‘Pines’: Physlab’s Earth Field Free Precessional Nuclear Magnetic Resonance System

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1 Introduction

Nuclear magnetic resonance (NMR) in the geomagnetic field is conventionally referred to as Earth’s field NMR (EFNMR). EFNMR is a special case of low field NMR. This work describes ‘Pines’ an EFNMR system develop by the authors. We intentionally keep the discussion brief. The user is guided to some excellent references on the the subject [1, 2, 3, 4, 5].

When a sample is placed in a constant magnetic field, NMR active nuclei resonate at characteristic frequencies. Examples of such NMR active nuclei are the isotopes carbon-13 and hydrogen-1. This work describes proton NMR. The resonant frequency f_o of each isotope is directly proportional to the strength of the applied magnetic field B_o through the following relationship

$$f_o = \frac{\gamma B_o}{2\pi} \tag{1}$$

where γ is gyromagnetic ratio whose value is determined at 42 MHz/T. The signal strength achieved in an inductively detected system, such as ours, depends on the polarization (differential number of spins in ‘up’ versus ‘down’ directions) as well as the Larmor frequency

$$\text{Signal strength} \propto \text{polarization} \times f_o \tag{2}$$

The polarization itself depends on the polarizing field B_p, while from Eq.(1) $f_o \propto B_o$. This means that the

$$\text{Signal strength} \propto B_p \times B_o \tag{3}$$

For conventional high field NMR, the polarizing and the static field are the same ($B_p = B_o$) resulting in the signal strength $\propto B_o^2$. However in EFNMR, B_o is equal to earth’s field which is only about 0.5 G $= 0.5 \times 10^{-4}$ T and if we were to use it for both polarization and detection, the signal would be elusively small. Hence in our scheme, we use a polarization coil to produce a polarizing field B_p, which magnetizes (or polarizes) the sample, and then detect in earth’s field. So we gain signal due

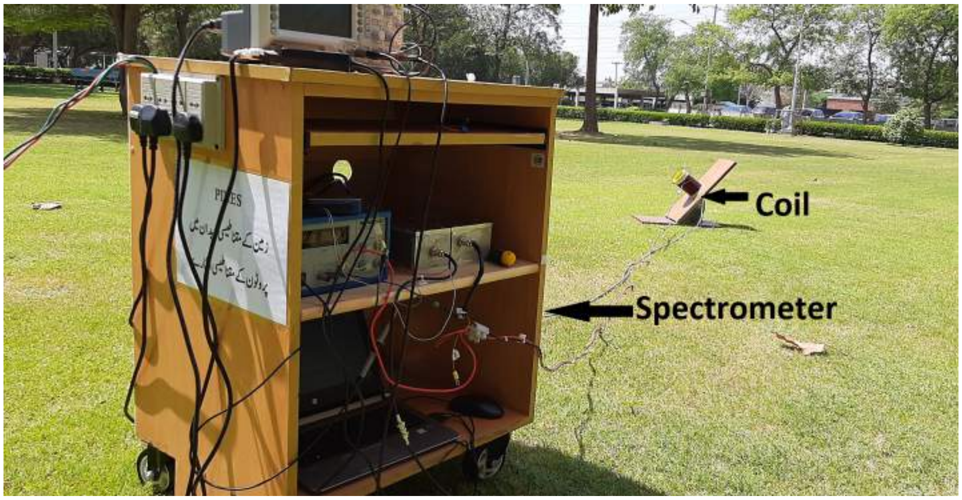

Figure 1: Complete setup of 'Pines': free precessional NMR in earth's magnetic field.

to the pre-polarization step and detect in the extremely homogeneous earth's field, expecting narrow linewidth. In the 21 Tesla magnetic field that may be found in high resolution laboratory NMR spectrometers with a $B_o = 12$ mT, protons resonates at approximately 900 MHz. However in the earth's magnetic field, the same nuclei have a Larmor frequency in the range of around 2 KHz and generate very weak signal of few micro volts. Detecting this small signal is a challenge and our work describes how the SNR can be enhance.

The complete setup and a block diagram of EFNMR are shown in Figure 1 and Figure 2 respectively. The polarizer coil contains two receiver (Rx) coils which are connected in opposite direction. The polarizer coil's current is controlled by a highly regulated power supply though a polarizing switch. The sample is placed in one of the Rx coils and output of both the Rx coils is given to a differential amplifier through a switch which is controlled by a relay. The signal is in micro volts so we pass it through an amplifier before given to a bandpass filter with center frequency around the Larmor frequency f_0. Filtered output is given to another amplifier and this amplified signal is acquired by a DAQ card. Then signal processing is applied to this collected data to acquire desired results. Figure 3 shows the approximate evolution of the sample magnetization in our precessional experiment.

2 Polarization coil

The polarization coil also called the pre-polarization coil, creates a polarizing magnetic field B_p. The field is rapidly switched off (quenched) leaving the magnetization instantaneously perpendicular to earth's field about which it begin to precess [6, 7]. Polarization coil and the surface upon which polarization coil rests must not contain any ferromagnetic material. Naturally, the earth's field is highly homogeneous. If there will be any ferromagnetic material near the coil, it will change the uniformity of the field, resulting in varying the precession frequency of the protons and the induced signal will be weak. The signal is of premium value in this experiment, so we

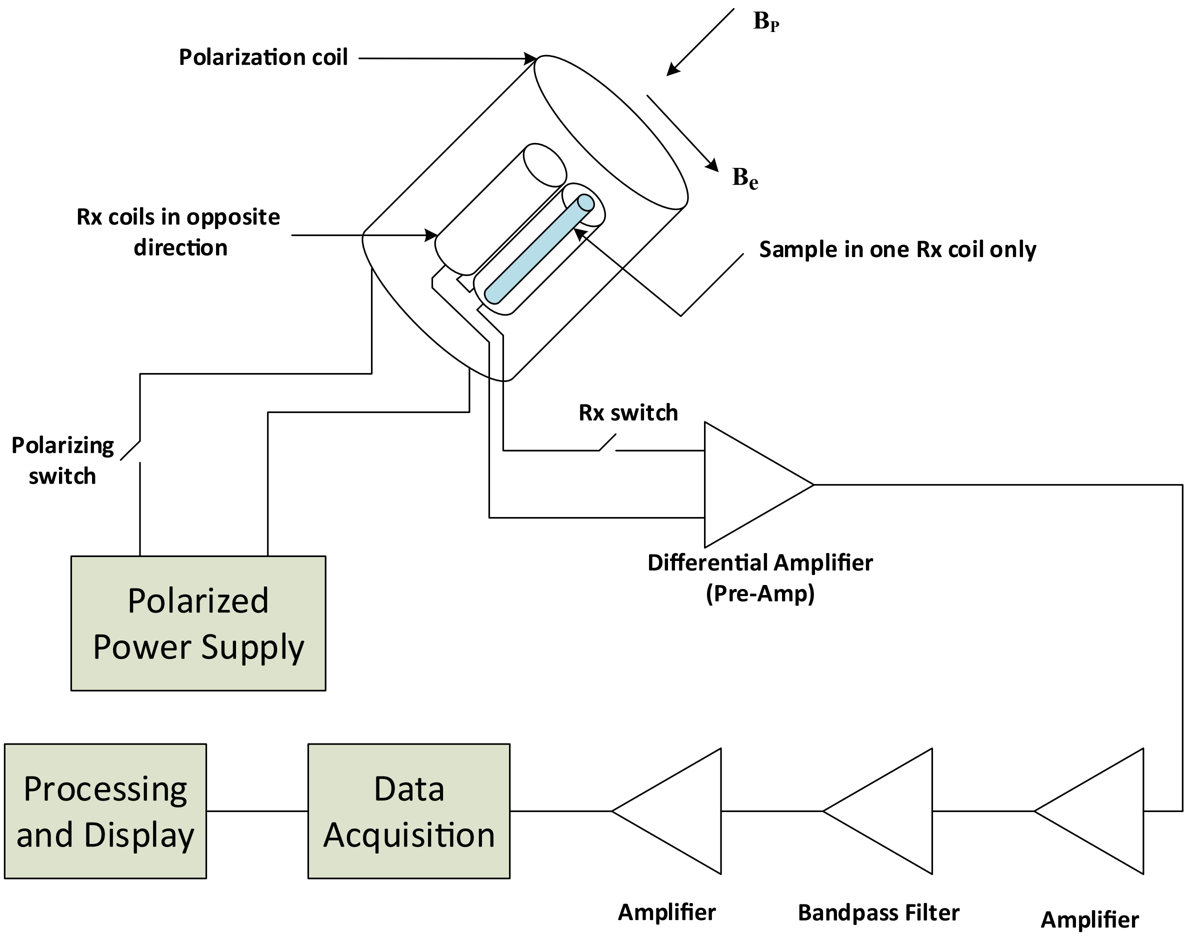

Figure 2: Block diagram of 'Pines' free precessional NMR in earth's magnetic field. The Field B_p and B_e represents the polarizing and earth's magnetic field respectively.

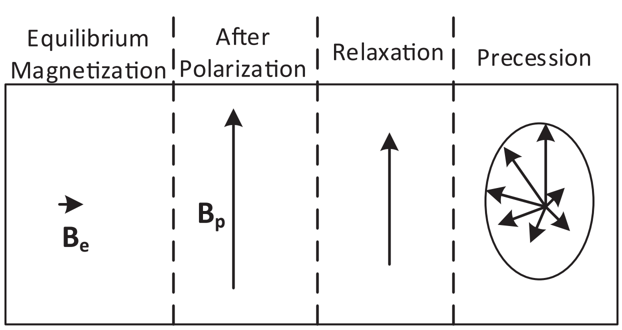

Figure 3: Evolution of the sample's magnetization.

Copper wire, wire diameter (with insulation)	1.7 mm or 14 AWG
Coil inner diameter	90 mm
Coil outer diameter	110 mm
Coil length	150 mm
Number of layers	2
Turns per layer	90
Approximate inductance	3.4 mH
Approximate resistance	841 mΩ
Approximate self capacitance	2 μF

Table 1: Specifications of the polarization coil.

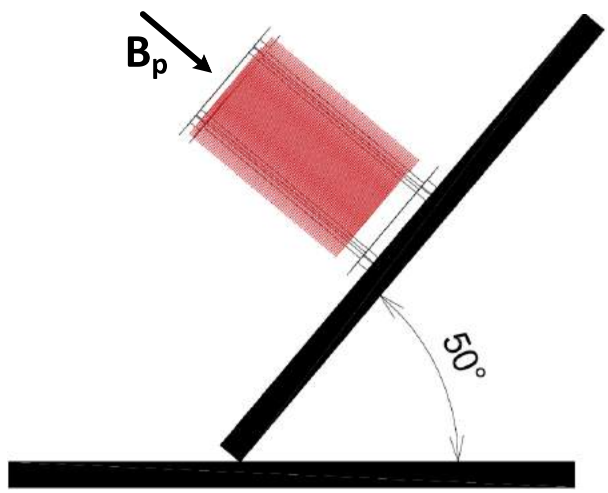

Figure 4: Polarization coil and tilted platform, the tilted platform is inclined at an angle of 50^o with respect to the surface.

can't lose it. During the normal experiment, the entire system is placed outside the building since buildings generally contain iron-rich materials.

The purpose of the polarizing coil is to produce a magnetic field much greater than of the Earth's magnetic field, so that the enhanced magnetization can precess about the field of the coil which is perpendicular to the earth's field. In order to polarize the sample, a current ≈ 10 A through the coil for $5 - 10$ sec. So the wire to wound polarized coil should be large enough to handle the current. Our chosen specifications of the polarized coil are given in Table 1.

2.1 Construction of the polarizing coil and tilted platform

The polarizing coil is made of polylactic acid (PLA) thermoplastic. It has three parts. Two end parts and a tube on which wire is wound. The tiltable platform is made of wood, avoiding the use of metal. Two wood surfaces are attached in such a way that they are inclined at an angle of 50^o. The polarized coil is placed at the center. Also there is a hole in the inclined surface to pass the wires through. Figure 4 shows the tilted surface. The tilt ensures that when B_p is quenched, the magnetization is perpendicular to the earth's field immediately prior to signal detection. This geometrical arrangement maximizes the signal strength. The earth's field at Lahore is at an inclination of 49.44° and declination of 2.55° [8].

2.2 Polarization circuit

There are two approaches of performing EFNMR. The first is suddenly quenched B_p and starting the detection immediately thereafter [**?**, 7]. The second is the adiabatic approach in which B_p is slowly switched off, bringing the magnetization slowly parallel to earth's field. In this adiabatic approach, the magnetization is not in the detectable plane, so another pulse is required to switch it back. This approach is conceptually similar to conventional high field NMR. In Pines, we follow the sudden quenching approach instead. However it's difficult to turn off the coil all of a sudden because it stores considerably amount of energy which must be safely dissipated.

Mechanical relays can be used to switch the polarized coil on and off but they are not the best option. Relays have multiple disadvantages. The relay operates like a basic switch and can produce electric arcing when turned off as the coil has large induced voltages. Relays also have short life and take some milliseconds to switch. In our case we require to switch the polarizing coil in microseconds. So the simplest solution to this problem is to use power MOSFETs whose switching time is reported to be in a mere nanoseconds.

2.2.1 MOSFET based switching

The MOSFET used to switch on and off the coil is N-Channel enhancement mode silicon gate power field effect transistor which is an advanced power MOSFET designed. It's part number is IRFZ250. It's maximum allowable drain to source voltage is 200 V and gate-to-source voltage is 20 V. The maximum current that can drain is 30 A. The breakdown voltage is 200 V as it is has a built in Zener diode of this specification connected between drain and source.

Furthermore, some of the limitations of a single MOSFET can be overcome by using several MOSFET's together. Breakdown voltages can also be increased by putting two or more MOSFET's together. If two of these MOSFET's are placed in parallel, the breakdown voltage will be increased to 400 V. However, we can't go on parallelizing indefinitely since the on resistance of MOSFET's also decreases.By decreasing on resistance, the polarizing field does not discharge smoothly and there are ripples in the field. In order to circumvent this ringing, we add a snubber circuit.

2.2.2 Circuit description

The circuit diagram for the polarization is shown in Figure 5. Four MOSFET's are connected in parallel. It means the circuit breakdown voltage is increased to 800 V and on resistance of the MOSFET's decreases four times. A single IRFZ250 has an on resistance 0.085 Ω.

A positive power supply of 12 V is connected to one end of the coil while the other end of the coil is connected to the drains of all the MOSFET's. The sources of all the MOSFET's are common and are connected to the negative end of the supply. A snubber circuit is also connected in parallel with the coil to smooth the response of the coil when it turns off. There is no need of a large capacitor in the snubber circuit as the capacitance of the coil itself is also very large.

The gates of all the four MOSFET's are controlled by an Arduino Nano controller. As there are large induced voltages during MOSFET's switching, the gate voltages are transmitted through an optocoupler 4N35 to avoid potential damage to the controller. The polarization coil charging and discharging is controlled by pin 7 of the controller. We take the output from the emitter of the optocoupler. When the voltage at pin 7 is high, the voltage at the emitter of the optocoupler is high and the MOSFET's are turned on and the current starts flowing through the supply, coil and MOSFET's. As the voltage at pin 7 drops to low, the MOSFET's are turned off and most of the current is diverted to the Zener diodes of the MOSFETs which maintains the current at the Zener voltage V_z. Now as the Zener conducts, the coil current decreases linearly and drops in approximately 700–800 μs as can be seen in Figure 6. Finally, When the Zener current drops, the Zener stops conducting and circuit starts ringing. The supply current should be highly stable during the switching for smooth discharging of the coil. The magnetic field is measured with the help of a Hall sensor and measured to be 12 mT with a polarizing current of 10 A. Note: 12 mT $\approx$120 G.

2.2.3 The polarizing circuit box

All the MOSFETs are mounted on an aluminium bar which provides an excellent heat sink and ties all the MOSFETs together thermally as well. The enclosed circuit is shown in Figure 7. Common thermal connection is important because the speed at which MOSFETs switch is temperature dependent, They slow down as they get hotter. The whole circuit is enclosed in an aluminium box. There are two seven pin screw plugs at the sides of the box which connect the enclosed circuit with polarization coil and the power supply. One end of the polarization coil is connected to +12 V power supply while other end is connected to the common drains of the MOSFET's through pin 1, pin 6 and pin 7 of the connector 1 to divide the current. Common source of the MOSFET's is connected to the ground of the supply through pin 2 and pin 3. This pin configuration of connector 1 is shown in Figure 8 and is given in Table 2. Now we come to connector 2. Pin 4 of the connector 2 is the pulse which triggers the polarized coil while pin 7 of connector 2 is the pulse which triggers the Rx circuit and DAQ card. Pin 6 is the supply for controller. The pin connections for connector 2 are enumerated in Table 3. These connections are also described in Figure 9.

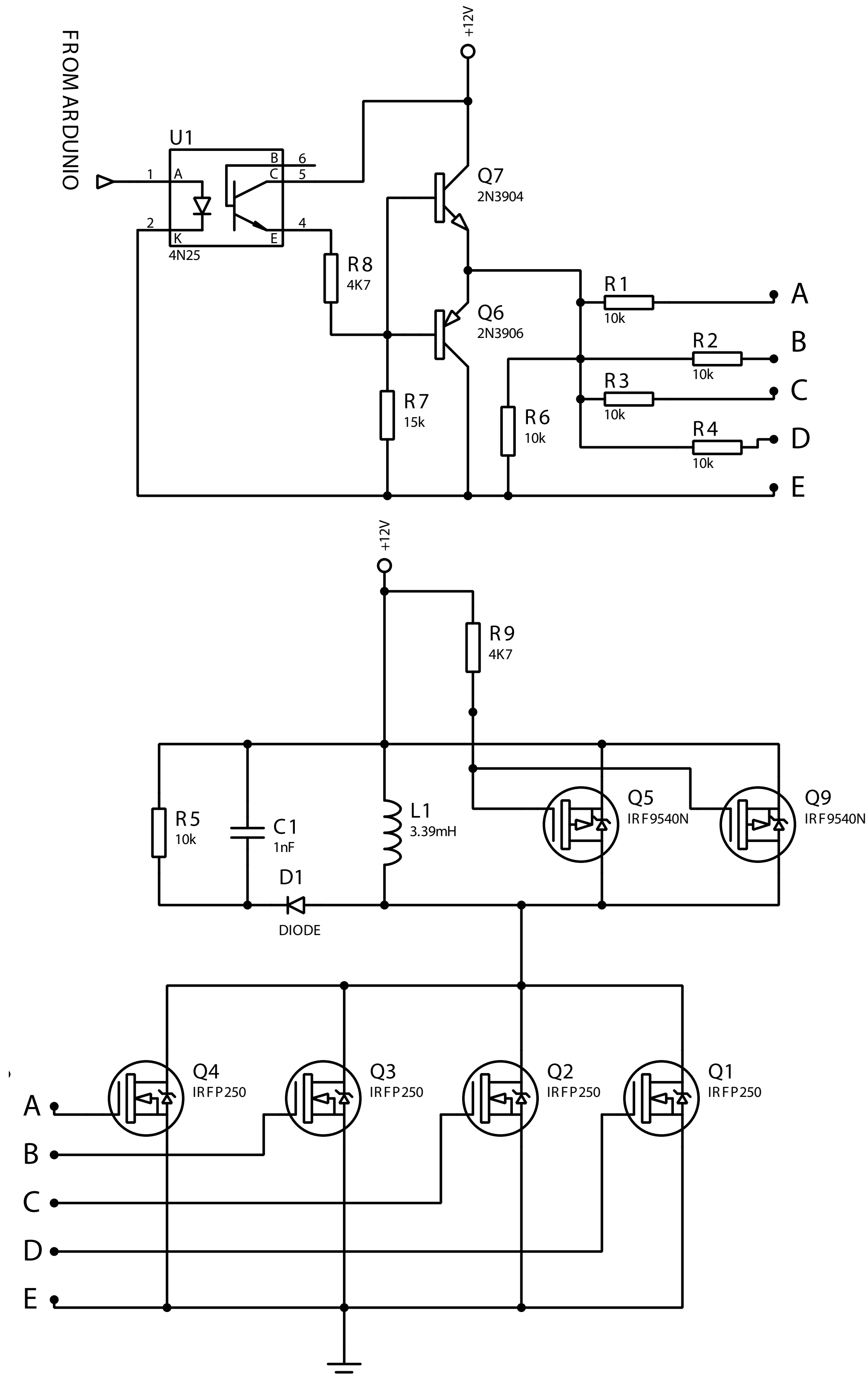

Figure 5: Circuit diagram for the polarization coil rapid switching. The switching signals are generated by an Arduino micro controller and are fed into U1 (top left of the diagram). The snubber circuit is shown in the dashed box.

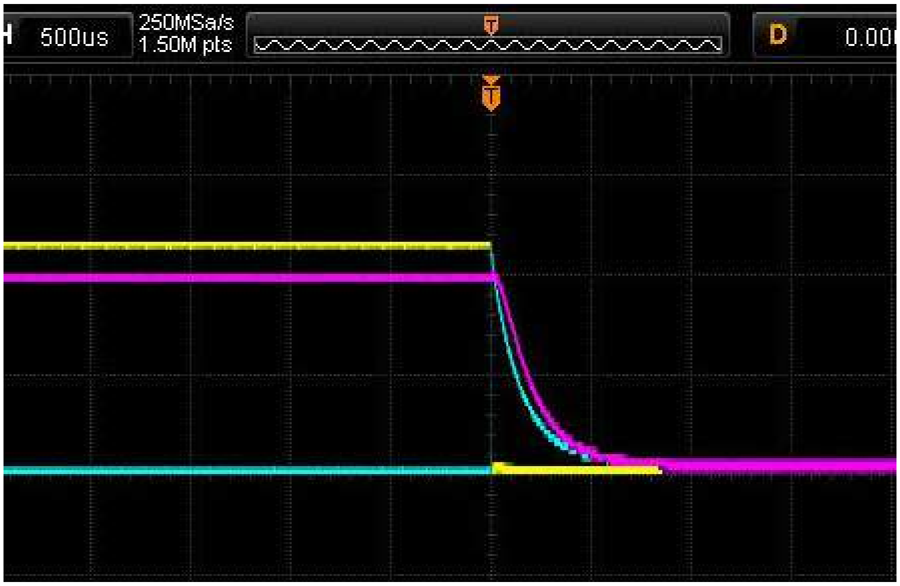

Figure 6: Current (turquoise) and magnetic field (purple) discharging curve. Each big division at horizontal axis corresponds to 500 μs.

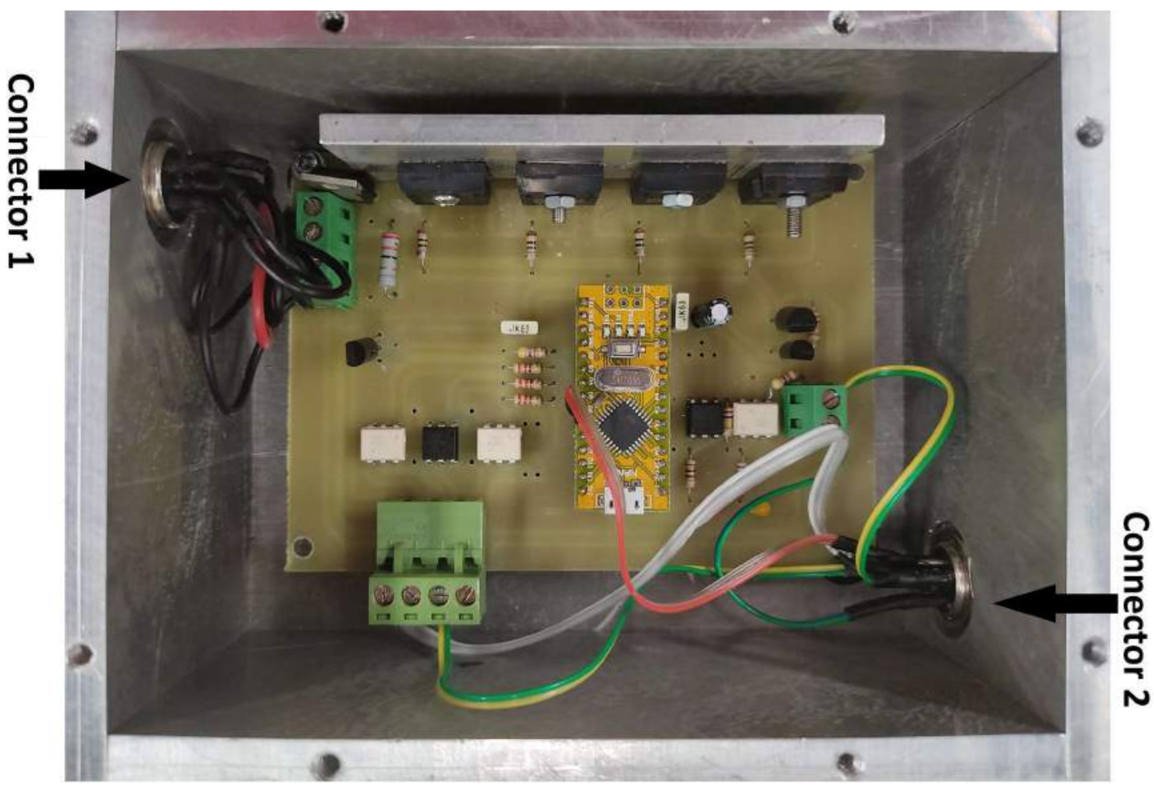

Figure 7: The polarizing circuit box. At the top we have MOSFET's mounted on the same surface. In the center, an arduino can be seen which is our pulse controller and at the both ends, there are connectors which connect this circuit with the coil and power supply.

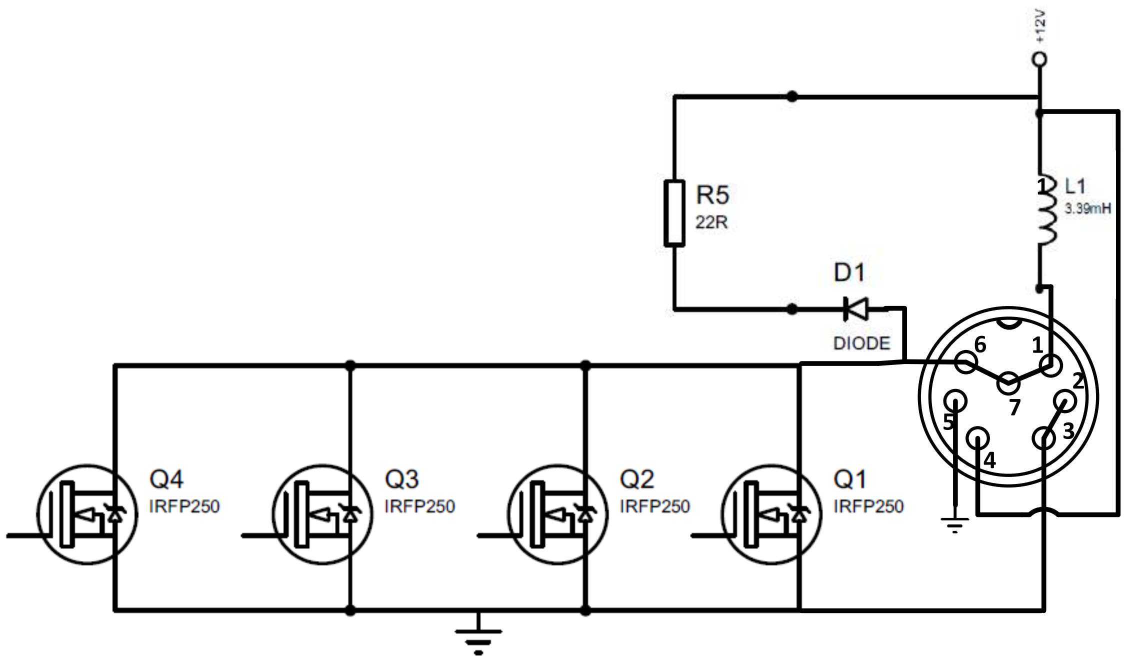

Figure 8: Connections of the connector with the enclosed polarization circuit.

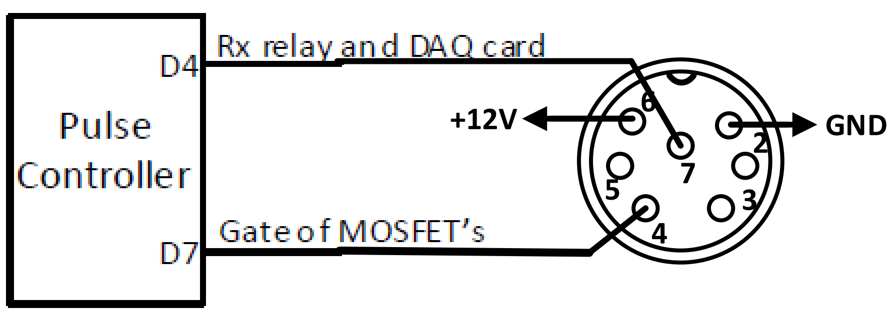

Figure 9: Connections of the connector 2 with the enclosed polarization circuit.

Pin 1, Pin 6, Pin 7	Coil connection with Drain of the MOSFET
Pin 2 , Pin 3	Source of MOSFET with GND
Pin 4	+Vcc for snubber circuit
Pin 5	GND

Table 2: Pin identification of connector 1. Also refer Figure 8

Pin 1	GND
Pin 2,Pin 3, Pin 5	NC
Pin 4	Polarized coil pulse
Pin 6	+12V
Pin 7	Pulse for Rx relay

Table 3: Pin identification of connector 2. Also refer Figure 8

Solid copper wire, diameter of the wire	21 AWG or 0.812 mm with insulation
Coil length	100 mm
Coil inner diameter	25 mm
Coil outer diameter	40 mm
Number of layers	4
Number of turns/layer	115
Approximate inductance/coil	2.56 mH
Approximate resistance/coil	2.5 Ω
Approximate self capacitance/coil	10 μF

Table 4: Specifications of the receiver coils

3 Receiver (Rx) coils

In the Pines EFNMR machine, the receiver (Rx) coil picks up the signal from the precessing pre-polarized sample. The signal is devastatingly small, many rounds of the experiments are therefore required to increase the signal to noise (SNR) ratio. We call this precess signal averaging.

3.1 Requirements for the Rx coils

In this apparatus, the major issue is noise and coils need to be designed in a way to minimize the noise. Besides signal averaging, we use two almost identical sensor coils to resolve this problem and maximize the SNR.

The two coils are wound in series but in opposite direction to each other. They are mounted on the same surface so that they cancel out the noise. To receive the signal, the sample is placed in only one the coils. If the sample is placed in both the coils, signal produced in both the coils will cancel each other and no signal will be received at the output.

The EFNMR is designed to operate using the earth's magnetic field so any ferromagnetic material nearby must be avoided. Metallic objects such as copper, aluminium and brass should also be kept away from the coil to avoid eddy currents which are induced as the B_p is rapidly switched off.

Wire size is also an important parameter. With thin wire, we have more turns and the signal is stronger but it also has a higher resistance and hence more Johnson noise $\propto \sqrt{R}$ which we don't want. On the other hand, with thick wire, we have lesser turns and the signal is weak as compare to thin wire but the noise is small and Quality factor can be higher. Johnson noise is thermal noise and is higher for larger resistance while Q is lower for larger resistance.

$$Q = \sqrt{4K_B T R \Delta f} \tag{4}$$

The achieved specifications of receiver's coil are summarized in Table 4.

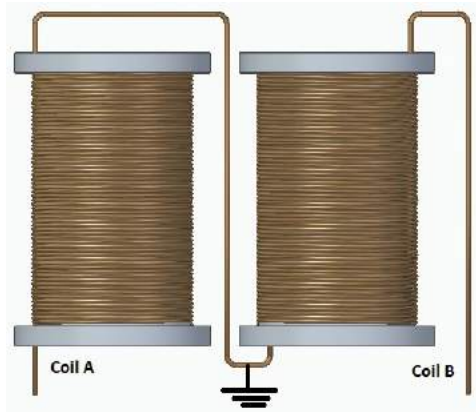

Figure 10: Construction of the Rx coils.

3.2 Construction of the Rx Coil

The one most important point for winding the coil is that both the coils should be identical as possible so that they can perfectly cancel the environmental noise. In engineering, this called common mode rejection. This can be achieved if the number of turns are equal for both the coils and wire is not twisted from anywhere. The material used for the coils is PLA and the coils are 3D model. To check similarity of the coils, one way is to weigh the coils before and after winding. Both the coils must also be wound in the opposite direction as shown in Figure 10.

3.3 Initial testing of the Rx coil

Receiver coils are connected in series but in opposite direction with each other to diminish the noise. Both coils are placed on the same surface and as close as possible to each other.

After connecting the coils and for preliminary tests , we place the Rx coils in the polarization coil. When a sine wave signal of 5 V amplitude from a function generator, is applied to the polarization coil, a sine wave is induced in both the Rx coils of the same amplitude and approximately 180° out of phase with the excitation source. Both the waves cancel each other and we have almost zero resultant signal as shown in Figure 11.

3.4 Circuit description of the Rx

The block diagram of the Rx circuit is shown in Figure 12. In receiver's circuit, there are six stages which are enumerated below.

1. Tuning capacitor
2. Relays

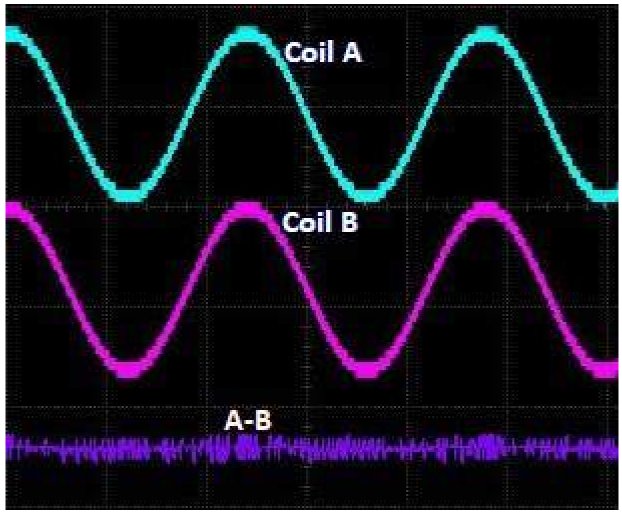

Figure 11: Differential output of two coils wound in series opposition (blue).

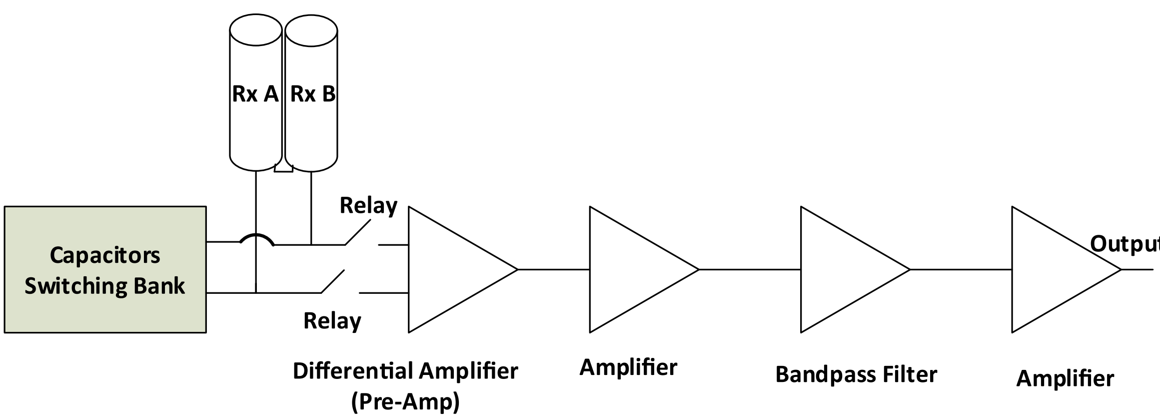

Figure 12: Block diagram of the Rx circuit.

3. Pre-amplifier comprising of the instrumentation amplifier AD 620
4. Amplifier OP271
5. Second order band pass filter
6. Final amplifier OP271

The complete circuit diagram of Rx circuit is given in Figure 13 to Figure 17. We now describes the major features of each of this stage in the Rx circuit.

3.4.1 Tuning Capacitor

Signal from the receiver coil is very small, so we first boost the signal before it gets to the instrumentation amplifier. This means that maximum power needs to be transferred to the receiver channel. This is achieved with the help of a tuning capacitor converting the Rx coil and parallel capacitor into a tuned tank circuit. We place a capacitor in parallel with both the coils. The value of the capacitor can be found using the resonant frequency formula

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{5}$$

where f is adjusted (by adjusting C) to be as close as possible to the proton's Larmor frequency f_o which is approximately 2.089 KHz. Here L is the combined inductance of both the coils and its value is 5.14 mH. The nominal value of the tuning capacitor is 1.13 μF. This value is achieved by bringing in capacitors through switches as shown in Figure 13.

3.4.2 Relay Circuit

The coils output is connected to relays which are operated by pulses programmed through Arduino that will be described later. When there is no Rx pulse at connector J4 from the Arduino, the relay is in off condition. The normally open pins of the relay are connected to Rx coils through the connectors J1 and J3. The common point of both the Rx coils is grounded through connector J2. The common pins of the both relays are grounded and the normally close pins are connected to inputs of the instrumentation amplifier. Power supply is connected to the circuit through connector J7. This circuit is described in Figure 14. We acquire the NMR signal for 5 sec and relays are on for this period. This time can be varied by the Arduino program. The pin configuration of these connectors is enumerated in Table 5.

3.4.3 The pre-amplifier

The pre-amplifier is a low noise instrumentation amplifier. For example our choice is the AD620 which is a low cost, high accuracy instrumentation amplifier that requires

J1	Rx coil A
J2	Common point of the Rx coils to the GND
J3	Rx coil B
J4, J7.1	GND
J7.2, J7.3	-12V, +12V
J7.4	Rx pulse from the controller

Table 5: Pin identification of J1, J2, J3, J4 and J7 connectors

only one external resistor to set gain from 1 up $10,000$. The signal is in microvolts that's why we can use only some kind of low noise amplifier. Both ends of the coil are connected to the inputs of the instrumentation amplifier while the sample is placed in only one of the coils as discussed earlier. As the signal emerges, the two inputs of the instrumentation amplifier differ and we have an output at output of the amplifier. The gain in this section is kept at 150.

3.4.4 Amplifiers

Two amplifiers are used in this circuit to boost the signal. The first amplifier is used after the instrumentation amplifier and before bandpass filter while the second amplifier is used after band pass filter. The gain of first and second amplifiers are 100 and 200 respectively. The amplifier is OP271 which is a stable monolithic dual op amp. The OP271 has a gain bandwidth of 5 MHz with a high phase margin. We have the final output at connector J5.

3.4.5 Bandpass filter

A second order bandpass filter of central frequency 2.1 KHz is also used. The 3dB lower and upper cut off frequencies set at 1.9 and 2.3 KHz respectively.

3.4.6 Power Supply

A regulated power supply of ± 12 V is designed to drive the receiver circuit and Arduino (pulse generator). Regulators 7812 and 7912 are used in this supply. A centre taped transformer steps down the 220 V to $15 - 0 - 15$ VAC and then the output is subsequently rectified before applying to the regulators. Connector J1 of the power supply is the output of regulated voltages +12 V, -12 V and GND. The power supply is shown in Figure 17.

3.4.7 Rx circuit box

The whole circuit is enclosed in an aluminium box and is shown in Figure 18. There are two screw plugs connector 1 and connector 2 having pins seven and six respectively.

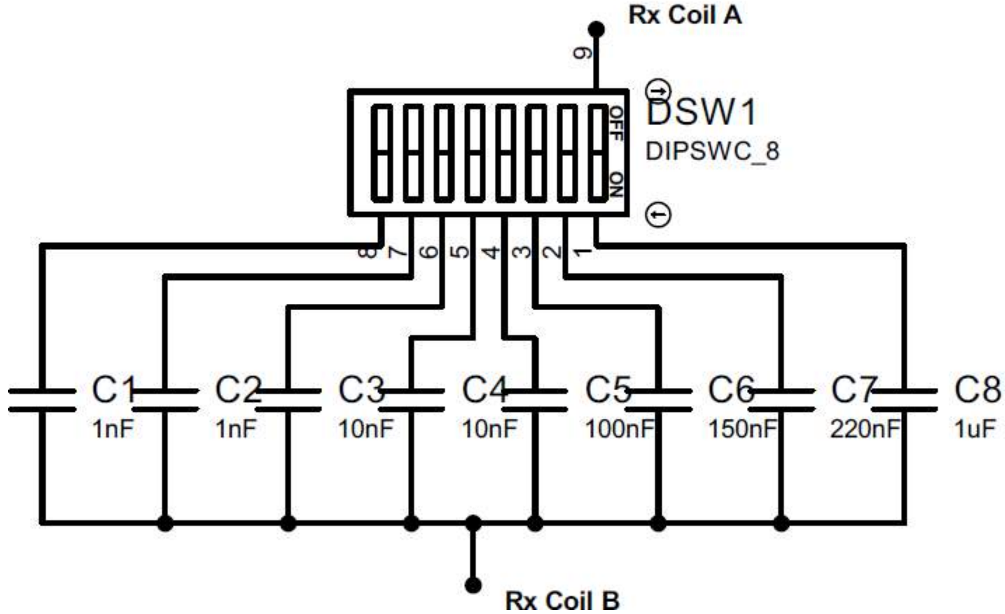

Figure 13: Tuning capacitors switching bank.

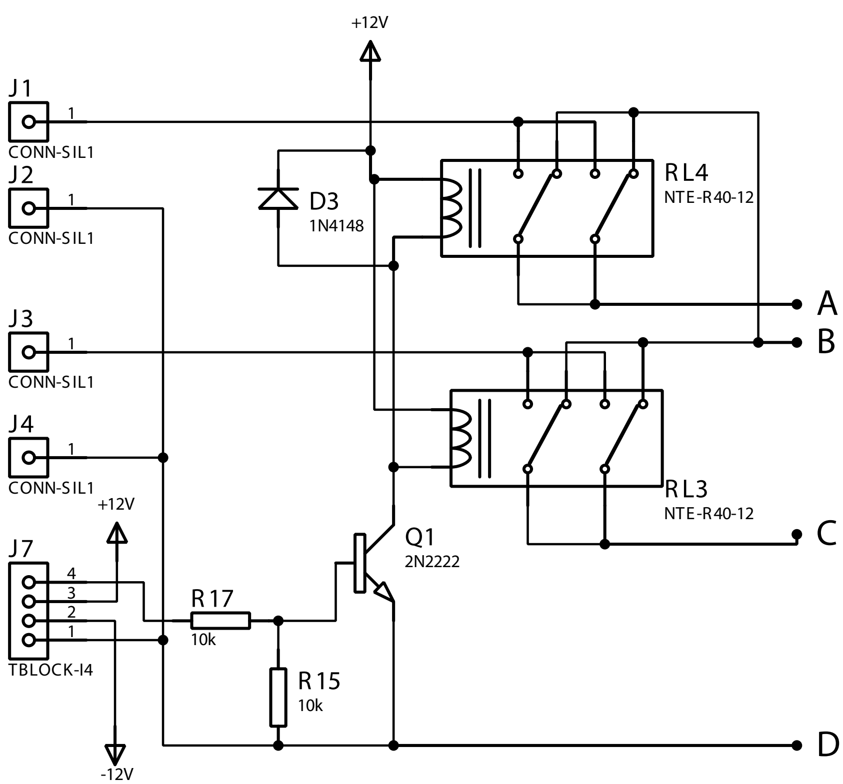

Figure 14: Relay circuit to acquire data for the desired time.

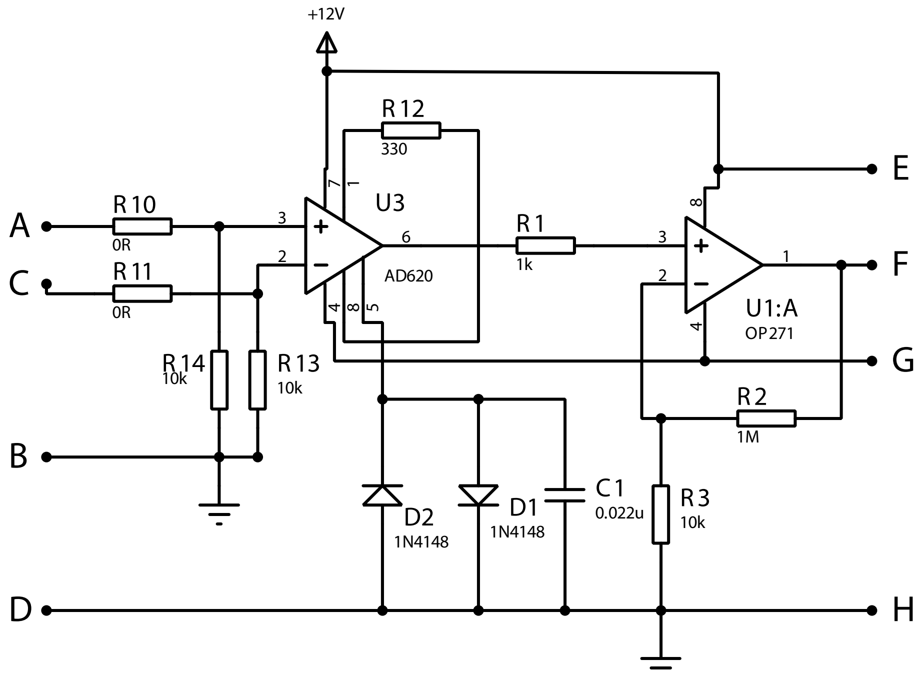

Figure 15: Pre-amplifier with gain of 150 and amplifier with gain of 100.

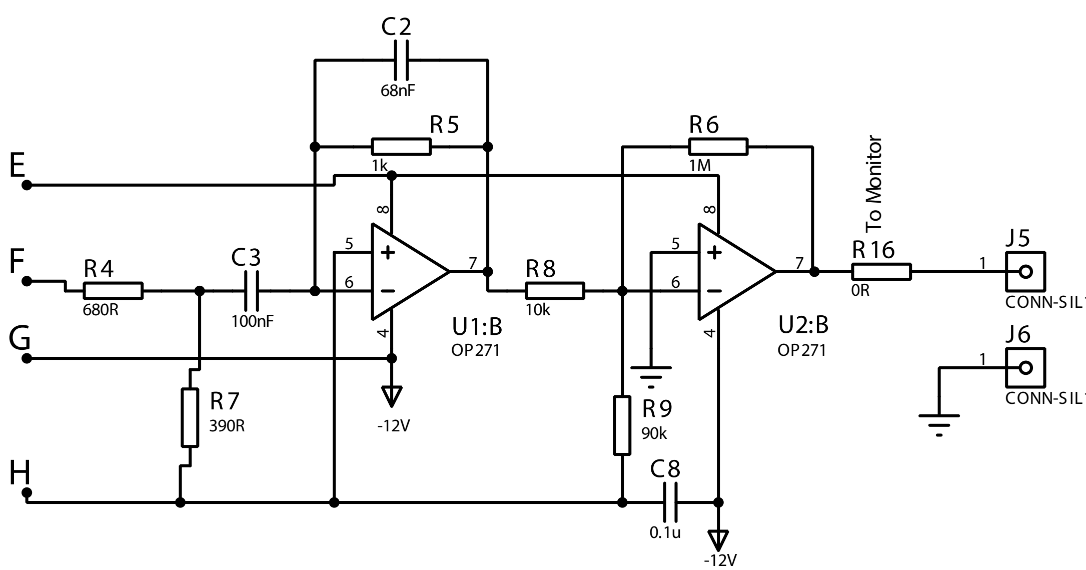

Figure 16: Bandpass filter and final amplifier with gain of 200.

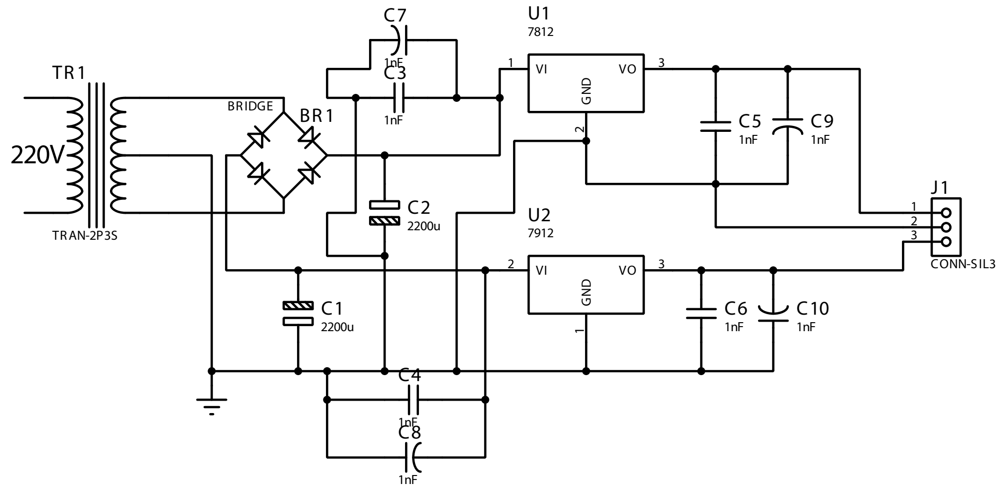

Figure 17: Power Supply of +12 V and −12 V.

Pin 1	Common point of both the Rx coils
Pin 2	Rx Coil 1
Pin 3	Rx Coil 2
Pin 4	+12 V
Pin 5	-12 V
Pin 6	Rx pulse from controller
Pin 7	GND

Table 6: Pin identification of Connector 1. Also refer Figure 19

Rx coils A and B are connected to the circuit through pin 2 and pin 7 of the connector 1. Pin 1 is the common point of both the coils while pin 6 is connected to the pulse which controls the relays. Pin 2 and pin 3 are +12 V and −12 V respectively. Similarly, Pin 1 and pin 5 are outputs while pin 4 and pin 6 are grounded respectively. The pin configuration for connector 2 and connector 3 are enumerated in Table 6 and Table 7. Figure 19 shows the connections of connector 1.

4 Pulse controller and data acquisition

4.1 Pulse Controller

As the experiment starts, the pulse controller sends the pulse to initiate the current to the polarization coil. After the polarization coil quenched, a signal is initiated to

Pin 1, Pin 5	Output
Pin 2, Pin 3	NC
Pin 4, Pin6	GND

Table 7: Pin identification of Connector 2

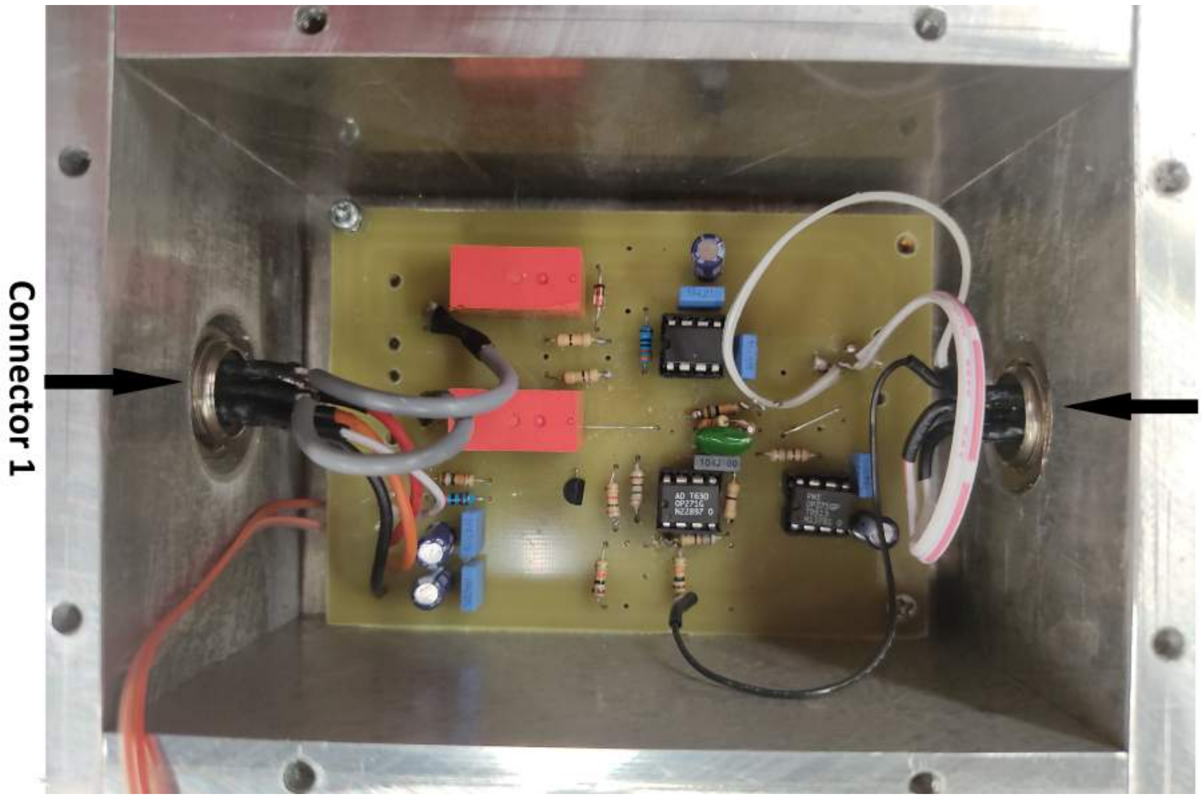

Figure 18: Rx enclosed circuit box.

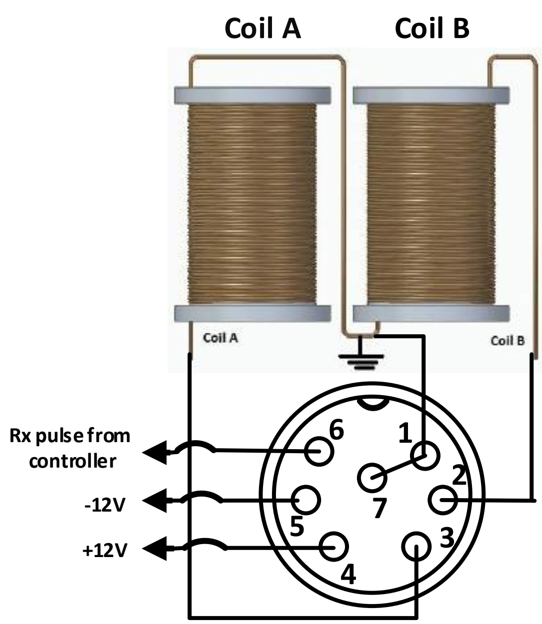

Figure 19: Connections of the connector 1 with Rx coil and enclosed Rx circuit in the box.

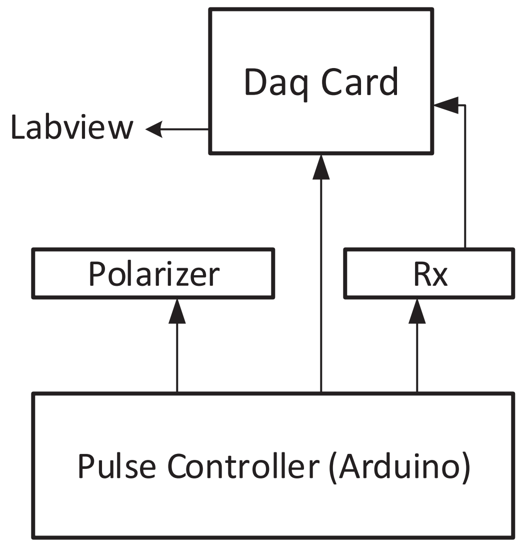

Figure 20: Block diagram of the pulse controller, two digital pins are employed to trigger the Rx coil circuit and polarization coil circuit.

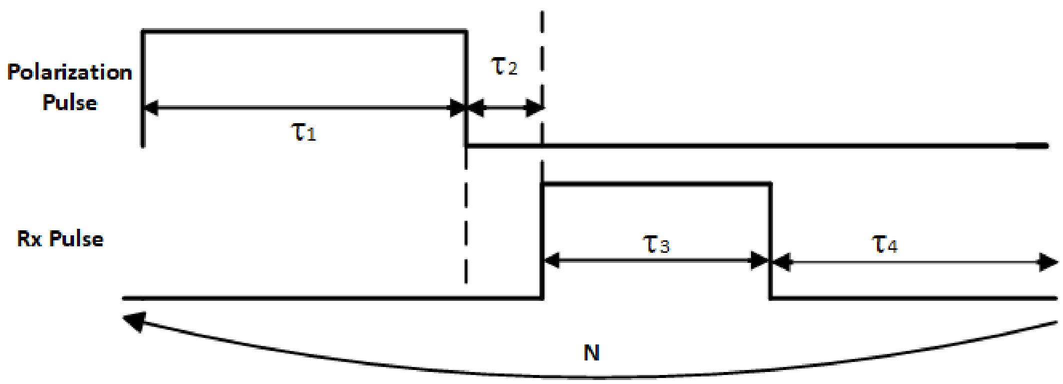

Figure 21: Timing sequence diagram for the EFNMR experiment: τ_1 is the polarization time, τ_2 is the pre-acquisition time, τ_3 is the acquisition time and τ_4 the time between two consecutive scans where N is the number of scans.

put the Rx circuit and the DAQ card to start receiving signal. Figure 20 shows the block diagram of the pulse controller.

Let's now discuss a timing sequence for the NMR free precessional instant. The controller sends the pulse to the polarization coil to polarize the coil for the time τ_1 . After this time, the controller waits for time τ_2 to turn the receiver circuit on. Data acquisition then continues for τ_3. After a blank period time τ_4, the controller starts the next iteration. A typical pulse program is shown in Figure 21.

To turn current on and off in the polarization coil and to switch receiver's circuit to acquire data, the pulse controller is implemented on Arduino Nano which is equipped with 14 Digital input/output (I/O). The polarization coil is controlled by D7 pin while Rx and DAQ card acquisition time are controlled by D4. Figure 22 shows the block diagram of Arduino Nano while Table 8 shows the typical parameters employed in the pulse controller.

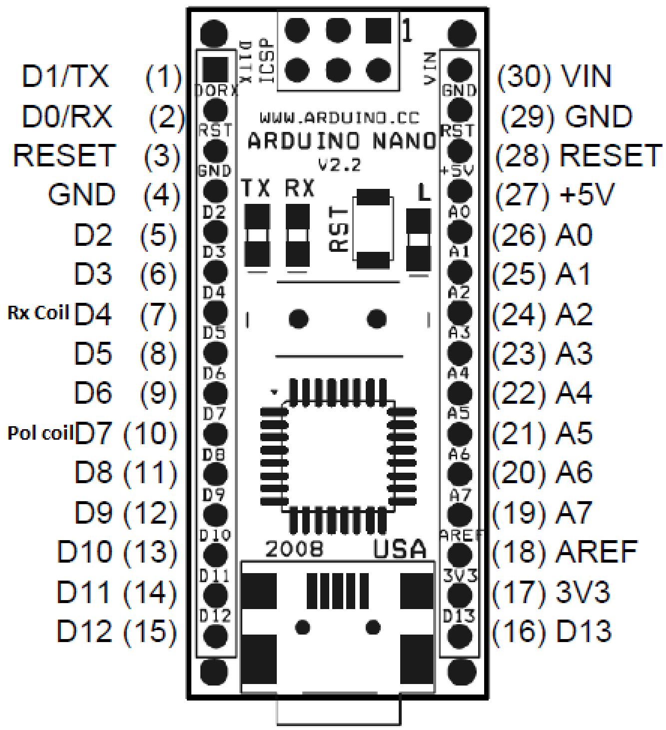

Figure 22: Arduino Nano block diagram. Digital pins D4 and D7 are used to control Rx circuit and polarization coil circuit respectively [arduino.cc].

Polarization Duration	τ_1	10 sec
Pre-Acquisition Time	τ_2	200 msec
Acquisition Time	τ_3	5 sec
Inter Scan Delay	τ_4	8 sec
Number of scans	N	650

Table 8: Typical controller parameters used in most experiments.

4.2 Data acquisition

To acquire data from the receiver's circuit output, we use a USB data acquisition (DAQ) card (6001, National Instruments) and a program in Labview to acquire data. The complete system is synchronized with our receiver's circuit pulse. The Arduino based control energies the polarizer coil and switches it off. It then turns on the RX circuit and routes the data to the DAQ card. Some important parameters that are useful to achieve optimal results are now described.

4.2.1 Sampling Rate

According to the Nyquist criterion, the sampling frequency must be at least twice the frequency of the highest component to acquire any signal. If a signal is acquired less than the sampling frequency, the signal becomes aliased with leading to its harmonic improper characterization. To avoid aliasing in our experiment, we use sampling frequency of 20 kS/s (kilosamples per second), which is about ten times the expected f_0 (≈ 2 KHz)

4.2.2 ADC resolution

ADC resolution refers to how many unique voltages levels the data acquisition system can recognize and this is determined by the number of bits used to represent each sample. The USB-6001 uses a 14 bits to represent each sample, so the resolvable levels number are $2^{14} = 16384$ which translates a voltage to resolution of above 1 mV. With a gain G, this would mean a voltage resolution of $1/G$ mV.

4.2.3 Acquisition Time and Number of Scans

The usable precession signal is no more than 2 to 3 seconds. So we acquire data for only that time, which is of course adjustable through our pulse program. The number of scans and other pulse parameters are also controlled by a Labview program. Multiple scans are required for enhancing the SNR.

5 Data Processing and Key Results

Data acquired from the Pines is highly noisy. Adding data sets of all the scans reduces the noise and strengthens the signal i.e. the SNR is improved. Hypothetically SNR is proportional to the square root of the number of scans. Figure 23 shows the raw signal called the free-induction-decay (FID) for 50, 100 and 650 scans.

To get the peak and to know the proton's precession frequency, we apply FFT to the average FID and we have a peak at $\approx$ 2.1 KHz. A six order Butterworth bandpass filter is also digitally designed to remove frequencies outside a frequency band. After

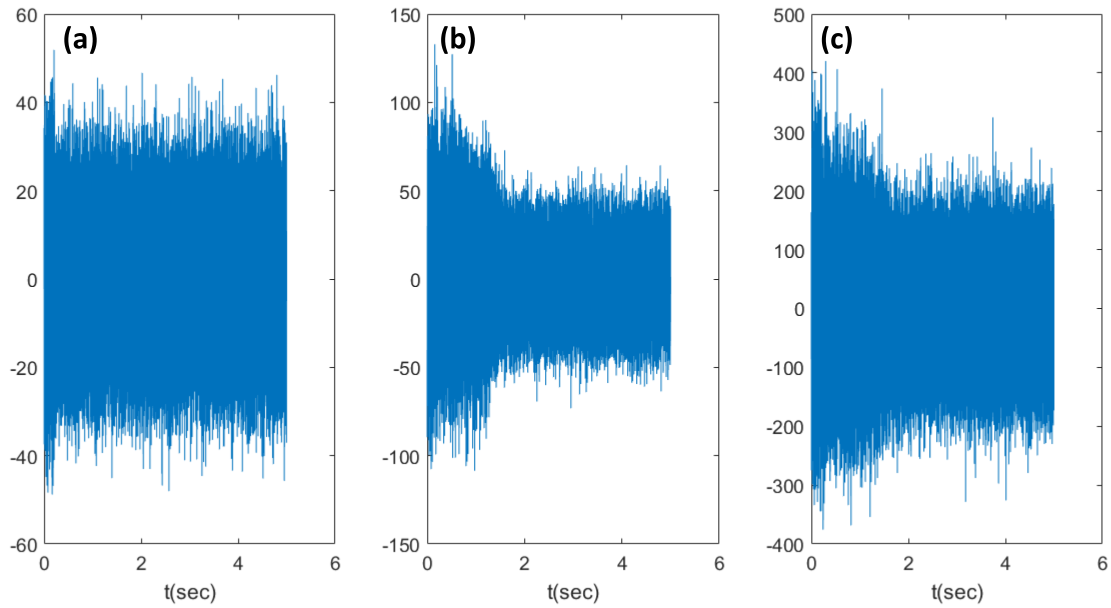

Figure 23: (a) FID for 50 scans (b) FID for 100 scans (c) FID for 650 scans.

Number of Scans	f_o (Hz)	FWHM (Hz)
50	2154	15
100	2156	7.3
650	2154	7.8

Table 9: f_o and FWHM for 50, 100 and 650 scans.

the optional digital bandpass filtering, one performs a fast Fourier transform (FFT) on the averaged data, to obtain the NMR spectrum. Sample results are shown in Figure 24.

In order to determine our peak with greater accuracy, we fit the Fourier transformed data to Lorentz peak defined as

$$\mathcal{L}(f) = a + \frac{b}{(f - f_0)^2 + c}. \tag{6}$$

where f is the frequency and a, b and f_0 fit parameters, whereas f_0 is the predicted parameter Larmor frequency and the full-width at half-maximum (FWHM) is given by $2\sqrt{c}$.

6 Control experiments

Besides this typical experiment, some control experiments were also performed.Data from these supplementary experiments are now shown.

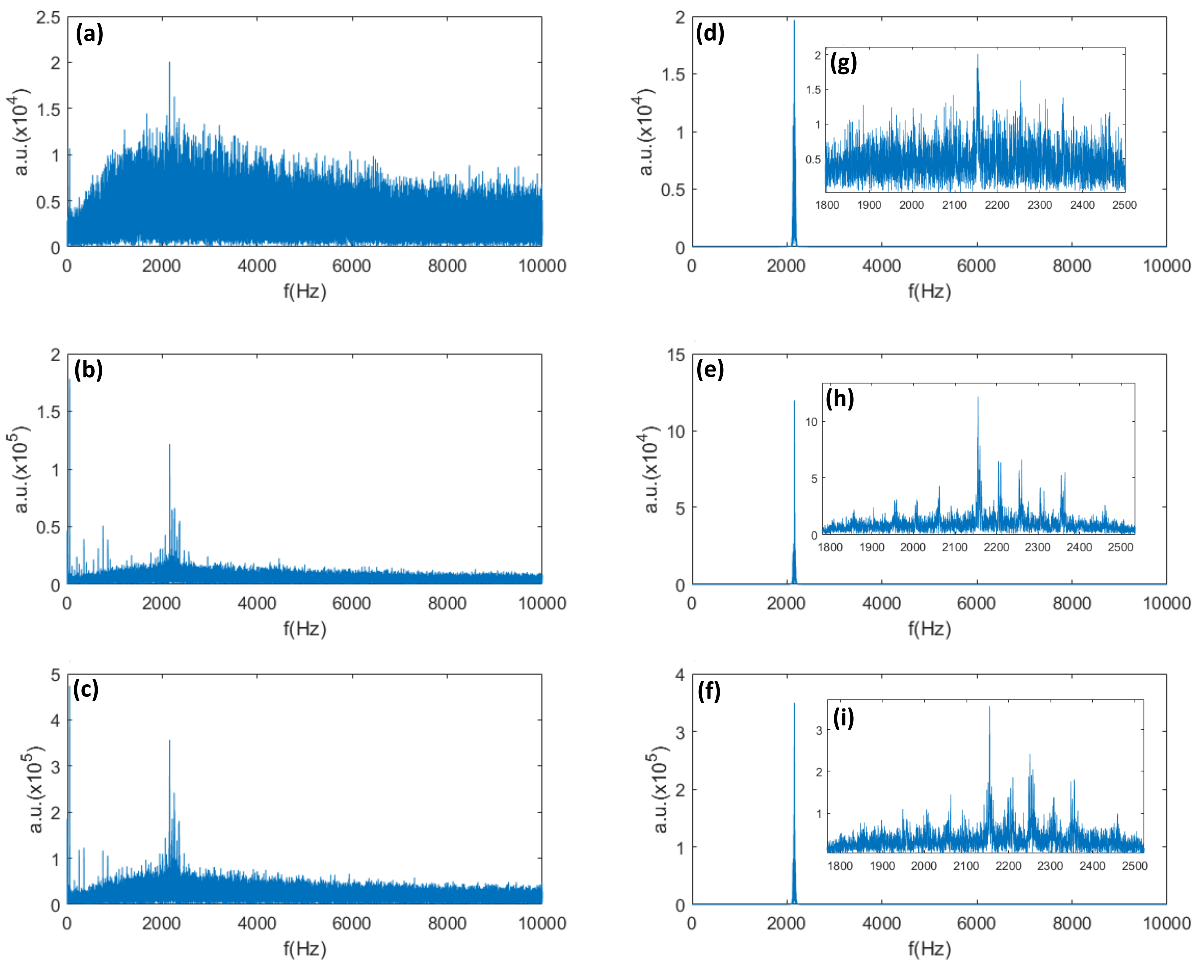

Figure 24: FFT of averaged data (a) 50, (b) 100 and (c) 650 scans while (d), (e), (f) show respectively the same data but after digital filtering. Zoom-in's (g), (h), and (i) show the spectrum for the frequency range 1800–2500 Hz. The sample is 10 mL of water and the timing parameters are the same as in Table 8. Note that the SNR is increasing as N increases (consider the vertical scale of the FID and Fourier spectra). The multiple smaller peaks are at the harmonics of the line noise (50 Hz.)

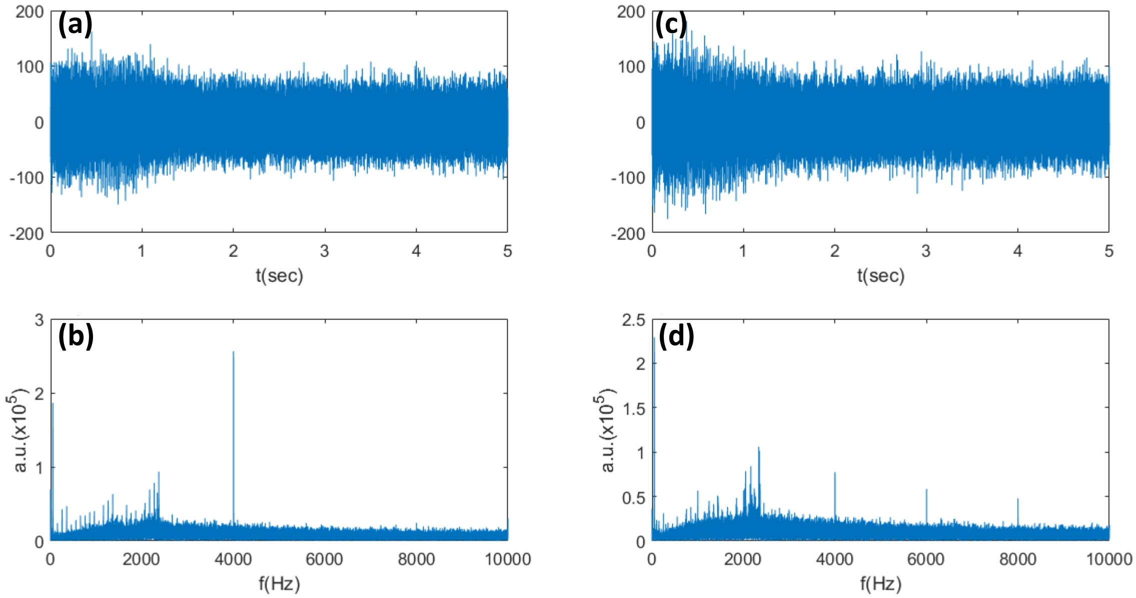

Figure 25: (a) and (b) show respectively the averaged data and FFT of that averaged data without sample in both the Rx coils while (c) and (d) are the results of averaged data and FFT with sample in both the Rx coils.

6.1 Experiment without sample and with sample in both the coils

For this case of the sample absent from both coils or the sample placed in both the coils, no single discernible peak in the spectrum was observed. Though for no sample present whatsoever, the noise was higher, while for both Rx coils being filled with the sample, multiple peaks were observed that are possibly due to digital artifacts. (See Figure 25.)

6.2 Experiment inside the building

Experiments were also performed inside the built environment but we find multiple peaks because of the ferromagnetic material inside the building. Signal is very small and distorted. The FFT and FID for this experiment is shown in Figure 26.

6.3 Experiment with TMS(tetramethylsilane)

Tetramethylsilane (abbreviated as TMS) is the organosilicon compound with the formula $Si(CH3)_4$. All twelve hydrogen atoms in a tetramethylsilane molecule are equivalent, its ^1H NMR spectrum consists of a singlet. The FID and FFT are shown in Figure 27.

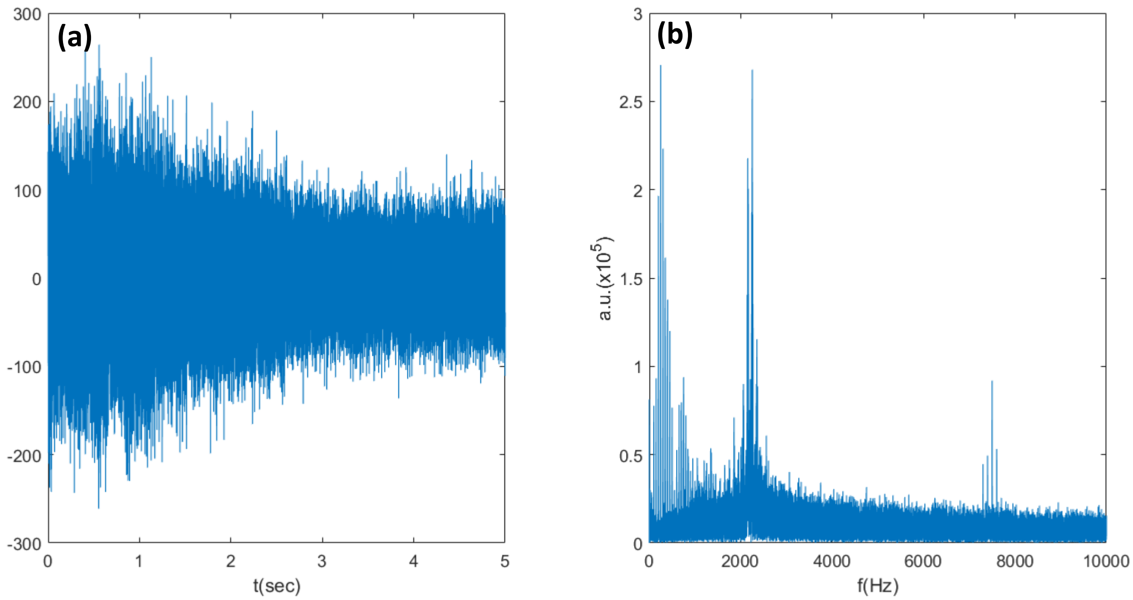

Figure 26: (a) Averaged data for the experiment performed inside the building (b) FFT of that data.

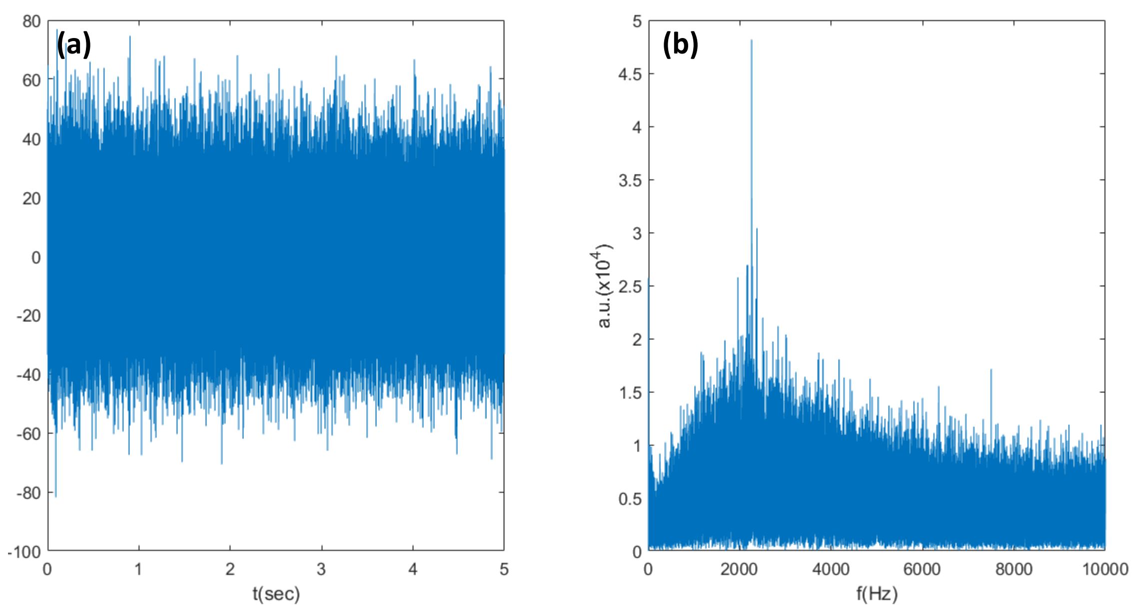

Figure 27: FID and FFT of average data for TMS. The data is plotted for $N = 100$.

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