Extension of 8 Step Phase Cycling Scheme for improved lipid suppression using four-pulse PRESS MRS Sequences

S. Sison[1], M. H. Buonocore[2], and R. J. Maddock[3]

[1]Biomedical Engineering, UC Davis Imaging Research Center, Sacramento, CA, United States, [2]Radiology, UC Davis Imaging Research Center, Sacramento, CA, United States, [3]Psychiatry, UC Davis Imaging Research Center, Sacramento, CA, United States

Introduction: Two standard phase cycling schemes used in PRESS MRS sequences are 8 Step [1] and 16 Step EXOR [2]. Both of these phase cycling schemes sum the spin echo formed from the combination of the three RF pulses in PRESS and cancel the FIDs and echoes formed from all other pulse combinations (except the stimulated echo which can be removed by choosing different moments for the first refocusing pulse spoilers and the second refocusing pulse spoilers). The signals created by one or two pulse combinations are created from entire columns or slices of spins and will contain large amounts of lipid signal if the slice or column includes a region of fatty tissue. It is very important to cancel these signals in order to obtain spectra that accurately represent the metabolites in the prescribed voxel. We have been investigating a modified PRESS sequence that requires an additional refocusing pulse to eliminate chemical shift misregistration artifacts in the spectra of coupled spin systems such as lactate and GABA [3]. This four RF pulse sequence creates new unwanted signals that will not be cancelled by the available 8 Step or 16 Step EXOR schemes. A phase cycling scheme that sums the spin echo formed from the combination of the four RF pulses and cancels all the other FIDs and echoes has been developed in order to cancel these unwanted signals.

Methods: Fig. 1 shows the spin phase diagram for the four pulse sequence, stimulated echoes were not included for reasons explained above. The equation for the phase of the FIDs and spin echoes in a three pulse sequence are given in [1]. We extended the equation to include the phase of a spin echo created from the combination of four RF pulses. This equation was derived to be $(2\phi_4 - 180°) + 2\phi_3 - 2\phi_2 + (\phi_1 + 90)$ where ϕ_n is the phase of the n^{th} RF pulse. From this equation, a 16 step phase cycling scheme was developed which cancels every FID and spin echo except the desired spin echo created by the combination of all four RF pulses. Table 1 shows ϕ_1, ϕ_2, ϕ_3, ϕ_4 and the receiver phase, ϕ_{Rec}, for each of the 16 steps.

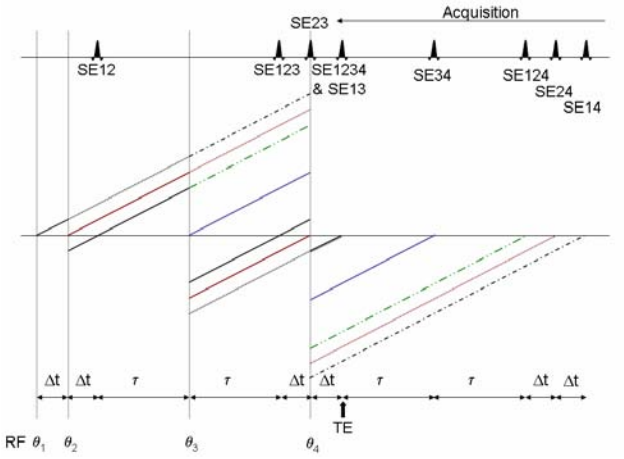

Figure 1. Spin Phase Diagram

The phase cycling scheme was implemented on a Siemens Trio 3T whole body MRI system (Siemens Medical Solutions, Erlangen, Germany) and tested on a standard GE MRS Brain spherical phantom (containing physiological concentrations of Creatine, Choline, NAA, and lactate) with a 1 cm thick package of fatty bacon in full contact with the undersurface of the phantom to serve as a source of contaminating fat signal. A 40mmx40mmx40mm voxel was formed inside of the MRS phantom with a location and size that caused the selected slices and columns of the PRESS sequence to intersect the fatty bacon. a Nova Medical, Inc. Bitemporal Lobe Array (Wilmington, MA) surface coil for signal reception. Scans were run without and with phase cycling using the new 16 step phase cycling scheme. Scan parameters were TR=1500ms, TE=144ms, and 256 averages. Post processing was done in jMRUI v2.2: hard phase water referencing, zero filling from 2048 to 4096 and apodization with a 4Hz Gaussian filter. Both scans were acquired with spoiler gradients surrounding each of the three refocusing pulses.

Results: Fig. 2 shows the inverted lactate doublet at 1.32ppm for both acquisitions. The arrows point to unwanted signals in the acquisition with no phase cycling that are suppressed with the new phase cycling scheme, resulting in an overall smoother baseline. This phase cycling scheme can be applied to any sequence that uses four RF pulses.

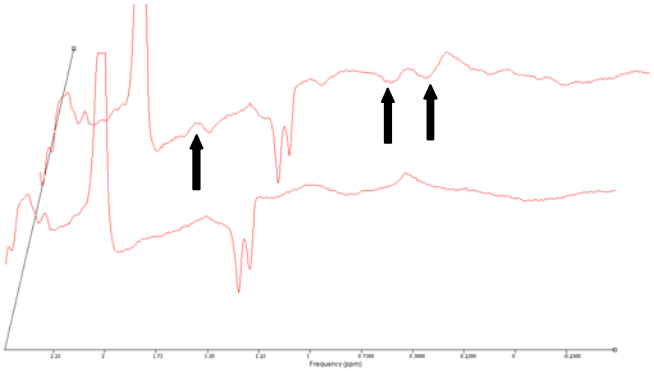

Figure 2. MRS + Lipid Phantom. No Phase Cycling (top) vs New Phase Cycling (bottom).

ϕ1	ϕ2	ϕ3	ϕ4	ϕRec
90	90	0	0	180
90	180	90	180	180
90	270	180	0	180
90	0	270	180	180
90	90	90	0	0
90	180	180	180	0
90	270	270	0	0
90	0	0	180	0
270	90	0	90	180
270	180	90	270	180
270	270	180	90	180
270	0	270	270	180
270	90	90	90	0
270	180	180	270	0
270	270	270	90	0
270	0	0	270	0

Table 1. 16 Step Phase Cycling for Four RF Pulses. Summation of 16 acquisitions with this phase cycling scheme will cancel all FIDs and spin echoes except SE1234.

References: 1) Hennig. *JMR* 96:40-49, 1992. 2) Bodenhausen. *JMR* 27:511-514, 1977. 3) Keltner *MRM* 36:458-461, 1996. 4) Haacke. Wiley 1999.

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