Time-Efficient Slab Selective Water Excitation

G. R. Lee[1], J. A. Tkach[1,2], and M. A. Griswold[1,3]
[1]Radiology, Case Western Reserve University, Cleveland, OH, United States, [2]Radiology, Imaging Research Center, Cincinnati Children's Hospital Research Foundation, Cincinnati, OH, United States, [3]Biomedical Engineering, Case Western Reserve University, Cleveland, OH, United States

Introduction

Spectral spatial (SPSP) RF pulses are simultaneously selective in both the spectral and spatial domains [1]. SPSP pulses consist of a train of slice selective RF subpulses applied simultaneously with an oscillating slice select gradient. When used for spatially selective water or fat excitation, the difference in frequency between water and fat, Δv_{wf}, limits the spacing between RF subpulses to $\tau \leq 1/(2\Delta v_{wf})$ [2]. At 3T and above, this leads to subpulse durations of less than 1 ms. This short subpulse duration limits the sharpness of the slab profile which can be achieved in 3D imaging applications. In the present work, time-efficient 3D slab-selective water-excitation pulses with sharp spatial profiles are designed. These pulses are superior to separate fat saturation and water excitation in: overall duration, flexible choice of T2*-weighting, and level of fat suppression in the presence of B1 inhomogeneity.

Methods

The VERSE algorithm [3] provides a way to simultaneously reshape an RF pulse and its slice select gradient waveform to either minimize pulse duration or reduce RF power. Unfortunately, VERSE only works well for on-resonant spins and cannot be directly applied to a SPSP pulse without degrading the excitation pattern. For this reason, we propose an iterative scheme where the RF pulses and gradient waveforms are alternatively redesigned as diagrammed in Fig 1. First, the gradient waveform is initialized to a standard oscillating trapezoidal waveform. A SPSP RF pulse is then designed to excite a desired pattern by using the iterative RF pulse design algorithm of Yip et al. [4]. For any subpulses during which the maximum B1 amplitude of the scanner is exceeded, the trapezoid is reshaped using minimum-time VERSE [5]. The existing RF waveform is then discarded, and a new RF waveform is designed for the reshaped gradient waveform. Alternations between RF pulse design and gradient reshaping continue until all samples of the RF pulse waveform fall below a desired peak RF power threshold (horizontal dashed line in each subplot). The effective tip-down time from which T2* contrast begins to accumulate is specified via the slope of the linear phase pattern along the spatial dimension of the excitation [6].

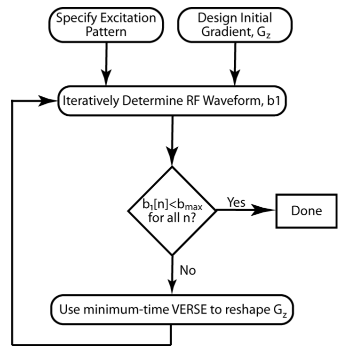

Fig. 1: Proposed Algorithm.

In order to validate this method, a volunteer was scanned on a 4T Siemens/Bruker system with an 8-channel head coil. Informed consent was obtained in accordance with local IRB regulations. Two 20 degree flip angle RF pulses were designed. Design 1 used: Ten 350 µs trapezoidal lobes, 10 cm slab and a 300 Hz stopband width. Design 2 used: Fourteen 600 µs lobes, 10 cm slab and 450 Hz stopband width. The effective tip-down time occurred during lobe 2 and 3 for designs 1 and 2 respectively. For each design, a maximal B_1 amplitude of 13µT was specified. Metrics in terms of duration, transition width and the number of required VERSE reshapings of the gradient waveform are given in Table 1.

All images were acquired using a 3D FLASH acquisition (TR/TE=30/12.2 ms, flip angle=20, matrix=192x160x72, FOV= 24x20x14 cm). TE=12.2 ms corresponds to a time when fat and water signals are in phase. For comparison, a scan with traditional 5.12 ms fat saturation followed by a 2.56 ms sinc slab excitation was performed. We found it was necessary to redesign the SPSP RF waveforms using a measured rather than ideal gradient trajectory for more accurate slab excitation.

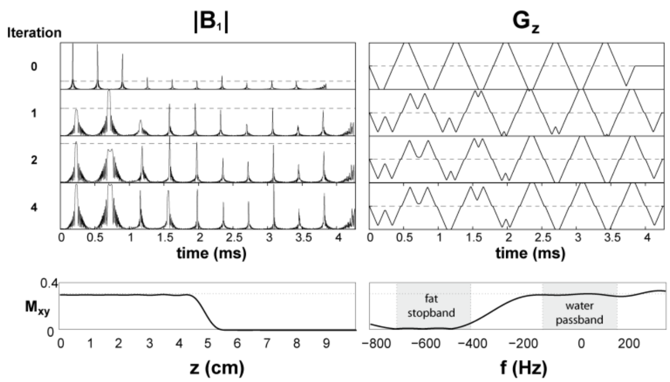

Fig 2: Iterated RF (subplots scaled independently) and gradient waveforms for Design 1. Dashed lines in each B_1 plot indicate the desired max power.

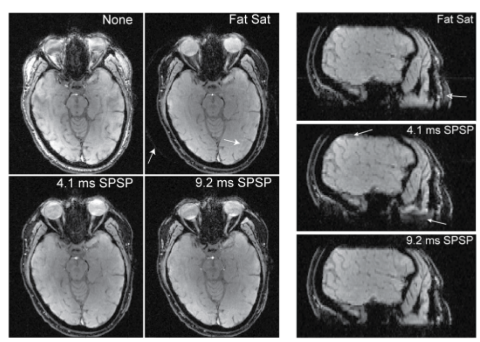

Fig 3: Example axial and sagittal views.

Table 1: Design Results

	Design 1	Design 2
Duration (ms)	4.15	9.25
Fractional Transition Width	0.14	0.07
VERSE Iterations	4	7

Results and Discussion

Fig 2 shows RF and gradient waveforms after individual iterations of the proposed algorithm. Before VERSE gradient redesign, the RF power limit of 13 µT (dashed horizontal line) was exceeded by nearly a factor of 5. Within 4 iterations, all samples are within the specified power limit. Note that the subplots were scaled independently to optimize the visualization of the pulses. The bottom row shows simulated spatial and spectral profiles for the final design. Fig 3 shows axial slices with traditional fat saturation as compared to 4.1 ms and 9.2 ms SPSP pulse designs. Good suppression of fat can be seen in all cases. Fig 3 also shows a sagittal view 5.5 cm right of isocenter. Poor performance of traditional fat saturation in the anterior portion of the slice (arrow) is likely due to poor B1 inhomogeneity. The sharp spatial profiles of the SPSP pulses are apparent, although there are some localized errors in the profile shape for the 4.1 ms pulse (see arrows). This may be due to residual imperfections in the timing between the SPSP RF and gradient waveforms. Computation times for the iterative SPSP pulse designs were less than 2 minutes on a workstation with 2.33 GHz Intel Xeon processors (8-cores).

Yip et. al. [4] demonstrated that RF pulse power can also be reduced through the use of regularization in their iterative RF pulse design algorithm. However, this approach results in a tradeoff between RF power and the accuracy of the excitation profile. For the pulses in the present work, the use of regularization alone to control RF power was found to give unsatisfactory results.

The authors thank Dr. Hargreaves and Dr. Yip for the public availability of the minimum-time VERSE [5] and iterative RF pulse design algorithms [7], respectively.

References: 1. Meyer et al. MRM 1990;15(2):287-304. 2. Zur et al. MRM 2000;43(3):410-420. 3. Conolly et al. JMR 1988;78(1):242-247 4. Yip et al. MRM 2006;56(5):1050-1059 5. Hargreaves et al. MRM 2004;52(3):590-597. 6. Grissom et al. MRM 2009;62(5):1242-1250. 7. http://www.eecs.umich.edu/~fessler/code

Support: This work was supported in part by Siemens Medical Solutions.