A Novel Three Dimensional Radiofrequency Pulse for Small Voxel Excitation

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Introduction: Three dimensional Radio Frequency (3D RF) excitation pulses are of interest in a variety of Magnetic Resonance (MR) applications (1,2). The major limitation of the true 3D RF pulses is long pulse length. To reduce the 3D RF pulse width particularly in a small field of view (FOV) is even more challenge due to the requirement of more sampling points to fill the extended kmax in the k-space. Several methods such as multi-shot(3), variable density(4,5), and a fast k-z 3D TRF pulse(6) have been used to mitigate the problem. We propose a novel approach which combined the multi-shot 3D RF pulse to the two half pulses design (7-9) to reduce pulse width for a small volume excitation. Numerical simulations of the RF pulse parameters the resultant transverse magnetization profiles are presented.

Theory: Base on the small tip angle approximation, the transverse magnetization, $M_{xy}(r,t)$ is the Fourier transform of a spatial frequency weighting function $W(k)$ and the RF field can be written as

$$B_i(t) = \Delta(k(t)) |G(t)| W(k(t))$$

When $\Delta(k(t))$ is the inverse sample density, $G(t)$ are the gradients simultaneously with RF or $B_i(t)$. From the equations above, the magnetization along x-y plane can be estimated from the Fourier transform of $B_i$ and vice versa. If we focus on the multiple shots of $M_{xy}$ at particular z, $M_{xy}$ becomes a function of $z$, $M_{xy}(z)$ or the slice profile $M_{xy}(z)$ is proportional to the Fourier transform of the $B_i(t)$ according to the small tip angle approximation. The full conventional pulse $B_i(t)$ along z direction can be further broken down into two half-pulses, $B_i^h(t)$ and $B_i^l(t)$ as

The two half excitations are combined, given that

$$M_{xy}(z) = \mathcal{F}\{B_i^h(t) + B_i^l(t)\}$$

The desired slice profile $M_{xy}$ is added and the imaginary or antisymmetric parts are canceled out.

Methods: The novel spiral 3DRF pulses were designed for 1.5 Tesla (T) MRI scanner with a 150 T/m/s gradient slew rate and a 40 mT/m maximum gradient to excite a 12-cm-diameter cylinder in x-y plane and 10-cm-in z plane with a 16x16x16 cm³ xzy field of FOV and a 1.5x1.5x1.25 cm³ xzy resolution the sampling time 4 microsecond and under sampling. The pulses were generated offline using MATLAB (The Math-works, Inc.,Natick MA). Figure 1(a) shows a diagram of the spiral 3D RF of one shot from a two-shot. We performed numerical simulations of Bloch equation to examine the effect of the 3D RF pulses on the accuracy of the desired slice profile.

Results: Figure 1(b) and (c) shows result from the numerical simulation of the transverse magnetization $M_{xy}$ 3D RF pulses that excited a 12x10-cm of cylinder in a 24x24x20 cm³ FOV. Figure 1(b) and 1(c) show mesh plots and images from the Bloch equation simulation of $M_{xy}$ and $M_{xy}$ in x-z plane and x-y plane respectively.

Conclusion: This work demonstrates that the spiral 3D RF pulses which combine multi-shot and half-pulse potentially reduce pulse length by a factor of approximately 0.34 compared to the conventional multi-shot 3D pulse. In addition, the side lobes are relatively less . Future work will focus on the optimization of pulse to a shorter pulse length, reduce the error in the x-y-z planes and validate the method in clinical applications.


Figure1(a) show the one shot of two shots, (b) Mesh plots in x-z plane(top) and x-y plane of simulation(bottom) and (c) Images from the simulation in k-z and x-y plane

![Figure1(a)](image1)