Comparative Study of an Optical Link with PIN and APD as Photo-Detector

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ABSTRACT

Exchange of information between any two devices across a communication channel involves using some type of electrical or optical signal which carries the information. Parameters considered while analyzing the optical link are desired transmission distance, data rate or channel bandwidth and BER. This paper presents variation in the BER with the change in the transmission distance and the length of the fiber considering the photo-detector as PIN and APD. With the increase in length of the fiber and transmission data rate, dispersion increases. Hence, optical signal incident on the detector is below the required sensitivity power requirement and system is not able to give the electrical output. APD with single mode fiber gives the better performance over PIN.

Keywords: PIN; APD; BER; Q-factor

1. INTRODUCTION

Ever since ancient times, people had a principle need to communicate with one another. This need created interests in devicing communication system for sending messages from one distant place to another. Optical communication methods were of special interest among the many systems. The basic function of an optical fiber link is to transport a signal from communication equipment at one location to corresponding equipment at another location with a high degree of reliability and accuracy. While analyzing the link, parameters considered are desired transmission distance, data rate or channel bandwidth and BER [1]. The main constituents of an optical fiber communication link are transmitter consisting of optical source, an optical cable and a receiver consisting of a photo-detector. Photo-detector is the first element of the photo receiver circuit which interprets the information contained in the optical signal. They demodulate the optical signal that are subsequently amplified and processed to obtain the actual information signal. For such applications, photo-detectors must have high sensitivity, high responsivity and minimum noise. In addition, the photo-detectors should be compact in size, use low biasing voltage and current, reliable under operating condition, and preferably integrated circuit compatible[2- 9]. For high-bit-rate long-haul fiber optic communications, the avalanche photodiode (APD) is frequently the photo-detector of choice owing to its internal gain, which provides a sensitivity margin relative to PIN photodiodes. APDs can achieve 5–10-dB better sensitivity than PINs, provided that the multiplication noise is low and the gain-bandwidth product is sufficiently high [10,11]. The single mode fiber has the advantage of low intermodal dispersion (broadening of transmitted light pulses), as only one mode is transmitted, whereas with multimode fiber dispersion may occur due to the differing group velocities of the propagating modes. This in turn restricts the maximum bandwidth attainable with multimode fibers, especially when compared with single mode fiber [1,2].

2. THEORY

The detector is an essential component of an optical fiber communication system and is one of the crucial elements which dictate the overall system performance. Its function is to convert the received optical signal into an electrical signal, which is then amplified before further processing. Therefore, when considering signal attenuation along the link, the system performance is determined at the detector. Improvement of detector characteristics and performance thus allows the installation of fewer repeater stations and lowers both the capital investments and maintenance costs. Requirements of the detectors are high sensitivity at the operating wavelength, high fidelity, large electrical response to the received optical signal, short response time to obtain a suitable bandwidth, minimum noise introduced by the detector, small size, low bias voltage, high reliability and low cost. Semiconductor photodiodes with or without internal gain provide good performance and compatibility with relative low cost. These photodiodes are made from semi-conductors such as silicon, germanium and an increasing number of III-V alloys, all of which satisfy in various ways most of the detector requirements. They are therefore used in all major current optical fiber communication systems.

2.1 Optical Detection Principle

The basic detection process in an intrinsic absorber is illustrated in Fig.1 which shows a p-n photodiode. This device is reverse biased and the electric field developed across the p-n junction sweeps mobile carriers (holes and electrons) to their respectively majority sides (p and n type material). A depletion region or layer is therefore created on either side of the junction. This barrier has the effect of stopping the majority carriers crossing the junction in the opposite direction to the field. However, the field accelerates minority carriers from both sides to the opposite side of the junction, forming the reverse leakage current of the diode. Thus intrinsic conditions are created in the depletion region.

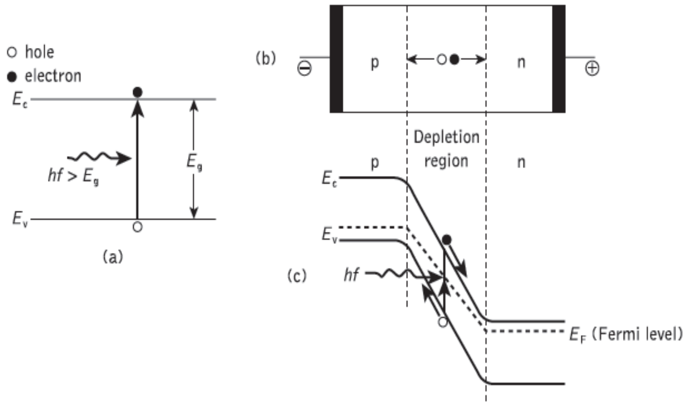

Fig.1. Operation of the p-n photodiode

A photon incident in or near the depletion region of this device which has an energy greater than or equal to the band-gap energy E_g of the fabricating material (i.e. hf (where h is Planck's constant and c is velocity of light in air)$>E_g$) will excite an electron from the valence band into the conduction band. This process leaves an empty hole in the valence band and is known as the photo-generation of an electron-hole (carrier) pair, as shown in Fig.1(a). Carrier pairs so generated near the junction are separated and swept (drift) under the influence of the electric field to produce a displacement by current in the external circuit in excess of any reverse leakage current (Fig.1(b)). Photo-generation and the separation of a carrier pair in the depletion region of this reverse biased p-n junction is illustrated in Fig.1(c).

3. TYPES OF PHOTO-DIODES

3.1 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.

3.2 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 as may be seen in Fig.3. 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).

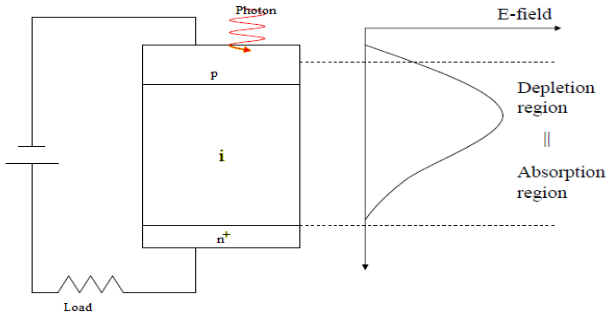

Fig.2. PIN photodiode showing combined absorption and depletion

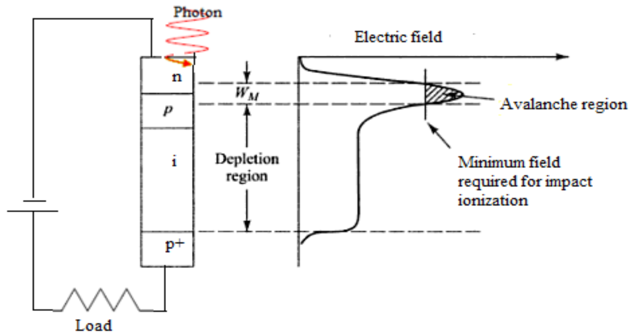

Fig.3. Avalanche photodiode showing high electric field region

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.

4 PARAMETERS FOR PHOTO-DETECTOR ANALYSIS

Conversion Efficiency

Conversion efficiency is the ratio of electrons generated to incident photons. It is defined as ability of the photo-detector to convert received optical power into the electrical power. It is transparent with the variation in the transmission data rate and decreases with the decrease in the incident optical power on it. When incident optical power is below the required sensitivity of detector conversion efficiency is almost equal to zero.

Bit Error Rate

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.

Fibers

Multimode fibers are with a core diameter of around 50µm or greater, which is large enough to allow the propagation of many modes within the fiber core. Single mode fiber allows the propagation of only one transverse electromagnetic mode (typically HE_{11}), and hence the core diameter must be of 2 to 10µm.

5 METHODOLOGY USE IN THE WORK

5.1 Optical Link To Be Characterized

Optical link which is characterized in this work is shown in Fig.5. This optical link consists of information source and optical source which is CW Lorentzian laser with the input power of 2mW at the transmitter side. It then consists of an optical fiber which is multimode fiber through which information is transmitted to the receiver side. Receiver section consists of preamplifier which amplifies the received signal followed by a filter which removes the unwanted signals. It then consists of photo-detector which converts the optical signal back to the electrical signal. Link characterization is done by varying transmission data rate and the length of the fiber which results in the variation of the bit error rate and Q-factor.

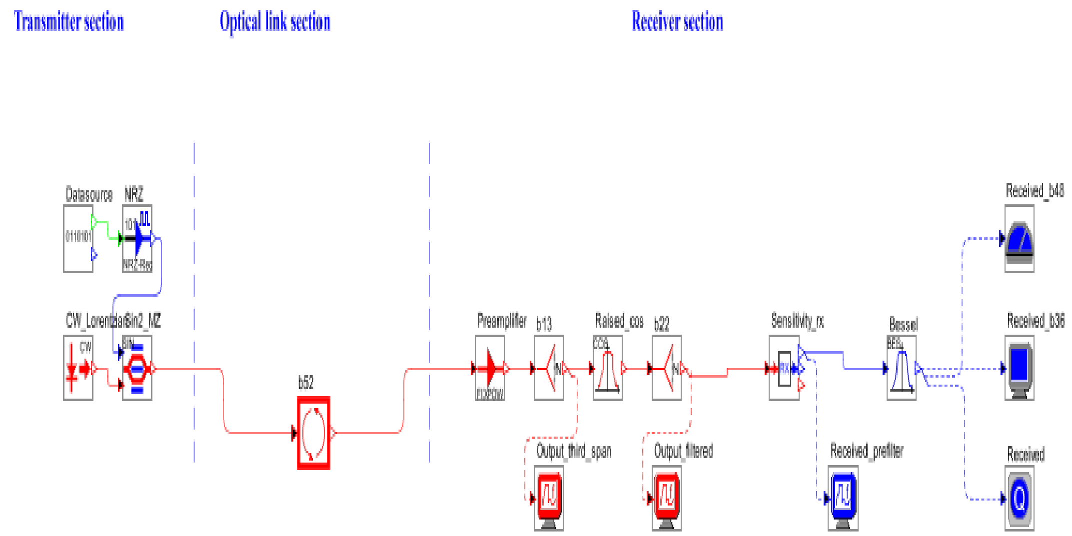

Fig.5. Optical Link

5.2 Tool To Be Used

This work includes characterization of an optical link with PIN and avalanche photo-detector with the variation in the data rate and length of the fiber. Optimization and Simulation Consulting (OPTSIM) is RSoft's award-winning software tool for the design and simulation of optical communication systems at the signal propagation level. Hence, OPTSIM is used for the characterization of link in this work.

6. RESULTS AND DISCUSSIONS

Simulation is performed with the input power of 2mW at the transmitter side and results show the variation of the BER for various length of the fiber. Fig.6 shows the variations in eye pattern with the length of the fiber as 100km, 200km, 300km, 400km and 500km at the data rate of 10 and 20Gbps and 30Gbps. At the data rate of 10Gbps and 20Gbps with the length of fiber as 100km, 200km and 300km. the receiver input is above its sensitivity power requirement. Therefore, it is able to convert the received optical signal into the electrical signal. At the data rate of 30Gbps, the optical signal incident on the detector is below the required sensitivity power requirement because with the increase in the data rate dispersion along the length of the fiber increases and hence is not able to give the electrical output. With the increase in the length of the fiber to 400km, at the data rate of 10Gbps the receiver is input is above its sensitivity power requirement and it is able to convert the received optical signal into the electrical signal because dispersion is within the tolerable limits but at the data rate of 20Gbps, with the increase in length of the fiber, dispersion increases and hence, optical signal incident on the detector is below the required sensitivity power requirement and is not able to give the electrical output. Further, increase in length of the fiber dispersion increases and hence, at a data rate of 10Gbps only receiver input is below its sensitivity power requirement and is not able to give the electrical output.

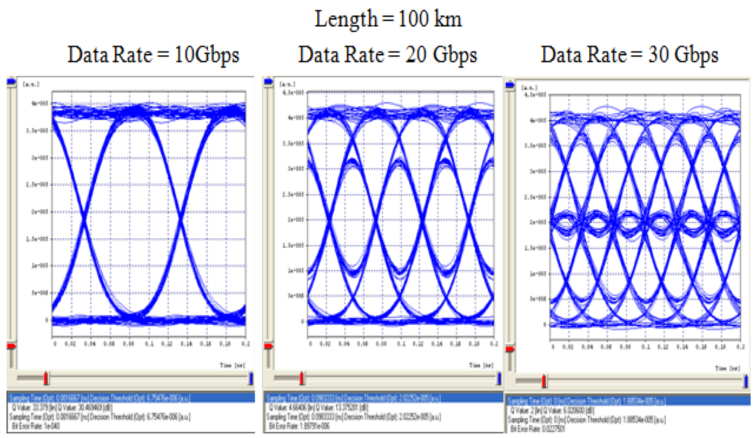

Fig.6 (a). Eye pattern for the length of fiber = 100km

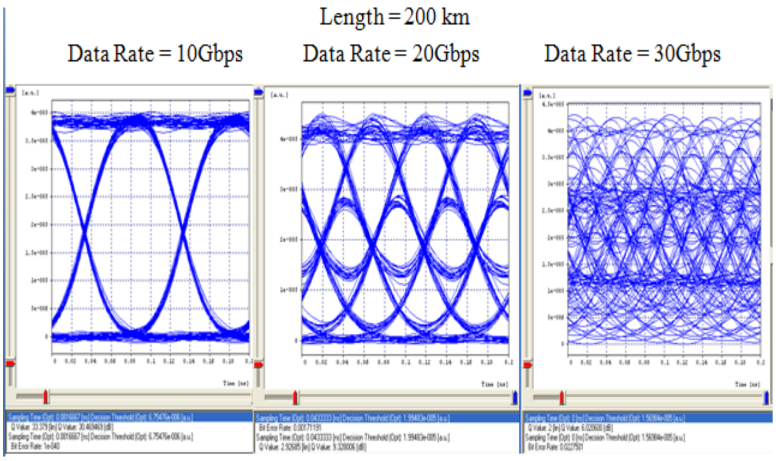

Fig.6 (b). Eye pattern for the length of fiber =200km

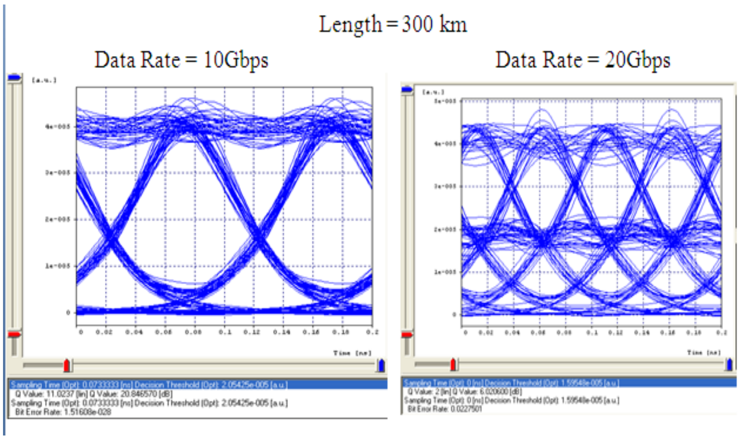

Fig.6 (c). Eye pattern for the length of fiber =300km

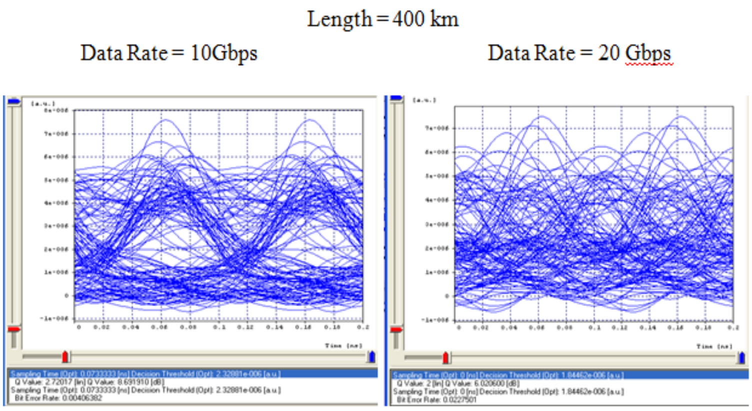

Fig.6 (d). Eye pattern for the length of fiber = 400km

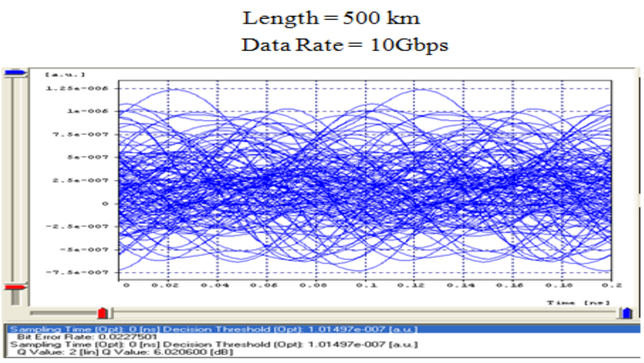

Fig.6 (e). Eye pattern for the length of fiber = 500km

Further, increase in length of the fiber dispersion increases and hence, at a data rate of 10Gbps only receiver input is below its sensitivity power requirement and is not able to give the electrical output. Fig.7 shows graphical representation of BER versus length of the fiber with the variation in transmission data rate.

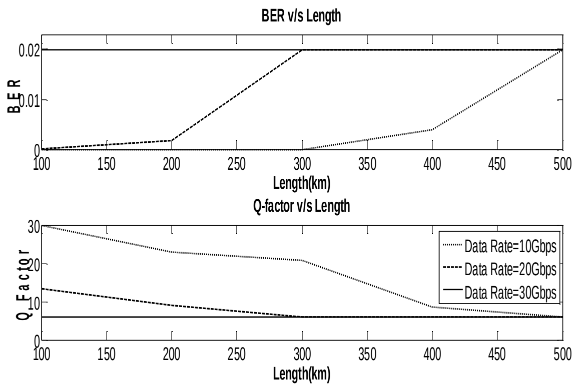

Fig.7. BER v/s Length and Q-factor v/s Length

Conversion efficiency of photo-detector is independent of the length of the fiber is as shown in Fig.8. It decreases with the increase in data rate.

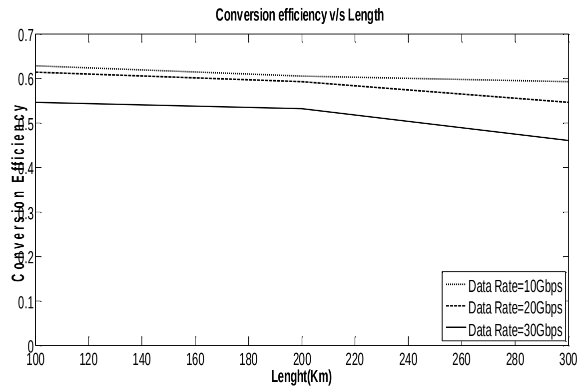

Fig.8. Conversion Efficiency v/s Length

Table1 shows BER and Q value with the PIN and Avalanche photo-diode when the fibers used are Single mode fiber (SMF) and Multi-mode fiber (MMF). It shows the SMF with the APD gives the better performance as compared to the PIN photo-diode because of the less dispersion in SMF and higher gain of the APD.

Table 1. BER and Q-value for SMF and MMF

Detector Type	BER		Q-Value	
	D=8μm SMF	D=80μm MMF	D=8μm SMF	D=80μm MMF
PIN	1.48e-4	3.19e-4	7.04	7.29
APD(Gain=2)	5.6e-8	1.49e-7	7.22	7.68
APD(Gain=3)	9.2e-9	7e-8	7.43	7.88

7. CONCLUSION

From the various results obtained it can be concluded that PIN photodiode and APD cannot handle the transmission data rate beyond 30Gbps. At a data rate of 30Gbps and above, receiver input is below the sensitivity limit because with the increase in data rate dispersion along the length of the fiber increases. Therefore, it cannot effectively and reliably convert the optical signal to electrical signal. Length of the fiber between two nodes is limited by the rate of data transmission. The responsivity curve shows that different semiconductor materials can be used as detector material depending on the range of wavelengths used for transmission. Also, the result depict that conversion efficiency of any detector is independent of link length but dependent on data rate and mode of transmission. That is, SMF gives better quality factor signal at the receiver compared to MMF for same link length and data rate.

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