Extending the sensitivity range for transmit array B1 mapping using relative B1 maps

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Introduction:
Accurate B1 mapping still lacks the desired speed of a fast adjustment scan. This holds particularly true for mapping the RF fields of transmit (TX) array coils where the scan time is not only kept long by the number of coil elements. Also the large dynamic ranges of such B1 field distributions generated by local TX array coils challenge B1 mapping. Areas of high B1 amplitude typically require time consuming acquisition strategies in order to encode the B1 field independently of T1 or T2 contrast. Areas of low B1 amplitudes typically suffer from poor noise figures of the B1 encoding. The acquisition of relative B1 maps from a set of FLASH images seems to be a practical way to get rather quickly and robustly B1 maps with a high sensitivity to low B1. Therefore, one or more additional flip angle maps are needed to estimate the common spatial TX efficiency weighting of the relative maps to yield the final quantitative B1 maps [1,2]. However, this hybrid B1 mapping method has a limited sensitivity range towards larger flip angles as it makes explicit use of the linearity between signal intensity and B1 amplitude. The goal of this study is to leverage the benefits of relative B1 mapping in the low flip angle regime to extend the sensitivity range of any quantitative B1 mapping method towards low B1 values. The requirements on quantitative B1 mapping techniques are relaxed and the validity of the low tip assumption for relative B1 maps are ensured based on measured data.

Methods:
The basic idea of the proposed method is to acquire a full set of quantitative B1 maps $mB1_i(x)$, where i indicates the coil index. These B1 maps have high fidelity for high B1 amplitudes but might be limited in their sensitivity to low B1 values. Additionally relative B1 maps $rB1_i(x)$ are acquired. A second set of quantitative B1 maps $cB1_i(x)$ is calculated from the relative B1 maps. Therefore the spatial scaling of the relative B1 maps is estimated using the measured B1 maps $mB1_i(x)$ [1,2]. For each voxel the maximum likelihood is calculated considering relative and quantitative B1 maps from all coils i.
The calculated B1 maps $cB1_i(x)$ have high fidelity for low B1 amplitudes. A weighted combination of measured and calculated B1 maps picks the B1 value of higher fidelity from either set of B1 maps to get the final B1 maps $B1_i(x) = s(x)*cB1_i(x) + (1-s(x))*mB1_i(x)$. The fidelity factor s(x) is one for voxels where the flip angle of $cB1_i(x)<20°$, zero where the flip angle of $cB1_i(x)>50°$ and else a transient function in between.
For demonstration a set of quantitative B1 maps was acquired using a pre-saturation technique in combination with a centrically reordered Turbo FLASH read out sequence [3]. For mapping 8 elements of a TX array coil the imaging sequence used a combination of all coils as described in [4]. The B1 maps were acquired in a water doped phantom using a Siemens 7T Magnetom TIM system equipped with an 8 channel TX array (Siemens Healthcare, Erlangen).

Results:
In the first row of figure 1 the measured quantitative B1 maps *m*B1 of each other coil are shown. In the second row the maps *c*B1 calculated from the relative B1 maps of the corresponding coils are shown. Combining these two sets of B1 maps according to their complementary sensitivity ranges results in the final B1 maps shown in row 3. A plot of the B1 values of coil 3 along the indicated cross section from posterior to anterior depicts the properties of the different maps quantitatively (figure 1 right). The sensitivity range of the measured quantitative flip angle maps cuts off around 20°. A localized minimum in the B1 amplitudes in pixel 81 is missed in this map and the noise figure gets poor towards the anterior part of the phantom. This part of low B1 is nicely encoded by the calculated maps *c*B1. However, the large tip angles towards the posterior parts of the phantom are overestimated in these B1 maps. This indicates that the linearity assumption (low tip angle regime) is violated for these flip angles due to the sinusoidal dependency of the signal intensity and steady state signal weighting applying a TR of 50ms. The values of the final B1 maps follow the values of the individual maps, which are selected based on their fidelity for the corresponding flip angle.

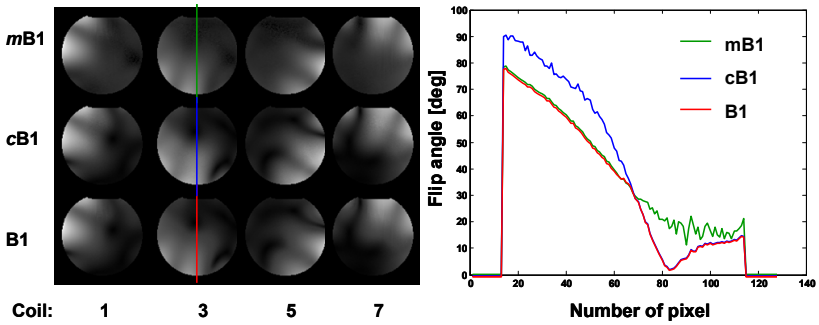

Fig. 1: B1 maps of each other coil as measured (row mB1), as calculated from relative B1 maps (row cB1) and as final B1 map (B1). On the right the B1 magnitudes are plotted along the lines indicated in the maps of coil 3 on the left hand side.

Discussion:
The general approach to extend the sensitivity range of a B1 mapping technique by an additional measurement is reminiscent to known techniques that step through different power levels in multiple repetitions of a B1 mapping acquisition like described e.g. in [5]. The main difference in the proposed method is to use different and dedicated mapping techniques to encode different ranges of B1 namely the low and high flip angle range. The use of relative B1 maps provides a fast and robust way to encode low B1 values. This is particularly beneficial for a number of recently published and popular techniques, which need to encode B1 amplitude and TX phase in separate scans like [4, 6-7]. To measure the relative TX phase maps, a set of FLASH images is typically required which can be used to realize the proposed B1 mapping extension without any need for additional acquisitions and scan time. This method can be combined with other methods increasing the sensitivity range for B1 mapping like interferometric acquisitions [6].

References: [1] P.-F. Van de Moortele et al, ISMRM 2007 p. 1676. [2] K. Setsompop et al, MRM 60:1422 (2008). [3] U. Klose. Med Phys 1992;19:1099. [4] H-P. Fautz et al, ISMRM 2008, p.1247. [5] A. Kerr et al. ISMRM 2006 p2561. [6] D. Brunner et al, MRM 61: 1480 (2009) [7] L. Sacolick et al, MRM 63: 1315 (2010).