Enabling photodetection electronics for fluorescent diamond based quantum sensing
Project plan

Vladislav Serafimov

September 10, 2025

Contents

Chapter 1

Introduction

This chapter introduces the assignment and some foundational concepts of quantum sensing.

1.1 Background

Nitrogen-vacancy (NV) centers [1] are imperfections in the atomic structure of diamonds, which have the useful property of spin-dependent luminescence. This means that the spin of the NV center affects the frequency of the light emitted by the structure[1]. Using this quality of the NV structure, different environmental metrics (e.g magnetic fields) can be measured.

The Applied Nanotechnology research group is working on a NV-center-based sensor setup. Processing data from the setup requires working with weak signals that are hard to distinguish from the environmental noise. While this is a significant problem, it is also a very common one. Because of this, there is already widely-used system used to isolate signals in such cases: the lock-in amplifier.

1.2 Purpose of the assignment

Implementing a lock-in amplifier is the main purpose of the assignment. To create a complete solution, there are several different functionalities and systems that need to be developed.

Before doing anything else, the raw sensor data needs to be extracted and then fed to a lock-in amplifier. This should be done in a standardized manner, in order to facilitate testing with different devices. After establishing connection, a control interface needs to be implemented. It needs to be programmed so that it can control all necessary features of the lock-in amplifier. Following the development of the program, a custom photodetection circuit needs to be designed. The circuit should accommodate the sensors and lock-in amplifier. Lastly, an OLIA[2] circuit needs to be tested and compared to conventional lock-in systems.

1.3 Assignment specifications

As already explained, the assignment is quite broad and involves both hardware and software, causing the need for a number of different tools.

Most of the hardware tools are already available at the Applied Nanotechnology lab. The lock-in amplifiers which will be used for the tests are the most important pieces of hardware. Zurich Instruments HF2LI is the benchmark lock-in amplifier. There are several different photodetectors available and the one which fits the project best will be picked at a later date.

In terms of software, there is more freedom of choice. Interfacing with the ZI HF2LI is done through proprietary software, but this is the only required program. There are various electronic computer-aided design (ECAD) software suites that offer the same base functionality. KiCad was selected because the client prefers open-source software. The program for retrieving data from the lock-in amplifiers can be written in both Python and MATLAB. Both languages have good integration with the main lock-in amplifier. They also offer graphic user interface (GUI) programming capabilities and are good for scientific computing overall.

[1]The NV center only emits light after absorbing photons, a phenomenon called photoluminescence [2]

[2]Open Lock-In Amplifier (OLIA) is an open-source microcontroller-based lock-in amplifier. It uses common components, which makes it easy to build [3]

1.4 Methodological approach

Chapter 2

Project boundaries

The project boundaries were initially based on the assignment form, but were later discussed with the client and refined further.

Must have

- Hardware platform for photodetection
- Software for signal processing and visualization

Should have

- Tests with different diamond samples

Could have

- Tests with different quantum protocols
- OLIA implementation
- Tests comparing OLIA to market solutions

Will not have

-

Chapter 3

Products and project objectives

This chapter describes all the required products and based on them sets up the objectives for the project.

3.1 Products

There are several technical products that need to be delivered, all of which fall into the categories of hardware, software and test data.

Developing a hardware platform for measurements is the most important part of the project. The photodiode subsystem needs to be in the form of a printed circuit board (PCB). It needs to have output connectors that can accommodate a lock-in amplifier. Additionally, an OLIA can also be built using the available schematics.

In terms of software, an application needs to be developed to process and visualize the signal readouts from a lock-in amplifier. It should be able to retrieve data from different lock-in amplifiers. If necessary, modifications to the OLIA firmware will also be made.

Lastly, performance measurements also need to be delivered to the client in a digestible manner. Test data should compare performance of different lock-in amplifiers using different diamond samples. The most important metrics are signal-to-noise ration (SNR), bandwidth and stability. If there is enough time at the end of the project, tests with alternative quantum protocols can be done. Finally, if an OLIA was built, it needs to be compared in the same way to the different lock-in systems available on the market.

3.1.1 Goals

Based on the MoSCoW priorities from Chapter 2, a set of goals was created to further specify all items from each prioritization category. Every goal was designed so that its outcome results in a tangible project milestone (e.g. a deliverable).

Goal 1 : Create a hardware setup, which measures and amplifies photodiode signals

Goal 2 : Develop software to process and visualize lock-in amplifier signals

Goal 3 : Compare the performance of different lock-in amplifiers

While these goals are practical, they are still not specific enough. To eliminate the possibility of confusion, a set of tasks were created. All tasks contribute to one of the three goals.

Task 1.1 : Design a photodiode PCB, which can accommodate different lock-in amplifiers

Task 1.2 : Build an operable OLIA

Task 2.1 : Develop software that acquires signals and is then able to visualize them

Task 3.1 : Use key performance metrics to compare the OLIA implementation to market solutions

Task 3.2 : Measure OLIA performance using different diamond samples and quantum protocols

Task 1.1 involves the design and production of a photodiode PCB. The PCB has to output signals that are not only compatible with lock-in amplifiers that are available on the market, but also with the OLIA. This part of the hardware design has the highest priority, which is why it will be done first.

Task 1.2 is to build an OLIA amplifier, which can be used at Applied Nanotechnology's laboratory. This will be done with the technical specifications and firmware provided by Harvie and de Mello [3]. The necessity for an OLIA is low, because the Applied Nanotechnology research group already has two lock-in amplifiers.

Task 2.1 is to write an application in Python or MATLAB. This can be done on a different setup, but ideally it will use the hardware setup from **goal 1**. Because the OLIA project uses open-source firmware that differs from proprietary solutions, there might need to be two separate applications. This task can only be completed once a measurement setup is built, so its execution will follow the first two tasks.

Task 3.1 requires all previous tasks to be finished. The completed setup needs to be used to measure the performance of lock-in amplifiers available on the market and the OLIA implementation. SNR, bandwidth and stability are the main metrics that need to be compared.

Task 3.2 is similar to **task 3.1**, but it is a much broader exploration of the performance of the lock-in amplifiers. Using different diamond samples and quantum protocols will show how the amplifier performs and how different conditions affect it. Because the task can be used to verify the setup from **goal 1**, it can also be done before **task 3.1**. Tests with varying diamond samples are more important to the client, which is why they will take precedence over tests with different quantum protocols.

3.1.2 Deliverables

The description of the tasks already provided context for the deliverables, but this subsection contains a formalized version of the deliverables.

1. Photodetection PCB
2. OLIA
3. Software application
4. Comparison visualization
5. Technical documentation

The only deliverable, which was not mentioned in Chapter 3.1.1 is the technical documentation. This is because it should contain information about every task.

Chapter 4

Project activities

4.1 Start phase

4.2 Realization phase

4.3 End phase

Chapter 5

Quality assurance

As with any assignment, quality is extremely important. Successful completion of the project is expected, but in order to receive a complete solution without corners being cut, the quality of the work of the student and the resulting products need to be monitored along the way.

Establishing a recurring meeting for discussions with the client is the most simple way of ensuring the output of the student remains consistent and focused. Frequent meetings also help mitigate some project risks borne out of miscommunication.

Based on these discussions, proper testing procedures can be set in place. By planning tests and then reviewing the results together with the client, the wanted level of quality can be achieved.

Chapter 6

Project organization

Some aspects of the project organization were already discussed very briefly, but this chapter is meant to explicitly define all organizational structures.

6.1 Organization

Table 6.1 shows all who is involved in the project and what their roles are.

Name	Work email	Role
Vladislav Serafimov	TBA	Student
Mehmet Can	m.can@saxion.nl	Saxion coach
Ari Ortiz-Moreno	a.r.ortizmoreno@saxion.nl	Client/Company coach

Table 6.1: People involved in the project

Out of the three people mentioned, only the student works on the project directly. It is their responsibility to organize and plan the work. Both coaches are only there to support the student and their execution of the assignment. However, their support functions are slightly different. The Saxion coach is there to ensure the student delivers all required documents to graduate, while the company coach is more concerned with the technical functioning of the student. One responsibility which both coaches share is grading. It is important to note that the company coach also doubles as a client representative. As such, they need to present the student with relevant information about the project and what the client requires from the student.

6.2 Communication

Online communication is convenient, because it offers instantaneous file sharing and storage. Furthermore, the Microsoft Teams environment is good for settling simple questions and issues quickly. Because of this, communication in this project will mainly be done online. However, in-person communication is also extremely important. As mentioned in 5, discussion meetings are vital. Meeting online is possible, but presenting progress is much easier and effective when done in-person.

Chapter 7

Planning

Chapter 8

Risk analysis

Risk analysis and management is closely related to quality assurance and is equally important. The complete risk breakdown can be found in the attached spreadsheet.

In terms of technical risks, there are several, but most of them are unlikely to happen. The most impactful risk is malfunction of devices such as the

Bibliography

[1] Wikipedia contributors, *Nitrogen-vacancy center — Wikipedia, the free encyclopedia*, [Online; accessed 3-September-2025], 2025. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Nitrogen-vacancy_center&oldid=1301369588.

[2] Wikipedia contributors, *Photoluminescence — Wikipedia, the free encyclopedia*, https://en.wikipedia.org/w/index.php?title=Photoluminescence&oldid=1309081879, [Online; accessed 4-September-2025], 2025.

[3] A. J. Harvie and J. C. de Mello, "Olia: An open-source digital lock-in amplifier," *Frontiers in Sensors*, vol. 4, p. 1 102 176, 2023.