

Excess Noise Factor in Avalanche Photodiodes with Dead Space Effect

Vignesh Reddy Angadi (✉ vrangadi@gmail.com)

Case Report

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Abstract

This project aims to produce a graphical user interface (GUI) for MATLAB programs written by J.S.Marsland as part of his research into the excess noise factor in avalanche photodiodes (APDs). The GUI will be produced using the GUIDE package supplied with the MATLAB software combined with the MATLAB programs. The GUI will then be used to compare this research work with the research work of others e.g. the Monte Carlo calculations made by the research group at the French Aerospace Laboratory (ONERA). Comparison with other research work will require the digitization of some graphs published in academic journals.

Introduction

Avalanche photodiodes (APDs) amplify photo generated currents by the process of impact ionization; however this is a random process which results in additional noise quantified by the excess noise factor. APDs with low excess noise factor and high multiplication (amplification) have many uses in low level light detection such as medical imaging, astronomy, military, etc. Understanding the physics of APDs is very important for the future development of better light detectors.

Avalanche multiplication occurs when energetic carriers create additional carriers by impact ionization. Typically an electron produces different multiplication with impact ionization and is a random process.

Mcintyre's Equation

An ionization coefficient ratio k is defined such that β divided by α and an equation for the excess noise factor is given that relates average multiplication M with k .

(1)

McIntyre [1] made the assumption that the ionization coefficient only depended on the local electric field and did not consider the 'dead space effect'.

Nonlocal ionization coefficients

Dead space is nonlocal effect. A nonlocal ionization coefficient $n(z)$ is defined by Marsland [2] such that $\alpha(z)dz$ is the probability that a carrier starting with no kinetic energy at $z = 0$ will impact ionize in the interval $(z, z + dz)$.

The ionization path length PDF, $h_1(z)$ can be defined such that $h_1(z)dz$ is the probability that a carrier will impact ionize for the first time in the given interval.

The probability that a carrier will travel to z without ionizing is called the survival probability $P_s(z)$.

The survival probability can be related to the ionization path length PDF:

$$P_s(z) = 1 - \int_0^z h_1(x) dx = \int_z^\infty h_1(x) dx \quad (2)$$

The nonlocal ionization coefficient $n(z)$ is related to the PDF $h_1(z)$:

$$\alpha(z) = h_1(z) + \int_0^z \alpha(x)h_1(z-x)dx \quad (3)$$

A model for ionization PDF

This behaviour can be described by the following expression where l is the length of dead space region and a and b are the constants governing the slope of the rise and fall of $h(z)$:

$$h(z) = \frac{ab}{b-a} \{ \exp(-a(z-l)) - \exp(-b(z-l)) \} U(z-l) \quad (4)$$

The above equation has been fitted to $h(z)$ calculated using Monte Carlo techniques [3] for electrons in *GaAs* at a field of $3 \times 10^7 \text{ vm}^{-1}$ using the following parameters; $a = 10\mu\text{m}^{-1}$, $b = 1\mu\text{m}^{-1}$ and $l = 0.15\mu\text{m}^{-1}$

Jacob et al. [3] have also calculated the ionization path length PDF for electrons at higher field of 10^8vm^{-1} . Again this result can be fitted using the following parameters; $a = b = 300\mu\text{m}^{-1}$ and $l = 0.0415\mu\text{m}^{-1}$:
and $l=0.0415\{\mu\text{m}\}^{-1}$:

Matlab Gui

The output graphs of the GUI obtained are as expected although the dotted lines of the axes component 2 is not displayed.

DIGITIZATION

Probability, $\sum P(M) = 1$

Mean multiplication, $\sum MP(M) = \langle M \rangle = 12.02$

Mean square, $\langle M^2 \rangle = \sum M^2 P(M) = 168$

Excess noise factor, $\frac{\langle M^2 \rangle}{\langle M \rangle^2} = 1.162$

Comparison of MJ03 with Derelle et al. [4]

MJ03	Monte Carlo
$\langle M \rangle = 12.02$	$\langle M \rangle = 13.07$
$F = 1.162$	$F = 1.052$

Conclusion

Ideally we would want the APD to have maximum multiplication and less noise. This scenario is shown using nonlocal ionization coefficients which gives stable multiplication and reduced noise. When dead

space is included noise is considerably reduced and is lesser than the noise predicted by McIntyre's curves. A model for ionization PDF is developed and is represented using a GUI for MATLAB program written by J.S.Marsland.

Declarations

Competing interests: The author declares no competing interests.

Acknowledgement

The final year project was proposed by Dr.J.S.Marsland as part of his research into excess noise factor in avalanche photodiodes. Dr Marsland provided the required theoretical background also provided lecture slides.

References

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Figures

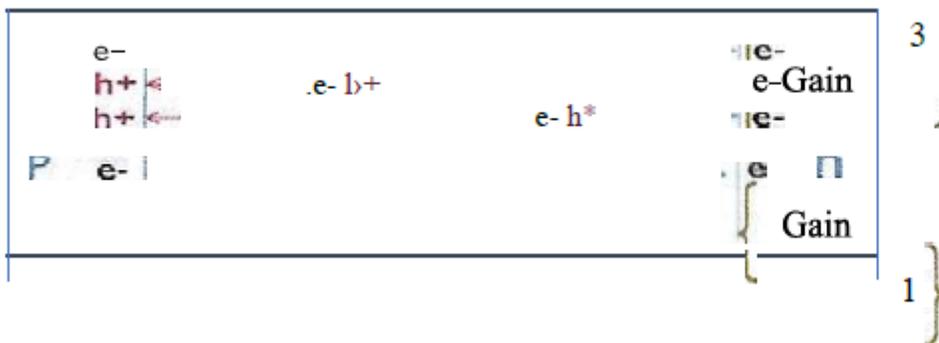


Figure 1

Avalanche multiplication

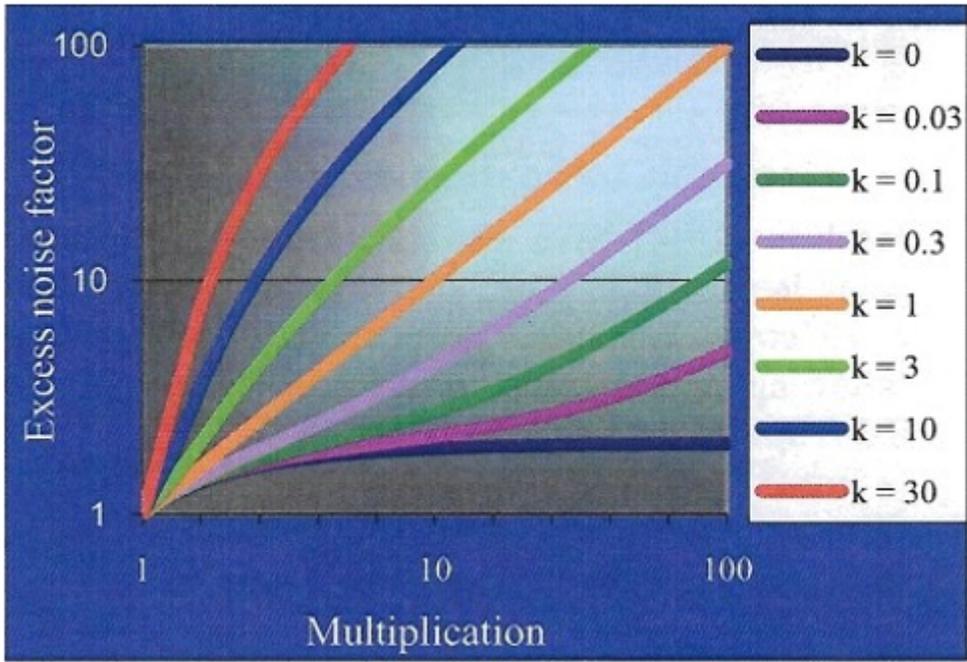


Figure 2

McIntyre's curves

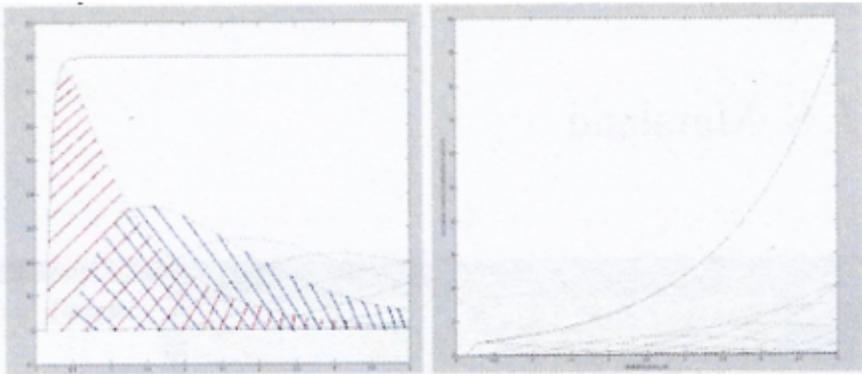


Figure 3

GaAS at 3×10^7 vm^{-1}

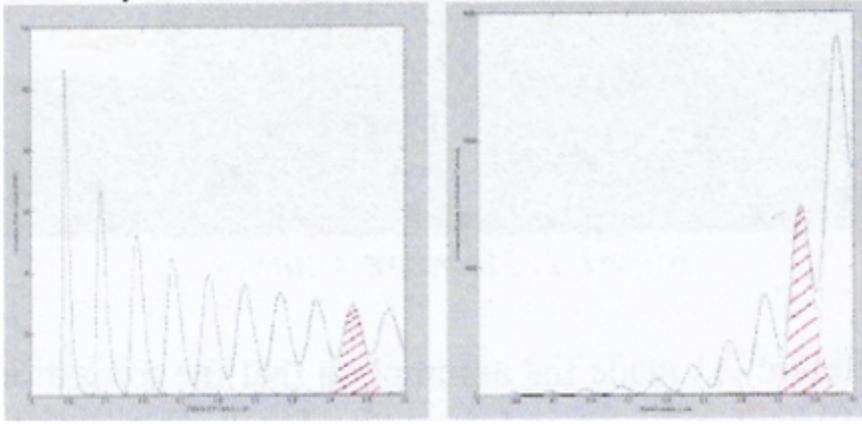


Figure 4

GaAs at 108 vm-1

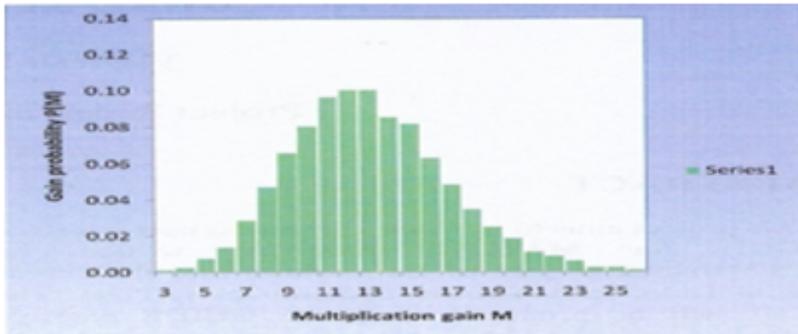


Figure 5

Digitized figure from Derelle et al. [4]

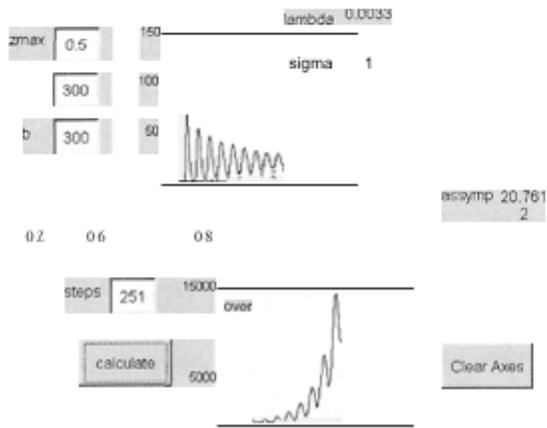
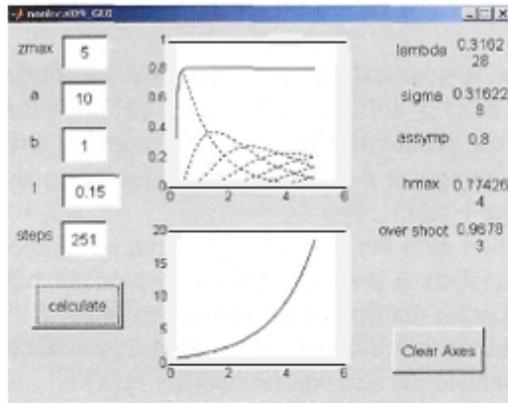


Figure 6

Output graph of the GUI