Optimized Sensitivity for 3D Mapping of the B1 Field using a Phase-Based Method

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Introduction: The advent of surface array coils specially design for parallel imaging makes it necessary to develop rapid methods for B_1 mapping, as the performance of the coil varies a lot within the sensitive volume and with different patient loadings. In this work we follow and modify a strategy previously presented [1, 2] both for proton and ^{3}He MRI. Furthermore, the recent ^{3}He price raise and the increasing difficulties in achieving it, motivated this work of optimization with simulations. This method can be incorporated in standard imaging sequences as GRE.

Theory: The application of a rectangular composite RF pulse of the kind $[\alpha_{-135}\ \alpha_{-45}\ \alpha_{+45}\ \alpha_{+135}]_{(hN)/2}$, similarly as in [1,2], rotates the magnetization **M** along a squared path hN/2 times (fig.1); the result is a net precession of **M** about an effective axis $\mathbf{B_{eff}}$, eigenvector of such total combination of rotations. For this case $\mathbf{B_{eff}}$ = (±R,0,1) where R =$\alpha/\sqrt{2}$ and one has ± for hN even or odd (in the case of hN/2 half-integer the operator is composed by the four pulses repeated an integer number of times and at the end only the first two pulses, exactly as in [2]). If hN=2 the precession angle is $\Omega=\alpha^2$, therefore the total angle after hN/2 cycles is Ω*hN/2. R and Ω are respectively the radius and the area of the circle circumscribed to the regular polygon represented by the rotation operators: for this case a square of side α [1]. In this view it appears clear that the sensitivity of such method can be increased in two ways: first as the phase is measured on the xy plane, but the precession occurs about a tilted axes, an initial pulse which moves **M** in the opposite direction of $\mathbf{B_{eff}}$ will maximize sensitivity with no use of extra longitudinal magnetization (fig. 1).
Second, if the phases of the composite pulses assume more than 4 values it will be possible to calibrate smaller flip angles because the same area (Ω) can be achieved with a polygon with a higher number of sides of shorter length (smaller α).

Methods: All the simulations have been implemented with a home written code on a MATLAB (© The MathWorks, Inc) platform. All the values correspond to the experimental conditions for hyperpolarized ^{3}He in our laboratory with B_0=1.5T. Our two proposed methods are: first the use of an initial pulse p_0 equal to $2R_{-90}$ or R_{-90} with the use of one less half-cycle (fig. 1). Second a cycle composed by 8 segments: $[\alpha_{+157.5}\ \alpha_{+112.5}\ \alpha_{+67.5}\ \alpha_{+22.5}\ \alpha_{-22.5}\ \alpha_{-67.5}\ \alpha_{-112.5}\ \alpha_{-157.5}]_{(hN)/2}$ (fig. 2).

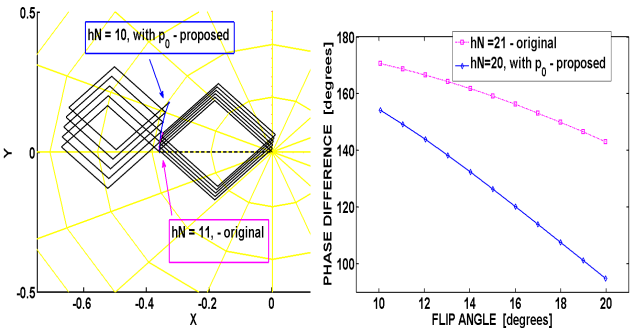

Fig. 1. Original and first proposed methods. Left: path of **M** in the transverse plane; the number of cycles is reduced for the illustration. Right: simulated results for the phase dispersion vs flip angle for 10 cycles (hN=20 and 21).

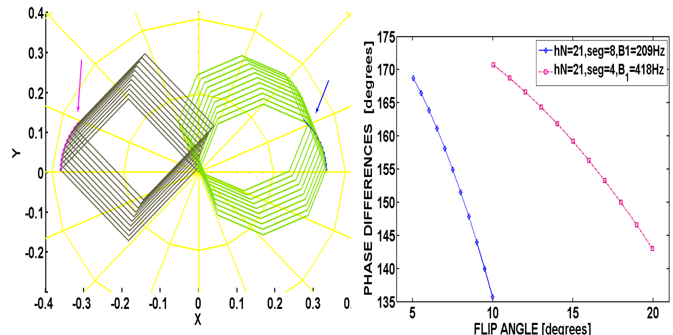

Fig. 2. Original and second proposed methods. Left: effective precession of **M** for the squared (magenta) and the ectagonal (blue) paths. Right: corresponding phase dispersion curves.

Results: Dispersion curves of the phase difference among isochromats VS flip angle are plotted similarly as in [1,2]. Sensitivity is defined as degree of phase difference per degree of flip angle [2]. Here we will limit our results to one single composite pulse; the approach of using 2 composite pulses with opposite rotation verse in order to double sensitivity and cancel out offset terms as in [2] can also be easily simulated but is omitted in here *per brevitas.* In figure 1 the result of the first improvement is shown: although **M** terminates approximately at the same distance from the **+z** axis for both approaches (same consumption of transverse magnetization), with the proposed method it will have accumulated a bigger angle Ω resulting in an improved phase dispersion of the isochromats by a factor > 2 (fig.1-right) for calibrating the same flip angle (α=15°). In figure 2 the result of the second improvement is shown: even if the areas of the two polygons are approximately the same (**M** has accumulated similar Ω) our dispersion curve calibrates a flip angle which is half of that of the original method, corresponding to half of the transmit power and resulting in another factor >2 improved sensitivity (fig.2-right). Combining both the improvements one can get a dispersion curve for the phase with an optimized sensitivity as shown in figure 3. The gain with respect to [2] is of factor > 5.

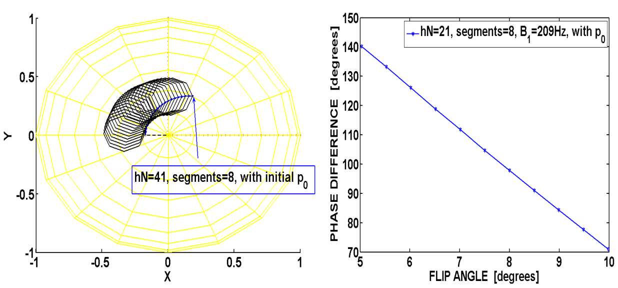

Fig. 3. Optimized method with 8 segments and $p_0=R_{-90}$.

Conclusions and Discussion: Following the strategy proposed in [1, 2], a method for 3D mapping of the B_1 field has been improved with simulations which show the precise evolution of **M** under composite pulses, and express the results in terms of eigenvectors and eigenvalues. This better understanding should lead to a better calibration, especially for small flip angles such as those used in fast acquisition techniques with hyperpolarized ^{3}He. The implementation of such method on a standard Siemens scanner is currently in progress. The presented method can of course be extended to an arbitrarily higher number of segments with even smaller side and therefore calibrating smaller flip angles.

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References: [1] Mugler JP et al. Proc. Intl. Soc. Mag. Reson. Med 13, 2005. [2] Mugler JP et al. Proc. Intl. Soc. Mag. Reson. Med 15 (2007).