Reduced Peak Power Dualband VSS Pulse Design

A. B. Kerr[1], P. E. Larson[2], D. B. Vigneron[2], and J. M. Pauly[1]

[1]Electrical Engineering, Stanford University, Stanford, CA, United States, [2]Radiology and Biomedical Imaging, UCSF, San Francisco, CA, United States

Introduction: Spectroscopic imaging based on conventional 3D PRESS localization is improved by using very selective suppression (VSS) pulses for outer volume suppression [1]. Cosine-modulated VSS pulses can be used to simultaneously suppress two parallel bands [2] but doubles the required peak RF amplitude. This abstract presents an efficient method for designing a dualband VSS pulse that requires only a $\sqrt{2}$ increase in peak RF amplitude.

Methods: RF saturation pulses with nonlinear phase profiles have reduced peak RF amplitudes. These phase profiles can be specified analytically as for quadratic-phase VSS pulses [3,4], or can be arrived at by manipulating the roots of the $B(z)$ polynomial [5,6] that describes the slice profile in an SLR-based RF design [7]. We will use the root-manipulation approach for calculation efficiency and also because the quadratic-phase profile will degrade to approximately linear phase in the dualband case.

Figure 1a shows the profile of a $B_s(z)$ polynomial designed to excite a single band using a minimum-phase FIR filter design method based on convex optimization and spectral factorization [8]. The filter has a ratio of passband to transition width of 10 with profile ripples (δ_1, δ_2, δ_3) of (.009, .064, .001) respectively. The dualband polynomial $B_d(z)$ (Fig. 1b) is obtained by modulating and superimposing $B_s(z)$ appropriately. The small ripple δ_3 ensures the overlapping profiles will meet ripple specifications corresponding to an M_z in-slice ripple of 0.02 and out-of-slice ripple of 0.004. The two-stage reduction in stopband ripples δ_2 and δ_3 increases the time-bandwidth (TBW) of the single-band pulse only 4.5% from 12.5 to 13.1 compared to a pulse with a stopband ripple of δ_2 alone. Conversely, if a single-band pulse with stopband ripple of δ_3 everywhere was specified, the TBW would increase almost 100%.

The zeros z_i of the $B_s(z)$ polynomial may be arbitrarily replaced by their conjugate reciprocals $1/z_i^*$ to introduce nonlinear phase while maintaining the magnitude profile. The steps in the design are as follows:

1) Randomly flip zeros in the passband of $B_s(z)$ to get $B_{sl}(z)$
2) Flip every zero in $B_{sl}(z)$ to get $B_{sr}(z)$
3) Interpolate, modulate and add to get $B_d(z) = B_{sl}(z)e^{ikt} + B_{sr}(z)e^{-ikt}$
4) Design RF pulse using inverse SLR transform on $B_d(z)$
5) Repeat steps 1-4 tracking minimum amplitude solution

Figure 2 shows the zero locations for root-flipped polynomials designed with this approach. Step 2 was motivated by the observation when flipping the two polynomials independently that the optimal solution generally had this form.

Results: A Monte Carlo simulation of 2000 trials was performed successively running through 200 iterations of the design procedure. This yielded a result within 10% of the optimal minimum RF amplitude 95% of the time. This relatively small search can be executed in only a few seconds making it feasible to integrate the procedure into the scan prescription process.

Figure 3a illustrates a dualband VSS pulse obtained by cosine modulating the unflipped $B_s(z)$ minimum-phase polynomial resulting in a peak amplitude of 0.48G. If we first root-flip a single-band pulse and then cosine modulate the peak amplitude is reduced 57% to 0.21G (not shown). Fig. 3b illustrates a further 29% reduction in peak amplitude to 0.15G for the optimal root-flip design. Figure 4 illustrates the excellent saturation achieved using the RF pulse, though the peak ripple is approximately 3-4% compared to a design of 2%. The increased ripple is likely due to RF system nonlinearity.

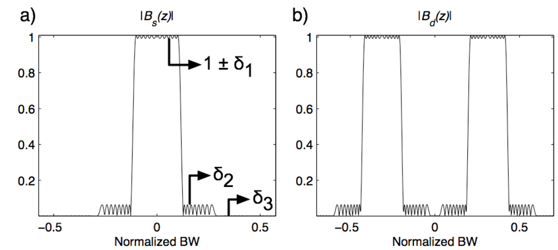

Figure 1: a) $B_s(z)$ polynomial describing single-band excitation evaluated on unit circle. b) $B_d(z)$ polynomial describing dualband excitation evaluated on unit circle.

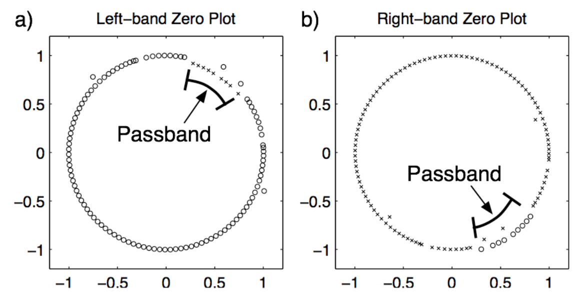

Figure 2: Zero locations of root-flipped a) left-band $B_{sl}(z)$ and b) right-band $B_{sr}(z)$ polynomials. Zeros unchanged from the reference $B_s(z)$ are circles while flipped roots are crosses.

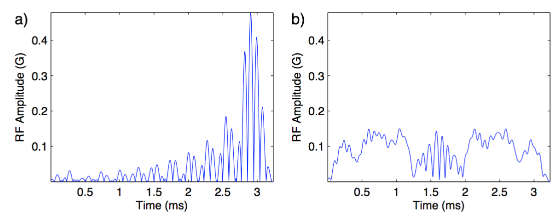

Figure 3: Dual-band RF pulse magnitude for a) cosine-modulated single-band pulse and b) optimal root-flip design.

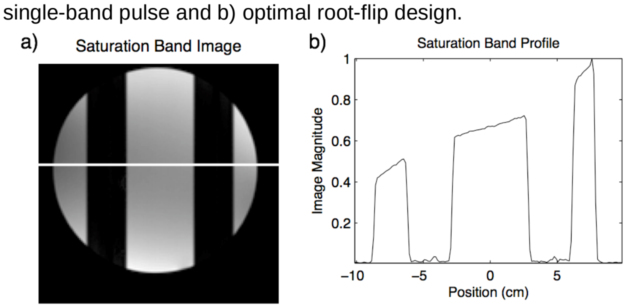

Figure 4: a) MR image acquired on GE Signa 1.5-T using dualband pulse as magnetization preparation prior to 2DFT acquisition. b) Saturation profile plotted along indicated image location. Receive-array sensitivities are responsible for the ramp in the signal intensity.

Discussion: An efficient root-manipulation based approach was developed to design reduced peak power dualband VSS pulses for clinical MRSI studies. The peak amplitude increase over a single-band reduced peak power VSS pulse is only 41%, which can be exploited to suppress more complex geometries or increase B_1 and T_1 insensitivity. The design method is appropriate for incorporation during scan prescription to allow for variable specification of band thickness, separation and tip-angle.

References: [1] Tran *et al.,* MRM 43:23-33, 2000. [2] Osorio *et al.,* Proc. ISMRM p1239, 2007. [3] Le Roux *et al.*, JMRI 8:1022-32, 1996. [4] Schulte *et al.*, JMR 166:111-22, 2004. [5] Shinnar *et al.*, MRM 32:658-60, 1994. [6] Pickup *et al.*, 33:648-55, 1995. [7] Pauly *et al.*, IEEE TMI 10(1):53-65, 1991. [8] Wu *et al.,* Dec. and Control, Proc. 35th IEEE, 1:271-6, 1996.

[Acknowledgement: This work partly supported by NIH R01 EB007588 & CA111291.]