EXPERIMENTAL STUDY ON THE ATMOSPHERIC ATTENUATION EFFECTIVE ON AUDIO SIGNALS IN FREE SPACE LASER COMMUNICATION LINKS

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Abstract

In this work an experimental study on the effects of the atmospheric attenuation on audio signals carried by a laser beam in Free Space Laser Communication system. Both of the attenuation factors, absorption &scattering has been studied utilizing a frosted glass test cell for environment simulation conditions. The results show an effective change on the signals amplitude& pulse duration for different locations of the test cell with respect to the receiver. Far-field location produce defocusing effects while near field location show focusing effects which reflects on the received signal quality. Where an improvement of 200% has occurred due to low divergence. Assuming constant noise effects in all of the system, the experimental results show an effective reduction in the S/N ratio and increase in the bit error rates.

1. ATMOSPHERIC EFFECTS

Absorption is caused primarily by the water vapour (H_2O) and carbon dioxide (CO_2) in the air along the transmission path [1]. Gases in the atmosphere have many resonant bands, called transmission windows, which allow specific frequencies of light to pass through [2]. These windows occur at various wavelengths. Absorption is not generally a big concern in an infrared laser transmission system. Scattering has a greater effect than absorption. The atmospheric scattering of light is a function of its wavelength and the number and size of scattering elements in the air. The most common scattering elements in the air that affect laser beam transmission are fog and smog, rain, and snow [3].

2. NOISE IN FREE-SPACE OPTICAL COMMUNICATION

2.1. Bit error rate (BER) in Present of Atmospheric Absorption and Scattering

A laser beam propagation through the a atmosphere is attenuated by absorption and scattering due to the presence of aerosols , dust , smoke, fog, clouds, rain, snow and atmospheric molecules. In this paper we focus only to the optical propagation causing absorption and scattering. First calculate the received signal power for a lasercom system for a given range and extinction (combined absorption and scattering). Consider a laser transmitting a total power Transmitter the wavelength 650 nm. The signal power received at the communications detector can be expressed as [4]

$$P_R = P_T \frac{A}{(\theta_T L)^2} * \tau * \tau_R * \tau_T \quad --1$$

where A is the active area ,θ_T is Beam divergence , τ is the atmospheric transmittance, τ_T is the transmitter optical efficiency and τ_R is the receiver optical efficiency. The detector noise that comes from the background power and the inherent detector noise, the amount of the generated current in photodetector (i_s) depends on the incident optical power on the photodetector P_r (μW), and the responsivity R_λ (A/W), the photocurrent induced by the received optical signal is given by

$$i_S = G * P_R * R_\lambda \quad ----------2$$

G is the photo detector gain ,for a Photodiode, we take G = 1.

There are 2 major detector noises in reception circuit: Thermal noise and Shot noise. Thermal Noise (Johnson or Nyquist noise), this is caused by a random electron movement in the load resistor R_L due to thermal energy. The value of thermal noise current, is given by [5]:

$$\langle i_{th}^2 \rangle = \frac{4kT\,\Delta f}{R_L} \quad [\mathrm{A}^2] --------3$$

where *K:* Boltzmann's constant, *T* is the temperature in Kelvin, Δf is the spectral frequency. Finally, R_L is the loading resistor and i_d is the dark current.

And the Shot Noise (Quantum Noise), this is caused by a random fluctuation in electron-hole pair generation in photodetector. The value Shot noise current, is given by [5]:

$$\left\langle i_{sh}^{2} \right\rangle = 2e\bar{I}\,\Delta f \qquad [\mathrm{A}^2]-----4$$

where e = electron charge and $\bar{I}$ = average current (dc current) = $I_{dc} + I_D$

2.2. Signal to Noise Ratio

The signal to noise ratio (S/N) is determined experimentally, as a ratio between the final output receiver voltage V_{ph} or current signal i_{ph} or photocurrent power P_{ph} and the voltage noise V_n (or current noise level i_n or noise photocurrent power P_n. The signal to noise ratio (S/N) is expressed in decibel [6].

$$SNR = \frac{(RP_r)^2 R_L}{2eR_L\,(I_D + RP_r)\Delta f + 4kT\,\Delta f} --5$$

If the incident optical power is high. The dark current is very small compared to the average signal current, so that I_D can be dropped. Also, the shot-noise power is much larger than thermal power.

$$2eR_L\,(I_D + RP_r)\Delta f \approx 2eR_L\,(RP_r)\Delta f >> 4kT\,\Delta f$$

Then we have

$$SNR = \frac{RP_r}{2e\Delta f}-----------6$$

This is called "Shot-noise-limited" or "Quantum limited **,** but if the incident optic power is low. Thermal is dominating over the shot noise [7].

$$4kT\,\Delta f \;>>\; 2eR_L\,(I_D + RP_r)\Delta f$$

$$SNR = \frac{(RP_r)^2 R_L}{4kT\,\Delta f}--------7$$

This is called "Thermal-noise-limited".

2.3. BER in digital modulation:

Bit Error Rate (BER) is a measurement of digital system quality. Noise makes it difficult to distinguish "0" from "1". BER is probability of error in "0" or "1" bit detection. In digital communication systems, BER $\leq 10^{-9}$ is good enough for many applications. The receiver will use a reference threshold current to decide whether it is "0" or "1" as

$< i_s >$ **>** $< i_{th} >$ then assigns "1"

$< i_s >$ **<** $< i_{th} >$ then assigns "0"

The BER can be expressed as [8]

$$BER = \frac{\exp^{\left(-SNR/2\right)}}{\left(2\pi SNR\right)^{0.5}} ---------8$$

3. EXPERIMENTAL DESCRIPTION

The general process of laser communications is to load information (speech, images) into the carrier, upon the transmitter processing (coding, modulation), the information contained in laser wave and transfer to reach the receiver, the receiver will process the received signal (amplification , decoding), the signal restored to the original information, as shown in fig. 1 The signal is modulated by the modulation circuit and loaded in a 80 KHz square wave on the other side to wave pulse width modulation, and thereby drive the semiconductor laser modulation signals, so that issuing a series of laser pulses of light modulation by the sound ,the light pulse into the test cell (Frosted Glass), when the laser passes through the frosted glass with a rough surface its scattering or transmitting and the light beam interference, there will be randomly distributed bright spots and dark spots in different shape and size in the region near the space of the test cell surface, as show in fig.2 .The laser is received by photodiode receiver and restored back to electrical signals. At this time we can observe from the oscilloscope all signals. The parameters used in FSO calculations are shown in table 1.

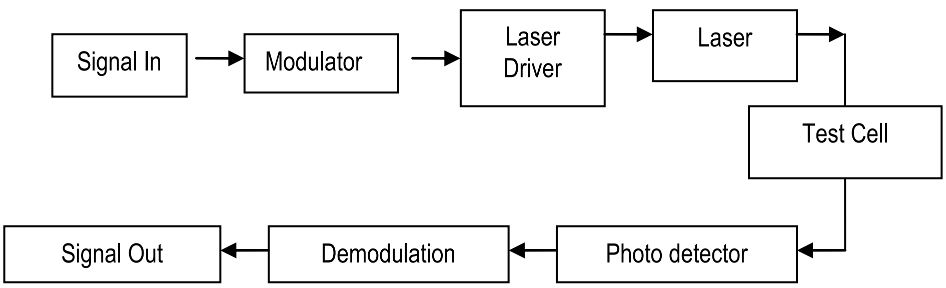


Figure 1. Block diagram of experiment setup

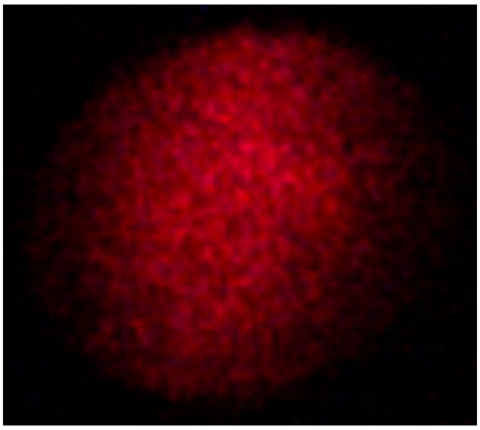


Figure 2. laser spot after passes through the frosted glass

***Table 1.** Parameters used in FSO calculation*

Parameter	Values
Transmitter optical power(mw)	5
Laser Wavelength (nm)	650
Beam divergence	<2 mrad
Photodetector Spectral range	390 - 900 nm
Spectral sensitivity @ 650nm	0.50 A/W
Bandwidth	240 MHz
Active area	1 mm2
Transmitter efficiency	1
Receiver efficiency	1
Background noise	0dB
Dark Current	0.35 nA
Total current noise	17.5 nA

4. RESULTS

4.1. Effective the test cell on beam propagation

The level of turbulence strength is controlled by placing the same frosted glass near and far away from the FSO transmitter. Ray tracing diagram in Figure 3 illustrates this concept. The optical beams shown in both Figure 3(a) and (b) could approximately experience the same degree of bending due to the same level-controlled turbulence source is used, however due to geometry configuration fluctuated in power will be collected at the receiver and desperation the pulse duration of signals shown in Figure 4(a,b and c).

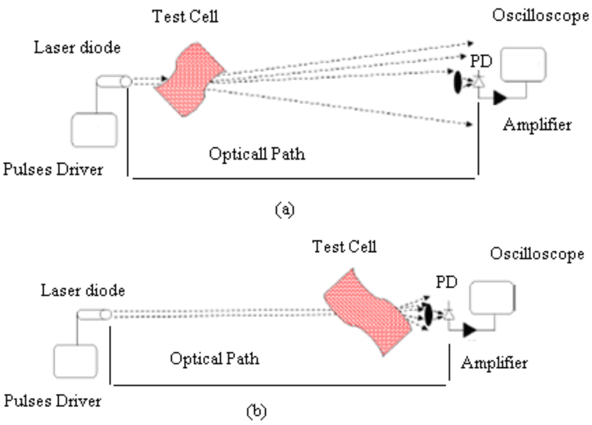
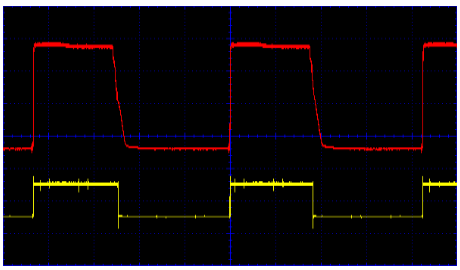
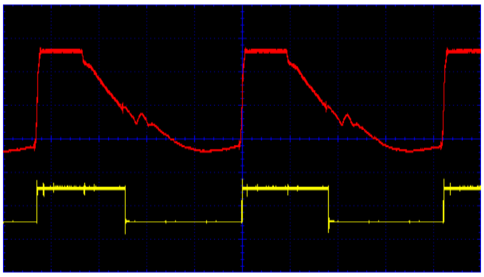


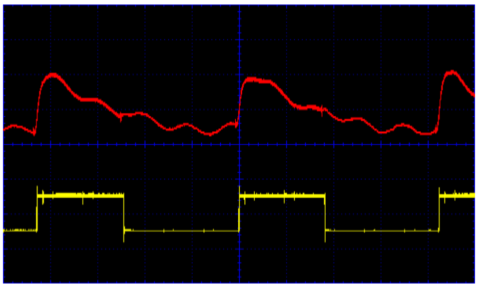
Figure 3. Sketch of diverted beams due to turbulence source positioned (a) near the transmitter and (b) near the receiver



(a)



(b)



(c)

Figure 4. The measured eye diagram of received signal in the condition of (a) no turbulence, (b) medium turbulence (c) weak turbulence

4.2. BER as a Function of Received Power

The theoretical and experimental calculations of the received optical signal power and S/N variation with atmospheric transmittance of the system can be calculated by substitute the values from table (1) in equation (1), (2) and (7) we obtain the table (2).

Fig. 2 illustrates empirical result for the BER performance of FSO links for various of different of received power between (200 –1000) μW this effective directly on SNR between (75 -90) dB. As the figure clearly illustrates, the improves BER with the increasing received optical power.

τ atmospheric transmittance	P_r (theoretical) μW	Is (theoretical) μA	S/N (theoretical) dB	Pr (experimental) μW	Is (experimental) μA	Table 2: The re-ceived power and S/N (theoretical and experimental) as a function of Atmos-pheric transmit-tanceS/N (experimental) dB
0.3	375	187.5	80.5	208	104	75
0.4	500	250	83	370	185	80
0.5	625	312.5	85	450	225	82
0.6	750	375	86.6	553	276	84
0.7	875	437.5	88	648	324	85
0.8	1000	500	89	750	375	86.6
0.9	1125	562.5	90	887	443	88
1	1250	625	91	1012	510	89.3

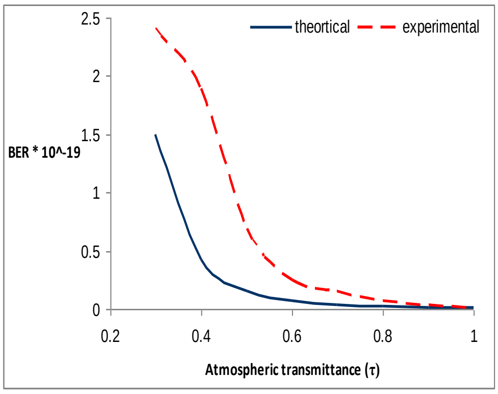
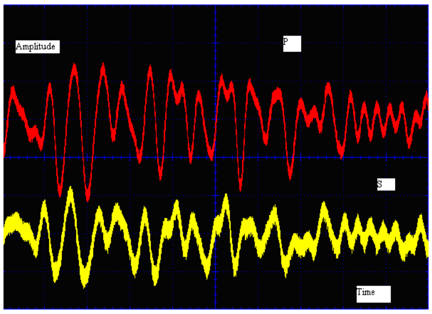


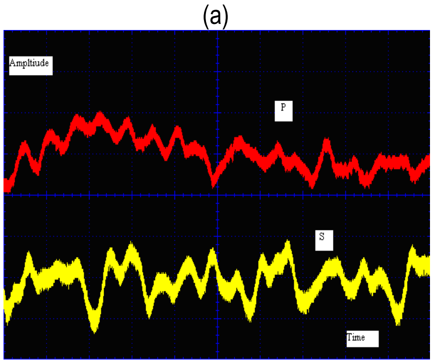
Figure 2. The theoretical and experimental of the BER as a function of atmospheric transmittance

4.3. Effective the weather conditions on Quality speech

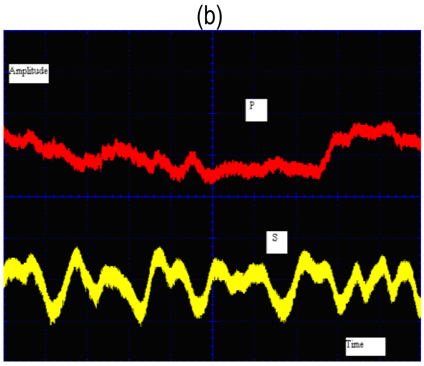
The speech 'input' and 'output' signals are illustrated in fig.4. It is evident that the synthesised speech signal at the receiver correlates well with the original analogue speech signal, under three different weather conditions (*T* of 100 %, 50 % and 30 %.). the quality of the decoded speech signals at the receiver dependent on the error bit rate for *T* = 100 % the atmosphere no effective in power transmitter lead to low bit error rate and getting good quality speech but for *T* = 50 % and 30 %, respectively, thus indicating the considerable effect of atmosphere on the received signal quality lead to more bit error rate finally poor quality speech. The system is not capable of measuring bit error rate, its performance was assessed subjectively by applying an intelligibility test, which is the usual practice in speech communications trials, sometimes deciding on a comparison category rating. Many listeners were asked to judge the quality of the decoded speech signals at the receiver. As expected, they commented that the subjective quality between good and poor dependent on the weather conditions.



(a)



(b)



(c)

(p) synthesised speech signal at the receiver (**s**) Analogue speech signal for transmission

Figure 5. Speech Signal received at different weather conditions (a-T 100 %,b- 50 % and c-30 %).

4. CONCLUSION

From the results, it has been shown that the performance deteriorates with high values of BER. Also the maximum distance of free space optical link is limited by the noise and atmospheric attenuation. It is noticed that signal to noise ratio (SNR) decreases with the increase of the range and the bit error rate (BER) increases with increase of the range, the power budget increases, as the transmitted optical power increases, however it decreases, as the minimum detectable power increases.

References

[1] Andrews L. C., "Free-Space Laser Propagation: Atmospheric Effects", IEEE Journal, Vol. 19, No. 5, P.6-8, October (2005).

[2] H. Yuksel "Studies of the Effects of Atmospheric Turbulence on Free Space Optical Communications," Ph.D. Thesis, University of Maryland, 2005.

[3] S. S. Muhammad, B. Flecker, E. Leitgeb and M. Gebhart, "Characterization of fog attenuation in terrestrial free space links," *Journal of Optical Engineering,* vol. 46, pp. 066001- 066006, 2007.

[4] Air Fiber " The physical of Free Space Optics ", 2001.

[5] A. Yariv, "Optical Electronics in Modern Communications" New York Oxford ,2007.

[6] David G. Aviv "Laser Space Communications" Published by ARTECH HOUSE, 2006.

[7] D. G. Baker, "Fiber Optic Design and Applications", Prentice-Hall, 1985.

[8] Larry E. Andrews, Ronald L. Phillips, and Cynthia Y. Hopen, Laser Beam Scintillation with Applications, SPIE Press, Bellingham, Washington (2001)