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

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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 B1-mapping and optimized pulse design. Considering the basis set of orthogonal birdcage coil modes, inclusion of the anti-circularly-polarized modes only marginally improves transmit-SENSE applications [2]. In this work we explore the possibility to drive an 8-channel transmit coil with only 2 independent transmit-channels, while retaining the ability to produce 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 \( (B_{\text{a}}+B_{\text{b}}) \) can be optimized such that \( |B_{\text{a}}(\pi) + B_{\text{b}}(\pi)| \) 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 stripe dipole 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 B1-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 \( \Delta B0 \)-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-linearity 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 (FA = 5°), which were then fixed to simulate the dual-channel system. For both the 8-channel and synthesized dual-channel system, \( k \)-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 \( \Delta B0 \) 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.

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. 2a - 32% FA variation across the whole brain). For comparison, a static RF shim, i.e. a single \( k \)-point optimized for 8 independent channels at the center of k-space, still produces considerable spatial variations in the excitation profile (Fig. 2b, 17% FA spread) Naturally the 8-channel transmit-system provided the best performance with 7 \( k \)-points (Fig. 2c - 5.2% FA spread, 470-μs pulse length). Still, the dual-system demonstrates only a mild degradation in excitation uniformity (Fig. 2d - 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, with the second \( k \)-channel corresponding to the CP-mode (Table). Furthermore, when using a generalized tailored excitation pulse based on \( B1 \)-maps obtained in previous subjects, significant improvements compared to both the static-shim and CP-mode were obtained (Table, 2-channel*).

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 (\( B1 \)-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 improvements 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: