International Journal of Engineering Innovation & Research
Volume 5, Issue 1, ISSN: 2277 – 5668

Gain And Excess Noise Analysis of Avalanche Photodetector Using Multilayer Perceptron Neural Network

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***Abstract* – In this paper, we predict gain and excess noise factor for different avalanche photodetectors using multilayer perceptron neural network. We assume the most important factors such as bias voltage, length, type and doping concentration of absorption and multiplication regions, as the inputs of network. Also, gain and excess noise are outputs. After training, we apply the test patterns to network and compare outputs with experimental results. Finally, we consider the behavior of excess noise for different values in input parameters, such as length of absorption and multiplication regions.**

***Keywords* – Avalanche Photodiode, Excess Noise, Impact Ionization, Multilayer Perceptron Neural Network.**

I. Introduction

An avalanche photodiode (APD) is a highly sensitive semiconductor electronic device that exploits the photoelectric effect to convert light to electricity. APDs can be thought of as photo-detectors that provide a built-in first stage of gain through avalanche multiplication [1]. By applying a high reverse bias voltage (typically 100-200 V in silicon), APDs show an internal current gain effect (around 100) due to impact ionization (avalanche effect) [2]. Impact ionization (hereafter II) Impact ionization occurs after electrons or holes gain at least the ionization threshold energy, Eth as they travel across the high field region [3,4]. It increases the number of carriers and means the gain concept. As the gain is increased, excess noise becomes more [5,6]. The excess noise factor, F is determined by the ratio of the electron (α) and hole (β) ionization coefficients and the mean multiplication, ‹ M › and is dependent on the length, w of the multiplication and absorption region [7]. Increased excess noise can cause instability of gain and device breakdown in high voltages. Separate absorption and multiplication (SAM) region APDs are widely using in optical communication and result in reduction of excess noise factor and dark current [2,8]. A sandwiched layer (charge layer) between the absorption and multiplication regions (SACM) can assist to reduce excess noise [9]. This layer is thin and high doped and reach the medium electric field in absorption region to high electric field in multiplication [10-13]. This issue redounds the electric field distribution in multiplication region becomes almost uniform [14-17].

Excess noise factor describes an instability concept for mean gain which can disturb performance of APD and result in breakdown. Consequently, prediction of excess noise factor for a defined gain is a key issue for fabrication and simulation [18-21].

To determine gain and related excess noise factor, we must use a tool or an efficient method which can cover the important mechanisms [22]. Interaction of them such as light absorption, drift and scattering complicates analysis of performance [2,23,24].

Neural network (NN) is an efficient tool that makes a relation between input and output spaces without complex formulas. It ignores the details and presents an overview for each device or system. One can see this tool is efficient to predict the excess noise and gain in APDs [25].

In this study, the most effective parameters on the gain and excess noise are supposed as inputs for multilayer perceptron (MLP) NN [26]. Inputs are reverse bias voltage, doping concentration, length and type of absorption and multiplication regions, and outputs are gain and excess noise factor. To learn, we apply the training patterns to MLP-NN and determine weighed links. Later, using the test patterns, we compare the results of NN with the experimental results to validate our model [1-29].

In next sections, we introduce APD and NN architecture. Finally, we present the predictions of MLP-NN and compare them with other works.

II. Avalanche Photodetector

When APD as the first element of the optical receiver absorbs optical information and convert them to related electrical signals. Figure 1 shows the structure of separate absorption and multiplication avalanche photodetector (SAM-APD). Using separation issue, we select type of absorption and multiplication regions according to light wavelength and dark current respectively [7].

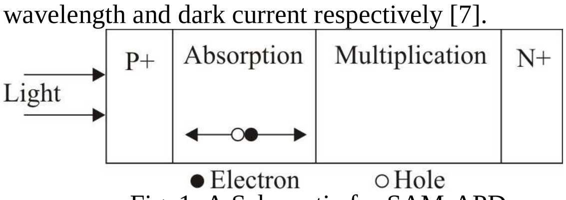


Fig. 1. A Schematic for SAM-APD

Photons are absorbed in absorption region and many electro-hole (e-h) pairs are generated. Initial energy of photo-carriers is equal to difference between photon energy and band-gap. Due to electric field in absorption region, photo-carriers drift to contacts. Electrons move to multiplication region whose electric field is high. They gain energy from the field to increase their kinetic energies in compare with threshold impact ionization energy (Eth). They can be ionized and new e-h pair generated when their energies are been more than Eth. Then, they can be ionized with the following rate:

$$S_{II}(E) = k\left(\frac{E - E_{th}}{E_{th}}\right)^{p} \quad (1)$$

Where E is the carrier energy. k and p are the impact ionization parameters which are known as intensity and softness factors respectively [9].

Excess noise (F) is due to random nature of different mechanisms such as impact ionization, scattering, etc. This issue causes the mean gain (M) is not be constant for an applied bias. The excess noise factor is given as following:

$$F = \frac{< M^2 >}{< M >^2} \quad (2)$$

Where bracket symbol is as the mean concept [9,13].

III. ARCHITECTURE OF MLP-NN

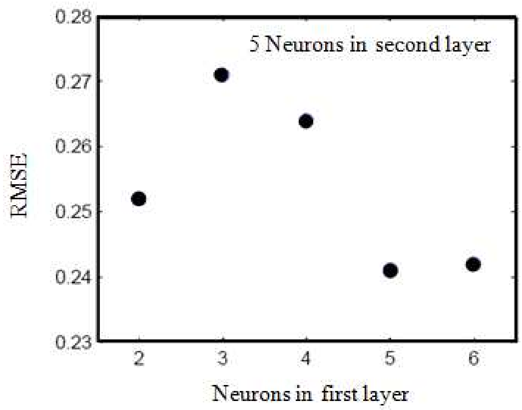
MLP-NN is an efficient tool which can convert a space to another space. Also, one can use it to predict outputs of devices or systems. To find the sufficient patterns, we searched in scientific papers and extracted two gain-bias and excess noise-gain curves.

For each voltage point, we found related gain and excess noise as a pattern. By following this issue, we obtained 430 patterns [1-14]. To have the good convergence for the weighed links, we normalized inputs in [0.05, 0.95] separately, using (3)

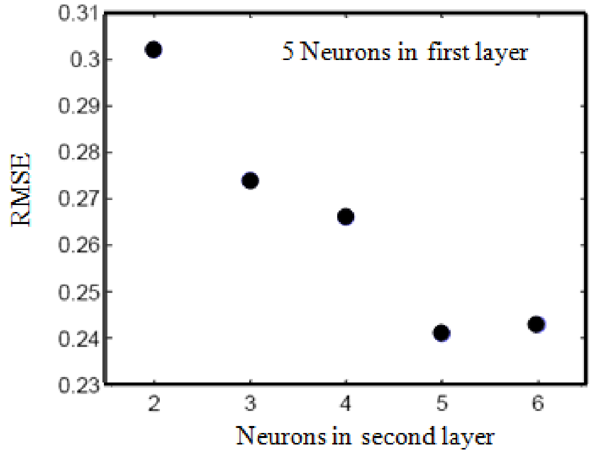
$$X_n = 0.05 + 0.9\frac{X_r - X_{min}}{X_{max} - X_{min}} \quad (3)$$

Where Xn and Xr are normalized and un-normalized quantities, respectively. Xmax and Xmin present the maximum and minimum values of each input.

To learn, we select 50000 epochs, two hidden layers and tangent hyperbolic for neurons. Then, we calculate root mean square error (RMSE) for different neurons in hidden layers (see in Fig.2). Minimum RMSE is obtained 0.241 for 5 neurons in hidden layers. Therefore, we select 7-5-5-2 arrangement for our model which has 7 neurons and 2 neurons for inputs and outputs respectively. To stability, we found values of learning rate, 0.3, 0.2, 0.2, and 0.15 for input, hidden and output layers respectively. Figure 3 compares RMSE values for 4 sample neuron arrangements.



(a)



(b)

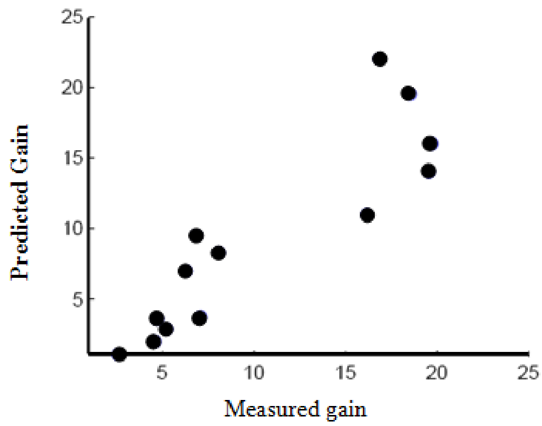
Fig. 2. RMSE for different neurons in two hidden layers.

IV. PREDICTION

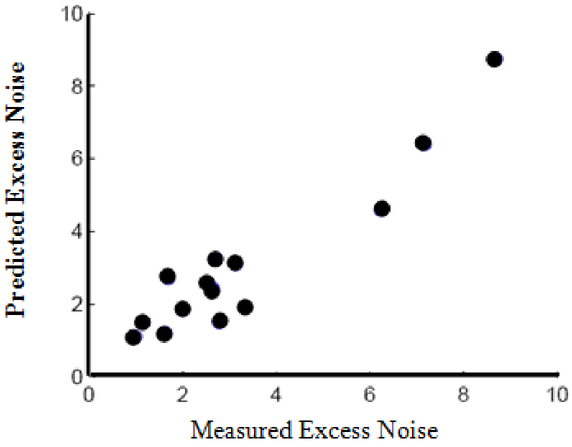
Using the mentioned arrangement in section 3, we apply the test patterns to network and compare the predicted results with experimental results (see in Fig.3) [3-6]. Figure 3 demonstrates the predicted results are good agreement with the experimental results for different devices.

Now, we can predict excess noise factor for different values of input parameters. Figure 4 presents the predicted excess noise with different values of multiplication length for reference [4].

The model demonstrates increasing of the multiplication length results in decreasing of the excess noise if other parameters are being constant. As the length is increased, electric field in multiplication region is decreased. Therefore, gain is decreased which results in decreasing for excess noise.



(a)



(b)

Fig. 3. Prediction of network compare to the experimental results for (a) gain and (b) excess noise [3-6].

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Figure 5 shows the excess noise is increased if the absorption length is increased and other parameters are being constant [3]. The more length for absorption causes the weaker electric field in this region. This issue causes the photoelectrons drift slowly and many times are been scattered to reach the multiplication region. Because of the random nature of scattering mechanism, distribution of energy for electrons will be wide when they are injected to multiplication region. Consequently, excess noise or variation of gain will be increased.

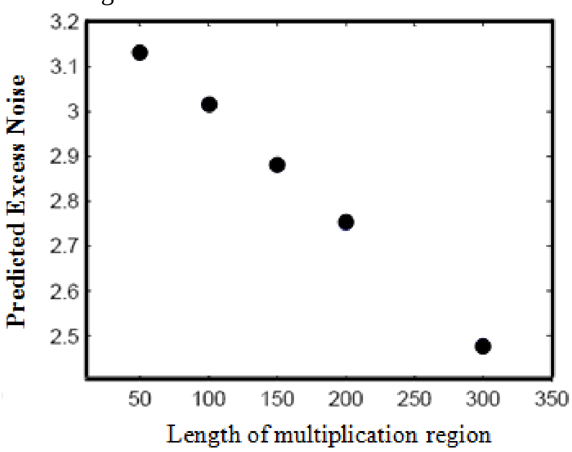

Fig. 4. The predicted excess noise for different multiplication length in reference [4].

Using the predicted figures, one can validate the presented MLP-NN for prediction of gain and excess noise factor in APDs. If the number of patterns is increased, one can hope to decrease the RMSE for training. To find the patterns, we must be used the published papers and reports. If one can be obtain the patterns experimentally and cover different input parameters, RMSE will be increased.

V. Conclusion

In this study, we presented a MLP-NN which predicted gain and excess noise factor for different APDs accurately. In our model, we selected the most effective parameters on the excess noise and gain as inputs for NN. Also, we set the gain and excess noise as outputs of the model. Finally, we predicted the excess noise factor for different lengths of absorption and multiplication regions.

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