Erdfeld-NMR Remote

Physikalisches Fortgeschrittenenpraktikum an der Universität Konstanz

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Abstract

TEXT

Alle Autoren haben zu jedem Abschnitt wesentliche Beiträge geleistet. Die Autoren bestätigen, dass sie die Ausarbeitung selbstständig verfasst haben und alle genutzten Quellen angegeben wurden.

Contents

1 Einleitung

2 Aufbau und Durchführung des Versuchs

3 Noisemeasurement

The first step in the EFNMR Remote experiment is to measure the external noise. The external noise depends on the location where the setup is placed, the orientation of the probe and by surrounding metal objects e.g. a metal desk. To detect this external noise, a measurement without an NMR signal is provided. The time domain noise signal is shwon in figure **??**. It is clearly visible that the noise is centered around $0\,\mu$V. To gain knowledge about the noise level, the computer calculates the root-mean-square (RMS). This means that it calculates the square of each data point, than sum up all squared values up, calculates the average and than applies a square root. With this method the noise level can be calulated. In this case it is $7.5\,\mu$V. This is an ecceptable noise value, because any value below $10\,\mu$V is good enough to provide good NMR data.

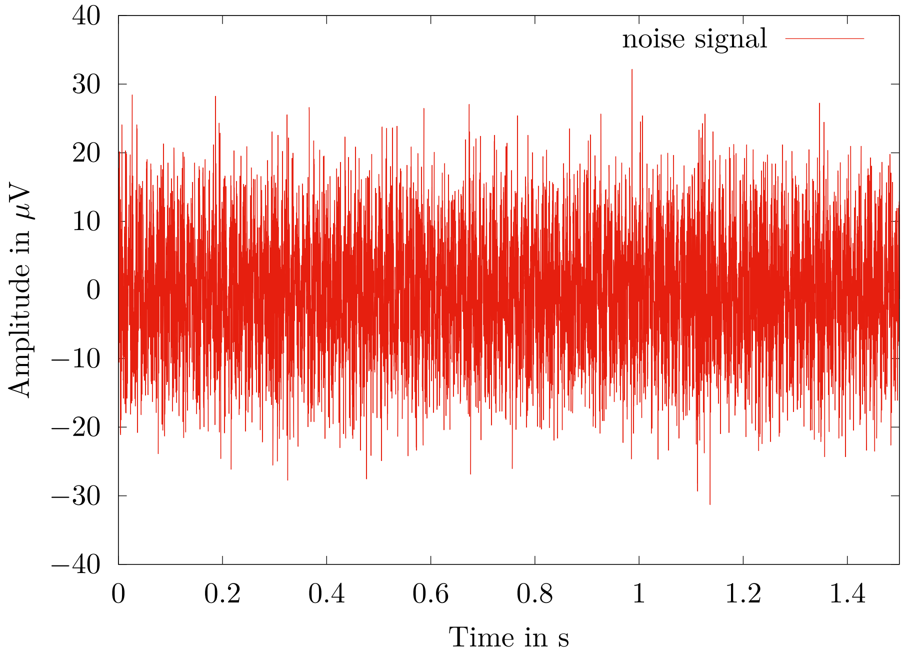

Figure 3.1: average cero, root square -> flip it positive

Figure **??** shows the frequency domain noise. This means that the time domain is fourier transformed into the frequency domain. This method is one of the basic principles we use in this experiment to make research about the properties of the measured signals. The frequency domain noise shows very specific sharp peaks every 50 Hz. To be more specific the peaks in the middle of every hundred Hz steps are way higher than those at 1400 Hz, 1500 Hz and so on. This results of the frequency in the power grid which is 50 Hz in

Germany. wieso sind die geraden kleiner??? Steckdose erklärt eig nur peak bei 50hz und nicht die alle 50 hz Despite all sharp peaks there is also a slight increase of the amplitude around 1850(1000) $\frac{\mu\text{V}}{\text{Hz}}$ visible. This is explicable by the resonance frequency of instrument and its sensitvity around the lamorfrequency (1841.4 Hz for water in Germany in July 2020). Nearby the lamorfrequency all our following measurements will be done that is why the instrument sensitvity is sharpend around this value.

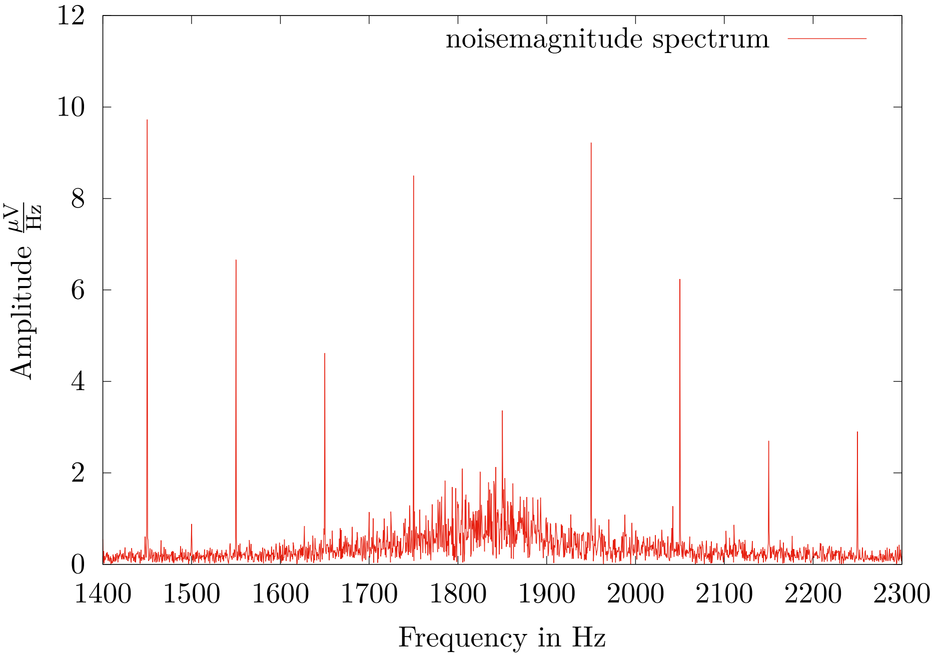

Figure 3.2

4 Coil Analysis

Now knowing that we have a acceptable noise value under 10 μV, we can analyse the coil. In order to do so we explain the general approach of NMR signals first. To measure a NMR signal a pulse and collect measurement has to be done. Therefore the B_1 coil (transmit and collect coil) has to apply a pulse. This pulse changes the spins direction out of its thermal equilibrium (along z-axes, due to the earths magnetic field B_e) into a direction with a component in the transversal plain. Therefore the B_1 coil collects a signal, because its aligned orthogonal to B_e. The transmit and collect procedure is based on Faraday's law of induction. Figure **??** exemplary shows such a collect signal by the B_1 coil. Every following measurement in this paper is based on the procedure of pulse and collect.

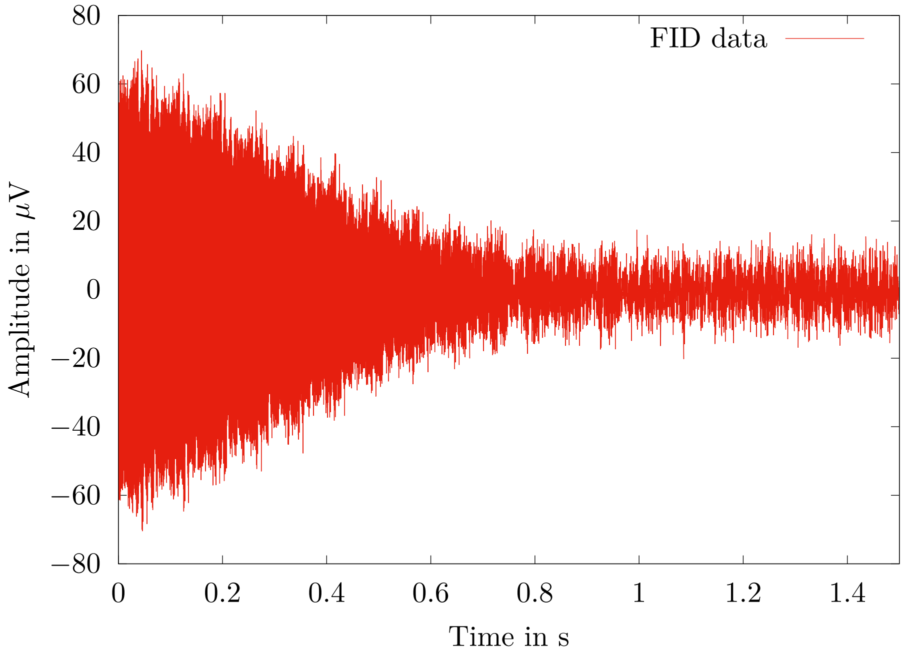

Figure 4.1: abc

Due to the fact that the B_1 coil is a tuned LCR circuit a resonance frequency exists, which can be caluclated by following formula:

$$\omega_{calc} = \frac{1}{\sqrt{L \cdot C}} \; . \tag{4.1}$$

To analyse the B_1 coil the resonance frequency versus the capacity is measured. Therefore the B_1 coil transmits a signal. Due to this signal the response of the coil can be measured. This signal is than fourie tranformed and the resonance frequency can be deduced from the frequency domain (maxmimum in the frequency domain). This procedure is repeated automatically by the computer programm "*Prospa*" for different capacities. By changing the capacity we can examen the best capacity in dependence of the lamor frequency. Figure **??** shows the measured and theoretically calculated resonance frequency (Equation **??**; $L = 0.417\,\mathrm{H}$) in dependence of the capacity. The horizontal line represents the lamor frequency of 1841.4 Hz for water in Germany in July 2020. To gain this value the vertical component of the earths magnetic field (43 248.8 nTQuelle Marc) is multiplied to the gyromagnetic ration $42.577\,\frac{\mathrm{MHz}}{\mathrm{T}}$. Quelle Marc. The vertical line represents the correct capacity we should use for our measurement, due to the resonance frequency of the lamor frequency. In this case the correct capacity is 13.8 nF. For the calculated resonance frequency the correct capacity would be 17.9 nF. It is not deniable that the measured curve is not parallel to the measured resonance frequency. This probably has its cause in the not fix inductance L. Due to heating of the coil L might change a little by increasing capacity and thus the calculated curve does not fit to the measured one.

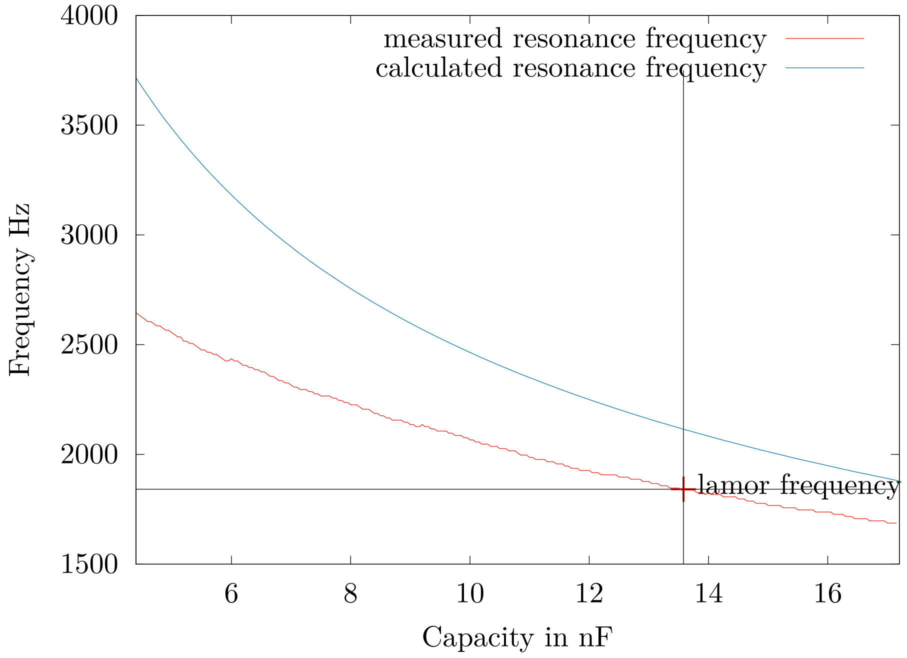

Figure 4.2

5 Optimization and Characterisation of FID in water sample

insert previous values On of the main goals of this experiment is to measure a good FID of the water sample. In order to do so we first have to optimize our FID signal of the water probe.

First the inhomogenity of the magnetic field has to be cancelled. The process to make the magnetic field more homogenious is to *autoshimm* the components of the gradient coil. The computer programm does this automatically. So it deshimms the system step by step and checks if the output maximizes or minimizes. By checking many different combinations it finds the best shimming values for the gradient coil. In our case they are:

$$x = 10.11\,\mathrm{mA}$$
$$y = 20.88\,\mathrm{mA}$$
$$z = -20.07\,\mathrm{mA}\ .$$

That means with those shimming values the magnetic field in the setup is homogenious. The secon optimization step is to change the B_1 pulse duration. The longer the pulse duration is, the bigger is the angle of the flipping spins and thus the signal will get stronger (only counts for flipping angles till 90°). The best signal is obtained for an flipping angle of 90°, because with this angle the spins only have a component in the transversal plane and therefore the signal is maximized. If the pulse duration is too long, than the flipping angle is bigger than 90° and the spins get a horizontal component again and the signal will decrease again. When a flipping angle of 180° is reached the signal will be at its minimum. Afterwards the signal will raise again, because the horizontal component will increase again. Figure **??** shows this issue. The maxmimum at a pulse duration of 1.35 ms is clearly visible. This means that after apllying a B_1 pulse with a duration of 1.35 ms the spins are in the transversal plane and therefore the best signal is obtained.

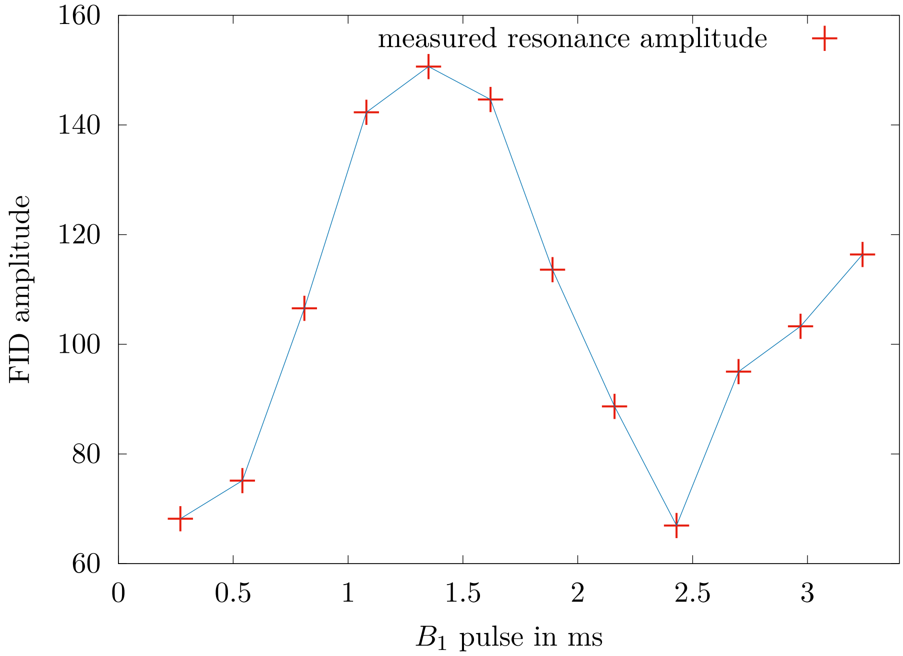

Figure 5.1: ask: periodicity due to duration of B_1, 0° -> 90° -> 180° -> 270°? -> yes

Figure ?? exemplarily shows the correlation of the B_1 pulse duration and the signal which the coil detects. It is clearly visible that the amplitude is better for the pulse duration of 1.35 ms than for the pulse duration of 0.27 ms. The signal that was taken for the pulse duration of 0.27 ms is at the minimum of the figure ?? and therefore it is correct that the amplitude of the spectrum with the pulse duration of 1.35 ms is higher.

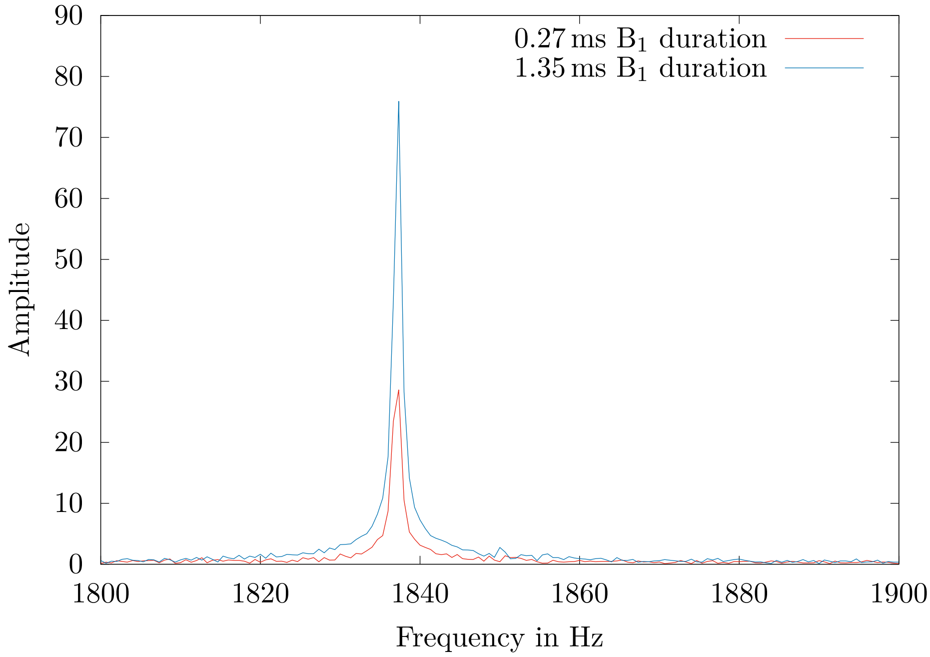

Figure 5.2

Now that the B_1 pulse duration is also optimized, we can have a closer look at the capacity of the LCR circuit of the B_1 coil again. First it is necessary to know that the B_1 pulse is applied by a *rectangular* function and the fourie transformation of a *rectangular* function is a *sinc* function. Therefore the fourie ransformed spectrum of the B_1 pulse signal is a *sinc* function. When we measure the signal shortly (acquisition delay: 2 ms) after the 90° pulse there shoud be a *sinc* function visible and indeed this is what we obtained (figure ??). In figure ?? there is also a really sharp peak visible. This is referd to the hydrogen signal. The hydrogen signal is independed of the applied capacity, but the B_1 pulse is, because the capacity changes the properties of the LCR-circuit of the B_1 coil. The best capacity is adjusted when the hydrogen signal is in the middle of the *sinc* function, because then the LC- circuit is tuned to the lamor frequency of the hydrogen signal. This is also visible by the amplitude of the spectrum in figure ??. The ampitude of the spectrum which was observed for a capacity of 13.8 nF is higher than for the ampitude of the spectrum which was observed for a capacity of 14.2 nF. As already explained before in the chapter **??** the capacity of 13.8 nF is indeed the best capacity in order to observe a maximized spectrum.

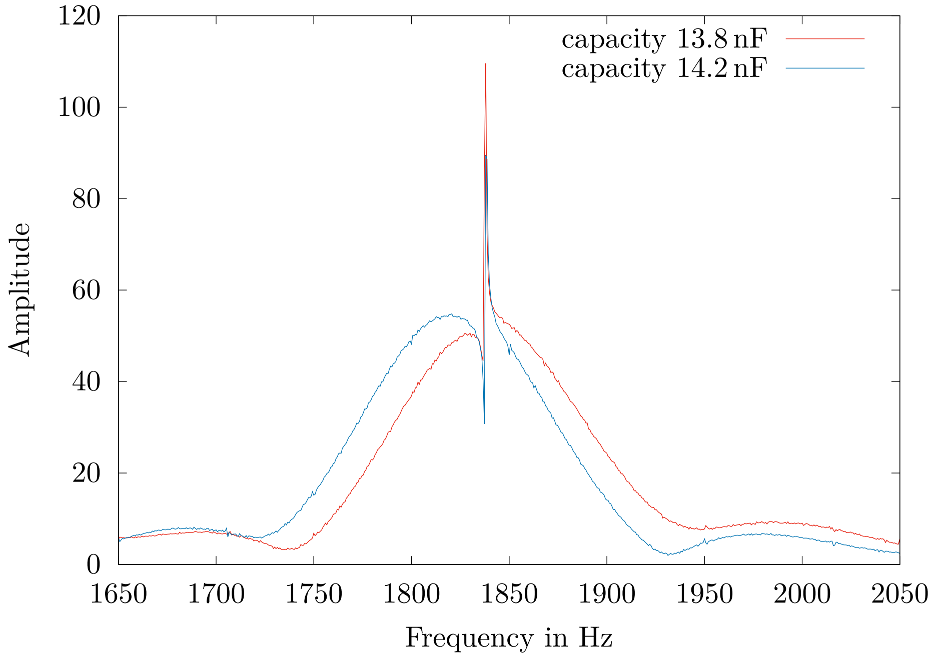

Figure 5.3: ask: what is the peak corresponding? hydrogen signal? -> yes

Now that the FID signal is optimized best we can start to characterize it. Therefore we measure a FID with a acquisition delay of 25 ms, because after this delay there are no effects from the rectangular applied B_1 pulse anymore (no *sinc* function in the spectrum). The figure **??** shows the observed spectrum and two different fit possibilities.
One option to fit a peak in a spectrum is by applying a *voigt*-profile ($V(x;\sigma,\gamma)$). This function is a convolution of the *Cauchy-Lorentz*- and *Gaussian*-distribution and is described by following formula:

$$V(x;\sigma,\gamma) = (G \star L)(x) = \int G(\tau)L(x-\tau)d\tau \tag{5.1}$$

$$G(x;\sigma) = \frac{exp\left(\frac{-x^2}{2\sigma^2}\right)}{\sigma\sqrt{2\pi}} \tag{5.2}$$

$$L(x;\gamma) = \frac{\gamma}{\pi\left(x^2+\gamma^2\right)} \ . \tag{5.3}$$

σ represents the standard deviation, γ is half of the peak width at half height from the *Lorentz*-distribution and x is the shift from the line center. In figure **??** the *voigt*-profile (green) is fitted to the measured spectrum (red). The problem about this fit is that is not as sharp as the measured data. This might be, due to the fact that the measured spectrum does not have many data points especially around the maximum. Therefore the peak is really sharp and a correct fit with the *voigt*-profile is rather difficult. Therefore a second fit function has been apllied. This time only the *Gaussian*-distribution. This fit function is better to calculate the width of the peak, due to the fact that it easier to fit to this narrow peak. The disadvantage of the *Gaussian*-fit is that area under the curve does not equal the measured one, especially around 1836 Hz and 1839 Hz.

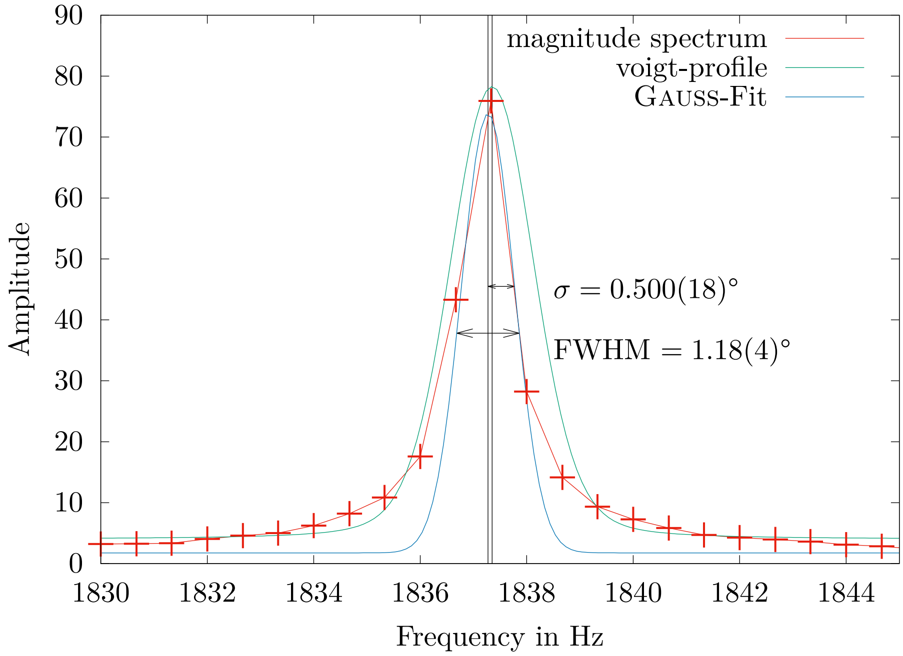

Figure 5.4: ask: gauss or voigt. this is gauss -> both
longer acquisition 25 ms -> only hydrogen siganal? is the peak the same than in the previous diagramm? -> yes
integral under curve with our measured fit? -> try to find soemthing, try shorter range and more points
signal to noise ratio: what to do? -> magnitude, which unit is the amplitude, tutor will send us an email, try back fouriertransform (only keep real values)
calculate: amplitude; crossbar for datapoints
sometimes 1/e sometimes 1/2 -> definition

real and imaginary signal -> explain it

6 Longitudinal relaxation measurements T1

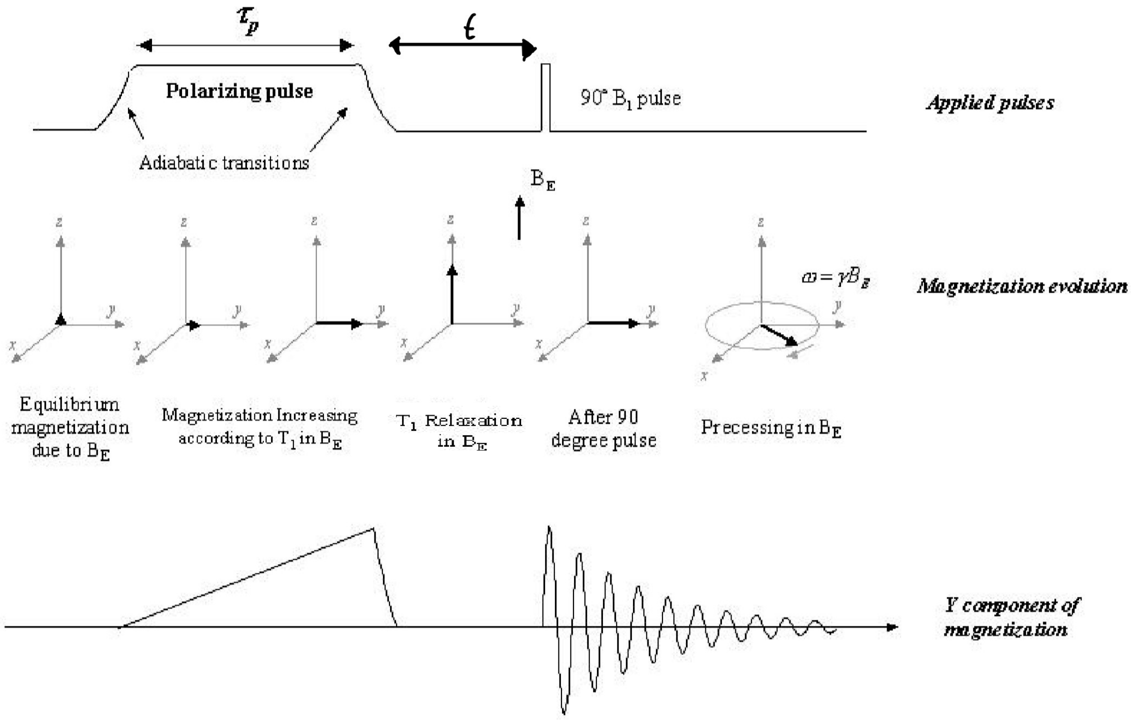

Figure 6.1: Anleitung von T Messung [?]

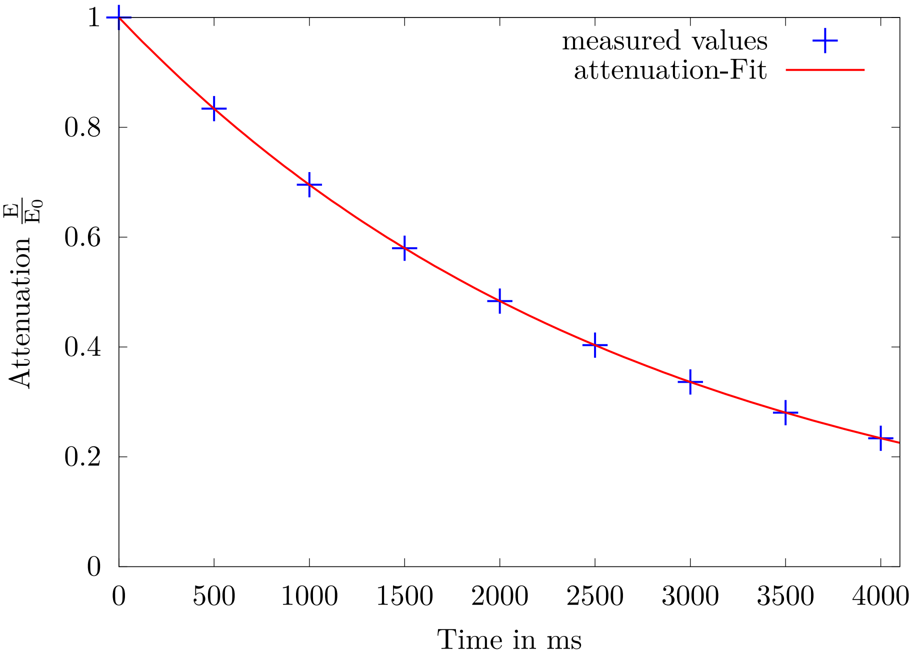

Figure 6.2: explain what happens; $S_0 * exp(-x/T_1)$ mit $T_1 = 2753.05\,\mathrm{ms}$

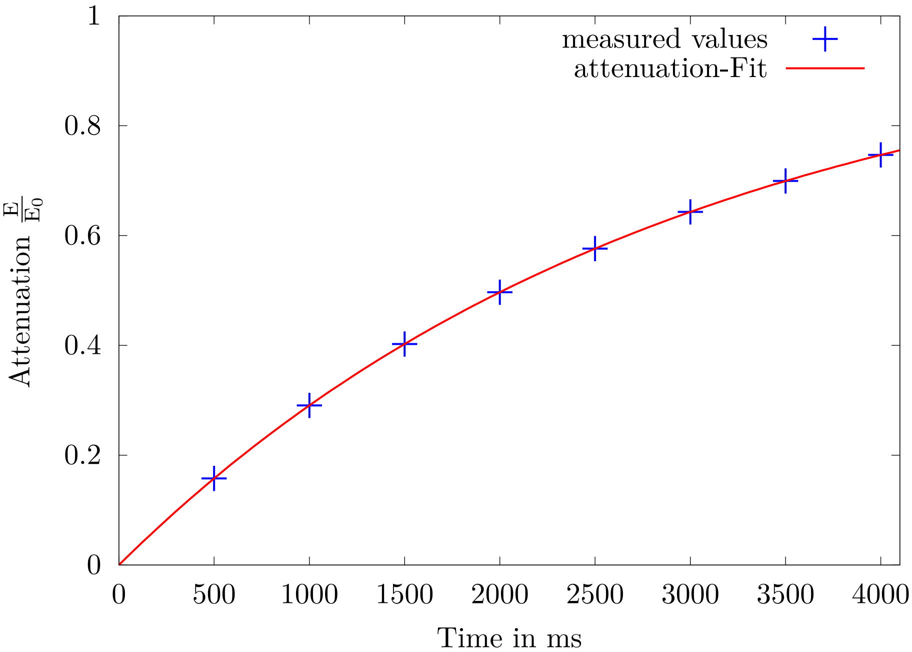

Figure 6.3: explain what happens. wieso 0.2 überall unterschied -> longer x-Axes, more datapoints; $S_0 * [1 - exp(-x/T_1)]$ with $T_1 = 2912\,88 ms$

7 Hahn echo

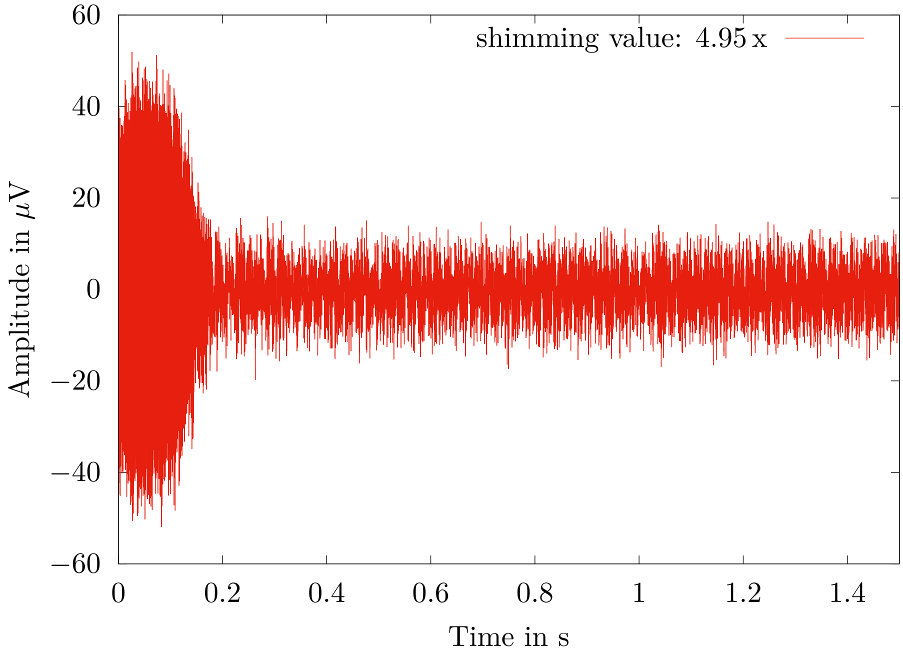

Figure 7.1: ask: wie safed no data for differnet τ, is it ok just to explain it that the amplitude will decrease and the maximum will be shifted to a different time? -> yes this is an example for a hahn echo with shimming value 4.95 x.

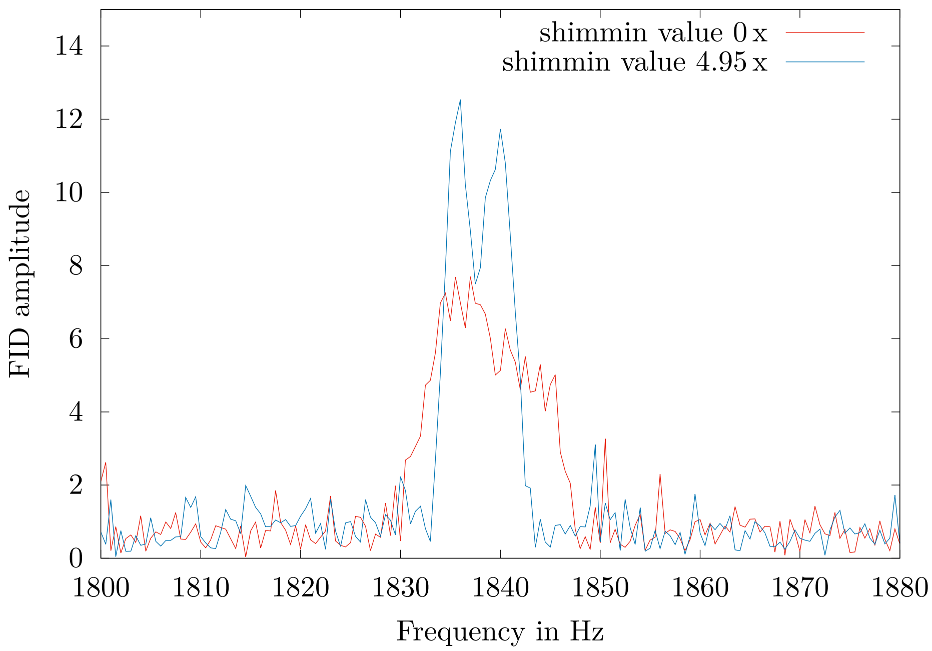

Figure 7.2: ask: why are there different peaks a different shimming values?-> more frequency is sean (random) depends on position
which formula should we use to fit it? -> area under normalized spectrum should be the same; just discuss it -> narinder will send email
for us: wieso signal schwächer-> mehr abweichung beim shimming (ursprünglich 10.11)-> abschwächung. integrale bei unterschiedlichen shimming; echo time 300ms bei beiden.

We can measure T_2 when we don´t change the shimming values, because T_2^* is dependent on a field inhomogeniousity. -> CPMG, Spin Hahn echo

8 Multiple echo sequences

explain timedomain -> short discussion: fucntion (sine-bell-squared function? Section 5.5.3.2) to smoothen (because it doesnt change physics)

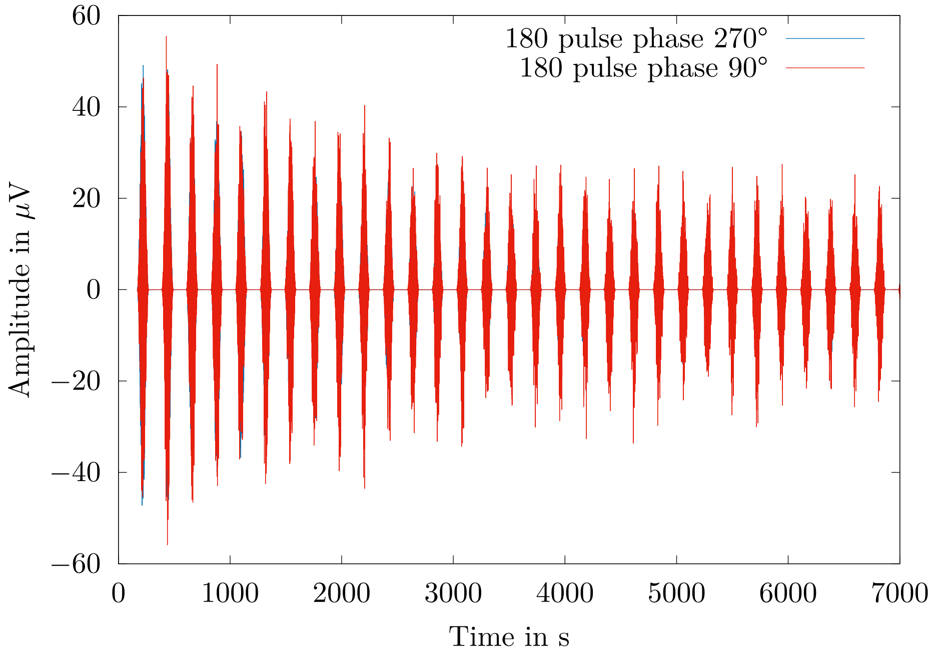

Figure 8.1: ask: what does pulse phase degree between 90° and 180° (or also between 180° and 180°) mean (Anleitung 9.)? -> minimize term of inhomogeniuos magnetic field; it is not the time between the pulses; phases
difference between alternating and constant 180° pulse phase-> alternating phase: computer does change phase degree; constant: manual change of phase degree-> look up manual for alternating; explain it
we only have data for 180 pulse phase degrees in 270° and 90°, but those two are the same and this is good, but we don´t hae values for 180° example. -> ask pther group for measuremtns at about 180 degree
we didn´t make measurements about 90 pulse phase degree

9 Transversal relaxation measurements

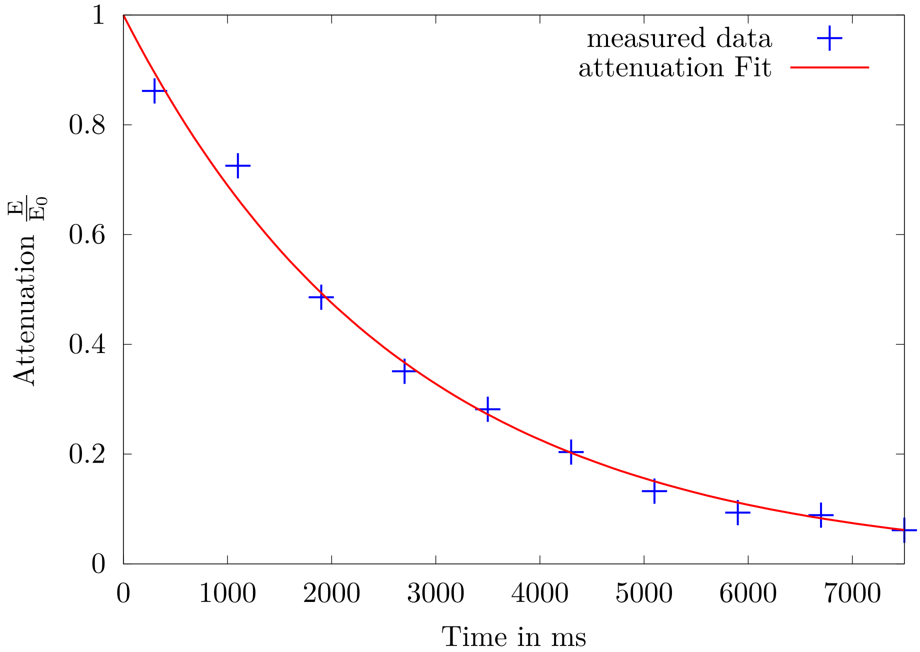

Figure 9.1: ask: why are two peaks visible in the magnitude spectrum?
normal FID-> T_2
$M(x) = M_0 \cdot exp(-x/T_2)$ with $T_2 = 2691\,06 ms$

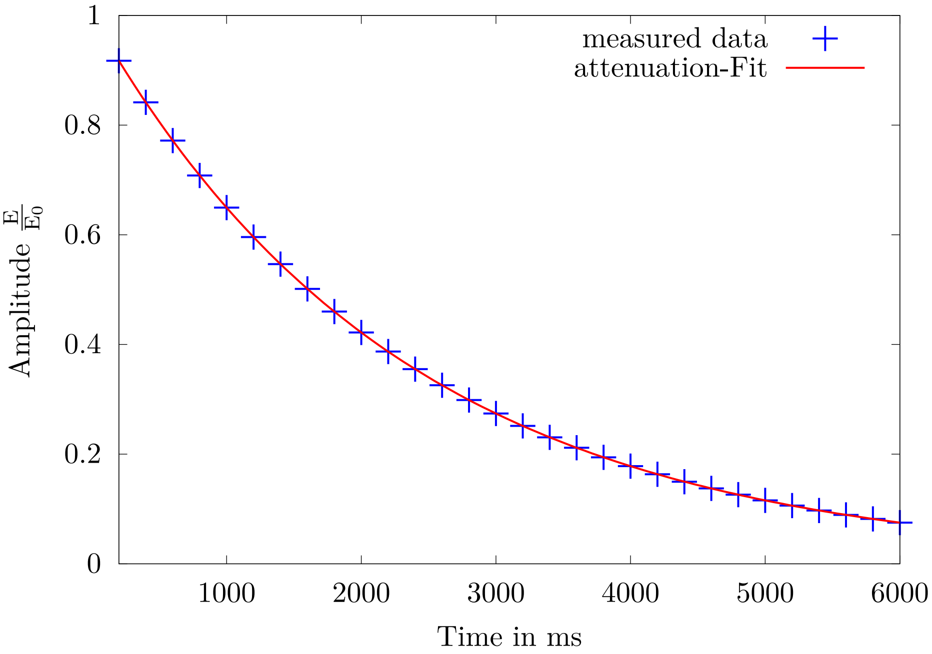

Figure 9.2: This is an CPMG with changeed values in the shimming; shimming value 0.45 x -> T_2^*.
Good to see that the T_2^* is here shorter than in the previous picture, due to inhomogeniousity of the magnetic field.
$M(x) = M_0 \cdot exp(-x/T_2)$ with $T_2 = 2317.76\,\mathrm{ms}$

10 Fehlerdiskussion und Fazit

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