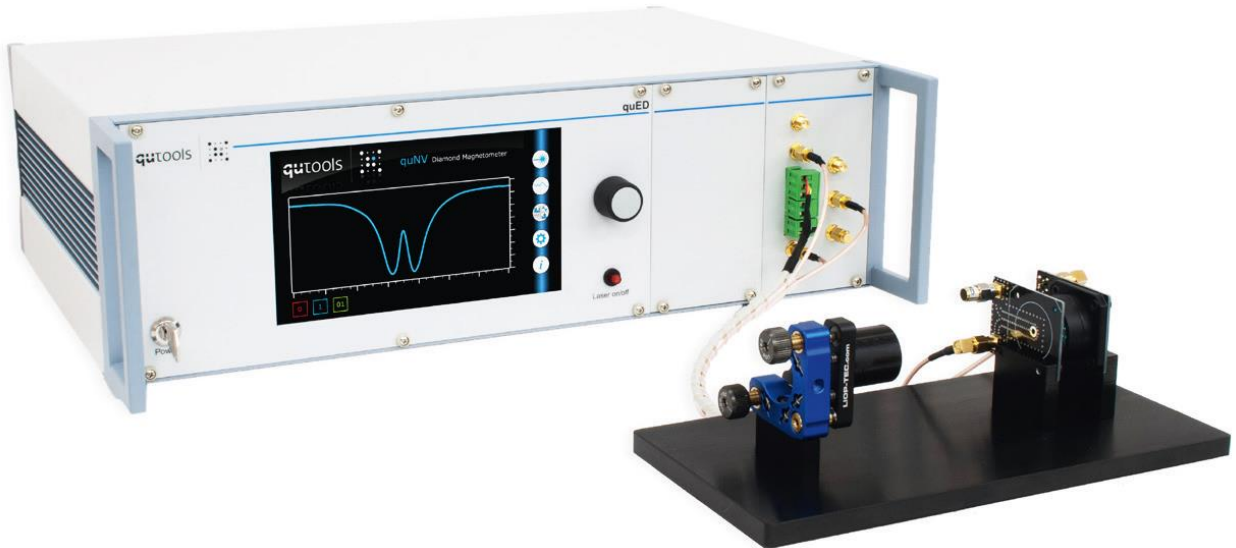




quNV

Manual V1.0



quTOOLS



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1. Introduction

This Quantum Diamond Magnetometer and its experiments will introduce students to the concepts of quantum sensing. This design is based on recent achievements of scientific research and demonstrates quantum sensing in a simple and user-friendly system for student lab courses at colleges and universities.

2. Safety and Maintenance

2.1. Legend



Caution

General risk of danger.



Warning

An instruction which draws attention to the risk of injury or death.



Warning

Risk of electric shock. High voltages present.

2.2. General Instructions



The equipment, as described herein, is designed for use by personnel properly trained in the use and handling of mains powered electrical equipment. Only personnel trained in the servicing and maintenance of this equipment should remove its covers or attempt any repairs or adjustments. If malfunction is suspected, immediately return the part to the vendor for repair or replacement. There are no user-serviceable parts inside the electronics. Modified or opened electronics cannot be covered by the warranty anymore. Take special care if connecting products from other manufacturers. Follow the General Accident Prevention Rules.



If this equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired. Do not operate the instrument outside its rated supply voltages or environmental range. In particular, excessive moisture may impair safety.



For laboratory use only. This unit is intended for operation from a normal, single phase supply, in the temperature range 5° to 40°C, 20% to 80% RH.

2.3. Environmental Conditions

Warning. Operation outside the following environmental limits may adversely affect operator safety:



- Indoor use only
- Maximum altitude 2000 m
- Temperature range 5°C to 40°C
- Maximum humidity less than 80% RH (non-condensing) at 31°C
- To ensure reliable operation the unit should not be exposed to corrosive agents or excessive moisture, heat or dust. If the unit has been stored at a low temperature or in an environment of high humidity, it must be allowed to reach ambient conditions before being powered up.

2.4. Electrical Installation



The unit must be connected only to an earthed fused supply of 100 to 240V (Japan, USA and Europe).

Use only power supply cables supplied by the manufacturer, other cables may not be rated to the same current. The unit is shipped with appropriate power cables for use in Europe. When shipped to other territories the appropriate power plug must be fitted by the user.



Never connect any cabling to the electronics when contacts are exposed!
Avoid short-cuts.



Prevent electrical shock from electronic. To prevent electrical shock do not remove the cover of the control unit. Unplug power cord and all other electrical connections and consult qualified service personnel when servicing or cleaning. Operate only under dry conditions and at room temperature conditions.

2.5. Preventive Maintenance



The equipment contains no user serviceable parts. There is a risk of severe electrical shock if the equipment is operated with the covers removed. Only personnel authorized by the vendor and trained in the maintenance of this equipment should remove its covers or attempt any repairs or adjustments. Maintenance is limited to safety testing and cleaning as described in the following sections.

2.5.1. Safety Testing



Safety testing in accordance with local regulations, should be performed on a regular basis, (typically once per year for an instrument in daily use). Caution. The instrument contains a power supply filter. Insulation testing of the power supply connector should be performed using a DC voltage.

2.5.2. Cleaning



Disconnect the power supply before cleaning the unit. Never attempt to clean the device by immersion into any liquid. Never allow water to get inside the case. The device contains parts sensitive to any kind of liquid. Do not use any type of abrasive pad, scouring powder, or solvent, e.g. alcohol or benzene. Please note that all parts of the unit are cleaned in our production facility.

2.6. Laser Safety



This product contains Class 3B laser according to IEC 60825-1 (or EN 60825-1) Safety Standards.

Class 3B lasers are hazardous to the eye from direct beam viewing, and from specular reflections even for short and unintentional exposures! Therefore, it is absolutely necessary to take overall safety measures when operating the source.

The quNV should be operated in a restricted area equipped with post warning signs to alert those present. To ensure adequate warning of hazards associated with the accessible laser radiation, relevant warning signs and labels are conspicuously affixed to the quNV. When removing the protective laser enclosure, always wear suitable safety glasses to prevent exposure to laser light. For additional information users should refer to appropriate documents specifying the safety standards such as IEC 60825-1 "Safety of laser products – Part 1: Equipment classification and requirements".

2.7. Additional Warnings

The following precautions should be thoroughly reviewed and followed to avoid the risk of any damage or failure.

- Avoid any back-reflection into the aperture of the laser head. Permanent damage to the laser diode can occur.
- Never connect or disconnect any of the cables between the control unit and the bread board while the control unit is turned on. These acts can lead to hazards for the operator and possible permanent damage to the device.
- The lifetime of the laser diode can be significantly shortened by applying the driving currents higher than the limiting value preset in the control unit. Therefore, the laser diode should be operated strictly below this value.
- ESD (electrostatic discharge) sensitive device! Electrostatic charges as high as several thousand volts might readily accumulate on the human body and equipment and can easily discharge. If this happens in the immediate vicinity of the laser diode, its permanent damage can occur. Therefore, proper ESD precautions are strongly recommended when handling and operating the device. These include avoiding wearing clothes, which easily generate ESD, putting on work gloves to protect against static electricity, maintaining environmental humidity 40–50% or more etc.
- Opening or removing the housing of the laser head might expose the user to the danger of laser radiation, and might cause a laser diode failure.
- Ensure, that the control unit is never turned on without an antenna or terminator connected to the RF outputs, since turning it on without any load can permanently damage the RF source.

3. Theoretical Background

3.1. Nitrogen-vacancy center in diamond

Carbon forms in one of the allotropes a cubic lattice, called diamond. Within the diamond lattice numerous types of defects can exist. One of these defects is the nitrogen-vacancy (NV) center. It is formed by a substitutional nitrogen atom associated with a neighboring vacancy in the diamond crystal structure.

The NV center can be excited by light in the green spectrum. The excited state decays back to the ground state either directly or via an intermediate shelving state with different fluorescence intensity.

The decay path depends on the electron spin of the NV center. This allows optical readout and initialization at room temperature. Further the electron spin can be manipulated by microwave radiation. Applying magnetic and electric fields the energy levels of the spins can be shifted. Hence, a vast amount of experiments and measurement applications are possible.

3.2. NV Center Applications

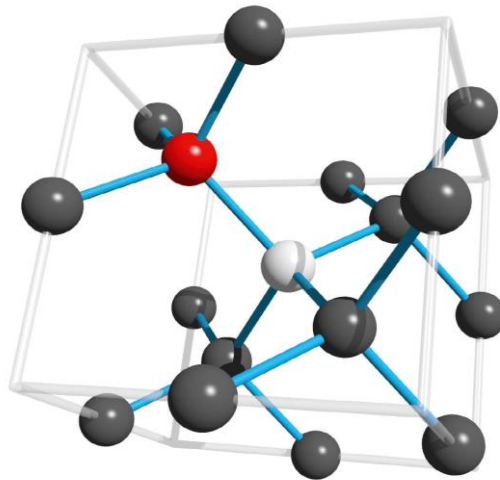


Figure 1: NV centers consist of a nitrogen atom (red) next to a vacancy

Therefore, the dynamics of the NV center allow applications like spin initialization and state readout. Therefore, the center is suitable for quantum sensing applications like magnetic field sensing, measuring spin relaxation time and optically detected magnetic resonance - ODMR. Due to their scalability, long coherence times and ability for interaction with photons, NV centers are of high interest for research in quantum information processing. Qubits can be defined as spin states of single electron or nuclear spins.

3.3. Electron Spin Manipulation

Applying microwave radiation with 2.87 GHz to the NV center drives the transition between $m_s = 0$ and ± 1 in its electronic ground state. Additional excitation with laser light in the green spectrum populates $m_s = \pm 1$ in the electronic excited state.

This state has a significant possibility of intersystem crossing from $3E$ to the shelving state $1A$ with a long lifetime. From there it decays with high probability back to the $m_s = 0$ ground state. Due to the longer lifetime, the fluorescence gets quenched by applying microwave radiation at the frequency D , resonant to the transition between the spin levels. Hence, the fluorescence of a NV center is brighter when it is in the $m_s = 0$ state.

Applying a magnetic field B , the $m_s = \pm 1$ levels of the ground state split up linearly according to the Zeeman effect. Thus, the microwave resonance frequency also shifts. This allows measurements of magnetic fields with high sensitivity and high spatial resolution.

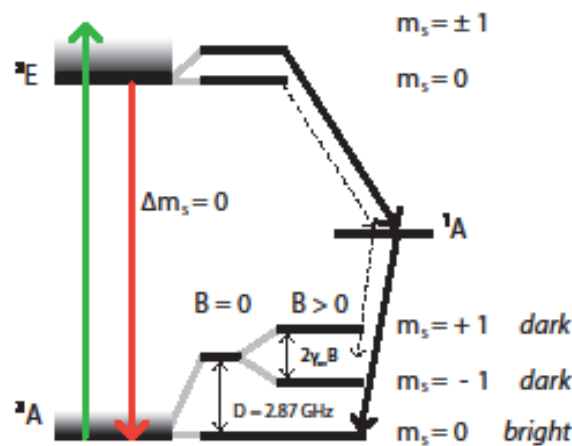


Figure 2: Energy-level scheme of the NV center. A green laser excites the NV center to the $3E$ state, from where it either decays to $3A$ or undergoes intersystem crossing to the metastable state $1A$, before decaying to the $m_s = 0$ ground state.

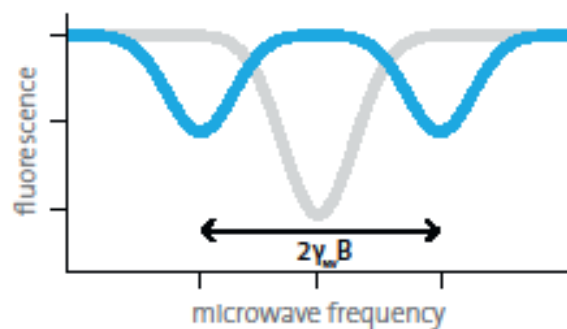


Figure 3: The grey curve shows the decrease of fluorescence at the resonance frequency. The $m_s = \pm 1$ ground level of the NV center splits up linearly by applying a magnetic field (blue) and indicate the shift in the resonance frequencies.

4. Unpacking and Installation

4.1. Package contents

When you have received the product, please make sure that the following parts are included:

- Aluminum bread board with laser module, sample holder and photodiode mounted and wired.
- Acrylic glass enclosure
- Control unit
- Power cord
- Set of magnets

4.2. Installation



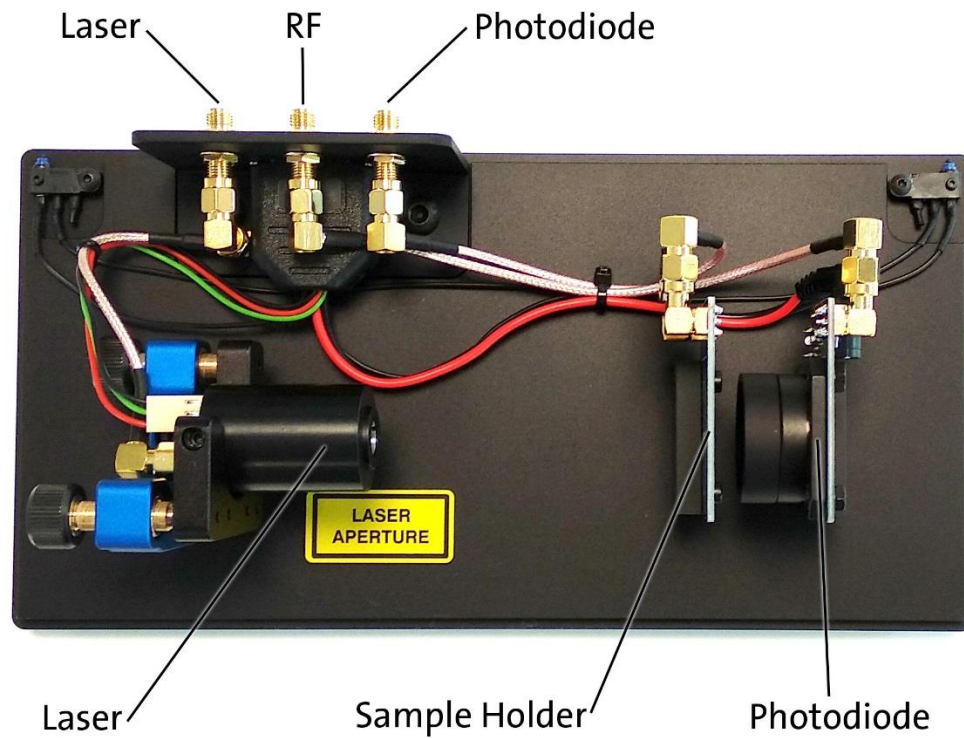
Before installing the system, make sure that you are familiar with and have obeyed all necessary laser safety precautions. Please refer to paragraph 0 for this purpose. Handle the source and all its components very gently. Especially, do not tilt the breadboard too far and be very careful with electrostatic discharges in the immediate vicinity of the laser diode. For additional warnings please see the relevant section (0) of the manual.

Please follow these steps:

- Place the control unit next to the breadboard.
- Connect the breadboard to the control unit.
 - The Sub-D connector shall be connected to the “GPIO” port of the control unit.
 - The laser module shall be connected to the “Laser Enable” connector of the control unit.
 - The sample holder shall be connected to the “RF Output 2” connector of the control unit.
 - The photodiode shall be connected to the “Photodiode” connector of the control unit.
- Ensure, that a terminator is connected to the “RF Output 1” connector of the control unit and to the second connector of the sample holder.
- Place the acrylic glass enclosure over the bread board. Please ensure to carefully slide it into the corresponding slot in the bread board from the back side, such that the interlock switched are engaged.
- Connect the control unit to a power socket.

5. Operation

5.1. Description

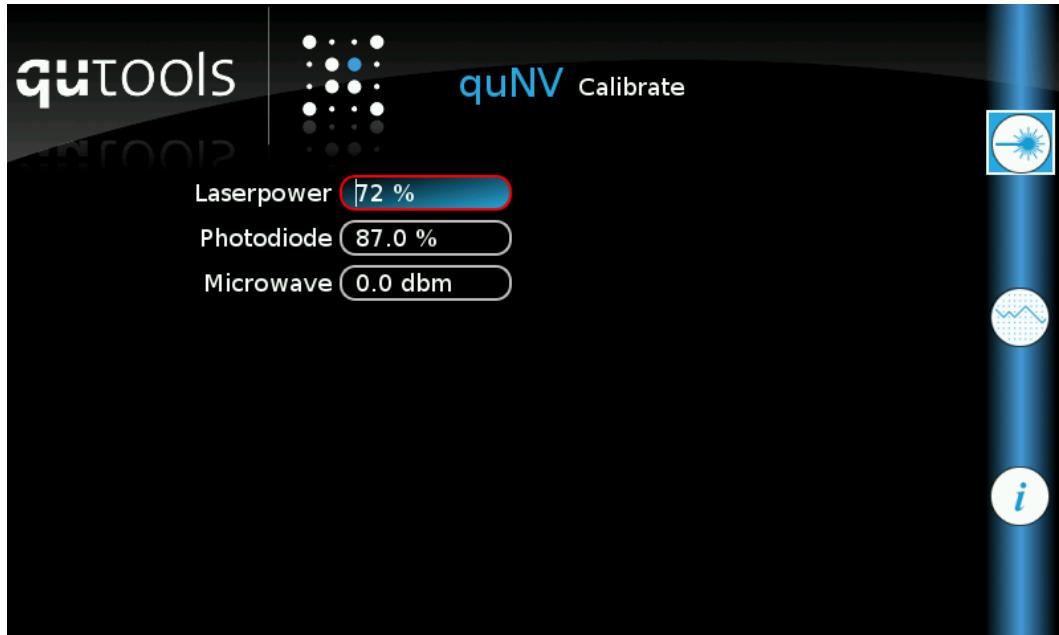


Above figure shows an overview of the bread board of the quNV setup. Mounted on the bread board there is 520nm laser module with 50mW on a kinematic mount, the sample holder with the microwave antenna and the diamond sample, the photodiode with the optical band pass filter.



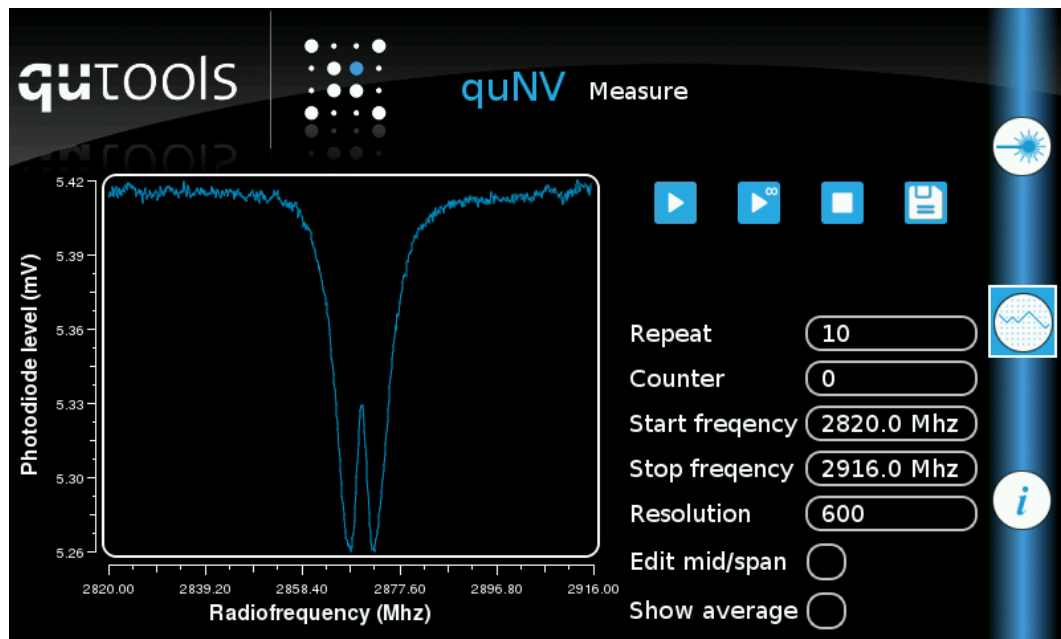
5.2. Experiments

5.2.1. NV center fluorescence



Before running any of the following experiments, always the laser power needs to be adjusted. This is done in the Calibrate tab (see figure above). Please turn on the laser by pressing the corresponding button the front panel and select the laser power line edit via the touch screen. The power can now be adjusted using the rotational encoder. The laser power should be increased until you can see the red fluorescence of the NV centers by eye, but it should be kept low enough to prevent saturation of the photodiode. A photodiode value between 80% and 90% should be a good starting point for the other experiments.

5.2.2. Optically Detected Magnetic Resonance (ODMR)



In order to perform an ODMR experiment, the laser power should be adjusted as described in section 5.2.1. Also, the RF power should be set to a meaningful value. A good starting point will be 0 dBm. Once these values are set in the Calibrate tab the frequency values should be adjusted in the Measure tab. If an experiment without magnetic field is performed, the start frequency should be set to about 2820 MHz and the stop frequency to about 2920 MHz.

Pressing the play button will start a measurement with the number of repetitions set in the Repeat line edit. The Counter will indicate the current measurement. Pressing the play button with the infinity symbol, will enable a continuous data acquisition. New data will be recorded until the stop button is pressed.

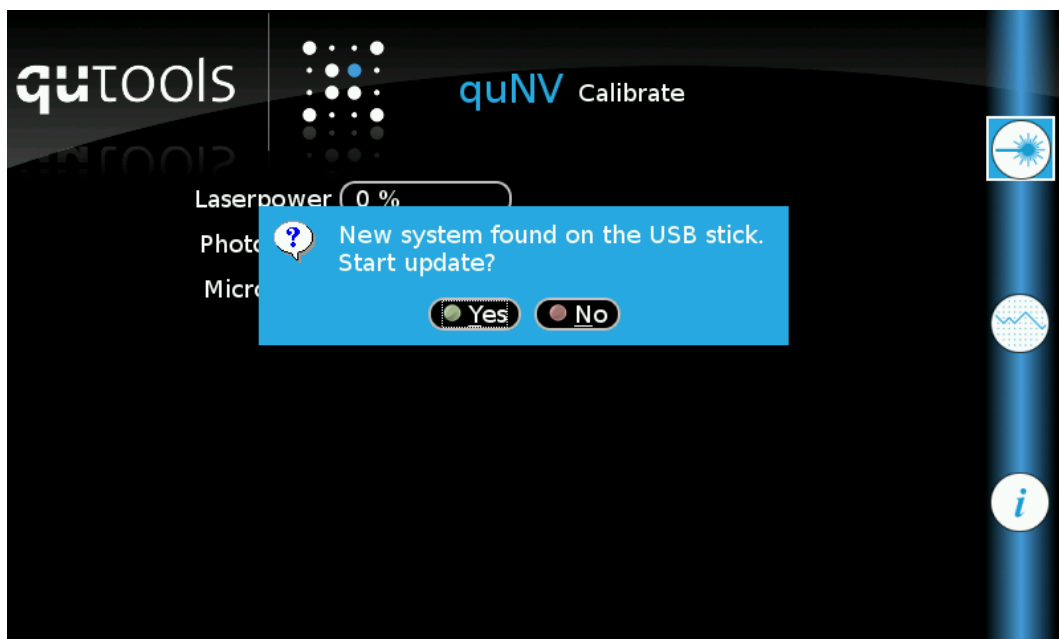
Clicking the Show average checkbox, will allow to display the average of previously recorded data. Averaging several measurements will significantly reduce the noise level. Pressing the stop button will clear the history and start a new average.

The button with the floppy disk symbol will allow to store the recorded data onto a USB drive.

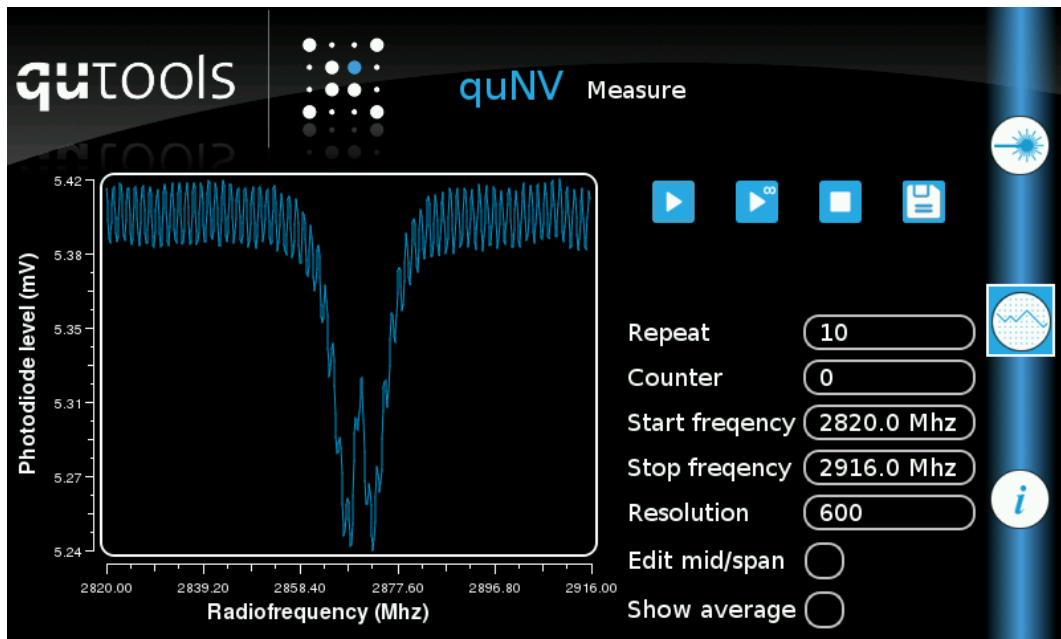
5.3. Update

Update: In case you want to update or restore the software of the control unit, please follow these steps:

- Copy the new version of the software to the root directory of an empty flash drive and ensure, that it is named “quNV”. If the update comes as a zip archive, please extract the content to the root directory of the drive and make sure the directory structure is maintained.
- Turn off the controller and plug in the prepared flash drive.
- Turn on the controller. The system should now start with the update. Please follow the steps shown on the screen to complete the update process (see figure below).
- After this process, the new version is installed permanently. Please remove the update files from the flash drive in order to avoid starting the update process in the future when using the drive with the controller.



6. Troubleshooting



A commonly encountered issue with the quNV experiment is 50 Hz noise caused by artificial light. If you get a measurement result similar to the one shown in above figure, your room lights interfere with the experiment. The suggested solution is to move the experiment to a room, that is only illuminated by sunlight, since this will not disturb the experiment.

7. Revision History

V1.0 (2019-07-09): initial release