UROP Report IAP 2025: Multi-Channel Photon Time Tagging and Hardware Diagnosis

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Abstract: Our system aims to enable high-precision optical control and readout of tin-vacancy qubits in diamond samples at cryogenic temperatures. It features a MEMS mirror for efficient scanning and an NI DAQ with Qudi for data acquisition. A piezoelectric stage with a custom GUI ensures precise alignment. CAD-designed aluminum components provide stability at sub-Kelvin temperatures. Future work will optimize time-tagging accuracy and real-time cryogenic monitoring.

1. Introduction

We are continuing to develop an optical setup for controlling and reading out tin-vacancy qubits in diamonds, key components for future quantum networks. The setup uses a cryogenic cooling system and a MEMS mirror for efficient, cost-effective confocal scanning, replacing conventional galvo mirrors to avoid dual-axis scanning aberrations. This enables fast characterization of multiple diamond nanostructures within a single field of view. By driving atomic transitions with diffraction-limited laser beams and using single-photon detection to read out qubits, the system aims to improve control, measurement, and quantum entanglement of tin-vacancy qubits, advancing quantum technologies.

2. Approach

2.1. *System Overview*

Our system features a confocal microscope scanner integrated into a cryogenic cooling setup. The scanner utilizes a two-dimensional MEMS mirror, enabling single-mirror imaging instead of a traditional two-mirror configuration. A sample is positioned on a piezoelectric-controlled stage within the cryogenic chamber, with a custom-built GUI allowing precise focus adjustments. An NI DAQ captures and processes images of the sample. New endeavors towards completing the system will be discussed in the following sections.

2.2. *Power Supply*

The system enables photon counting by powering avalanche photodiodes (APDs) with a dedicated power supply. Over time, the cooling fan of the supply failed, necessitating a repair. Figure 1a illustrates the voltage requirements of the APD system. Notably, the fan now operates at 12[V] as opposed to 20[V]. The current specifications are written on the front panel of the power supply.

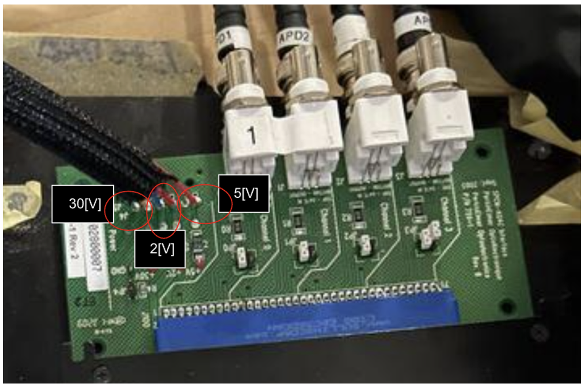
2.3. *Time Tagging Wiring*

Our time-tagging system leverages the Moku Pro. During characterization, we observed a significant discrepancy in time jitter between wired and internal connections. Notably, the bandwidth of external connections remained approximately 40 ps, regardless of whether an SMA or BNC connector was used. Figure 1b illustrates these findings.

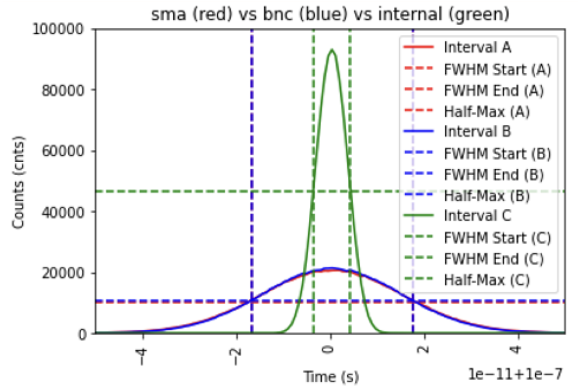
2.4. *Photon Counting*

After resolving issues with time-tagging jitter, we utilized the Moku Pro's oscilloscope feature to measure counts and dark counts across different setups. Initially, we employed a laser and a fiber optic beam splitter to analyze the output voltage pattern of each beam, ensuring that the laser intensity remained below the system's saturation threshold. Figure 2a illustrates a set of square waves entering the system's detection range. The sinusoidal features at the edges of the squares result from slight imperfections in our equipment, such as photon-counting jitter time. Figure 2b provides a direct comparison of the waveform produced by counts and dark counts.

3. Results

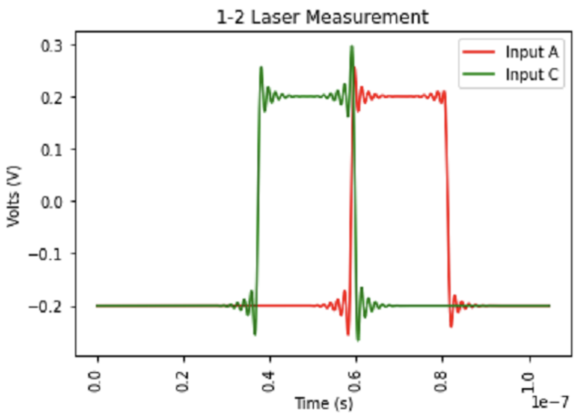


(a) APD Required Voltage Values

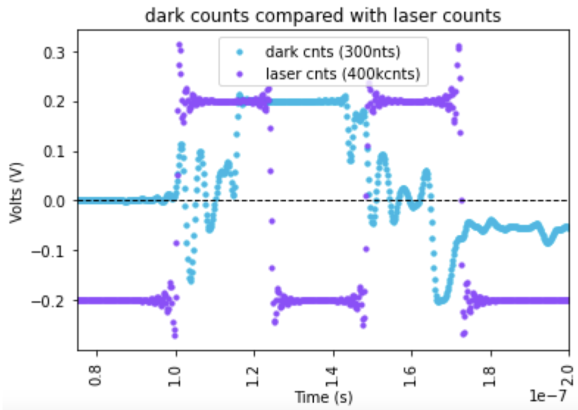


(b) Moku Pro SMA vs BNC vs Internal Wiring Connection

Fig. 1



(a) Counts response to laser source



(b) Counts waveform compared with dark counts waveform

Fig. 2

4. Future Endeavors

We have demonstrated the preliminary functionalities of the confocal microscope, implemented a Python-based open-source control console for quantum emitter cryogenic microscopy, and benchmarked the time-tagging accuracy of an FPGA-based single-photon counting module.

Further refinements are needed to achieve a reliable second-order correlation function $g^2(\tau)$ measurement, as validating these calculations is crucial for assessing qubit states and stability in future experiments. In addition, a full-system test is required to verify the functionality of our camera and projector system. We are looking to take inspiration from Lin, Z., *Schweickert, L., Gyger, S., & Zwiller, V. (2021). Efficient and versatile toolbox for analysis of time-tagged measurements. Journal of Instrumentation, 16(08), T08016* and *Ballesteros, G. C., Proux, R., Bonato, C., & Gerardot, B. D. (2019). readPTU: a python library to analyse time tagged time resolved data. Journal of Instrumentation, 14(06), T06011* to improve our g2 measurement capabilities.