MARAN Ultra
Imaging Manual

MARAN Ultra Imaging Manual (for RINMR software release version 3.2 or later)
(RI Advanced Imaging Display software release 5 for IDL version 5.2 or later)
v2.0 April 2006

Note: It is recommended that users access the CD-ROM supplied with the instrument for the latest version of this manual.

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Contents

Chapter 1 Introduction

This manual describes:

i) How to set up a simple T2 weighted imaging sequence using the MARAN Ultra and RINMR data acquisition software.

ii) How to perform more sophisticated imaging experiments and optimise acquisition times via techniques such as oversampling and zero filling.

iii) The RI Advanced Image Display Software for image visualisation and processing.

iv) A description of the MARAN Ultra imaging pulse sequences.

v) A description of the MARAN DRX imaging pulse sequences.

Users should note that the aim of this manual is not to educate the non-expert user in imaging techniques. Users should refer to the appropriate textbooks if more information on basic MRI techniques is required.

Chapter 2 Imaging using RINMR

2.1 Introduction

This Chapter explains how to set up the pulse sequence IMAG90XZ for producing images with the RINMR data acquisition software.

Basic imaging sequences using the MARAN Ultra software can be set up by conducting the series of steps described in the following sections. A general overview of each step can be found in section 2.2.

The following MARAN Ultra imaging programs are required:

IMAGESET
IMAG90XZ
SL90XYZ

Information describing the parameters available when using these pulse sequences and timing diagrams can be found in Chapter 5 of this manual.

Once acquired data may be processed using the RI Advanced Image Display Software. Information on this software can be found in Chapter 4.

2.2 Setup Steps

2.2.1 Selecting a Phantom

Prepare a cylinder of smaller dimensions than the RF coil with a short T1 / long T2 liquid inside it. Vegetable oil (5*T1 < 0.5 seconds) is a good choice.

2.2.2 Setting Up the System Parameters

Set up O1, the 90 and 180-degree pulse lengths (P90 and P180), the repetition time and the receiver gain using the AUTOO1, AUTOP90 and AUTORG macros. More information on setting these parameters may be found in the RINMR Users Manual if required.

2.2.3 Calibrating the Gradients Using IMAGESET

Measure the strength of the read, phase encode and slice select gradients.

This document will assume from this point onwards that GX controls the read gradient, GY controls the slice gradient and GZ controls the phase gradient.

2.2.4 Setting the Image Matrix dimensions and Filter Widths

The user should determine the size of image matrix required. The size of image matrix normally is determined by the signal to noise ratio required, the required image resolution and the required acquisition time. For example a 64 by 64 image matrix requires 64 separate experiments or 64*RD seconds to acquire (where RD is the repetition time in seconds). A 256 by 256 image matrix requires 256 separate experiments or 256*RD seconds. If RD needs to be long (i.e. for bulk water) or more than a single average is required (i.e. NS > 1) the time for an image acquisition can be prohibitive for a large image matrix size.

2.2.5 Setting the Slice Excitation Pulse Width

In imaging experiments shaped pulses are usually kept constant and the tip angle of a shaped pulse is altered by varying a global amplitude scalar. This scalar must be set correctly to produce a reasonable slice excitation profile.

After the slice excitation pulse has taken place the transverse magnetisation is distributed in the transverse plane as a function of spatial position. To restore phase coherence it is necessary to apply a short pulse of slice gradient of opposite sign to rephase the magnetisation. The correct gradient is applied when a maximum is observed in the echo amplitude.

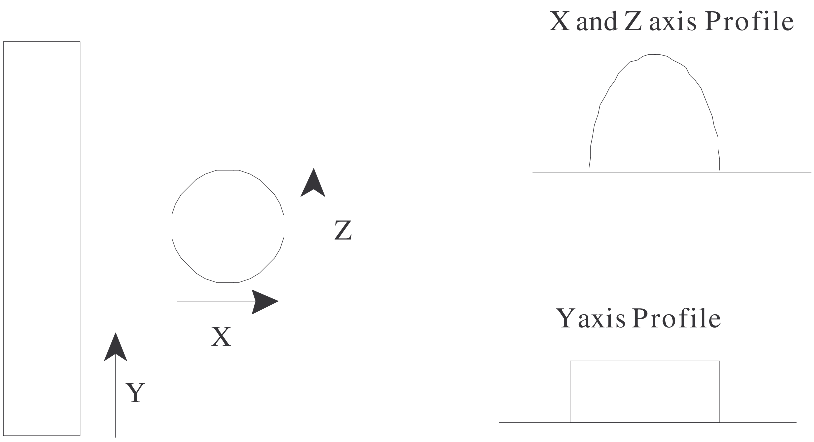
The receiver gain of the instrument must be set to maximise the signal before acquisition.

2.2.6 Set Phase Encode Gradient Amplitude
The phase encode gradient strength must be set correctly to ensure the image has the correct dimensions following the Fourier Transform.

2.2.7 Set Averaging Parameters
NS must be set to control the number of scans per phase encode step.

2.3 Selecting a Phantom
For the purposes of this experiment, a cylinder makes an ideal test sample or phantom. Fill a cylinder (for benchtop systems a standard tube will suffice) with a short T1 liquid (vegetable oil or doped water) so a fast repetition time (RD) can be used.

1D Profiles from a cylinder of uniform spin density are as follows:



Measure the length of the sample carefully in the X,Z (ID of the cylinder) and Y directions. Take care not to overfill the tube in the Y direction (make sure the entire sample lies well within the RF coil).

2.4 Setting the Image Matrix Size and Filter Widths
Before starting the set up procedure it is necessary to decide on an image matrix size. The following points should be noted when selecting an image matrix:

i) The total acquisition time in seconds is given by the equation:

   IG4*RD*1e-6*NS.

   Where IG4 is the number of phase encode steps, 64 for a 64*64 matrix, 128 for a 128*128 matrix etc, RD is the experiment repetition time in microseconds and NS is the number of Scans per phase encode step.

ii) The image should fill the image matrix (acquiring an image significantly smaller than the image matrix is an inefficient use of time).

   If the image matrix size is set relatively large:

The acquisition time will be long.
The relative signal to noise ratio per pixel will be low.
The resolution of the image will be high.

If the image matrix size is set relatively small:

The acquisition time will be relatively short.
The relative signal to noise ratio per image pixel will be high.
The resolution of the image will be low.

(Assuming the image fills the image matrix in both cases).

iii) Bear in mind that setting up imaging protocols often involves the repetition of many experiments. For this reason it is recommended that the image matrix size is set to 64*64 for setting up the system, i.e. SI and IG4=64.

Once the user determines the image matrix size, the dwell time (DW) and the filter width FW should be set to optimise the signal to noise ratio.

The filter bandwidth should be equal to the acquisition bandwidth or sweep width, defined by the following equation:

FW=1/DW

for the optimum signal to noise ratio.

2.5 Calibrating the Gradients Using IMAGESET

NOTE: All systems require different setup parameters to function correctly. The parameters given are guidelines for demonstration purposes. Please contact OIMBL for advice before setting up imaging sequences.

NOTE: The script gradcalib can be used to perform many of the gradient strength and slice thickness calibrations.

To produce a 1D profile, first set the values for P90, P180, O1 and RG correctly. Set RD to a suitable value (approx. 1S in the case of vegetable oil).

Load the IMAGESET pulse sequence and use the following parameters:

D1: This is the pre slice select gradient settle time. This is used to allow the slice select gradient to stabilise before the application of the slice select pulse. Set this to a nominal value of 500 us.

P90: This is the length of the hard 90-degree pulse in microseconds. This should be set to the current 90-degree pulse length for this instrument.

RFA0: The hard RF pulse amplitude for the instrument - set this to 100.

D2: This is slice rephase gradient duration and is not used in this part of the set up. Set to a nominal value of 1000 us.

D3: This is the read/phase gradient dephase time, which in conjunction with G3 governs the magnitude of the dephase read/phase gradient. Set this to an appropriate value (for example 2 milliseconds).

TAU: The distance between the 90 and 180-degree pulses. Set this to an appropriate value (for example 20 milliseconds). Note that TAU must be greater than (D2+D3+P90/2+P180/2).

D4: This is the time following the start of the rephase read gradient before data are acquired. Set this to (D3/2), i.e. in this example 1000 ms.

G3: The read gradient dephase amplitude. Set this to 0.

G5: The read gradient rephase amplitude. Set this to 0.

GX: The read gradient global scalar. Set this to 32767.

P180: The duration of the 180-degree pulse in microseconds (twice the 90 degree pulse will suffice).
DW: The dwell time in microseconds. Set this to 31.3 us for this example, or D3/(SI) if another value of D3 is used.

SI: The read dimension of the image matrix, set this to 64.

FW: The filter width should be set to 1/DW or 32 KHz in this example.

IG4: The phase dimension of the image matrix, set this to 0.

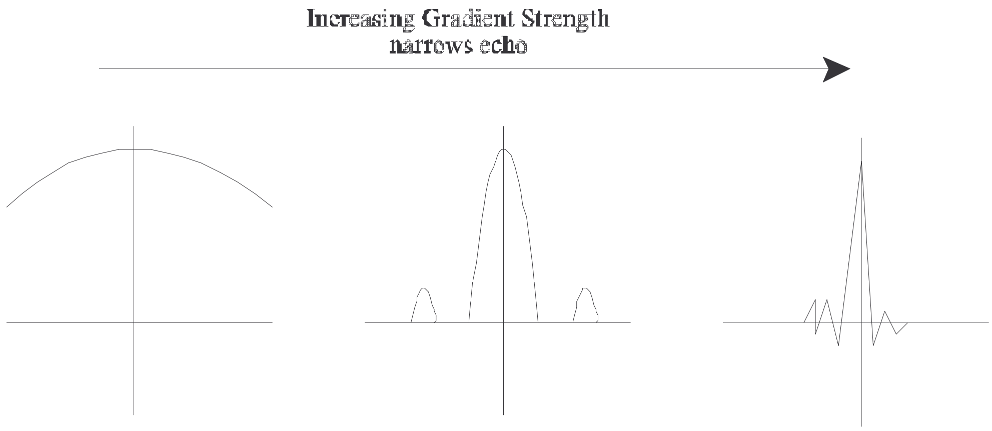
Ensure that GY (slice gradient global scalar) and GZ (phase gradient global scalar) are set to zero.

Ensure PH1 is set to 02, PH2 to 02 and PH3 to 11.

Set NS to 1 and run the pulse sequence using GS. A broad echo should appear, with its maximum centred on the acquisition window. For some systems the echo may be so broad it appears as a straight line.

Increase G3 and G5 (keep the values identical). The echo should narrow.

Increase G3 and G5, making sure the echo stays in the acquisition window. If the echo moves out of the acquisition window increase/decrease D4 to bring the echo back into the centre. Note that ideally G3 must be kept approximately equal to G5 for the echo to be centred correctly.



Once the echo has narrowed FT the echo interactively via the view menu to produce a 1D profile.

Increase/decrease G3 and G5 until the parabolic 1D profile fills the acquisition window. Finally, return to the time domain data (select A and B from the view menu) and alter the value of G3 (only, not G5) to centre the echo in the middle of the acquisition window.

Note the values of G3 and G5 (they will be needed later). If G3 and G5 are large (over 25000) it is an indication that the value of D3 is insufficient. This is undesirable as it causes the read gradient waveforms to have a non-rectangular shape and the echo acquisition to occur under a non-linear gradient. If G3 and G5 are large, increase D3 and repeat the setup process. Note that if D3 is altered several other parameters (including TAU) may need changing.

Calibrate the gradient strengths by acquiring some data (use 2 scans, NS=2, which will remove the large DC spike from the profile). After the data has been acquired, FT the profile and measure the width in Hz using the cross hair (expand areas of the image for greater accuracy if necessary).

GradXStrength (Hz/cm/gradient unit) = (Width of Profile in Hz)/(Phantom diameter*G5)

Repeat this process for the phase encode gradient Z (change GX and to zero and enter suitable 32767 for the GZ value instead). Note that two of the gradients (normally X and Y) should have similar gradient strengths. The Z gradient is normally significantly stronger.

Finally repeat for the Y gradient by changing GX and GZ to zero and entering 32767 for GY. Note that the 1D profile produced by the Y gradient should be rectangular in shape.

Finally calculate the ratio of transverse (X and Y) gradient strength to longitudinal (Z) gradient strength by dividing the X gradient strength by the Z gradient strength (GScaleXY).

Record the figures for the gradient strength that have obtained permanently - write them in the boxes below. Once the calibration process has been performed it will not need to be repeated.

GradXStrength=
GradYStrength=
GradZStrength=

GScaleXY=

On completion set GX to 32767, G3 and G5 to the values obtained earlier (to produce a good 1D profile in the read direction (GX)) and GY and GZ to zero. Save the parameters to a .RiPar file (Parameter Set 1).

Note that this calculation may also be performed by running the GRADCALIB script (more information on this script can be found in the RINMR Pulse Sequence and Script Manual). Values for the gradient strength are given in G/cm, T/m/A and also Hz/cm/gradient unit.

2.6 Configuring the Slice Excitation Pulse

In imaging experiments it is not usual to alter the length of the excitation pulses. It is more usual to define a pulse length, then tune the tip angle by altering the amplitude of the applied RF field.

2.6.1 Setting the Shaped Pulse Amplitude Using SL90XYZ

A special sequence, called SL90XYZ is used for tuning the amplitude of the slice excitation pulse. The sequence utilises a constant slice select gradient to produce a slice excitation profile along the Y-axis as shown below:

By increasing the B1 amplitude of the slice excitation pulse (RFA1) steadily until the excitation slice looks reasonable we can determine the correct amplitude for the slice excitation pulse. Figure 2 shows the typical result of varying the slice select pulse amplitude in a SL90XYZ experiment.

Load in the SL90XYZ program. Load in the parameters obtained from the IMAGESET program (parameter set 1).

Set the following parameters:

D1:=500 us.
P1:=2000 us.
D2:=1000 us (or half P1).
G1:=0;

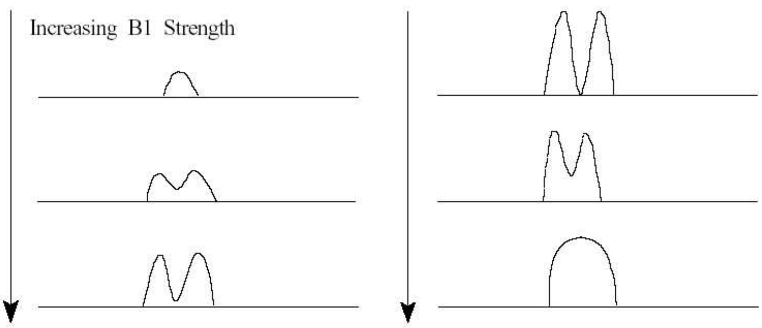
Set GX to 0, GY to 0 and GZ to 0.

Load in the pulse shape by typing SH1 and the name of the pulse shape file (SINC256 and GAUSS256 are included as standard). It is recommended for this demonstration that the Gaussian pulse shape is used.

Run the SL90XYZ pulse sequence using GS (set NS to 2). Set RFA1 to 10 to achieve an echo. Set GY (slice gradient global scalar) to 32767 and increase G1 until the echo narrows. Once the echo is suitably narrowed perform an interactive FT. This should now show a slice excitation profile.

If a profile is not seen, try increasing / decreasing G1 until it is observed.

Once a slice excitation profile is observed set RFA1 to 0. Increase RFA1 slowly until the slice excitation profile looks reasonable (like a Gaussian). The slice excitation profile will change shape according to the following diagram:



(Note that the shape of the slice is also dependent on the nature of the excitation pulse, for example a Gaussian excitation pulse (like the one used in this example) will produce a Gaussian shaped slice excitation profile, whereas a sinc pulse will produce a rectangular shaped slice excitation profile).

Once RFA1 has been set correctly to produce a good slice excitation profile (note that amplitude as well as shape is important), acquire a slice excitation profile and measure its width in Hz (in a similar manner to that described in section 4 for the gradient profile calibration). The slice width is given by the expression:

SliceWidth (cm)=Width of Slice Excitation Profile in Hz /(GradYStrength*G1)

where GradYStrength is in Hz/cm/gradient unit.

Note that changing the slice select gradient strength (G1), the slice select pulse length (P1) and the slice select pulse shape (SH1) will all have an effect on the slice excitation thickness (if P1 is changed note that D2 must also change).

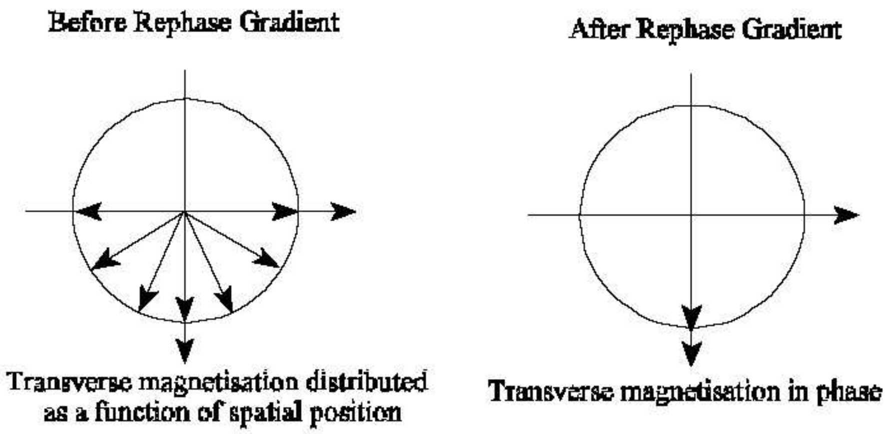
The slice excitation thickness can also be calculated using the GRADCALIB script.

To decrease the slice width, increase G1. Note that the narrower the slice width the lower the resulting signal to noise ratio of the final image.

Save the current parameters to another .RiPar file (Parameter Set 2).

2.6.2 Setting the Slice Rephase Gradient

The transverse magnetisation following a slice select pulse is in a dephased state and must be rephased by applying a small amount of negative slice gradient following the slice select pulse. Failure to apply a correct amount of slice rephase gradient leads to a loss of signal intensity and a reduction in the signal to noise ratio of the experiment.



To set the slice rephase gradient load the IMAG90XZ pulse sequence. Load in the parameter set saved earlier (parameter set 2).

Ensure that the phase gradient parameters (G4 and IG4) are set to zero. Set G2 to -G1. Set GX to 32767 to re-activate the read gradient.

Run the experiment in interactive mode. Vary the value of G2 (slice rephase gradient amplitude) until a maximum in echo amplitude is observed.

Ideally, G2 should equal -G1 and D2 should be P1/2 for the magnetisation to be refocused correctly.

2.6.3 Setting the Receiver Gain

Since only a small slice of the sample is selected in an imaging experiment, the receiver gain RG is higher than that required to take an FID from an entire sample. The maximum signal observed in the Fourier Imaging method always occurs when the phase encode gradient is set to zero (in our example when no Z gradient is used).

Run IMAG90XZ interactively (in this mode no phase encode gradient is applied). Alter RG until the echo fills the acquisition buffers.

Finally, FT the echo and observe the 1D profile. Ensure that the profile is centred and fills the entire window. Leave IMAG90XZ pulse sequence loaded and proceed to section 2.7.

2.7 Setting the Phase Encode Gradient Strength

It is important to set the phase encode gradient strength correctly - if it is not set correctly the image will be distorted (an image of a circular phantom will appear oval in shape). Setting the value of the phase encode gradient strength is not as simple as it might appear. As much of k-space must be traversed in the phase encode direction as in the read direction for the image to be undistorted. In addition, k-space must be sampled in the same interval in the phase encode direction as the read direction. Thus the phase encode gradient strength necessary to make the image appear circular is dependent on both the dwell time (DW), the number of points acquired (SI and IG4) and the read gradient strength (G3).

The correct phase encode gradient strength and increment may be found using the following equation:

$$GZ=(G3.DW/D3)*(IG4/2)$$

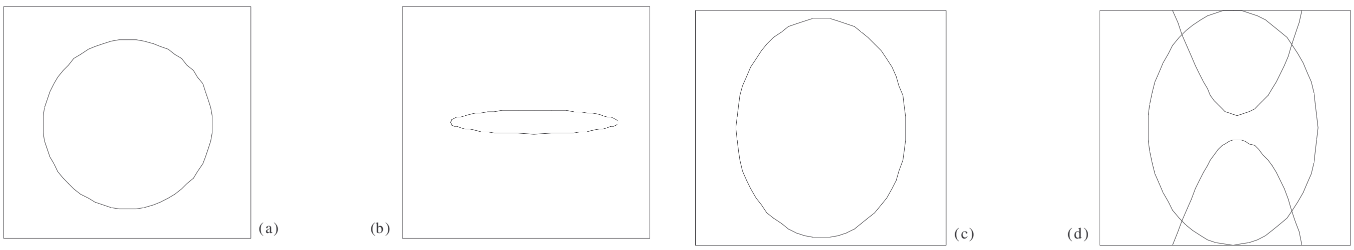
where D3 is the gradient dephase duration (both read and phase), DW is the dwell time, G3 is the read gradient amplitude and IG4 is the image matrix size in the phase encode direction.

After setting GZ, set IG4 to the image matrix size in the phase encode direction (64 if SI is set to 64).

Note that the above formula is only valid if the read and phase gradients have identical strengths (the X and Y gradient strengths differ from the Z gradient strength).

Alternatively set GZ to a low value (e.g. 500) and proceed to sections 2.8 and 2.9. After acquiring an image visualise it (using the RI Advanced Image Display or another package).

The diagram shows a correct value of GZ (a), too small a value of GZ (b) and too large a value of GZ (c). Increase/decrease GZ until (a) is observed (Note that if GZ is set extremely large, the image will be folded back in the Z direction (d) - in this case reduce GZ significantly).



(a) (b) (c) (d)

2.8 Imaging Sequence Averaging

A single form of averaging may take place, controlled by NS.

NS controls how many times each phase encode increment is performed before proceeding.

Formula for acquisition time (assuming RD is long in comparison with experiment time):

Acquisition Time=(IG4*NS*RD).

2.9 Acquisition

The instrument should now be set up to acquire an image. Use GO to acquire the data, then save the data using the WRI command. Refer to Chapter 4 for more information on image visualisation.

Chapter 3 Other Imaging Techniques

3.1 Introduction

A number of advanced imaging techniques exist that can be used to optimise image acquisition time / introduce relaxation contrast / increase signal to noise. These will be described in the following sections.

Note that many of the techniques are used in conjunction with data processing algorithms that are described in Chapter 3 - RI Advanced Image Display.

The advanced techniques are:

Zero-filling - reduce image acquisition time by lowering the number of phase encode steps.

Oversampling - increase the image acquisition bandwidth to allow post acquisition digital processing for removal of artefacts due to imperfect anti-aliasing filters.

T1 - produce a series of T1 weighted images using an inversion recovery pulse sequence.

Multi Slice - acquiring a set of images in different slice planes.

Multi Echo - acquiring several images simultaneously using a CPMG echo train.

3.2 Zero Filling

The time for data acquisition can be considerably reduced by assuming that the data acquired for certain phase encode steps contains only noise (these correspond to steps with high values of phase encode gradient strength). Rather than acquiring data for these phase encode steps, we can substitute zeros and provided not too many phase encode steps are replaced, little or no degradation in image quality will be observed.

To acquire data sets suitable for zero filling two parameters must be altered. IG4 must be changed to the new number of phase encode steps required and GY should be changed to:

$GY = GY*IG4_{new}/IG4_{old}$

Note that the RI Advanced Image Display software will only allow FFT's of a square time domain matrix, so any non square matrix acquired must be zero filled before the Fourier transform can take place.

Note that the degree of image degradation observed increases as more and more phase encode steps are zero filled.

3.3 Oversampling

During image acquisition an anti-aliasing filter is normally applied in order to enhance the image signal to noise ratios. Noise aliased by the anti-aliasing filter can be removed by sampling at a greater bandwidth than the anti-aliasing filter followed by digital filtering and or decimation (reduction of the data set). To oversample by a factor of two halve DW and double SI while maintaining the same filter width. Note that the RI Advanced Image Display software only allows digital filtering of data sets where SI=2^n and that the time domain data must be reduced to a square matrix before Fourier transform can take place.

3.4 T1 Weighted Images

Pulse sequences can be given T1 weighting by placing an 180 degree inversion pulse a set time period before the start of the imaging sequence. A pulse sequence (T190XY) exists for performing T1 weighted experiments. In all other respects, T190XY is identical to IMAG90XY.

3.5 Multi Slice Imaging
Multi Slice Imaging allows the user to produce a full 3 dimensional data set of a sample in a reduced acquisition time.

Multi slice acquisitions are expedited by the fact that each slice of the sample is excited separately, which means the user does not have to wait 5*T1 between phase encode steps on different slices.

RINMR is supplied with a multi slice pulse sequence called MULSLXY which allows multislice imaging in the transverse place (X=read, Y=phase, Z=slice).

This program requires three additional parameters over the standard imaging sequence IMAG90XY:

C1 - The number of slices to excite per excitation.

C2 - The frequency shift per excitation slice.

D9 - The repetition time between slices (as opposed to RD, which governs the time between each multiple slice excitation).

Note that an odd number of slices must be specified if the slices are to be positioned symmetrically about the central slice. For example, for six slices (C1=6) slices are positioned at:

-3*C2+O1,-2*C2+O1,-1*C2+O1,O1,1*C2+O1,2*C2+O1

For five slices (C1=5) slices are positioned at:

-2*C2+O1,-1*C2+O1,O1,1*C2+O1,2*C2+O1

Widths for C2 can either be calculated or estimated using the SL90XYZ program. Note that the frequency shift per multi slice must be greater than the slice excitation width to avoid T1 effects due to slice overlap and that users should be wary of exceeding gradient duty cycles when setting D9.

3.6 Multi Echo Imaging
Multi echo imaging allows acquisition of several images simultaneously via the use of 180 degree rephasing pulses. Multi echo experiments are performed with the MULECHXY and MULECHXZ pulse sequences. These have the following parameters in addition to those used by IMAG90XY:

C1 - crusher gradient increment.

G7 - Read gradient pad value.

G7 - Crusher gradient start value.

D5 - Crusher gradient duration.

The multi echo pulse sequences incorporate a crusher gradient to eliminate the effects of stimulated echoes.

Chapter 4 RI Advanced Image Display

4.1 Introduction
The RI Advanced Image Display software may be used to display and process image data acquired with RINMR. The RI Advanced Image Display software is written for use with the IDL (Interactive Data Language) software supplied by Research Systems Inc. [1].

4.2 Installing RI Advanced Image Display
i) Create a directory called c:\image.

ii) Copy all the files from the RINMR IDL Utilities floppy into the c:\image directory.

iii) Install a new shortcut by right clicking on the Windows 95 desktop by selecting 'New'‟Shortcut'.

Browse the PC hard drive and specify the IDL 5.x .exe file (usually idlde.exe in the c:\RSI\IDL5x directory in the default installation).

Click on the Next button and call the shortcut 'Image'.

Click on the Finish button to install the shortcut to the desktop.

Once the icon is installed on the desktop right click on it and select properties. Click on the Shortcut tab and enter the path c:\image in the Start In box.

iv) Finally, run IDL from the Windows Start menu and select 'Preferences' from the main File menu.

iv) Select the Startup Tab and enter the filename and enter the filename 'start.idl'.

v) Exit IDL and run RI Advanced Image Display from the shortcut.

If in doubt, contact OIMBL for advice.

WARNING: RI advanced image display will only run with the specific version of IDL that it was compiled for. If RI advanced image display fails to run contact OIMBL for advice.

4.3 The Image Display Window
The image display window is the area where images and time domain data is displayed.

The cursor position is displayed in the top left hand corner of the display window. Note that 1D profiles of the currently loaded image may be visualised by left clicking with the mouse at the required co-ordinates in the data window.

Note that the Image Display window can be refreshed by clicking on it with the mouse and that and that sometimes data may be scaled so it lies outside the region of the data display window.

4.4 The Main Menus
File: Allows the user to load and save data sets, write images to disk and specify process options.

Display: Allows the user to specify display options such as the colour map, image zoom window, image scale value and the data type (real/imaginary/phase) displayed.

Edit: Allows the user to FFT data sets and drop out of the IDL image display utilities to the IDL command line.

Process: Allows time domain processing options including digital filtering, zero filling, reduction, apodization filtering and FFT's. Automatic time domain processing on data set loading may also be specified.

3D: Allows 3D visualisation, multi-slice visualisation and animation.

Modify: Allows region of interest calculations, image annotations and image subtraction.

About: Specifies the current version number of the software and the release version of IDL that it was compiled for.

4.5 The Side Widgets

The side widgets allow the user to perform common tasks or display useful information about the current data set.

The position display shows the current position of the cross hair in the image matrix.

The intensity display shows the value of the data at the current crosshair position.

The data type display shows the current type of the data (for example Image Data, Raw Data).

The component type display shows which component is currently displayed (real, imaginary or phase).

The slider may be used to display different slices of a multi-dimensional data set. Note that the slider will be inactive if the current data set is only 2 dimensional.

The restore button restores the last loaded time domain data set to the image display window. This button provides a fast way of restoring data after unwanted time domain processing has taken place.

The print button allows the user to print the currently displayed image to the local printer.

The information button displays the RINMR acquisition parameters that were used to acquire the data set.

The Fast Load button automatically loads in a data set (whose filename may be specified using the Edit Fast Load option of the File menu). This button is particularly useful when running test images.

Directly below the side widgets is the multi slice window which displays all the slices of the currently loaded 3 dimensional data set (nothing is displayed if the data set has only 2 dimensions).

4.6 The File Menu

Save As - Allows the user to save the current image as a bitmap or GIF image.

Load 2D - Allows the user to load single/multidimensional .RIImage data files.

Load Series - Allows the user to load a series of single images and compile them into a three dimensional data set.

First select an image as the seed image (this seeds the x and y dimensions of the image, images can only be assembled into a 3D data set if they have identical x and y dimensions and a z dimension of 1). Note that the seed image is ONLY used to establish the x and y dimensions of the final data set and will not be incorporated within it.

Then specify the number of images that will be loaded in to make the 3D data set.

Finally click on each of the separate files in turn to assemble the 3D data set.

Load SPRITE - Allows the user to load 2D SPRITE data.

Edit Fast Load - Allows the user to specify the filename of the .RIImage data set that is automatically loaded into the image display software and processed when the 'Fast Load' button is pressed.

4.7 The Display Menu

4.7.1 Colours
Allows the user to alter the colourmap using the IDL Xloadct widget. More information of the xloadct widget can be found by clicking on the help button after the widget has been executed.

4.7.2 Zoom
The zoom menu allows the user to display a portion of the image in another window.

After selecting one of the zoom options (*2, *4 or *8) position the cursor in the main display window and left click to select the target area. A second window will appear which will display the zoomed image. The zoom window origin can be altered interactively by moving the crosshair in the main display window. To finish the zoom process, right click on the main display window.

4.7.3 Edit Max
This function allows the user to threshold the image in the main display window.

When the image data is displayed in the main window, they are automatically scaled so they occupy the full colour range. This may cause problems if DC artefacts exist. When max is set, any data values greater than max will not be used in the scaling calculation and in the final image will be assigned maximum intensity.

When max is first selected it displays the maximum value of the current data set.

4.7.4 Type
Allows the user to select the real, imaginary, phase and magnitude components of the image data /raw data for display.

4.7.5 Surface Plot
Allows the user to display a surface plot of the current data.

4.7.6 Two Dimensional
Allows the user to display an image rather than a surface plot.

4.7.7 Result Buffer
Allows the user to display the result buffer, which displays the result of the last calculation performed (e.g. velocity map calculation, image subtraction).

4.7.8 Histogram
Displays a histogram of the pixel intensities of the currently loaded data set.

4.7.9 Contour
Overlays a contour plot on top of the current image.

4.8 Edit menu
Edit Time Domain - Allows the user to edit the time domain data.

Edit Frequency Domain - Allows the user to edit the frequency domain data. This allows the user to remove DC spikes etc.

Interactive - Allows the user to enter IDL's interactive mode and process data from the IDL command line. Please refer to the IDL manuals for more information.

4.9 Process Menu
The process menu allows the user to specify processing parameters and also apply data processing functions (such as FFT, apodisation and zero filling) to the currently loaded data set.

4.9.1 Parameters
This option allows the user to specify processing parameters. Three different types of parameters may be specified:

Apodisation Parameters: Allows the user to set a decay constant (in image pixels) for the exponential apodisation filter. Also the type of apodisation filter may be selected (either exponential or sine bell). Note that the sine bell filter does not allow a decay constant to be specified.

Digital Filter Parameters: Allows the user to select parameters for the digital filtering of oversampled data. The parameters are:

Order: the number of filter co-efficients used. Must be < than the current dimensions of the image matrix (dimx or dimy).

Gibbs: The target Gibbs noise value of the filter in dB (defines in band / out of band ripple).

Low Value: Low frequency value of filter (as a fraction of the Nyquist frequency, 1=Nyquist).

High Value: High frequency value of digital filter (as a fraction of the Nyquist Frequency, 1=Nyquist).

Filter Type	Low Value	High Value
High Pass	>0	1
Low Pass	0	<1
Band Pass	>0	<1

Zero Fill Parameters: This allows the user to specify the number of rows to zero fill the current data set to, or the number of rows that will be set to zero in a zero fill simulation. Either the x (usually read) or y (usually phase encode) directions may be specified.

Reduction Parameter: The reduction parameter allows the user to decimate the data set after digital filtering. Only powers of two reduction are allowed.

4.9.2 Auto Process
Allows the user to set which processing functions are performed automatically when a data set is loaded. If a box is checked then that processing function will be applied to ALL slices of a data set.

Note that in addition to the processing options there is also an option to FFT on loading and autoscale the data on loading (if the data is autoscaled it is automatically scaled to fit the data buffer). These options are automatically checked when RI Advanced Image Display is executed.

4.9.3 Digital Filter
Apply: Applies the digital filter to the current data set (parameters specified in the ProcessParameters menu).

Test: Allows the user to visualise the Fourier transform of the data acquired with the phase encode gradient set to zero (the 1D projection of the data on the read gradient axis) and the digital filter. This function allows the user to ensure that the filter is set correctly on over sampled data.

4.9.4 Zero Fill

Allows the user to zero fill non square raw data sets in the phase encode direction, or to overwrite square data matrices with zeros in the phase encode direction to investigate the effect of zero filling.

Simulate: Takes a square data matrix and fills the number of rows (x and y dimensions) defined in the Process-Parameters menu with zeros.

Fill Current: Zero fills the current raw data set to produce a square image matrix. Note that only square image matrices may be produced by zero filling.

4.9.5 Apodize

Allows the user to apply a radially symmetric exponential apodization function to the currently loaded data set. Note that apodization filters may only applied to raw square data matrices and that either an exponential or sine bell shaped filter may be applied. The parameters / filter type are specified using the Process-Parameters menu.

Plot 3D: plots a 3D representation of the apodization filter on screen.

Plot 2D: plots a 2D representation of the zero phase encode step time domain data and its current corresponding apodization function.

Apply: Applies the apodization filter to the current data matrix.

4.9.6 Reduce

Allows the user to reduce data sets oversampled in the read direction. Not that only data sets over sampled by a power of 2 may be reduced correctly.

Apply: Perform the data reduction.

4.10 3D Menu

The 3D operation allows the user to conduct 3D operations on data sets.

Display Slices: Allows the user to display all slices of the current data set on screen simultaneously. Note that this function may only be used on data sets containing more than one slice (multi dimensional data sets).

Slicer: Starts IDL's interactive 3D slicer. Refer to the IDL manuals and the online help from within the slicer tool for more information.

Animate: Loads all current slices into the IDL animation tool.

T2 Map: Fits all current slices to a single exponential and displays the result of the fit on screen. (Not implemented in version 5 of RI Advanced Image Display).

Add Slices: Sums either the odd, even or all the slices in a multi dimensional data set.

Motion: Allows the user to specify parameters and perform a velocity map and diffusion map calculation. (Only the velocity map calculation is implemented in version 5).

4.11 Modify Menu

4.11.1 ROI

The ROI menu allows the user to define regions of interest and calculate average values/integrals within the region. ROI's only function with non zoomed image data.

Load ROI: Allows the user to save a region of interest to disk following definition.

Save ROI: Allows the user to load in a previously saved ROI for application to a new image.

Draw Freehand: Allows the user to draw a region of interest. Left click and drag the mouse to define the region. Right click to enclose the region and finish.

Display ROI: Toggles the Display of the current ROI on or off.

Calculate: Computes the average and integral value of the current ROI.

Exit: Returns the user to the Main Menu.

4.11.2 Annotate

Allows the user to annotate the current image using IDL's annotation tool. Refer to the on line information supplied with the annotation tool for more information.

4.11.3 Subtract

Allows the user to load images into buffers for subtraction.

4.11.4 Signal to Noise

Allows the user to define two regions to perform a basic signal to noise ratio calculation.

4.11.5 User Functions

Allows the user to define his/her own functions from within the IDL programming environment and access them from within the IDL software. Contact OIMBL for more information.

4.12 Technical Details

This section describes various technical aspects of the data processing routines implemented in RINMR Image Display.

4.12.1 Digital Filter

The digital filter algorithm returns the coefficients of a non-recursive, digital filter for evenly spaced data points. Frequencies are expressed in terms of the Nyquist frequency, 1/2T, where T is the time between data samples.

4.12.2 Apodize

The apodize processing function produces a radially symmetric apodization filter of the form:

$$y_{n,m} = e^{\left(-\frac{\sqrt{n^2+m^2}}{a}\right)}$$

where n and m are the pixel positions of the co-ordinate in the time domain matrix and a is the decay constant.

Note that the apodization filter currently only works on square time domain matrices of less than 256*256 elements.

4.12.3 Velocity Map Calculation

The velocity map calculation works by a standard FT technique described in the book by Callaghan [2]. Users should note that the algorithm assumes that the flow encoding gradient is incremented in a linear fashion. The output of the algorithm is in m/s. The threshold value is used as a mask to ensure that noise values are suppressed in the final calculation of the velocity map.

The parameters are defined as follows:

DELTA - Time duration between flow encode pulses.

delta - Time duration of flow encode pulses.

Gradient increment - Increment of flow encode gradient pulses per q-step in RINMR units.

Number of Gradient values - Number of Q steps.

Maximum gradient strength - Maximum strength of the flow encode gradient (note not the maximum gradient applied - this is defined by Number of Gradient Values*Gradient Increment) in G/cm.

Gradient Multiplier - Gradient scalar value.

Gamma - Magnetogyric ratio in SI units (1H default).

Threshold value - data points below this value in the magnitude maps of the individual Q steps will not be represented in the final image.

4.13 References

[1] Research Systems Inc. 2995 Wilderness Place, Boulder, CO 80301, USA.
[2] Principles of Nuclear Magnetic Resonance Microscopy, P. T. Callaghan, Clarendon Press, Oxford.

Chapter 5 Programming using RI Advanced Image Display

5.1 Introduction

RI Advanced Image display allows users to create their own functions and implement them within the IDL environment. User functions may be accessed from the Modify menu.

Once user functions have been created, a new version of the IDL RI Advanced Image Display binary may be compiled, incorporating the new user functions.

5.2 IDL Source Files

A number of source files are released with the RI Advanced Image display binary:

MRI.pro - A list of MRI functions used within the Advanced Image Display Software.

common.pro - Contains all the common variables used by the software, along with a description of each variable.

user.pro - the .pro file where the user functions should be written.

info.txt - A list of useful routines that may be incorporated into user subroutines.

5.3 Variables used in RI Advanced Image Display

In order to perform useful tasks using RI Advanced Image Display, the user must access common variables where data is stored.

The main data arrays are as follows:

currentraw - The currently displayed raw (un FFT'd) data. The data matrix will have dimensions dimx or dimy.

Currentfft - The currently displayed FFT data. The data matrix will have dimensions dimx or dimy.

RawDataC - The currently loaded rawdata. The data matrix will have dimensions dimx by dimy by dimz. RawDataC is a complex array, the individual components are held in RawDataR, RawDataI, RawDataM (Real, imaginary and magnitude components respectively).

FFTDataC - The currently loaded fftdata. The data matrix will have dimensions dimx by dimy by dimz. FFTDataC is a complex array, the individual components are held in FFTDataR, FFTDataI, FFTDataM (Real, imaginary and magnitude components respectively).

ResultData - Array which holds the result of the last processing calculation (dimx, dimy).

5.4 Example Program

The following program adds all the slices of a 3D data set into a single slice, which is placed in the result buffer, then displayed.

```
; User Function 1

Pro UserFunction1

; User Function Number 1 Here

COMMON NMRPar
COMMON Data
```

```
COMMON System

result=fltarr(dimx,dimy)

for n=0,dimz-1 do begin result=result+FFTDataM[*,*,n] endfor

Datatype=resultdata
Updatedisplay

END
```

Three common blocks are declared at the beginning of the program, NMRPar, which contains the values of dimx, dimy and dimz, data (which contains the arrays result and FTTDataM which contains the magnitude of the currently FFT'd data set) and System which contains the variables datatype and resultdata.

First the result array is defined, next a loop adds the contents of the FFTData array into the result array. Finally the display type is switched to display the result buffer and the display updated to show the result buffer on screen.

5.5 Compiling RI Advanced Image Display User Functions

To compile a user function run RI Advanced Image Display as usual, then select Interactive from the Edit menu. Load in the file user.pro and make the necessary modifications, then compile the user.pro file using the Run menu. Return to RI Advanced Image display by typing .CONT and operate the required user function from the modify menu.

Chapter 6 MARAN Ultra Imaging Pulse Sequences

6.1 Introduction

This Chapter describes the imaging sequences supplied as standard with Oxford Instruments MARAN Ultra imaging systems.

The pulse sequences supplied are:

IMAGESET: A 1D profiling sequence that allows users to calibrate read gradient strengths and set up basic parameters in preparation for imaging experiments. This pulse sequence differs from the standard PROFILE pulse sequence in the respect that its parameters are directly compatible with the IMAG90XY, IMAG90XZ and T190XY pulse sequences.

SL90XYZ: A slice select sequence that allows users to set up slice select parameters such as RF pulse lengths, slice select gradient strengths and RF pulse amplitudes.

IMAG90XY: An imaging sequence for performing a T2 weighted image in the XY plane (X gradient read, Y gradient phase, Z gradient slice) using a slice selective 90 degree pulse.

IMAG90XZ: An imaging sequence for performing a T2 weighted image in the XZ (X gradient read, Z gradient phase, Y gradient slice) using a slice selective 90 degree pulse.

T190XY: An imaging sequence for performing a T1 weighted image in the XY plane (X gradient read, Y gradient phase, Z gradient slice) using a slice selective 90 degree pulse.

MULSLXY: An imaging sequence for performing multi-slice acquisitions in the XY plane.

MULSLXZ: An imaging sequence for performing mult-slice acquisitions in the XZ plane.

MULECHXY: An imaging sequence for performing multi-echo acquisitions in the XY plane.

MULECHXZ: An imaging sequence for performing multi-echo acquisitions in the XZ plane.

Users should refer to the notes section at the end of each pulse sequence description for more information on individual imaging sequences.

Three pulse shapes are supplied in the C:\Program Files\Resonance\RINMR\Shape directory. The pulse shapes are:

GAUSS256 - 256 point Gaussian function.
5SINC256 - 256 point 5 lobe sinc function.
7SINC256 - 256 point 7 lobe sinc function.

IMAGESET

Introduction

The IMAGESET pulse sequence allows the user to set up an imaging sequence on the instrument using a 1D profile. The IMAGESET program is identical to the 1D profiling sequence PROFILE, but uses parameters compatible with the imaging sequences.

Parameters

Parameter	Description
P90	90 Degree Pulse (us)
P180	180 Degree Pulse (us)
Dead1	Probe Dead Time (us)
Dead2	Receiver Dead Time (us)
SF	Spectrometer Frequency (MHz)
O1	Offset from SF (Hz)
FW	Filter Width (Hz)
DW	Dwell Time (us)
SI	Size of Acquisition Buffer (points)
NS	Number of Scans
RG	Receiver Gain (%)
RD	Relaxation Delay (us)
TAU	90-180 Degree Pulse Gap (us)
D1	Pre Slice Select Delay (us)
D2	Slice Rephase Delay (us)
D3	Read Gradient Pulse Duration (diphase) (us)
D4	Pre Acquisition Settle Time (us)
G3	Read Gradient Pulse Amplitude (diphase) (-32768 to + 32767)
G5	Read Gradient Pulse Amplitude (rephase) (-32768 to +32767)
GX	Read Gradient Pulse Scalar (0 to 32767)
GY	Read Gradient Pulse Scalar (0 to 32767)
GZ	Read Gradient Pulse Scalar (0 to 32767)
PH1	90 Degree Pulse Phase List (rec: 0213)
PH2	Receiver Phase List (rec: 0213)
PH3	180 Degree Pulse Phase List (rec: 1122)
DS	Dummy Scans
RFA0	RFA0 RF Amplitude

Notes

The gradient strength is given by the expression:

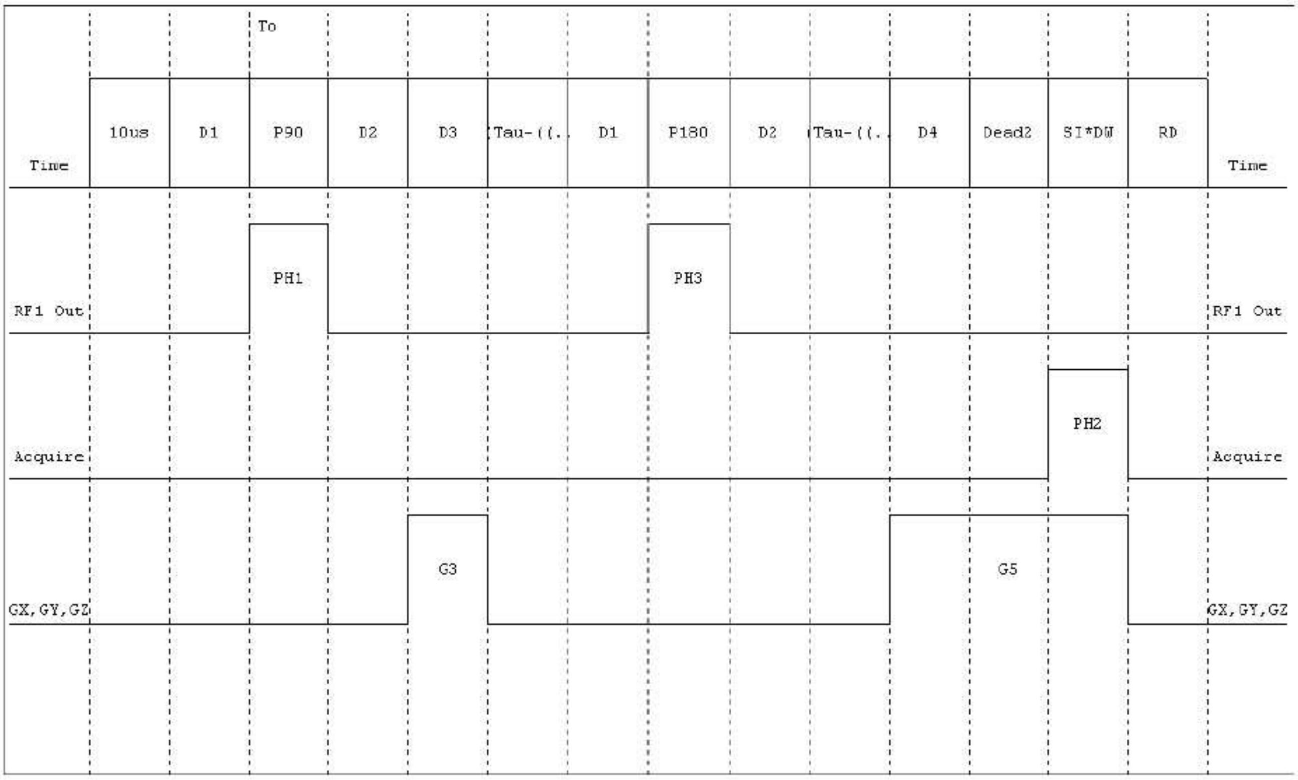
$$Output\ Gradient\ Strength = \frac{GN \times G1}{32768^2}\ GMax$$

where GMAX is the maximum output strength of the gradient amplifier, GN (where n may equal X, Y or Z) is the gradient scalar value and G1 is the gradient pulse amplitude.

Either the X, Y or Z gradient may be used as the read gradient.

OIMBL recommends that the DEGAUSS macro is run after IMAGESET experiments to restore magnet homogeneity.

Timing Diagram



SL90XYZ

Introduction

The SL90XYZ pulse sequence allows the user to check slice excitation widths and set the correct slice select pulse amplitude.

Parameters

Parameter	Description
P180	180 Degree Pulse (us)
Dead1	Probe Dead Time (us)
Dead2	Receiver Dead Time (us)
SF	Spectrometer Frequency (MHz)
O1	Offset from SF (Hz)
FW	Filter Width (Hz)
DW	Dwell Time (us)
SI	Size of Acquisition Buffer (points)
NS	Number of Scans
RG	Receiver Gain (%)
P1	Slice Select Pulse Length (us)
RD	Relaxation Delay (us)
TAU	90-180 Degree Pulse Gap (us)
D1	Pre Slice Select Delay (us)

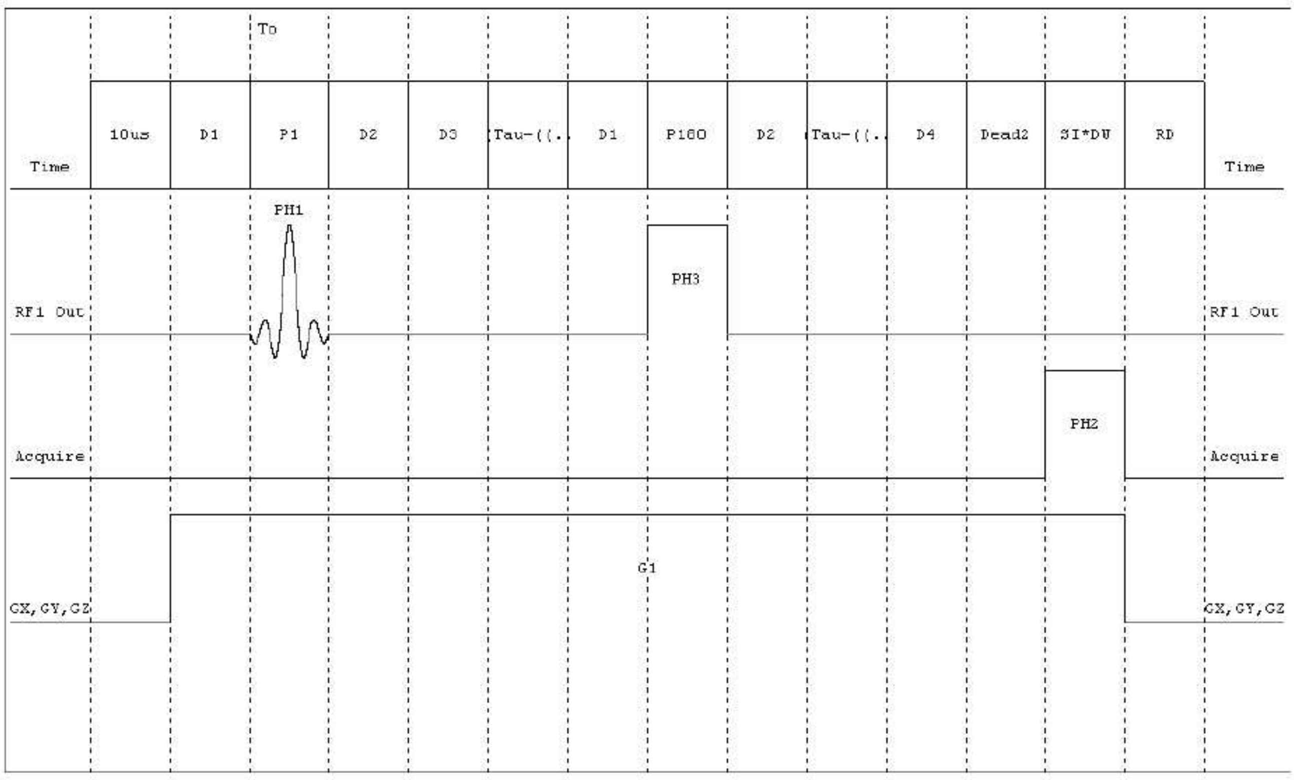
D2	Slice Rephase Delay (us)
D3	Read Gradient Pulse Duration (diphase) (us)
D4	Pre Acquisition Settle Time (us)
G1	Slice Gradient Pulse Amplitude (-32768 to +32767)
GX	Slice Gradient Pulse Scalar (0 to 32767)
GY	Slice Gradient Pulse Scalar (0 to 32767)
GZ	Slice Gradient Pulse Scalar (0 to 32767)
PH1	90 Degree Pulse Phase List (rec: 0213)
PH2	Receiver Phase List (rec: 0213)
PH3	180 Degree Pulse Phase List (rec: 1122)
DS	Dummy Scans
RFA0	RF Amplitude (180 Degree Pulse) (%)
RFA1	RF Amplitude (90 Degree Pulse (Slice Select (%)
SH1	90 Degree Pulse (Slice Select) Shape

Notes

Either the X, Y or Z gradient may be used as the slice select gradient.

OIMBL recommends that the DEGAUSS macro is run after SL90XYZ experiments to restore magnet homogeneity.

Timing Diagram



IMAG90XY

Introduction

The IMAG90XY pulse sequence allows the user to conduct imaging sequences in the XY plane (X gradient read, Y gradient phase and Z gradient slice).

Parameters

Parameter	Description
P180	180 Degree Pulse (us)
Dead1	Probe Dead Time (us)
Dead2	Receiver Dead Time (us)
SF	Spectrometer Frequency (MHz)
O1	Offset from SF (MHz)
FW	Filter Width (Hz)
DW	Dwell Time (us)
SI	Size of Acquisition Buffer (points)
NS	Number of Scans
RG	Receiver Gain (%)
P1	Slice Select Pulse Length (us)
RD	Relaxation Delay (us)
TAU	90-180 Degree Pulse Gap (us)
D1	Pre Slice Select Delay (us)
D2	Slice Rephase Delay (us)
D3	Read Gradient Pulse Duration (diphase) (us)
D4	Pre Acquisition Settle Time (us)
G1	Slice Gradient Pulse Amplitude (-32768 to +32767)
G2	Slice Rephase Gradient Pulse Amplitude (-32768 to +32767)
G3	Rear Gradient Pulse Amplitude (dephase) (-32768 to +32767)
IG4	Number of Phase Encode Steps (image matrix size in phase encode direction)
G5	Read Gradient Pulse Amplitude (rephase) (-32768 to +32767)
GX	Read Gradient Pulse Scalar (0 to 32767)
GY	Phase Gradient Pulse Scalar (0 to 32767)
GZ	Slice Gradient Pulse Scalar (0 to 32767)
PH1	90 Degree Pulse Phase List (rec: 0213)
PH2	Receiver Phase List (rec: 0213)
PH3	180 Degree Pulse Phase List (rec: 1122)
DS	Dummy Scans
RFA0	RF Amplitude (180 Degree Pulse) (%)
RFA1	RF Amplitude (90 Degree Pulse (Slice Select)) (%)
SH1	90 Degree Pulse (Slice Select) Shape

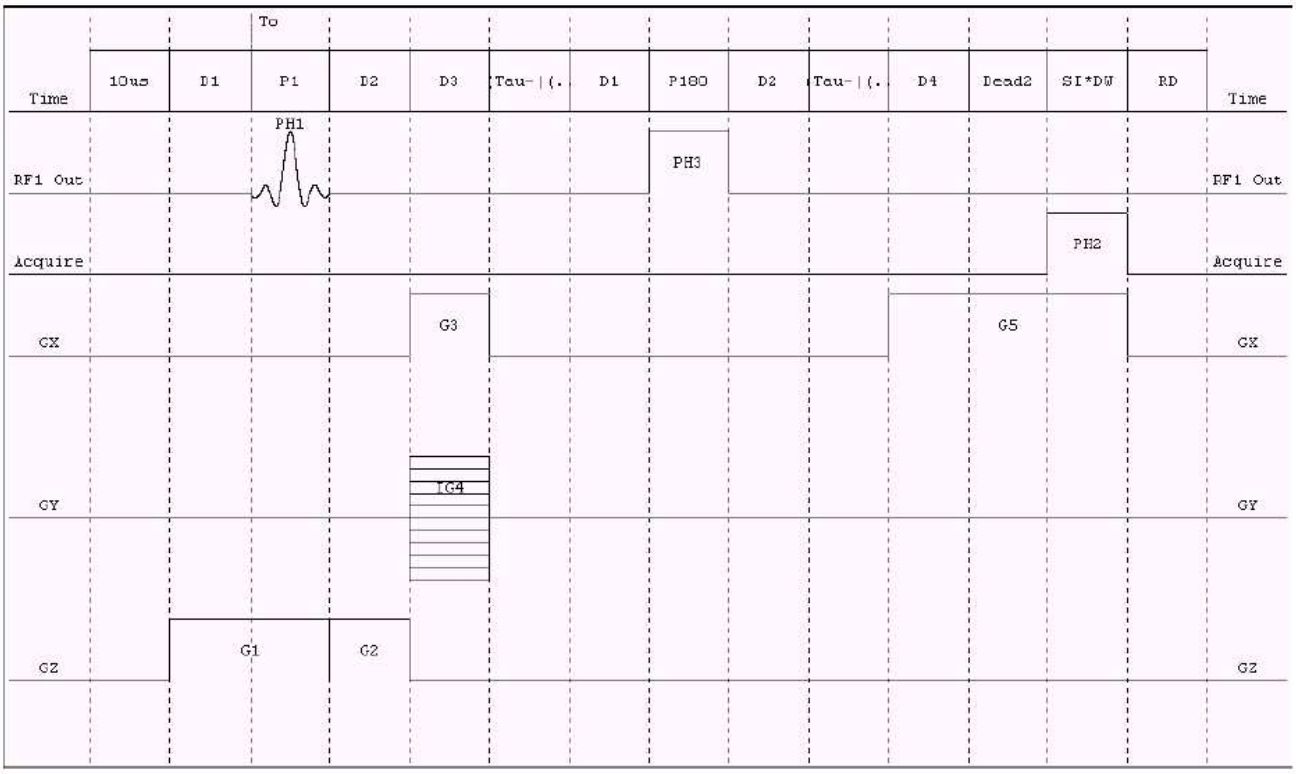
Notes

In interactive setup mode (GS or GS1) the pulse sequence runs with GY set to zero (i.e. no phase encode gradient is applied).

The magnitude of the phase encode gradient applied is totally governed by GY. The number of phase encode steps used is defined by IG4. The pulse sequence will perform an imaging experiment with IG4 phase encode steps, ranging from GY to -GY.

OIMBL recommends that the DEGAUSS macro is run after IMAG90XY experiments to restore the magnet homogeneity.

Timing Diagram



IMAG90XZ

Introduction

The IMAG90XZ pulse sequence allows the user to conduct an imaging experiment in the XZ plane (X gradient read, Z gradient phase and Y gradient slice).

Parameters

Parameter	Description
P180	180 Degree Pulse (us)
Dead1	Probe Dead Time (us)
Dead2	Receiver Dead Time (us)
SF	Spectrometer Frequency (MHz)
O1	Offset from SF (MHz)
FW	Filter Width (Hz)
DW	Dwell Time (us)
SI	Size of Acquisition Buffer (points)
NS	Number of Scans
RG	Receiver Gain (%)
P1	Slice Select Pulse Length (us)
RD	Relaxation Delay (us)

TAU	90-180 Degree Pulse Gap (us)
D1	Pre Slice Select Delay (us)
D2	Slice Rephase Delay (us)
D3	Read Gradient Pulse Duration (diphase) (us)
D4	Pre Acquisition Settle Time (us)
G1	Slice Gradient Pulse Amplitude (-32768 to +32767)
G2	Slice Rephase Gradient Pulse Amplitude (-32768 to +32767)
G3	Read Gradient Pulse Amplitude (dephase) (-32768 to +32767)
IG4	Number of Phase Encode Steps (image matrix size in phase encode direction)
G5	Read Gradient Pulse Amplitude (rephase) (-32768 to +32767)
GX	Read Gradient Pulse Scalar (0 to 32767)
GY	Phase Gradient Pulse Scalar (0 to 32767)
GZ	Slice Gradient Pulse Scalar (0 to 32767)
PH1	90 Degree Pulse Phase List (rec: 0213)
PH2	Receiver Phase List (rec: 0213)
PH3	180 Degree Pulse Phase List (rec: 1122)
DS	Dummy Scans
RFA0	RF Amplitude (180 Degree Pulse) (%)
RFA1	RF Amplitude (90 Degree Pulse (Slice Select)) (%)
SH1	90 Degree Pulse (Slice Select) Shape

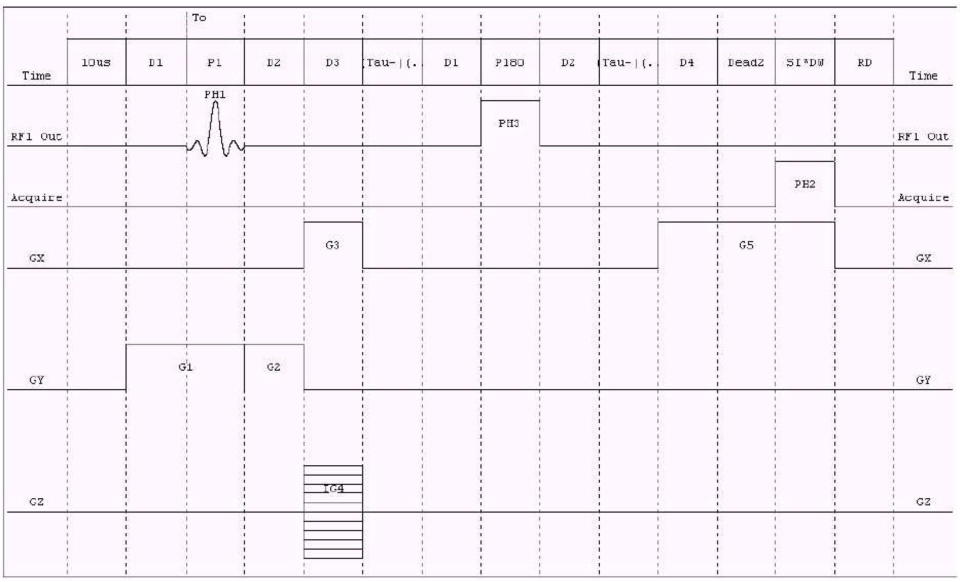
Notes

In interactive setup mode (GS or GS1) the pulse sequence runs with GZ set to zero (i.e. no phase encode gradient is applied).

The magnitude of the phase encode gradient applied is totally governed by GY. The number of phase encode steps used is defined by IG4. The pulse sequence will perform an imaging experiment with IG4 phase encode steps, ranging from GZ to -GZ.

OIMBL recommends that the DEGAUSS macro is run after IMAG90XZ experiments to restore the magnet homogeneity.

Timing Diagram



T190XY

Introduction

The T190XY pulse sequence allows the user to conduct T1 weighted imaging sequences in the XY plane (X gradient read, Y gradient phase and Z gradient slice). The imaging sequence is preceded by an inversion pulse which is used to provide the T1 weighting.

Parameters

Parameter	Description
P180	180 Degree Pulse (inversion and imaging) (us)
Dead1	Probe Dead Time (us)
Dead2	Receiver Dead Time (us)
SF	Spectrometer Frequency (MHz)
O1	Offset from SF (MHz)
FW	Filter Width (Hz)
DW	Dwell Time (us)
SI	Size of Acquisition Buffer (points)
NS	Number of Scans
RG	Receiver Gain (%)
P1	Slice Select Pulse Length (us)
RD	Relaxation Delay (us)
TAU	90-180 Degree Pulse Gap (us)
D1	Pre Slice Select Delay (us)
D2	Slice Rephase Delay (us)
D3	Read Gradient Pulse Duration (dephase) (us)
D4	Pre Acquisition Settle Time (us)
D5	Inversion Gap (us)
G1	Slice Gradient Pulse Amplitude (-32768 to +32767)
G2	Slice Rephase Gradient Pulse Amplitude (-32768 to +32767)
G3	Read Gradient Pulse Amplitude (diphase) (-32768 to +32767)
IG4	Number of Phase Encode Steps (image matrix size in phase encode direction)
G5	Read Gradient Pulse Amplitude (rephase) (-32768 to +32767)
GX	Read Gradient Pulse Scalar (0 to 32767)
GY	Phase Gradient Pulse Scalar (0 to 32767)
GZ	Slice Gradient Pulse Scalar (0 to 32767)
PH1	90 Degree Pulse Phase List (rec: 0213)
PH2	Receiver Phase List (rec: 0213)
PH3	180 Degree Pulse Phase List (Imaging) (rec: 1122)
PH4	180 Degree Pulse Phase List (Inversion) (rec: 1111)
DS	Dummy Scans
RFA0	RF Amplitude (180 Degree Pulse) (%)
RFA1	RF Amplitude (90 Degree Pulse (Slice Select)) (%)
SH1	90 Degree Pulse (Slice Select) Shape

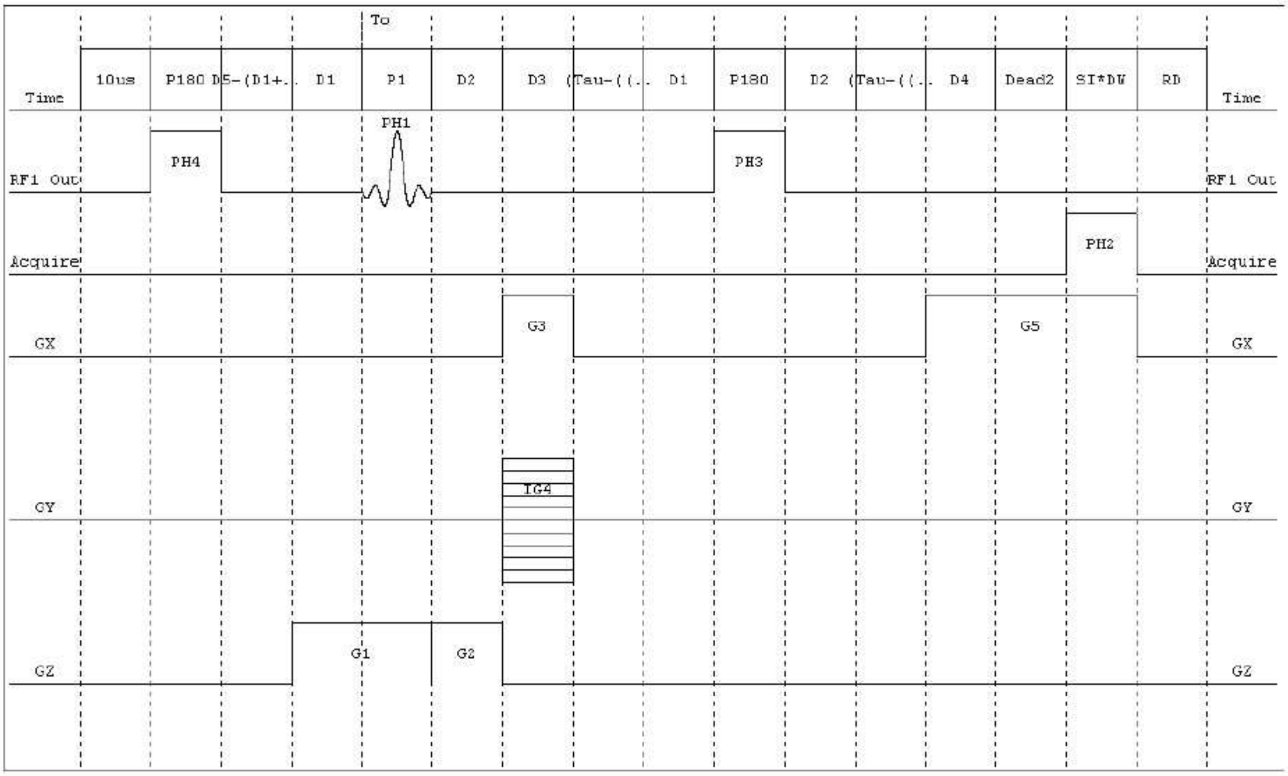
Notes

In interactive setup mode (GS or GS1) the pulse sequence runs with GY set to zero (i.e. no phase encode gradient is applied).

The magnitude of the phase encode gradient applied is totally governed by GY. The number of phase encode steps used is defined by IG4. The pulse sequence will perform an imaging experiment with IG4 phase encode steps, ranging from GY to -GY.

OIMBL recommends that the DEGAUSS macro is run after T190XY experiments to restore the magnet homogeneity.

Timing Diagram



MULSLXY

Introduction

The MULSLXY pulse sequence allows the user to conduct multi slice experiments in the XY plane (X gradient read, Y gradient phase and Z gradient slice).

Parameters

Parameter	Description
Dead2	Receiver Dead Time (us)
SF	Spectrometer Frequency (MHz)
O1	Offset from SF (MHz)
FW	Filter Width (Hz)
DW	Dwell Time (us)
SI	Size of Acquisition Buffer (points)
NS	Number of Scans
RG	Receiver Gain (%)

P1	90 Degree Pulse Length (us)
P2	180 Degree Pulse Length (us)
RD	Relaxation Delay (us)
TAU	90-180 Degree Pulse Gap (us)
D1	Pre Slice Select Delay (us)
D2	Slice Rephase Delay (us)
D3	Read Gradient Pulse Duration (dephase) (us)
D4	Pre Acquisition Settle Time (us)
G1	90 Degree Pulse Slice Gradient Pulse Amplitude (-32768 to +32767)
G2	90 Degree Pulse Slice Rephase Gradient Pulse Amplitude (-32768 to +32767)
G3	Read Gradient Pulse Amplitude (dephase) (-32768 to +32767)
IG4	Number of Phase Encode Steps (image matrix size in phase encode direction)
G5	Read Gradient Pulse Amplitude (rephase) (-32768 to +32767)
G6	180 Degree Pulse Slice Rephase Gradient (-32768 to +32767)
GX	Read Gradient Pulse Scalar (0 to 32767)
GY	Phase Gradient Pulse Scalar (0 to 32767)
GZ	Slice Gradient Pulse Scalar (0 to 32767)
PH1	90 Degree Pulse Phase List (rec: 0213)
PH2	Receiver Phase List (rec: 0213)
PH3	180 Degree Pulse Phase List (rec: 1122)
DS	Dummy Scans
RFA1	RF Amplitude (90 Degree Pulse, %)
RFA2	RF Amplitude (180 Degree Pulse, %)
SH1	90 Degree Pulse Shape
SH2	180 Degree Pulse Shape
C1	Number of Slices
C2	Slice Frequency Increment (Hz)
D9	Slice Repetition Time

Notes

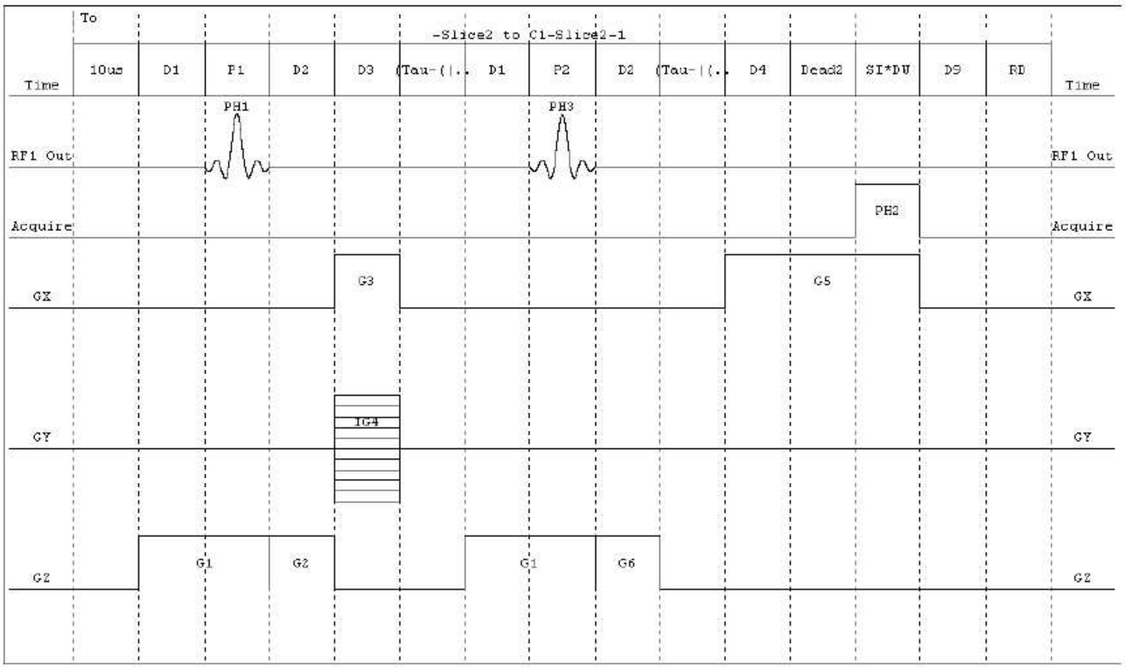
In interactive setup mode (GS or GS1) the pulse sequence runs with GY set to zero (i.e. no phase encode gradient is applied).

The magnitude of the phase encode gradient applied is totally governed by GY. The number of phase encode steps used is defined by IG4. The pulse sequence will perform an imaging experiment with IG4 phase encode steps, ranging from GY to -GY.

OIMBL recommends that the DEGAUSS macro is run after MULSLICE experiments to restore the magnet homogeneity.

Both the 90 degree and 180 degree pulses are slice selective.

Timing Diagram



MULSLXZ

Introduction

The MULSLXZ pulse sequence allows the user to conduct multi slice experiments in the XZ plane (X gradient read, Z gradient phase and Y gradient slice).

Parameters

Parameter	Description
Dead2	Receiver Dead Time (us)
SF	Spectrometer Frequency (MHz)
O1	Offset from SF (MHz)
FW	Filter Width (Hz)
DW	Dwell Time (us)
SI	Size of Acquisition Buffer (points)
NS	Number of Scans
RG	Receiver Gain (%)
P1	90 Degree Pulse Length (us)
P2	180 Degree Pulse Length (us)
RD	Relaxation Delay (us)
TAU	90-180 Degree Pulse Gap (us)
D1	Pre Slice Select Delay (us)
D2	Slice Rephase Delay (us)
D3	Read Gradient Pulse Duration (dephase) (us)
D4	Pre Acquisition Settle Time (us)
G1	90 Degree Pulse Slice Gradient Pulse Amplitude (-32768 to +32767)
G2	90 Degree Pulse Slice Rephase Gradient Pulse Amplitude (-32768 to +32767)

G3	Read Gradient Pulse Amplitude (dephase) (-32768 to +32767)
IG4	Number of Phase Encode Steps (image matrix size in phase encode direction)
G5	Read Gradient Pulse Amplitude (rephase) (-32768 to +32767)
G6	180 Degree Pulse Slice Rephase Gradient (-32768 to +32767)
GX	Read Gradient Pulse Scalar (0 to 32767)
GY	Phase Gradient Pulse Scalar (0 to 32767)
GZ	Slice Gradient Pulse Scalar (0 to 32767)
PH1	90 Degree Pulse Phase List (rec: 0213)
PH2	Receiver Phase List (rec: 0213)
PH3	180 Degree Pulse Phase List (rec: 1122)
DS	Dummy Scans
RFA1	RF Amplitude (90 Degree Pulse, %)
RFA2	RF Amplitude (180 Degree Pulse, %)
SH1	90 Degree Pulse Shape
SH2	180 Degree Pulse Shape
C1	Number of Slices
C2	Slice Frequency Increment (Hz)
D9	Slice Repetition Time

Notes

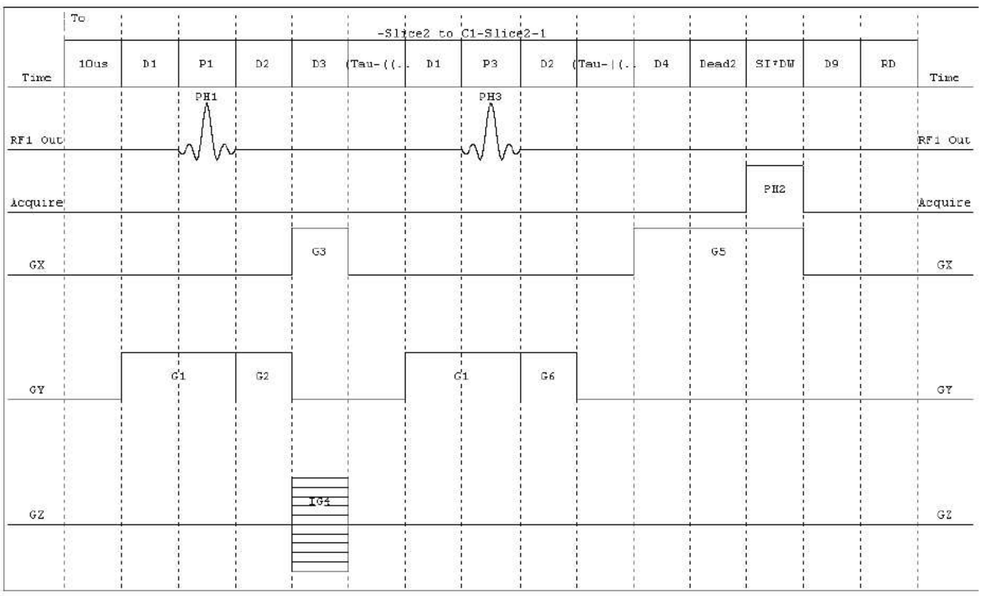
In interactive setup mode (GS or GS1) the pulse sequence runs with GZ set to zero (i.e. no phase encode gradient is applied).

The magnitude of the phase encode gradient applied is totally governed by GZ. The number of phase encode steps used is defined by IG4. The pulse sequence will perform an imaging experiment with IG4 phase encode steps, ranging from GZ to -GZ.

OIMBL recommends that the DEGAUSS macro is run after MULSLICE experiments to restore the magnet homogeneity.

Both the 90 degree and 180 degree pulses are slice selective.

Timing Diagram



MULECHXY

Introduction

The MULECHXY pulse sequence allows the user to acquire multi echo experiments in the XY plane (X gradient read, Y gradient phase and Z gradient slice).

Parameters

Parameter	Description
P180	180 Degree Pulse (us)
Dead1	Probe Dead Time (us)
Dead2	Receiver Dead Time (us)
SF	Spectrometer Frequency (MHz)
O1	Offset from SF (MHz)
FW	Filter Width (Hz)
DW	Dwell Time (us)
SI	Size of Acquisition Buffer (points)
NS	Number of Scans
RG	Receiver Gain (%)
P1	Slice Select Pulse Length (us)
RD	Relaxation Delay (us)
NECH	Number of Echoes
TAU	90-180 Degree Pulse Gap (us)
D1	Pre Slice Select Delay (us)
D2	Slice Rephase Delay (us)
D3	Read Gradient Pulse Duration (dephase) (us)
D4	Pre Acquisition Settle Time (us)
D5	Crusher Gradient Duration (us)
G1	Slice Gradient Pulse Amplitude (-32768 to +32767)
G2	Slice Rephase Gradient Pulse Amplitude (-32768 to +32767)
G3	Read Gradient Pulse Amplitude (dephase) (-32768 to +32767)
IG4	Number of Phase Encode Steps (image matrix size in phase encode direction)
G5	Read Gradient Pulse Amplitude (rephase) (-32768 to +32767)
G6	Crusher Gradient Start Value (-32768 to +32767)
G7	Read Gradient (pad) (-32767 to 32768)
GX	Read Gradient Pulse Scalar (0 to 32767)
GY	Phase Gradient Pulse Scalar (0 to 32767)
GZ	Slice Gradient Pulse Scalar (0 to 32767)
PH1	90 Degree Pulse Phase List (rec: 0213)
PH2	Receiver Phase List (rec: 0213)
PH3	180 Degree Pulse Phase List (rec: 1122)
DS	Dummy Scans
RFA0	RF Amplitude (180 Degree Pulse) (%)
RFA2	RF Amplitude (90 Degree Pulse) (%)
SH1	90 Degree Pulse Shape
C1	Crusher Gradient Increment

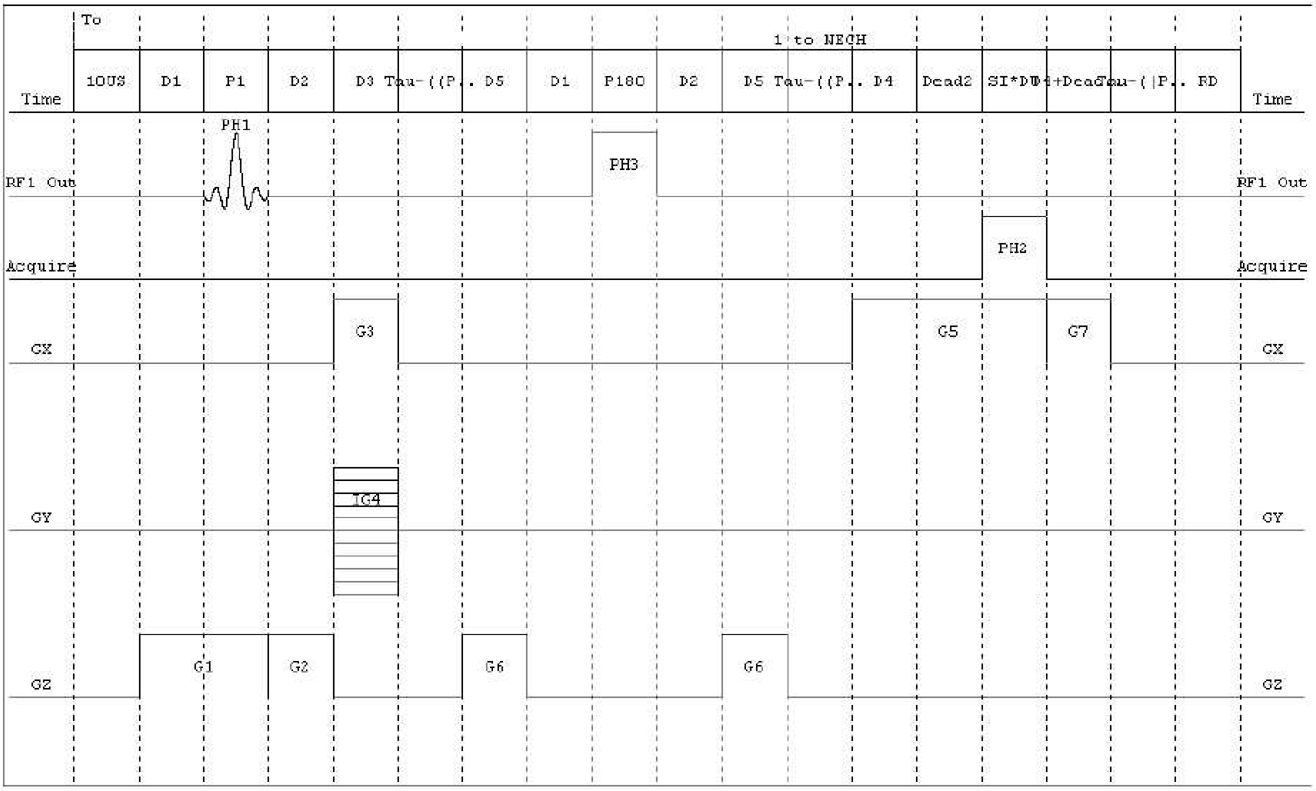
Notes

In interactive setup mode (GS or GS1) the pulse sequence runs with GY set to zero (i.e. no phase encode gradient is applied).

The magnitude of the phase encode gradient applied is totally governed by GY. The number of phase encode steps used is defined by IG4. The pulse sequence will perform an imaging experiment with IG4 phase encode steps, ranging from GY to -GY.

OIMBL recommends that the DEGAUSS macro is run after MULECHXY experiments to restore the magnet homogeneity.

Timing Diagram



MULECHXZ

Introduction

The MULECHXY pulse sequence allows the user to acquire multi echo experiments in the XZ plane (X gradient read, Z gradient phase and Y gradient slice).

Parameters

Parameter	Description
P180	180 Degree Pulse (us)
Dead1	Probe Dead Time (us)
Dead2	Receiver Dead Time (us)
SF	Spectrometer Frequency (MHz)
O1	Offset from SF (MHz)
FW	Filter Width (Hz)

DW	Dwell Time (us)
SI	Size of Acquisition Buffer (points)
NS	Number of Scans
RG	Receiver Gain (%)
P1	Slice Select Pulse Length (us)
RD	Relaxation Delay (us)
NECH	Number of Echoes
TAU	90-180 Degree Pulse Gap (us)
D1	Pre Slice Select Delay (us)
D2	Slice Rephase Delay (us)
D3	Read Gradient Pulse Duration (dephase) (us)
D4	Pre Acquisition Settle Time (us)
D5	Crusher Gradient Duration (us)
G1	Slice Gradient Pulse Amplitude (-32768 to +32767)
G2	Slice Rephase Gradient Pulse Amplitude (-32768 to +32767)
G3	Read Gradient Pulse Amplitude (dephase) (-32768 to +32767)
IG4	Number of Phase Encode Steps (image matrix size in phase encode direction)
G5	Read Gradient Pulse Amplitude (rephase) (-32768 to +32767)
G6	Crusher Gradient Start Value (-32768 to +32767)
G7	Read Gradient (pad) (-32767 to 32768)
GX	Read Gradient Pulse Scalar (0 to 32767)
GY	Slice Gradient Pulse Scalar (0 to 32767)
GZ	Phase Gradient Pulse Scalar (0 to 32767)
PH1	90 Degree Pulse Phase List (rec: 0213)
PH2	Receiver Phase List (rec: 0213)
PH3	180 Degree Pulse Phase List (rec: 1122)
DS	Dummy Scans
RFA0	RF Amplitude (180 Degree Pulse) (%)
RFA2	RF Amplitude (90 Degree Pulse) (%)
SH1	90 Degree Pulse Shape
C1	Crusher Gradient Increment

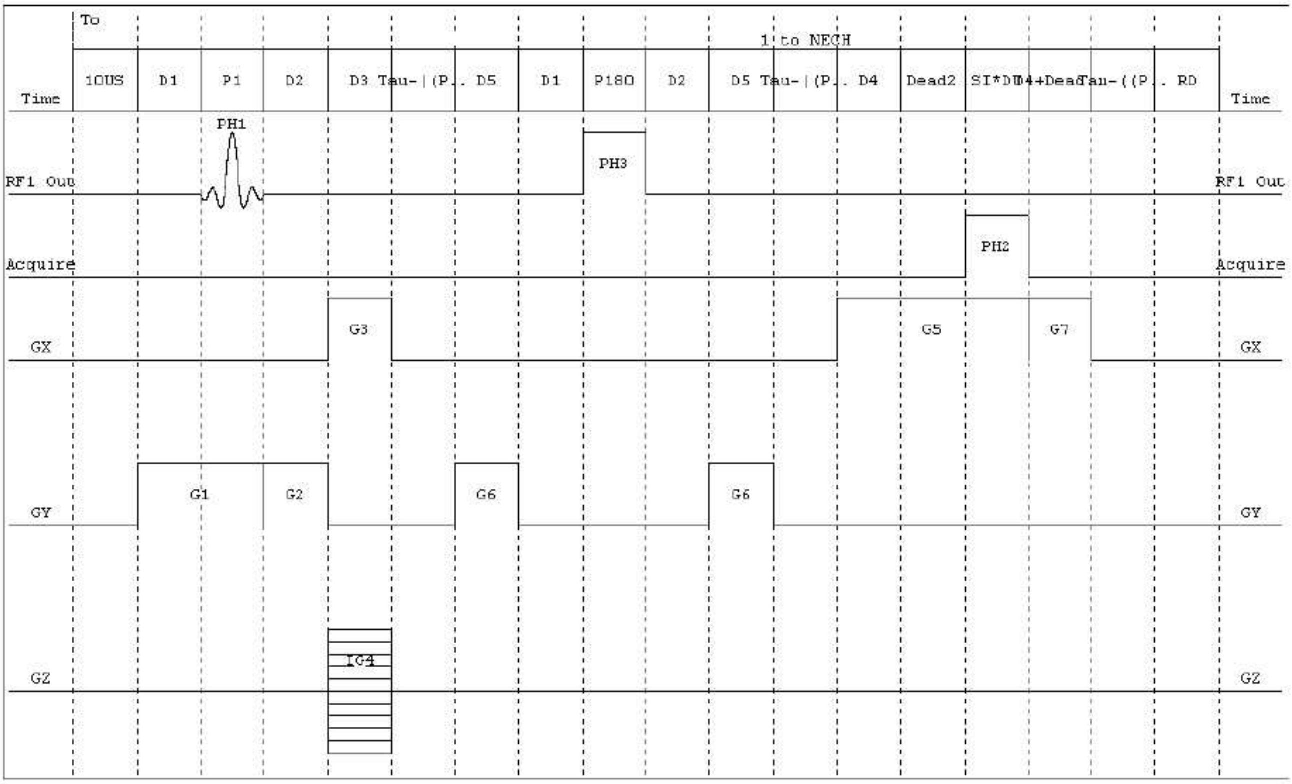
Notes

In interactive setup mode (GS or GS1) the pulse sequence runs with GZ set to zero (i.e. no phase encode gradient is applied).

The magnitude of the phase encode gradient applied is totally governed by GZ. The number of phase encode steps used is defined by IG4. The pulse sequence will perform an imaging experiment with IG4 phase encode steps, ranging from GZ to -GZ.

OIMBL recommends that the DEGAUSS macro is run after MULECHXZ experiments to restore the magnet homogeneity.

Timing Diagram



Chapter 7 MARAN DRX (Digital) Imaging Pulse Sequences

7.1 Introduction

This Chapter describes the imaging sequences supplied as standard with OIMBL MARAN DRX (Digital) imaging systems.

The pulse sequences supplied are:

IMAGESET: A 1D profiling sequence that allows users to calibrate read gradient strengths and set up basic parameters in preparation for imaging experiments. This pulse sequence differs from the standard PROFILE pulse sequence in the respect that its parameters are directly compatible with the IMAG90XY, IMAG90XZ and T190XY pulse sequences.

SLICESET: A slice select sequence that allows users to set up slice select parameters such as RF pulse lengths, slice select gradient strengths and RF pulse amplitudes.

HARDIMAG: An imaging sequence using non slice selective RF pulses.

IMAG90: An imaging sequence for performing a T2 weighted image using a slice selective 90 degree pulse and a hard 180 degree pulse.

MULSLICE: A multi slice imaging sequence with soft 90 and 180 degree pulses.

GRADECHO: A gradient echo imaging sequence with a slice selective 90 degree pulse.

SPIN3D: A 3D spin echo imaging sequence.

FSE: An FSE multi slice imaging sequence with Melki phase encode sampling.

Users should refer to the notes section at the end of each pulse sequence description for more information on individual imaging sequences.

Three pulse shapes are supplied in the C:\Program Files\Resonance\RINMR\Shape directory. The pulse shapes are:

GAUSS256 - 256 point Gaussian function.
5SINC256 - 256 point 5 lobe sinc function.
7SINC256 - 256 point 7 lobe sinc function.

IMAGESET

```
-System
P90         90 Degree Pulse (us)
P180        180 Degree Pulse (us)
SF          Spectrometer Frequency (MHz)
O1          Offset from SF (Hz)
-Application
SW          Sweep Width (Hz)
SI          Size of Acquisition Buffer (points)
NS          Number of Scans
DS          Dummy Scans
RG          Receiver Gain (%)
```

```
RD          Relaxation Delay (us)
TAU         90-180 Degree Pulse gap (us)
D1          Slice Gradient Settle Duration (us)
D2          Slice Gradient Rephase Duration (us)
D3          Dephase Duration (Phase and Read) (us)
D4          Pre Acquisition Settle Duration (us)
PH1         90 Degree Pulse Phase List
PH2         Receiver Phase List
PH3         180 Degree Pulse Phase List
GRead       Read Gradient Scalar (0 to +32767)
GReadX      Amount of X Gradient in Read (-1 to 1)
GReadY      Amount of Y Gradient in Read (-1 to 1)
GReadZ      Amount of Z Gradient in Read (-1 to 1)
G3          Read Gradient (dephase) (-32768 to +32767)
G5          Read Gradient (rephase) (-32768 to +32767)
RFA0        RF Amplitude (%)
```

Notes

IMAGESET only applies a gradient along the read axis. The orientation defined as the read axis can be specified using the GreadX, GreadY and GreadZ parameters.

SLICESET

```
-System
P180        180 Degree Pulse (us)
SF          Spectrometer Frequency (MHz)
O1          Offset from SF (Hz)
-Application
P1          90 Degree Pulse Length (us)
SW          Sweep Width (Hz)
SI          Size of Acquisition Buffer (points)
NS          Number of Scans
DS          Dummy Scans
RG          Receiver Gain (%)
RD          Relaxation Delay (us)
TAU         90-180 Degree Pulse gap (us)
D1          Slice Gradient Settle Duration (us)
D2          Slice Gradient Rephase Duration (us)
D3          Dephase Duration (Phase and Read) (us)
D4          Pre Acquisition Settle Duration (us)
PH1         90 Degree Pulse Phase List
PH2         Receiver Phase List
PH3         180 Degree Pulse Phase List
GSlice      Slice Gradient Scalar (0 to +32767)
GSliceX     Amount of X Gradient in Slice (-1 to 1)
GSliceY     Amount of Y Gradient in Slice (-1 to 1)
GSliceZ     Amount of Z Gradient in Slice (-1 to 1)
G1          Slice Gradient (-32768 to +32767)
RFA0        RF Amplitude 90 Degree Pulse (%)
RFA1        RF Amplitude 180 Degree Pulse (%)
SH1         90 Degree Pulse Shape
```

Notes
SLICESET applies a single gradient along the slice gradient axis to allow the user to observe the slice select profile. Only the 90 degree excitation pulse (P1) is slice selective.

HARDIMAG
```
-System
P90         90 Degree Pulse (us)
P180        180 Degree Pulse (us)
SF          Spectrometer Frequency (MHz)
O1          Offset from SF (Hz)
-Application
SW          Sweep Width (Hz)
SI          Size of Acquisition Buffer (points)
NS          Number of Scans
DS          Dummy Scans
RG          Receiver Gain (%)
RD          Relaxation Delay (us)
TAU         90-180 Degree Pulse gap (us)
D1          Slice Gradient Settle Duration (us)
D2          Slice Gradient Rephase Duration (us)
D3          Dephase Duration (Phase and Read) (us)
D4          Pre Acquisition Settle Duration (us)
PH1         90 Degree Pulse Phase List
PH2         Receiver Phase List
PH3         180 Degree Pulse Phase List
GRead       Read Gradient Scalar (0 to +32767)
GPhase      Phase Gradient Scalar (0 to +32767)
GReadX      Amount of X Gradient in Read (-1 to 1)
GReadY      Amount of Y Gradient in Read (-1 to 1)
GReadZ      Amount of Z Gradient in Read (-1 to 1)
GPhaseX     Amount of X Gradient in Phase (-1 to 1)
GPhaseY     Amount of Y Gradient in Phase (-1 to 1)
GPhaseZ     Amount of Y Gradient in Phase (-1 to 1)
G3          Read Gradient (dephase) (-32768 to +32767)
IG4         Number of Phase Gradient Steps
G5          Read Gradient (rephase) (-32768 to +32767)
RFA0        RF Amplitude (%)
```

Notes
A non slice selective imaging sequence.

IMAG90
```
-System
SF          Spectrometer Frequency (MHz)
O1          Offset from SF (Hz)
-Application
P1          90 Degree Pulse Length (us)
SW          Sweep Width (Hz)
SI          Size of Acquisition Buffer (points)
NS          Number of Scans
DS          Dummy Scans
RG          Receiver Gain (%)
```

```
RD          Relaxation Delay (us)
TAU         90-180 Degree Pulse gap (us)
D1          Slice Gradient Settle Duration (us)
D2          Slice Gradient Rephase Duration (us)
D3          Dephase Duration (Phase and Read) (us)
D4          Pre Acquisition Settle Duration (us)
PH1         90 Degree Pulse Phase List
PH2         Receiver Phase List
PH3         180 Degree Pulse Phase List
GRead       Read Gradient Scalar (0 to +32767)
GPhase      Phase Gradient Scalar (0 to +32767)
GSlice      Slice Gradient Scalar (0 to +32767)
GReadX      Amount of X Gradient in Read (-1 to 1)
GReadY      Amount of Y Gradient in Read (-1 to 1)
GReadZ      Amount of Z Gradient in Read (-1 to 1)
GPhaseX     Amount of X Gradient in Phase (-1 to 1)
GPhaseY     Amount of Y Gradient in Phase (-1 to 1)
GPhaseZ     Amount of Y Gradient in Phase (-1 to 1)
GSliceX     Amount of X Gradient in Slice (-1 to 1)
GSliceY     Amount of Y Gradient in Slice (-1 to 1)
GSliceZ     Amount of Z Gradient in Slice (-1 to 1)
G1          Slice Gradient (-32768 to +32767)
G2          Slice Rephase Gradient (-32768 to +32767)
G3          Read Gradient (dephase) (-32768 to +32767)
IG4         Number of Phase Gradient Steps
G5          Read Gradient (rephase) (-32768 to +32767)
RFA0        RF Amplitude 90 Degree Pulse (%)
RFA1        RF Amplitude 180 Degree Pulse (%)
SH1         90 Degree Pulse Shape
```

Notes

A slice selective imaging sequence. Only the initial excitation pulse is slice selective. Use MULSLICE with a single slice (C1=1) if both slice selective 90 and 180 degree pulses are required.

MULSLICE

```
-System
SF          Spectrometer Frequency (MHz)
O1          Offset from SF (Hz)
-Application
P1          90 Degree Pulse Length (us)
P2          180 Degree Pulse Length (us)
SW          Sweep Width (Hz)
SI          Size of Acquisition Buffer (points)
NS          Number of Scans
DS          Dummy Scans
RG          Receiver Gain (%)
RD          Relaxation Delay (us)
TAU         90-180 Degree Pulse gap (us)
D1          Slice Gradient Settle Duration (us)
D2          Slice Gradient Rephase Duration (us)
D3          Dephase Duration (Phase and Read) (us)
D4          Pre Acquisition Settle Duration (us)
```

```
D9          Slice Repetition Time (us)
PH1         90 Degree Pulse Phase List
PH2         Receiver Phase List
PH3         180 Degree Pulse Phase List
GRead       Read Gradient Scalar (0 to +32767)
GPhase      Phase Gradient Scalar (0 to +32767)
GSlice      Slice Gradient Scalar (0 to +32767)
GReadX      Amount of X Gradient in Read (-1 to 1)
GReadY      Amount of Y Gradient in Read (-1 to 1)
GReadZ      Amount of Z Gradient in Read (-1 to 1)
GPhaseX     Amount of X Gradient in Phase (-1 to 1)
GPhaseY     Amount of Y Gradient in Phase (-1 to 1)
GPhaseZ     Amount of Y Gradient in Phase (-1 to 1)
GSliceX     Amount of X Gradient in Slice (-1 to 1)
GSliceY     Amount of Y Gradient in Slice (-1 to 1)
GSliceZ     Amount of Z Gradient in Slice (-1 to 1)
G1          Slice Gradient (-32768 to +32767)
G2          Slice Rephase Gradient (-32768 to +32767)
G3          Read Gradient (dephase) (-32768 to +32767)
IG4         Number of Phase Gradient Steps
G5          Read Gradient (rephase) (-32768 to +32767)
RFA0        RF Amplitude 90 Degree Pulse (%)
RFA1        RF Amplitude 180 Degree Pulse (%)
SH1         90 Degree Pulse Shape
SH2         180 Degree Pulse Shape
C1          Number of Slices
C2          Slice Frequency Increment
```

Notes

A multi slice imaging sequence. The number of slices is controlled by C1. Even slices are placed symmetrically about the centre frequency (SF+O1), Odd slices are placed with a single slice at the centre frequency.

SPIN3D

```
-System
P90         90 Degree Pulse (us)
P180        180 Degree Pulse (us)
SF          Spectrometer Frequency (MHz)
O1          Offset from SF (Hz) -Application
SW          Sweep Width (Hz)
SI          Size of Acquisition Buffer (points)
NS          Number of Scans
DS          Dummy Scans
RG          Receiver Gain (%)
RD          Relaxation Delay (us)
TAU         90-180 Degree Pulse gap (us)
D1          Slice Gradient Settle Duration (us)
D2          Slice Gradient Rephase Duration (us)
D3          Dephase Duration (Phase and Read) (us)
D4          Pre Acquisition Settle Duration (us)
PH1         90 Degree Pulse Phase List
PH2         Receiver Phase List
PH3         180 Degree Pulse Phase List
```

```
GRead       Read Gradient Scalar (0 to +32767)
GPhase      Phase 1 Gradient Scalar (0 to +32767)
GSlice      Phase 2 Gradient Scalar (0 to +32767)
GReadX      Amount of X Gradient in Read (-1 to 1)
GReadY      Amount of Y Gradient in Read (-1 to 1)
GReadZ      Amount of Z Gradient in Read (-1 to 1)
GPhaseX     Amount of X Gradient in Phase 1 (-1 to 1)
GPhaseY     Amount of Y Gradient in Phase 1 (-1 to 1)
GPhaseZ     Amount of Y Gradient in Phase 1 (-1 to 1)
GSliceX     Amount of X Gradient in Phase 2 (-1 to 1)
GSliceY     Amount of Y Gradient in Phase 2 (-1 to 1)
GSliceZ     Amount of Z Gradient in Phase 2 (-1 to 1)
G3          Read Gradient (dephase) (-32768 to +32767)
IG4         Number of Phase 1 Gradient Steps
IG6         Number of Phase 2 Gradient Steps
G5          Read Gradient (rephase) (-32768 to +32767)
RFA0        RF Amplitude (%)
```

Notes
A 3D spin echo imaging sequence. Note that the imaging time is approximately equal to IG4*IG6*NS*RD so acquisitions with NS>1 may lead to extremely long acquisition times.

FSE

```
-System
SF          Spectrometer Frequency (MHz)
O1          Offset from SF (Hz)
-Application
P1          90 Degree Pulse Length (us)
RFA0        RF Amplitude 90 Degree Pulse (%)
PH1         Phase List 90 Degree Pulse
SH1         90 Degree Pulse Shape
P2          180 Degree Pulse Length (us)
RFA1        RF Amplitude 180 Degree Pulse (%)
PH3         Phase List 180 Degree Pulse
SH2         180 Degree Pulse Shape
SW          Sweep Width (Hz)
RG          Receiver Gain (%)
PH2         Phase List Receiver
TAU         Pulse Gap (us)
D1          Slice Gradient Stabilisation Duration (us)
D2          Slice Rephase Gradient Duration (us)
D3          Read Gradient Encode Duration (us)
D4          Phase Gradient Duration (us)
D5          Read Gradient Stabilisation Duration (us)
D7          Slice Crusher Gradient Duration (us)
D9          Slice Repetition Duration (us)
RD          Relaxation Delay (us)
NS          Number of Scans
DS          Dummy Scans
SI          Size of Acquisition Buffer (points)
C1          Number of Echoes (ETL)
C2          Number of Slices
```

```
IG4         Number of Bursts
C3          Slice Crusher Gradient Increment
C4          Slice Frequency Increment (Hz)
GSlice      Slice Gradient Scalar (0 to +32767)
GRead       Read Gradient Scalar (0 to +32767)
GPhase      Phase Gradient Scalar (0 to +32767)
GReadX      Amount of X Gradient in Read (-1 to 1)
GReadY      Amount of Y Gradient in Read (-1 to 1)
GReadZ      Amount of Z Gradient in Read (-1 to 1)
GPhaseX     Amount of X Gradient in Phase (-1 to 1)
GPhaseY     Amount of Y Gradient in Phase (-1 to 1)
GPhaseZ     Amount of Y Gradient in Phase (-1 to 1)
GSliceX     Amount of X Gradient in Slice (-1 to 1)
GSliceY     Amount of Y Gradient in Slice (-1 to 1)
GSliceZ     Amount of Z Gradient in Slice (-1 to 1)
G1          90 Degree Pulse Slice Select Gradient (-32768 to +32767)
G2          90 Degree Pulse Slice Rephase Gradient (-32768 to +32767)
G3          Read Encode Gradient (-32768 to +32767)
G5          Read Decode Gradient (-32768 to +32767)
G7          Read Gradient Balance (-32768 to +32767)
G8          180 Degree Pulse Slice Select Gradient (-32768 to +32767)
G9          180 Degree Pulse Slice Rephase Gradient (-32768 to +32767)
```

Notes

Additional information on the FSE pulse sequence is available from OIMBL.