Comparing Bloch-Siegert B1+ Mapping using Single Channel and Channel Combination Tx Methods

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Purpose: One of the major applications of the Bloch-Siegert (B-S) B_1^+ mapping method [1] is in parallel transmit (pTx) RF pulse design, which requires B_1^+ mapping of a large dynamic range. Channel combination has been used to improve the dynamic range of B1 mapping methods such as "dual angle method" (DAM) and "actual flip angle imaging" (AFI) [2,3]. Recently, it has been also suggested for B-S B_1^+ mapping [4]; however, the B-S method, unlike DAM and AFI, is mostly limited by SAR constraint and any optimization should consider that into account. Here we first optimize the Adiabatic Bloch-Siegert (ABS) B_1^+ mapping [5] using a) single channel Tx and b) channel combination methods and then compare their performance in a pTx application.

Theory: In B-S B_1^+ mapping, the imaging phase and the B_1^+ encoding phase of the sequence are separate. The imaging phase is done using all Tx channels and optimized to get the highest signal in order to maximize angle to noise ratio (ANR). In the B1 encoding phase, the B-S pulse amplitude is maximized within both local and global SAR limits to get the highest ANR. In single channel Tx case, because the B-S pulse is interleaved between channels, the local SAR is lower compared to channel combination method and therefore higher B-S amplitude can be achieved within SAR limits. For instance the maximum B-S pulse amplitude in single channel Tx is $(N-1)^{½}$ times greater than the maximum B-S pulse amplitude in channel combination method , which transmits on all channels but one.

Methods: A 6ms optimized ABS pulse, designed with -40 dB in-band (±500 Hz) attenuation and K_{BS}=440 rad/G^2 was inserted in a Gradient Echo sequence [5] for B_1^+ mapping. The imaging parameters were selected as TE=10 ms, TR=100 ms, Slice Thickness=5 mm, FOV=24 cm, matrix=64x64 and BW=±31.25 kHz. The B_1^+ mapping sequence was repeated 13 times on a GE MR950 7T scanner (GE Healthcare, Waukesha, WI) with a spectroscopy phantom inside Nova 8ch Tx, 32ch Rx head coil (Nova Inc, Welmington MA) using both single channel Tx and channel combination Tx methods. In order to match both local and global SAR limits, the ABS pulse amplitude was set to 5 μT for single channel Tx and 1.9 μT for channel combination Tx method. The B1 maps were averaged for each method and SNR maps were calculated (Fig 1). Each set of B1 maps from either method was used to design a 3-spoke pTx pulse [6] (Fig 3) and the pTx FA maps were generated (Fig 4).

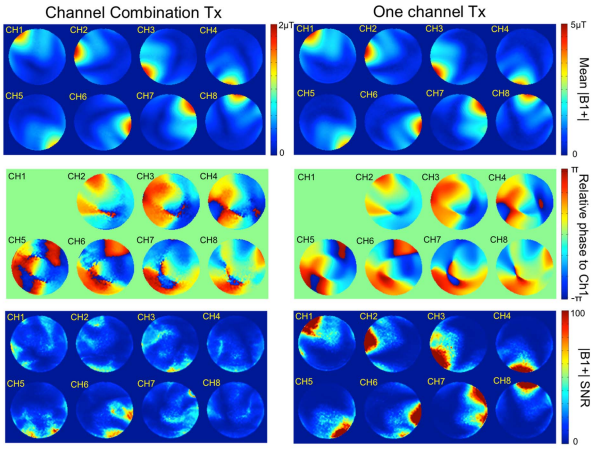

Fig 1: Comparing ABS B_1^+ maps using channel combination and single channel Tx methods. Channel combination results in noisier B1 phase maps and has a higher B1 magnitude SNR in low B1 areas.

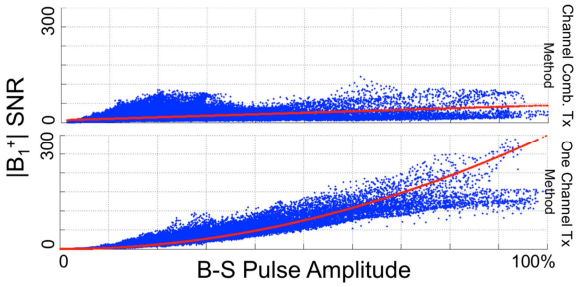

Fig 2: B1 mag SNR vs. relative BS pulse amp. Single channel Tx method has a better SNR in 75% of all B1 amplitudes. Channel combination method has a higher SNR only if the B1 amplitude is less than 1/4th of the maximum B1.

Results: Fig 1 shows the comparison between single channel Tx and channel combination Tx methods. As expected the single channel Tx methods generates higher ANR in areas with high B_1^+ while channel combination Tx method performs better in areas with low B_1^+ values. The B_1^+ relative phase has higher SNR in single channel Tx method because in the channel combination Tx method, the B_1^+ phase is calculated using both phase and amplitude of combined channels B_1^+ maps. Fig 2 shows the ANR vs. B-S amplitude for all pixels. It shows that the single channel Tx method outperforms channels combination Tx method where the measured B_1^+ is more than 25% of the maximum B_1^+. Fig 3 shows a typical 3-spoke pTx pulse designed with one set of measured B_1^+ maps. Fig. 4 shows that a 3-spoke pTx pulse can improve the FA homogeneity by ~4 times compared to RF shimming. The single channel Tx method was able to reduce the B_1^+ inhomogeneity to 3.8% compared to 4.3% achieved by channel combination Tx method.

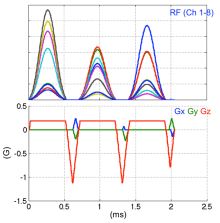

Fig 3: 3-Spoke Parallel Tx RF pulse design

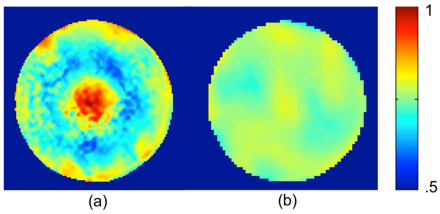

Fig 4: FA map comparison. (a) RF shimming with 14.2% inhomogeneity vs. (b) 3-Spoke pTx with 3.8% inhomogeneity with one ch Tx and 4.3% with channel combination Tx method.

Discussion: ABS B_1^+ mapping using channel combination is compared with single channel transmission method for pTx pulse design application. While both methods achieve significant reductions in FA inhomogeneity, the single channel Tx in B-S method outperforms combined channels Tx, both in B_1^+ ANR and final pTx homogeneity (unlike DAM and AFI methods). This is because 1) B-S optimization is governed by SAR limits 2) unlike DAM and AFI, all channels are used for the imaging part of B-S method.

References: [1]Sacolick et al., MRM 63:1315-1322, 2010. [2]Brunner et al., MRM 61:1480-1488, 2009. [3]Nehrke et al., MRM 63:754-764, 2010. [4]Wyss et al., 21st ISMRM, SLC Utah 2594, 2013. [5]Khalighi et al., MRM 70: 829–835, 2013.[6]Grissom et al., MRM 68: 1553–1562, 2012.
Acknowledgement: GE Healthcare and Stanford University Lucas center.