Control and Readout of NV Color Centers

Pulsed NV Color Center Experiments with Precise Timing

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Pulsed experiments with nitrogen-vacancy (NV) centers require precise synchronization between microwave control signals and fluorescence photon detection to ensure high fidelity in spin manipulation and measurement. *Zurich Instruments*' *SHFSG Signal Generator*, with its arbitrary waveform generation capability and double superheterodyne architecture operating from DC to 8.5 GHz, combined with *Swabian Instruments*' *Time Tagger Ultra* (*TTU*), renowned for its picosecond timing resolution and high data transfer rate of up to 90 MTags/s, provides an ideal framework for these demanding experiments.

EXPERIMENTAL SETUP

The experimental setup integrates the *SHFSG* with the *TTU* for precise control and readout of NV centers (Fig. 1). The *SHFSG* generates microwave pulses for spin manipulation, emits marker signals to define gated detection windows, and triggers the three Acousto-Optic Modulators (AOMs) to reset the qubit to its ground state (m_s=0) at the start of each sequence. Following the reset, the *SHFSG* orchestrates subsequent operations on the qubit and reactivates the laser for fluorescence detection. The *TTU* records the arrival times of fluorescence photons with picosecond precision, ensuring accurate data acquisition. The entire setup is controlled using *LabOne Q*, which seamlessly integrates the *TTU* via its Python-wrapped API [1]. This allows for synchronized and real-time management of all instruments configuration, access to the Time Tagger's versatile measurement functions, and support for Near-Time Callbacks for Time Tagger hardware adjustments (e.g. trigger levels or input delays) in one seamless workflow. For detailed guidance on the experimental setup and configuration, refer to *Zurich Instruments*' blog post [2].

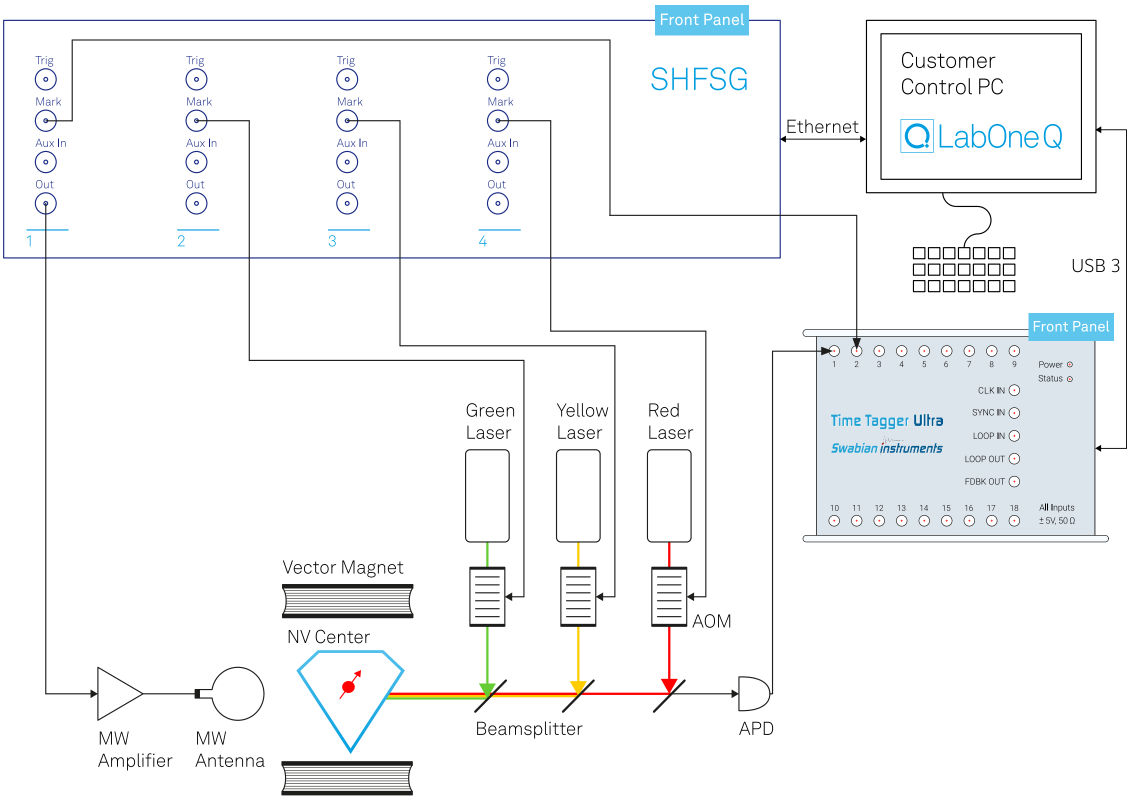

Fig. 1: Illustration of the experimental setup for color centers experiments with SHFSG and TTU.

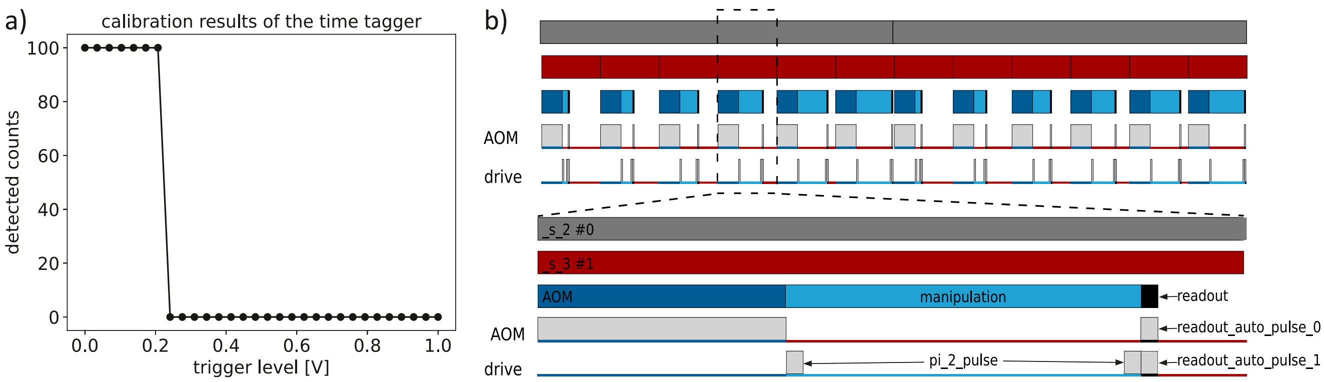

Fig. 2: a) Trigger level calibration of the TTU. b) Overview of a Ramsey Experiment as displayed in LabOne Q, adapted from Ref. [2].

MEASUREMENT

We show how to perform color centers experiments with the *TTU* and the *SHFSG*, simulating NV center signals to assess the system's timing precision and synchronization. For simplicity, we assume a single green laser is in use, focusing on two main channels of the *SHFSG*: Channel 1 for simulated microwave control pulses and Channel 2 for APD-like fluorescence detection signals (Fig. 1).

Proper configuration of the *TTU* is possible via LabOne Q: *i)* The optimal trigger level threshold is calibrated from a series of hundred of *SHFSG*-generated TTL pulses that mimic APD output (Fig. 2a), to ensure reliable detection of simulated photons; and *ii)* The *TTU* input delay is calibrated to synchronize incoming signals with detection gates, ensuring precise timing.

As an example, the Ramsey fringe sequence (Fig. 2b) is constructed using *LabOne Q*'s domain-specific language. Two π/2 microwave pulses are generated on Channel 1 with a controllable delay between them, while Channel 2 simulates fluorescence signals. The delay is systematically varied in real time using a *LinearSweepParameter* within the *Experiment* to capture the Ramsey fringe pattern [2]. Callback functions in *LabOne Q* allow to add to the experiment sequence any functionality available in the Time Tagger API. This is used to configure the *TTU*'s detection gates and counts photons within the gated window via the *CountBetweenMarkers* measurement class [1]. For each delay, photon counts are recorded for analysis.

The experimental framework is general and adaptable to other protocols beyond the Ramsey sequence, including Optical Detection Magnetic Resonance (ODMR), Hahn Echo, Dynamical Decoupling, Rabi, Relaxometry experiments [2].

CONCLUSION

This application note demonstrates the integration of *Zurich Instruments*' *SHFSG* and the *Swabian Instruments*' *Time Tagger Ultra* for NV center experiments, showcasing their precise synchronization and flexibility. By leveraging *LabOne Q*'s capabilities, the framework enables streamlined measurements and broad adaptability, providing a robust platform for advancing NV center research and related quantum technologies.

For questions regarding the implementation of this experiment in LabOne Q, please contact support@zhinst.com.

REFERENCES

[1] https://www.swabianinstruments.com/static/documentation/TimeTagger/api/index.html
[2] https://www.zhinst.com/ch/de/blogs/control-your-nv-centers-combining-zurich-instruments-and-swabian-instruments

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