Comparison of NRZ, RZ-OOK Modulation Formats for FSO Communications under Fog Weather Condition

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ABSTRACT

In this paper, the performance of an FSO wireless communications system is theoretically analyzed, using NRZ, RZ-OOK modulation formats and a Si PIN photodiodes receiver over fog weather conditions. Based on different fog models for optical beam propagation horizontally at 850 nm1550nm on an FSO, the visibility of weather and power of the transmitter under fog weather are analyzed. The characteristics of bit error rate BER for NRZ and RZ-OOK optical modulation formats are studied under different fog models. Simulation results indicate that the performance of 1550nmis more suited for an FSO communication system. On the other hand, we discuss the suitability of fog models under these modulation formats.

Keywords

FSO, fog attenuation, visibility, bit error rate BER, NRZ-OOK, RZ-OOK.

1. INTRODUCTION

Free space optics (FSO) is an optical communication technology that uses light propagating in free space to transmit data between two points. This technology is useful where a fiber optic cable is impractical. It is similar to fiber optic communications in that data is transmitted by modulated laser light [1]. Light travels through air faster than glass, so FSO is communication at the speed of light in atmosphere. The stability and quantity of the link is highly dependent on atmospheric factors such as rain, fog, dust and heat. The quality of the transmission is characteristics by the realized bit error rate [2]. Simplest form of FSO links are on-off keying (OOK) modulated links which involve presence and absence of optical pulse for binary '1' and binary 'o' respectively. Besides ease of modulation and development, following features have made unbeatable option in comparison to conventional RF systems, (i) FSO links use unlicensed IR frequency spectrum (ii) immunity to electromagnetic interference (iii) huge bandwidth and data rates as high as 10 Gbps (iv) FSO links are plug and play devices independent of transmission protocol (v) high end user privacy due to infrared based on line of sight (LOS) [3]. The transmission of modulated light is greatly affected by the atmospheric parameters such as absorption, scattering, and non-selective scattering. Absorption is caused due to gases present in the atmosphere, whereas scattering and non-selective scattering is caused by big sized rain drops. In temperature regions, fog and heavy snow are the primary weather conditions that affect FSO link [4]. The channel characterization in real atmospheric fog is accomplished by using the empirical approach [4-6]. The empirical approach uses the measured visibility and fog attenuation to evaluate the link performance. The visibility is normally measured using a visibility device called the transmissometer. However, it is sometime difficult to accurately measure the visibility and therefore the corresponding fog attenuation because of inhomogeneous for along FSO path. In addition measurement equipment and systems required are complex and very costly [7].

2. ATTENUATION BY FOG

For a terrestrial FSO link transmitting optical signal through the atmosphere, the received signal power at a distance, L from the transmitter signal power for FSO is

given by [8, 9]
$$p_r = P_t \tau_t \tau_r \frac{D^2}{\theta^2 . L^2} 10^{-\gamma(\lambda).L/10} \tag{1}$$

Where D is the receiver diameter, θ is the full divergence angle; γ is the atmospheric attenuation factor (dB/km), τ_r and τ_t are the receiver and transmitter optical efficiency respectively.

The function of $\gamma(\lambda)$ is the total extinction coefficient per unit length, which represents the attenuation of the transmitted light. It is composed of terms for scattering and absorption, and general it is the sum of the following

terms [10]
$$\gamma(\lambda) = \alpha_m(\lambda) + \alpha_a(\lambda) + \beta_m(\lambda) + \beta_a(\lambda) \tag{2}$$

The first two terms represent the molecular and aerosol absorption coefficients, respectively while the last two terms are the molecular and aerosol scattering coefficients respectively. The wavelengths used in FSO are basically chosen to coincide with the atmospheric transmission windows [4, 11], resulting in the attenuation coefficient being dominated by scattering the attenuation is reduce to:

$$\gamma_{specific}(\lambda) \cong \beta_a(\lambda) \tag{3}$$

Attenuation coefficient based on empirical measurement data was calculated by the following empirical model [12]

$$\beta_a(\lambda) = \frac{3.91}{V} \left(\frac{\lambda}{550} \right)^{-\delta} \tag{4}$$

Where V is the visibility in (km), λ represent the wavelength in (nm). The parameter δ depends on the visibility distance range, according to Kruse model δ is given as [13]

$$\delta = \begin{cases} 1.6, & if \ V \succ 50km \\ 1.3, & if \ 6km \succ V \succ 50km \\ 0.585.V^{1/3}, & if \ V \prec 6km \end{cases} \tag{5}$$

While Kim model defines δ as [4]:

$$\delta = \begin{cases} 1.6, & if \ V \succ 50km \\ 1.3, & if \ 6km \succ V \succ 50km \\ 0.16V + 0.34, & if \ 0.5 \ km \prec V \prec 6km \quad (6) \\ V - 0.5, & if \ 0.5 \ km \prec V \prec 1km \\ 0, & if \ V \prec 0.5km \end{cases}$$

Al-Naboulsi proposed expressions to predict the wavelength dependent fog attenuation coefficient for the convection and advection fogs for wavelengths from 690 to 1550 nm [6]. The attenuation coefficient for convection fog is given by:

$$\gamma_\lambda (con) = \frac{0.11478 \lambda + 3.8367}{V(km)} \quad (7)$$

The attenuation coefficient for advection fog is given by:

$$\gamma_\lambda (adv) = \frac{0.18126.\lambda^2 + 0.13709 + 3.7205}{V(km)} \quad (8)$$

The specific attenuation coefficient for both types of fog is

given by $\gamma_{specific} (\lambda) \left(\frac{dB}{km} \right) = \frac{10}{\ln(10)} \gamma(\lambda) \quad (9)$

3. SIGNAL TO NOISE RATIO AND BIT ERROR RATE

The main features of an FSO communication system is the signal to noise ratio SNR. When transmitted optical signals arrive at the receiver, they are converted to electronic signals by photo detectors. There are many types of photo detectors in existence, photodiodes are used almost exclusively in optical communication applications because of their small size, suitable material, high sensitivity, and fast response time [14]. For the PIN photodiode the signal to noise ratio (SNR) is given by [15]:

$$SNR = \frac{I_p^2}{2qB(I_p + I_D) + 4KTBF_n / R_L} \quad (10)$$

Where I_p is the average photocurrent, q is the charge of an electron(C), B represents the bandwidth, I_D is the dark current, T is the absolute photodiode temperature (K), F_n is the photodiode figure noise equal to 1 for PIN photodiode, R_L is the PIN load resistor. The average photocurrent I_p can be expressed as [16]

$$I_p = P_r . R \quad (11)$$

where Pr is the average optical power received to the photodetector, R is the responsivity of the photodetector.

Another main feature of FSO communication systems is the bit error rate BER [17]. The effect of fog on the Bit Error Rate BER of an FSO link is reported in [18] which correlate the atmospheric transmission with the BER. However, RZ-OOK and NRZ-OOK modulation schemes are widely used in commercial FSO communication systems because of their ease of implementation,

bandwidth efficiency and cost effectiveness [19]. The relation BER and SNR for NRZ-OOK modulated signal is as follow [20]:

$$BER_{NRZ-OOK} = \frac{1}{2} erfc \left(\frac{1}{2\sqrt{2}} \sqrt{SNR} \right) \quad (12)$$

While BER for RZ-OOK modulated signal is given by [21]:

$$BER_{RZ-OOK} = \frac{1}{2} erfc \left(\frac{1}{2} \sqrt{SNR} \right) \quad (13)$$

4. NUMERICAL RESULTS

In this section, using the above mentioned formulations, the simulation is carried out to study the fog attenuation channel and its effect on FSO optical wireless communication employing RZ-OOK, NRZ-OOK modulation techniques in the transmitter and Si PIN receiver over fog weather condition. The values of the simulation parameters and constants are given in table (1)

4.1 Attenuation Coefficient for Fog Weather Condition

In FSO communication system, attenuation is an important indicator. It is meaningful to study achievable distance L of optical beam under the fog weather. Let us see the effect of the specific attenuation coefficient $\gamma(\lambda)$ on the visibility for optical beam propagation horizontally in FSO. It is shown in Figure (1, 2) Specific attenuation coefficient (dB/km) as a function of visibility (km) for wavelength 850, 1550 nm under four fog attenuation models (Kim, Kruse, Al-Naboulsi Advection and Al-Naboulsi Convection). The simulation shows that we do not find any difference in Specific attenuation coefficient of the different fog model.

Table 1. System parameters used in the simulation [16, 22]

Parameter	Value
Transmission Wavelength (λ)	(850, 1550)nm
Distance (L)	1 km
Transmitter power (P$_T$)	5 mw
Optical efficiency of transmitter τ$_t$	0.75
Optical efficiency of receiver τ$_r$	0.75
Laser beam divergence angle θ	$2*10^{-3}$ rad
Receiver diameter	1cm
Electron charge (q)	1.6×10^{-19} C
PIN load resistance (R$_L$)	1kΩ
Boltzmann constant (k)	1.38×10^{-23} J.k
Temperature (T)	298K
Dark current (I$_D$)	10nA
Responsivity (R)	0.6A/W`
Bandwidth (B)	0.5GHz

It can be observed that the attenuation coefficient does not show wavelengths dependent behavior. In figure. (2) the Specific attenuation coefficient has a minor difference behavior when a visibility less than 1km, furthermore, Kruse model shows sensitive for long wavelength.

4.2. BER Characteristics for FSO Communication

BER plays a crucial role in an optical communication system. We present here simulation results to compare the performance of fog attenuation under different mathematical models. On the other hand, we consider OOK modulation format in the transmitter side because of its simplicity and resilience in the FSO communication system.

4. 2.1 The Impact of the Visibility

Let us consider the BER performance as a function of the visibility. Figure (3) shows that BER for RZ-OOK modulation format under different fog models when an 850nm is used. In this case, we notice that for BER 10^{-10}, the visibility about 1.7 km for Kim and Kruse models and its increase for Al-Naboulsi model becomes about 2.15 km. It is noticed in Figure (4) a significant increase in the visibility can be achieved by using a NRZ-OOK modulation format, the maximum data rate is about 2.1 km for Kim and Kruse model and 2.8 km for Al-Naboulsi model. Another important simulation was evaluated the performance of the BER for 1550nm under RZ-OOK modulation format. In Figure (5) a significant improvement in the visibility can be achieved by using 1550nm, for the BER 10^{-10}, the maximum data transmission is about 1.33 km for Kim and Kruse model while its about 2.15 km for Al-Naboulsi model. When we applied NRZ-OOK modulation format, the maximum data transmission is increasing for 1550nm compared with 850nm for Kim and Kruse Model as shown in figure (6). The maximum data transmission reached to 1.5 km for Kim and Kruse models, while an approximately occurs in the BER performance for Al-Naboulsi model comparing with figure (4). The maximum data transmission for Al-Naboulsi model reached to 2.8km.

4.2.2 The Impact of the Transmitter Power

It has investigated the effect of transmitter power on BER under fog weather condition. We compare the performance of the fog models when an RZ-OOK and NRZ-OOK used as a modulation formats under a PIN photodiode. Figure (7) shows BER versus transmitter power when a distance 1 km and visibility 1km. If we consider required 10^{-10}, when used a RZ-OOK modulation format and 850 nm as a carrier signal the transmitter power about -40dBm for Kim and Kruse models while the increase for Al-Naboulsi model reached to -32dBm. When a NRZ-OOK applied as is evident in Figure (8). An increase occurs in the BER leads to increase in the transmitter power reached to -35 dBm for Kim and Kruse models while -28 for Al-Naboulsi model.

We performed the same calculations also for 1550 nm under the same conditions. Figure (9) shows the BER for RZ-OOK modulation format, where an improvement occurs when applied 1550 nm as a carrier signal. In this case, notice that for BER 10^{-10}, a decreasing occur in the transmitter power reached to -48dBm and -46dBm for Kruse and Kim models respectively, and -33 dBm for Al-

Naboulsi model. In figure (10) assume that an FSO communication system operating under NRZ-OOK modulation format, it is clear that the BER required an increasing for the transmitter power. In this case, the data of the transmission about -45 dBm for Kruse model and -44 dBm for Kim model while reached to -30 dBm for Al-Naboulsi model.

5. CONCLUSION

This paper provides a theoretical performance analysis of an FSO wireless communication link using NRZ-OOK and RZ-OOK modulation formats in the transmitter and Si PIN as a receiver with four mathematical models for fog attenuation. The specific attenuation coefficient of the laser beam through fog weather has a significant effect on the performance of FSO communication systems. The effect of fog attenuation, visibility, and transmitter power are investigated. The suitable choice of wavelength has a strong influence on the attenuation coefficient, which leads to long transmission in free space. When weather has increased visibility, this causes a decrease in attenuation coefficient. The BER characteristics of the NRZ and RZ-OOK modulation formats under different fog models are studied. The results show that the wavelength 1550nm has a greater advantages than the other wavelength, therefore, a 1550nm is a more suitable wavelength compared with 850nm for FSO under fog effect. Furthermore, the performance of RZ-OOK is better than the NRZ-OOK, the Kruse model is more sensitive for fog attenuation compared with the other models.

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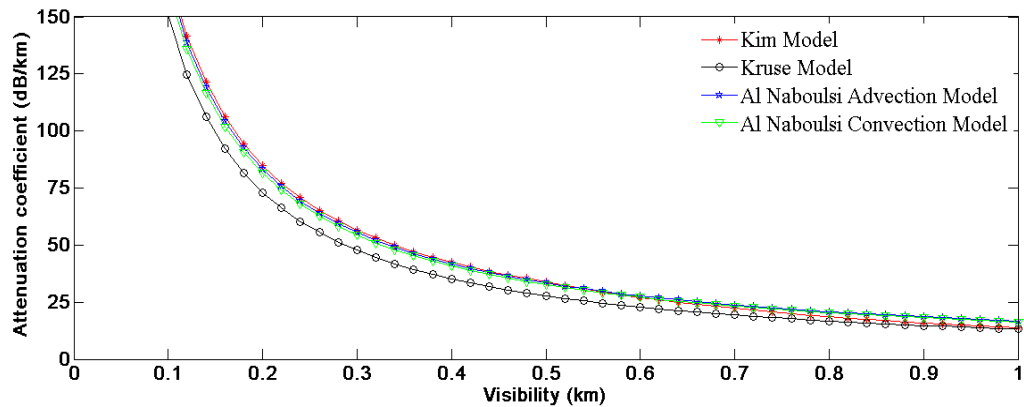[22] Agrawal, G. P., Fiber-Optic communication system, John Wiley and Sons, 4th edition, 2010.

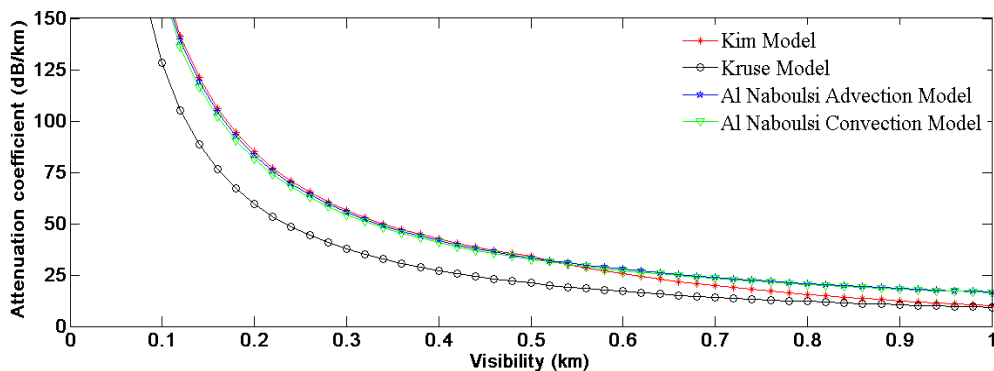**Fig (1) Specific attenuation coefficient for different models for 850 nm**

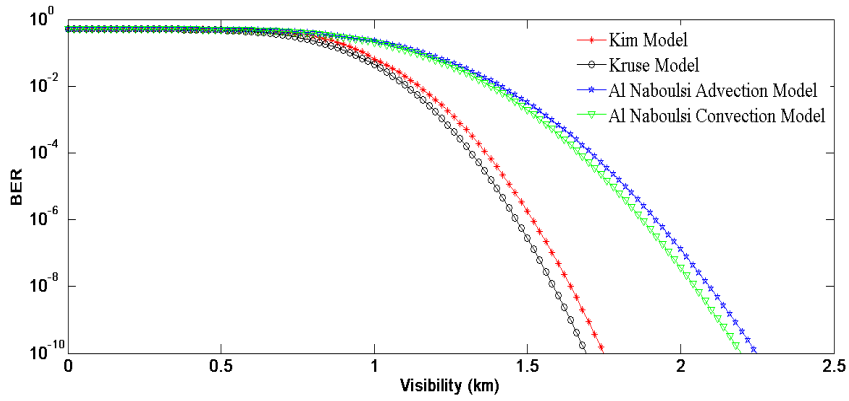**Fig (2) Specific attenuation coefficient for different models for 1550 nm**

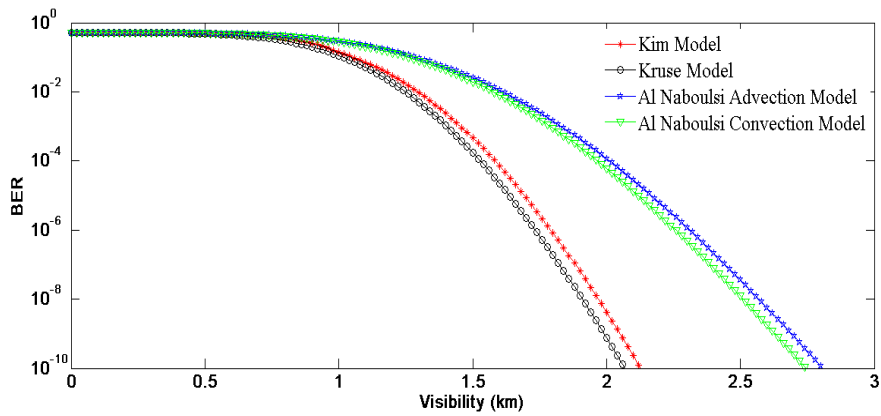**Fig. (3) BER as a function of visibility for RZ-OOK, 850 nm.**

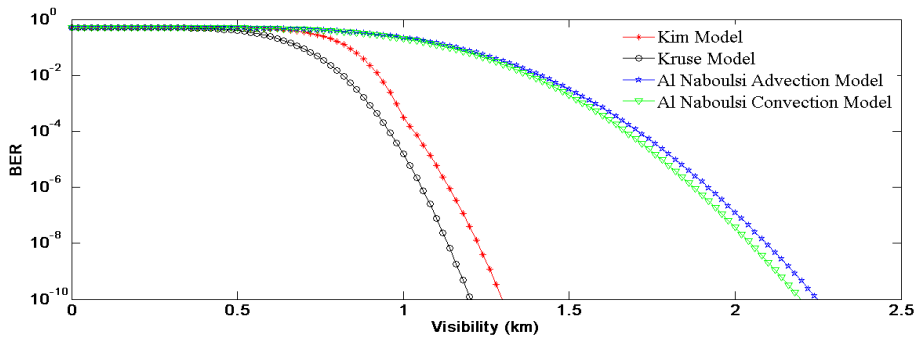**Fig. (4) BER as a function of visibility for NRZ-OOK, 850 nm.**

Fig. (5) BER as a function of visibility for RZ-OOK, 1550 nm.
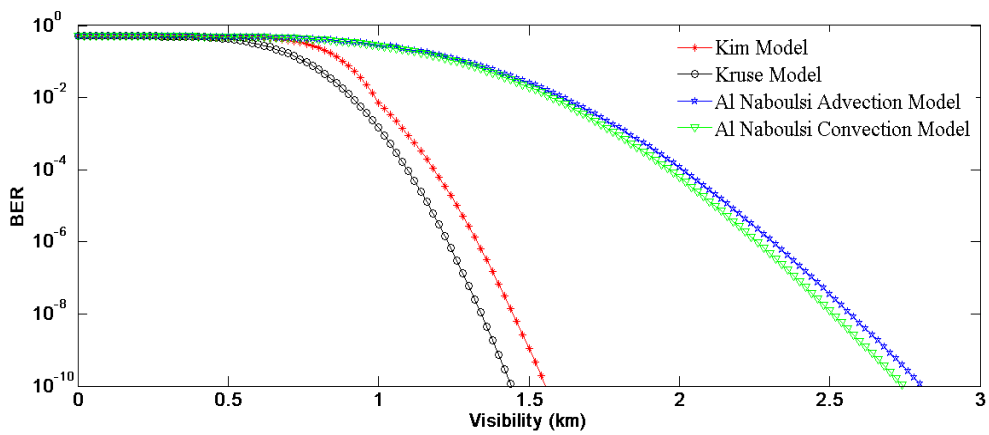

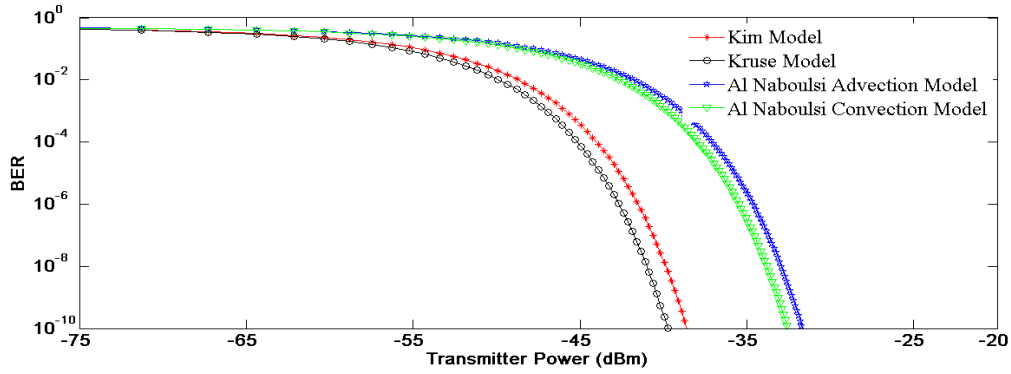**Fig. (6) BER as a function of visibility for NRZ-OOK, 1550 nm.**

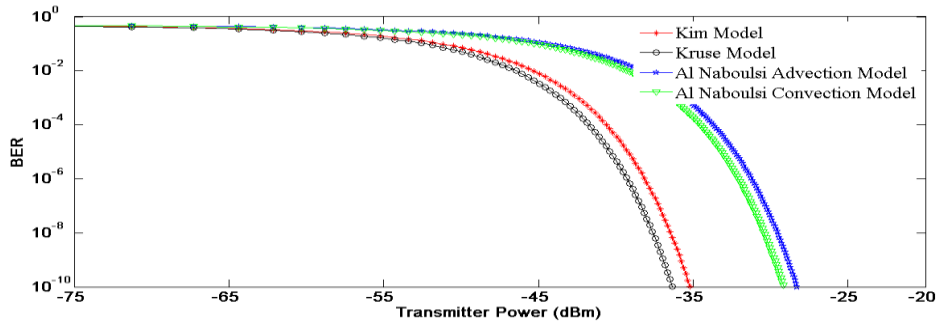**Fig. (7) BER versus Transmitter Power for RZ-OOK 850 nm, V=1km.**

Fig. (8) BER versus Transmitter Power for NRZ-OOK 850 nm, V=1km.
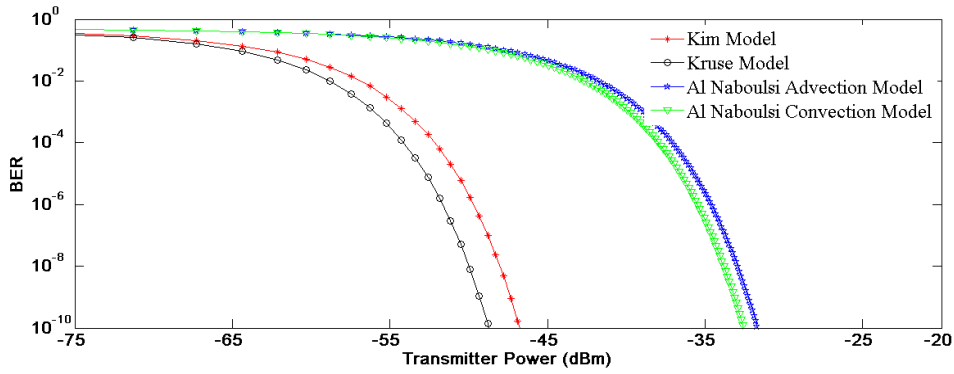

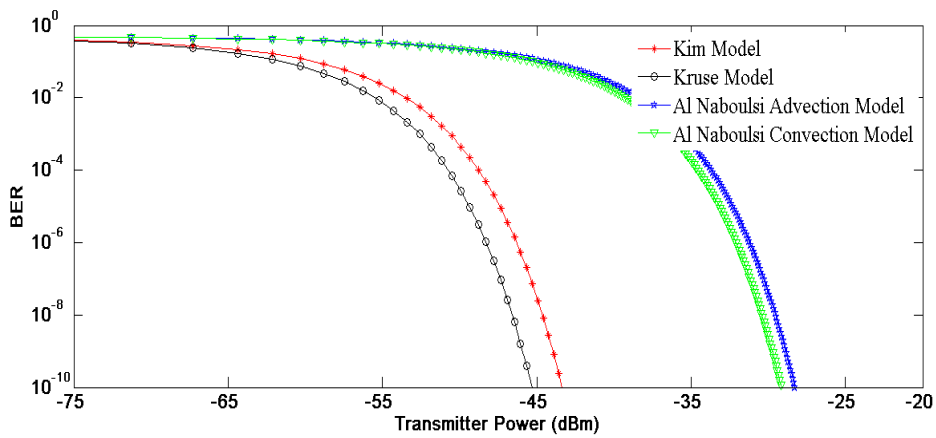**Fig. (9) BER versus Transmitter Power for RZ-OOK, 1550 nm, V=1km**

Fig. (10) BER versus Transmitter Power for NRZ-OOK, 1550 nm, V=1km