

# Improvement of the Performance of Free Space Optics Channel Based on Optimized Systems Parameters

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**Abstract**—With the technology of free space optical communication, information can be transmitted from the transmitter to receiver wirelessly without the necessity of fiber optic cables. This technology offers system security, extended bandwidth, high data rate, and simple installation. This work aims to improve the optical channel based on the optimization of different optical amplifiers and filters. Performance analysis is carried out using a rectangular optical filter (ROF) and two electrical amplifiers named automatic gain control (AGC) and transimpedance amplifier (TIA). The results are presented in terms of maximum quality factor as a function of link range. The proposed systems (represented by ROF and AGC) brought better performance than traditional one (represented by TIA) via the same link range and data rates used. The findings displayed the progress of the AGC which has better quality factor than TIA and ROF. For instance at 5 m length, the AGC achieves a maximum Q-factor of 12.29, while the ROF and ATI reveal a Q-factor in the range of 9.8 and 7.01, respectively.

## 1. INTRODUCTION

The investigation of optical free space technique supported with higher data rates becomes one of the interesting research areas and hot issues. This technique has played a vital role and contributes to reducing the limitation in fiber optic construction [1–4]. Optical wireless channels starting from the source information to the receiver end are used to send parallel energy radiation as an alternative to a guided optical fiber. However, the performance of the optical wireless network is greatly affected by atmospheric and ground conditions. The optical signal is intercepted by a photo detector at the destination, and the data are drawn out from the light radiation and demodulated. The output signal is reshaped and then submitted to the free space optics (FSO) hardware to be obtainable for several distances. The communication process is perfectly accomplished if there is a clear match between the input source and output destination. The reflection of the energy depends on the positions of mirrors despite the absence of a direct line of vision. With little or no existence of attenuation, the laser beam can transmit optimally through a window. The optical wireless communication system can provide a rising transmission rate and big capacity channel in optical communication; therefore, it presents a perfect solution for various broadband networks. However, the climate condition can obstruct the transmission way and shut the network, which is one of the most important restrictions. With the technology of optical wireless communication, different applications have been recently developed to meet the needs of modern life [5–13]. This work proposes the design and implementation of a free space optical network in the presence of various climatic obstacles. System performance was analyzed based on various influencing factors such as link range, data rate, optical amplifier, and optical filter.

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*Received 8 July 2021, Accepted 17 October 2021, Scheduled 19 October 2021*

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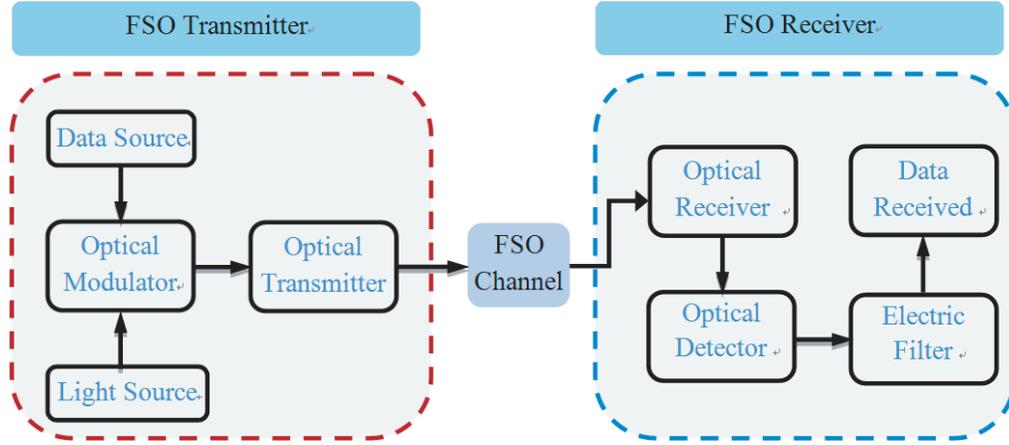
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## 2. OPTICAL TRANSMISSION SYSTEM MODEL

Free space communication has been known for its remarkable successes in bit rates, security, cheaping in installation, and no spectrum incense. In addition, it displays high immunization to electromagnetic interference, never detected using the RF meter nor health serious. Furthermore, it brings improvement in the bit error rate, exactly contrary from RF antennas, and also installation is fast and inexpensive. However, despite all mentioned, the FSO is affected by atmospheric properties which can decrease the signal efficiency [14–19]. In general, the wireless optical link consists of transmitting system, optic channel, and receiving system presented in Fig. 1. Utilizing an optical modulator, the system of transmitter sends the information and modifies it as an optical signal. Next, this signal propagates via optical channel media and then is detected by the receiver system to convert it as beneficial electrical shape. Information in an electrical form is carried by pulses that are generated via a pulse generator. The modulating system transforms the baseband signal to frequency with higher value which is more adequate for transmission. The climate conditions could noticeably diminish the signal in wireless channel. More specifics about the calculation of attenuation are described in [20].

$$\alpha_{total} = \alpha_{Fog} + \alpha_{Snow} + \alpha_{Haze} + \alpha_{Rainy} + \alpha_{Mist} \quad (1)$$

where  $\alpha$  is the attenuation in dB/km.



**Figure 1.** Free space optical channel.

On the other hand, detector system, low pass filter, and data received construct the receiver to demodulate the received signal.

The FSO channel module includes three main components: sender telescope, free space, and receptor telescope. Signal power received obeys different attenuation factors. Modeling relation between the power transmitted and power received could be described as [20]:

$$P_{received} = P_{transmitted} \times \frac{d_R^2}{(d_T + \theta_R)^2} \times 10^{-\alpha \frac{R}{10}} \quad (2)$$

where:  $P_{received}$  is the received signal power;  $P_{transmitted}$  is the transmitted power;  $d_R$  is the aperture diameter of receiver (m);  $d_t$  is the aperture diameter of transmitter (m);  $\theta$  is the angle of beam divergence (ARC);  $R$  is the link range (km), and  $\alpha$  is the atmospheric attenuation (dB/km).

The data of the transmission loss and receiving loss can adjust both transmitting-receiving telescopes. Additional losses can be assumed by the additional losses parameters, and the delay between transmitter and receiver can be adjusted by propagation delay parameters. If parameter intensity scintillation is used, the Gamma-Gamma distribution used to present the attenuation of the weather. For this matter, the probability I for a given strength is:

$$P(I) = \frac{2(\alpha\beta)^{(\alpha+\beta)}}{\Gamma(\alpha)\Gamma(\beta)} \times I^{(\alpha+\beta)/2-1} k_{\alpha-\beta} \left(2\sqrt{\alpha\beta I}\right) \quad (3)$$

where  $1/\alpha$  and  $1/\beta$  are the variance of large and small disturbances, respectively;  $\Gamma()$  is the Gamma-Gamma distribution function; and  $k_{\alpha-\beta}()$  is the second form of the improved Basal function

$$\alpha = \exp \left[ \frac{0.49\sigma_R^2}{\left(1 + 1.11\sigma_R^{12/5}\right)^{5/6}} \right] - 1 \tag{4}$$

$$\beta = \exp \left[ \frac{0.51\sigma_R^2}{\left(1 + 0.69\sigma_R^{12/5}\right)^{5/6}} \right] - 1 \tag{5}$$

The signal to noise ratio (SNR) on the FSO system is [21]:

$$SNR_{FSO} = \frac{S}{N} \tag{6}$$

where:  $S$  is the signal power at the receiver at  $\lambda = 1550$  nm, and  $N$  is a noise power caused by weather disorder.

The bit error rate (BER) represents the correctly received bits probability from the total bits sent

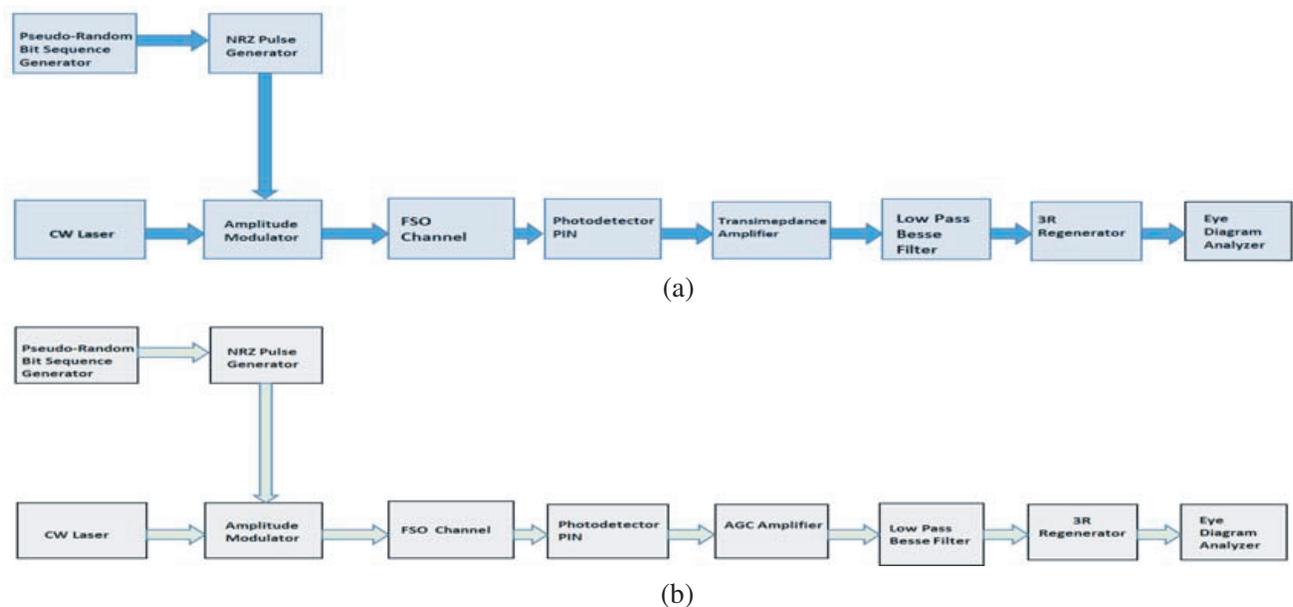
$$BER = \frac{\text{Number of errors}}{\text{Total number of bits transmit}} \tag{7}$$

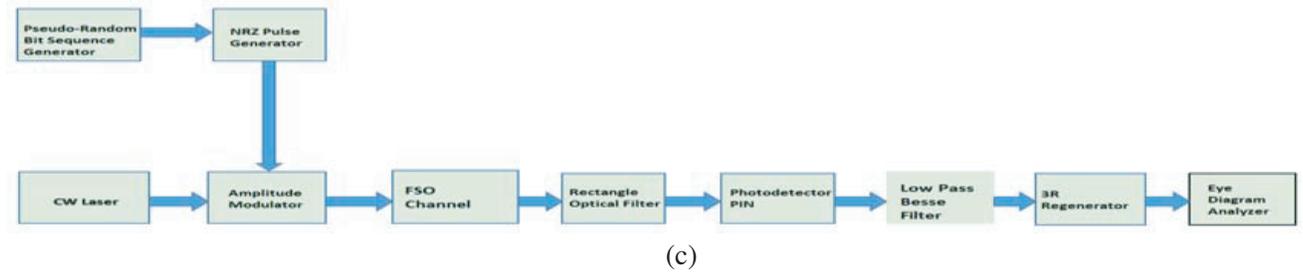
On the other hand, the BER can be calculated from the SNR of the received information [22]:

$$BER = \frac{2}{\pi \times SNR} e^{-\frac{SNR}{8}} \tag{8}$$

### 3. PRACTICAL SYSTEM DESIGN AND ANALYSIS

FSO system consists of a transmitter, propagation channel, and receiver. The traditional system configuration is clarified in Fig. 2(a). The optical transmitter is formed of a message signal generated using bit sequence (in the shapes of 0 and 1). The pulse generator creates the electrical pulse using non-return to zero (NRZ) method. The NRZ pulse mixed with laser beam is modulated using an electro-optic modulator called Mach Zender modulator (MZM). The transmitting antenna transmits the modulated optical signal to the FSO channel. The signal properties are handicapped in this optical





**Figure 2.** Schematic diagram of the free space network for (a) traditional system using TIA, (b) proposed system 1 using an AGC amplifier, and (c) proposed system 2 using an ROF.

channel caused by diverse climate state. The receiving antenna allows the receiver to receive the signal in optical domain and transform it to electrical domain using a photo detector. An Avalanche Photo Diode (APD) is employed here as a photo detector. The received signal is followed by a transimpedance amplifier (TIA). The low pass filter (LPF) passes the low frequency signals and stops the signal with high frequency in the form of noise. The efficiency of a received electrical signal is analyzed with the aid of a BER analyzer. Simulation parameters used in the system are described in Table 1. Two circuits are proposed to improve the performance of the optical wireless network, which were simulated, implemented, and compared with the traditional design in literature. In the first design, an electric amplifier named automatic gain control (AGC) was applied, while in the second design, a rectangle optical filter was used. Both designs were implemented as an alternative to the TIA in the conventional circuit system as shown in Figs. 2(b)–(c). The optical filter with a rectangle frequency transfer function

**Table 1.** Main parameters of the FSO simulation [6].

Optical wireless transmitter Parameters		
Parameter	Value	Unit
Input Power	6	mW
Wavelength	1550	nm
Bit rate	2, 4, 6	kb/s
Mark probability of Pseudo-Random Bit Sequence Generator	0.5	MHz
No of channels (N)	1	
Optical wireless channel		
Parameter	Value	Unit
Link range	5–11	m
Attenuation	30	dB/km
Beam divergence	170	mrad
Transmitter aperture diameter	5	cm
Receiver aperture diameter	4	mm
Optical Receiver Parameters		
Parameter	Value	Unit
Photo detector dark current	10	nA
Photodetector responsivity	0.7	(A/W)
Cut off frequency of low pass Bessel filter	3000	Hz

is described as

$$H(f) = \begin{cases} \alpha, & f_c - \frac{B}{2} < f < f_c + \frac{B}{2} \\ d, & \text{Otherwise} \end{cases} \quad (9)$$

The simulation parameters of the AGC amplifier, TIA, and rectangular optical filter are explained in Table 2. The FSO atmospheric parameters are illustrated in Table 3. The whole system design parameters of free space optical system have been adjusted according to recent published papers [6, 23] which are always based on recommendation ITU-T G.640.

**Table 2.** Simulation Parameters of AGC amplifier, TIA, and ROF.

<b>Transimpedance Amplifier</b>		
<b>Parameter</b>	<b>Value</b>	<b>Unit</b>
<b>Voltage gain</b>	<b>500</b>	<b>Ohm</b>
<b>Noise Equivalent Bandwidth</b>	<b>0.8 × Data rate</b>	<b>Hz</b>
<b>Noise Figure</b>	<b>6</b>	<b>dB</b>
<b>Input Noise Density</b>	$4 \times 10^{-24}$	<b>W/Hz</b>
<b>AGC Amplifier</b>		
<b>Output Voltage</b>	<b>0.005</b>	<b>V</b>
<b>Noise Equivalent Bandwidth</b>	<b>0.8 × Data rate</b>	<b>Hz</b>
<b>Noise Figure</b>	<b>6</b>	<b>dB</b>
<b>Rectangle Optical Filter</b>		
<b>Frequency</b>	<b>1550</b>	<b>nm</b>
<b>Bandwidth</b>	<b>2</b>	<b>dB</b>
<b>Insertion loss</b>	<b>10</b>	<b>GHz</b>
<b>Depth</b>	<b>100</b>	<b>dB</b>

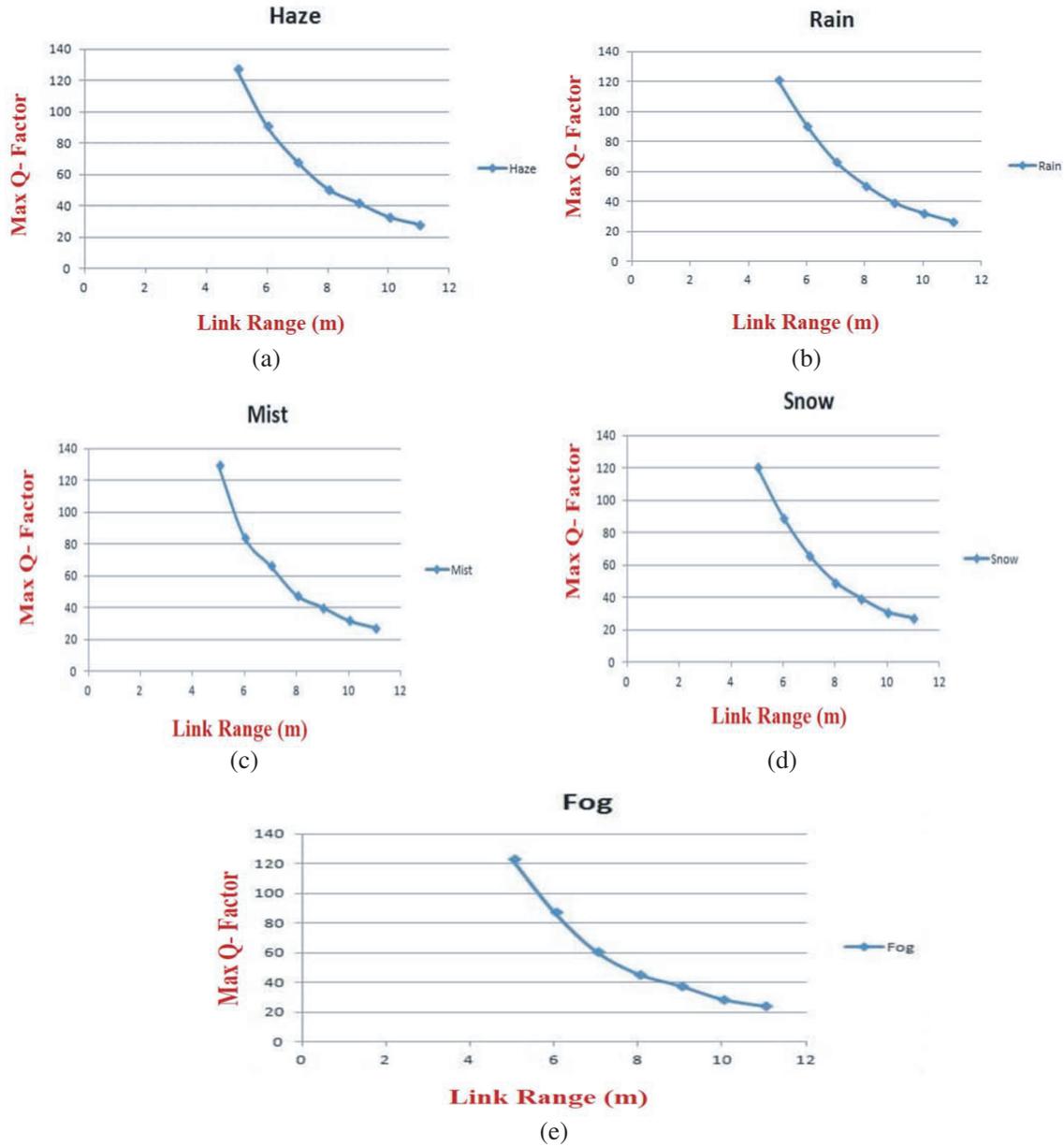
**Table 3.** FSO atmospheric parameters [6, 23].

<b>Atmospheric conditions</b>	<b>Attenuation (dB/km)</b>
<b>Haze</b>	<b>10.9–20.6</b>
<b>Rain</b>	<b>6–30</b>
<b>Mist</b>	<b>28.5–31.4</b>
<b>Snow</b>	<b>40</b>
<b>Fog</b>	<b>70</b>

## 4. RESULTS AND DISCUSSION

### 4.1. Performance Analysis of Q-Factor under Different Weather Conditions

The impact of various weather cases on the FSO performances has been investigated in Figs. 3(a)–(e). It is clear that there is an inverse relationship between the attenuation and Q-factor in such a way that increasing the attenuation leads to degrading the Q-factor and vice versa. High Q-factor appeared under Haze effect where  $\alpha = 20.6$  dB/km while lower Q-factor appeared under Fog effect where  $\alpha = 70$  dB/km. To enhance the system performance under worse atmosphere circumstances, two proposed systems have been tested and compared with a traditional system. All findings obtained are shown in Figs. 4–6.



**Figure 3.** Quality factor vs optical link range for different weather conditions at (a) Haze, (b) Rain, (c) Mist, (d) Snow, and (e) Fog.

#### 4.2. Performance Analysis of Q-Factor and Eye Diagram for Proposed Models

In this section, the performances of the prior and enhanced models in terms of maximum quality factor and optical link range at different data rates are displayed. Figs. 4(a)–(c) show the relationship of max Q-factor as a function of link range for three values of data rate 2, 4, and 6 kb/s. The results state that with the raised link range, the max quality factor is reduced for the prior and modified models at different rates. Our modified model has achieved better results than the previous model. For instance, at 6 kb/s data rate, the AGC amplifier offered better performance than other models where at 5 m link rang, the Q-factor was 12.29 as compared with the TIA and rectangle optical filter (ROF) where the Q-factors were 7 and 9.8, respectively.

Figures 5(a)–(c) present the eye diagram after simulations at 11 m link range with bit rate of 6 kb/s

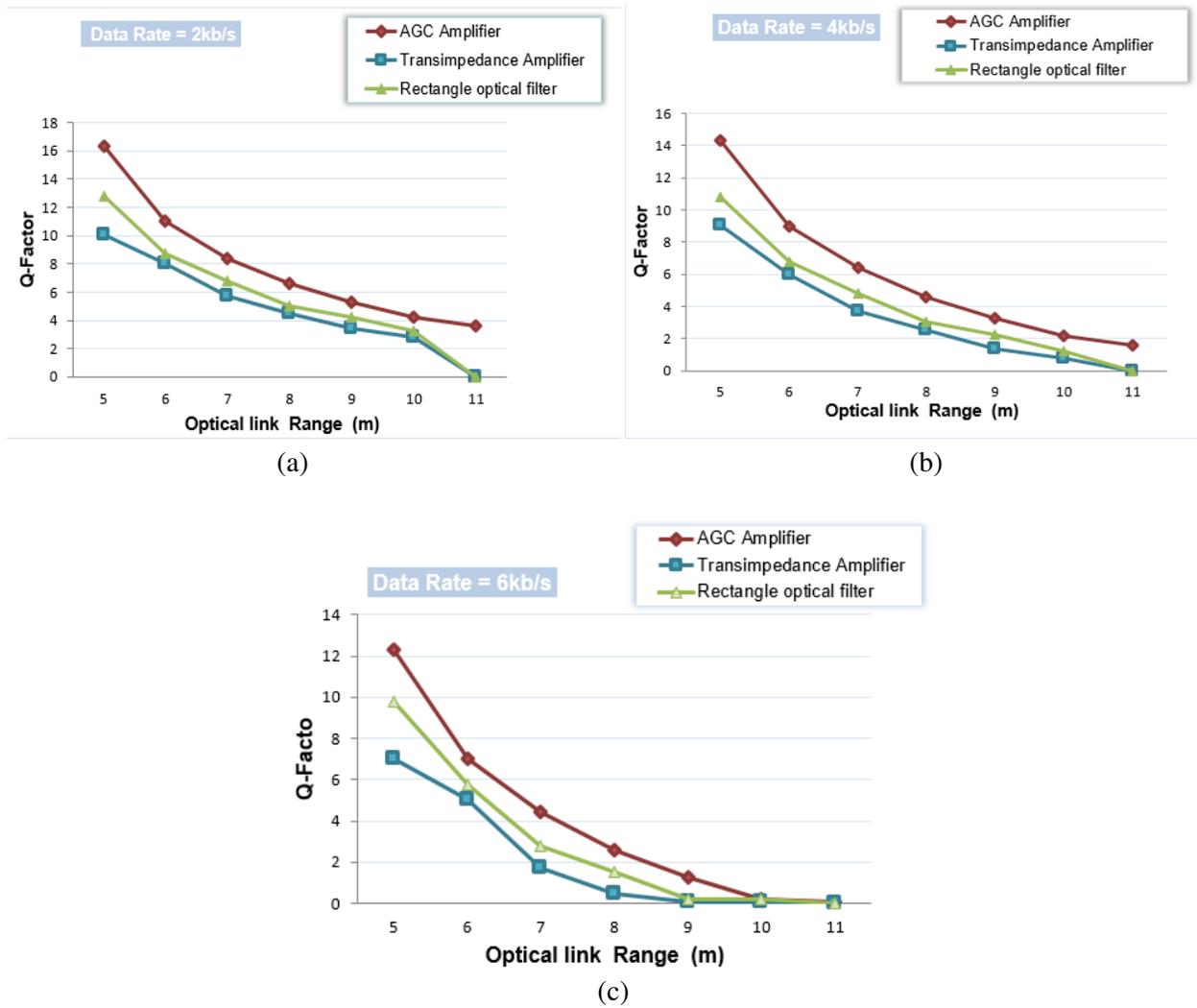
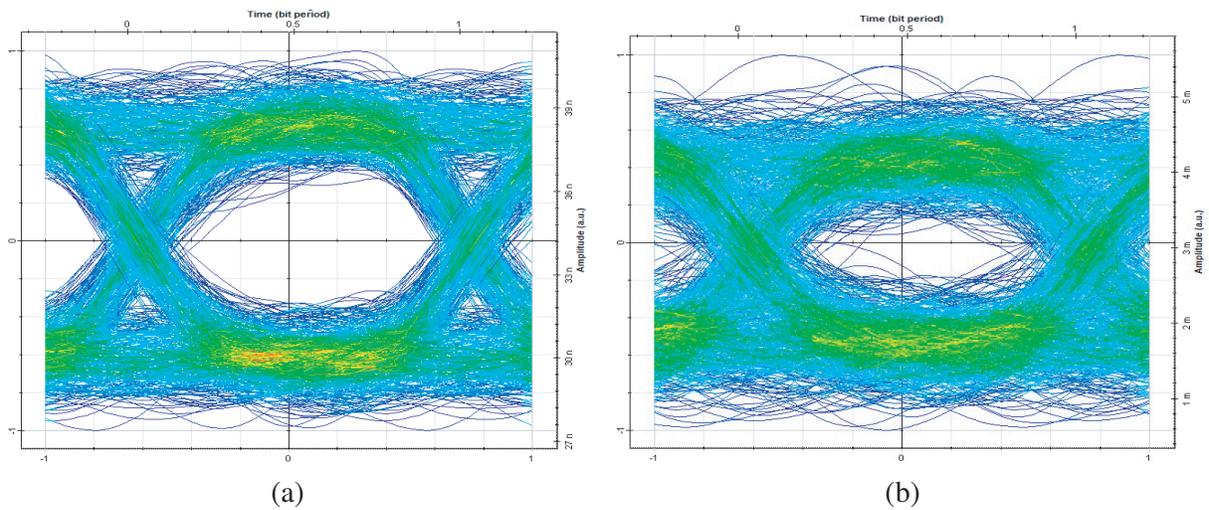
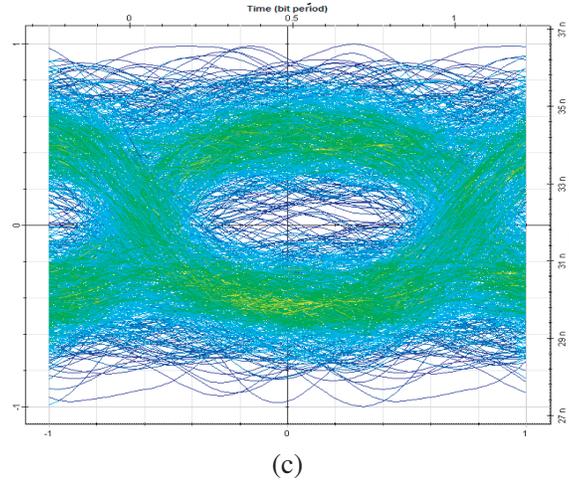


Figure 4. Max quality factor vs optical link range of AGC amplifier, TIA, and ROF at (a) 2 kb/s, (b) 4 kb/s, (c) 6 kb/s.



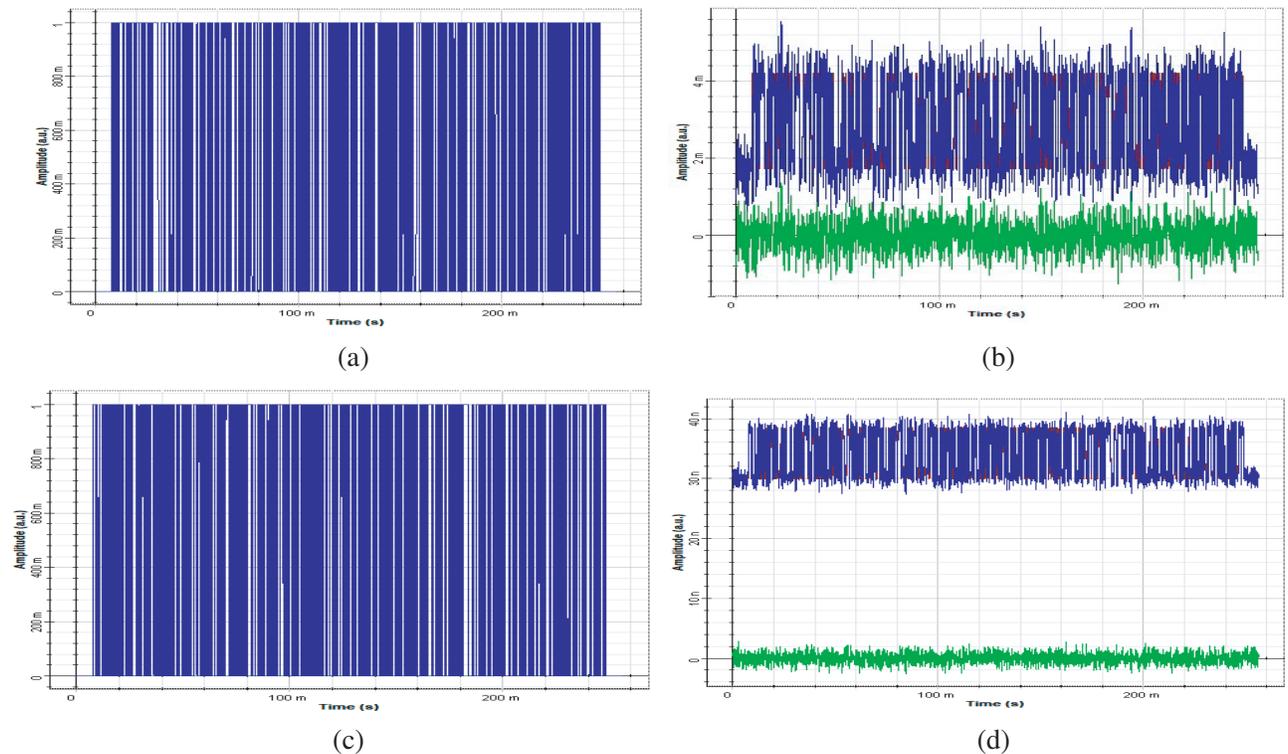


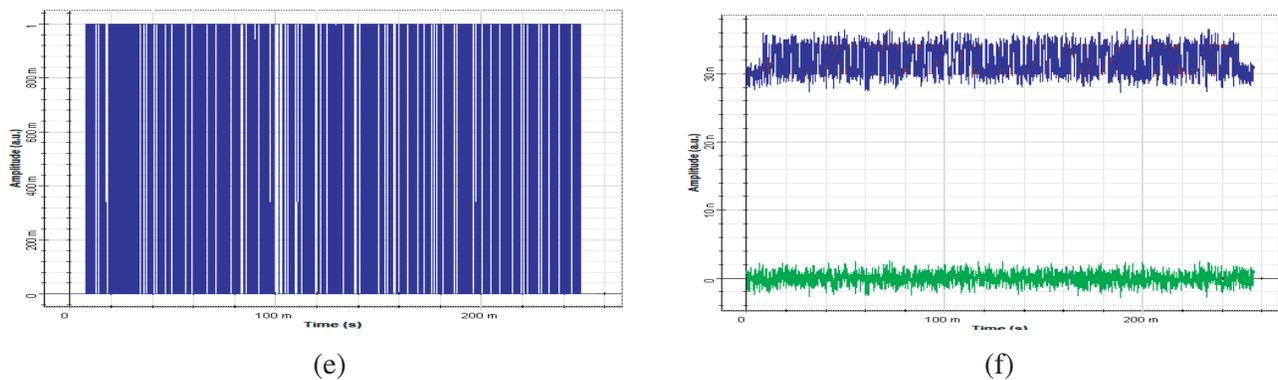
**Figure 5.** Eye diagram Performance of the FSO network for 6 kb/s at (a) AGC amplifier, (b) optical rectangle filter, and (c) TIA.

are performed at 6 dBm input power. AGC amplifier has better eye diagram ( $Q = 12.29$ ), while in the case of the TIA and ROF, the eyes are less clear, with the  $Q$ -factors ( $Q = 7$ ) and ( $Q = 9.8$ ) at the same input condition. Thus, this gives significance that efficient eyes diagram means the system in optimal status and successful in extracting of (1, 0) without noise crosstalk.

### 4.3. FSO Link Simulation Results of the Transmitted and Received Signal

Figure 6 illustrates the results of the simulation of the optical wireless system for the transmitted and received signals for both the conventional system and the two proposed systems which are shown in Figs. 6(a)–(f). The simulation results proved that the first proposed system (AGC amplifier) gave higher





**Figure 6.** FSO link simulation results for transmitter signal and receiver signal of three cases, (a) transmitted signal of AGC amplifier, (b) received signal of AGC amplifier, (c) transmitted signal of rectangle optical filter and (d) received signal of Rectangle optical filter, (e) transmitted signal of TIA and (f) received signal of TIA.

received signal than the other systems used (ROF and TIA). The quality in the received signal reflects the optimum SNR.

## 5. CONCLUSION

FSO is an attractive communication that enables improved bandwidth and security. However, the wireless link effortlessly degraded the optical transmission. Both bit rate and system performance are largely affected by the climate status which strongly diminishes the signal. This study has proposed optimization factors to enhance the optical communication link based on optical filter and amplifier. Performance analysis is done using ROF and two electrical amplifiers which are AGC and TIA. The proposed systems imparted better performance than the traditional one under same input conditions. It was found that at 5 m link range the max quality factor was obtained using AGC in the range of Q-factor of 12.29, while in the case of both ROF and TIA, the Q-factors were 9.8 and 7.01, respectively. Finally, bad weather conditions which have a significant effect on signal quality can be improved based on the AGC amplifier.

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