Matched Phase Dualband Spatial-Spectral 90º-180º Pulse Pair for MRSI at 3T

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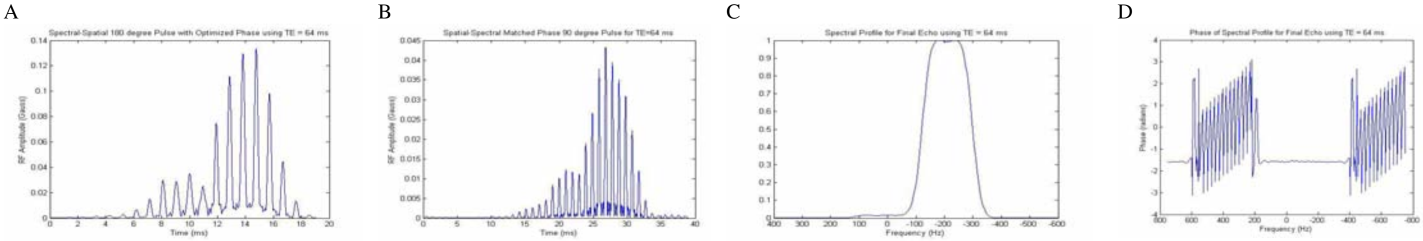
Introduction: ^{1}H MRSI is a useful technique for obtaining spatially localized profiles of metabolites of interest in the breast, brain and prostate. However, MRSI usually suffers from: 1) Inadequate water or lipid suppression; 2) spectral shifts due to B_0 inhomogeneity; 3) low SNR of metabolite signals; 4) spatially varying phase profiles due to B1 inhomogeneities; 5) chemical shift artifacts and 6) insufficient data for metabolite quantification. At 3T, higher SNR and increased frequency separation can be possible as compared to 1.5T; however, staying below RF peak power limits becomes a challenge. A pulse sequence has been designed for use at 3T that utilizes a dualband spatial-spectral matched phase 90º-180º pulse pair to excite a thin slice. It offers the following solutions to some of the aforementioned problems: 1) the use of spatial-spectral pulses allows for the excitation of a spectral band that encompasses the metabolites of interest but excludes lipids; 2) dualband spatial-spectral pulses have a partial water passband so that water may be used as a frequency reference in the presence of B_0 inhomogeneities; 3) Unlike current 3T PRESS sequences that use spatial-spectral 180º pulses [1], this sequence uses two pulses instead of three making it possible to achieve shorter echo times resulting in significantly higher SNR at 3T [2]; 4) Using a matched phase 90º-180º pulse pair yields a final echo with a flat phase profile and 6) The higher spatial bandwidth of spatial-spectral compared to standard spatial pulses (3.5 kHz vs. 1.2 kHz) results in less severe chemical shift artifacts. The first set of pulses have been designed for breast MRSI, however it is not difficult to adapt the pulses to the brain or prostate.

Method: Initially a linear-phase 180º dualband spatial-spectral pulse that encompassed choline at 3.2 ppm and suppressed all lipid resonances was designed. The partial water band was designed to excite 1% of the water signal at 4.7 ppm. Short echo times require short pulses; however, shorter pulses result in low selectivity and increased ripple in the final profile. A 20 ms pulse resulting in TE= 64 ms exhibited acceptable ripple and selectivity. Using the Shinnar Le-Roux (SLR) algorithm [3] for RF pulse design, each RF pulse can be described by a pair of complex polynomials ($\beta(k_z,k_\omega)$, $\alpha(k_z,k_\omega)$) or just (β, α). In order to bring the linear 180º pulse below RF peak power limits, the roots of the β polynomial that fell outside the unit circle were computed and every possible root flipped configuration was traversed to find the one that resulted in the lowest RF peak power [4]. In order to compensate the non-linear phase profile introduced by root flipping, the β from the 180º pulse was used to create a phase matched β for the 90º pulse. See equation 1 for the final spectral profile, given in terms of terms of the transforms of the β and α polynomials. To compensate the phase across the 180, the matched phase 90 has to have a β such that its transform is given by equation 2. This results in a final spectral profile given by Equation 3.

$$S(z,\omega) = (2\alpha_{90}(z,\omega)\beta_{90}(z,\omega)^*)\,(\beta_{180}(z,\omega))^2 \qquad [1]$$
$$\beta_{90}(z,\omega) = (\beta_{180}(z,\omega))^2 \qquad [2]$$
$$S(z,\omega) = (2\alpha_{90}(z,\omega)\,(\beta_{180}(z,\omega)^2)^*)(\beta_{180}(z,\omega))^2 \qquad [3]$$

This technique flattened the phase considerably. However, some phase was still contributed by $\alpha_{90}(z,\omega)$. This phase was removed by adding the phase of $\alpha_{90}(z,\omega)$ to $\beta_{90}(z,\omega)$ so that $\beta_{90}(z,\omega)$ completely compensated the residual phase introduced by $\alpha_{90}(z,\omega)$ in the final spectral profile. See Figure 1 for simulations of A) the root-flipped 180º pulse, B) the matched phase spatial-spectral 90º pulse, C) the spectral profile of the final echo and D) the phase across the spectral profile of the final echo.

A B C D



A B

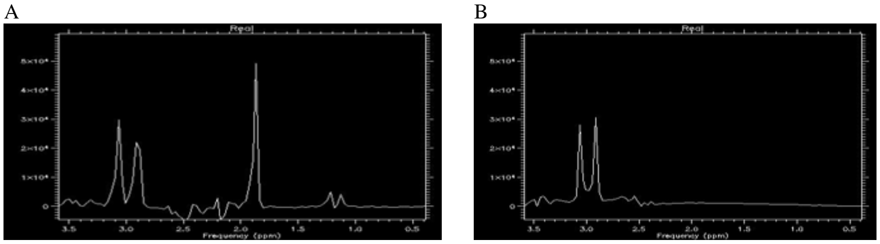


Figure 1: (Above) Simulations for 3T matched phase 90º-180º pulse pair for the breast (A) Root flipped 180º spatial-spectral RF pulse, (B) the matched phase spatial-spectral 90º pulse, (C) spectral profile of the final echo, (D) phase across the spectral profile of the final echo.

Figure 2: (Left) Results from GE MRS Sphere phantom scanned at 3T (A) spectrum obtained using standard GE 3T PRESS sequence with TE= 64 ms. (B) spectrum obtained using the matched phase 90º-180º pulse pair for the breast with TE=64 ms.

Results: Results from an experiment on the GE MRS Sphere phantom are shown in Figure 2. Figure 2A shows the spectrum obtained from exciting a 20 mm slice using the GE 3T PRESS sequence with TE= 64 ms. Figure 2B is the spectrum obtained using the matched phase 90º-180º pulse pair with TE=64 ms. It can be seen that the matched phase sequence for the breast successfully passes a 1 ppm band encompassing the metabolites present in the breast (i.e. choline at 3.2 ppm, creatine at 3 ppm) and suppresses all other resonances. The passband can also be slightly shifted to include citrate (at 2.6 ppm) making it possible to use this particular pulse pair for prostate imaging.

Conclusions: A matched phase 90-180 sequence has been developed for MRSI at 3T and offers many advantages. First, it enables shorter echo times while still having a spectrally selective profile. Second, it makes possible flat phase profiles using just two pulses. Third, it partially excites water making it possible to use this signal for quantification. Adapting the sequence to the brain or prostate, involves lengthening the metabolite passband while still suppressing lipids. For the brain this will require a short transition band between NAA and lipids, and thus longer pulses.

References:[1] Cunningham CH, et al. *Magn Reson Med.* 2005 May;53(5):1033-9. [2] Barker PB, et al. *Magn Reson Med.* 2001 May;45(5):765-9.
[3] Pauly J, Le Roux P, Nishimura D, Macovski A. *IEEE Trans Med Imaging* 1991; 10: 53-65. [4] Cunningham CH, et al. *Magn Reson Med.* 2004 Jul;52(1):147-53.

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