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EXCESS NOISE FACTOR IN AVALANCHE PHOTODIODES WITH DEAD-SPACE EFFECT

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ABSTRACT

This project aims to develop a graphical user interface (GUI) for MATLAB programs written by J. S. Marsland as part of his research on the excess noise factor in avalanche photodiodes (APDs). The GUI will be developed using the GUIDE package supplied with MATLAB. The GUI will then be used to compare this research with other works—for example, the Monte Carlo calculations performed by the research group at the French Aerospace Laboratory (ONERA). A comparison with other works will require the digitisation of graphs, some of which have been published in academic journals.

INTRODUCTION

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

Avalanche multiplication occurs when energetic carriers create additional carriers via impact ionisation. Typically, an electron produces random multiplications with impact ionisation.

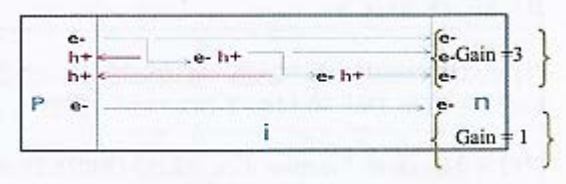


Figure 1: Avalanche multiplication

McINTYRE'S EQUATION

An ionisation coefficient k is defined by α divided by β; thus, an equation for the excess noise factor is given that relates the average multiplication M with k, as follows:

$$F(M) = kM + (1-k)\left\{2 - \frac{1}{M}\right\}; k = \frac{\alpha}{\beta} \qquad (1)$$

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

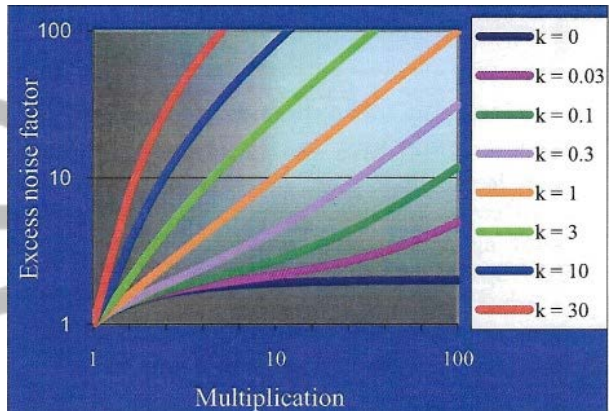


Figure 2: McIntyre's curves

NONLOCAL IONISATION COEFFICIENTS

Dead-space is a nonlocal effect. A nonlocal ionisation coefficient $\alpha(z)$ was defined by Marsland [2] such that $\alpha(z)dz$ is the probability that a carrier starting with no kinetic energy at $z = 0$ would impact ionisation in the interval $(z, z + dz)$. The ionisation path length PDF, $h_1(z)$, can be defined such that $h_1(z)dz$ is the probability that a carrier will impact ionisation for the first time in a given interval. The probability that a carrier will travel to z without ionising is called the survival probability $P_s(z)$.

The survival probability can be related to the ionisation path length PDF as follows:

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

The nonlocal ionisation coefficient *n(z)* is related to the PDF $h_1(z)$.

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

MODEL FOR IONISATION PDF

This behaviour can be described by the following expression, where 1 is the length of the dead-space region and a and b are the constants governing the slope of the rise and fall of $h(z)$.

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

The above equation—fitted to $h(z)$—was computed using Monte Carlo techniques [4] for electrons in $GaAs$ at a field of $3\ x\ 10^7\ vm^{-1}$ using the following parameters.

$$a = 10\ \mu m^{-1};\ b = 1\mu m^{-1};\ l = 0.15\ \mu m^{-1}$$

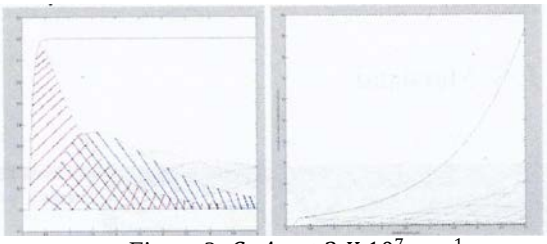


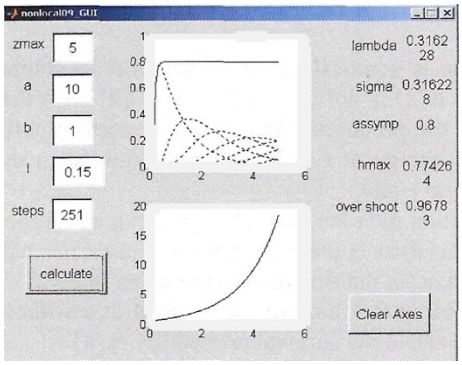
Figure 3: GaAs at $3\ X\ 10^7 vm^{-1}$

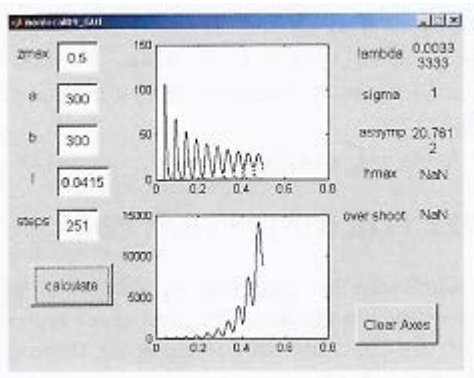
Jacob *et al.* [4] also calculated the ionisation path length PDF for electrons at a higher field of $10^8 vm^{-1}$. Similarly, this result can be fitted using the following parameters:

$$a = b = 300\ \mu m^{-1};\ l = 0.0415\ \mu m^{-1}$$

Figure 4: GaAs at $10^8 vm^{-1}$

MATLAB GUI





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

DIGITISATION

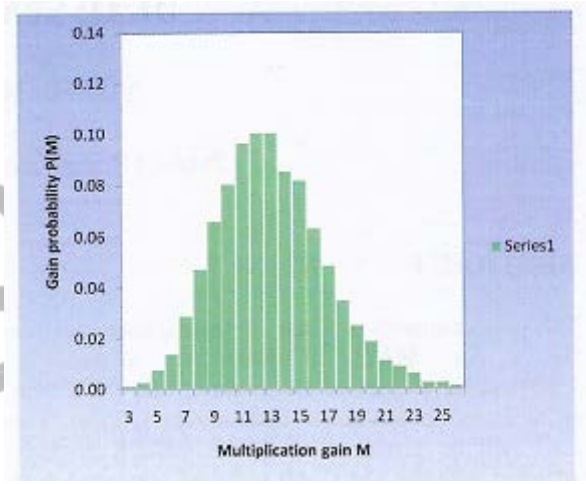


Figure 5: Digitised figure from Derelle et al. [3]

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 results from Derelle *et al.* [3]

MJ03	Monte Carlo
M = 12.02	M = l3.07
F = 1.162	F = 1.052

CONCLUSION

Ideally, the APD would be required to achieve maximum multiplication and less noise. This scenario is shown using nonlocal ionisation coefficients which provide stable multiplication and reduced noise. When dead space is included, noise is considerably reduced compared to the noise predicted by McIntyre's curves. Accordingly, a model for ionisation PDF was developed and reproduced using a GUI for

the MATLAB program written by Marsland.

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Author Biography

My name is Vignesh Reddy Angadi and I help people and large-scale organisations to meet and exceed their goals through information technology, networking, and IT systems support. I have rich background in defining and prioritising business requirements, building and configuring virtual networks, providing expert-level user support as well as consultations and guidelines to streamline IT activities, managing high performing technical teams in building and deploying desktop and laptop computers for various users.

I have this honed ability to provide comprehensive secure network design and systems analysis. I have developed deep understanding and in-depth knowledge of network analysis, programming, networking, incident investigation, reporting, and threat assessment and mitigation.

I consistently maximise sales and business development efforts to optimise fiscal performance and revenue generation. I have strong communication skills with the distinctive ability to build robust relationships with management team, stakeholders, and C-level executives and manage competing demands that resulted in achieving challenging goals.

Feel free to email me at vigneshangadi@hotmail.com

Some of my key milestones including:

Ø Delivered expert-level information technology support and conducted in-depth analysis to monitor and maintain the computer systems and networks by troubleshooting hardware/software faults and developing appropriate IT solutions.
Ø Developed prototype listing of company to improve its online presence and marketing publicity to clients.

Career Experience

Odyssey Logistics Pvt Ltd, Hyderabad, Telangana, India Aug 2020 - Present

Information Technology Consultant

Provided consultations and guidelines to streamline IT activities as per company's expectations as well as improved social media advertising and created a sample advert.

- Delivered expert-level information technology support and conducted in-depth analysis to monitor and maintain the computer systems and networks by troubleshooting hardware/software faults and developing appropriate IT solutions.
- Developed prototype listing of company to improve its online presence and marketing publicity to clients.

- Led and ensured the successful redesigning of the company website, improving usability to highlight company's image.

Odyssey Logistics Pvt Ltd, Hyderabad, Telangana, India Apr 2019 – July 2020

Associate Vice President

Engaged and collaborated with Pharma companies, generated sales leads, and streamlined marketing operations of specified routes around the world. Optimised the progress of business targets by monitoring client contracts. Interacted with clients on a regular basis to nurture and maintain robust relationships.

- Build and maintained strong relationships with leaders in industry and created shared vision and goals for an event.

- Organised grand event with Pharma Companies and Airline Carriers with the involvement of local government and created a platform for business promotions of company to award various clients for their accomplishments.

Business Venture with Partnership Nov 2011 – Dec 2018

Managed significant challenges associated with the construction of apartment complex and promotions of luxury living spaces along with sales.

Y Axis Overseas Careers Mar 2011 – July 2011

Senior Process Consultant

Advised and guided clients for visa documentation as well as collected documents for highly skilled professions for overseas work permits and despatched these documents to Embassy for consideration and follow-up with High Commission.

Dell International Services India Pvt Ltd Feb 2009 – June 2009

Senior Technical Support Executive

Pivotal in diagnosing and troubleshooting Dell computer systems and providing resolution along with case logging.

Education

BEng (Honours) in Computer Science & Electronic Engineering, 2:1

University Of Liverpool, Liverpool, Merseyside, UK