MICRO-429: Metrology Practicals

T5 - Timing jitter measurements in single-photon detectors

Edoardo Charbon, Claudio Bruschini, Georg Fantner

Institute of Electrical and Micro Engineering (IEM), School of Engineering (STI)

Ecole polytechnique fédérale de Lausanne (EPFL), Neuchâtel, Switzerland

TAs: Yang Lin, Yating Zou

Acknowledgement: Utku Karaca, Ekin Kizilkan

10.03.2024

Objective:

- Time-correlated single-photon counting (TCSPC)
- Single-photon timing resolution (SPTR)
- Pile-up effect

Reading & reference material:

- Read reference [1] for a general understanding of SPAD technology
- Read MICRO-428 Week 8 lecture notes – *Introduction to single-photon detection*
- Read reference [2] to learn about typical characteristics – breakdown voltage, DCR, photon detection probability (PDP), timing jitter, afterpulsing probability – of a SPAD23™ pixel
- Complementary information:
    - ★ SPAD23™ Operating Manual
    - ★ Training data (to optimize your own Matlab routines)
    - ★ MICRO-428 Week 2 and Week 3 lecture notes (SPAD related examples, basic statistics)

Setup:

- 1 SPAD23™ detection unit
- 2 x Pulsed laser source
- 1 Laser controller
- 1 NIM to TTL converter
- Absorptive neutral density filters
- Mirrors
- 1 laptop

Methodology:

- Power up the SPAD23™ module, set up the user interface, and explore the different display and data acquisition options in the dark and when exposed to (dim) light.
    - Use the timestamping option from the interface and collect the timing histogram of the arrival photons.
    - Write a Matlab code to calculate the single-photon timing resolution (SPTR).
    - Compare the effect of two different light sources on the jitter parameters.
- Document your findings in the *Lab Notebook* along the way.

References:

[1] E. Charbon, “Single-photon imaging in complementary metal-oxide semiconductor processes”, Phil. Trans. Royal Society, 28 March 2014. DOI: 10.1098/rsta.2013.0100.

[2] I. M. Antolovic, C. Bruschini, and E. Charbon, "Dynamic range extension for photon counting arrays." Optics Express 26.17 (2018): 22234-22248.

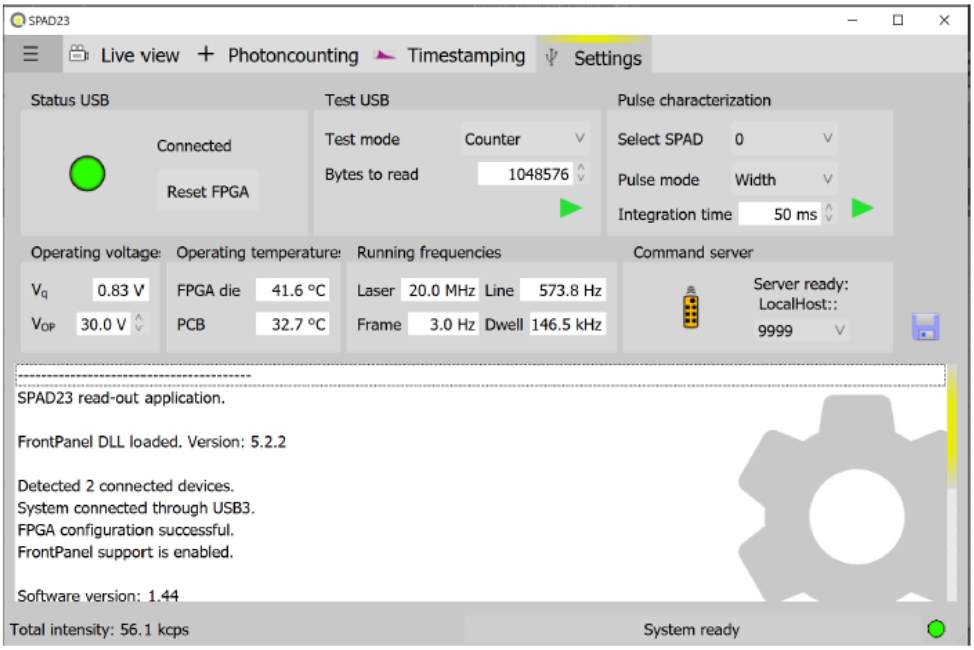
Methodology:

Part 0: Preparation (*before the practical*)

1) Prepare your Matlab code which normalizes the count rates (i.e. divides all the counts by the maximum value), and calculates the full width at half-maximum (FWHM) of the timing histogram based on the practice data provided on Moodle.
2) Plot the timing histogram in log scale and highlight the points which you used for the FWHM calculation.
3) Practice data contains (all text files):
   a) "pixtimeaxis": time bins of the histogram in units of picoseconds.
   b) "pix11": total number of counts corresponding to each time bin.
   c) "import": code to import these two data sets (pixtimeaxis and pix11) into Matlab.
4) Write a piece of code that makes a Gaussian fit to the experimental data.

Part 1: Timing Jitter Measurement with a Pulsed Source - System Set-up

5) Connect the power cable of the SPAD23™ unit to a power plug.
6) Place the SPAD23™ unit inside the black box.
7) Connect the power cable of the SPAD23™ unit to a power plug.
8) Connect the data cable of the SPAD23™ unit to the computer.
9) Open the SPAD23™ user interface. Go to the "Settings" tab and check if the unit is recognized by the software. "Status USB" sub-section should turn green. The screen should be seen as follows:



10) Check the "Operating voltages" sub-section, and set the "Vop" voltage to 31.5 V.

11) Disable the "Vop" from the interface.

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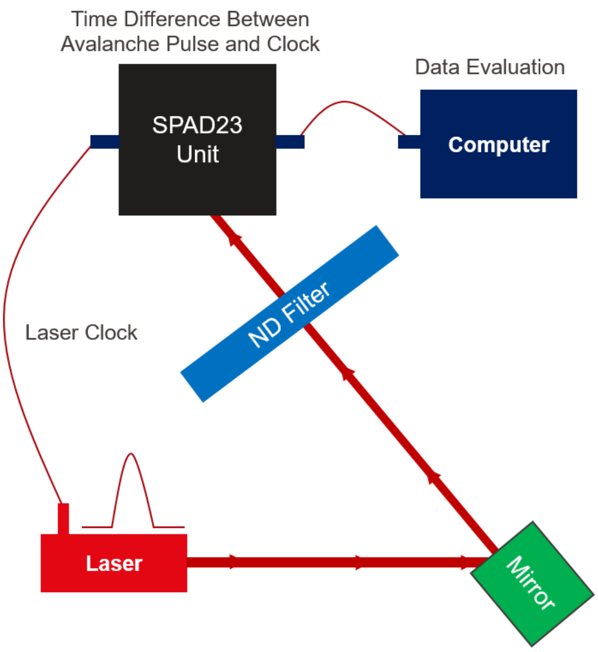
12) You will now construct the optical setup to direct the laser light onto the SPAD23 unit. For this purpose, you will use a mirror, and adjust (with micrometers)/fix its position.



13) **WEAR GOGGLES**, **first, according to your laser wavelength for your eye protection**.

14) Power on the pulsed light source:

850 nm laser diode (NKT Photonics): Turn the key of the laser to power it up, and set its frequency to 10 MHz and tune value to 40%.

15) When you click on:

Red “laser” button on the laser controller (850 nm),

the laser light will be fired. In order to spot where the laser beam is, use your “Detector Card” available on your table. Thanks to this card you will be able to see the laser beam while you are wearing goggles.

16) To check if the laser clock is synchronized with the SPAD23 interface, click on “Change clock SMA mapping” from the upper left-most tab on the SPAD23 interface. Observe that the “Laser clk” on SMA2 becomes:

10 MHz when the 850 nm laser is on.

17) To do the optical alignment:

Place your mirror to the empty holder on your setup and adjust its angle (850 nm)

such that the laser beam will be directed on SPAD23. Again, use your detector card to see where the laser beam is.

18) Turn off your laser from the “Laser On/Off” button.

19) To reduce the optical power, and to avoid saturating the SPADs:

Place your absorptive ND filters NE40A/B (ND4) + NE10A (ND1) (to form ND5 filter) to a holder, and put it in front of the SPAD23 unit (850 nm).

Note: You may need to tilt the filter to avoid reflections.

20) Set your laser frequency to 10 MHz and tune value to 52%. (850 nm)

Part 2: Timing Jitter Measurement with a Pulsed Laser Source - SPTR Measurements

21) Enable “Vop” from the interface.

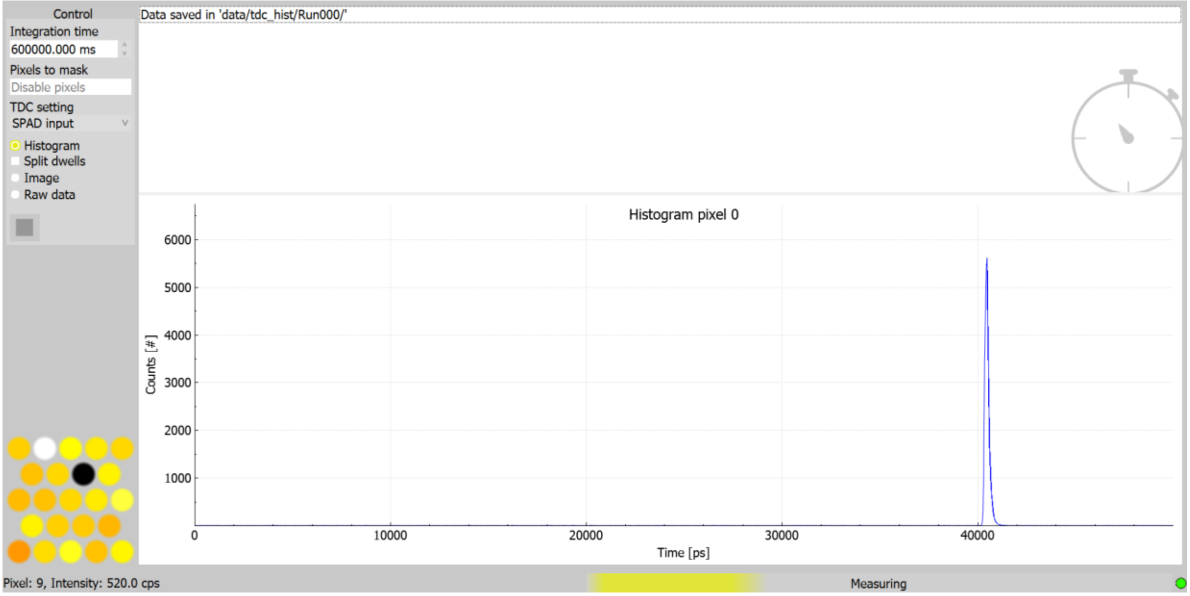
Set your pixel count rates to around 100k cps by doing fine-tuning with the micrometers on the mirror. (850 nm)

Note: Make sure that ambient light is negligible while setting your cps.

22) Switch to the “Timestamping” tab, and click on the green “Run” to calibrate the time-to-digital converters (TDCs) before starting your TCSPC measurement.

23) After the calibration is done, make sure the TDC setting becomes “SPAD input”, and choose the “Histogram” option.

24) Perform a histogram measurement for an integration time of 600’000 ms (10 minutes).



25) Import the histogram data from “./data/tdc_hist/ folder to Matlab, plot the histogram.

Calculate the jitter of a pixel you choose (not a hot one) by deconvolution of the laser pulse width. Assume Gaussian distribution of events and 50 ps laser pulse width. (850 nm)

26) Comment on the plot. Does the curve look like an exact Gaussian? If not explain why.

27) (Optional) Make a Gaussian fit to your histogram on Matlab. Comment on the differences between the fit and the real data, and the reasons causing those differences. Calculate the FWHM of your fit and compare it with the FWHM of the original data.

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28) Open the lid of the box, and turn off your laser from the red “Laser” button on the controller. Remove your ND4 filter and keep only ND1 one. Set your tune value to 65%. Turn on your laser again, and close the lid of the box. (850 nm)

29) Investigate and note down the count rate readings.

30) Perform again a histogram measurement for 10 minutes of integration time.

31) Import the histogram data from “.../data/tdc_hist/ folder to Matlab, plot the histogram and calculate the jitter of a pixel you choose (not a hot one) by taking the FWHM of the histogram.

32) Comment on the plot. Does the curve look like an exact Gaussian? If not explain why.

33) (Optional) Make a Gaussian fit to your histogram on Matlab. Comment on the differences between the fit and the real data, and the reasons causing those differences. Calculate the FWHM of your fit and compare it with the FWHM of the original data.

34) Compare the histograms and FWHMs with the previous measurement. Comment on the differences and the reasoning.