Diffusion

NMR

User Manual

Version 004

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1 Introduction

This manual targets the **installation engineer**, helping them to understand all of the features available for the diffusion accessory. The manual also provides valuable information for entry level users who are getting started with the diffusion system.

The manual is based on TopSpin 3.5, but most of the content is also valid for previous and future versions. TopSpin 3.5 supports two versions of the diff program in parallel, diff-4.13, herein after referred to as **diff4**, and diff-5.3, herein after referred to as **diff5**. The two versions coexist for the most part, but diff5 does not have all the methods offered by diff4, and likewise diff 4 does not have all the new methods offered by diff5. This coexistence offers the advantage of still using the old version while learning the new. Most of the steps described in this manual showing diff5, but the step by step guide and the program reference manual are provided for both versions.

Due to the similarity of the imaging and diffusion hardware and software, this manual overlaps the AVANCE Imaging Manual in parts. Therefore, the reference to **imaging** will often appear, but can be used interchangeable with **diffusion**.

1.1 Disclaimer

The diffusion accessory should only be used for its intended purpose as described in this manual. Use of the unit for any purpose other than that for which it is intended is taken only at the users own risk and invalidates any and all manufacturer warranties.

- Service or maintenance work on the diffusion accessory must be carried out by qualified personnel.
- Only those persons schooled in the operation of the diffusion accessory should operate the unit.
- Read this manual before operating the unit. Pay particular attention to any safety related information.

Introduction

2 Installation

This chapter provides information on setting up the hardware and software required in the diffusion system. The chapter is especially important when setting up the system for the first time. The manual is designed for AVANCE III and newer systems running TopSpin3.5.

2.1 Installing the Diffusion Software

This manual describes diffusion software version diff-5.3, called by the command **diff5** in TopSpin 3.5. However, most of the content discussed in this manual will be valid for all diff 4.x versions and, to some extent, older versions as well.

The diffusion package is part of the micro-imaging package. To activate the package, check the checkbox Micro-Imaging and Diffusion Systems during the **expinstall** procedure.

2.2 Installing the Diffusion Hardware

The installation of the diffusion/imaging rack is described in detail in the Micro-imaging Manual for AVANCE III Systems. Therefore this step has been omitted in this manual. Nevertheless some details of the imaging rack are provided in the chapter *Imaging and Diffusion Hardware [143]*.

2.3 Gradres

The parameter GRADRES defines the step width for the Digital Pre-emphasis Processor (DPP). Although this should work over a wide range of values, currently this parameter must be set to 8, i.e. 8 µs for GREAT40/GREAT60 systems. Other values may work as well, but only 8 have been extensively tested.

Note: Currently the parameter GRADRES can only be checked or modified by editing the file: <*TopSpinHome*>*/conf/instr/spect/uxnmr.par*

2.4 Installing a Diffusion Probe

The following sections describe how to set up the diffusion probe in TopSpin. For specific details on diffusion probes, refer to the chapter *Probes and Gradients [▷ 135]*.

2.4.1 Defining a Probe in Edprobe

Before a probe can be used in the diffusion system, it must be defined in Edprobe as follows:

- Connect the PICS cable to the probe.
- Type **edprobe** in the TopSpin command line, the Edprobe dialog will appear:

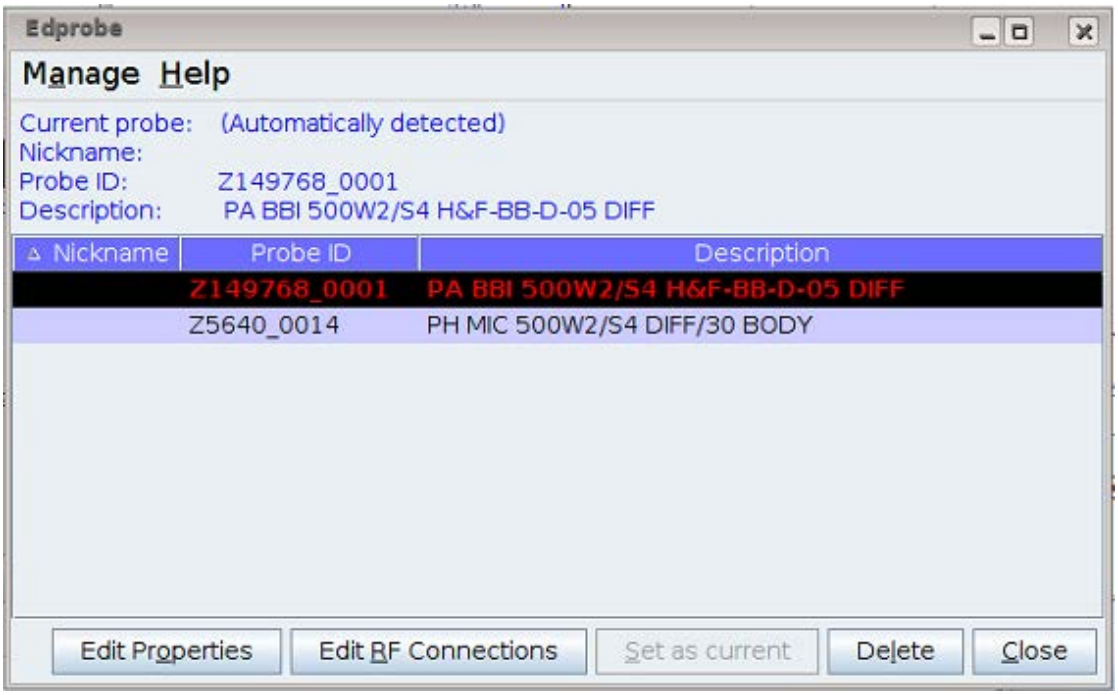


Figure 2.1: Edprobe Window

If the probe has correct PICS information, as shown in the figure above, the definition is already finished.

If the probe has no or incomplete PICS information, which is usually the case with older probes, the PICS cable should stay connected for the rest of the installation. However if the PICS information is incorrect for the probe, the PICS cable must be disconnected and remain disconnected for the rest of the installation. Information on determining whether the information is right or wrong will be discussed in the following sections.

2.4.2 Probes with PICS

If the probe has PICS data, the first step is to check the consistency of the data.

- In *edprobe* click **Edit Properties**.

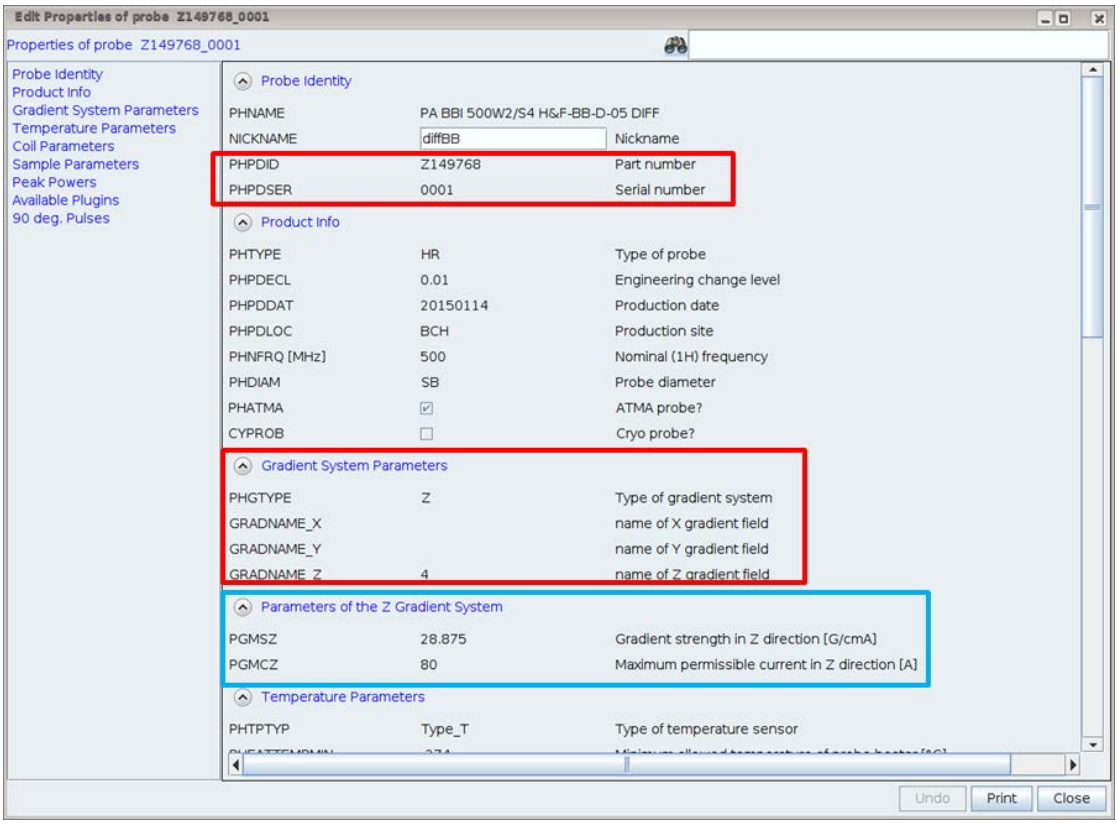


Figure 2.2: Edprobe Properties, First Part. Important Parameters are Framed Red, Blue Framed Parameters are Optional.

- Enter the correct part and serial number In the *Probe identity*.
- The *Gradient System Parameters* are very important for TopShim. If they are not set correctly, TopShim will most likely fail. The GRADNAME values for different gradient systems are given in the table below.

Gradient system	Part number	PHGTYPE	GRADNAME_X	GRADNAME_Y	GRADNAME_Z
diff30	M81113	Z	-	-	4
diff50	W122305	Z	-	-	19
diff60	M81163	Z	-	-	11
micro5	M81111	XYZ	104	204	304
diffBB		Z	-	-	4

Table 2.1: **Gradient Names for Topshim**

- The *Temperature Parameters* must be set to reasonable values, TopSpin 3.5 uses them automatically. All diffusion probes have the PHTPTYP = *Type_T*.

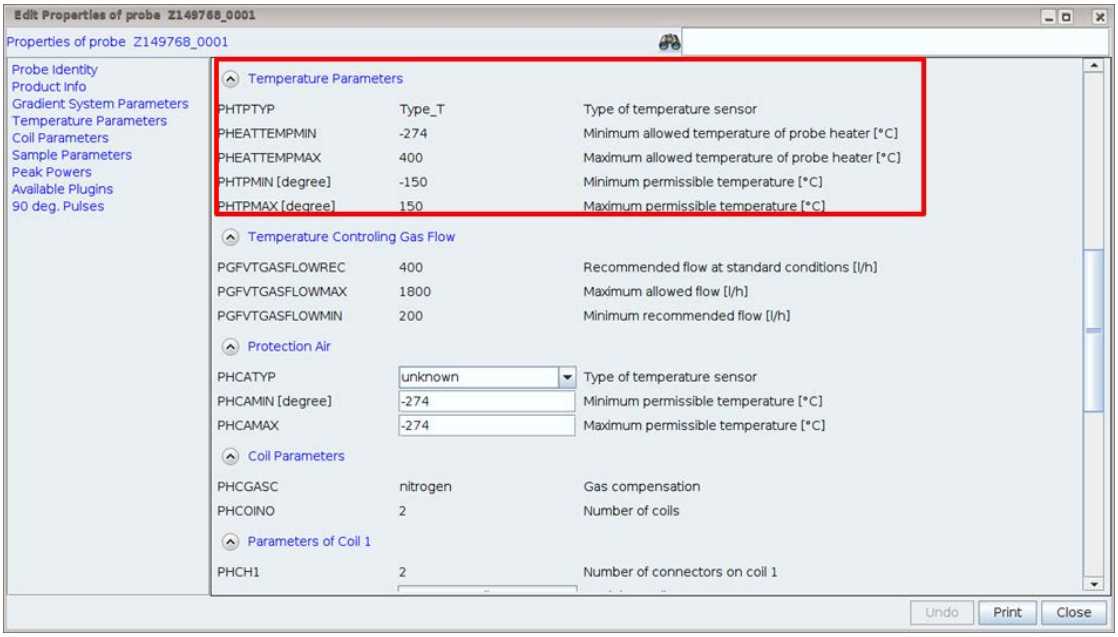


Figure 2.3: Edprobe Properties, Second Part. Important Parameters are Framed Red.

- The *Parameters of Coil 1* and *2* must be defined allowing the routing later on.
- If *power check* is used, the *Peak Powers* levels must be set for each used nucleus.

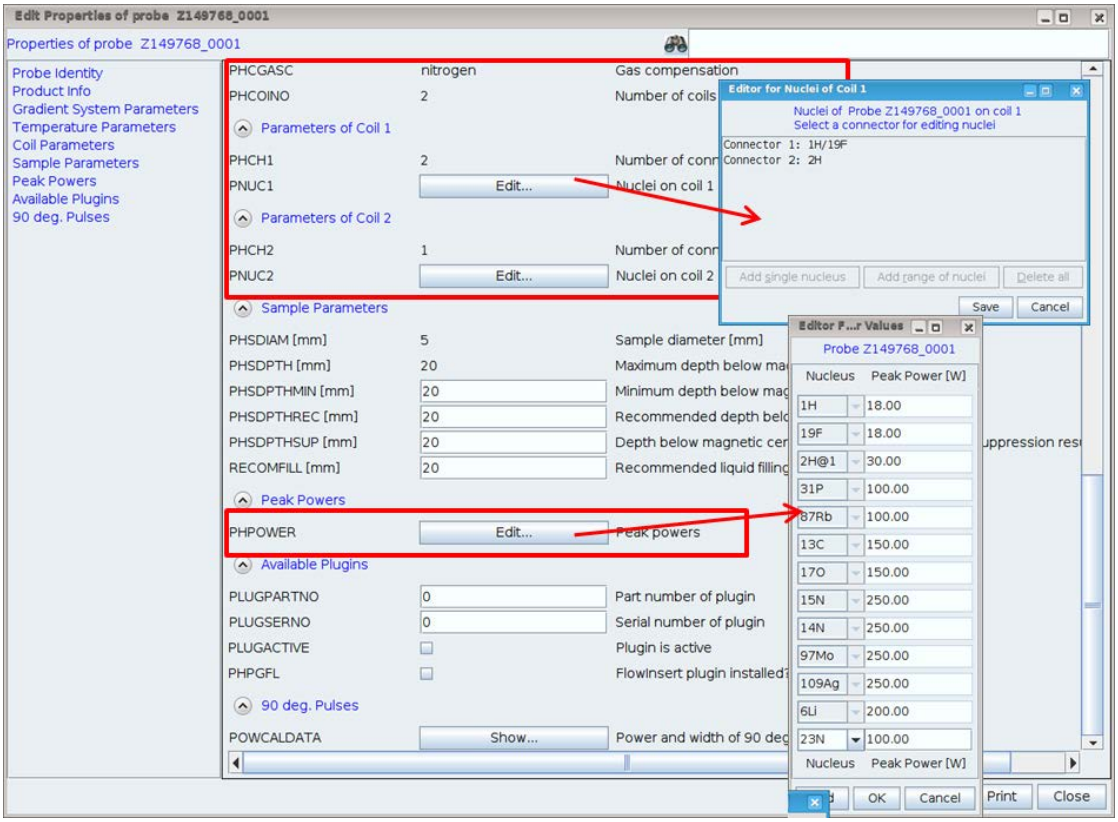


Figure 2.4: Edprobe Properties, Third Part. Important Parameters are Framed Red.

Note: At the moment the PICS description is only completely valid for probes with fixed inserts like the diff30L or diff50L, or the new diffBB. New probes must be sent back to the factory, if the PICS is not correct. Probes with exchangeable inserts are described below.

2.4.3 Probes without PICS

If a probe has no PICS or incorrect PICS data, which is often the case with older probes, the procedure to verify the information is as follows:

- Disconnect the PICS cable.
- Type **edprobe** in TopSpin.

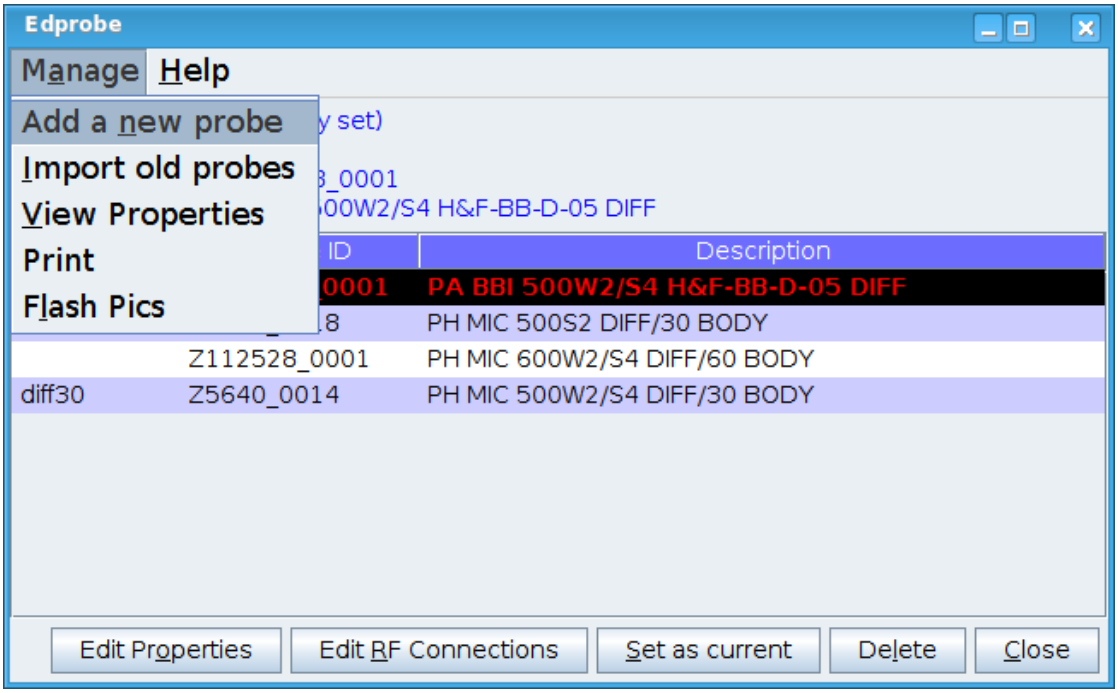


Figure 2.5: Edprobe: Create a New Probe

- Select **Add a new probe** in the *Manage* pull-down menu.

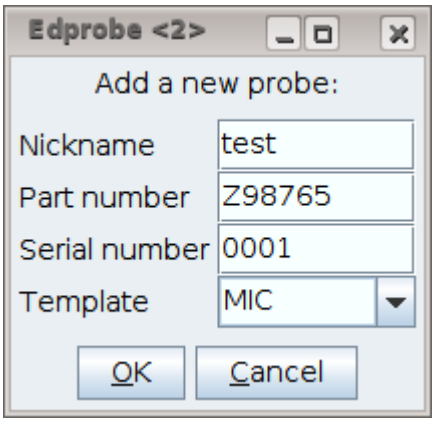


Figure 2.6: Edprobe: Add a New Probe

- Enter a *Nickname*, this can be anything.
- Fill in the *Part Number* and the *Serial Number*, these are mandatory.
- Select the template **MIC.**
- Press **OK.**
- In *Edprobe* click **Edit Properties** and set the parameters. The most important are described in *Probes with PICS [▸ 11]*.

2.4.4 Probes with Exchangeable Inserts

Probes with exchangeable inserts are currently not supported by TopSpin 3.5. For the future a plugin concept handling these cases is planned. For the time being some workarounds are described here.

- Probes with only one insert can be treated as fixed probes, as described in *Probes with PICS [▸ 11]* and *Probes without PICS [▸ 13]*.
- Probes having a set of inserts with similar layout, e.g. all having 1H on the inner coil and an X-nucleus on the outer coil or vice versa, can be treated like a broadband probe. In this case add the available nuclei to the corresponding coil and set the power for each nucleus. For nuclei appearing on different inserts the lowest power must be used.

In these cases the PICS cable can be connected, if the PICS description is complete, or if it does not overwrite the setting made here. Otherwise the PICS cable must be disconnected.

- If the restrictions mentioned above do not apply, or lead to restrictions in the application of the probe, a formal new probe must be defined for each insert or for each group of similar inserts:
  - Disconnect the PICS cable
  - For each insert, proceed as described in *Probes without PICS [▸ 13]*.
  - This implies introducing a fake identification in order to identify the different probes. Usually the serial numbers can be adjusted for this purpose, for example, assuming the probe has serial number 0005 use 0005, 0105, 0205, … for the different inserts.

In this case the PICS must always be disconnected.

2.4.5 Defining the Diffusion Probe as the Current One

If the probe has a proper PICS description, connect the PICS cable; otherwise make sure it is disconnected.

Type **edprobe** in TopSpin and select the diffusion probe, or if the PICS is connected, let it be auto-selected.

This must be done before adjusting the pre-emphasis and calibrating the gradient strength. This step is also required each time you switch back from another probe, in order to provide access to the proper gradient calibration. See also *Probe Exchange [▸ 43]*.

2.4.6 Preparation for NMR Adjustments

It is highly recommended to use the doped water sample (Z10906) for all setup experiments. If this sample is not available, a similar sample consisting of 1% H_2O in D_2O, plus 0.1% $CuSO_4$ should be prepared. The exact concentration is not important for the pre-emphasis adjustment, but it is useful for the later gradient calibration. Low concentrations of H_2O are important in preventing radiation damping. The $CuSO_4$ is mainly used to save time, but it also helps prevent radiation damping. The sample filling height should be about 40 mm.

Note: Never use pure H_2O for these adjustments.

1. Setup a 1D experiment on protons.
2. Shim the sample to a line width of less than 10 Hz at half height and less than 100 Hz at 10% height. Good shimming at this point provides better sensitivity later on for the pre-emphasis adjustment. The relaxation agent does not allow a line width below about 3 Hz at half height.
3. Adjust the 90 degree pulse. Pre-emphasis experiments are usually done using 30 degree pulses, but when using the doped sample 90 pulses can also be used.

2.5 Starting the Diff5 Program for the First Time

Note: All parameters in the following adjustments are controlled by *Setpre [▶ 127]*.

When the **diff5** program starts, it first tries to read the pre-emphasis file of the selected probe in order to get the gradient calibration constant of the system (GRADCC). GRADCC is the product of the gradient sensitivity and the maximum current provided by the amplifier. On a user system it will usually be specific for the probe, because the amplifier is usually the same.

If no probe was selected in edprobe, the following error message will be displayed:

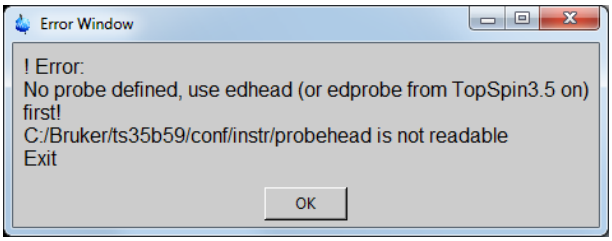


Figure 2.7: Diff5 Error: No Probe Selected.

- If the error message above appears please select a proper probe in **edprobe**, see *Defining the Diffusion Probe as the Current One [▶ 14]*.

  If the pre-emphasis file is not found, the following error message will be displayed:

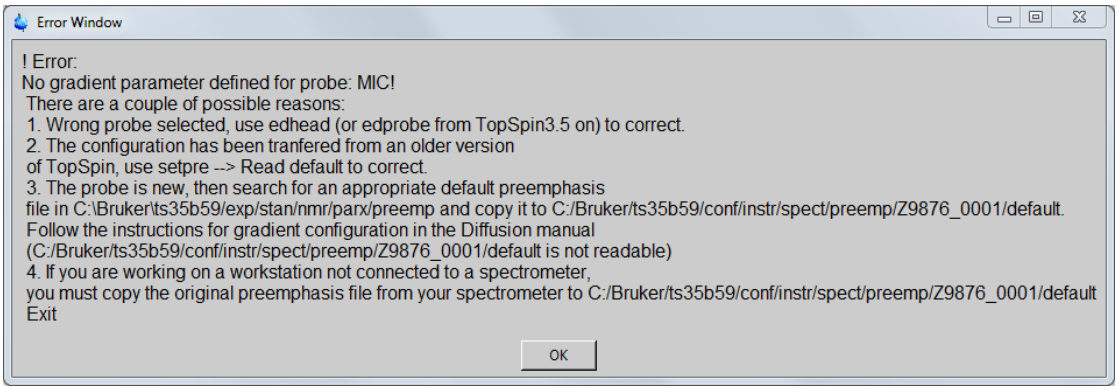


Figure 2.8: Diff5 Error: Missing Gradient Calibration

- If the error message above appears, a new pre-emphasis default file must be created. Usually the best method is to copy a pre-emphasis template provided in TopSpin, see *Pre-emphasis Files [▷ 17]*.
- Start **setpre** in TopSpin.
- Select **File** | **Read from**. Since TopSpin3.5 **setpre** allows to read from a different directory.
  - Browse to <TopSpinHome>/exp/stan/nmr/parx/preemp/
  - Select the gradient system, e.g. diff30
  - Select the amplifier type, e.g. GREAT60
- Select **File** | **Write default.**

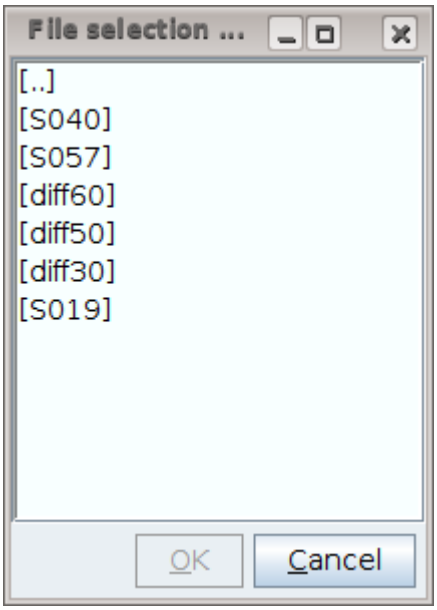


Figure 2.9: Setpre: Find Template, Select Gradient System

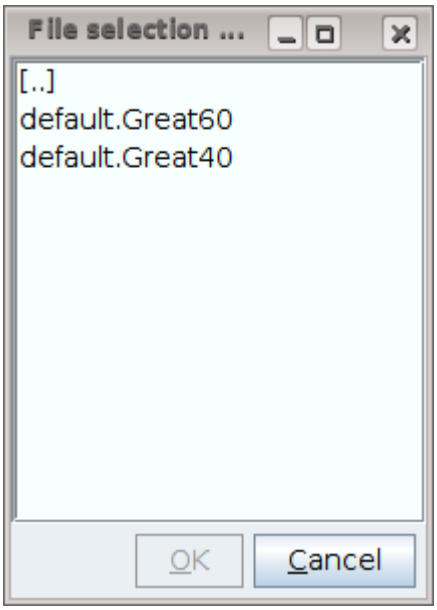


Figure 2.10: Setpre: Find Template, Select Amplifier Type

2.5.1 Pre-emphasis Files

The active pre-emphasis files are stored in <TopSpinHome>/conf/instr/spect/preemp/<probeId>/. Beginning with TopSpin 3.5, the *Probe Id* is “part number_serial number”, e.g. Z149768_0001. The required file must have the name *default*.

The pre-emphasis templates are in TopSpin3.5 still stored in: <TopSpinHome>/exp/stan/nmr/parx/preemp/<probeType>/default.

The <ampType>, probeType is e.g. diff30; ampType is at the moment GREAT40 or GREAT60. In TopSpin3.5pl3 there is no template for the diffBB, the diff30 template can be used as a replacement.

The templates provide the gradient calibration constant (GRADCC), the loop parameters, the safety parameters, ramp type, etc. The pre-emphasis and B0 settings are all zero. In future TopSpin versions some of these parameters may move to edprobe.

2.6 Impedance Matching of the Gradient Amplifier to the Gradient System

The following section is a brief description of how to do the impedance matching of the gradient amplifier to the gradient system. This step is explained in more detail in the Micro-imaging Manual for AVANCE III Systems.

Note: This adjustment must be done prior to the pre-emphasis adjustment.

The default pre-emphasis file templates (see *Pre-emphasis Files [▶ 17]*) provide reasonable loop parameters to get started, but they must be verified during installation. This is particularly important when using the diff60 probe.

Use the same setup as for a pre-emphasis experiment, see the figure in *Pre-emphasis Adjustment Experiment [▶ 21]*.

Make sure the water cooling is running properly, the loop parameter adjustment is usually one of the most demanding experiments in terms of heating of the gradient coil.

- Select **File** | **Read default** in the default pre-emphasis file.
- Set all pre-emphasis gains of the observed channel to zero (refer to *Pre-emphasis, B0, and Cross-Pre-emphasis Parameters [▶ 127]*).
- Connect an oscilloscope to the output labeled **I** on the gradient amplifier front panel.
- Look at the gradient pulses in gs-mode and adjust the loop parameters (refer to the loop parameters in *Setpre Options [▶ 133]*) in order to match the pulse shape seen on the oscilloscope to the input gradient shape. Usually trapezoidal pulses are the best choice. Examples are given below.

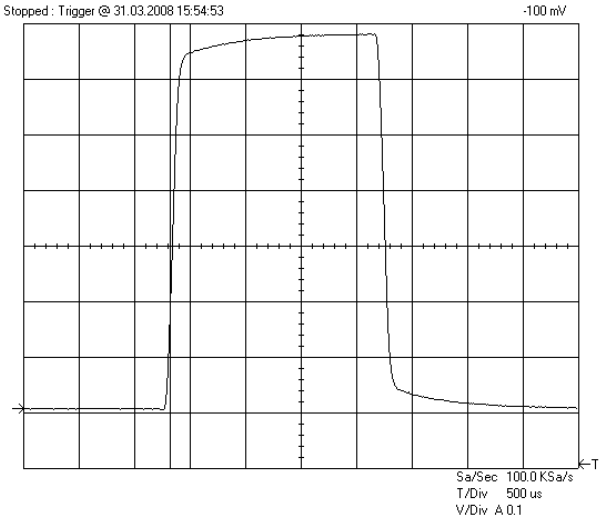


Figure 2.11: Gradient Pulse with too High "Resistors/Capacitors" Values, Leading to Slow Regulation Behavior.

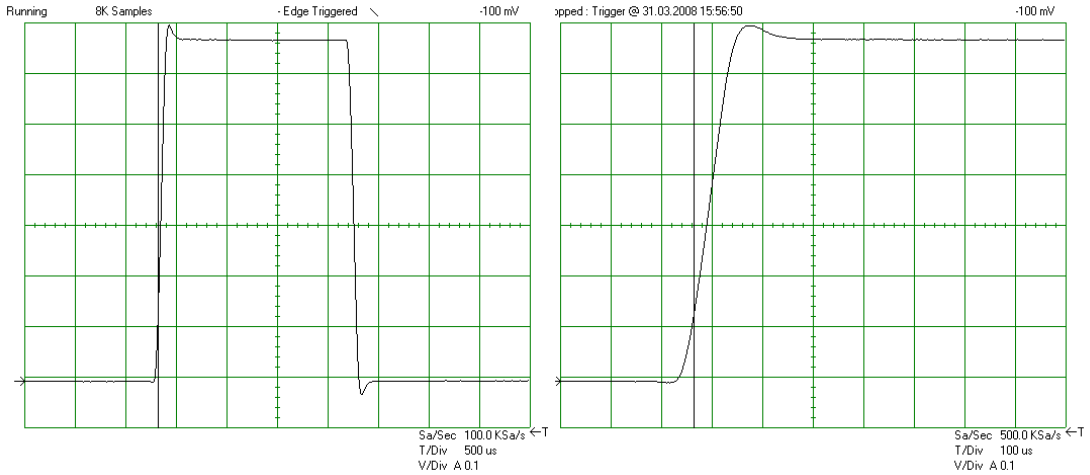


Figure 2.12: Gradient Pulse with too Low "Resistors/Capacitors" Values, Leading to a Current Overshoot.

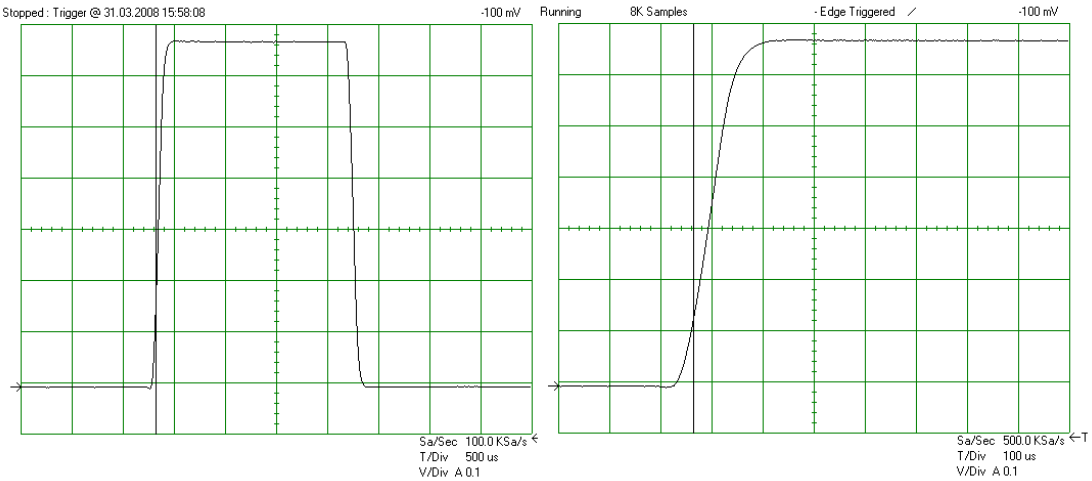


Figure 2.13: Optimal adjusted loop values leading to the fastest rise time without current overshoot.

If any changes have been made, save them using **Setpre** | **File** | **Write default**.

2.7 Offset Adjustment

To adjust the offset automatically press the **Auto** button on the left of the offset slider.

For AVANCE III type instruments using GREAT1/60 amplifiers (P/N W1209612), or GREAT1/40 amplifiers (P/N W1211690), the auto adjustment might fail. In this case the coarse offset needs to be adjusted prior to the auto adjustment:

- Set the offset to zero first and then adjust the coarse offset.
- Press the Auto button to adjust the offset automatically.

The coarse offset values will usually be in the range of -4 to -6.

In general the offset can be finely adjusted manually, but usually this will not be necessary. If fine adjustment is required, proceed as follows:

- Copy the 1D data set described in *Preparation for NMR Adjustments [▷ 15]*.
- If the probe has a lock, lock now.
- Change the pulse program to *diffoffset*. Run the experiment in gs mode. This will open gradient blanking. Alternatively the gate input of the amplifier can be disconnected. The observed spectrum will usually show a much wider line than before.
- If the probe has a lock, adjust the offset by maximizing of the lock level using the offset slider.
- If the probe has no lock, adjust the offset by optimizing the line shape using the offset slider.
- If a voltage meter is available, one can also measure the output voltage at the amplifier while diffoffset is running or the gate input is disconnected, and minimize it using the offset slider.

If any changes have been made, save using **Setpre** | **File** | **Write default**.

Note: After the adjustment don't forget to reconnect the gate input and the current monitor of the amplifier. Failure to reconnect the gate input will lead to poor quality spectra. Failure to reconnect the current monitor will break the safety circuit.

2.8 Pre-emphasis Adjustment

2.8.1 Background

The shape of an FID or an echo, acquired a short time after a gradient pulse, may be distorted by eddy currents caused by gradient switching. The influence of the eddy currents can be decreased by modifying the shape of the gradient pulses. Three exponential functions, with different amplitude and time constants, are available to accomplish this.

The figure below shows an example of two gradient pulses, one positive, and the other negative. In order to get this desired gradient behavior in the presence of eddy currents, the current pulse shapes have to be modified as indicated in the figure below. Usually the required values are much smaller than the ones shown there.

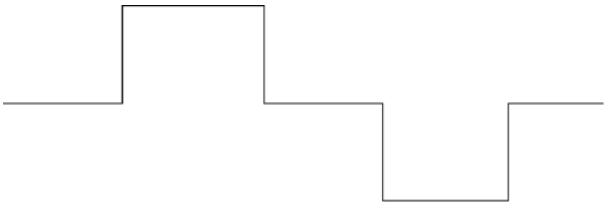


Figure 2.14: Desired Gradient Pulse Shape

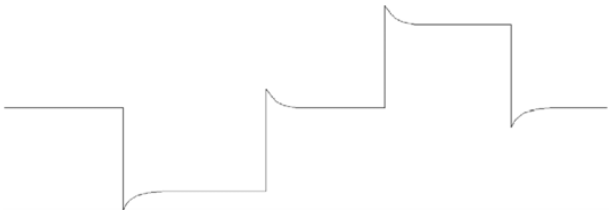


Figure 2.15: Gradient Pulses with Pre-emphasis (overemphasized)

The amplitudes and time constants are set in a control window and are stored for individual gradient systems. This is described in the following section.

The pre-emphasis parameters are adjusted by observing FID's at varying delays after a gradient pulse. Typical time variations after gradient switching are in the range between 100 µs and 1 sec, depending on the type of gradient system.

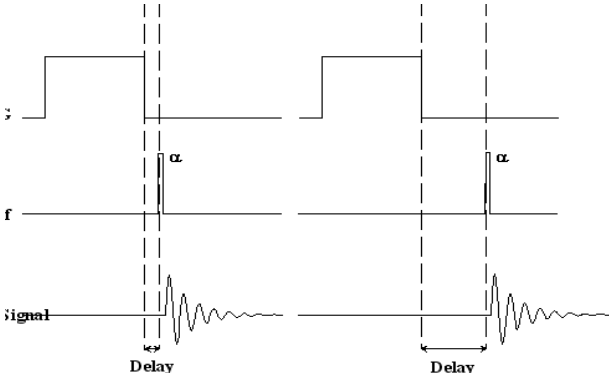


Figure 2.16: Pre-emphasis Adjustment Program

2.8.2 Pre-emphasis Adjustment Experiment

- Copy the 1D data set described in *Preparation for NMR Adjustments [▶ 15]*.

Beginning with TopSpin 3.5 pl6, the parameters in the pre-emphasis protocols have changed, longer gradient pulses with smaller amplitudes are used.

- Start *diff5* and load a pre-emphasis protocol, e.g *diff30Preemp*. Select a protocol best suited to your gradient system type. When nothing else is available, *diff30Preemp* will serve for diffBB and micro5.
- Set the offset to about 2 kHz off resonance.

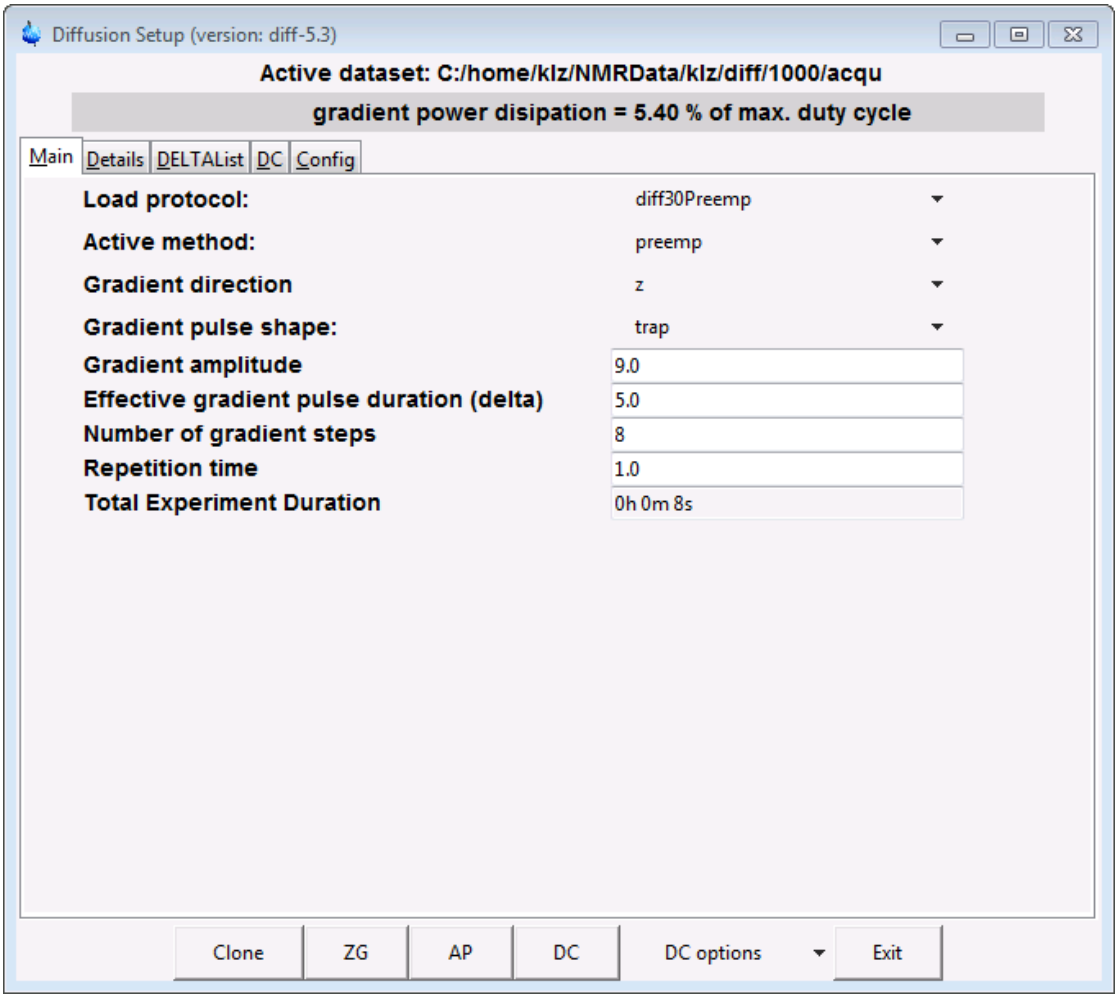


Figure 2.17: Diff5 Showing preemp Method after Loading diff30Preemp

Make sure the water cooling is running properly, the pre-emphasis adjustment is usually the most demanding experiment in terms of heating of the gradient coil.

2.8.3 Adjustment

With diff5 new protocols for the different gradient systems are provided. In contrary to older versions the default gradient ramp setting is always used.

diff30/diffBB	diff50	diff60
0.3	0.5	0.5
0.75	1.2	1.2
1.9	2.8	2.8
4.9	6.5	6.5
12.3	15.3	15.3
31.2	36.1	36.1
79.0	85.0	85.0
200.0	200.0	200.0

Table 2.2: **Default Pre-emphasis Delay Lists**

As default:

- The gradient amplitude is set to 3 T/m for diff30 and diffBB, and 6 T/m for diff50 and diff60.
- The gradient duration is set to 100 ms.
- The repetition time is set to 1 s.
- The other parameters are set to commonly used values.

Note: The values above have been significantly changed beginning with TopSpin 3.5 pl6. The new values are shown in the table above.

The protocol switches the gradient banking on, which is always correct for AVANCE III instruments. If the blanking is active the gradient amplifier will be blanked after the individual variable delay. When using the new BGMU-E (master unit) in the AVANCE III instruments the unblanked period is automatically prolonged until the pre-emphasis has decayed. This works well, if the offset has been adjusted properly. On older instruments it may sometimes be useful to switch off the blanking to see the effect of the pre-emphasis.

If not familiar with this experiment one can first set the gradient amplitude to zero. Start **gs** and watch the signals in the acquisition window. The signals should then look like those in the figure below. If this is not the case, go back and check the steps above.

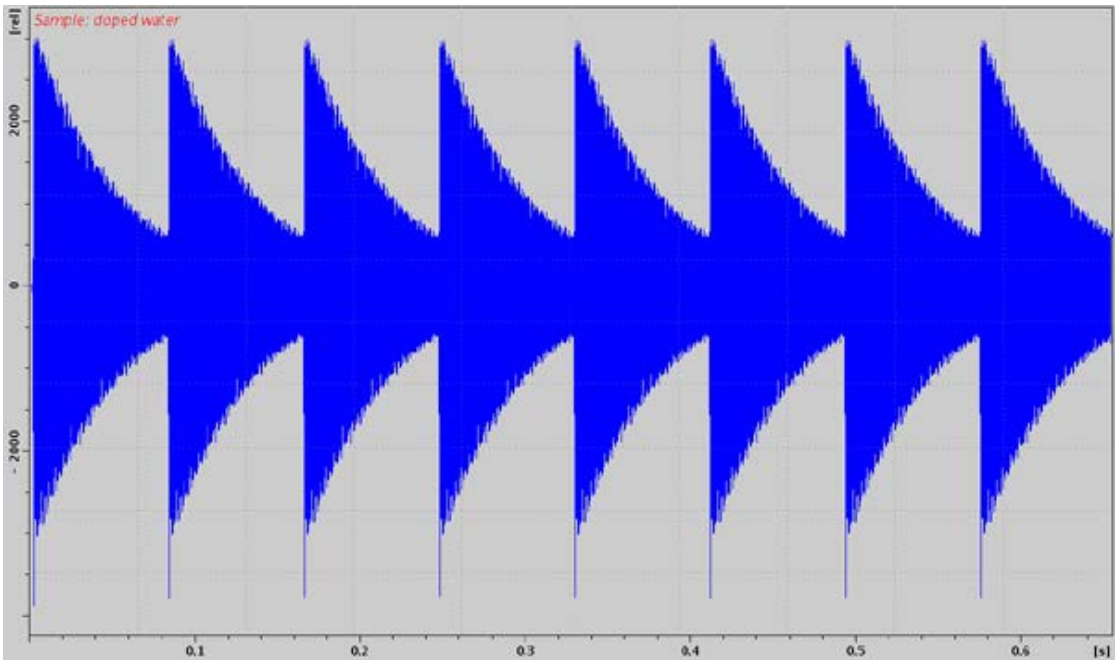


Figure 2.18: Eight FID's Without Gradient Switching.

Stop the acquisition and set the gradient amplitude back to 50%.

Note: Gradient amplitudes and timings cannot be changed in gs-mode. The acquisition must always be stopped and restarted after the parameters have been changed.

Adjustment: Watch the FID's in the acquisition window in gs mode. The screen should now look like that in the figure below. If you don't see any effect of the gradients, most likely the gradient rack is not switched on or the master unit needs a reset, e.g. after changing the probe.

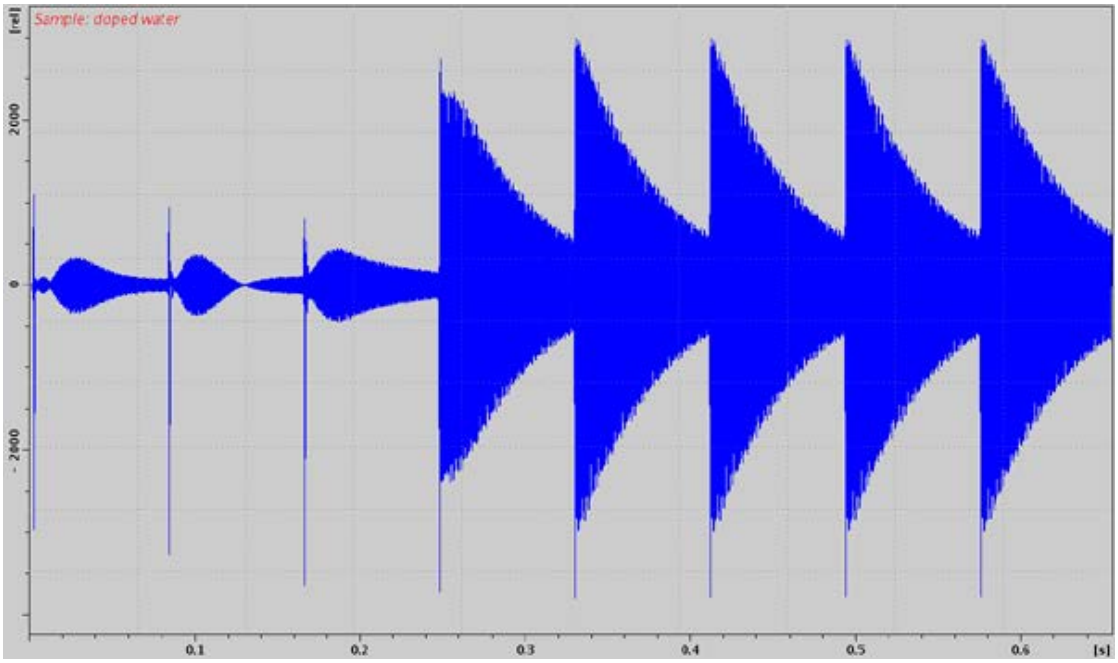


Figure 2.19: FID's After Gradient Pulses.

Modify the gradient pulse shape by changing the time and gain parameters in the setpre menu until all FID's are identical. The FID on the right hand side is used as a reference, since the delay between gradient switching and start of data acquisition is the longest for this FID. It is assumed that all eddy currents are decayed before the last FID.

It is recommended to first adjust the long time constants and continue with the middle and short time constants afterwards. This procedure corrects the shape of the FID's from right to the left.

As a starting point for the time constants the following rules of thumb can be used:

- If FID 7 is distorted, a time constant in the range of 100 ms is required.
- If FID's 5 and 6 are distorted, a time constant in the range of 10 to 20 ms is required.
- If FID's 3 and 4 are distorted, a time constant in the range of 1 to 2 ms is required.
- If FID's 1 and 2 are distorted, a time constant in the range of 0.1 to 0.5 ms is required.

These rules can be applied recursively starting with the long time constants, because the long time constants also effect the earlier FID's.

After the correction, the FID's should look like those below:

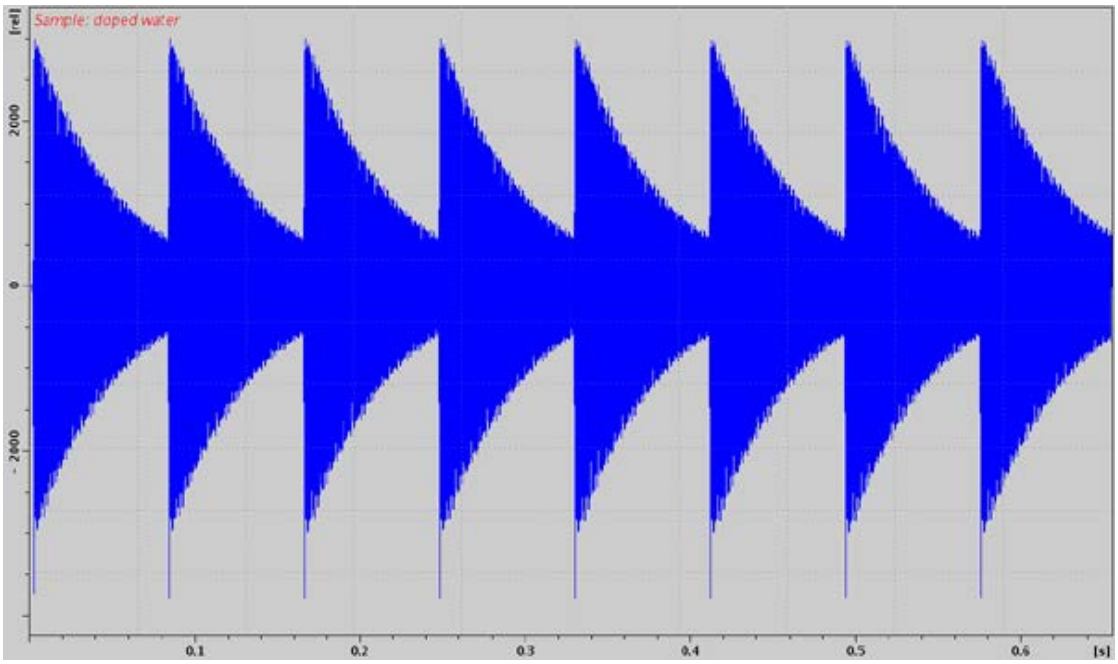


Figure 2.20: FID's After Pre-emphasis Adjustment.

The pre-emphasis result may not always look as good as that shown in the figure above. Particularly for the diff60 probe the first, and sometimes also the second, FID cannot be matched with the later ones.

If any changes have been made, save using **setpre** | **File** | **Write default**.

2.9 B0 Shift Compensation

The shape of an FID or an echo, acquired with only a short delay after gradient pulses, may be distorted by shifts of the B0 field caused by gradient switching. Such field shifts can be lessened by applying compensation pulses to the field coil of the shim system. Beginning with AV3, this field correction is replaced by a frequency correction, basically the receiving frequency follows the distorted field in order to stay on-resonance during the entire FID or echo. The adjustment in *setpre* is exactly the same as it was for older systems. Select *z->B_0 cross-pre-emphasis* instead of *z-pre-emphasis* in **setpre**

Note: For the B_0 compensation the optional B_0 compensation unit is required.

The procedure is exactly the same as described for the pre-emphasis in *Pre-emphasis Adjustment Experiment [▶ 21]*, except the resonance frequency must be set to on resonance. The corresponding pictures are shown below.

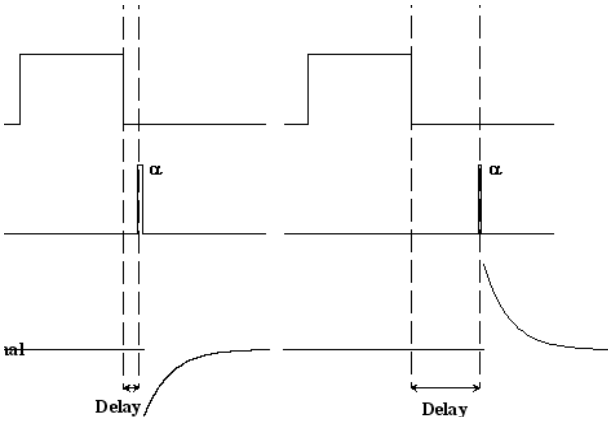


Figure 2.21: B0 Shift Adjustment Program.

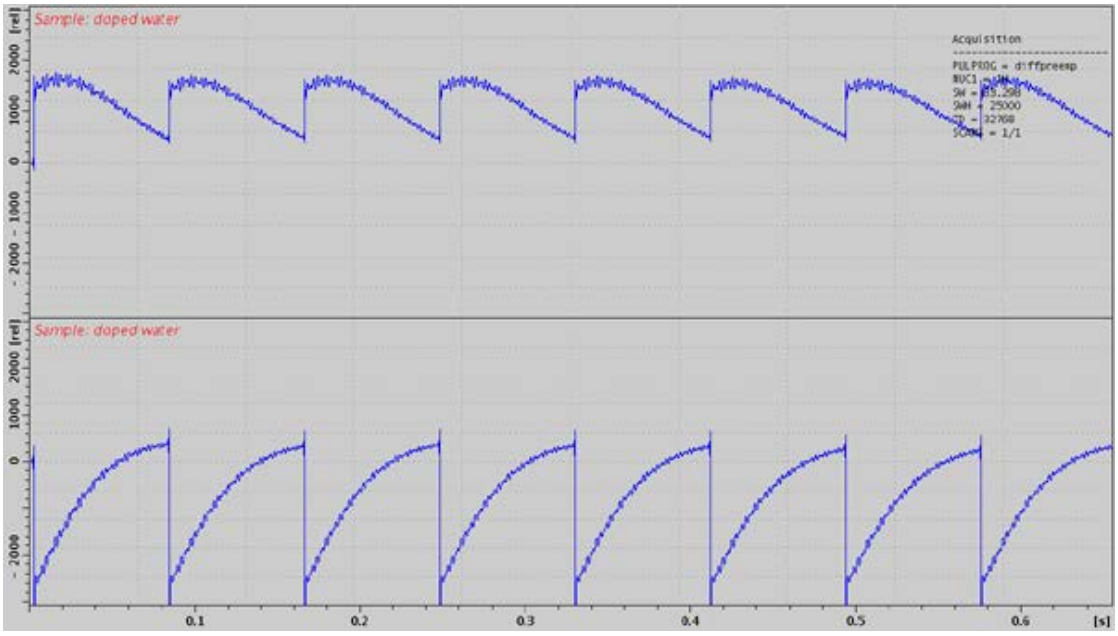


Figure 2.22: Eight FID's on Resonance without Gradient Switching.

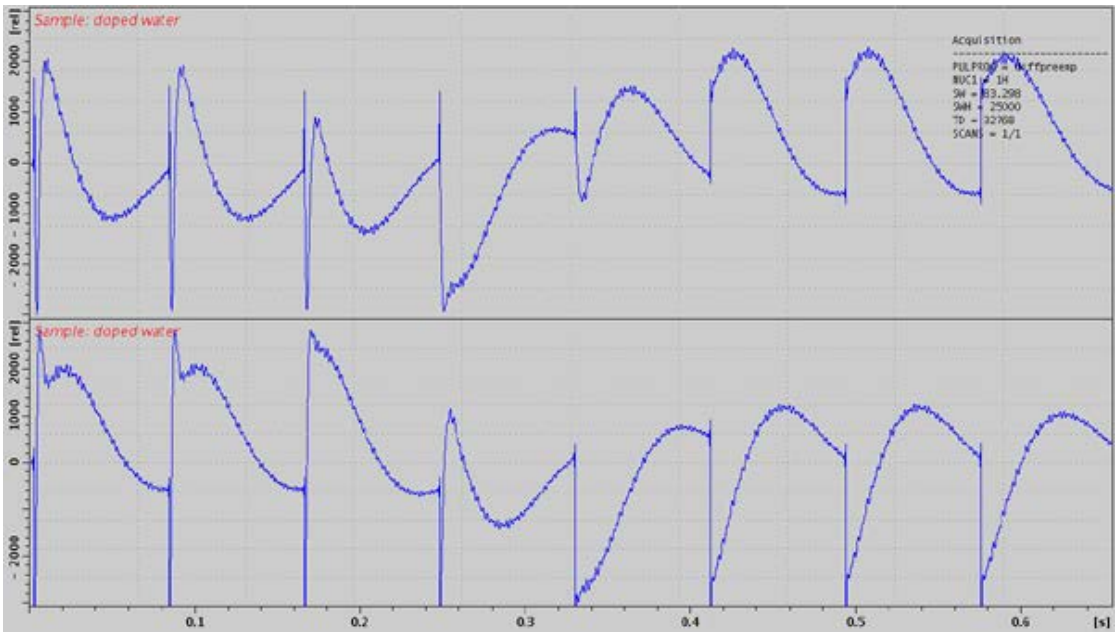


Figure 2.23: Eight FID's on Resonance with Gradient Switching.

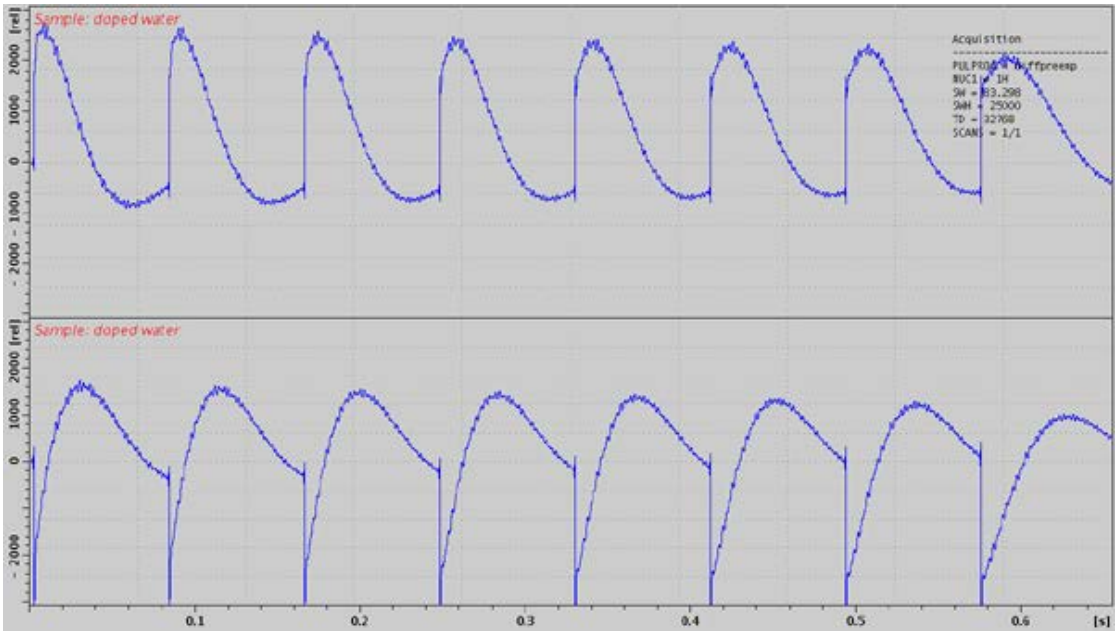


Figure 2.24: Eight Unshuffled FID's After B_0 Adjustment.

2.10 Gradient Calibration

Nowadays gradient calibration is not as essential as it used to be. The gradient systems production is very reproducible, however if the gradient strength deviates a lot, it can mean the gradient system is defective. The pulse current strength of the gradient amplifier can be measured reasonably with an error of ±1%. Using the standard values we expect an accuracy of better than ±2%. However for accurate diffusion measurements this still might not be good enough. Furthermore, the effective gradient strength depends on the sample size, the further away from the center the gradient is taken, the more the gradient strength deviates. These deviations are small, but can be visible under certain conditions.

The relative gradient strength (also called gradient sensitivity) is measured in Gauss/(cmA) or mT/(mA). Values for different gradient systems and start values for the gradient calibration constant are provided in the table in *Gradient Systems [▶ 137]*.

The only way to precisely calibrate gradient systems is to carefully measure the diffusion coefficients of a well-known sample and compare the results with the literature values. Some values are listed below, more can be found in the “Bruker Almanac“.

Nucleus	Sample	Temperature [C]	D [$10^{-9}m^2/s$]
^{1}H	H_2O	20	2.031
^{1}H	H_2O	25	2.299
^{1}H	D_2O	25	1.872
^{1}H	“Doped Water“	25	1.91
^{1}H	DMSO	25	0.730
^{7}Li	0.25 m LiCl in H_2O (ca. 10 g LiCl /l H_2O)	25	0.960
^{23}Na	2 m NaCl in H_2O (ca. 117 g NaCl / l H_2O)	25	1.135

Table 2.3: **Some useful diffusion coefficients**

The *doped* water sample already mentioned above in *Pre-emphasis Adjustment Experiment [▶ 21]*, is used as a standard for the calibration. If the doped water sample is not available, other mixtures of H_2O and D_2O can be used. The diffusion coefficient of protons at 25 °C can be calculated using the following equation*. Low H_2O concentrations are preferable in order to avoid radiation damping.

$$D(x_D) = (2.3 - 0.4652 \cdot x_D + 0.0672 \cdot x_D^2) \cdot 10^{-9} \frac{m^2}{s}$$

$$x_D = mole\ fraction\ of\ deuterons$$

Figure 2.25: Equation 1

[* Calibration in Accurate Spin-Echo Self-Diffusion Measurements Using 1H and Less-Common Nuclei, Holz et al., *JMR 92*, 115-125 (1991)].

Note: Diffusion coefficients of liquid samples are extremely temperature dependent.

2.10.1 Calibration Procedure for a Single Axis Gradient System

- Set the temperature to 25 ˚C.

  In order to avoid convection artefacts the temperature must be controlled using water cooling. Air flow should not be connected to the probe, as the real temperature may differ from the water temperature. Check the reading for the thermocouple in *edte*. For exact results the temperature must be calibrated using an NMR temperature standard. Refer to the *Variable Temperature Unit User Manual* on the BASH CD for details.
- Check for the correct initial setting of the gradient calibration constant GCC (see the table in *Gradient Systems [137]*).
- Measure the diffusion coefficient as described in the *Step by Step Guide [33]*. Calculate the corrected gradient calibration constant:

$$GCC_{new} = GCC_{old}\sqrt{\frac{D}{D_{Literature}}}$$

Figure 2.26: Equation 2

- Store the new constant using **setpre**-->**File**-->**Write default**.

2.10.2 Calibration Procedure for a Triple Axis Gradient System

- Set the temperature to 25 °C.

  In order to avoid convection artefacts the temperature must be controlled using water cooling. Airflow should not be connected to the probe, as the real temperature may differ from the water temperature. Check the reading for the thermocouple in *edte*. For exact results the temperature must be calibrated using an NMR temperature standard. Refer to the BVT manual for details.
- Check for the correct initial setting of the gradient calibration constant.
- Measure the diffusion coefficient using the actual calibration independently in all 3 gradient directions independently.
- Correct the relative gradient scaling factors, called S_x, S_y, S_z in the following equation:

$$S_{i,new} = GCC_{old}\sqrt{\frac{\min(D_x, D_y, D_z)}{D_i}}$$

$$i = x, y, z$$

Figure 2.27: Equation 3

- Calculate the corrected gradient calibration constant:

$$GCC_{new} = GCC_{old}\sqrt{\frac{\min(D_x, D_y, D_z)}{D_{Literature}}}$$

Figure 2.28: Equation 4

- Store the new values of S_x, S_y, S_z and GCC using **setpre** | **File** | **Write default**.

2.11 Gradient Ramp Time Calibration

The calibration of the ramp time is usually not necessary, because diff automatically sets reasonable ramp times depending on the maximum gradient amplitude used in the actual experiment.

The default values can be changed in the configuration, see *Config Tab [118]* on the *hardware* sub tab. The default values are fixed in the program and cannot be changed in the configuration (this may change in the future).

In order to be able to access the ramp time temporarily, uncheck the check button at the desired ramp time, see *Details Tab [105]*.

When the ramp time is calibrated, make sure the output voltage of the gradient amplifier always stays within reasonable limits. For the GREAT40 and GREAT60 amplifiers this means below 100 V.

In order to calibrate the ramp time, measure the gradient current and the output voltage of the amplifier at the same time. The newer amplifiers display the current and voltage monitor outputs, please read *Monitor Output [147]* carefully. Older amplifiers only display the current outputs, however the voltage can be measured by connecting to the voltage probes, one to the positive and one the negative current outputs, and looking at the voltage in differential mode.

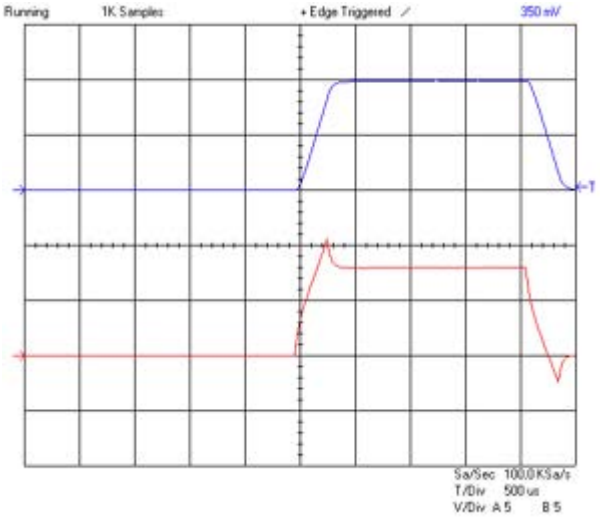


Figure 2.29: Oscilloscope view Showing Current (blue, 30 A/div) and Voltage (red, 50 V/div) of a Trapezoidal Pulse with a Ramp Time of 300 µs and an Amplitude of 60 A.

The figure above shows a trapezoidal pulse with equal up and down ramp times of 300 µs and a current of 60 A on a diff30 gradient system. The voltage slightly exceeds the limit of 100 V of the GREAT40/60 amplifiers, showing the lower limit of a reasonable ramp up time. It also shows that the ramp down time could be much faster.

In contrary, the figure below shows a case where the ramp up time of 100 µs is too short. The voltage reaches the limit of the power supply, and then it decays as the capacitors are discharged. The power supply is overloaded. Although the current pulse shape still looks quite reasonable the next pulse in the sequence will not have exactly the same integral, because the power supply cannot recover completely. The reproducibility of the integral is the most critical point for diffusion experiments, in some cases only a few ppm of mismatch can be detected.

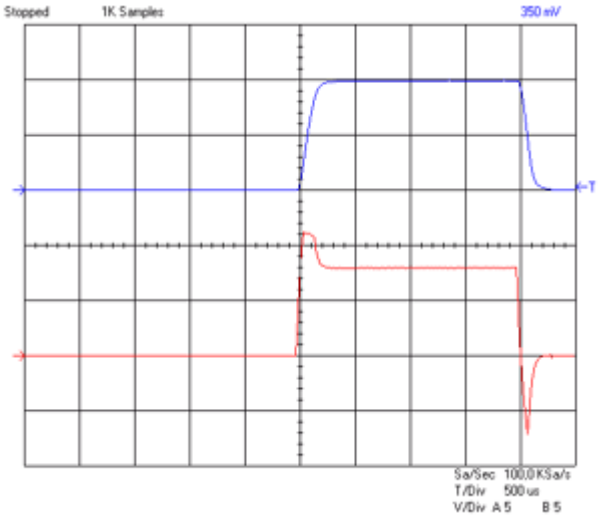


Figure 2.30: Oscilloscope view Showing Current (blue, 30 A/div) and Voltage (red, 50 V/div) of a Trapezoidal Pulse with a Ramp Time of 100 µs and an Amplitude of 60 A.

For the frequently used half sine, the corresponding picture should look like the figure below:

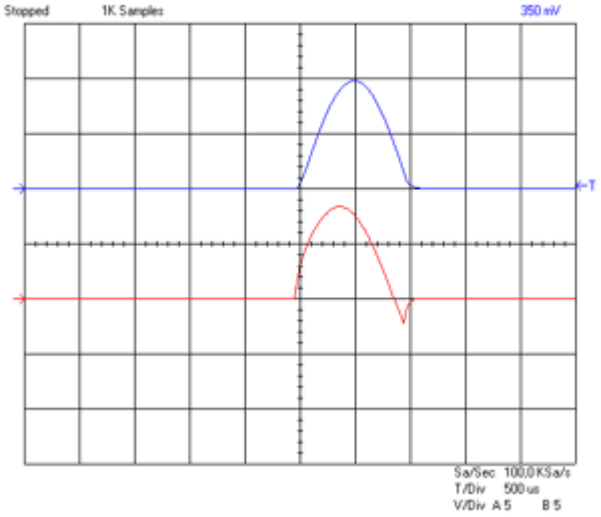


Figure 2.31: Oscilloscope view Showing Current (blue, 30 A/div) and Voltage (red, 50 V/div) of a Sine Shape Pulse with Duration of 2 ms and an Amplitude of 60 A.

For this pulse shape the amplifier can also be overloaded by making the pulse too short. An extreme example is shown in the following figure. Thus diff also controls the minimum duration of half sine shapes as a function of the maximum used amplitude.

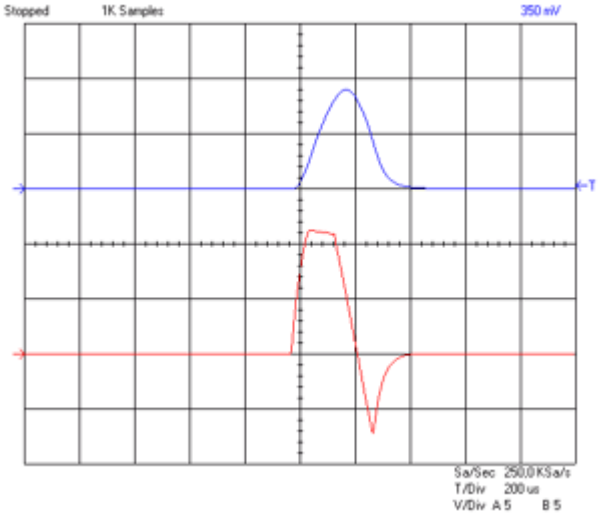


Figure 2.32: Oscilloscope view Showing Current (blue, 30 A/div) and Voltage (red, 50 V/div) of a Sine Shape Pulse with Duration of 0.3 ms and an Amplitude of 60 A.

3 Step by Step Guide

3.1 Setup

The complete setup described in this chapter usually only has to be fully performed once. At any point during the setup, parameters can be stored as standard parameters and recalled. The required changes depend only on the variety of samples to be measured.

The setup is simplified by using the setup program *diff5*. Diff5 in it's current version is a TclTk script. Examples of the use of diff are described in the description of the experiment setup.

The setup is performed in 3 major steps:

- The setup of the **spectroscopic parameters**, i.e. RF pulse length, RF power, spectral width and receiver gain.
- The setup of the **diffusion parameters**, gradient pulse length and maximum amplitude, and the diffusion time.
- The setup of the 2D **measurement parameters**, including the number of gradient steps, scans, and repetitions.

The sample used for all experiments shown below is the Bruker standard sample:

Doped Water (P/N Z10906), consisting of 1% H_2O in D_2O, with 0.1% $GdCl_3$ and 0.1% CH_3OH (^{13}C).

3.1.1 Probe Exchange

If the probe has to be changed, two important steps have to be performed:

- Select the correct probe using **edprobe**.
- Read in the corresponding pre-emphasis parameters and load them in the pre-emphasis unit.
  - Run **setpre** and execute **Setpre-->Read default** (see *Pre-emphasis Adjustment [▶ 20]*).

3.1.2 Spectroscopic Parameters

- Create a new 1D data set using your standard method.
  - Read in a standard parameter set if applicable.
- Perform the standard setup procedure.
  - Tune the probe using wobb, or run ATMA on a diffBB.
  - Lock, if a lock channel is available.

Note: If you don't use the lock, set LOCNUC to **off** before starting. Diff will automatically disable the lock blanking in the pulse program.

- Shim the probe.

- Set the RF pulses and the power level. This can be done by typing **getprosol**, if this was preset for your probe.
  - Set plw1 to the required power level for the selected nucleus and RF coil.
  - Set p1 to the corresponding 90° pulse length.
  - Set SW or SW_h to a value suitable for your sample.
  - Setup the receiver gain, e.g. using **rga**.

Note: Correct pulse settings are particularly important for diffusion sequences using bipolar gradients.

Usually the best results in diffusion experiments can be achieved using DIGMOD=baseopt. Diff5 allows setting this automatically where it applies, see *Config Tab [118]* for details.

The receiver gain value found for a 1D experiment is usually a good starting value for the diffusion experiment.

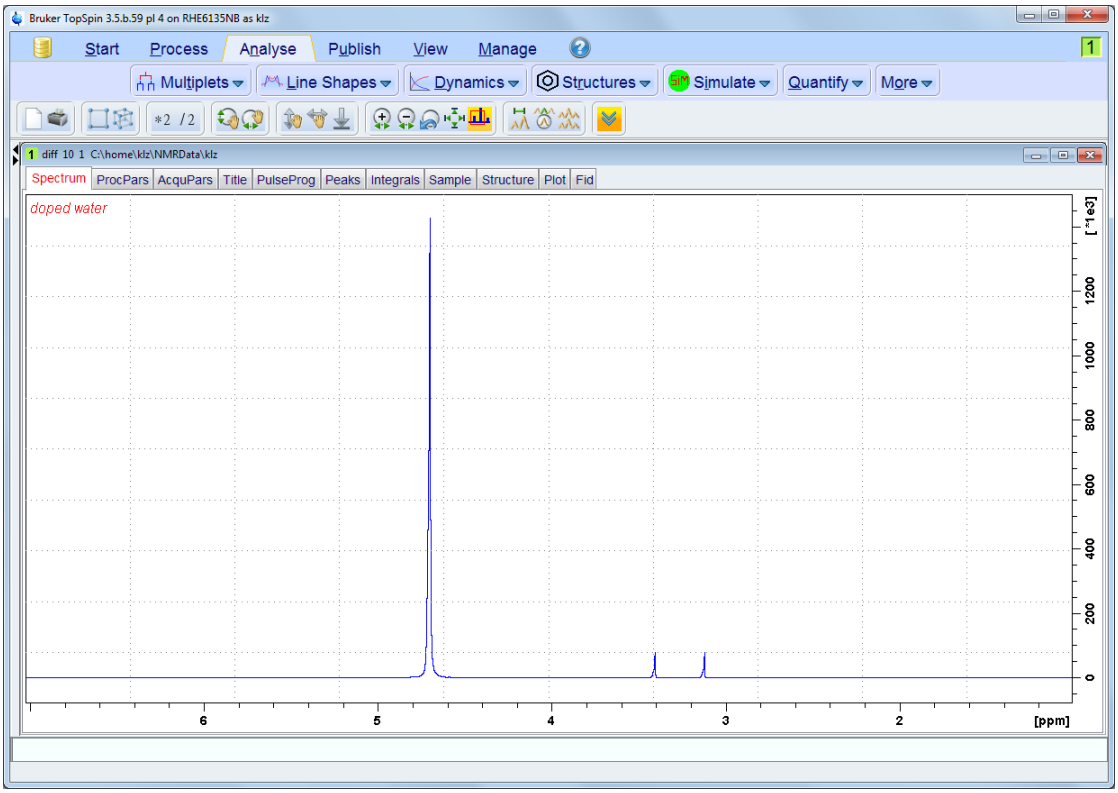


Figure 3.1: 1D Spectrum of Doped Water Sample

- After finishing the 1D experiment create a new data set, using e.g. **iexpno**, or load a parameter set.

Note: If using **diff5** it is no longer necessary to change the dimension of a data set, **diff5** does it automatically as required for the method.

3.1.3 Diffusion Parameter Setup

- Type **diff5** to start the setup program. The following will appear. Because it was started with a fresh data set, very little information will be visible.

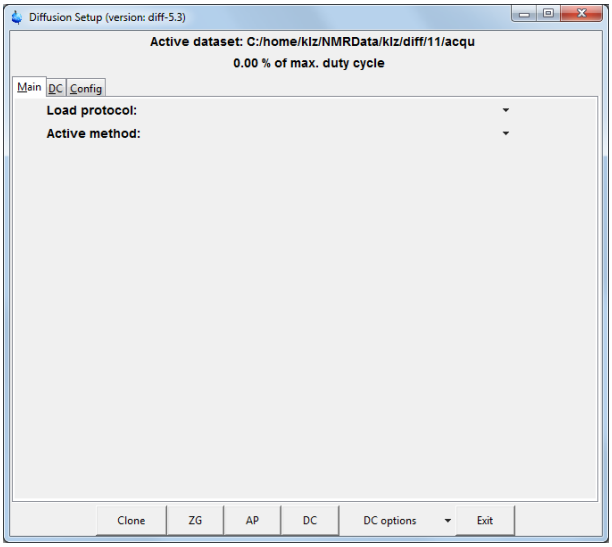


Figure 3.2: The diff5 Program on a Fresh Data set

The window can be kept open as long as needed; it will always display the parameters of the active data set in TopSpin.

When starting from scratch, it is easiest to load a protocol. A protocol is a set of *high level* parameters, like the expected diffusion coefficient, from which diff can derive all diffusion relevant parameters automatically. For example, select the protocol **steWater** from the pull down menu next to *Load protocol*:

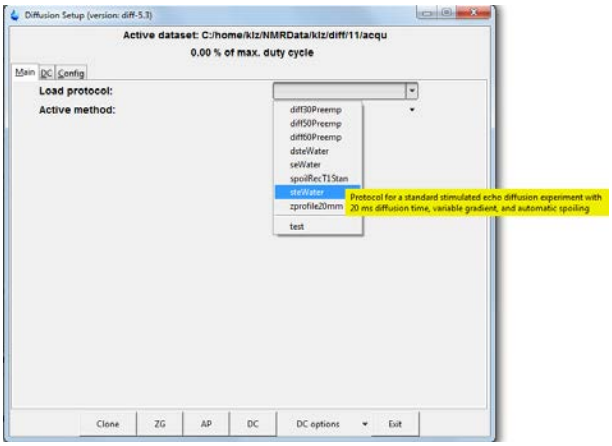


Figure 3.3: The diff5 Program Showing Protocol Selection

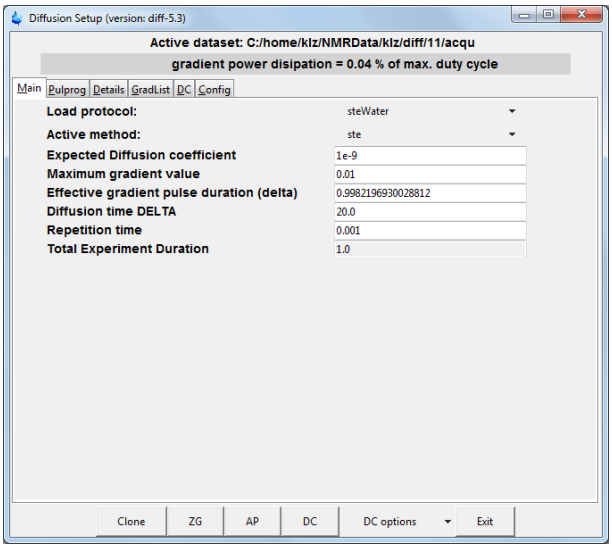


Figure 3.4: The diff5 Program Showing Parameters of "ste"

The parameters shown here can be used for water or similar liquids without any change. In general the parameters have to be adjusted according to the sample properties and/or experimental needs. Details about the parameter settings, their meaning, and parameter relations are given in *Diffusion Experiments [▷ 61]* and in *Diff5 Program Reference [▷ 101]*

To change the values:

- Click on the entry field.
- Delete the numbers and type in the new number you want.
- Press **return** or move the cursor out to activate the relations.

Depending on the parameter hierarchy, the parameters will be checked and e.g. set to the minimum possible value, derived from the other related parameters.

When leaving the diff window the parameters are automatically stored in the data set.

Note: The parameters are automatically stored each time the cursor focus leaves the diff window. The very first time this action is performed, the AU program "diff_t1pars", which runs in background, will be compiled automatically and the corresponding message will be displayed.

3.2 Running the Experiment

- Set the receiver gain either by pressing the **Gain** button in the **Acquisition** flow bar or by typing **rga**.
- Start the acquisition by pressing the **Go** button in the Acquisition flow bar or by typing **zg**. Pressing the **ZG** button in diff5 is absolutely equivalent.

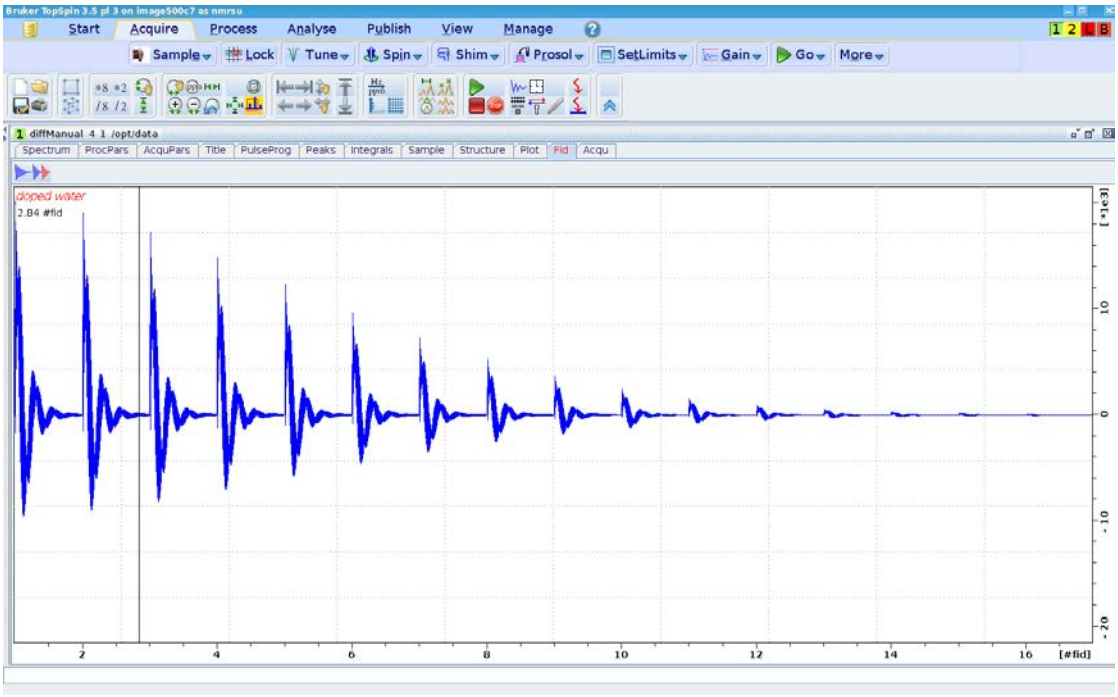


Figure 3.5: Echo Decay Caused by Growing Diffusion Gradients.

3.3 Processing and Analysis

Processing and analysis of the data is shown here using the Dynamics Center program available on TopSpin DVD or from the Bruker website. The Dynamics Center (DC) runs under the TopSpin license, so each TopSpin user has access. Dynamics Center has an extensive user manual therefore the description here is kept short. The old style processing is still available, see *Processing [▸ 48]* in the *Step by Step Guide, Old Style [▸ 43]* and *The T1/T2 Analysis Module [▸ 82]* for details.

There are many possible ways to go, the fastest almost fully automatic way is shown here first.

3.3.1 Automatic Processing and Analysis using diff5

Press the **AP** (automatic processing) button in **diff5**. The following actions will be performed automatically in background in TopSpin by the AU program *diff_apk2d 2*:

- Fourier transform in F2 direction (xf2).
- Automatic phase correction of the first row (apk or apk0, if *baseopt* was used).
- Application of the phase correction found in row 1 to all the other rows.
- If *baseopt* was not used, automatic baseline correction will be applied (abs2).

When Dynamics Center is started, the data set is loaded from TopSpin, and the tree executed up to **View**.

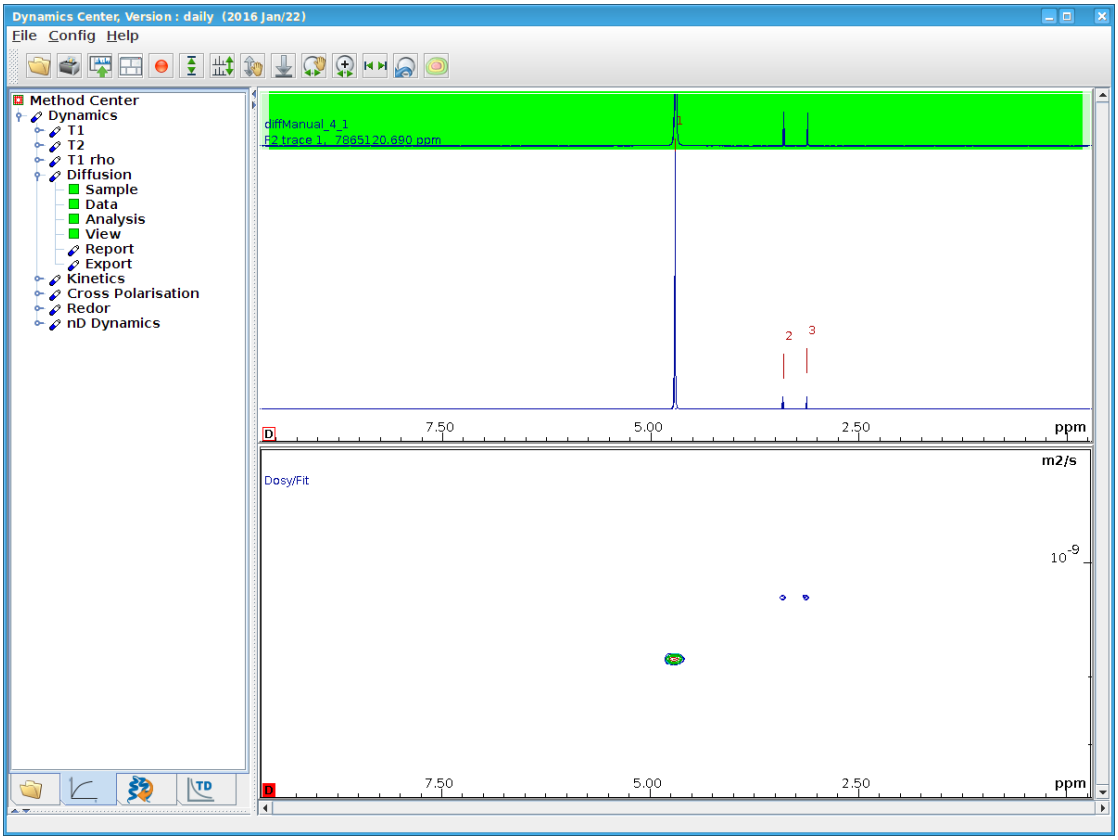


Figure 3.6: Dynamics Center View after Starting with AP

The default view shows the spectrum in the first row and the DOSY plot. When moving the cursor to a peak in the spectrum the display changes:

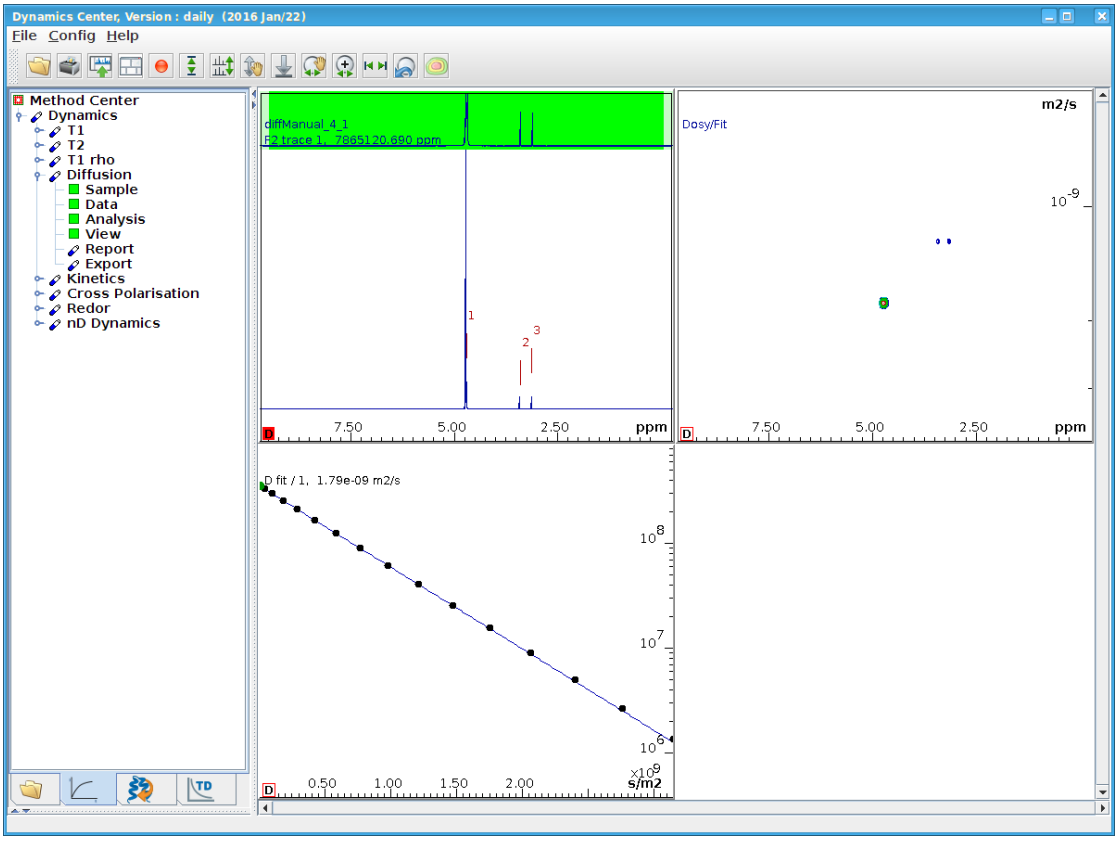


Figure 3.7: DC View after Moving the Cursor to Peak # 1

Further analyzing in **DC** and the different display options are shown in the sections that follow.

3.3.2 Automatic Processing and Analysis using the Dynamics Flow Bar

In TopSpin select **Analyze** | **Dynamics** | **Prepare for Dynamics Center**:

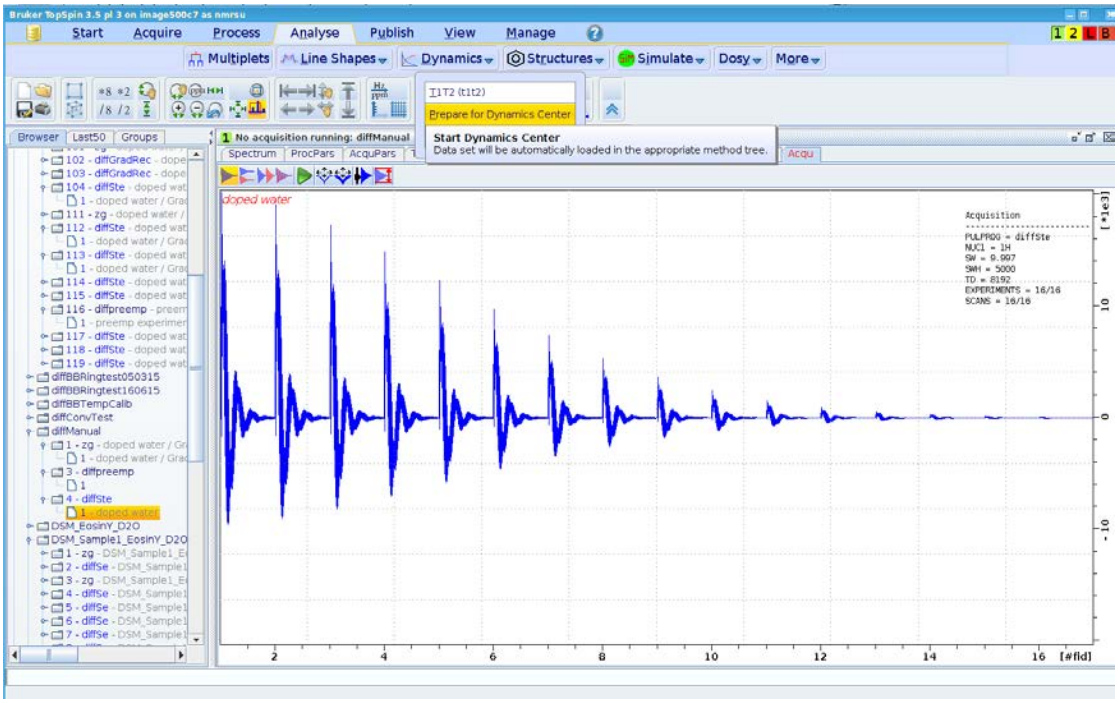


Figure 3.8: Using the Dynamics Flow Bar

Then the flow bar will change:

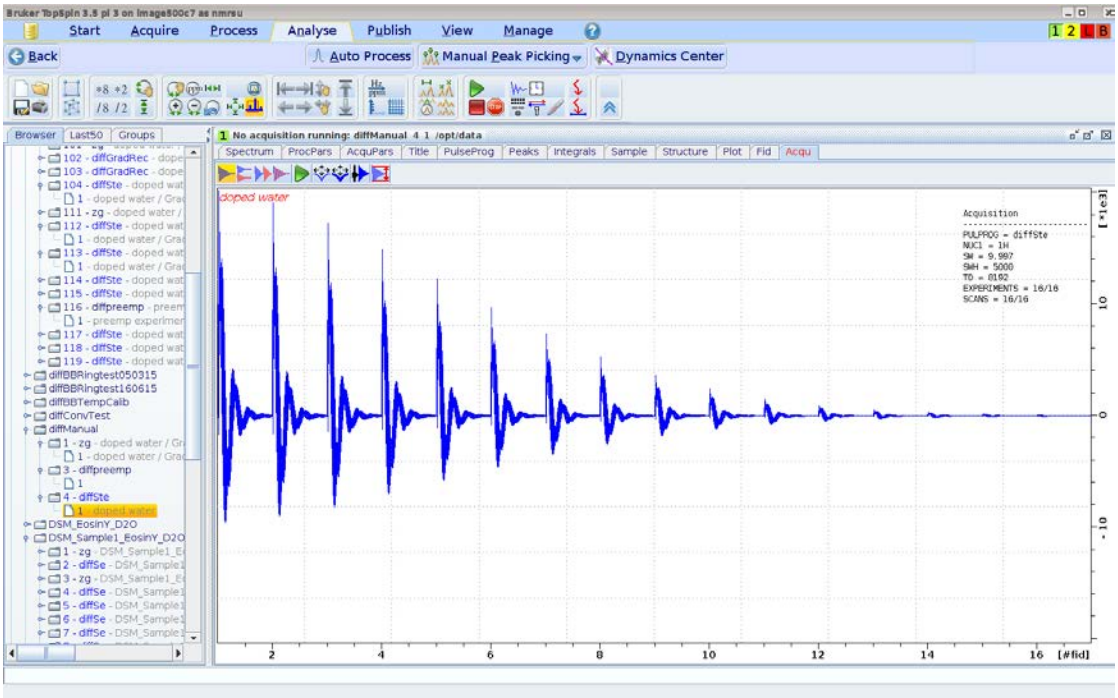


Figure 3.9: Dynamics Flow Bar

When you press the **Auto Process** button, it will perform the following steps automatically in the background in TopSpin using the AU program *diff_apk2d 2*, (as described in *Automatic Processing and Analysis using diff5 [▶ 38]*):

- Fourier transform in F2 direction (xf2).
- Automatic phase correction of the first row (apk or apk0, if *baseopt* was used).
- Application of the phase correction found in row 1 to all the other rows.
- If *baseopt* was not used, automatic baseline correction will be applied (abs2).

The result is shown here:

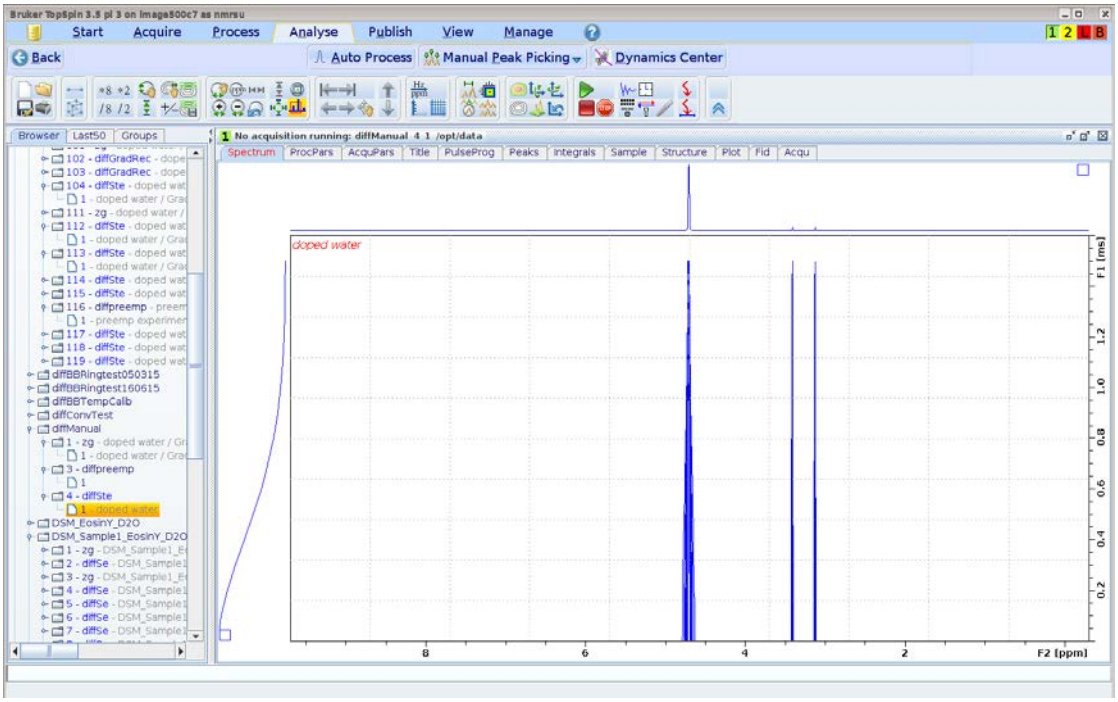


Figure 3.10: View after Pressing Auto Process

- When you press the **Dynamics Center** button, it will lead to the same behavior as shown in *Automatic Processing and Analysis using diff5 [▶ 38]*

  Optionally you can do peak picking or manual integration in TopSpin and transfer the parameters to the Dynamics Center.

- When you press the **Manual Peak Picking** button, it will load the first row into a 1D viewer and select a peak picking mode.

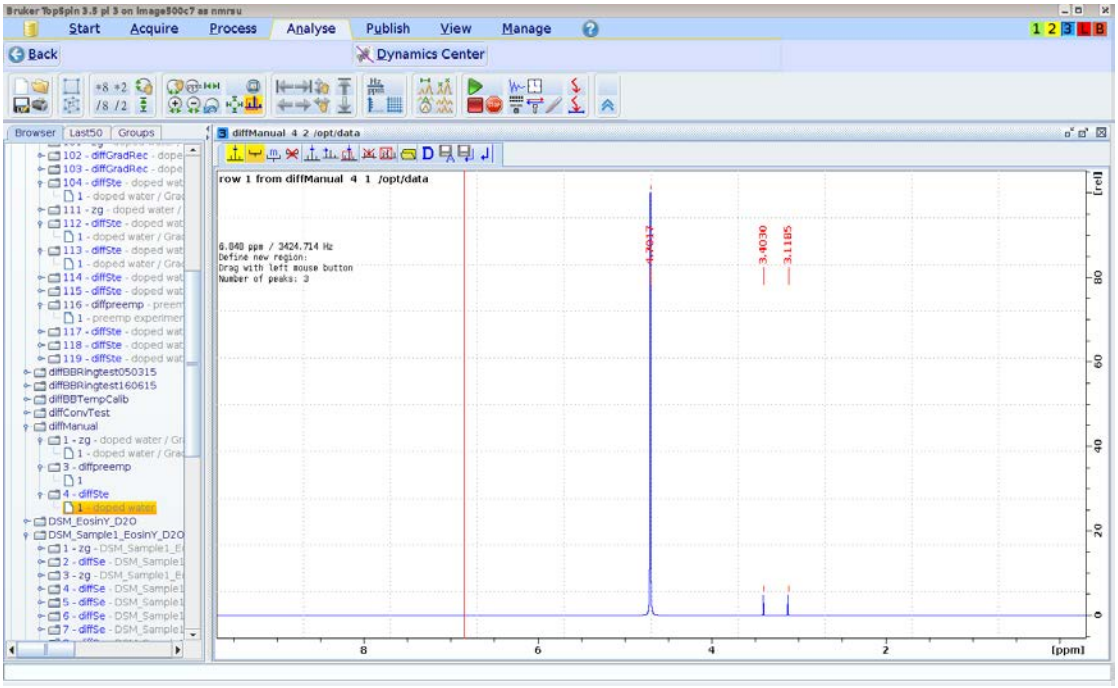


Figure 3.11: Manual Peak Picking

When you press the **Dynamics Center** button, the Dynamics Center will start as show in *Automatic Processing and Analysis using diff5 [▶ 38]*.

Manual integration works the same way, just press the little arrow on the **Manual Peak Picking** button and select **Manual Integration.**

Further analyzing in **DC** and the different display options are shown in the chapter *Dynamics Center [▶ 75]*.

Note: The next time you press the **Dynamics Center** button, the last manual settings will be used.

4 Step by Step Guide, Old Style

4.1 Setup

The complete setup described in this chapter usually only has to be fully performed once. At any point during the setup, parameters can be stored as standard parameters and recalled. The degree of changes depend only on the variety of samples to be measured.

The setup is simplified by using the setup program *diff*. Diff in it's current version is a TclTk script. Examples of the use of diff are described in the description of the experiment setup.

The setup is performed in 3 major steps:

- The setup of the **spectroscopic parameters**, i.e. RF pulse length, RF power, spectral width and receiver gain.
- The setup of the **diffusion parameters**, gradient pulse length and maximum amplitude, and the diffusion time.
- The setup of the 2D **measurement parameters**, including the number of gradient steps, scans, and repetitions.

The sample used for all experiments shown below is the Bruker standard sample:

Doped Water (P/N Z10906), consisting of 1% H_2O in D_2O, with 0.1% $GdCl_3$ and 0.1% CH_3OH (^{13}C).

4.1.1 Probe Exchange

If the probe has to be changed, three important steps have to be performed:

- Select the correct probe using **edhead**.
- Read in the corresponding pre-emphasis parameters and load them in the pre-emphasis unit.
- Run **setpre** and execute **Setpre** | **Read default**. See also *Pre-emphasis Adjustment [▷ 20]*.

4.1.2 Spectroscopic Parameters

- Create a new 1D data set using your standard method.
- Perform the standard setup procedure.
  - Tune the probe using **wobb**.
  - Lock, if a lock channel is available.

Note: If you don't use the lock, set LOCNUC to **off** before starting. Diff will automatically disable the lock blanking in the pulse program.

- Shim the probe.
- Set the RF pulses and the power level. This can be done by typing **getprosol**, if this was preset for your probe.
  - Set pl1 to the required power level for the selected nucleus and RF coil.
  - Set p1 to the corresponding 90° pulse length.
  - Set p2 to the corresponding 180° pulse.
  - Set SW or SW_h to a value suitable for your sample.
  - Setup the receiver gain, e.g. using **rga**.

Note: Correct pulse settings are particularly important for diffusion sequences using bipolar gradients.

The receiver gain value for a 1D experiment is usually a good starting value for the diffusion experiment.

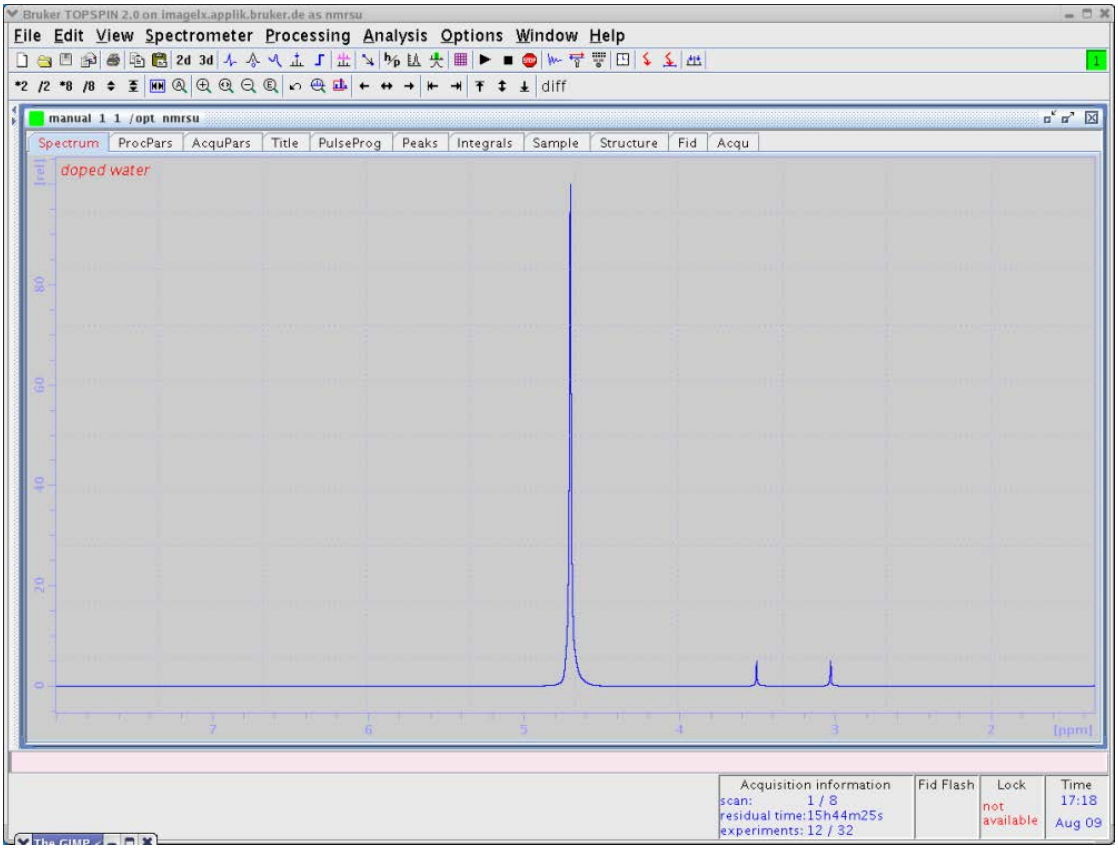


Figure 4.1: 1D Spectrum of Doped Water Sample

- After finishing the 1D experiment create a new data set and change it to 2D.

4.1.3 Diffusion Parameter Setup

- Type “diff” to start the setup program. The following will appear. Because it was started with a fresh data set, very little information will be visible.

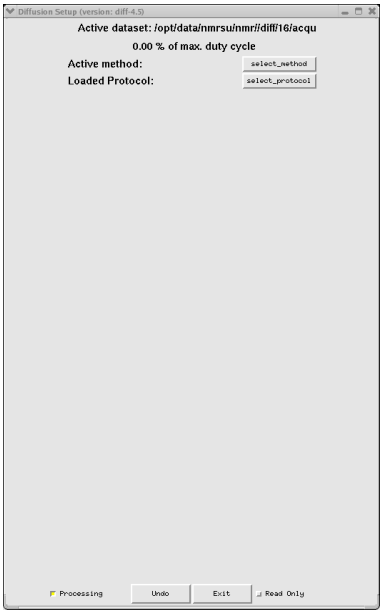


Figure 4.2: The diff Command Started within a Fresh Data Set

The window can be kept open as long as needed, it will always display the parameters of the active data set in TopSpin.

Note: When called from a 2D data set, Diff will only allow diffusion experiments!

When starting from scratch, it is easiest to load a protocol. A protocol is a set of *high level* parameters, like the expected diffusion coefficient, from which diff can derive all diffusion relevant parameters automatically. For example, select the protocol **steWater** from the pull down menu next to *Loaded Protocol*:

Figure 4.3: The diff Command Showing Protocol Selection

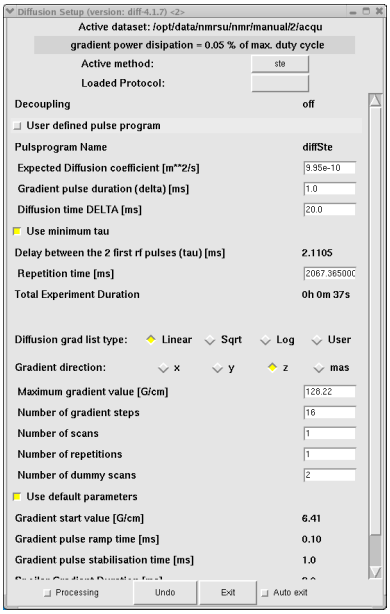


Figure 4.4: The diff Command Showing Parameters of “ste”

The parameters shown here can be used for water or similar liquids without any change. In general the parameters have to be adjusted according to the sample properties and/or experimental needs. Details about the parameter settings, their meaning, and parameter relations are given in *Diffusion Experiments [▶ 61]* and in *Diff Program Reference [▶ 91]*.

To change the values:

- Click on the entry field.
- Delete the numbers and type in the new number you want.
- Press **return** or move the cursor out to activate the relations.

Depending on the parameter hierarchy, the parameters will be checked and e.g. set to the minimum possible value, derived from the other related parameters.

When leaving the diff window the parameters are automatically stored in the data set.

Note: In contrary to older versions of diff, no active saving is required, the parameters are automatically stored each time the cursor focus leaves the diff window. The very first time this action is performed, the AU program “diff_t1pars”, which runs in background, will be compiled automatically and the corresponding message will be displayed.

4.2 Running the Experiment

- Type **zg** to run the experiment.

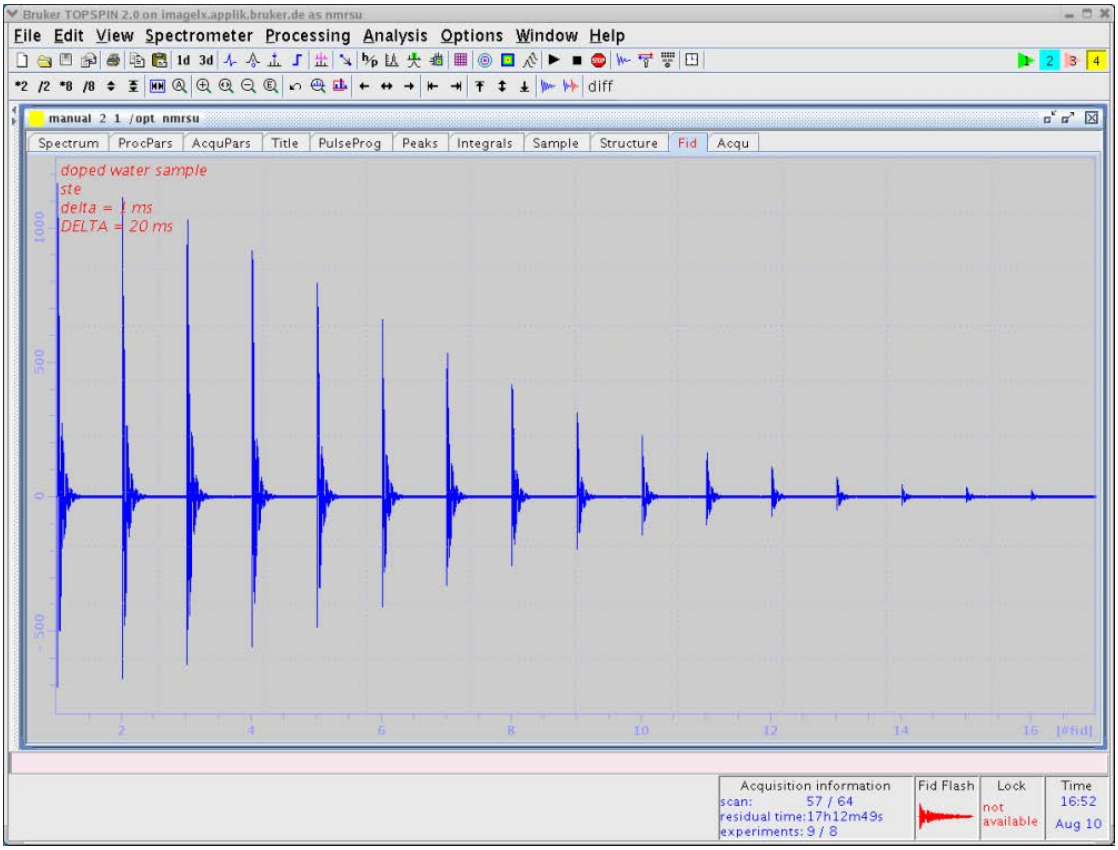


Figure 4.5: Echo Decay Caused by Growing Diffusion Gradients.

4.3 Processing

The processing can be done in phased or in magnitude mode depending on the type and quality of the NMR signals. For pure liquids, the phased mode is typically used. This section shows a straight forward way of processing the data. More details are given in the section *The T1/T2 Analysis Module [▷ 82]*.

- Type **xf2** and phase correct the data in the F2 direction. Using the doped water sample, the result should look like this:

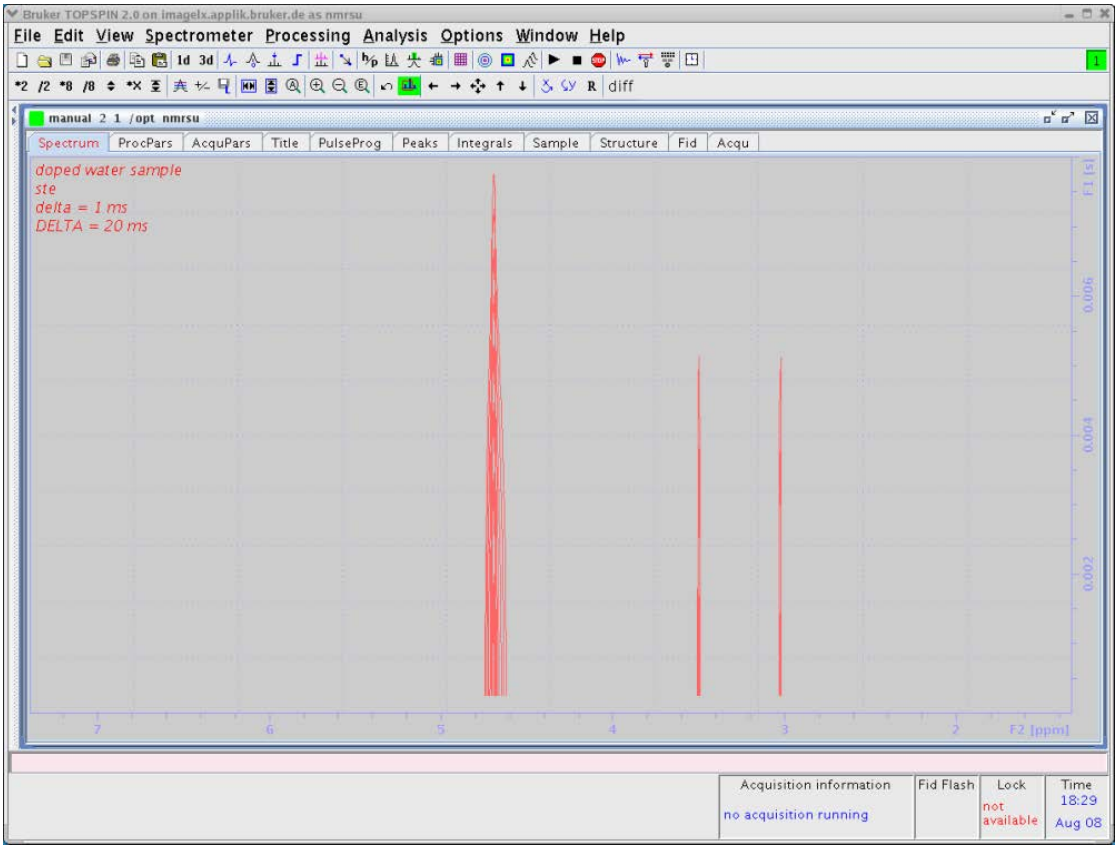


Figure 4.6: Echo Decay After xf2.

- Select the **NMR Relaxation Guide** by clicking on **T1/T2 Relaxation** in the Analysis pull-down menu. The TopSpin data window should look like this:

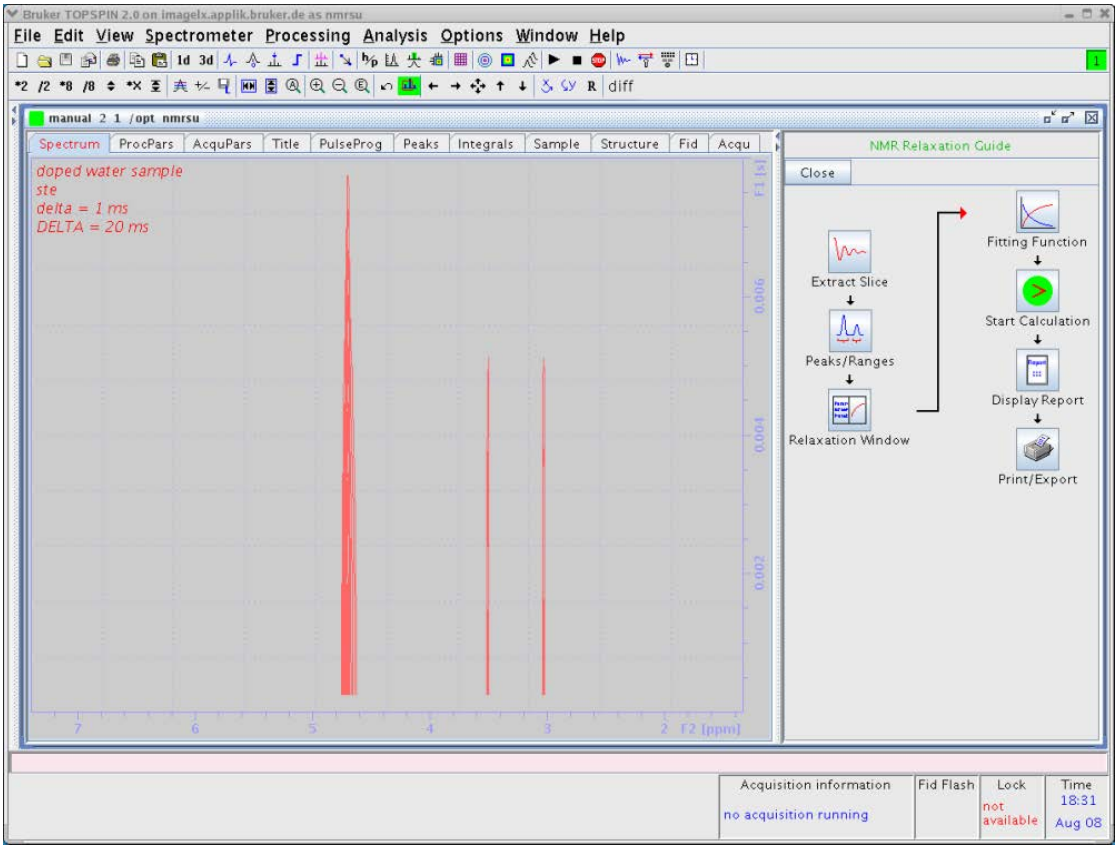


Figure 4.7: Pseudo 2D Spectrum with NMR Relaxation Guide.

- Begin the processing by clicking the icons in the guide sequentially and follow the advice given. When you select the first icon, **Extract Slice**, a section pop-up window will appear:

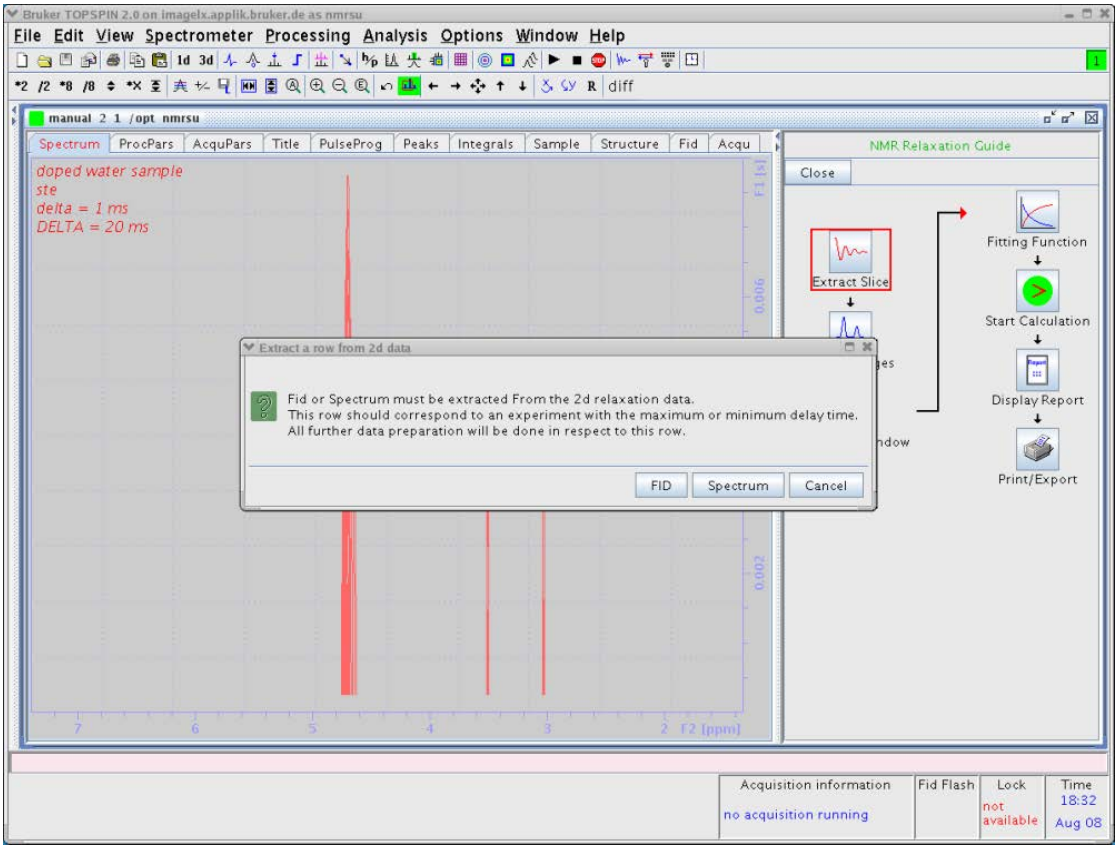


Figure 4.8: Pseudo 2D Spectrum with NMR Relaxation Guide: Step 1.

- There are 2 possibilities offered, to start with an FID or to start with a spectrum. As we have already performed the phase correction, select **Spectrum**. This is usually the preferable way.
- After selecting **Spectrum** another pop-up window will appear and request the slice number. In diffusion experiments usually the first experiments provide the strongest signals, therefore select one of these. The default is 3, as number 1 and 2 sometimes show artefacts. This is more a tradition than a rule.

The result of this selection is shown here:

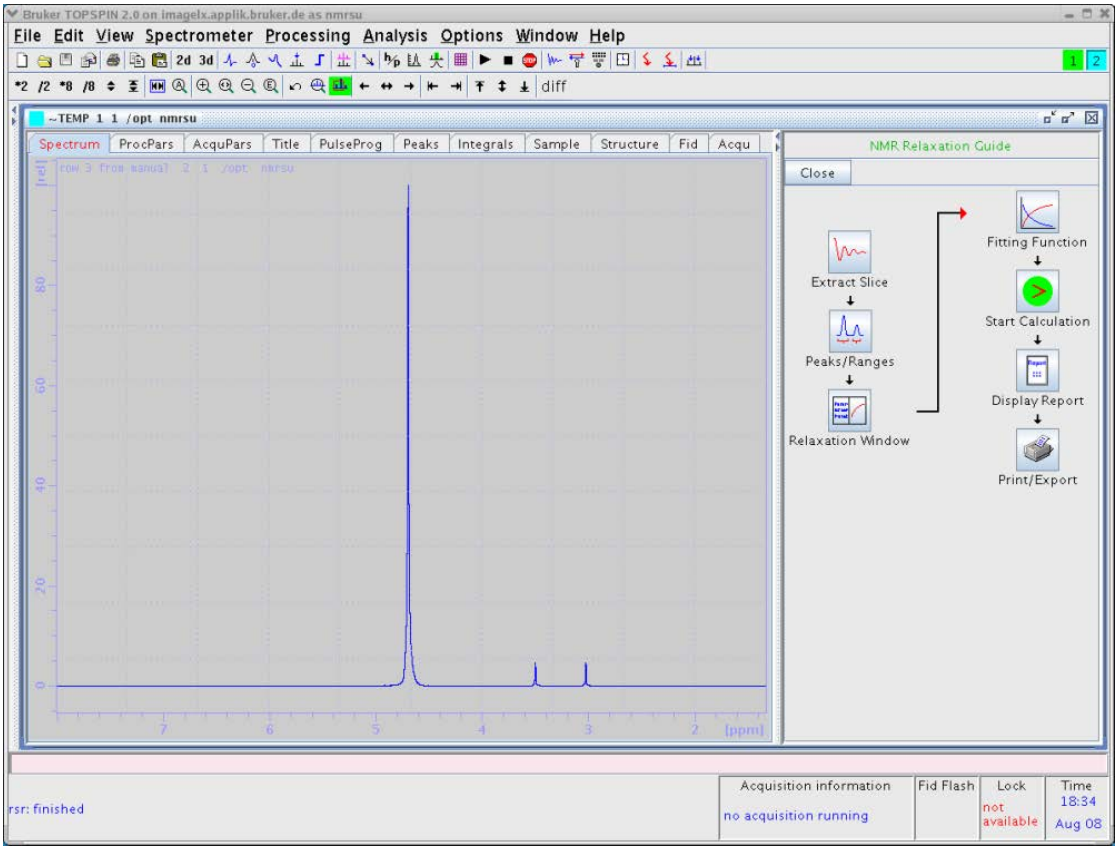


Figure 4.9: Selected 1D Spectrum from the 2D Data Set.

- Click on the next button in the NMR Relaxation Guide, **Peaks/Ranges**.

A pop-up window offering **Manual Integration** or **Manual Peak Picking** appears:

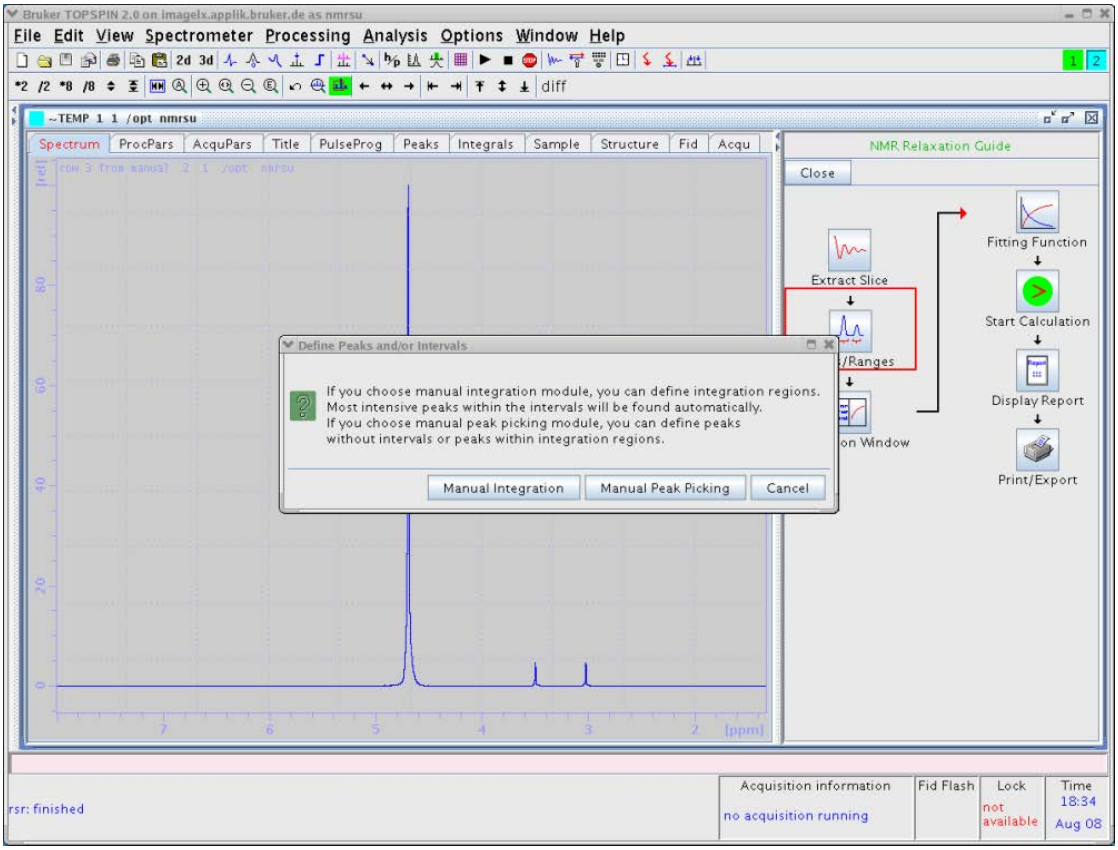


Figure 4.10: Selected 1D Spectrum with NMR Relaxation Guide: Step 2.

- Select **Manual Integration**. This will open the 1D integration window, where the peaks can be selected by dragging the left mouse button:

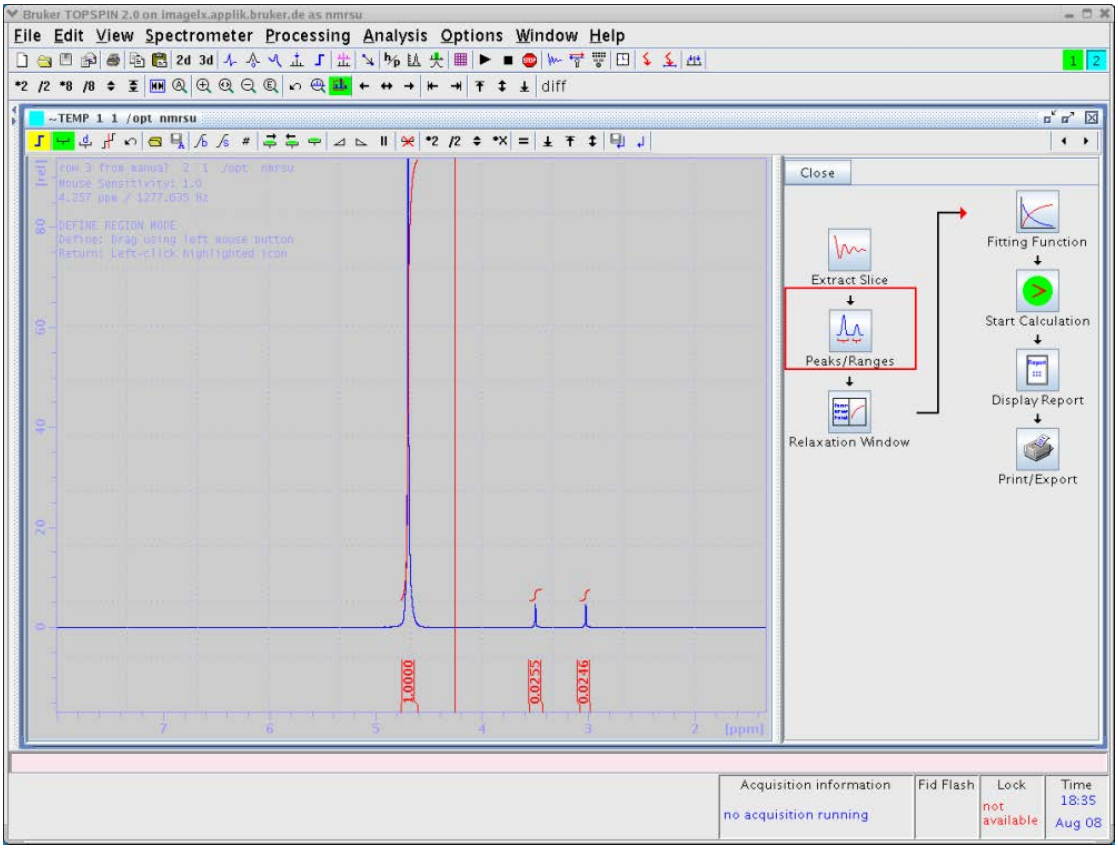


Figure 4.11: Spectrum with Integrated Peaks.

- Click on the left button to exit the integration window and select **Export Regions to Relaxation Module and ret.**:

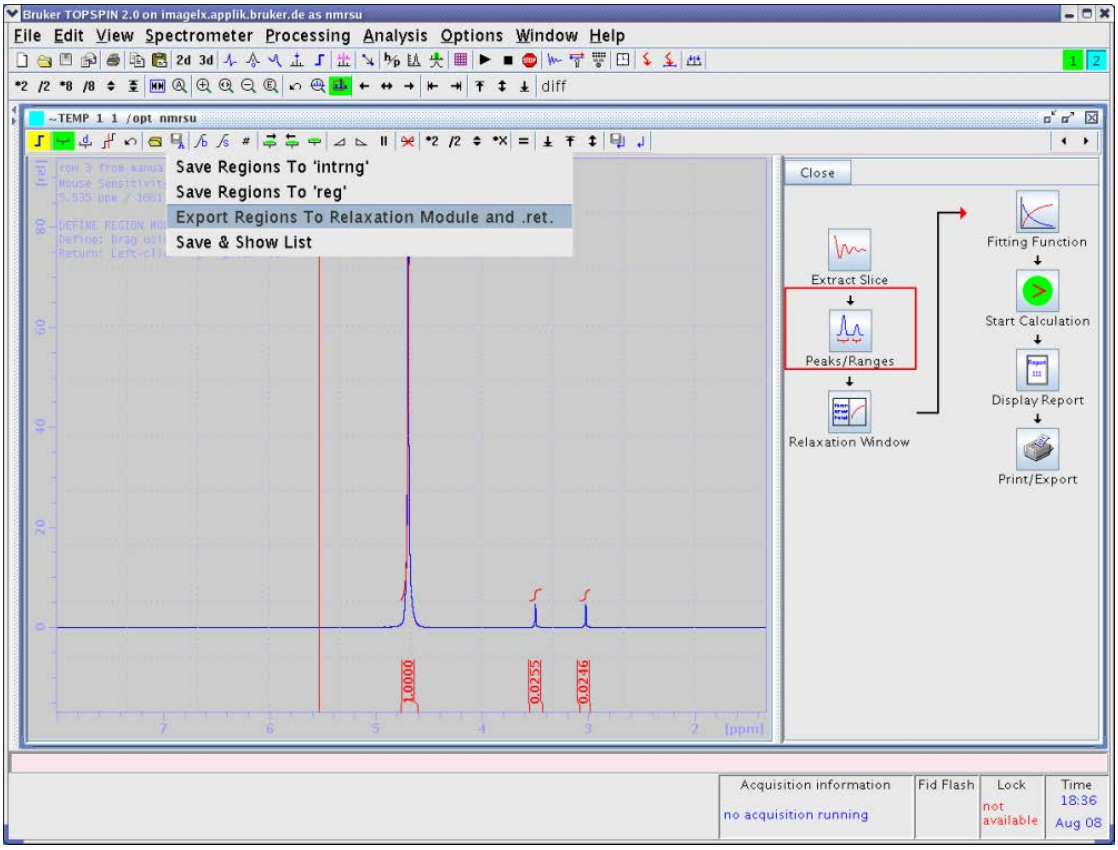


Figure 4.12: Leaving the Integration Module.

- Click the **Relaxation Window** button. The relaxation window will open showing the automatically selected data points:

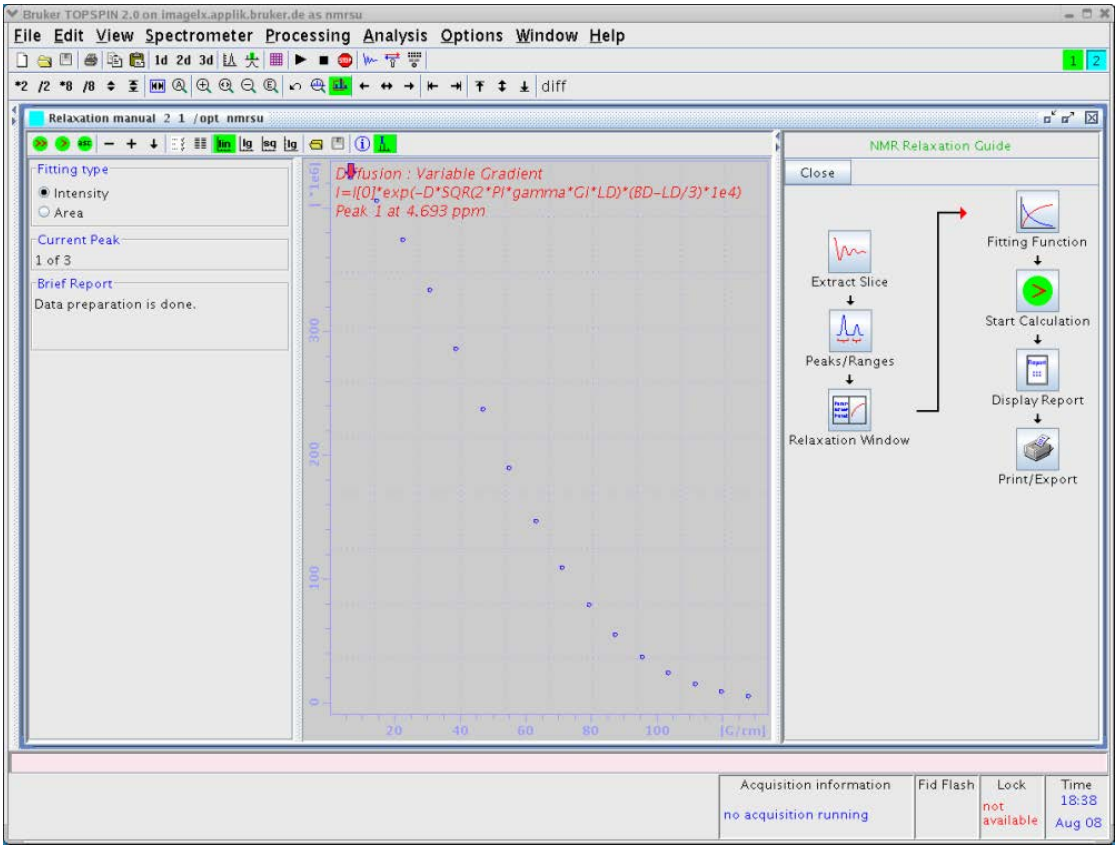


Figure 4.13: Relaxation Window with Data Points.

Automatic peak selection only takes place when this window is opened the first time in a data set. If data are already present, the data will be preserved.

- Click on the **Fitting Function** button. This will open a parameter editor:

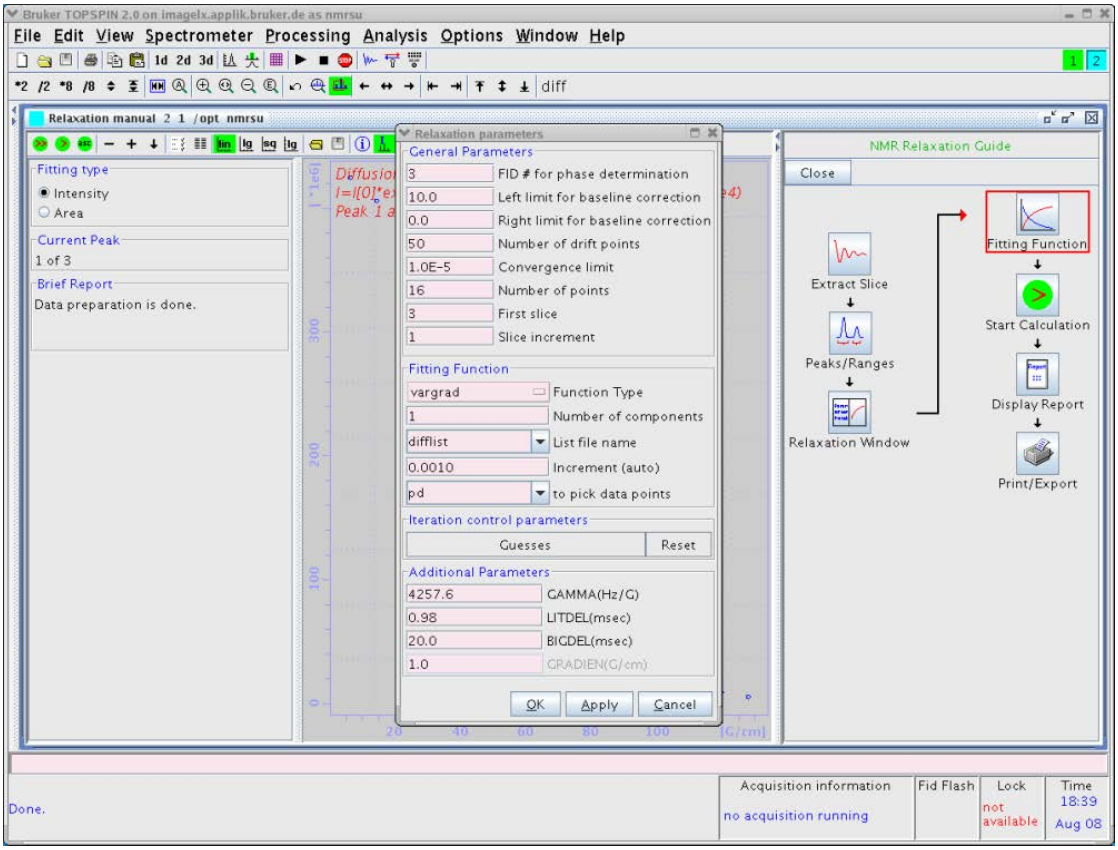


Figure 4.14: Relaxation Parameter Editor.

This editor shows and allows all the relevant parameters for the fitting procedure (e.g. d and D.) to be changed. Details about these parameters are described in *Parameter Dialog Box [▷ 84]*. All of these parameters have been preset by **diff** and usually do not need to be changed.

- Click on the **Start Calculation** button. This fits the fitting function to the data points and plots the curve together with the data points. The results are shown in a brief report field on the left side of the window, and also in the title displayed in the plot window:

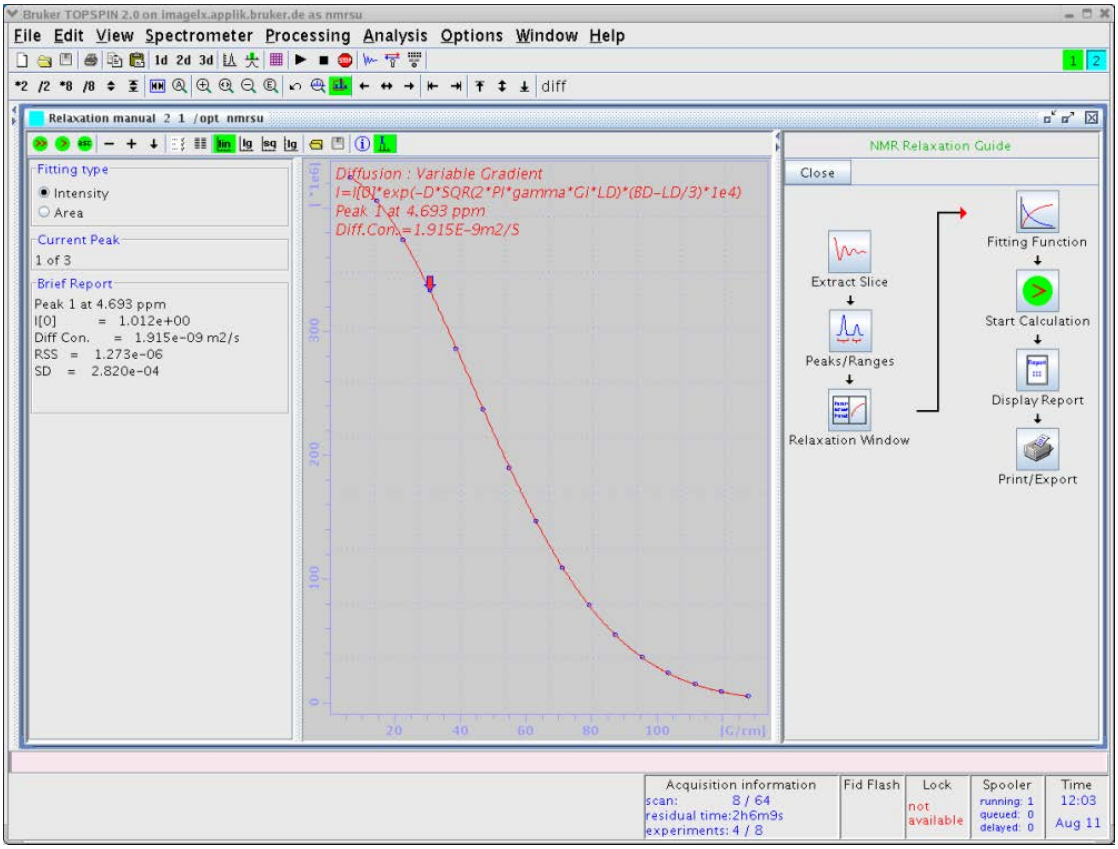


Figure 4.15: Data Points with Fitted Curve.

- Click on the **Display Results** button. An editor window is opened showing the results in a more detailed view, together with the measured data and the calculated points.

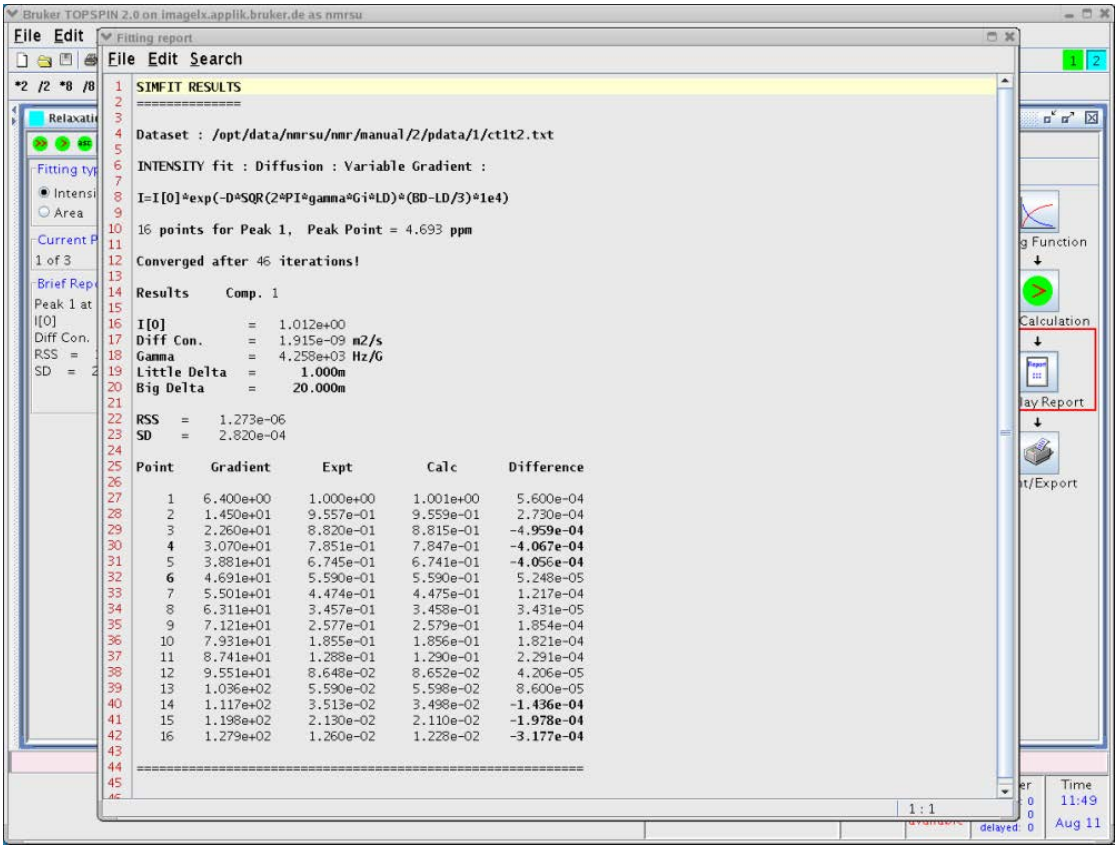


Figure 4.16: Simfit Results.

The results are also stored in the file ct1t2.txt in the processed data directory.

- Click the **Print Option** button, a list of print and export options will be shown:

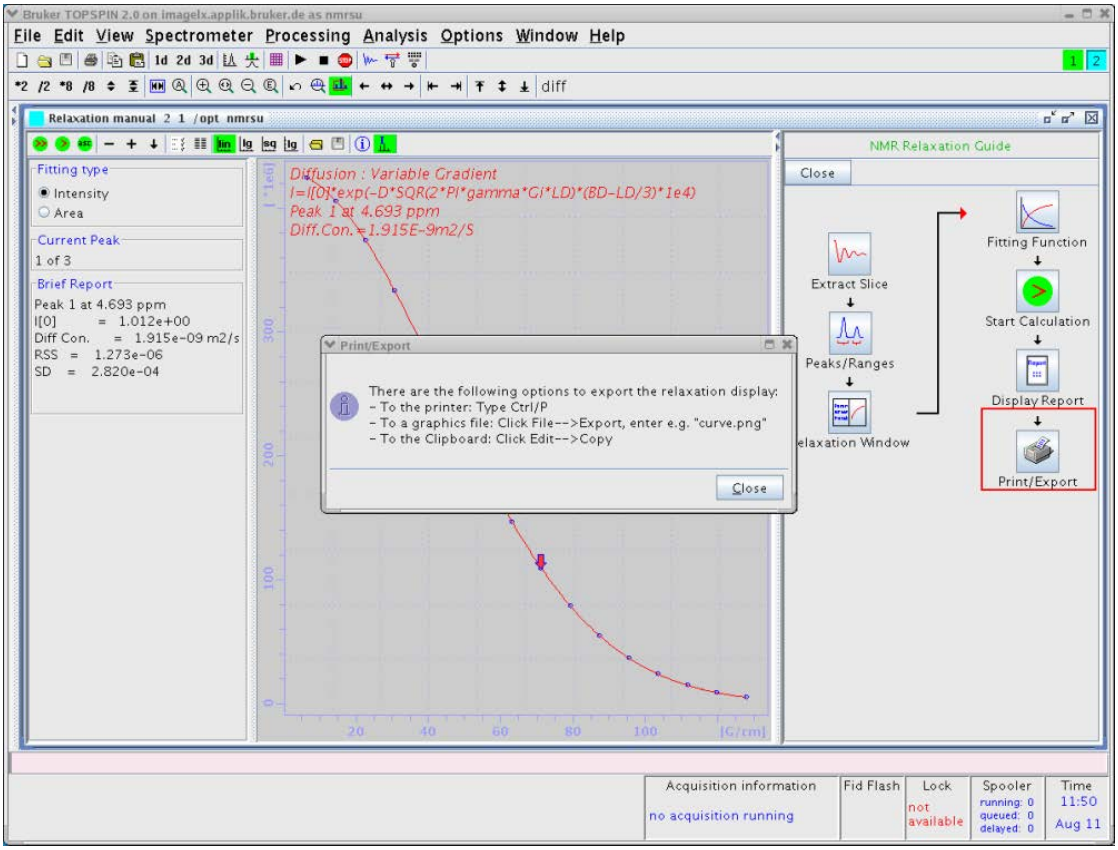


Figure 4.17: Print Options.

Step by Step Guide, Old Style

5 Diffusion Experiments

Diffusion experiments are usually based on two standard types of pulse sequences, the spin echo diffusion sequence[1] and the stimulated echo sequence[2]. All other published sequences can be understood as modifications of these two sequences.

- For samples with $T_1 = T_2$ the PGSE sequence is usually the preferred one; for samples with $T_1 >> T_2$ the PGSTE sequence is often used, as during most of the diffusion time the magnetization can be stored in the Z direction.
- For the PGSE sequence, the maximum diffusion time is limited by T_2.
- For the PGSTE sequence the maximum diffusion time is limited by T_1.

A growing number of sequences are supported by the diff program. Some sequences are explained here in some detail, mainly in order to show the meaning of the parameters.

All pulse programs supported by diff are written in a way, whereas they can all be processed by the same equation, the Stejskal-Tanner Equation:

$$\frac{S}{S_0} = e^{-\gamma^2 g^2 \delta^2 \left(\Delta - \frac{\delta}{3}\right) D} = e^{-BD}$$

$$B = \gamma^2 g^2 \delta^2 \left(\Delta - \frac{\delta}{3}\right)$$

Figure 5.1: The Stejskal-Tanner Equation

Note: In diff5 the conformity to the Stejskal-Tanner equation is given up in order to allow different gradient pulse shapes to be taken properly into account. B values are calculated according to different formulae given in the literature in order to have correct B values even in the case of short Δ and long δ where the error of not taking the pule shape into account is most prominent (see also *Gradient Pulse Shapes [▶ 62]*).

Overall the errors introduced before were in the order of a few percent in extreme cases and below one percent in usual cases.

In order to measure the diffusion coefficient D usually a series of experiments with different values of B are usually performed. The Stejskal-Tanner equation is then fitted to the experimental signal amplitudes S. The algorithm then calculates the signal amplitude S_0 (B=0) and the diffusion coefficient D as fit parameters. The parameter B holds all the experimental parameters, the gradient strength *g*, the diffusion time Δ, and the gradient pulse length δ. It also contains the gyro magnetic ratio γ in units of rad/s.

In most experiments the timings are kept constant in order to avoid signal attenuation caused by the spin-lattice relaxation time T_1 or the spin-spin relaxation time T_2. In case of inhomogeneous broadening, T_2^* is usually cancelled by means of spin echos.

The approach describing diffusion experiments using the parameter B, is only valid in the case of non-restricted diffusion, i.e. liquid state samples. In the case of restricted diffusion, i.e. porous media, the NMR diffusion experiments can only measure an apparent diffusion coefficient. The magnitude of the apparent diffusion coefficient will usually depend on the diffusion time Δ. Therefore experiments that vary the diffusion time are also available.

[1] PGSE - E. O. Stejskal and J. E. Tanner, J. Chem. Phys. 42 (1965)
[2] PGSTE - J. E. Tanner, J. Chem. Phys. 52(1970)

5.1 Gradient Pulse Shapes

To generate rectangular gradient pulses using a real gradient coil having a finite resistance and inductance (described in the literature for simplification), an infinite voltage would be required. Shaped gradient pulses allow the required voltage to be limited to a value the amplifier can reasonably produce. Driving a gradient amplifier with rectangular input pulses leads to more or less distorted output pulses depending on the resistance and the inductance of the gradient coil. Even when this distortion does not matter, this is an issue for the gradient pulse reproducibility. Therefore only shaped gradients are used within the Bruker diffusion programs. More details and how to measure and adjust the ramp time are given in *Gradient Ramp Time Calibration [▷ 30]*.

In older versions of diff only trapezoidal gradients with equal ramp up and down times were available. Beginning with Topspin2.1 pl1, the new gradient shapes sin and opt are also available in diff. Additionally, the pulse program syntax has been changed to make it easier to have a matching number of gradient shape steps at any ramp or shape duration. The gradient pulses can be selected using radio buttons in the diff interface, (refer to *Diffusion Parameter Setup [▷ 45]*).

The default gradient shape is always the sine shape.

Since diff version 5 (**diff5**) a new pulse, the so called smsq smoothed square pulse was added.

In order to fulfill the Stejskal-Tanner equation, the gradient pulse duration is calculated in a way that a virtual rectangular pulse of the length δ have the same integral as the real pulse. This method is not absolutely accurate, but the error is usually negligible. Since diff version 5.3 the exact corrections are implemented according to:

- W. S. Price and P. W. Kuchel, J. Magn. Reson. 94, 133-139 (1991),
- Röding, M. and Nydén, M. (2015), Stejskal-Tanner equation for three asymmetrical gradient pulse shapes used in diffusion NMR. Concepts Magn. Reson., 44: 133–137

The corrections are affecting the so called B values, which are used for the data analysis in general. The stored g and q values are calculated using the old convention.

5.1.1 Sine Shape

The sine shape should be more accurately called the half sine shape, but sine shape is the usual nomenclature. In order to allow the data to fit to the usual diffusion equation, the durations are used as described above.

$$\delta = \frac{2}{\pi} t_g$$

Figure 5.2: Equation 2

The gradient pulse duration is then:

$$t_g = \frac{\pi}{2} \delta$$

Figure 5.3: Equation 3

5.1.2 Trapezoidal Shape

The trapezoidal shape can now have different durations for the up and down ramps, tr_{up} and tr_{down}. Currently stage tr_{down} must not be larger than tr_{up}. The equations below are a bit more complicated:

$$\delta = 0.5\left(tr_{up} + t_{down}\right) + t_{on}$$

Figure 5.4: Equation 4

$$t_g = tr_{up} + t_{on} + tr_{down} = \delta + \frac{1}{2}(tr_{up} + tr_{down})$$

Figure 5.5: Equation 5

5.1.3 Opt Shape

The **opt** shape stands for optimal shape, which is mainly useful for gradient systems with a high resistance and inductance.

The opt shape is a composite shape, it starts with a quarter of a sine wave, then a constant gradient and finally a ramp down. In most cases using this sequence will provide the biggest gradient integral for a given time. The equations shown in the previous section have to be modified as follows:

$$\delta = \frac{2}{\pi} tr_{up} + t_{on} + \frac{1}{2} tr_{down}$$

Figure 5.6: Equation 6

$$t_g = tr_{up} + t_{on} + tr_{down} = \delta + \left(1 - \frac{2}{\pi}\right) \cdot tr_{up} + \frac{1}{2} tr_{down}$$

Figure 5.7: Equation 7

The advantages of this pulse include not only that the factor 0.636 shows up in the first equation above, but also tr_{up} can usually be significantly shorter compared to the trapezoidal pulse.

5.1.4 SMSQ

The smsq shape has similar properties as the opt shape, but it is more symmetric and smooth. This pulse is often used nowadays in HR-NMR.

The smsq shape is a composite shape starting with a quarter of sine, then a constant gradient, and finally a quarter of sine down. The ramp up time tr_{up} and the ramp down time tr_{down} are usually the same. The corresponding equations are as follows:

$$\delta = t_{on} + \frac{4}{\pi} tr$$

Figure 5.8: Equation 8

$$t_g = tr_{up} + t_{on} + tr_{down} = \delta + \left(2 - \frac{4}{\pi}\right) \cdot tr$$

Figure 5.9: Equation 9

5.2 Variable Gradient Experiments

In all of these experiments the times are kept constant, while the gradient amplitude is varied. The gradient strength usually starts at a small *gradient start value* and is increased in different ways up to the so called *maximum gradient value*. The selector for the different ways of varying the gradient strength is called the *diffusion grad list type*. The first mode is *linear*, were the gradient is incremented in constant increments between the *gradient start value* g_{start} and the *maximum gradient value* g_{max} (see the equation below).

In the following equation i stands for the index of the gradient value and n for the number of gradient steps. In the *default mode* g_{start} is set to g_{max}/n, but not larger than 5% of g_{max}.

$$g_i = g_{start} + \frac{(g_{max} - g_{start})}{n - 1}$$

Figure 5.10: Equation 10

The second mode is called sqrt, here the gradient values grow following the square root of their index. Here g_{start} is implicitly calculated and therefore not variable:

$$g_i = \sqrt{\frac{i}{n}}\, g_{max}$$

Figure 5.11: Equation 11

The third mode is the *log* mode, here the gradient values increase exponentially:

$$g_i = exp\left[ln(g_{start}) + (i-1)\frac{ln(g_{max}) - ln(g_{start})}{n-1}\right]$$

Figure 5.12: Equation 12

The forth mode, available only since version 5, is the so called *prop* mode for propagator mode, is used for propagator measurements. The gradient amplitude varies linearly between $-g_{max}$ and g_{max} in order to be able to measure the direction of the flow as well as the velocity. It is calculated using the equation 10 with $g_{start} = -g_{max}$.

The last mode is the so called *user* mode, where the user can edit the gradient list.

5.2.1 Pulse Gradient Spin Echo (PGSE)

The PGSE is the basic experiment, called **se** in the *diff* program. During a π/2 - π spin echo sequence two absolutely identical gradient pulses *g* are applied after the first and the second RF pulse. In this variant of the PGSE sequence, the gradient pulses are placed immediately the RF pulses in order make the available time for gradient ring down as long as possible. The distance between the centers of the two gradient pulses is called diffusion time Δ.

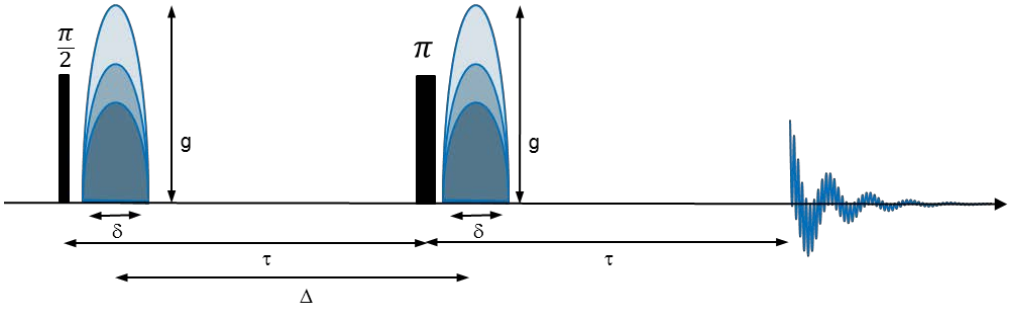


*Figure 5.13: PGSE Pulse Sequence (diffSe) in **Left** Mode*

During the sequence the signal decays according to the T_2 value, at an effective echo time (T_e) of 2*D*. Because all delays are kept constant during the whole experiment, the T_2 relaxation delivers only a constant attenuation factor while the decay is caused purely by diffusion.

$$T_e = 2\Delta$$

Figure 5.14: Equation 13

Since **diff5** is available, different modes of the PGSE experiment with different gradient positions are available: **left**, **long**, and **centered**.

Left stands for the *left most* gradients, i.e. the gradients are as close as possible after the RF pulses, as shown above. This was the only experiment in earlier versions. This mode is considered to be the best available to help prevent eddy currents, because the gradient pulses are as far as possible away from the signal.

Long stands for the longest possible diffusion time in a given echo time, i.e. the first gradient is placed left most while the last is right most, i.e. as close as possible to the echo position, as shown below. In this mode the maximum diffusion time is available within a given echo time, which might be limited by T_2. Besides that, it can be useful if strong solvent signals are present in keeping the magnetization defocused for most of the experiment time in order to minimize the effect of radiation damping. Equation 13 converts to:

$$T_e = \Delta + \delta$$

Figure 5.15: Equation 13a

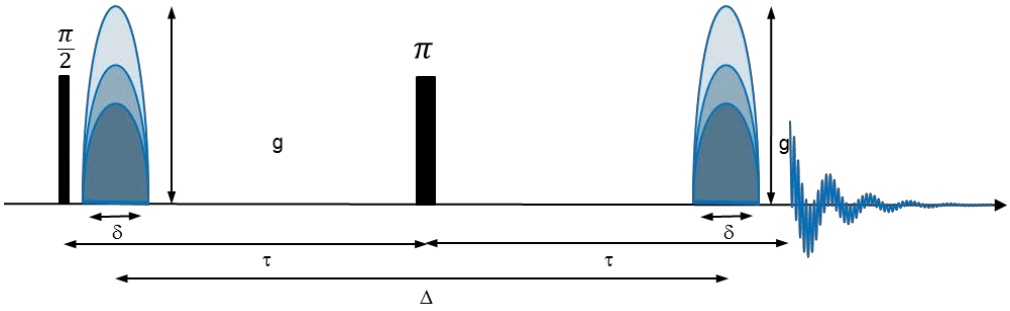


*Figure 5.16: PGSE Pulse Sequence (diffSe) in **Left** Mode*

Centered stands for the mode, where the gradients are centered in the delays between the rf pulses and the echo respectively, see below. Here equation 13 is valid.

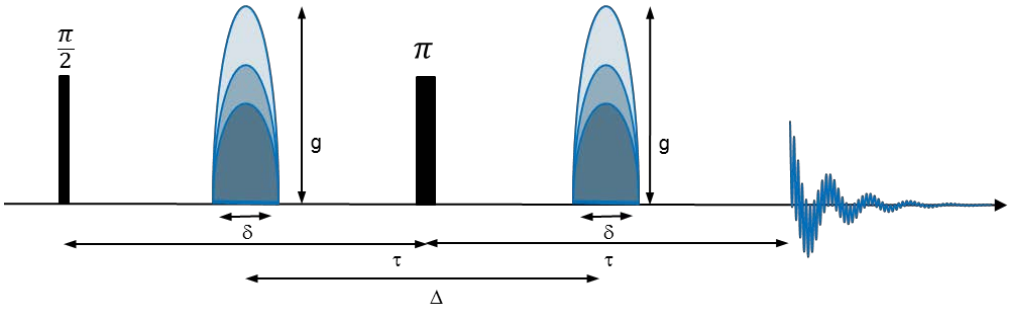


*Figure 5.17: PGSE Pulse Sequence (diffSe) in **Centered** Mode*

The gradient pulses can have different shapes as described above. The effective length of the gradient pulses describing the phase encoding strength of the gradient pulse is called δ. Depending on the pulse shape the duration of the gradient pulse is longer than δ (see equations 3, 5, 7, 9).

Note: If a J-coupling is present, long echo times may lead to spectra, which cannot be phased.

5.2.2 Pulse Gradient Stimulated Echo (PGSTE)

The PGSTE is called **ste** in the *diff5* program. During a *π/2 - π/2 - π/2* stimulated echo sequence two absolutely identical gradient pulses (*g*) are applied immediately to the first and the third RF pulse. The PGSTE sequence delivers only half of the signal compared to the PGSE sequence. The period between the two first RF pulse is called *t*, during *t* the magnetization decays according to the T_2 value at an effective echo time of 2*t*.

$$T_e = 2\tau$$

Figure 5.18: Equation 14

During the period between the second and the third RF pulse the magnetization points in the z direction and therefore the T_1 value applies. In many cases, this behavior allows use of rather long diffusion observation times. Because all delays are kept constant during the whole experiment, the T_1 and the T_2 relaxation contributions deliver only a constant attenuation factor whilst the decay is caused purely by diffusion.

The amplitude of these gradient pulses is incremented between experiments in order to get a variable attenuation of the NMR signal (see *Variable Gradient Experiments [▶ 64]*). In this variant of the PGSTE sequence, the gradient pulses are placed immediately after the RF pulses in order to allow for the shortest possible *t* value.

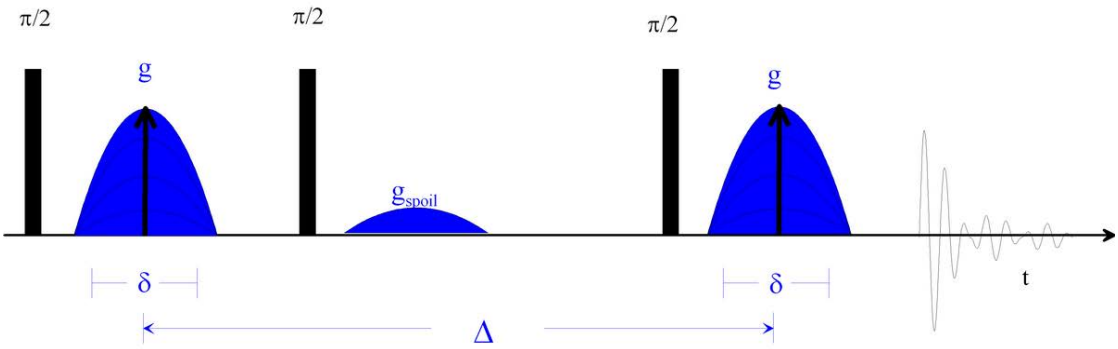


Figure 5.19: PGSTE Pulse Sequence (diffSte)

The gradient pulses can have different shapes, see *Gradient Pulse Shapes [▶ 62]*. The effective length of the gradient pulses describing the phase encoding strength of the gradient pulse is called δ. Depending on the pulse shape, the duration of the gradient pulse is longer than δ (see Equations 3, 5, 7, 9).

The distance between the centers of the two gradient pulses is called the *diffusion time* Δ.

An optional gradient spoiler or crusher gradient pulse is used in this sequence in order to get rid of coherent magnetization during the evolution period.

5.2.2.1 Spoiler Gradients

In the current version of the diff program, only mixing time spoilers are used for all stimulated echo experiments. Mixing time means the spoiler gradient is in the period between the 2nd and the 3rd π/2 pulse. In this period the usable magnetization is stored in the z direction and the spoiler dephases the remaining magnetization using spatial phase encoding. This is particularly important, when running a sample with a long T_2 value. The area of a spoiler pulse should not match the value of any of the diffusion gradients throughout the experiment.

In the default mode the spoiler gradient is calculated so that it's area equals 2/3 of the initial gradient step. If this area is too small for proper spoiling, the value is set between the first and the second step, and so forth.

The minimum spoiling gradient $g_{spoil,min}$ area is set arbitrarily to a value which corresponds to 33*360° phase shift over a 1 cm sample length.

$$g_{spoil,min} = \frac{33}{\gamma \delta_{spoil}}$$

Figure 5.20: Equation 15

Whereas, δ_{spoil} stands for the effective spoil pulse duration resulting from the first equation in *Sine Shape [▶ 62]*. For protons with a typical spoil duration of 2 ms, the $g_{spoil,min}$ would be 3.9 G/cm (39 mT/m).

5.2.3 PGSTE Using Bipolar Gradients

The PGSTE using bipolar gradients, also called 13 interval sequence[3], is quite similar to PGSTE (see *Pulse Gradient Stimulated Echo (PGSTE) [▶ 66]*). The single gradient pulses of the PGSTE sequence are split into a pair of 2 pulses with opposite signs enclosing a π-pulse. This pulse sequence is used to remove the effect of internal gradients in the sample. The dephasing resulting from internal static gradients is removed by means of the π-pulse. The effect of the applied gradients is kept by reversing the gradient after the π-pulse. In this sequence the gradient pulses are centered in the gaps between the RF pulses.

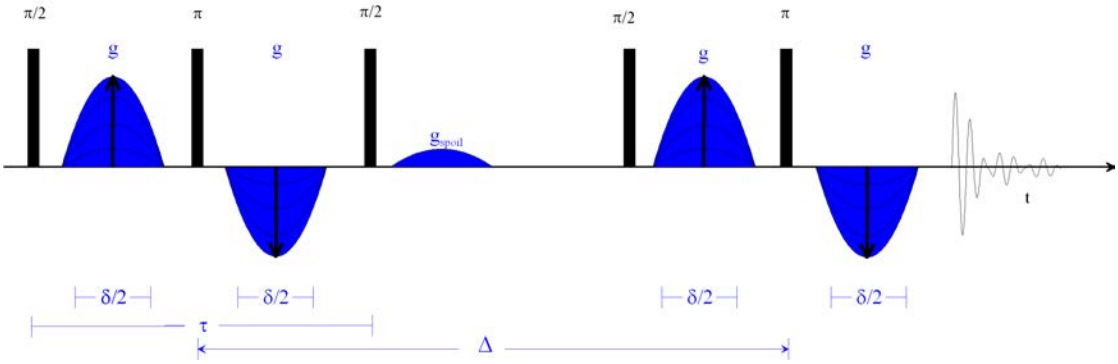


Figure 5.21: PGSTEBP Pulse Sequence (diffSteBp)

The delay between the first two π/2-pulses is called τ similar to the PGSTE sequence. τ is usually much longer here compared to the standard PGSTE sequence. This is mainly because of the gradient ring down delays, which also have to be in front of the gradient pulses in order to center them.

This sequence is also often used in liquid type experiments using the lock, because the bipolar sequence disturbs the lock less than the monopolar.

The gradient pulses can have different shapes (see *Gradient Pulse Shapes [▶ 62]*). The effective length of the gradient pulses describing the phase encoding strength of the two gradient pulses is called δ. The duration of the individual gradient pulse might be shorter than δ here. For this experiment the equations 2 to 9 to must be converted to:

$$\delta = \frac{4}{\pi} t_g$$

Figure 5.22: Equation 16 (sine)

$$t_g = \frac{\pi}{4} \delta$$

Figure 5.23: Equation 17 (sine)

$$\delta = \left(tr_{up} + t_{down}\right) + 2 \cdot t_{on}$$

Figure 5.24: Equation 18 (trap)

[3] PGSTEBP - R. M. Cotts, M. R. Hoch, T. Sun, and J. T. Markert, JMR 83, 252-266(1989)

$$t_g = tr_{up} + t_{on} + tr_{down} = \delta - t_{on}$$

Figure 5.25: Equation 19 (trap)

$$\delta = \frac{4}{\pi} tr_{up} + 2 \cdot t_{on} + tr_{down}$$

Figure 5.26: Equation 20

$$t_g = tr_{up} + t_{on} + tr_{down} = \delta + \left(\frac{\pi - 4}{\pi}\right) t_{up} - t_{on}$$

Figure 5.27: Equation 21 (opt)

$$\delta = 2 \cdot t_{on} + \frac{8}{\pi} tr$$

Figure 5.28: Equation 22 (smsq)

$$t_g = tr_{up} + t_{on} + tr_{down} = \delta + \left(2 - \frac{4}{\pi}\right) tr$$

Figure 5.29: Equation 23 (smsq)

The distance between the two π-pulses, which are the effective centers of the two gradient pulse pairs, is called the *diffusion time* Δ.

An optional gradient spoiler, or crusher gradient pulse, is used in this sequence in order to get rid of coherent magnetization during the evolution period (see *Spoiler Gradients [▶ 67]*).

5.3 Variable Δ Experiments

Currently, only one method using a variable D is built into diff, a stimulated echo experiment. The advantage of this method is, because T_1 is often significantly larger than T_2, the range of possible D values is larger in the stimulated echo experiment compared to a spin echo experiment. The disadvantage is that in such an experiment the signal amplitude does not only have decay caused by the molecular diffusion, but decay is also caused by spin-lattice relaxation T_1. Because of this, equation 1 must be modified:

$$\frac{S}{S_0} = e^{-\gamma^2 g^2 \delta^2 \left(\Delta - \frac{\delta}{3}\right) D} e^{-\frac{\Delta}{T_1}}$$

Figure 5.30: Equation 24

In order to compensate for this effect, each D increment is performed twice, one increment with g = 0, the other with g = g_0. This way the relaxation term can be removed by dividing the amplitude of experiment two by the amplitude of experiment one.

5.3.1 PGSTE with Variable Diffusion Time

The PGSTE with variable diffusion time is called DELTA in the *diff* program. During a π/2 - π/2 - π/2 stimulated echo sequence, two absolutely identical gradient pulses (g) are applied immediately after the first and the third RF pulse. The PGSTE sequence delivers only half of the signal compared to the PGSE sequence. The period between the two first RF pulse is called τ. During τ the magnetization decays according to the T_2 value at an effective echo time of 2τ (see Equation 12). During the period between the second and the third RF pulse the magnetization points in z direction and therefore T_1 applies. In many cases this behavior allows use of rather long diffusion observation times.

The amplitude of the gradient pulses is constant throughout the experiment. The diffusion time Δ, which is the distance between the centers of the two gradient pulses, is incremented between experiments in order to get a variable attenuation of the NMR signal. In this variant of the PGSTE sequence, the gradient pulses are placed immediately after the RF pulses in order to allow for the shortest possible t value.

Because the delays are not kept constant during the whole experiment, the T_1 relaxation contribution cannot be neglected. Therefore the experiment is always performed in two steps. For each diffusion observation time the experiment is performed once with and once without diffusion gradients. The experiment without diffusion gradients measures the relaxation contribution, while the experiment with gradient shows the attenuation caused by diffusion and relaxation.

The data are then processed by dividing the spectra acquired with diffusion gradients by the ones acquired without at the same timings. This way the relaxation effect is removed without further calculations. This is handled automatically by **DC** when called from the **diff5** program; see *Automatic Processing and Analysis using diff5 [▷ 38]*. Using *Automatic Processing and Analysis using the Dynamics Flow Bar [▷ 40]* will also automatically recognize this experiment and process it accordingly in **DC**. Interactively this kind of preprocessing can be selected in **DC** in the **Scaling** tab of the **Data** node.

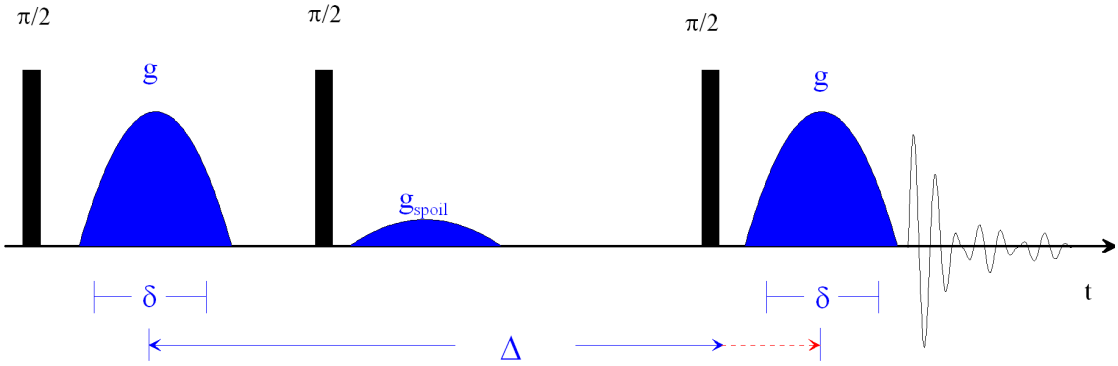


Figure 5.31: PGSTE Pulse Sequence with Variable Δ (diffDELTA)

The gradient pulses can have different shapes (see *Gradient Pulse Shapes [▷ 62]*), depending on the TopSpin version used. The effective length of the gradient pulses describing the phase encoding strength of the gradient pulse is called *δ*. Depending on the pulse shape the duration of the gradient pulse is longer than *δ*.

An optional gradient spoiler or crusher gradient pulse is used in this sequence in order to get rid of coherent magnetization during the evolution period.

5.4 Convection Compensated Sequences

Diffusion measurements are measurements of slow molecular motion, thus superimposed macroscopic motions like vibrations can corrupt the results. Convective flow is often a reason for artefacts in diffusion experiments. Convection is driven by temperature gradients in the sample (see *Convection Artefacts [▷ 123]*). The smaller the viscosity of the solvent or the sample itself, the larger the velocity of the convective flow will be.

To explain the convection compensation a short explanation of the effects of gradients on the signal phase is given here. In general the phase evolution of the spin signal at a certain position (r_0) caused by gradients in any NMR experiment, can be described using the equation:

$$\Phi(t) = \gamma\vec{r}_0 \int \vec{g}(t)dt + \gamma\vec{v}_0 \int \vec{g}(t)tdt + \ldots$$

$$\Phi(t) = \gamma M_0\vec{r}_0 + \gamma M_1\vec{v}_0 + \ldots$$

Figure 5.32: Equation 25

Because the magnetic field is position dependent in the presence of a gradient, the gradient induced phase is dependent on the position r_0, and its derivatives. The expansion shown in equation 25 stops at the first derivative of *r*, the velocity v_0. For the treatment of convection in an NMR tube the constant velocity term v_0 is usually enough in this geometry. This is because one can assume two constant flows, one up, the other down. The time integrals of $g(t)\cdot t^i$ are usually abbreviated using M_i, or moments.

In a diffusion experiment like e.g. the PGSE (see figure in *Pulse Gradient Spin Echo (PGSE) [▷ 65]*), the effect of M_0 is exactly zero. This is because the phase shifts caused by the two gradient pulses are exactly the same, but with opposite sign because of the π pulse in between. The first moments of the two gradient pulses are not identical, because they occur at a different time. If then the velocity is zero, the M_1 term is also zero. In this case only the signal attenuation caused by the random diffusive motion, which is neglected in the equation above, will be visible (see Equation 1).

If convection is present, v_0 is not zero and will be different in various radial positions in the sample, usually $+v_0$ and $-v_0$. The signal will show a superposition of the attenuation caused by diffusion and the phase shifts caused by two opposite flows.

To compensate for this, the pulse sequence must be modified in a way, that M_1 is inherently zero. This can be accomplished by adding suitable additional gradient pulses in order to fulfill to following condition:

$$M_0 = M_1 = 0$$

Figure 5.33: Equation 26

There are many possible ways to do this, also the compensation of higher orders is possible. In diffusion experiments usually the simplest solution is used, the double stimulated echo [4], whereas the second part compensates the first moment of the first part.

[4] sequenceA. Jerschow & N. Mueller, J. Magn. Reson. A 123, 222-225 (1996)

5.4.1 Pulsed Gradient Double Stimulated Echo PGDSTE

The PGDSTE sequence is a duplicated version of PGSTE (see *Pulse Gradient Stimulated Echo (PGSTE) [▶ 66]*), whereas only the initial π/2-pulse is not copied. This pulse sequence is used to remove the effect of constant flows in the sample. In this variant of the PGSE sequence, the gradient pulses are placed immediately after the RF pulses making the available time for gradient ring down as long as possible. The distance between the centers of the two gradient pulses is called half diffusion time Δ/2.This allows the data to be processed afterwards in the same way as the PGSTE data. Details about this are given in the section *Conversion of the Cotts 13 Interval to the Stejskal/Tanner Equation [▶ 99]*.

In this experiment two identical, optional spoiler gradient pulses are used.

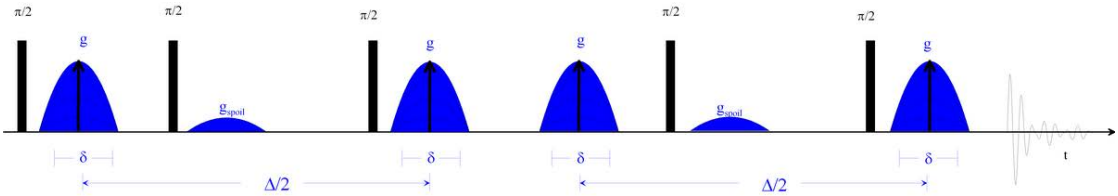


Figure 5.34: PGDSTE Pulse Sequence (diffDste)

5.5 Spoiler Recovery (SRC) Sequence

The so called **S**poiler **Rec**overy (**SRC**)[5] sequence is mainly used to speed up diffusion experiments. Exact diffusion experiments normally require a recovery time of 3 to 5 times T_1. The SRC sequence allows setting this time much shorter. The SRC sequence consists of 2 p/2 pulses and 2 gradient pulses of opposite sign and not matching gradient integral. This is used to destroy all remaining coherence. After the end of the second gradient pulse the magnetization starts to recover from zero.

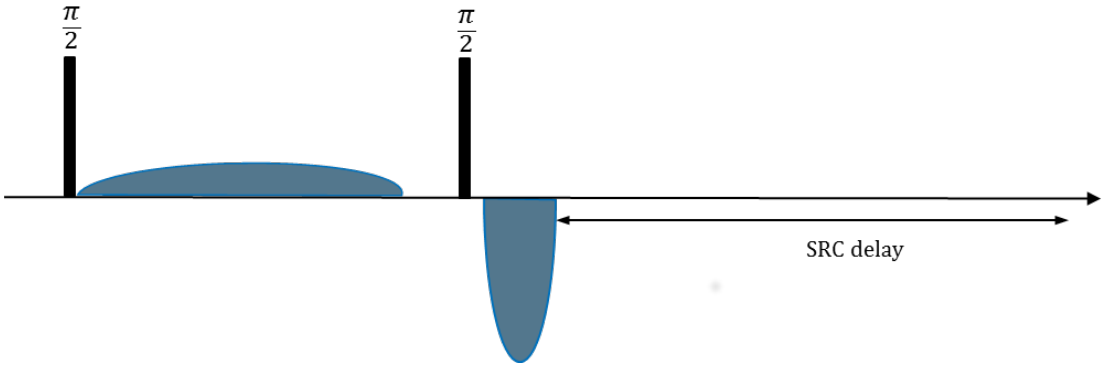


Figure 5.35: Spoiler Recovery Sequence (SRC delay is also Called SRD)

The SRC delay is usually set to about T1, but it could be also much shorter, but with a loss of signal intensity. The recovery delay can be set very short, practically zero, except for the time the lock needs to work, if lock is used.

Note: Duty cycle is another limiting factor, which can become important in the context of SRC.

[5] G.H. Sørland, H.W. Anthonsen, K. Zick, J. Sjöblom, and S. Simon, Diffusion-Fundamentals.org 15 6, 1 (2011)

5.6 Multiple Acquisitions

Note: In general multizg does not work for diffusion experiments as easy as for other experiments.

In order to allow multizg to run, the parameter **Use variable gradient ramp file name** must be set to **yes**, see *Config Tab [▶ 118]*.

All experiments must be prepared using diff5, and then multizg will work as usual. Alternatively individual experiments can be prepared and sent to the spooler.

Full automatic cloning and running of diffusion experiments is in development and will be available soon.

6 Analysis

From now on the recommended way of data analysis and DOSY processing is using Dynamics Center. The description of the older methods are kept here for completeness, but will be removed in future versions of this manual. New users should concentrate on learning to use Dynamics Center, because the other options will no longer be supported in the future.

6.1 Dynamics Center

The **Dynamics Center**, is a standalone Java program communicating with TopSpin in various ways, already partly described in *Automatic Processing and Analysis using diff5* *[38]*. Dynamics Center was designed to analyze all kinds of non-FT NMR data and Diffusion is an important part of it. Dynamics Center has an extensive manual as part of the program distribution, click on **Help** in Dynamics Center to access the manual. Some diffusion and DOSY relevant points are described in more detail in this chapter.

6.1.1 Installation

Dynamics Center can be installed from the TopSpin DVD as an option in the TopSpin installer.

As the Dynamics Center is continuously being improved, it is recommended to check the Bruker web server for the latest version. Open *https://www.bruker.com/* and browse to **Service** | **Support & Upgrades** | **Software Downloads** | **Nuclear Magnetic Resonance**. At this point you must login, either use an existing customer account or create a new one. After logging in you must select your operating system, and then you will find the latest Dynamics Center download for your operating system.

After starting Dynamics Center it is recommended to set the standard spectrum path. This is done by selecting **Config** | **Preferences** | **Default Spectrum Path**. A window will open allowing you to set the default spectrum path. It is usually recommended to set it to **Get latest spectrum from TopSpin**. As there may be more than one TopSpin installation on the system, the TopSpin installation path used must be specified here.

By default the setup uses the active data set in TopSpin for the data path.

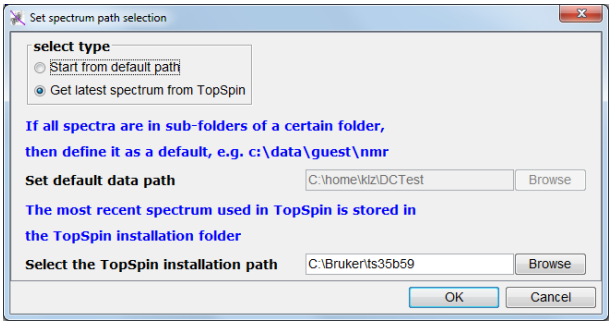


Figure 6.1: Default Spectrum Path

6.1.2 Peak Picking

Proper peak picking is very important for good data extraction. Normally, fully automatic peak picking does a very good job, but it might fail in some cases:

- If the spectra are shifting a little due to temperature or field drift, or due to eddy current effects and the **peak epsilon in F2** is too small, the algorithm might lose a peak during.
- If the **peak epsilon in F2** is too big, the algorithm may jump between real peaks during the analysis, i.e. the ID mixes up neighboring peaks.

The automatic peak picking in DC works as follows:

- First all peaks are picked in all spectra, i.e. in each row of the pseudo 2D data-set.
- Then the algorithm checks which peaks belong to each other. Ideally, these are of course the ones at the same chemical shift, but if the spectra are not ideally stable, the algorithm can search for the matching peaks in a range given by **peak epsilon in F2**.

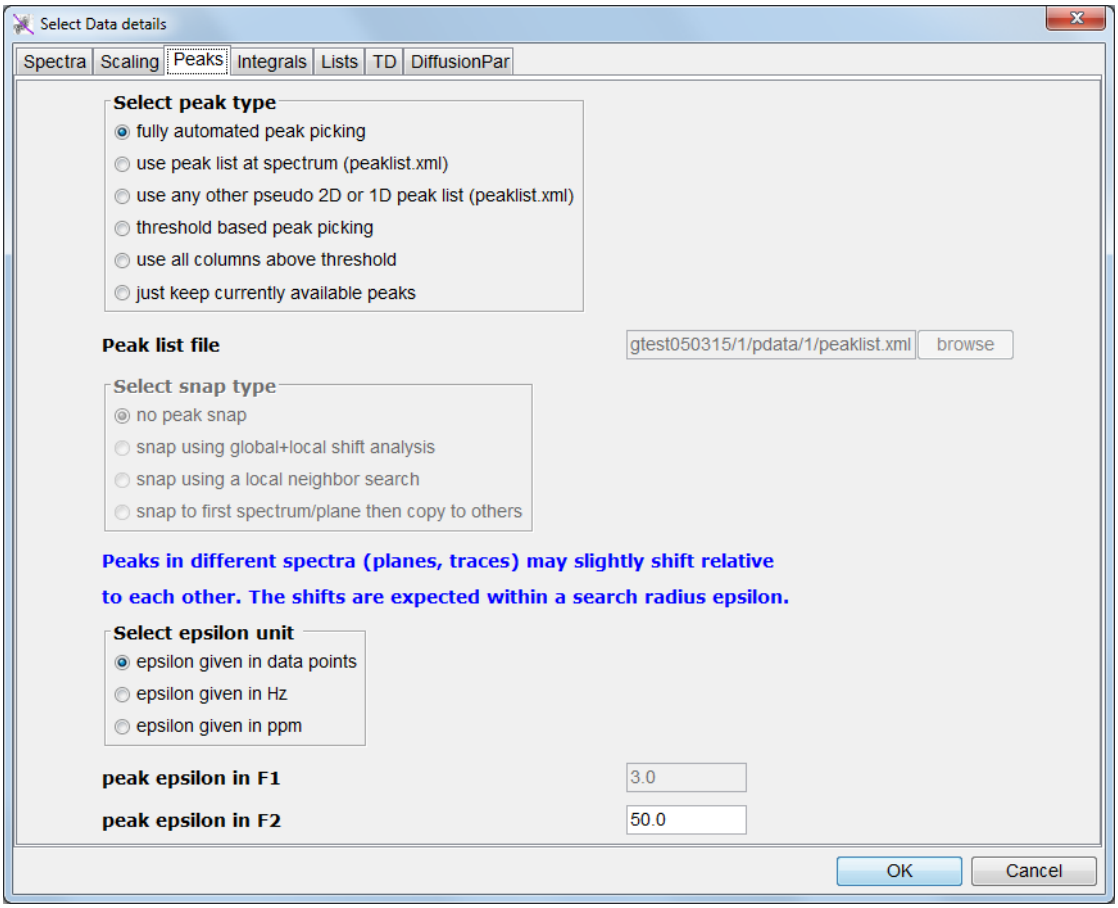


Figure 6.2: Dynamics Center Data Node, Peaks Tab

This value typically defaults to 3 points, but if Dynamics Center was called from diff5 it defaults to the value defined in *Config Tab [▷ 118]*, here 50. If diffusion fit curves look strange or the DOSY plot looks scattered, it is recommended to check the peak positions by browsing through the spectra using the slider as indicated below:

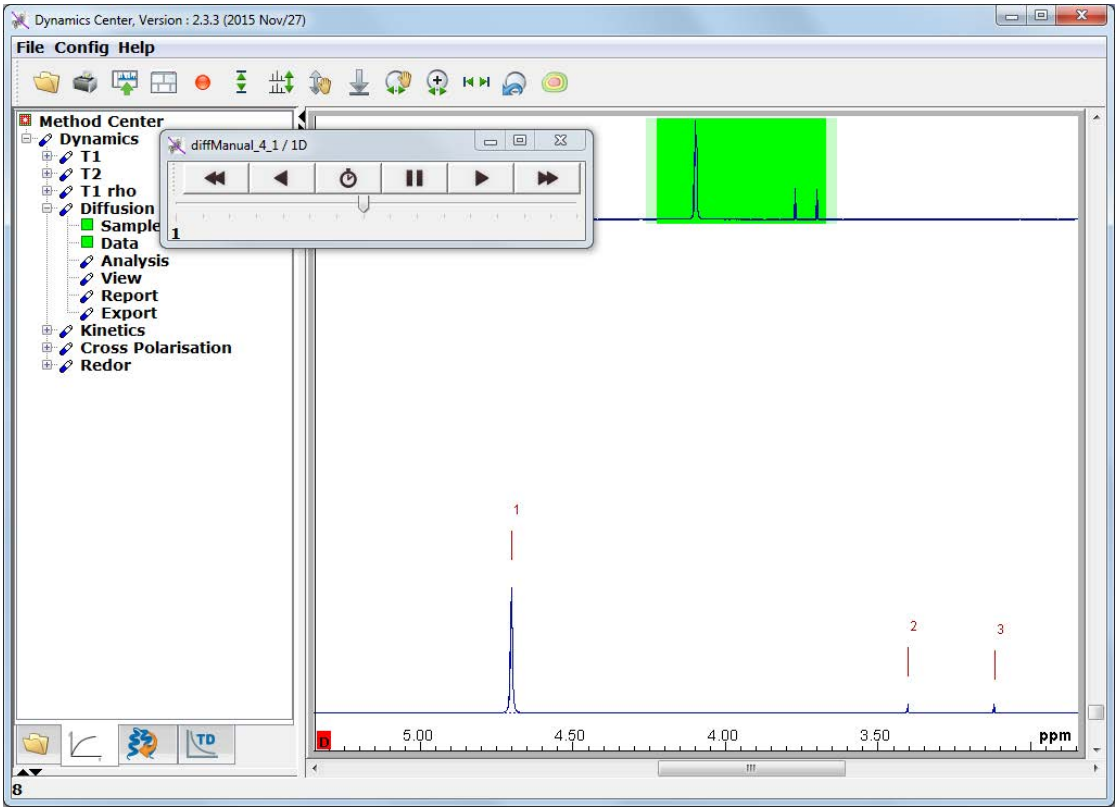


Figure 6.3: Browsing Spectra using the Slider

The second option, **use peak list at spectrum** can only be used, if a peak list was generated within Dynamics Center. This is because **TopSpin** cannot create 2D peak lists for pseudo 2D spectra.

The third option allows a 1D peak list to be used as the source of the peaks. In this case the options in the **Select snap type** box can be used. This third option is also used when the peak picking function in the peak picking option in the *Automatic Processing and Analysis using the Dynamics Flow Bar [▷ 40]* is used.

Option number 4, **threshold based peak picking** is only applicable in purely interactive mode. It will take all peaks above a user defined threshold in the first row. These peak positions are then fixed and the intensities in the following spectra are taken exactly at the same positions. Selecting this option requires the user to select the threshold immediately after pressing **OK**. Clicking on the left mouse button will show a threshold line, releasing the button will take the actual position of the line as threshold.

Option number 5, **use all columns above threshold** is used to create a DOSY plot like in TopSpin. In interactive mode the threshold is defined interactively, like in option 4. In automatic mode a reasonable value for the threshold is assumed.

Option number 6, **just keep currently available peaks** is for interactive mode, when peaks are manually picked and/or deleted. If no peak was selected, this option will be called **define peaks later**.

6.1.3 Integrals

In most cases peak amplitudes will be the best choice for the source of the signal amplitude used for the data analysis. Nevertheless in some cases other methods might be useful, such as option 2 **use peak area (user defined) integrals**. These integrals can be defined rather conveniently in TopSpin as described in *Automatic Processing and Analysis using the Dynamics Flow Bar [40]*, or in various other ways in Dynamics Center. Integrals in Dynamics Center are always linked to a virtual peak located in the center of the integral region. This is because DC always refers to peaks in many contexts. Refer to the Dynamics Center manual for details.

Here is one way how integrals can be defined in Dynamics Center.

- First select **use peak area (user defined) integrals** in the **Integrals** tab.
- If peaks where found, there are 2 possibilities:
  - If the peaks are useful, the corresponding boxes can be adjusted interactively.
  - If the peaks are not useful move the mouse close to a peak. Right clicking will display a context menu as shown below:

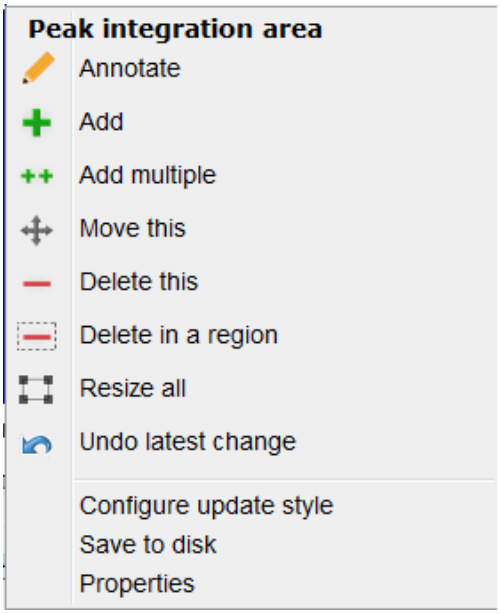


Figure 6.4: Spectrum Peak Context Menu in Case of User Defined Integrals.

- Select **Delete in a region**, drag the region over the whole spectrum, and then all peaks will be deleted.

- After right clicking the context menu should show:

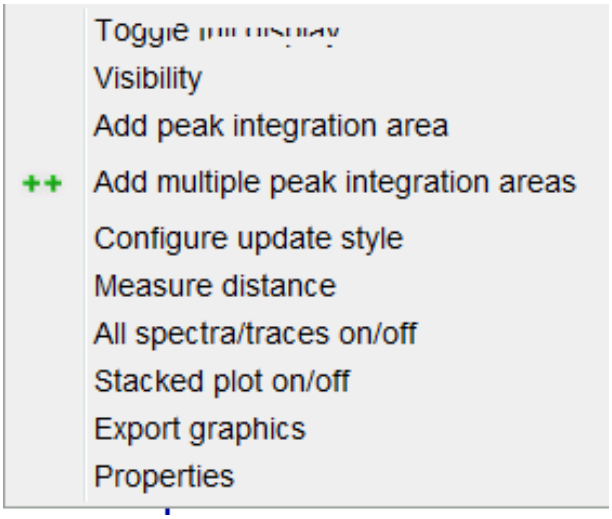


Figure 6.5: Context Menu away from Peak in Case of User Defined Integrals.

- Select **++Add multiple peak integration areas**. Then you can create new peak integration areas just by drag and release. Don't forget to terminate this mode.

Peaks and areas can always be stored to disk using the **Save to disk** option in the peak context menu.

6.1.4 Diffusion Profile

In order to check the quality of diffusion experiments it is recommended to look at the diffusion profiles or diffusion decays of the individual peaks. In the default View setting this is accomplished by moving the mouse to the peak of interest. Then the diffusion profile will be displayed in a separate window.

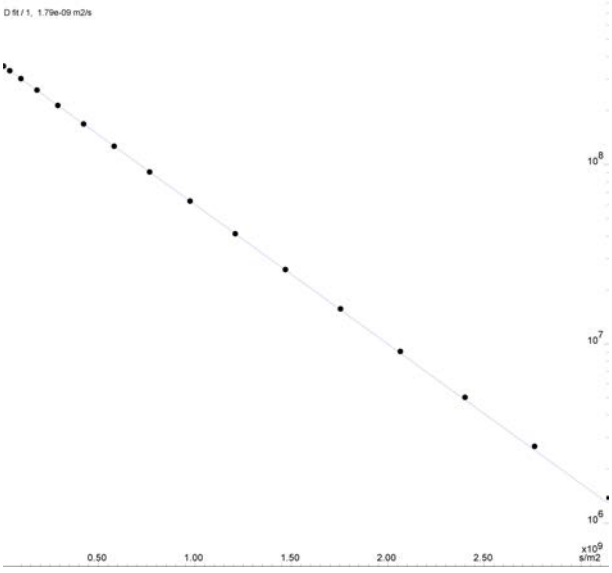


Figure 6.6: Diffusion Profile, log(I) Plotted with Respect to B

From this display all numbers can be accessed via right **mouse click** | **properties**.

Multiple lines can be displayed in a cumulative plot. In the plot shown below the peaks 2 and 3 are almost identical and therefore overlap in the plot.

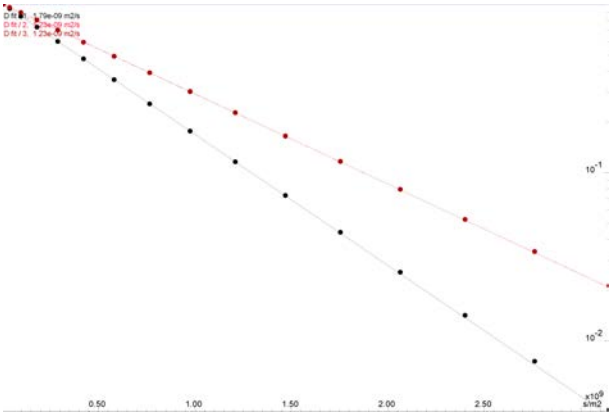


Figure 6.7: Cumulative Plot of 3 Diffusion Profiles. The Signals are Individually Normalized for the Plot.

If many peaks are present, the DOSY plot representation is often preferred, as it holds less information, but gives a better overview.

6.1.5 DOSY Plot

The DOSY plot is an artificial 2D spectrum showing a chemical shift axis in F2 and a diffusion axis in F1 direction. The diffusion direction is often plotted logarithmically.

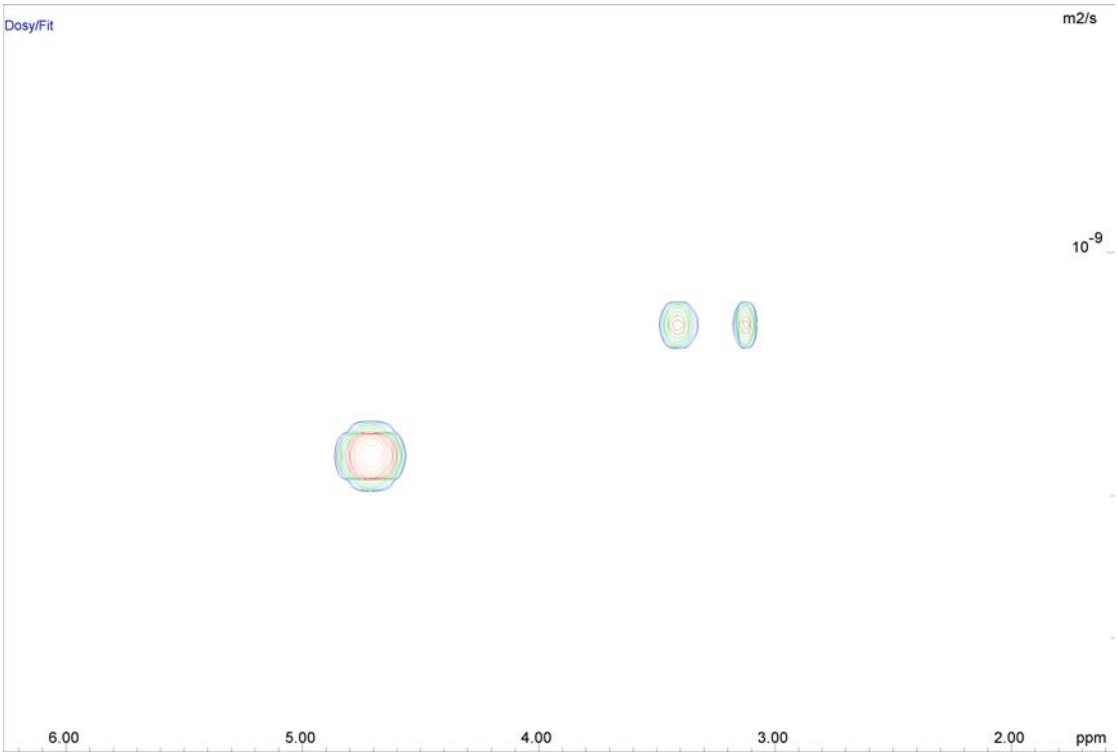


Figure 6.8: DOSY Plot Using Peaks

The DOSY plot shown above is *completely artificial*. The peaks shown here represent the chemical shifts of 3 picked peaks in F2 direction and their fitted diffusion coefficient in the F1 direction. The width of the peaks in a chemical shift direction is taken from the width at half

height in the spectra. The width in diffusion direction is derived from the error of the fit. As this error is so small, an artificial broadening of the line (**apply minimum width/F1** in the **DOSY plot** tab of the **View** node) was applied in order to make it easier to view. The height of the peaks represents the fitted intensity.

In TopSpin another method of creating a DOSY plot is used. The amplitudes of each column in a 2D spectrum are fitted and then the spectrum created in a similar way as described above. This has the advantage of not depending on the peak picking. The disadvantage is that it overemphasizes spectral instabilities as artefacts in the DOSY plot.

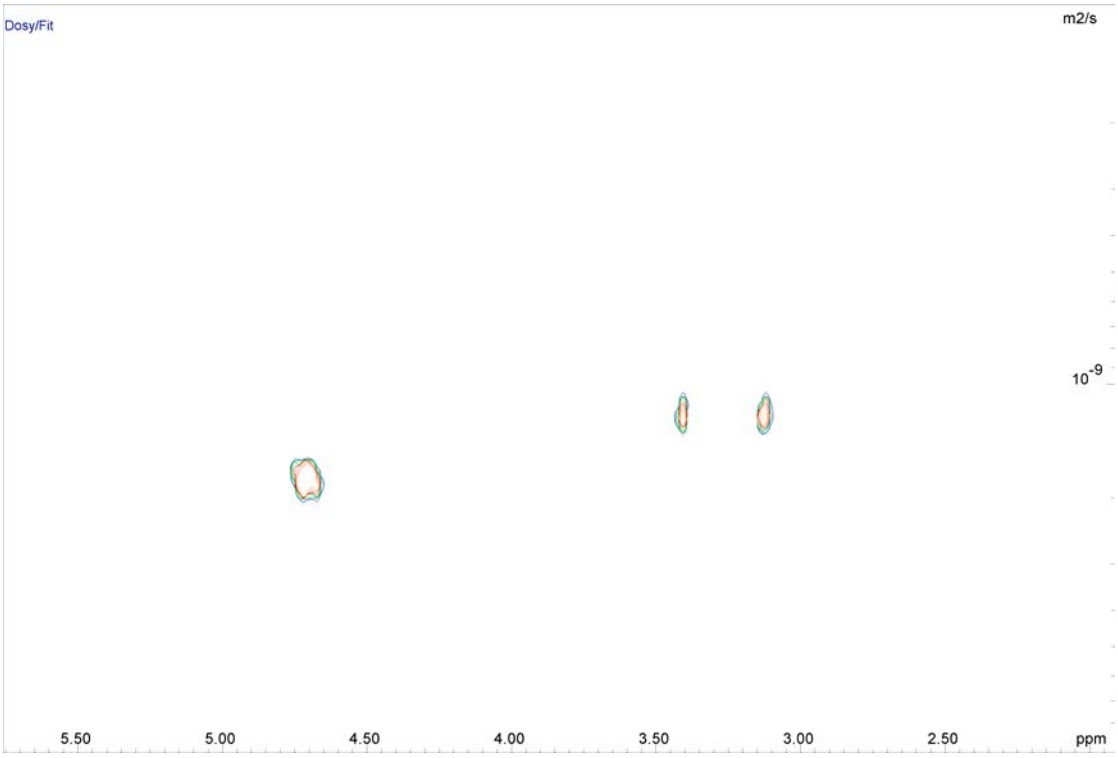


Figure 6.9: DOSY Plot Using Columns

The DOSY plot shown above is created by selecting **use all columns above threshold** in the **Peaks** tab of the **Data** node as mentioned in *Peak Picking [▶ 76]*. The spectral lines are slightly distorted using rather high quality input data. If the quality is poor DOSY spectra created in this way may look much worse although all the required information is still present. Nevertheless, this way of processing can sometimes find peaks not picked by the peak picking, and therefore ignored by the other method.

Usually DOSY using peak picking will be the method of choice, but care must be taken in selecting the peak picking method, depending on the kind of spectrum under investigation.

6.2 The T1/T2 Analysis Module

The T1/T2 analysis tool is described in detail in the TopSpin User Manual in the chapter Relaxation Analysis (TopSpin2.1). In future TopSpin versions a separate T1 manual may be used. This section provides details relevant for diffusion experiments.

6.2.1 New Display Features

Beginning with TopSpin 2.1, the T1/T2 Analysis Tool provides options for plotting logarithmic axis for the x- and y-axis, and a squared axis for the x-axis. The log x-axis usually has no meaning for diffusion experiments, but squared x- plus log y-axis provide the common semi-logarithmic display.

The buttons **lin**, **log**, and **sq** for the x-axis work like radio buttons, whereas the **log** button for the y-axis can be toggled.

The next three figures give examples of what this should look like.

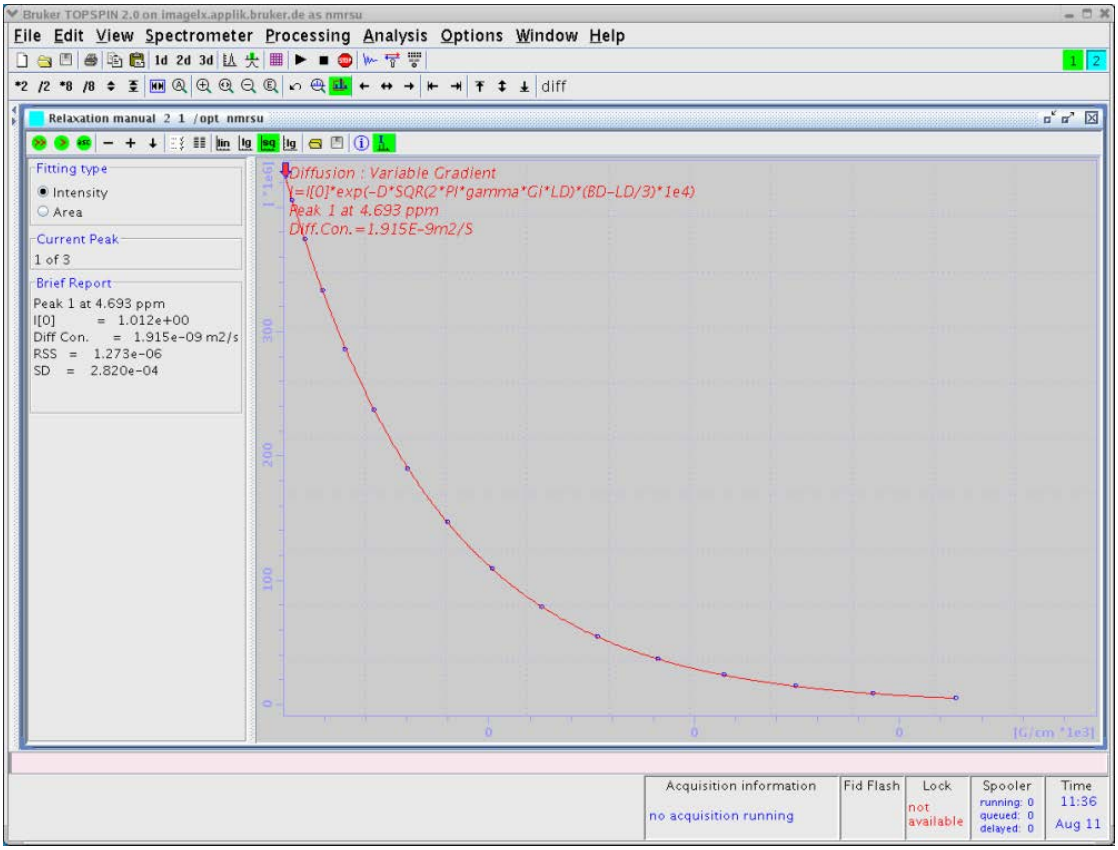


Figure 6.10: Diffusion Curve Displayed Using the sq Option of the X-axis

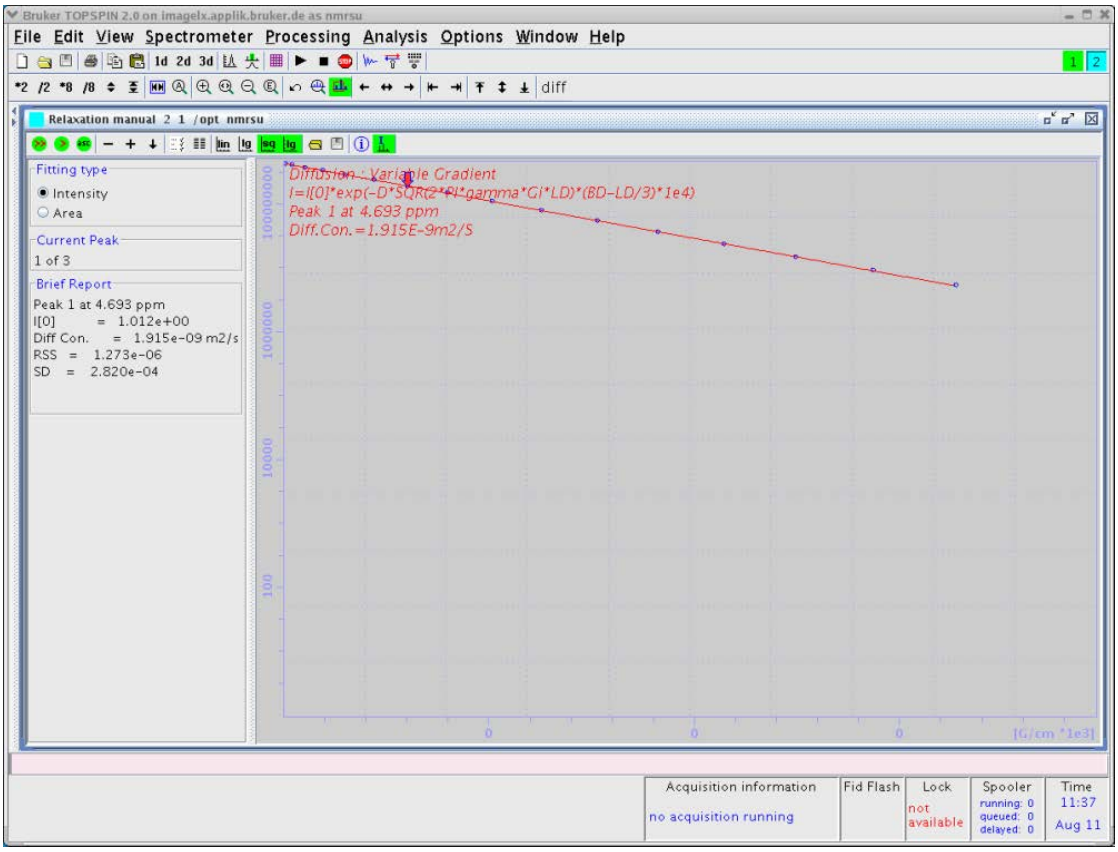


Figure 6.11: Diffusion Curve Displayed Using the sq Option of the X-axis and the Log Option of the Y-axis

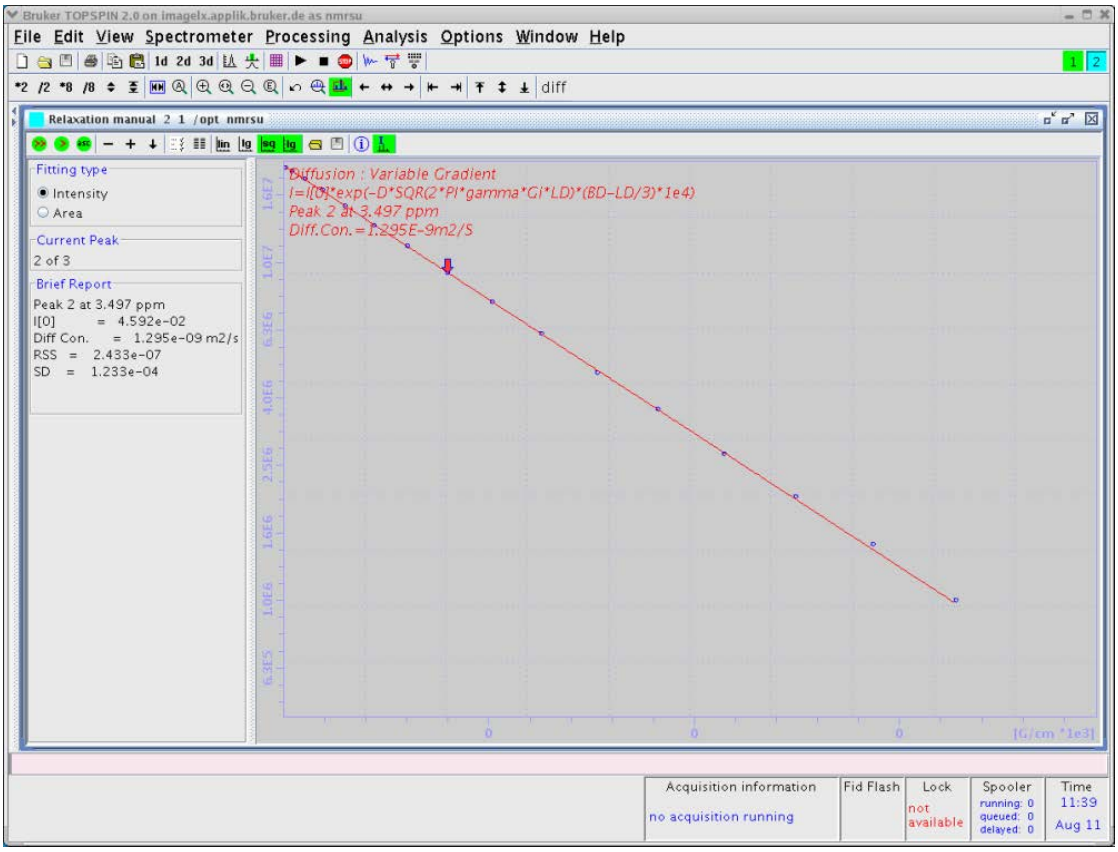


Figure 6.12: Diffusion Curve Displayed After Manual Scaling

6.2.2 Parameter Dialog Box

In routine operation these parameters do not need to be modified, as the diff program sets them automatically. But sometimes it might become necessary to adjust some of the parameters, therefore a description of their meaning is given here.

If it becomes necessary to change parameters, change the values, then click on **Apply** followed by **OK**. If an error occurs due to incorrect parameter setting (see below), the changes made are not lost.

FID # for phase determination: This parameter has no meaning at the moment, but it must be in the range of the number of the experiments performed. A value of zero, for example, leads to an error message.

Left and right limit for baseline correction: These are the same parameters as in *edp*.

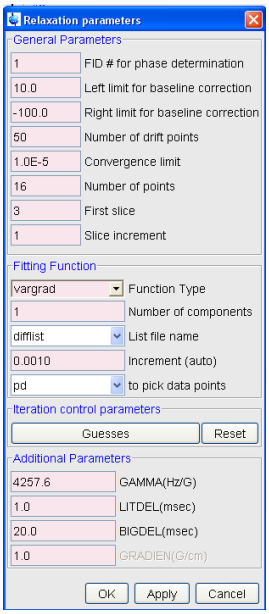


Figure 6.13: Parameter Dialog Box

Number of drift points: This number is the maximum allowed drift range for the peak picking method **pd**. The value is preset to 50 by *diff*.

Convergence limit: Parameter used to control the simfit algorithm. This normally does not need to be changed.

First slice: This parameter is not used, but must be in the range of *td1*, zero is not allowed.

Slice increment: Must be a value of „1“.

Function type: The function type can be selected from a pull-down menu. For diffusion experiments only 3 functions apply: *vargrad*, *varlitdel*, and *varbigdel*. The correct value is set by diff.

Number of components: Number of exponential functions to be fitted to the data. The parameter can be 1 to 6, while for diffusion experiments more than 2 or 3 is normally not useful. The default set by *diff* is 1.

List file name: Name of a file in the acquisition data directory containing the varied experimental values, e.g. gradient amplitudes. Besides the file name, this parameter can also contain a keyword from a list of predefined keywords, but they are not used here. Diff always creates a file called *difflist* containing the gradient amplitude for variable gradient experiments, or the delays for large variables, or small delta methods.

Increment (auto): This parameter is used by the auto keyword of the parameter list file name above, and is not used by *diff*.

To pick data point: This parameter is used to select the peak picking mode. The default method **pd** searches for the peak maximum in each individual spectrum allowing for a maximum shift as given in the number of drift points field.

Guesses: Clicking on the button **Guesses** opens an additional dialog box, shown in the figure below, if one exponential (Number of Components) is used. The fitting algorithm used by the *T1/T2 Analysis Module* needs initial *Guesses* for the fit. For single exponential fitting the algorithm is very tolerant, but for multi exponential fitting these values must be carefully set and sometimes varied a bit in order to get proper fitting.

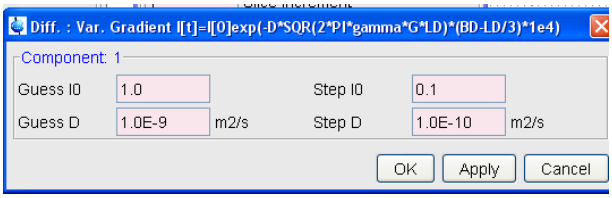


Figure 6.14: Guesses Dialog Box for One Exponential

Diff always presets the *Guesses* for the amplitudes to 1.0. The Guess for the diffusion coefficient of the first component is set to the value of the *expected diffusion coefficient* (see *The Expected Diffusion Coefficient [98]*). The Guess of the second diffusion coefficient is set to 0.1, the third to 0.01 of the *expected diffusion coefficient*. The steps, i.e. the initial step width of the iteration of the algorithm, are always set to 10% of the corresponding Guess, which is the maximum allowed value.

The dialog box changes depending on the selected number of exponents, e.g. for 2 exponents it should look like:

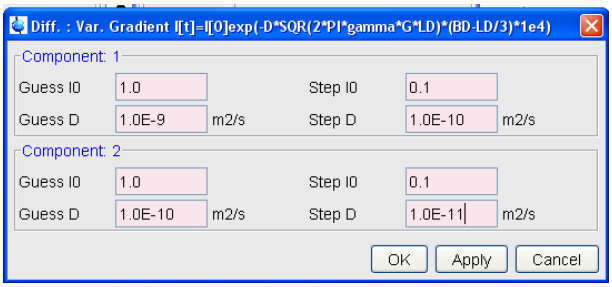


Figure 6.15: Guesses Dialog Box for Two Exponential

In the title of the *Guesses* window, the actually fitting function used is displayed.

Reset: This button also opens the *Guesses* dialog box, but resets the parameters to values present at the start of the *T1/T2 Analysis Module*.

6.2.2.1 Additional Parameters

The Additional Parameter section allows adjustment of the remaining fixed parameters in the fitting function. All these parameters are automatically set by *diff*.

- **Gamma**: Gyro-magnetic ratio in Hz/Gauss (©/2π), depends on the observed nucleus.
- **LITDEL(ms)**: Little delta (δ), active for vargrad and varbigdel.
- **BIGDEL(ms)**: Big delta (Δ), active for vargrad and varlitdel.
- **GRADIEN(g/cm)**: Gradient amplitude (g), active for varbigdel and varlitdel.

6.3 DOSY Processing

Diffusion **O**rdered **S**pectroscop**y** (DOSY), is another way to process and display diffusion experiments. DOSY is described in detail in a separate manual, so only a few hints shall be given here.

Most of the relevant parameters for the DOSY processing are set by diff automatically. To check and set the DOSY parameter type, open the DOSY parameter editor window, *eddosy*:

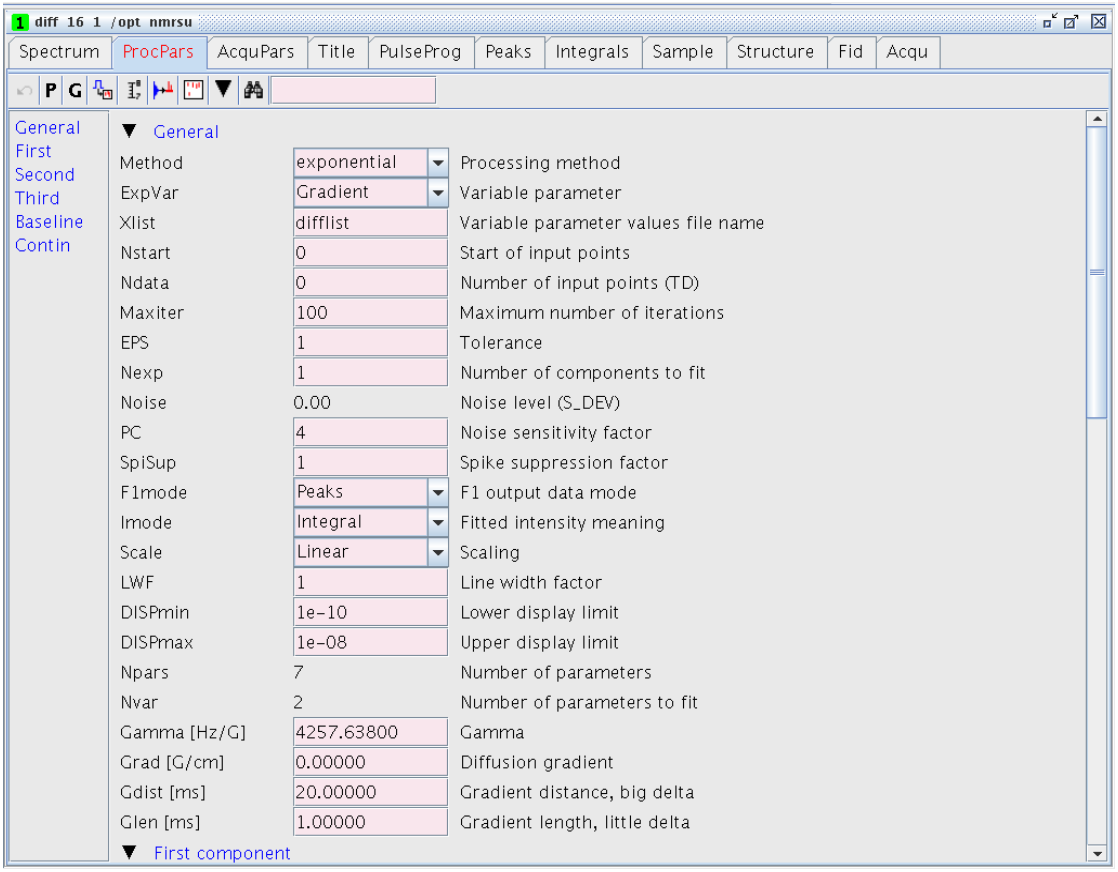


Figure 6.16: DOSY Parameter Editor Window, eddosy

The algorithm must be first selected in the eddosy window. The pull-down menu next to the parameter Method allows for 4 different algorithms:

- Exponential
- Gifa-maxent
- Decra
- Contin

6.3.1 Exponential

Exponential solves the problem of displaying diffusion experiments by fitting up to 3 exponential functions in the individual columns of the 2D data matrix. By default the Nexp exponential is selected. If the number of exponential to fit is increased, the user has to check and in most cases, enable the fitting of the corresponding parameters, *I2vary*, *D2vary*, I3vary, *D3vary*.

Important is to set the range of the displayed diffusion coefficients, *DISPmin*, *DISPmax* correctly in order to have all expected values in the displayed window.

Usually it is better to select the logarithmic display mode, Scale, because often the diffusion coefficients can vary over several orders of magnitude.

For better display quality use zero filling in the F1 direction, i.e. set the SI in the F1 direction to double, or 4 times the number gradient steps prior to *xf2*

6.3.2 Gifa-maxent

Gifa-maxent is a special algorithm, which needs an extra software license, and is explained elsewhere.

6.3.3 Decra

Decra is an algorithm, which can separate 1D spectra of different species, if they differ sufficiently in their diffusion coefficient.

Decra requires that the squares of the gradient amplitudes are spaced linearly. In diff the sqrt list must be selected prior to acquisition.

6.3.4 Contin

Contin is a long established inverse Laplace algorithm. It delivers similar results as the exponential method, but often is somewhat smoother and easier to view. It requires significantly more calculation time, therefore it is useful to keep the number of data points small, 1K or 2K in the F2 direction will usually be reasonably fast.

The scaling and oversampling settings are the same as for exponential.

6.4 Processing Using Diff

The *diff* program is mainly a tool to set-up experimental parameters, but it also provides a processing section. This has two main purposes:

- First, it can convert the data from the TopSpin t1t2.dx file to different spreadsheet like files, containing the experimental data, together with formats of the abscissa data, e.g. gradient strength, q-values, and B-values.
- Secondly, it allows processing of a series of similar experiments and creates a spreadsheet file containing all the experiments. This makes the handling of large numbers of experiments a bit more convenient. The spreadsheet files cannot be processed by TopSpin or by *diff*. The files can only be viewed with third party programs such as Microsoft Excel.

6.4.1 Single Experiment Processing

In order to use the processing features of *diff*, the data must be processed so that simfit can use it. If the raw data will only be used within another program, it is not essential that simfit delivers useful results. On the other hand, if the simfit results are required later on, the fitting parameters should be set to allow for a good simfit result.

Be sure to close the T1 analysis window, or to switch to another window in TopSpin, to display the data set to be processed before starting diff.

If not already selected, click on the processing check button, which is always visible on the bottom of the window on the left side (see *Diffusion Parameter Setup [▶ 45]*). Once the button is checked you should see the window displayed in the figure below:

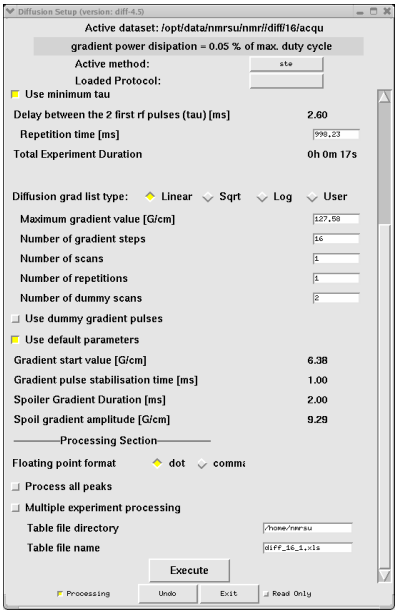


Figure 6.17: diff Showing the Processing Section

Pressing the **Execute** button will cause the following actions:

- Execution of simfit in TopSpin.
- Depending on the experiment type, two column csv files (e.g. SBi.dat), which contain the B values in the first column and signal amplitudes in the second will be created. The *i* in the file name stands for the index of the peak. If the *process all peaks* check button in the figure above is not checked *i* will be equal to one, regardless of which peak was selected (e.g. SB1.dat). When only one peak is present *i* will also be equal to 1.

  An additional file called DiffData.xls, containing all the columns of the other files plus the fit parameters, is also created. If more than one peak is processed they are sequentially placed in the file from top to bottom. The file is not an EXCEL type spreadsheet as the name implies, but rather a tab separated csv file, which can be read directly using EXCEL or Open Office. In this conversion the data acquired by the DELTA method is treated automatically, i.e. the amplitudes of the odd data points are divided by the amplitudes of the even.
- The file DiffData.xls is copied to a name and location specified in the setup window (see the figure above). The default values are the user's home directory and a name, that is constructed out of the data set name, the experiment number, and the processing number.

6.4.2 Multiple Experiment Processing

This feature is used to process a series of experiments acquired with consecutive experiment numbers and to create a single spread sheet file containing all data from all experiments.

When the *Multiple experiment processing* check button is checked (see the figure in the previous section), the window will change as shown:

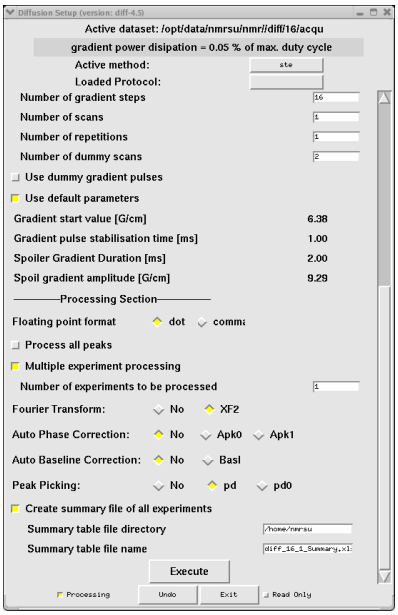


Figure 6.18: Diff Showing Multi Experiment Processing

If *Fourier Transform and Peak Picking* are not selected, and *Create Summary file of all experiments* is not checked, the program will assume that peak picking is already performed and the same actions as described in *Single Experiment Processing [▶ 89]* will be performed.

If the check button *Create Summary file of all experiments* is checked, all the DiffData.xls files are copied into the specified summary file, sequentially left to right.

If *Peak Picking* is selected, the program uses the same peak picking parameter for all in the series, i.e. the files *intrg* and *baslpnts* are copied from the first experiment in the series to the rest of the series, and peak picking is performed afterward.

If *Fourier Transform* is selected, than a Fourier transformation is performed on all the raw data prior to the peak picking. Automatic phase correction and/or automatic base line correction can be performed upon request.

7 Diff Program Reference

This part of the manual describes the *diff* program, referencing existing material already discussed and providing information not given elsewhere.

7.1 Diff Program

The *diff* program is a tool to simplify the set-up of diffusion experiments. The main idea is to replace machine level parameter settings with experiment level parameters representing physically relevant parameters. For example, rather than setting the gradient strength in percent, the gradient strength is given in Gauss/cm. In other words, the user does not need to know, which delays form the diffusion time, they only have to specify the diffusion time and the program will automatically set the other parameters.

Most of the parameters will be checked for reasonable upper and lower limits. When pressing <return> or moving the cursor out of the entry field, this calculation is lost. However typing 0 in a parameter window will show the minimum possible value for that parameter. This method may vary depending on the operating system and the desktop settings.

Parameters like the diffusion time, and in particular their minima, depend on other adjustable parameters, thus a parameter hierarchy is necessary. Using the PGSTE experiment as an example, the hierarchy of the delays is as follows:

- Level One: Effective gradient pulse duration, spoiler gradient duration (if default mode is off), gradient ramp time (if default mode is off), RF pulse duration, τ (if minimum echo time ID is off).
- Level Two: Diffusion time.
- Level Three: Repetition time.

Parameters in level one can be adjusted independently, but they will affect the parameters in level two and three.

When changing a parameter in level one, it increases the minimum diffusion time, whereas the new minimum diffusion time is larger than the old diffusion time, thus the diffusion time will be increased until it is as big as the new minimum.

Likewise, when the minimum diffusion time is reduced by changing a parameter in level one, or the new minimum diffusion time is smaller or equal than the old diffusion time, the diffusion time will remain the same.

The same mechanism applies between members of level one and level two, with respect to parameters in level three.

7.2 Diff Menu of the PGSTE Experiment

As various methods used similar menus, this section will describe the contents of a menu line by line. This example can then be used to help understand the other method menus.

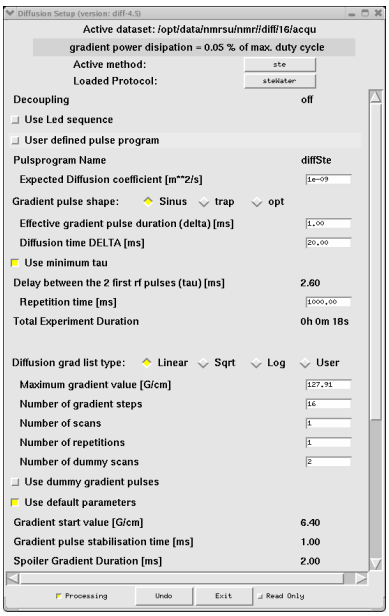


Figure 7.1: Diff Showing Parameters of ste

- The title of the window *Diffusion Setup (version 4.1.7)* <2> displays the actually running version of the diff program and, if more than one diff window is open, which is currently selected.
- The location of the acqu file for the active data set is provided directly under the title.
- The Gradient power dissipation is calculated from the resistance of the gradient system and the applied current scheme. This value is then compared to the maximum allowed duty cycle of the gradient system. If the duty cycle exceeds 90% the display changes (see figure below). If the duty cycle exceeds 100%, the repetition time is automatically increased in order the reduce the duty cycle to 100%. If an individual pulse exceeds the maximum allowed value, the gradient strength is reduced.

  The gradient system parameters are taken from the data given in the pre-emphasis files, if available (see *Pre-emphasis Files [▶ 17]*). If not, the type of gradient system is guessed from the gradient strength, and standard parameters for the type are then used. If the parameters are not already set, they can be set via setpre (see *Gradient Safety Parameters (AVANCE III only) [▶ 132]*).

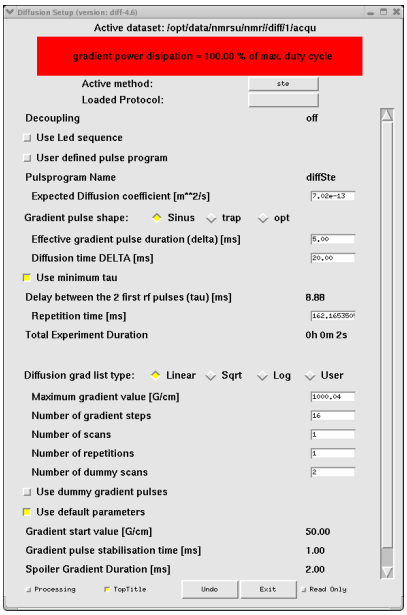


Figure 7.2: Diff Showing Duty Cycle Warning

- The **active method** button shows the selected method out of the list of installed methods shown when clicking the button. The main methods are described in *Diffusion Experiments [▶ 61]*.

  The method files are located in *<TopSpinHome>/prog/tcl/xwish3_scripts/difflib*. Details about the syntax are given in the method file ste.

- The **loaded protocol** button shows the last protocol loaded during the current run of diff. If no protocol was loaded it will show select-protocol. Clicking the button displays a list of available protocols (see *Diffusion Parameter Setup [▶ 45]*), that can be selected.

  Protocols are prepared lists of parameters, which can be used to easily setup an experiment. The different protocols are in different files in the directory *<TopSpinHome>/prog/tcl/xwish3_scripts/difflib/protocols*. The file name is used as the protocol name. With the current software version, protocols can only be changed by editing the protocol file using a text editor. Likewise, protocols can only be created by copying existing protocols and modifying the content using a text editor.

  All protocols must be located in the directory named previously and must begin with the line: `#DiffProtocol --Don't change this line--`

- *Decoupling* will show **off**, if a second nucleus is not defined in TopSpin. If a nucleus is selected, *diff* assumes this nucleus should be decoupled and shows on.

  Diff sets the pulse program parameter I14 = 0 for off, and I14 = 1 for on. During the pulse program compilation decisions will be made on which parts of the pulse program to be selected depending on whether the decoupling is on or off.

- The check button *Use LED sequence* will activate the LED module used to move the echo away from the last gradient, which will reduce the effect of eddy currents. When this option is selected, the applied LED delay will be visible and can be adjusted. Currently this option is only available for *ste*. The LED option uses a separate pulse program.

- The check button *User defined pulse program* allows the user to change the pulse program name, e.g. to make small modifications in a pulse program, but still use the general set-up with *diff*.

- The Pulse program name displays the name of the pulse program. If *User defined pulse program* is checked, the pulse program name can be edited.

- The parameter *Expected diffusion coefficient* allows the user to see which value of a diffusion coefficient the selected parameter is useful. It also can be changed in order to calculate a suitable gradient strength for the expected diffusion coefficient (see *The Expected Diffusion Coefficient [▶ 98]*).
- *Effective Gradient Pulse Duration (delta)* is the effective duration of the gradient pulse δ. Details are given in *Gradient Pulse Shapes [▶ 62]*.
- The *Diffusion Time (DELTA)* is the diffusion observation time Δ.
- *Use minimum tau*: If this check button is selected, the program calculates the minimum possible tau (τ), the delay between the first two RF pulses (see *Pulse Gradient Stimulated Echo (PGSTE) [▶ 66]*), for the given delays. If not, the parameter τ is accessible for the user and can be set longer than the minimum.
- *Repetition time* means the sum of all delays within one scan (see *Relaxation Parameters [▶ 98]*).
- The radio button *Diffusion Gradient List Type* is used to select the way the gradient amplitude is varied between the different rows in the 2D experiment (see *Variable Gradient Experiments [▶ 64]*).

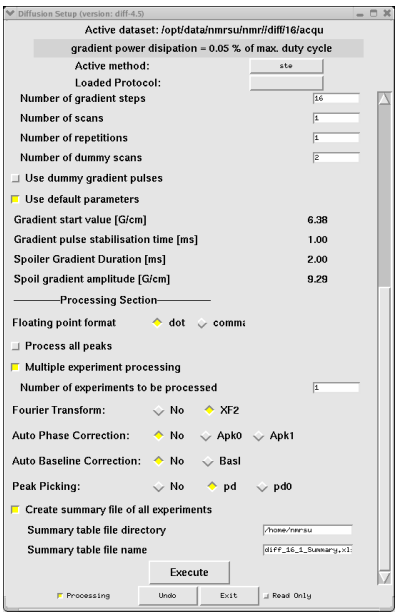


Figure 7.3: Diff Showing Parameters of ste, Second Part

- The radio buttons *Gradient direction* allow selection of the gradient direction when using a 3 axis gradient system. When using a single axis gradient, these buttons will usually not be displayed. The direction *mas* means a combination of all 3 gradients then pointing in direction of the magic angle. Which combination is used is defined in the configuration, see *Configuration Parameters [▶ 96]*.
- The *Maximum Gradient Value* is the maximum amplitude of the gradient in the sequence. It is related to the *expected diffusion coefficient*.
- The *Number of gradient steps* is the length of the gradient list, or the number of increments in the 2D experiment, or the value TD1.
- The *Number of scans* is the same as *NS* in TopSpin, in can be from either program, i.e. in *diff* or in TopSpin. The NS value should usually be a multiple of the number of steps in the phase cycle, but most experiments will also work with smaller numbers.

- In contrast, the *Number of repetitions* repeats the entire experiment summing up the data in the same file. In the pulse program it is represented by the loop counter “l1“. This parameter corresponds to the parameter *NAE* (Number of Averaged Experiments) in ParaVision. A NAE value larger than one is particularly useful, when many averages are required and the experiment uses a larger variation of gradient strength. This may result in temperature changes caused by different heating of the gradient system during the experiment.

Note: When multiple accumulations are required, it is good practice to set the *number of scans* to the length of the phase list in the pulse program, and to increase the *number of averages* by increasing the number of repetitions.

- The *Number of dummy scans* is the same as *DS* in TopSpin, it can be from either program, i.e. in *diff* or in TopSpin.
- The option *Use Dummy Gradient Pulses* allows pre-gradient pulses to be sent before the first RF pulse with the same distance as in the measurement part, in order to warm up the amplifier. When selecting this option the number of dummy pulses becomes accessible. This option is normally not used and under normal circumstance not required. It is available in all diff pulse programs, but only shown in the menu *ste*.

Note: Dummy gradient pulses will increase the duty cycle. Do not use them unless required.

- If the option *Use default parameters* is selected, the following default parameters are loaded when a protocol is loaded. However these parameters can also be adjusted by the user.
  - The *Gradient start value*, see *Variable Gradient Experiments [▶ 64]*.
  - The *Gradient pulse stabilization time* is set to the default value, see *Configuration Parameters [▶ 96]*.
  - The option *Use Spoiler gradient* is activated and is not visible in the default mode.
  - The *Spoiler gradient duration* is set to the default value, see *Configuration Parameters [▶ 96]*.
  - The *Spoiler gradient amplitude* is calculated as described in *Spoiler Gradients [▶ 67]*.

The processing parameters shown were described in detail in *Processing Using Diff [▶ 88]*.

7.3 Configuration Parameters

There are a couple of parameters, which can be configured. By default they are set to typical values used, so in most cases there is no interaction required. As there is no configuration user interface, configuration parameters must be modified using a text editor. The configuration parameters are located in the main program file, *<TopSpinHome>/prog/tcl/xwish3_scripts/diff*. The corresponding section is shown below. The sequence of parameters was developed historically, only a few of them can be modified by the user. Before changing any parameter a backup copy of diff, e.g. *diff.orig* should be made. This copy can also be run directly by typing *diff.orig* in the TopSpin command line.

Be aware, that modifying parameters here can lead to *diff* program malfunctions, as well as with the experiments setup using *diff*.

Diff program code showing configurable parameters mixed with others:

```
##-------------- define some constants -----------

set diffVersion "diff-4.5"
variable maxDutyCycle 32400.0
variable maxPulsePower 16200000.0
variable gradstabDefault 1.0
variable spoilDurDefault 2.0
variable constSlopeRampConst 0.0004
variable grampMin 0.1
variable backUp 0
variable Focus 1
variable pid [pid]
##-------------- check and create directory $HOME/.diff ----
##-------------- used to store default values -----------

variable diffHome [Gethome .diff]
variable diffHistory 1
variable diffHistFile [createDiffHome $diffHome $diffHistory]

variable configUnblank 0.01
variable is1D 0
variable minDelay 0.005
variable DigPnts 2
set gradresDefault 0.008
variable gradres [readGradres $gradresDefault]
variable minGradDelay [expr 10.0 * $gradres]
option add *RadiobuttonFont: *-helvetica-bold-r-normal-*-14-*-
iso8859-1
variable labelFont "-*-helvetica-bold-r-normal-*-14-*-iso8859-1"
variable xMasFactor 1
variable yMasFactor -1
variable zMasFactor 1
variable maxGrad 0.99
```

Note: Parameters which must not be changed are not displayed:

```
variable gradstabDefault 1.0
```

Default gradient stabilization delay [ms]:

```
variable spoilDurDefault 2.0
```

Default spoiler duration [ms]:

```
variable grampMin 0.1
```

Default minimum ramp duration, up and down [ms]. Should not be set to less than 0.05:

```
variable configUnblank 0.01
```

Unblank time before the gradient pulse [ms]. Must be set to 0.15 for BAFPA amplifiers:

```
variable xMasFactor 1
variable yMasFactor -1
variable zMasFactor 1
```

Definition of the MAS direction in a micro2.5 gradient system: Normally this should be already set correctly, but in older installations the gradient wiring might be different and therefore changes may be required.

Please note that this will be changed in future versions of the program. Check *diff config* to see, whether the parameters are accessible in the user interface.

7.4 Diff Command Line Options

The *diff* program offers a couple of command line options. They are not necessary for the standard work flow, but are useful. Typing **diff help** in the TopSpin command line will result in:

```
diff command line options

syntax: diff [options]

options: help config ii -exec readOnly r status s

options: help: Print this text.
config: Switch to configuration mode.
r, readOnly: Switch to read only mode.
ii: Reset experiment type.
-exec cmd1 cmd2 ...cmdn: Switch to noninteractive mode and execute
cmd1 .. cmdn.
cmdi can be any Tcl script, defined within the method.
```

Here is a brief description of the options.

- The *config* option switches *diff* to configuration mode, which means it can run without a pre-emphasis file. Currently only preemp configuration methods are available. The figures in chapter *Starting the Diff5 Program for the First Time [▶ 15]* show *diff* working in configuration mode.
- The *ii* option makes the data set forget that *diff* was working on it. Using the *ii* option the parameters remain unchanged, except for the parameter *USERA1*, which normally contains the method name now being cleared.
- In *readOnly* mode *diff* only shows the parameters, but does not allow them to be changed. The *readOnly* mode can also be switched on by checking the *Read Only* check button on the bottom right side of the *diff* window, but this will delete any changes made. The *readOnly* mode was introduced to be able to safely look at data sets, when it is unclear, whether they have been setup by diff, or by an older version. The *readOnly* mode will remain until the *Read Only* check button is unselected.
- In *status* mode *diff* will start reading the status parameters, whereas it will automatically switch to the *readOnly* mode, i.e. without changing anything. Once the *Read Only* check button is released, the parameters are saved in the background. This option was introduced to help prevent parameters of previously acquired data sets from being accidentally deleted.
- The *-exec* option allows the method specific procedures to be executed in the background. This is used e.g. in the *diffmultizg* au program.

7.5 Background Information

7.5.1 The Expected Diffusion Coefficient

The expected diffusion coefficient D_e is calculated using the following equation, assuming a signal attenuation of one order of magnitude. In other words S/S_0 is set to 0.1 and D_e can be calculated:

$$D_e = -\frac{\ln(attFactor)}{B}$$

Figure 7.4: Equation 1

If D_e is modified by the user, the g_{max} value is recalculated using the equation:

$$g_{max} = \sqrt{-\frac{\ln(attFactor)}{\gamma^2\delta^2\left(\Delta - \frac{\delta}{3}\right)D_e}}$$

Figure 7.5: Equation 2

7.5.2 Relaxation Parameters

The relevant time for the T_2 relaxation, the echo time T_e is implicitly defined in most of the experiments.

In the spin echo experiment T_e is defined as:

$$T_e = 2\Delta$$

Figure 7.6: Equation 3

In the stimulated echo experiments T_e is defined as:

$$T_e = 2\tau$$

Figure 7.7: Equation 4

Where t stands for the delay between the first p/2 pulses. Usually t is set to the minimum possible value t_{min}, but it can also be increased in order to act as a T_2 filter.

The value of t_{min} depends on the type of the experiment, it will usually contain the gradient pulse length t_g and the gradient stabilization time.

For the T_1-Relaxation diff uses the parameter repetition time t_r, which is not the relaxation delay, but rather the sum of all delays in one scan. Nevertheless t_r is usually dominated by the acquisition time aq and the relaxation delay d1. In the spin echo experiment it is defined as:

$$T_r = 2\Delta + aq + d1$$

Figure 7.8: Equation 5

In the stimulated echo experiments it defined as:

$$T_r = 2\tau + \Delta + aq + d1$$

Figure 7.9: Equation 6

7.5.3 Conversion of the Cotts 13 Interval to the Stejskal/Tanner Equation

The idea to use the standard Stejskal-Tanner calculation for the 13 interval Cotts sequence can be described as follows:

The equation [5] in the Cotts paper[6], neglecting the background gradients, looks like:

$$\ln\left(\frac{M}{M_0}\right) = -\gamma^2 D\delta^2 g^2 (4\Delta + 6\tau - \frac{2}{3}\delta)$$

Figure 7.10: Equation 7

This replaces:

$$\Delta^* = \Delta + \frac{3}{2}\tau + \frac{\delta}{2}$$

$$\delta^* = 2\delta$$

Figure 7.11: Equation 8

Where Δ*, and δ* stand for the corresponding parameters used by diff. This results in the following equation:

$$\ln\left(\frac{M}{M_0}\right) = -\gamma^2 D\delta^{*2} g^2 (\Delta^* - \frac{1}{3}\delta^*)$$

Figure 7.12: Equation 9

The equation above is an exact representation of the Stejskal-Tanner equation introduced in the equation in *Diffusion Experiments [▷ 61]*.

[6] R. M. Cotts, M. R. Hoch, T. Sun, and J. T. Markert, JMR 83, 252-266(1989)

8 Diff5 Program Reference

This part of the manual describes the *diff5* program, the successor version of the *diff* program described in the chapter before. In TopSpin 3.5 both versions exist in parallel allowing the user to choose either the already well known *diff* program of its successor the *diff5* program.

8.1 Diff5 Program

The *diff5* program is a tool to simplify the set-up of diffusion experiments. The main idea is to replace machine level parameter settings with experiment level parameters, which represent physically relevant parameters. For example, rather than setting the gradient strength in percent, the gradient strength is given in physical units. The user can select between Gauss/cm, mT/m, T/m and Hz/cm (^{1}H). For experimentally relevant parameters, like the diffusion time, the *diff5* program calculates all relevant delays building the diffusion time and provides a lower limit given by the unavoidable delays in the sequence. In other words, the users do not need to know, which delays form the diffusion time, they just have to specify the diffusion time and the program will automatically set the other parameters.

Most of the parameters will be checked for reasonable upper and lower limits. When pressing <return> or moving the cursor out of the entry field, this calculation is lost. However typing 0 in a parameter window will show the minimum possible value for that parameter. This method may vary depending on the operating system and the desktop settings.

Parameters like the diffusion time, and in particular their minima, depend on other adjustable parameters, thus a parameter hierarchy is necessary. Using the PGSTE experiment as an example, the hierarchy of the delays is as follows:

- Level One: Effective gradient pulse duration, spoiler gradient duration (if default mode is off), gradient ramp time (if default mode is off), RF pulse duration, τ (if minimum echo time ID is off).
- Level Two: Diffusion time.
- Level Three: Repetition time.

Parameters in level one can be adjusted independently, but they will affect the parameters in level two and three.

When changing a parameter in level one, it increases the minimum diffusion time, whereas the new minimum diffusion time is larger than the old diffusion time, thus the diffusion time will be increased until it is as big as the new minimum.

Likewise, when the minimum diffusion time is reduced by changing a parameter in level one, or the new minimum diffusion time is smaller or equal than the old diffusion time, the diffusion time will remain the same.

The same mechanism applies between members of level one and level two, with respect to parameters in level three.

New in *diff5* are a couple of “2D” methods, where “2D” stands for 2 non FT or dynamic dimensions, for example like DDCOSY having 2 orthogonal diffusion dimensions, or DRCOSY having a diffusion and a relaxation dimension. The number of available methods will continue to grow in the future.

There are also some new setup experiments and pure T_1 and T_2 experiments.

8.2 Diff5 Window Showing the PGSTE Experiment

The contents of all tabs in the window shown in the figure below will not described here line by line, because most parameters are described by means of tool tips. Nevertheless the PGSTE method called “ste” in *diff5* is used as an example for other similar methods. The top of the window is like the top of the *diff* window showing the version number the active data set and the energy dissipation in the gradient system.

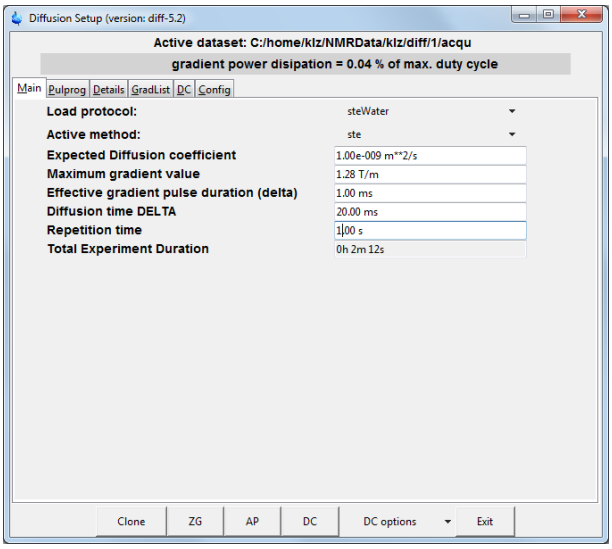


Figure 8.1: Diff5 Showing Main Tab of ste

- The gradient power dissipation is calculated from the resistance of the gradient system and the applied current scheme. This value is then compared to the maximum allowed duty cycle of the gradient system. If the duty cycle exceeds 90% the display changes (next figure). If the duty cycle exceeds 100%, the repetition time is automatically increased in order to reduce the duty cycle to 100%. If an individual pulse exceeds the maximum allowed value, the gradient strength is reduced.

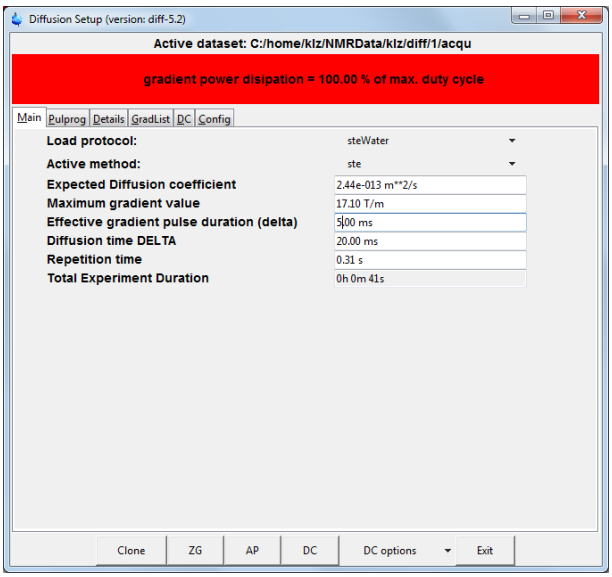


Figure 8.2: Diff Showing Duty Cycle Warning

- The gradient system parameters are taken from the PICS data, if available, otherwise from the data given in the pre-emphasis files, if available (see *Pre-emphasis Files [▷ 17]*). If there is no information, the type of gradient system is guessed from the gradient strength, and standard parameters for the type are then used. If the parameters are not already set, they can be set via setpre (see *Gradient Safety Parameters (AVANCE III only) [▷ 132]*).

  The buttons at the bottom are used to control the interaction of the *diff5 program* with TopSpin and the Dynamics Center.
- The **Clone** button searches for the next unused experiment number in the current data set, copies all parameter files into this experiment number, and sets this experiment number as the active data set in TopSpin.
- The **ZG** button saves all parameters to the active data set and starts the acquisition. This is effectively identical to moving the focus into TopSpin and type **zg** there, except the focus stays in *diff5.*
- The **AP** (automatic processing) button does a fully automatic processing of the data in TopSpin using **xf2** and “diff_**apk2d 2**”. The latter one does an automatic phase correction on the first row of the pseudo 2D spectrum and applies the same correction to all other rows. If **baseopt** was not used, **apk** will be used and **abs2** will be applied, otherwise **PHC1** will be set to zero and **apk0** used for phase correction. Then the data set is loaded into the Dynamics Center and an automatic basic analysis is performed there. The setup for that will be described later in this chapter.
- The **DC** (Dynamics Center) button does the same as the **AP** button, but skips the processing in TopSpin. This is useful, if the processing in TopSpin is already done and the user does not want to overwrite it by the default processing.
- The **DC Options** pulldown menu is an extension of the **DC** button, starting *DC* with different options. See the tooltip for details.
- The **Exit** button terminates the *diff5* session after saving all parameters.

8.3 Main Tab

- The *Load protocol* item list shows the last protocol loaded during the current run of diff. If no protocol was loaded it will show a blank button. Clicking the button displays a list of available protocols (see *Diffusion Parameter Setup [▷ 45]*), which can be selected by clicking on the name.

  Protocols are prepared lists of parameters, which can be used to easily setup an experiment. Loading a protocol includes setting the required method, therefore it comes first in the list. The different provided protocols are in different files in the directory *<TopSpinHome>/prog/tcl/xwish3_scripts/difflib5/protocols*. The file name is used as the protocol name. Diff5 allows user defined protocols to be saved in a directory. This directory must be writeable for the user and the user must specify the directory in the configuration described below.
- The *Active method* shows the selected method from a list of installed methods shown when clicking the button. The main methods are described in *Diffusion Experiments [▷ 61]*. A method can also be selected and exchanged without loading a protocol.
- The term *method* stands for an experiment with its pulse sequence, the problem oriented parameters in the diff environment and their relations between each other and the machine related parameters in TopSpin, as well as the graphical user interface adapted to the requirements of the individual method.
- The parameter *Expected Diffusion coefficient* allows the user to see which values of a diffusion coefficient are useful for the selected parameter. It also can be changed in order to calculate a suitable gradient strength for the expected diffusion coefficient (see *The Expected Diffusion Coefficient [▷ 120]*).

- *Maximum gradient value* is the maximum gradient value anywhere in the gradient list. Its' value can be displayed in different units (see *Config Tab [▶ 118]*).
- *Effective Gradient Pulse Duration (delta)* is the duration of a thought rectangular gradient pulse of equal amplitude having the same integral as the actual pulse (see *Gradient Pulse Shapes [▶ 62]*).
- *Diffusion Time (DELTA)* is the diffusion observation time Δ.
- *Repetition time* means the sum of all delays within one scan, i.e. time between the 1st RFpulse of the 1st scan, and the 1st RF pulse of the 2nd scan (see *Relaxation Parameters [▶ 120]*).

8.4 Pulprog Tab

The **Pulprog** tab shows parameters controlling the functionality of the pulse program. Only a few shall be described here, the rest are considered self-explanatory.

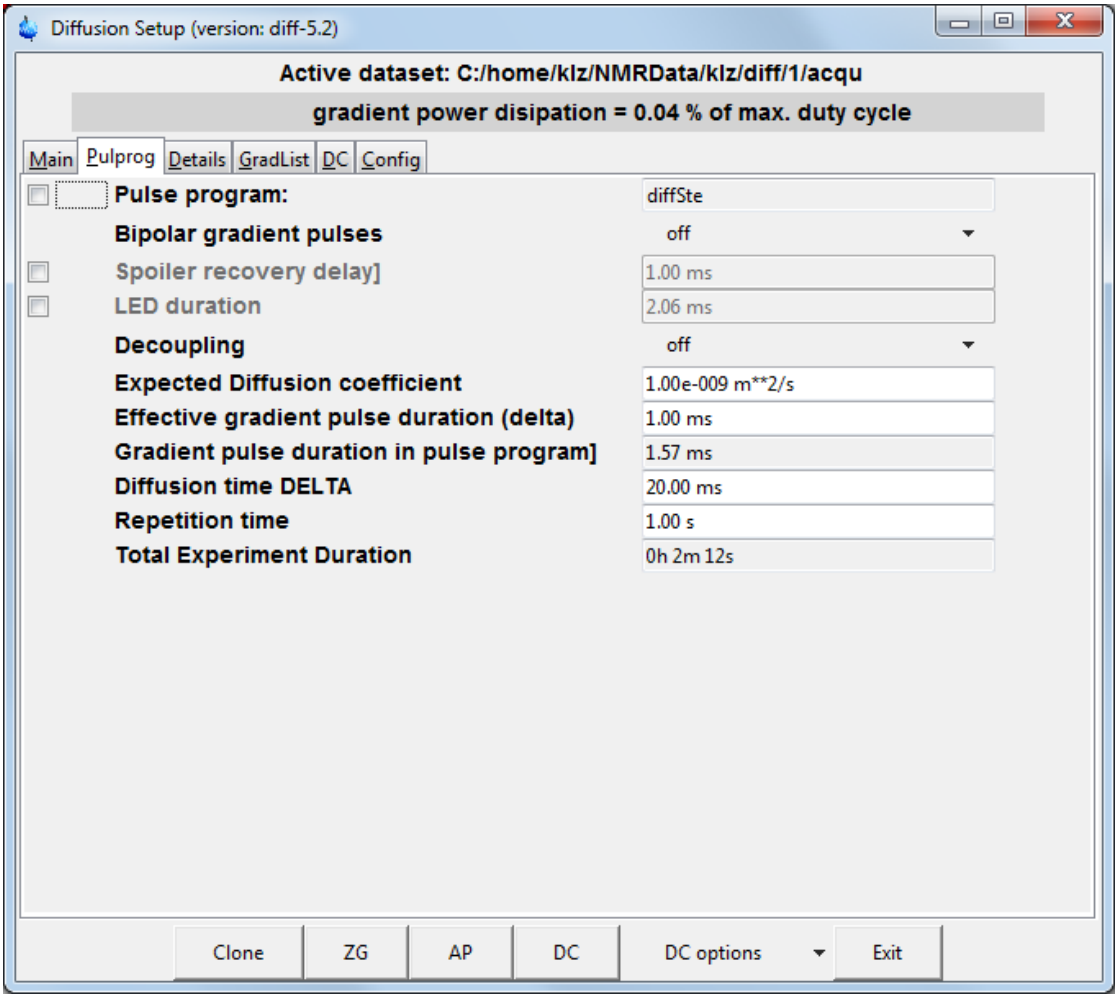


Figure 8.3: Diff5 Showing Pulprog Tab of ste

- *Pulse program* shows the name of the default pulse program used by the current method. If the check button on left is checked, the user can change the pulse program name. This will not change the functionality of the method, but allows some functionality to be added to the default pulse program without changing the core pulse sequence.

- *Spoiler recovery*: If checked a sequence destroying the magnetization prior to the beginning of each scan of the experiment will be activated in the pulse program. This can be used to speed up the experiments (see *Spoiler Recovery (SRC) Sequence [72]*).
- *LED Duration*: If strong gradients are used, it is strongly recommended to activate the LED sequence in order to suppress eddy current effects. The LED sequence stores the magnetization for the time of the LED delay in the longitudinal direction waiting for the eddy currents to decay. As a rule of thumb for a diff30 we assume: If gradients higher than 5 T/m (500 G/cm) are used it is highly recommended to use the LED method, usually using an LED delay of 20 ms. Details may vary on different systems.
- *Decoupling*: The *decoupling* control has completely changed compared to diff. Decoupling will be no longer automatically switched on, if a second nucleus is selected in *edasp*. It can be directly set here by the user as required.

8.5 Details Tab

The **Details** tab shows a number of parameters that are usually set automatically by the protocol. The meaning of these parameters is considered to be evident. The only new option here is the possibility of storing protocols at the bottom. Storing a protocol means saving all the parameters in an xml file, in a directory specified in the configuration. These parameters can be read in later using the load protocol button on the main tab.

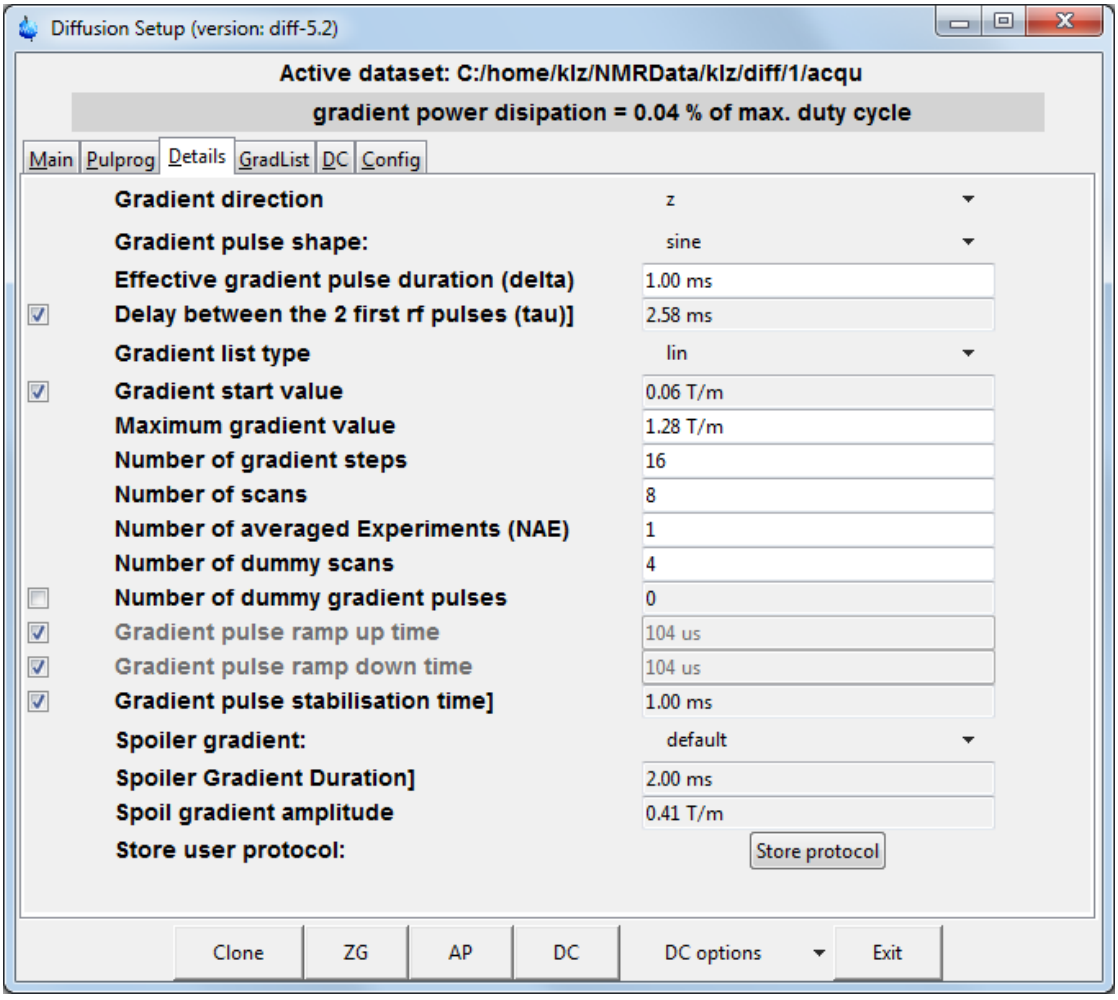


Figure 8.4: Diff5 Showing Details Tab of ste

- *Gradient direction* allows selection in the gradient direction, if a 3 axis gradient system is in use. The direction is forced to *z* when using a single axis gradient system. The direction *mas* means a combination of all 3 gradients pointing in the direction of the magic angle. Which combination is used is defined in the configuration (see *Config Tab [▷ 118]*).
- *Gradient pulse shape* allows selecting different gradient pulse shapes (see *Gradient Pulse Shapes [▷ 62]*).
- *Effective Gradient Pulse Duration(delta)* is the duration of a thought rectangular gradient pulse of equal amplitude having the same integral as the actual pulse (see *Gradient Pulse Shapes [▷ 62]*).
- *Delay between the 2 first rf pulses (tau):* If the check button is checked, the program calculates the minimum possible tau (τ), for the given gradient pulses and delays. If not, the parameter τ is accessible for the user and can be set longer than the minimum. See *Pulse Gradient Stimulated Echo (PGSTE) [▷ 66]* for details.
- *Gradient list type* describes the way the gradient amplitude is varied in the experiment; see *Variable Gradient Experiments [▷ 64]* for details.
- *Gradient start value* is used in case of *Gradient list type* = *lin* or *log* (see *Variable Gradient Experiments [▷ 64]* for details. If the check button is selected reasonable start values are automatically calculated.
- *Maximum gradient value* is the maximum gradient value anywhere in the gradient list. Its' value can be displayed in different units (see *Config Tab [▷ 118]*).
- *Number of gradient steps* is the length of the gradient list; it corresponds to the number of increments in the 2D experiment, and the value TD1.
- *Number of scans* is the same as *NS* in TopSpin, in can be set by either program, i.e. in *diff* or in TopSpin. The NS value should usually be a multiple of the number of steps in the phase cycle, but most experiments will also work with smaller numbers.
- In contrast, the *Number of averaged Experiments* (formerly called Number of repetitions in diff versions <= 4) repeats the entire experiment summing up the data in the same file. In the pulse program it is represented by the loop counter "l1". This parameter corresponds to the parameter *NAE* (Number of Averaged Experiments) in ParaVision. Setting NAE larger than one is particularly useful, when many averages are required and the experiment uses a larger variation of gradient strength. This may result in temperature changes caused by different heating of the gradient system during the experiment.

Note: When multiple accumulations are required, it is a good practice to set the *number of scans* to the length of the phase list in the pulse program, and to increase the *number of averages* by increasing the number of repetitions.

- The *Number of dummy scans* is the same as *DS* in TopSpin, it can be set by either program, i.e. in *diff* or in TopSpin.
- *Number of Dummy Gradient Pulses*, if selected, allows gradient pre-pulses with the same distance as in the measurement part, to be sent before the first RF pulse in order to warm up the amplifier. This option is normally not used and under normal circumstances not required.

Note: Dummy gradient pulses will increase the duty cycle. Do not use them unless required.

- *Gradient pulse ramp up time* is the duration of the rising edge of a gradient pulse, *Gradient pulse ramp down time* is the duration of the trailing edge. If the check button is selected, this value is calculated automatically for the maximum gradient value used in the sequence, the selected gradient pulse shape, the gradient system type, and the default amplifier (GREAT60). If other amplifiers are used, different values might apply. This parameter does not apply for sine shape gradient pulses.

Note: In case of very short relaxation times it might be worthwhile to reduce the values above. This can be done by the user, without any expected damage, but inaccurate results due to amplifier instability are possible.

- *Gradient pulse stabilization time* is the delay applied after each gradient pulse allowing for eddy current decay. After this delay the gradient amplifier blanking is initiated. Normally the check button is selected and then the default value set in the configuration is used (see *Config Tab [▶ 118]*).

Note: In case of very short relaxation times it might be worthwhile to reduce the gradient pulse stabilization time in order to shorten the echo time. This can be done by the user, without any expected damage, but inaccurate results due to amplifier instability are possible.

- *Spoiler gradient* has 3 possible values, *default*, *user*, *no*.
  - *Default*; The spoiler pulse will have the default length as defined in the configuration (see *Config Tab [▶ 118]*). The amplitude is calculated not to match any of the gradient pulses used in the sequence and strong enough to spoil the unwanted magnetization sufficiently.
  - *User*: The user can define the length and amplitude. Only in this case the parameters *Spoiler Gradient Duration* and *Spoil gradient amplitude* are accessible.
  - *No*: There will be no spoiler gradient. This might be useful to shorten the sequence, but may result in artefacts due to unwanted magnetization being detected.
- The shape of the spoiler gradient is always sine.
- *Store user protocol* allows the current set of parameters to be stored in an XML file, in the directory the user has defined in the configuration (see *Config Tab [▶ 118]*). These parameters can then be reloaded at any time, if required. The file name is forced to end with *.xml.*

8.6 GradList Tab

The **GradList** tab shows the list of gradients calculated for the current experiment together with the corresponding q and B values. If *Gradient list type* is set to **user**, the values can be edited here.

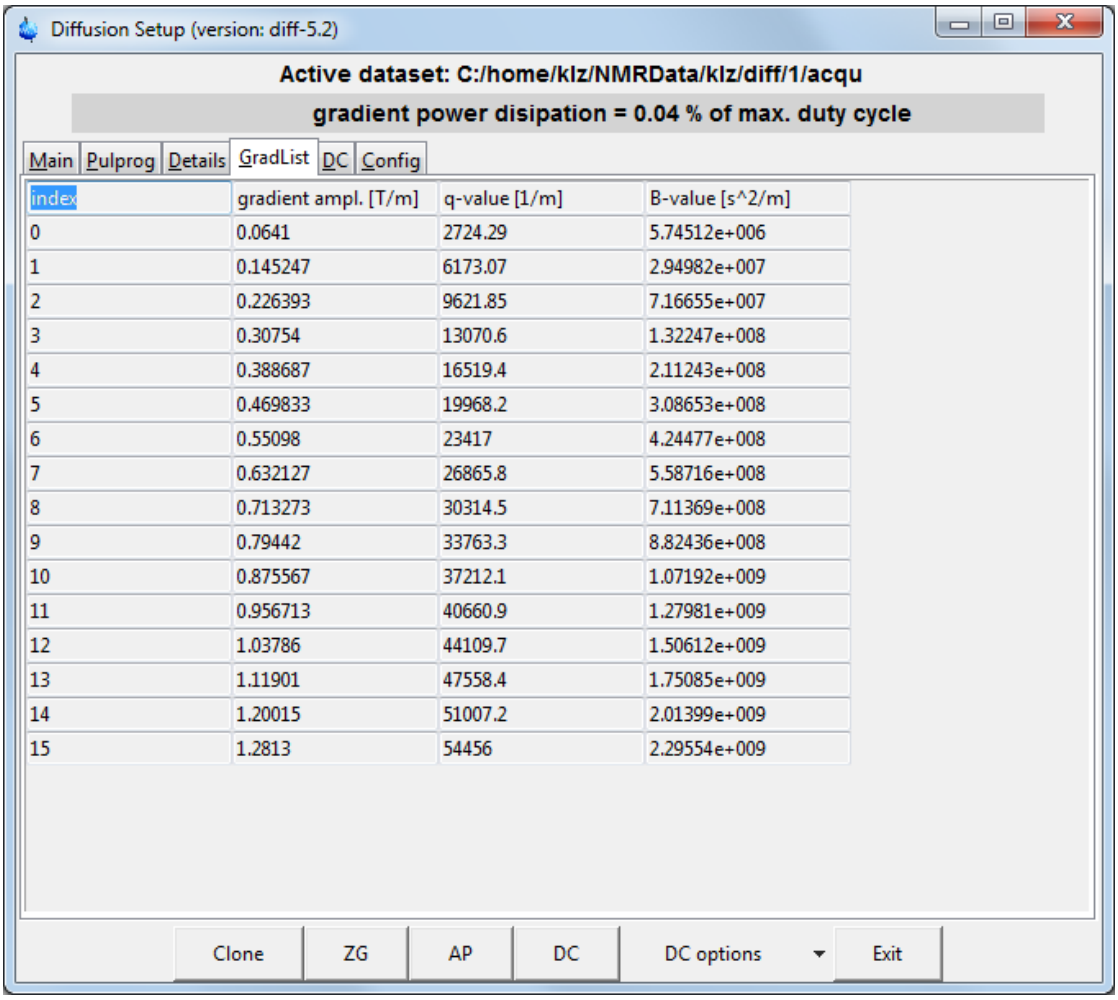


Figure 8.5: Diff5 Showing GradList Tab of ste

8.7 DC Tab

The **DC** tab gives access to many of the parameters in Dynamic Center. The sup tabs shown in the figure below resembles the tree structure in Dynamics Center. The values can be preset in *diff5* for automation purposes. The usual way is running Dynamics Center automatically up to the view mode using automatic peak picking, then to use user defined peak picking, fitting modes, or viewing options.

The *diff5* creates an XML file (TopSpinDC.xml) in the processed data directory containing all relevant parameters allowing Dynamic Center to run fully or semi automatically. This file is then sent to the Dynamic Center to control its operation.

Note: Once this file is created it will not be changed by a new run of diff5, so settings are static.

Note: If the user makes changes in Dynamics Center, and wants them to be saved for future use, use the **Close** button to close the method in Dynamics Center, the changes will be saved in the TopSpinDC.xml file.

8.7.1 DC Subtab Sample

The next figure shows typical content found in the **Sample** sub tab, which for the most part corresponds to the content of the Dynamics Center Sample Node shown below.

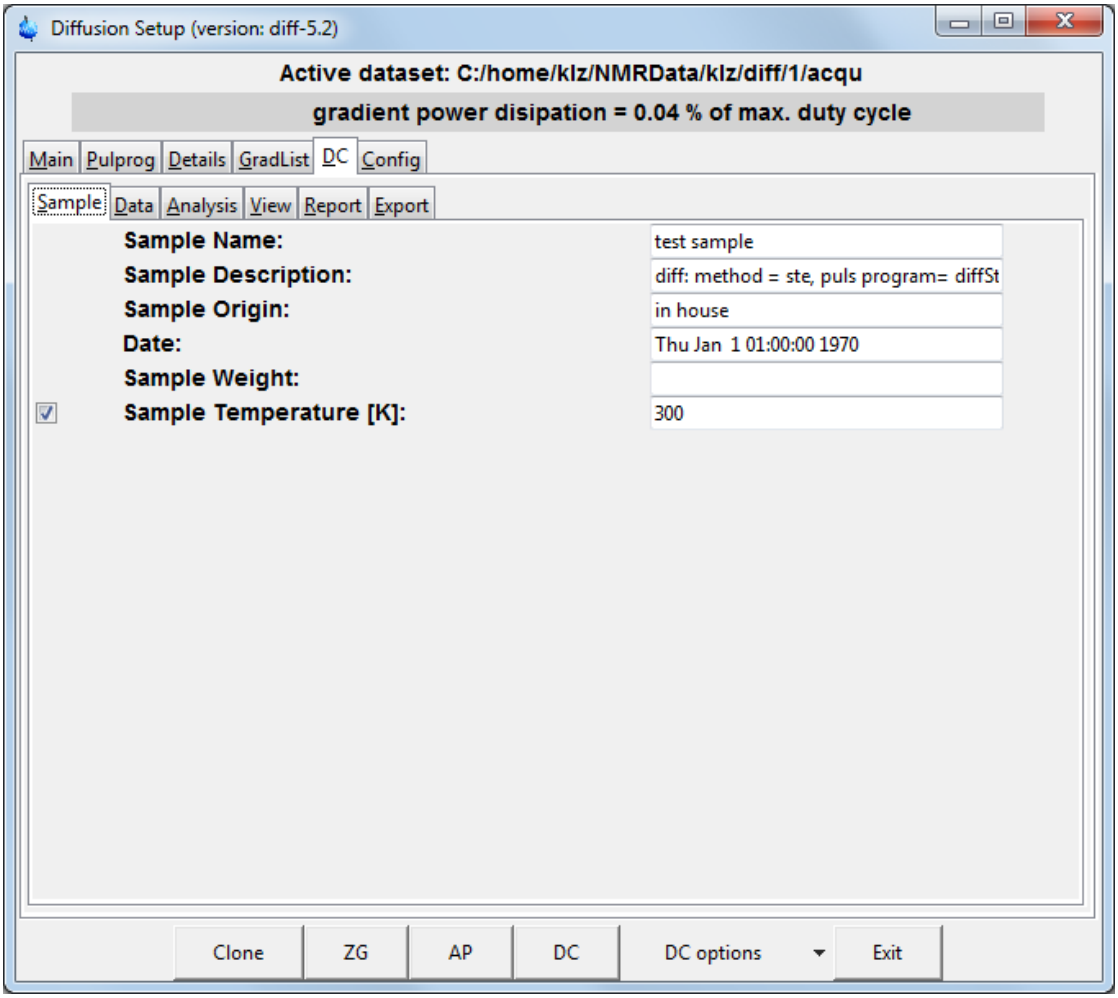


Figure 8.6: Diff5 Showing DC Tab of ste, Subtab Sample

- The *Sample Description* is automatically filled by the content of the TopSpin title file.
- The *Sample Temperature* appears in the Dynamics Center report output, if the check button is activated the TopSpin status temperature is filled in here.

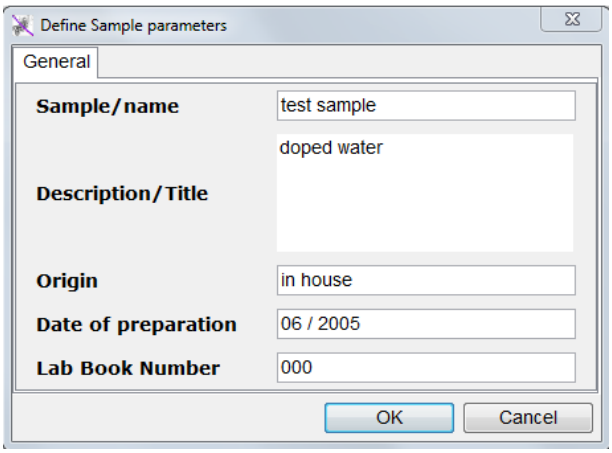


Figure 8.7: Dynamics Center Sample Node

8.7.2 DC Data Subtab

The next figure shows typical content found in the **Data** subtab which for the most part corresponds to the content of the Dynamics Center data details shown in the figures below for the *ste* experiment.

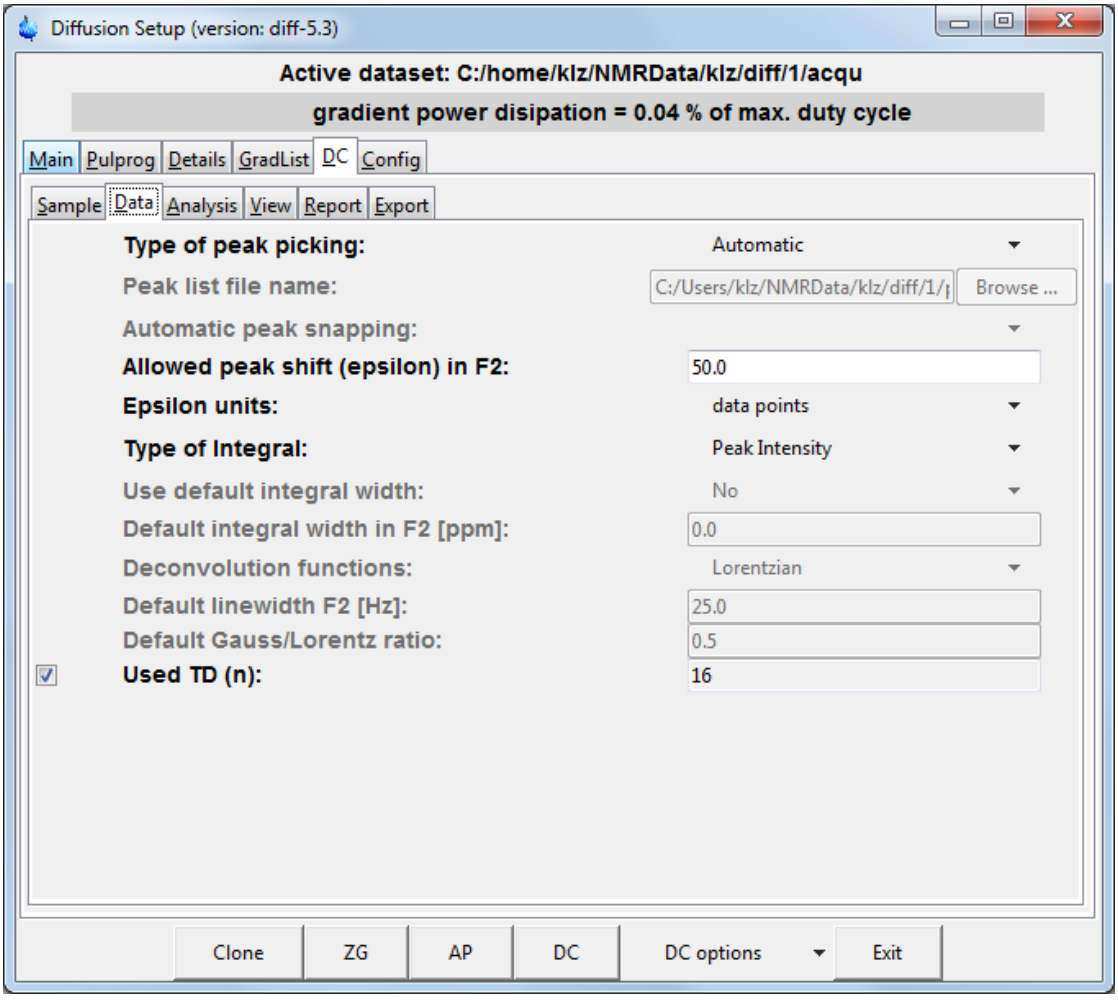


Figure 8.8: Diff5 Showing DC Tab of ste, Subtab Data

The **Spectra** tab in Dynamics Center offers several types of input spectra; *ste* always creates a spectrum of type *pseudo2D*. Therefore no option is shown in the *diff* menu, but *pseudo 2D* is automatically set in the background. The path to the spectrum is also automatically set in the background to the current spectrum.

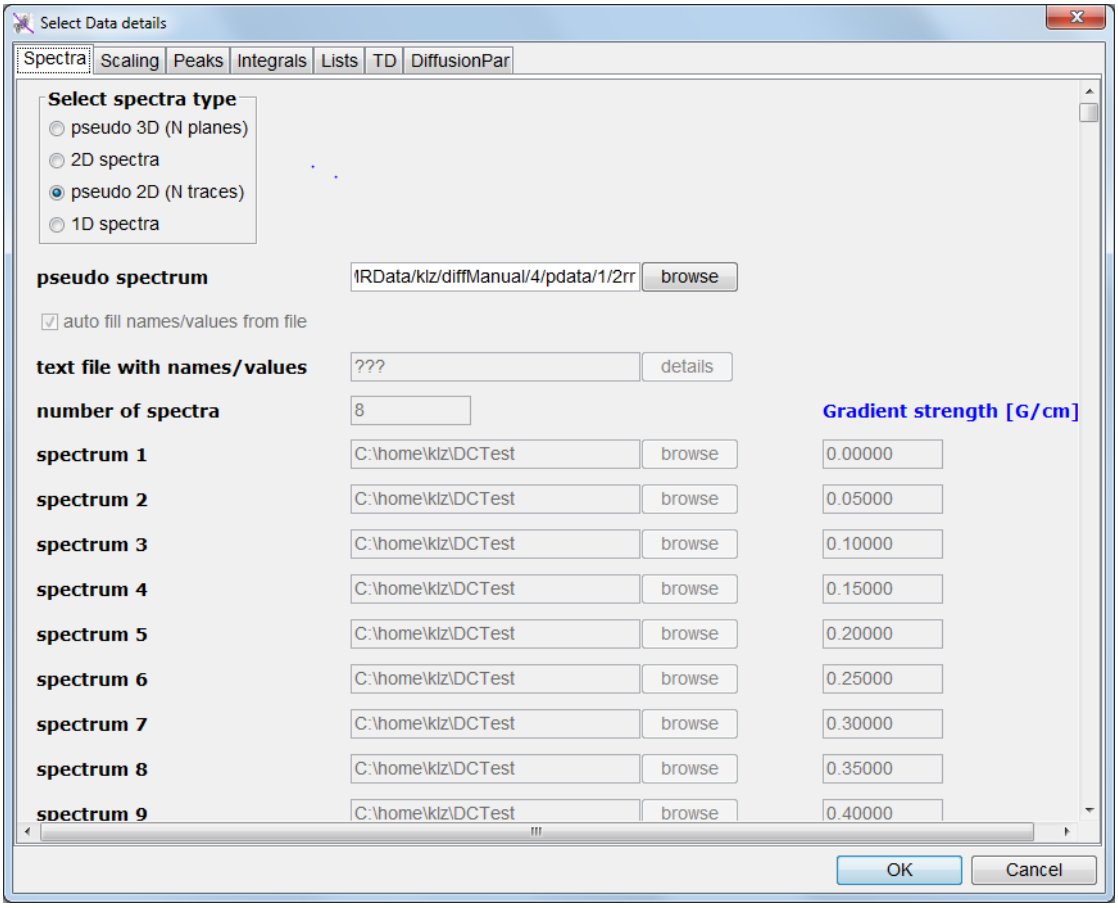


Figure 8.9: Dynamics Center Data Node, Spectra Tab

For *ste* the spectra scaling must always be set to no scaling, therefore *diff5* does this automatically in the background.

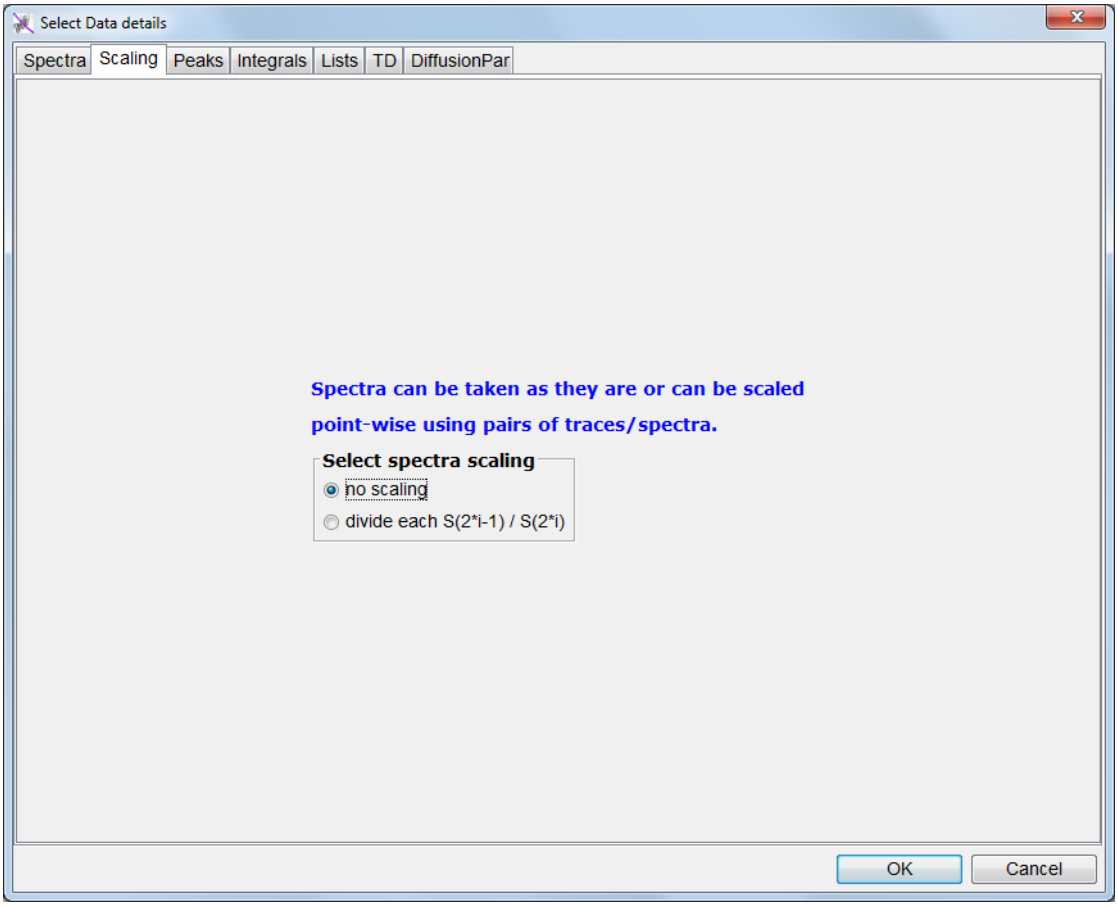


Figure 8.10: Dynamics Center Data Node, Scaling Tab

The Peaks tab is the first interactive part of the diff5 **DC Data** subtab. By clicking on one of the **Select peak type** radio buttons you can select one of the first 3, or the 5th option, which are applicable for automatic access from the Dynamics Center. The other parameters on the Peaks tab correspond to the contents on the **diff5 DC Data** subtab.

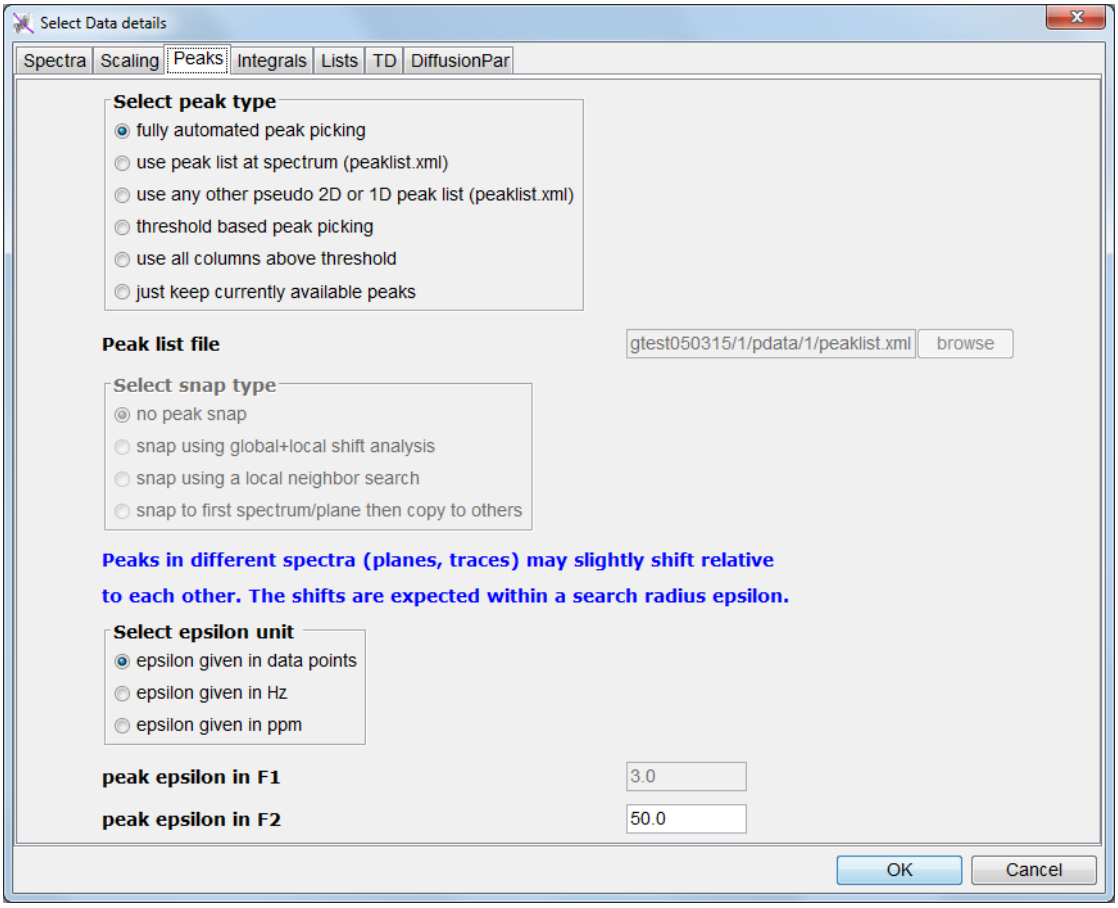


Figure 8.11: Dynamics Center Data Node, Peaks Tab

The different peak picking modes are explained in detail in the Dynamics Center Manual, but a few hints are given here.

- *Fully automated peak picking* means the program searches in each 1D spectrum for peaks. Then it tries to match between the different 1D spectra in the range allowed by *peak epsilon in F2*. If a peak appears in a significant number of consecutive spectra, it is considered to be relevant and is later used in the analysis.
- *Use peak list at spectrum (peaklist.xml)* means using 2D peak list, which can only be produced by Dynamics Center, TopSpin cannot create 2D peak lists for pseudo spectra.
- *Use any other pseudo 2D or 1D peaklist (peaklist.xml)* allows the user to take a peak list from another spectrum and use it on the current data set. In this case the settings in *Select snap type* apply.
- *Use all columns above threshold* means that a DOSY plot will be created using columns rather than peaks. In automatic mode, called from diff5, the threshold is automatically calculated. In interactive mode the threshold must be set by the user.

Almost all parameters on the **Integrals** tab correspond to the *diff5* **DC Data** subtab. Only the *Calculation mode* is not set, it defaults to fast.

Usually *use peak intensities* will be used for diffusion experiments. If *peak area (user defined) integrals* is used, *diff5* provides an additional option, *Use default integral width*. If this is set to *Yes*, an integral width for all peaks can be specified. In interactive operation in Dynamics Center this corresponds to the peak context option *Resize all*.

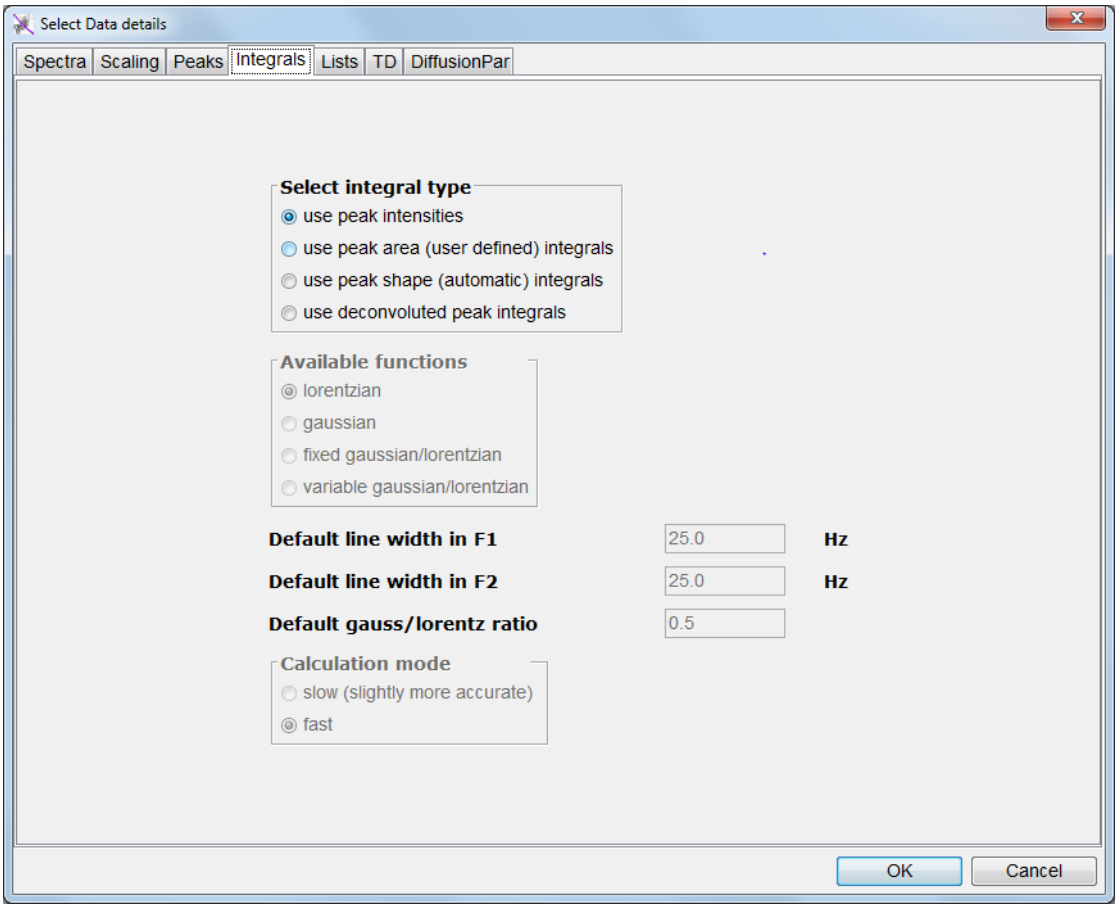


Figure 8.12: Dynamics Center Data Node, Integrals Tab

The **Lists** tab on the **DC Data** node is used to handle repetitive experiments used to improve statistics. It has normally no meaning in the *ste* experiment, but a user defined gradient list having more than one identical gradient amplitude would allow this feature to be used. *Diff5* does not support this feature at the moment.

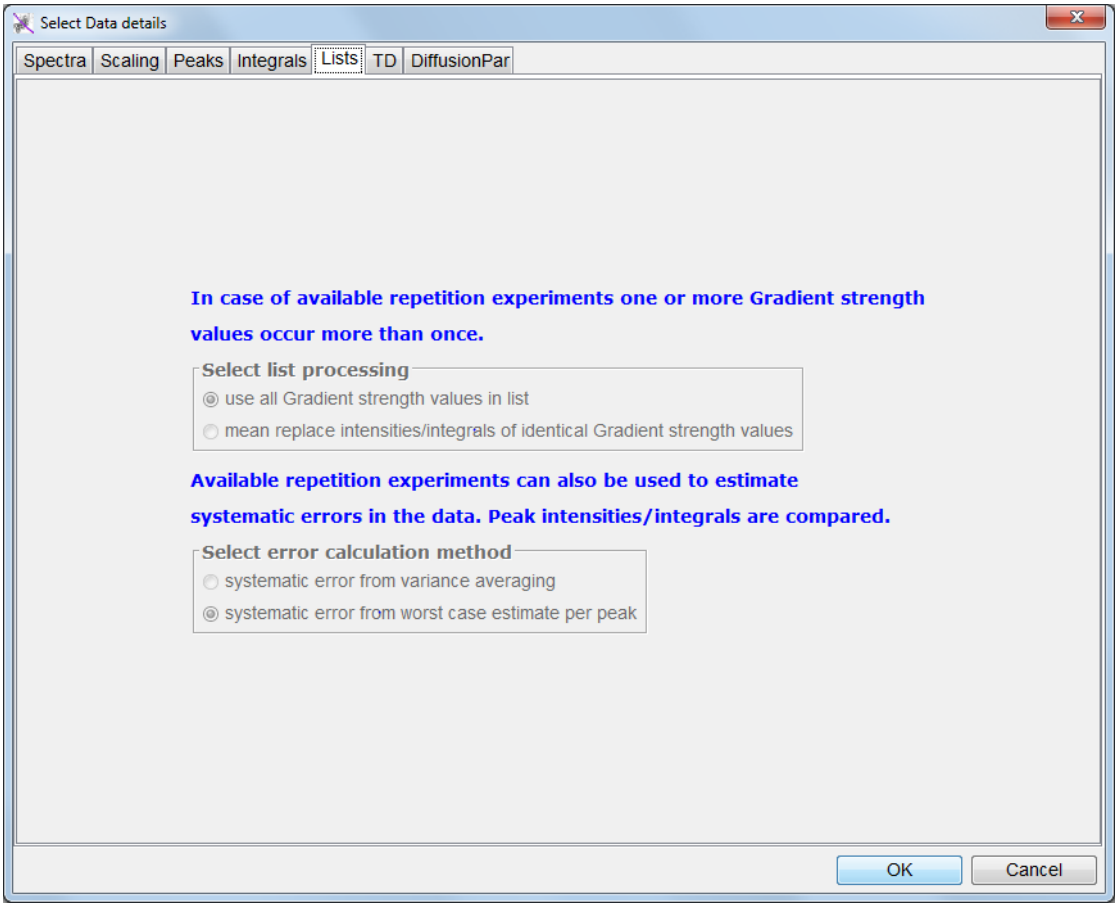


Figure 8.13: Dynamics Center Data Node, Lists Tab

The **TD** tab on the **DC Data** node is also resembled on the **Data** subtab of the *diff5* **DC** tab.

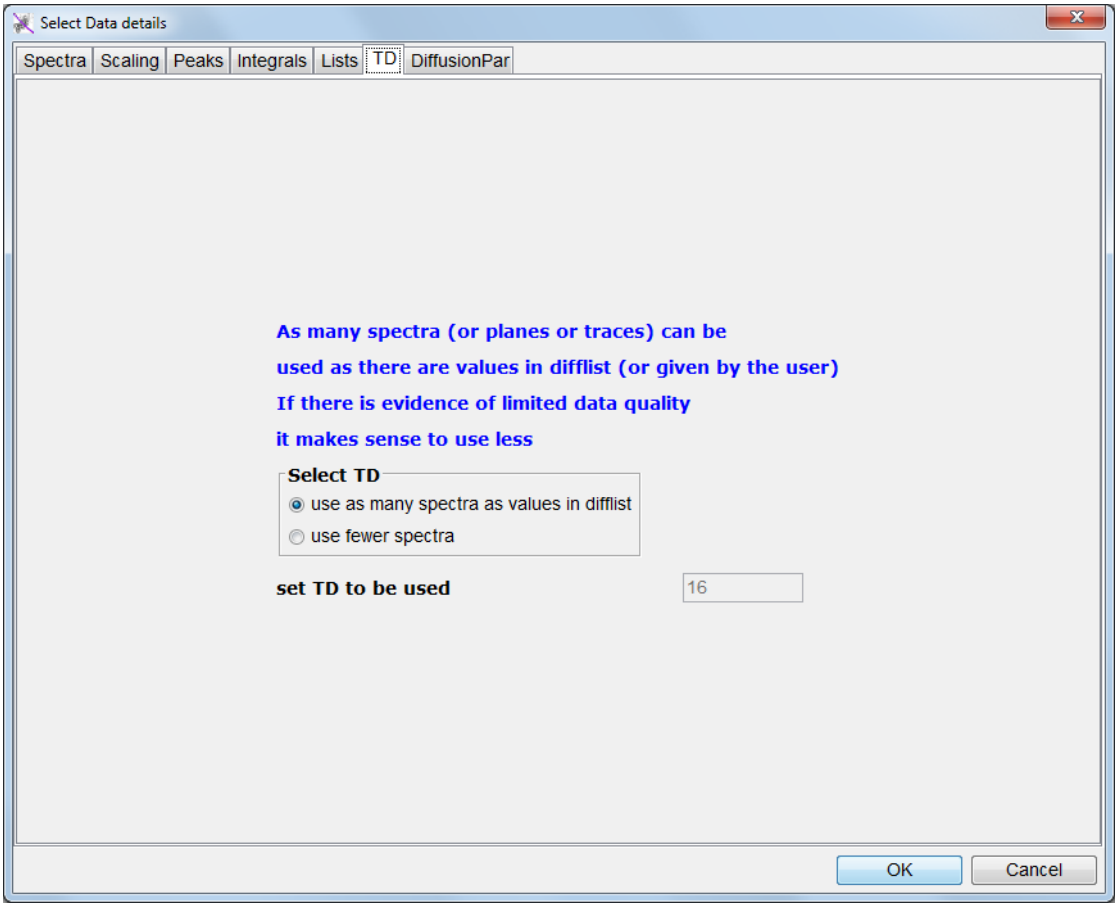


Figure 8.14: Dynamics Center Data Node, TD Tab

The **DiffusionPar** tab only contains read-only information; all values are automatically filled by *diff5* via the file TopSpinDC.xml. If Dynamics Center is used completely interactively, this will show, what Dynamics Center found in the t1par file and allows it to be corrected. If the experiment was setup using **diff5** the t1par file is also filled correctly.

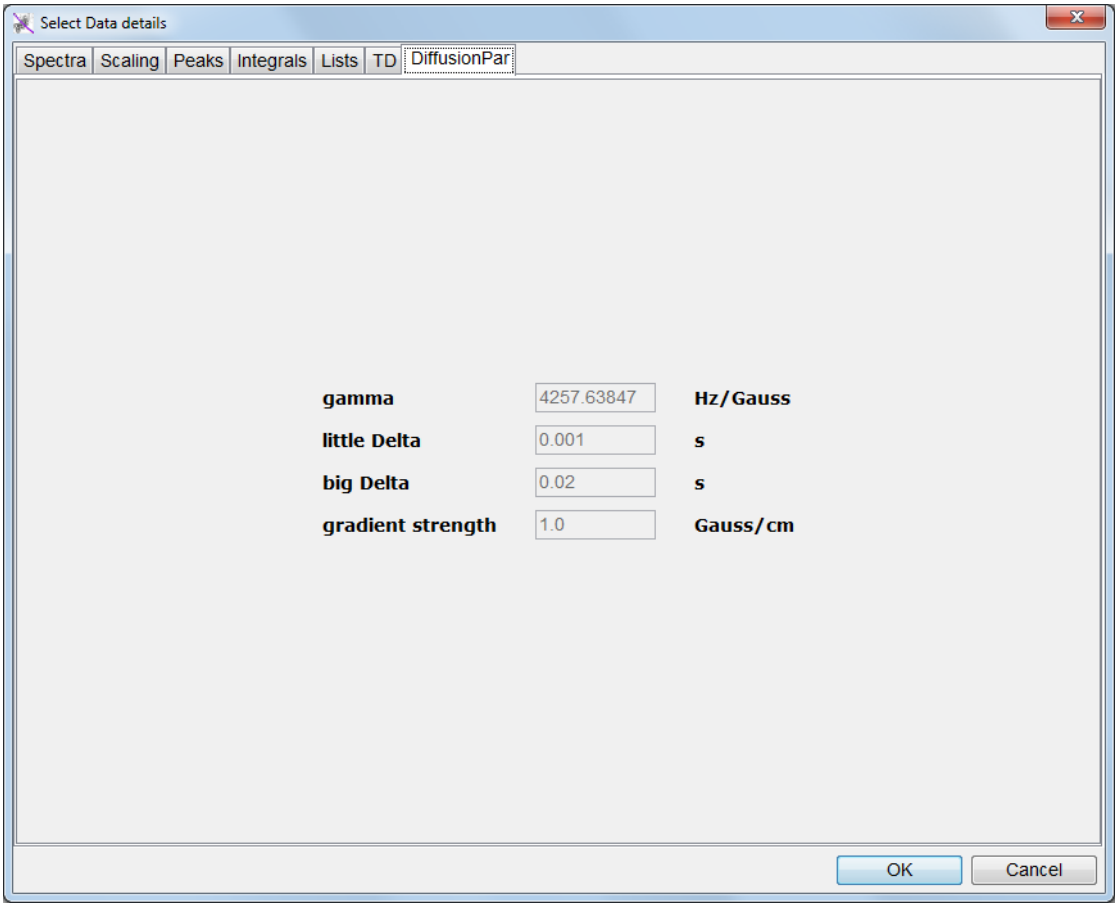


Figure 8.15: Dynamics Center Data Node, DiffusionPar Tab

8.8 Config Tab

The **Config** tab is always present, independent of the selected method. In the sub tab **preferences** the user can set some preferences.

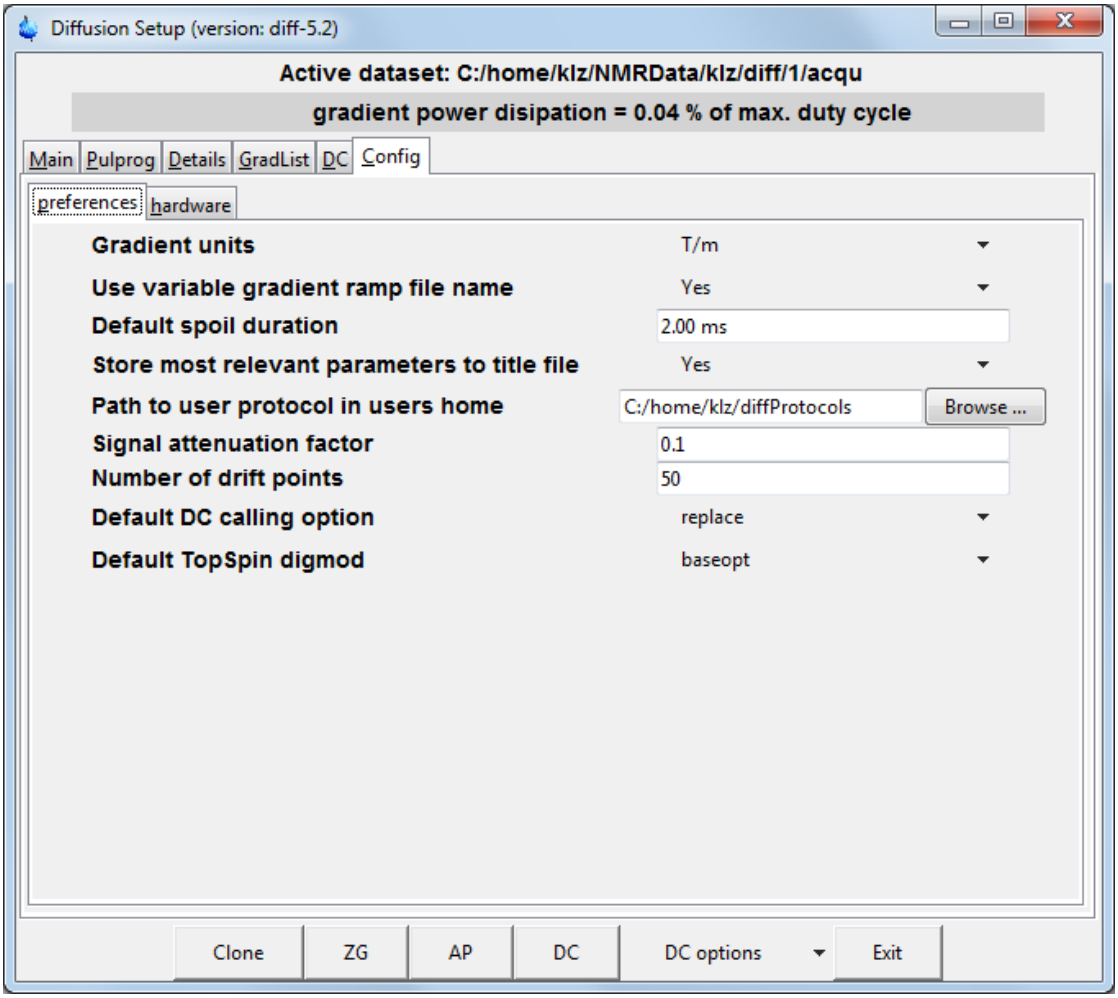


Figure 8.16: Diff5 Showing Config tab, Sub Tab Preferences

- *Gradient units*: Hz/cm, Gauss/cm, T/m, or mT/m
- *Use variable gradient ramp file name*: If yes, the gradient ramp file name is set to dataName_expno. The default is yes.
- *Default spoil duration*: Spoiler gradients are set to this duration, if the default spoiler setting is used, the default is 2 ms.
- *Store most relevant parameters to title file*: If yes, the most relevant parameters for the diffusion experiment, like little delta and big delta, are stored as a separate line to the title file.
- *Path to user protocol in users home*: Used to define a path where the user has write permission to store user specific protocol files, usually in the user's home directory.
- *Signal attenuation factor* (attFactor): Used in the calculation of the expected diffusion coefficient, default attFactor = 0.1.
- *Number of drift points*: Number of points the peak is allowed to drift during peak picking, default is 50.

- *Default DCcalling option*: Dynamics Center can be called in different ways, the default way is selected here (default = replace).
  - *new*: Start new Dynamics Center window.\n\
  - *add*: Add a second analysis into the latest Dynamics Center window.\n\
  - *replace*: Replace the latest analysis in the latest Dynamics Center window.\n\

Note that all option commands can only operate on the latest/newest Dynamics Center window, older ones are forgotten!

- *Default TopSpin digmod*: Used to set default TopSpin *digmod* for standard experiments. Some experiments need a special value and set it automatically (default = baseopt).

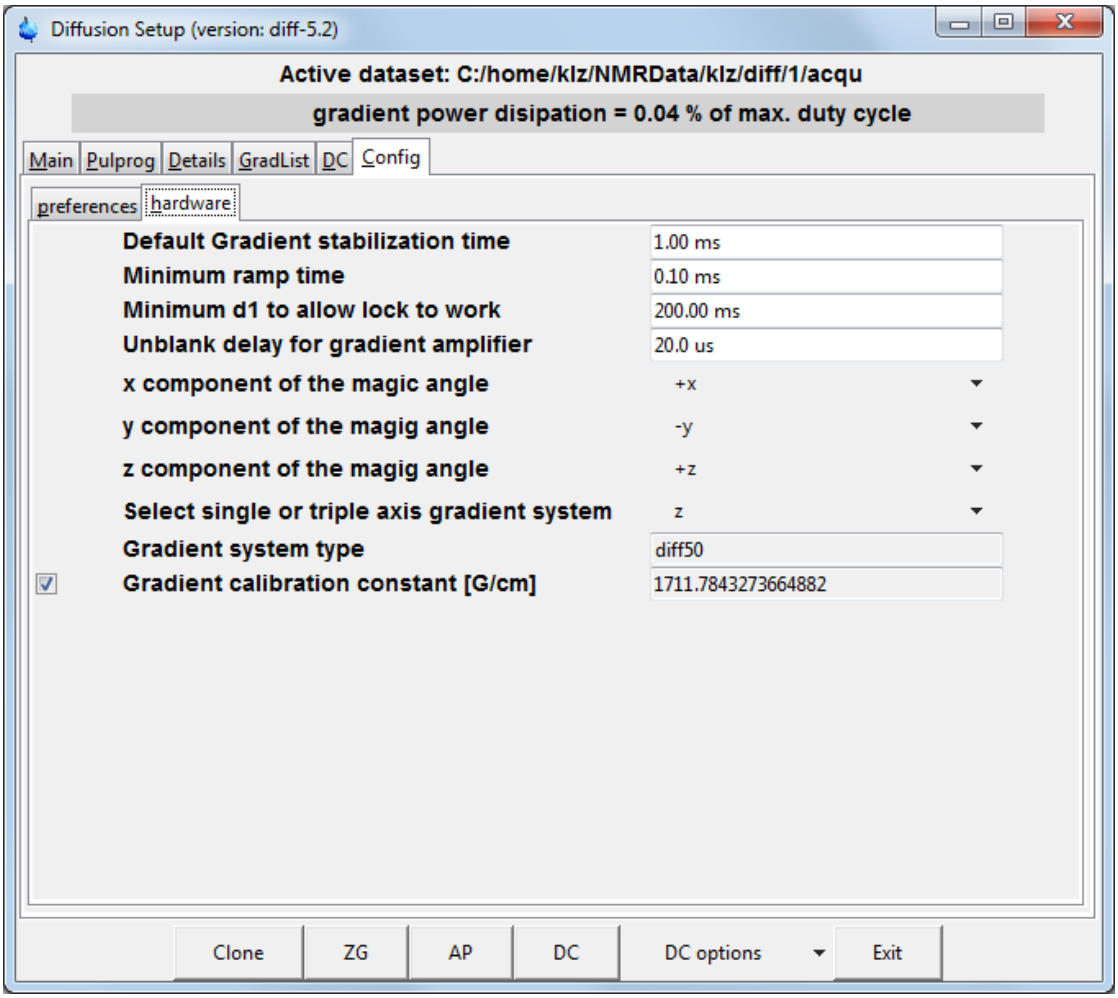


Figure 8.17: Diff5 Showing Config Tab, Sub Tab Hardware

- In the sub tab **hardware** some default timings and gradient directions can be set. These parameters should only be changed by experienced users understanding the background. Incorrect settings may lead to erroneous results. The default settings can normally be used and are conservative.
- *Default Gradient stabilization time*: This delay is used after each gradient pulse in a sequence, as long as standard calculations are used. The default value of 1 ms is in most cases a conservative value, which can be reduced, if short relaxation times are an issue.

- *Minimum ramp time*: Minimum allowed duration of a gradient ramp, default setting 100 µs.
- *Minimum d1 to allow lock to work*: If *locnuc* in TopSpin is not off, the lower limit of d1 is defined here. This is an empirically defined value, it might turn out that this delay is too short on certain systems under certain conditions.
- *Unblank delay for gradient amplifier*: This delay is always applied before each gradient pulse to allow the amplifier to be unblanked. Blanking means, the amplifier is disabled when no pulses are required in order to avoid the noise and hum of the running amplifier. Unblanking means enabling of the amplifier. This takes some time depending on the amplifier type. The default value for GREAT amplifiers is 20 µs.
- *X, y, and z component of the magic angle*: These 3 parameters are used to match the direction of magic angel gradients to the direction of the magic angle in the probe. This is only applicable for MAS diffusion/imaging systems. The values are determined by measuring profiles along the MAS direction.
- *Select single or triple axis gradient system*: The type of gradient system is normally detected automatically but can be changed if required.
- *Gradient system type*: Shows the current gradient system type, this cannot be changed.
- *Gradient calibration constant [G/cm]*: Shows the gradient calibration constant used. This value can be temporally changed for processing only.

8.9 Background Information

8.9.1 The Expected Diffusion Coefficient

The expected diffusion coefficient D_e is calculated using the following equation, assuming a signal attenuation of one order of magnitude. In other words S/S_0 is set to 0.1 and D_e can be calculated:

$$D_e = -\frac{\ln(attFactor)}{B}$$

If D_e is modified by the user, the g_{max} value is recalculated using the equation:

$$g_{max} = \sqrt{-\frac{\ln(attFactor)}{\gamma^2\delta^2\left(\Delta - \frac{\delta}{3}\right)D_e}}$$

8.9.2 Relaxation Parameters

The relevant time for the T_2 relaxation, the echo time T_e is implicitly defined in most of the experiments.

In the spin echo experiment T_e is defined as:

$$T_e = 2\Delta$$

In the stimulated echo experiments T_e is defined as:

$$T_e = 2\tau$$

Where τ stands for the delay between the first $\pi/2$ pulses. Usually t is set to the minimum possible value t_{min}, but it can also be increased in order to act as a T_2 filter.

The value of t_{min} depends on the type of the experiment, it will usually contain the gradient pulse length t_g and the gradient stabilization time.

For the T_1 Relaxation diff uses the parameter repetition time t_r, which is not the relaxation delay, but rather the sum of all delays in one scan. Nevertheless t_r is usually dominated by the acquisition time aq and the relaxation delay d1. In the spin echo experiment it is defined as:

$$T_r = 2\Delta + aq + d1$$

In the stimulated echo experiments it defined as:

$$T_r = 2\tau + \Delta + aq + d1$$

8.9.3 Conversion of the Cotts 13 Interval to the Stejskal/Tanner Equation

The idea to use the standard Stejskal-Tanner calculation for the 13 interval Cotts sequence can be described as follows:

The equation [5] in the Cotts paper[7], neglecting the background gradients, looks like:

$$\ln\left(\frac{M}{M_0}\right) = -\gamma^2 D\delta^2 g^2 (4\Delta + 6\tau - \frac{2}{3}\delta)$$

Figure 8.18: Equation 7

This replaces:

$$\Delta^* = \Delta + \frac{3}{2}\tau + \frac{\delta}{2}$$

$$\delta^* = 2\delta$$

Figure 8.19: Equation 8

Where Δ*, and δ* stand for the corresponding parameters used by diff. This results in the following equation, which is an exact representation of the Stejskal-Tanner equation introduced in the equation in *Diffusion Experiments [▶ 61]*:

$$\ln\left(\frac{M}{M_0}\right) = -\gamma^2 D\delta^{*2} g^2 (\Delta^* - \frac{1}{3}\delta^*)$$

Figure 8.20: Equation 9

[7] R. M. Cotts, M. R. Hoch, T. Sun, and J. T. Markert, JMR 83, 252-266(1989)

9 Troubleshooting

9.1 Line Broadening

9.1.1 No Blanking

If the lines in a spectrum are broadened as soon as the gradient cable is connected and the amplifier reset, it usually means the blanking is not active and the offset is not adjusted.

- Adjust the amplifier offset, see *Offset Adjustment [▶ 19]*.
- Check, whether the pulse program unblanks the amplifier. All Bruker pulse programs called *diff...* include gradient blanking commands. If not, check the imaging rack wiring (see *The Imaging Accessory Wiring [▶ 156]*).

9.1.2 Cooling Water

When the lines in a spectrum become broadened after the cooling water was inserted to the empty case, this is to some extend normal, because the environment has been modified. However, this effect can become severe in the following cases:

- If there are air bubbles in the gradient system. The air bubbles create a field gradient because of the different susceptibility of air and water. In this case remove the air bubbles by taking the probe out of the magnet with the water running. Turn the probe upside down and back a couple times, then the bubbles should be out. Often air bubbles can be heard clicking when putting the gradient system next to one’s ear. See also *Water Cooling Set-up [▶ 141]*.
- If the water is dirty and contains magnetic, or conducting materials. If uncertain, exchange the cooling water.

9.2 Convection Artefacts

Convection in the sample usually occurs due to temperature gradients. For samples having a very low viscosity, even smallest temperature gradients can lead to convection.

Convection effects usually lead to an artificially increased diffusion coefficient. Sometimes phase changes in the signal function of the gradient strength are visible. In extreme cases the signal can change the sign and oscillations of the signal amplitude, as a function of the gradient strength can be observed.

Other macroscopic motions, like flow or vibrations, can lead to similar effects as convection. These are summarized under the term convection in the following section.

If the diffusion of big molecules in low viscous solvents is investigated, even small convection artefacts, as compared to the diffusion of the solvent, can lead to a significant error for the small diffusion coefficient of the big molecule.

9.2.1 Diagnosis

If the existence of convection is suspected, the safest test is to measure the diffusion coefficient at different diffusion times. In case of convection the apparent diffusion coefficient will grow as a function of the observed diffusion time. This effect is only observed in case of convection or other macroscopic motions as mentioned above.

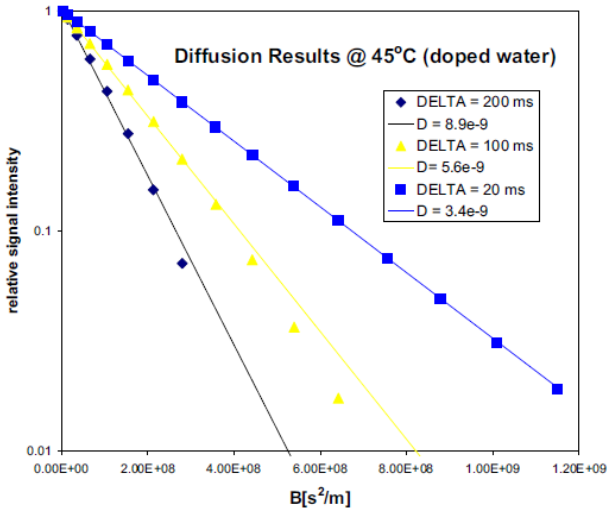


Figure 9.1: Diffusion Time Dependence of the Apparent Diffusion Coefficient in the Presence of Strong

9.2.2 Avoiding Convection

There are a few general rules on avoiding convection, which of them applies and/or is necessary depends on the individual situation.

- The sample should be as short as possible. In order to allow proper shimming usually a compromise value of 40 mm in 5 mm samples is used.
- It is also very useful to use a tube with a smaller diameter, e. g. 3 mm.
- In water cooled probes the water temperature should be set to the desired sample temperature, if possible within the allowed temperature range. The airflow should be switched off if the desired temperature can be reached by means of the water temperature and no decoupling is required.
- In extreme cases, double sample tubes should be used. With double sample tubes, the sample is put into the inner tube and a low viscous, fully deuterated (for proton observation) solvent is filled in the outer tube. The convection in the outer tube will equilibrate the temperature in the inner tubes.

9.2.3 Compensating Convection

In order to compensate for convection, flow compensated pulse sequences can be used to some extent. Usually the double stimulated echo *dste* is used to remove the effect of constant flow, which will be the main component in case of moderate convection.

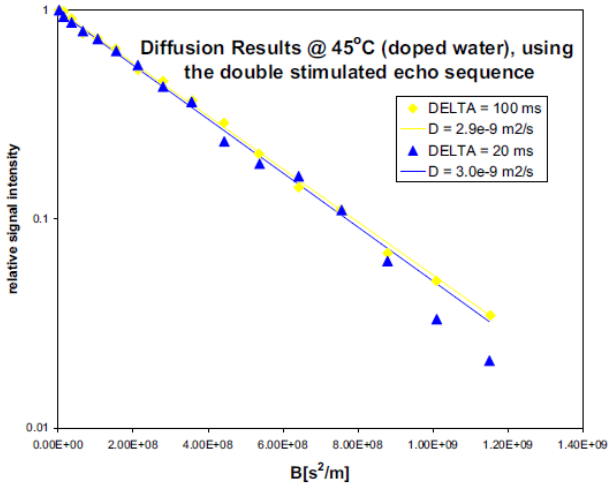


Figure 9.2: Results Obtained Using dste in the Presence of Strong Convection

Note: The double stimulated echo causes at least 50% of the signal to be lost. Therefore avoiding convection is always preferable.

The double stimulated echo sequence is more sensitive to eddy current effects.

9.3 Software

If problems concerning the *diff* program show up, save the file *diffHistory* in the *.diff* subdirectory of the user file running TopSpin, then send it together with the data-set in a tar or zip file, and a description of the problem to:

micdiff@bruker.com

In newer versions of diff and in diff5 the history file is stored with the data, so sending the data will be sufficient.

9.3.1 Error: No gradient parameters found, only configuration mode possible

Often this means, that an incorrect probe was selected in edhead (see *Probe Exchange [▶ 43]*).

If a properly configured probe is not available, follow the description given in *Installing a Diffusion Probe [▶ 10]*.

Troubleshooting

10 Setpre

The program module *setpre* is used to adjust all gradient related parameters. A short description of how to use setpre is give here.

10.1 Pre-emphasis, B0, and Cross-Pre-emphasis Parameters

The parameters for pre-emphasis adjustment are shown in the following figure, the menu is activated using the **setpre** command.

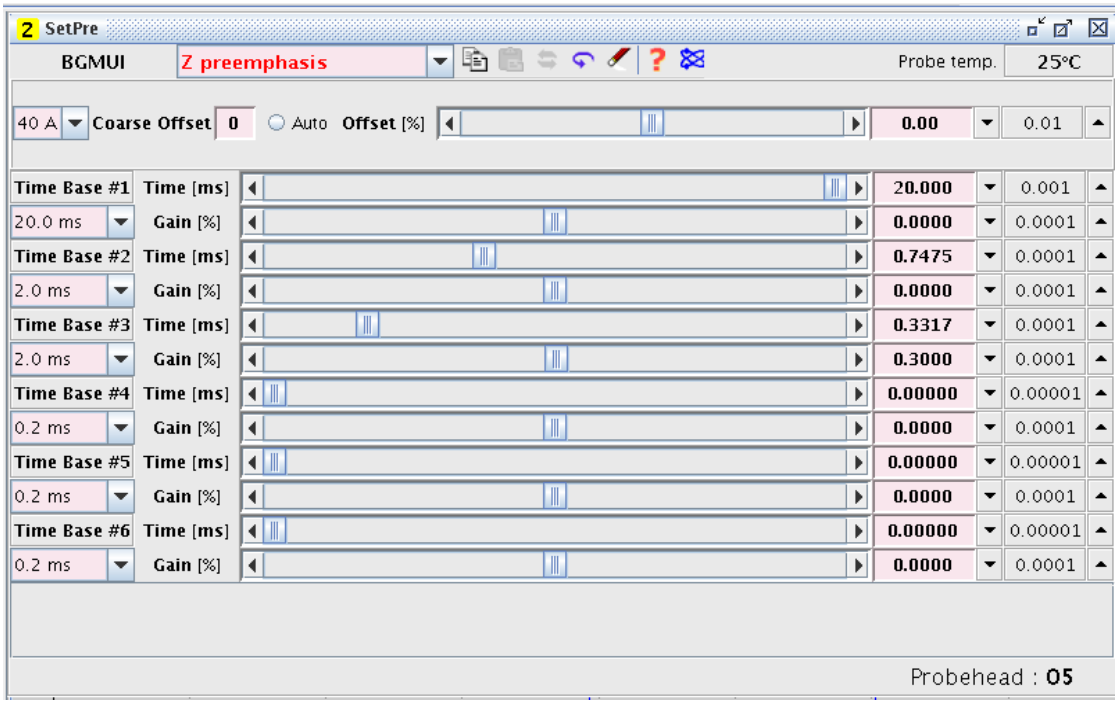


Figure 10.1: Pre-emphasis Control

Prior to the real pre-emphasis parameters being display, a group of other parameters appear in the pre-emphasis control window:

- The first row in the figure above shows the type of gradient generation hardware connected, here the *BGMUI*. This is followed by the selected channel for adjustment, then the actual gradient coil temperature.
- The second row shows the gain, the coarse offset (AVANCE III only), the auto offset adjustment button, and the offset accessible by slider or number.
- Following the header information is the pre-emphasis block. Three timeframe‘s out of a possible four can be specified for the time constants of the exponential functions. The precise values of these time constants and the amplitudes are adjusted using the slider control on the Time and Gain bars. Values can also be typed in directly after selecting the corresponding field with the mouse. Each value change is loaded directly to the pre-emphasis unit.

In Avance systems previous to Avance III, the timeframe‘s for the analog pre-emphasis system was related to hardware components, therefore it was useful to use a very short timeframe. For the new digital pre-emphasis (AVANCE III) these switches have no real meaning and are only there for compatibility.

When *setpre* is started it first reads the parameters from the pre-emphasis unit, e.g. the GREAT Master Unit (BGMU), or from the DPP (AVANCE III), and displays the parameters for the Z-gradient channel. The channel can be changed using the channel pull-down menu (see figure below).

The channel pull-down menu also gives access to the B0 compensation parameters, if the corresponding hardware is available. These parameters are referred to as X-B_0, Y-B_0, or Z-B_0 cross pre-emphasis parameters in the pull-down menu in the figure below.

If more than one gradient amplifier is active, cross pre-emphasis parameters are also available (only AVANCE III).

Note: Setpre always shows the parameters corresponding to the available gradient hardware generation. Some probes will not react on all possible channels, e.g. a Z-only gradient probe will not react on any non Z-adjustment.

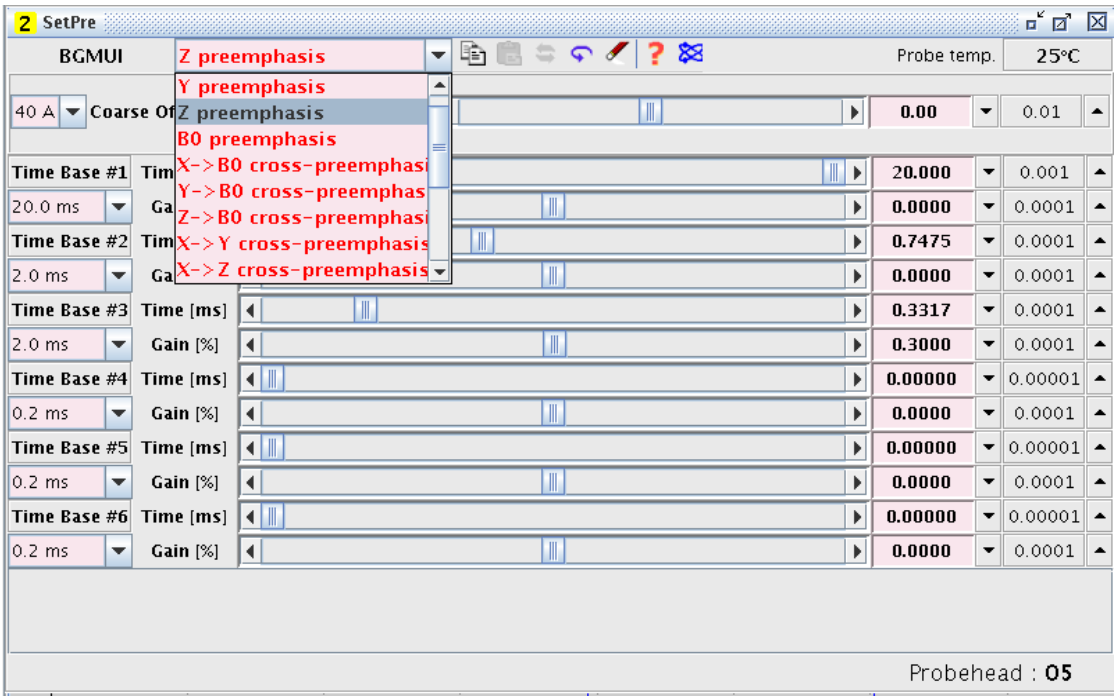


Figure 10.2: Channel Pull-down Menu

10.2 Parameter Storage

All pre-emphasis parameter are stored in the pre-emphasis files. There is a special file, the *default file*, also named *default*, see *Pre-emphasis Files [▷ 17]*. Other files can be created and read in from the same directory. Pre-emphasis parameters can be read from a file or written to a file by selecting the **File** entry in the *Setpre* pull-down menu:

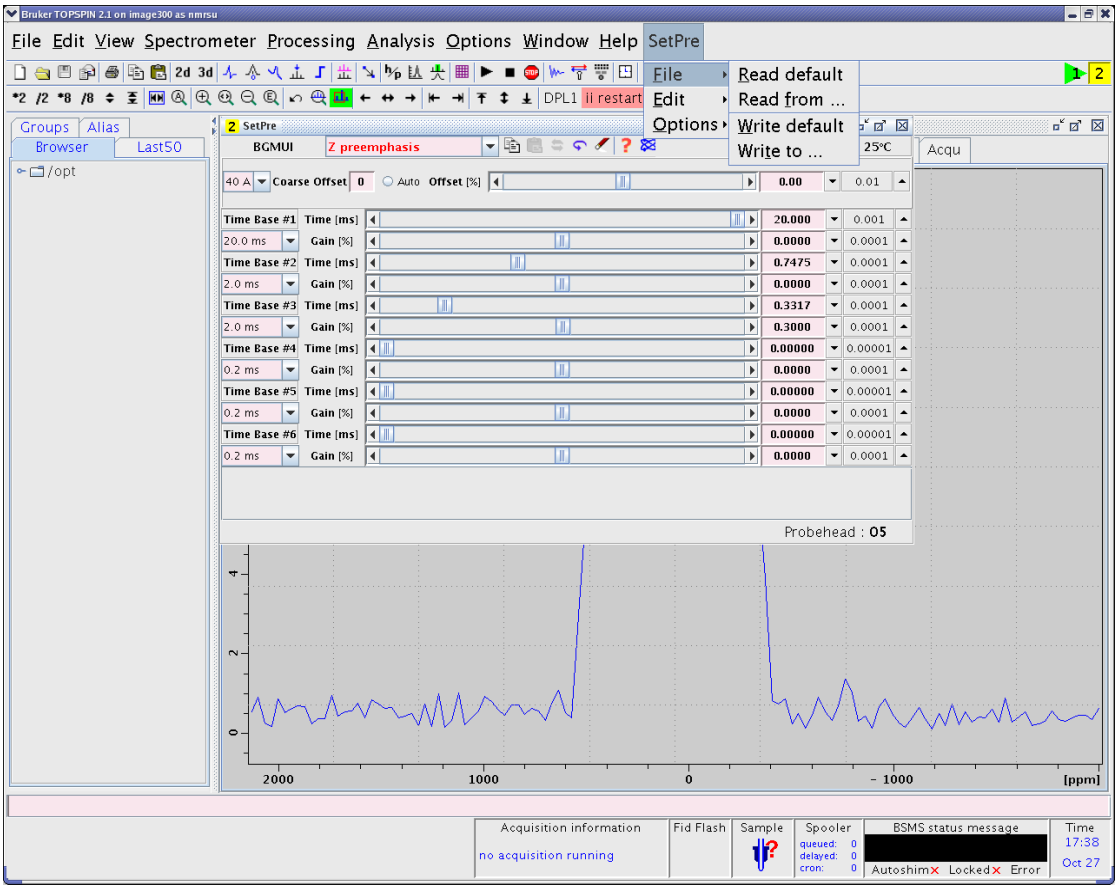


Figure 10.3: Reading and Writing Pre-emphasis Files

Each time pre-emphasis files are read or written, the file *<TopSpinHome>/conf/instr/gradient_calib* is updated in order to provide the proper gradient calibration for the older imaging au programs and the DOSY au programs.

10.3 Gradient Parameters

The gradient calibration and the relative gradient scaling can be edited using the option Gradient parameters in the **Setpre** | **Edit** pull-down menu.

After changing any parameter press Apply and afterwards use **Setpre** | **File** | **Write default** to save the parameters to disk and to update the gradient_calib file.

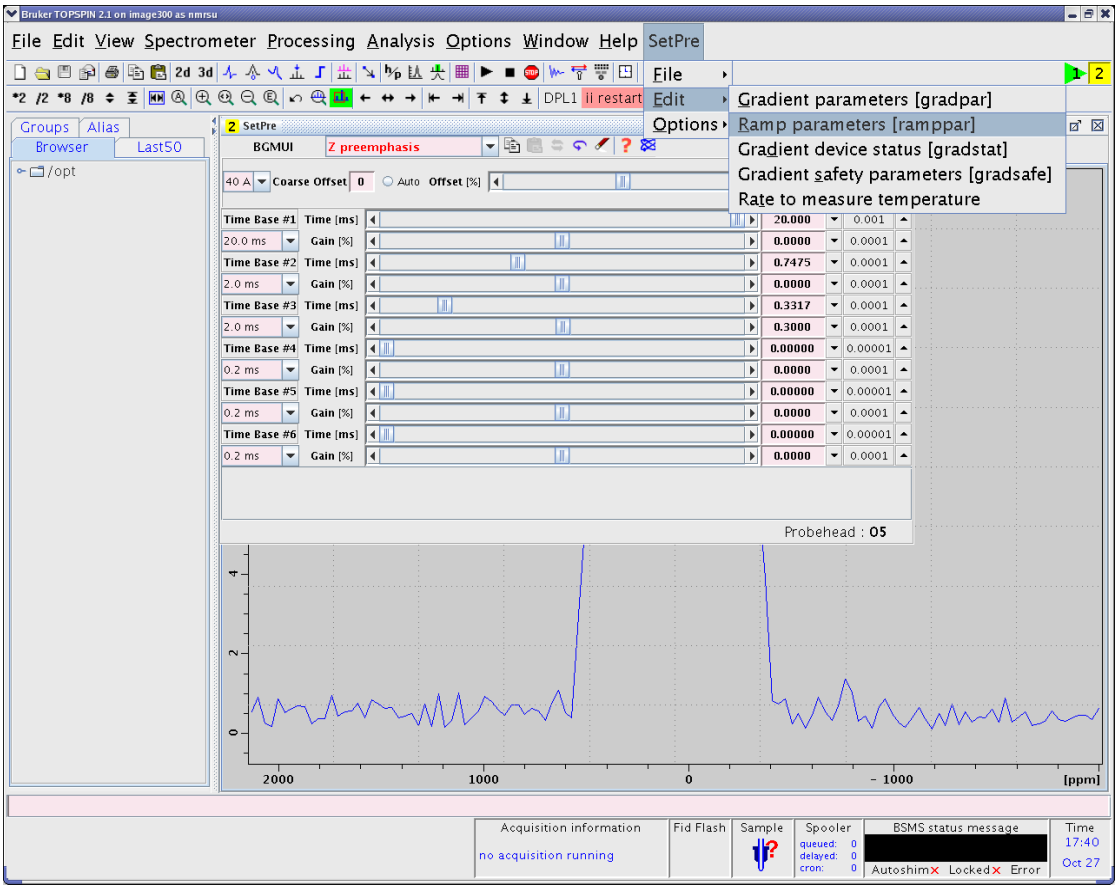


Figure 10.4: Other Parameters

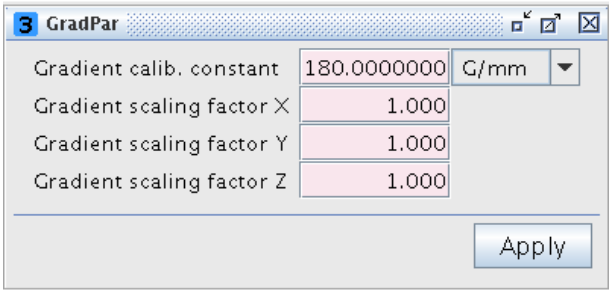


Figure 10.5: Gradient Parameters

10.4 Ramp Parameters

The ramp parameters must be set to Ramp off in all TopSpin 2.x versions, in older versions these parameters are not available. The ramp parameters are found under **Setpre** | **Edit** | **Ramp parameters**.

After changing any parameter press **Apply** and afterwards use **Setpre** | **File** | **Write default** to save the parameters to disk.

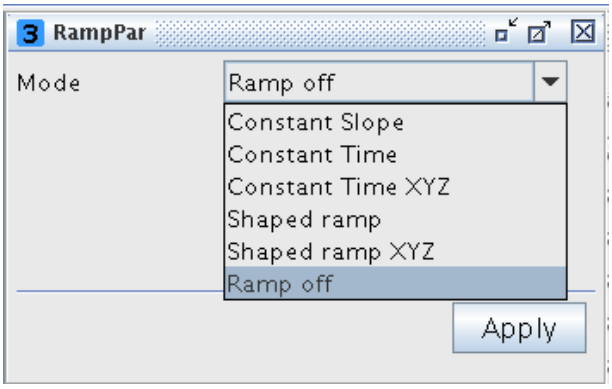


Figure 10.6: Ramp Parameters

10.5 Gradient Device Status (AVANCE III only)

The gradient device status can be displayed by selecting **Setpre** | **Edit** | **Gradient device status**:

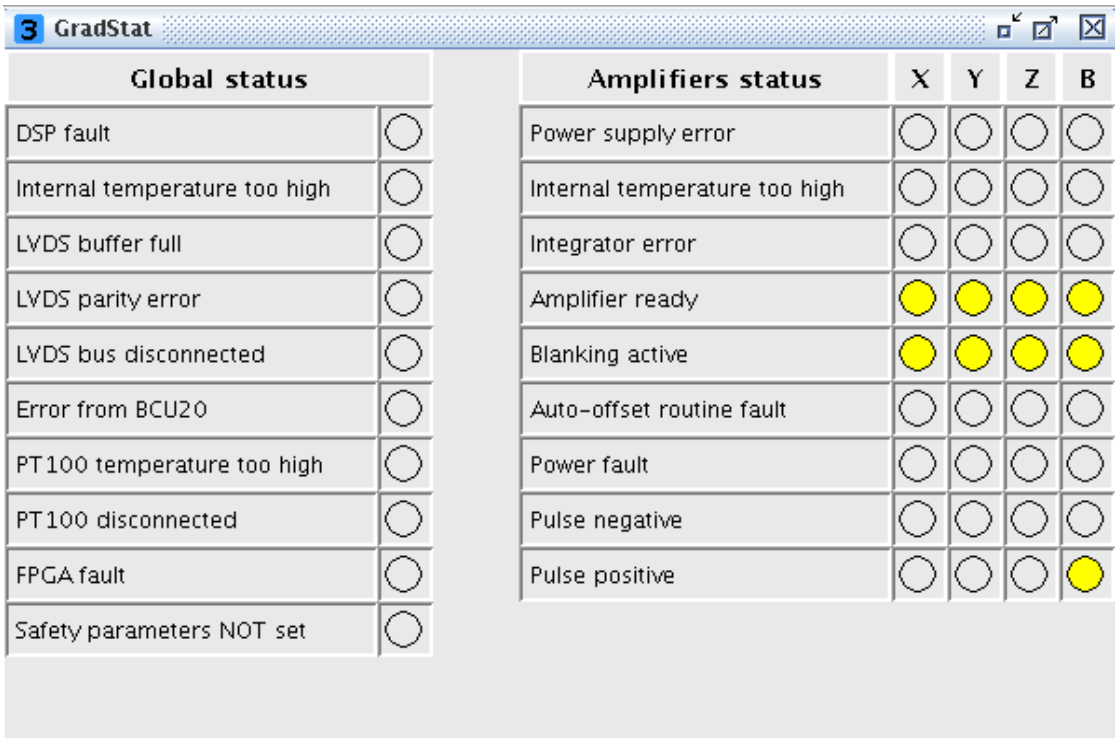


Figure 10.7: Gradient Device Status

10.6 Gradient Safety Parameters (AVANCE III only)

The safety parameters are found under **Setpre** | **Edit** | **Gradient safety parameters**. The gradient safety parameters should normally be provided within the default pre-emphasis files, no interactions should be necessary. A list of standard safety parameters is given in *Micro-imaging Manual for AVANCE III Systems*, the values might change in future due to technical development.

If the safety parameters are not set, the master unit will not switch on and a C01 status error will result.

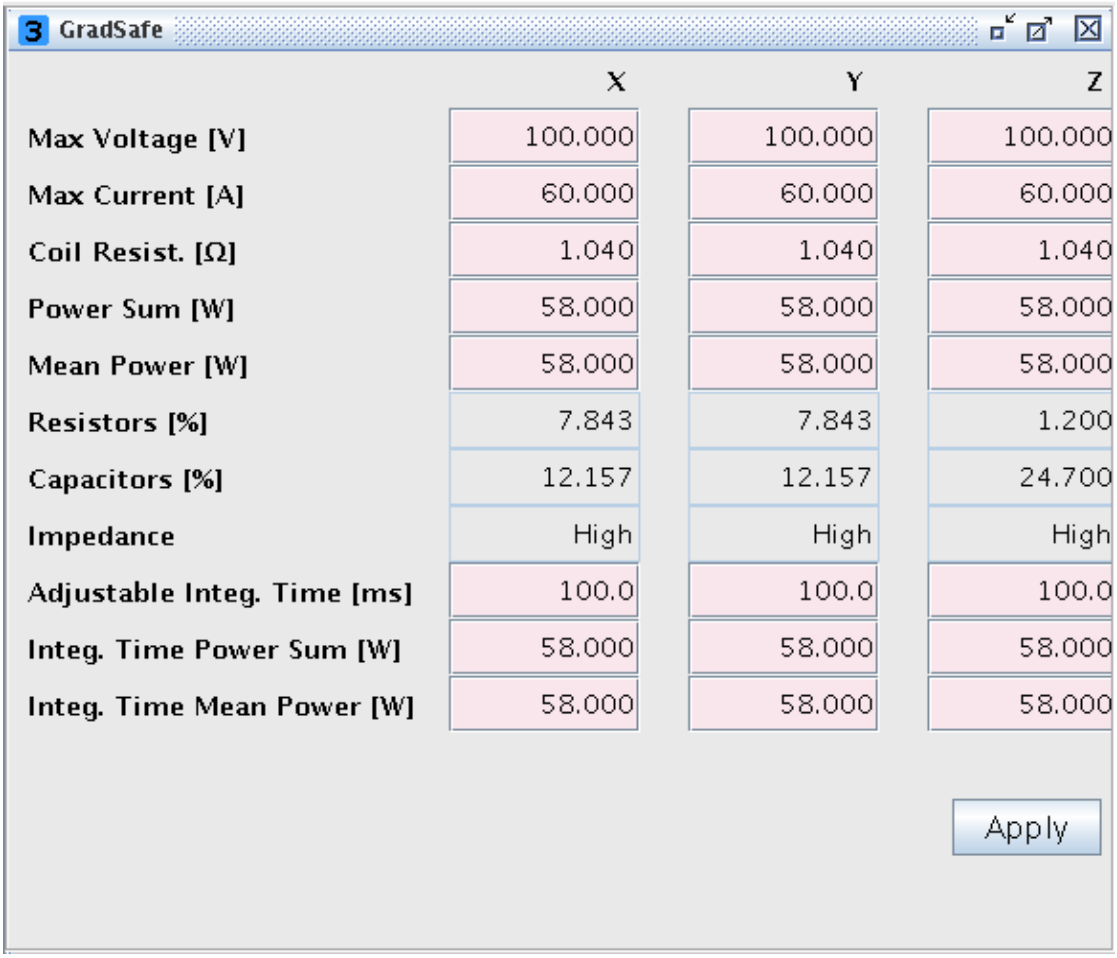


Figure 10.8: Gradient Safety Parameters

After changing any parameter press Apply and afterwards use **Setpre** | **File** | **Write default** to save the parameters to disk.

10.7 Rate to Measure Temperature

The rate to measure temperature parameter is found under **Setpre** | **Edit** | **Rate to measure temperature**. This parameter defines the rate the gradient temperature for the display in *setpre* is measured.

Figure 10.9: Rate to Measure Temperature

After changing any parameter press **Apply** and afterwards use **Setpre** | **File** | **Write default** to save the parameters to disk.

10.8 Setpre Options

The options submenu is found under **Setpre** |**Options** as shown in the following figure. The options available will be discussed in the following section.

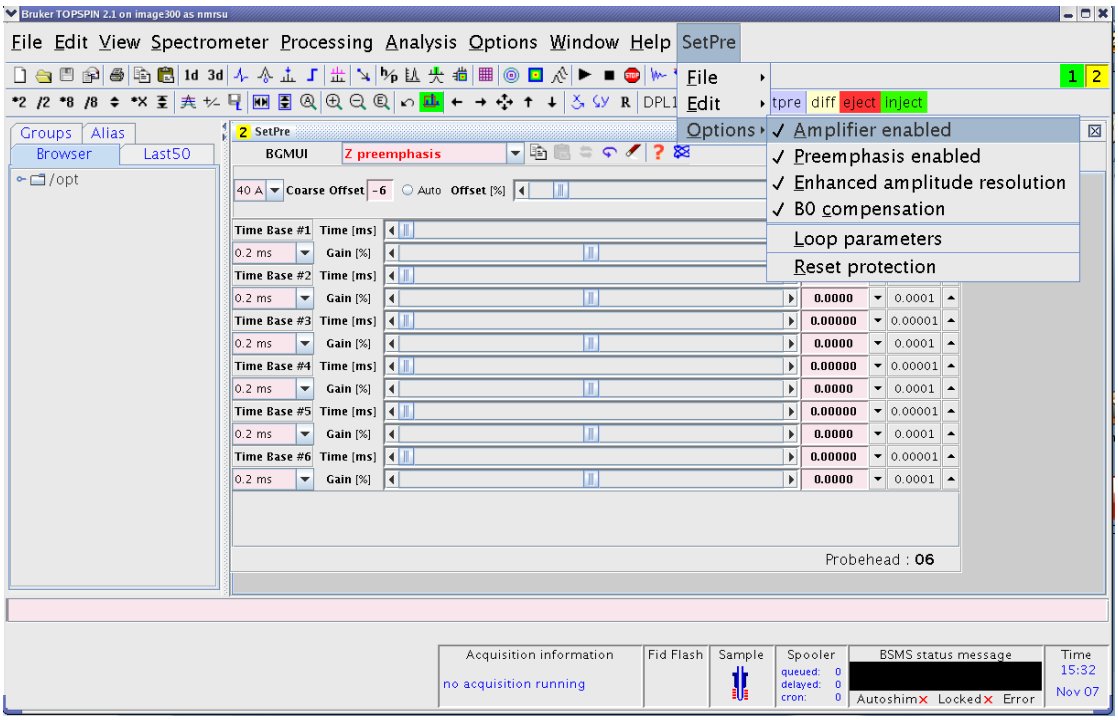


Figure 10.10: Setpre Options

Amplifier enabled

Allows the amplifiers to be disabled/enabled (default on).

Pre-emphasis enabled

If this option is checked the pre-emphasis corrections will be applied (default on).

Enhanced amplitude resolution (AVANCE III only)

Allows switching between enhanced (19 bit) and standard (16 bit) amplitude resolution. This option was added for testing, normally enhanced should be used (default on).

B0 compensation

This option appears if a B0 compensation unit is present. It allows the unit to be switched on or off. This switch also switches the relay for the field current from the BSMS.

Loop parameters

Clicking on this button will enhance the setpre menu by the loop parameters, which are used to match the output impedance of the amplifier to the gradient coil. This option will first ask for the NMR Administrator password, it should be only necessary at installation.

Reset protection

Does the same as the red reset button on the front panel of the master unit.

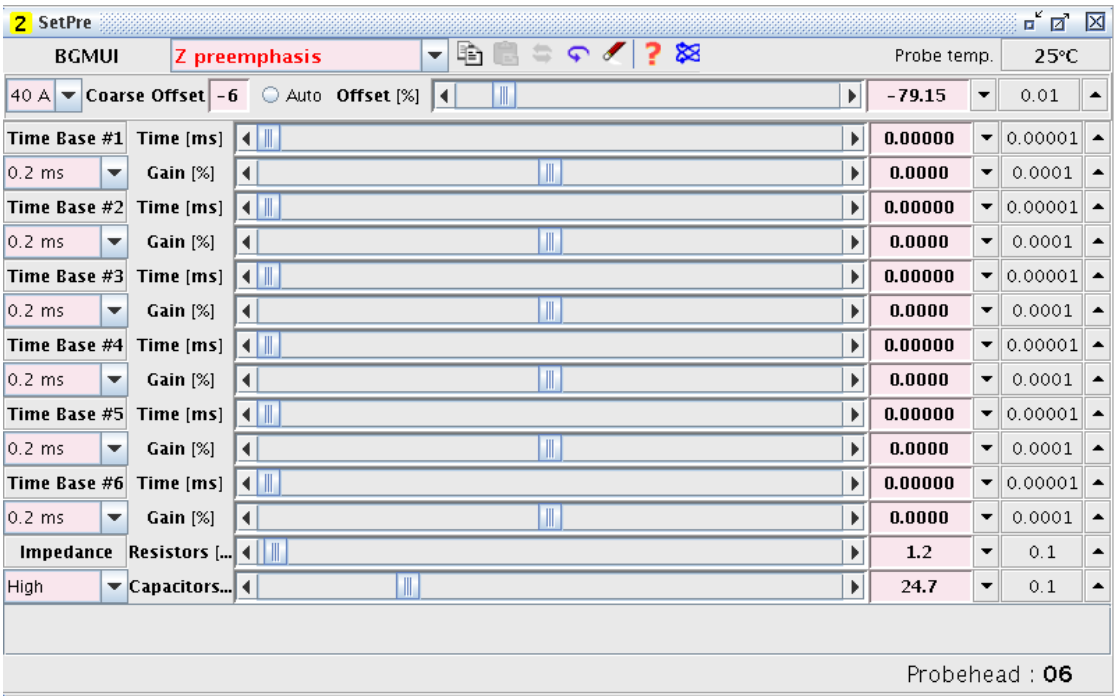


Figure 10.11: Setpre Window Showing Loop Parameters

11 Probes and Gradients

11.1 DiffBB

The diffBB probe is almost identical to a standard high resolution BBI or BBO probe. It holds a ^{1}H channel tunable to ^{19}F, an X-channel tunable from ^{31}P down to ^{15}N, and a lock channel. The RF channels are equipped with an automatic tune and match unit (ATMA).

The temperature control is also identical to a standard high resolution probe. It uses a thermocouple type T.

The obvious difference is the much stronger gradient system and the water cooling. Handling of strong gradients is what this manual in total is mainly about. The water cooling is described in *Water Cooling Set-up [▶ 141]*.

Table 11.1: DiffBB with WB Adapter at the Bottom

Gradient Direction:	z
Theoretical gradient sensitivity α:	285 mT/m/A
Typical gradient strength @ 60 A:	> 17 T/m
Peak-peak deviation from const. gradient in a cylinder of 5 mm diameter and 15 mm length:	< 5 %
Inductance (L):	≅ 180 µH
Resistance (R):	≅ 850 mΩ
Rise time 10 - 90 % of 60A, 120V using a GREAT60 amplifier:	≤ 300 ms
Slew rate at 1 V (αV/L):	ca. 1600 T/m/s
Cooling:	water
Maximum current tested:	60 A
Maximum pulse length at maximum current:	5 ms
Variable temperature range:	-40°C to 150°C

Table 11.2: DiffBB Specifications

11.2 Diff30, Diff60, Diff50, Micro5

The diff30, the diff60, and the micro5 probes consist of a probe body with exchangeable RF coils of different diameters and type.

The bodies and most of the RF inserts are identical for all of the 3 probes.

They only differ in the gradient system. These probes have 2 RF channels, which can be used in different ways depending on the RF insert mounted on the probe.

The X-channel normally has a low pass filter to reduce cross talk between the channels.

Table 11.3: Diff30 (left), diff60 (right) Probe

11.2.1 RF Inserts

There are two different types of RF inserts:

- Single-tuned
- Double-tuned

11.2.1.1 Single-Tuned Inserts

Saddle coil inserts with a diameter of 5 mm, 8 mm, and 10 mm are available. They can hold a ^{1}H or a ^{19}F coil on the ^{1}H-channel. Coils tunable from ^{1}H to ^{19}F can be built upon request. Usually the load range will be reduced in the tunable case.

Alternatively, fixed frequency X nucleus saddle coils with a diameter of 5 mm, 8 mm, and 10 mm are available for the X-channel. The range of possible nuclei is ^{31}P down to 40 MHz. Below 40 MHz modifications on the probe body might be necessary.

Additionally, EVT (extended variable temperature) 5 mm inserts are available. The handling of the EVT inserts is described separately in the section *Mechanical EVT Insert Handling [▷ 140]*.

Single tuned solenoids coils can also be built upon request.

11.2.1.2 Double-Tuned Inserts

Double tuned inserts with 2 crossed saddle coils can be built as direct inserts, i.e. X on the inner coil and ^{1}H or ^{19}F on the outer coil, or as inverse inserts, i.e. 1H on the inner coil X on the outer. The X range is the same as described above.

^{1}H - ^{19}F double tuned coils are also possible, but need a modification of the probe body.

11.2.2 Diff30L, diff60L

Direct or inverse double-tuned probes with an additional lock channel are also available. These probes have fixed frequencies, no exchangeable inserts. The frequency ranges are the same as above.

11.2.3 Gradient Systems

The gradient system specifications are shown in the following table:

Gradient system	diff30	Diff50	diff60	micro5
Part number	M81113	W122305	M81163	M81111
Gradients	z	Z	z	x, y, z
Gradient sensitivity [mT/Am] ([G/Acm])	300 (30)	500 (50)	600 (60)	50 (5)
ID/OD	19/40 mm	19/72	19/72	19/40
Usable volume diameter / length [mm / mm] (nonlinearity < 3% peak-peak)	10 / 15	10 / 15	10 / 15	10 / 18
Inductance [µH]	250	540	1000	10 - 20
Resistance [mΩ]	1000	830	1500	120
Rise time [µs] from 10% to 90% of 40 A @ 120 V	< 200	< 500	< 800	< 50
Usable ring-down time [µs] @ current [A]	500 @ 60	500 @ 50	1200 @ 50	100 @ 60
Maximum current tested [A]	60	60	50	60
Expected gradient calibration constant [G/mm] @ Gain [A] [a]	120 @ 40 180 @ 60	200 @ 40 300 @ 60	240 @ 40 300 @ 50 [b]	20 @ 40 30 @ 60
Maximum average power (R*I2) [W]	40	85	40	35
Loop parameter R [c]	12.5	1.0	1.0	50.2
Loop parameter C [c]	30.0	27.0	30.0	5.0
[a] The gain of the GREAT amplifiers is defined by the current at maximum input. [b] Maximum possible current using GREAT1/60 amplifiers. [c] The loop parameters are start values and must be checked, particularly for the diff60				

Table 11.4: **Gradient Specifications**

11.2.4 Handling of the Diff30, Diff60, Micro5 Probes

Take extreme care when changing inserts, they are fragile.

11.2.4.1 Removal of the Gradient Coils from the Probe Body

- Remove the cooling water using forced air, before disconnecting the gradient coil system from the probe body.
- Unscrew the coupling nut (counter clockwise looking from the bottom of the probe), see also *Mounting the Gradient Coils [▶ 139]*. Hold the probe at the gradient system while unscrewing.
- Carefully detach the gradient from the probe body by using a screwdriver as shown in *Removal of the Gradient Coils from the Probe Body [▶ 137]*.

- Remove the gradient system completely without tilting it, otherwise the glass on the RF insert will break!

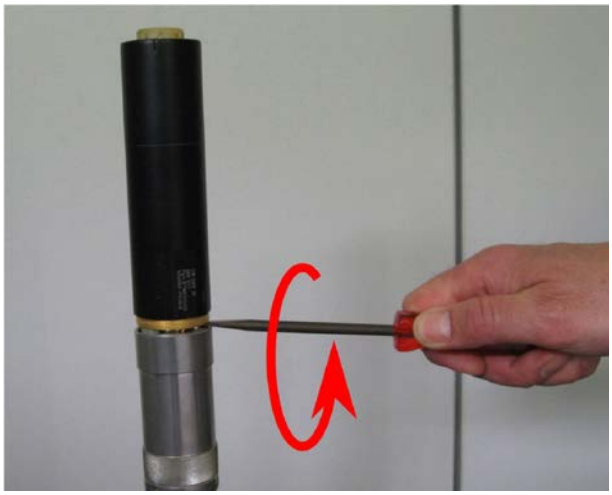


Figure 11.1: Gradient Coil Removal

11.2.4.2 Exchanging Saddle Coil RF Inserts

After the removal of the gradient system, the RF insert can be pulled off. Another insert can be plugged onto the socket on the probe.

Check the orientation, the insert fits in only one position. No force is required.

11.2.4.3 Mounting Solenoid Coils

Solenoid coils must be fixed by a screw. This is accomplished by removing the ground pin and using this thread for fixing:

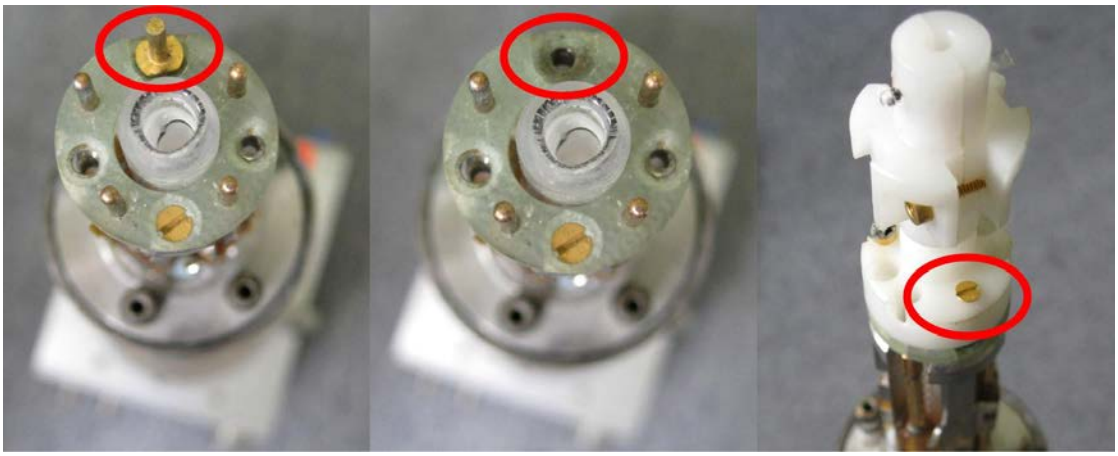


Figure 11.2: Mounting of a Solenoid Coil

11.2.4.4 Mounting the Gradient Coils

⚠ CAUTION

Equipment or personal damage from glass breakage.

Tilting the gradient system while pushing it over the RF insert may lead to glass breakage and bending of the connectors.

▶ Do not tilt the gradient system while pushing it over the RF insert.

- Make sure no water drops from the gradient cooling interfere into the electronics of the probe body. Remove any water drops with a tissue or a fan.
- Push the gradient coil system carefully over the RF inserts.
- Screw the coupling nut on (clockwise looking from the bottom of the probe). The gradient system fixes the glass type RF inserts on the probe body. Do not use too much force to fix the ring:

Figure 11.3: Mounting the Gradient System

11.2.5 Mechanical EVT Insert Handling

The mechanical installation of the EVT inserts is quite simple, however a few points must be carefully checked in order to ensure the correct sealing of the gas channel. This is both important for the correct variable temperature operation and for the protection of the gradient system, especially in the case of high temperatures.

- First check whether a sealing ring is present at the bottom of the insert. This can be either a silicon rubber or a Teflon ring:

Figure 11.4: Bottom View Showing Silicon Rubber Sealing

- Place the insert on top of the probe body, only one position is possible, for details check *Handling of the Diff30, Diff60, Micro5 Probes [▶ 137]*.
- Without applying any additional force, ensure that there is a gap of about 1 mm between the insert bottom and the probe body (see figure below). If the gap is too small a thicker silicon rubber ring must be installed. Use 2 rings if necessary, but at least one of them must be silicon rubber.

Figure 11.5: Bottom Gap

- Set the gradient onto the gradient system. After fixing it, there must be no gap at the top between the upper end of the insert, and the greenish epoxy ring on top of the gradient system, no copper must be visible:

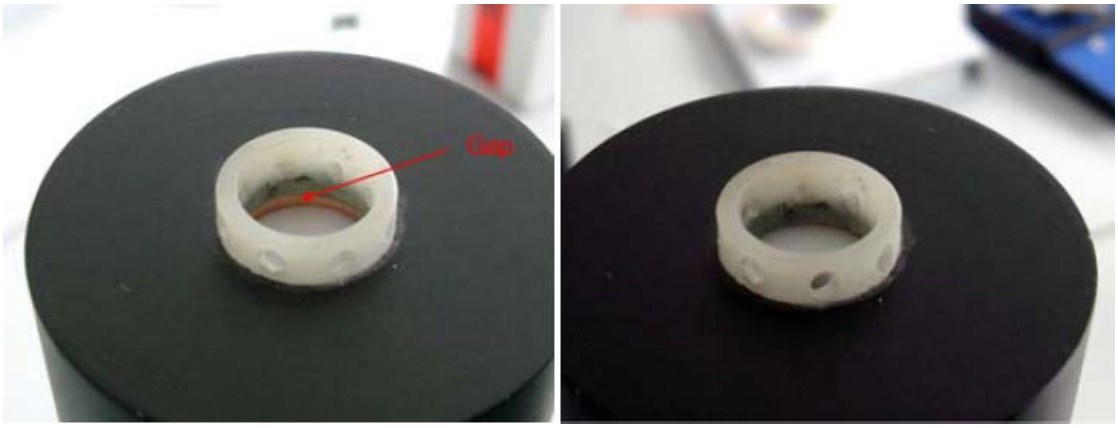


Figure 11.6: Top View with (left) and without (right) Gap

- If a gap shows up at this point, this can usually be corrected by increasing the gap at the bottom.

  The gap at the bottom should not exceed 2 mm, this would cause too large of a thermal bridge. If bigger gaps seem to be required, use a Teflon ring on the top of the insert in order to compensate for it.

11.3 Water Cooling Set-up

Never run a diff30, diff60, or micro5 probe without water cooling! DiffBB and diff50 probes can be run with air cooling using a maximum of 10 A, usually by using a GREAT3/10 amplifier.

- Connect the water cooling to the probe before putting the probe into the magnet.
- Start the BCU20 and set the 3 way valve to *flow*.
- Wait a couple of minutes, then check, whether the wheel on the front of the BCU20 is spinning. If not, most likely the filter is blocked (see *Cooling Unit BCU20 (W1210722) [▶ 152]*).

On newer systems the gradient generation is automatically interrupted when the water is not flowing. On older systems the operator has to monitor this.

- The next step is to remove air bubbles from the gradient system. This is done by putting the probe upside down and back a few times.
- After this the probe can be installed in the magnet as usual.

Note: DiffBB and diff50 probes can be inserted into the magnet before the water is connected, they do not hold air bubbles.

12 Imaging and Diffusion Hardware

The AVANCE III compatible micro-imaging system is based on 3 Great gradient amplifiers (Great1/40 or Great1/60), a Master Unit (BGMUI-E), and optionally a B0 compensation unit (B0-2). The components are installed in a single bay stainless steel rack, called the imaging rack.

Additionally, all micro-imaging systems are equipped with a DPP board (Digital Pre-emphasis H12513F1), which modifies the gradient shapes by numerically adding pre-emphasis terms to compensate for eddy currents. This DPP board is located inside the IPSO 19" rack, connected to the systems internal PCI bus and to the gradient controller.

12.1 Master Unit BGMUI-E (W1522066)

The Master Unit BGMUI-E is a dedicated unit to interface the Great 1/40 or Great 1/60 amplifiers to the AVANCE III system. In addition to the main function of distributing the digital signals to the Great amplifiers, the Master Unit contains a PT100 temperature and an external enable security feature. A DSP based feedback structure is implemented which allows calculation of the applied power rate and comparison with maximum values for coil protection.

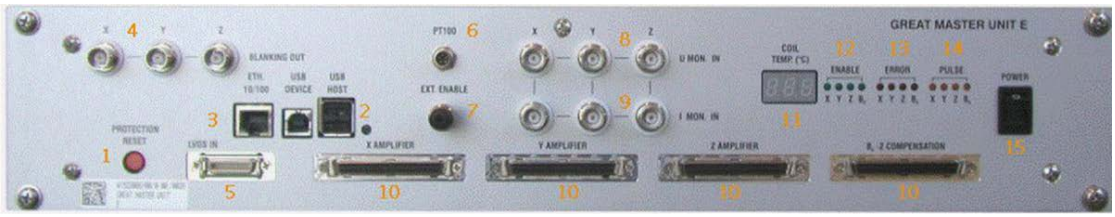


Figure 12.1: Master Unit BGMUI-E Front Panel

The Master Unit must be the last device which is switched on in the imaging rack, since it detects the connected amplifiers only during the boot process. During the boot process, the Master Unit will stop with a *C01* message in the 7 segment LED display, whereas in normal operation mode the LEDs show the coils PT100 temperature (11). The error message *C01* means, that safety parameters for the coil protection need to be loaded. Refer to chapter *Gradient Safety Parameters (AVANCE III only) [▶ 132]* for details about this procedure.

The LED display is also used for numerous error messages, which are indicated as *Exx*, where *xx* is an error code that can be found in the Web interface of the unit (accessible by the **ha** command in TopSpin). If the source for the error message is eliminated, the unit can be reset to normal operation mode by pressing the red reset button (1).

12.1.1 Master Unit In/Out Data Connection

The Master Unit can be connected either to a DPP (Digital Pre-emphasis board) or directly to the GCtrl (gradient controller) of the IPSO board via LVDS (48 bit wide and 80 MHz bus clock) (5). The maximum allowed cable length for this connection is 5 m. The internal logic distributes the incoming digital signals to the desired gradient/B0 output connectors (10), where the Great amplifiers or B0-2 compensation unit can be directly connected. The communication between the Master Unit and the mentioned amplifiers is via an unidirectional parallel bus for the gradient shape data, and a bidirectional I2C bus for the communication between the units.

The Master Unit can be controlled via the Web interface. Thus the unit is connected directly to the systems Ethernet switch (3) to allow any browser to access the service pages, e.g. for firmware updates.

12.1.2 Security Features

The Master Unit includes 3 security features:

- A PT100 temperature check.
- A check of the external enable signal e.g. from the gradient cooling water chiller.
- A DSP based power calculation.

A PT100 can be connected directly to the PT100 connector (6). If the PT100 shows a resistance which indicates a temperature below 5°C (101.95) or above 50°C (119.4), the Master Unit will switch the Great60 amplifiers off. Valid temperatures for the Great operation are between 5°C and 50°C. The PT100 is measured in 4-wire mode, to eliminate cable resistances. This guarantees an accuracy of +/- 1°C from the actual value.

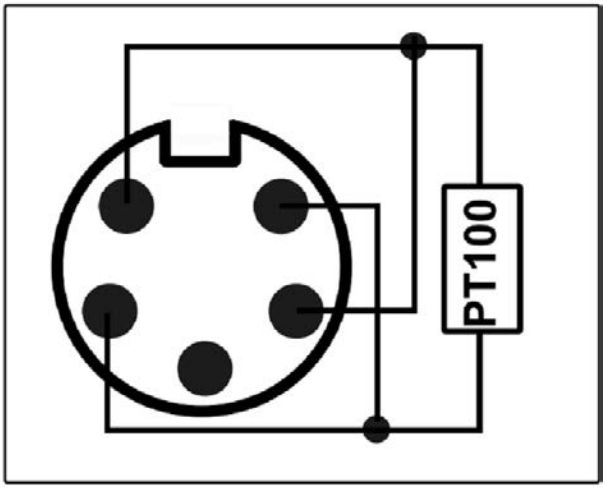


Figure 12.2: Pin Layout of the Pt100 Connector

The external enable connector (7) is used to check the current state of the BCU20 cooling unit. In case the BCU20 is switched off, or no water is flowing, the BCU20 opens a short between 2 pins. This is detected at the Master Unit by the external enable connector. If the short is missing, the Master Unit switches the Great amplifiers off.

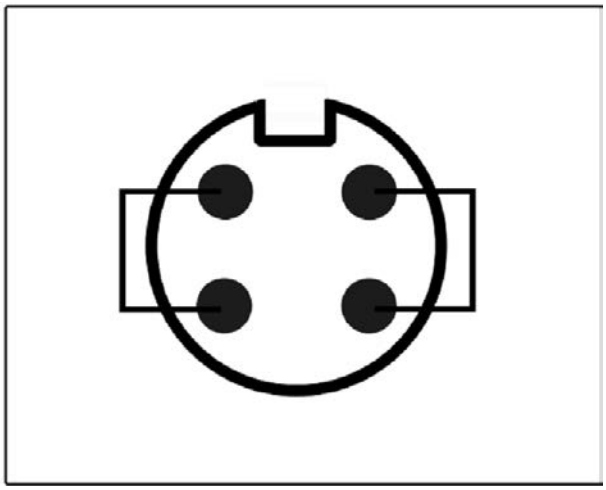


Figure 12.3: Pin Layout of the External Enable Connector

The DSP security feature uses the 6 analog monitor output signals of the Great amplifiers to calculate the power dissipation in the gradient coil on the fly. From each amplifier the current signal and the voltage signal are fed back to the *U mon* (8) and *I mon* (9) input connectors of the Master Unit. A 10V U-monitor voltage corresponds to the maximum voltage (100V for the Great1/40 and Great1/60), a 10V I-monitor voltage to the maximum current (40A for Great1/40, 60A for Great1/60). The analog signal is AD-converted within a 25 µsec dwell time, and the power applied to each individual gradient coil is calculated by the formula:

$$\frac{1}{T}\int_{T} R_{ch} \cdot i_{ch}^{2}(t)dt < P_{\lim_{ch}}$$

Figure 12.4: Equation 1

R_{ch} is the DC-resistance (stored in the safety parameters in *setpre*) of the gradient coil, i_{ch} is the current detected by the *I-mon* input and T is the time in which the energy is integrated. $P_{lim\text{-}ch}$ is the maximum power value, which is specific for each channel of each gradient system. On triple axis gradient coils, the power sum of all 3 channels must be less than 3 times the maximum power for one channel.

$$\frac{1}{T}\sum_{ch=x,y,z}\int_{T} R_{ch} \cdot i_{ch}^{2}(t)dt < P_{tot}$$

Figure 12.5: Equation 2

The Master Unit checks the power on 2 different time bases. One time base is fixed to 1 sec, which checks for the average power applied to the gradient coil. Another time base is configurable between 25 µsec and 1sec and is mandatory to detect short (msec range) gradient pulses with high currents, which might burn the coil in <<1 sec. See chapter *Gradient Systems [▶ 137]* for typical values for different coils.

12.1.3 Blanking Pulses

The Master Unit BGMUI-E delivers 3 blanking output signals (4), which can be directly connected to the gating input of the Great1/40 and Great1/60 amplifiers. The blanking pulses are TTL level, TTL-low (0V) forces the amplifiers to switch on (unblank) its output, TTL-high (5V) disables (blank) the amplifiers output.

The blanking output of the BGMUI-E is *soft-blanking*. In contrast to the *hard-blanking* which was used in previous imaging systems, the *soft-blanking* takes care of residual amplifier output currents. The blanking is switched off by a command in the pulse program (see *Gradient Amplifier Blanking Modes [▶ 157]*), and stays off until a second command is executed in the pulse program and until the digital input signal to the individual Great amplifier is 0. As a result, the blanking takes care of pre-emphasis adjustments and keeps the Great output enabled, until the added pre-emphasis terms are fully decayed. The previously used 'hard-blanking' switched off the Great output immediately when the particular command was executed in the pulse program without taking care of any residual currents.

12.1.4 Control LEDs

The Master Unit has 3 LED groups (12, 13, 14), which show the status of the connected amplifiers. If an *Error* LED is illuminated, the connected amplifier is switched off because of an error or because it is not initialized. If the amplifiers are fully operable, the *Enable* LED is switched on. If an amplifier delivers a current, the *Pulse* LED shows this by flickering. The pulse LED is only switched on for currents >3% of the maximum amplifier current, for lower currents the LED stays off. A 2nd mode can be selected in the Master Units Web interface which displays digital input data at the Master Unit LVDS input instead of the amplifier output current. If a B0-2 compensation unit is connected to the Master Unit and the *Field* value of the BSMS-2 is not 0, the B0 *Enable* LED is always on, since the B0-2 unit has to deliver a DC current.

12.2 Great 1/40 (W1211690 or W1215322) and Great 1/60 (W1209612 or W1215323)

The Great1/40 and Great1/60 are current regulated amplifiers that provide the gradient current to the gradient coils at dedicated times. Both amplifiers are basically identical, the only difference is the maximum output current, which is 40A for a Great1/40 and 60A for a Great1/60. The signal input of the amplifiers is digital. The digital to analog converter is located inside the amplifiers to avoid ground loops from not ideal analog cable wiring.

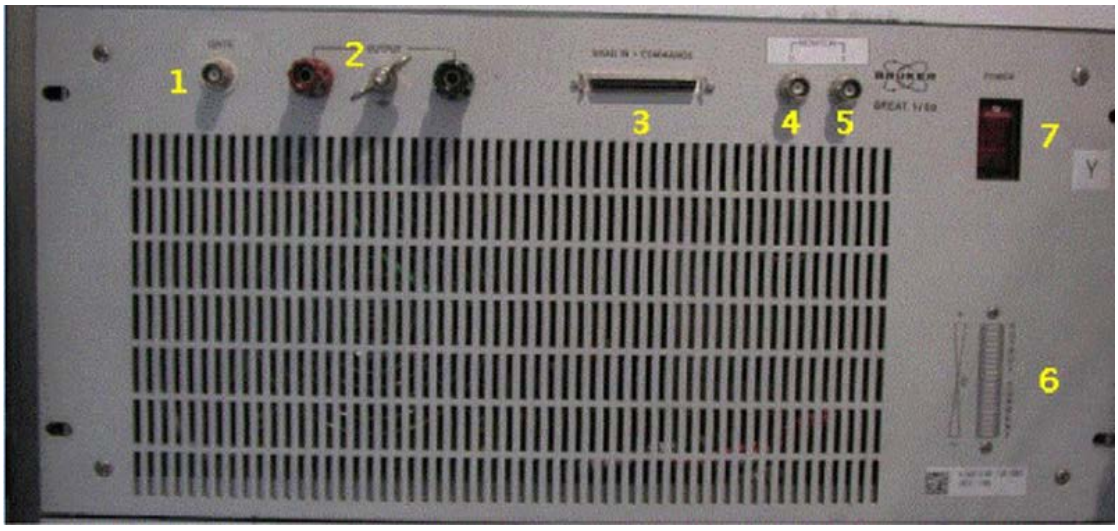


Figure 12.6: Great Amplifier Front View

12.2.1 Gate Input; Blanking

The Gate input (1) of the Great amplifiers enables an external signal to enable or disable the output of the Great amplifier. In case the output is disabled, the amplifier output is disconnected from the gradient coil, so that no amplifier noise is introduced to the sample spin system. The gate pulse must be TTL level, where TTL-LOW enables the amplifier output and TTL-HIGH disables the output. If nothing is connected to this input, the amplifier is always enabled.

The gating pulse is delivered by default from the BGMUI-E Master Unit (output 4 of the Master Unit) or alternatively from the IPSO T0 connector (see *Trigger Signals (in and out) at the T0 Connector [▶ 161]*).

12.2.2 Data Input

The Data input (3) is directly connected to the Master Unit. The gradient data are delivered parallel, whereas the bidirectional communication between the Master Unit and Great amplifier is handled by an I2C bus. Both communication protocols can be found on the Data Input connector and are distributed via a single cable (HZ10202).

12.2.3 Signal Output

The gradient coil current is provided at the red and black clamps (2). Typically, the gradient filter cable with ring cable lugs is connected to the output clamps, which lead to the gradient filter. The output can have a maximum of 100V/40A at the Great1/40, or 100V/60A at the Great1/60.

Be sure to switch off (7) the amplifier before manipulating the output clamps or the connected cables.

12.2.4 Monitor Output

Both Great amplifiers have a monitor output for the output current, labelled *Monitor I* (5) and a monitor output for the output voltage, labelled *Monitor U*. Both can be used to control the output current on an oscilloscope, e.g. to adapt the amplifiers regulator to the connected load.

The scaling for the outputs is 1V/10V for the voltage monitor of both Great amplifiers and 1V/4A at the current monitor output of the Great1/40, and 1V/6A at the current monitor output of the Great1/60. The maximum monitor voltage is 10V on each monitor output. If an externally connected device, such as an oscilloscope or a voltage meter is not ground free, it can lead to ground loops which heavily disturb the output stability of the amplifier and thus the NMR signal.

During routine work, these monitor outputs have to be connected to the *U mon* and *I mon* inputs of the BGMUI-E Master Unit. The Master Unit can only calculate the power dissipation to the gradient coils and protect them from over power when this connection is established.

12.2.5 LED Bar

The LED bar on the bottom right of the figure in *Great 1/40 (W1211690 or W1215322) and Great 1/60 (W1209612 or W1215323) [▶ 146]* (6) is an easy way to control the output current during an experiment. The bar shows the output current of the amplifier in 10% steps, so currents below 10% cannot be seen, but for typical experiments the resolution is sufficient.

12.2.6 Fuses

The Great amplifier itself has 2 different fuses, the line fuse and the power supply fuse.

The *line fuse* is located directly in the housing of the mains adapter. If this fuse is blown, nothing on the amplifier will work anymore, even the illumination of the mains switch. After removal of the mains connector, a little insert can be pulled out of the mains plug (#1 in the figure below) with the help of a small screwdriver. The fuses are 20 mm x 5 mm in size and have values of 6.3 A (Great 1/40) or 10A (Great 1/60).

If the mains switch illumination is still working but nothing else on the amplifier, the *power supply output fuses* might be blown. These fuses are located below or to the right of the mains connector (depends on the hardware revision, see #2 in the figure below). There are 2 separate fuse housings that can be opened manually, or with the help of a screwdriver, which contain fuses 32 mm x 6 mm in size with a value of 20A.

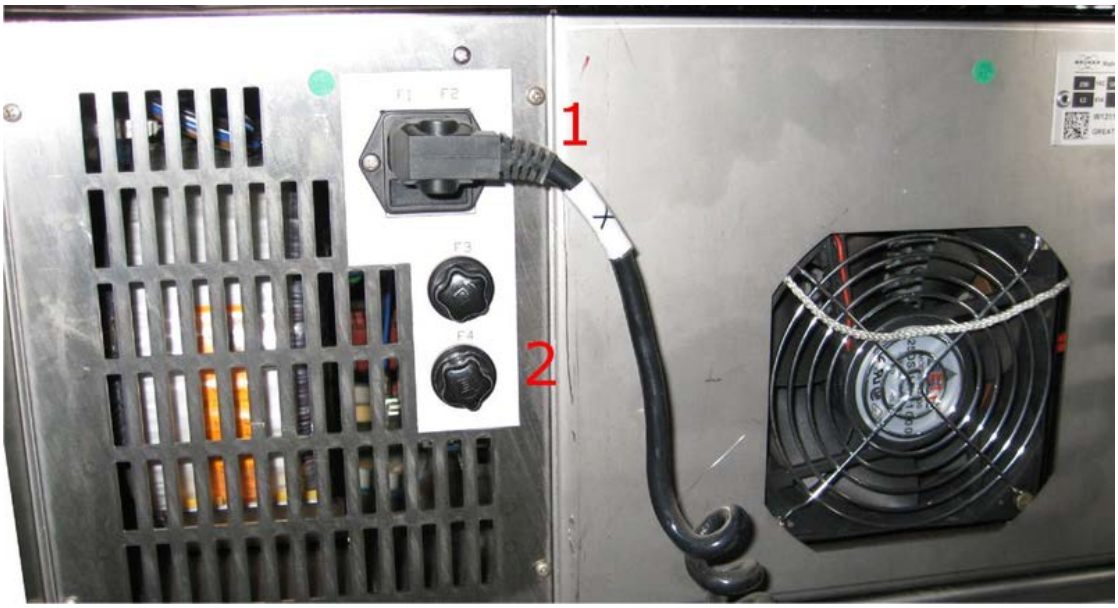


Figure 12.7: Back Side View of the Great Amplifier Showing the Location of the Fuses

12.3 B0-2 Compensation Unit (W1214106)

The B0-2 compensation unit is the 4th amplifier, which can be connected to the Master Unit. A B0-2 compensation unit is required to compensate for 0th order field distortions caused by gradient switching of not ideally shielded gradient systems. In this case, a current is introduced in the surrounding conductive material, which leads to a shift in the B0 field and thus in the behavior of the samples spin system. To eliminate these effects, a current which causes an opposite field shift, is introduced to the field coil of the shim system. This coil is typically used to control the field stability (Lock), to shift the field by a static value, or by the automatic drift compensation.

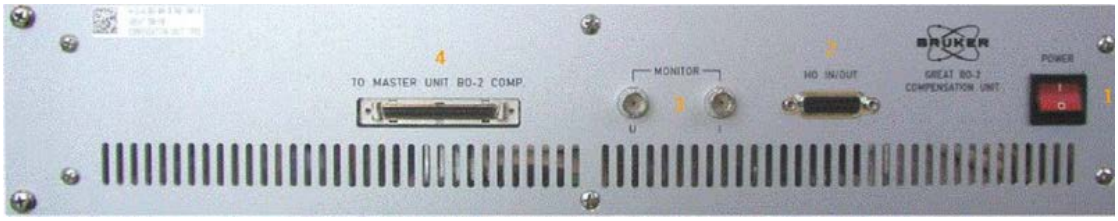


Figure 12.8: Front Plate of the B0-2 Compensation Unit

12.3.1 Digital Data Input

The digital data is handled via the connector *To Master Unit B0-2 Comp* (4). The communication between the B0-2 unit and the Master Unit BGMUI-E is via an unidirectional parallel bus for the B0 compensation current data and a bidirectional I2C bus for the communication between these units. The digital input data for the B0 current is already fully calculated including all direct and cross terms by the DPP. This means, as opposed to the Great gradient amplifiers, that the B0-2 unit will not work without a DPP in the ISPO (if the Master Unit is directly connected to the GCtrl).

12.3.2 Analog Signal Input/Output

The analog B0 current is provided by the *H0 Output* (4) connector. Through this connector the B0-2 unit is directly connected to the *Field* coil of the BOSS shim system. The BOSS shim system is used by the BSMS to stabilize the magnetic field (Lock), to shift the field by a static value and for the automatic drift compensation. Since the BSMS-2 functionality must still be operable, the output signal from the BSMS-2 (ELCB board) is feed into the B0-2 compensation unit through connector (4), and added to the B0 compensation terms. The output signal of the B0-2 unit is then the B0 compensation and BSMS-2 output, which includes all the required signals. Since this is an active summation with analog devices, the B0-2 unit might introduce a bit of noise to the BSMS-2 signals.

When the B0-2 compensation unit is switched off, an internal relay is set in a way that the BSMS-2 signals are passed passively through the unit, without any modification and without any additional noise or hum.

The maximum output voltage of the B0-2 compensation unit is of 100V, and the maximum output current is 200 mA.

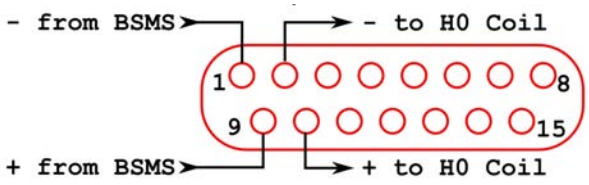


Figure 12.9: Pin Layout of the Analog Input/Output Connector at the B0-2 Front Plate

12.3.3 Monitor Output

The analog monitor outputs (3) of the B0-2 unit can be used to check the field coil current since it shows the sum of the BSMS-2 output current plus the B0 compensation terms. The ratio is 1V/10V of the voltage monitor and 1V/20 mA on the current monitor. During the routine work, these connectors are not connected and it has to be taken care that no grounded devices are connected to them, since they can create ground loops.

12.3.4 Link to the BSMS-2

To connect the B0-2 unit to an existing BSMS-2/BOSS system, an adaptor board with part number Z108181 is required. This board is mounted on the right most SCB20 board in the BSMS-2 between the output of the board and the cable leading to the shim system.

Figure 12.10: BSMS-2 to B0-2 Adaptor Board, Mounted on the Most Right SCB20 Module

It is basically a 1-1 connection of the shim connections, but the connection going to the field coil is cut and wired to the connector on the lower part of the adapter board.

A cable (HZ12200) is connected from the adaptor board connector to the analog signal input/output of the B0-2 unit. This connector provides the *Field* output current to the BSMS-2. This field current reaches the B0-2 unit via the cable, is summed up with the B0 current or shifted through, and then returned via the cable to the BSMS-2 adaptor board, where it is directly connected to the field coil of the BOSS shim system. As a result, if the adaptor board is installed, but no cable to the B0-2 unit, the field coil is not connected to the BSMS-2. In this case no lock, field shift, or field drift compensation is active.

12.3.4.1 Gradient Filter (W1212109)

The gradient filter is integrated in the gradient cable, which is connected between the Great outputs and the gradient coil. Its basic function is to eliminate high frequency distortion, which can be introduced to the gradient cable itself. Additionally, the filter has some standard fuses included, to protect the gradient coil from any gradient amplifier failure or programmer errors. The fuses are accessible after removal of a little metal cover, fixed by 4 screws. There are 5 fuses in the filter box, where only fuse 1, 3, and 5 are in the gradient lines and fuses 2, and 4 are spare parts. Each fuse has a value of 15A.

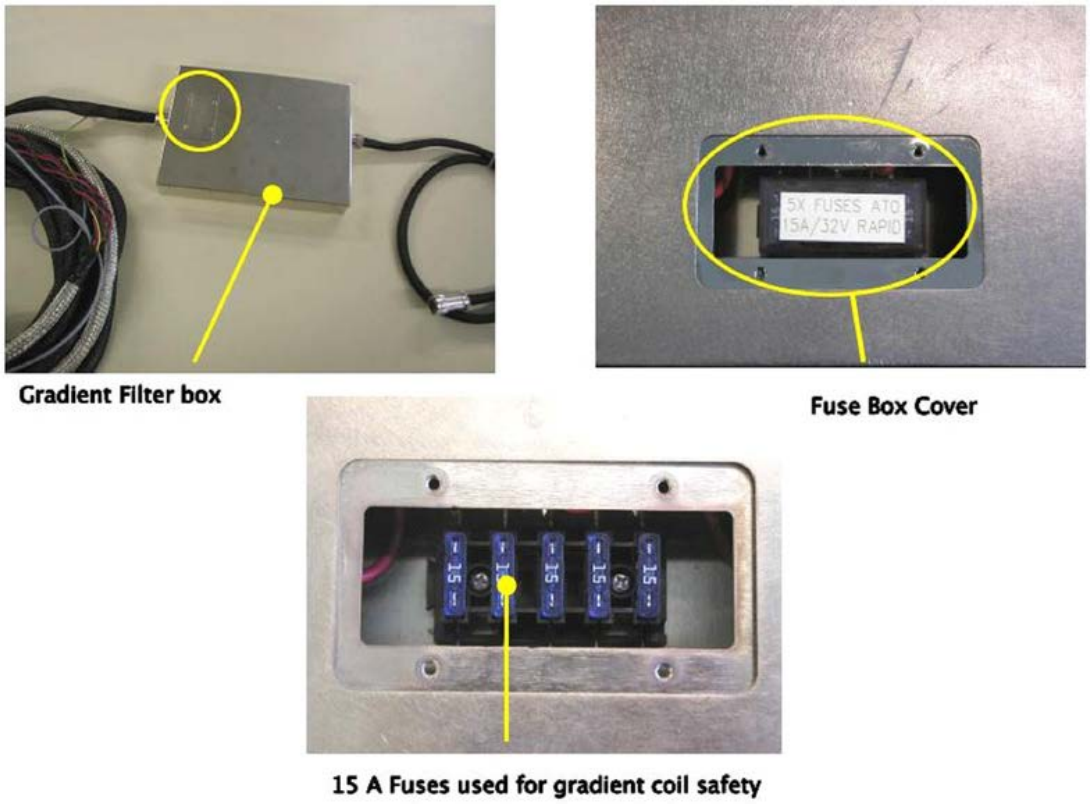


Figure 12.11: Gradient Filter and Fuses

Since the gradient filter is used to remove high frequency noise from the gradient cables, ground conditions are important. The filter must have a good ground connection to the gradient body. This is established on new gradient bodies, but on older bodies the connection might be missing. To check this, the probe body can be controlled. There must be a pin in position G of the Burndy gradient connector, which leads to a ring cable lug connected to the metal of the probe base. If this connection is missing, it has to be established to provide full shielding performance.

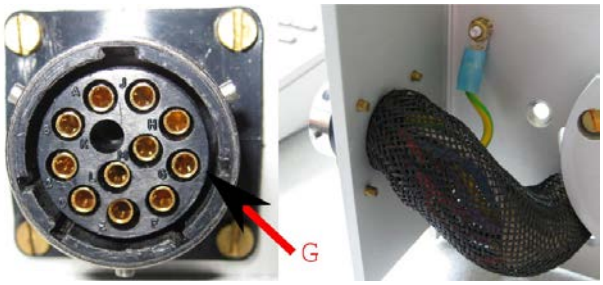
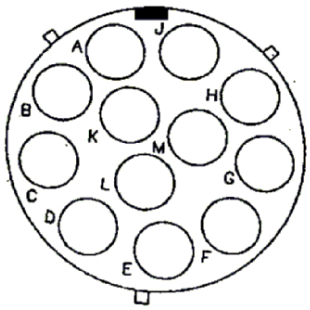


Figure 12.12: Location of Pin G at the Probe Base Connector (left) and Grounding of the Pin (right)

For AVANCE III systems, filter cables with part number W1212109 and ECL2 have to be used. If a lower ECL or a different filter cable exists, it needs to be upgraded. By using filter cables with part number W1212109/ECL2, 2-wire and 4-wire gradient probe bodies can be driven by the AVANCE III imaging rack.



Burndy Connector	Signal
C	+X Gradient
D	-X Gradient
E	+Y Gradient
F	-Y Gradient
A	+Z Gradient
B	-Z Gradient
L	PT100 Current
M	PT100 Current
H	PT100 Sense
J	PT100 Sense
G	Ground

Figure 12.13: Pin Layout of the 12 Pin Burndy Connector (front view of the plug at the probe base)

12.4 Cooling Unit BCU20 (W1210722)

The standard cooling unit for the water cooled micro-imaging and diffusion gradient systems is called BCU20. The BCU20 is a closed loop chiller unit, with a water volume of about 3.5 liters which can actively heat and cool the water with a power of approx. 250 W. Thus the water temperature can be set to values between 5 and 50 °C at standard flow rates of up to 1litre/min. at 0.35 bar.

In addition to this basic functionality, the BCU20 provides more features such as:

- A 3-way valve to blow out the water of the gradient before removal.
- Manual and software controlled temperature control.
- A flow control.
- A water filter and noise optimized air-bubble free operation.

The figure below shows the schematic of the cooler.

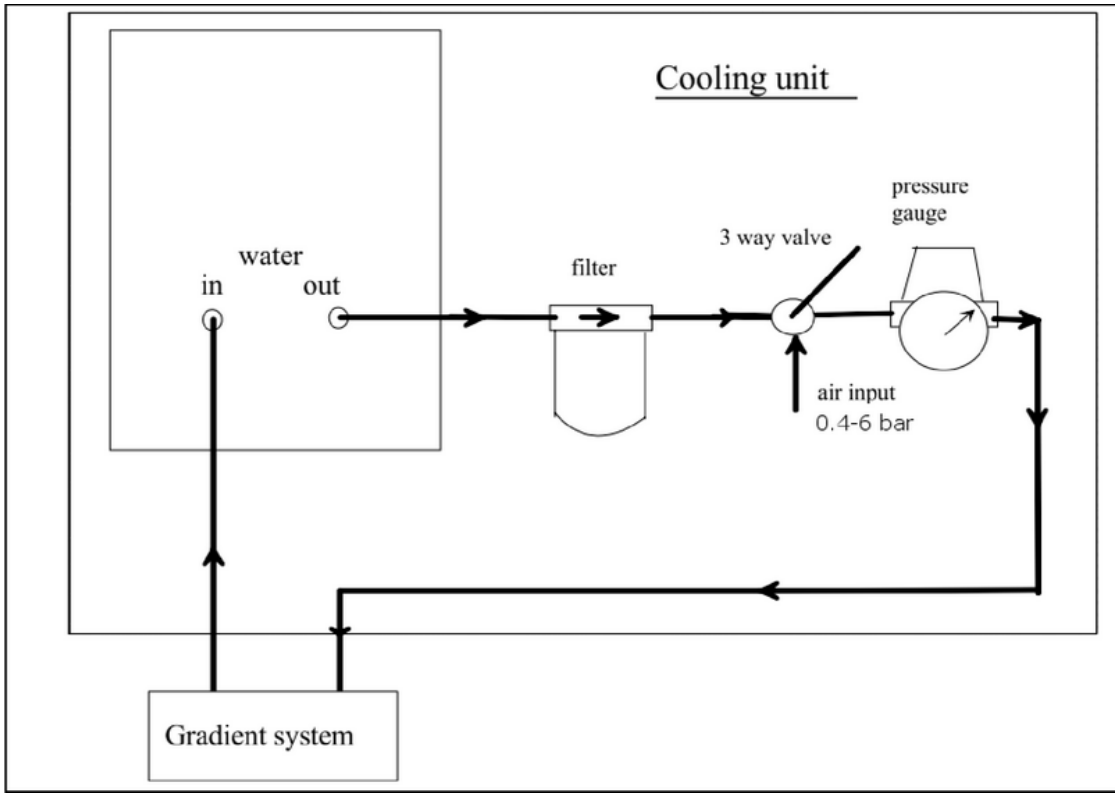


Figure 12.14: BCU20 Schematic Diagram

12.4.1 Installation of the BCU20

During the installation of the BCU20, the flow needs to be adjusted to its maximum. This must be done by opening the top cover of the BCU20 and screwing down the flow needle as far as possible. At the same time, distilled water can be filled in until the level reaches the maximum mark. A water conditioner should be used to prevent the growth of algae. The recommended concentration is 0.5 ml water conditioner (Art. 9025.1 ROTH) for 3.5 liters of water.

12.4.1.1 Hose and Cable Connections

Various cables and hoses need to be connected to the backside of the BCU20. The rest of this section will discuss this in detail. The numbers listed in the text, refer to the following figure.

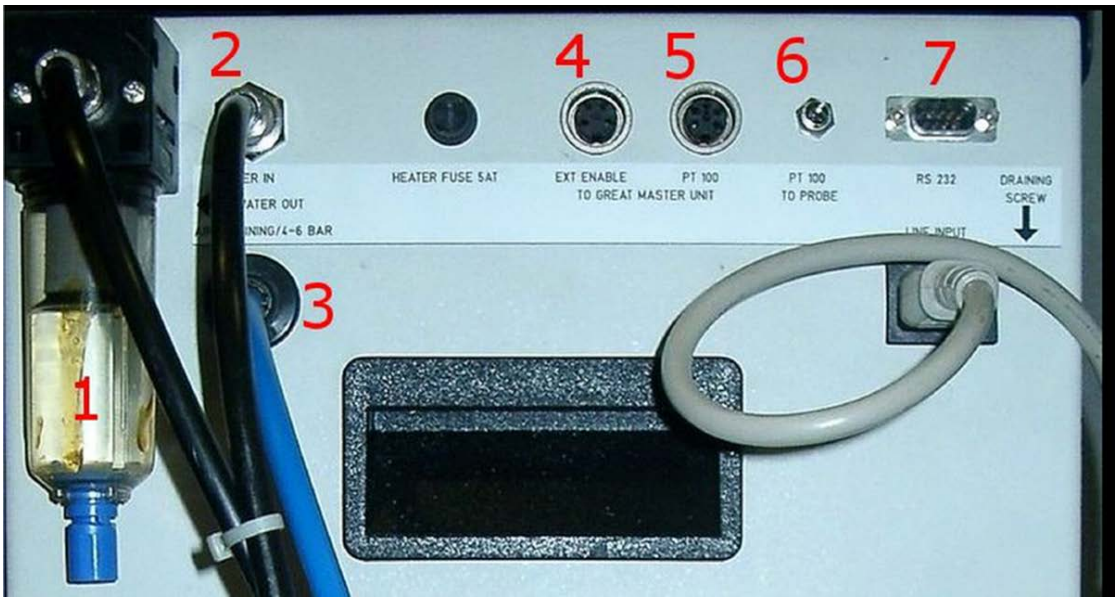


Figure 12.15: Backside View of the BCU20

The *water and air hoses* are connected to the rear of the BCU20, on the left side, as shown in the figure above. The cooling water output is equipped with a filter (1), which prevents small particles from entering the gradient coil. Over time they may block the water flow and thus destroy the gradient coil. For this reason the filter element needs to be checked from time to time and, if its color of the exchangeable filter element is no longer white, it has to be replaced.

The 8 mm water hose leads from this filter to the gradient coil and from there another 8 mm hose returns to the *Water In* (2) connector providing a closed loop system.

Below the *Water In* connector is the *Draining* connector (3) which is connected to the system‘s compressed air or nitrogen supply. This enables water to be blown out from the gradient coil before it is disconnected from the chiller unit.

The *Ext. Enable* connector (4) is connected to the Master Unit. The BCU20 delivers a continuous signal to the Master Unit through this cable, when the BCU20 is fully operational. When the water level becomes too low, the BCU20 stops the water flow and sounds an alarm. Whenever the water flow stops, the BCU20 no longer delivers the enable signal, and the Master Unit switches off the amplifiers to protect the gradient coil from overheating.

The PT100 of the gradient coil is directly connected to the BCU20 via the *PT100 to Probe* connector (6). Since its cable is in the gradient filter cable, the connection has to be established by an extension cable from the imaging rack to the BCU20. As a consequence, the BCU20 receives the temperature information from the gradient coil and has to remit it to the Master Unit.

The *PT100 to Great Master Unit* (5) is the connection for the PT100 signal to the Master Unit. Since the PT100 thermo-resistor of the gradient probe is not directly connected to the Master Unit, a connection is needed that transfers a signal indicating whether the unit is operating within a temperature range of 5 to 50°C, which is required to enable the Great amplifiers. This signal is provided through the output connector (5).

The BCU20 has a serial connection via the *RS232* connector (7) to the IPSO unit. This enables the BCU20 temperature to be set and controlled through software using the TopSpin command **edtg**. The command **edtg** behaves identical to the BVT control program **edte**, for which a manual can be found under TopSpin help. The TTY configuration information (default is TTY04) has to be entered during **cf**.

12.4.2 Operation of the BCU20

During normal operation the BCU20 must only be switched on and runs without any user interaction. Prior to this a few settings have to be checked or set. The following section describes these settings, for the location of the parts refer to the following figure:

Figure 12.16: BCU20 Top View with Opened Cover

It is critical that the *3-way valve* (2) is set to flow during gradient operation. This position lets the cooling water flow through the gradient coil. In case the gradient coil needs to be disconnected, the water can be blown out of the coil by switching the valve to *Draining*. After a few seconds air bubbles in the *water reservoir* (3) can be observed. This is an indication that the gradient and the water hoses are empty. The 3 way valve can be rotated by 90 degrees (pointing downward in the figure above), in this position the output is disabled and the gradient coil can be removed.

The BCU20 can regulate the temperature in 2 different ways:

- The BCU20 uses its internal PT100 to regulate the temperature of the water in the water reservoir. In this case the switch (4) has to be set to *PT100 BCU20*. In this operation mode, the water may heat up or cool down during the flow to the gradient coil, so the gradient coil may indicate a slightly different water temperature. The PT100 of the gradient coil is looped through the BCU20 to the Master Unit in this mode, so the real gradient coil temperature can be read at the Master Units temperature display. This is the default mode for imaging, since it is often helpful to control the gradients temperature in high duty cycle experiments.
- The BCU20 uses the PT100 of the gradient coil to regulate the temperature of the water. In this case switch (4) has to be set to *PT100 Probe*. In this mode, the BCU20s regulator regulates the temperature of the gradient coil, so the water itself can have a different temperature. The coil, however, should have exactly the set temperature. The temperature of the gradient coil is visible in the upper line of the Eurotherm temperature regulator unit (1, in the figure below) on the front of the BCU20. The temperature value which is forwarded to the Master Unit is only a dummy value (due to technical reasons). Thus the Master Unit only shows a temperature values between 5 to 50°C, which is not related to the real gradient coil temperature. This operation mode is the default mode for diffusion applications, since the temperature of the gradient coil (and much more important the temperature of the sample) is a critical parameter for precise measurements.

Figure 12.17: Front View of the BCU20

The above mentioned temperatures can be set manually at the Eurotherm (1) with the up and down arrows, or can be computer controlled by the **edtg** program in TopSpin. The set temperature is displayed in the lower line of the Eurotherm. The upper line shows the temperature of the water in the reservoir (PT100-BCU20) or the temperature of the gradient coil (PT100-Probe).

12.5 The Imaging Accessory Wiring

The imaging rack is internally wired, so there should be no need to change any wiring. Externally there are up to 7 cables that need to be connected, they will be discussed in this section.

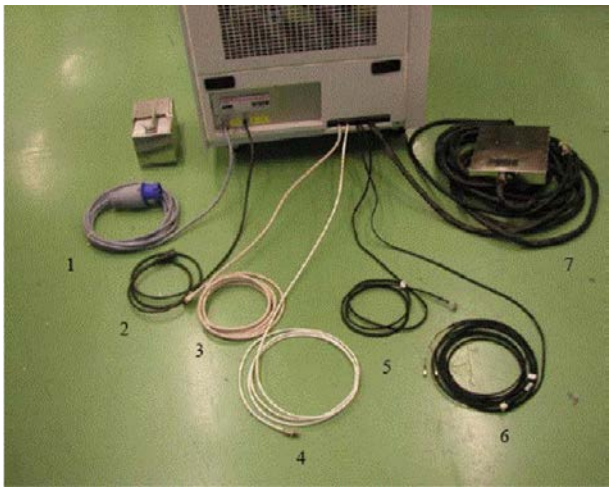


Figure 12.18: External Imaging Rack Cables

1. Insert the mains plug (1) into a 240V/32A outlet.
2. Plug the control cable (2) to the backside of the console. This cable switches off the rack when the console is switched off.
3. Connect the LVDS-in cable (3) to the DPP-Out connector of the DPP board.
4. Connect the Ethernet connection (4) to the switch.
5. If available, connect the B0-Out cable to the BSMS-2 adapter board, typically on the right side of the SCB20 board in the BSMS-2.

6. If required (typically not with AVANCE III systems), the external blanking cable (6) can be plugged into the T0 interface of the IPSO board.
7. The gradient filter (7) is connected between the imaging rack and the gradient coil.

For the full wiring of the imaging rack, including the BCU20 refer to the following illustration:

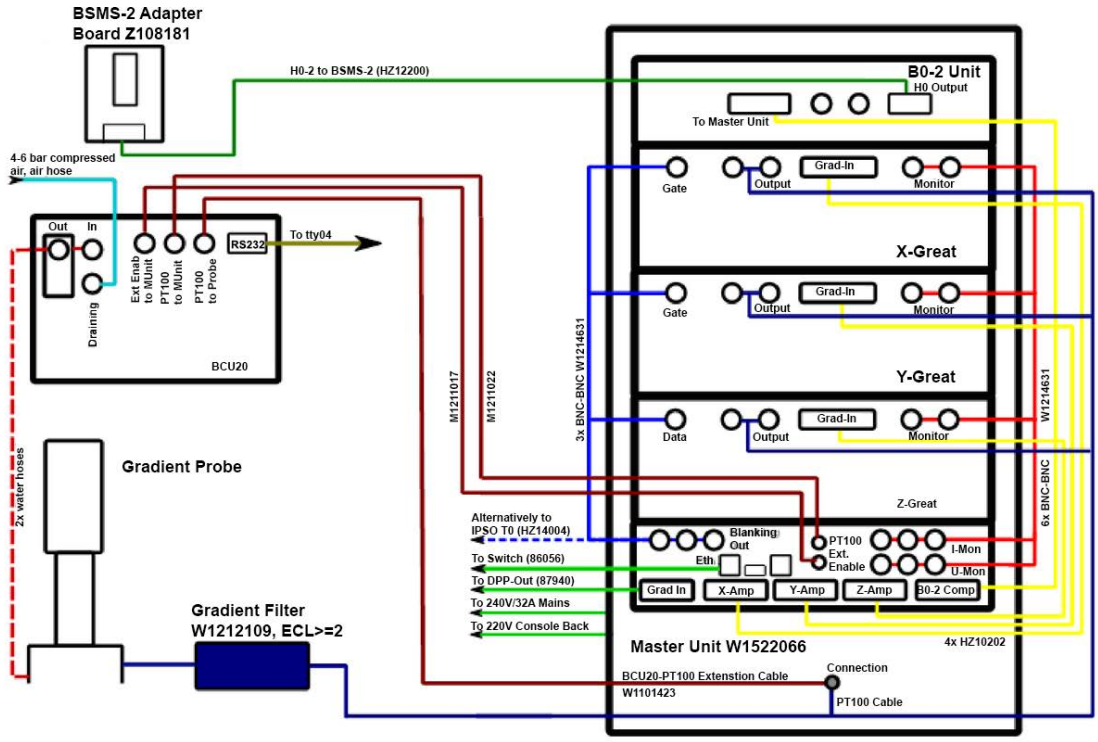


Figure 12.19: Wiring of the Imaging Accessory

12.6 Gradient Amplifier Blanking Modes

The Great amplifiers can operate in 2 different blanking modes, soft and hard blanking. A low level (TTL) at the *Gate* input of the Great amplifiers enables their outputs; a high level (TTL) disables the outputs. In imaging experiments the amplifiers are often unblanked during the complete experiment (realized in the include file MRI.include) due to 2 reasons:

- The experiments are quite fast, so there is almost no time to blank the amplifiers.
- The current to gradient ratio is not as high compared to the diffusion gradient systems.

Blanking is essential for experiments with diffusion gradient systems (Diff30/60), since they have a high current to gradient ratio, so even weak amplifier noise introduces strong effects to the spin system.

The amplifier needs about 10 µsec to enable its output. The blanking command must be executed minimum 15 µsec before the **grad** command in the pulse program. Shorter times can lead to unforeseeable effects.

12.6.1 Hard Blanking

On previous instruments, there was only one blanking mode available which is now called *hard blanking*. This blanking mode is controlled by a **setnmr** command in the pulse program, which enables or disables the amplifier output exactly at that moment, where it is executed, independent from any residual gradient current. This can be well controlled if all pre-emphasis values are set to zero, but if the pre-emphasis compensation adds an exponential decaying current to the gradient shape, it can hardly be predicted in the pulse program when the current will be dropped down to zero and blanking can be switched. In this case, the pre-emphasis compensation current will be cut off and doesn't produce the desired effect. The gating input of the Great amplifiers is directly connected to the IPSO T0 connector for the hard blanking mode. For the T0 pin connections please refer to *Trigger Signals (in and out) at the T0 Connector [▶ 161]*.

To *blank* all amplifiers in this mode, bit 32, 33 and 34 of nmrword0 have to be set to 1 (5V at the T0 connector) using the command **setnmr0^32^33^34** in the pulse program.

To *unblank* the amplifiers, the bits have to be set to 0 (0V at the T0 connector) using the command **setnmr0|32|33|34**, where bit32 is for AmpX, bit33 for AmpY, and bit34 for AmpZ.

The following lines show a pulse program example for the hard blanking:

```
...
15µ setnmr0|32|33|34
1m grad { (10) | (t0) | (0) }
200µ groff 2m ; time for the pre-emphasis current to decay
10µ setnmr0^32^33^34
...
```

setnmr ppg command	AmpX	AmpY	AmpZ
setnmr0^32^33^34	D	D	D
setnmr0^32^33|34	D	D	E
setnmr0^32|33^34	D	E	D
setnmr0^32|33|34	D	E	E
setnmr0|32^33^34	E	D	D
setnmr0^32|33^34	D	E	D
setnmr0|32|33^34	E	E	D
setnmr0|32|33|34	E	E	E
D=amplifier disabled (blanked), E=amplifier enabled (unblanked)			

Table 12.1: Hard Blanking Parameters

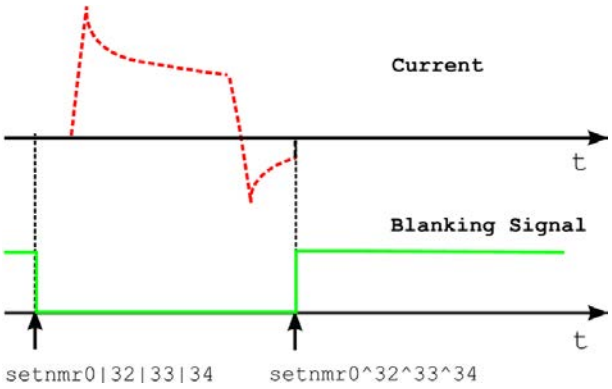


Figure 12.20: Hard Blanking of a Gradient Pulse with Pre-emphasis Components

12.6.2 Soft Blanking

The Master Unit BGMUI-E used on AVANCE III systems can generate soft blanking pulses. The soft blanking is controlled in the pulse program using the **ctrlgrad** commands. If a **ctrlgrad** command is executed in the pulse program to blank an amplifier, the Master Unit checks if the digital data of the amplifier is zero. As long as the input data is not zero, the amplifier stays enabled (unblanked). As soon as the input becomes zero, the Master Unit generates the blanking signal for the amplifier.

The main advantage of the soft blanking is that residual currents from the pre-emphasis are no longer clipped. If, for example, all the pre-emphasis values are zero, the amplifier is blanked immediately when the **ctrlgrad** command is executed. If the pre-emphasis compensation adds an exponentially decaying current, the amplifier is first blanked when the compensation current is fully decayed. The gating input of the Great amplifiers has to be connected to Master Unit, see chapter *Master Unit BGMUI-E (W1522066) [▶ 143]*.

The following lines show a pulse program example for the soft blanking:

…

```
15µ ctrlgrad 0
1m grad { (10) | (t0) | (0) }
200µ groff
2m ctrlgrad 7 ; blanking stays open for pre-emphasis decay
```

…

The soft blanking of the amplifiers is executed using the keyword *ctrlgrad <value>* in the pulse program. To unblank the amplifiers, the <value> bits must be set. To blank the amplifiers, the bits must be reset to 0, where bit0=AmpX, bit1=AmpY, and bit2=AmpZ.

Value (bin)	ppg command	X	Y	Z
000	ctrlgrad 0	E	E	E
001	ctrlgrad 1	D	E	E
010	ctrlgrad 2	E	D	E
011	ctrlgrad 3	D	D	E
100	ctrlgrad 4	E	E	D
101	ctrlgrad 5	D	E	D
110	ctrlgrad 6	E	D	D
111	ctrlgrad 7	D	D	D
D=amplifier disabled (blanked), E=amplifier enabled (unblanked)				

Table 12.2: Soft Blanking Parameters

The command **Ctrlgrad** opens the amplifier at the next gradient command in the pulse program. If a **ctrlgrad 7** is not immediately followed by a **grad{…}** command, the amplifiers remains blanked.

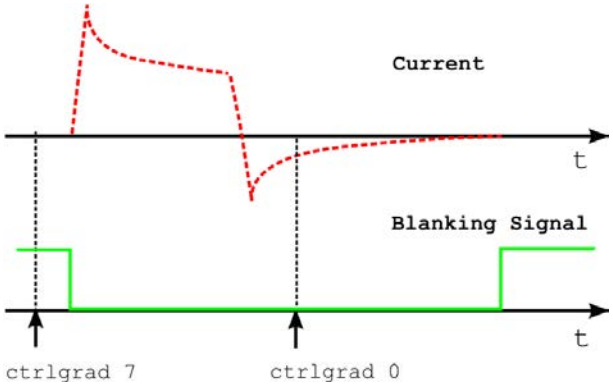


Figure 12.21: Soft Blanking of a Gradient Pulse with Pre-emphasis Components

Typically all amplifiers are blanked/unblanked at the same time. Therefore the macros BLKGRAD and UNBLKGRAD are defined in the include file pp/Grad.incl. These macros execute a *soft* and a *hard* blanking event, so the behavior of the amplifier depends on where the gating input is connected.

12.7 IPSO

This section contains useful information about the IPSO.

12.7.1 Trigger Signals (in and out) at the T0 Connector

T0 Name	Description/Label	Ppg Command	Connection Point
Signal Outputs			
TTL1	TTL Out 1	TTL1_LOW TTL1_HIGH (nmrword 3#28)	T0 / I1
TTL2	TTL Out 2	TTL2_LOW TTL2_HIGH (nmrword 3#29)	T0 / I2
TTL3	TTL Out 3	TTL3_LOW TTL3_HIGH (nmrword 3#30)	T0 / I3
TTL4	TTL Out 4	TTL4_LOW TTL4_HIGH (nmrword 3#31)	T0 / I4
STAMP1	ECG_STAMP	STAMP1_LOW STAMP1_HIGH (nmrword 3#6)	T0 / C1
NV_CLOCK	DPP NV_CLOCK		T0 / Z1
BlankXAmp		nmrword 0#32	T0 / A4
BlankXAmp		nmrword 0#33	T0 / A5
BlankXAmp		nmrword 0#34	T0 / A6
Signal Inputs			
TRIG_IN1	ECG_TRIG	Trig[np][le]1	T0 / C5
TRIG_IN2	TTL IN 1	Trig[np][le]2	T0 / C6
TRIG_IN3	GRAD_SYNC	Trig[np][le]3	T0 / E1
TRIG_IN4	TTL IN 2	Trig[np][le]4	T0 / E2

Table 12.3: T0 Trigger Signals

13 Contact

Manufacturer

Bruker BioSpin GmbH
Silberstreifen 4
D-76287 Rheinstetten
Germany
http://www.bruker.com

WEEE DE43181702

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