Predistorted B1 shimming: a new concept based on mutual enhancement between static B1 shim and 1D spoke RF pulse design. Application for cardiac imaging at 7 Tesla.

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INTRODUCTION. Large spatial variations of transmit B1 (B_1^+) magnitude at 7T yield non-uniform contrast. In small targets, e.g. prostate, the phase of all transmit (Tx) channels can be set to achieve locally a same B1+ phase value. This efficiently optimizes B_1^+ magnitude with satisfactory homogeneity [1], but this is not suitable in large targets, e.g. the heart, where achieving uniform B_1^+ magnitude with static B1 shim results in very low B_1^+ efficiency [2]. Taking advantage of typical $|B_1^+|$ profiles observed with transceiver arrays in the heart at 7T, we propose a new concept where, instead of aiming at a homogeneous $|B_1^+|$ profile, B1 shim is apply to explicitly achieve a predefined spatially distorted $|B_1^+|$ pattern which, in turn, allows for efficient use of 1D spoke RF pulse design to provide homogeneous excitation in the heart wile preserving high B_1^+ efficiency.

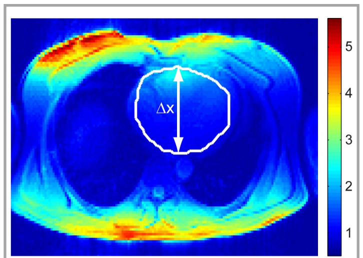

Fig.1: b1+ SOM of 16 channels in a.u.; ROI is marked by white line.

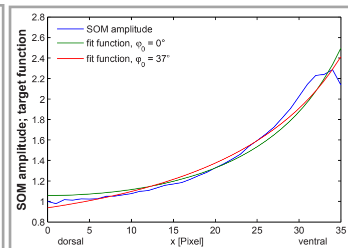

Fig.2: two different solutions for fitting the average SOM profile in dorsal-ventral direction (x).

PRINCIPLE. We define as "B_1^+ Efficiency" (B1Eff) with a RF coil array the ratio between the magnitude of sum (MOS) and the sum of magnitude (SOM) of complex $B_{1,k}^+$ vectors of all coil elements *k* (B1Eff varies between 0 and 1) [3]. With one chest surface coil, $|B_1^+|$ profile decreases through the heart (anterior to posterior, A-P), and it was proposed at lower field to utilize 1D spoke RF pulses to achieve more homogeneous excitation [4]. We observed at 7T with transceiver arrays that B1 shim solutions maximizing B1Eff provide highly heterogenous in space, but fairly reproducible $|B_1^+|$ profiles. By contrast, B1 shim solutions maximizing $|B_1^+|$ homogeneity result in very low B1Eff, thus high SAR. We propose to calculate a static B1 shim solution generating a spatially distorted B_1^+ profile and then use efficient 1D-spoke RF excitation to generate B1+ variation along the A-P direction.

METHODS. For feasibility evaluation, a two step procedure was applied on a data set collected in a healthy volunteer at 7T with a 16 ch transceiver array [5]. 16 $B_{1,k}^+$ complex maps were estimated in an axial view with a fast B1 mapping technique [6]. ***Step 1***: a static B1 shim solution (with phase modulation) is calculated in a ROI over the heart (see Fig.1) using a pre-distorted target for B_1MOS defined by $t(x) = \lambda/\cos(\Delta\varphi x/\Delta x + \varphi_0)$, with x the A-P position, Δx the excitation FOV along the same axis and λ a free scalar. ***Step 2***: a 1D 2-spoke RF pulse is designed with two SINC sub-pulses symmetrically placed around excitation k-space center to achieve a cosine shaped A-P excitation profile through the ROI: $p(x) = 1/t(x)$. The RF profile multiplied by the pre-distorted B_1MOS profile ideally tends to provide uniform excitation through the ROI. For step 1, initial values for $\Delta\varphi$ and φ_0 were obtained by fitting the projection of B_1SOM on the left-right axis with a 3-parameter function identical to t(x), where φ_0 is either fixed or unconstrained. To calculate B1+ shim phases, $t(x)$ was then used with multiple values for $\Delta\varphi$ and φ_0, and for each case B1+ phases were obtained with nonlinear optimization algorithm aiming at minimizing the standard deviation of [B_1MOS – $t(x)$], while maximizing the mean value of B_1MOS. For each B1 shim solution and fitting result, the mean values of $B_1\text{MOS} \cdot p(x)$ were computed as well as the Inhomogeneous Coefficient (IC) defined as the ratio (standard deviation)/(mean). For comparison, these numbers were also obtained with a conventional B1 shim solution aiming at "flattening" B_1MOS through the ROI by minimizing IC of B_1MOS.

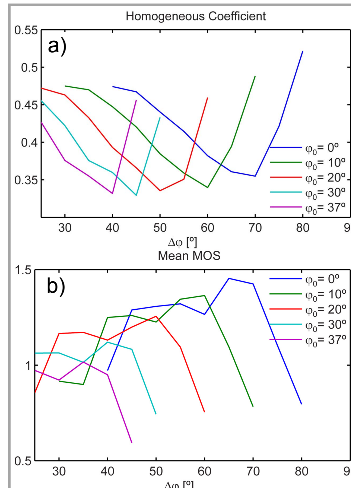

Fig.3: HC (a) and mean MOS*p(x) (b) within the ROI as a function of $\Delta\varphi$ for different φ_0.

RESULTS. Fig.2 shows left-right projections of B_1SOM (blue) and two fitting solutions for t(x) (green: $\Delta\varphi$=0, red: $\Delta\varphi$ unconstrained). Note that [$\Delta\varphi + \varphi_0$] must be <90°. Fig. 3 shows mean (B_1MOS*p(x)) values and IC for B1+ shim solutions based on different values of $\Delta\varphi$ and φ_0 for $t(x)$, relative to mean B_1MOS values obtained with a constant target. In general $\Delta\varphi + \varphi_0$ ≈70° seemed acceptable. As seen in Fig. 3b, setting φ_0 to 0 improves mean(B_1MOS), to the cost of increasing IC. Fig. 4 shows an α map generated with the 2 spoke RF pulse from Bloch simulations for *a*) conventional B1 shim (uniform target) (the 2 spokes were plaid at k-space center), and *b*) predistored B1 Shim with φ_0 =0° and $\Delta\varphi$ = 70°. The flip angle in a) increased by 62% compared with b) while using same excitation RF power in the simulations.

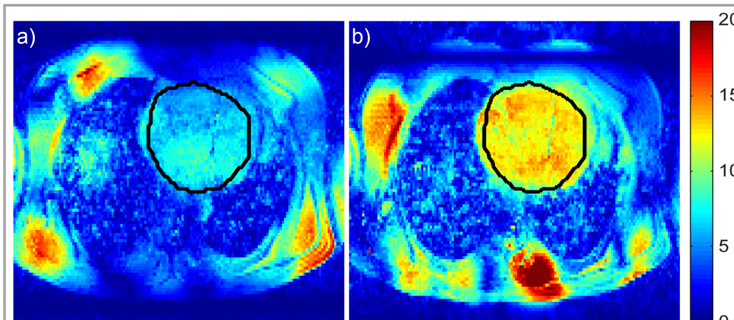

Fig.4: resulting flip angle map (in °) obtained from Bloch simulation for the B1+ phase shim with flat target (left) and predistored target (right).

DISCUSSION. Single Transmit channel MR consoles can be retrofitted with static B1 shim hardware at a cost significantly lower than a multi Transmit channel console. Static B1 shim, however, hardly provide satisfactory solutions in targets of large size. We propose to merge a pre-distorted B1 shim solution with 1D spoke RF pulse to achieve homogeneous excitation through the heart at 7T with higher B1eff, thus lower SAR, while requiring only static B1 shim hardware resources.

ACKNOWLEDGMENTS:
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