The Impact of Varying the Detector and Modulation Types on Inter Satellite Link (ISL) Realizing the Allowable High Data Rate

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***Abstract*—**This paper investigates the dependence of the transmission speed and the system performance of an inter satellite link (ISL) on the modulation technique and the type of detector used. In ISL links, the modulation technique used in transmission and the type of detector used for reception are significant factors that directly affect the quality of transmission between satellites. The paper proposes a transmission link model to obtain the maximum allowable data rate over different orbits. In this study, the Q-factor and the bit error rate (BER) are measured and analyzed for all scenarios in order to optimize the ISL performance.

Keywords- free space optics (FSO), field of view (FOV), inter satellite link (ISL), optical wireless communication (OWC)

I. INTRODUCTION

LASER communication links are rapidly developing technologies that have recently found applications in several areas including all-optical networks and free space optical (FSO) links indoors and outdoors [1]. An outdoor FSO link can be demonstrated ground to ground, satellite to ground or in deep space. Recently, FSO became a more promising technology for inter satellite links (ISLs) due to its less transmitted power, size and weight and higher speed, immunity, efficiency and reliability compared to microwave links [2].

Space based communications have been reported in the literature and implemented in laboratory demonstration systems for more than 30 years [3]. The ISL between different orbits is demonstrated in the SILEX program by ESA and JAXA [4]. These orbits are named low earth orbit (LEO), medium earth orbit (MEO) and geosynchronous orbit (GEO) and are categorized by their distances as listed in Table 1 [5]. Artemis satellite was placed in the GEO while SPOT 4 was in LEO at altitude of 832 km [6]. In December 2005, a full-duplex communication between Artemis and Kirari was practically achieved to validate the possibility of an ISL [7].

TABLE I. THE DISTANCES OF DIFFERENT ORBITS

Orbit Name	Distance between orbits, (km)
LEO - LEO	200 – 1,200
MEO - MEO	1,200 – 35,000
GEO	36,000

As listed above most of the communication systems were simplex links similarly in this paper the proposed simulated link will be simplex as well. In this paper we study the impact of both the modulation scheme and the detector used on the transmission of high speed data rate over an ISL between different orbits. The following section presents the proposed simulated model for the ISL investigated in this paper. The Q-factor and the bit error rate (BER) results for all investigated conditions are presented and analyzed in section III to optimize the system performance. Finally, section IV concludes the paper findings.

II. SYSTEM MODELING

In examining ISL performance, it is important to take several system specification parameters into consideration which affect the performance of the link. These parameters can be divided into two different categories: internal parameters and external parameters. Internal parameters are related to the design of an ISL which include optical power, wavelength (λ), transmission bandwidth, types of lasers used in the transmitters, divergence angle, and optical loss on the transmit side. In addition to receiver sensitivity, BER, receive lens diameter, receiver FOV, and receiver's detector on the receive side [8]. External parameters are related to the environment in which the system must operate and include visibility and atmospheric attenuation, scintillation, deployment distance, window loss, and pointing loss [9].

Nevertheless the effort of this paper mainly will depend on some internal parameters neglecting the external

978-1-4799-2975-7/13/$31.00 ©2013 IEEE

parameters because in deep space there is no requisite for turbulence environmental effect.

A typical FSO communication system is like any other communication technology as shown in Fig. 1. Intended for ISL is consists of an optical transmitter which is a semiconductor device like an LED or a laser but in this proposed link is Continues Wave (C.W) laser with frequency of the transmitter is set to be approximately 353 THz or 850 nm in wavelength with input power 12 dBm, a modulator which is Mach Zender modulator, an irradiation device and in the most cases either a telescope or a lens. The receiver is basically composed of a photo detector whatever PIN photodiode or the avalanche photodiode (APD), a decoder and again a telescope or a lens to collect the arriving optical signal. The signal performance is observed on BER analyzer. This signal propagates through the free space therefore the free space represents the link channel as seen in Fig. 1. The proposed link is modeled and simulated using the OptiSystem Optiwave simulation.

The selection for 850 nm wavelength as a fixed parameter because is consider the most commonly used in ISL specifications, in plus there are several vendors provide higher power laser sources that operate in this region [9]. The rest of these fixed parameters are listed in table 2.

TABLE II. SIMULATED ISL FIXED PARAMETERS

Parameters	Value
Wavelength	850 nm
Input power	12 dBm
MZ modulator with Extinction ratio	26 dB
Responsivity	1 A/W
Dark current	10 nA

By varying the detector and modulation type at different distances between the two satellites depending on orbit type, the value of maximum allowable data rate is achieved, Q-factor, minimum BER and received power as well is obtained and discussed in next section.

IV. RESULTS AND DISCUSSION

This paper simulates the link using parameters as in table 2 under LEO and MEO distances with varying in the detector type using APD or PIN at different data rates depending on each orbit. The used data rate is 2.5 - 40 Gbps at LEO orbit and 30-100 Mbps at MEO orbit. We valued that the best Q-factor is about 40 which give zero minimum BER at distance 600 km for LEO orbit in case of APD and is decreased comparing by using PIN as observed in Fig. 2. Also by increasing the distance in case of using PIN the Q – factor will decrease to be zero which is give deprived indication for system performance.

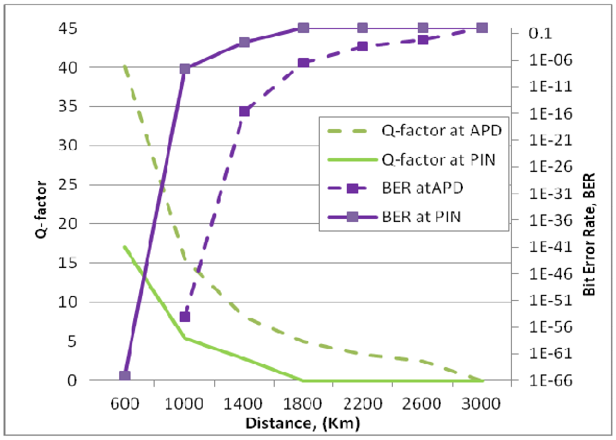

Fig. 2. System performance in terms of Q-factor and Min BER in different detectors

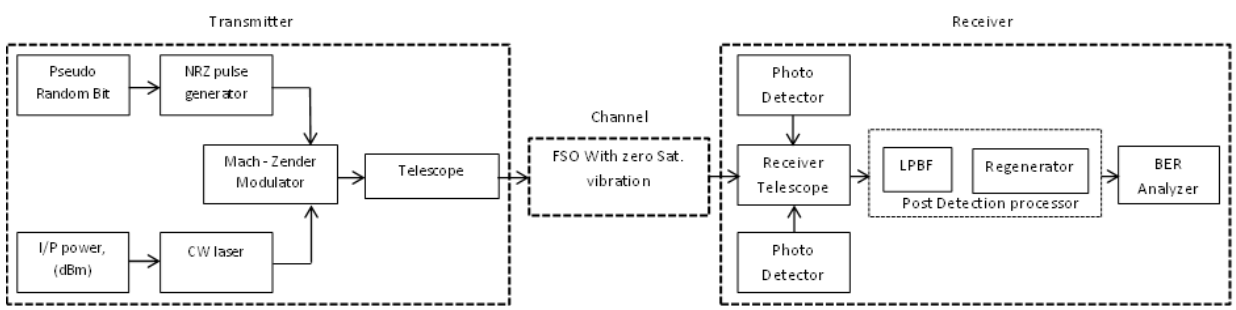

Fig. 1. FSO Communication System

Referring to the simulated results in Fig. 3 and 4 we noticed that in case of using PIN detector the Q- factor of the system is too small comparing to APD. Since using PIN detector is reducing the size of eye-opening which will increase the potential occurrence for data errors and jitter as well. Comparing the eye-opening using APD it will be wider and the jitter is decreased which give better system performance. So it is preferred to use APD rather than PIN detector.

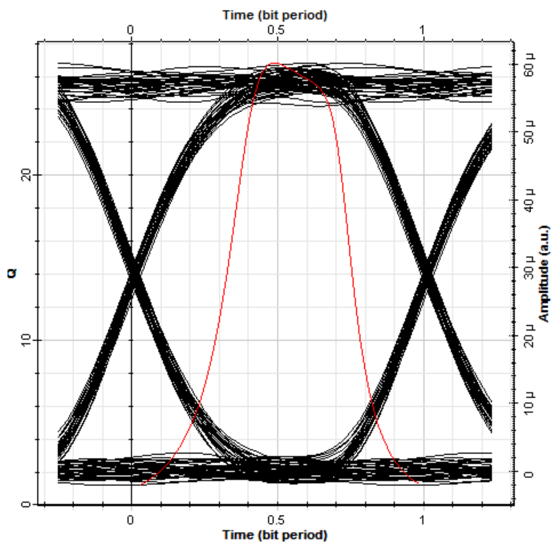

Fig. 3 Eye diagram and Q- factor at the receiver of data rate 5.6 Gbps at 600-LEO distance using APD detector

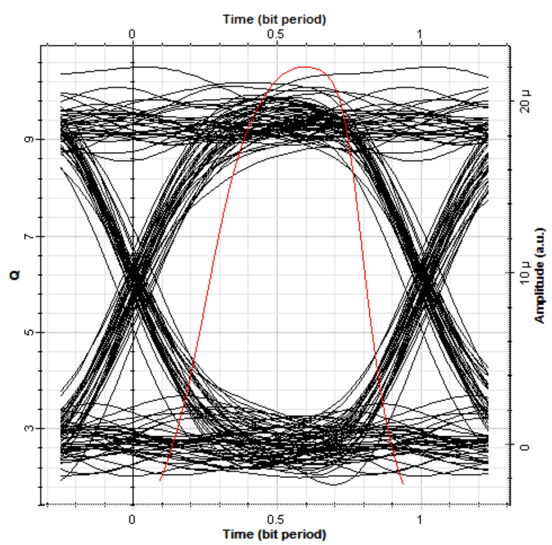

Fig. 4 Eye diagram and Q- factor at the receiver of data rate 5.6 Gbps at 600- LEO distance using PIN detector

Consequently the next circumstances in this paper will work on APD detector with changing in distance. Noticed from Fig. 5 that at sending the same data rate at different increasing distances the Q – factor is decreased. Then each distance has own max data rate for instance is 2.5 Gbps for 1400 km LEO distance and that rate cannot be sent for more than 3000 Km because the Q- factor will decrease to be zero.

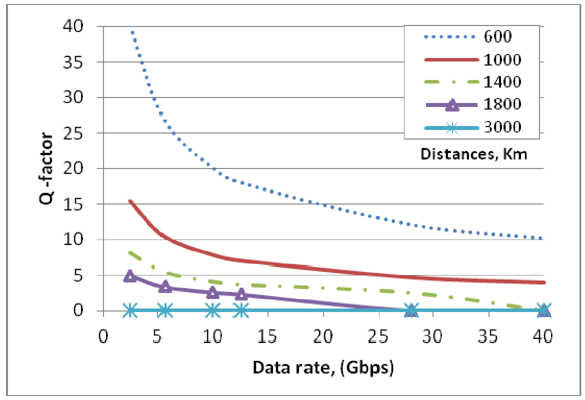

Fig. 5 Q-factor in relation with bit rate at LEO different distances

Similarly the maximum data rate at MEO distance which gives adequate performance in terms of BER≈10^{-6} using APD detector is listed in table 3.

TABLE III. COMPARISONS BETWEEN SYSTEM PERFORMANCE AND DATA RATES USING APD AT DIFFERENT DISTANCES

Orbit	Distance, (km)	Data rate	Q- factor
LEO	600	40 Gbps	10
	1000	28 Gbps	4.7
MEO	6000	30 Mbps	4
	12,000	1 Mbps	4.3

Although our model can accommodate various modulation schemes, in this paper, we consider modulation type to be NRZ otherwise RZ because of their relatively simple implementation. These modulations also in optical systems they are referred to as on-off keying (OOK). OOK is an intensity modulation scheme where the light source (carrier) is turned on to transmit a logic ”one” and turned off to transmit a ”zero”.

It is interesting to compare system performance in terms of Q –factor and BER of the different modulation schemes using APD detector. Table 4 shows the results of comparison and as mentioned in using RZ modulation the system performance decreased.

TABLE IV. SYSTEM PERFORMANCE AT DIFFERENT MODULATION TYPES AT LEO DISTANCE, 600 KM

Item	Data rate, (Gbps)	NRZ	RZ
Q- factor	2.5	40.1219	34.1866
	10	20.0617	17.1531
Min BER	2.5	zero	1.91E-256
	10	7.94E-90	2.97E-66

After simulating the link found that is much better to use NRZ modulation rather than RZ because as shown in Fig.6 the wider eye opening it will reduce the potential occurrence for data errors and give better system performance. However in RZ modulation scheme the system performance decreased as seen in Fig. 7.

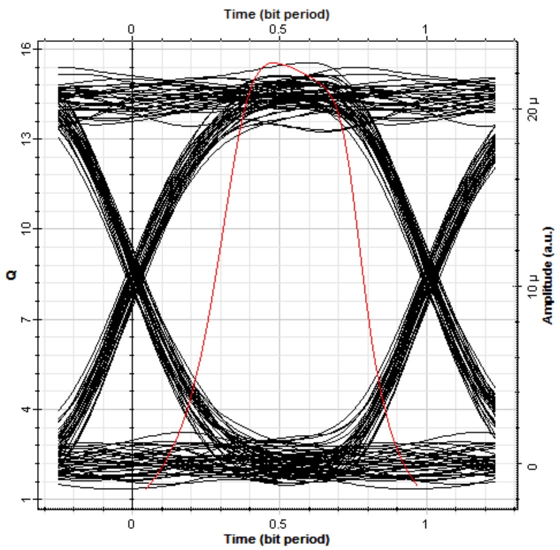

Fig. 6 Eye diagram and Min BER at data rate 2.5 Gbps at 1000 Km LEO orbit using NRZ modulation

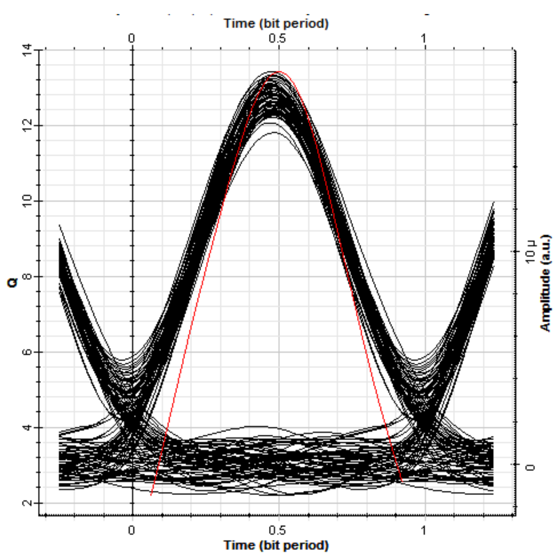

Fig. 7 Eye diagram and Min BER at data rate 2.5 Gbps at 1000 Km LEO orbit using RZ modulation

Also in case of using RZ the maximum data rate could be send over different orbits is decreased comparing by using NRZ as observed in Fig. 8.

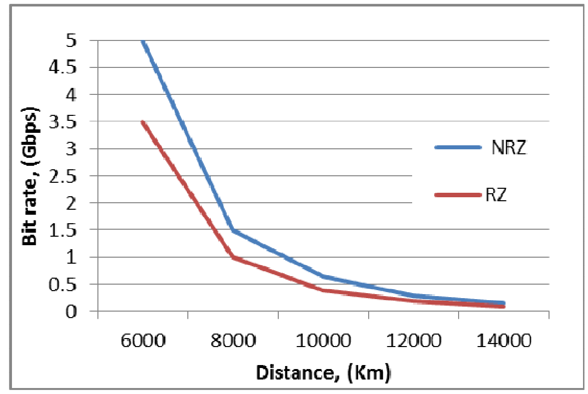

Fig. 8. The max allowable data rate at differnet modualtion types – MEO Distance

V. CONCLSION

The goal of this paper is to optimize the ISL performance in terms of Q – factor and BER which they are affected by variation on detector type and modulation scheme. This paper studied the impact of using APD detector on the quality of the system which is improved with 10^{-56} as Min BER at 1000 km LEO orbit.

This paper investigated the maximum data rate could be send over different orbits that give adequate system performance. We conclude that by varation in modulation scheme is superior to use NRZ modulation rather than RZ for same previous reasons. So as exposed in several papers and practical trials always the ISL is supposed to work using NRZ modulation and APD detectors.

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