

Design of Microwave Antenna for Orbital Angular Momentum Transfer Research Using Electron Spins in Diamond

Rose Huang,^{1,2,3} Kento Sasaki,³ Eisuke Abe,³ Yasuaki Monnai,³ and Kohei M. Itoh³

¹*Department of Applied Physics and Applied Mathematics, Columbia University, New York, New York, U.S.A.*

²*Nakatani RIES: Research and International Experience for Students Fellowship in Japan, Rice University, Houston, Texas, U.S.A.*

³*School of Fundamental Science and Technology, Keio University, Yokohama, Japan*

Nitrogen vacancy (NV) defects in diamond have promising applications in quantum information processing and quantum sensing. Electrons of a NV center form a spin-1 system, and can be excited from $m_s = 0$ to $m_s = \pm 1$ using circularly polarized microwaves. We can readout the final spin state with photoluminescence (ODMR: optically detected magnetic resonance). The transfer of orbital angular momentum to spin angular momentum in a NV center will enable larger transitions between spin states. We report on a microwave antenna that generates a twisted magnetic field. The design consists of 8 copper loops on a square FR-4 substrate with a layer of copper behind it. There is a linear phase delay between each excitation port attached to the end of the copper loops. Simulated on CST MICROWAVE STUDIO[®], this antenna emits 2 GHz twisted microwave with a 4π rotation. We expect that the antenna will excite electrons from $m_s = -1$ to $m_s = +1$ for a (111)-oriented diamond. The excitation of the NV center will be assessed with twisted microwave light by an ODMR setup. The electrons of the NV center will be excited from $m_s = 0$ to $m_s = -1$ with linearly polarized microwaves, and then further excited from $m_s = -1$ to $m_s = +1$ using the twisted light microwave antenna. This additional transition between the NV spin states will allow for increased sensitivity in NV-based sensors.

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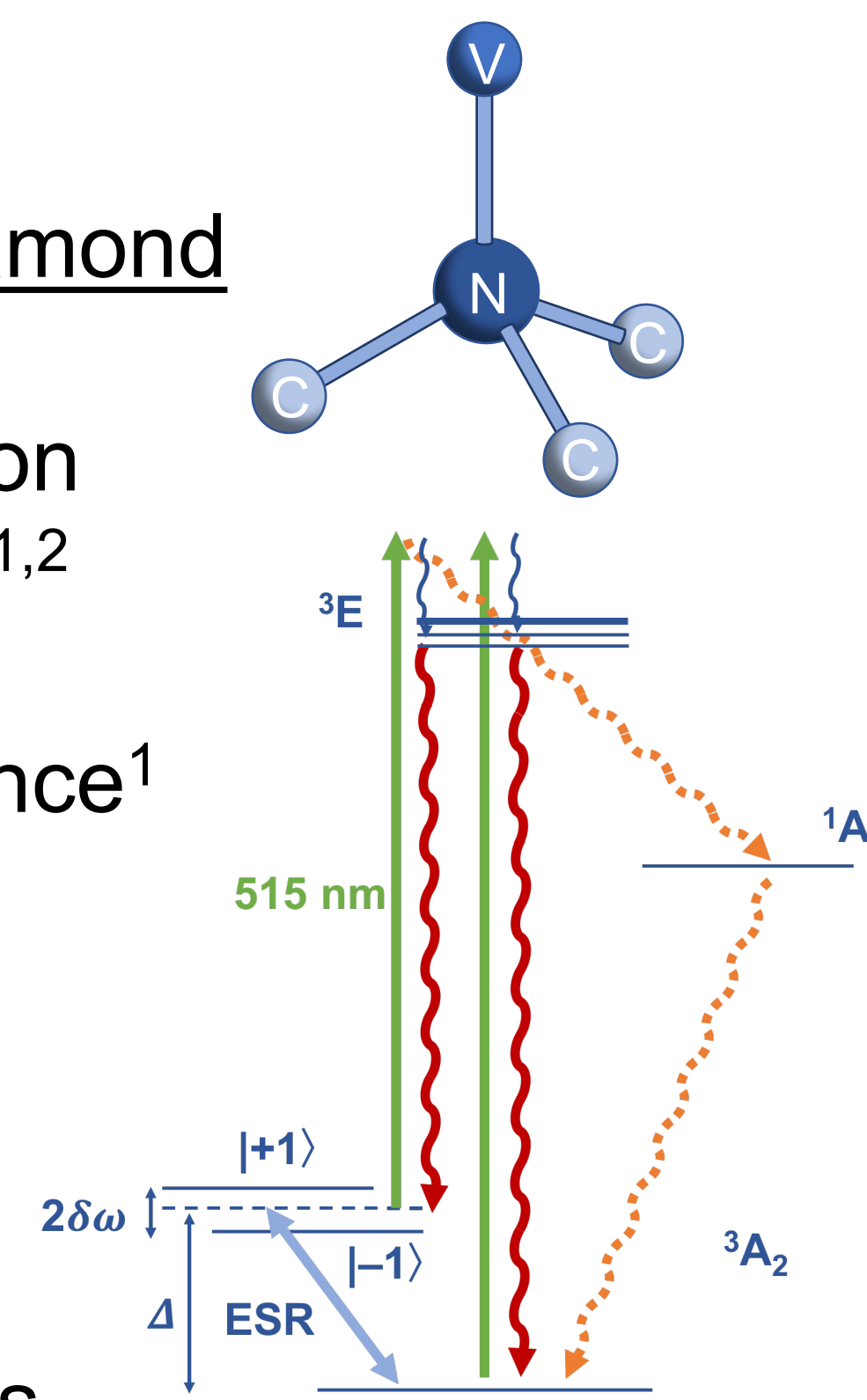
³School of Fundamental Science and Technology, Keio University, Yokohama, Japan



Introduction

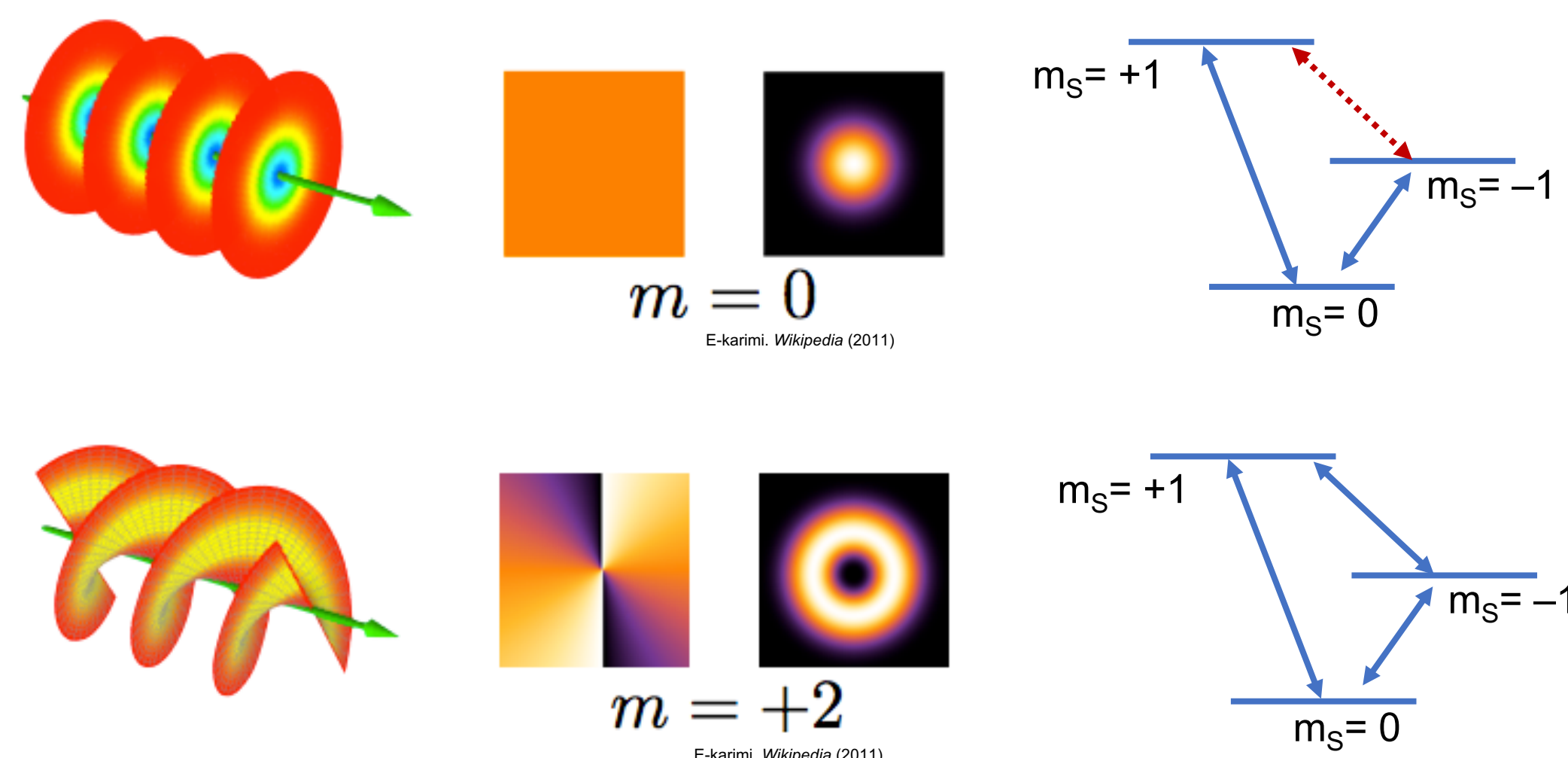
Nitrogen Vacancy (NV) defect in diamond

- Control of NV spin allows for applications in quantum information processing and quantum sensing^{1,2}
- S=1 system
- Spin-dependent photo luminescence¹
- Spin initialization
- Long coherence time at room temperature¹



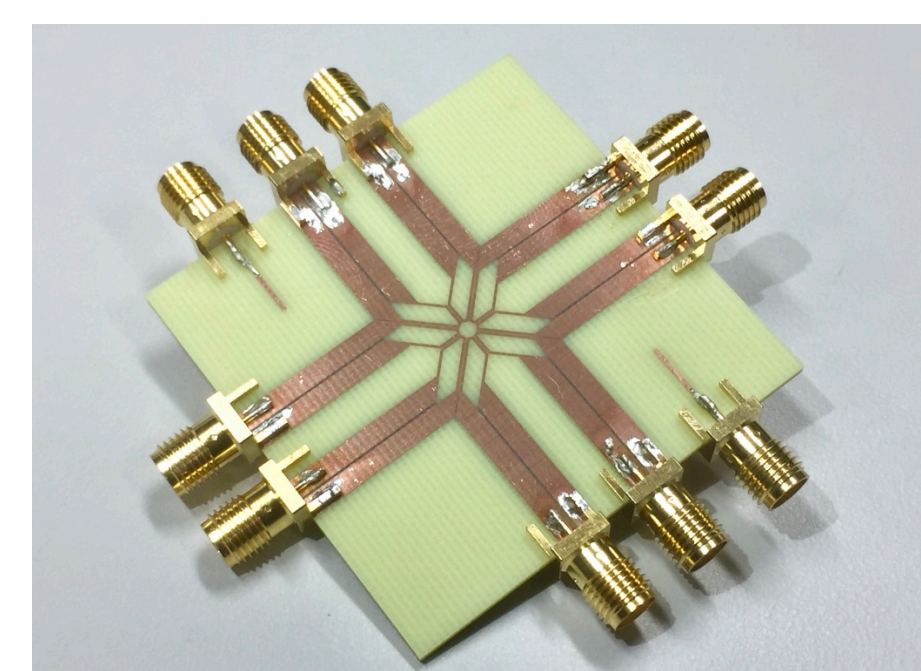
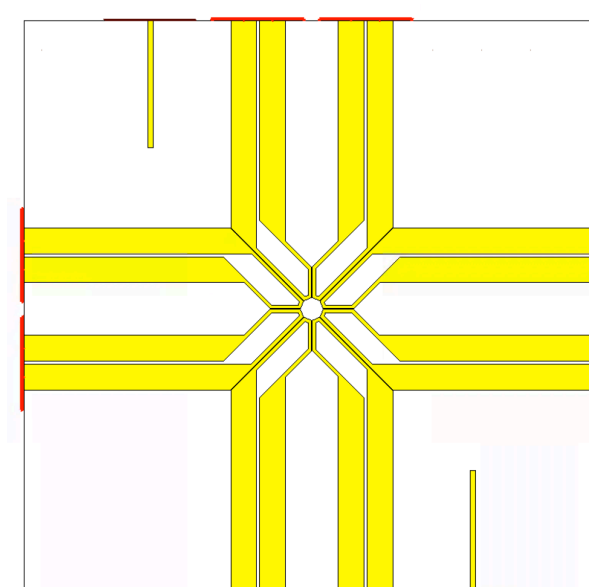
Spin State Transitions in NV Centers

- Can currently excite electrons of NV center from $m_S = 0$ to $m_S = -1$ or $m_S = +1$ using circularly polarized light³



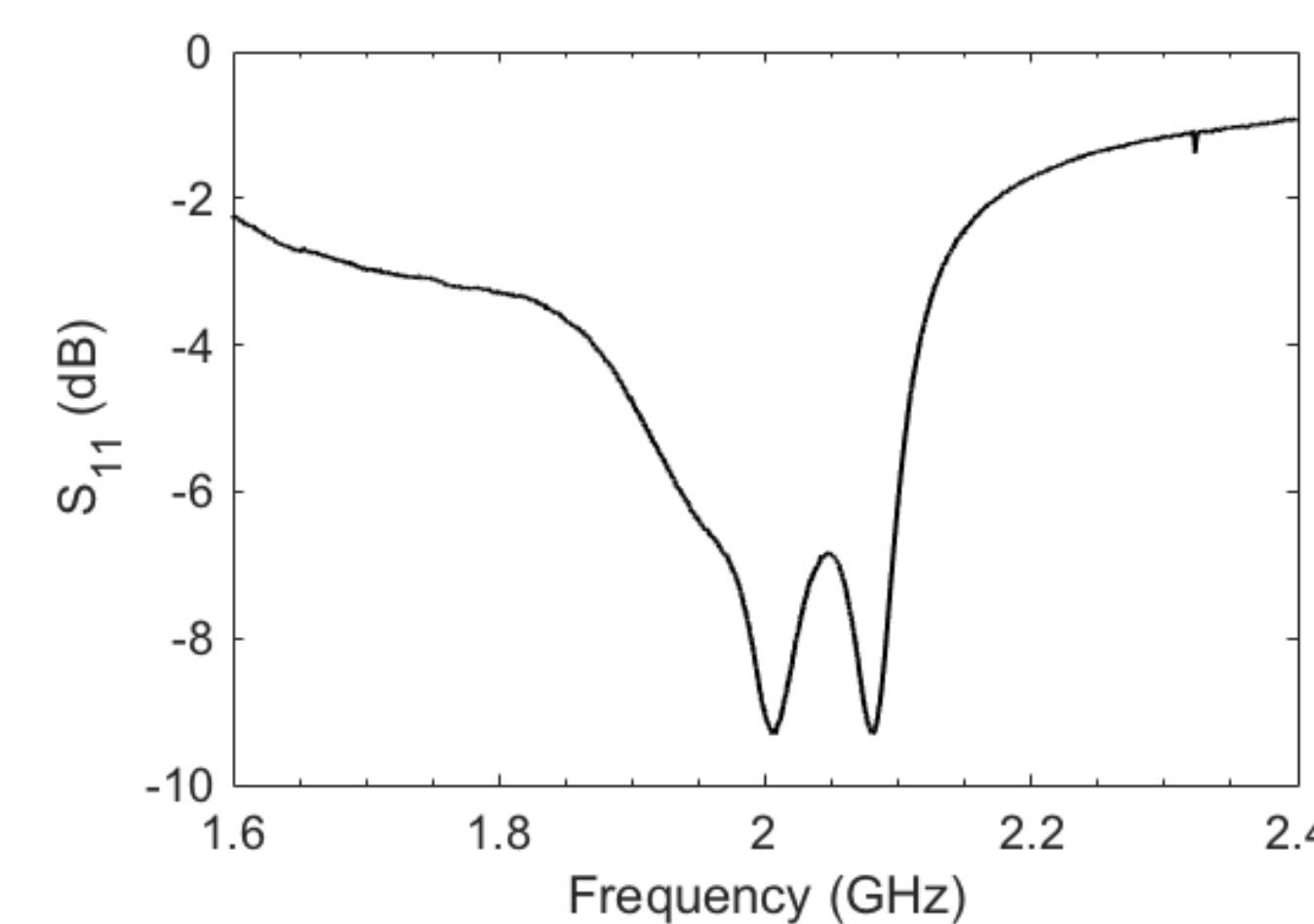
- Transfer of orbital angular momentum will enable larger transitions between spin states

Antenna Design



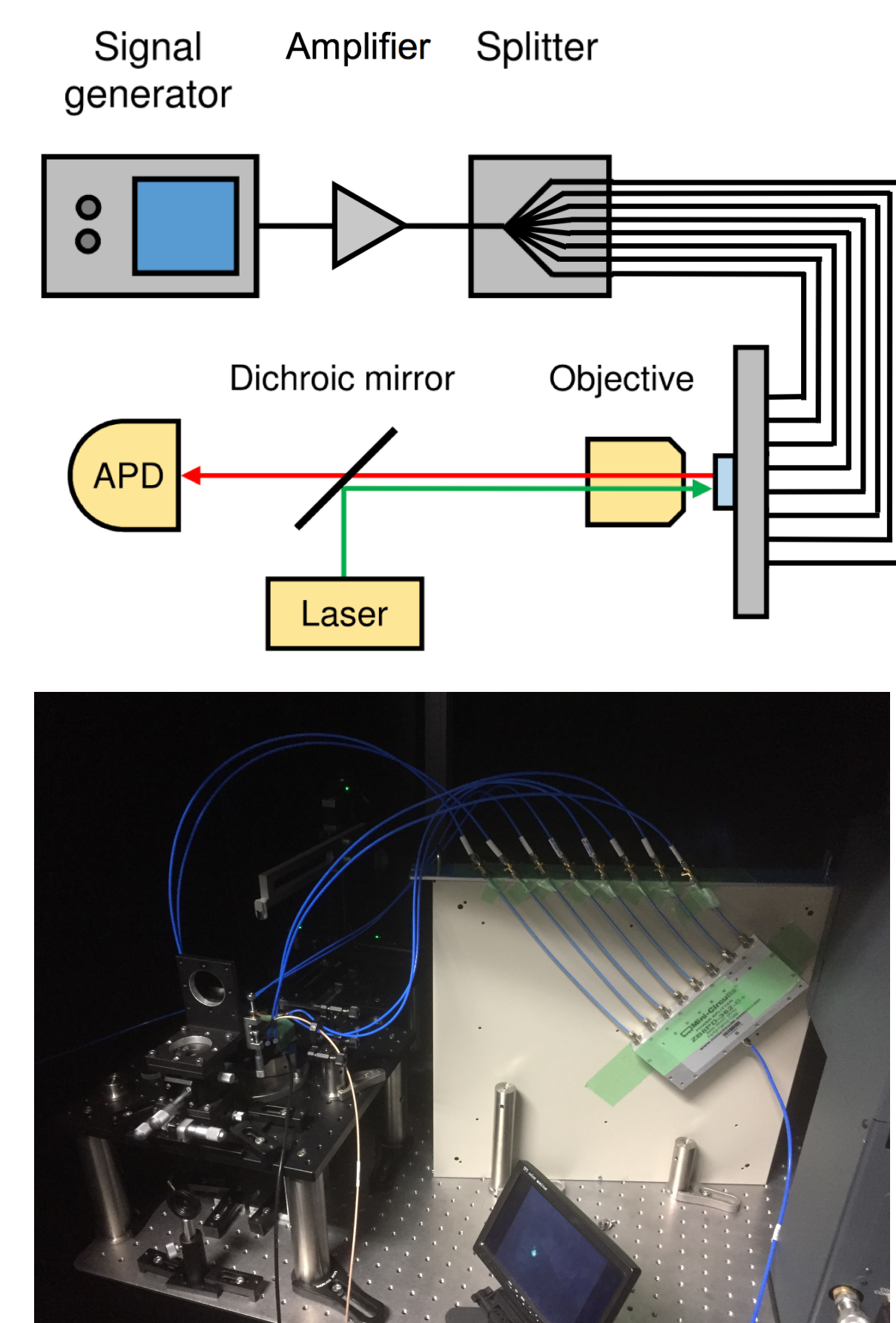
- Square FR-4 substrate (50 mm x 50 mm)
- Copper layer behind substrate
- 8 copper loops
- 2 copper strips connected by thin copper wire
- 8 excitation ports with linear phase delay between ports to create 4π rotation

S-Parameter Measurement



- Network analyzer result around 2 GHz frequency
- S_{11} is around -9 dB (transmission 87%)

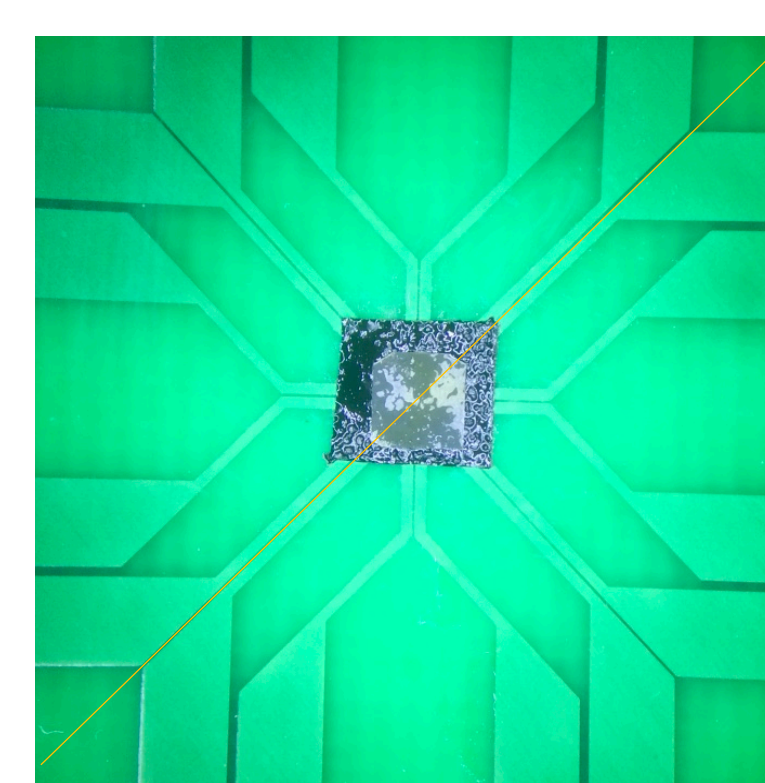
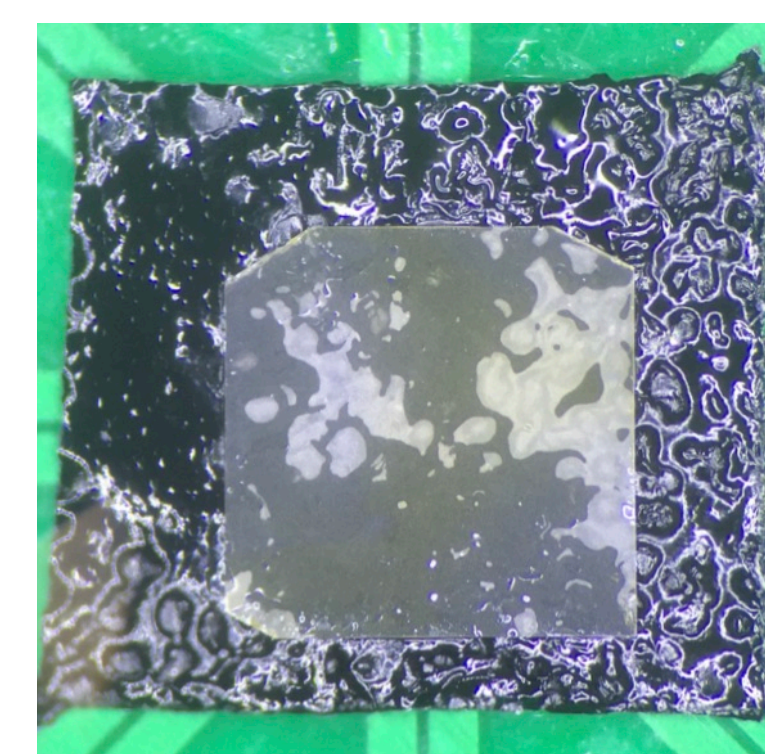
Measurement Setup



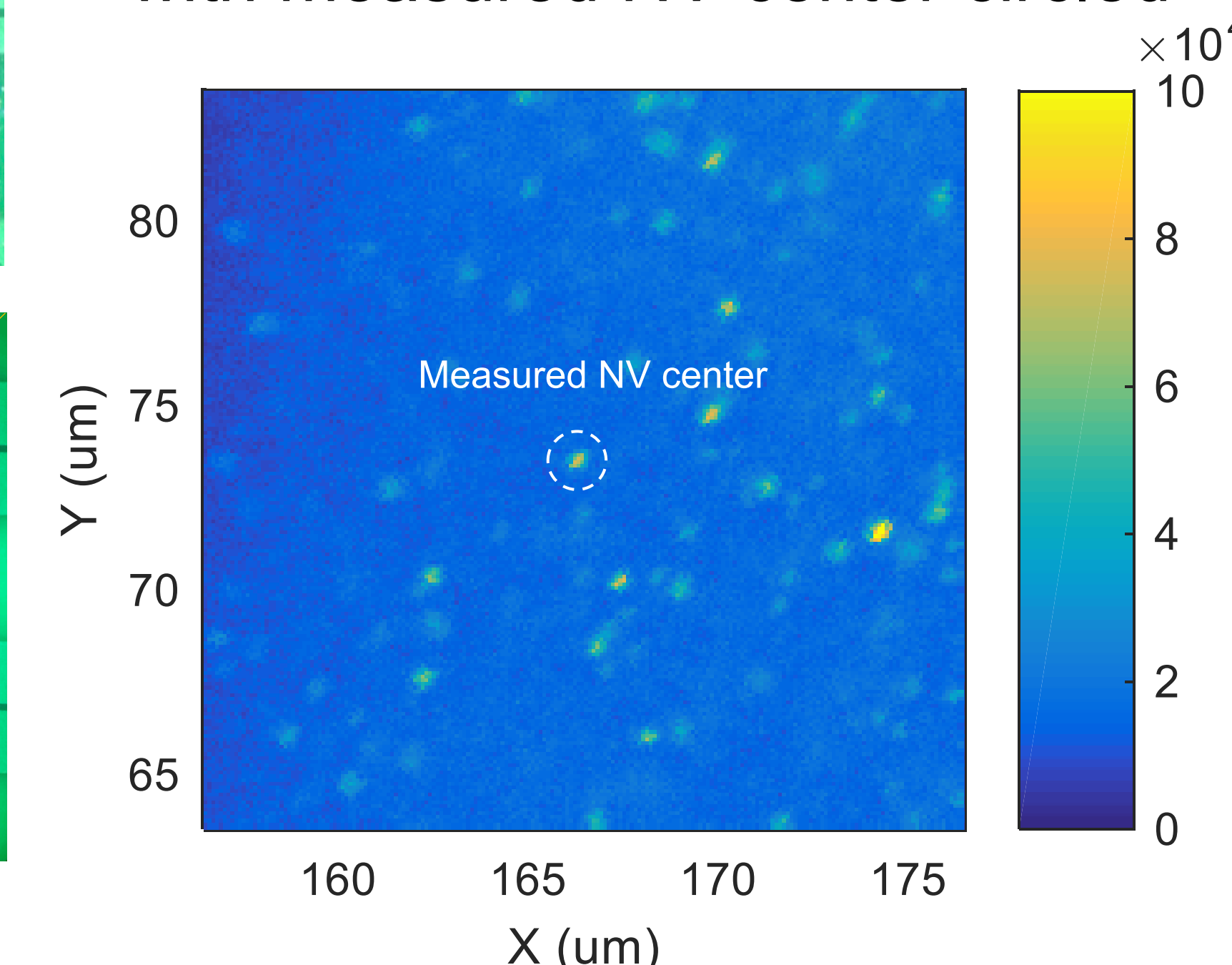
Optically Detected Magnetic Resonance (ODMR) for initialization, control, and readout

- 515 nm green laser excites electrons in NV center
- Red photons emitted by NV center counted by avalanche photodiode (APD)
- Pulses of sinusoidal magnetic field B_{ac} from signal generator transmit through amplifier and splitter to the antenna

Diamond Sample



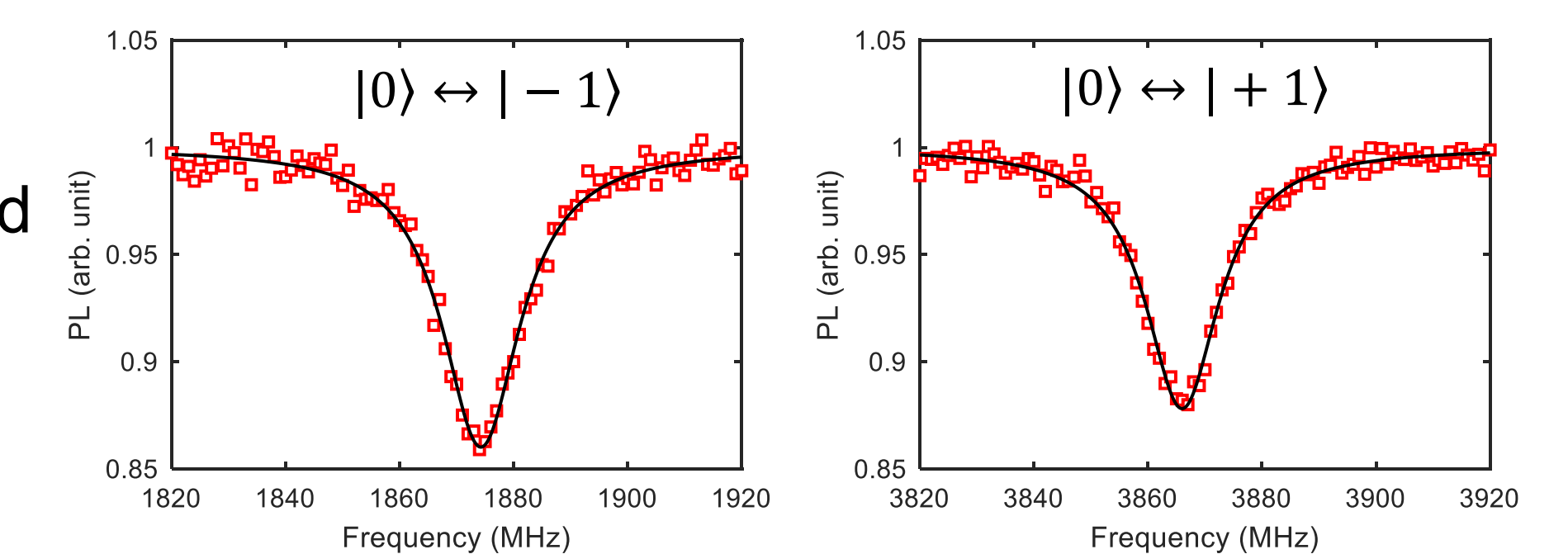
- 50 μm thick (111)-oriented diamond
- Mapping near the center of sample with measured NV center circled



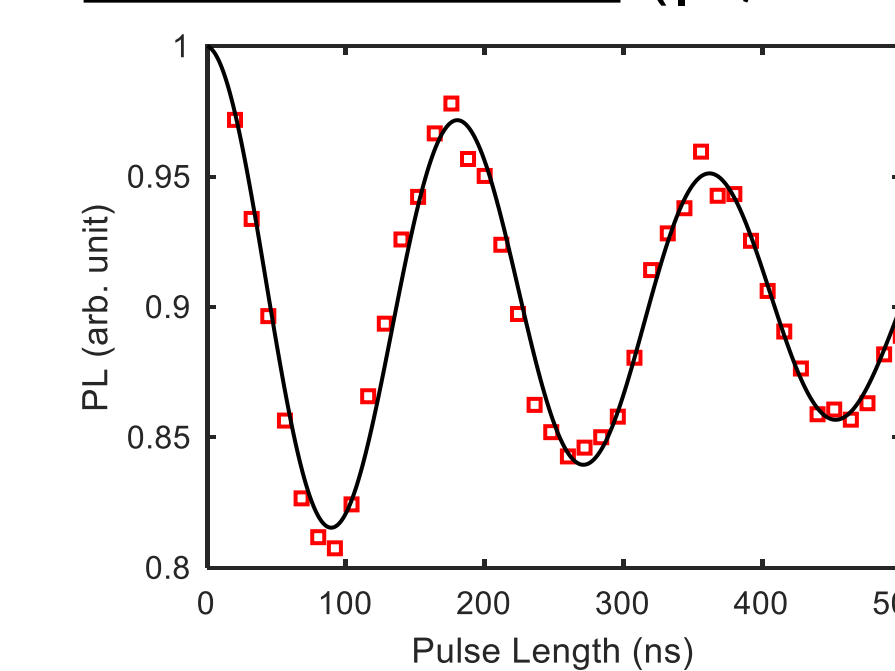
ODMR Measurement

Continuous Wave (CW) ODMR

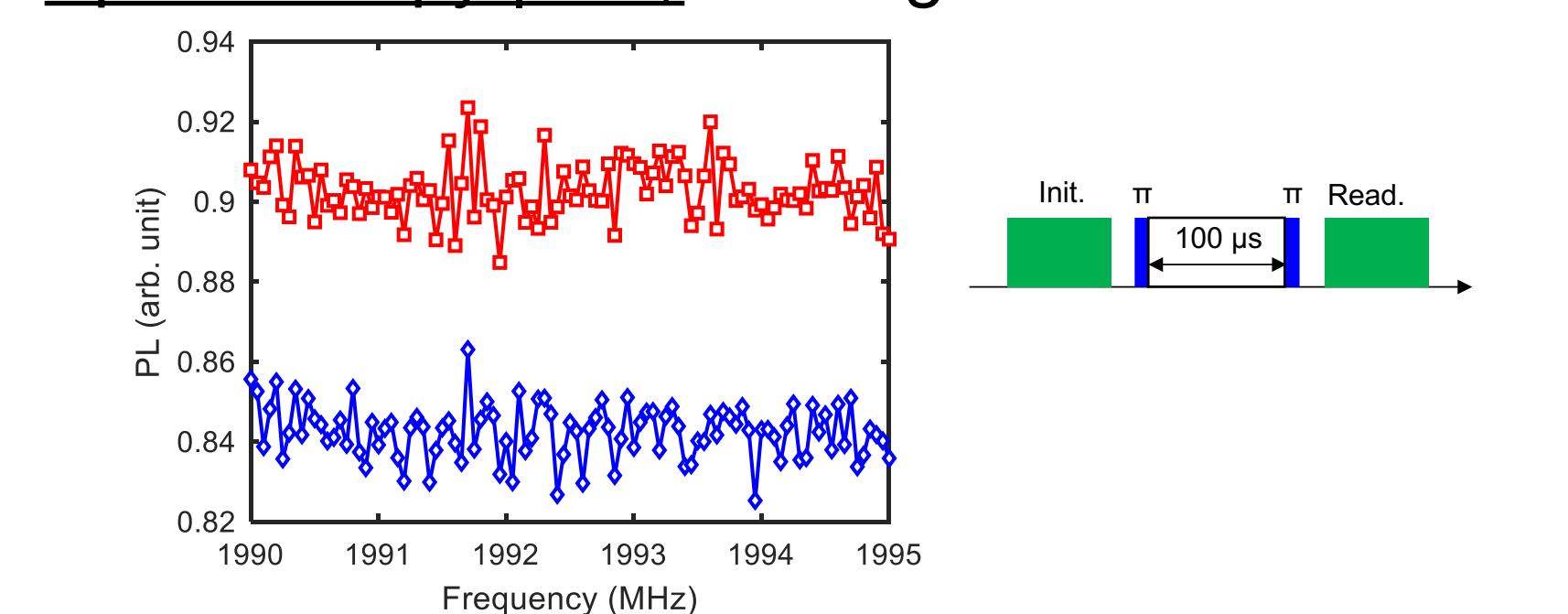
- Magnetic field aligned to 111 direction
- Resonant frequency difference is 1992 MHz



Rabi oscillation ($|0\rangle \leftrightarrow |-1\rangle$)

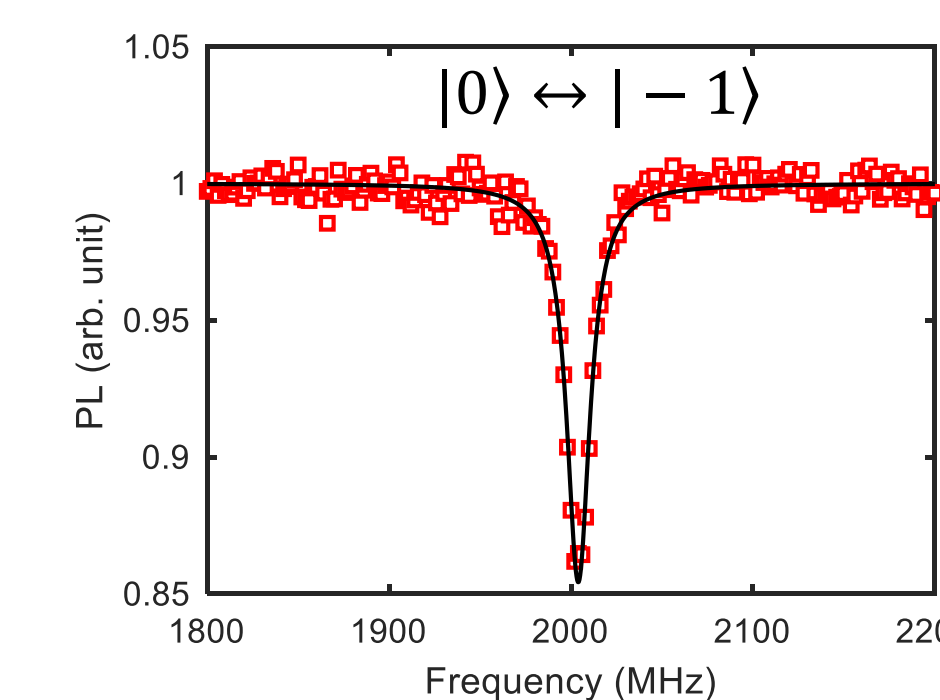


Spectroscopy $| -1 \rangle$ - no signal

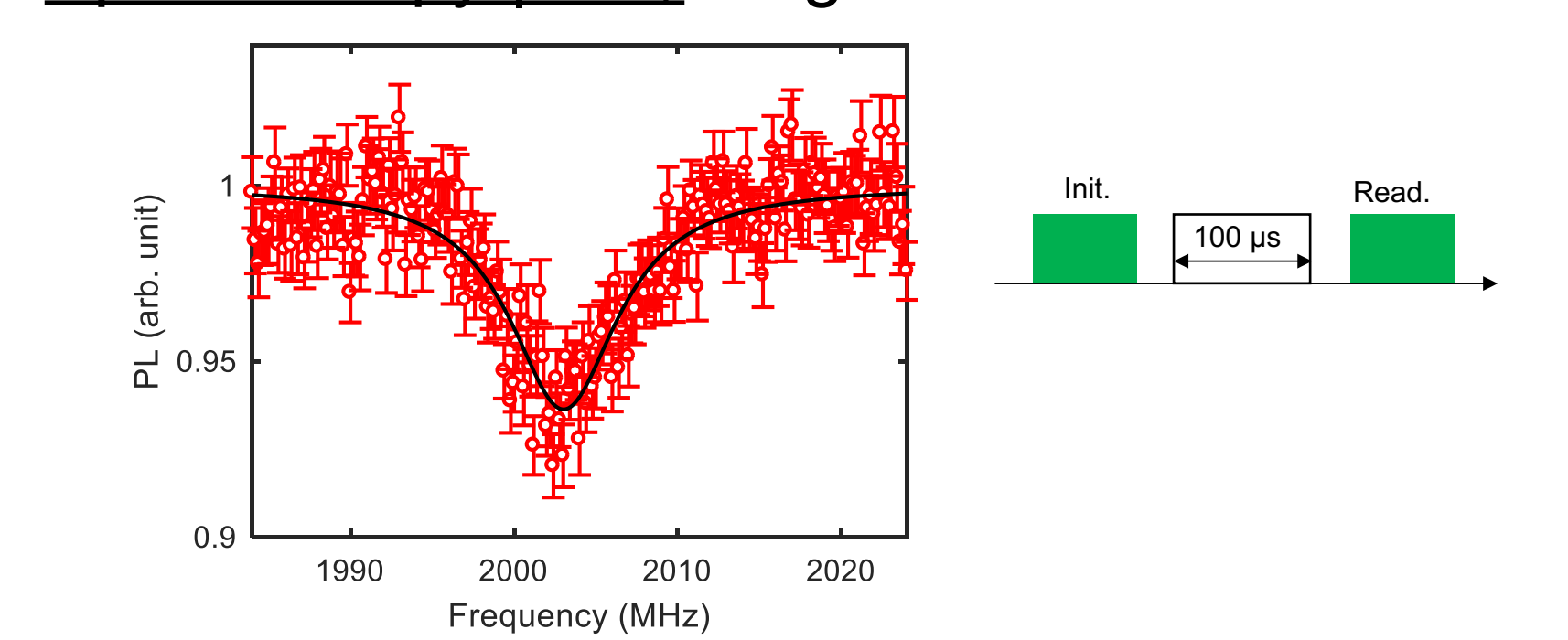


CW ODMR

- NV resonance tuned to 2 GHz



Spectroscopy $| -1 \rangle$ - signal at 2003 MHz



Summary and Future Work

Summary

- Designed antenna and implemented setup for generating microwave field vortex
- Antenna generated microwave signal that can excite NV center from $|0\rangle$ to $|-1\rangle$
- $|-1\rangle$ to $|+1\rangle$ transition could not be observed

Future Work

- Confirm antenna magnetic field vortex generation
- Input stronger microwave power to generate stronger magnetic field

References

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Acknowledgements

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