Optically Detected Magnetic Resonance in LabVIEW

Maya Dunn

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Abstract: Diamond magnetometry enables the measurement of small-scale magnetic fields using nitrogen vacancy (NV) defect centers in diamond. Nanoscale magnetic field detection has a range of applications in biology and chemistry, such as imaging of magnetically-tagged molecules for the study of biological processes. Diamond magnetometry uses optically detected magnetic resonance (ODMR), a technique which combines radio frequency (RF) magnetic fields with optical excitation to control the defect spin. To detect DC magnetic fields, typically continuous wave RF and optical fields are used. This project demonstrates an ODMR system executed in LabVIEW. This program will enable easier measurements of biological systems where orientation matters.

I. INTRODUCTION

Optically detected magnetic resonance (ODMR) is a technique which combines radio frequency (RF) magnetic fields with optical excitation to control a defect spin in a material. The intensity of light produced by the nitrogen-vacancy (NV) center depends on the magnetic field of the environment. Figure 6 is a sample curve taken with this project. The sensitivity of this measurement depends both on the quantum properties of the NV center and how the measurement is taken. This project performs continuous-wave ODMR on a platform that can be adapted to improve sensitivity using pulsed excitation [1].

II. HOW ODMR WORKS IN NITROGEN VACANCY CENTERS

Diamond magnetometry uses ODMR by controlling a nitrogen-vacancy center spin. A nitrogen-vacancy (NV) center is a point defect in diamond where a nitrogen atom and a vacancy take the place of two carbon atoms, creating spin states that can be read out with a laser.

The energy levels of a nitrogen-vacancy center are depicted in Figure 1. During ODMR, the diamond sample is optically excited with 532 nm light and produces photoluminescence at 630-750 nm. The radio frequency (RF) is swept through a resonance.

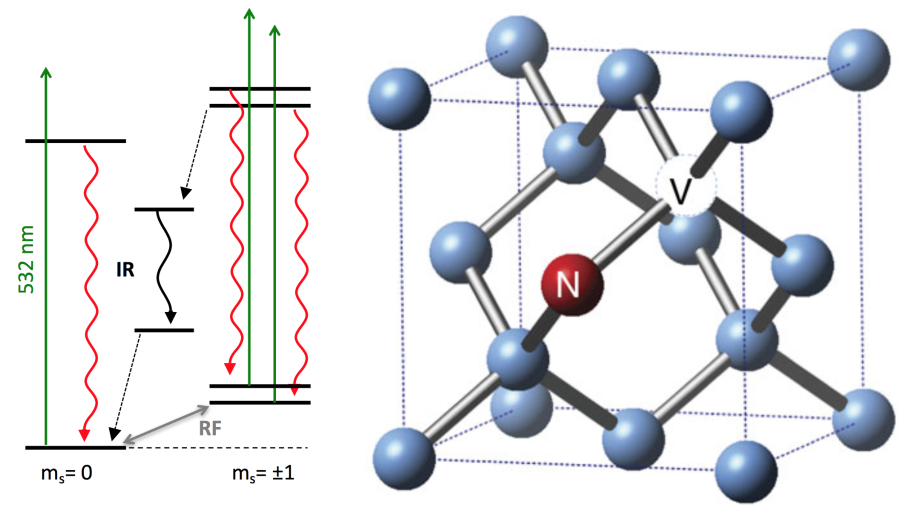

FIG. 1. A diagram of the energy levels in a nitrogen-vacancy center.

When on resonance, the RF drives Rabi flopping between the bottom two energy states. The flopping makes the dark transition, which is labeled as IR in Figure 1, slightly more likely. Due to the Zeeman the bottom two energy levels, the resonance frequency moves linearly with magnetic field as $\nu_{res} = \nu_0 \pm g\mu_B B$ where ν_0 is 2.87 [2]. The dark transition does not produce photoluminescence, which causes the characteristic dip shown in Figure 6.

III. MOTIVATION

Diamond magnetometry enables the measurement of small-scale magnetic fields using nitrogen vacancy (NV) defect centers in diamond.

Nanoscale magnetic field detection has a range of applications in biology and chemistry, such as imaging of magnetically-tagged molecules for the study of biological processes.

The goal of this project is to implement ODMR in LabVIEW to enable future experiments using with a pulsed readout.

IV. HARDWARE

Figure 2 is a diagram of the hardware used to perform ODMR.

The laser frequency was 532 nm. The beam was focused through a microscope onto the diamond sample, pictured in Figure 3, which was mounted on a piece of silicon with indium.

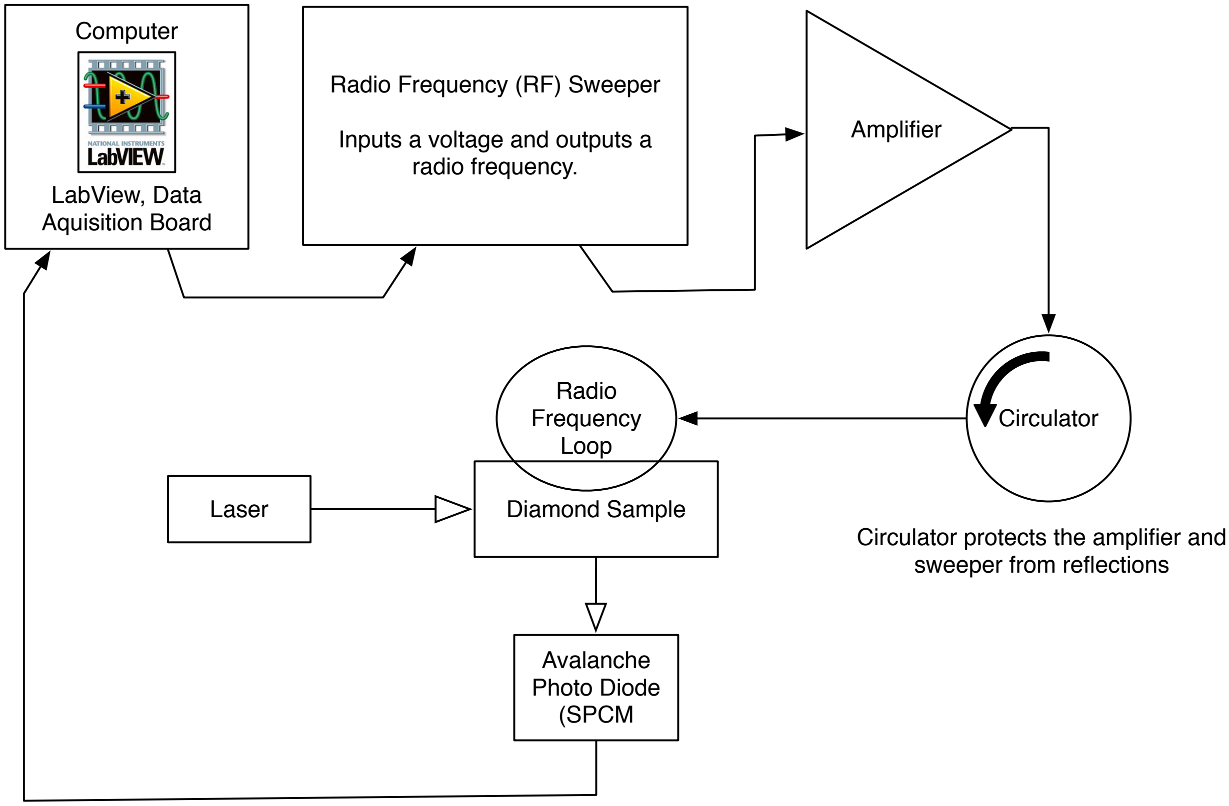

FIG. 2. A diagram of the hardware used in the experiment.

This frequency causes diamond to emit photoluminescence (PL) at 630-750 nm. The PL is collected by the same objective and filtered from the 532 excitation light and collected by an avalanche photodiode.

The microwave circuit was the majority of the apparatus. The RF sweeper was controlled by the sawtooth wave generated by the National Instruments DAQ [3]. The frequency range was set to 2.7-3.0 GHz through the majority of the trials. This signal was fed into an amplifier to increase the power. Afterward a circulator prevented reflections of the high power signal from entering the amplifier.

The frequency loop was a small piece of wire in a loop shape that was placed directly above the sample to create microwave excitation. This loop is pictured in Figure 4. It was mounted on a stage so that it could be moved into place. The excitation beam was focused through the loop.

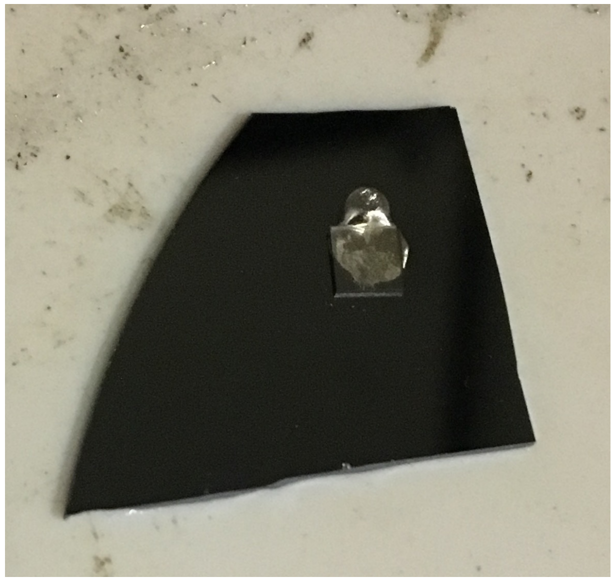

FIG. 3. The diamond sample.

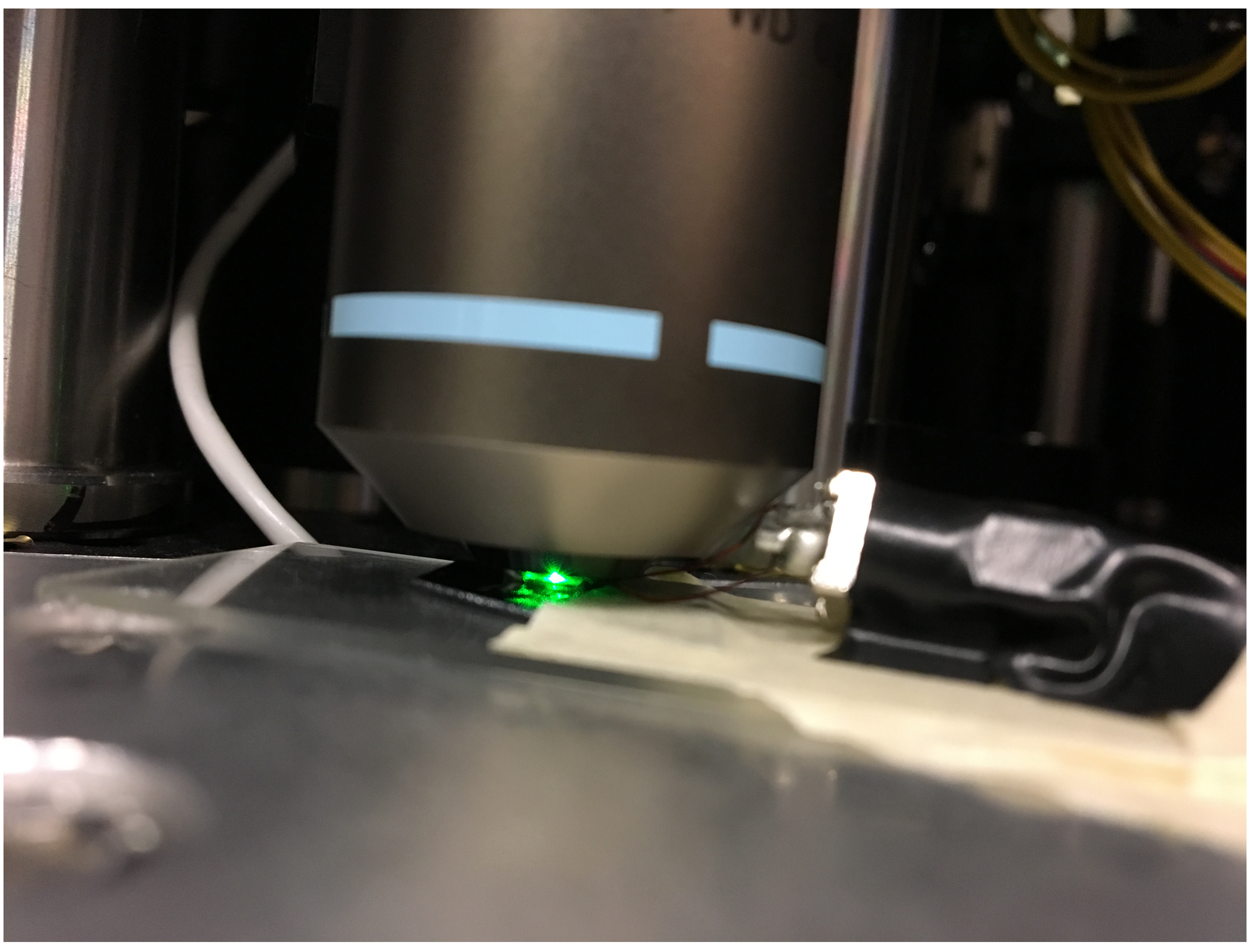

FIG. 4. The thin wire is the radio frequency loop under the microscope objective.

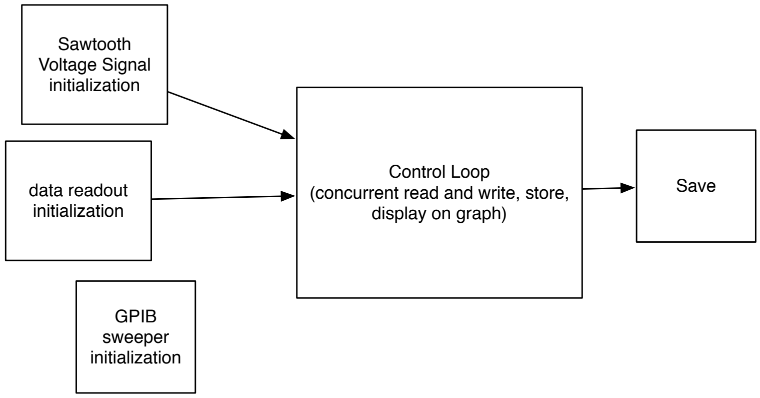

FIG. 5. An abstraction mapping what each region of the LabView code does.

TABLE I. A table of the parameters controlled by the user interface

Parameter	Description
Counter Input Terminal	The DAQ input port connected to the avalanche photodiode
Sweeper Output Channel	The DAQ output port connected to the Sweeper's external input port.
Num Samples	The number of samples taken per sweep
Sweep Time (ms)	The length of time that each sweep lasts
Chunk Size	Should be set to the same number as num samples
Address	The sweeper's GPIB address
Start f (GHz)	The starting frequency of the sweep
Stop f (GHz)	The ending frequency of the sweep
Power (dBm)	The sweeper power in decibels
Save File Path	The file path that data will be saved to after each sweep

V. SOFTWARE DESIGN

The program has three functions:

1. To produce a sawtooth voltage to drive the microwave sweeper from 2.7 to 3.3 GHz.
2. Synchronized collection of photoluminescence data.
3. Save data after each sweep.

The layout of the LabView code is shown in Figure 5. The program parameters are controlled by a graphical user interface (GUI). These parameters are listed in Table I

The sawtooth wave block encompasses 'subMakewaveform.vi', 'subMakeOutput3.vi', and 'DAQmx Write.vi'. These three VIs, and the parameters that feed into them instruct a

National Instruments DAQ to create a sawtooth wave that ranges from 0 to 10 volts [4]. This wave is used to drive the radio frequency sweeper from the beginning of its range to the end of its range. The output voltage maps linearly to sweeper frequencies in the range. The range and power are set using GPIB commands in the GPIB initialization section.

The data readout initialization block consists of 'subMakeCounter.vi' and the array initialization blocks. The counter block interfaces with a single photon counting module that serves as the photoluminescence detector in a microscope. This will bin counts into a time period provided by the user. The number of samples is the number of bins that the counter uses, and the sweep time specifies how long the total time period of the sweep is. The length of each bin can be found as the sweep time divided by the number of samples.

The array that is initialized has the same number of bins as the counter, and is used to store data after a sweep. Each sweep in the array is summed with the previous in 'subDataFlatten.vi' in the control loop. The data is saved without being summed.

The control loop runs the program after initialization. It starts the sawtooth wave, starts the counter, then processes the counter data and saves it. The processing involved is taking the differential, as the counter reports the total number of counts from the sweep in each bin, and the user needs only the new counts from each bin.

Saving is managed by LabVIEW's built in save function. Each sweep is saved as a row on a spreadsheet.

VI. RESULTS

Figure 6 is the sum of 8 sweeps over the 2.7-3.3 GHz frequency range and 0 magnetic field. Each sweep was one second long and was sampled every millisecond.

The resonance dip is centered around 2.869 GHz, which matches the expected value of around 2.87 GHz. The full width at half maximum is 0.021 GHz.

Better RF power stabilization and more consistent voltage output is required for better results. Changes in radio power are creating uncertainty in the data taken.

VII. USER NOTES

The software is stored in the 'Labview ODMR' folder of the group's dropbox.

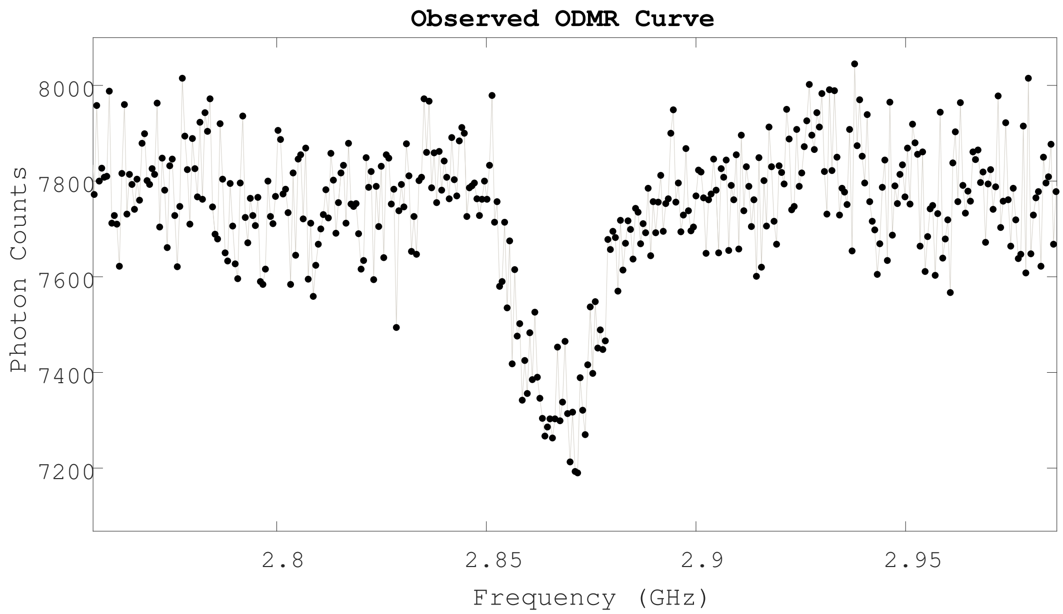

FIG. 6. An ODMR curve observed with this setup, taken with no magnetic field.

Before running the program, adjust the parameters as desired. LabVIEW cannot adjust parameters while in the control loop, so everything must be set ahead of time. Sweep time is the total amount of time the RF sweeper will spend on the frequency range. The number of samples is amount of data points that will be collected in this range. 'Chunk size' should be set to be the same as the number of samples.

When the power diode is in place, the RF sweeper should not output above 0 dBm. The power output is noticeably larger for smaller frequencies and may affect the data taken.

The loop becomes very hot during use, and does not cool down for several minutes. It should not be handled directly or placed near flammable materials.

If saving to a file that already exists, data will be appended. Data is saved in tab separated columns.

VIII. FUTURE STEPS

Looking forward, this work will be used to create a system in which optical and radio excitation are pulsed and staggered. This will narrow the resonance dip. In a pulsed setup a switch would be placed before the amplifier to toggle the power into pi pulses. Instead of continuously changing, frequency would be stepped between pulses. This would be accomplished with the SpinCore PulseBlaster card.

The realtime data display, which is controlled by the ‘chunk size’ parameter needs to be edited so that the sweeper pulse is started outside of the innermost loop in the LabVIEW code. Until then attempts to use this parameter will result in the sweep being restarted every few samples. After making this change, timing will need to be measured with a variety of ‘chunk size’ settings.

Saving should also record other parameters so that the user does not need to keep a separate file recording parameters manually.

IX. ACKNOWLEDGEMENTS

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[1] A. D. au, M. Lesik, L. Rondin, P. Spinicelli, O. Arcizet, J.-F. Roch, and V. Jacques, “Avoiding power broadening in optically detected magnetic resonance of single nv defects for enhanced dc magnetic field sensitivity,” *Physical Review B*, vol. 84, November 2011.

[2] E. O. Shafer-Nolte, *Development of a Diamond-based Scanning Probe Spin Sensor Operating at Low Temperature in Ultra High Vacuum.* PhD thesis, University of Stuttgart, 2014.

[3] Hewlett-Packard Company, *Operating and Service Manual: HP 8350 Sweep Oscillator*, 3 ed., October 1992.

[4] National Instruments, *DAQ X Series User Manual*, February 2012.