

pTX Array Optimized Composite Pulse for B₁⁺ inhomogeneity compensation at 3T

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Introduction: Inhomogeneous RF fields and the resultant spatially varying excitation are a significant issue at high field strength, and a variety of approaches have been investigated to compensate for this effect [1,2,3,4,5]. One approach to solving this problem on a parallel transmit system is to utilize a composite pulse consisting of two RF pulses, with adjustable amplitude and phase per channel and per pulse. This work presents an implementation of an array optimized composite pulse (ACP), first described in [3]. This performance of this pulse design is investigated in phantoms and in-vivo at 3T.

Methods: All experimental results were obtained on a Siemens 3T Tim Trio, equipped with a Siemens 8 Channel pTX system. An eight channel Tx/Rx head coil (MR Instruments) was utilized in this study. Both phantom and in-vivo studies utilized a B₁⁺ mapping technique described in [6]. Low flip angle images for each channel were acquired to estimate relative transmit magnitude and phase. An additional acquisition utilizing the AFI flip angle mapping technique, combined with the relative B₁⁺ magnitude map, provided an absolute estimate of B₁⁺ magnitude. ΔB₀ mapping was integrated into the relative transmit phase mapping acquisition, and provided an off-resonance map.

A non-linear optimization routine utilized the acquired B₁⁺ and ΔB₀ maps to calculate the shimmed amplitude and phase coefficients for each channel and for each pulse. There are a total of 32 free parameters considered in the optimization, (8 Magnitude Coeffs + 8 Phase Coeffs) x 2 pulses. This optimization routine was also utilized to calculate amplitude and phase coefficients for RF shimming with a single pulse and only 16 free parameters. Optimization performed in the brain only considered pixels within a ROI that excluded the skull. All pulses considered in the optimization are non-selective square pulses.

The ACP pulse was tested in a 18 cm diameter spherical water phantom provided by Siemens and the brains of two volunteers. The water phantom test utilized the AFI technique to map the flip angle distribution created by three configurations: 1) RF pulse utilizing a quadrature drive configuration 2) single pulse utilizing a RF shimming configuration 3) the ACP pulse. Pulses optimized for target flip angle of 30, 60, and 85 degrees were computed. The in-vivo brains scans were acquired in the same manner as the phantom scans, with the exception that RF shimming was not performed due to time constraints. All tests utilized non-selective square pulses.

The potential for a slice-selective version of this pulse design was tested with a slice-selective ACP pulse that utilized 2 ms sinc pulses, but with optimized coefficients from a non-selective square pulse. This approach is valid so long as off-resonance is minimal. The slice profile was measured in a water phantom with a 3D GRE sequence that placed the readout gradient along the slice select direction.

Results: Figure 1 displays representative AFI flip angle maps acquired in the water phantom, for a target FA of 60 degrees. Both RF shimming and the ACP pulse improve the uniformity of the FA distribution, with the ACP pulse producing the best result. Figure 2 displays the acquired FA maps from the brain of a volunteer, for a target FA of 60 degrees. The improvement in the excitation homogeneity is significant. Figure 3 displays the measured slice profile of the slice-selective version of the ACP pulse. Table 1 contains the statistics (mean and standard deviation) for the various pulse configurations and target FA's in the water phantom and the brain. The mean and SD were computed over all pixels in the flip angle map of the water phantom. Computation of the mean and SD in the brain were done within the same ROI utilized for optimization.

Discussion: Array optimized composite pulses are a simple and effective method to compensate for B₁⁺ inhomogeneity. They offer improved excitation uniformity relative to RF shimming in phantoms, and significant improvement over a quadrature drive configuration in-vivo. This work was performed at 3T, and it is expected the usefulness of this pulse design will be more pronounced at higher field strengths. An advantage of this pulse design is the lack of a broadband excitation characteristic, which will allow for usage in slice-selective applications with minimal modification to the coefficient optimization routine. Future work will include modifying the optimization to consider slice-selective pulses, and possible investigation of performance at a higher main field.

References: [1] Boulant et al. Magn Reson Med 2008; 60:701-708 [2] Katscher et al. Magn Reson Med 2003; 49:144-150 [3] Collins et al. Magn Reson Med 2007; 57:470-474. [4] Moore et al. Journ of Magn Reson; 2010 205:50-62 [5] Gumbrecht et al. Proc. Intl. Soc. Mag. Reson. Med. 18 (2010) [6] Van de Moortele et al. Proc. Intl. Soc. Mag. Reson. Med. 15 (2007) Pg 1676 **Acknowledgement:** We would like to acknowledge support from R01 EB000454.

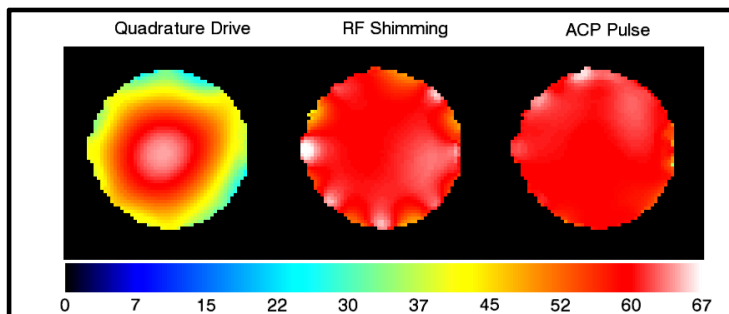


Fig 1. AFI flip angle maps acquired in a water phantom, with a target FA of 60 degrees. The unit of the color bar is degrees.

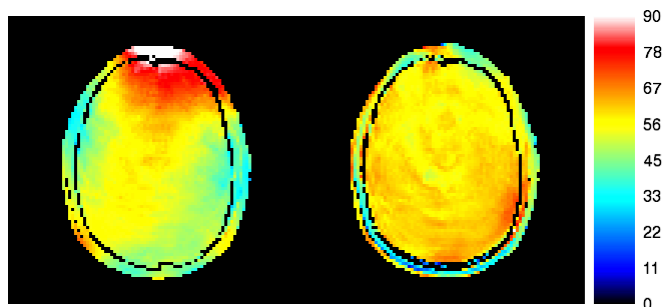


Fig 2. AFI flip angle maps acquired in a human brain for quadrature drive (left) and ACP pulse (right), with a target FA of 60 degrees. The unit of the color bar is degrees. The in-plane resolution is 2.1 x 2.1

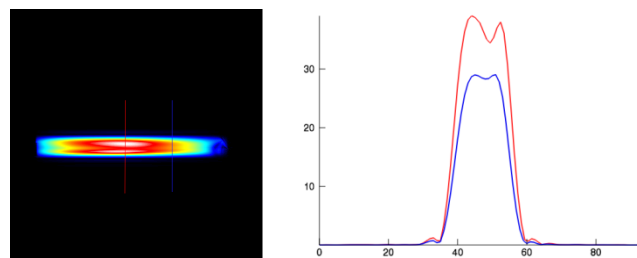


Fig 3. Slice profiles excited by an ACP pulse.

Table 1	Target Flip Angle		
	30	60	85
Phantom (Quadrature)	30.5 ± 5.0	60.2 ± 10.5	85.3 ± 15.7
Phantom (RF Shimming)	29.3 ± 1.8	59.9 ± 3.1	85.6 ± 4.8
Phantom (ACP Pulse)	29.2 ± 1.7	60.1 ± 1.9	84.1 ± 2.9
Brain (Quadrature)	30.6 ± 3.4	59.4 ± 9.2	84.1 ± 13.4
Brain (ACP Pulse)	29.1 ± 1.9	59.3 ± 2.6	83.5 ± 5.7