Neither Flat Profile Nor Black Spots: A Simple Method to Achieve Acceptable CP-like Mode Transmit B1 Pattern for Whole Brain Imaging with Transmit Arrays at 7 Tesla

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INTRODUCTION. A major challenge at ultra high filed (UHF) of >=7T is the short transmit B1 (B1+) RF wavelength. As a consequence, complex interference of incident/reflected RF field components lead to spatial variations of B1+ including possible B1+ nodes of fully destructive interference. To mitigate such spatial B1+ heterogeneity, RF phase shimming using multi-channel TX coils is becoming increasingly popular [1], and is more affordable than an actual multi transmit channel console. However, in practical routine, a 'good starting phase set' without B1+ dark nodes and with reasonably high B1+ efficiency is not necessarily known before starting a scanning session. Yet, such "CP-like" mode is indispensable for whole brain anatomical imaging, as well as for B0 mapping and initial RF power calibration. A straightforward approach, to insure that a large part of the brain is properly excited, is to maximizing RF efficiency in the center of the brain by setting a common local B1+ phase for all TX channels. However, such a solution most of the times also includes the formation of local nodes of destructive interferences, as the head shape lacks overall cylindrical or spherical symmetry. This problem is even more severe with tight fitting RF coil arrays that offer the advantage of higher SNR and efficiency [2], but to the cost of higher likelihood of local destructive interferences [3]. In this work we present a simple but efficient method to determine a good starting set of "CP-like" RF phases for multi channel head coils at 7T.

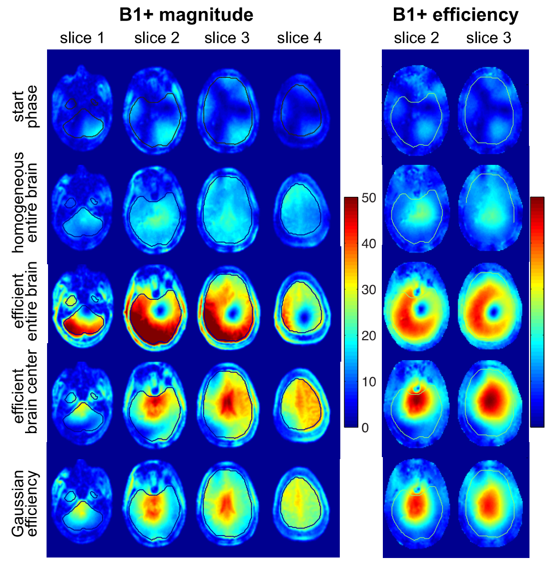

Fig. 1: estimated B1+ maps [a.u.] and efficiency maps for 5 different B1+ shim configurations.

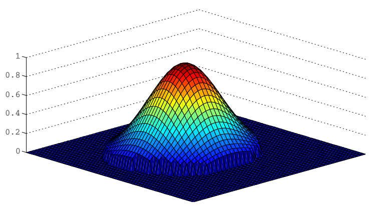

Fig. 2: Gaussian B1 Efficiency target shape

METHODS. Measurements were performed on a 7T system (Siemens, Germany) equipped with 16x1kW amplifiers and a B1+ shimming control unit (CPC, USA), using a 16 channel elliptical transceiver coil [4]. In this work only RF phase shimming (not magnitude) was considered. All measurements deliberately started with a random set of RF phases. B1+ transmit maps for each channel were estimated in small flip angle regime [5]. These maps were acquired on 4 equidistant axial slices (6mm thick) covering 8 cm of the brain along Z. RF phase shimming strategies were implemented in Matlab, using non linear optimization methods. The following B1 shimming results were compared, using as a B1 shimming region for all computations four ROIs manually drawn (one per slice) to contain only brain tissues (Fig.1), except when mentioned otherwise: **1)** random phase set (starting point), **2)** B1+ homogeneity optimized by minimizing an inhomogeneous coefficient (IC) defined as $std\left|\sum_{i=1}^{16} B1_i^+\right| \Big/ mean\left|\sum_{i=1}^{16} B1_i^+\right|$, **3)** RF phases optimized by maximizing the mean B1+ efficiency (B1Eff) defined as the magnitude of the sum over the sum of the magnitude of all B1+ vectors, i.e. mean($\left|\sum_{i=1}^{16} B1_i^+\right| \Big/ \sum_{i=1}^{16}\left|B1_i^+\right|$), **4)** same approach as in 2) but here the RF efficiency was optimized only for a small ROI in the center of each slice, **5)** similar approach as in 3), but here the B1 shimming target consists of a gaussian shaped pattern of B1 Efficiency (Fig.2), and the optimization routine aims at minimizing the residual (RMS) differences between this pre-defined B1Eff pattern and B1Eff resulting from B1 shimming. For quantitative comparison the mean and minimum values of B1Eff, as well as of B1+ magnitude, were calculated for each of the five B1 shimming strategies through the combined 4 ROIs. Actual flip angle maps (AFI) were obtained in each case for direct quantitative measurement of the corresponding |B1+| pattern.

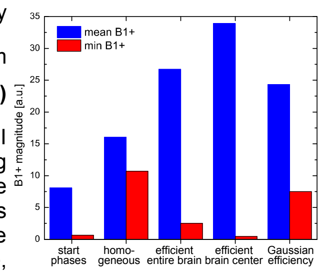

Fig. 3: mean and minimum B1+ for the 5 shim settings

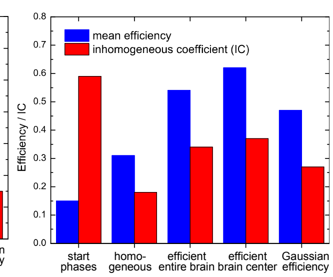

Fig. 4: IC and mean efficiency for 5 settings

RESULTS. Fig.1 shows predicted B1+ magnitude maps for all 4 acquired slices and efficiency maps for the 2 central slices. Corresponding mean and minimum values are given in Figure 3, mean efficiency and IC values are illustrated in Fig.4. As expected, the mean efficiency for the homogeneous shim is only 0.15 however the IC is with 0.18 the lowest (row 2, see also Fig. 4). In contrast a shim with pure efficiency constraint over the entire volume (row 3) likely generates a B1+ node, despite high average efficiency (0.62). Constraining the RF efficiency only in small ROIs in the center of the brain (row 4) is a reasonable approach to obtain a high B1+ efficiency (0.54) and it avoids solutions where a dark node take place in the brain center as in 2. However, such solutions typically generate areas of low B1+ magnitude in brain periphery. The shim solution calculated based on the Gaussian target efficiency shape (row 5) reduces significantly this effect compared to 3) (minimum B1+ increases from 2.5 to 7.5) while improving the IC (from 0.34 to 0.27), even though the maximum efficiency is now moderately reduced (0.54 to 0.47). Figure 5 shows measured AFI maps after effectively applying the B1 shim solution, in very good agreement with the predicted B1+ magnitude pattern (bottom row Fig. 1).

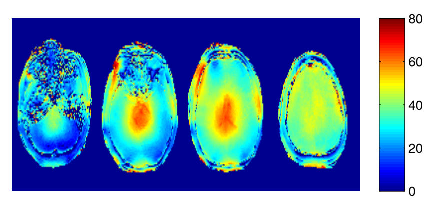

Fig. 5: AFI map for the Gaussian efficiency shim

DISCUSSION. In this work we present a simple method for calculating a B1+ phase shim set providing reasonable B1+ magnitude over the whole brain at 7T while avoiding dark B1+ nodes. This CP-like mode is critical for whole brain imaging as well as B0 and RF power calibration. We specifically utilize this approach to collect a single 3D large flip angle map which, combined with relative B1 maps, yields absolute B1 maps for each channel [6], allowing for the computation of any specific B1 shimming solution. Without a good starting set of phase, a dark B1+ node could necessitate repeating a large flip angle map with another set of phases to properly map the 16 individual channels [6]. The presented approach is not restricted to a CP-like mode and can be altered to obtained different categories of B1 shimming patterns.

Acknowledgements: NIH P41 - RR008079, S10 - RR026783, R21-EB009133, KECK Foundation. **REFERENCES** [1] Metzger, MRM 2008, [2] Adriany et al, MRM 2005, [3] Van de Moortele et al, ISMRM 2006 [4] Adriany et al, MRM 2008,59:590-597 [5] Van de Moortele et al. ISMRM 2009; 367 [6] Van de Moortele et al. ISMRM 2007