Enhanced whole brain excitation performance of parallel transmission with a Z-encoding RF coil array at 7T

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Introduction: Multi-channel transmit B1 (B1+) manipulation techniques, such as static B1 shimming [1] and parallel transmission (pTX) [2,3], can be used to reduce the severe B1+ inhomogeneities that arise at 7T [4,5] and above [6]. Those techniques manipulate B1+ field distribution and/or spin excitation by adjusting some or all of the degrees of freedom of an RF pulse, i.e. phase, amplitude, shape and duration, during which encoding gradients can be added. One of the fundamental limits of multi-channel B1 manipulation is determined by the spatial encoding capabilities of the utilized multi-element RF coil, although different B1 methods, e.g. static B1 shim vs. spoke trajectories or vs. Transmit SENSE, will not be affected similarly by a given RF coil geometry. In a previous study [7] it has been shown that distributing individual elements of a 7T head array coil in two rings along Z direction provided better RF efficiency than a standard single ring array when applying static B1 shimming over a large brain area, a superiority especially readable in difficult areas such as the cerebellum and the lower temporal lobes. The goal of the current study was to determine, by comparing two transceiver arrays, whether, and to what extent, the use of k_T points [5], a promising approach recently proposed to achieve homogeneous excitation over the whole brain at 7T, would also benefit from RF coil elements distributed along the Z axis.

Methods: Healthy volunteers were imaged with a 7T whole body MR scanner driven by a 16-channel prototype pTX system (Siemens, Erlangen, Germany) with each RF channel powered by a 1kW RF amplifier. One utilized transceiver array, labeled "z-shim" [7], consisted of 30 elements arranged in two rings distributed along Z to cover the upper (16 elements) and lower (14 elements) part of the head. Only 16 out of the 30 elements of this array (8 elements from the upper ring and 8 elements from the lower ring) were chosen for RF transmission and reception. Non-selective pTX RF pulses based on k_T points were designed to create a uniform excitation over the whole brain. The unity target was manually drawn in nine axial slices encompassing the brain tissues including the cerebellum and the lower temporal lobes. RF magnitude and phase modulations for individual k_T points and individual RF channels were calculated based on magnitude least squares optimization [4]. The placement of the k_T points in 3D k-space was constrained to be symmetric about the origin and was optimized over a grid defined in spherical coordinates with a number of different radii, inclination and azimuth angles.

The RF pulse was designed with 3 k_T points and was 360 µs in length. Fig. 1 shows an example of such RF pulse design. B1+ and B0 maps used in pulse design were obtained within the same nine slices used to define the unity target. Complex valued B1+ maps were acquired with a fast hybrid multi-channel B_1^+ mapping technique [8] by combining a 3D actual flip angle image [9] with a series of small tip angle gradient echo (GRE) images. B0 maps were derived from two GRE images at different TE's and were incorporated into RF pulse design to minimize off-resonance effects. It should be noted that a 3D B1 phase shimming targeting a CP-mode B1+ distribution [10] was performed prior to the field mapping in order to avoid severe signal loss due to B1+ destructive interference [1]. Excitation patterns were imaged using a modified 3D GRE pulse sequence. Relevant imaging parameters were as follows: FOV=256×176×252mm³, matrix size=256×256×144, TR/TE=50/2.5 ms, GRAPPA=2 and phase/slice partial Fourier=6/8. Those GRE images were further normalized with respect to receive B1 in order to mainly retain signal variations due to B1+. All calculations were conducted in Matlab (Mathworks, USA). For comparison, the same subject was also imaged during the same session with a single-ring 16 channel transceiver array [5] built with matching spatial coverage. The subject was carefully positioned similarly in the two coils.

Results and Discussion: Fig. 2 displays one coronal and one sagittal view of the 3D excitation patterns in the brain obtained with 3 k_T points RF pulses designed when using each of the two RF arrays. As can be seen, with the single-ring 16 channel array significant residual weak spots of excitation were observed in the cerebellum and frontal cortex areas. By contrast, those weak excitation areas were either reduced or eliminated with same RF pulse design algorithm but using the z-shim coil array. These results indicate that, even RF pulse design methods that enjoy larger degrees of freedom than static B1 shimming to achieve homogeneous brain excitation at 7T, readily benefit from distributing coil elements along Z. It remains to be seen if using two rings of 16 channels rather than two rings of 8 channels would keep increasing RF performance and/or reducing SAR.

References: 1. Van de Moortele et al., MRM 54:1503-1518(2005). **2.** Katscher et al., MRM 49:144-50(2003). **3.** Zhu, MRM 51:775-84(2004). **4.** Setsompop et al., MRM 60:1422-1432(2008). **5.** Cloos et al., MRM (2011). **6.** Wu et al., ISMRM 2011 p4441. **7.** Adriany et al., ISMRM 2010 p3831. **8.** Van de Moortele et al., ISMRM 2007 p1676. **9.** Yarnykh et al., MRM 57:192-200(2007). **10.** Schmitter et al., submitted to ISMRM 2012.
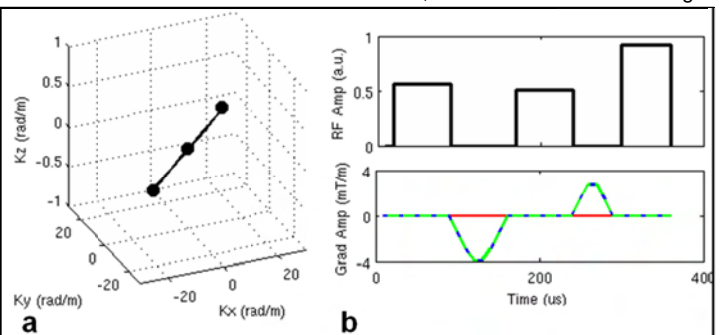
FIG. 1. (a) Placement of 3 kT points in k-space. (b) Corresponding RF amplitude solution of 1 channel, Gx (blue), Gy(green) and Gz (red) blips.
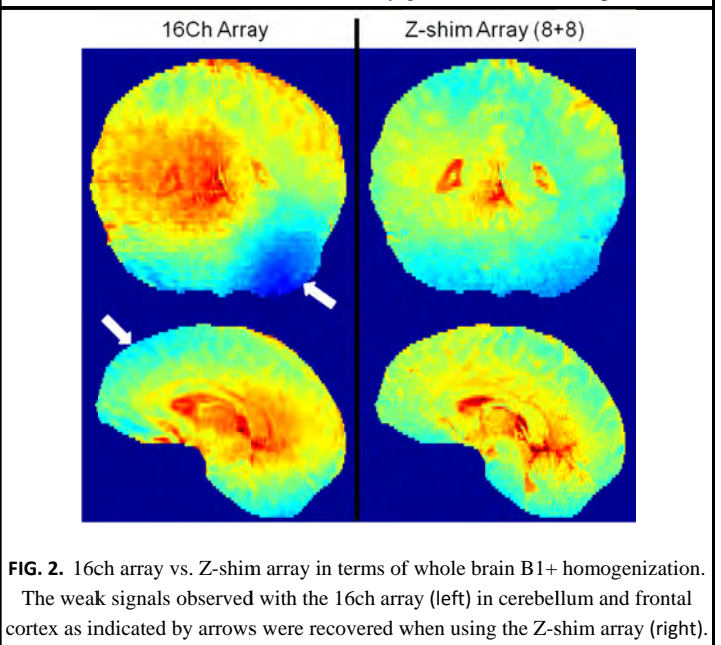

FIG. 2. 16ch array vs. Z-shim array in terms of whole brain B1+ homogenization. The weak signals observed with the 16ch array (left) in cerebellum and frontal cortex as indicated by arrows were recovered when using the Z-shim array (right).