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Performance Analysis of Photodetectors and Effect of Photodetection Noises in Optical Communication Systems

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ABSTRACT: The photodetector plays a very important role in detecting luminous wave carrying information along the optical fiber, and then transforms it into an electrical signal from which the transmitted information can be extracted easily. PIN and APD are the main types of photodiodes. Several physical sources that affect the signal at the output of the photodetector, focusing on thermal noise, quantum noise and noise of multiplication. This project deals with study about the physical origins of fundamental photodetection noises in PIN and APD photodiodes through an optical high debit transmission chain and also to analyse and compare between PIN and APD photodiodes in terms of their functional parameters. Photoreceivers or detectors are main component in every optical system. Performance of photoreceivers in various systems such as FSO, WDM PON networks etc can also be evaluated and simulated by using optisystem software.

KEYWORDS: APD, Johnson noise, Multiplicative noise, PIN, Shot noise, WDM PON

I. INTRODUCTION

Photodetector are transducers that alter one of their characteristics when light energy falls on them. Photodetectors having sufficiently fast response gives a output for a small amount of incident light, are reproducible, and are economical for applications in optical communications. This consist of avalanche photodiodes (APDs) and positive intrinsic negative photodiodes (PINs). Photodetectors are characterized by certain key parameters such as spectral response, photosensitivity, quantum efficiency, dark current, internal gain, terminal capacitance, frequency bandwidth, noise equivalent power and cut off frequency.

An inevitable component in the reception module of the optical communication chain, the photodiode (PIN or APD) plays a very important role in detecting light signals carrying information along the optical fiber, then transforms it into an electrical signal and extract transmitted information easily. In this concept several studies were being developed to evaluate the major drawbacks caused in such optoelectronic component "the photodiode" by processing their physical origins [1]. At the reception, because of the corpuscular nature of electromagnetic luminous rays, absorption process of photons will be discrete and carries creation will be contingent in terms of time providing a random process, by consequence, the detection of incident optical rays becomes very inhibited because of photodetection noise. In this sense, the noise of photodetection is generated in form of random intrinsic fluctuations which perturb the useful signal carrying information that makes them extraction very difficult at the photodetector output. In fact, the measurement of the photodetection noise in the presence of luminous signals is based on the evaluation of signal-to-noise that expresses the noise associated to the photocurrent generated through the conversion of photons into electron-hole pairs.

There are mainly 3 types of photodetection noises. First, thermal noise or "Johnson noise" which is due to the random collisions of carriers with crystal atoms which permanently vibrate that introduces a thermal agitation [2]. Second, photonic or quantum noise arises due to collision of incident photons. Third, noise of multiplication "Multiplicative noise" which is actually a photonic noise which get multiplied by the avalanche effect (multiplication process).

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II. Related Works

In [1] authors analysed the performance of photodetectors by comparing different optical windows such as 850nm,1310nm and 1550nm. Minimum attenuation is for the third window.so the optimal choice for the transmission is this 1550nm. In [3] authors evaluated and compared between the PIN photodiode and APD photodiode in terms of performance in an optical multiplexed transmission link using WDM “Wavelength Division Multiplexing” technique, they demonstrated that the capacity to transport data along 15 km can attain up to 5 Gbit/s per user if the APD photodiode is used in the receiver module.

Comparison between PIN and APD performances in atmospheric turbulences of a satellite system for different modulation positions, is performed in [4] and found that the performance of the APD photodiode is better than that of the PIN photodiode. In [5] authors found that APD has better performance as compared to PIN. The gain and high SNR of APD has made it more suitable for long haul communication is studied in [7].

III. System Modelling

A. *Fundamental noise analysis of photodiodes*

Analysis of fundamental photodetection noises generated in PIN and APD photodiodes using an optical high debit transmission chain simulated by the "Optisystem" software. Figure.1 displays the block diagram of a high debit transmission chain. This chain is considered as an environment for tests and observations to evaluate the performance of PIN and APD photodiodes in terms of their functional parameters to practically compare between PIN and APD used as detectors for the actual optical communication systems [1].

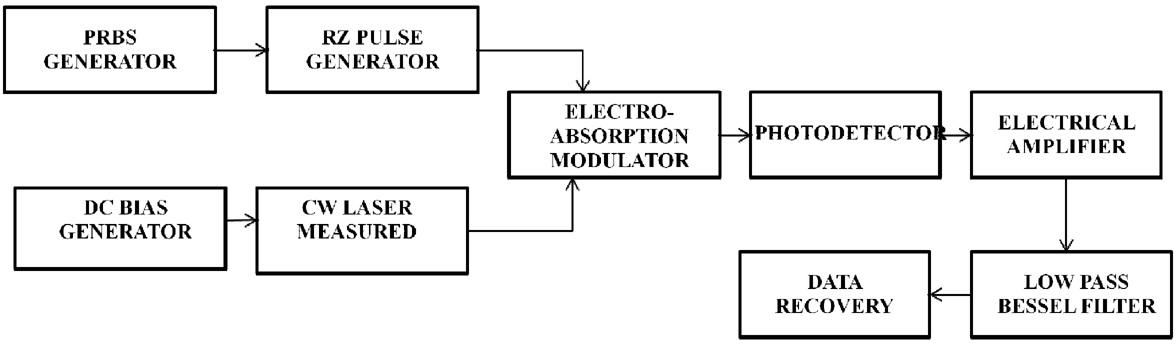

Fig.1 Block diagram of a high debit transmission chain.

The aim of this study is to examine the noise of photodetection caused in PIN and APD photodiodes used as detectors in the transmission chain basing on a temporal visualization (in terms of time using an optical time domain visualizer) or a spectral visualization (in terms of frequency using an optical spectrum analyser).

In specific, it is distinguished that the photodiode constitutes the seat of the noise which is observed additive to the useful signal; this noise has a random character manifested by parasitic fluctuations that distort the electrical pulses containing information. It is the noise of photodetection whose the sources are internal generated in the photodiode core; this noise has a low power but it equivocally influences the received signal consequently the transmitted information [4]. The objective of this study extends to define the dominant noise contribution in both PIN and APD photodiodes considered as detectors for the studied transmission chain in order to compare and evaluate their performances, in fact, this simulation consists of two major steps:

1. Analysis of photodetection noise in PIN and APD photodiode.
2. Evaluation of performances of PIN and APD photodiodes.

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B. *Comparison between PIN and APD*

Different characteristics of PIN and APD are comparing here such as receiver sensitivity and Q factor. In this case APD and PIN are connected in the same circuit using a power splitter. Mach-Zehnder modulator has two input ports, one for laser diode input and other for electrical signal. Electrical signal here act as modulating signal and the other one act as carrier wave [3]. After modulation an optical signal is generated, which then pass through optical fiber. Figure. 2 shows the block diagram comparing PIN and APD in terms of Q factor and receiver sensitivity.

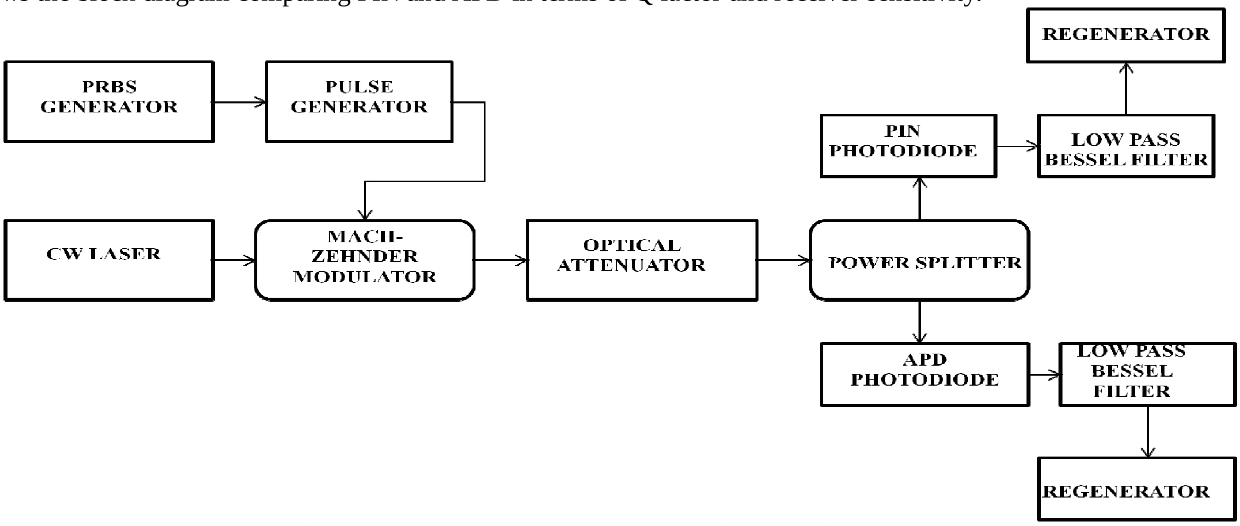

Fig. 2 Block diagram for comparing PIN and APD in terms of their Q factor and receiver sensitivity.

The main components of the optical link are shown. A pseudo-random-bit-sequence (PRBS) generates binary inputs pulse generator converts it into pulsed electrical signals, which is used as a modulating input signal. CW laser generate a light signal which is used as carrier signal. Modulation is performed at Mach-zehnder modulator. Power splitter splits signals into two outputs, which are detected by both the PIN photodiode and APD photodiode and are converted into electrical output signals again [2]. These electrical signals are filtered out using a low-pass Bessel filter, which gives the voltage pulse. Its purpose is to reduce the noise and distortion without having inter-symbol interference (ISI).

IV. Design and Simulation

High debit transmission chain, performance analysis of PIN and APD and fundamental noise of photodiodes are simulating by using OptiSystem software**.**

A. *Simulation setup of a high debit transmission chain*

High debit transmission chain is considered as an environment for tests and observations where the objective is to evaluate the performance of PIN and APD photodiodes in terms of their functional parameters and to compare between these two different photodiode types used as detectors for the optical communication systems [1].

The simulation part was executed using the Optisystem software which constitutes an interactive environment that permits to simulate, observe and analyze the transmitted signal at the level of all modules of the optical high debit transmission chain considered as a model for the study in a form of schematic blocks as displays the Figure 3. Emitted power Pe = 50 mW, binary debit D = 10 Gbit/s, laser diode wavelength λ = 1552.52 nm corresponding to the 3rd optical window, mono-mode fiber length L = 50 Km, photodiode sensitivity S = 0.8 A/W, photodiode dark current ID = 5 nA. Figure.3 shows the simulation set up of a high debit transmission chain.

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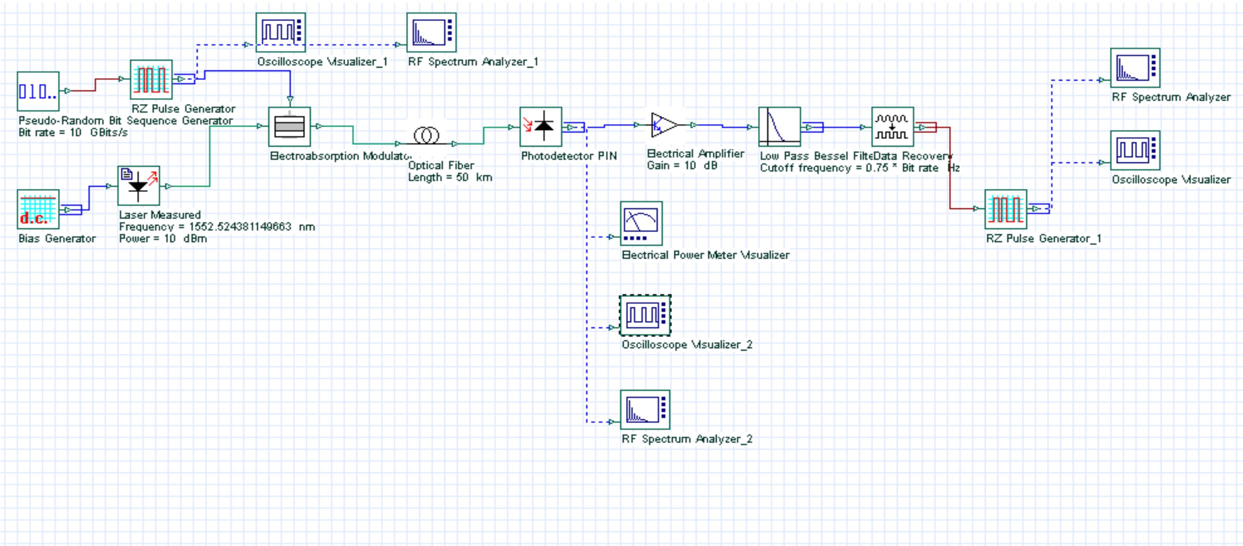

Fig.3. Simulation model of optical high debit transmission chain using PIN.

B. *Performance comparison of PIN and APD photodetectors for use in optical communication system*

The main components for this simulation set-up are: PRBS generator, pulse generator, laser diode source, attenuator, PIN, APD, low-pass filter, and BER and eye diagram analysers for assessing the performances of the link. The laser diode source with 1550nm is used here and its output power is set as 20dB the rise and fall times for the laser signal are equal to 0.05 bit. The insertion losses taken as 1 dB and depth 100 dB are taken in consideration for a 4th order low pass Bessel filter. PIN and APD photodiode have a responsively set to 1 A/W and a dark current of 10 nA. PRBS generator generates binary sequences, and then converted into electrical pulses signals by pulse generators, and passed into a directly modulated laser [1]. The electrical signals generated in pulse generator have amplitude 1 a.u. A low-pass Bessel filter with cut off frequency 0.75 bit rate and depth 100 dB, is employed after the photodetectors to remove distortion in the electrical signals. Figure.4 shows simulation set up to compare PIN and APD.

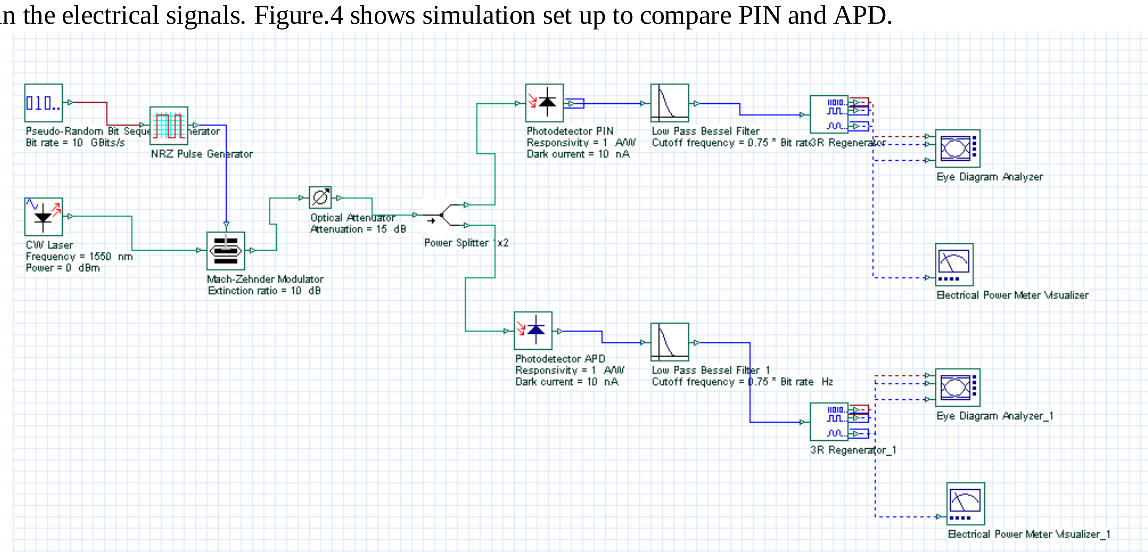

Fig .4 Simulation layout for PIN and APD comparison in terms of Q factor and receiver sensitivity.

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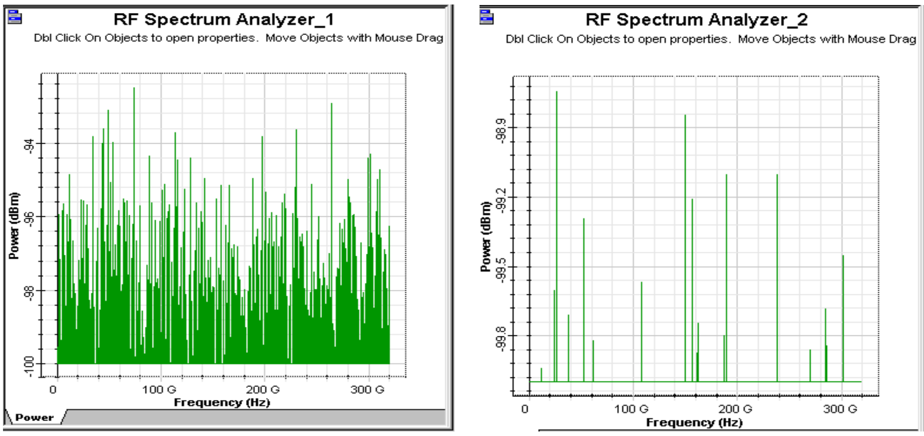
V. RESULT AND DISCUSSION

A. *Analysis of photodetection noise in PIN and APD photodiode*

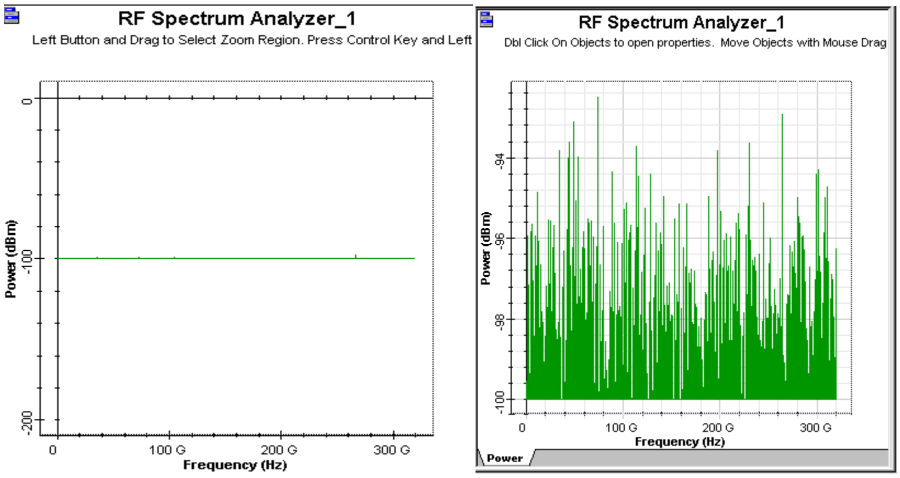
The first step consists to simulate the optical chain using respectively the PIN photodiode and the APD photodiode in order to visualize the shape of thermal and quantum noises caused in these photodiodes using a power spectrum analyzer.



5(a) PIN photodiode 5(b) APD photodiode

Fig. 5(a), (b) Spectral visualization of Johnson noise caused in PIN and APD.

As displays the figure 5 (a, b), the thermal noise power caused in the PIN photodiode is higher than it in the APD photodiode.



6(a) PIN photodiode 6(b) APD photodiode

Fig. 6 (a),(b) Spectral visualization of quantum noise “Shot noise” caused in PIN and APD photodiodes.

The quantum noise power caused in the APD photodiode is denser than it in the PIN photodiode as displays the figure 6 (a, b). The dominant noise in the PIN photodiode is that of thermal noise derived from the various circuits contained in the photodiode such as the resistance and the preamplifier which cause thermal agitation of electrons which consequently influences on the photodiode responsivity, however the APD photodiode resists against the thermal noise thanks to its internal gain produced by the avalanche process, but this process causes a rising of quantum noise that

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reduces the photodiode detection speed, this is due to the noise of multiplication generated particularly in *APD* photodiode by impact of carriers in the depletion region[5].

B. *Performance comparisons between PIN and APD photodetectors for use in optical communication systems*

Main comparison between PIN and APD is performed in terms of Q factor and receiver sensitivities. Both the Q factor and receiver sensitivity are measured with respect to extinction ratio [7]. Major component of the transmitter is the modulator. Mach–Zehnder modulator arrangement having two inputs, one for the laser diode and the other for the modulating data. Modulator transforms the electrical signal into optical signal form, where extinction ratio can be specified. We can figure of the extinction ratio, and then calculate the Q factor and sensitivity at the receiver.

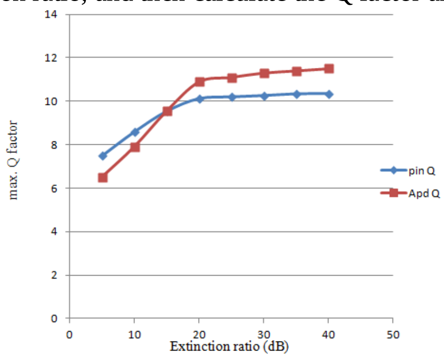

Fig.7 Q factor of PIN and APD

Figure.7 shows a plot of extinction ratio versus maximum Q factor. From this plot it is clear that for both PIN and APD photodiodes the Q factor increases with extinction ratio. The rise in Q factor is greater in APD. So APD have better performance compare to PIN.

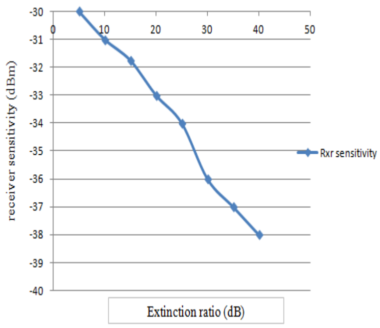

Fig.8 Receiver sensitivity of PIN and APD

Figure.8 indicates the plot of extinction ratio versus receiver sensitivity. Sensitivity of both the PIN and APD decreases with extinction ratio. Q factors of both the photodetectors increases with extinction ratio and receiver sensitivity decreases with extinction ratio.

VI. CONCLUSION

APD photodiode retains always the better performance comparing with the PIN photodiode for the reason that the manipulation used particularly a low input power. High gain of APD made it suitable for long haul communication. PIN is more suited to low bandwidth and short distance applications. APD gives better Q factor than PIN photodiodes.

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BIOGRAPHY

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