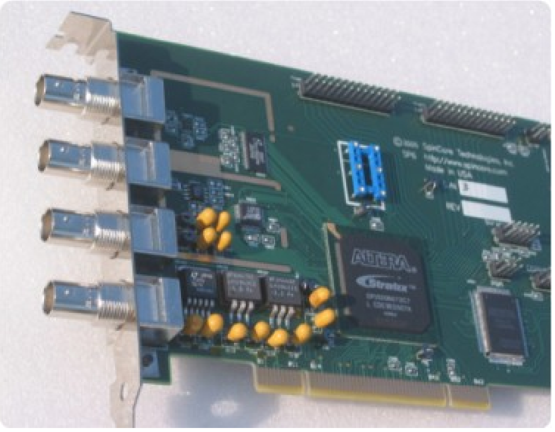
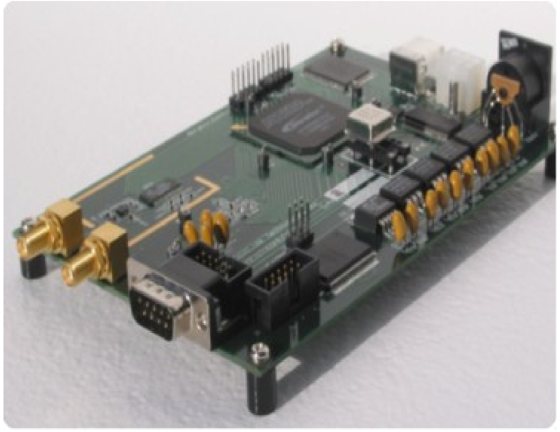
RadioProcessor™

Owner's Manual





SpinCore Technologies, Inc.
http://www.spincore.com

Congratulations and *thank you* for choosing a design from SpinCore Technologies, Inc.

We appreciate your business!

At SpinCore we try to fully support the needs of our customers. If you are in need of assistance, please contact us and we will strive to provide the necessary support.

SpinCore Technologies, Inc. makes every effort to verify the correct operation of the equipment. This equipment version is not intended for use in a system in which the failure of a SpinCore device will threaten the safety of equipment or person(s).

Table of Contents

I. Introduction

Product Overview

The RadioProcessor™ is a general purpose radio frequency (RF) excitation and broadband data acquisition system. The RadioProcessor™ can serve as a complete system for Nuclear Magnetic Resonance (NMR) or Nuclear Quadrupole Resonance (NQR) experiments with spectrometer frequencies from 0 to 100 MHz (certain restrictions apply, vide infra). The system integrates SpinCore's high-performance PulseBlaster™ timing engine for agile control of internal system components as well as TTL pulse/pattern generation for control of any external hardware.

The RadioProcessor™

- Integrates excitation and acquisition components onto a single PCI or USB card.
- Directly captures and digitally demodulates IF/RF signals using quadrature detection. The desired baseband bandwidth is user definable through software filters.
- Generates completely formed RF excitation pulses as well as high resolution digital control signals.
- Supports 2 analog I/O channels and 4 digital output channels.
- Maintains signal coherence between excitation and acquisition systems at all frequencies.
- Autonomously signal-averages the baseband data between multiple acquisitions.
- Saves data in several different formats. Currently supported file formats are ASCII, Felix, and JCAMP-DX 5.0.

This unique digital system is housed on a small form factor printed-circuit board available in either PCI or USB format, providing users with a compelling price/size/performance proposition unmatched by any other device on the market today. The RadioProcessorUSB board is available assembled into a single-bay enclosure. Please contact SpinCore for more details.

System Architecture

Figure 1, below, presents the architecture of the RadioProcessor™. The RadioProcessor consists of three major components: the data acquisition core, the excitation core, and the PulseBlaster timing engine which provides high-resolution timing control for the entire system.

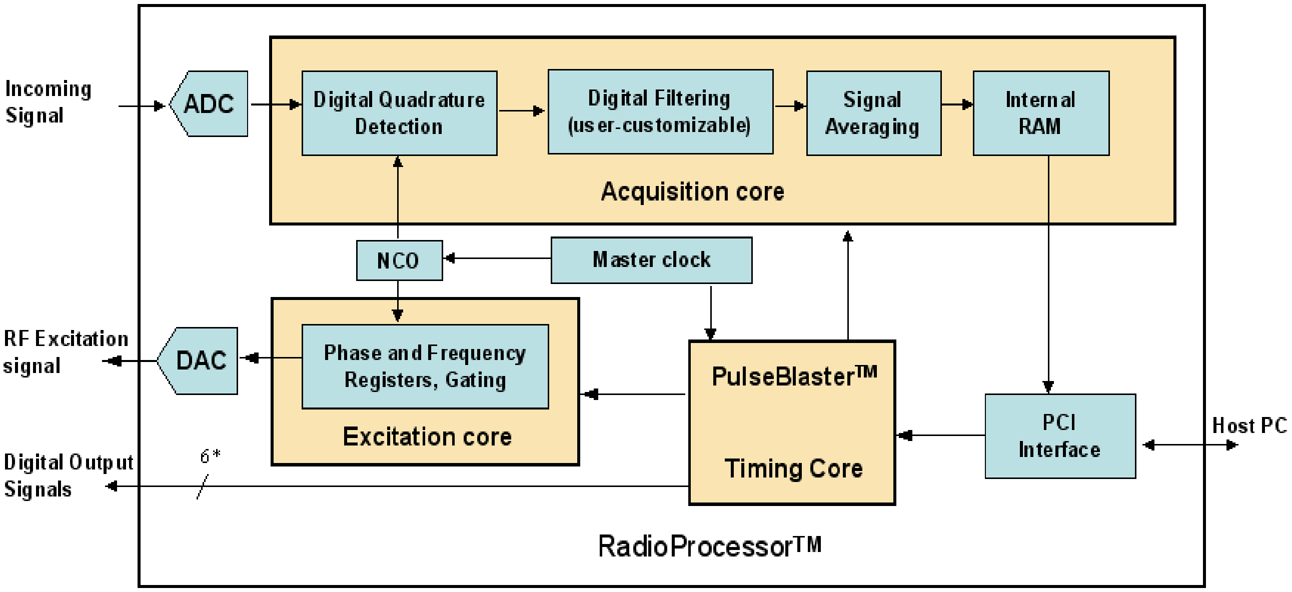


Figure 1: RadioProcessor Architecture. The master clock oscillator signal is derived from an on-chip PLL circuit typically using a 50 MHz on-board reference clock.

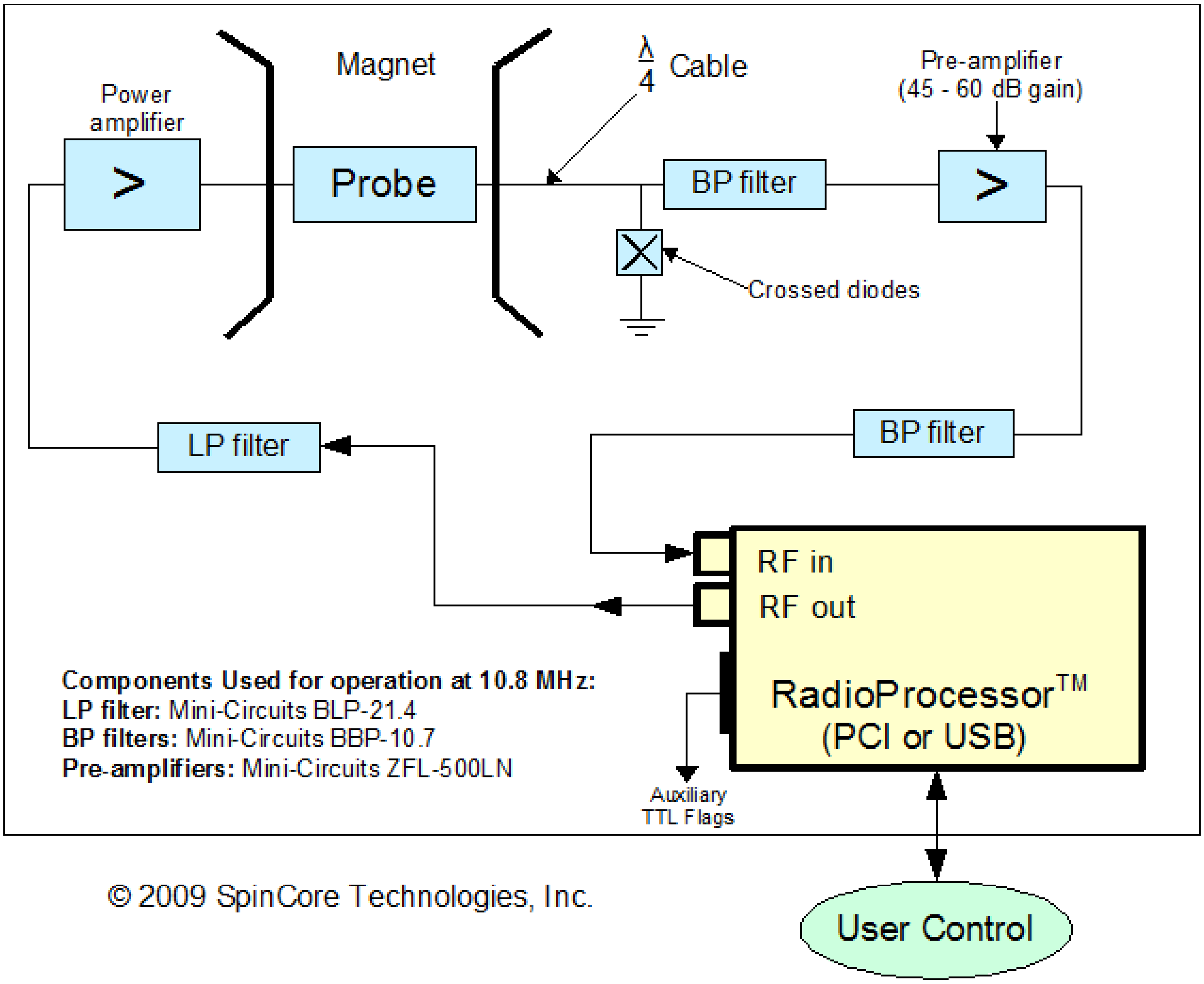
The acquisition core captures an incoming RF signal using a high-speed, high resolution Analog to Digital converter (ADC). This signal is then demodulated digitally using quadrature detection and filtered to reduce the signal to baseband. The detection and filtering system is highly configurable and can easily be customized by the user for a wide variety of applications. The baseband signal can then be averaged with previous data acquisition scans and is stored in an internal RAM. This data is then available to be retrieved onto the host computer at the user's convenience.

The excitation core can produce both RF Analog signals as well as digital outputs. The RF output is generated using an internal DDS (Direct Digital Synthesis) core, and can generate frequencies from DC up to half the DDS clock. The generated signal is converted to the Analog output by an on board digital-to-analog converter (DAC) This DDS core also drives the detection of the acquisition core, so signal coherence is maintained between acquisition and excitation cores. High resolution programmable digital outputs are also available for use in controlling external hardware.

At the heart of the system is the PulseBlaster™ pulse/pattern generator timing core, which uses a robust instruction set designed to allow the creation of complex pulse sequences with ease. This timing core controls all aspects of the systems functionality, such as triggering data acquisition, controlling the frequency and gating RF output, etc. The digital outputs are also controlled with this core. Six digital outputs are available by default, and more are possible if some features of the excitation and acquisition cores are not used.

Example Application

A major application for the RadioProcessor is to serve as an advanced digital NMR/NQR spectrometer. Using the RadioProcessor, a complete NMR/NQR system can be constructed with the addition of a power amplifier and a pre-amplifier. An example setup is shown below in Figure 2.



Components Used for operation at 10.8 MHz:
LP filter: Mini-Circuits BLP-21.4
BP filters: Mini-Circuits BBP-10.7
Pre-amplifiers: Mini-Circuits ZFL-500LN

Figure 2: Typical application of the RadioProcessor. By adding a power amplifier and a small-signal pre-amplifier, a complete NMR/NQR system can be built.

If you are building a system with the RadioProcessor board, SpinCore Technologies Inc. can also supply a power amplifier, TX/RX switch, and pre-amplifiers, if desired. SpinCore also offers a complete mobile NMR system, the iSpin-NMR, that can perform NMR/NQR experiments immediately out of the box. Please visit our website for more details.

Using a setup as described above with a 10.8 MHz permanent magnet, sample spectrum of a household cooking oil sample was obtained as shown below. Using only a single scan, a signal to noise ratio of 62 dB was achieved. The spectral width of the figure below is 60 kHz.

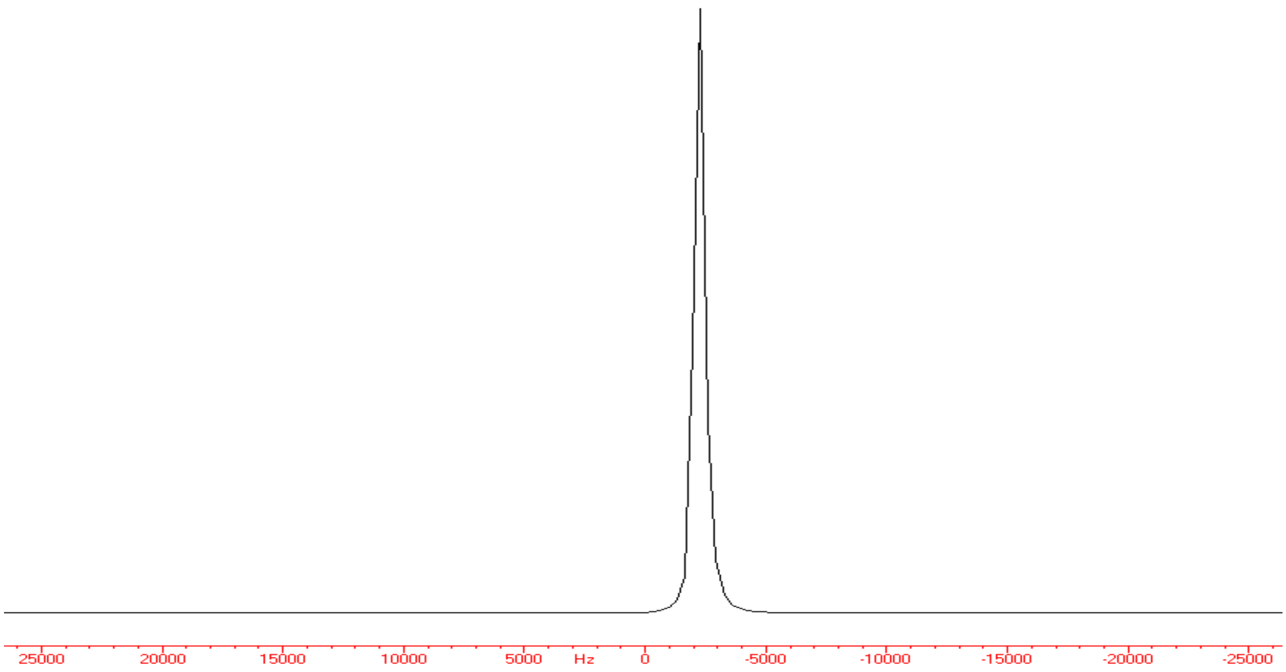


Figure 3: Sample single-scan proton spectrum obtained at 10.8 MHz with the RadioProcessor board and the system described in the text above.

Specifications

The RadioProcessor is currently available with a 75 MHz Analog-to-Digital (A/D) sampling clock frequency. Specifications for this configuration are given below. For information specific to a certain RadioProcessor firmware revision, see Appendix VII or contact SpinCore Technologies, Inc.

Parameter		***Min***	***Typ***	***Max***	***Units***
Analog Input	A/D Sampling Frequency		75(3)	80	MHz
	A/D Sampling Precision			14	bits
	Input Voltage Range (peak-peak)			1.13	V
	Input Frequency Range			100	MHz
Analog Output	D/A Sampling Rate		300		MHz
	D/A Sampling Precision			14	bits
	Output Voltage Range (peak-peak)			1.2(9)	V
	Phase resolution			0.09	deg.
	Frequency resolution		.28(6)		Hz
Digital Output	Number of Digital Outputs	4	6	24(2)	
	Logical 1 output voltage		3.3(1)		V
	Logical 0 output voltage		0		V
	Output drive current			25	mA
	Rise/Fall time			< 1	ns
Digital Input (HW_Trig, HW_Reset)	Logical 1 Input voltage	1.7		4.1	V
	Logical 0 Input voltage	-0.5		0.7	V
Data acquisition	Spectral width (SW) of acquired data	0.28 Hz(11)		10 MHz(7)	
	# Complex points	8192(10)		256k (8)	
Pulse Program	# of Instruction words			1024	words
	Pulse resolution(4)		13.3		ns
	Pulse length(5)	66.6 ns		693 days	

Table 1: Product Specifications.

Notes

(1): This is the value seen without using termination. When the line is terminated with 50Ω, the output voltage will be slightly lower.

(2): Custom designs are available. Please contact SpinCore if you require more digital outputs (or DDS registers).

(3): If the signal to be detected is very close to ¼ of the sampling rate, there will be problems with aliasing during the detection process. To alleviate this problem, a slightly higher or lower clock speed can be used.

(4): Pulse resolution equals one clock period of the master clock oscillator.

(5): Minimum pulse width is five clock periods of the master clock oscillator. Maximum pulse width is 2^52 clock periods of the master clock oscillator.

(6): Frequency resolution is .30 Hz when using a 80 MHz clock.

(7): This number is dependent on the A/D clock frequency (i.e., A/D clock frequency divided by 8). NOTE: when acquiring data directly from A/D, the spectral width is ½ the A/D clock frequency.

(8): This number is 16k for PCI boards. The number of points directly acquired without any digital detection is greater – it is 1M on RadioProcessor-USB boards.

(9): Analog output voltage is factory adjustable up to 4V. See Transmitter Output Level section on the next page for more information.

(10): Fewer points may be observed, however, the number of points retrieved from board memory must be a multiple of 8k.

(11): This value is with the FIR Enabled. With FIR Bypassed, min SW is 72 Hz. Some older designs have a min SW of 4.5 Hz (1.2 kHz with FIR Enabled).

Transmitter Output Level

There are currently two different options for RadioProcessor transmitter output voltage. The standard gain RadioProcessor has an output voltage of one volt peak-to-peak at 10 MHz, with a 3 dB bandwidth of about 85 MHz. The high gain transmitter output amplifier has a maximum output voltage of about 3.75 Volts peak-to-peak, with a 3dB bandwidth of about 21 MHz, while covering the same frequency range as the standard gain board. Figure 4 below shows the transmitter output voltage vs. frequency plot for the two RadioProcessor options. Please contact SpinCore for more information.

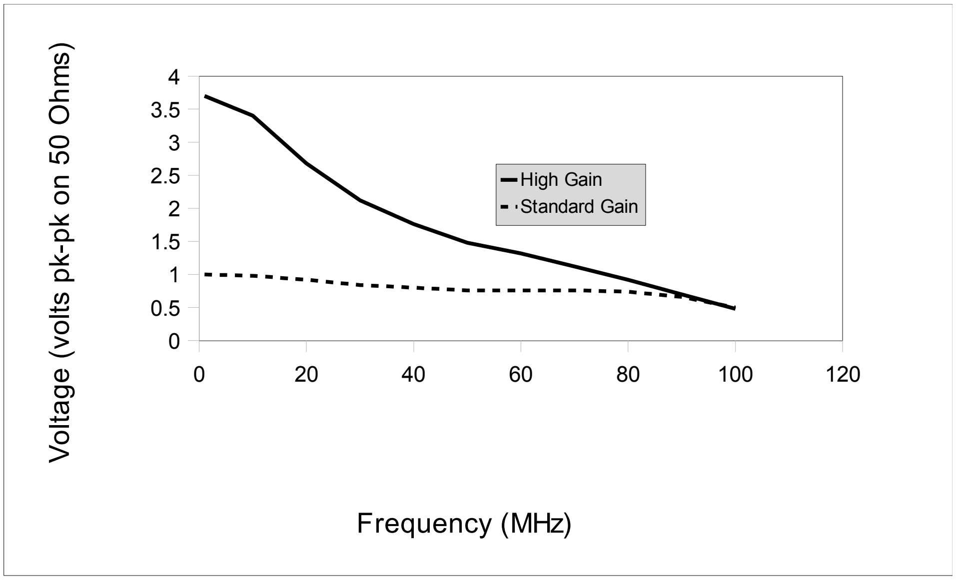


Figure 4: RadioProcessor transmitter output voltage vs. output frequency. The dotted line represents the standard gain transmitter output amplifier, and the solid line represents the high gain transmitter output amplifier. The voltage values are for 50 Ohm load impedance. The 0 dBm (1 mW, 0.63 Vpp on 50 Ohm) output value for both transmitter amplifiers occurs at approximately 90 MHz.

II. Board Installation

Installing the RadioProcessor

To install the board you must complete the following steps:

1. Download and install the latest SpinAPI software package on your computer. SpinAPI is available at: http://www.spincore.com/support/spinapi/.
    - SpinAPI is a custom Application Programming Interface package developed by SpinCore Technologies, Inc. SpinAPI is designed to be used only with SpinCore Technologies, Inc. products. SpinAPI can be utilized using C/C++, or graphically (described in Appendices III and IV).
2. Download and install the latest SpinAPI Examples for your device based on the SpinAPI library. The Examples are available at: http://spincore.com/CD/spinapi_examples/.
3. Shut down the computer.
4. For the PCI: Insert the RadioProcessor card into an available PCI slot and fasten the PC bracket securely with a screw.
5. For the USB: Plug one end of the USB cable into the RadioProcessor board and the other end into the host computer. Next, power the board through the 5-pin DIN-type connector or 6-position Molex-style connector. We recommend purchasing the RadioProcessorUSB Power Supply, which has the 6-pin output connector and is pin-compatible with the power connector of the RadioProcessorUSB board. For more information on powering the RadioProcessor USB board please read Power Connectors in Section V. Connecting to the RadioProcessor.
    - **Warning:** Do not connect PEG (PCI Express Graphics) power connectors available in some computers directly to the 6-position Molex-style power connector. Doing so will cause irreparable damage to the board. SpinCore Technologies is not liable for any damage caused by this.
6. Turn on the computer.

Now you are ready to run the test programs you downloaded from the SpinAPI Examples. We recommend running the example programs when you first receive a RadioProcessor device to verify that your device is functional.

Testing the RadioProcessor

The simplest way to test whether the RadioProcessor has been installed properly and can be controlled as intended is to run a simple test program. The excite_test program, that is available for download online at: http://www.spincore.com/support/spinapi/spinapi_examples.shtml, will produce a 1 MHz output on the Analog Out connector which will turn on for 10 µs and off for 1 ms. This sequence will be repeated indefinitely. To test the board, run excite_test and observe the Analog Output with an oscilloscope. The 1 MHz sinusoid should appear as specified by the program.

If using a high input impedance oscilloscope to monitor the RadioProcessor's output, place a resistor that matches the characteristic impedance of the transmission line in parallel with the coaxial transmission line at the oscilloscope input. (e.g., a 50 Ω resistor with a 50 Ω transmission line, see Figures 5 and 6 below.). When using an oscilloscope with an adjustable bandwidth, set the bandwidth to as large as possible. Failure to do so may yield inaccurate readouts on the oscilloscope.

Figure 5: Left: BNC T-Adapter and Right: BNC 50 Ohm resistor

Figure 6: BNC T-Adapter on the oscilloscope with coaxial transmission line connected on the left and BNC 50 Ohm resistor connected on the right, to terminate the line.

Once this behavior has been verified, the user can be confident the board is installed properly and may move on to evaluation of the acquisition subsystem. If the RadioProcessor is to be used to perform NMR experiments, the easiest way to do this is to use the provided `singlepulse_nmr` example program. The use of this program is described in detail in the next section.

III. Example Single-Pulse NMR Experiment

Precompiled C Programs with Batch File Control

Several precompiled NMR experiments are included with the SpinAPI Examples (Single-Pulse NMR, Hahn Echo, and CPMG, for example). The following steps describe how to run the Single-Pulse NMR experiment with the RadioProcessor board and SpinCore Technologies software:

1. Complete the steps in Section II. Board Installation for Installing the RadioProcessor before proceeding.

2. Connect the RadioProcessor as shown in Figure 2 (page 7) of this manual. Note that all components shown in Figure 2 may be purchased from SpinCore Technologies.

3. Create your own working directory somewhere outside of the SpinCore directory and copy the contents of the SpinCore RadioProcessor directory to your new working directory. The SpinCore RadioProcessor directory can be found by in the location where you downloaded the RadioProcessor Examples.

4. Edit the singlepulse_nmr_example.bat batch file by right-clicking and selecting 'edit' and save the batch file when finished. The parameters of interest for this experiment are described below:

`BOARD_NUMBER`: Selects which board to program if multiple SpinCore Technologies boards are connected to your system.
`ADC_FREQUENCY`: Clock frequency of the board. Always 75 MHz, unless a custom clock is being used as input to the RadioProcessor.
`ENABLE_TX`: A 1 enables the transmitter, a 0 disables the transmitter.
`ENABLE_RX`: A 1 enables the receiver, a 0 disables the receiver.
`REPETITION_DELAY`: Repetition delay in seconds between scans. See Figure 5.
`NUMBER_OF_SCANS`: Number of times to repeat the scan and average the results together.
`NUMBER_OF_POINTS`: Number of complex points to be captured.
`SPECTROMETER_FREQUENCY`: Spectrometer frequency in MHz.
`SPECTRAL_WIDTH`: Desired base band spectral width in kHz.
`PULSE_TIME`: Duration of TX excitation pulse in µs. See Figure 5.
`TRANS_TIME`: Ringdown time in µs. See Figure 5.
`TX_PHASE`: Phase of the TX output channel in degrees.
`AMPLITUDE`: TX output amplitude scaling factor (between 0.0 and 1.0).
`SHAPED_PULSE`: Uses a 'sinc' shaped pulse for the TX output.
`BYPASS_FIR`: A 1 bypasses the FIR filter, 0 enables it.
`FNAME`: File name to save the acquired data in. Data will be saved in ASCII, Felix, and JCAMP formats.
`VERBOSE`: A 1 enables normal output, a 0 disables normal output and the program outputs nothing.
`BLANKING_EN`: Enables the TTL blanking feature necessary to control SpinCore Technologies RF Power Amplifier modules if used with the RadioProcessor in the NMR setup. For more information see the RF Power Amplifier manual at: http://www.spincore.com/CD/RFPA/RFPA_Manual.pdf
`BLANKING_BIT`: Specifies which TTL Flags to use for blanking.
`BLANKING_DELAY`: Delay needed to warm-up the SpinCore RF Power Amplifier prior to the RF pulse. See Figure 7.

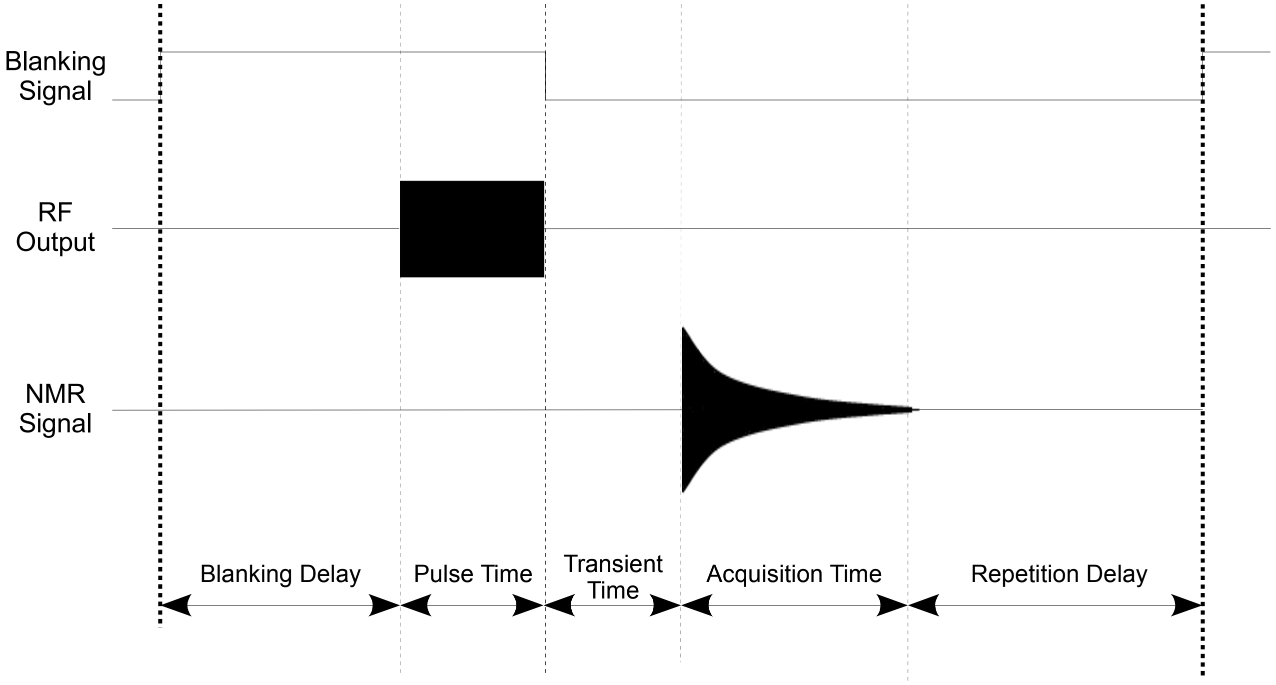


Figure 7: General timing diagram of the basic single-pulse sequence (not to scale). A single scan is performed as follows: A blanking TTL pulse is applied to allow for RF Power Amplifier warm-up (Blanking Delay), a single RF pulse is applied to the sample for a specified amount of time (Pulse Time). The high voltage induced on the sample coil is allowed to ring down (Transient Time), after which the Free Induction Decay (FID) signal is acquired (for length Acquisition time). The sample is then allowed to relax for a time (Repetition Delay). This scan procedure is then repeated an arbitrary number of times as desired to improve the signal to noise ratio.

5. Run the singlepulse_nmr_example.bat file by double-clicking. Once the singlepulse_nmr.bat file has completed, three new files (*.fid, *.jdx, *.txt) will be created in the directory from which the batch file was executed.

6. Open the Felix file (.fid) in Felix for Windows, or open the .jdx file in any program that supports JCAMP-DX. An easily parsed text file containing the NMR data will also be generated. For information on installing and using Felix to view your .fid files, go to http://www.spincore.com/CD/RadioProcessor/felix/Felix_Instructions.html

Tips on obtaining data using singlepulse_nmr

The ability of this program to capture usable data is highly dependent on entering the correct parameters for a given NMR setup. It is expected that the user is familiar with how to best specify PULSE_TIME, TRANS_TIME, TX_PHASE, SPECTROMETER_FREQUENCY, etc. Setting the SPECTRAL_WIDTH, however, may not immediately be obvious.

If the signal is very short (on the order of microseconds), for example as in NMR with solid samples or with inhomogeneous magnetic fields, there is ample room in the on board RAM to capture the entire signal with a very large spectral width (1 MHz or more). Often this is the best approach, even if the signals are near DC (i. e. near or at spectrometer frequency) and thus do not require a large spectral width to be represented. To do this, the FIR filter can be bypassed with the BYPASS_FIR parameter to achieve the large spectral width. This will result in signals being attenuated near the edge of the passband, but this will not matter since the signal of interest is near DC.

For longer FID signals, where a smaller spectral width is more useful, the FIR filter may be bypassed as well. The FIR filter is necessary only for very low spectral widths (on the order of several Hz) when a flat response is needed over the entire spectrum. Please note that when the FIR is enabled, the spectral width must be the ADC_FREQUENCY divided by some multiple of 8. If such a value is not specified, the spectral width will be rounded appropriately. The FIR filter also adds an initial latency to any acquired data that is dependent on the number of FIR coefficients. These initial points should be discarded. In general, lowering the spectral width will reduce the noise in the signal.

The source code of the `singlepulse_nmr.c` program is included in the SpinAPI Examples and is well commented. Users wishing to create custom programs may refer to this to get the details of how to control the RadioProcessor.

Graphical User Interfaces

In addition to the Single Pulse NMR code included with SpinAPI, graphical user interfaces have been created for use with MATLAB and LabVIEW. Please see Appendices III and IV for sample screenshots, or visit the following links for further information.

MATLAB: http://www.spincore.com/support/RadioProcessor/MATLAB/
LabVIEW: http://www.spincore.com/support/PBLV/RP.shtml

IV. Creating Custom Pulse Programs

Controlling the RadioProcessor with SpinAPI

SpinAPI is a control library which allows programs to be written to communicate with the RadioProcessor board. The most straightforward way to interface with this library is with a C/C++ program, and the API definitions are described in this context. However, virtually all programming languages and software environments (including software such as LabVIEW and MATLAB) provide mechanisms for accessing the functionality of standard libraries such as SpinAPI.

For more information on using SpinAPI functions, please download the RadioProcessor Examples available online at: http://spincore.com/CD/spinapi_examples/.

A reference document for all SpinAPI functions is available online at:

www.spincore.com/CD/spinapi/spinapi_reference

The RadioProcessor is a highly versatile excitation and acquisition system, and as a result there are many possible approaches to program the board. However, most applications will follow five basic steps:

1. Load the frequency and phase registers with desired values.
2. Specify data acquisition related parameters.
3. Specify all parameters that control the timing of the experiment, i.e., pulse times, delays, etc.
4. Trigger the pulse program. The experiment will then proceed autonomously.
5. Retrieve the captured data from the board at any time without interrupting the acquisition process.

These steps are described in detail below. For each of the steps, the relevant SpinAPI functions are listed which control the actions needed to perform that particular step.

DDS (Frequency and Phase) Registers

The RadioProcessor contains three DDS channels, two of which are internal and used for digital detection (cos and sin), and one which drives the digital-to-analog converter (DAC) that forms the TX channel (see figure 5 below). The frequency and phases of these three channels are controlled by selecting values from a bank of on-board registers. These registers are typically programmed during board initialization , and then the pulse program is used to select which register is used at any given time during an experiment. All three channels share a common frequency, but their phase may be set completely independent of each other. The number of available registers for each channel is given in the table below*.

Register Bank	***Number of registers***
Frequency	16
Cos phase (real channel)	4
Sin phase (imaginary channel)	4
TX phase	16

Table 2: DDS Register information.*

Relevant spinapi functions:
`pb_start_programming()`

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*Certain RadioProcessor firmware revisions have different register allocation. For information about a specific RadioProcessor firmware revision see Appendix VII or contact SpinCore Technologies, Inc. Custom designs with more DDS registers are available.

```
pb_set_phase()
pb_set_freq()
pb_stop_programming()
```

Firmware revision 10-18 supports “on the fly” frequency and phase register programming. Please see Appendix V for more information.

Acquisition Parameters

The RadioProcessor performs quadrature signal detection, as shown in Figure 8 below. The incoming RF signal as captured by the ADC is multiplied by the internal cos and sin signals to form the real and imaginary signal channels respectively. These channels are then filtered and decimated to produce a baseband signal, which can optionally be averaged with previous scans, and is then stored in the internal ram.

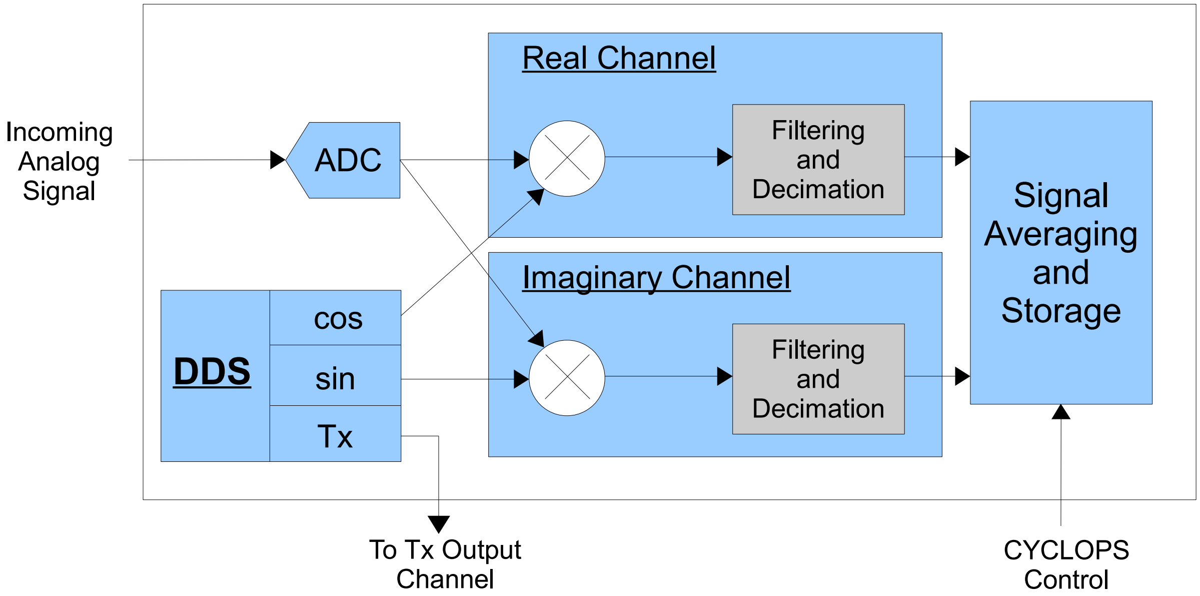

Figure 8: Quadrature detection block diagram. The incoming analog signal is digitized and mixed with the receiver cosine and sine waveforms to create the real and imaginary channels. Those channels are then filtered and stored in on chip memory for the user to read back. The RadioProcessor's agile control system allows for all aspects of the data acquisition to be user programmable.

Basic acquisition parameters that need to be set are the desired spectral width of the stored baseband data, the number of points to capture, and the number of scans that will be performed. Based on these values, the driver will set the internal acquisition and filtering parameters appropriately. This method of setting up the acquisition hardware should suffice for many if not most applications. Complete control over all filtering parameters is possible however, and users wishing to take advantage of this should contact SpinCore Technologies.

Spectral width: This is the bandwidth of the captured baseband (i.e., after quadrature detection) data.
Number of points: Number of complex basedband (FID) points to capture. This is typically set to the maximum number of points, although smaller numbers may be used if a lesser number of points is sufficient.
Number of scans: Number of scans that are intended to be taken. The actual number of scans is determined by the number of times the `trigger_scan` bit is enabled in the pulse program, but the maximum number of scans that will be performed needs to be specified here so that the acquisition system can be setup to avoid overflows.

Relevant spinapi functions:
`pb_set_num_points()`
`pb_setup_filters()`

NOTE: To bypass the Digital Quadrature Detection use the spinapi function: `pb_get_data_direct()`

Timing and Flow Control Parameters

The RadioProcessor contains an integrated PulseBlaster pulse generation timing core. This timing core controls all aspects of the systems functionality by setting internal control lines at user specified times. Six user programmable digital outputs are also available for control of external hardware. The internal control lines and user programmable outputs are collectively referred to as flags. The pulse program modifies these flags in a user-defined way to control all aspects of an experiment.

Op-code and Explanation

The PulseBlaster uses a robust instruction set to enable the creation of complex pulse programs with ease. Each instruction is defined by an opcode which specifies the action of that instruction and an optional Instruction data (inst_data) field which elaborates on that action. In addition, each instruction specifies the desired value for the flags, as well as a time delay until the next instruction executes. The “next” instruction is not necessarily the next sequential instruction, as the instruction set contains branching and looping instructions which can cause the program to be executed out of sequential order. A list of the available instructions is given in the table below.

Op Code #	***Instruction***	***Inst_data field***	***Function***
0	CONTINUE	Unused	Program execution continues to next instruction
1	STOP	Unused	Stop execution of program. All TTL values remain from previous instruction, and analog outputs may turn off (1)
2	LOOP	Number of desired loops. This value must be greater than or equal to 1.	Specify beginning of a loop. Execution continues to next instruction. Data used to specify number of loops
3	END_LOOP	Address of beginning of loop	Specify end of a loop. Execution returns to begging of loop and decrements loop counter.
4	JSR	Address of first subroutine instruction	Program execution jumps to beginning of a subroutine
5	RTS	Unused	Program execution returns to instruction after JSR was called
6	BRANCH	Address of instruction to skip to	Program execution continues at specified instruction. This behaves like the goto statement found in many programming languages
7	LONG_DELAY	Number of desired loops. This value must be greater than or equal to 2.	For long interval instructions. Data field specifies a multiplier of the delay field. Execution continues to next instruction
8	WAIT	Unused	Program execution pauses and waits for a software or hardware trigger to resume it. The latency between a trigger occurring and the program resuming is the time used as the delay for the wait instruction plus a fixed time of 6 clock cycles.

Table 3: PulseBlaster instructions.

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(1) On RadioProcessor boards with firmware versions 10-13 and 10-14, both analog *and* TTL outputs return to ground when a STOP command is encountered.

Control lines

To control the operation of the RadioProcessor, each instruction in the pulse program specifies a flag word which sets both the internal control lines and user programmable digital outputs. The control lines stay in the given state for the duration of the instruction. The internal control lines are described below:

Control Line	***Function***
frequency select	Selects between the available frequency registers
cos channel phase select	Selects between the available cos phase registers
sin channel phase select	Selects between the available sin phase registers
TX channel phase select	Selects between the available TX phase registers
`tx_enable`	Enables TX output on the Analog Out connector. If this control line is disabled, the Analog Out channel is turned off (zero output voltage).
`phase_reset`	When this control line is enabled, all DDS channels will be reset to their time=0 phase. For example, if a channel is set to use a phase register with 90deg, it will be reset to the midpoint output level and stay that way until the phase reset control line is disabled. This allows the the phase of pulses to be synchronized between scans.
`trigger_scan`	When this control line is enabled, a scan will be triggered and data acquisition will begin. Acquisition continues until the desired number of complex points have been captured as specified by the acquisition parameters. Once scanning has been triggered, it will continue until all points have been captured, regardless of the state of this control line. A scan is triggered when this control line transitions from a 0 to 1, so to start a new scan, the value of this line must be returned to 0 before being set to 1 again.

Table 4: Internal control lines.

Relevant spinapi functions:

```
pb_start_programming()
pb_inst_radio()
pb_inst_radio_shape()
pb_inst_radio_shape_cyclops()
pb_stop_programming()
```

Triggering

The RadioProcessor can be triggered in two ways, either by software trigger or hardware trigger. The software trigger is initiated by sending a command from the host PC. Because RadioProcessor boards are typically used with non real-time operating systems, the exact time between issuing a software trigger and the board acting on that trigger cannot be precisely specified. For precision control, the pulse program can also be triggered by setting the HW_Trigger pin to a logical 0. This will cause the pulse program to be triggered within two clock cycles (starting a program), or a minimum of 8 clock cycles (resuming from WAIT instruction).

Triggering the pulse program has one of the following three effects:

1. Begin execution of a pulse program.
2. Restart execution of a pulse program after the board has been reset.
3. Resume execution of a pulse program which is currently paused by a WAIT instruction.

The data acquisition system cannot be directly triggered by the hardware or software trigger described above. Instead, it is triggered by an internal control line (called trigger_scan) which can be set by the instructions of the pulse program. If the user desires to start the acquisition based on the hardware trigger, the user can create a pulse program which sets the trigger_scan line in the first instruction. Thus the data acquisition component will be triggered as soon as the hardware trigger causes the pulse program to begin.

Relevant spinapi functions:
`pb_start()`

Retrieving data from the board

Once an experiment has been completed, the data is retrieved from the board so it can be viewed and analyzed on the host computer.

The `pb_read_status()` function can be used to determine when the experiment has been completed. Once it has finished, the data is retrieved from the board using `pb_get_data()`, and then can be written to a file in several different formats. Currently supported file formats are ASCII, Felix, and JCAMP-DX 5.0.

NOTE: The data-acquisition process and the data-downloading process are completely independent. Therefore, data can be downloaded, using the `pb_get_data()` function, at anytime during the acquisition process and it is not necessary to wait for the acquisition to complete.

ASCII : Plain ASCII data with each value on a new line. The first line contains the number of complex points, the second line contains the spectral width of the data (in MHz), and the remaining lines contain the complex points themselves. Real and Imaginary components of the complex points are given on alternate lines. Thus, the real and imaginary components of the first point are given on lines 3 and 4 respectively. The second point is given on lines 5 and 6, etc.

Felix : Output data in a form readable by the Felix spectrometer software by Accelrys. A demo version of this software is available online at:

http://www.spincore.com/support/RadioProcessor/Felix/Felix_Instructions.shtml

JCAMP-DX 5.0: The JCAMP-DX file format is a scientific standard for the exchange of information across platforms and software packages and is accepted by many NMR software programs such as Bruker's TopSpin and is also readable in MATLAB via the Bioinformatics Toolbox. Output data is stored as type NMR FID.
Note: The pre-acquisition delay field '##.DELAY=' is set to 0 μs by default; the actual delay is not measured. This value can be modified after the acquisition has been completed via any text editor or with the software program used to open the JCAMP-DX file.)

Relevant spinapi functions:
`pb_read_status()`
`pb_get_data()`
`pb_write_ascii()`
`pb_write_felix()`
`pb_write_jcamp()`

Note: pb_get_data() can only transfer multiples of 8K data points.

V. Connecting to the RadioProcessor

PCI RadioProcessor Boards Connector Information

There are two main connector types on the RadioProcessor board: the BNC connectors and the IDC headers – see Figure 9, below. BNC connectors are mounted on the PCI bracket and are available outside of the computer. The IDC connectors are mounted on-board and are available inside the computer only. There are two long IDC headers and one short IDC header.

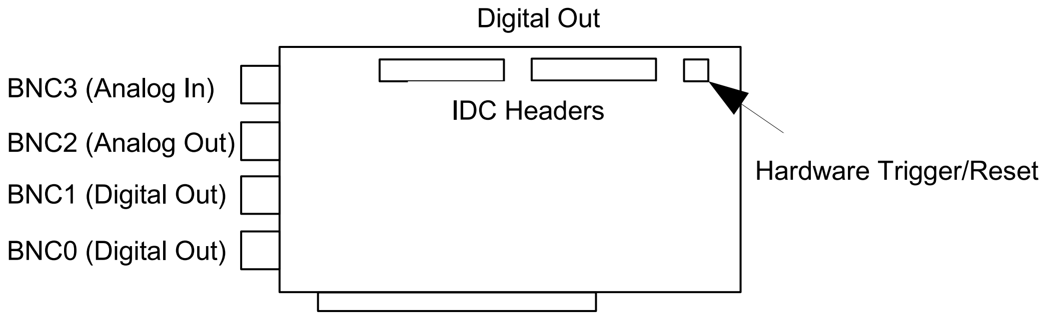


Figure 9: RadioProcessor PCI Connector Locations

BNC Connectors

The four BNC connectors provide the primary interface with the RadioProcessorPCI board. All headers are impedance matched to 50 Ohm. BNC3 is the Analog Input, used for data acquisition. BNC2 is the Analog Output port. BNC1 and BNC0 are both general purpose digital outputs which can be controlled through the pulse program.

The analog output connector (BNC2), is not equipped with an interpolating filter. This allows for maximum flexibility in output frequency, but it means that the output may appear somewhat quantized if no filter is used at the output. To eliminate this behavior and obtain a smooth RF pulse, the user may wish to filter the output with a band-pass or low-pass filter which will cut off the undesired frequency components above the intended RF signal.

Long IDC Headers

14	15	16	17	18	19	20	21	22	23	24	25	26
1	2	3	4	5	6	7	8	9	10	11	12	13

Figure 10: IDC header pinout

There are two long (2x13 pins) IDC headers on the RadioProcessor board. The headers provide access to all 24 bits of the flag word, six of which are available to the user as general purpose digital outputs. These are labeled Flag0..11_Out and Flag12..23_Out. On each IDC header the top row of pins (14-26) are grounds, and the signals are carried on pins 1-13.

Each pin on an IDC header corresponds to a bit in the flag field of an instruction. The association between bits and pins is shown in the table below. In the RadioProcessor design, most of the flag bits are used to select frequency and phase registers. However these bits are still output to the IDC connectors so external hardware can be used to determine the state of the program.

Bit in flag word	Function	Pin on Flag12..23
N/A	Ground	14-26
N/A	Unused	13
23	sin (imaginary channel) phase register select	12
22		11
21	cos (real channel) phase register select	10
20		9
19	TX phase register select	8
18		7
17		6
16		5
15		4
14		3
13		2
12	tx_enable	1

Bit in flag word	Function	Pin on Flag0..11
N/A	Ground	14-26
N/A	Unused	13
11	Frequency register select	12
10		11
9		10
8		9
7	trigger_scan	8
6	phase_reset	7
5	Digital outputs	6
4		5
3		4
2		3
1	Digital output BNC1	2
0	Digital output BNC0	1

Table 5: IDC connector pin outs for boards without AWG capability (firmware 10-4 and older).

Bit in flag word	Function	Pin on Flag12..23
N/A	Ground	14-26
N/A	Unused	13
23	sin (imaginary channel) phase register select	12
22		11
21	cos (real channel) phase register select	10
20		9
19	TX phase register select	8
18		7
17		6
16		5
15	tx_enable	4
14	Frequency register select	3
13		2
12		1

Bit in flag word	Function	Pin on Flag0..11
N/A	Ground	14-26
N/A	Unused	13
11	Frequency register select	12
10	trigger_scan	11
9	phase_reset	10
8	Shape period select	9
7		8
6		7
5	Amplitude select	6
4		5
3	Digital output	4
2	Digital output	3
1	Digital output BNC1	2
0	Digital output BNC0	1

Table 6: IDC connector pin outs for boards with AWG capability (firmware 10-5 and newer).

Note: Some designs may not follow this exact flag partitioning scheme. Please contact SpinCore Technologies for more information.

HW Trigger/Reset Header

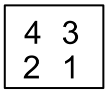


Figure 11: Hardware Trigger/Reset Header pin-out.

The short 2x2 IDC header is the Hardware Trigger/Reset connector. This is an input connector, for hardware triggering (HW_Trigger) and resetting (HW_Reset). Pins 3 and 4 are grounds, and pins 1 and 2 are the reset and trigger inputs, respectively. Both inputs are pulled high by an on board 10kΩ pull up resistor.

HW_Trigger (pin 2) When this input is set to logical 0 (for example by shorting it with pin 4), a hardware trigger is produced. This has the same effects as issuing a trigger through software, although the hardware trigger is more precise, since there are no software latencies involved.

HW_Reset (pin 1) When this input is set to logical 0 (for example by shorting it with pin 3), the pulse program is reset.

USB RadioProcessor Boards Connector Information

The RadioProcessorUSB board comes in a 4” x 6” form factor and requires USB 2.0 to operate. A fully enclosed option is also available that includes power supply and and access to all connectors. Contact SpinCore Technologies for more information.

The connector layout of the RadioProcessorUSB board is depicted in Figure 12 below.

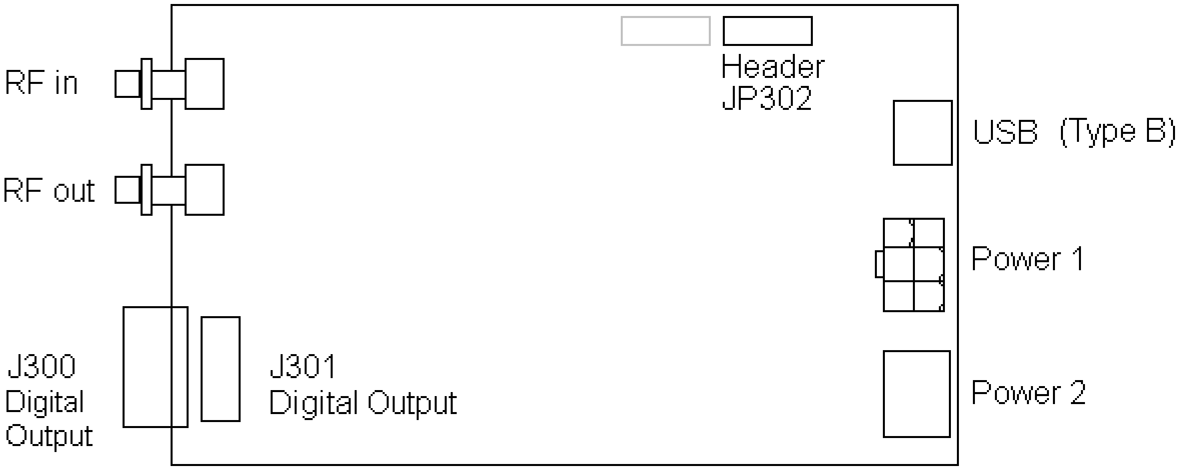
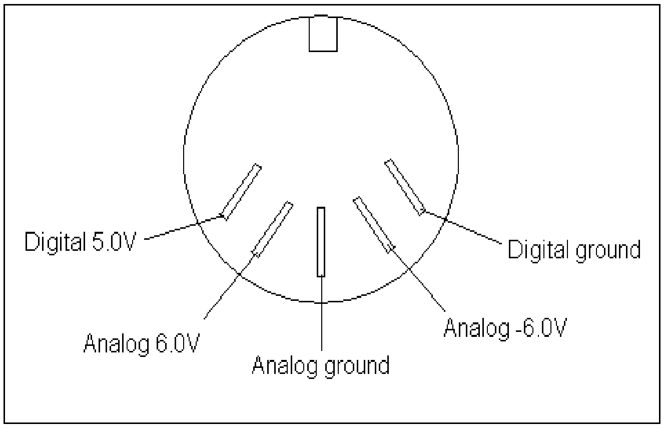


Figure 12: RadioProcessor-USB Connector Locations.

Power Connectors

The RadioProcessor-USB™ has two power connectors wired in parallel: A 5-pin DIN-type connector (Power 2) and a 6-position Molex-style connector (Power 1). The pin and signal arrangements for these two connection points are shown below in Figure 13.



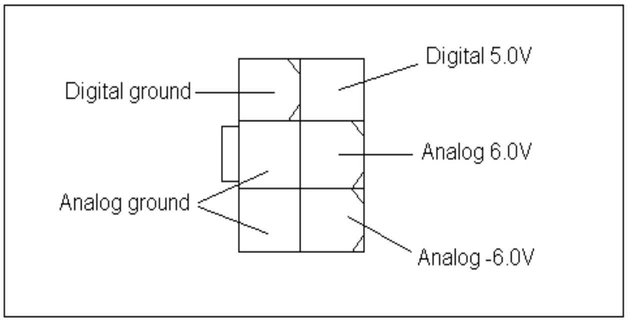


Figure 13: RadioProcessor-USB power connectors. DIN-5 Power Connector (left) and 6 position Molex-style Power Connector (right).

Recommended values and maximum currents for RadioProcessorUSB Power:

+5 V, 2.0 A (Digital Section)
+6 V, 1.0 A (Analog Section, Positive Voltage)
-6 V, 0.2 A (Analog Section, Negative Voltage)

All three voltages need to be applied simultaneously or damage to the board will result.

Two independent grounds exist: Digital Ground and Analog Ground. Power sources should be connected as follows:

- Digital Ground should be connected to the ground point of +5 V supply.
- *Analog Ground should be connected to the center point (Ground Point) of the +6V and -6V supplies.*

If you will be making your own power supply to connect to the Molex-style power connector, you will need the following parts or their equivalents: One 6-pin female Mini-Fit Jr.™ connector (DigiKey part No. WM23702-ND) and six Mini-Fit Jr.™ crimp receptacles (DigiKey part No. WM2501-ND).

Warning: Do not connect PEG (PCI Express Graphics) power connectors available in some computers directly to the 6-position Molex-style power connector. Doing so will cause irreparable damage to the board. SpinCore Technologies is not liable for any damage caused by this.

RF Connectors

The RadioProcessorUSB has two Female SMA Jack connectors for RF signals. These connectors are labeled as RF Out and RF In for the transmitter output and receiver input respectively.

Digital Output Connector

The digital outputs of the RadioProcessorUSB are present on both the J300 and J301 connectors. J300 is a standard DB-9 connector and J301 is a 5x2 shrouded IDC header. The pinouts of these connectors and the corresponding signal names are shown below in Figures 14 and 15 and Tables 7 and 8 respectively.

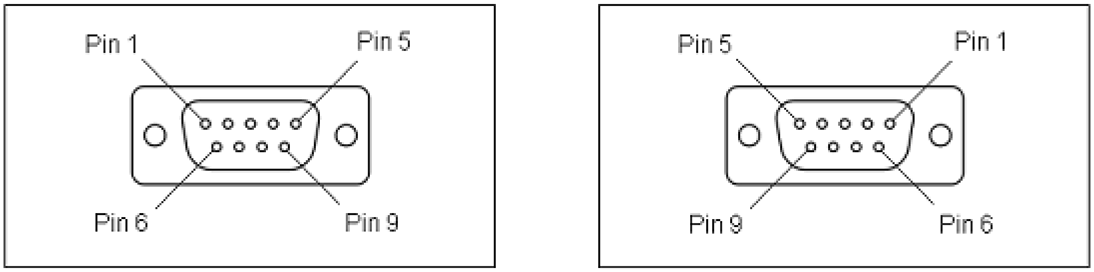


Figure 14: DB-9 Output Connector J300. Left: DB-9 Male. Right: DB-9 Female.

Pin number	Function
1	Reserved
2	Flag bit 2
3	Flag bit 3
4	Flag bit 1
5	Flag bit 0
6	Ground
7	Ground
8	Ground
9	Ground

Pin number	Function
1	Flag bit 0
2	Flag bit 1
3	Flag bit 3
4	Flag bit 2
5	Reserved
6	Ground
7	Ground
8	Ground
9	Ground

Table 7: DB-9 Output Connector J300 signal list, Male (left) and Female (right).

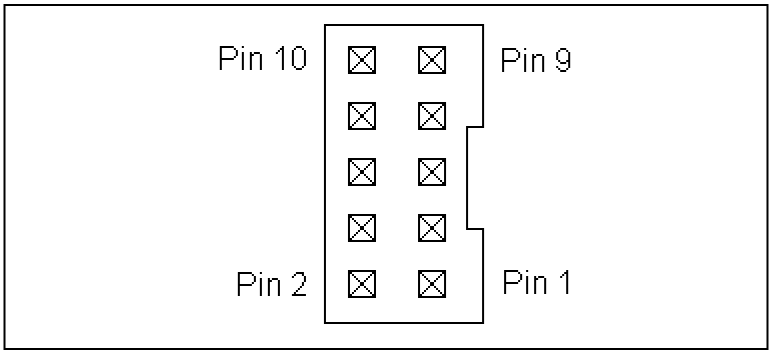


Figure 15: Shrouded IDC Output Header J301

Pin number	Function
1	Ground
2	Flag bit 0
3	Ground
4	Flag bit 1
5	Ground
6	Flag bit 3
7	Ground
8	Flag bit 2
9	Ground
10	Reserved

Table 8: Shrouded IDC Output Header J301 signal list.

Header JP302 (HW Trigger/Reset)

The unshrouded male header labeled JP302 contains the *Hardware Trigger* and *Hardware Reset* lines. On RadioProcessorUSB boards equipped with firmware version 12-4,12-5, or 12-7, this header also offers a 10 MHz output that is derived from the master clock oscillator. This signal is ideal for synchronization purposes and is present on pin 2 of the header.

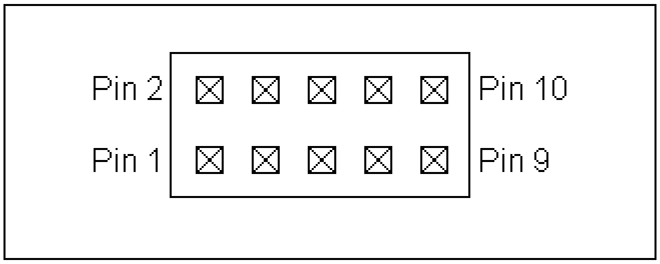


Figure 16: Output Header JP302

Pin number	Function
1	Ground
2	10 MHz out or N/C
3	Ground
4	N/C
5	Ground
6	N/C
7	Ground
8	Hardware Trigger
9	Ground
10	Hardware Reset

Table 9: Output Header JP302 signal list.

USB RadioProcessor Board in a Single-bay Enclosure Connector Information

The RadioProcessorUSB board is available assembled into a single-bay enclosure, as show in Figure 17. The single-bay enclosure contains the USB Board and a DC power supply. The back panel connections for the RadioProcessorUSB single-bay enclosure are shown in the Figure 18 and described below.

Figure 17: USB RadioProcessor board in a single-bay enclosure.

Figure 18: Back panel connections for the single-bay enclosure.

Power Connector

The RadioProcessorUSB in a single-bay enclosure is provided with an internal auto-sensing universal AC power supply. An IEC C14 male connector is exposed at the read of the enclosure which may be connected to 120/240 V, 50/60 Hz main power.

RF Connectors

The input and the output of the RadioProcessor board are connected directly to the BNC connectors mounted on the back panel (as shown in Figure 18). These connectors are labeled as RF Out and RF In for the transmitter output and receiver input respectively.

Digital Output Connector

The digital outputs of the RadioProcessorUSB are present on the female DB9 connector. The pin-outs of the female TTL DB-9 connector and the corresponding signal names are shown below in Figure 19 and Table 10. **CAUTION: Please note that the female TTL DB-9 port is an OUTPUT port.**

In lieu of the AC power, the DC +12 V male DB-9 connector can be used to input +12 V DC to power the system for portable, battery-power operation. Please contact SpinCore for more details regarding this option.

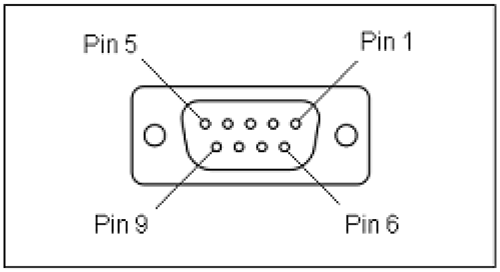


Figure 19: Female DB-9 Output Connector

Pin number	Function
1	Flag bit 0
2	Flag bit 1
3	Flag bit 3
4	Flag bit 2
5	Reserved
6	Ground
7	Ground
8	Ground
9	Ground

Table 10: Female DB-9 Output Connector.

HW Trigger/Reset

The white RCA plug is connected to the Hardware trigger pin on the RadioProcessor board and the red RCA plug is connected to the Hardware reset pin.

Appendix I: Using the Undersampling Capabilities of the RadioProcessor - 70 MHz IF Application

The standard A/D sampling frequency of the RadioProcessor board is 75 MHz. At this 75 Ms/s sampling frequency, input signals up to 37.5 MHz (the Nyquist frequency, i..e., ½ of the sampling frequency) can be sampled without any aliasing effects occurring. In addition to this, it is also possible to use the RadioProcessor with input signals higher than 37.5 MHz by taking advantage of the high bandwidth of the input amplifier and A/D (Analog-to-Digital) converter.

In general, when input signals are above the Nyquist frequency, the signal is folded back to a lower apparent frequency when it is sampled by the A/D. The folded frequency can be calculated with the following formula (1):

$$f_{folded} = \left| n \cdot \frac{f_{AD}}{2} - f_{input} \right| \qquad (1)$$

f_{folded} : Frequency that appears to the RadioProcessor system
f_{AD} : Sampling frequency of the A/D (75 MHz in this case)
f_{input} : Input frequency applied to the RadioProcessor
n : Integer which results in $f_{folded} < \frac{f_{AD}}{2}$

The rest of this document demonstrates the use of the RadioProcessor Model TRX-I-50-75-300 with a 70 MHz IF (intermediate frequency) signal in a high-field NMR spectrometer. This particular models uses a 50 MHz reference frequency, 75 MHz A/D sampling frequency, and 300 MHz D/A frequency. Transmitting (Tx) and Receiving (Rx) performance at and around 70 MHz will be presented.

Excitation Section

In order to be usable for 70 MHz applications, the RadioProcessor must output short pulses with a carrier frequency of 70 MHz and agile phase and frequency modulation. This can be accomplished with RadioProcessor's Tx excitation section which is equipped with the on-board 300 MHz 14 bit DAC converter followed by a wide-band output amplifier. The figure below shows an example RF *output pulse* that was generated by the RadioProcessor. This data was captured using a Tektronix TDS224 oscilloscope. Notice the time base of 25 ns/division.

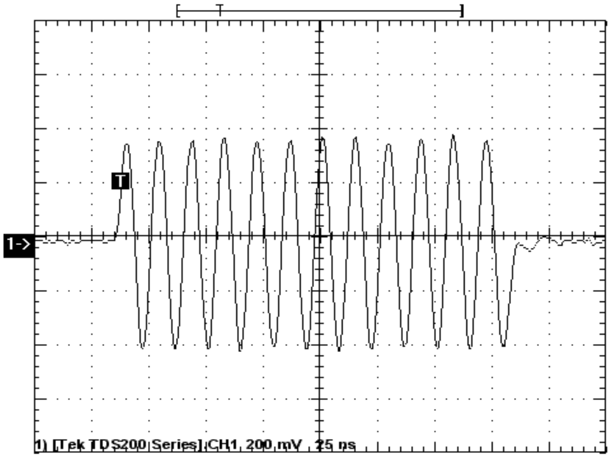


Figure A1.1: 185 ns 70 MHz RF/IF output pulse.

To demonstrate the zero-latency phase- and frequency-switching agility, two short back-to-back pulses were recorded - with a 180-degree phase offset (Figure A1.2, left panel, 70 MHz RF, expanded view), and with a frequency shift from 20 MHz to 10 MHz (Figure A1.2, right panel).

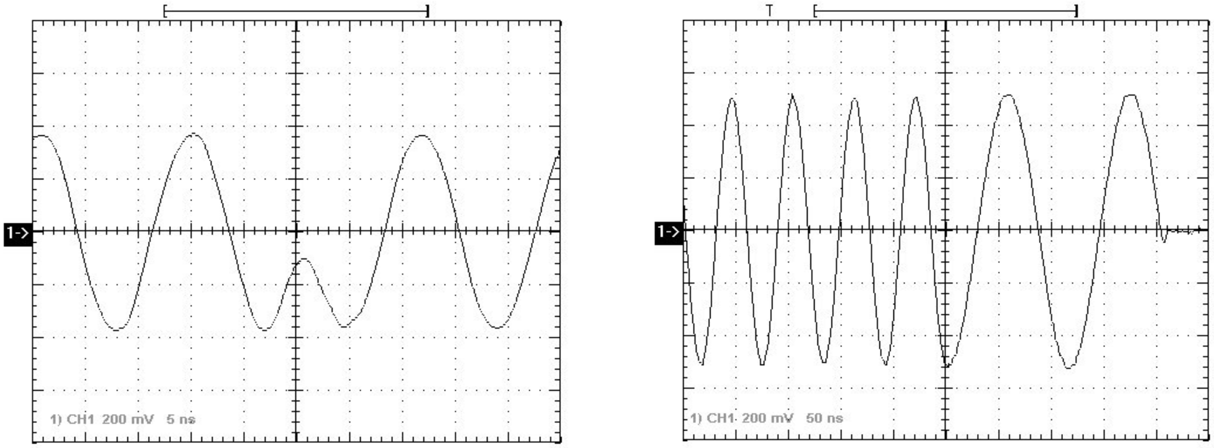


Figure A1.2: Two RF output pulses, back to back, with 180 degree phase switch and 70 MHz RF frequency (left panel), and frequency shift from 20 MHz to 10 MHz (right panel).

The standard gain output amplifier of the RadioProcessor is DC-coupled, and the frequency response of the entire Tx section is within 3dB from DC to 85 MHz. RadioProcessor can generate RF pulses in this entire range, while maintaining the required phase coherence with the receiving section through the use of a common frequency source.

Receiving Section

The receiving section consists of a fast, 14-bit A/D converter intended for undersampling applications, followed by digital quadrature detectors, filters, and an autonomous signal averager. To evaluate the performance of the receiving section of the RadioProcessor, the most important thing is to examine the performance of the A/D converter. Figure A1.3 shows a 5 MHz signal that was directly captured by the A/D without being passed through the detectors or any of the internal digital filters. Figure A1.4 (next page) shows a 70 MHz under-sampled signal (which has been folded back to 5 MHz) captured with the same setup. A comparison of the two spectra indicates that the noise introduced by the undersampling process is relatively small. Therefore, the RadioProcessor can be used with input frequencies higher than Nyquist (37.5MHz) with performance comparable to regularly sampled input frequencies below Nyquist.

The input signals for these tests were generated by a PTS 250 Frequency Synthesizer (running un-locked to the RadioProcessor's clock), and the spectra were generated by reading the captured data into MATLAB and performing a complex FFT. The negative frequencies are the result of having only one (the real) component sampled, with the imaginary values all set to zero.

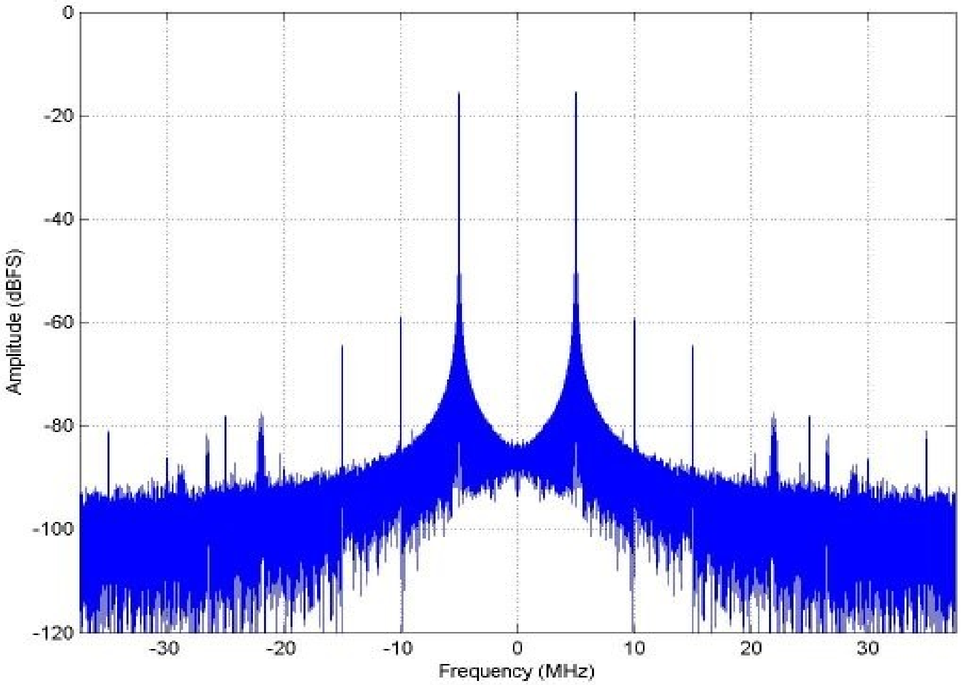


Figure A1.3: 5 MHz signal directly captured.

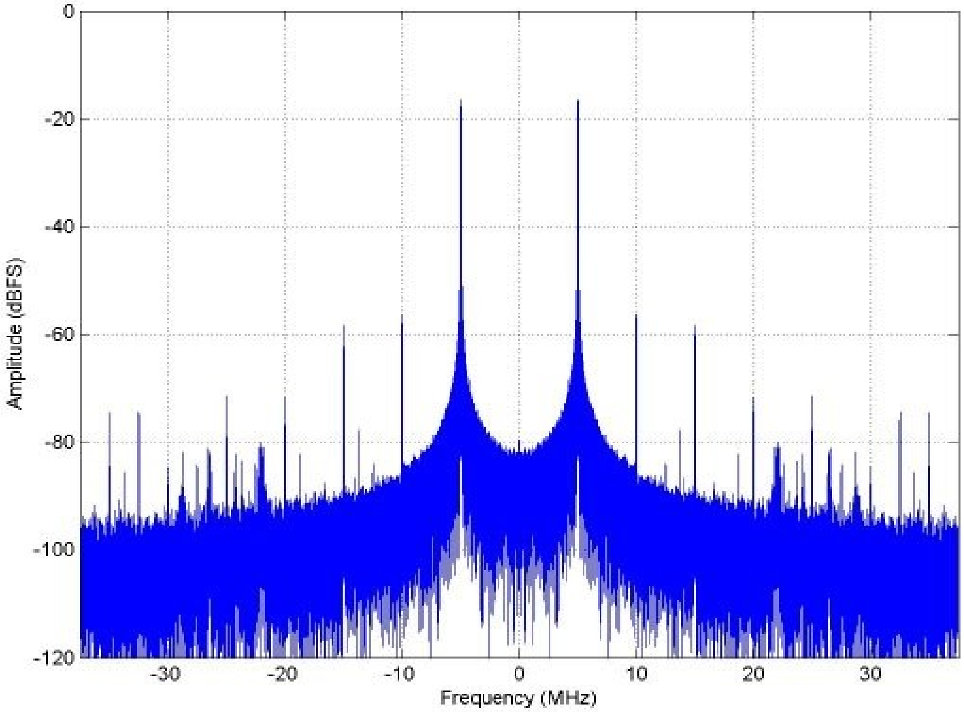


Figure A1.4: 70 MHz signal directly captured (undersampling).

Most NMR/NQR applications will require that the RadioProcessor can capture a certain bandwidth around the spectrometer frequency (or IF frequency). To show that the amplitude remains the same when the input frequency is changed, an additional signal was captured - at 65 MHz, as shown in Figures A1.5. A 75 MHz value would fold back to the apparent frequency value of 0 Hz. Any larger offset of the input frequency at this specific sampling frequency would result in a fold back into the same spectral region, making it indistinguishable from each other. Therefore, when the center frequency is 70 MHz, the maximum usable bandwidth that can be accommodated in the undersampling mode without distortions is +- 5 MHz.

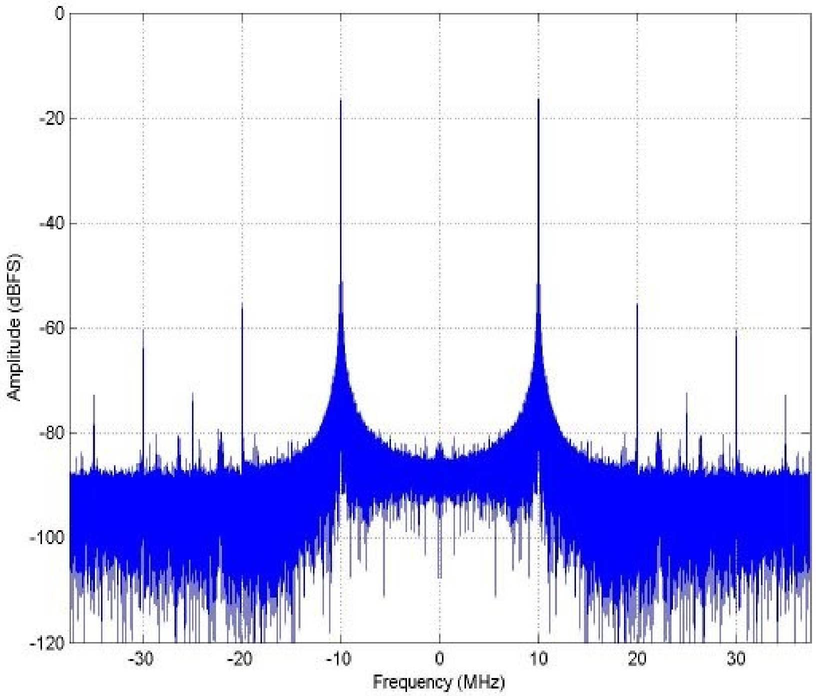


Figure A1.5: 65 MHz input signal directly captured (undersampling).

For reference, the noise floor of the A/D was captured by placing a 50 ohm resistor across the Analog Input of the RadioProcessor. This is shown below in Figure A1.6.

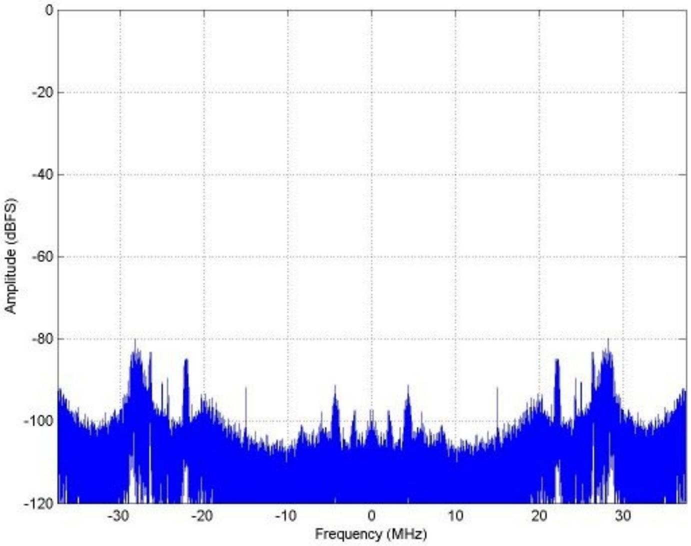


Figure A1.6: Noise floor.

These figures demonstrate that the RadioProcessor's A/D can handle frequencies above Nyquist (37.5MHz) because undersampling performance is comparable to standard sampling. Since the quadrature detection and filtering components are not even aware of whether aliasing is taking place in the A/D converter, they will perform exactly the same as for the standard sampling case.

Integration of RadioProcessor into a High-field System

In order to utilize the RadioProcessor as an IF excitation and detection system for high-field NMR applications above 100 MHz, a phase-coherent up- and down-conversion is required. The diagram in Figure A1.7, below, presents a simplified system that would utilize the RadioProcessor as a 70 MHz IF system and maintain the required phase coherence. The RadioProcessor utilizes a 50 MHz on board clock to derive the 75 MHz clock frequency for the A/D section, the 300 MHz clock for the D/A converter and the 10 MHz clock output. In the proposed system, the 10 MHz clock output of the RadioProcessor board would then drive the high-frequency synthesizer (e.g., the PTS brand) directly. As the RadioProcessor is broad-band, intermediate frequencies other than 70 MHz can be selected as well.

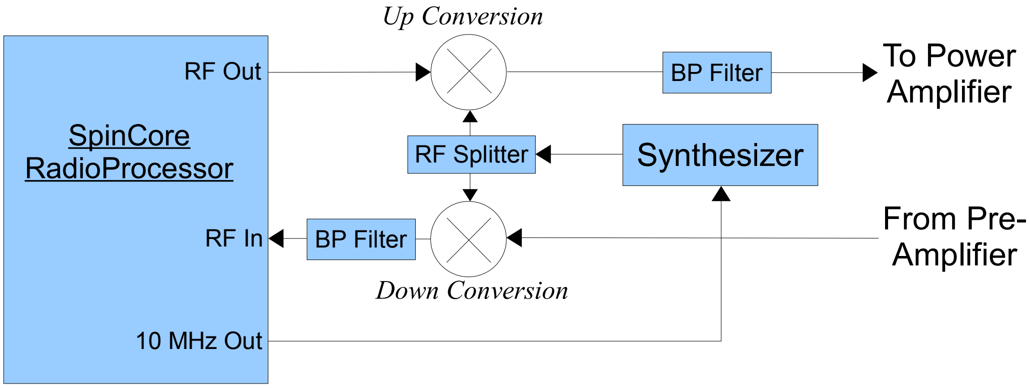


Figure A1.7: Simplified block diagram of a complete, phase-coherent high-field system with the use of RadioProcessor. Mini-Circuits mixers (ZAD-1) can be used for high-field operation up to 500 MHz. To split the signal from the synthesizer into two mixer signals, a Mini-Circuits splitter (ZFSC-2-1) can be used. Band-pass filtering is essential for quality results.

Appendix II: Arbitrary Waveform Generation

This document describes the shaped-pulse feature available on certain models of the RadioProcessor. If equipped, the RadioProcessor is capable of arbitrary waveform generation on its analog output. This feature allows for the following:

- RF outputs can be shaped by an arbitrary waveform. (for example, a sinc waveform)
- RF outputs can be scaled by a constant value.
- The RF output itself can be set to waveforms other than a sinewave (e.g., triangle wave, square wave, etc.).

This allows, for example, the generation of soft pulses as shown below in Figure A2.1.

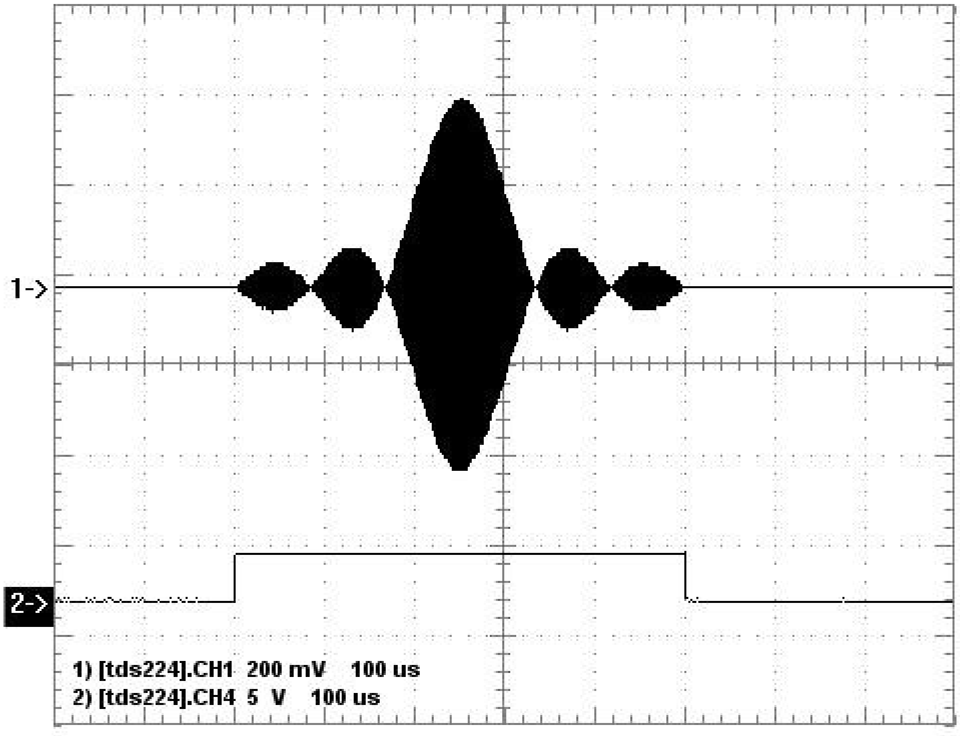


Figure A2.1: Sinc-shaped soft pulse. Pulse duration is 0.5 ms.

The AWG system is flexible and can be programmed with a wide variety of parameters. For example, as shown in the figures below, pulse sequences that have pulses with multiple different amplitudes can be generated and it is also possible to generate both hard and soft pulses in a single pulse program. The shape of the pulse is not limited to a sinc-shape; it is user-loadable with any arbitrary waveform.

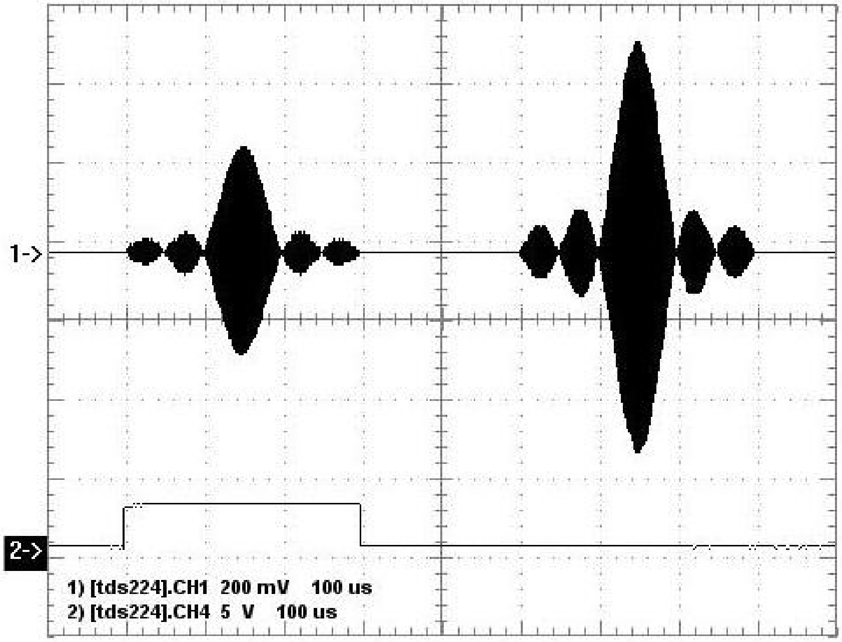


Figure A2.2: Combinations of RF pulses - variable amplitudes.

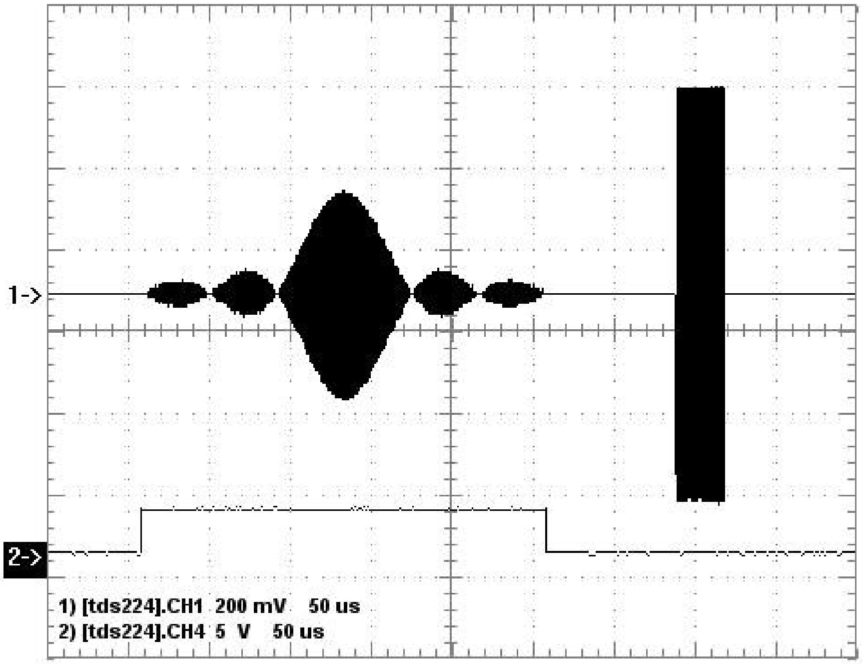


Figure A2.3: Combinations of RF pulses - soft- and hard-pulses in a sequence.

Using the AWG feature

To make use of the AWG feature, use the `pb_inst_radio_shape()` function to generate the instructions of your pulse program. This function has two additional parameters over the standard `pb_inst_radio()` function. They are:

use_shape:	if this is 0, no shape will be applied to the pulse. If it is nonzero, whatever waveform is loaded as the shape will be used to shape the RF pulse. The shape waveform can be loaded by the user with the pb_dds_load() function
amp:	This selects which amplitude register to use. The values stored in the amplitude register can be set with the pb_set_amp() function.

If a shaped pulse is used, the shape will be stretched to last the duration of the entire instruction. There are two other functions which are also used to control the AWG features:

`pb_set_amp()` - This function sets the values of the amplitude registers to the given values. There are 4 amplitude registers, so any pulse program can use four distinct amplitude values on its output.

`pb_dds_load()` - This function loads both the DDS waveform, and the shape waveform. The DDS waveform is loaded with a sinewave by default, so you do not need to re-load it unless you wish to use a different shape.

Example programs

An example program is included with the SpinAPI Package in the RadioProcessor directory to demonstrate how the AWG capabilities are used.

The example program is `awg.exe`, which is a simple demo program which you can use to view the AWG outputs on your oscilloscope. By default, this program generates two sinc-shaped pulses back to back followed by a 1ms delay. You can enter the amplitude for each one, as well as the desired RF frequency to be used. The TTL outputs are enabled at the same time the pulses are generated, and can be used as the trigger for the oscilloscope. The RF output can be viewed on another channel.

The source code for this program is well documented, please take a look to gain a better understanding on how the AWG features of the board are controlled.

Backwards compatibility with older code.

If you have a AWG-capable RadioProcessor board, you can still use older code which uses the `pb_inst_radio()` function. This code will still behave correctly; it will default to not using any shape and will default to using amplitude register 0. The `pb_set_defaults()` function always initializes amplitude register 0 to 1.0, and the DDS waveform is loaded with a sinewave, so the code will continue to operate the same as it did on previous generations of the RadioProcessor board which did not have AWG capabilities.

Relevant spinapi functions:
`pb_inst_radio_shape()`

Appendix III: RadioProcessor NMR Interface for MATLAB

Overview of SpinCore MATLAB GUI Interface

The SpinCore MATLAB GUI Interface is a series of programs created for the MATLAB environment that allows quick and easy interaction with the iSpin-NMR system. Specifically, this interface is designed to allow users to perform a variety of useful experiments with their system.

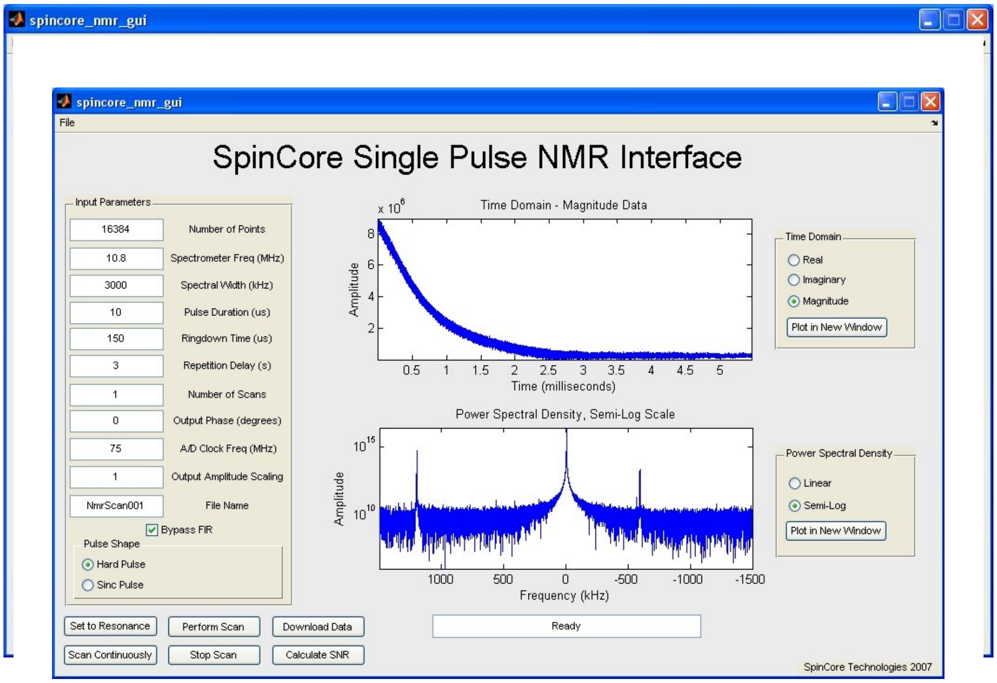
Complete documentation for the SpinCore MATLAB GUI can be found here:

http://www.spincore.com/support/RadioProcessor/MATLAB/Documentation.html

General Features:

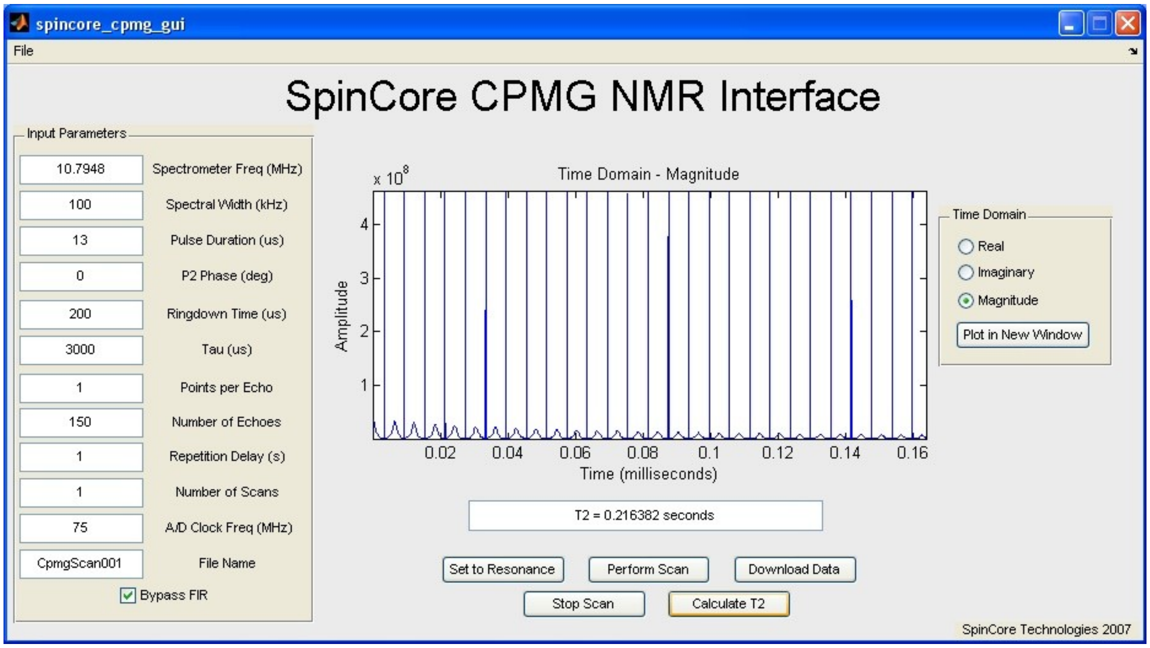
- Run NMR experiments with ease, including Single Pulse, CPMG, and 90 Degree Pulse-Width Determination
- Change experiment parameters quickly and easily
- Preview data in MATLAB immediately after the scan
- Combines the versatility of the RadioProcessor with the power of the MATLAB environment
- Quickly find resonant spectrometer frequency through automatic detection
- 90 Degree Pulse-Width Finder allows quick and simple detection of important pulse width parameters
- CPMG NMR includes a feature to calculate T2 relaxation times for samples with a single exponential
- Continuous Scan setting for Single Pulse NMR
- Load and review data from previous Single Pulse NMR experiments within the interface.

Sample Screenshots



16384 Number of Points
10.8 Spectrometer Freq (MHz)
3000 Spectral Width (kHz)
10 Pulse Duration (us)
150 Ringdown Time (us)
3 Repetition Delay (s)
1 Number of Scans
0 Output Phase (degrees)
75 A/D Clock Freq (MHz)
1 Output Amplitude Scaling
NmrScan001 File Name
☑ Bypass FIR
● Hard Pulse
○ Sinc Pulse
● Magnitude
● Semi-Log
Ready

Figure A3.2: Output as above, displaying Magnitude plot and Semi-log FFT.



Input Parameters

10.7948	Spectrometer Freq (MHz)
100	Spectral Width (kHz)
13	Pulse Duration (us)
0	P2 Phase (deg)
200	Ringdown Time (us)
3000	Tau (us)
1	Points per Echo
150	Number of Echoes
1	Repetition Delay (s)
1	Number of Scans
75	A/D Clock Freq (MHz)
CpmgScan001	File Name

☑ Bypass FIR

Time Domain

○ Real
○ Imaginary
● Magnitude

T2 = 0.216382 seconds

Figure A3.3: Sample output after running CPMG NMR experiment on household cooking oil.

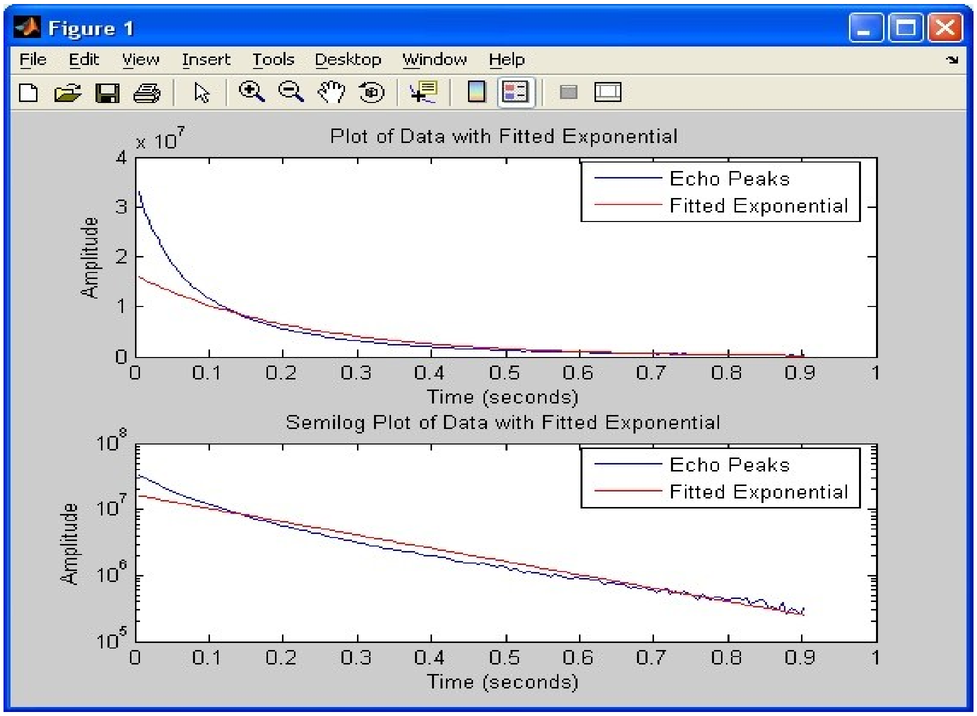
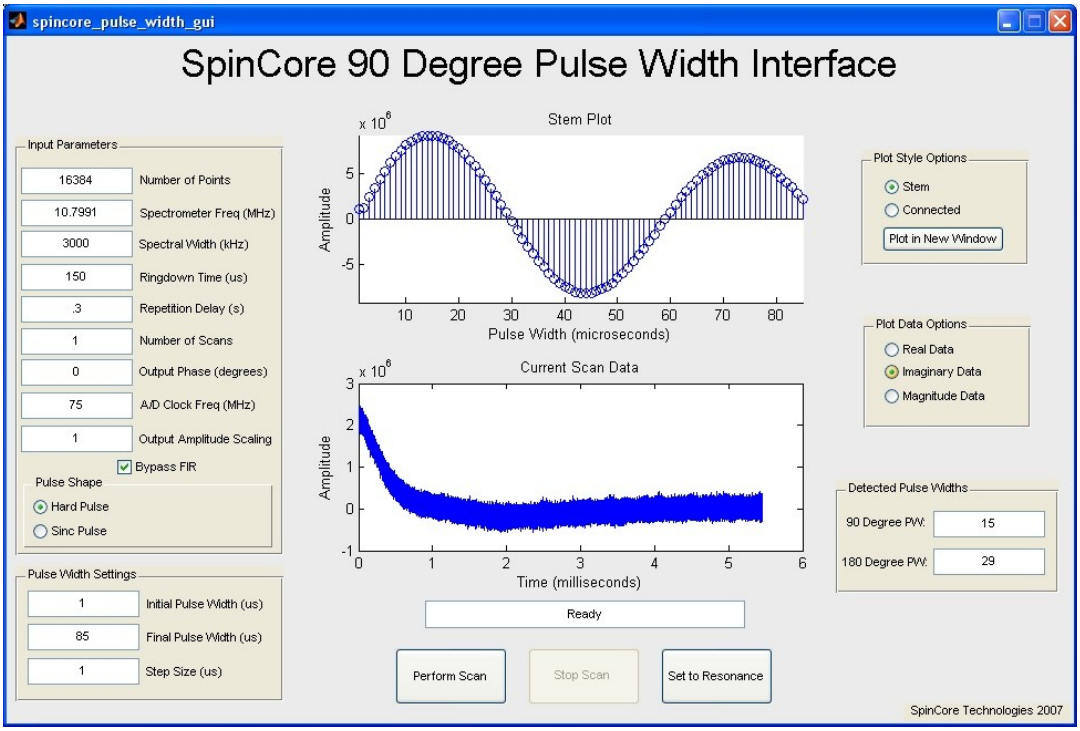


Figure A3.4: Sample T2 calculation and curve fitting.



Input Parameters

16384 Number of Points
10.7991 Spectrometer Freq (MHz)
3000 Spectral Width (kHz)
150 Ringdown Time (us)
.3 Repetition Delay (s)
1 Number of Scans
0 Output Phase (degrees)
75 A/D Clock Freq (MHz)
1 Output Amplitude Scaling
☑ Bypass FIR

Pulse Shape

● Hard Pulse
○ Sinc Pulse

Pulse Width Settings

1 Initial Pulse Width (us)
85 Final Pulse Width (us)
1 Step Size (us)

Ready

Plot Style Options

● Stem
○ Connected

Plot Data Options

○ Real Data
● Imaginary Data
○ Magnitude Data

Detected Pulse Widths

90 Degree PW: 15
180 Degree PW: 29

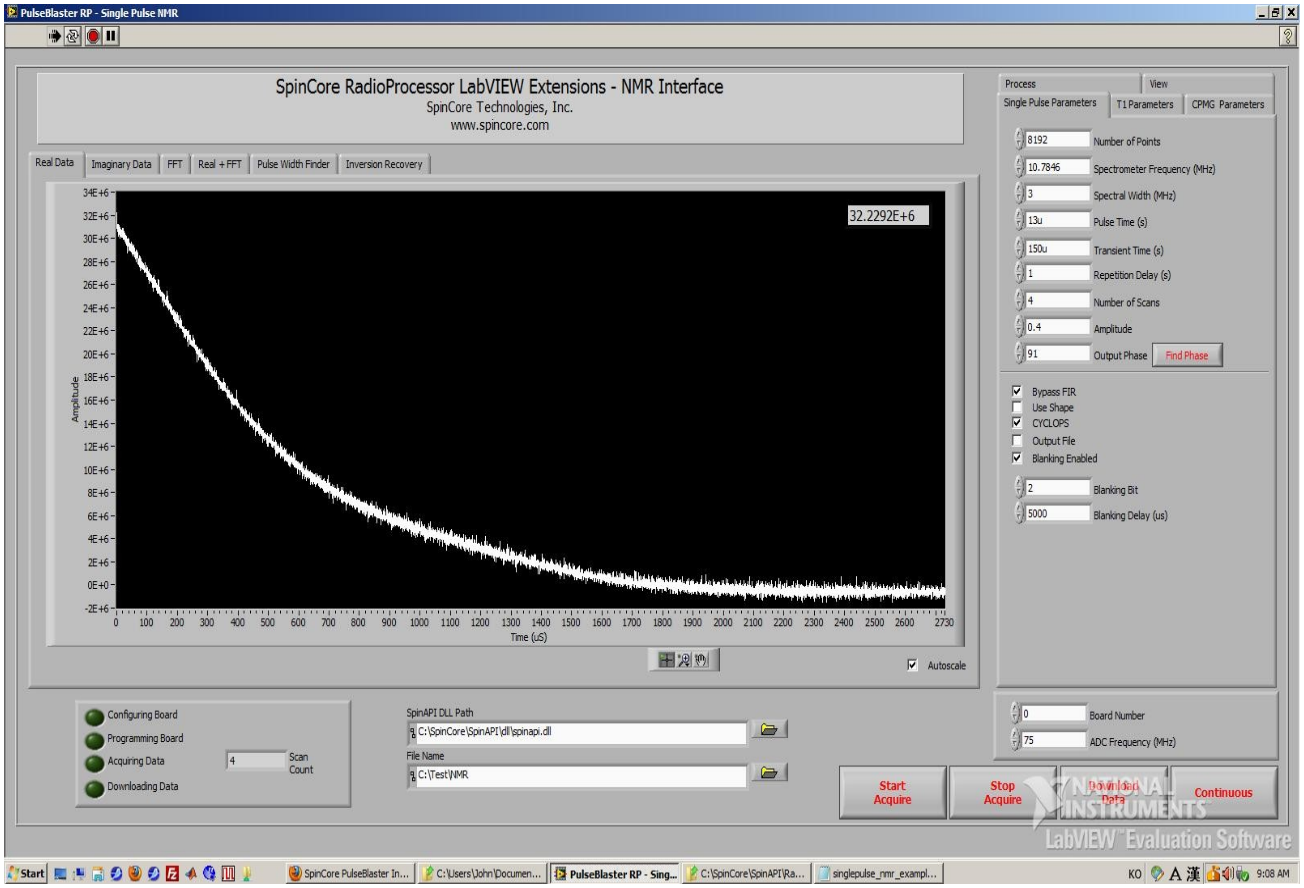
Figure A3.5: Automatic 90 Degree Pulse Width Determination.

Appendix IV: RadioProcessor NMR Interface for LabVIEW

Overview of SpinCore LabVIEW GUI Interface

SpinCore has developed an easy-to-use LabVIEW Graphical User Interface (GUI) that combines the Single Pulse NMR, T1 Inversion Recovery, and CPMG interfaces into one interface. It allows the user to run basic NMR experiments by simply setting the experiment parameters as described elsewhere in this manual. Extra features in LabVIEW GUI include lightning fast resonance finder, built-in FFT and phasing, CYCLOPS phase cycling experiments, 90 degree pulse width finder, and continuous scan mode. Some sample screenshots are shown below.

For more information see the LabVIEW manual at:
http://www.spincore.com/support/PBLV/PBLV_RP_NMRinterface_Manual.pdf



8192 Number of Points
10.7846 Spectrometer Frequency (MHz)
3 Spectral Width (MHz)
13u Pulse Time (s)
150u Transient Time (s)
1 Repetition Delay (s)
4 Number of Scans
0.4 Amplitude
91 Output Phase

☑ Bypass FIR
☐ Use Shape
☑ CYCLOPS
☐ Output File
☑ Blanking Enabled

2 Blanking Bit
5000 Blanking Delay (us)

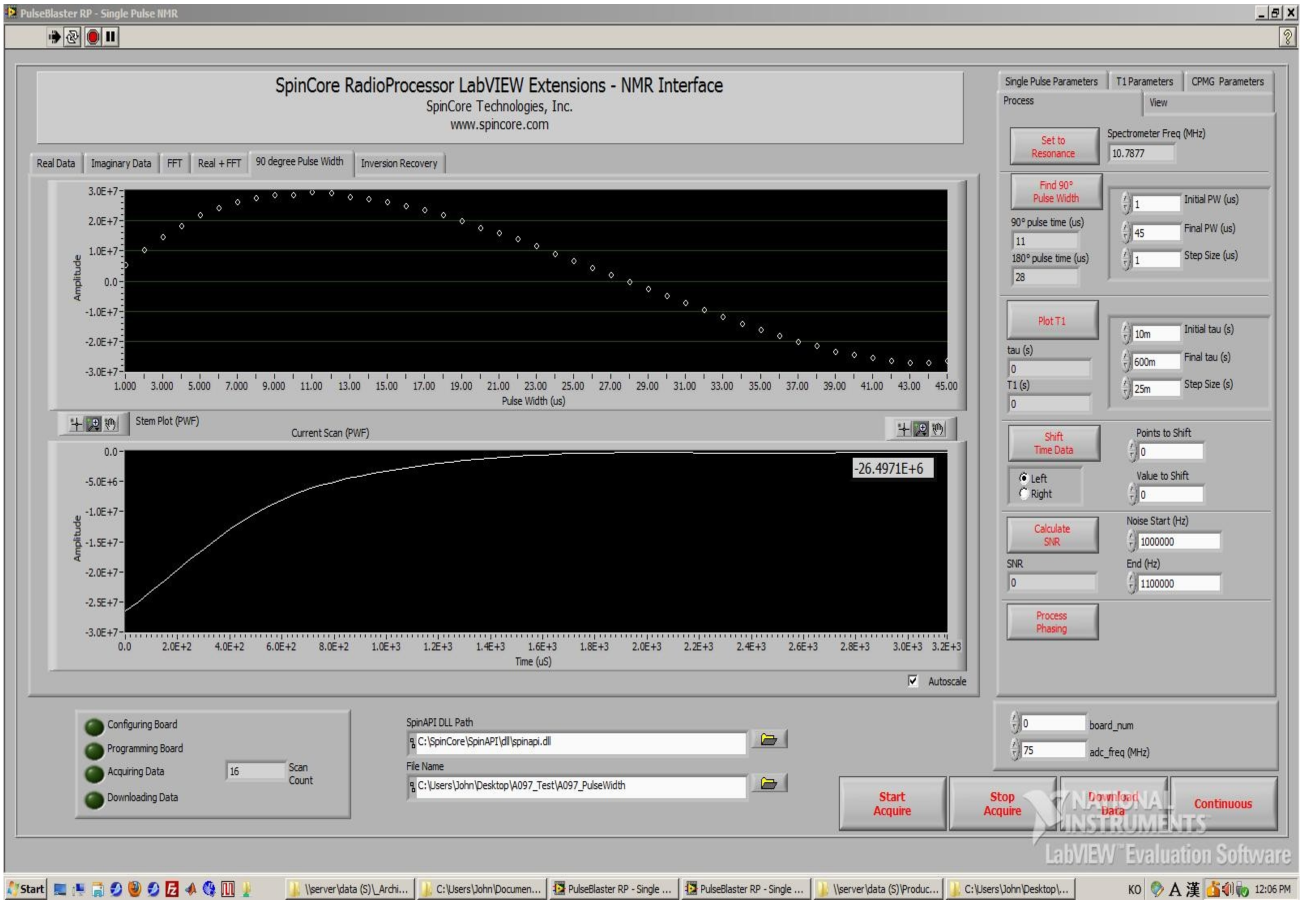
0 Board Number
75 ADC Frequency (MHz)

4 Scan Count

SpinAPI DLL Path: C:\SpinCore\SpinAPI\dll\spinapi.dll
File Name: C:\Test\NMR

☑ Autoscale

Figure A4.1: Example of RadioProcessor LabVIEW Extensions User Interface.



Spectrometer Freq (MHz): 10.7877

90° pulse time (us): 11

180° pulse time (us): 28

Initial PW (us): 1

Final PW (us): 45

Step Size (us): 1

tau (s): 0

T1 (s): 0

Initial tau (s): 10m

Final tau (s): 600m

Step Size (s): 25m

Points to Shift: 0

● Left ○ Right

Value to Shift: 0

Noise Start (Hz): 1000000

End (Hz): 1100000

SNR: 0

☑ Autoscale

board_num: 0

adc_freq (MHz): 75

Scan Count: 16

SpinAPI DLL Path: C:\SpinCore\SpinAPI\dll\spinapi.dll

File Name: C:\Users\John\Desktop\A097_Test\A097_PulseWidth

Figure A4.2: Example of Pulse Width Finder for LabVIEW NMR Interface.

Appendix V: Miscellaneous Functionality

10 MHz Clock output on BNC0

RadioProcessorPCI boards with firmware revision 10-13 or newer have the capability of outputting a 10 MHz signal on the BNC0 connector. This signal is a 50% duty cycle square wave derived directly from the on-board 50 MHz clock oscillator, and is intended for synchronization purposes.

To enable this output, call the following SpinAPI function:

pb_set_radio_control(BNC0_CLK);

To have BNC0 return to normal pulse program behavior, call:

pb_unset_radio_control(BNC0_CLK);

If this clock output is enabled, loading the board with another pulse program will not affect the output clock signal. The 10 MHz signal will continue to be present on BNC0 until one of the following events occurs: (1) the computer is turned off, (2) *pb_unset_radio_control(BNC0_CLK)* is called, or (3) *pb_set_defaults()* is called. Condition 3 may occur if you are using multiple programs to control your RadioProcessor, and can be avoided by making sure that only one of the programs calls *pb_set_defaults()* and that this program is not run after the one that calls *pb_set_radio_control(BNC0_CLK).*

NOTE: When enabled, this option does not affect the functionality of the Digital Output 0 pin on the IDC connector. This pin will still serve as a digital output under control of the pulse program.

NOTE: This feature is only available for PCI versions of the RadioProcessor board.

Controlling Signal Averaging Behavior

RadioProcessor boards with firmware revision 10-14 (and above) allow the user to average data across multiple sets of scans via *Forced Averaging*. Forced Averaging is different than the already-existing signal averaging behavior; this new feature allows the user to run a scan (or a set of averaged scans), vary a parameter like the content of a particular frequency register, trigger the program again, and have the results from the second program run be averaged with the results of the first program run.

To enable Forced Averaging, call the following SpinAPI function:

pb_set_radio_control(FORCE_AVG);

To turn off Forced Averaging, call:

pb_unset_radio_control(FORCE_AVG);

If Forced Averaging is enabled, loading the board with another pulse program will not turn off Forced Averaging. Forced Averaging will remain on until one of the following events occurs: (1) the computer is turned off, (2) *pb_unset_radio_control(FORCE_AVG)* is called, or (3) *pb_set_defaults()* is called. Condition 3 may occur if you are using multiple programs to control your RadioProcessor, and can be avoided by making sure that only one of the programs calls *pb_set_defaults()* and that this program is not run after the one that calls *pb_set_radio_control(FORCE_AVG).*

“On the fly” Register Programming with SpinAPI

What is “on the fly” register programming?

“On the fly” register programming refers to the ability to modify the frequency and phase registers of the RadioProcessor using your PC during Pulse Program execution.

How can I use this feature?

If you have firmware revision 10-18, you can use functions in SpinAPI to easily update the frequency and phase registers at any time.

What is the latency associated with updating the registers?

Since the amount of data transferred to the board is small, the load time will be on the order of a millisecond. Since the conditions of the host PC will affect data transfer rates to the board, an exact number cannot be given. A heavily loaded system will take longer to update the register values than an unloaded system.

The phase and frequency registers can be updated at any time using *pb_start_programming(..)* and *pb_stop_programming()*.

Note: *The following examples assume that pb_init() and pb_close() are included in the program.*

```
pb_start_programming(FREQ_REGS);
     pb_set_freq(1.0*MHz);
pb_stop_programming();
```

Example A5.1a: “On the fly” frequency register 0 update.

```
pb_start_programming(TX_PHASE_REGS);
     pb_set_phase(0.0);
pb_stop_programming();
```

Example A5.1b: “On the fly” phase register 0 update.

The following register banks can be programmed “on the fly” :
FREQ_REGS, TX_PHASE_REGS, COS_PHASE_REGS, SIN_PHASE_REGS.

See the following example *(Example A5.2)* on how to perform a frequency sweep using the “on the fly” programming feature.

```
//RadioProcessor “On the Fly” register programming.
//Note: It is assumed that there is a Pulse Program already running using
frequency register 0.
int main()
{
      if(pb_init())
      {
                  printf ("Error initializing board: %s\n",
pb_get_error());
            return -1;
      }

      int i;

      for( i=0 ; i <10 ; i++ )
      {
            pb_start_programming(FREQ_REGS);
                  pb_set_freq( ( ( (double)i )+1.0)*MHz);
            pb_stop_programming();
            pb_sleep_ms(1000); //Wait 1 second.
      }

      pb_close();
      return 0;
}
```

Example A5.2: Using SpinAPI to perform a frequency sweep from 1 to 10 MHz using frequency register zero. The frequency is incremented once every 1000 ms.

Clock Input Signal Standard

It is also possible to use an external 50 MHz clock source to drive the RadioProcessor board, but **this should be done with extreme caution**. The RadioProcessor is a digital system built in CMOS technology and powered off a 3.3 V DC source and will accept external clock signals that conform to the low-voltage 3.3 V TTL standard only. Negative voltage below 0.2 Volts would damage the processor chip, and thus **any external sinusoidal signal would need to be converted to the positive-only TTL signal prior to using with the RadioProcessor.**

Alternative Sampling Frequencies

The RadioProcessor can be customized to operate with alternative sampling frequencies. An example alternative A/D sampling frequency value also suitable for 70 MHz IF applications (demonstrated in Appendix I) would be 60 MHz. At this frequency, the 70 MHz input signal would fold, when sampled, into the apparent 10 MHz frequency. This apparent 10 MHz signal would be handled by the RadioProcessor's digital detection and filtering system in the same way as any other signal within the Nyquist range. To operate in the coherent mode at 60 Ms/s, the RadioProcessor master clock source would need to be 40 MHz. With the reference clock frequency of 40 MHz, the Tx DAC would operate at 240 MHz.

Appendix VI: CYCLOPS Control

Select SpinCore RadioProcessor designs have internal hardware controls that allow for phase cycling experiments. A particularly useful phase cycling experiment for quadrature detection systems is called CYCLOPS (CYCLically Ordered Phase Sequence). In a CYCLOPS experiment, scans are run with the transmitter phase cycling in 90° increments and the controls mentioned above changing with each scan so that the acquired data is averaged coherently, while any non-coherent noise is simply canceled.

The three control parameters for CYCLOPS (and other phase cycling experiments) are described below:

•`int` *real_add_sub*: A '1' will add the incoming real signal with the real value stored in memory. A '0' will subtract the incoming real signal from the real value stored in memory.

•`int` *imag_add_sub*: A '1' will add the incoming imaginary signal with the imaginary value stored in memory. A '0' will subtract the incoming imaginary signal from the imaginary value stored in memory.

•`int` *channel_swap*: A '0' will keep all real values in the real part of the signal averager (and all imaginary values in the imaginary part of the averager), while a '1' will cause the incoming **real** signal to be added (or subtracted) from the **imaginary** value stored in memory, and will cause that value to be stored in the **imaginary** section of memory. A '1' will also cause the incoming **imaginary** signal to be added (or subtracted) from the **real** value stored in memory, and will cause that value to be stored in the **real** section of memory.

Relevant spinapi functions:
`pb_inst_radio_shape_cyclops(...)`

Table A6.1 below shows the necessary values to run CYCLOPS experiments.

Scan	Transmitter Phase	Receiver Phase	Real	Imag.	Swap?
0	0°	cos: 90° sin: 0°	Add	Add	No
1	90°	cos: 90° sin: 0°	Add	Sub	Yes
2	180°	cos: 90° sin: 0°	Sub	Sub	No
3	270°	cos: 90° sin: 0°	Sub	Add	Yes

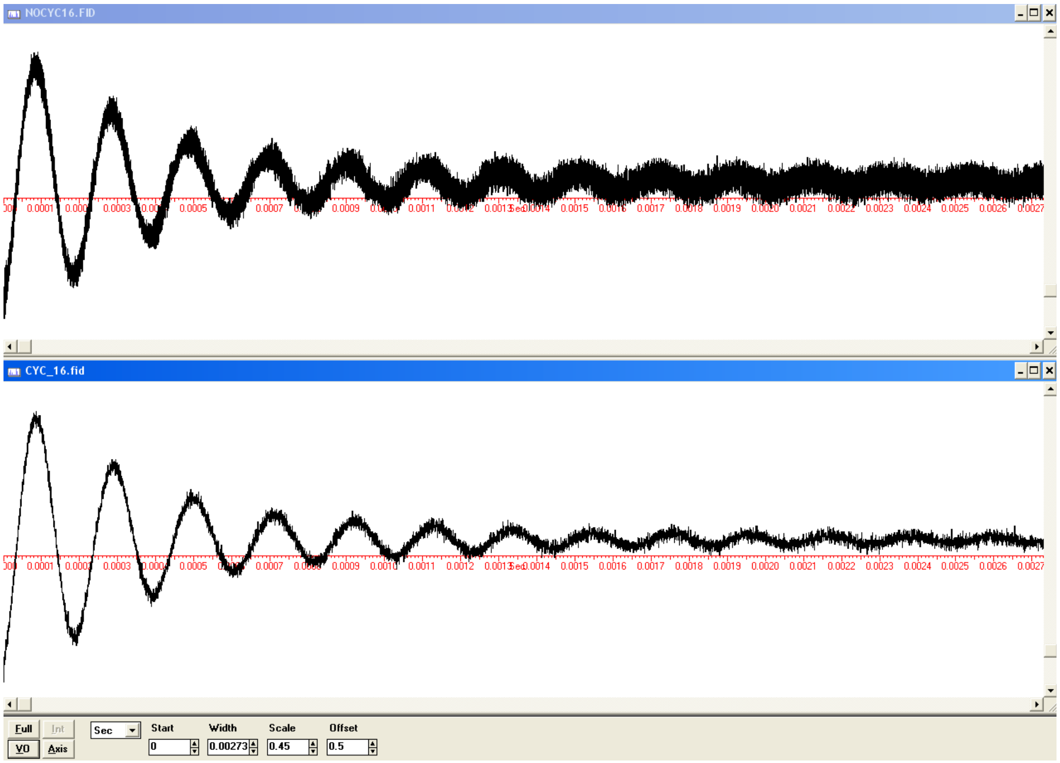
Table A6.1: Parameters used for CYCLOPS experiments.

A CYCLOPS example batch program, CYCLOPS_nmr_example.bat, can be found in the SpinCore RadioProcessor directory (.../SpinCore/SpinAPI/RadioProcessor/CYCLOPS). The parameters in this batch file are identical to the singlepulse_nmr_example.bat program, with 12 extra parameters (4 instances of the real_add_sub, imag_add_sub, and channel_swap parameters). The parameters are listed below:

- REAL_ADD_SUB_#
- IMAG_ADD_SUB_#
- SWAP_#

where "#" is either 0, 1, 2, or 3 for each of the four CYCLOPS scans. A '1' will add or swap and a '0' will subtract or not swap. In order to achieve the full CYCLOPS effect, the NUMBER_OF_SCANS parameter should be a multiple of 4, however any number of scans may be run.

Sample data showing performance gain with CYCLOPS is shown in the following figures. Figure A6.1 shows NMR data acquired in the presence of non-coherent noise using 16 scans. The data on top was acquired using normal averaging, while the data on the bottom was acquired using CYCLOPS averaging. Notice the signal-to-noise ratio improvement when using CYCLOPS. Figure A6.2 shows the same data represented in the frequency domain. The data on the left was acquired with CYCLOPS, while the data on the right was acquired without CYCLOPS.



Start 0
Width 0.00273
Scale 0.45
Offset 0.5

Figure A6.1: NMR signal averaged over 16 scans without CYLOPS (top) and with CYCLOPS (bottom).

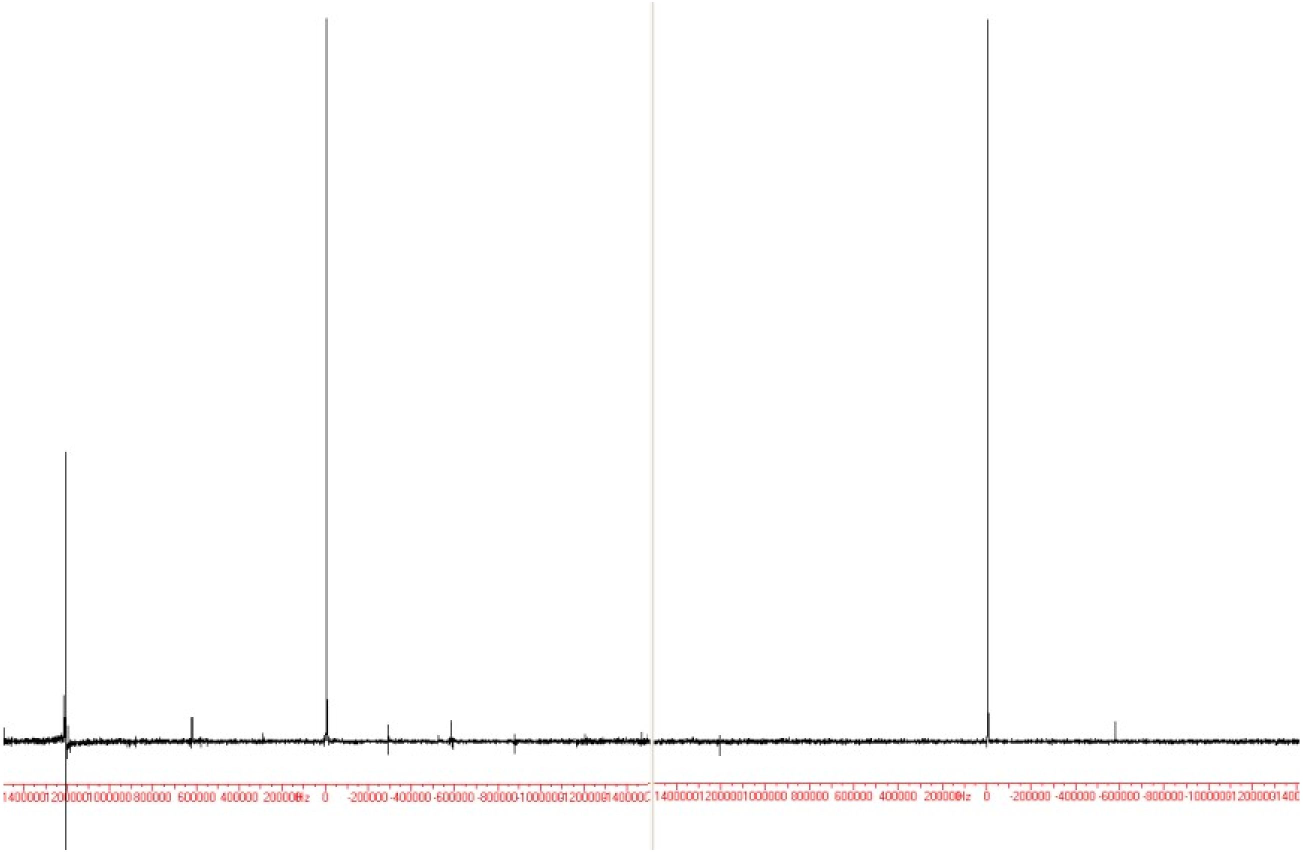


Figure A6.2: NMR signal averaged over 16 scans without CYLOPS (left) and with CYCLOPS (right). Notice the absence of the large noise spike, and the reduction of other noise spikes when CYCLOPS is used.

Appendix VII: RadioProcessor Firmware Designs

The chart below shows specifications for different RadioProcessor firmware designs. The RadioProcessor firmware design can be read from the board using the `read_firmware.exe` example (located in: ...\SpinCore\SpinAPI\general). (Note: the firmware ID can also be physically read from the label placed on the design EEPROM of each board).

	Firmware ID 10-22 (PCI SP6 board)	Firmware ID 15-2 (PCI SP16 board)	Firmware ID 12-15 (USB SP7 board)
# Frequency Registers	8	16	8
# Tx Phase Registers	4	16	4
# Cosine Phase Registers	4	4	4
# Sine Phase Registers	4	4	4
# TTL Output Flags/Bits/Channels	4	4	4
Spectral Width Range (at 75 MHz A/D Clock Frequency)	1.2 kHz to 9.38 MHz (4.47 Hz to 9.38 MHz w/ FIR Enabled)	72 Hz to 9.38 MHz (0.28 Hz to 9.38 MHz w/ FIR Enabled)	72 Hz to 9.38 MHz (0.28 Hz to 9.38 MHz w/ FIR Enabled)
CYCLOPS Control	Yes	No	Yes

Table A7.1: RadioProcessor Firmware Designs.

Note: Most parameters can be customized. Please contact SpinCore Technologies, Inc for pricing and availability of custom designs.

Related Products and Accessories

1. RadioProcessorUSB Power Supply. For more information, please visit http://spincore.com/products/SP11/RadioProcessor-USB-Power-Supply.shtml
2. iSpin-NMR - Complete mobile NMR system. For more information, please visit http://spincore.com/products/iSpinNMR/
3. If you require a broadband pre-amplifier, Oven Controlled Clock Oscillator (sub-ppm stability) or a custom design, please inquire with SpinCore Technologies through our contact form, which is available at http://spincore.com/contact.shtml

Contact Information

Thank you for choosing a design from SpinCore Technologies, Inc. We appreciate your business! At SpinCore we try to fully support the needs of our customers. If you are in need of assistance, please contact us and we will strive to provide the necessary support. Please see our contact information below for any feedback or questions you may have.

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Web Contact Form:	http://www.spincore.com/contact.shtml

Document Information

Revision history is available by contacting SpinCore Technologies, Inc. at the address above.