Slice with Non-Parallel Boundaries

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Introduction: There has been a long-standing interest in the MRS field to develop the capability to select spectroscopic signals from nonrectangular volumes (1-2) because it is difficult to place a sizable rectangular box in many anatomical structures (e.g., the hippocampus in the brain) without incurring a large partial volume effect. Although slice boundaries are normally in parallel they are merely perpendicular to the slice gradient vector when viewed in the gradient vector space. Therefore, if one changes the initial and final direction of the slice gradient vector for an adiabatic frequency sweep by time-varying gradient waveform modulation, non-parallel slice boundaries can be generated (3). To search for optimal gradient waveforms several nonlinear gradient waveforms were investigated. The feasibility of generating slices with nonparallel boundaries was also demonstrated using phantom and invivo experiments.

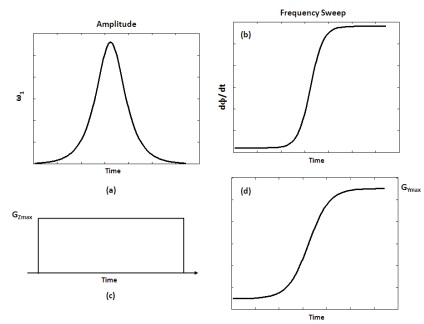

Figure 1 A proposed scheme for generating nonparallel inversion slice. RF pulse amplitude ω_1 (a), frequency sweep $d\phi/dt$ (b), and gradient waveforms of Z (c) and Y (d) directions. A standard hyperbolic secant (sech) RF pulse was used without any modification.

Method: All simulation work was performed using in-house MATLAB (The MathWorks, Inc., Natick, MA, USA) programs for solving Bloch equations without the relaxation terms. These programs were used to compute transverse and longitudinal components of magnetization generated by an AFP pulse, a constant Z-gradient and a time-varying Y-gradient (Fig. 1). The angle between the two slice boundaries calculated by Bloch simulation (ϕ_{slice}) were compared with the angle between the initial and final gradient vectors ($\phi_{gradient} = |\arctan(G_Y(t=0)/G_Z) - \arctan(G_Y(t=T_p)/G_Z)|$. Experimental measurements were performed on a Bruker AVANCE spectrometer (Bruker Biospin, Billerica, MA, USA) interfaced to an 11.7 T (500.14 MHz) 89-mm inner diameter (ID) bore vertical magnet (Magnex Scientific, Abingdon, UK) and a 56-mm ID water-cooled Mini0.5 gradient coil with maximum gradient strength of 30 G/cm and rise time of 100 μs (Bruker Biospin, Billerica, MA, USA). A home-built one loop surface RF transmit and receive coil with a 15mm ID integrated to an animal handling system was used.

Results and Discussion: Fig. 2 compares three different G_Y waveforms. In Fig. 2(a), the linear waveform was used with G_{Ymax} = 400 Hz/mm. The middle panel shows the two-dimensional map of the simulated residual transverse magnetization M_{XY}. The inversion bands shown in the right panel correspond to the three colored arrows in the middle panel. In Fig. 2(b), an arctan G_Y waveform was applied with the same G_{Ymax}. A marked narrowing of the transition bands for off-centered magnetization was observed. A further improvement was seen in Fig 2(c) where a hyperbolic tangent (tanh, truncation level = 1%) G_Y waveform was used to produce the time-varying Y gradient waveform. The gradient angle is 21.8° for all three waveforms, whereas the slice angles are 10.0°, 20.0°, and 22.0°, corresponding to linear, arctan and tanh gradient waveforms. Based on the numerical simulation results, 2D spin echo imaging experiments were performed on the cylindrical water phantom (Fig. 3) Fig. 3(a) shows the YZ image of the cylindrical water phantom which is typical for that generated by a surface transceiver coil. In Fig. 3(b), $\phi_{gradient}$ = 35.0°, ϕ_{slice} from Bloch simulation = 37.5°, and ϕ_{slice} measured from the image acquired experimentally ≈ 39.5°. Fig. 4 shows results of *in vivo* ^{1}H MR spectroscopy of rat brain with a conventional rectangular (b) and a trapezoidal (c) ROI. In conclusion, we demonstrate a novel scheme to directly generate slice with nonparallel boundaries. The performance of this method may be further improved using sophisticated numerical optimization of both the RF and gradient waveforms. We expect that this method may find applications in many MRS as well as MRI applications where localizing a nonrectangular volume is of interest.

References

1. Sacolick *et al.*, MRM 2007; 57:548-553

2. Valette *et al.*, JMR 2007; 189 : 1-12

3. Park and Shen, ISMRM 2010; 972

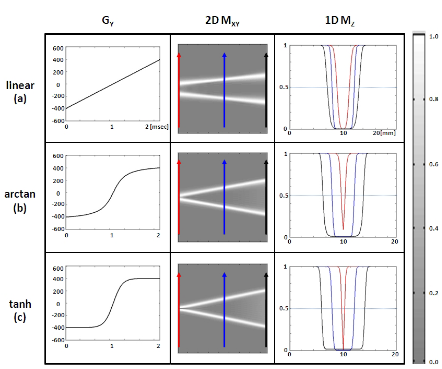

Figure 2 Comparison of three different G_Y waveforms. (a) Linear waveform as depicted in Fig. 1 with G_{Ymax} = 400 Hz/mm. The color of the cross-sectional profiles of the inversion bands corresponds to the color of arrow in the 2D map which marks the Y ordinate of the cross-sectional profile. (b) arctan G_Y waveform with G_{Ymax} = 400 Hz/mm. (c) Hyperbolic tangent (tanh) G_Y waveform with G_{Ymax} = 400 Hz/mm.

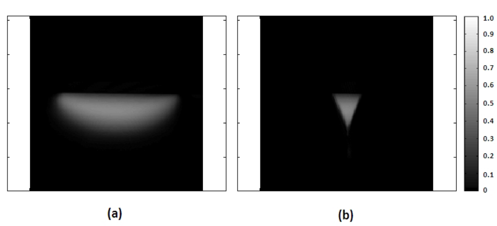

Figure 3 Experimentally acquired 2D phantom image without (a) and with (b) a time-varying hyperbolic tangent gradient using a cylindrical phantom of water and a single loop coil to transmit and receive signal. TR/TE = 600/30.7 ms, FOV = 40×40 mm, T_p = 2 ms, G_Z = 2550 Hz/mm. (a) YZ image of the cylindrical water phantom with G_{Ymax} = 0. (b) YZ image of the cylindrical water phantom with G_{Ymax} = 893 Hz/mm. Slice angle from Bloch simulation is 37.5° and gradient angle of 35.0°. The measured slice angle from the image acquired experimentally is about 39.5°.

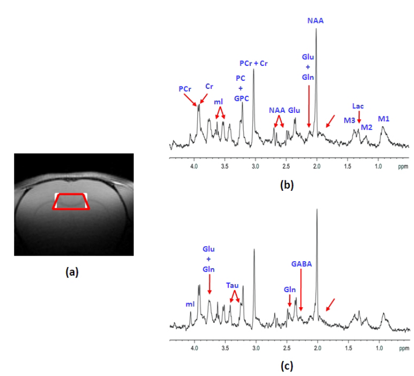

Figure 4 (a) Spin echo coronal anatomical image. TR/TE = 3000/11.6 ms, FOV = 20×20 mm^2, slice thickness = 1 mm, matrix size = 128×128, number of average = 1. Two ROIs are displayed in (a) with white (rectangle) and red (trapezoid) color. Localized in vivo proton MRS spectra acquired at 11.7 T from a rectangular (b) and a trapezoidal (c) ROI in the rat brain.