Correction of B0 induced slice profile distortion using parallel transmit

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Introduction: With the advent of parallel transmit (PTx), there has been much interest in creating complex spatially localised excitations. The algorithms which calculate the requisite pulses [1,2] require an estimate of the B_1 field produced by each coil, and also a map of the B_0 (off resonance) field, since this distorts the excited magnetisation profiles. In fact spatially localized excitations are a core feature of virtually every MRI acquisition, usually in the form of a slice or slab, and these too suffer from off resonance particularly at higher field strengths. The resulting distortions are often not apparent because imaging is usually in the plane of the slice/slab . A special case is pre-saturation, for which slab bending is directly visualized when the saturation band intersects the imaging plane. Distortion is most severe when selection gradients are weak, e.g. when selecting thick slabs or for delivering high-power pre-saturation pulses, and when considering a large field of view, over which it is difficult to achieve a good B_0 shim. In this work we have explored the possibility of correcting for B_0 induced slice profile distortion using parallel transmission.

Methods: Experiments have been performed using a whole-body 3T Achieva MRI system (Philips Healthcare, the Netherlands) equipped with an 8-element parallel transmission body coil [3] on a 400 mm diameter mineral oil phantom placed in a transverse orientation at isocentre. Slice selective B_1 maps were acquired using AFI [4] with the array element mapping technique described in [5]. B_0 maps were obtained from a low flip angle multi-echo gradient echo sequence with five echoes. The target excitation in all cases was a 60 mm wide sagittal slab centred 70 mm to the left of isocentre, with a rectangular profile convolved with a narrow Gaussian. Pulses were designed to correspond with a selection gradient of strength 1 mT/m and duration 2.5ms using the image domain small tip angle approximation (STA) formalism from [1]. Solutions were found using magnitude least squares optimization (MLS) [6]. As a control, a standard pulse was designed for the same target without knowledge of the B_1 or B_0 fields. Imaging was performed using the calculated pulses with the specified selection gradient, with a 3D gradient echo (FFE) readout. Displayed images are in transverse orientation, for the slice for which B_0 and B_1 data were obtained.

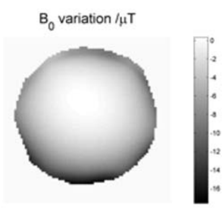
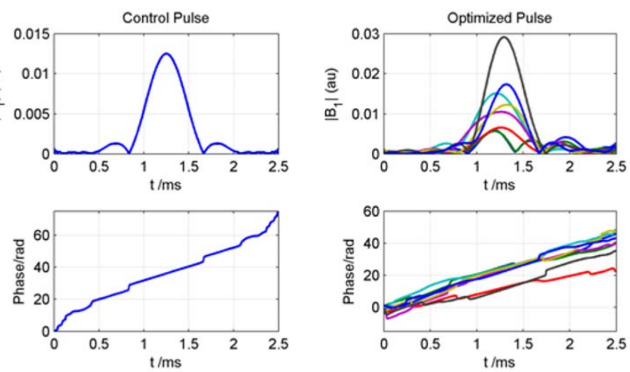


Figure 1 **Top**: measured B_0 variation. **Right**: control pulse (same for all channels) and **far right**: optimized pulses.



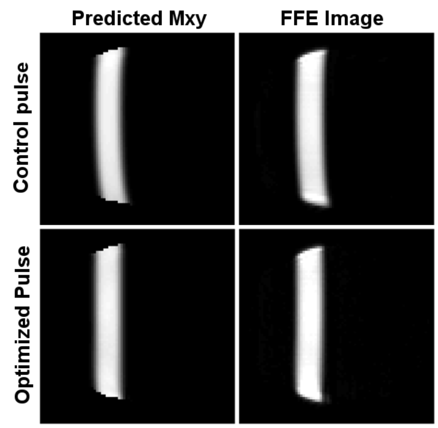


Figure 2 Predicted transverse magnetization and gradient echo images for control and optimized pulse

Results: Figure 1 shows the measured B_0 variation and both the control and optimized pulse profiles. Figure 2 shows predicted excitations from both pulses (by putting the pulses into the STA model), and the imaged excitations. The predicted and measured slices using the control pulse are each distorted and are in good qualitative agreement. The excitation from the optimized pulse has been straightened, and prediction and experiment are again in good geometric agreement.

Discussion: The control and optimized pulses were scaled to generate the same flip angle in the selected slab, making relative power comparison possible. The integrated square amplitude is 46% higher for the optimized pulse than the control pulse. It is understandable that a solution using parallel transmit in this way would lead to higher fields, since the gradient trajectory only allows spatial modulation in one direction. Figure 3 shows the excitation which would be produced by each coil if it were driven on its own. The bend is present in each excitation, since all use the same selection gradient. However, they have a higher bandwidth than the control pulse and so produce excitations over a wider region; these cancel to give zero net excitation outside the target region. The increased bandwidth results in higher integrated power. MLS optimization mitigates power increases by leaving phase unconstrained. The resultant phase variation can make the method unsuitable for slice excitation but still valid for slab selection or pre-saturation. Finally, this study has used STA however other pulse design methods could be used where this approximation is not valid.

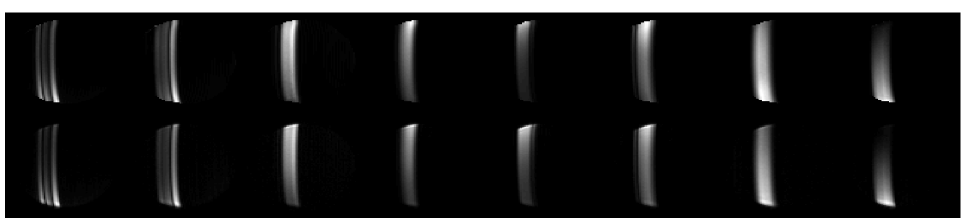


Figure 3: Excitations produced from optimised RF pulse driving one coil at a time. **Top row:** predicted transverse magnetization. **Bottom row:** Corresponding FFE images

Conclusions: We have demonstrated that parallel transmission can be used to correct for the effects of off resonance on slice selection. The penalty for this correction is increased RF power, however in conditions where this is tolerable, this type of optimisation may prove useful. The approach taken here was to directly use the extra degrees of freedom available from a PTx system without introducing changes in gradient trajectory, meaning that results can be easily integrated into existing sequences. Optimal implementation for any given examination will depend on what scope there is for gradient profile changes as these can be used to enhance parallel transmit performance, but also imply a time penalty. The results shown here indicate that parallel transmit provides degrees of freedom that can be harnessed to directly impact on the most common MRI acquisition schemes.

References: [1] Grissom et al, MRM 2006:56; [2] Katscher et al, MRM 2003:49; [3] Vernickel et al, MRM 2007:58; [4] Yarnykh, MRM 2007:57; [5] Nehrke et al, ISMRM'08 #353; [6] Kassakian, UCB PhD Thesis 2006