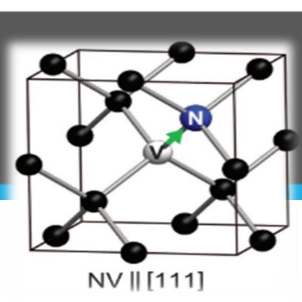
האוניברסיטה העברית בירושלים
THE HEBREW UNIVERSITY OF JERUSALEM

The Bar-Gill Lab
Quantum Information, Simulation and Sensing

Towards Femtotesla Broadband AC Diamond Magnetometry

Yachel Ben Shalom

NV center



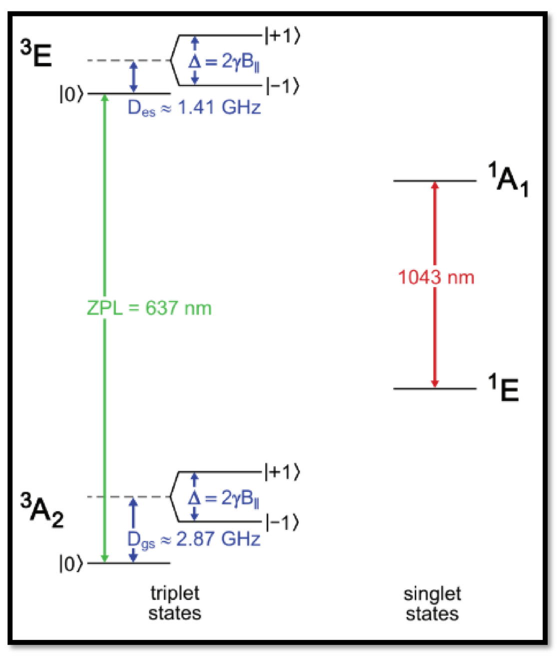
In recent years, the interest in quantum metrology has been growing both in Academia and in Industry. A significant aspect of quantum metrology relates to magnetic sensing and specifically sensing AC magnetic fields, with several quantum systems being employed to enhance the sensitivity in this context.

The Nitrogen-Vacancy (NV) center is a nanoscale defect in a diamond's crystal structure, and it can be initialized via optical pumping, read out via fluorescence intensity, and coherently manipulated by microwave (MW) fields.

NV magnetometry

One of the main usages of NV centers is sensing magnetic fields. There are three types of sensing protocols for different fields:

- DC vectorial field measured from the Zeeman splitting in the ODMR spectrum.
- Low-frequency field by NMR protocols.
- High-frequency field using the Rabi oscillations.

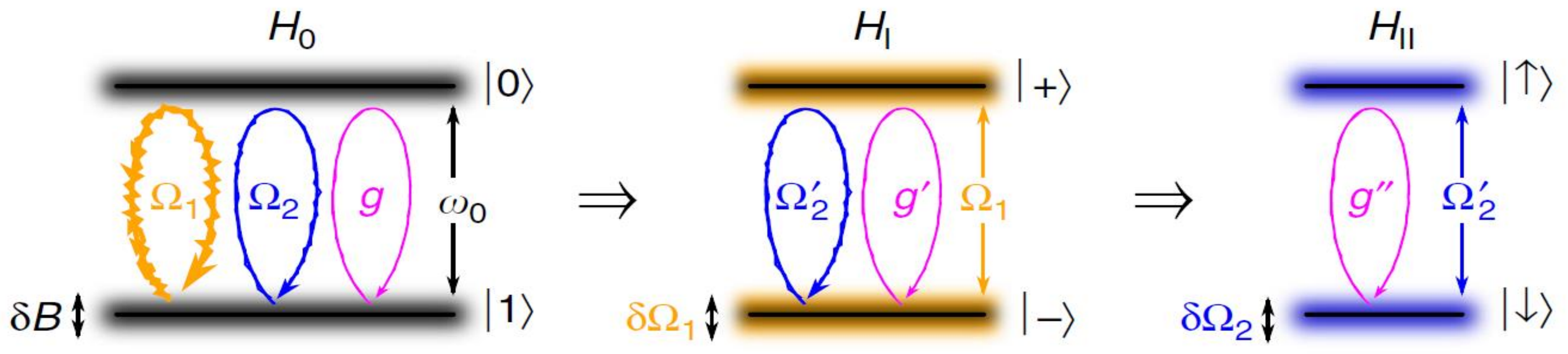


The advantage of DC sensing is mainly for achieving high spatial resolution, and low-frequency sensing have better sensitivity than classical sensors.

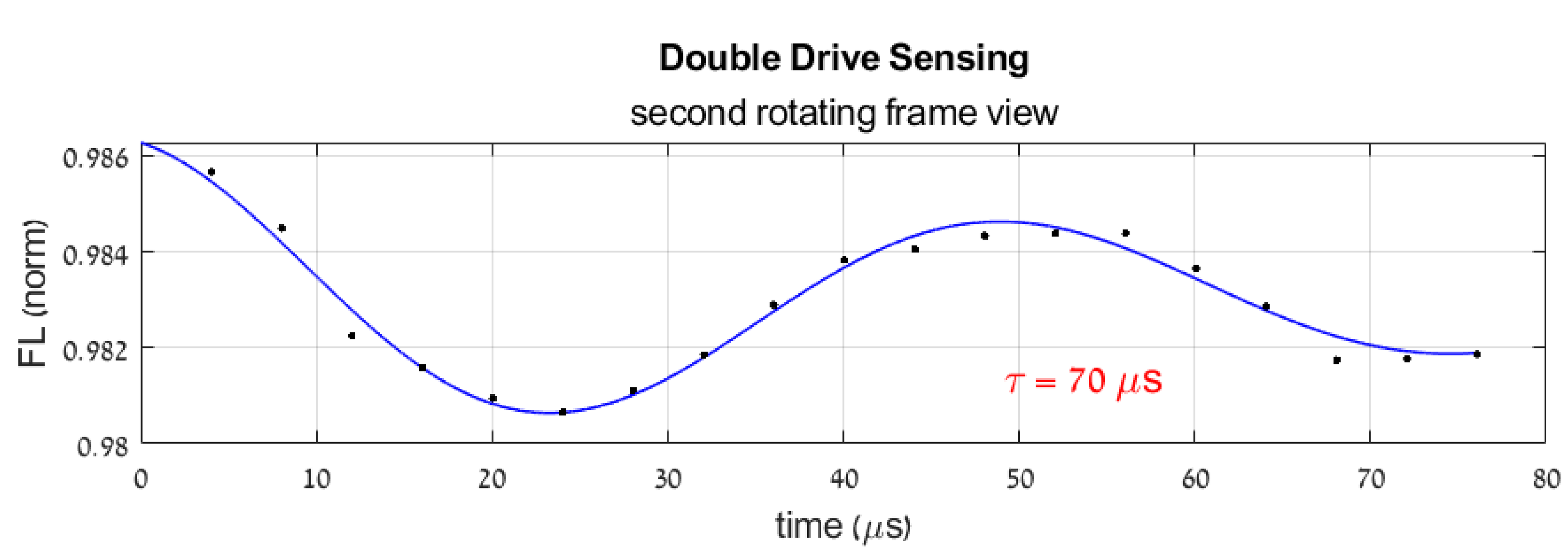
RF Magnetometry using NVC

The RF magnetometry method was developed in the last few years. In this method, the measurement happens in the presence of continuous dynamical decoupling (CDD) - a constant drive that reduces noise. A second drive can be added to further improve the coherence time.

Under these drives, the measurement is done in the rotating frame (dressed state) and the behavior is similar to the Rabi experiment.



STARK, Alexander, et al. *Nature communications*, 2017, 8.1: 1-6.



Large volume

While the NV center possesses very high sensitivity per unit volume, realizing an ensemble sensor that can overcome state-of-the-art classical sensors is still difficult. The main challenge is to achieve efficient control in a large volume of all relevant control fields:

- Optical excitation
- Fluorescence collection
- Microwave control
- Bias magnetic field

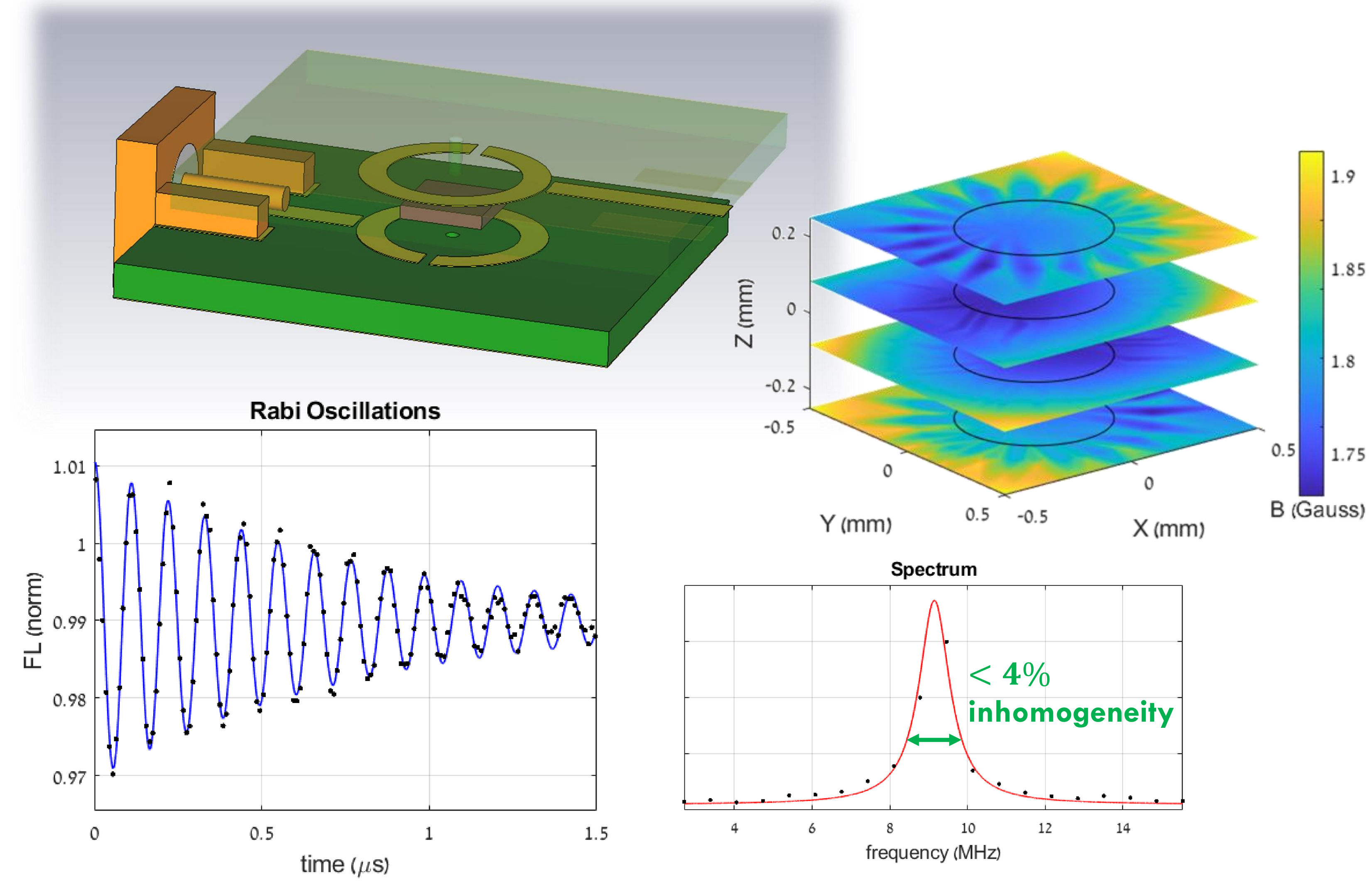
Currently, the best sensitivity achieved with large volume is about $1\ pT/\sqrt{Hz}$, but theoretically it can reach approx. $fT/\sqrt{Hz}$.

Modified Split Ring Resonator

The main challenge in large volume control, mainly for high-frequency sensing protocols, is achieving a strong and uniform MW field.

We imported a structure called Modified Split Ring Resonator (MSRR) from the field of left-handed meta-materials, and used it as a resonator to control the NV centers.

Based on our simulations, we can achieve 0.4% inhomogeneity, and a strong enough field, over a volume of $0.1\ mm^3$.



High efficiency collection

The second important challenge is the efficient collection of the isotropic emission from the diamond. Most of the solutions have low efficiency or require a lot of space around the diamond.

We developed a simple collector, that besides cutting the diamond into a trapezoid shape, can collect more than 50% of the fluorescence.

The collector is easy to manufacture and has a thin profile that can be placed between the resonator boards.