B_1^+ Homogenization Capabilities at 9.4T from a Simulation Approach

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Target Audience Coil designers with an interest in high field, parallel transmit coil development.

Purpose Multi-element transmit coils have been advocated as a key component for mitigating the effects of inhomogeneous transmit field (B_1^+) distribution in high field imaging systems. In combination with either B_1 shimming or full parallel transmission (pTX) they can achieve homogeneous excitation in biological samples as large as the human head at field strength of 7 T and 9.4 T. First results on whole body imaging at 7 T using B_1 shimming approaches have also been reported [1]. However, recent studies indicate that at 9.4 T eight transmission elements might not be sufficient to create homogeneous B_1^+ over the complete human brain when employing B_1 shimming [2]. Stacking transmit elements in z-direction was demonstrated to achieve homogeneous whole brain coverage at the cost of increasing the number of TX channels. Since most scanners capable of full parallel transmission are currently only equipped with eight transmit channels an eminent question for coil designers is to find out B_1 shimming and pTX performance of intended eight-channel coil designs. Ideally this performance should be evaluated prior to actually constructing the coil. This can be achieved using combined electromagnetic (EM) and Bloch simulations as demonstrated in [3]. Here we investigate whether an eight-element loop transceiver coil is capable of homogenising B_1^+ for human head imaging within the SAR limits of normal operating mode at 9.4 T.

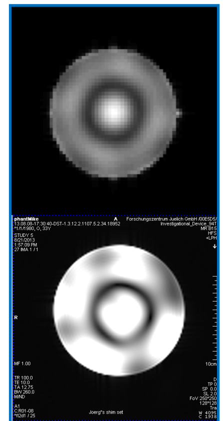

Figure 1: Simulated (*top*) and measured (*bottom*) CP in a phantom

Methods An unshielded eight-loop transceiver coil was modelled and simulated inside a commercial EM simulator (CST AG, Darmstadt, Germany) using the finite integration method in the time domain when loaded with a voxel model of the human head [4]. The obtained E- and H-field distributions were exported using Matlab (Mathworks, Massachusetts USA) and fed into the numerical Bloch simulator JEMRIS [5] together with the voxel model that had been assigned T1 and T2 properties assembled from literature. Parallel pulse design – using spokes for the coil performance evaluation – was carried out according to the method described in [6] and code downloaded from http://www.vuiis.vanderbilt.edu/~grissowa/. Measurements were carried out on a 9.4 T scanner (Siemens Medical Solutions, Erlangen Germany) using a home-built transceiver coil [7] after having obtained written consent within the framework of a clinical trial approved by the local ethics committee and the Federal Institute for Drugs and Medical Devices.

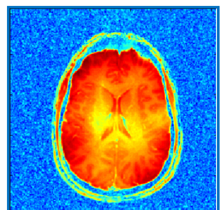

Figure 2: Flip angle map obtained for "no hole" optimization using B_1 shimming

Results Good agreement between simulated and measured B_1^+ maps has been previously demonstrated [7]. Simulated MR images using the fields obtained from EM simulation and measurements when the coil is driven in CP mode also show close similarity (compare Fig. 1). In agreement with the results presented in [2], B_1 shimming for whole-brain coverage could not be achieved without regions of complete signal dropout. On a slice-by-slice basis B_1 shimming can remove regions of signal dropout, especially when the optimization uses the "no holes" [2] cost function (compare Fig. 2). However, the achieved homogeneity was not sufficient for advanced imaging applications. We thus investigated by simulation the performance of the coil for flip angle homogenisation using spokes. Fig. 3a shows the MR image obtained from Bloch simulations for a 5 spoke excitation. For comparison the simulated CP mode image is shown in Fig. 3b. Using the advantage of knowing the phase relationship of the EM fields, the local SAR has been computed revealing that the spokes sequence can be run within SAR limits (Fig. 3c).

Discussion EM simulation is widely employed and accepted as a verified tool in MR coil design. However, when designing for higher field strengths, not all questions can be answered with EM simulations alone. Imaging performance evaluation of envisaged designs requires Bloch co-simulation, e.g. to evaluate image homogeneity for complex pulse sequences in non-low flip-angle regime and in order to evaluate safety parameters like local SAR.

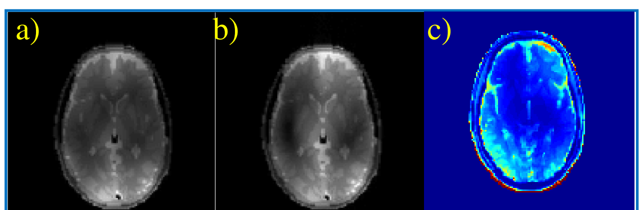

Figure 3: Simulated 5-spokes GRE image (*a*), CP mode GRE image (*b*) and local SAR (*c*) in a selected slice

Conclusion The possibility to combine EM field with numerical Bloch simulation is a valid method to investigate the performance of parallel transmit coils in all aspects of their performance.

References [1] Vaugham et. al., MRM 61:244-248 (2009). [2] Hoffmann et. al., MAGMA 27:373-386 (2014). [3] Cao et. al., J Magn Reson Imaging. doi: 10.1002/jmri.24689. (2014) [4] Christ et. al., Physics Med. Biol. 55:N23-N38 (2005) [5] Stöcker et. al., MRM 64:186-193 (2010). [6] Grissom et. al., MRM 56:620-9 (2006). [7] Felder et. al., Proc. ISMRM 20:2609 (2012). [8] Tse et. al., Proc. ISMRM 22:4336 (2014).