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IMPACT OF DETECTOR AND MODULATION FORMATS ON LEO-ISLS

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ABSTRACT

Communication via Inter-satellite links (ISLs) is crucial for LEO constellation satellites. ISLs are favoured due to their ability to support high data rates with small propagation delay. Investigations with different detectors show the advantage of using APD for ISLs. Q-factor is used to measure the performance of ISLs which is shown to depend heavily on the choice of modulation formats with CSRZ outperforming NRZ, RZ and Duo-Binary formats. The investigations are performed for 2.5-50Gbps data rate over distance of 200-1200 kms. At 1200 kms for 40Gbps, the Q-factor of CSRZ is 20.2 more than those of NRZ, RZ and Duo-binary.

Keywords: Low Earth Orbit (LEO), Inter-Satellite Link (ISL), Detector, Modulation Formats, Q-Factor.

I. INTRODUCTION

The Low Earth Orbit or LEO as it is popularly known is used for a large number of satellite based applications. As the name implies, Low Earth Orbit is relatively low in altitude; the definition of LEO stating that the altitude range is between 200 and 1200 kms above the Earth's surface .LEO has several important features which are useful for real time communication and Earth observations. The most notable application includes the International Space Station which is in a LEO that varies between 320 kms and 400 kms above the Earth's surface [1]. Inter-Satellite links (ISLs) are used to provide connections between earth stations in the service area of one satellite to earth stations in the service area of another satellite when neither of the satellites covers both sets of earth stations. There are two different links possible: radio and optical links depending on the mass and power consumed. Radio links are more advantageous for low throughputs (less than 1 M bit/s). and optical links are preferred for high capacity links (in Gbps) [2].The performance of the ISLs depend heavily on the type of detector and modulation formats used [3-4].NRZ and RZ are the two most commonly used data formats in optical communication. In this paper ,two more modulation formats namely, Carrier suppressed return to zero (CSRZ) and Duo-Binary modulation formats have been considered. CSRZ is the advanced modulation format used in optical communication. The difference between CSRZ and conventional RZ is that the CSRZ signal has the 'π' phase shift between adjacent bits. This phase alternation, in the optical domain, produces no DC component; thus, there is no carrier component for CSRZ [5]. Duo-binary modulation can be described as a combination of a conventional ASK-based modulation and phase shift keying (PSK).

This paper focuses on different detector types and modulation formats and their impact on the speed of transmission for LEO ISLs. This paper aims to find the most suitable detector and modulation format for supporting high speed ISLs up to 50Gbps**.** The simulation model with the necessary parameters is presented in section II. The performance for various modulation types have been investigated using the Q-factor, the results and discussion is presented in section III. Finally, section IV concludes the paper findings.

II. SYSTEM MODELLING

The ISL link for LEO constellation has been modelled using OptiSystem v9 software. The arrangement is as shown in Fig 1.The system consists of a transmitter, OWC (Optical Wireless Channel) and a receiver section. A CW laser operating at 850nm or approximately 353 THz with input power of 12dBm is considered .It is externally modulated by MZ modulator. The OWC channel consists of a pair of telescope lenses and the free space channel between them. The major loss of signal power is due to the free space path loss of the channel. The receiver section essentially consists of a photodetector, filter and 3R regenerator as shown in Fig1.

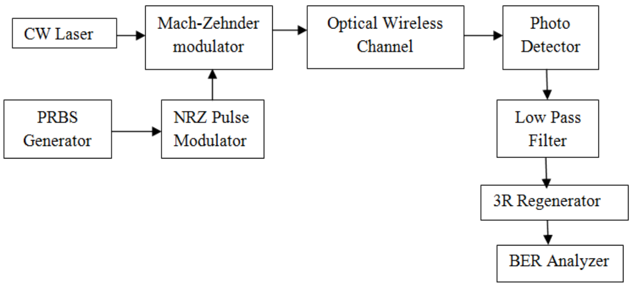

Fig 1: Block Diagram of Inter-Satellite Link

TABLE I: Static Parameters for IS -OWC System

Parameters	Value
Input power of CW Laser	12dBm
Wavelength	850 nm
Responsivity	0.8A/W
Dark current	10nA
Transmitter and Receiver aperture diameter	15cm

The static parameters considered in this paper are given in Table I. LEO distances from 200-1200 kms have been considered for simulation. The detector and modulation type has been varied and the resulting Q-factor is observed for each case.

III. RESULTS AND DISCUSSION

Fig. 2 shows the simulation setup for NRZ format on Optisystem software. This paper simulates the ISL and the performance of the link is interpreted through the Q-factor. The data rates are varied from 2.5-50Gbps and distance from 200-1200kms.The subsequent effect on Q-factor is observed from the BER analyser.

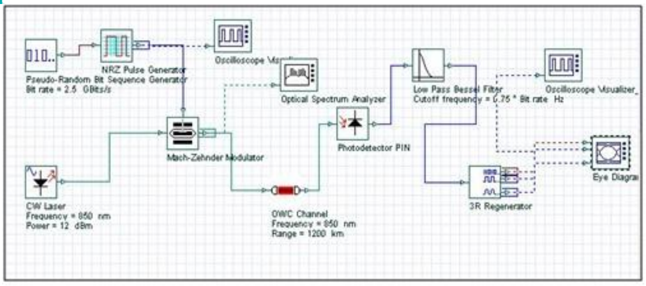

Fig 2: Simulation set-up for ISL

The PSRB Generator is varied through 1Mbps, 10Mbps, 100Mbps, 1Gbps and 10Gbps. This binary bit is converted into NRZ format before being modulated by the Mach-Zehnder modulator. The frequency of the CW laser is fixed at 1550 nm and power at 10 dB. The IS-OWC consists of transmitter telescope, free space channel and receiver channel. The default size of aperture diameter for transmitter and receiver telescope is 15 cm. Free space path loss is enabled. On the receiver side, the APD photodetector converts the optical to electrical signal from which the original data is recovered by means of 3R regenerator. The eye diagram and Q-factor are viewed using the BER analyzer.

Case 1: Effect of APD and PIN detector on eye diagram

Fig. 3(a) shows the eye –diagram for APD detector for data rate 5Gbps transmitted over a distance of 600kms. The eye opening is wide with a Q-factor of 26.42 and BER of 3.81e-154.

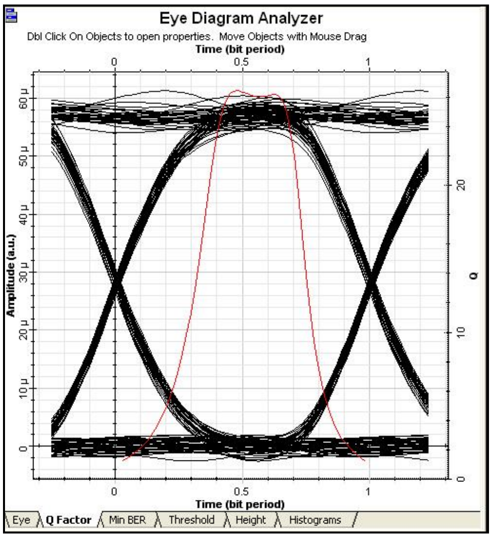

Fig 3(a): Eye diagram for APD detector

Fig. 3(b) shows the eye –diagram for PIN detector for data rate 5Gbps transmitted over a distance of 600kms.

From Fig.3 (a) and Fig.3 (b), it is seen that the Q-factor degrades from 26.42 in the case of APD to 10.77 in the case of PIN and BER has increased to 2.18e-027. This is due to the reduction in eye opening in the case of PIN detector. The smaller eye opening is not preferable since it leads to a greater chance of data errors and jitter in the receiver. Thus, it is preferable to use APD detector over PIN detector. For the rest of the paper APD detector has been considered.

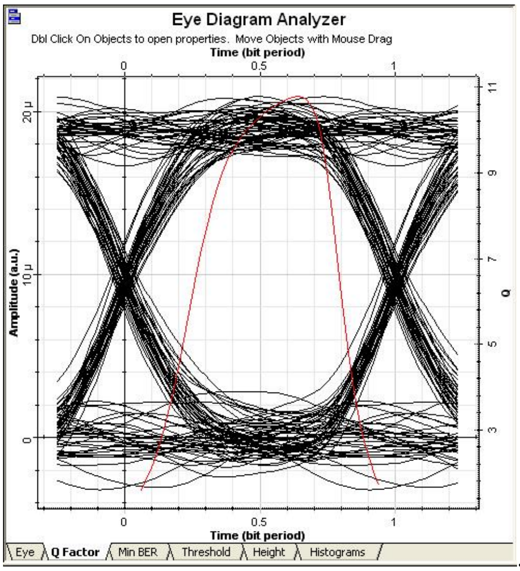

Fig 3(b): Eye diagram for PIN detector

Table II: Comparisons between Q-factor and data rates for LEO a using APD detector (NRZ format)

Orbit	Distance (km)	Data Rate (Gbps)	Q-Factor
LEO	600	45	9.01
LEO	1000	25	5.02

Table II shows the variation of Q-factor with data rate and distance for NRZ format. The Q-factor is seen to decrease with the increase in data rate and distance. This is because the free space loss increases with distance .Thus for a larger distance the data rate which can be supported is much smaller. It is evident that for a distance of more than 1000 kms data rate beyond 25Gbps cannot be supported.

Case 2: Effect of different modulation formats on system performance

Here, NRZ, RZ, CSRZ and Duo-binary modulation formats have been considered. For each modulation format, the distance is varied from 200 -1200 kms and the data rate is varied from 2.5 Gbps upto 50 Gbps. The Q-factor for the different instances as a measure of overall system performance is noted using the BER analyser.

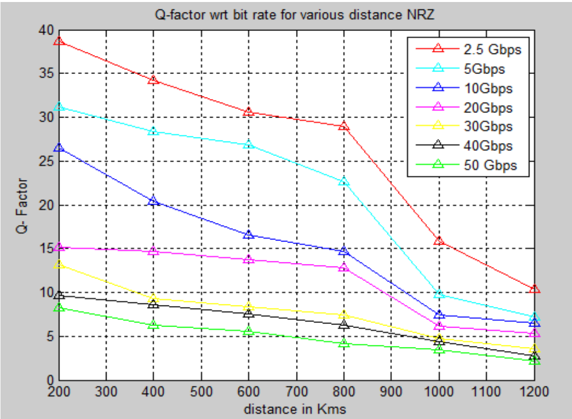

Fig 4: Q-Factor versus distance for NRZ format

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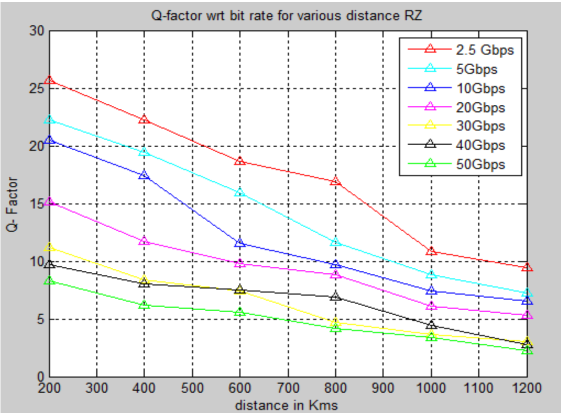
From Fig 4, it is seen that for NRZ format for a given distance, data rate of 2.5Gbps has the best performance in terms of Q-factor, but as distance increase the Q-factor decreases. Data rate of 50Gbps can be supported up to a distance of around 400 kms only for a Q-factor of 6.2.

For RZ format the Q-factor also decreases with the increase in distance and data rate. For a distance of 1200 kms, data rate of 10 Gbps corresponding to a Q-factor of 6.2 can be supported at most as seen from Fig 5.

In the case of CSRZ format the data rate up to 50 Gbps with a Q-factor of 6.4 can be comfortably sent even at 1200 kms as seen from Fig 6.CSRZ cannot support any higher data rate for 1200kms as the Q-factor decreases rapidly.



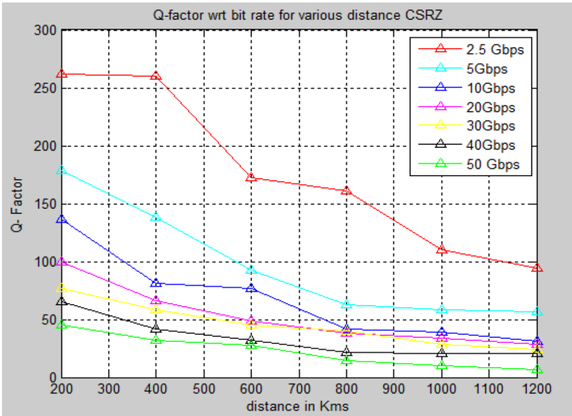


Fig 5: Q-Factor versus distance for RZ format   Fig 6: Q-Factor versus distance for CSRZ format

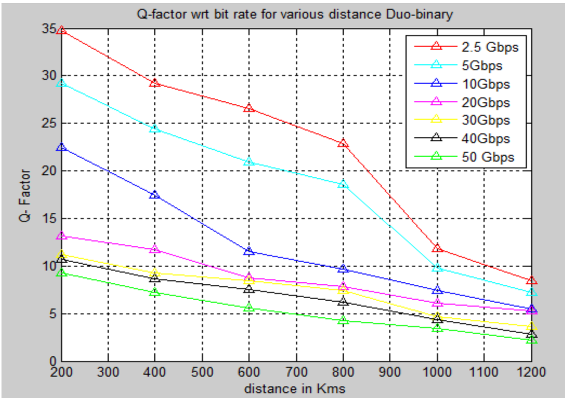


Fig 7: Q-Factor versus distance for Duo-Binary format

Fig 7 shows that in the case of Duo-Binary format at most 5Gbps may be sent at a distance of 1200kms for a Q-factor of 7.2. This is very less as compared to 40Gbps in the case of CSRZ.

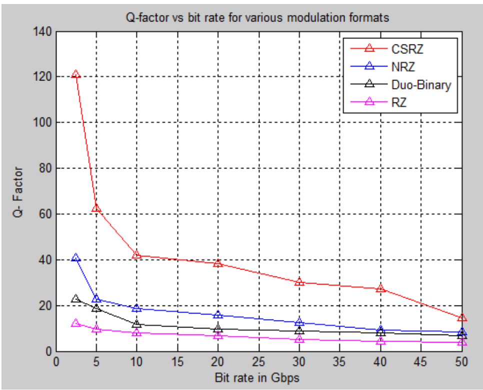


Fig 8: Variation of Q-factor with bit rate for NRZ, RZ, CSRZ and Duo-Binary formats.

From Fig 8 the performance of CSRZ is the best amongst the four. It outperforms for all data rates and at all distances. The performance of NRZ and Duo-Binary are comparable with NRZ being slightly better. RZ performs poorly as compared to others.

IV. CONCLUSIONS

The goal of this paper was to find the most suitable detector and modulation format for high speed ISLs. This paper investigated the impact of using APD vs. PIN detector, where APD showed a distinct improvement in eye opening. APD achieved a Q-factor of 26.42 as compared to 10.77 in the case of PIN detector when data rate and distance for both were fixed at 5Gbps and 600kms respectively. The performance of the ISL was also investigated in terms of Q-factor for NRZ, RZ, CSRZ and Duo-Binary formats. The Q-factor for CSRZ for 50Gbps is 14.4, for NRZ it is 8.2, for RZ it is 6.8 and for Duo –Binary it is 3.7, thus CSRZ emerges as the best modulation format for data rates up to 50 Gbps.

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