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Dynamic Nuclear Polarization in Diamond

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01. *Introduction and Background*

Dynamic Nuclear Polarization (DNP) is a technique used to amplify the signal in Nuclear Magnetic Resonance (NMR). Magnetic resonance is a phenomenon that occurs when spins in a magnetic field are excited by a resonant electromagnetic field. In our experiment, we apply a radio-frequency (RF pulse) to the nucleus of a sample at the same frequency that the nuclear spin is precessing. We use diamond in our experiment because diamond is one of the only materials that can be examined at room temperature.

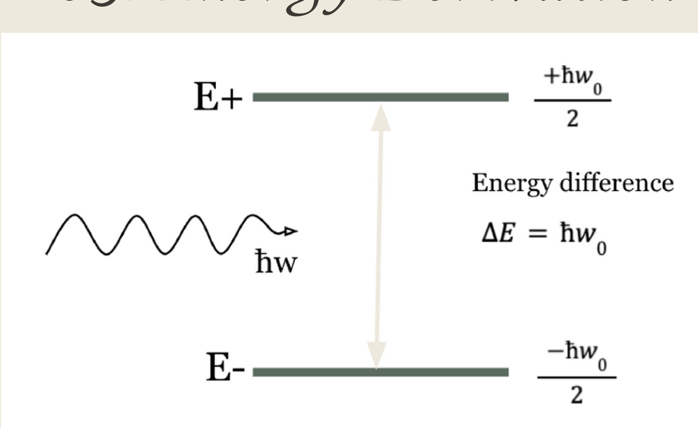
02. *The Physics behind NMR*

The magnetic moment of a particle depends on its spin angular momentum.

$\mu = \gamma \bar{S}$
μ = magnetic moment
γ = gyromagnetic ratio
$\bar{S}$ = Angular momentum spin

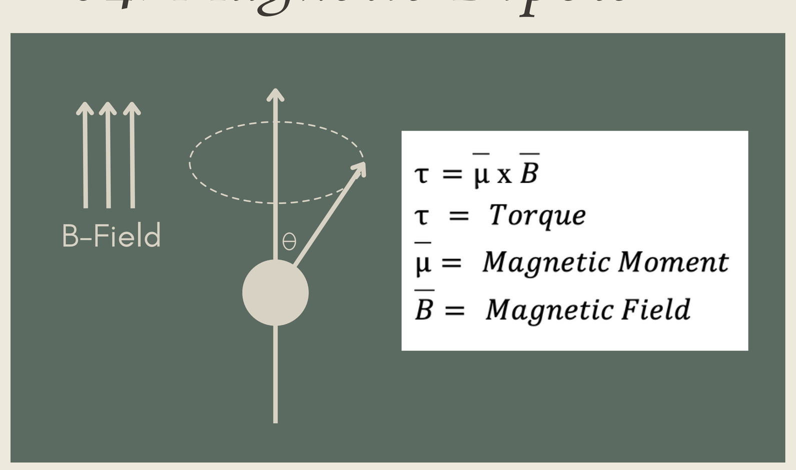
1. Quantum Perspective
From an energy perspective, we must externally excite the energy of a photon to the next energy state by an absolute quantized difference. We insert this specific amount of energy in the form of a microwave (RF wave).
2. Classical Perspective
We evaluate resonance from a classical perspective by looking at precession. From this perspective, we can look at the magnetic moment of the particle which will make it twist and rotate until it loses energy and reaches equilibrium.

03. *Energy Derivation*



On a quantum level, we have discrete energy levels. Thus, the energy of the radiofrequency photon should the energy difference between the spin states.

04. *Magnetic Dipole*



Classically, we have a Larmor frequency at which the spins are precessing. This is caused by a magnetic field.

THE FREQUENCY IN THE ENERGY DERIVATION IS THE SAME AS THE LARMOR FREQUENCY FROM THE PRECESSION DIAGRAM

04. *Why do we need DNP?*

The NMR signal is **proportional** to the difference between the number of spins in the up state and the down state. $S \propto |n_+ - n_-|$

The **ratio** between the number of spins in the up state (excited state) and down state (ground state) is $\frac{n_+}{n_-} = e^{-\frac{\Delta E}{k_t}}$

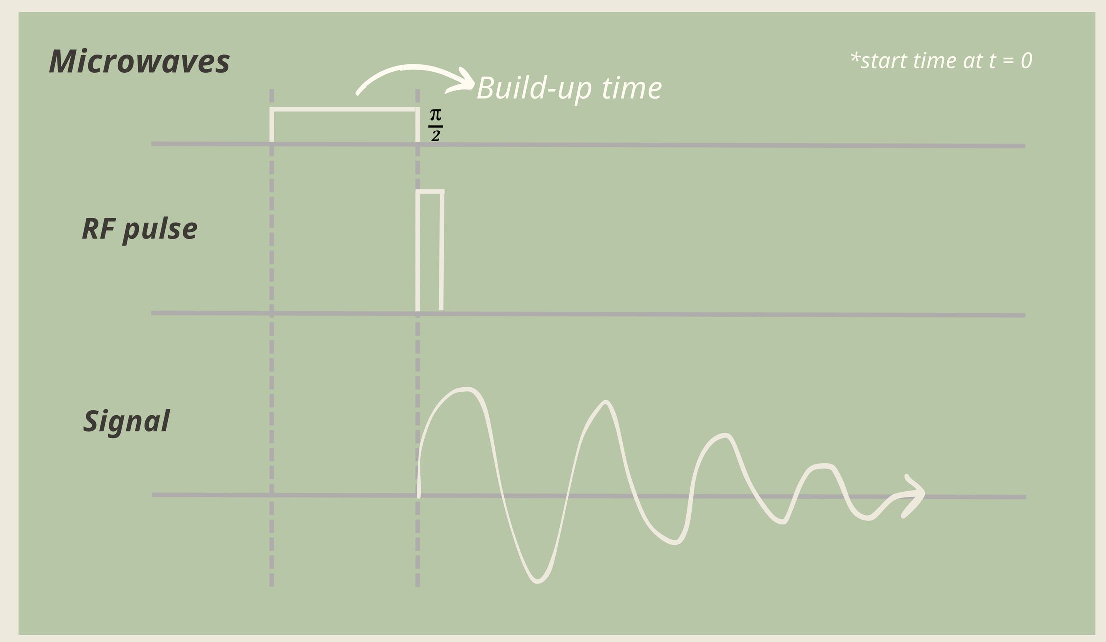
At room temperature: $\Delta E << k_B T$
so the ratio is super super small

$$\frac{n_+}{n_-} \sim 1 - \frac{\Delta E}{k_B T}$$

$$(n_+ - n_-) \propto \frac{\Delta E}{k_b T}$$

05. *What is DNP*

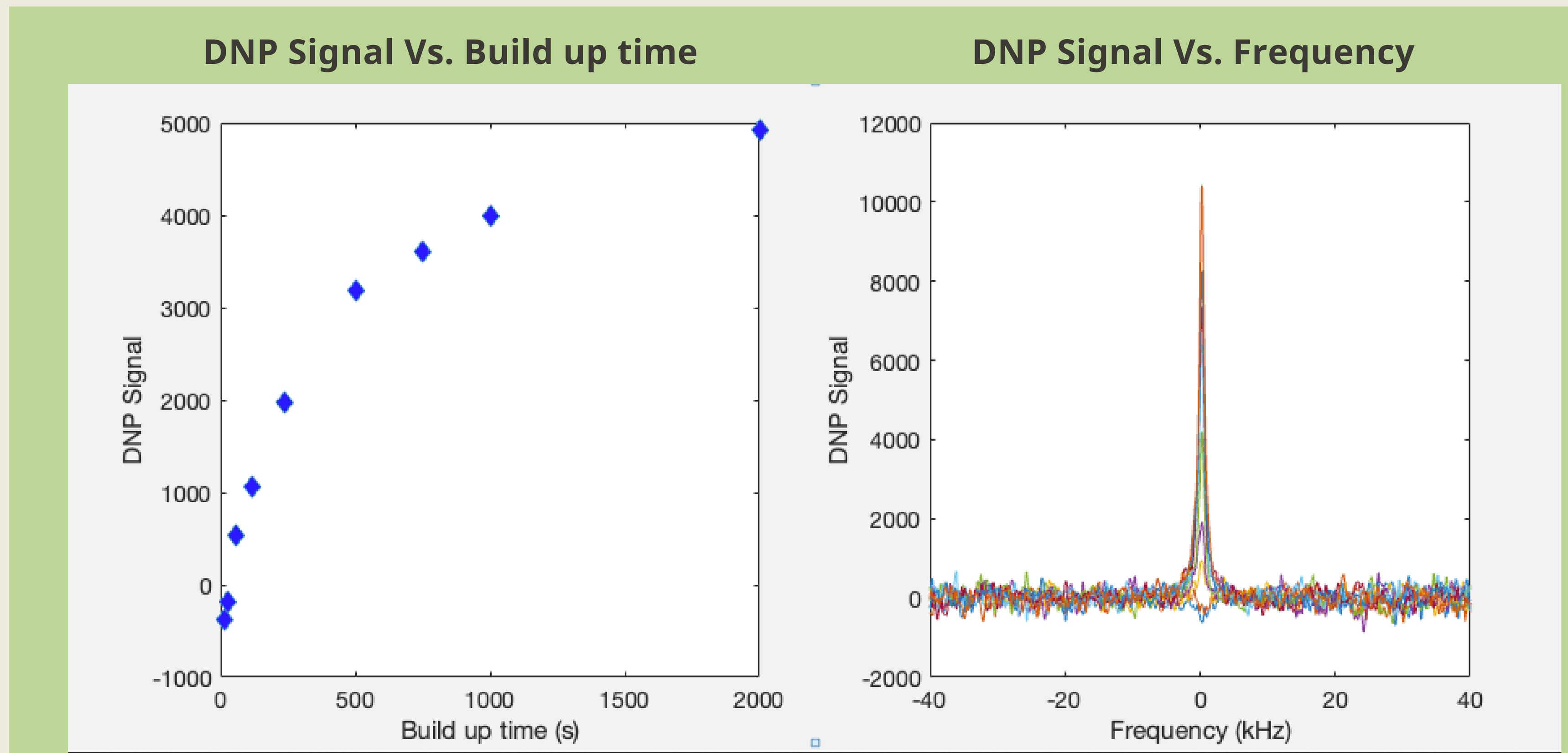
DNP allows us to boost NMR signals by exciting adjacent electron spins near their Larmor frequency



- We use a microwaves to excite the electron spins as they have a higher Lamor frequency. We then, analyze the DNP signal, shown in the last line of the diagram above, via an NMR experiment.
- In our experiment, we turn on the microwaves for a set amount of time (buildup time) during which the NMR signal grows. We then apply an RF pulse to the nuclear spins to read the signal.
- Physically, the signal in the graphs in the ***Results*** section is a voltage through the NMR coil that's detected and amplified.

06. *The DNP Experiment*

Our experiment varies the DNP signal with microwave frequency and build up time.



Build up curve and DNP signal above corresponds to frequency 93.793

07. *Analysis*

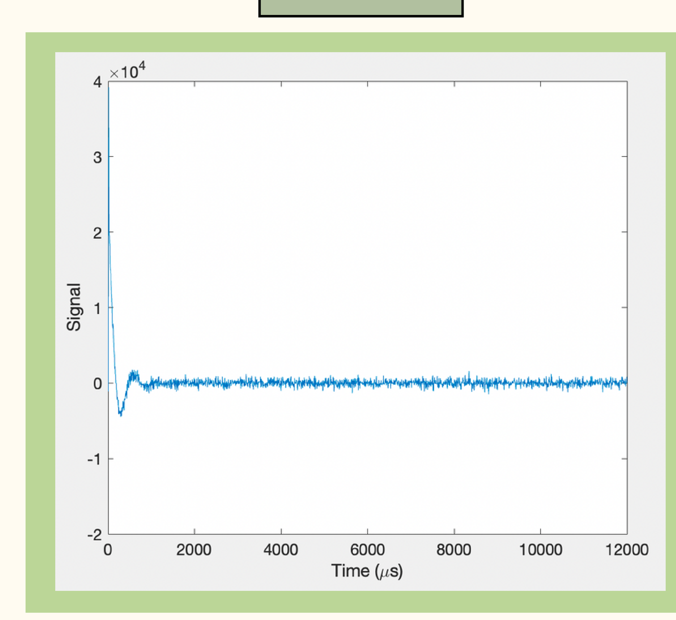
We have extracted two points: one with positive signal and and one with negative.

The top graph is the **Signal v. Time** domain graph. The bottom graph is the first graph fourier transformed onto the frequency axis: **Signal v. Frequency**

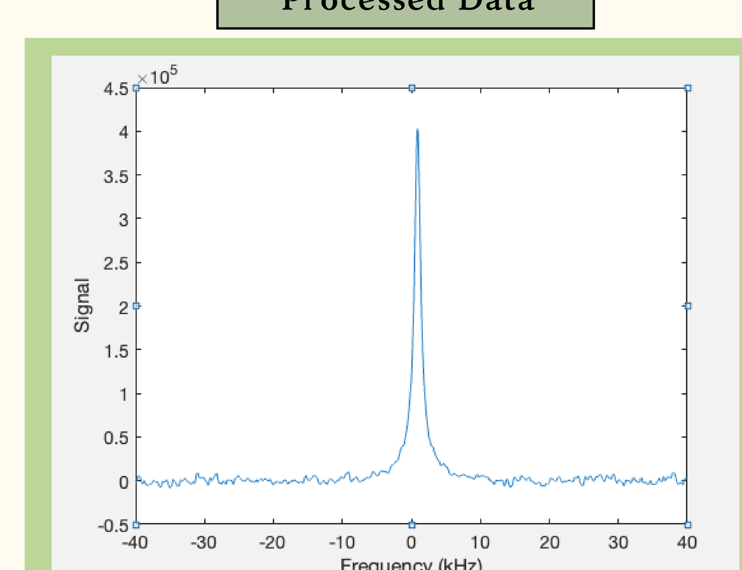
DATA COLLECTION

We process data by first collecting the raw data from the spectrometer. We then reorganize and modify the data before performing a Fourier transform from signal to frequency. Finally, we phase the Fourier transform.

Raw Data

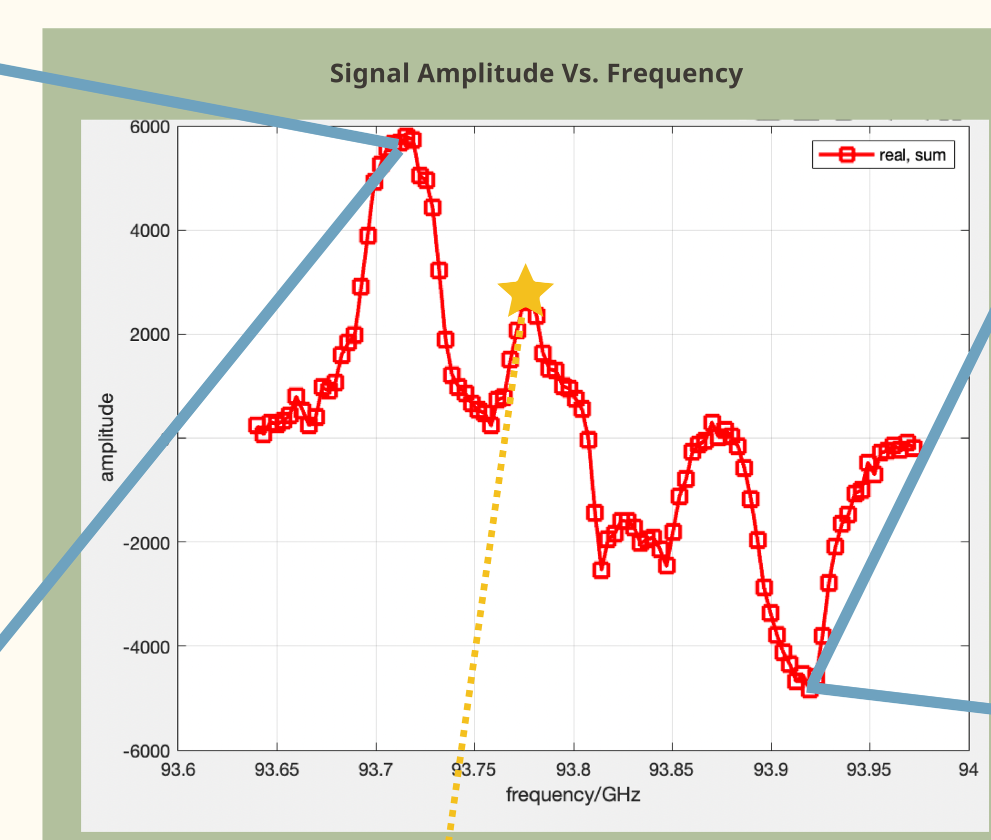


Processed Data



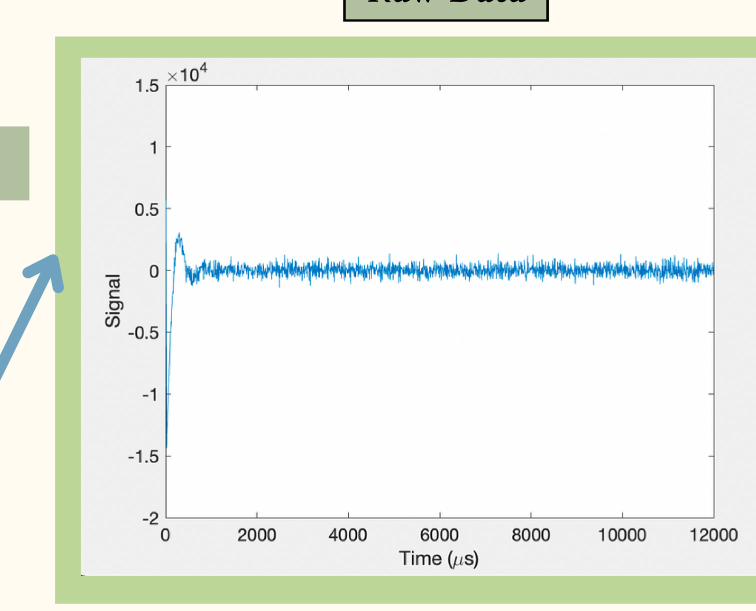
At point 22, frequency = 93.709 GHz

At point 82, frequency = 93.906 GHz

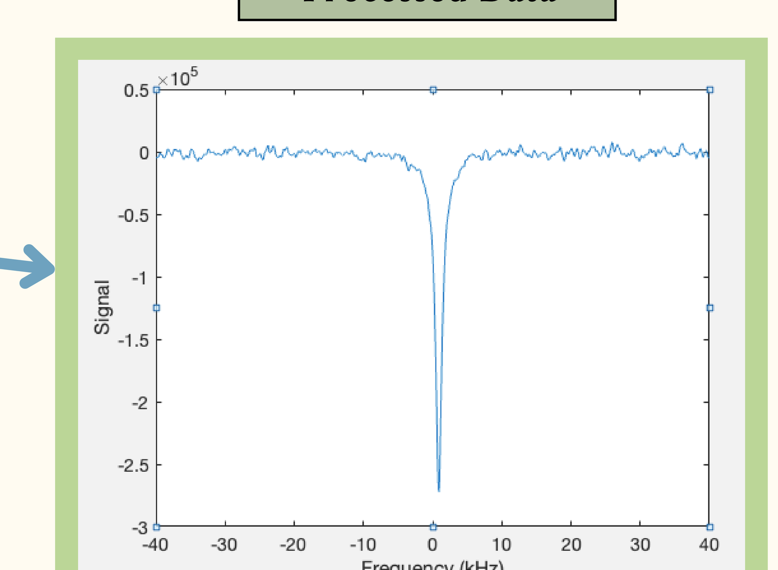


At frequency 93.763, which correspond to build up graphs

Raw Data



Processed Data



08. *Conclusion and Discussion*

Our experiment demonstrates the long time scale for the build-up time for the DNP signal. We also discovered that microwave frequency has a strong effect on the DNP signal

09. *References and Acknowledgements*

I want to thank Professor Ramanathan for his continuous support and guidance in my research and project. I'd also like to acknowledge Smitakshi Goswami for her help. Finally, I am thankful to the WISP program for providing this research opportunity.