Automated Characterization of Single Photon Avalanche Diodes with Enhanced Near Infrared Sensitivity

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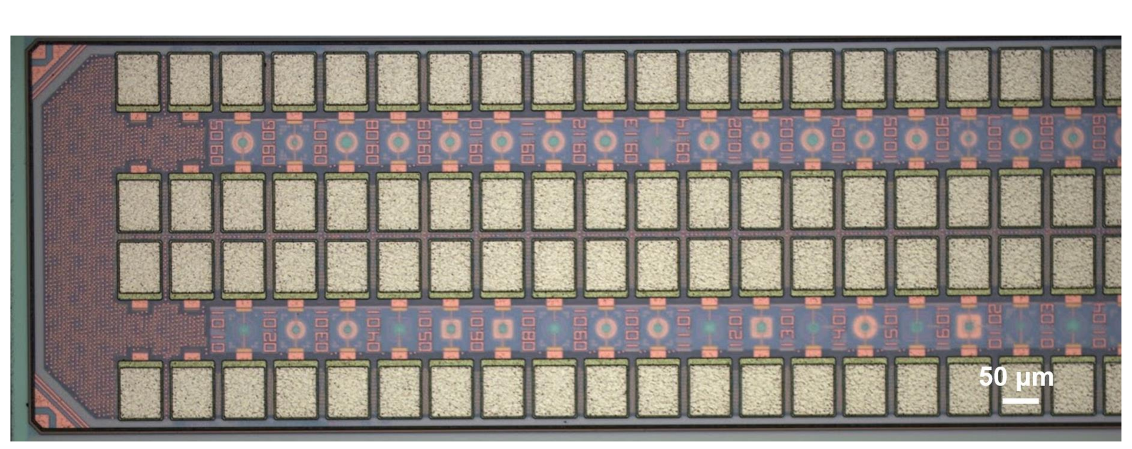
BACKGROUND[1]

- How does a Single Photon Avalanche Diode (SPAD) work?
  - Photoelectric effect
  - Avalanche multiplication
  - Passive quenching[2]
- Why are SPADs useful?
  - Comparison to alternative photodetectors
    - Photomultiplier Tube (PMT)
    - CMOS Photodiode
    - Charge Coupled Device (CCD)
  - Applications
    - Fluorescent Lifetime Imaging (FLIM)
    - Near Infrared Spectroscopy (NIRS)
    - Light Detection and Ranging (LIDAR)
    - Time of Flight imaging (ToF)
    - And much more!
- What metrics determine how "good" a SPAD is?
  - Dark Count Rate (DCR)
  - Photon Detection Probability (PDP)
  - Jitter
  - Afterpulsing Probability (AP)
  - Fill Factor
- What factors affect the outcome of these metrics?
  - Geometry
  - Layer structure
  - Implant types
  - Shielding

OBJECTIVES

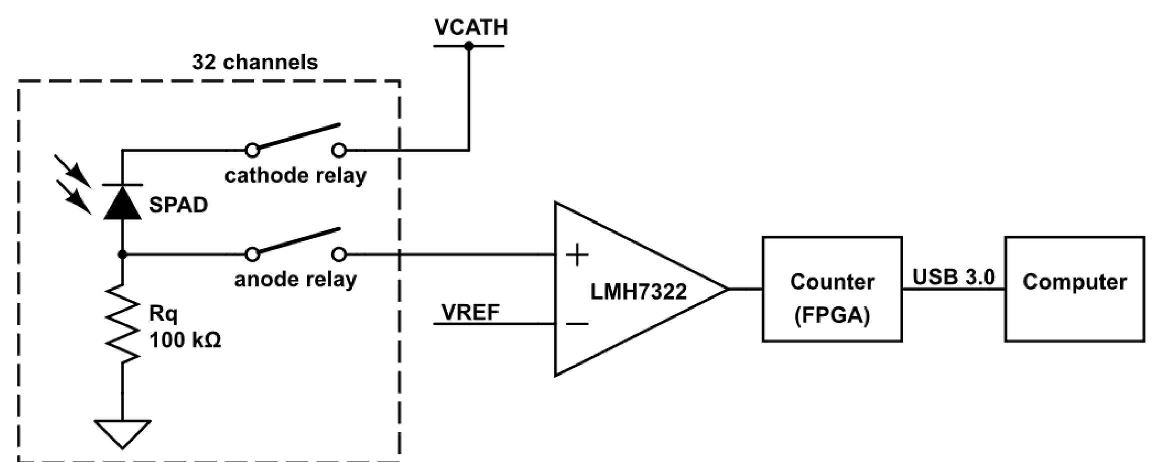
- How do you experimentally determine whether a SPAD design is suitable for a given application?
- How can you automate this experimental process for hundreds of devices?

Array of Various SPAD Designs on Custom Chip

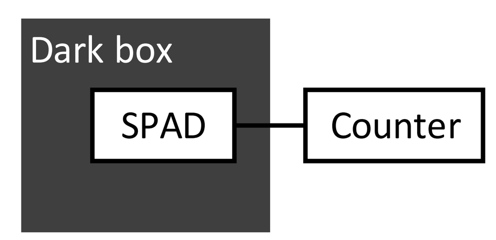


METHODS

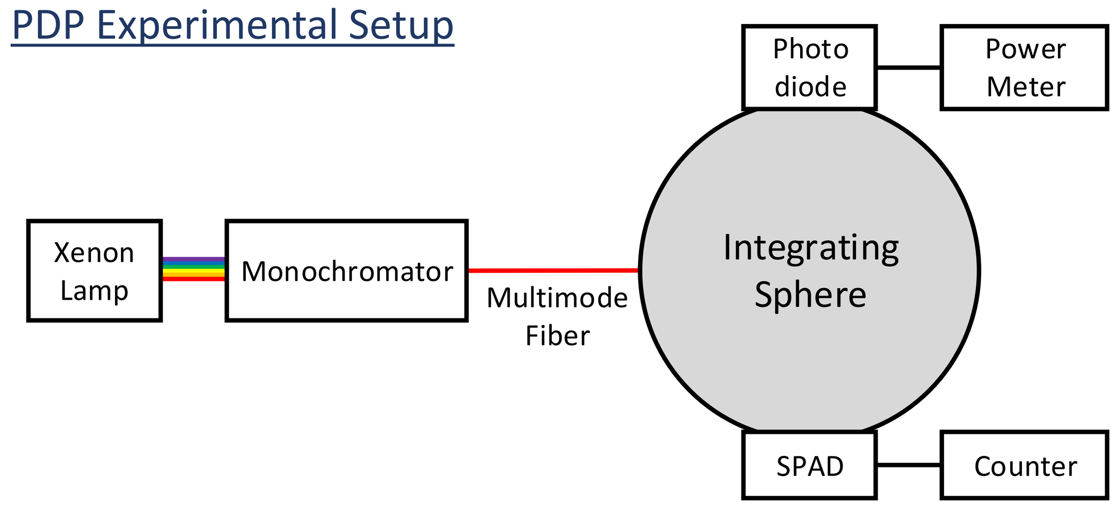
Simplified Schematic[1]

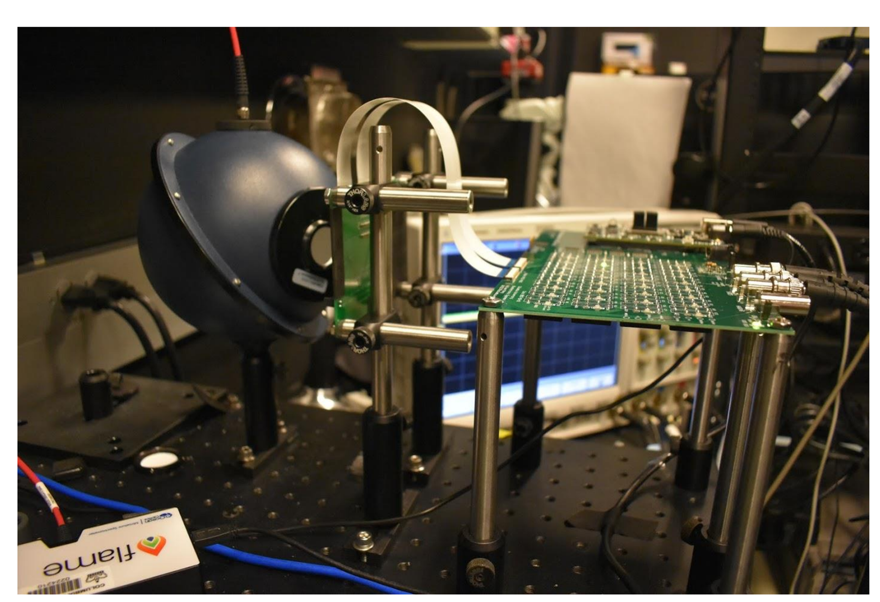


DCR Experimental Setup

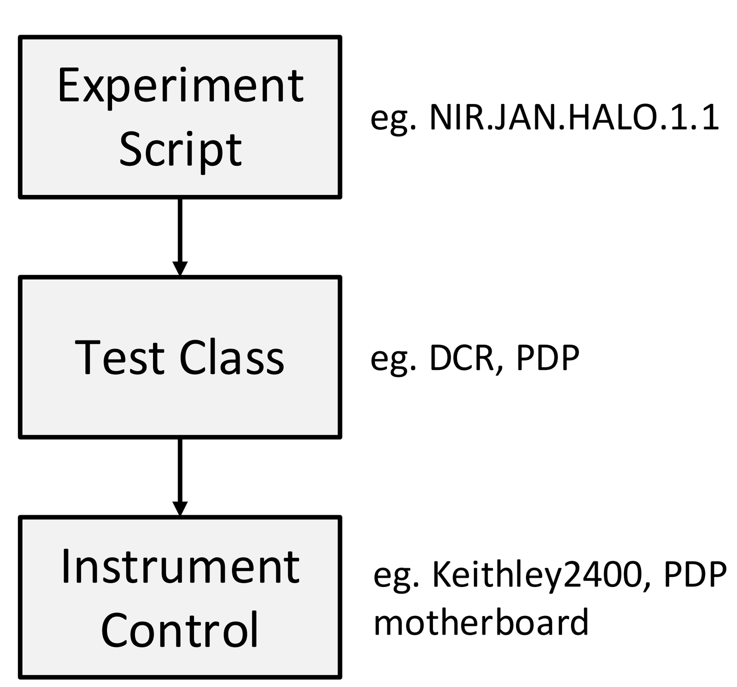


PDP Experimental Setup



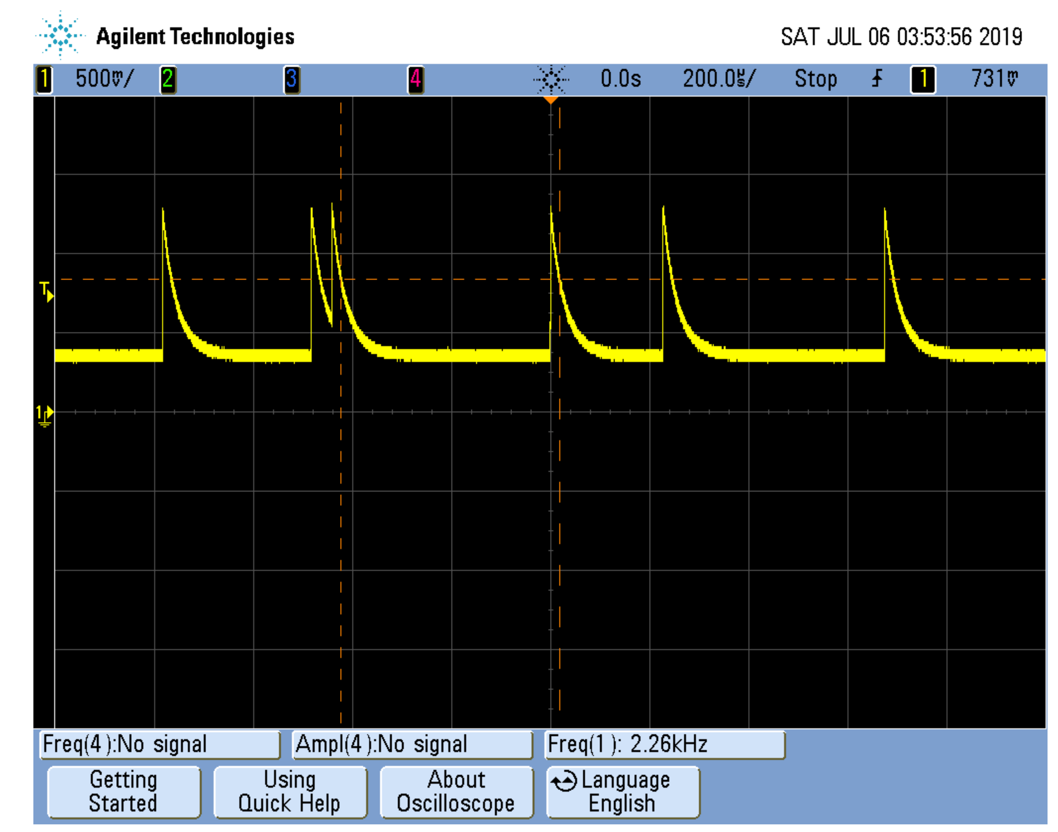


Software Hierarchy

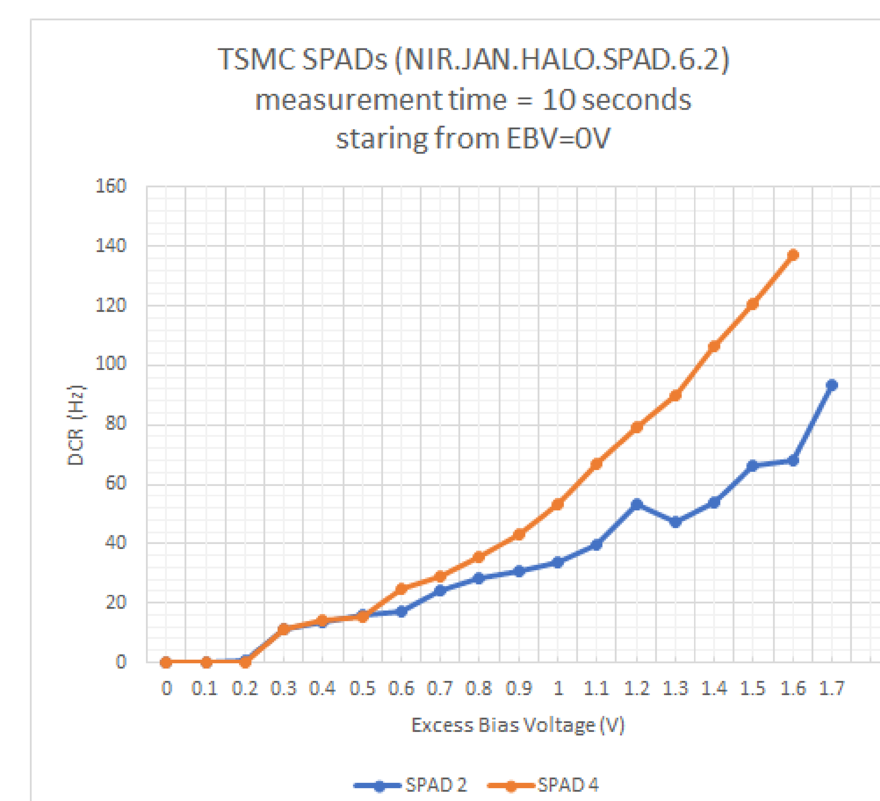


RESULTS

SPAD Avalanche Waveform



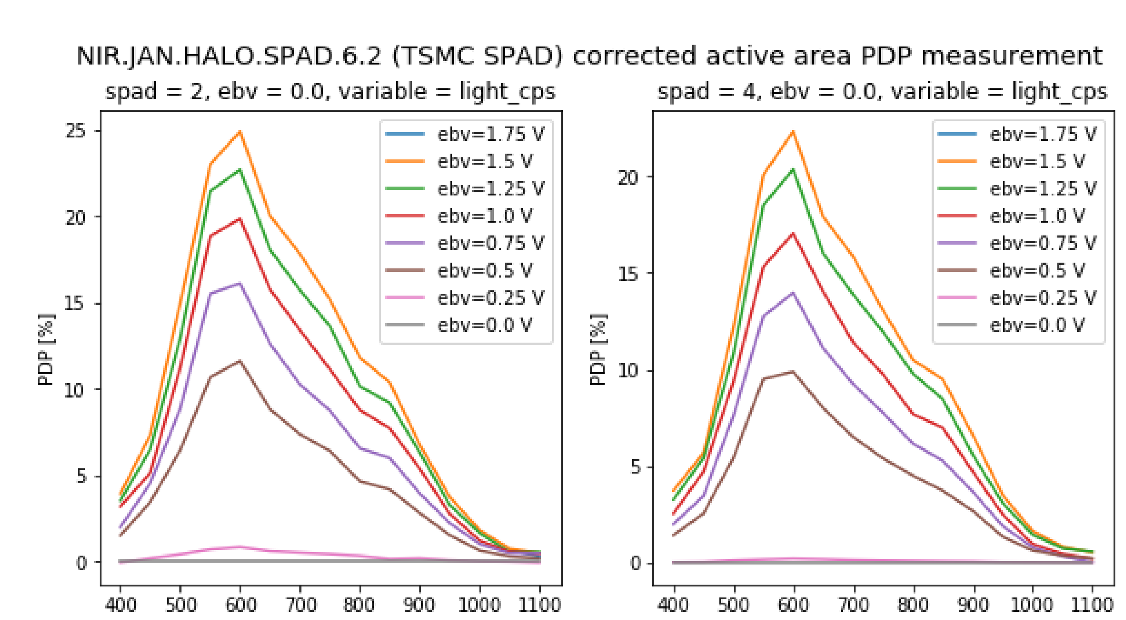
Dark Count Rate (DCR)



Photon Detection Probability (PDP)

$$\text{PDP} = \frac{(\text{light cps} - \text{DCR}) \cdot E_{\text{photon}}}{P_{\text{Newport}}} \cdot \frac{A_{\text{Newport}}}{A_{\text{SPAD}}} \cdot 100\%$$

(NOT accounting for afterpulsing or photon pile-up)



CONCLUSION

- Measured DCR and PDP for over 100 SPAD designs
- Successfully identified suitable SPAD for usage in a next generation photonic neural interface
- Automation system can save time and effort for SPAD researchers
- Future Work
  - Utilize polymorphism to perform hardware agnostic experiments
  - Implement Active Quenching Circuit (AQC) to minimize dead time
  - Fix issue with comparator circuit to allow for wider range of excess bias voltage (EBV)
  - Characterize devices across a range of temperatures
  - Characterize intra and inter-wafer variations
  - Characterize Afterpulsing Probability (AP) and factor this into the PDP calculation[3]
  - Determine optimal excess bias voltage (EBV) to maximize Signal-to-Noise Ratio (SNR)[4]
  - Identify cause-and-effect relationships between device design parameters and resulting metrics

REFERENCES

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[3] M. A. Wayne, J. C. Bienfang, S. V. Polyakov, "Simple autocorrelation method for thoroughly characterizing single-photon detectors," *Optics Express*, vol. 25, no. 17, Aug. 2017.

[4] K. Kolb, "Signal-to-noise ratio of Geiger-mode avalanche photodiode single-photon counting detectors," *Optical Engineering*, vol. 3, no. 8, Mar. 2014.

ACKNOWLEDGEMENTS

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