Measuring LED Switching Times Using Avalanche Photodiodes

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Abstract

The switch-on times for high pulse-rate LEDs have been detected using a Silicon Avalanche Photodiode, and measured with an oscilloscope. The times measured were mapped against the resistance of the LED circuit, and computed using linear regression. We found a strong correlation between resistance and LED switch time. Therefore, for optical communication, LED circuits should aim to minimise total resistance.

I. Background

The main concept for our project was to investigate sensitive methods of detecting light, using silicon avalanche photodiodes. We were inspired by a webinar [1] which discussed how it is possible to get a detectable signal from just a single photon. Whilst initially hoping to use this theory to detect individual photons, and apply it to random number generation, as inspired by a YouTube video [2], this proved to be too challenging given the time, budget and expertise of the group members. Instead, we settled upon investigating fast pulsed LEDs, measuring the time it takes for LEDs to switch on once a voltage source is connected. This is an important property of LEDs in high speed optical communications that is often not listed when buying an LED. We also decided upon seeing how this time was impacted by circuit resistance, by changing the value of a resistor in series with our LED, to get further insight into what the best values are for LEDs which need to be pulsed in the microsecond and nanosecond ranges.

The goals of the project were:

- to use silicon avalanche photodiodes to detect both higher intensity and lower intensity light;
- to build a circuit that can pulse a laser effectively in the microsecond and nanosecond ranges;
- to get measurements of switching times for LEDs through data analysis in Python;
- to vary the resistance of the LED circuit to observe how this impacts the switching time of the LED.

II. Description of Project Work

A. Project start-up

The project commenced on the 9th of May 2025, with an initial meeting with our Supervisor in the first week as well as two meetings amongst the four team members (**NS**, **DL**, **AS** and **YY**).

We continued having weekly meetings with the Supervisor, on the 9th, 12th, 21st, 23rd, 30th of May and the 3rd of June. All lab time was used (55 hours total, before display). A further 4-8 hours was spent each week discussing the project, planning future lab work and learning relevant skills, such as designing PCB boards ready to be ordered.

The four members met several times a week to work on the project. The initial goal was to test the quantum nature of light by firing single photons through a beam-splitter and showing it only goes through one of the two paths. We spent two days deciding together how best to build the circuits for both the LED and the photodetectors after buying all the necessary parts. The progress of the project was recorded daily on a OneNote lab book owned by **AS**.

B. Initial data-taking and circuit development

Testing of the LED, voltage source and pulse generator was performed on the 13th of May, with the soldering of the PCB boards, custom designed by **AS**, to the photodetectors and testing of the silicon avalanche photodiodes in ambient lighting completed by the 21st of May with all four members contributing to testing.

The main focus was to find a solution to be able to pulse the LED in a consistent double-digit nanosecond period, which were worked on for a week from the 21st of May, with the idea of logic gates circuit being tested out between 22-23rd of May to attempt to get a faster pulsed LED circuit. This was abandoned by the 27th due to lack of consistent pulses compared to the pulse generator.

Following on from the successful tests of all components, from the 27th of May onwards, focus shifted to building the full circuit itself. The components were mounted on an optical table by **YY** and **NS** with the LED and photodetector circuits mounted vertically on small breadboards. The entire set-up was covered with a black optical enclosure to prevent external light sources from affecting the readings on the photodetectors. One collimator holding ring was sourced from our Supervisor but the other required 3D printing, which was designed by **DL**.

At the same time, we brainstormed further on the possibilities for improvements to the circuit design and how to attach the collimator from the LED to the beam-splitter with significant input from our Supervisor.

C. Further circuit refinement and project goal switch

We had wanted to make sure the collimators fully fit into the circuit and hence filing was undertaken to ensure a secure fit between the collimator and the holding ring. The position of the breadboards were finalised and placed in such a way that they could be moved on a single axis to facilitate the changing of resistors or LEDs as required.

By the beginning of June, collimators were attached to the circuit but no light could be seen from LED. Apparent signals being seen from LEDs on the oscilloscope after collimator, however this also appeared when LED was removed. This issue was worked on from by **AS**, **DL** and **NS** 2-3rd of June, with only partial success at fixing it. One issue was resolved, which was due to incorrect biassing of photodetectors. The issue with the unusual signal appearing was due to background signals being produced by the switching on and off. To reduce the effects of this, any coupled wires were twisted together to minimise the loop area, all power supplies were connected to different parallel mains sources. Once solved, no light was detected whatsoever after collimation. An attempted fix was suggested by increasing the fibre optic size but no collimator ended up fitting and data was still unusable. 3rd-5th of June was the period within which we selected an ulterior final project, making use of what equipment we already had.

D. Pursuing ulterior final goal and finalising results

On the 5th and the 6th of June a new project title was finalised being 'Measuring LED Switching Times Using Avalanche Photodiodes'. On these days, a variety of wavelengths of LEDs were tested by **AS**, **NS** and **YY**, with a new optical design. This ended up being the LED being placed directly into an optical cap placed on a beam-splitter, which was connected to the original two photodetectors. A variety of resistances were also tested, with this being the new focus as the switching times vary depending upon the resistance of the circuit. Data was taken and **DL** produced a program in Python, which was 170 lines long, to plot the data, identify the times where it was on/off/switching, and measure the switching times.

For the Open Day Presentation, **AS** is explaining the electronic theory behind avalanche photodiodes, **YY** is explaining the physical build of the circuit, **DL** is demonstrating the code that plotted the switch-on, switch-off time periods of the diode, and **NS** showing and explaining how the LEDs were pulsed and the importance of this in fibre optic communication. The final results were put together by all four members, and this write-up was produced by us in equal parts, using an online shared-document system.

E. Application of skills learned in the First Year Lab course

We made use of the following skills that were taught in the First Year Lab course in Terms 1 and 2:

- Set-up and alignment of the optical circuit consisting of LEDs, a beamsplitter and mounting these on an optical table
- Creation of circuits on breadboards for both the LED and Photodiode circuits
- Changing of oscilloscope settings to get readable, insightful displays of data
- Troubleshooting of electronic, optical and display problems when gathering data, including making use of oscilloscope probes to identify circuit issues
- Data analysis in Python to get quantitative results from the data collected, including making use of the libraries NumPy, SciPy and MatPlotLib

We also learnt and applied the following skills:

- Design of PCB boards using KiCad 9.0 to fit our photodiode
- Design of equipment using Blender to be 3D printed

III. Summary of Results

Twenty-nine different resistors were tested and the times recorded. When plotted against each other, the data sets had an a substantial correlation of $r = 0.997$ indicating that they are directly linked. This confirms the hypothesis that LEDs exhibit capacitor-like behaviour when examined across a microsecond range for any non-trivial value of resistance. Furthermore, the plot of switching time vs resistance can be used to calculate the internal capacitance of the LED, a useful measurement often not quoted on LED datasheets.

IV. Conclusion

With our experiment, we were able to meet our project goals, in spite of our inability to reduce the photon count to the single photon range, and produce a fast pulsing LED that could be detected using an avalanche photodiode.

The results for the switch-on time were successfully mapped against varying resistance, showing a direct correlation between them, showing that for high-speed LED applications such as optical communications, it is preferable to use lower resistances.

V. Purchases, Existing Items and Use of 3D-Printing

A. Equipment used and purchased

We purchased the following items:

- 3x AFBR-S4N22P014M Avalanche Photodiode, £55.41
- 5x TLHR4400 LED, 3MM, Red, £1.63
- 5x Custom-designed PCB Board for Avalanche Photodiode, £3.75
- The total shipping and VAT of these items was a further £28.13

We also made use of these items which were borrowed or already in our possession:

- RTB2004 Oscilloscope
- TPG110 10MHz Pulse Generator
- TAC60-3R Voltage DC Source
- Other electronics equipment, such as LEDs, wires and breadboards
- Thorlabs Optical Table and Optical Devices (stands, beamsplitter etc.)

DL used Blender software to design the following item to fit our optical equipment:

- Collimator holder, made of acrylic, printed by the lab technicians on the 30th of May (not used in final project)

VI. Bibliography

The literature that we consulted is listed below, with a brief comment on each item's role in the project.

[1] HAMMAMATSU PHOTONICS,"SPAD and SPAD Arrays: Theory, Practice, and Applications", https://www.youtube.com/watch?v=l_U4i-SWOvY)
Was used in the understanding of low light detection, and aided the choice of avalanche photodiodes as our method of doing so.

[2] Muon Ray,"Quantum Entanglement Random Number Generator Experiment using Arduino and Python (ft. Fractals!)", https://www.youtube.com/watch?v=6RGLiOdyLfo)
Gave some initial inspiration regarding photon detection and the possible methods of doing so.

[3] R. Paschotta, article on "Photon Counting" in the RP Photonics Encyclopedia, https://doi.org/10.61835/6rq
Gave more insight into methods of photon detection, with details on avalanche photodiodes as well as other photodiodes.

[4] S. Cova, M. Ghioni, A. Lacaita, C. Samori, and F. Zappa (1996), "Avalanche photodiodes and quenching circuits for single-photon detection", https://doi.org/10.1364/AO.35.001956
Introduced methods and effectiveness of both passive and active quenching circuits, allowing us to decide upon the simple resistor passive quenching circuit.

[5] P. Windischhofer, W. Riegler (2023), "Passive quenching, signal shapes, and space charge effects in SPADs and SiPMs", https://doi.org/10.1016/j.nima.2022.167627.
Gave far more detail regarding the mathematics of both avalanching in photodiodes, as well as the role of passive quenching in the circuit.

[6] E.Linares-Vallejo, N. Dahnoun, J.G. Rarity (2017). LED as a low cost single photon source, https://research-information.bris.ac.uk/ws/portalfiles/portal/135958853/The_LED_as_low_cost_single_photon_source.pdf
Provided the idea for using LEDs as a close to single photon source, and was the foundation for our initial idea of measuring single photons before we changed our goals.

[7] Broadcom. AFBR-S4N22P014M Data Sheet. https://www.farnell.com/datasheets/4142304.pdf
Gave us the breakdown voltage for our photodetector, and the mechanical drawings required for designing the PCB board.