High Bandwidth Dualband Selective Saturation RF Pulses for Prostate Proton MRSI

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Introduction

Very Selective Saturation (VSS) pulses are critical for PRESS localized spectroscopy by providing outer volume suppression and reducing chemical shift artifacts [1]. Typically, 6 bands are placed at the transition bands of the PRESS localization pulses. Since these bands are placed in parallel pairs on the three axes, cosine modulation in the time domain has been utilized to generate two parallel bands with a single pulse, thereby saving time in the suppression pulse train by eliminating some crusher gradients [2]. However, cosine modulation requires doubling the pulse duration (and thus halving the bandwidth) if the peak power is held constant. The method presented by Kerr *et al* [3] generates a dual band saturation pulse with a $\sqrt{2}$ reduction in peak amplitude. Here we applied this same approach along with an optimized root flipping strategy for generating a high $T(BW)$ product dual band saturation pulses which have a $\sqrt{2}$ improvement in bandwidth and similar peak amplitude of cosine modulated pulses of the same duration.

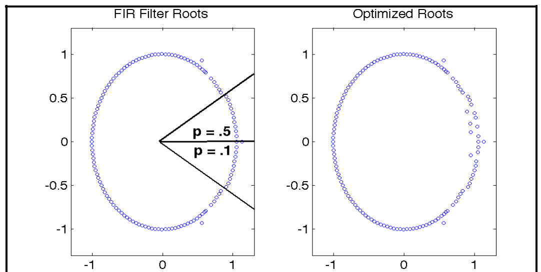

Fig 1) Original roots of the optimized filter (left) showing the root flipping probabilities used. The right figure is the root configuration minimizing $|B_1(t)|+|B_1(\tau-t)|$. This configuration is typical of minimum power pulses, with most of the flipped roots on one side of the real axis.

Methods

A $T(BW)$=26 minimum phase $B(z)$ polynomial with a two-stage step-down in stop band ripples was computed using the convex optimization / spectral factorization method described by [3]. This polynomial was then factored using the *lroots* software which utilizes the method described in [4] to minimize factorization / expansion error and to increase computation speed. A Monte Carlo algorithm was then implemented to flip a random selection of passband zeros to their conjugate reciprocals [5]. After each root flipping iteration, the corresponding minimum phase $A(z)$ was computed followed by $B_1(t)$ via the inverse SLR transform [6]. Similar to the high bandwidth pulse design algorithm presented in [7], we used a Monte Carlo algorithm with a probability bias to expedite computation. Passband zeros in the upper half of the z plane were flipped with a higher probability (0.5) versus the zeros in the lower half of the plane (0.1) (Fig 3). This was motivated by the observation that the waveforms minimizing $|B_1(t)|+|B_1(\tau-t)|$ tended to have most of the flipped roots on one side of the passband.

Once the desired amplitude is reached, this waveform $B_{1,min}$ is modulated by the frequency ω corresponding to half the PRESS box width and then added to its reversed counterpart (which is modulated by −ω): $B_1(t)=B_{1,\min}(t)e^{i\omega t}+B_{1,\min}(\tau-t)e^{-i\omega t}$.

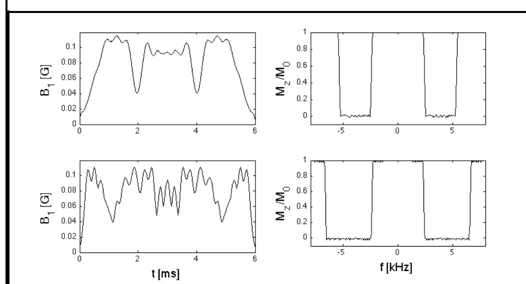

Fig 2) *TBW*=17.5 VSS pulse (top left) lengthened to twice it's nominal duration, and its simulated cosine modulated profile (top right). Bottom left is a $T(BW)$=25.6 dual band pulse of the same duration and its simulated profile (bottom right).

Results

For a 6 ms saturation pulse, the dual band pulse produced two bands of 4.26 kHz FWHM, a factor of 1.46 higher than the $T(BW)$=17.5 cosine modulated pulse played over the same duration (Fig 2). The two pulses had comparable peak amplitude (0.11 G). The dual band pulse had a significantly improved fractional transition width of a full factor of two less.

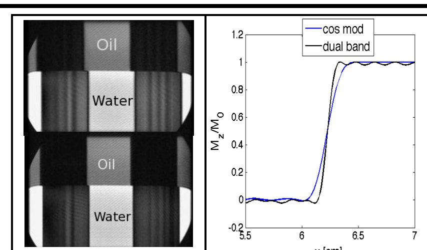

Fig 3) Cosine modulated pulse (top left) showing greater slice misregistration than the optimized dual band pulse (bottom left) in a water / oil phantom at 3T. Simulated fractional transition width comparison (right).

Conclusion

Dual band selective saturation pulses are useful for spectroscopy since the saturation pulse train can be shortened by the exclusion of crusher gradient lobes. This study demonstrated that the exponential modulation of a root-flipped optimized pulse can achieve the dual band profile and provide a higher bandwidth and/or reduced peak power than its cosine modulated counterpart. This additional bandwidth reduces chemical shift displacement which is important for exclusion of peri-prostatic lipids (Fig 3).

References

[1] T.-K. C. Tran, et al., *MRM* **43**(1), 23 (2000). [2] J. A. Osorio, et al., *MRM* **61**(3), 533 (2009). [3]A. B. Kerr et al,in *Proc ISMRM* (2009). [4]G. A. Sitton, et al, *IEEE Sig Proc Mag* **20**(6), 27 (2003). [5] M. Shinnar, *MRM* **32**(5), 658 (1994). [6] J. Pauly et al, *IEEE T Med Imaging* **10**(1), 53 (1991). [7] M. Lustig et al, in *Proc ENC* (2006).