B1+ Non-uniformity Correction using 2D RF Pulse Design

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Introduction: B1 non-uniformity causes variations in intensity and contrast across MR images. Non-uniform B1 transmission (B1+) produces spatially varying flip-angles, causing intensity and contrast to be non-uniform, and complicating quantitative imaging. In this work, we use 2D pulse design [3] to compensate for B1+ non-uniformity in slice selective excitations. B1+ non-uniformity increases with static field strength and, in cardiac imaging, tends to vary primarily along one direction over the heart (into the chest) [2]. We design slice selective pulses whose flip angle varies linearly along one in-plane direction. In order to achieve uniform excitation over a region of interest (ROI), we design this variation to be approximately the reciprocal of the measured B1+ variation over the ROI.

Methods: 2D RF pulses were designed using tools developed by Pauly et al. [3]. To minimize total duration, we used three sub-lobes and a time-bandwidth product of two for the spatial selection (z-direction), defined by the shape of each sub-lobe [1]. For the in-plane variation (y-direction), defined by sub-lobe weighting, we used 1-2-1 weighting with $\pi/2$ phase shifts between each sub-lobe. A fly-back design (RF is only transmitted during positive gradient lobes) was chosen to reduce motion and off-resonance effects (see Fig. 1).

The linear profile variation was characterized by two parameters – range of interest (cm) and variation percentage (%). The chosen sub-lobe weighting produces a shifted and raised cosine variation in flip angle. The Gy amplitude determines Δk_y, which determines the period of the cosine and hence the amount of variation over the ROI. The relation between ΔK_y and the control parameters are

$$\Delta K_y = \frac{1}{\Delta y}\cdot\left[\cos^{-1}\left(\frac{x}{200+x}\right) - \cos^{-1}\left(\frac{-x}{200+x}\right)\right]$$

where Δy is the range of interest (cm) and x is the variation percentage (%).

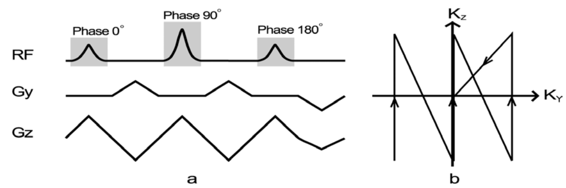

Fig 1: **(a)** Pulse sequence with 3.024 ms pulse duration of the slice thickness 5 mm and **(b)** excitation k-space trajectory.

Results: Experiments were performed on a GE Signa 3.0T EXCITE system with gradients supporting 40 mT/m and 150 T/m/s. Fig 2 contains a comparison between measured and simulated excitation profiles with and without off-resonance. Profiles were simulated using Bloch simulation (in Matlab), and were measured using a slab phantom and spin-echo pulse sequence. Measured profiles were slightly thicker (<22%), and with off-resonance there was a shift in the slice selective direction. Fig 3 illustrates the simulated profiles for two different ROI and percentage variations. Next we scanned a large ball phantom (diameter – 28cm) placed at the edge of the head-coil to artificially generate B1+ non-uniformity. B1+ profiles were measured using the double angle method (DAM) [5] and found to have 28% variation over 7cm (shaded region). After compensation we reduced this to 8% (see Fig 4).

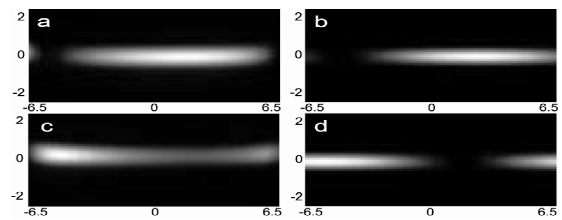

Fig 2: Excitation profiles with slice thickness of 5mm. **(a)** experimentally measured excitation profile and **(c)** with off-resonance (-440Hz), **(b)** numerically computed excitation profile and **(d)** with off-resonance (-440Hz)

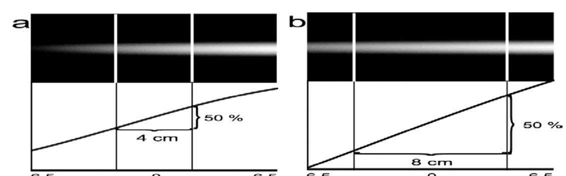

Fig 3: Excitation profile (top) and cross-section plot (bottom). **(a)** 50% variation over 4cm **(b)** 50% variation over 8cm.

Discussion: Linearly varying and slice selective excitation profile was achieved by using 2D pulse design. For more complicated B1+ profiles over the ROI, we can use more than 3 sub-pulses resulting in longer pulse duration. Although this RF pulse works well on-resonance, the profile becomes shifted along the in-plane selectiveness for off-resonant spins. This is shown in Figure 2 (c) and (d).

To shorten the pulse duration, we can also apply non-flyback (forward-backward) design where RF power is applied during both positive and negative gradient lobes. This design experiences greater off-resonance and motion-induced artifacts but these drawbacks may be improved by calibrated forward-backward pulse design [4].

Conclusion: We have demonstrated new RF pulse designs that are slice selective and produce linear variations in flip angle. These designs can be dynamically adapted to different percentage variations. Our goal is to use these pulses to compensate for non-uniformity in the B1+ field, in order to achieve uniform flip angle excitation. This is particularly important for high field imaging and quantitative imaging.

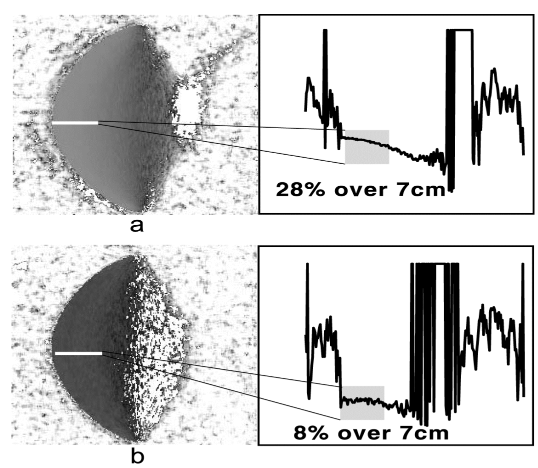

Fig. 4: Flip angle as a function of spatial position (left) and cross-section plot (right) **(a)** before and **(b)** after using B1+ compensating pulse.

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References

[1] Nayak K. S., et al., MRM, **51**, p655-660, 2004
[2] Wen H., et al., JMR, **125**, p65-71, 1997
[3] Pauly J. M., et al., JMR, **81**, p43-56, 1988
[4] Oelhafen M., et al., MRM, **52**, p1136-1145, 2004
[5] Stollberger R., et al., MRM, **35**, p246-251, 1996