

5 Gbps P-i-N vs. Avalanche Photo Diode: Performance Analysis in Optical Communication

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Abstract: The fiber optic technology has been in our lives for a while now. It eases the communication and the transmission of information and it becomes more and more indispensable, especially in the business world. Pin and APD are two different types of photodiodes used in optical communication systems. In this paper, a performance comparison of the conventional PIN photodiode with the Avalanche Photodiode (APD) in an optical communication system is presented. We considered 5 Gbps PIN and APD photo diodes for this purpose. We analyzed bit error rate (BER) and Q factor to achieve this goal. We found that 5 Gbps APD with single mode fiber gives the better performance over 5 Gbps PIN. Similarly, the value of Q-factor is maximum when APD has been used as the receiving photodiode at 1550nm wavelength and minimum when PIN diode has been used as receiving photodiode at 1550nm wavelength. We used Opti System and MATLAB software for our investigation.

Keywords: PIN, APD, BER, Q-factor, Opti System.

1 Introduction

While optical-transmission techniques have been researched for quite some time, optical "networking" studies have been conducted only over the past dozen years or so. The field has matured enormously over this time: many papers and Ph.D. dissertations have been produced, a number of prototypes and test beds have been built, several books have been written, a large number of startups have been formed, and optical WDM technology is being deployed in the marketplace at a very rapid rate. Communications have been evolved from wired to wireless, underwater sensors [1-2] to optical medium. However, P-i-N (PIN) diodes and avalanche photo-diodes (APD) are the most commonly used photo-detectors in terrestrial FSO systems. Free Space Optics (FSO) is a promising solution for very high data rate point-to-point communication [3], [4], [5]. By FSO, the information-bearing laser beam is projected onto the optical receiver along the line of sight.

At the receiver, the transmitted optical signal is converted to an electrical one thanks to a photodetector (PD).

Concerning the PD, solid-state devices are mostly used in commercial FSO systems since the quantum efficiency of phototube devices is too low for the commonly used wavelengths [6]. Several previous works have considered, directly or indirectly, the receiver noise effect in optical communication systems. We cite here some works that have considered the noise modeling. These works, however, either use more or less simplified models for the receiver noise or consider a very different context from terrestrial FSO systems: Sorensen et al. numerically evaluated in [7] the performance of an APD-based optical receiver by considering only shot-noise and thermal noise. Leeb analyzed in [8] the effect of background radiations on the signal-to-noise ratio for direct and heterodyne/homodyne receivers in optical space links. In a previous work, we studied the impact of background radiations on the performance of FSO systems and proposed to use two laser wavelengths and differential data detection to reduce its effect [9], [10]. Also, we studied in [11] the spatial diversity receivers for thermal- and background-noise-limited receivers. Dolinar et al. studied in [12] the capacity of PPM channel in the case of using an APD and in the

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absence of scintillation. In [13], Srinivasan and Vilnrotter considered the use of APD-based detector arrays for space-to-ground optical communication systems. Manor and Arnon investigated in [14] the wavelength dependence of the performance of FSO systems using a PIN diode under different weather conditions. Kiasaleh studied the optimal average APD gain for the case of pulse position modulation (PPM) in [15]. Also, Cole and Kiasaleh considered the use of APD detector arrays for the cases of binary PPM and on-off keying (OOK) modulations in [16]. Lastly, Cvijetic et al. considered in [17] the impact of spatial diversity in a channel subject to turbulence for the two cases of PIN and APD detectors. In this paper, we have considered 5 Gbps PIN and APD photodiodes for their performance analysis. At first, we generate the system set up using OptiSystem software then calculate the BER of the system using 5 Gbps PIN and APD photodiodes. We also view the eye diagram for the two types of photo diodes. Finally, we compare the results corresponding the two types of photo diodes using MATLAB software.

1.1 Types of Photo-Diodes

There are generally two types of photo diodes in stu. The details description is illustrated bellow:

1.1.1 PIN Photo-Diode

In order to allow operation at longer wavelength where the light penetrates more deeply into the semiconductor material a wider depletion region is necessary. To achieve this the n type material is doped so lightly that it can be considered intrinsic, and to make low resistance contact a highly doped n type (n^+) layer is added. This creates a PIN structure, as may be seen in Fig.2 where all absorption takes place in the depletion region.

1.1.2 Avalanche Photo-Diode

The second major type of optical communications detector is the avalanche photodiode (APD). This has a more sophisticated structure than the PIN photodiode in order to create an extremely high electric field region. Therefore, as well as the depletion region where most of the photons are absorbed and the primary carrier pairs generated there is high field region in which holes and electrons can acquire sufficient energy to excite new electron-hole pairs. This process is known as impact ionization and is the phenomenon that leads to avalanche breakdown in ordinary reverse biased diodes. It often requires high reverse bias voltages (50 to 400 V).

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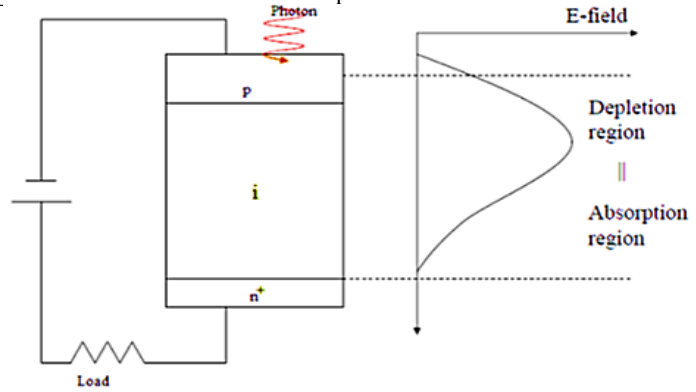


Fig. 1: PIN photodiode showing combined absorption and depletion.

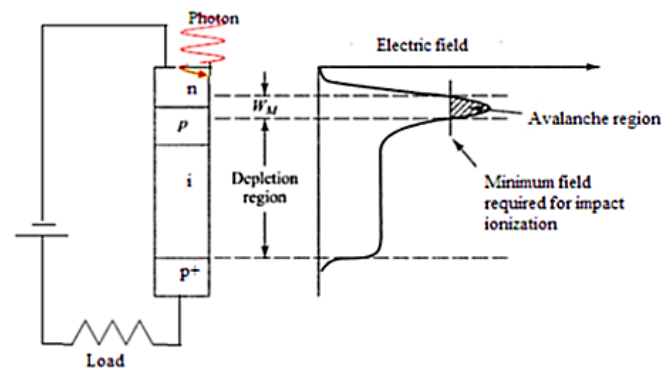


Fig.2: Avalanche photodiode showing high electric field region.

APD can give carrier multiplication factors as great as 10^4 . Most of the III-V semiconductors have nearly equal value of electron and hole ionization rate and as a result the APDs made with these materials become very noisy. For silicon, the Si-APDs are comparatively less noisy.

2 System Setup

The main components of the optical link are shown in Fig. 3. Signals are split into two outputs signals, which are detected by both the PIN photodiode (PIN-PD) and APD photodiode (APD-PD) and are converted into electrical output signals again. These electrical signals are filtered through a low-pass Bessel filter, which shapes the voltage pulse. Its purpose is to reduce the noise and distortion without introducing much inter-symbol interference (ISI). The key components of the simulation set-up are: PRBS generator, pulse generator, laser diode source, attenuator, PIN PD, APD PD, low-pass filter, and BER and eye diagram analyzers for assessing the performances of the link. The laser diode source's nominal chosen wavelength was 1550 nm, with output power set to 0 dBm.

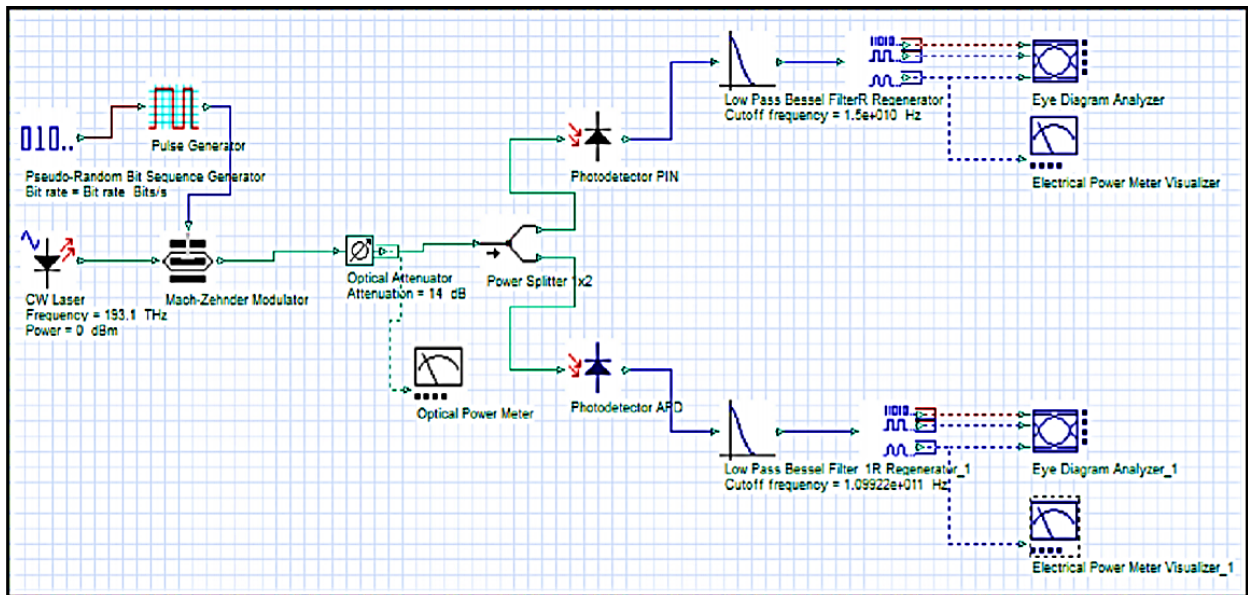
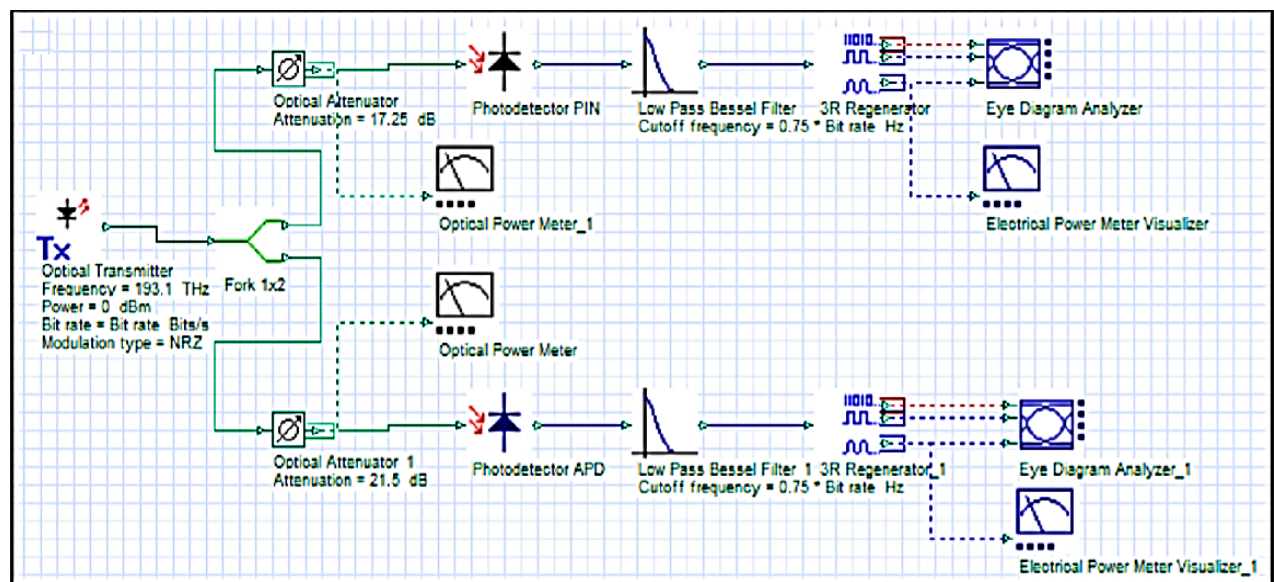


Fig. 3: Systematic layout of the simulation set-up.

3 Eye Diagram Comparison

An eye pattern, also known as an eye diagram, is an oscilloscope display in which a digital signal from a receiver is repetitively sampled and applied to the vertical input, while the data rate is used to trigger the horizontal sweep. It is so called because, for several types of coding, the pattern looks like a series of eyes between a pair of rails. It is a tool for the evaluation of the combined effects of channel noise and inter-symbol interference on the performance of an optical communication system. To determine the minimum received powers (dBm) which

were required to achieve our desired goal Q factors of 7, using the set-up shown in Fig. 4(a). The transmitter power was selected again to be around 0 dBm, and the bit rate 10 Gb/s. In the PIN, the sensitivity was shown to be about -19.9 dBm when the optimized attenuation was 17.25 dB. In the APD, the average sensitivity was higher, at around -24 dBm, when the optimized attenuation was 21.5 dB. The eye diagrams in this case are shown in Fig. 4(b) and (c). They show the maximum Q factor with respect to the received power for PIN and APD, respectively.



(a)

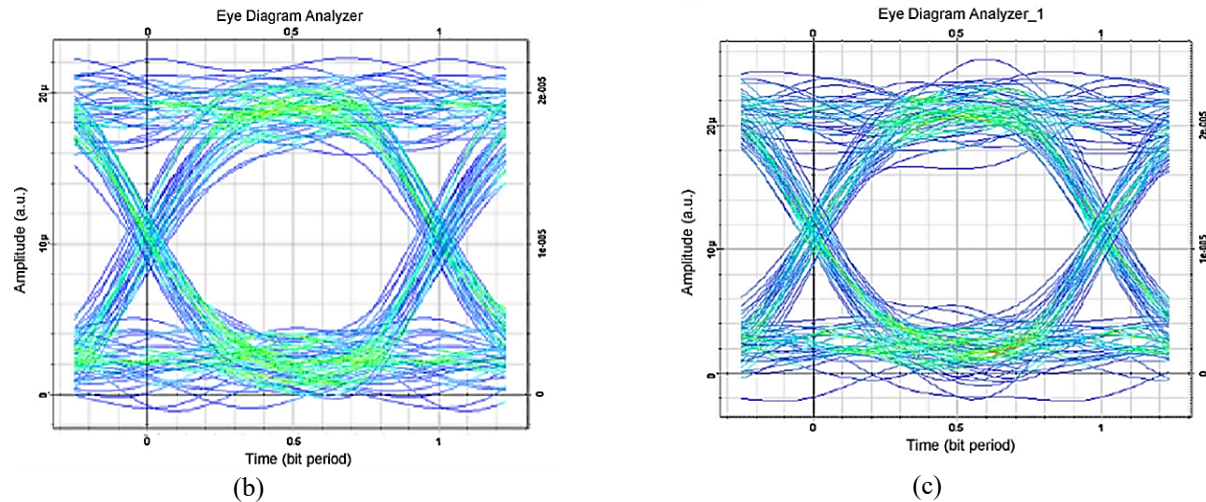


Fig. 4. (a) Set-up for goal attainment attenuation optimizations of Q-factor of 7, (b) eye from PIN Q = 6.9 and (c) eye from APD Q = 6.9.

4 Bit Error Rate (BER) Comparison

In telecommunication transmission, the bit error rate (BER) is the percentage of bits that have errors relative to the total number of bits received in a transmission, usually expressed as ten to a negative power. For example, a transmission might have a BER of 10^{-6} , meaning that, out of 1,000,000 bits transmitted, one bit was in error.

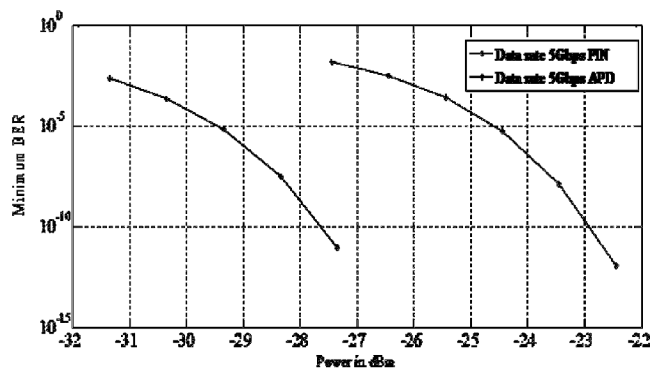


Fig. 5: Power in dBm vs. minimum bit error rate for 5 Gbps PIN and APD photo diodes.

In this paper, the evaluation has been done of performance of an optical system based on type of photodiode used at the receiver side namely PIN and APD photodiode. The minimum BER we found with respect to Power in dBm is plotted in MATLAB. We plot it for both PIN and APD diodes. The resultant graph can ensure better photodiode. We have considered here 5 Gbps PIN and APD photo diodes during finding our results from Opti System. Figure 5 shows a comparison of 5 Gbps PIN and APD diode where the green line with red stars signifies 5 Gbps 5 Gbps APD and blue line with purple stars represents 5 Gbps PIN diode. From Fig. 5, we can see that the APD diode maintains better BER in lower power compared to PIN photodiode. This signifies that 5 Gbps APD is optimum.

5 Conclusion

In this study, we evaluated the BER and eye diagram of an optical communication system with respect to 5 Gbps PIN and APD photodiode. We found that 5 Gbps APD can show less BER than 5 Gbps PIN at similar power (dBm). Similarly, APD shows better Q factor than PIN photodiodes. So, we can say that in optical communication APD photodiode gives better performance as a receiver than PIN photodiode.

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