Journal of Engineering and Applied Sciences 13 (7): 1644-1648, 2018
ISSN: 1816-949X

Characteristics of RF Signal in Free Space Optics (RoFSO) Considering Rain Effect

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Abstract: Radio over Free Space Optics (Ro-FSO) is promising future communication techniques. In this study, design Ro-FSO with mathematical analysis for transmission and simulation comparison of radio frequency RF (20, 60) GHz for transporting 2.5 and 10 Gbps over acceptable maximum distance are possible of FSO under clear air, light rain, moderate rain and heavy rain weather condition. To knowing the ability radio frequencies for carrying difference values of information (data rate) over the same optical source 1550 nm.

Key words: Radio over Free Space Optics (Ro-FSO), Radio Frequency (RF), Signal to Nnoise Ratio (SNR), turbulence (C_n^2) and Bit Rate Error (BER), source, difference

INTRODUCTION

Communication system transmissions Radio Frequency Signal Over (Ro-FSO) free space optics channel by modulation it with optical wave like laser source or Light Emitting Diodes (LEDs) (Tsukamoto *et al.*, 2007). FSO technology provides many advantages such as immune to radio frequency interference, provide high data rate, low power, high security, low cost and high bandwidth (Vigneshwaran *et al.*, 2013; Rahman *et al.*, 2012). When light transmission through atmosphere between transmitter and receiver section high effected by weather condition such as fog, rain, haze, snow and smoke. Where fog consideration the major source of attenuation in FSO (Gebhar *et al.*, 2004). While the rain considered the major source of attenuation where causing degradation in transmission signal (Leitgeb and Plank, 2015). Ro-FSO technology is a solution for many problems removing RF spectrum overcrowding in current wireless network (Amphawan *et al.*, 2014; Yue *et al.*, 2012) and has much of specification, it ability of send RF signals with optical carrier with low power exhaustion, high band width, low attenuation and without need of using optical fiber (Kazaura *et al.*, 2010). This study is design Ro-FSO system investigations radio frequencies that carrying 2.5 Gbps then 10 Gbps data rate over maximum link of FSO under clear air and rain weather condition.

MATERIALS AND METHADS

Mathematical system description: Ro-FSO communication system design would be tracked by mathematical equations for each step of program operations (Fig. 1). Mathematical model of RF modulation (Kazemi *et al.*, 2015). Information signal:

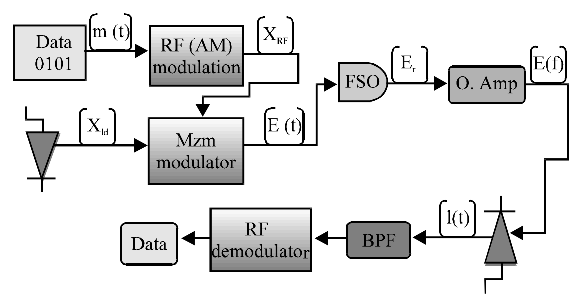

Fig. 1: Transmission of radio frequency over FSO system

$$m(t) = V_m \cos(w_m.t) \quad (1)$$

Carrier signal (RF):

$$RF = V_c \cos(w_c.t+\Phi) \quad (2)$$

Electric signal (X_{RF}) formed when information modulated on radio frequency by (AM):

$$X_{RF} = V_c + m(t) \cos(2\pi f_c.t+\Phi) \quad (3)$$

$$X_{RF} = \{Vc+V_m \cos(2\pi f_m.t)\}\cos(2\pi f_c.t+\Phi) \quad (4)$$

Modulation index $m = V_m/V_c$ That offset in Eq. 4 can get (Eq. 5):

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$$X_{RF} = \{V_c + mV_c \cos(2\pi f_m .t)\} \cos(2\pi f_c .t + \Phi) \quad (5)$$

$$X_{RF} = \{1 + m \cos(2\pi f_m .t)\} V_c \cos(2\pi f_c .t + \Phi) \quad (6)$$

Suppose:

$$G = \{1 + m\cos(2\pi f_m .t)\}$$

$$X_{RF} = GV_c \cos(2\pi f_c .t + \Phi) \quad (7)$$

Where:
V_m = Amphase of carrier signal
V_c = Amplitude of carrier signal
ϕ = Phase of carrrier singnal
f_m = Freaquency of information
f_c = Frequency of carrire

The electric signal after amplitude modulation where the change occurs only in amplitude, adverse with frequency and phase would remain constant. Optical signal:

$$x_{LD} = A_{LD} \exp(j2\pi f_{LD}.t) \quad (8)$$

The output optical signal E(t) from optical modulator MZM (Wooten *et al*., 2000):

$$E(t) = x_{LD} \cos\left(\frac{\pi}{4}[1-\cos(2\pi f_c .t)]\right) \exp j(2\pi f_{LD} .t + \Phi_c) \quad (9)$$

Where:
f_{LD} = Frequency of Laser
A_{LD} = Amplitude of Lasersoure

The equation of FSO channel system (Bloom *et al*., 2003):

$$P_r = P_t \frac{d_r^2}{(d_t + \theta R)^2} 10^{-\frac{\alpha R}{10}} \quad (10)$$

Where:
P_r = The received Power
P_t = The transmitter Power (dBm)
dr and dt = The received and transmitted aperture (cm)
θ = Thedivergence angle (mrad)
R = The Range link (km)
α = The atmosphere attenuation

The relation between power and irradiance, E = P/A

$$E_r .A = E_t .A \frac{d_r^2}{(d_t + \theta R)^2} 10^{-\frac{\alpha R}{10}}$$

Where:
A = The area
E_t = E(t) = The transmission signal from MZM

When offset in Eq. 9 in Eq. 10 can get Eq. 11:

$$E_r = E(t) \frac{d_r^2}{(d_t + \theta R)^2} 10^{-\frac{\alpha R}{10}} \quad (11)$$

The optical amplifier used to boost the incoming signal by amplified gain (G):

$$G = \frac{\text{Signal out } E(f)}{\text{Signal in } E_r} \quad (12)$$

$$E(f) = E_r .G \quad (13)$$

Then the optical signal received by APD for convert it to electric signal (Lim *et al*., 2009):

$$i(t) = R.G./E(f)/ + n(t) \quad (14)$$

Where:
R = The Responsively, signal noise
n (t) = The $i_d + i_{en} + i_{sh}$ i_d: dark cuurent
i_{th} = The thermal noise current
i_{sh} = The shot noise current

$$i(t) = R.G^2.E_r + n(t) \quad (15)$$

Band pass filter used to extract the RF and finally, can extracted the transmitted data rate (information) by AM De-modulation.

Design analysis: The Ro-FSO system was designed by Optisystem V 7.0 that shown in Fig. 1. This design consist transmitter, FSO channel, receiver. Transmitter section consisting Pseudo Random Bit Sequence generator (PRBS) and Non Return to Zero pulse generator (NRZ) which are generated the digital information (data rate) to modulated on high radio frequency by Amplitude Modulator (AM), output an electrical signal. The electrical signal and CW Laser source are apply to MZM, mach-zender modulator which have two input arms (one modulated electrical signal arm input and one un-modulated optical wave arm input) these arms combiner together at output (Prabu *et al*., 2012). The output optical signal passes over FSO under rain weather condition. The receiver section consists of optical amplifier, APD photodiode, BPF to extract the transmitted RF and de-modulator for extracting input data. This design using constant parameter is fixed.

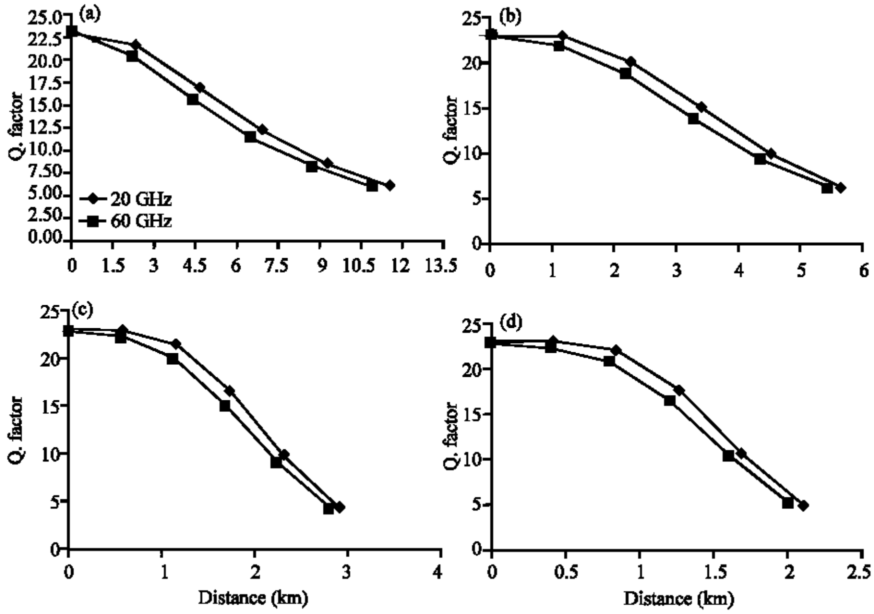

Fig. 2: a-d) Transporting 2.5 Gbps under clear, light rain, mod rain and heavy rain

RESULTS AND DISCUSSION

The values of weather condition were operated from (Kazemi *et al*., 2015). From Table 1-3 know that distance of FSO inversely proportional with bit rate. In Table 2 transporting of low bit rate 2.5 Gbps by using two RF modulations with the same optical wavelength (1550 nm) to transmit through FSO; 20 GHz operated longest distance compared with 60 GHz. In contrast, Table 3 of transporting high bit rate 10 Gbps noticed that RF 60 GHz could operate the longest distance of FSO than 20 GHz. The reason behind this difference is the broad bandwidth of high radio frequency, the high frequency capable of carrying more data than low radio frequencies (Ng'oma, 2005).

Figure 2 showing the difference between radio frequencies (20 and 60) GHz by clarification the relation between Q-factor and distance of FSO can operated to transporting 2.5 Gbps. In clear air weather RF 20 GHz get a maximum distance was 11.5 km with acceptable Q.factor was 6.056 but when distance increasing above 11.5 km the Q.f will become un-acceptable, while RF 60 GHz could has maximum distance 10.9 km with Q.f was 6.003. Also in light rain weather RF 20 GHz can operate a longest link than 60 GHz the max distance could get it was 5.6 km while RF 60 GHz has 5.4 km. Similarly in moderate rain weather RF 20 GHz could bring 2.89 km while 60 GHz operated 2.80 km. likewise heavy rain weather of high attenuation the max link could RF 20 GHz operate was only 2.1 km while RF 60 Ghz has 2 km. This net to us that RF 20 GHz get a further distance by currying the same information of RF 60 GHz due to the lowest RF facing less losses than high RF (Ng'oma, 2005). Figure 3 showing the difference between radio frequencies (20 and 60) GHz to transporting 10 Gbps

Table 1: Fixed value of simulation Ro-FSO design

Variables	Values
Source wavelength	1550 nm
Source transmit power	10 dBm
Source transmit line width	1 MHz
Transmitter aperture diameter	5 cm
Receiver aperture diameter	20 cm
Divergence angle	1.5 mrad

Table 2: The results that provide of transmitted 2.5 Gbps at maximum link

W.C	α (dB/km)	C_n^2	RF (GHz)	Max link	BER	Q.factor
Clear air	0.43	5×10^{-14}	20	1105 km	6.9×10^{-10}	6.056
			60	10.9 km	9.5×10^{-10}	6.003
Light rain	1.98	0.6×10^{-14}	20	5.6 km	4.7×10^{10}	6.117
			60	5.4 km	7.1×10^{-10}	6.051
Mod rain	5.84	0.5×10^{-14}	20	2.89 km	7.2×10^{-10}	6.048
			60	2.80 km	7.2×10^{-10}	6.048
Heavy rain	9.29	0.4×10^{-10}	20	2.1 km	4.4×10^{-10}	6.127
			60	2 km	3.5×10-11	6.516

Table 3: The results that provide of transmitted 10 Gbps at maximum link

W.C	α (dB/km)	C_n^2	RF (GHz)	Max link	BER	Q.factor
Clear air	0.43	5×10^{-14}	20	7 km	5.9×10^{-10}	6.080
			60	7.3 km	8.9×10^{-10}	6.013
Light rain	1.98	0.6×10^{-14}	20	4 km	8.5×10^{-10}	6.022
			60	4.1 km	8.9×10^{-10}	6.014
Mod rain	5.84	0.5×10^{-14}	20	2.22 km	8.1×10^{-10}	6.030
			60	2.26 km	7.5×10^{-10}	6.040
Heavy rain	9.29	0.4×10^{-14}	20	1.66 km	7.2×10^{-10}	6.049
			60	1.69 km	8.2×10^{-10}	6.026

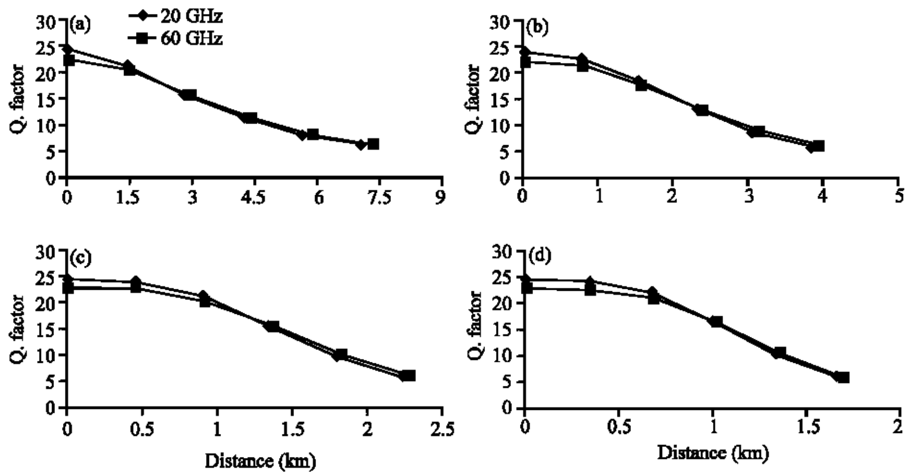

Fig. 3: a-d) Transporting 10 Gbps under clear, light rain, mod rain and heavy rain

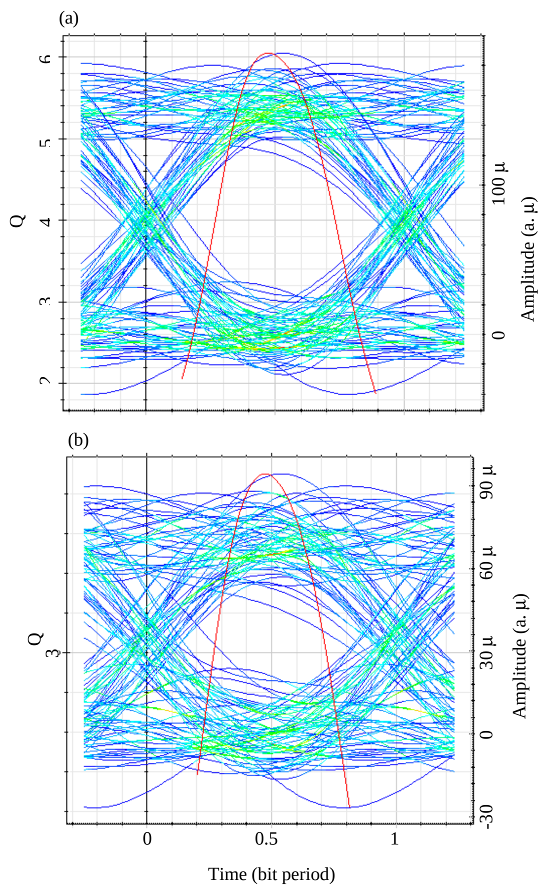

Fig. 4: Eye diagram for A. acceptable max link, B. un-acceptable link (for RF 20GHz): a): At 1.66 km in heavy rain and b) At 1.9 km in heavy rain

by clarification the relation between Q.factor and distance of FSO can operated. In clear air weather RF 60 Ghz operated a maximum distance 7.3 km with acceptable Q.factor 6.031 while RF 20 GHz could has maximum distance 7 km with Q.f 6.080. That because the lowest RF carrying high bit rate cannot travel through long link. Also in light rain RF 60 GHz can operate longest distance 4.1 km than RF 20 GHz that operated 4 km. Again in moderate rain weather RF 60 GHz reach to 2.26 km and RF 20 GHz got 2.22 km. similar in heavy rain weather the max link could RF 60 Ghz operate was only 1.69 km while RF 20 GHz has 1.66 km. this net to us that RF 60 GHz get a further distance by currying the same information of RF 20 GHz due to the high bit rate information which the highest RF is the better carrying capacity (Ng'oma, 2005).

Figure 4 showing the eye diagram for transmission 10 Gbps bit rate with RF 20 GHz over (a) 1.66 km of FSO and (b) 1.9 km of FSO, under heavy rain weather condition.

CONCLUSION

In this study the simulation transmission of 2.5 Gbps and 10 Gbps data has been comparison under clear air and rain weather condition by Ro-FSO communication design system. It's was found RF 20 GHz transfer 2.5 Gbps over longest distance of FSO compared with 60 GHz and RF 60 GHz transfer 10 Gbps over longest distance than 20 GHz. Thus due to the wider bandwidth of highest radio frequency make it enable of carrying high data rate.

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