# Development of Nuclear Magnetic Resonance (NMR) Mobile Universal Surface Explorer (MOUSE)

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## Abstract

The purpose of the project is to develop a mobile NMR unit that can be used to determine pore size distribution of geological samples. Standard NMR machines are fairly large, expensive, and have a restricted sample size. A NMR MOUSE can be transported to take quicker preliminary readings on large samples, with decreased cost. This work is focused on the design aspect of creating an NMR MOUSE, future work will go into the build process.

## How NMR Works

NMR takes advantage of the magnetic moment (also known as angular momentum or nuclear spin) of certain atoms and their resulting resonance frequency. These readings are obtained in the presence of an external magnetic field, $B_0$. When in an external field, a proton's magnetic moment will align itself in the direction of that field. At this point they are known to be at thermal equilibrium. However, if a perpendicular, $90^o$, magnetic pulse is applied, $B_1$, it produces a magnetic torque on the proton. This proton will begin to oscillate around $B_0$. An example of this can be seen in Figure 1

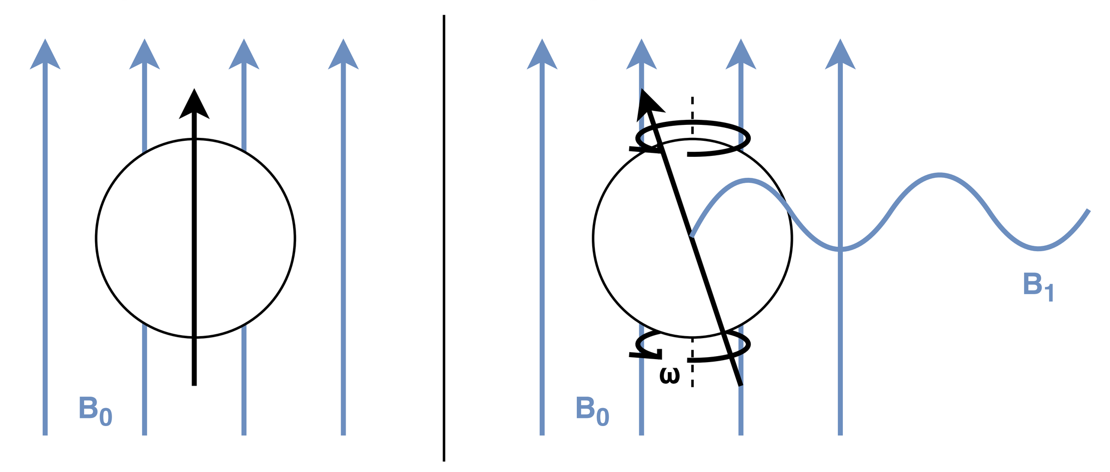


**Figure 1:** Simulation of Hydrogen atom. $B_0$ is ever present constant magnetic field and $B_1$ is magnetic pulse whose waveform is always perpendicular to $B_0$ and in phase with $\omega$

This is analogous to a spinning top on a table. The top will oscillate around a center axis if its not perfectly in line with the present gravitational field as seen in Figure 2.

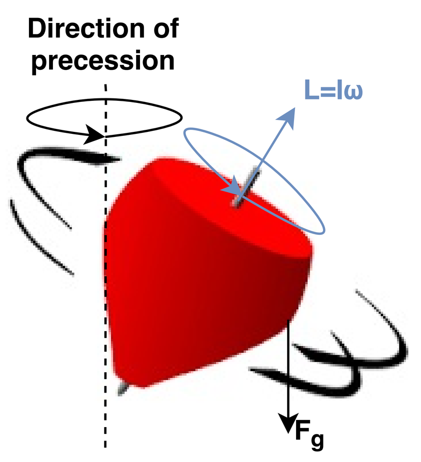


**Figure 2:** Simulation of a spin top that is off kilter from axis

This resonance frequency at which the proton will oscillate at is called the Larmor precession rate, defined as

$$\omega = -\gamma B \tag{1}$$

Where $\omega$ is the resonance frequency, B is the applied constant magnetic field and $\gamma$ is the gyromagnetic ratio.

The resonance is detected using an RF coil due to the induction current from the fluctuating magnetic field of the proton. Because of the need of an intrinsic magnetic moment, only nuclei with an odd number of protons and/or neutrons can be studied. For the use of determining porosity $^1$H is used due to its abundance and ease of detecting a signal. As such, core samples need to be saturated with water before a NMR reading can be taken. For $^1$H, the gyromagnetic ratio $\gamma$ is $267.513 \times 10^6 s^{-1}T^{-1}$. Once the hydrogen proton in the sample and has begun its resonance, it will eventually return to its equilibrium position. Due to inhomogeneity in the applied magnetic field, surrounding protons will become out of phase with each other and result in a decay of the magnetic signal. This is called transverse (T2*) relaxation. In our application, we want to observe the decay resulting from other interactions. To do this a $180^o$ pulse can be applied that flips the protons spins causing them to come back into phase, which is referred to as an echo. This can then be repeated until the all atoms return to its equilibrium. Figure 3 demonstrates a typical signal with both relaxations shown.

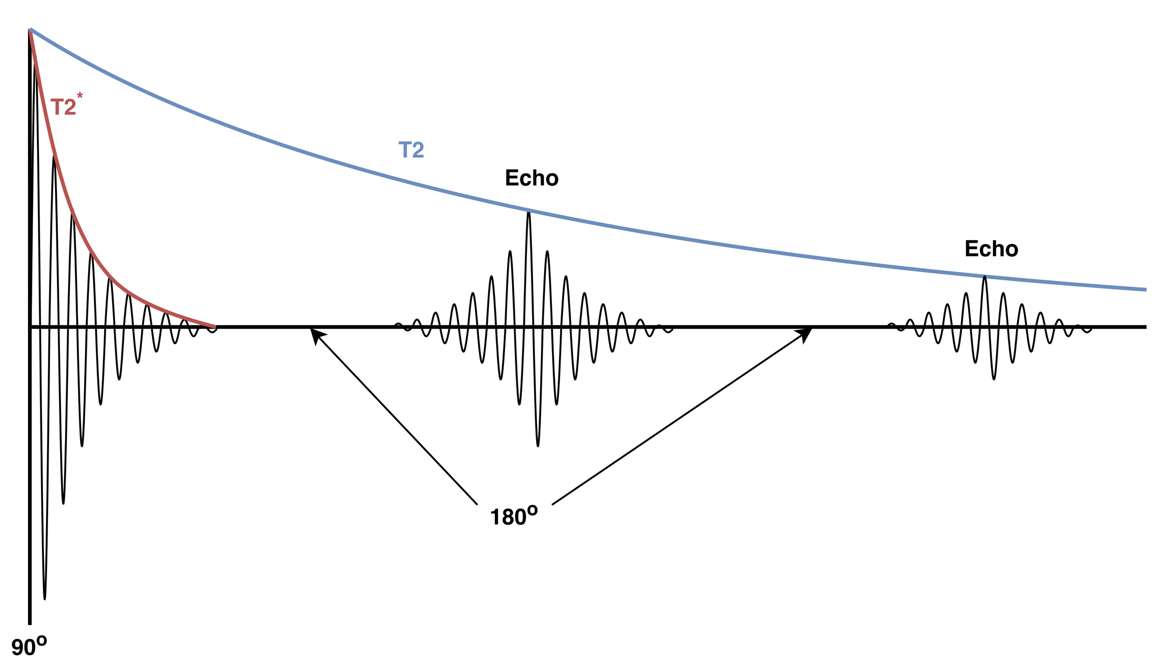


**Figure 3:** Example spectrum obtained from NMR. Initial 90° pulse followed by data collection. 180° pulse is exactly between maximum peaks.

In rock samples this T2 relaxation is dominated by surface interactions with the walls of the rock. While there are several other factors that will contribute to relaxation, this surface interaction the dominate relaxation mechanism. By measuring the time of relaxation a pore size can be correlated. For future reference T1 relaxation is the natural return to thermal equilibrium.

## Design Process

There are two major different designs for an NMR MOUSE probe. One involves placing a probe onto the surface of the sample, Figure 4 left, while the other is placed into a bore hole, Figure 4 right.

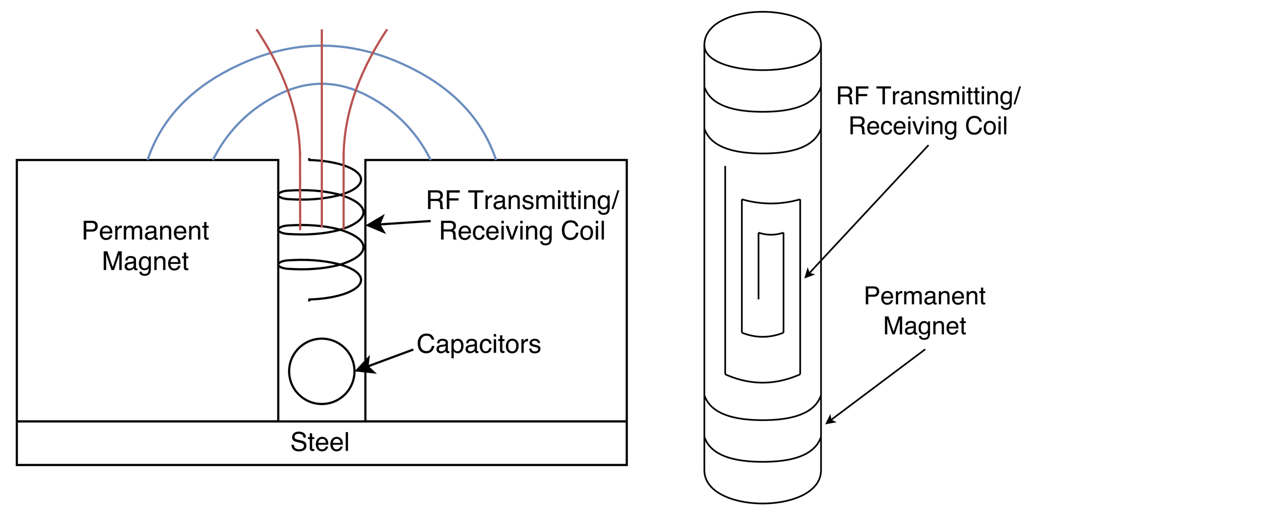


**Figure 4:** (Left) Surface design concept, blue lines represent $B_0$ and red $B_1$. (Right) Bore hole design concept

For this project, the former design was chosen due to its simplicity in design and for being able to use on a variety of samples without damaging them. Once this criteria was determined, the next design factor is the RF coil used for transmitting/receiving a signal. Again, there are two major designs.

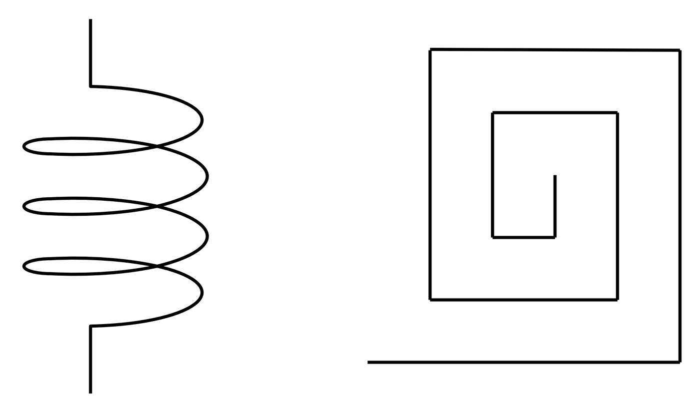

**Figure 5:** Coil designs

The right most coil in Figure 5 is a flat coil existing in a 2 dimensional plane. The benefits of this coil is that a depth profile can be taken of the sample, but has limitations. It tends to produce an inhomogeneous field which can create a noisy signal and can be a challenge to design. The left most coil is a typical coil similar to an inductor. It produces a more homogeneous field and a cleaner signal. After considerations, the left coil was chosen as an average pore size is what is being looked at and not the change in features at a variation in depth. For this coil, ringing will occur in the coil that can lead to a noisy signal, so it will need to be cemented into place with an epoxy that has few hydrogen atoms in its makeup. From this a circuit schematic for the probe was designed in Figure 6.

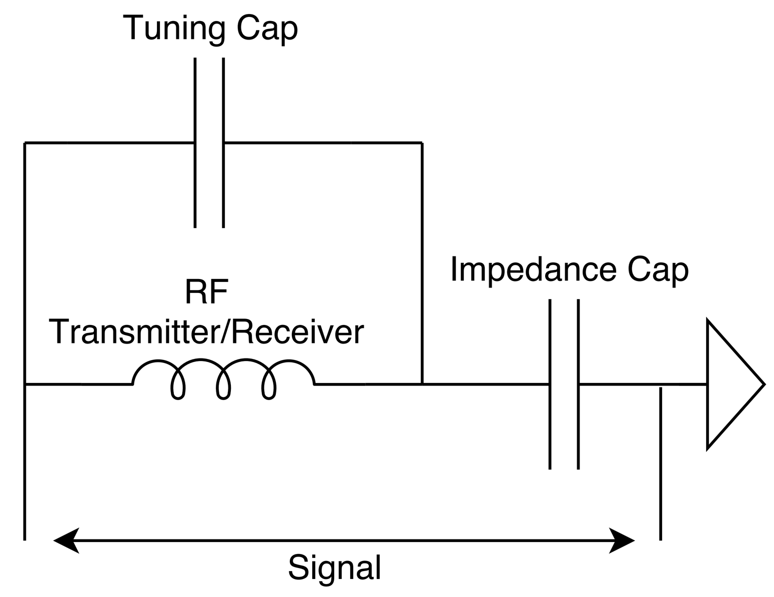


**Figure 6:** LC circuit design for probe. Both capacitors are variable.

There are two capacitors, the one in parallel with the inductor is used to tune the circuits resonance frequency which is determined by the Larmor frequency. In order to acquire a signal the value of the capacitors is dependent on the resonance frequency of the hydrogen in the sample region as the resonance frequency of the LC circuit will have to be the same. From equation 1 we know its dependent on the B in the region, this can be found by using

$$B = \frac{\mu_0 M}{4\pi} \frac{3cos^2\theta - 1}{l^2} \tag{2}$$

where M is the magnetic dipole moment of the permanent magnets used. Once $\omega$ is calculated from equation 1 & 2, the capacitance can be solved for using the resonance frequency for an LC circuit, $\omega = \frac{1}{\sqrt{LC}}$. The second capacitor is for altering the impedance of the system. Due to the capacitors being on the order of $\mu$F, the capacitors will have to be inside the probe and as close to the inductor as possible. If the leads of the wires where too long the resulting capacitance in the wires can overtake the values of the capacitors themselves.

To power this circuit a CW RF generator into a pulse amplifier will be used to generate the 90 and 180 degree pulses. An oscilloscope will also be used in parallel with these to read the resulting signal.

## Conclusion

Preliminary design factors have been achieved in this work. There are still many factors that need to be considered such as research into RF generation and amplification. Once these elements are considered the next goal is to start building an operation prototype for this work.

## Acknowledgments

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