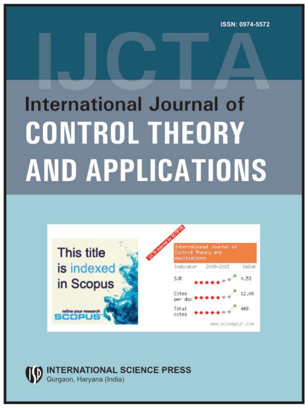

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Performance Analysis of Optical Wireless Communication System in Relation with SNR, Q-factor and BER

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Abstract: This paper presents the quality of service and system performance of optical wireless communication system. In this project, audio signals is transferred as far as 15 meters. As the link distance between the transmitter and receiver increases, the bit error rate increases, signal-to-noise ratio and quality factor decreases. In this research, OptiSystem was used to build the simulated model and MATLAB was used to assist signal-to-noise ratio calculations. The simulated and experimental receiver's power output were compared and it is found that the experimental model's efficiency is at 66.3%.

***Keywords*:** Optical Wireless Communication (OWC), Free Space Optics (FSO), Quality of Service (QoS), Bit-Error-Rate (BER), Q-Factor.

1. INTRODUCTION

The optical wireless communication system mainly comprises of three major parts: the transmitter, receiver and propagation channel. OWC is also known as Visible Light Communication (VLC) or Free Space Optical (FSO) has been propagating signals through at a wavelength between 380nm to 740nm for VLC and 750nm to 1600nm for laser through free and open spaces [1]. Similar with fibre optics, OWC system sends signals from the transmitter to receiver in the form of light. Though fibre optics propagates through glass fibre medium, OWC propagates light through air. Although it shares the same term of being wireless, but OWC is an optical technology that uses properties of light such as IR or laser to propagate [2]. Hence, many industry players are favouring the usage of IR because it brings numerous advantages such as IR is not affected by certain regulations on RF and OWC requires no spectrum licences, thus saving acquiring cost [3]. OWC is promising as a solution for the "last mile" bottleneck in wireless communications. As for radio frequency (RF), it is facing a soon to be congested spectrum, emerging security and terrorism issues, lower data rate and high cost of installation [3]. In the market today, many users are subscribing to RF wireless LAN products as WiFi hotspots commercially or at residential. However, RF wireless LAN uses the unregulated "free" spectrum region of 2.4 GHz and it has limited channel bandwidth [4]. As for fibre optical technology, it does offer good QoS but unable to reach everyone especially in the rural areas and has no mobility advantage because it is a wired technology [5]. OWC system has applications ranging from short range to ultra-long range. Currently, OWC systems are being used by military and space operations. A few vendors have started providing OWC system to industrial and commercial players as well. It is projected that by 2020, RF technologies power consumption will dominate the global network. However, optical link has the best bit rate and the lowest normalised energy consumption compared to the rest of RF wireless communication standards [6].

The main reason behind optical link's efficiency is due to having optical properties as baseband, resulting in a simpler transmitter and receiver architecture [6]. Whereas for RF systems, its complex transceiver architecture causes substantial dissipation loss of power [6]. In the recent years, there has been an emerging research and applications of integrating both optical and RF wireless network also known as radio over fibre (RoF). RoF systems are capable of reaching data rates up to 500 Mbps but the transmission is still limited by the low carrier frequency [7].

2. METHODOLOGY

The hardware's results will be obtained by collecting the receiver's output and feed it to the multimeters and digital oscilloscopes. By manipulating the propagation distance between the transmitter and receiver, the receiver's output voltage, current and signal waveforms will be collected. Due to the limited equipment in the engineering lab, Optiwave OptiSystem software will be used to produce a simulated circuit and calculate the model's BER. As for SNR, MATLAB software will be used to calculate it. The following subchapters will discuss more details.

2.1. System Model

Figure 1 shows the system model when the audio is transmitted by a laser diode. The transmitter circuit is intended to be designed such a way that it can transmit wirelessly to the receiver. The input signal is an audio signal that will fed by the audio generator. The laser is responsible to transmit the light at a distance. The phototransistor at the receiver's end supposed to be directed Line of Sight (LOS) link to the transmitter's laser beam.

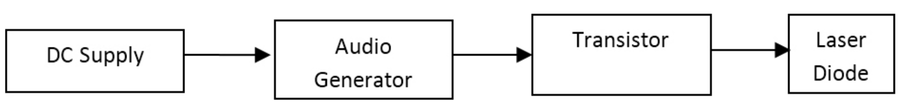

Figure 1: The audio is transmitted by a laser diode

Figure 2 shows the audio is being received by the phototransistor The receiver circuit is proposed to use phototransistor to receive laser signals from the transmitter. As the received signals produce voltages, it is further amplified with the signal amplifiers. Then, it will be converted back to audio signals and to be heard by the speaker. The speaker has an in built gain or volume dial to further boost the signal amplification.

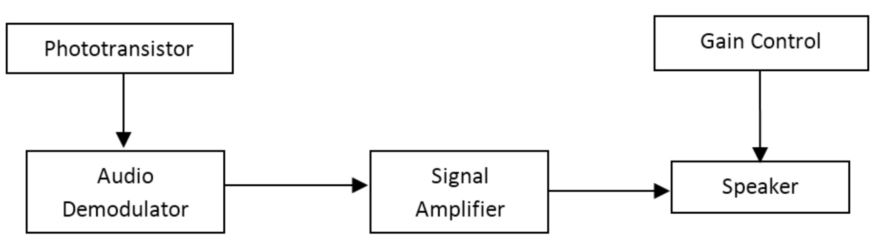

Figure 2: The audio is being received by the phototransistor

Table 1 shows the fixed parameters for both the experimental and software OWC model to reduce fluctuations of the results.

Table 1
OWC system parameters for this project

Transmitter Front End (Laser + Modulator)		*Receiver Front End (Photodetector + Amplifiers)*	
Operating Wavelength	*650 nm*	*Type of Photodetector (PD)*	*PIN Photodetector (Solar Cell)*
Class	Class 3A	PD Responsivity	0.233A/W
Average Optical Output Power	5 mW	PD active area	0.5 cm^2
Bit Rate	320 kbps	Amplifier Frequency Response	100 Hz – 10 Khz
Input Signal	Audio Song (Pseudo-Random NRZ bits)	Amplifier Power Output	200 mW
Transmitter Aperture Diameter	0.2 cm	Receiver Aperture Diameter	0.8 cm

After identifying the project hardware specifications. Figure 3 introduces the experimental model of the OWC system and Figure 4 introduces the simulation model of the OWC system using OptiSystem software.

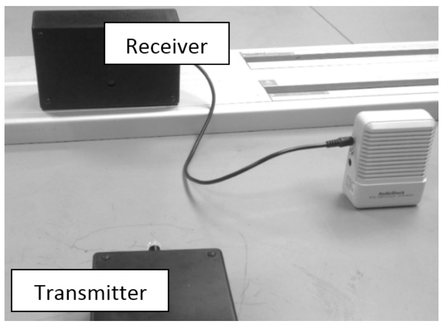

Figure 3: Experimental model of OWC system

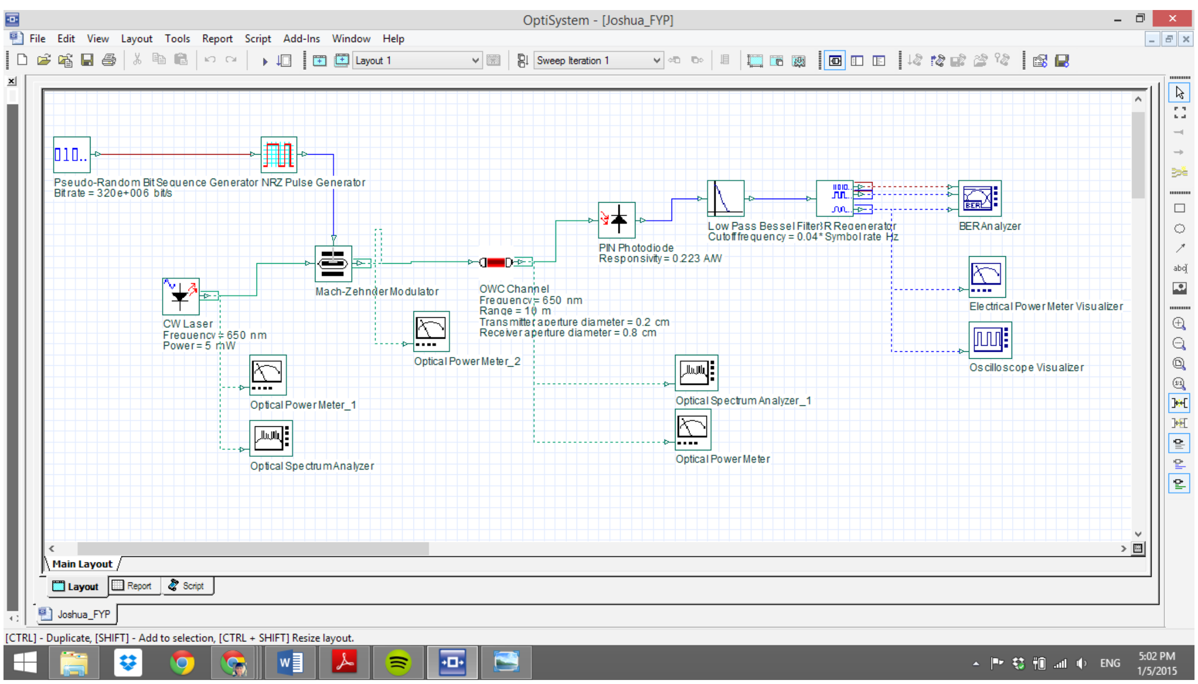

Figure 4: OWC System in OptiSystem

2.2. System Efficiency between Simulated and Experimental Model

Comparison will be made between the simulated data by using OptiSystem and experiment data. The manipulated variable will be the propagation link distance given a 320 kbps audio signal. The responding variable will be the output power produced at the PIN photodetector. Once the comparison is made, the efficiency of both the transmitter and receiver circuit can be calculated in terms of output (refer eq. 1). Repeat the whole process again by manipulating the propagation distance between the transmitter and receiver from 0.5 meter to 15 meters.

$$\text{system efficiency}, \eta = \frac{P_{\text{oexperimental}}}{P_{\text{osimulated}}} \times 100\% \tag{1}$$

2.3. Signal-To-Noise Ratio (SNR)

Signal-to-noise ratio is a measure of how a certain signal is being corrupted by noise. Defined as the ratio of signal power to the noise power along the signal, a ratio of more than 1 indicates more signal than noise. In communication system, higher SNR is favourable. Eq. 2 shows that the SNR in decibels (dB) [16]. For this project, SNR will be calculated with MATLAB by using Eq. 2 [16] because there is a limitation of tools to measure background noise power.

$$SNR_{dB} = 10\log_{10}\left(\frac{P_{\text{signal}}}{P_{\text{noise}}}\right) \tag{2}$$

2.4. Quality Factor (Q-Factor)

In optical communication, the common existence of signals are power and noise. That is why SNR is an important parameter for any communication systems. Q-factor is a dimensionless measurement where it simply indicates quality factor of the system whether it is underdamped or overdamped [8]. Given SNR, Q-factor is able to be calculated as shown in Eq. 3 [9]. T is the bit period and Bopt is the bandwidth of the optical filter used. In Optisystem, the Q-factor are calculated based on this equation.

$$Q = \frac{SNR\sqrt{2TB_{opt}}}{1+\sqrt{1+2SNR}} \tag{3}$$

2.5. Bit Error Rate (BER)

Bit error rate is usually a standard data given by any transmission devices. BER is the number of bit errors received by the total bits of the transmission media. These bit errors are usually due to noises or other interferences. The BER formula for this OWC system is shown in Eq. 4 [9]. This project will be built and simulate in OptiSystem software in order to get the BER and the Q-Factor using the BER analyser tool as shown in Figure 5 and 6.

$$BER = erfc\left(Q/\sqrt{2}\right)/2 \tag{4}$$

3. RESULTS AND DISCUSSIONS

The project prototype has successfully built and various experiments have been done to obtain the data for analysing. After performing experiments with the project prototype, the model is being built and simulated in OptiSystem software to further validate, verify and compare the actual experimental results. More details will be discussed in the subchapters.

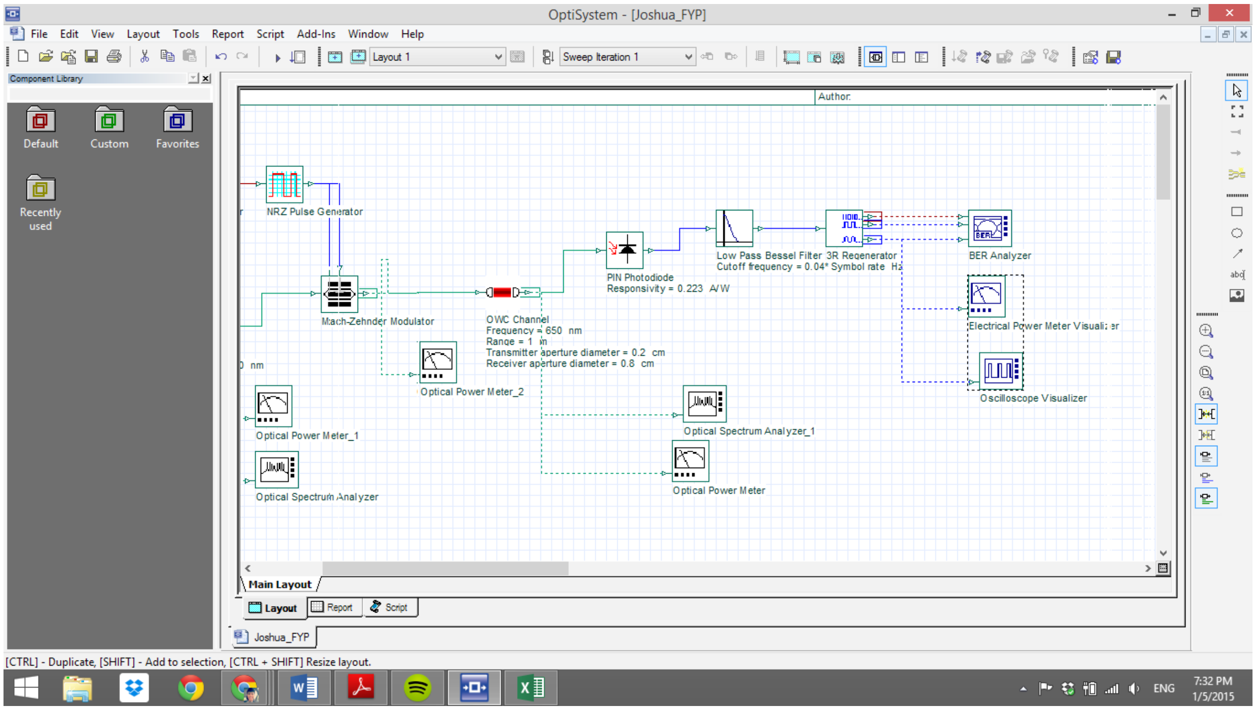

Figure 5: BER analyzer tool is connected to the simulation model output

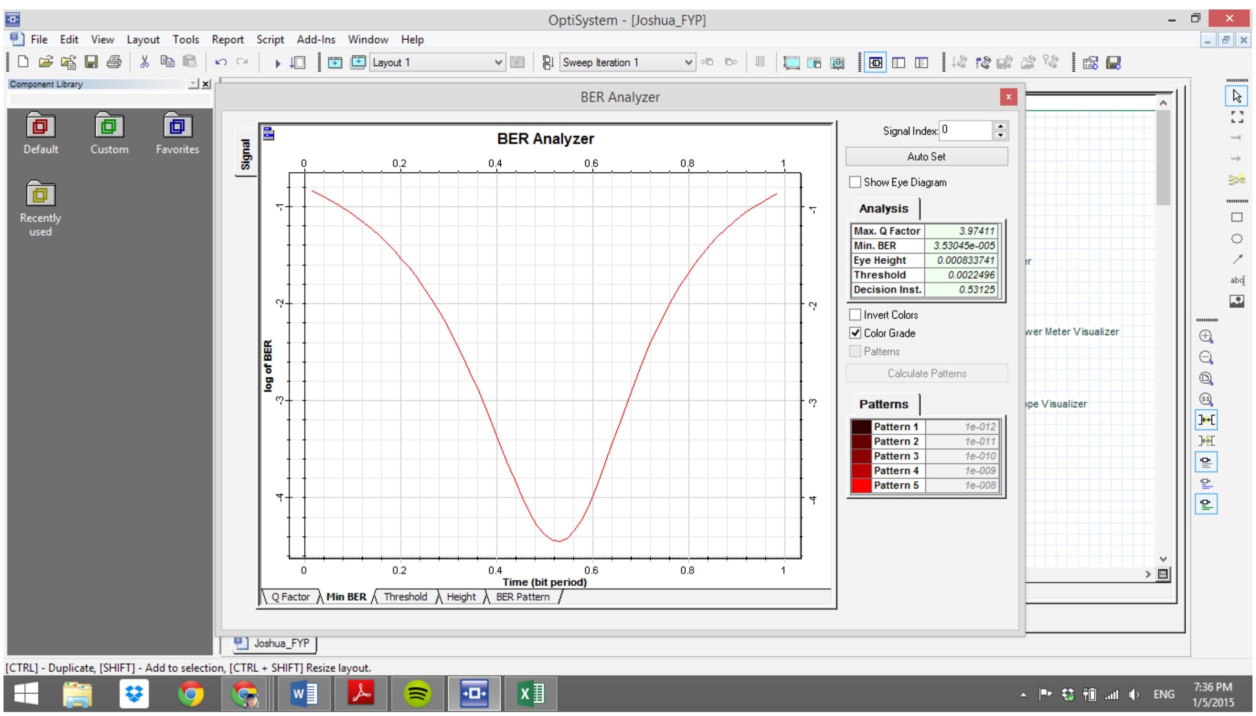

Figure 6: BER Graph in the Analyzer Tool

3.1. Receiver's Power Output vs. Link Distance

An audio signal that has a bit rate of 320 kbps was made as input of the transmitter. The laser then transmit light to the receiver at a distance ranging from 0.2 m to 15 m. A multimeter was tapped onto the output of the receiver's circuit for data collection. Once the experiment is done, a simulated model was performed sing OptiSystem 12. The power output of the simulated design is also being recorded.

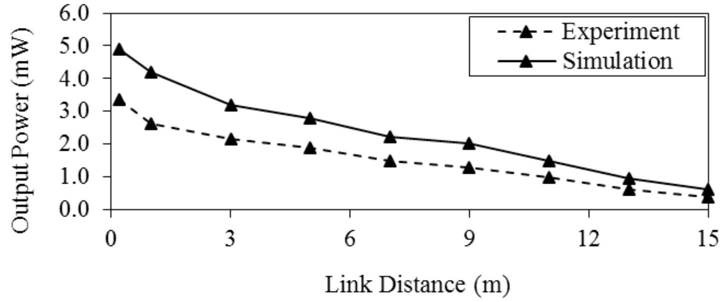

Figure 7: Receiver's output power vs. link distance

From Figure 7, results has shown that the receiver's power output is experiencing a decrease as the propagation link distance increase; just as expected in the initial proposal. At 0.2 m, the experimental receiver managed to give an output of 3.35 mW, the highest recorded; while the simulation model gives 4.91 mW. Bear in mind that the transmitter is sending a signal power 5 mW. At close proximity, the sound amplifier gives a very clear and loud audio sound. This is a classic trend in any audio wireless signal system where it shows that power signals become weak as propagation distance increases. At 9 m and beyond, the power loss became very obvious when the sound amplifier produced a very faint and soft audio sound. Unless the transmitter source increases its signal power, the receiver will suffer from poor signal power reception. In the case of laser, it is challenging to increase transmitting power because of the eye safety regulations that are in place. A higher power laser may cause harm and damage to human eyes. By comparing the simulated and experimental output, the overall system efficiency is at 66.3%. Generally, hardware components are bound by power losses such as heat dissipation, power supply fluctuations, minor current and voltage leakage, conversion rate of input signal to output signal. However, the major factor of such drop in efficiency is the atmospheric effect. Dust particles found in atmosphere can cause particle absorption and scattering. Thus, the drop in receiver's ability to achieve maximum 5 mW power given by the transmitter.

3.2. SNR vs. Link Distance

To aide calculations, MATLAB algorithms has been used to find out the SNR at link distance of 0.2 m to 15 m. Figure 6 show the results of SNR vs. link distance curve.

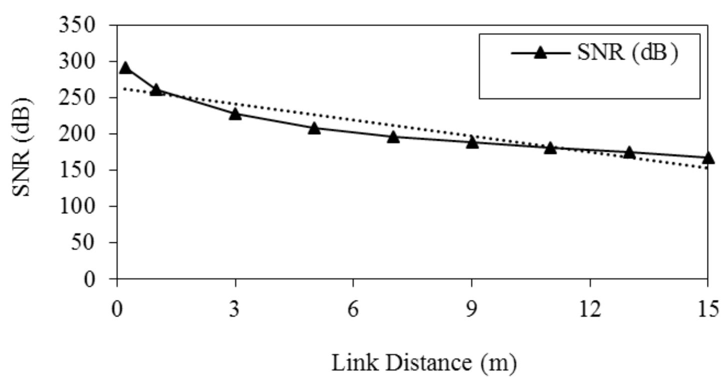

Figure 8: SNR vs. Link Distance

The SNR results demonstrated in Figure 8 that SNR decreases as the link distance increases. As explained in the research methodology, it is known that SNR is the ratio of signal power over noise power. Logically as the link distance increases, the receiver's output power would decrease too. As a result, the signal power diminish quickly and the noise power steadily increases. Hence, the SNR has decreased in respect of link distance just as expected. Poor SNR is a major concern in communication systems, therefore it is a priority to find ways improving the performance. Other than keeping both the transmitter and receiver distance at closer range, the introduction of signal processing filters at both ends are good methods to curb noise signals.

3.3. Q-Factor vs. Link Distance

Quality Factor (Q-factor) is a very useful parameter to indicate the performance of any communication systems. As mentioned in the research methodology, Q-factor at different link distance is being recorded by using the OptiSystem model. The BER Analyzer tool measured both BER and Q-Factor. Figure 9 shows the results of this OWC system Q-factor at distance of 0.2 m to 15 m.

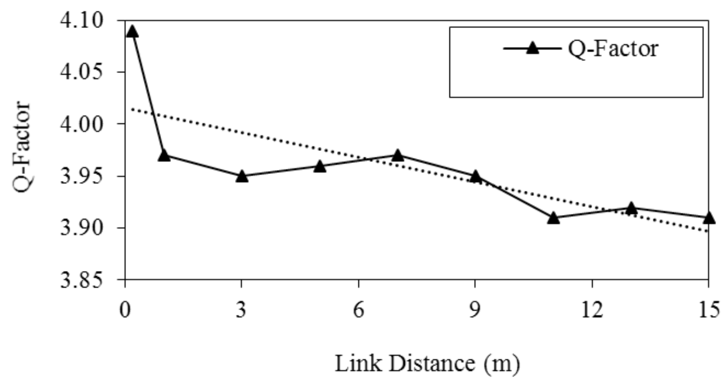

Figure 9: Q-Factor vs. Link Distance

The Q-Factor of this OWC system reflects the same trend as the BER and SNR. As explained in the previous chapter, Q-factor is a way of measure the quality performance of any communication system. Just as expected in the initial proposal, the Q-factor decreases as link distance. However at 0.2 m to 15 m, the Q-factor decreases at a very small rate. Just like the BER results (refer 3.4), the laser optical properties do not have immediate impact towards the system performance at such ranges of link distance. According to the simulated model, the system's non-functional point is at 600 meters. That is when the Q-Factor approaches 0.

3.4. BER vs. Link Distance

With the implementation of this OWC system in OptiSystem, the BER of this OWC system is able to be collected. Simply by connecting a BER Analyser Tool to the model's output, readings such as the eye diagram, BER and Q-Factor are able to be displayed. From Figure 10, higher BER indicates that the data signal has higher probability of error in its propagation. This is not favourable in all communication systems. However in this project, the BER is still within the range of 10-5 at 0.2 m to 15 meters. It was initially expected to increase exponentially but it shows that it increased steadily instead. This is due to the property of laser diode at a narrow 1 nm optical bandwidth, which is less prone to particle scattering and fading signals compared to IR LEDs. Figure 10 illustrates the trend of the BER vs. Link Distance from 0.2 m to 15 m. It shows a linear increase in the BER as link distance increases. Since the range of 0.2 m to 15 m did not display a significant decrease in performance, a larger link distance range (250 m – 600 m) has been investigated. In order to investigate the maximum distance when the BER is 1 for this system, the simulated model in OptiSystem was used. When BER is 1, it signifies that the probability of error in this system is unavoidable. According to Figure 11 output results, it is found that the maximum distance for this system to achieve BER=1 is 600 meters. From the results, it is inevitable that BER increases as link distance increases.

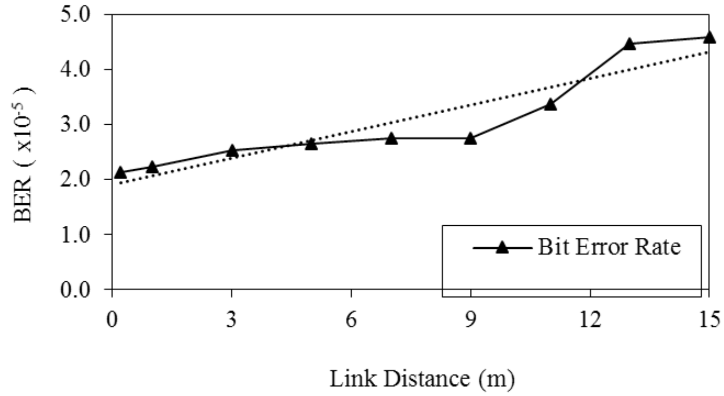

Figure 10: BER vs. Link Distance (0.2m-15m)

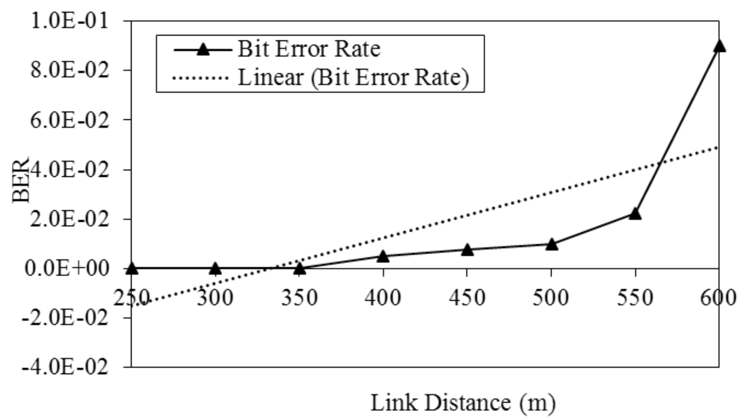

Figure 11: BER vs. Link Distance (250m-600m)

4. CONCLUSIONS

From the results collected, it can be seen that the efficiency of experimental vs. simulation model is at 66.3%. As the link distance increases, the BER increased, SNR and Q-Factor decreased. These outcomes are in line with hypothesis. According to the OptiSystem simulated model, this OWC system has a break down limit at 600 meters; where the BER is at 1 and Q-Factor at 0.

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