A Novel Three Dimensional Radiofrequency Pulse for Small Voxel Excitation

N. Ina[1], and S. Saekho[1,2]
[1]Radiological Technology, Chiang Mai University, Muang, Chiang Mai, Thailand, [2]Biomedical Engineering Center, Chiang Mai University, Muang, Chiang Mai, Thailand

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 k_{max} 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, $M_{xy}(\mathbf{r},t)$ is the Fourier transform of a spatial frequency weighting function W(**k**) and the RF field can be written as

$$B_1(t) = \Delta(k(t))\left|\gamma G(t)\right|.W(k(t))$$

When $\Delta(k(t))$ is the inverse sample density, G(t) are the gradients simultaneously with RF or B_1(t). From the equations above, the magnetization along x-y plane can be estimated from the Fourier transform of B_1 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 $B_1(t)$ according to the small tip angle approximation. The full conventional pulse B_1(t) along z direction can be further broken down into two half-pulses, $B_1^+(t)$ and $B_1^-(t)$ as

The two half excitations are combined, given that

$$M_{xy}(z) = \Im\left\{B_1^+(t) + B_1^-(t)\right\}$$

$$\Im\left\{B_1^+(t)\right\} + \Im\left\{B_1^-(t)\right\} = \frac{1}{2}\left[B_1(s) - \frac{i}{\pi s}\otimes\left(B_1(s)\right)\right] + \frac{1}{2}\left[B_1(s) + \frac{i}{\pi s}\otimes\left(B_1(s)\right)\right]$$

$$M_{xy}(z) = B_1(s)$$

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 cm^3 xyz field of FOV and a 1.5x1.5x1.25 cm^3 xyz 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 cm^3 FOV. Figure 1(b) and 1(c) show mesh plots and images from the Bloch equation simulation of M_{xz} and M_{xy} in x-z plane and x-y plane respectively.

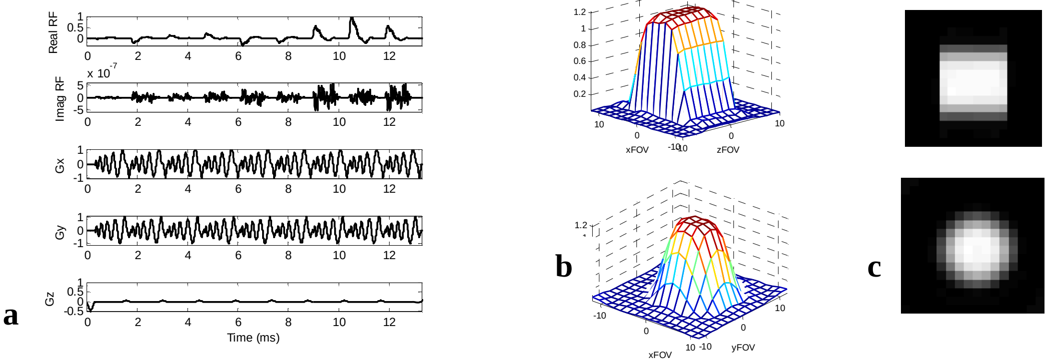

Figure1(a) show the one shot of two shots, (b) Mesh plots in x-z plane(top) and x-y plane of simulation(bottom) and (c) Images from the simulation in x-z and x-y plane

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.

References: (1) Stenger VA, et al., MRM, 44:525-531, 2000 (2) Saekho S, et al., MRM, 53(2):479-484, 2005 (3) Stenger VA et al., MRM, 48:157-165, 2002 (4) Stenger VA et al., MRM, 50(5):1100-1106, 2003 (5) Spielman DM et al., MRM, 34:388-394, 1995 (6) Saekho S et al., MRM, 55(4):719-724,2006 (7) Pauly J et al., Proc. of the 8th SMRM, 1989 p28 (8) Neilsen HTC et al., Proc. of the 5th ISMRM, 1997 p255. (9) Hatsumi TC et al., MRM, 41:591-599, 1999