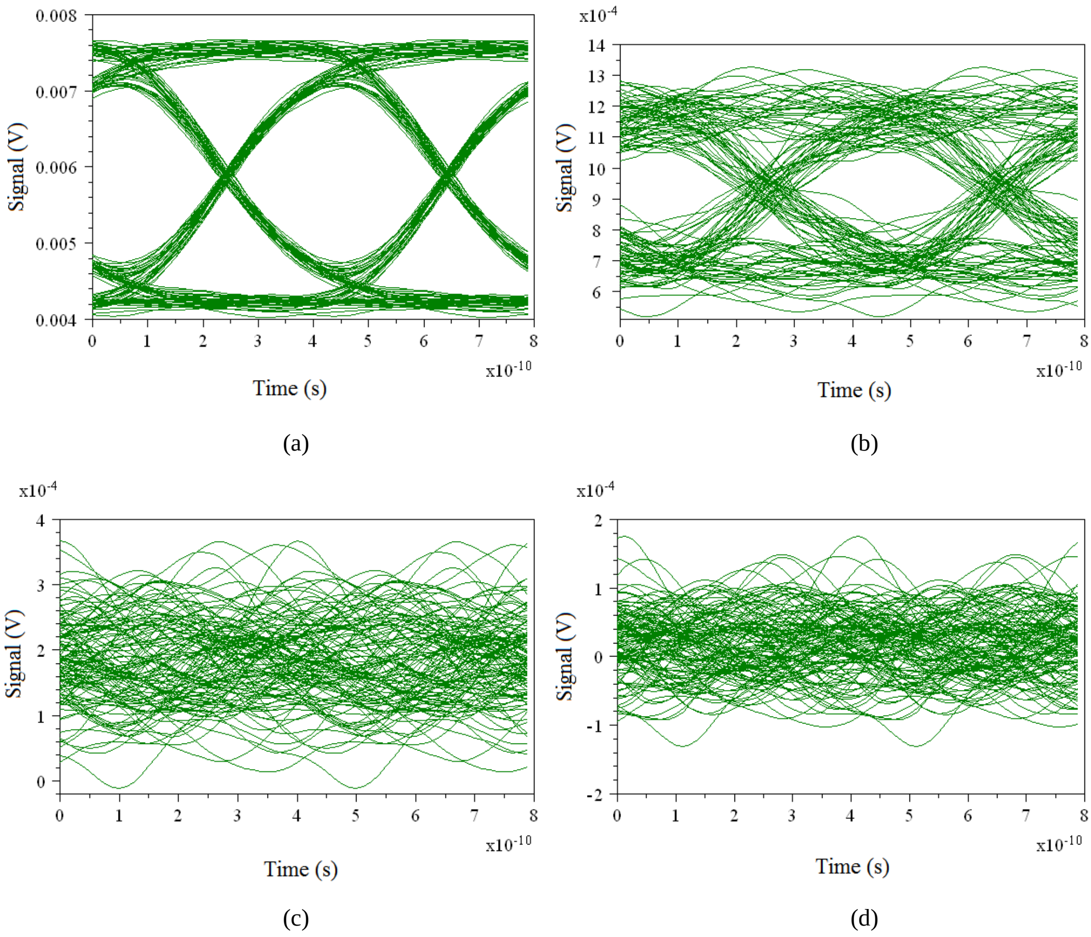

Figure 2. The eye patterns of the FSO system for different weather conditions a) heavy rain, b) extreme downpour, c) heavy snow or light fog, d) blizzard or heavy fog.

In Figure 2, the eye patterns of the FSO system in different weather conditions are given. If the atmospheric and geometric losses are taken into account, the eye pattern in the heavy rain in Figure 2.a can be easily analyzed, but as the weather conditions got worse, especially in Figure 2.c and in Figure 2.d the eye pattern could not be analyzed and signal is lost.

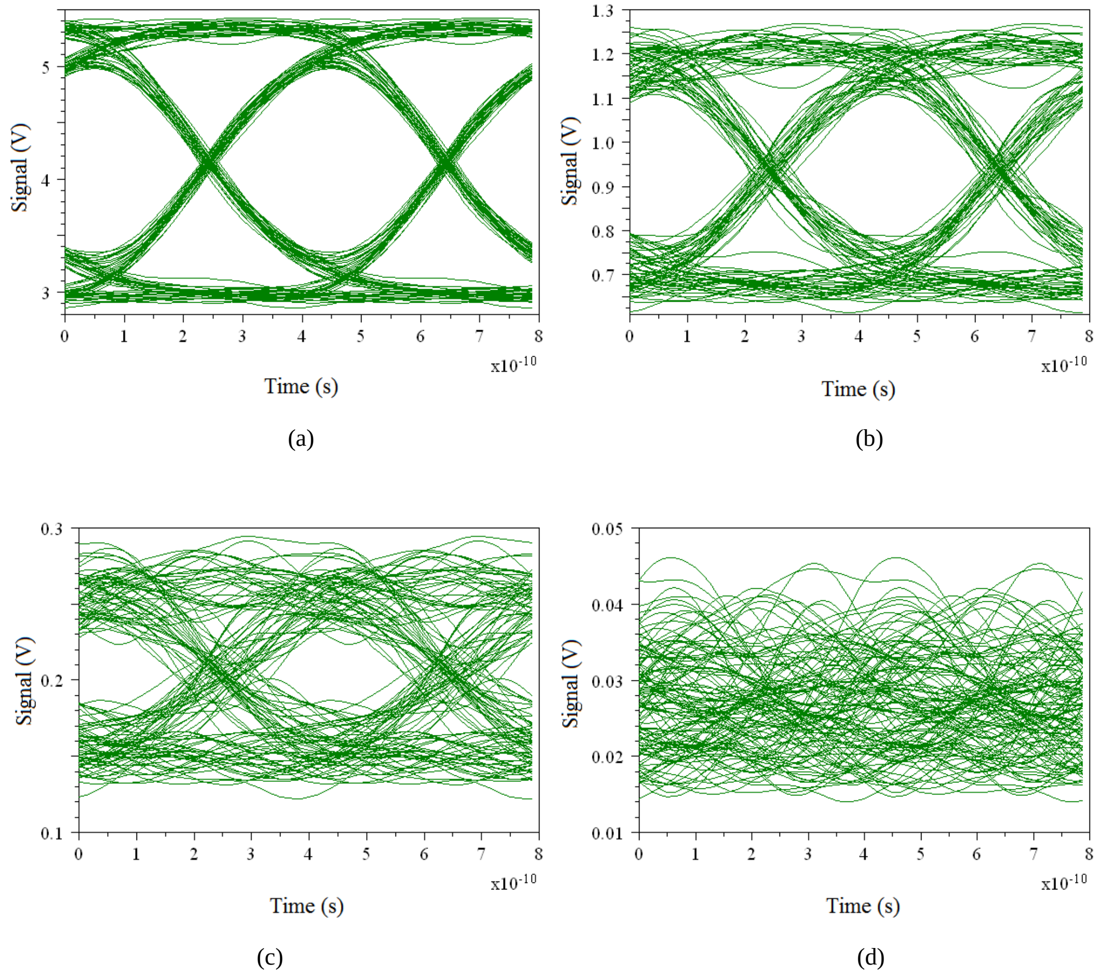

Figure 3. The eye patterns of FSO system in which EDFA is used in different weather conditions, a) heavy rain, b) extreme downpour, c) heavy snow or light fog, d) blizzard or heavy fog.

In Figure 3, the eye patterns of FSO system in which EDFA is used are given. When the weather conditions turn from heavy rain to blizzard or heavy fog, the attenuation can be clearly seen. However when it is compared with Figure 2, in the worst weather condition, it is seen that the eye pattern fails. The attenuation curves of the FSO system in different weather conditions are shown in Figure 4. If the weather conditions got worse, transmission distance range decreases. The FSO model in which FSO links are used, commonly have optical ranges between -30 dB to -60 dB dependent on the distance between receiver and transmitter. If the lower range -30 dB is taken in to account, there exists no problem in the distance of 1000 m under heavy rain or extreme downpour. Under heavy snow or light fog, the distance is decreased to 600 m and under the blizzard or heavy fog; it is decreased to about 200 m.

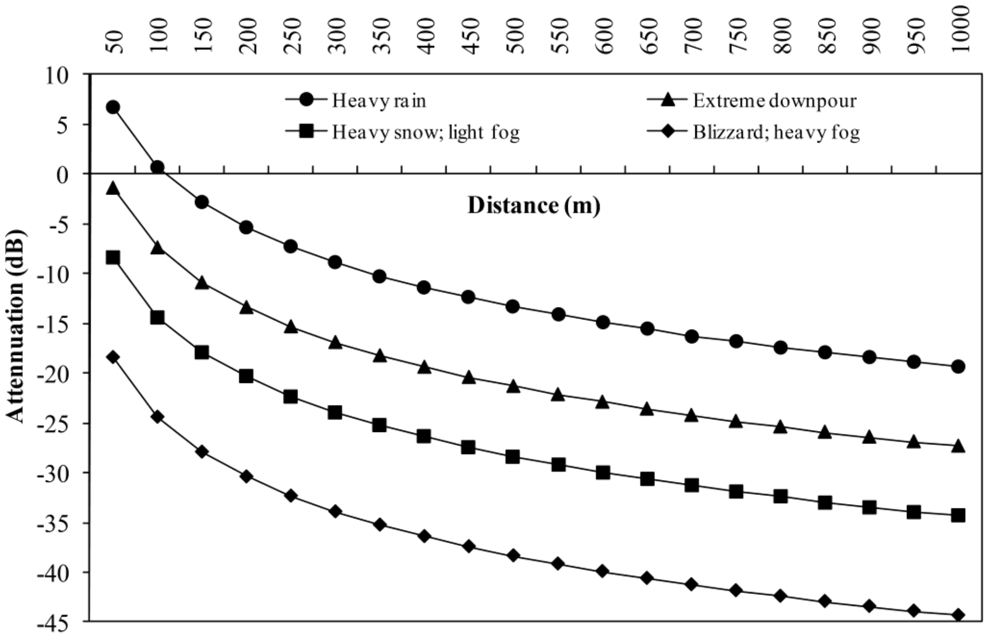

Figure 4. The attenuation curves of the FSO system in different weather conditions.

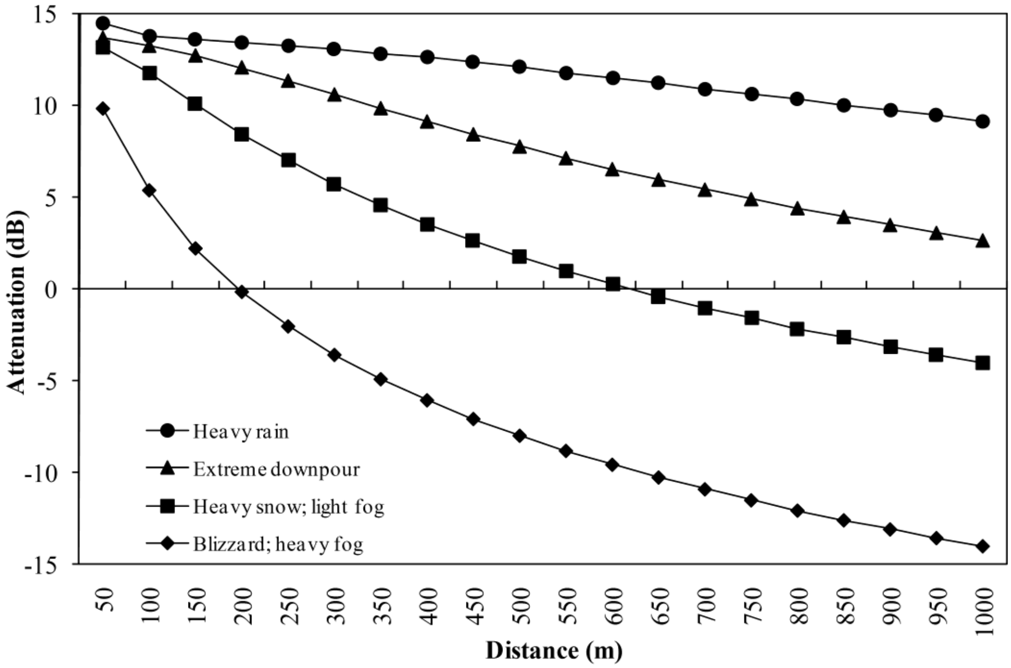

Figure 5. The attenuation curves of the FSO system in which EDFA is used.

In Figure 5 the attenuation curves in the range of 1000 m of the FSO system in which EDFA is used is given. If the 30 dB range that is considered in Figure 4 is taken into consideration, it is obvious that for all weather conditions, there is exist no problem and even the range can easily reach over 1000 m.

4. CONCLUSION

In this paper, developed simulation component for modeling geometrical and atmospheric losses for FSO systems. The FSO simulation component will allow for rapid determination of FSO systems performance for a variety of applications and customer requirements. In addition, the range of FSO systems that are designed without optical amplifiers can significantly decrease related with the atmospheric conditions. In order to sustain that range for the variable weather conditions; optical amplifiers such as EDFA can be used and transmitting distance can be increased.

REFERENCES

[1] Bloom, S., "The Physics of Free Space Optics", ***White Paper*, *AirFiber* , *Inc.*,** (2001).

[2] Bloom, S., "The Last Mile Solution: Hybrid FSO Radio", ***White Paper*, *AirFiber* , *Inc.*,** (2002).

[3] Ramasarma, V., "Free Space Optics: A Viable Last-Mile Solution", ***Bechtel Telecommunications Technical Journal,*** 1(1): 22-30 (2002).

[4] Bloom, S., Korevaar, E., Schuster, J., Willebrand, H., "Understanding the Performance of Free-Space Optics", ***Journal of Optical Networking,*** 2(6):178-200 (2003).

[5] Szebesta, D., "Free Space Optical Communication," ***White Paper*, *Date Services and System Outsourcing, COLT Telecom,*** (2002).

[6] LighPointe Communications Corp., "Free Space Optics: A Viable Last-Mile Alternative", ***White Paper***, (2002).

[7] Karatay, O., Dinleyici, M.S., "Low-cost Free-Space Optical Communication System Design", ***Signal Processing and Communications Applications Conference, Proceedings of the IEEE 12th***, 700-703 (2004).

[8] Gagliardi, S.M., Karp, S., "Optical Communications", ***Wiley-Interscience***, 2nd Edition, New York, 368 (1995).

[9] Lambert, S.G., Casey, W.L., "Laser Communications in Space", ***Artech House***, Boston, 390 (1995).

[10] Akbulut, A., Özek, F., "Serbest ortamda lazer ile optiksel iletişim sistemleri için bilgisayar simülasyonu", ***J. Fac.Eng.Arch. Selcuk Univ.,*** 20(4):27-38 (2005).

[11] Saleh, A.A.M., Jopson, R.M., Evankow, J.D., Aspell, J., "Modeling of gain in erbium doped fiber amplifiers", ***IEEE Photonics Technology Letters,*** 2(10):714-716 (1990).

[12] Chapman, D.A, "Erbium-doped fibre amplifiers: the latest revolution in optical communications", ***Electronics&Communication Engineering Journal,*** 6(2):59-67 (1994).

[13] Yücel, M., Göktaş, H.H., "Design of gain flattened ultra-wide band hybrid optical amplifier", ***J. Fac. Eng. Arch. Gazi Univ.,*** 22(4):863-868 (2007).

[14] Yücel, M., Göktaş, H.H., "The effect of pumping wavelength and directions on the erbium doped fiber amplifiers gain of EDFA", ***Journal of Polytechnic,*** 6 (4):627-635 (2003).

[15] Yamada, M., "Overview of wideband optical fiber amplification technologies", ***NTT Technical Review,*** 2(12): 34 (2004).

[16] Sakamoto, T., Mori, A., Masuda, H., Ono, H., "Wideband rare-earth-doped fiber amplification technologies – Gain bandwidth expansion in the C and L bands", ***NTT Technical Review***, 2(12): 38 (2004).

[17] Yucel, M., Goktas, H.H., Celebi, F.V., "Temperature independent length optimization of L-band EDFAs providing flat gain", ***Optik - Int. J. Light Electron Opt.,*** 122(10): 872-876 (2011).

[18] OptiSim Version 4.0; "Design and Validate Your Optical Transmission Systems", (Copyright © 2004 RSoft Design Group, Inc.), (2004).

[19] Tjondronegoro, P., "Free Space Optics for Fixed Wireless Broadband", ***Seminar in Communications Engineering***, (2004).

[20] Galtier, S., Nazarenko, S.V., Newell, A.C., Pouquet A., "A Weak Turbulence Theory for Incompressible Magnetohydrodynamics", ***J. Plasma Physics,*** 63(5):447-488 (2000).

[21] Hansel, G., Kube, E., "Simulation in the Design Process of Free Space Optical Transmission Systems", ***Proc. 6 th Workshop "Optics in Computing Technology,*** 45-53 (2001).

[22] Becker, P.C., "Erbium-Doped Fiber Amplifiers: Fundamentals and Technology", Chapter 7, ***Academic Press***, (1999).