Precise and robust B1+ characterization of transmit coil arrays

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Introduction: A common approach to B1+ characterization of TX-arrays involves transmitting with different combinations of array elements and decoding the combined field maps to obtain single channel field maps [1,2]. This leads to an improved SNR behavior compared to the straightforward approach of B1+ characterization where only one array element with limited spatial TX-sensitivity in the FOV is successively used for transmission. This combined transmission approach can in principle be used with any common B1+ mapping technique.

TX-element combination can be employed in a more sophisticated manner when using a B1+ mapping method based on a saturation pulse with different flip angles and on imaging the remaining longitudinal magnetization with a gradient echo sequence. In such a method B1+ values are determined by fitting a function to the measured data [3]. When using TX-arrays it is possible, as proposed by Fautz et al. [4], to perform the saturation with a single transmit element while the excitation pulse can be performed with a B1+-shimmed TX-element combination ensuring a sufficient B1+ amplitude and therefore a sufficient SNR in the whole FOV. With this technique the decoding process can be omitted which prevents errors occurring during the fitting process to be propagated to the B1+ maps of all elements.

The present study proposes improvements for the common combined transmission approach for TX-array B1+ mapping as well as for the saturation-based technique. Furthermore, the performance of the improved techniques is experimentally compared to the classical single-element B1+ mapping approach.

Methods: When using the combined transmission technique for B1+ mapping of TX-arrays an element combination having a low matrix condition number is desired because errors in the combined scans are less amplified by the decoding. Nehrke et al. [2] proposed using all channels for transmission except for one, leading to a condition of 7 for an array with $N = 8$ elements. Brunner et al. [1] suggested phase encoding, which was realized by changing the phase of a single channel by 180° and resulted in a condition of 3. We propose the application of Fourier encoding which changes the phase offsets of the transmission channels in each of the N measurements according to the Fourier matrix. This matrix consists of elements $p(m,n) = \exp(2\pi i m n/N)$, with the experiment number $m = 1, \ldots, N$, and the array elements $n = 1, \ldots, N$. Its advantage is that it has a matrix condition number of unity and therefore errors are not amplified.

For the saturation-based technique we propose the combination of two methods: first, the precise and fast B1+ mapping method by Brunner et al. [5], in which B1+ is reconstructed by fitting of a simulation of the experiment, incorporating B1+ and T1 as free parameters, to measured data acquired with different saturation flip angles. The second method is the single-element saturation / multi-element excitation approach by Fautz et al. [4]. In the latter approach the spatial variation of the flip angle during the saturation pulse differs from that during the excitation pulse. In the present study a novel reconstruction was developed for this combination of methods which considers the spatial variation of the excitation flip angle as an additional parameter. The simulation is extended by this additional parameter which is determined iteratively: in the first fit of simulated to measured data the excitation flip angle is assumed to be homogeneous throughout the FOV. Then an approximation of the flip angle distribution of the excitation pulse is calculated numerically using the B1+ characterization of each transmission channel. The next iteration uses the approximated values of the distribution of the excitation pulse flip angle for the function fit. The iteration is stopped when the difference between the new and the previous approximations is smaller than a desired precision.

Parallel transmission experiments in this study were realized on a 9.4 T Bruker BioSpec system (Bruker BioSpin MRI GmbH, Ettlingen, Germany). An 8-element TX/RX-array in loop coil design was used.

Results:
The B1+ characterization of one channel of the coil array is visualized in fig. 1. Large B1+ values are mapped in a very similar way by all methods (see upper row). However, the B1+ characterization techniques perform differently in characterizing low B1+ amplitudes (see differently scaled maps in the bottom row). Transmitting with only one channel results in a noisy B1+ map (a). Errors caused by noise are better tackled by combined transmission with several array elements (b,c). However artifacts from the fitting process are visible in the decoded single channel B1+ maps (see arrows).

The single-channel saturation / multi-channel excitation technique performs well in measuring low B1+ amplitudes, too. Decoding is not necessary. In the new B1+ reconstruction the approximation of the distribution of the excitation flip angle converged after approximately 10 iterations.

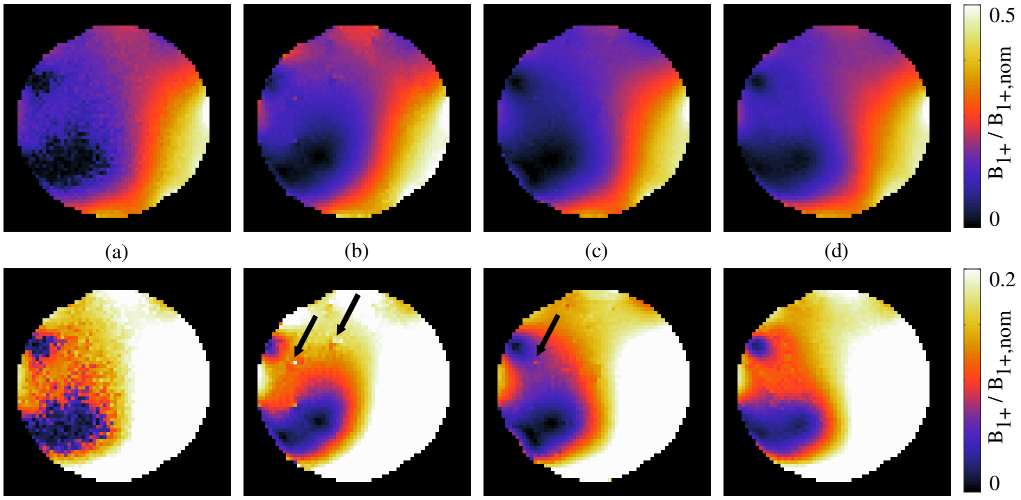

Fig. 1: B1+ characterization of the 4-th channel of the coil array using (a) single channel transmission, (b) combined transmission using all channels except for one, (c) Fourier encoding, and (d) single-channel saturation / multi-channel excitation with the new reconstruction technique. The images in the bottom row are scaled differently to better visualize the performance of the methods in areas with small B1+ values. (Method parameters: TR = 50 ms, TE = 6ms, $\alpha = 50°$, saturation with 1ms block pulse with seven different flip angles 0°, 60°, …, 360°, FOV 64 x 64 mm)

Discussion and Conclusions:
The present study confirms the utility of using combined transmission with multiple elements for the B1+ characterization where the preferred combination method should be Fourier encoding because it has a matrix condition number of unity.

The saturation-based B1+ mapping technique using the same single channel for the saturation and excitation pulses results in a particularly severe SNR penalty: in regions where B1+ is small only little longitudinal magnetization is saturated and at the same time the tiny differences in remaining magnetization in these regions are further covered up by noise due to a very low excitation flip angle. This drawback is overcome by the single-channel saturation / multi-channel excitation approach. This technique bears the great advantage that there is no need for the error susceptible decoding step due to single-channel saturation, while on the other hand the multi-channel excitation pulse ensures a good SNR performance. Together with the iterative B1+ reconstruction process developed in this study, which takes into account the spatial variation of the excitation flip angle, a precise and robust B1+ measurement is obtained which was confirmed in experiments with an 8-channel TX-array.

References: [1] D. Brunner et al. Proc. ISMRM 16:354 (2008) **[2]** K. Nehrke et al. Proc. ISMRM 16:353 (2008) **[3]** J.T. Vaughan et al. MRM 46:24 (2001) **[4]** Fautz et al. Proc. ISMRM 16:1247 (2008) **[5]** D. Brunner et al. Proc. ISMRM 15:353 (2007)

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