Dual-channel transmit-SENSE for flip-angle homogenization in the human brain at 7 Tesla: a feasibility study

M. A. Cloos[1,2], G. Ferrand[2], N. Boulant[1], M. Luong[2], C. J. Wiggins[1], D. Le Bihan[1], and A. Amadon[1]
[1]LRMN, CEA, DSV, I2BM, NeuroSpin, Gif-Sur-Yvette, ile-de-France, France, [2]CEA, DSM, IRFU, Gif-Sur-Yvette, ile-de-France, France

Introduction: Transmit-SENSE gives the opportunity to implement short excitation pulses with good flip-angle homogeneity [1]. Commonly, a transmit-array system used for brain imaging at 7 Tesla consists of 8 independently modulated amplifiers in combination with a dedicated 8-channel RF coil. Due to the additional degrees of freedom introduced by the separate transmit-channels, uniform excitation can be achieved with short excitation pulses. On the other hand, including additional transmit-channels is not only financially demanding, it also complicates B_1^+-mapping and optimized pulse design. Considering the basis set of orthogonal birdcage coil modes, inclusion of the anti-circularly-polarized modes only marginally improve transmit-SENSE applications [2]. In this work we explore the possibility to drive an 8-element transmit coil with only 2 independent transmit-channels, while retaining the ability to perform adequate flip-angle (FA) homogenization in the human brain at 7 Tesla.

Methods: Instead of driving the coil-elements individually or grouped in circularly polarized (CP) modes [2], it is possible to drive the coil-elements in any arbitrary linear combination thanks to an appropriate splitting hardware device located between the RF-amplifiers and the transmit coil. For a dual-channel system, two linear combinations (B_{1a}^+, B_{1b}^+) can be optimized such that $|B_{1a}^+(\mathbf{r})| + |B_{1b}^+(\mathbf{r})|$ is approximately constant in the volume of interest (an entire brain) and have similar efficiencies [3]. Considering that these linear combinations would be fixed for a dual-channel system, they should be optimized to perform well on all subjects. This could be done using a series of simulations, or measurements for a given coil. When the modes have been determined, these could be implemented in the form of a passive RF-circuit based on couplers and transmission lines.

Experimental data were collected on a Siemens 7T Magnetom scanner (Erlangen, Germany), equipped with 8 separate transmit-channels. A home-made transceiver-array head coil was used, which consists of 8 stripline dipoles distributed every 42.5° on a cylindrical surface of 27.6-cm diameter, leaving an open space in front of the subject's eyes. First a set of relative B1-maps [3] was obtained from Fast Low Angle Shot (FLASH) images (sequence parameters: FA < 6°, TR = 50ms, 5-mm isotropic resolution with a 48x48x36 matrix). In order to increase the overall accuracy, this was implemented in the framework of the matrix-based B_1^+-mapping method [4]. Furthermore, actual FA-maps were obtained for two approximately orthogonal phase combinations contained in the set of FLASH acquisitions. To this end, the AFI sequence [5], including 2 additional echoes for ΔB0-mapping [6], was used with the following sequence parameters: TR1/TR2 = 40/200ms, TE1/TE2/TE3=1/2/3.5ms, same acquisition matrix as for the FLASH sequence. Small non-linearities in the relative B1-mapping procedure due to T1-effects were corrected based on the spoiled GRE signal equation. As a result, the 8 individual-channel FA-maps were obtained from 4 human volunteers and used to validate the concept by synthesizing a dual-channel system.

The first two sets of data (subject #1 & #2) were used to determine appropriate linear combinations to drive the 8 coil-elements from 2 hypothetical independent transmit-channels (Fig 1). These combinations were then fixed to simulate the dual-channel system. For both the 8-channel and synthesized dual-channel system, k_T-point-based excitation pulses were designed targeting a uniform excitation profile (FA = 5°) throughout the brain [9]. Pulse design was performed using the spatial domain method [10] in combination with the MLS approach [11]. Obtained tailored pulses were analyzed by numerical evaluation of the full Bloch equations including the measured ΔB0 evolution.

In addition, a generalized excitation pulse was constructed by simultaneously designing a single excitation pulse for the first 3 subjects with the dual-channel system. Subsequently, the performance of this dual-channel tailored pulse was analyzed for all 4 subjects, to check its robustness against various head shapes and ultimately avoid subsequent B1-mapping calibration.

Informed consent was obtained from all subjects in accordance with guidelines of our institutional review board.

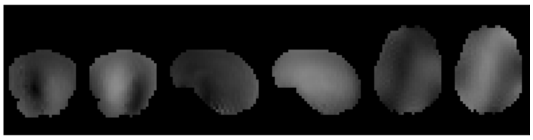

Fig 1: Simulated B1+-maps for the dual-channel system. The two linear combinations are shown side by side in three orthogonal slices trough the brain (Subject #1).

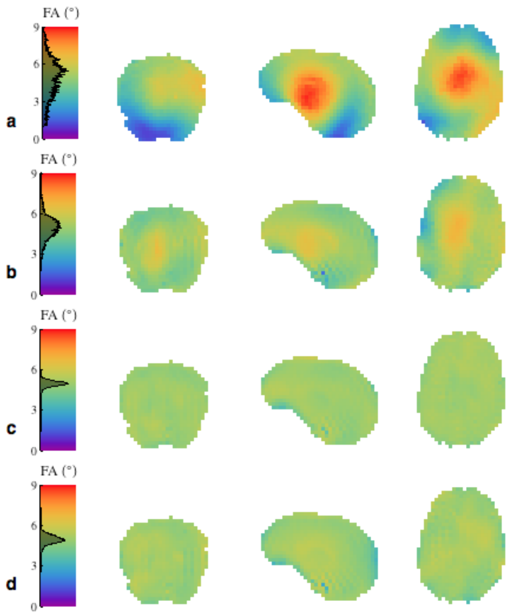

Fig. 2: Simulated FA distributions in the human brain of subject #1. For each measurement, the corresponding histogram is superimposed on the color bar. **a**: Pseudo CP-mode. **b**: Subject-specific static shim. **c**: Eight-channel transmit system, patient-specific 7-k_T-point-tailored RF excitation. **d**: Dual-channel transmit system, patient-specific 7 k_T-point-tailored RF excitation.

Results: Full Bloch simulations of the pseudo CP-mode (phase alignment in central voxel) revealed the central brightening effect, commonly observed with birdcage coils applied to brain imaging at 7 Tesla (Fig. 2**a** - 32% FA variation across the whole brain). For comparison, a static RF shim, i.e. a single k_T-point optimized for 8 independent channels at the center of k-space, still produces considerable spatial variations remain in the excitation profile (Fig. 2**b,** 17% FA spread) Naturally the 8-channel transmit-system provided the best performance with 7 k_T-points (Fig. 2**c** - 5.2% FA spread, 470-μs pulse length). Still, the dual-system demonstrates only a mild degradation in excitation uniformity (Fig. 2**d** - 7.4% FA spread, 550-μs pulse length). In this initial demonstration, optimization of the dual-channel system included data from only 2 subjects. Even so, all subjects showed a reduction in FA variation of approximately a factor 3 compared to the CP-mode (Table). Furthermore, when using a generalized tailored excitation pulse based on B_1^+-maps obtain in previous subjects, significant improvements compared to both the static-shim and CP-mode were obtained (Table, **2-channel***).

	#1	#2	#3	#4
CP-mode	31.7%	31.7%	31.5%	38.5%
Static-shim	16.7%	22.8%	20.7%	17.9%
8-channel	5.2%	5.1%	6.3%	6.1%
2-channel	7.4%	8.8%	9.5%	9.5%
2-channel*	8.2%	11.1%	11.1%	10.9%

Table: Simulated FA spread in the brain for 4 different subjects. CP-mode indicates alignment of the 8 channel phases in the center of the brain. For comparison, the static-shim was optimized from the 8 individual B_1^+-maps for each subject individually. N-channel indicates 7-k_T-point-based tailored RF pulses played on either the 8- or 2-channel system. 2-channel* refers to a generalized tailored pulse designed for all subjects.

Discussion & Conclusion: Even though these preliminary results need further validation on a larger subject population, they indicate the possibility to obtain considerable improvements in excitation uniformity using only a dual-channel transmit system for human brain imaging at 7 Tesla. Depending on the level of FA-homogeneity deemed adequate for a given application, this system could be accepted as a more cost-effective trade-off compared to 4- or 8-channel Tx-arrays. Apart from the reduced hardware requirements, the reduction in preparation time (B_1^+-mapping & pulse design) significantly simplifies transmit-SENSE application in human brain imaging at 7Tesla. Regarding the specific absorption rate (SAR), the risk of producing a local hot-spot still applies to the dual-transmit system. Further investigation of the impact of local SAR needs to be performed. Even so, the dual-channel system also significantly simplifies both SAR assessment and monitoring due to the minimal number of variables involved.

References: [1] Setsompop, et al., MRM 59:908-915 (2008). [2] Alagappan, et al., MRM 57:1148-1158 (2007). [3] Ferrand, et al., ISMRM 2010; p 1474
[3] van de Moortele ISMRM 2007; p1676. [4] Brunner, et al., ISMRM 2008; p354. [5] Yarnykh, MRM 192-200 (2007).
[6] Amadon, et al., ISMRM 2008; p1248. [7] "IEC Standard", 60601-2-33. [8] Cloos, et al., ISMRM 2010; p102.
[9] Grissom, et al., MRM; 56:620-629 (2006). [10] Setsompop, et al., MRM; 59:908-915 (2008).