Nuclear Magnetic Resonance with a Low-Cost Vector Network Analyzer

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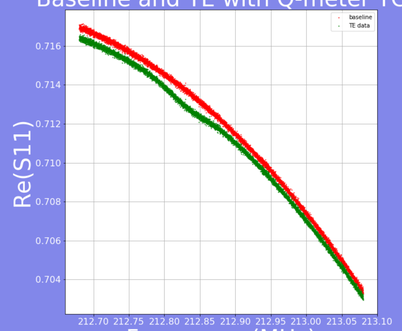
Introduction

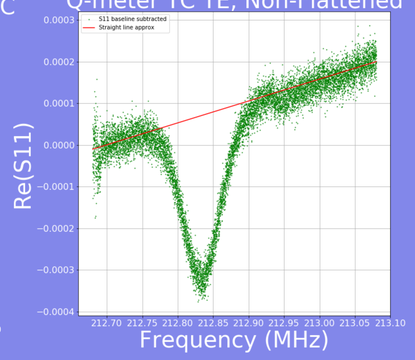
Nuclear Magnetic Resonance (NMR) systems typically cost thousands of dollars. However, we are attempting to make an NMR system that costs a total of $810 using a low-cost Vector Network Analyzer (VNA), and part of my research involves trying to figure out if this system has enough resolution to be used for room temperature NMR experiments. The other part is to cross compare data from a 4K NMR signal from the low-cost VNA with a Q-meter in order to determine if a VNA can be used for enhanced polarization measurements.

Methods

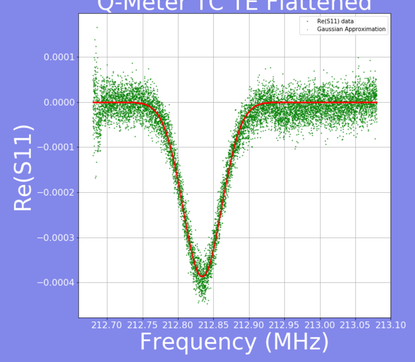
Baseline and TE with Q-meter TC



Q-meter TC TE, Non-Flattened



Q-Meter TC TE Flattened



$$\frac{\gamma_p}{2\pi} = 42.577\ \frac{MHz}{T}$$

$$f = \left(\frac{\gamma_p}{2\pi}\right) B$$

$$P\left(\frac{1}{2}\right) = \tanh\left(\frac{\gamma\hbar B}{2k_B T}\right)$$

$$P = A * C$$

References

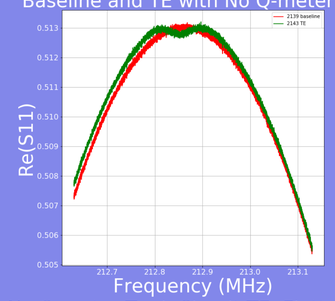
D. G. Crabb, W. Meyer. *SOLID POLARIZED TARGETS FOR NUCLEAR AND PARTICLE PHYSICS EXPERIMENTS,* 1997, Annual Review of Nuclear and Particle Science, 67-109, 47.

Room Temperature NMR

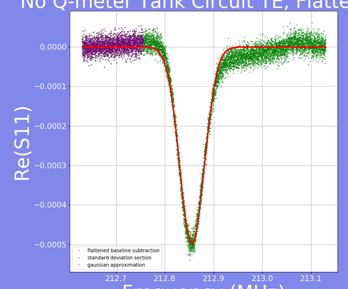
Can we see a simulated room temperature signal based on a real 4.2K TE signal?

- S11 data and baseline from Thermal Equilibrium NMR
- Subtract Baseline and offset to 0
- Flattened Signal
- Integrate to find A
- Polarization @ 4.29K in $B = \frac{f}{\left(\frac{\gamma_p}{2\pi}\right)} \approx 5T$
- $C = \frac{Polarization}{Area}$
- Polarization @ 290K in B
- $RT\ Area = \frac{RT\ Polarization}{C}$
- Make a gaussian with RT Area and add into fitted curves
- $\boldsymbol{Resolution = \frac{RT\ Amplitude}{10}}$
- $\boldsymbol{\frac{\sigma}{\sqrt{N}} < Resolution}$
- $\boldsymbol{N > \left(\frac{\sigma}{Resolution}\right)^2}$

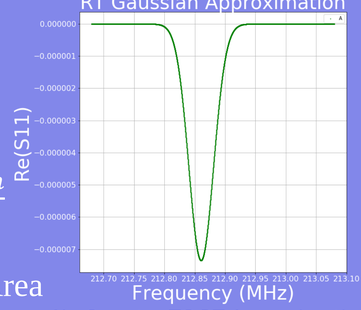
Baseline and TE with No Q-meter TC



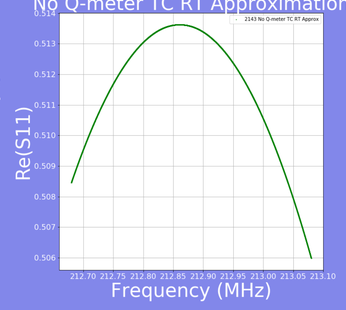
No Q-meter Tank Circuit TE, Flattened



RT Gaussian Approximation



No Q-meter TC RT Approximation



Conclusion

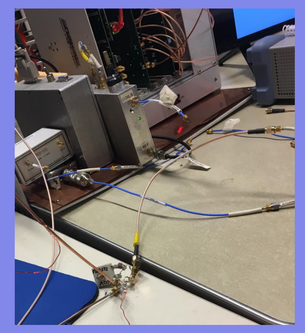
Finding the standard deviation of the scattered datapoints results and finding N results in the VNA needing at least 13,193 sweeps for us to see the signal (1 sweep ≈ 1 second, so this would take around 3.7 hours). This is feasible, but efforts would be made to reduce this time.

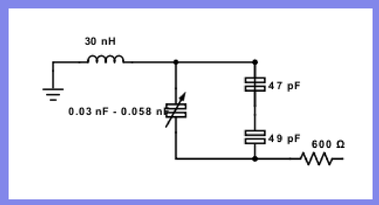
Q-meter Comparison

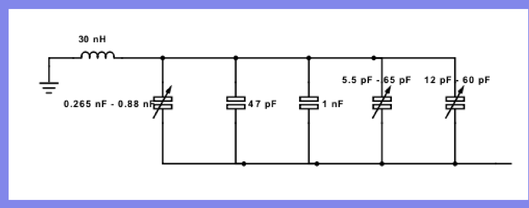
Can we compare VNA data to Q-meter data**?**

- The Q-meter is the ‘gold standard’ of tools for enhanced polarization measurements by the polarized target physics community.
- Cannot simply measure “the real part of the impedance”
- Q-meters are no longer in production so finding a replacement for it is key

- Q-meter Tank Circuit

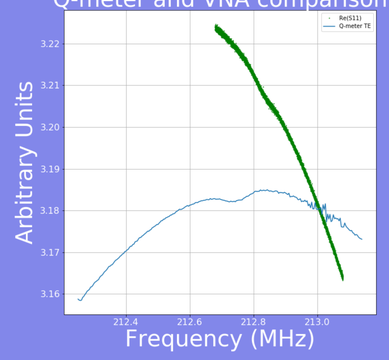






$$Z_{Re} = Z_0 \frac{\sqrt{\left(1 + Re(S11)\right)^2 + Im(S11)^2}}{\sqrt{\left(1 - Re(S11)\right)^2 + \left(-Im(S11)\right)^2}} \cos\left[\arctan\left(\frac{Im(S11)}{1 + Re(S11)}\right) - \arctan\left(\frac{-Im(S11)}{1 - Re(S11)}\right)\right]$$

Q-meter and VNA comparison



Conclusion

Due to a complication in our data extraction, I was unable to correctly compare the Q-meter TE to the VNA TE in time, so it is unclear as of right now if the VNA can be used in place of the Q-meter for enhanced polarization measurements

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