Mitigate B1+ inhomogeneity by slice-selective composite excitation pulses

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TARGET AUDIENCE Scientists interested in exciting homogeneous high flip angle under $\mathbf{B}_1^+$ inhomogeneity effect.

INTRODUCTION In high field MRI (3T, 7T), the wavelength of the transmitted radio-frequency field in the imaging object is similar to the size of the imaging object. Therefore, the flip angle distribution inside the imaging object after standard RF excitation is inhomogeneous. Consequently, this causes spatially dependent T_1 contrast, which makes clinical diagnosis difficult. Different methods using spatially-selective excitation, parallel RF transmission, or non-linear gradient[1-3] have been proposed to improve the flip angle homogeneity. However, under the small flip angle approximation, these methods are usually limited to low flip-angle excitation. Composite pulses can successfully excite homogeneous 90° flip angle under an inhomogeneous radio-frequency field[4] in slice-selective or non-selective MRI[5-8]. It has also been shown that parallel RF excitation with optimized amplitude and phase in each transmitter coil in two excitation pulses can achieve even better results[6-8]. However, to our knowledge, the theory of composite pulses is only limited to predicting spin dynamics using non-selective pulses. Furthermore, the refocusing gradient between two excitation pulses[5,7] under the off-resonance condition can cause signal loss.

Here, we propose a new two-pulse composite slice-selective excitation, which transmits two RF pulses in two gradient lobes with the opposite polarity. Without waiting for the refocusing gradient between two excitation pulses, we can reduce the RF excitation time and accordingly decrease off-resonance effects. We use empirical data at 3T MRI and Bloch equation simulation on spin magnetization to demonstrate that slice-selective composite pulses can efficiently improve the homogeneity of the flip angle distribution.

METHODS Our method of achieving 90° excitation uses two excitation pulses with flip angle θ_x and θ_y and a 90° phase difference between them, The second excitation pulse will leave the excited x-component of magnetization unchanged and flip the remaining z-component of the magnetization to the y axis. By the end of two pulses, the remaining z-component, $\cos(\theta_x) \times \cos(\theta_y)$, is small, if θ_x and θ_y are close to 90°. [See Figure 1]. To demonstrate our proposed method, we modified the gradient echo pulse sequence (Figure 2(a)) to our θ_x - θ_y composite pulses (Figure 2(c)) and compared the results from standard gradient echo pulse sequence (Figure2(a)) and composite pulses proposed before[5,7] (Figure 2(b)). All scans were performed on a 3T MRI (Skyra, Siemens, Erlangen, Germany). We used a spherical saline phantom with 250 mm FOV and 5 mm thick slice. Each pulse strength is nominal 90° pulse. The duration for each excitation pulse is 2.56ms, and the refocusing slice-selective gradient between two pulses for the previously proposed method is 2.14ms. The ramp duration between 2 pulses in our method is 1.2ms.

We also used the Bloch equation to simulate the magnetization after two-pulse excitation with 8 mm slice thickness over a 20 mm slice FOV with flip angles ranging from 45° to 135°. The maximal strength of the gradient used in the simulation was 40mT/m with an infinite slew rate. The duration of each pulse was 2.35ms.

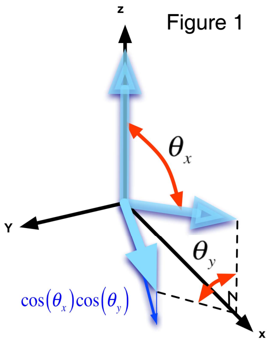

Figure 1

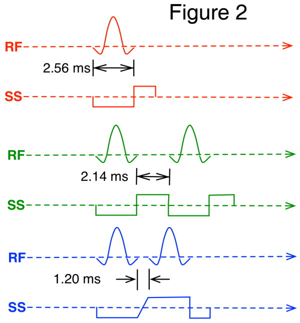

Figure 2

RESULTS Figure 3 shows the distribution of the transverse magnetization after excitation using (a) one-pulse excitation (b) two-pulse composite excitation[5,7] (c) our two-pulse composite excitation. Figure 2(d) shows the profile of Figure 2(a)-(c). The mean absolute error (MAE) between the result and targeted homogeneous transverse magnetization were 0.088, 0.078, and 0.037. Figure 4 shows the simulations of (a) one-pulse excitation and (b) our proposed method. The flip angle distribution at different slice-selection (z) axis and nominal flip angles. Figure 4(c) shows the MAE within the excited slice for different pulse strengths using one and two pulses.

DISCUSSION Comparing to the previously reported composite pulse method (MAE = 0.078), our proposed pulse sequence can excite a slice closer to the desired 90° flip angle (MAE=0.037), amounting to 47% improvement. Because the latency between two pulses was shortened to from 2.14 ms to 1.2 ms, we expect that the effect of field inhomogeneity will be reduced accordingly. Based on the simulation, we also conclude that slice-selective composite pulse can achieve homogeneous 90° flip angle within the selected slice. The MAE < 10 region using our proposed method (nominal flip angle 66° -122°) is 2.67 times larger than that using the single-pulse method (nominal flip angle 82° -103°).

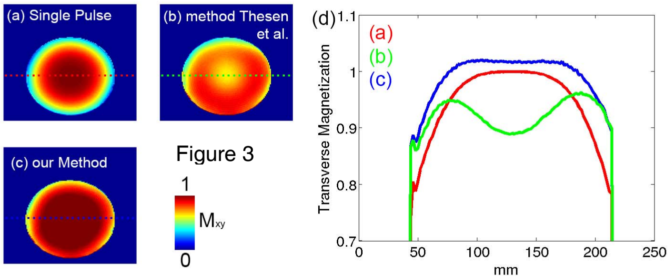

Figure 3

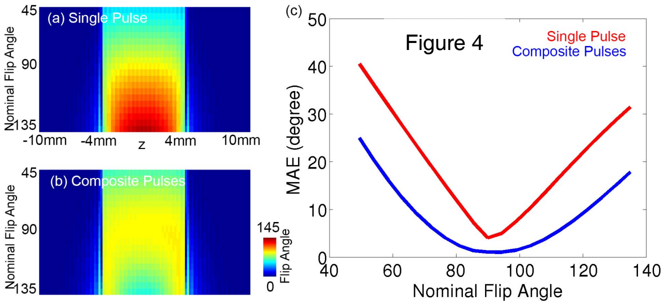

Figure 4

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