

ΦFA Cup: Phase Based Flip Angle Calibration Using the P0 Pulse for Proton MRI at 7T

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INTRODUCTION: High field MRI combined with parallel transmit technology has increased the need of calibrating the transmit coils with fast methods to generate flip angle (FA) maps and/or individual B_1^+ maps to be opportunely combined (RF-shimming). Here we demonstrate the applicability of a 3D- B_1^+ mapping method, proposed [1] for hyperpolarized ^3He MRI at 1.5T, for proton MRI at 7T. The method is based on the acquisition of two phase images where the effective flip angle is encoded in the phase of the non-slice selective rectangular composite pulse used as excitation in a gradient recall echo (GRE) sequence, as in [2,3,4,5].

THEORY: The application of a rectangular composite RF-pulse of the kind $[\alpha_{-135} \alpha_{-45} \alpha_{+45} \alpha_{+135}]_{hN/2}$, as in [2,3,4], rotates $hN/2$ times the magnetization \mathbf{M} along a squared path of side α ; the result is a net precession of \mathbf{M} about an effective axis $\mathbf{B}_{\text{eff}} = [\pm \sin(R), 0, \cos(R)]$, where $R = \alpha/\sqrt{2}$ and one has + for hN even, -for odd. For $hN=2$ the eigenvalue is $\square = \alpha^2$. In [1] it is shown that the modified scheme $\{p0_{-90} [\alpha_{-157.5} \alpha_{-112.5} \alpha_{-67.5} \alpha_{-22.5} \alpha_{+22.5} \alpha_{+67.5} \alpha_{+112.5} \alpha_{+157.5}]_{hN/2}\}$ with $hN=2$ and the initial $p0$ pulse ($p0 \leq \alpha$) holds higher sensitivity in respect of B_1 inhomogeneities than the original scheme with hN odd and no $p0$ [2,3,4]. The scheme of [1] is adopted here for proton MRI at 7T. Two images with opposite rotation sense of \mathbf{M} are needed for subtraction of the phases [1,2,3,4,5]; these are denoted as $cw2$ and $cw1$.

METHODS: MATLAB (The MathWorks, Inc, Natick, USA) is used to simulate the calibration surfaces from which the FA map is obtained from 2D interpolation of the difference of two phase images.¹ MR images were acquired on a spherical water phantom with salt (50mM [^{23}Na]) for validation of the method and on healthy volunteers on a 7T MR-scanner (Siemens, Erlangen, Germany) using a CP transmit/receive head coil (Siemens basic coil). Two interleaved GRE images with a composite pulse of 420 μs were acquired with TR/TE=20ms/2.5ms, total acquisition time TA=41s, FOV=(210mm)³, matrix 64x64x16, nominal $\alpha = 10^\circ$, $p0=0.4\alpha$ corresponding to a nominal total FA of the composite pulse of 84° (reference=118V, amplitude=147V, $\Delta t=420\mu\text{s}$). Two standard GRE images (TE 2.5ms/4.5ms, same matrix, TR=8ms, TA=16s) are acquired to generate the B_0 map necessary for the interpolation. For comparison, a FA map of the same phantom is obtained with the double angle method (DA) [6,7] using two GRE images with nominal $\alpha=60^\circ$, $2\alpha=120^\circ$ (reference=118V, amplitude 147V, $\Delta t=300\mu\text{s}$, 600 μs), TR/TE=2s/2.5ms, TA=68mins.

RESULTS: **Fig1-3** show the steps of our method ΦFA to obtain the 3D FA map (only the central partition is shown): **Fig1** shows the calibration surface demonstrating high sensitivity for the RF inhomogeneities, as well as dependence on the B_0 offset. **Fig2-left** shows the measured B_0 map, **Fig2-right** shows the phase map obtained from the subtraction of the two phase images. **Fig3-left** shows the magnitude image of image $cw1$, for reference only. **Fig3-right** shows the FA map obtained from interpolation of the phase map using the curve in Fig1 and the B_0 map, this shows higher FA values at the centre of the coil, consistently with the reference magnitude image. **Fig4** shows a sagittal partition of the 3D FA map acquired with ΦFA in the brain of a healthy volunteer at 7T with a total acquisition time of 102s. For comparison **Fig5** shows the 3D FA map obtained with the DA approach with a total acquisition time of 68mins. The magnitude images (left and centre) show a similar intensity distribution than the magnitude image in Fig3 but with much higher SNR. The central dark area of image with $\alpha=120^\circ$ can be attributed to an effective FA $\approx 180^\circ$, as the FA is higher than nominal value at the coil centre. Both FA maps show the interference pattern occurring at a wavelength of 11.7cm at 7T.

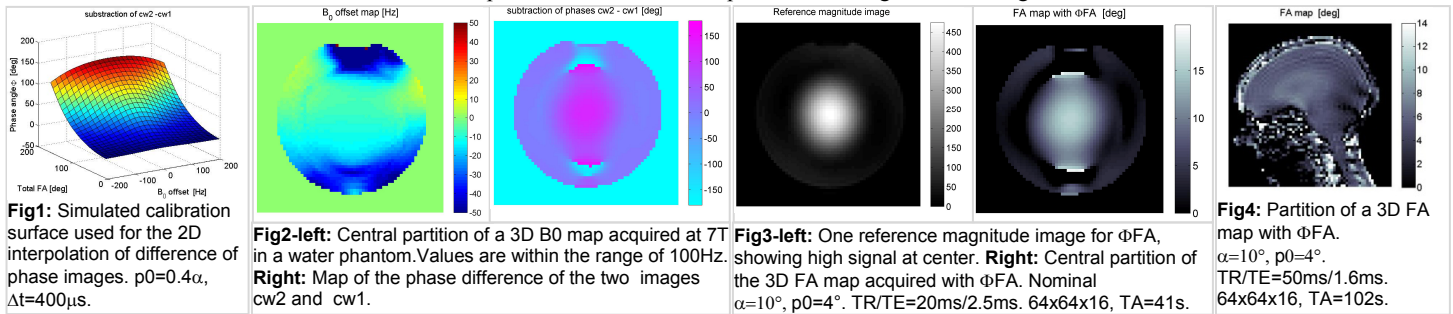


Fig1: Simulated calibration surface used for the 2D interpolation of difference of phase images. $p0=0.4\alpha$, $\Delta t=400\mu\text{s}$.

Fig2-left: Central partition of a 3D B_0 map acquired at 7T in a water phantom. Values are within the range of 100Hz. **Right:** Map of the phase difference of the two images $cw2$ and $cw1$.

Fig3-left: One reference magnitude image for ΦFA, showing high signal at center. **Right:** Central partition of the 3D FA map acquired with ΦFA. Nominal $\alpha=10^\circ$, $p0=4^\circ$. TR/TE=20ms/2.5ms. 64x64x16, TA=41s.

Fig4: Partition of a 3D FA map with ΦFA. $\alpha=10^\circ$, $p0=4^\circ$. TR/TE=50ms/1.6ms. 64x64x16, TA=102s.

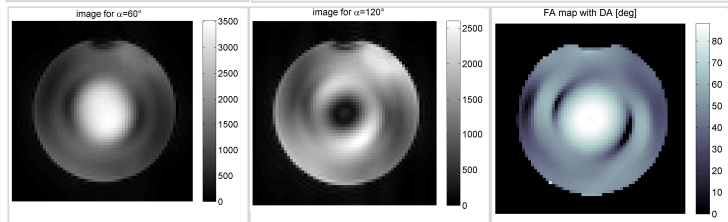


Fig5-left: GRE image with nominal $\alpha=60^\circ$ showing high signal at center. **Centre:** GRE image with $2\alpha=120^\circ$. **Right:** FA map obtained with DA approach. TR/TE=2s/2.5ms, TA=68mins.

CONCLUSIONS: The adopted scheme makes the ΦFA approach highly sensitive to B_1 inhomogeneities. Hence the total FA of the composite pulse is lessened to 84° . Consequently its duration can be shortened to 400 μs , which relaxes the effect of B_0 offsets. The FA map obtained on phantom shows agreement with that obtained with DA at the coil centre. As the flip angle drops at the edges, also the sensitivity of our method decreases being proportional, for small angles, to α^2 : when this is expected, the use of $\alpha > 10^\circ$ is suggested. *In vivo*, without incurring SAR problems a TR of 50ms is feasible, resulting in a total acquisition time of 102s for a 64x64x16 3D matrix. No saturation effect is observed

due to the little consumption of longitudinal magnetization of the scheme [1].

REFERENCES: [1] Santoro D, Proc. ISMRM, 17(2009)#2611. [2] Mugler JP, Proc. ISMRM, 13(2005)#789. [3] Mugler JP, Proc. ISMRM, 15(2007)#351. [4] Storey P, Proc. ISMRM, 17(2009)#374. [5] Morrell G. MRM 60:889(2008). [6] Akoka, Mag. Res. Im. 1993; 11(3):437-441. [7] Insko E, Bolinger L. J Magn Reson 1993;103:82-85.