Accelerating Bloch-Siegert B1+ Mapping Using Modified Iterative SENSE and ESPIRiT (iSENSE)

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Purpose: Bloch-Siegert (B-S) B_1^+ mapping [1] has been shown to be a fast and accurate method for B_1^+ mapping which makes it a great choice for parallel transmit (pTx) RF pulse design. Although B-S B_1^+ mapping is fast but it still takes a long time on a a multi-channel pTx system, or it may not fit in one breath-hold for cardiac B_1^+ mapping, therefore fast imaging methods such as accelerated readout [2] or parallel imaging [3] have been used to achieve shorter scan times. Because B_1^+ maps are spatially slow varying, they are acquired in low resolution to achieve shorter scan times as well as higher signal to noise ratio (SNR), which makes the auto-calibrated parallel imaging methods less efficient due to fully sampled central k-space. Here, we propose a modified iterative SENSE method (iSENSE) for parallel imaging acceleration, which takes advantage of one of B-S B_1^+ mapping properties i.e. all acquired images of each slice have the same magnitude.

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 to maximize SNR. On the other hand, the B-S pulse is only played to encode the phase of the image with B_1^+ magnitude while the image magnitude is not changed. To accelerate B-S B_1^+ mapping, the complex sensitivities maps are obtained from a short calibration acquisition using ESPIRiT method [4, 5]. After data acquisition with acceleration factor of R, the images are un-aliased with SENSE, then each Rx channel magnitude image is replaced with the mean of all magnitude images of that channel and then the data is converted back into k-space in order to re-enforce the acquired k-space lines. Such reconstruction i.e. enforcing sensitivity maps, consistent magnitude image across Rx channels, and acquired k-space data is repeated iteratively until convergence (iSENSE) and then the B_1^+ maps are reconstructed using fully recovered k-space.

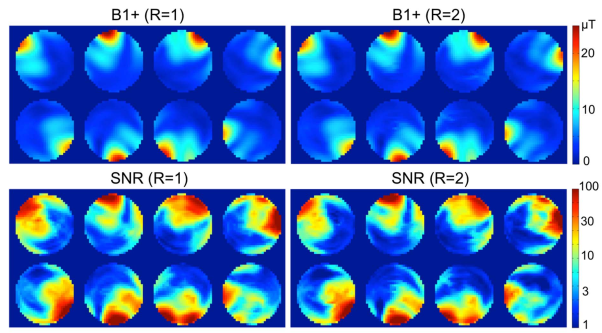

Fig 1: Comparing B_1^+ maps using fully sampled k-space (R=1) and iSENSE with acceleration of R=2. The SNR loss with R=2 is only 24% as compared to 46% loss with the conventional SENSE.

Methods: A 6ms Fermi pulse at ±4kHz off resonance was used with a Gradient Echo (GRE) sequence for B-S B_1^+ mapping [1] of a spectroscopy phantom inside Nova 8ch Tx, 32ch Rx head coil (Nova Medical Inc, Wilmington MA) on a GE MR950 7T scanner (GE Healthcare, Waukesha, WI). The imaging parameters were TE=10ms, TR=70ms, Slice Thickness=5mm, FOV=24, matrix=32x32 and BW=±31.25kHz with 55s scan time to measure B_1^+ magnitude and phase of 8 Tx channels for one slice. This experiment was repeated 10 times. A regular GRE scan with the same parameters except TE=4ms and 2s scan time was run and used to calculate the sensitivity maps using ESPIRiT. The B_1^+ maps were reconstructed using both fully acquired k-space (R=1) and also with acceleration factor R=2 using our proposed iSENSE method. Each set of B_1^+ maps from either method was used to design a 3-spoke pTx pulse [6] (Fig 2). For each design the mean B_1^+ maps were used to calculate the pTx FA map (Fig 3).

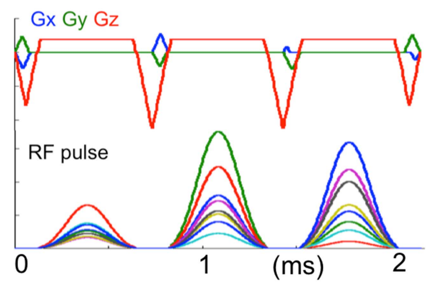

Fig 2: 3-Spoke Parallel Tx RF pulse design

Results: Fig 1 shows the comparison between full k-space reconstruction (R=1) and iSENSE reconstruction with R=2. Using a 20μT B-S pulse, the difference between the B_1^+ maps of the two methods is less than 0.5μT. Comparing the SNR of the two methods, the iSENSE method shows a 24% drop in SNR, while the SNR drop is 46% for conventional SENSE [7]. Fig 2 shows a typical 3-spoke pTx pulse designed with one set of measured B_1^+ maps. Fig. 3 shows that a 3-spoke pTx pulse can improve the FA homogeneity by ~3 times compared to RF shimming. The B1+ maps from iSENSE (R=2) performed equally with fully sampled method (R=1) as the remaining inhomogeneity in FA map were 6% for both of them.

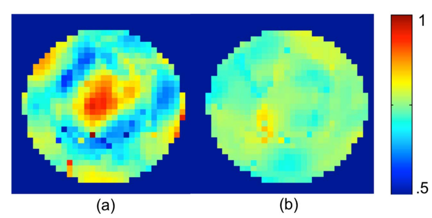

Fig 3: FA map comparison. (a) RF shimming with 16% inhomogeneity (b) 3-Spoke pTx with 6% inhomogeneity. iSENSE reconstructed B_1^+ maps (R=2) and fully sampled B_1^+ maps resulted in the same pTx homogeneity.

Discussion: B_1^+ maps acquired with acceleration R=2 with the proposed iSENSE method are compared with full k-space reconstructed maps. The iSENSE reconstructed B_1^+ maps with R=2 show only 24% drop in SNR, providing about 2x improvement compared to conventional SENSE. Our results show iSENSE also performs equally to fully reconstructed B_1^+ maps in a pTx RF pulse design application.

References: [1] Sacolick et al., MRM 63:1315-1322, 2010. [2] Khalighi et al, 19th ISMRM, p578, 2011. [3] Tandanki et al., MRM 10.1002/mrm24804, 2013. [4] Lai et al, 17th ISMRM, p345, 2009. [5] Uecker et al., MRM 10.1002/mrm24751, 2013. [6] Grissom et al., MRM 68:1553-1562, 2012. [7] Pruessmann et al., MRM 42:952-962, 1999.

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