Basics of MRI
Project work manual

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Department of Electrical Engineering and Automation

Manual revised: February 2019

** Note: This manual is prepared based on Pure-Device manuals which were obtained from the system's and experiments' manuals which are available on http://www.pure-devices.com/index.php/downloads.html

Safety Instructions

The instructions below are obtained from the MRI's system manufacturer manuals, although not all of them are relevant to this experiment, still we strongly recommend to read them all carefully as it is important to know them all.

- Please refer to these instructions below as needed to ensure the continued safe operation of the system.
- The system should be placed on an even, stable, and vibration free surface.
- The magnet should never be placed on any metallic (ferromagnetic) surfaces.
- Never attach other devices than the magnet to the control unit. This may damage the control unit and the unsupported device.
- The appliance may only be installed and operated in dry, well ventilated and dust-free rooms.
- Always check voltages and polarization of the adaptor before connecting it.
- Operational elements on the front of the machine (mains switch) must be easily accessible.
- The louvers at the bottom and front of the devices must be free at all times during operation to allow sufficient heat transfer from inside the device.
- Care should be taken so that objects do not fall and liquids are not spilled into the enclosure through openings of the devices including the magnet.
- Do not operate the device if power cord, power supply unit, or test unit are damaged!
- After use, turn the device off. Constant operation is not allowed. The maximum recommended operation time is 10 hours per day.
- The operation of mobile phones or other radio equipment should be avoided in immediate vicinity.
- The length of each cable has to be below 2 meters. Use only the provided cables for cabling/wiring. To ensure compliance, use only the provided manufacturer's approved power cord.
- Electrostatic Discharges (ESD) may affect the function and reliability of the devices as they contain electronic components that are very sensitive to ESD. So, the MRI device cannot be used on carpeted floors.
- In the case of damage, the appliance must only be opened by an authorized service technician. In this case, inform your lab supervisor so that the device will be returned to the manufacturer for repairing.
- Strong magnets can damage technical devices and storage media. A safety distance should be maintained. The following are some of the items that may be affected: computer, monitor, television, hard disks, floppy disks, magnetic tape, USB-sticks, credit and EC cards, watches, speaker, microphones, electricity meter, hearing aid, pacemaker and RFID-chips.
- Metallic objects may be attracted by the magnet. Maintain an adequate safety distance from these parts.

Caution: Any person with individual device for cardiac assistance (pacemaker, defibrillator) and pregnant women have to maintain a safety distance of 1 meter.
Caution: Unplug the power cord before attaching or detaching any cable connection!
Caution: Don't unplug ANY cable while the system is running!
Caution: Never block the air intake (bottom) or fan outlets (front).

Notes on Care:
- Remove any contamination with a suitable solvent.
- Do not use aggressive cleaning agents such as thinner or acetone for cleaning the surface.

MRI System

The magnetic resonance tomograph system you will be using comprises the control unit *drive* **/** and the magnet *magspec 24.55MHz*. In this section you will find a description of the control elements and interfaces of system used in the lab.

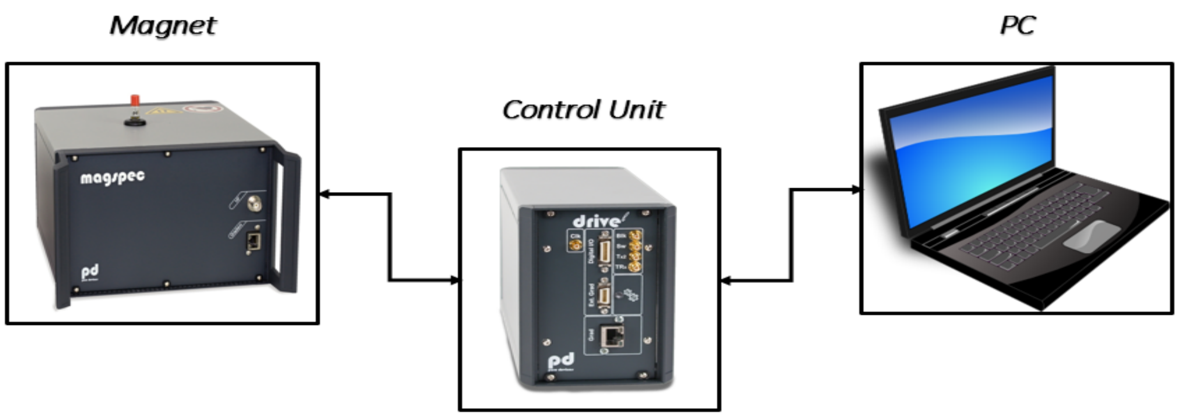


Figure 1: System's Block Diagram

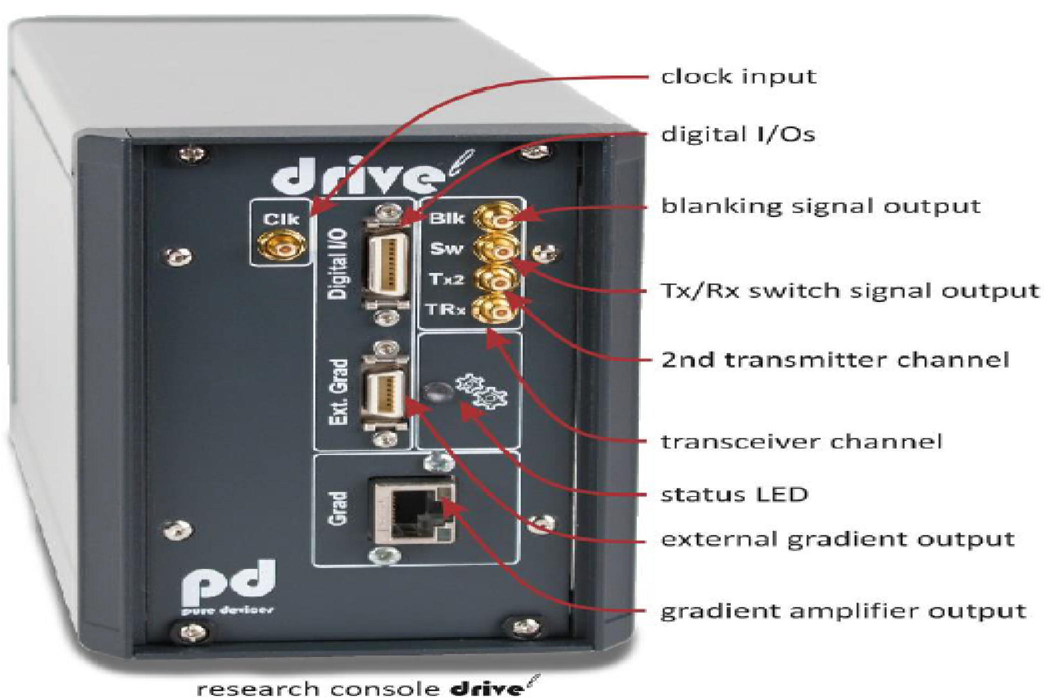


Figure 2: Interfaces of the control unit – front panel Digital I/O – pin allocation

I. Front Panel Control Unit

Interface: clock input (Clk): The interface Clk is an input for external clocks (e.g. 10 MHz) to synchronize different systems and devices.
Interface: digital I/O (not functional yet): The interface digital I/O allows you to control external devices or receive trigger signals.

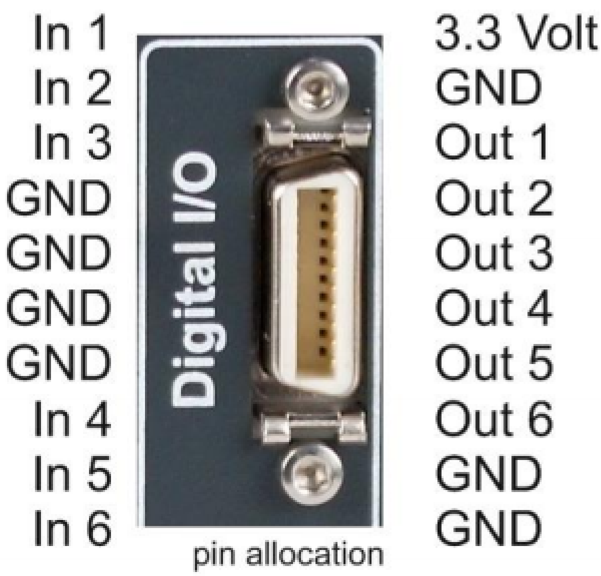


Figure 3: Digital I/O – pin allocation

Interface: blanking signal output (Blk): The interface Blk is an output interface delivering a blanking signal which may be required for the usage of external RF power amplifiers. Signal is high (5V) when the system is transmitting a RF pulse.
Interface: Tx/Rx switch signal output (Sw): The interface Sw is an output which provides the signal for an external Tx/Rx switch.
Interface: 2nd transmitter channel (Tx2): The interface 2nd transmitter channel is a second RF output.
Interface: transceiver channel (TRx): The interface TRx is an output for the radio-frequency transmitter coil (rf-pulse) and an input for the received MR signal. It should be connected with the magnet. It is standardized and has an impedance of 50 Ohm. The usage of other cable may require a calibration of the receiver/transmitter unit.
Indicator: status LED: The status LED provides information about the current state of the control unit.

- *Green*: The control unit is on and ready for measurements.
- *Yellow (light green) flashing*: A measurement is in progress.
- *Red*: An error has been detected. Please restart the control unit.

Caution: If the *status LED* is glowing red then unplug the power supply and all other cables. Please contact your instructor for support.

Interface: External gradient output (*Ext. Grad*): The interface *Ext. Grad* is the differential output of the unamplified gradient signal. Use this interface to connect an external high power gradient amplifier.

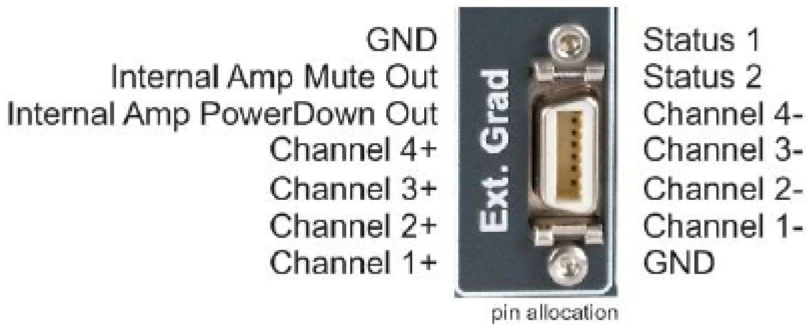


Figure 4: External gradient amplifier – pin allocation

Interface: Gradient (*Grad*): The interface *Grad* is the output of the gradient amplifier of the control unit. It should be connected with the magnet. The usage of other cables than the delivered may require a calibration of the gradient unit.
Furthermore this interface provides the current for the optional upgrade “B0 shift”.
The socket *Gradient* has two LEDs that indicate the following:

- *Yellow*: The power supply is connected to the control unit and main switch is ON.
- *Green*: The internal gradient amplifier is active.

Caution: It is not allowed to unplug the gradient cable if the LED is lit green!

II. Back Side of Control Unit

Socket: *DC 12V 2A* (*power supply*): he power supply must be connected to the socket *DC 12V 2A*.

Caution: Only use the provided power supply. Other than the given values for the power supply may destroy the control unit.

Interface: ***USB:*** The connection between the control unit and the PC is established via the USB interface. Use the supplied USB-2.0-high-speed cable. The length of the cable should not exceed 2 meter for proper operation.
Switch: POWER: The toggle switch POWER turns the control unit on or off.
The software for will automatically set the device into a stand-by mode on exit. If the device is not used for a long period of time, switch off the main switch (POWER). This will entirely disconnect the device from the power supply.

III. Front Panel Magnet

Figure 5: Interfaces of the magnet

Interface: ***Gradient*****:** The integrated gradient system of the magnet can be accessed on the socket Gradient.
Socket: ***HF*****:** The transmitter and receiver coil is attached to the BNC-socket via a coupling circuit. The Radio Frequency (RF) excitation of the sample and its signal detection is done via this interface. Connect the socket HF of the magnet with the correspondent socket of the control unit. Only use the provided BNC-cable cable for wiring. It is standardized and has an impedance of 50 Ohm. The usage of other cable may require a calibration of the receiver/transmitter unit.
Bore: ***Opening for the sample*****:** On the top of the magnet is the bore for inserting the sample. The samples can have a size of 10 mm in diameter.

Caution: The opening for the sample provides direct access to the inner of the magnet. Never put magnetic or ferromagnetic items into the bore. Prevent foreign material, such as dust or liquids from entering the magnet.

Experiments

This section contains five basic MR experiments on adjusting important MRI parameters and one 2D spin echo imaging experiment.

Moreover, the section contains instructions which should be followed while implementing the different parts of the experiment using the MRI system and the software installed on the PC connected. For each part below, please follow the instructions carefully and save your results at each experiment part in order to include them in your after-lab report along with your observations and explanations.

I. MR Frequency

A. General MRI Background

When placed in a magnetic field, MRI active nuclei (such as 1H) absorb electromagnetic radiation at a frequency characteristic of the isotope. The resonant frequency, energy of the absorption, and the intensity of the signal are proportional to the strength of the magnetic field. For example, for a magnet with 11.7 Tesla magnet strength, the frequency that 1H will resonate at is 500 MHz, while for a magnet with 21.1 Tesla magnet strength, the 1H will resonate at 900 MHz.

B. Experiment Background

One of the most important parameters in MR experiments is the Larmor frequency ν_L. It depends on the gyromagnetic ratio γ and the field strength of the magnet B0.

The Larmor frequency can be calculated by:

$$\nu_L = \frac{\gamma}{2\pi} \cdot B_0$$

$$\gamma = 26{,}75 \cdot 10^7 \, \frac{rad}{s \cdot T} \text{ for } {}^1\text{H nuclei.}$$

In this part, we want to adjust the transmitter and receiver frequency (system frequency) of the MR tomography device.

The pulse sequence for this measurement contains a simple 90° RF pulse for excitation of the spins. In this part you can freely adjust the frequency of the RF pulse. When the frequency of the RF pulse matches the Larmor frequency the longitudinal magnetization is tipped into the XY plane. An electrical current is induced in the receiver coil and a **Free Induction Decay (FID)** of the signal can be observed (Figure 6).

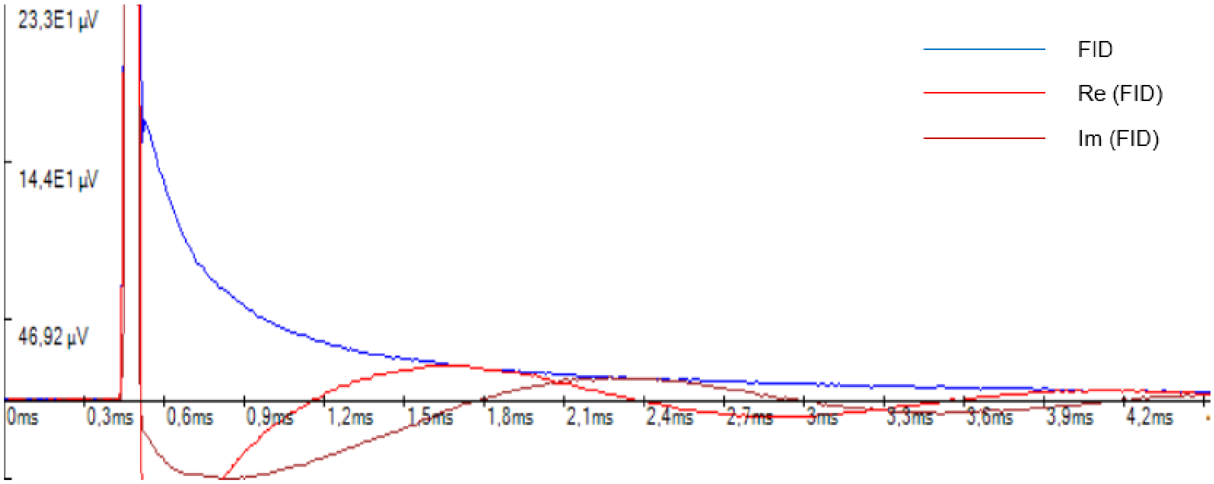


Figure 6: Pulse sequence for the experiment MR frequency

C. *Experiment Steps*

The green button on the magnet box is used to turn the temperature stabilizer on. Make sure the stabilizer is turned on and (as it takes about 15 minutes for the temperature to reach the required 30° C, the stabilizer has been turned on before your arrival). Afterwards, turn on the control unit (button is on the back side of control unit). In this experiment, the 10 mm oil sample is used. Place the test tube labeled 10 mm Oil into the bore of the magnet.

Select the lesson *MR frequency*. The panel *Parameters* shows the slider for the frequency, the checkbox Rough adjustment for changing the frequency span and the checkbox for the real and imaginary part of the signal. These parameters can be accessed in this experiment. Please compare your panel with Figure 7.

Please make sure, the checkbox for the real/imaginary part is selected.

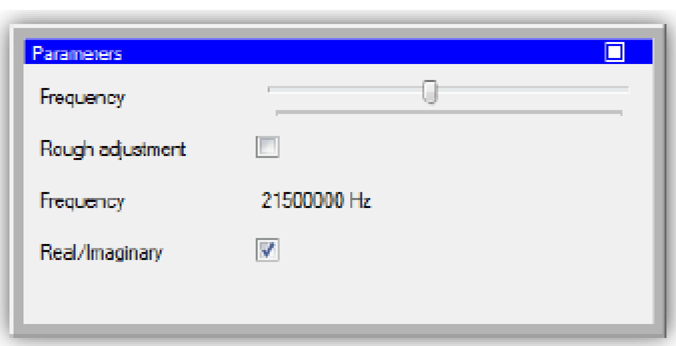


Figure 7: Parameters for experiment MR frequency

With the slider *Frequency* you can adjust the transmitter and receiver frequency of the tomography. Activating the option Rough adjustment sets the frequency range to 1.3 MHz.

When this option is deactivated the frequency, range is set to 100 kHz which allows fine tuning of the frequency.

The checkbox Real/Imaginary enables the visualization of the real and imaginary parts of the received data.

1. **Press Start for starting the measurement.**
2. **Change the system frequency by varying the slider *Frequency*. What do you observe?**
   Please note that the oscillation frequency of the displayed signal is not the Larmor frequency. It is the difference between the Larmor frequency and the system frequency.
3. **Now calibrate the frequency. An optimum calibration is achieved when the number of visible oscillations in the FID is as low as possible.**
4. **What can be observed when changing the sample?**
5. **Simply exchange the test tube with oil against water.**

II. MR Excitation Angle

A. General MRI Background

MR excitation angle is known also as Flip Angle (FA), tip angle, nutation angle or angle of nutation. It is the angle to which the net magnetization is rotated or tipped relative to the main magnetic field direction via the application of an RF excitation pulse at the Larmor frequency. Flip angles between 0° and 90° are typically used in gradient echo sequences, 90° and a series of 180° pulses in spin echo sequences and an initial 180° pulse followed by a 90° and a 180° pulse in inversion recovery sequences.

B. Experiment Background

One of the key requirements for magnetic resonance experiments is to know the 90° pulse duration. The highest NMR signal can be obtained when the pulse tips the magnetization exactly 90° into the XY plane of the rotating frame of reference. The amplitude of the NMR signal depends on the pulse duration of the RF pulse. Further experiments rely on the 90° pulse duration being correctly set.

For the determination of the correct 90° pulse duration, an RF pulse with adjustable duration is transmitted. Directly after the excitation of the sample, the signal of the FID is acquired. Figure 8 shows the sequence and exemplary measurement signal for this experiment.

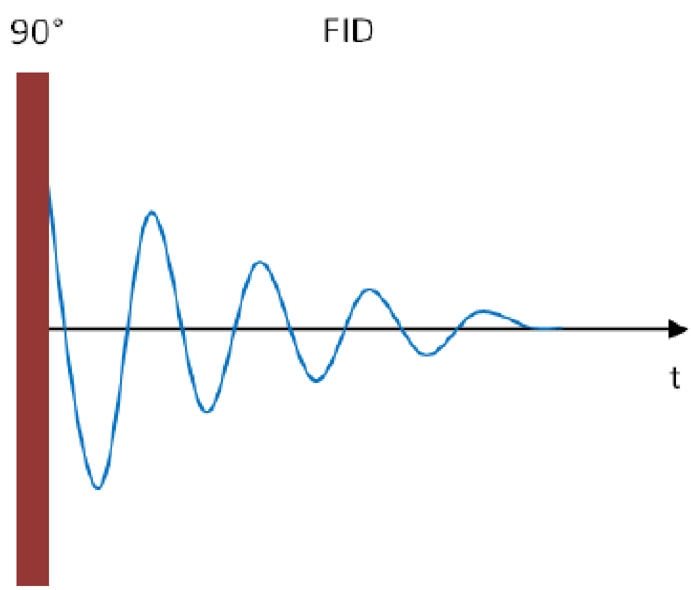


Figure 8: Sequence for the experiment MR excitation angle

C. Experiment Steps

In this experiment, the 10 mm oil sample is used. Place the test tube labeled 10 mm Oil into the bore of the magnet.

Select the lesson *MR excitation angle*. The panel *Parameters* shows the slider for the duration of the 90° excitation pulse and the checkbox for the real and imaginary part of the signal. These parameters can be accessed in this experiment. Please compare your parameter panel with Figure 9.

Please make sure the checkbox for the real/imaginary part is selected.

1.

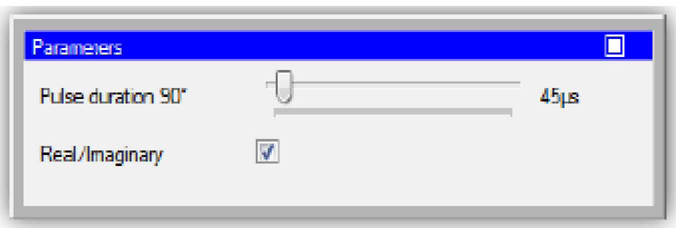


Figure 9: Parameters for experiment MR excitation angle

With the slider *Pulse duration 90°,* you can adjust the duration of the 90° RF pulse.

The checkbox Real/Imaginary indicates if the real and imaginary parts of the received data are displayed additionally to the absolute value.

1. **Press Start for starting the measurement.**
2. **Change the pulse duration of the 90° RF pulse by varying the slider *Pulse duration 90°*. What do you observe?**
3. **What duration will give the best (Maximum Amplitude) 90° pulse and why?**

III. B0 Homogeneity (Magnet Shim)

A. General MRI Background

Shimming is the process by which the main magnetic field (B0) is made more homogenous. Shimming may be passive, active, or both. In passive shimming small pieces of sheet metal or ferromagnetic pellets are affixed at various locations within the scanner bore. In active shimming, currents are directed through specialized coils to further improve homogeneity.

B. Experiment Background

Objective of this part is to observe how the FID depends on the homogeneity of the magnetic field.

Right after applying the excitation pulse, the FID starts to decay depending on the surrounding environment which is affected by static and time-dependent disturbances of B0.

The simplest case of static disturbances is the inhomogeneity of the magnetic field B0. This means that the field strength that the spins observe depends on their location. Thus, the precession frequency is different depending on the location of the respective spins. The observed signal is a superposition of all of these different frequencies. The more inhomogeneous the magnetic field, the more different frequencies superimpose and the faster the signal cancels.

To improve the homogeneity of the static magnetic field, it can be superimposed by an additional magnetic field. This field is generated by the so-called shim coils. The field generated by the shim coils has to be adjusted such that the signal after applying a 90° RF excitation pulse takes as long as possible before it disappears.

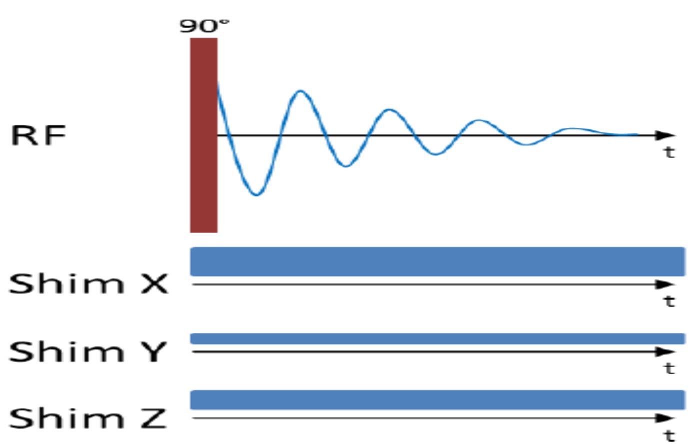


Figure 10: Sequence for experiment B0 homogeneity (magnet shim)

C. *Experiment Steps*

In this part, the 10 mm oil sample is used. Place the test tube labeled 10 mm Oil into the bore of the magnet.

Select the lesson *B0 homogeneity (magnet shim)*. The panel *Parameters* shows three sliders for the additional magnetic fields that will be generated by the corresponding shim coils. These parameters can be accessed in this experiment. Please compare your panel with Figure 11.

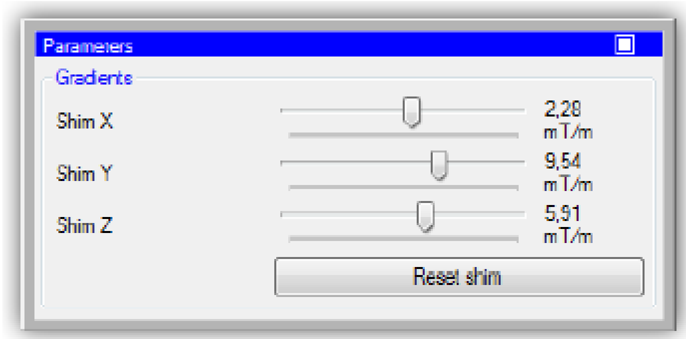


Figure 11: Parameters for experiment B0 homogeneity (magnet shim)

The unit of the shim field is mT/m.

Set all parameters to 0 mT/m by pressing the button Reset shim before running this experiment.

1. **Press Start for starting the measurement.**
2. **Change the values for the shim field. What do you observe?**
3. **Adjust the sliders to improve the homogeneity of the magnetic field. It might be necessary to adjust all sliders several times to achieve the maximum homogeneity. To do so, follow these instructions:**
    - **Set all shim values to zero by pressing the button *Reset shim*.**
    - **Start the procedure by adjusting slider *Shim X* until the decay of the FID cannot be extended any further.**
    - **Now, adjust the slider for *Shim Y* to extend the duration of the decay as far as possible.**
    - **Do the same with *Shim Z*.**
    - **Re-start with *Shim X* and repeat this procedure until the decay cannot be improved any further.**
    Note down the values for *Shim X*, *Shim Y* and *Shim Z*.

IV. Quantity Determination

A. General MRI Background

Repetition Time (TR) is the amount of time that exists between successive pulse sequences applied to the same slice. Changing TR value has an important effect on the control of image contrast characteristics. For example, relatively short values of TR (< 1000 ms) are common in images exhibiting T1 contrast, while relatively long values of TR (> 1500 ms) are common in images exhibiting T2 contrast. TR is also a major factor contributing to the total scanning time.

B. Experiment Background

The objective of this part is to observe the impact of the substance quantity in the test tube on the signal amplitude.

In this part, the pulse sequence from part I; ***MR Frequency***, is used. A 90° RF pulse is used for excitation. The measurement is repeated continuously with a user defined repetition time. After each measurement, the FID is displayed. Figure 12 shows the pulse sequence for this measurement.

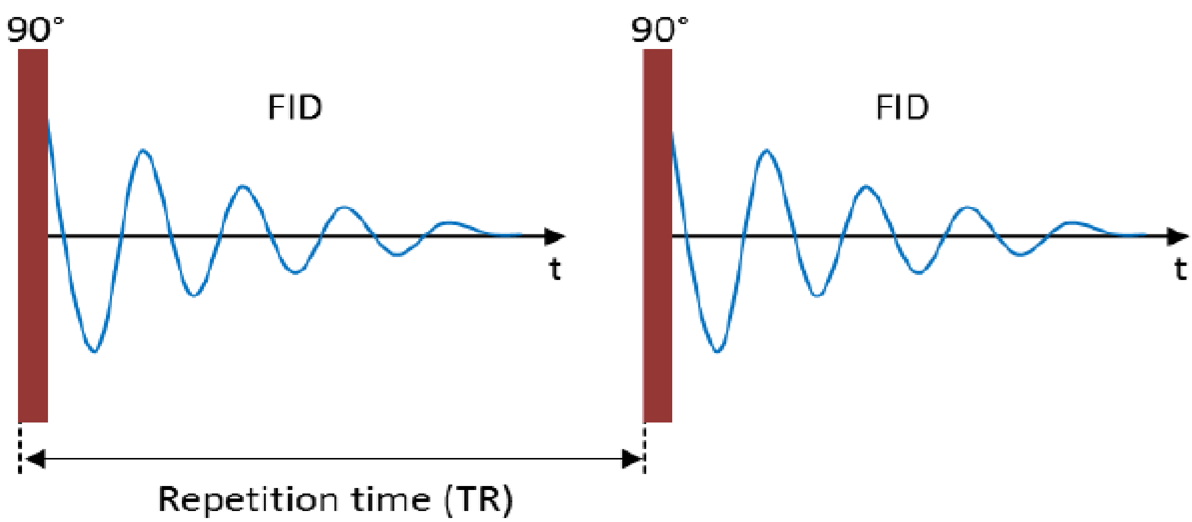


Figure 12: Sequence for experiment Quantity determination

C. Experiment Steps

In this part, the 10 mm and 5 mm water samples are used. At first, place the test tube labeled 10 mm Water into the bore of the magnet.

Select the lesson *Quantity determination*. The panel *Parameters* shows the slider for the repetition time of the experiment and the checkbox for displaying the real and imaginary part of the signal. These parameters can be accessed in this experiment. Please compare your panel with Figure 13.

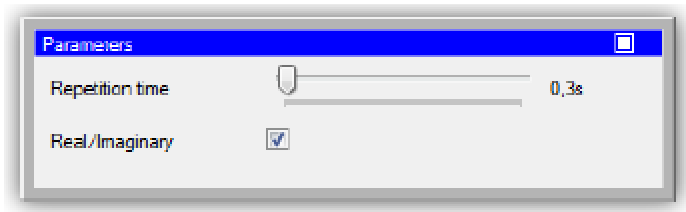


Figure 13: Parameters for experiment Quantity determination

With the slider *Repetition time* you can adjust the time between experiments. The checkbox *Real/Imaginary* indicates if the real and imaginary parts of the received data are displayed.

1. **Set the repetition time to 5 seconds. Press *Start* for starting the measurement.**
2. **Determine the amplitude of the FID directly after the 90° pulse. Note that the duration for the 90° pulse is automatically set to the value determined in the 2nd experiment (*MR excitation angle)*. Make sure that you have successfully completed the experiment *MR excitation angle.* What signal amplitude do you observe?**
3. **Repeat the measurement with the 5 mm test tube. What signal amplitude can you observe now?**
4. **Compare the signal amplitudes from 1st and 2nd points.**
5. **Why should you set the repetition time to at least 5 seconds when determining the amplitude of the water? Try changing the repetition time to smaller values.**

V. Spin Echo

A. General MRI Background

In the spin echo sequence, a 90° pulse which rotates the magnetization down into the X'Y' plane is first applied to the spin system. Then the transverse magnetization begins to diphase. At some point in time after the 90° pulse, a 180° pulse is applied. This other pulse rotates the magnetization by 180° about the X' axis. The 180° pulse causes the magnetization to at least partially re-phase and to produce a signal called an echo.

Echo Time (TE) is defined as the time between the 90° pulse and the maximum amplitude in the echo.

The signal equation for a repeated spin echo sequence is formulated as a function of TR, TE, proportionality constant (k), and density of spins in the sample (ρ) as shown below:

$$S = k\,\rho\,(1 - e^{-TR/T1})\,e^{-TE/T2}$$

This equation is only valid for the spin echo sequence when TR >> TE. Figure below shows the process of generating the spin echo.

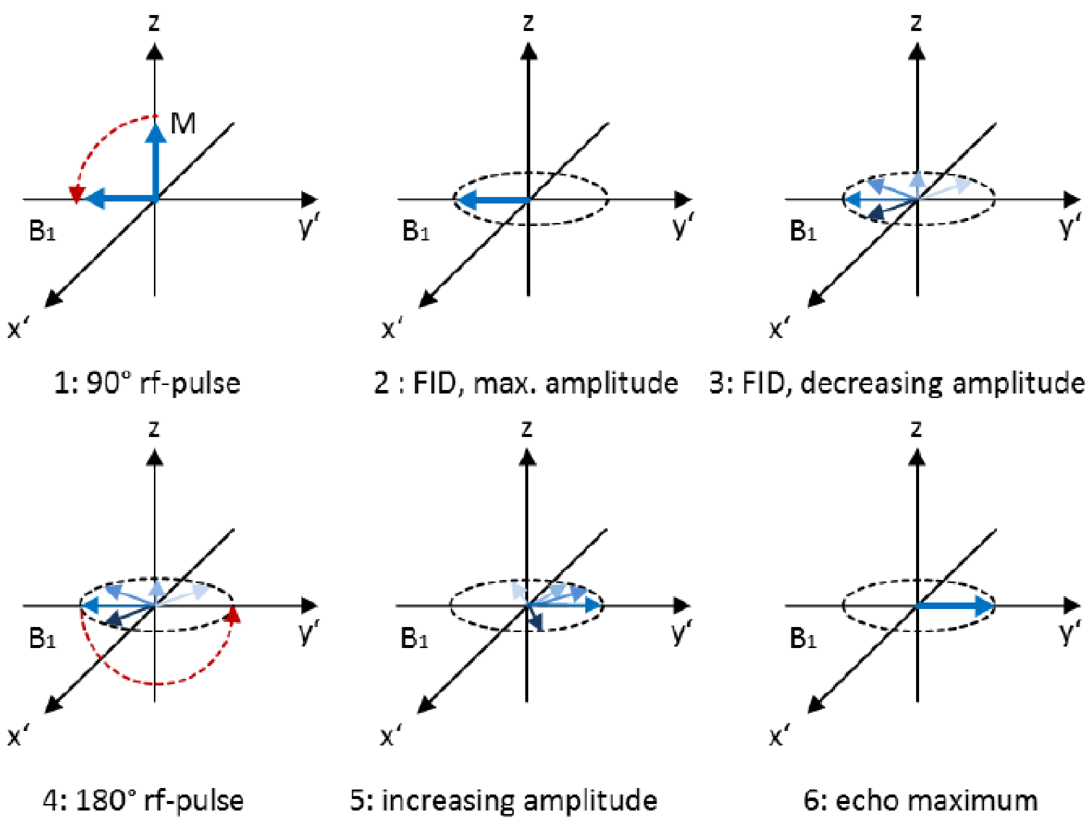


Figure 14: Generation of the Spin Echo

B. Experiment Background

The objective of this part is to generate a spin echo signal. The spins in the sample are affected by static as well as time dependent disturbances. A FID with a short decay time will be the result of these disturbances. Please refer to the results of the 3rd experiment; ***B0 homogeneity (magnet shim)***.

If the disturbances are constant over time – like for example the inhomogeneity of the magnetic field – the phase relationship that got imprinted onto the spins with the 90° RF pulse remains even if the total signal disappears. A 180° RF pulse re-phases the signal by "reversing" the precession motion of the spins. The signal amplitude reaches a maximum after which it decreases again. This maximum is called spin echo.

The sequence for this part is shown in Figure 15. At first, the sample is excited by a 90° RF pulse which generates an FID. After some time, a 180° RF pulse is applied to start re-phasing the signal. The time when the spin echo signal has its maximum is called echo time. This time depends on the time delay between the 90° and the 180° pulse.

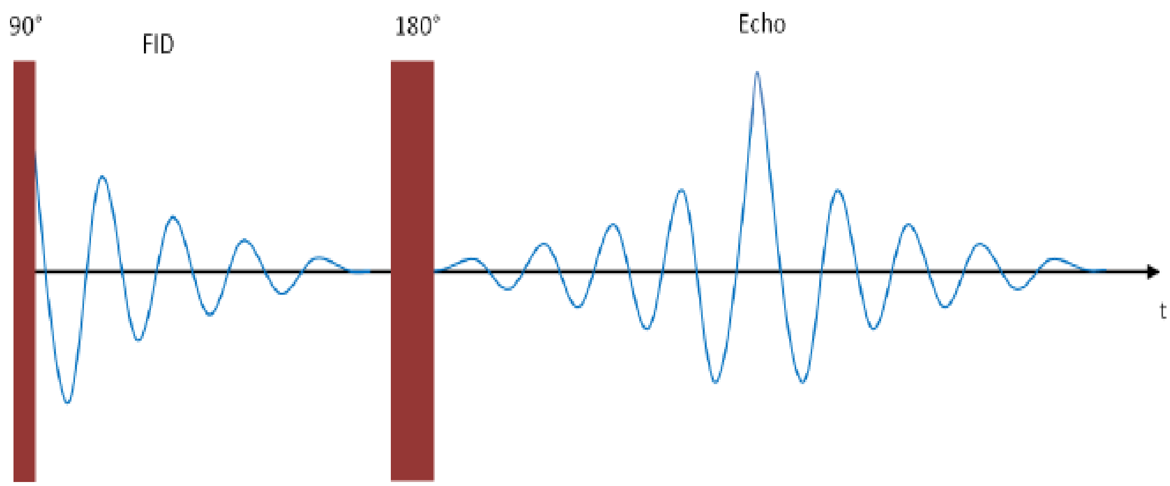


Figure 15: Pulse sequence for experiment Spin Echo

C. Experiment Steps

In this part, the 10 mm oil sample is used. Place the test tube named 10 mm Oil into the bore of the magnet. Select the lesson *Spin Echo*. The panel *Parameters* shows the sliders for the duration of the 90° pulse and for the second pulse. Furthermore, there is an option to adjust the echo time and a checkbox for the real and imaginary part of the signal. These parameters can be accessed in this experiment. Please compare your panel with the parameter panel shown in Figure 16. Please make sure checkbox for the real/imaginary part is selected.

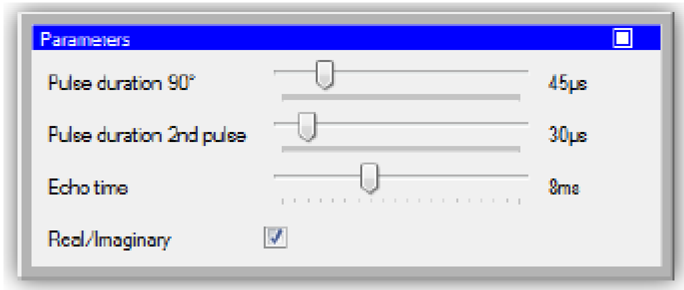


Figure 16: Parameters for experiment Spin Echo

With the slider *Pulse duration 90°*, you can adjust the duration of the 90° pulse.

The slider *Pulse duration 2nd pulse* is for adjusting the duration of the second RF pulse (180°).

With the slider *Echo time*, the echo time can be set by varying the time between the two pulses.

The checkbox Real/Imaginary indicates if the real and imaginary parts of the received data are displayed.

1. **Press Start for starting the measurement.**
2. **Change the duration of the second pulse by varying the slider *Pulse duration 2nd pulse*. What can you observe? Adjust the control *Pulse duration 2nd pulse* to obtain an optimum spin echo.**
3. **Now vary the pulse length of the 90° pulse with the slider *Pulse duration 90°*. How does this affect the FID and the spin echo?**
4. **Alter the echo time with the slider *Echo time*. What can you observe? (Hint: spin echo amplitude)**
5. **Set the duration of the first pulse to an optimum 90° pulse. An optimal 90° RF pulse is applied when the FID amplitude has a maximum. A further indication for an optimal 90° RF pulse is the disappearing of the FID after the 180° RF pulse. Why?**

VI. Spin Echo 2D

D. General MRI Background

During the de-phasing in the spin echo sequence which is usually performed in the period between the 90° and 180° RF pulse. The spin echo signal is acquired while the magnetic field gradient for the encoding of the location is turned on. To get a two-dimensional image you have to acquire a set of location encoded signals in two directions. By performing a suitable transformation (for example back transformation or Radon transform), the image can be reconstructed by calculating the Fourier transform in both directions. For example, to reconstruct an image with 128 x 128 pixels, 256 Fourier transformations are necessary – one transformation for each row and one for each column.

E. Experiment Background

The objective of this experiment is to acquire a 2D magnetic resonance image of a sample.

A 2-dimensional cross section of the sample is acquired. The acquisition is based on the spin echo method. In this measurement, the parameters can be set freely – similarly to clinical magnetic resonance tomography devices.

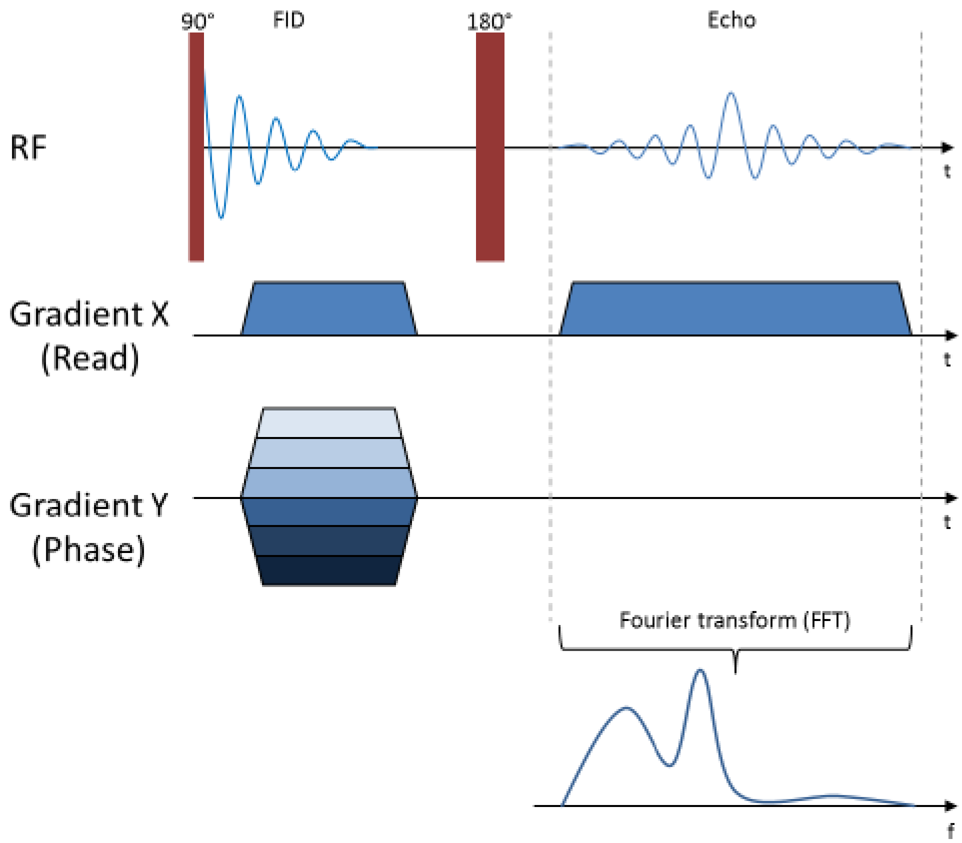


Figure 17: Pulse sequence for experiment Spin Echo 2D

F. Experiment Steps

In this experiment, both 5 mm test tubes containing water and oil and the 10 mm structure sample are used. You can also bring a non-metallic object of your own choosing that fits a 10 mm diameter test tube. At first, place both 5 mm test tubes into the bore of the magnet so that they are in one line and parallel with the rear edge of the magnet.

Select the lesson Spin Echo 2D. The panel Parameters shows the following controls:

6. Data points: The number of data samples acquired per phase step in read direction.
7. Phase steps: The number of phase encoding steps in phase direction.
8. Slice orientation: The plane of the cross section through the sample.
9. Read gradient: The gradient strength of the read gradient. The higher this value the bigger the size of the sample in read direction appears in the image.
10. Phase gradient: The gradients strength of the phase encoding gradient. The greater this value the bigger the size of the sample in phase direction.
11. Repetition time: The repetition time for each phase encoding step.
12. Averages: The number of averages.
13. Echo time: The echo time.

These parameters can be accessed in this experiment. Please compare your panel with Figure 18.

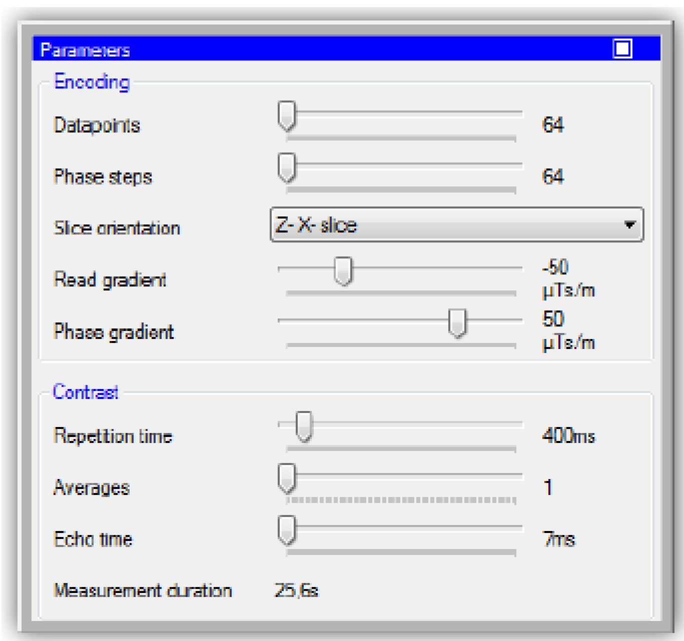


Figure 18: Parameters for experiment Spin Echo 2D

- **For the first MR image, choose the parameter as follows:**
  Data points: 64
  Phase steps: 64
  Slice orientation: Z-X-slice
- **Estimate the gradient strength for the read and phase gradient. Compare with the Spatial Profile obtained in Lab Work 3. Furthermore, set appropriate values for the repetition time and the echo time.**
- **Start the measurement. Save the acquired image.**
- **Vary the values for the repetition time and the echo time and repeat the measurement. What can you observe?**
- **Place the sample 10 mm Structure into the bore of the magnet and repeat this measurement. Save the acquired image.**
- **Download the *k*-space data and use MATLAB to reconstruct the MR image. Include your MATLAB code and the results obtained in your after-lab report. To preprocess the data, use the provided preprocess.m script.**

Experiment Expected Results

This section contains the expected results for each part of the experiment following the same flow as in previous section. You should be expecting to obtain similar results to the ones below, therefore, consider the results below as your reference results. However, you are expected to generate your own results and include them in your report after following all the steps in the ***Experiment Steps*** section.

I. MR Frequency

Figure 19 shows no NMR signal; check if the magnet and the control unit are connected and a sample is placed into the magnets bore.

- Activate the option Rough adjustment.
- Activate the option Real/Imaginary.
- Change the frequency by varying the slider *Frequency*

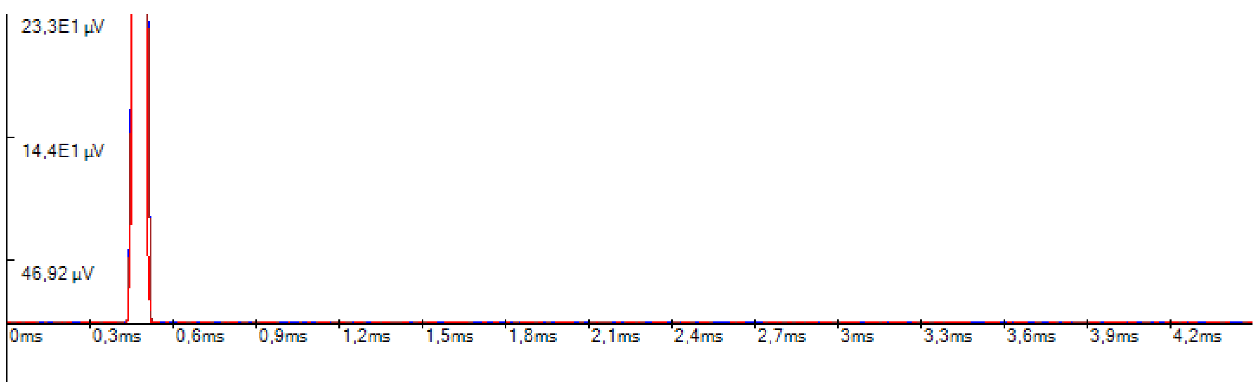


Figure 19: No NMR-signal

Figure 19 shows that the NMR signal is now detected; deactivate the option Rough adjustment. Change the frequency by varying the slider *Frequency* until there are hardly any oscillations left.

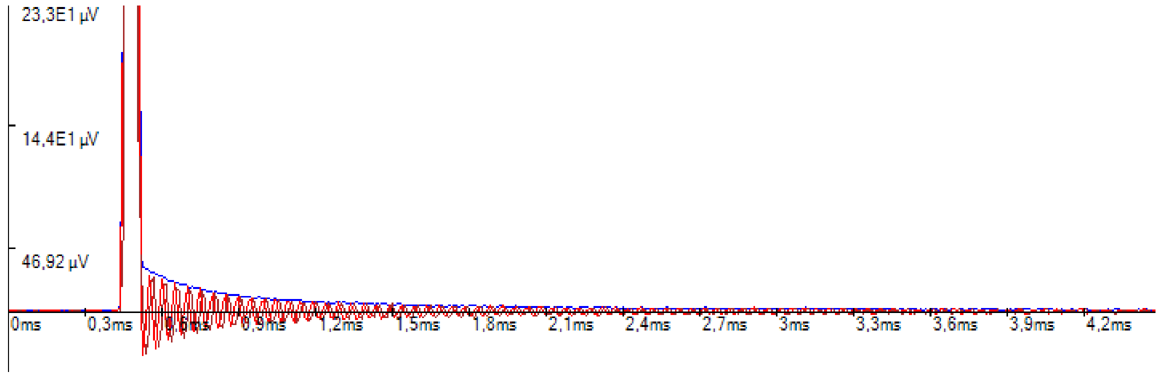


Figure 20: NMR-signal detected (fine adjustment)

Figure 20 shows when the system frequency matches the Larmor frequency; if there are hardly any oscillations left then the frequency is set right.

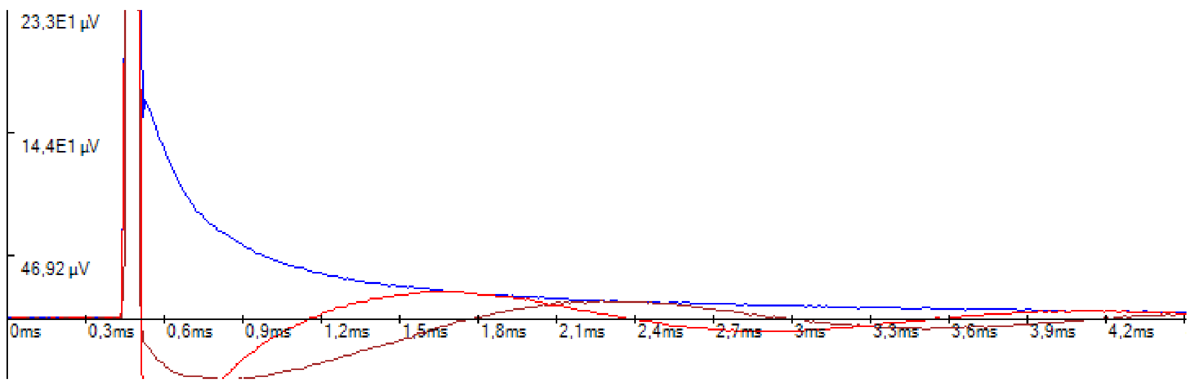


Figure 21: System frequency matches Larmor frequency

Note: All other experiments will make use of this setting so it is extremely important to set it right.

II. MR Excitation Angle

It is essential for all following experiments that this value is set correct. It is best when the amplitude of the FID (Free Induction Decay) is at its maximum. For Pure-Device magnets the default values are in the range between 30 µs to 60 µs and normally the optimum is around 45 µs.

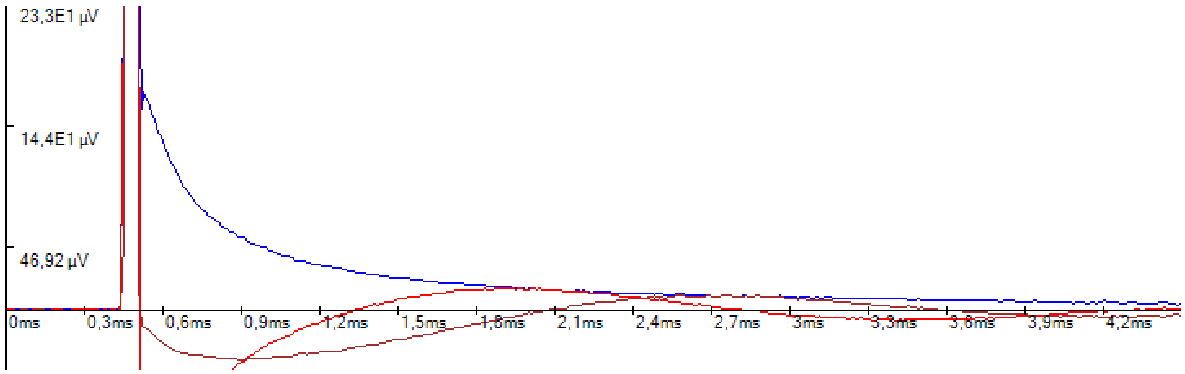
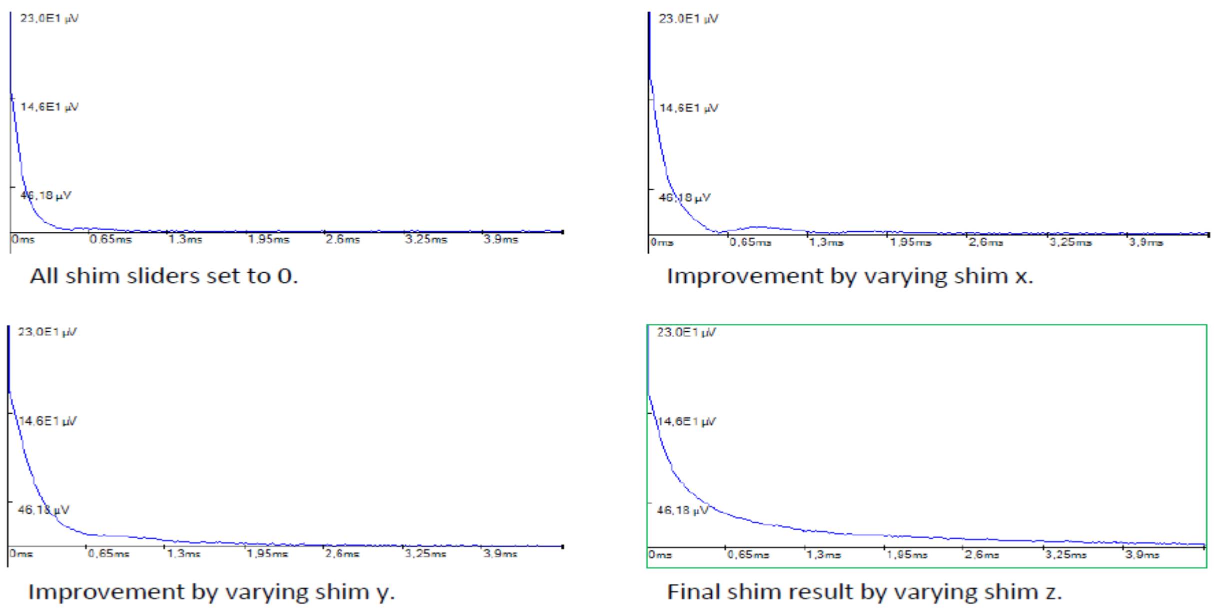


Figure 22: Maximum FID Amplitude achieved

Note: It is recommended to use a sample with a short T1-relaxation time like the 10 mm oil sample.

III. B0 Homogeneity (Magnet Shim)

It is best when the decay of the FID is as long as possible. To obtain the optimal FID you can vary the shim x, y, and z as below in Figure 23.



All shim sliders set to 0.
Improvement by varying shim x.
Improvement by varying shim y.
Final shim result by varying shim z.

Figure 23: Parameters for experiment B0 homogeneity (magnet shim)

Note: It is recommended to use a sample with a short T1-relaxation time like the 10 mm oil sample.

IV. Quantity Determination

In Figure 24 and Figure 25, you can see the optimal graphs which shows the highest amplitude for water 10 mm and water 5 mm samples, respectively.

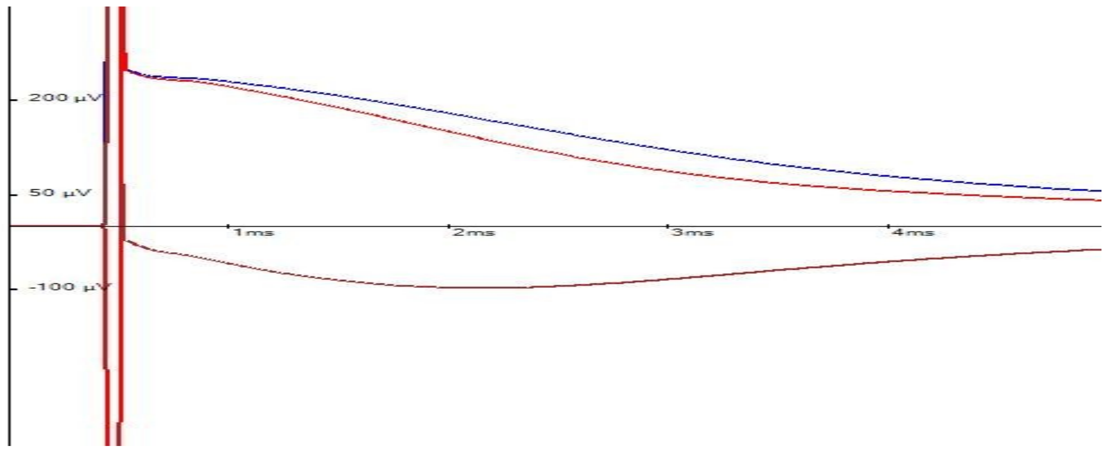


Figure 24: Signal obtained for 10 mm Water Sample

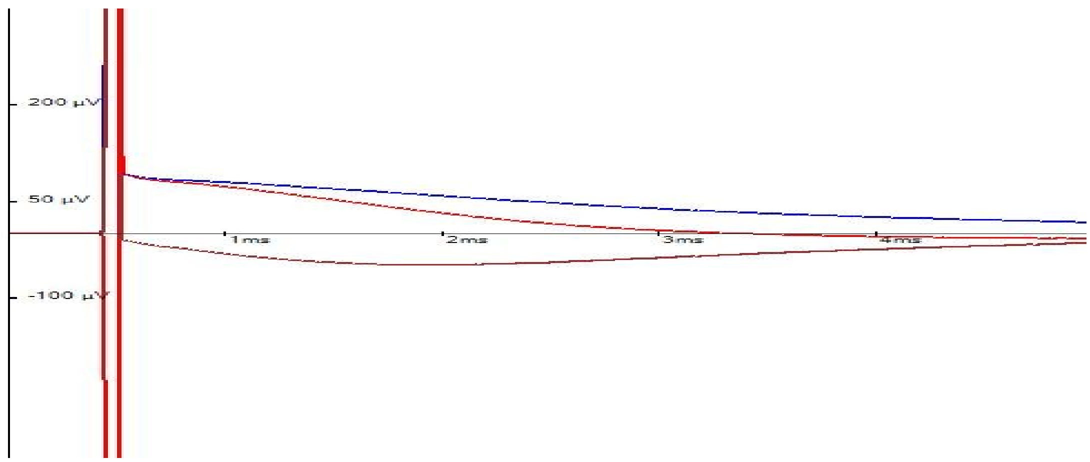


Figure 25: Signal obtained for 5 mm Water Sample

V. Spin Echo

Figure 26 shows the optimal spin echo signal for the 10 mm oil sample.

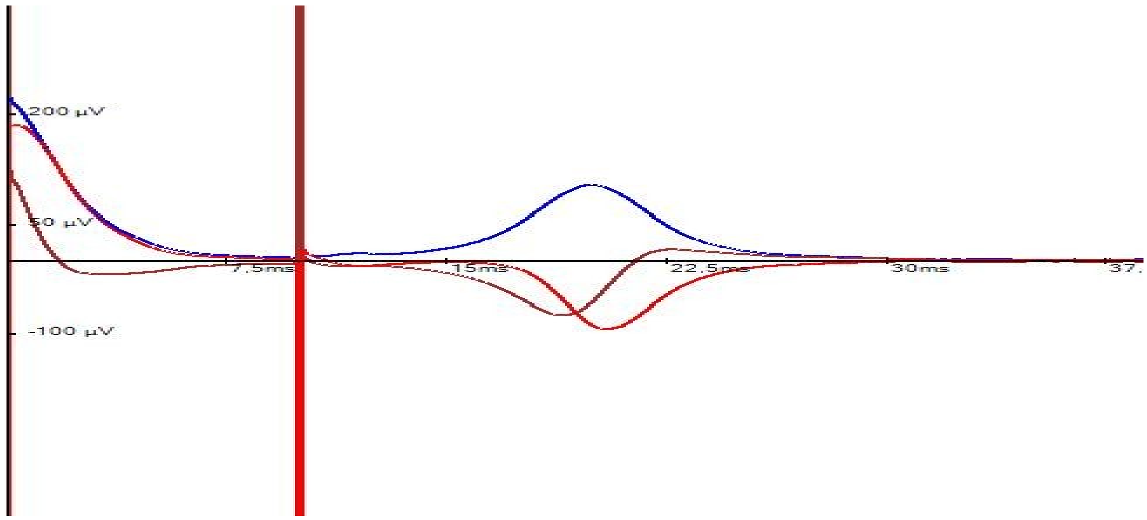


Figure 26: Optimal Spin Echo Signal for 10 mm Oil Sample

VI. Spin Echo 2D

Figure 27 below shows the Spin Echo 2D image for the 5 mm oil and water samples when they are placed together in the bore of magnet. While Figure 28 shows the Spin Echo 2D image for the structure sample.

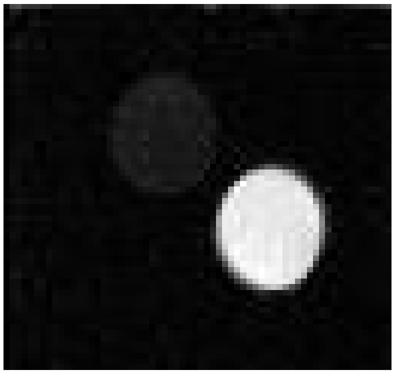


Figure 27: Spin Echo 2D for 5 mm oil and water samples

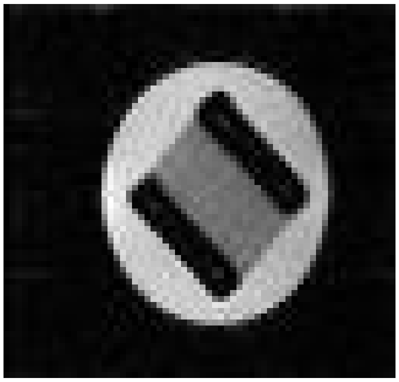


Figure 28: Spin Echo 2D for structure sample

Conclusion and Report Preparing

- Please include your answers and observations for the questions addressed in the ***Experiment Steps*** sections in your after-lab report, then submit it by the deadline announced.
- Your after-lab report is expected to include figures with their captions showing the results you were obtaining at each step of your experiment (preferable to have as many figures as possible).
- You can compile the report using, for example, Word or LaTeX.
- The report is to be returned on MyCourses (Project work section) by **April 29**.