**بسم الله الرحمن الرحيم**

قَالَ تَعَالَىٰ:

﴿ قُلْ بِفَضْلِ ٱللَّهِ وَبِرَحْمَتِهِۦ فَبِذَٰلِكَ فَلْيَفْرَحُواْ هُوَ خَيْرٌ مِّمَّا يَجْمَعُونَ ﴿٥٨﴾ ﴾

يونس: ٥٨

**صدق الله العظيم**

# Dedication

TO MY FAMILY

# ACKNOWLEDGEMENT

First and foremost, I must acknowledge our limitless thanks to Allah; I would like to take this opportunity to express my profound gratitude and deep regard to my supervisor **Dr. Fatah Elrahman Ismail Khalifa**, for his exemplary guidance, valuable feedback and constant encouragement throughout the duration of the project. His perceptive criticism kept me working to make this project in a much better way. Working under him was an extremely knowledgeable experience for me.


# ABSTRACT

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. Shot noise and thermal noise added by avalanche photodiode (APD) and Positive intrinsic negative photodiode (PIN) degrade the received signal on optical communication receivers systems. There for this affects in the overall performance of fiber optic communication system. This thesis will evaluate the performance of optical communication receivers systems by using optimal gain of APD to reduce affect of shot noise and thermal noise in detected signal, Performance of photo receivers in optical communication receivers evaluated and simulated by using optisystem software. From simulation results, found the PIN gives better performance than APD in existing of shot noise, also APD gives better performance than PIN in existing of thermal noise because it have internal gain that not achieved in PIN and observed the maximum gain for APD is 16 to maintain best performance.

## المستخلص

الكاشف الضوئي هو أحد العناصر الأساسية لنظام اتصالات الألياف الضوئية، وهو واحد من العناصر الفعاله التي تحدد الأداء العام للنظام. ضوضاء الطلقة والضوضاء الحرارية تقلل من الإشارة المستقبله في نظم استقبال الاتصالات البصرية باستخدام الثنائي الضوئي العادي و الثنائي الضوئي الانهياري. وهذا يؤثر في الأداء العام للنظام في هذه الأطروحة سيتم تقييم أداء النظام باستخدام أمثل كسب للثنائي الضوئي الانهياري للحد من تأثير ضوضاء الطلقة والضوضاء الحرارية في الكشف عن الإشارة، وذلك باستخدام برنامج المحاكاة اوبتيسيستم تم الحصول علي افضل اداء للثنائي الضوئي العادي عند تاثير ضوضاء الطلقة وافضل اداء للثنائي الضوئي الانهياري عند تاثير الضوضاء الحرارية عند امثل كسب 16 .

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# List of Abbreviations

| | |
|---|---|
| PIN | intrinsic negative photodiode |
| APD | avalanche photodiode |
| SNR | signal to noise ratio |
| PD | photodiode |
| FSO | free space optical |
| DPSS laser | diode pumped solid state laser |
| IM/DD receiver's | intensity modulated with direct detection |

# List of symbols

| | |
|---|---|
| $P_{in}$ | Incident optical power |
| $I_P$ | Average current |
| $R$ | Responsitivity |
| $i_{s(t)}$ | Current fluctuation |
| $\sigma^2{}_T$ | Variance of the thermal noise |
| $k_B$ | Boltzmann constant |
| T | Receiver temperature |
| $R_L$ | APD's load resistor |
| $F_n$ | Amplifier noise |
| $\Delta f$ | Effective noise bandwidth |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Preface

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. Therefore, when considering signal attenuation along the link, the system performance is determined at the detector. performance Improvement allows the installation of fewer repeater stations and lowers maintenance costs[1].

The photo detector 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. Positive intrinsic negative photodiodes (PINs) and avalanche photodiodes (APDs) are the main types of photodiodes. Several physical sources that affect the signal at the output of the photo detector, this thesis focusing on thermal noise and shot noise PIN and APD [2].

In the PIN photodiode, thermal noise plays the dominant role in the performance of the receiver. In the APD, both the thermal and shot noise is significant[3].

Performance of photo receivers in optical communication receivers can be evaluated and simulated by using optisystem software.

## 1.2 Problem statement

Shot noise and thermal noise added by PIN and APD degrade the received signal on optical communication receivers systems. There for this affects the overall performance of fiber optic communication system.

## 1.3 Proposed Solution

This thesis will evaluate the performance of optical communication receivers systems by using optimal gain of APD to reduce affect of shot noise and thermal noise in detected signal.

## 1.4 Objectives

The main objectives of this thesis are:

- To evaluate the performance of optical communication receivers systems using PIN and APD affected by shot noise and thermal noise.
- To detect high electrical power signal with minimum BER.

## 1.5 Methodology

Analysis of fundamental photo detection noises generated in PIN and APD photodiodes simulated by the "Optisystem" software in optical communication receivers system. The simulation includes three scenarios with shot noise and thermal noise in APD and PIN.

First scenario describe detected signal without thermal noise and with shot noise in PIN and APD with different gains, second scenario show detected signal without shot noise and with thermal noise 1.85e-025 w/Hz in PIN and APD with different gains and final scenario describe detected signal with thermal noise 1.85e-025 w/Hz and with shot noise in PIN and APD with different gains. The detected signal evaluated by BER analyzer and electrical power meter visualize.

## 1.6 Thesis Outlines

This thesis contains five chapters, outlines as follows:

**Chapter One**: contains introduction, problem statement, and proposed solution for this research.

**Chapter Two**: represents background on optical systems, type of photo detector, receiver noise and literature review show the researchers' results related to this thesis.

**Chapter Three**: describes methodology of this research by using optisystem simulation tool and explains the simulation process by change in simulation parameters.

**Chapter Four:** gives of result graphs of simulation and discussion.

**Chapter Five:** concludes the all research and proposes recommendations some subjects that can be investigated for future work.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Background

The need for economical and reliable transmission media with large information carrying capacity has been a motivating force in telecommunication research [4].For over 20 years, since the invention of the laser and the development of low-loss optical fiber, fiber systems have become the dominant backbone of the information-carrying infrastructure around the world, due to their high capacity, high speed, low cost, and high security. There are three essential parts in an optic communication system: a transmitter, a transmission medium, and a receiver. A laser is the core of a transmitter, with its output beam modulated by an input electric signal and then coupled into an optical fiber, which serves as the transmission medium to carry the signal to the receiving end. The photo detector 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 photo detector, in this research focusing on thermal noise and shot noise [2].

### 2.1.1 General Descriptions of Optical systems

The basic components of such an optical communication systems are the transmitter, the medium of transmission and the photo receiver. There is also an optical encoder, through which the electrical information signal is converted to an optical signal by modulating the optical emission from the optical transmitter. This optical transmitter is usually a light emitting diode or a laser diode together with a relevant modulating and driving circuits. After that, the optical signal is transmitted through a medium that provides suitable propagating conditions for the carrier signals. This transmission medium is usually an optical fiber with optical amplifiers and repeaters depending on its length used single mode fiber. Finally, at the photo receiver, the optical signal is converted back into an electrical signal [5].the optical fiber communication system shown in Figure 2.1

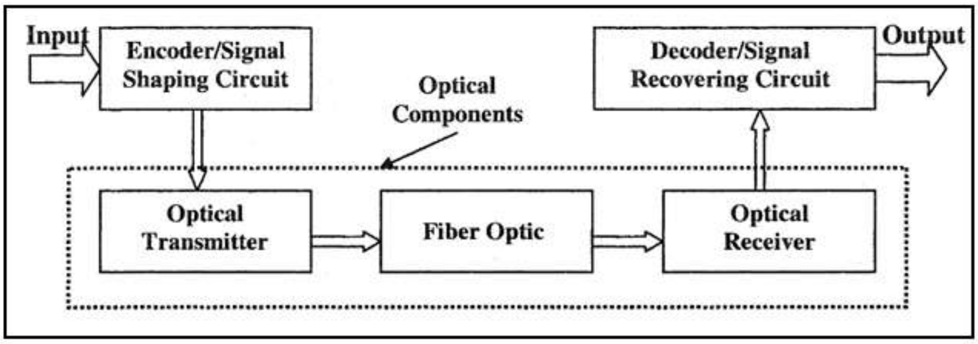


Figure 2.1: Schematic representation of an optical fiber communication system [2].

The photo receiver contains a photo detector converts optical signal to electrical signal and pre-amplifier amplifies the detected signal with relevant biasing and demodulating circuits to recover the original signal.

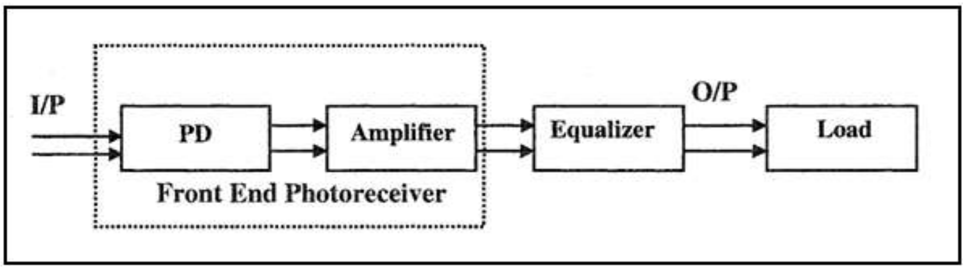


Figure 2.2: Schematic representation of the photo receiver of the optical Communication system [2].

### 2.1.2 Advantages of Optical Communication

- *Long transmission distance*
- *Large information capacity*
- *Small size and low weight*
- *Immunity to electrical interference*
- *Enhanced safety*
- *Increased signal security*

### 2.1.3 Photo detectors

Photo detectors are widely used in the optical communication at the transmission end of the photonic system which converts the incident light to current. So, it is needed to make photo detectors with high quantum efficiency for better detection of light and efficient working of the photonics system[6].The main type of photodiodes PIN and APD.

The role the detector plays demands that it must satisfy very stringent requirements for performance and compatibility. The following criteria define the important performance and compatibility requirements for detectors which are generally similar to the requirements for sources.

1. *High sensitivity at the operating wavelengths*.

2. *High fidelity*. To reproduce the received signal waveform with fidelity, for analogy transmission the response of the photo detector must be linear with regard to the optical signal over a wide range.

3. *Large electrical response to the received optical signal*. The photo detector should produce a maximum electrical signal for a given amount of optical power; that is, the quantum efficiency should be high.

4. *Short response time to obtain a suitable bandwidth*. Current single-channel, single mode fiber systems extend up to many tens of gigahertz.

5. *A minimum noise introduced by the detector*. Dark currents, leakage currents and shunt conductance must be low. Also the gain mechanism within either the detector or associated circuitry must be of low noise.

6. *Stability of performance characteristics*. Ideally, the performance characteristics of the detector should be independent of changes in ambient conditions. However, the detectors currently favored (photodiodes) have characteristics (sensitivity, noise, internal gain) which vary with temperature, and therefore compensation for temperature effects is often necessary.

7. *Small size*. The physical size of the detector must be small for efficient coupling to the fiber and to allow easy packaging with the following electronics.

8. *Low bias voltages*. Ideally the detector should not require excessive bias voltages or currents.

9. *High reliability*. The detector must be capable of continuous stable operation at room temperature for many years.

10. *Low cost*. Economic considerations are often of prime importance in any large scale communication system application.

## 2.1.3.1 PIN Photodiode

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, where all absorption takes place in the depletion region. Figure 2.3 shown PIN photodiode.

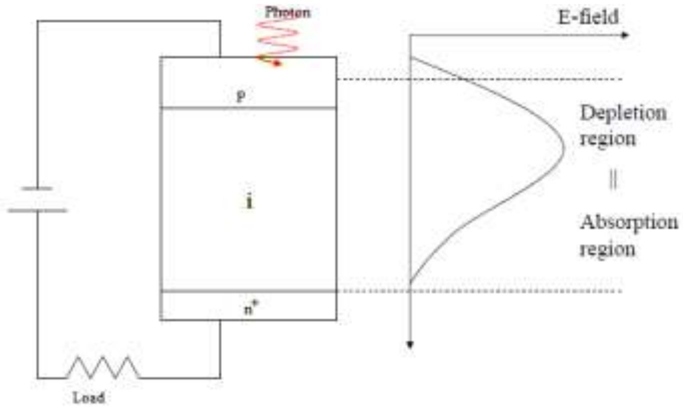


Figure 2.3 PIN photodiode[2]

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## 2.1.3.2 APD photodiode

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 2.4. 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).

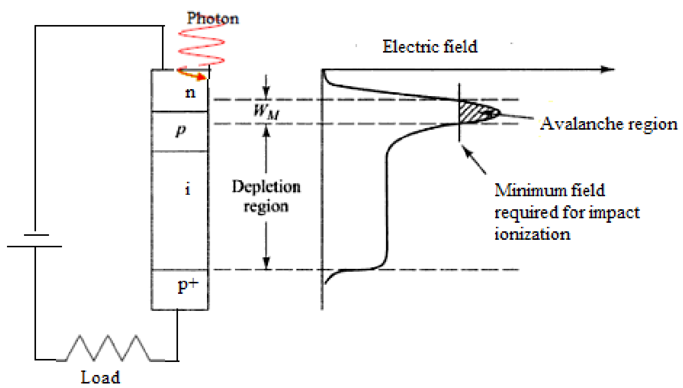


Figure 2.4 APD photodiode[2]

## 2.2 Noise Mechanisms

Noise is everything that is not the signal we would like to measure. Noise in optical detectors causes random fluctuations in the output that cannot be distinguished from the signal, so noise degrades the quality of the output signal.

Optical receivers convert incident optical power $P_{in}$ into electric current through a photodiode. The relation $I_P = RP_{in}$ assumes that such a conversion is noise free. However, this is not the case even for a perfect receiver. Two fundamental noise mechanisms, shot noise and thermal noise, lead to fluctuations in the current even when the incident optical signal has a constant power. The relation $I_P = RP_{in}$ still holds if we interpret $I_P$ as the average current. However, electrical noise induced by

Current fluctuations affect the receiver performance. The objective of this section is to review the noise mechanisms and then discuss the signal to noise ratio (SNR) in optical receivers[7]. The *pin* and APD receivers are considered in separate subsections, as the SNR is also affected by the avalanche gain mechanism in APDs [4].

The shot noise and thermal noise are the two fundamental noise mechanisms responsible for current fluctuations in all optical receivers even when the incident optical power $P_{in}$ is constant. of course, additional noise is generated if $P_{in}$ is itself fluctuating because of noise produced by optical amplifiers. This section considers only the noise generated at the receiver [4].

### 2.2.1 Johnson Noise and Nyquist's Theorem

At a finite temperature, electrons move randomly in any conductor. Random thermal motion of electrons in a resistor manifests as a fluctuating current even in the absence of an applied voltage. The load resistor in the front end of an optical receiver (see Fig.2.2) adds such fluctuations to the current generated by the photodiode. This additional Noise component is referred to as thermal noise. It is also called *Johnson noise* or *Nyquist noise* after the two scientists who first studied it experimentally and theoretically. Thermal noise can be included by modifying Eq. (1) as

$$I(t) = = I_P + i_{s(t)} + I_T\ (t) \qquad (2.1)$$

Where $I_T$ $(t)$ is a current fluctuation induced by thermal noise. Mathematically, $I_T$ $(t)$ is modeled as a stationary Gaussian random process with a spectral density that is frequency independent up to $f \sim 1$ THz (nearly white noise).

The variance of the thermal noise [5] is given by

$$\sigma^2{}_T = \frac{4k_B}{R_L} \Delta f F_n \qquad (2.2)$$

Where

$k_B$ Is the Boltzmann constant

T is the receiver temperature

$R_L$ Is the APD’s load resistor

$F_n$ Is the amplifier noise and

$\Delta f$ Is the effective noise bandwidth

The thermal agitation of the charge carriers in any circuit causes a small, yet detectable, current to flow. J.B. Johnson was the first to present a quantitative analysis of this phenomenon, which is unaffected by the geometry and material of the circuit. [8]Nyquist showed in his landmark 1928 that the problem of determining the amplitude of the noise was equivalent to summing the energy in the normal modes of electrical oscillation along a shorted transmission line connected to two resistors of resistance R [3].

### 2.2.2 Shot Noise

The quantization of charge carried by electrons in a circuit also contributes to a small amount of noise. Consider a photoelectric circuit in which current caused by the photo excitation of electrons flow to the anode. Over a relatively long time T, an average current I avg is observed

Primary photocurrent $I_P$ is directly proportional to the optical power level is given by

$$I_P = \mathrm{R}P_R \tag{2.3}$$

Where R is the responsivity and $P_R$ is the received optical power.

The shot noise is because of the random fluctuation of the electric current of the number of photons respectively. The shot noise was first investigated by Schottky in 1918. In time domain the instantaneous current $I(t)$ of the photo detector can be written as

$$I(t) = I_P + i_{s(t)} \tag{2.4}$$

Where $i_{s(t)}$the current fluctuation due to the shot is noise and $I_P$ is the primary photocurrent. The noise variance of the shot noise becomes

$$\sigma^2{}_S = (i^2{}_s(t)) = 2\mathrm{q}I_P\Delta f \tag{2.5}$$

Where q is the electronic charge and $\Delta f$ is the effective noise bandwidth of the receiver.

## 2.3 Related Works

In [9] study compared the sensitivity and performance of the coherent detection and IM/DD receivers. The probability was analytically derived by taking into account the atmospheric turbulence and receiver noise, which includes the shot noise and thermal noise and it is modeled as additive white Gaussian noise. The atmospheric turbulence is modeled by Gaussian distribution. In comparison to the coherent and incoherent

receivers with the same fading vector under atmospheric turbulence, sensitivity of the coherent receiver gives the best result and it is proven
In the sensitivity comparison and the performance of the coherent receiver gives the best result at the target BER rate and it is proven in the BER.

1n [10]study dark current, the noise components due to the instability of laser intensity, and the internal PIN thermal noise are practically negligible provided a complete and precise model for the receiver noise for the case of terrestrial FSO systems. When background noise is negligible, the PIN PD is thermal-noise-limited. Under such conditions, in order to reduce the thermal noise, should choose the load resistor R as large as possible. For the case of an APD, should still choose a load resistance as large as possible, although in this case the receiver is shot noise limited. When background radiations are not negligible, an APD-based receiver is shot-noise limited obviously. For a PIN-based receiver, on the other hand, the limit of the background noise level Pb beyond which the receiver sensitivity is affected, depends on the load resistance. For larger R values, this limit is lower, that is, the receiver performance is more considerably affected by background radiations.

In [11]study theory and with an experimental demonstration, the optimal recovery of light pulses via balanced detection. They developed a theoretical model for a balanced detector and the noise related to the detection of optical pulses. They minimized the technical and electronic noise contributions obtaining the optimal (model based) pattern function. The results presented better polarization-rotation angle estimations when using pulses leading to probe magnetic atomic ensembles in environments with technical noise. This possibility is especially attractive for balanced detection of sub-shot noise pulses, for which the acceptable noise levels are still lower.

In[12] study inherent noise sources be it mechanical or electrical in nature, This noise is called 1/f-noise, since it is predominant in the lower frequency range and falls off like 1/f, where f denotes the frequency of the observable. Study characterizes the noise properties of several radiation detectors using a low-frequency spectrum analyzer. It is obvious

That the modern DPSS laser performed much better almost over the entire frequency range covering 40 MHz also see that the measurement didn’t approach the theoretical shot-noise floor before approximately 2 MHz it is therefore doubtful that we can measure the shot-noise floor at 100 kHz with the available equipment in the teaching lab.

# CHAPTER THREE

# System Setup

## 3.1 Overview

This chapter describes in details simulation of optical communication receivers using APD and PIN using optisystem tools, also Analysis fundamental of photo detection noises generated in PIN and APD photodiodes simulated by the "Optisystem" software in optical receivers system. 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 photo detection 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. The objective of this study extends to define the dominant noise contribution in both PIN and APD photodiodes considered as detectors compare and evaluate their performances, in fact, this simulation consists of two major steps:

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

## 3.2 Simulation Tool Description

Optisystem is an innovative optical communication system simulation package for the design, testing and optimization of virtually any type of optical link in the physical layer of a broad spectrum of optical networks. Optisystem represents an optical communication system as an interconnected set of blocks. Each block is simulated independently using the parameters specified by the user for that block and the signal information passed into it from other blocks. As physical signal are passed between components in a real-world communication system, “signal” data is passed between components models in the simulation. These blocks are graphically represented as icons in Optisystem[13]. There are many benefits to use this simulation software like, the visual representation of design options, scenarios to present prospective, and low cost prototyping. As shown in Figure 3.1 the optical receiver model

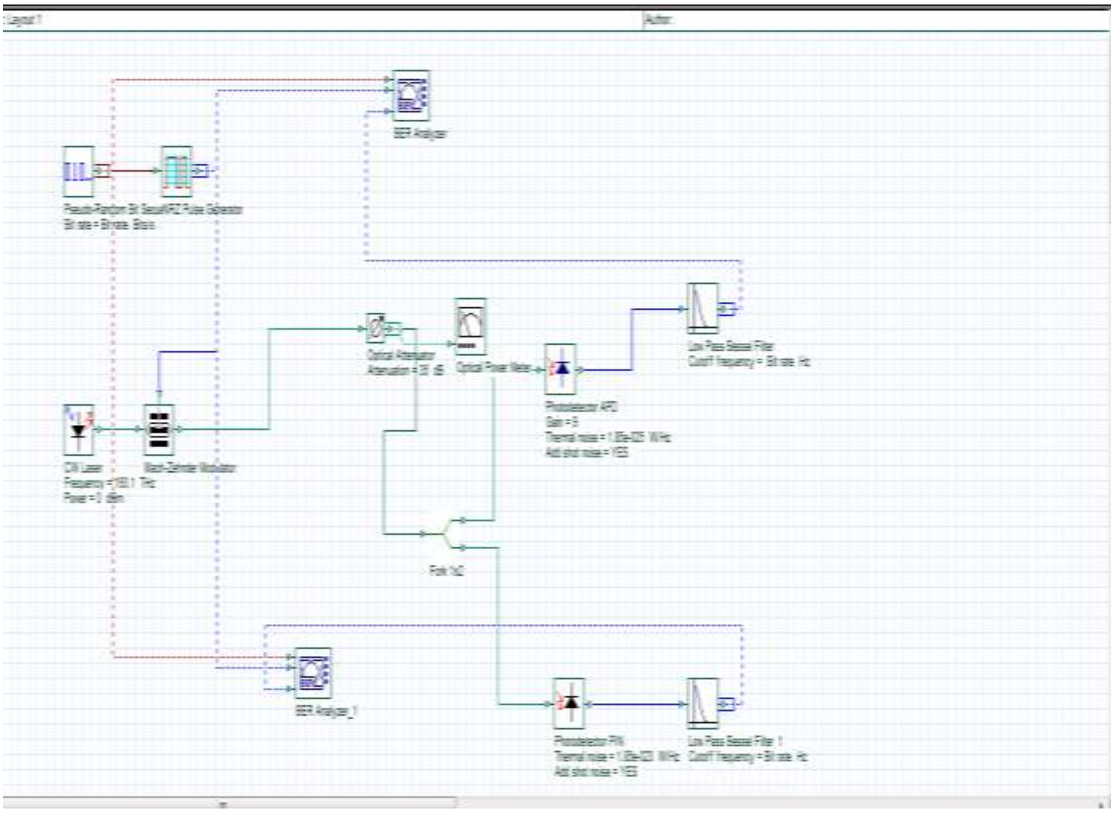


Figure 3.1 receiver PIN and APD simulation model

The component of this model is:

PRBS is a pseudo random a binary sequence is a deterministic repeatable signal, useful type of periodic signals, Which have bipolar signal and series of 1’s and 0’. the PRBS exhibits a uniform power spectral density over a wide frequency band[14].

NRZ pulse generator is Line coding defines the arrangement of symbols in a particular pattern for transmission that represent binary data. NRZ coding is a line code in which binary value ‘1’ is represented by positive voltage and ‘0’ is represented by negative voltage. The pulses have more energy than others. It requires only half the bandwidth than other coding[15].

Mach-Zehnder Optical modulator is used for controlling the amplitude of an optical wave. The input waveguide is split up into two waveguide interferometer arms. If a voltage is applied across one of the arms, a phase shift is induced for the wave passing through that arm**.**

CW Laser diode refers to a laser that produces a continuous output beam, sometimes referred to as "free-running," as opposed to a q-switched, gain-switched or mode locked laser, which has a pulsed output beam. The simulation parameter illustrate in Figure 3.2

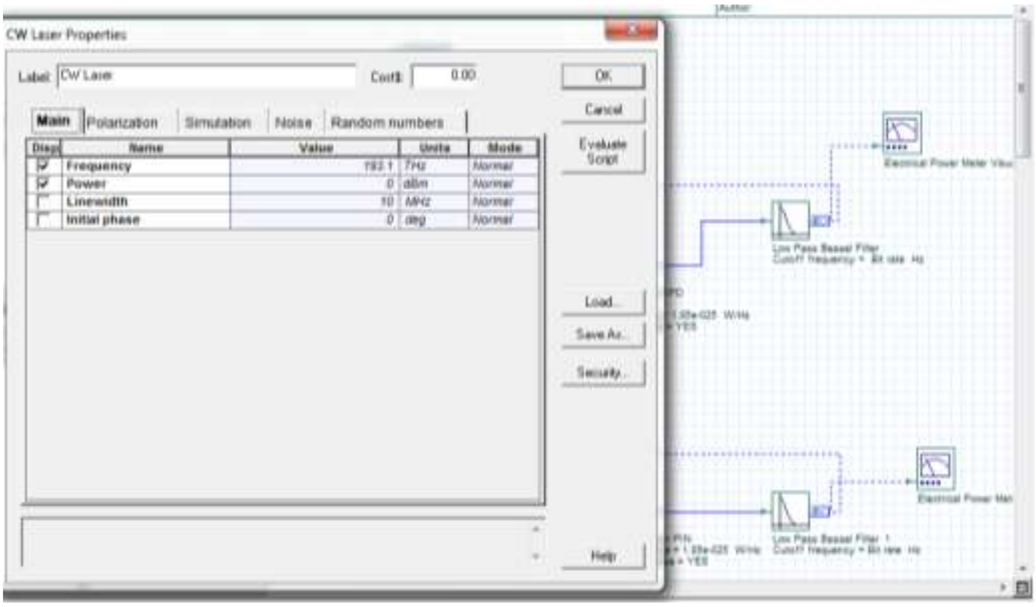


Figure 3.2 simulation parameter of CW

**Optical attenuator**, or fiber optic attenuator, is a device used to reduce the power level of an optical signal used in fiber_optic communications installed permanently to properly match transmitter and receiver levels.

**Fork or fiber optic splitter**, also known as a beam splitter of an integrated waveguide optical power distribution device. Simulation parameter as shown in Figure 3.3

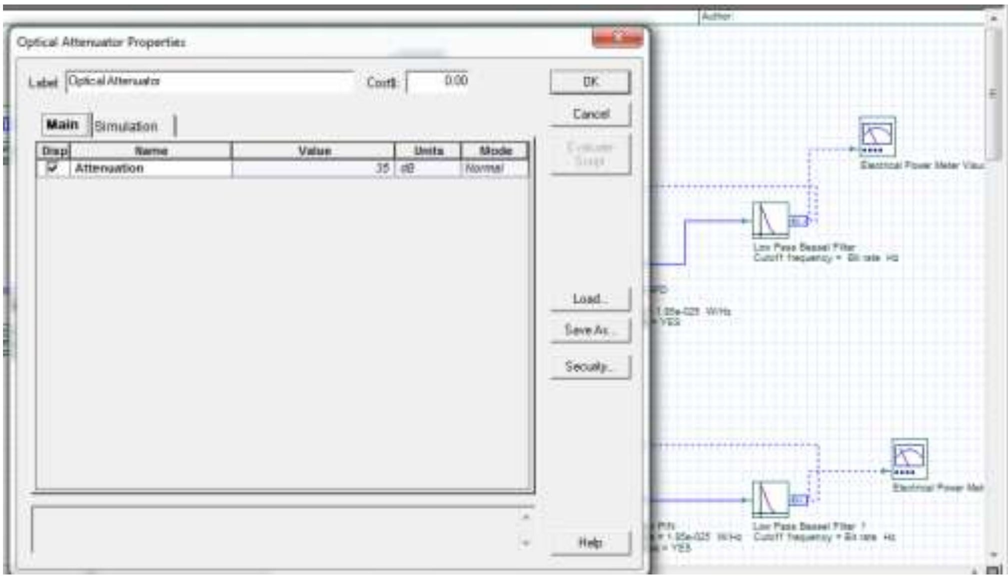


Figure 3.3 simulation parameter of optical attenuator

**Optical power meter** is a device used to measure the power in an optical signal. The term usually refers to a device for testing average power in fiber optic systems.

**BER TEST** the ratio of the number of incorrect bits and the total number of received bits[16].

**low-pass filter** is a filter that passes signals with a frequency lower than a certain cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency. Its purpose is to reduce the noise and distortion without having inter-symbol interference (ISI)**.**

**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, where all absorption takes place in the depletion region. The parameters of PIN photodiode as shown in Figure 3.4

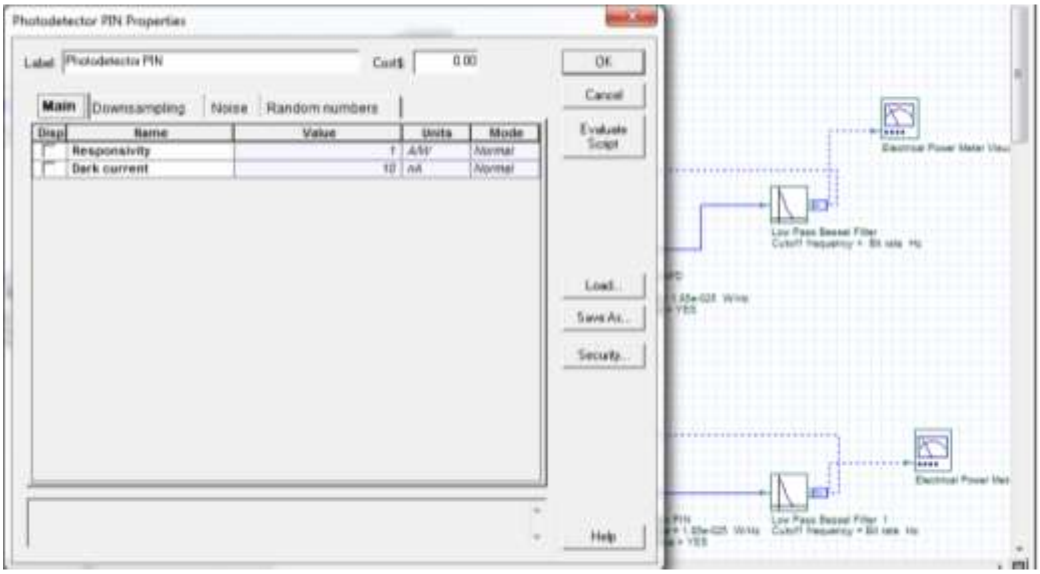


Figure 3.4 simulation parameter of PIN

**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). The parameters of APD photodiode as shown in Figure 3.5

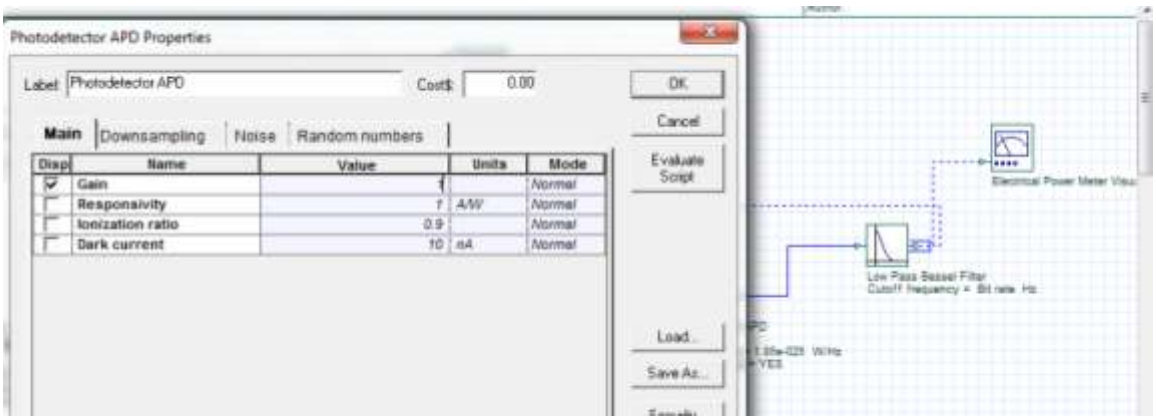


Figure 3.5 simulation parameter of APD

## 3.3 Simulation Setup

In this model APD and PIN are connected in the same circuit using a power splitter. First since simulation running a pseudo-random-bit-sequence (PRBS) generates binary inputs then connects to 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 which has two input ports, one for laser diode input and other for electrical signal. After modulation an optical signal is generated, 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. 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).

In this simulation three scenarios for shot noise and thermal noise applied and change in gain of APD to 9, 16 and 30. In any scenario they are:

First scenario with shot noise and without thermal noise in both PIN and APD with change in gain of APD.As shown in Figures 3.6 and 3.7

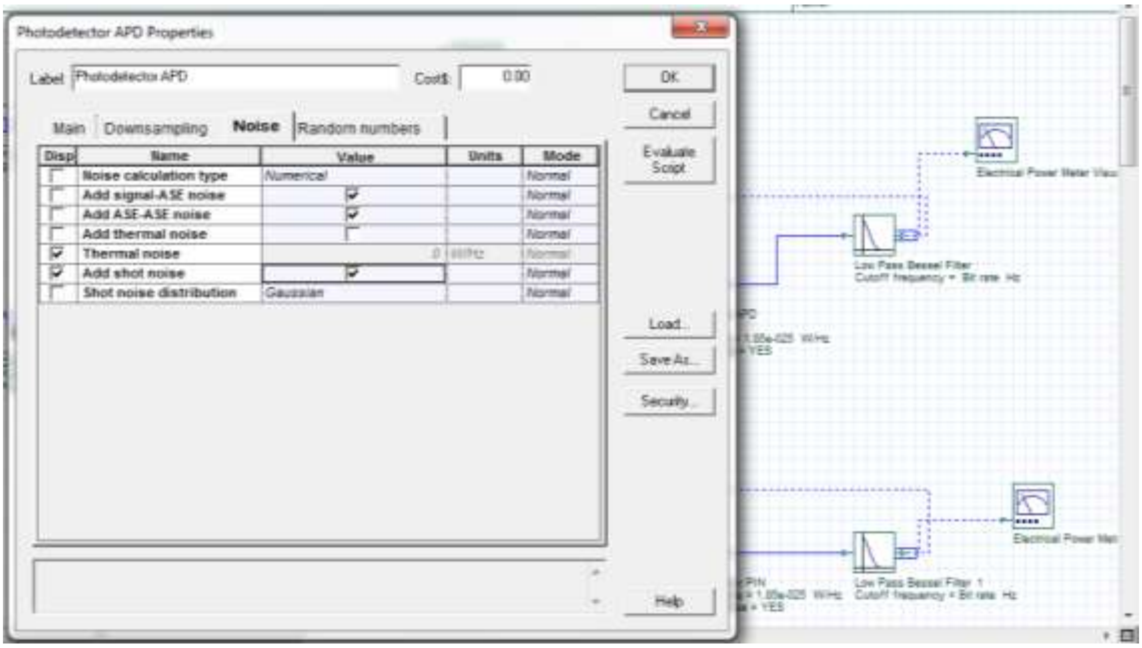


Figure 3.6 APD with shot noise and without thermal noise

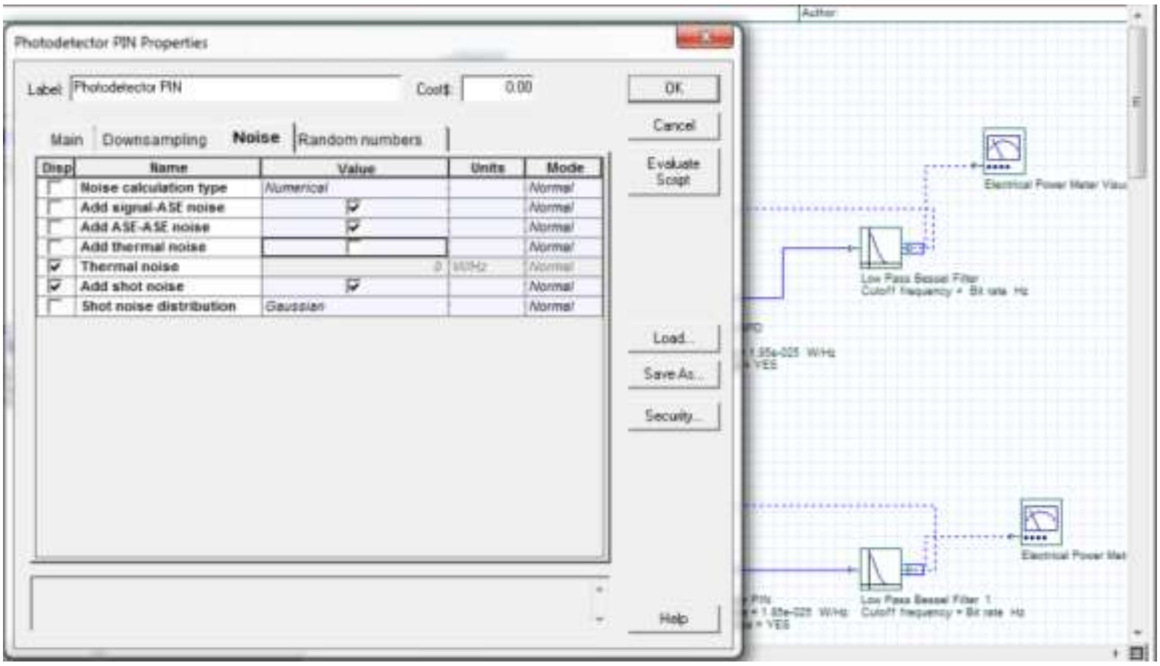


Figure 3.7 PIN with shot noise and without thermal noise

Second scenario without shot noise and with thermal noise 1.85e-025 w/Hz in both PIN and APD with change in gain of APD.As shown in Figures 3.8 and 3.9.

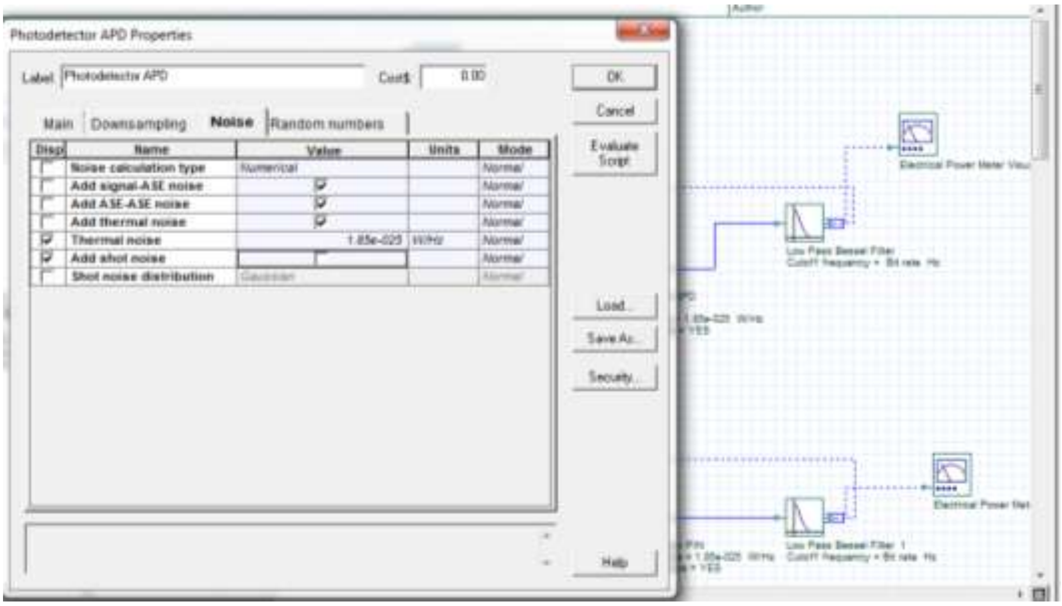


Figure 3.8 APD without shot noise and with thermal noise 1.85e-025

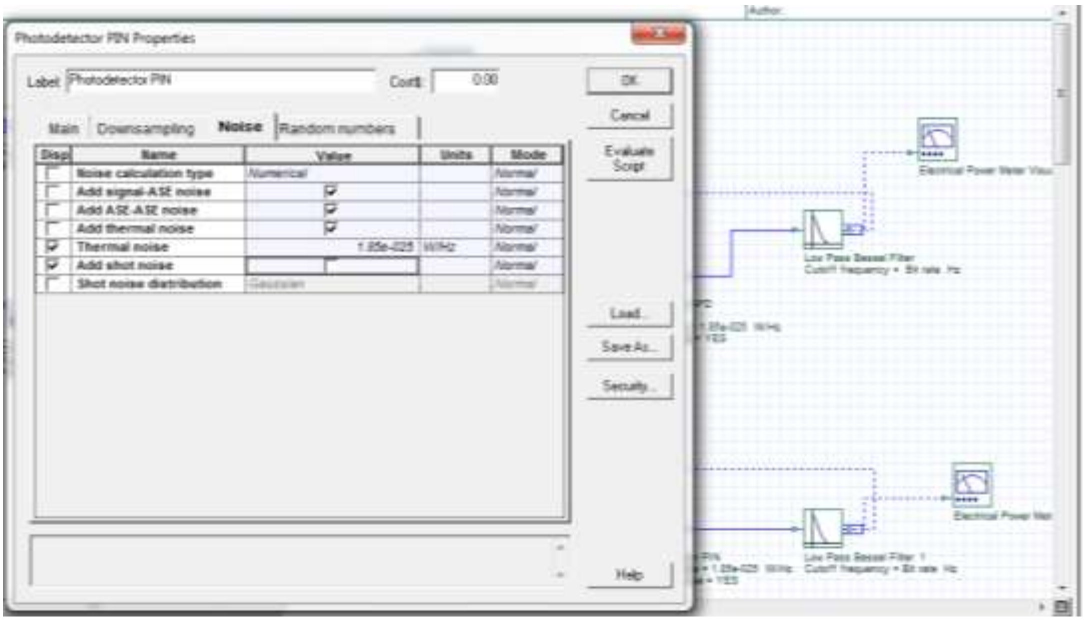


Figure 3.9 PIN without shot noise and with thermal noise 1.85e-025 w/Hz

Third scenario with shot noise and with thermal noise 1.85e-025 w/Hz in both PIN and APD with change in gain of APD.As shown in Figures 3.10 and 3.11

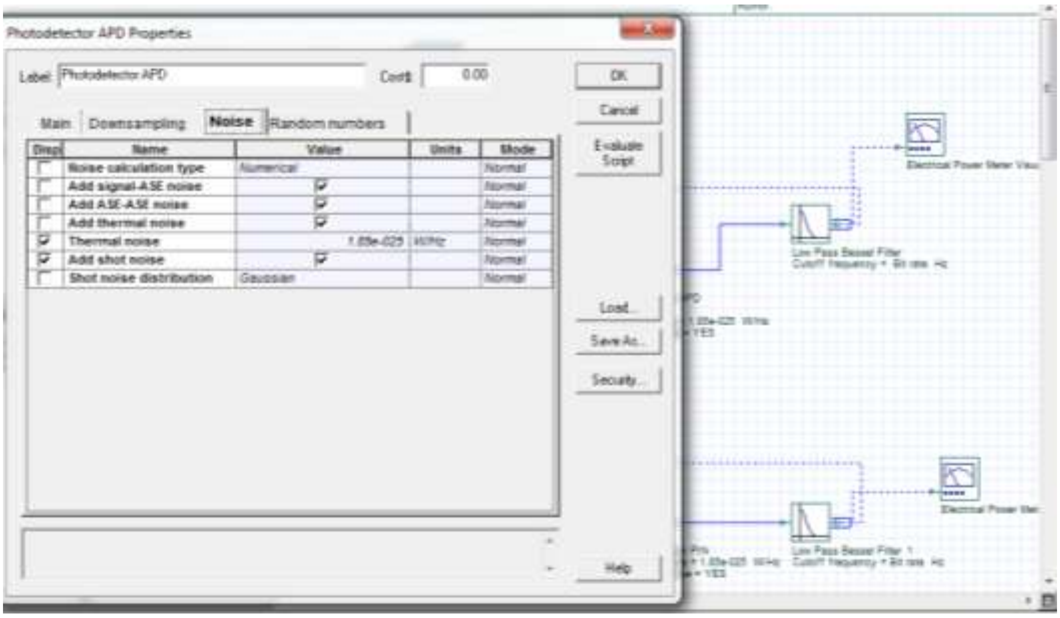

Figure 3.10 APD with shot noise and with thermal noise 1.85e-025 w/Hz

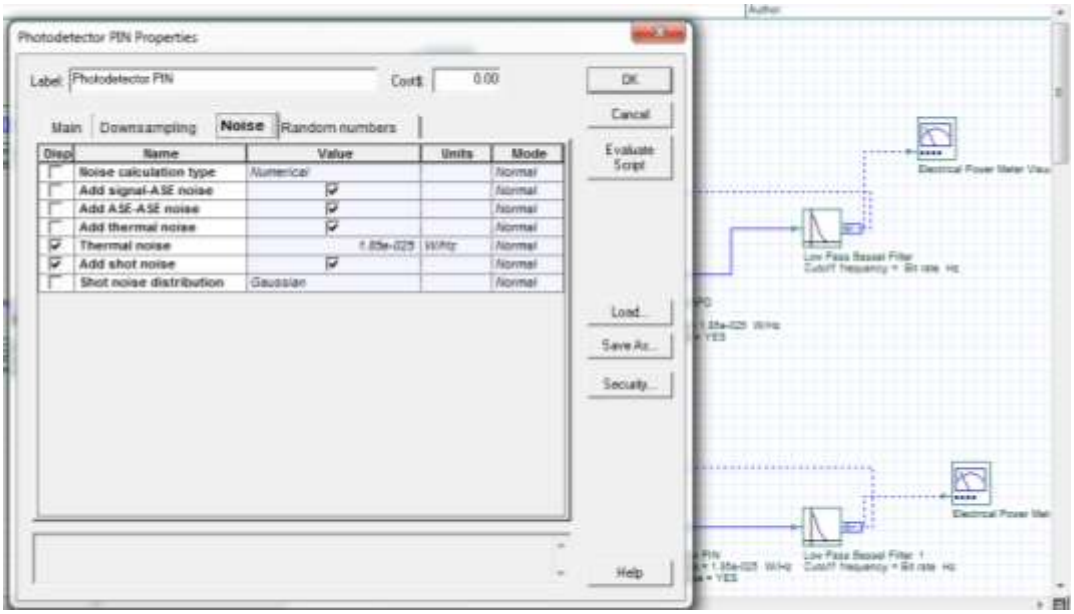

Figure 3.11 PIN with shot noise and with thermal noise 1.85e-025 w/Hz

# CHAPTERFOUR

# RESULTS AND DISCUSSION

## 4.1Overview

This chapter provides simulation results of shot noise and thermal noise in both PIN and APD using optisystem simulation tools , discusses the results under change in gain of APD and evaluate the best performance between two photo detectors with shot noise and thermal noise using BER analyzer and electrical power meter.

## 4.2 Simulation Results

Three scenarios obtained for simulation shot noise and thermal noise in both PIN and APD with change in gain of APD to obtain the results.

### 4.2.1 Shot noise in PIN and APD

The first scenario of simulation is shows shot noise in the two photo detectors and without introducing thermal noise in both PIN and APD.

#### 4.2.1.1 Shot noise in PIN

Figure 4.1 shows shot noise in PIN and without thermal noise from figure the minimum BER is $3.53\times10^{-9}$ and detected power is $1.46\times10^{-5}$ W.

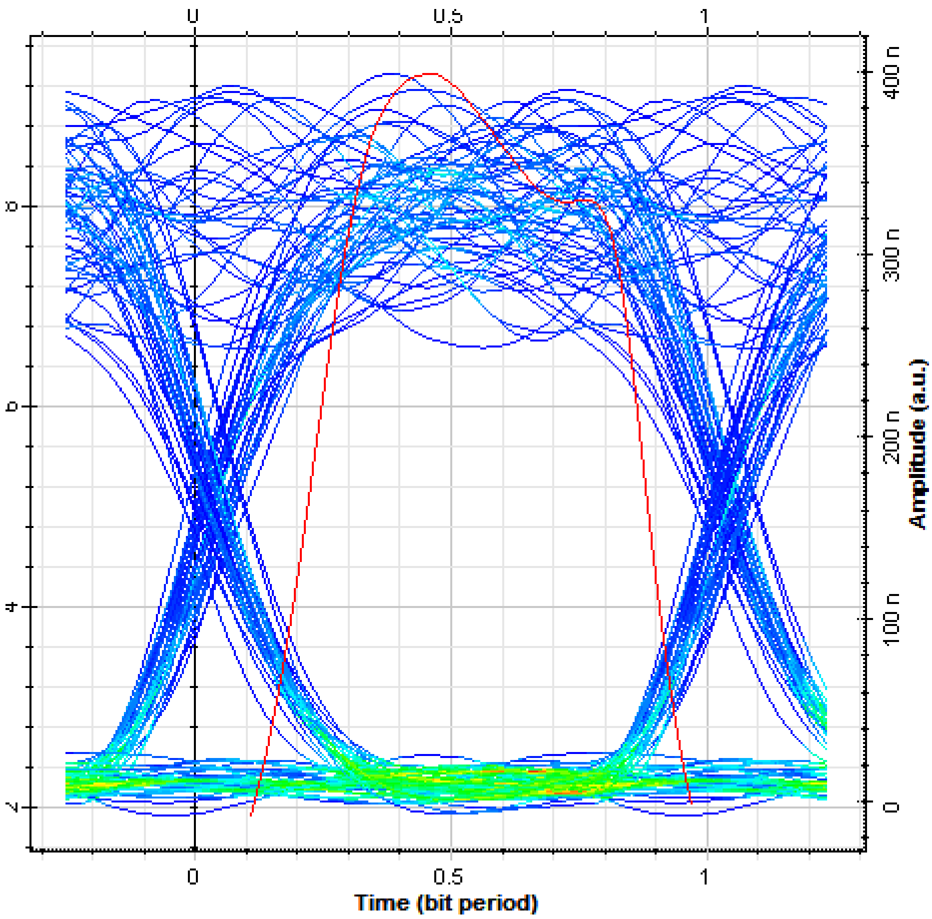


Figure 4.1 shot noise in PIN

### 4.2.1.2 Shot noise in APD

Figure 4.2 describes the effects of shot noise in APD which have gain 9 and without introducing thermal noise. From this figure, the minimum BER is $9\times10^{-4}$ and detected power is $2.58\times10^{-5}$ W. compare this BER by BER in detected signal by PIN the BER in detected signal by APD is higher than BER detected in signal by PIN because increase gain to 9, but detected power increase with gain increasing.

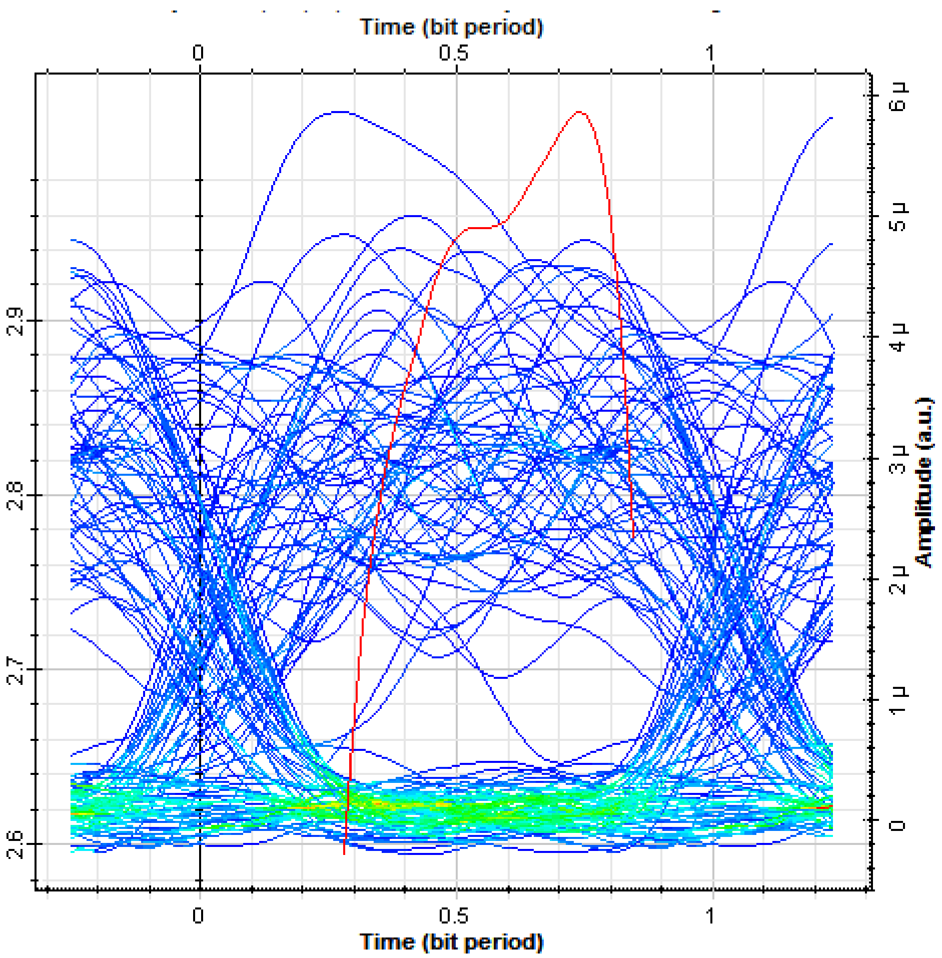


Figure 4.2 shot noise in APD with gain 9

Figure 4.3 gives the effects of shot noise in APD which have gain 16 and without introducing thermal noise from this figure minimum BER is $9\times10^{-3}$ and detected power is $8.67\times10^{-5}$ W. Compare this result with PIN imply increasing gain of APD increase BER and increase detected power.

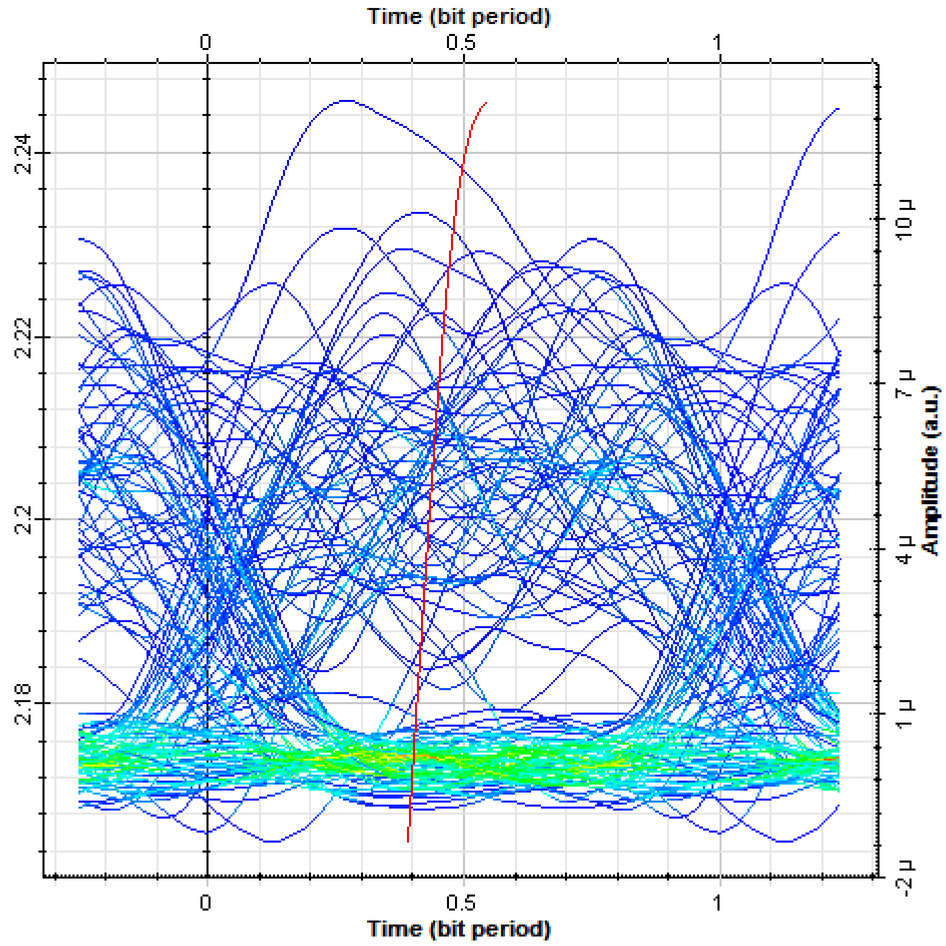


Figure 4.3 shot noise in APD with gain 16

The figure 4.4 shows shot noise in APD which have gain 30 and without thermal noise from this figure minimum BER is 1 and detected power is $3.43\times10^{-4}$ W, this indicated that the detected signal with high BER at increasing gain above 16.observed increasing internal gain of APD causing enlarge effect of shot noise in detected signal by increasing BER and this not achieve in PIN because not have internal gain.

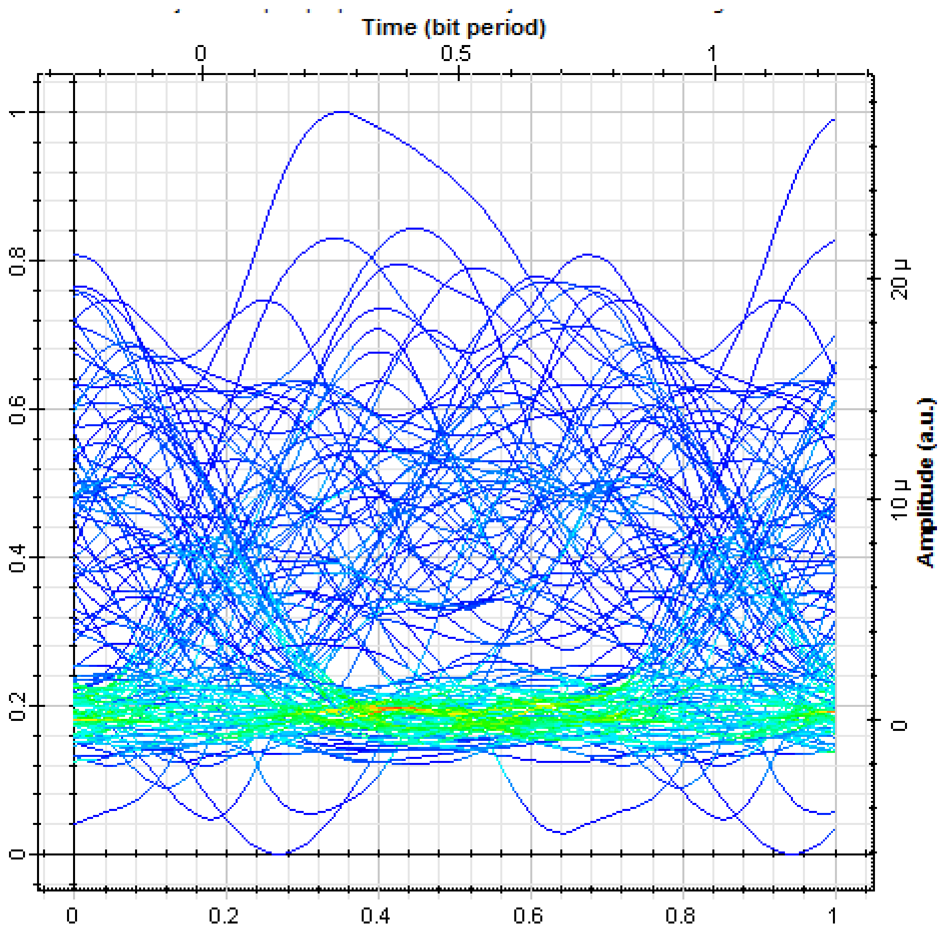


Figure 4.4 shot noise in APD with gain 30

### 4.2.2 Thermal noise in PIN and APD

The second scenario of simulation is obtained thermal noise in two photo detectors and without obtained shot noise in both PIN and APD.

#### 4.2.2.1 Thermal noise in PIN

Figure 4.5 shows thermal noise in PIN 1.85e-025 and without shot noise from figure the minimum BER is $1\times10^{-3}$ and detected power is $1.55\times10^{-5}$ W. Compare this result with result by shot noise in PIN in figure 4.1 imply the thermal noise increases BER in detected signal more than shot noise in PIN.

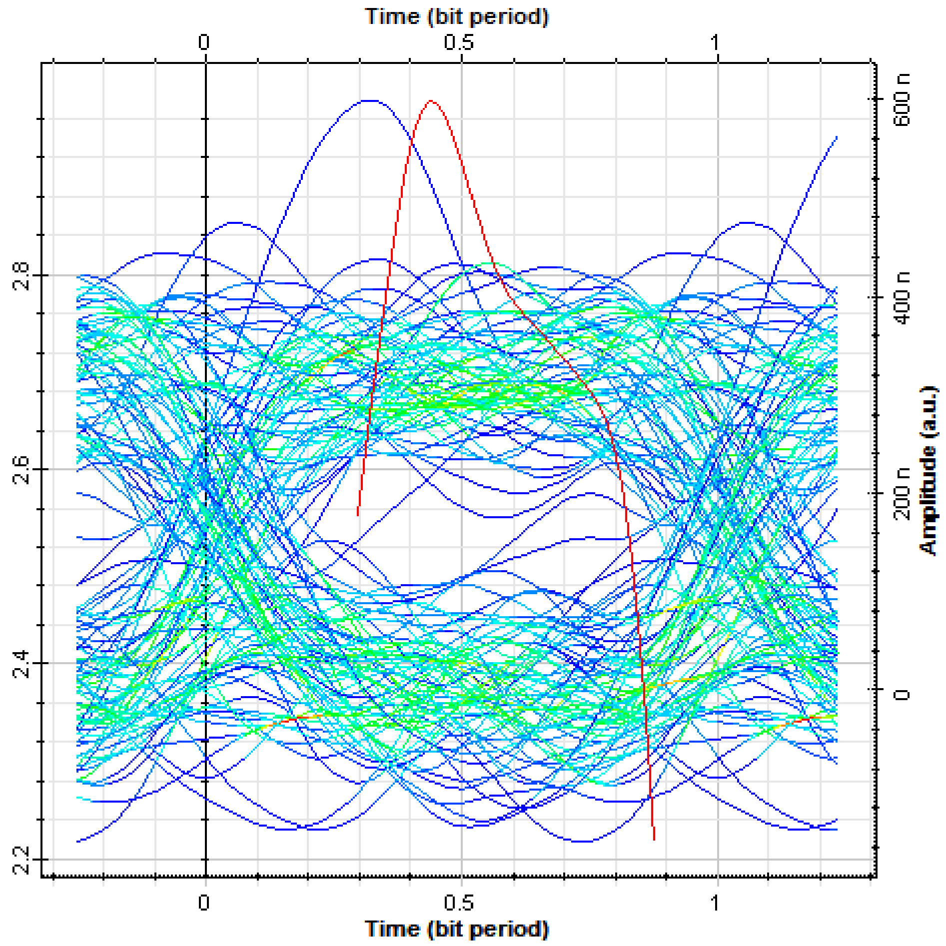


Figure 4.5 thermal noise in PIN

### 4.2.2.2 Thermal noise in APD

Figure 4.6 describes thermal noise 1.85e-025 in APD which have gain 9 and without shot noise from this figure minimum BER is $9.26\times10^{-55}$ and detected power is $2.35\times10^{-5}$ W. compare this BER by BER in detected signal by PIN the BER in detected signal by APD is less than BER detected in signal by PIN because increase gain to 9, but detected power increase with gain increasing, mean that the thermal noise more effect in received signal by PIN than APD.

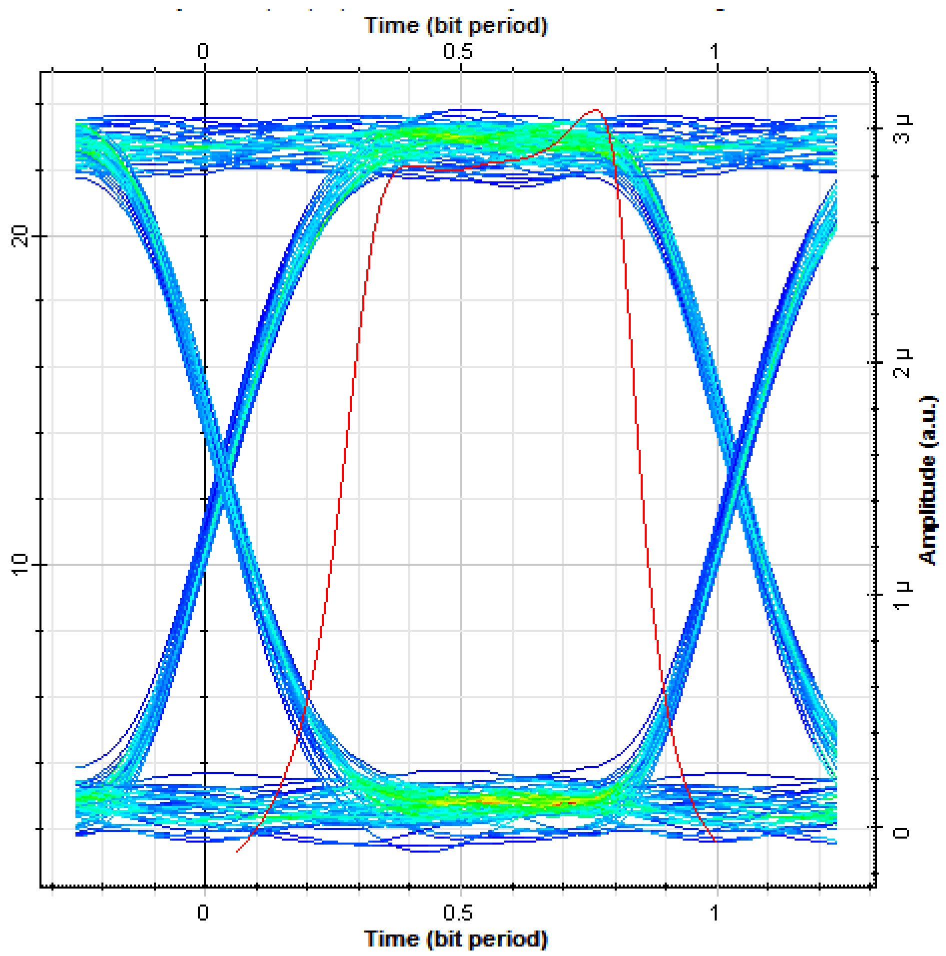


Figure 4.6 thermal noise in APD with gain 9

Figure 4.7 gives thermal noise in APD which have gain 16 and without shot noise from this figure minimum BER is 0 and detected power is $7.41\times10^{-5}$ W. Compare this result with PIN imply increasing gain of APD decrease BER.

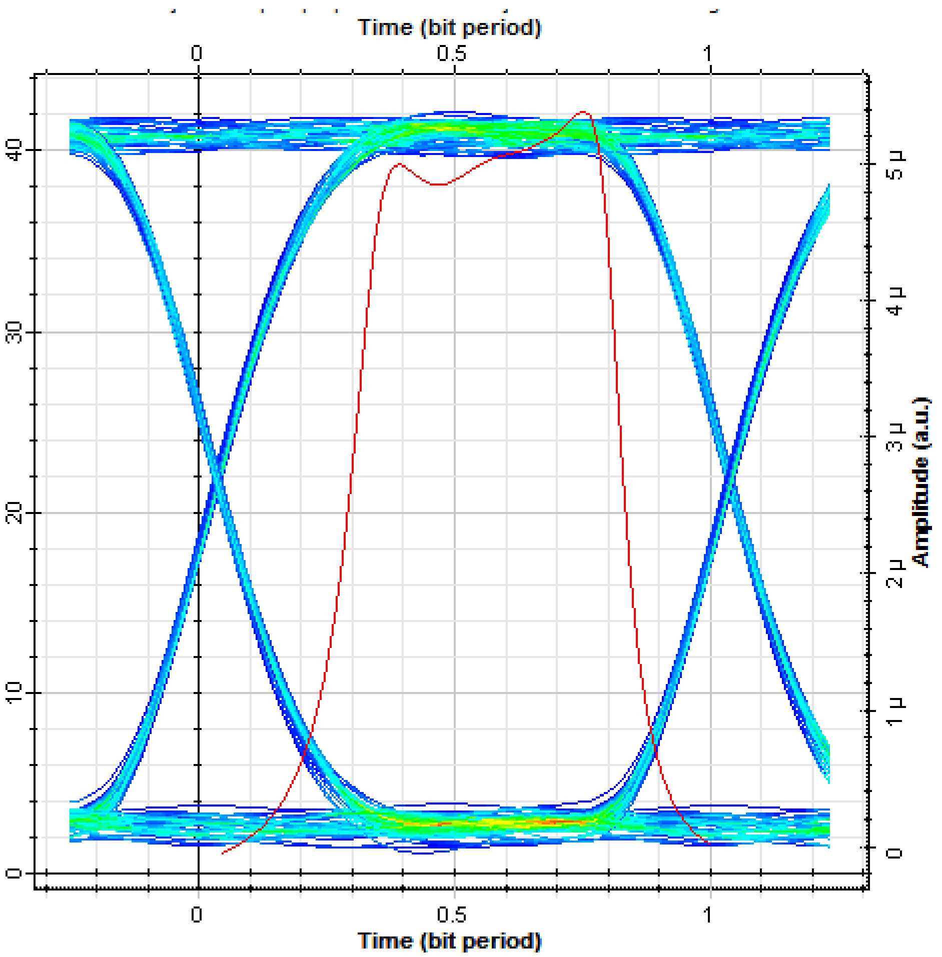

Figure 4.7 thermal noise in APD with gain 16

The figure 4.8 shows thermal noise in APD which have gain 30 and without shot noise from this figure minimum BER is 0 and detected power is $2.61\times10^{-4}$ W, this indicated that the detected signal with less BER at increasing gain above 16.observed increasing internal gain of APD causing decrease effect of thermal noise in detected signal by decreasing BER and this not achieve in PIN because not have internal gain.

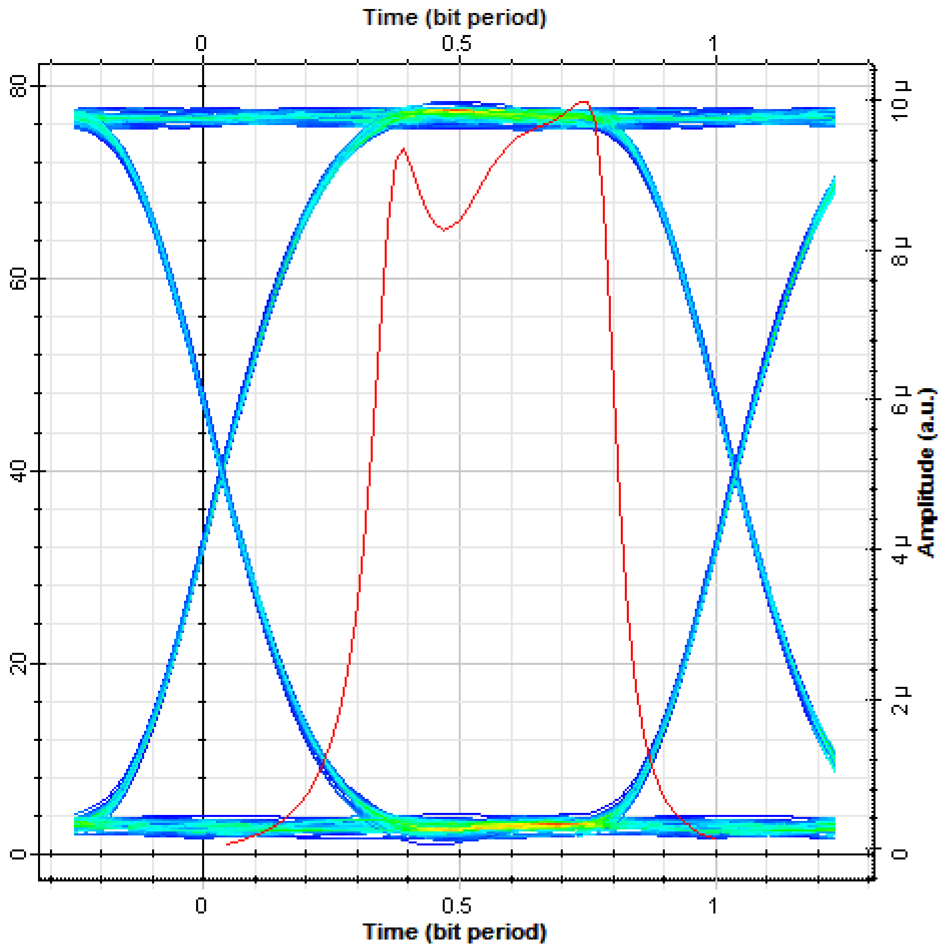


Figure 4.8 thermal noise in APD with gain 30

### 4.2.3 Thermal noise and shot in PIN and APD

The third scenario of simulation is obtained thermal noise and shot noise in two photo detectors.

#### 4.2.3.1 Thermal noise and shot noise in PIN

Figure 4.9 shows thermal noise in PIN 1.85e-025 and with shot noise from figure the minimum BER is $3\times10^{-3}$ and detected power is $1.57\times10^{-5}$ W.

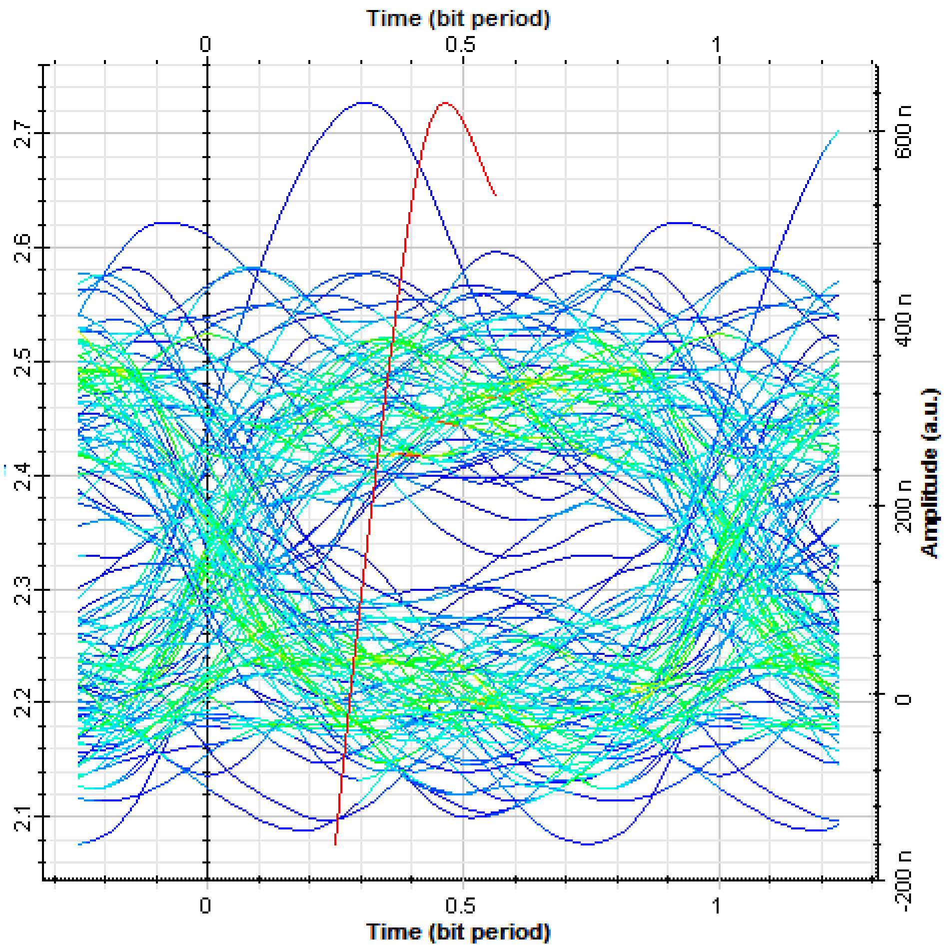


Figure 4.9 thermal noise and shot noise in PIN

### 4.2.3.2 Thermal noise and shot noise in APD

Figure 4.10 describes thermal noise 1.85e-025 in APD which have gain 9 and with shot noise from this figure minimum BER is $1\times10^{-3}$ and detected power is $2.57\times10^{-5}$ W. compare this BER by BER in detected signal by PIN the BER in detected signal by APD is less than BER detected in signal by PIN because increase gain to 9, but detected power increase with gain increasing, mean that the thermal noise and shot noise together more effect in received signal by PIN than APD.

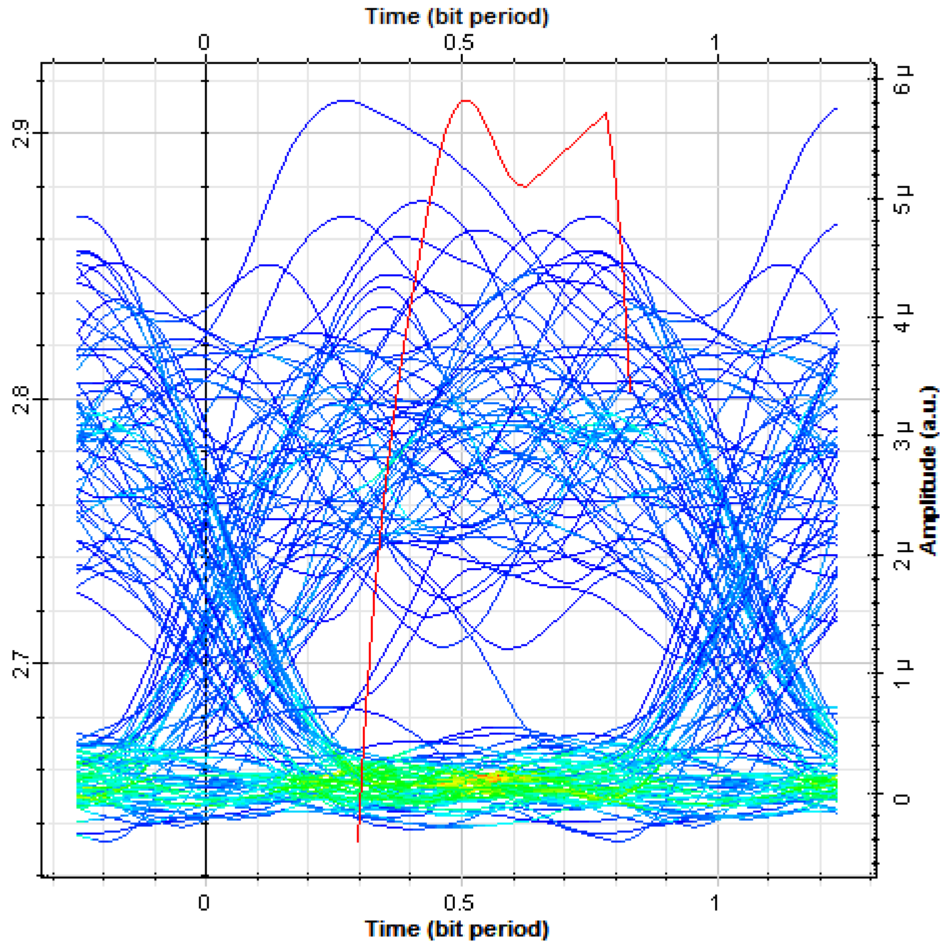


Figure 4.10 thermal noise and shot noise in APD with gain 9

Figure 4.11 gives thermal noise in APD which have gain 16 and with shot noise from this figure minimum BER is $9\times10^{-3}$ and detected power are $8.67\times10^{-5}$ W. Compare this result with PIN imply increasing gain of APD increase BER and increase detected power.

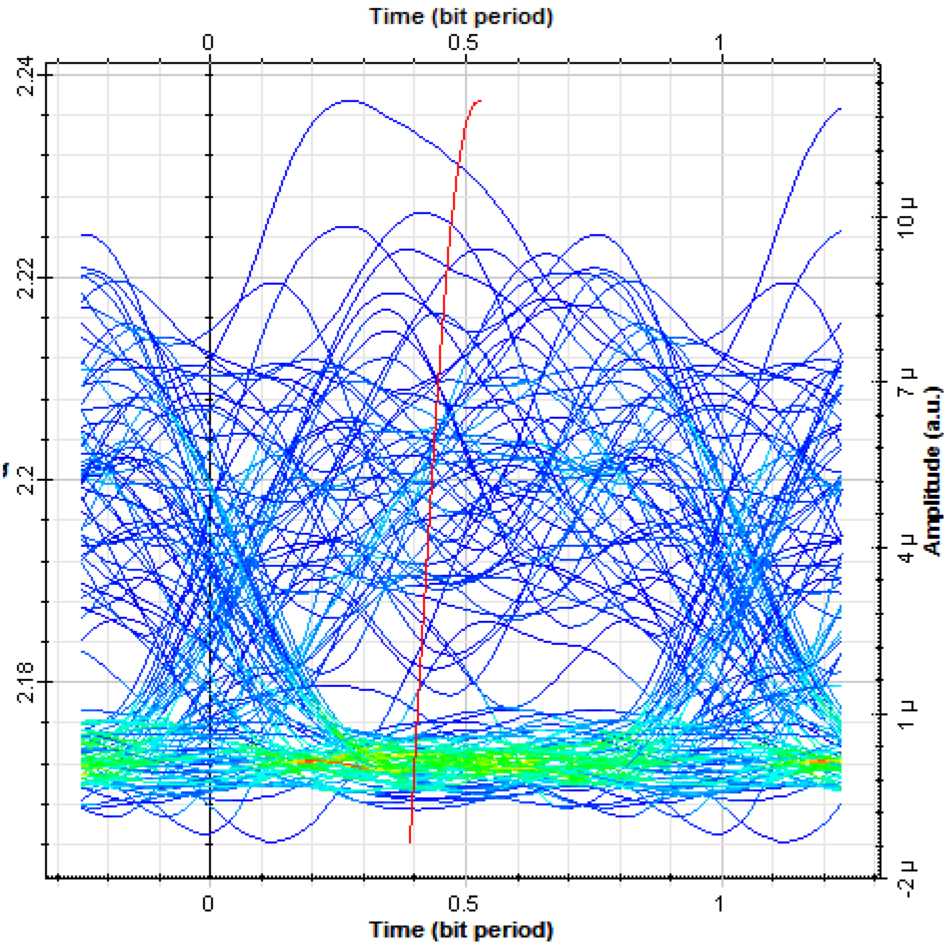


Figure 4.11 thermal noise and shot noise in APD with gain 16

The figure 4.12 shows thermal noise in APD which have gain 30 and with shot noise from this figure minimum BER is 1 and detected power is $3.43\times10^{-4}$ W, this indicated that the detected signal with higher BER at increasing gain above 16.observed increasing internal gain of APD causing increase effect of thermal noise and shot noise in detected signal by increasing BER and this not achieve in PIN because not have internal gain.

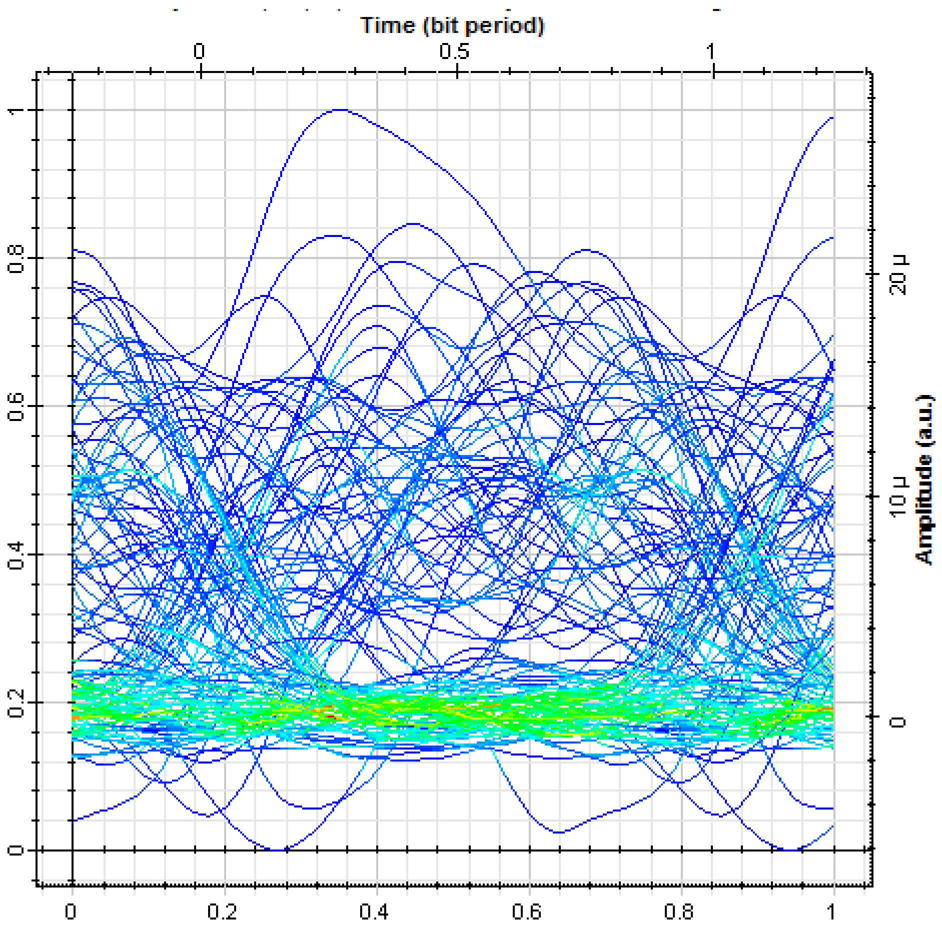


Figure 4.12 thermal noise and shot noise in APD with gain 30

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATION

## 5.1CONCLUSION

This work mainly aimed to evaluate the performance of photo detection noises caused in photodiodes APD and PIN in optical receiver systems used three scenarios of shot noise and thermal noise by optisystem simulation tools. From simulation results of scenarios found the PIN gives better performance than APD in existing of shot noise, also APD gives better performance than PIN in existing of thermal noise because it have internal gain that not achieved in PIN and observed the maximum gain for APD is 16 to maintain best performance.

## 5.2 RECOMMUNDATION

Finally, it is very interesting to extend this research by studying the other photo detection noises which are the excess noises summarized in *“Flicker noise”* and *“generation-recombination noise”*, as it is very important to model all types of photo detection noise in order to get a good performance of photo detector that establishes a topical subject making the optical communication systems more efficient.

# References


[1] D. L. J. Preetam Jain1 "Comparative Study of an Optical Link with PIN and APD as Photo-Detector," *International Journal of Application or Innovation in Engineering & Management (IJAIEM),* vol. 3, 2014.

[2] G. P. Nija Shafi1, "Performance Analysis of Photodetectors and Effect of Photodetection Noises in Optical Communication Systems," *International Journal of Innovative Research in Computer and Communication Engineering,* vol. 4, 2016.

[3] D. F. Osayd M. Kharraz, "Performance comparisons between PIN and APD photodetectors for use in optical communication systems," *International Journal for Light and Electron Optics,* 2013.

[4] R. K. A. Prachi Sharma1, Suraj Pardeshi3, Mandeep Singh4, "Fibre Optic Communications: An Overview," *International Journal of Emerging Technology and Advanced Engineering,* vol. 3, 2013.

[5] J. M. SENIOR, "Optical FiberCommunications Principles and Practice," *book,* 2009.

[6] J. K. Salil Gupta1 and "A Review on Silicon-Based Photodetectors," *International Journal of Innovative Research in Science, Engineering and Technology,* vol. 5, 2016.

[7] J. W. Sons, "Fiber-Optic Communications Systems," *book,* 2002.

[8] D. V. Perepelitsa, "Johnson noise and shot noise," *Dept. of Physics, MIT,* 2006.

[9] M. K. Akbar, "PERFORMANCE EVALUATION AND COMAPRISON OF COHERENT AND INCOHERENT RECEIVERS UNDER ATMOSHPERIC TUBULENCE," *Master Thesis Electrical Engineering with Emphasis on Signal Processing.2013*

[10] F. Xu, M.-A. Khalighi, and S. Bourennane, "Impact of different noise sources on the performance of PIN-and APD-based FSO receivers," in *Telecommunications (ConTEL), Proceedings of the 2011 11th International Conference on*, 2011, pp. 211-218.

[11] Yannick A. de Icaza Astiz, ∗ Vito Giovanni Lucivero,1 R. de J. Le´on-Montiel,1 and Morgan W. Mitchell1" ,2 ,Optimal Signal Recovery for Pulsed Balanced Detection," *ICFO-Institut de Ciencies Fotoniques, Mediterranean Technology Park, 08860 Castelldefels (Barcelona), Spain 2ICREA-Instituci´o Catalana de Recerca i Estudis Avan¸cats, 08015 Barcelona, Spain,* 201.5

[12] D. S. H. D. Carsten Langrock* Mathieu CharBonneau-Lefort, "Optical Radiation Detectors & Noise," *AP304 Laser Laboratory Course, Lab 1,* 2002.

[13] B. F. D. Alla Abbas Khadir1, Xiquan Fu3, "Achieving Optical Fiber Communication Experiments by OptiSystem

"*International Journal of Computer Science and Mobile Computing,* vol. 3, 2014.

[14] G. Y. P. S.Y. Hwang, D.H. Kim and K.S. Jhang, "Efficient implementation of a pseudorandom sequence generator for high-speed data communications," *ETRI Journal,* vol.2010 ,32 .

[15] N. G. N. P. SATYENDRA JAIN 1, "REVIEW PAPER FOR OPTICAL RECEIVER COMMUNICATION USING CODING SCHEME," *International Journal of Application or Innovation in Engineering & Management (IJAIEM),* vol. 2, 2013.

[16] S. M. Yongquan Fan, "BER Testing of Communication Interfaces," *IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT,* vol. 57, 2008.