IMPROVING THE PERFORMANCE OF TURBULENT FREE SPACE OPTICAL LINK BY USING A FOURIER FILTER

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Abstract

*In the free space terrestrial optical communication (FOSC) the laser beam, as an information carrier, is subject to degradation due to atmospheric turbulence. In this work, the decrease in the signal to noise ratio (SNR) and the increase in the value of the bit-error rate (BER), due to this turbulence, are experimentally investigated. In addition, a pin-hole, as a Fourier low-pass filter, has been utilized to suppress turbulence noise. The results show a dramatic improvement in the received optical signal, and hence the link BER. The values of the SNR have been enhanced from (18.8940 dB), to (46.1365 dB) by reducing the pin-hole diameter. The value of BER has been also reduced from (0.7246*10^{-5}) to (5.6*10^{-12}) in a strong turbulent environment.*

Keywords: FSO link, Atmospheric turbulence, Laser beam, Signal-to-noise ratio, Bit-error-rate, Fourier Optics Filter Pinhole.

1. INTRODUCTION

The free space terrestrial optical communication (FSOC) systems have very promising applications for its very well-known advantages such as the large bandwidth, flexibility and low-cost investment [1]. However, the FSOC technology has major weaknesses to be overcome, namely the presence of attenuation and fluctuations in intensity. The attenuation is caused by absorption and scattering due to various gases and particles in atmospheric propagation medium. The fluctuation of intensity is caused by atmospheric turbulence due to the temporal and spatial temperature variation of the atmosphere [2] and [3].

In an optical communication system, the bit error rate BER is greatly affected by these losses due to attenuation and atmospheric turbulence. The atmospheric attenuation and turbulence lead to degrade the signal-to-noise ratio (SNR) and increases the (BER), i.e., increase the probability of errors in the received signal [4]. In addition to the attenuation, there are three effects of atmosphere turbulence: scintillation, laser beam spreading, and laser beam wander. Scintillation is due to variation in the refractive index structure of air, so if the laser beam travels through scintillation, it will experience intensity fluctuations. The SNR and BER depend on atmospheric turbulence and geometric losses represented by scintillation. Therefore, FOS systems should be designed to minimize the effects of scintillation.

In this work we present an experimental investigation on a technique that can be utilized to suppress optical signal noise. In this technique a circular pinhole is used as a low-pass spatial filter. The circular aperture of the receiver optics diffracts the laser beam forming an Airy pattern. The information signals concentrates at the central disc with low spatial frequencies, while noise signal is usually characterized by its high spatial frequencies. Therefor a pinhole rejects the high frequencies, hence improves the optical signal at the receiver focal plane. In other words using the pinhole enhances the BER of the optical communication system.

2. THEORY

The SNR and the BER are the main parameters that characterize the quality of communication systems. BER depends on the SNR which in turn depends on the scintillation strength, the beam spreading and the average received power [5]. The active area of the optical detector, in the receiver unit, is assumed to be large enough so that the SNR value includes the scintillation effects. The scintillation index σ_i^2 describes the intensity fluctuation as the normalized difference of the intensity fluctuations. The strength of scintillation can be measured in terms of the variation of the beam amplitude or the irradiance σ_i^2 which can be expressed as follows [6]:

$$\sigma_i^2 = \frac{\langle I^2 \rangle}{\langle I \rangle^2} - 1 \qquad (1)$$

where I: is the irradiance of signal (or intensity).

For weak fluctuation regime (scintillation index less than 1), the scintillation index is proportional to the

Rytov variance of a plane wave, which is given by [7]:

$$\sigma_i^2 = 1.23\, C_n^2\, k^{7/6}\, l^{11/6}$$

From this equation we can find the value of C_n^2 as follows:

$$C_n^2 = \frac{\sigma_i^2}{1.23\, k^{7/6} l^{11/6}} \qquad (2)$$

where: C_n^2 is the refractive index structure parameter, k is the optical number, and l is the length of the transmission path.

The first feature of a FSO communication system is the SNR. Based on Kolmogorov's theory, the SNR and BER from turbulence were expressed as follows [8][9]:

$$SNR = (0.31\, C_n^2\, k^{7/6}\, l^{11/6})^{-1} \qquad (3)$$

and

$$BER = \frac{\exp(-SNR/2)}{(2\pi\, SNR)^{\,0.5}} \qquad (4)$$

To suppress the turbulence noise and improve the BER, a pinhole is used as a spatial low-pass filter. The noise signals are usually characterized by their high spatial frequencies while the information signal has low spatial frequencies.

3. EXPERIMENTAL SET-UP

Figure (1) shows the schematic diagram of the turbulence cell. This cell is designed and built in the laboratory to accomplish the simulation of turbulence. The setup includes a He-Ne laser source with an appropriate collimating lens, a turbulence cell, variable size pinholes (0.2, 0.4, 0.6, 1, 1.5) mm, a 10 cm focal length lens, and an oscilloscope.

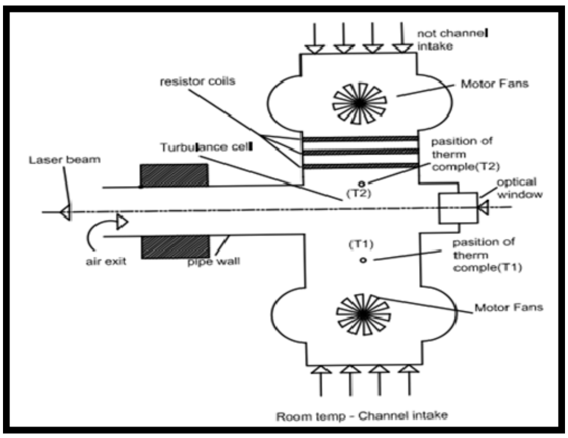


Figure 1: Schematic diagram of a turbulence cell

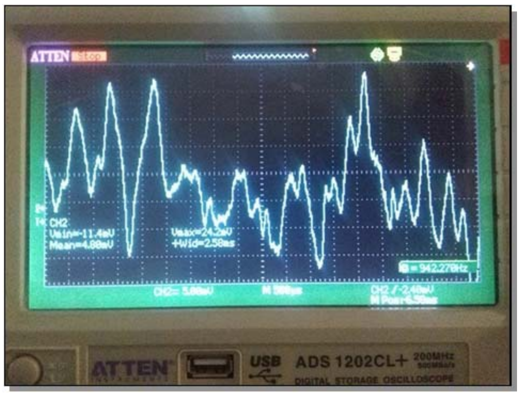
3.1. Results and Discussion

A controllable pseudo-turbulent weather has been created in the lab by using the design described in the previous section. The refractive index structure parameter ($C_n^2 \sim 10{*}10\text{-}9\ m^{-2/3}$) is measured at a a temperature difference (ΔT |T1-T2|= 47.5 K) and flow speed of (V=3.4 m/s) for a short range link (l=1.6 m).

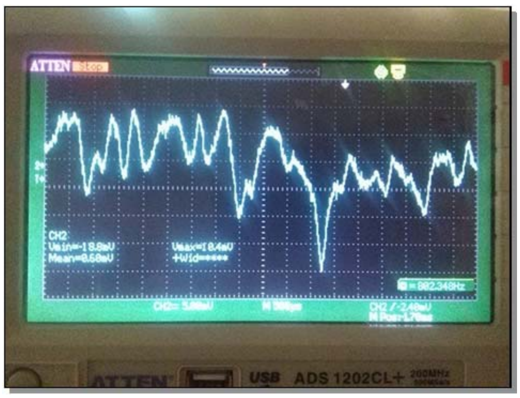
The values of scintillation, SNR, and the BER are measured under different conditions, where a pinhole aperture of variable diameters (0.2 mm, 0.4 mm, 0.6 mm, 1 mm, and 1.5 mm) have been used as Fourier spatial filters. Figures (2 a, b, c, d, and e) show the real time fluctuations with different aperture size.

The measured values for signal intensity and the scintillation are shown in figures (3) & (4).

As shown the turbulence effect, due to the refractive index structure parameter has been reduced from (0.5*10-9 $m^{-2/3}$) to (0.2*10-9 $m^{-2/3}$). Accordingly, the (S/N) ratio has increased from (0.7*10^{-5}) to (5.6*10^{-12}) as shown in figures (5) & (6).These results are in a good agreement with those in Refs. [10][11].



a)



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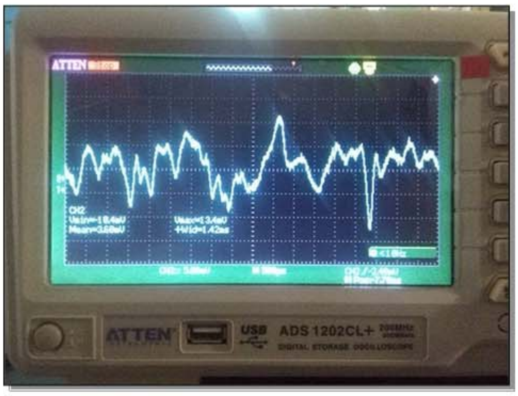

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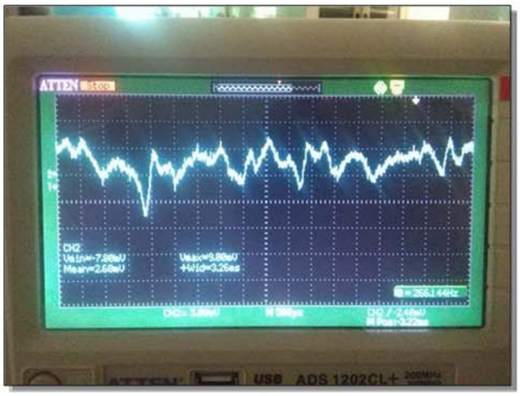
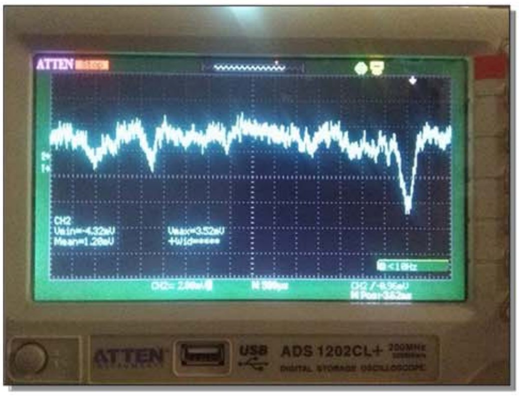


d)



e)

Figure 2: The effect of aperture size on signal variation

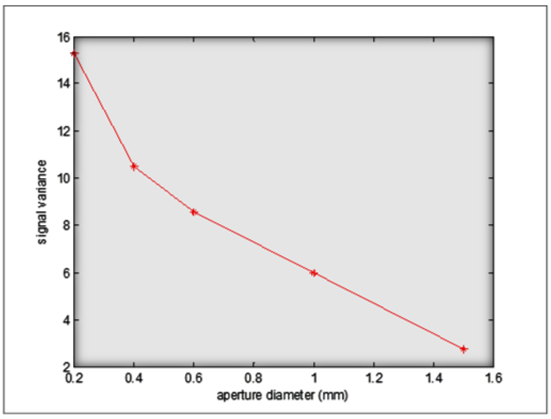


Figure 3: The effect of changing the aperture diameter on signal variance

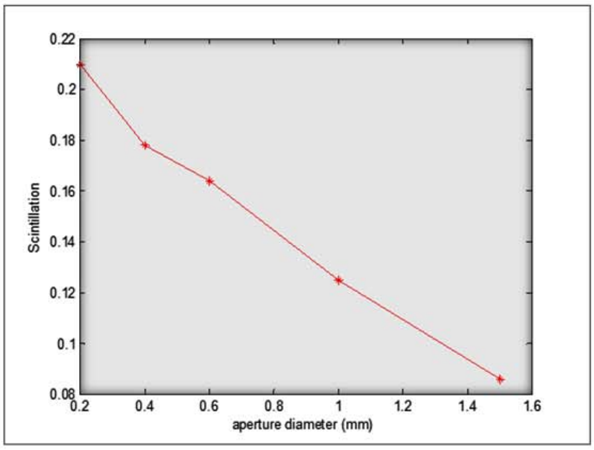


Figure 4: The effect of aperture diameter on the scintillations

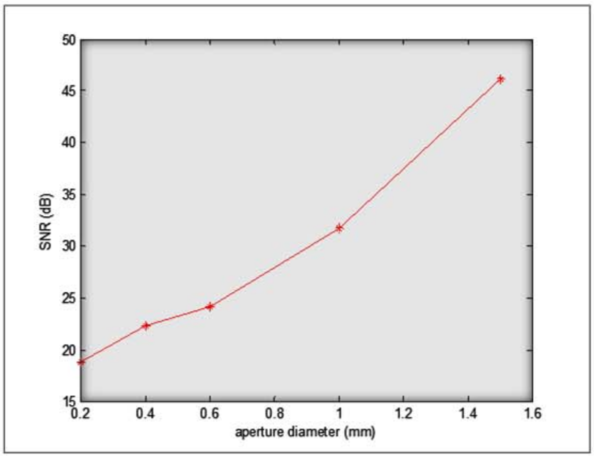


Figure 5: The effect of aperture diameter on the SNR

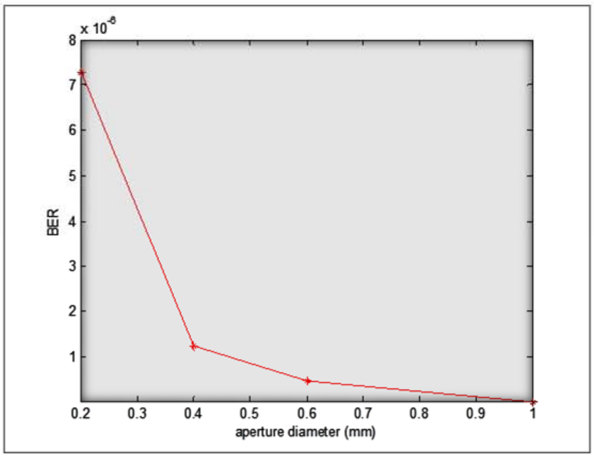


Figure 6: The effect of aperture diameter on the BER

The calculated value of the signal spot size is about (15 μm) while the optimum signal is obtained by utilizing a (1.5 mm) aperture spatial filter. This discrepancy is due to beam wandering, where the average received signal power covers an area of ($2.5*2.6\ mm^2$) as shown in figure (7).

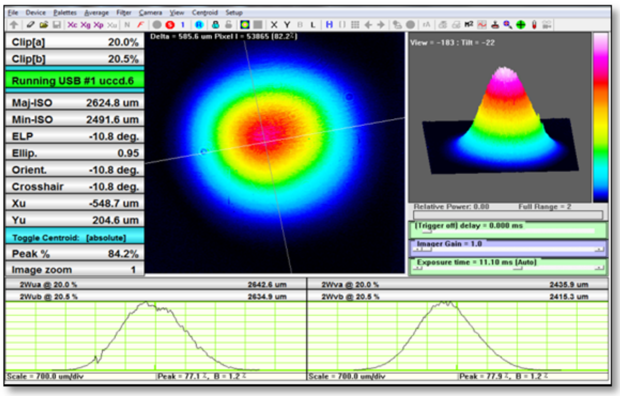


Figure 7: Laser beam profile under high turbulence

Table 1: The effect of aperture diameter on the SNR and BER values

aperture diameter (mm)	σ_i^2	$C_n^2\ (m^{-2/3})$	SNR	BER
0.2	0.21	$0.4958*10^{-9}$	18.88	$0.728*10^{-5}$
0.4	0.178	$0.42*10^{-9}$	22.279	$0.1228*10^{-5}$
0.6	0.164	$0.3872*10^{-9}$	24.18	$0.455*10^{-6}$
1	0.125	$0.2951*10^{-9}$	31.725	$0.9*10^{-8}$
1.5	0.086	$0.2*10^{-9}$	46.1125	$5.6*10^{-12}$

4. CONCLUSION

Both SNR and BER are clearly affected by atmospheric turbulences. When the turbulence is low, the value of the SNR increases, hence the values of BER reduces.

The proper spatial filter aperture size that gives the optimum performance, for this specific system, is about (1.5 mm).

REFERENCES

[1] Davis, Christopher C., Igor I. Smolyaninov, and Stuart D. Milner., "Flexible optical wireless links and networks.", IEEE Communications Magazine, Vol. 41, No. 3, pp. 51-57, 2003.

[2] Henniger, Hennes., "Transmission performance analysis of free-space optical communications using gilbert-erasure channel.", IEEE Transactions on Communications, Vol. 60, No. 1, pp. 55-61, 2012.

[3] R. N. Ali, Jassim, Jassim Mohammed, and Hawraa Hassaball Khribet, "Determine the optical turbulence parameter (C_n^2) in Babylon City-Iraq.", International Journal of Current Engineering and Technology, Vol. 5, No. 1, pp. 221-226, 2015.

[4] Jassim, Jassim Mohammed. "Experimental Study on the Atmospheric Attenuation Effective on Audio Signals In Free Space Laser Communication Links.", International Journal of Engineering and Innovative Technology (IJEIT), Vol. 3, No. 4, pp. 53-57, 2013.

[5] A. Chaman Motlagh, V. Ahmadi, Z. Ghassemlooy and K. Abedi, " The Effect of Atmospheric Turbulence on the Performance of the Free Space Optical Communications", In Communication Systems, Networks and Digital Signal Processing, CNSDSP, 6th International Symposium on Communication Systems., IEEE, pp. 540-543, July 2008.

[6] Zhang, Yixin, Tuo Zhu, and Chunkan Tao., "Aperture-averaging effects for weak to strong scintillations in turbulent atmosphere", Chinese Optics Letters, Vol. 2, No. 7, pp. 373-375, 2004.

[7] Andrews, Larry C., Ronald L. Phillips, and Cynthia Y. Hopen. "Laser beam scintillation with applications.", Vol. 99. SPIE press, 2001.

[8] Altowij, Khaleel S., Abdulsalam Alkholidi, and Habib Hamam., "Effect of clear atmospheric turbulence on quality of free space optical communications in Yemen", Frontiers of Optoelectronics in China, Vol. 3, No. 4, pp. 423-428, 2010.

[9] Xu, G., Zhang, X., Wei, J., and Fu, X., "Influence of atmospheric turbulence on FSO link performance.", In Asia-Pacific Optical and Wireless Communications, International Society for Optics and Photonics, pp. 816-823, May 2004.

[10] Babu, P. Latsa, and B. Srinivasan. "Characterizing the atmospheric effects on laser beam propagation for free space optical communication." Proc. National Conf. Commun., pp. 332-334, 2008.

[11] Priambodo, Purnomo Sidi, Ucuk Darusalam, and Eko Tjipto Rahardjo, "Free-space optical propagation noise suppression by Fourier optics filter pin-hole.", International Journal of Optics and Applications, Vol. 5, No. 2, pp. 27-32, 2015.