Bloch-Siegert Shift B1 Mapping with multi-band excitation

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Introduction: Parallel excitation was proposed to accelerate multidimensional selective excitation using multiple coils driven with independent waveforms and could be a potential solution for mitigating the B1 inhomogeneity and SAR problems at the ultra-high field, such as 7T. As the prerequisite of a pTx experiment, the B1 maps must be known for each Tx channel. As the number of the transmit channel increases, the total scan time of B1 mapping could increase significantly. In light of this, there is a tremendous motivation to find a fast B1 mapping method for pTx applications in the recent years. One of B1 mapping method recently proposed [1] used the Bloch-Siegert shift effects that encode the $B1^+$ field information into the phase maps to allow fast B1 mapping. However, the long (typically 10ms) non-selective off-resonance pulse employed to create the desired phase shifts turned out to cause excessive SAR at 7T for multi-slice measurement. This, in turn, prolonged the TR (thus B1 mapping scan time) and limited to the number of measured slices to a few slices to avoid exceeding SAR. The multi-band excitation (MB) imaging technique was developed to boost the speed of 2D data acquisition (2,3). In this study, we implemented MB acceleration to the Bloch-Siegert Shift B1 mapping sequence. We demonstrated that the SAR limitations of this method are partially mitigated and the slice coverage can be increased by a couple of times.

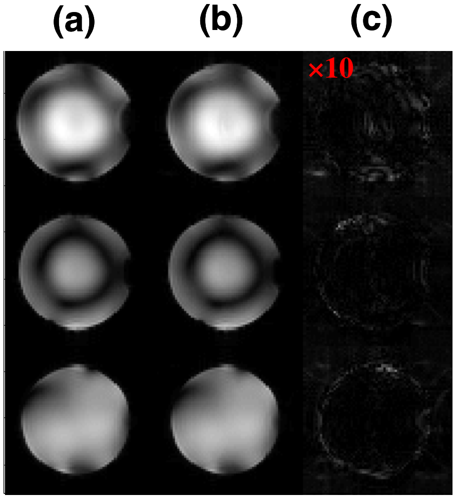

Fig. 1 Amplitude images. (a)Conventional multi-slice images, (b) images from MB accelerated sequence, and (c) the difference between the two (x10).

Methods: The gradient echo sequence is modified by replacing the excitation pulses with multi-band excitation pulses. The sequence also implemented the CAIPIRINHA technique for improved acceleration, which was achieved by adding a specific phase shifts for each phasing encoding lines for a given slice during the multi-band RF pulse design. Following the excitation pulse, an off-resonance Fermi pulse (off-resonance frequency, ±6kHz and the pulse duration, 8ms) was immediately applied to create the Bloch-Siegert shifts according to the B1 field. The Matlab were used to reconstruct and process all the images.

Results and Discussion: All experiments were carried out on the 7T Siemens scanner with an 8-ch pTx system. The home-made RF coil with 20-channel Tx and 32-channel Rx inserter was used. The multiple slices' B1 maps (128×128) for a random combined transmit mode was obtained with the modified 2D GRE sequence with TR = 500ms and TE = 11ms. For this study, we used a 3-folder slice acceleration factor. For the reference data for fitting the GRAPPA-like kernel for multi-band imaging, we also acquired the k-space center (20 lines) of the regular multi-slice GRE sequences together with the multi-band excitation data. The regular multi-slice GRE imaging for Bloch-Siegert B1 mapping was also acquired for comparison and verification of the MB results. The nominal excitation flip angle is 60 degree for both the MB excitation RF pulse and normal Sinc excitation pulse.

Fig.1 shows the comparison of reconstructed amplitude images of the selected three slices from normal multi-slice imaging, the MB method, and the amplitude difference between the two set of images (the difference is amplified by a factor of 10). Except at the edge of the phantom, the two set of images were in great agreements. The total energy reported from the TALES of the MR scanner for the regular multi-slice method (acquired with total 9 slices, only three slices are shown in the Figs) is about 12.3 W for the 10s average. The MB sequence with a slice acceleration factor of 3 reported 5.1W for the 10s average. The reduction of SAR deposition is mainly due to the fact that the MB sequence reduced number of the Fermi pulses needed by a factor of three as there is only one Fermi pulses for each MB excitations that excited three slices simultaneously. Fig.2 showed the comparison of phase maps from the two experiments with the +6kHz and -6kHz off-resonance frequency for the Fermi pulse, respectively. The phase map is directly propositional to the B1 square. The phase maps from the usual multi-slice sequence and the MB accelerated sequence are clearly almost the same, which demonstrated that the MB method can be used to reduce SAR and/or increase slice coverage for the Bloch-Siegert B1 mapping method. In this study, we used a random phase combination of the 20 Tx channels that rendered a big B1 field variation across slices for the testing and verifications of the sequences. It is clear from Fig.2 that the Bloch-Siegert's dynamic range is not well suited for all slices (especially the middle slice) with the huge varied B1 fields. The low B1 region failed to be measured accurately. It is possible to vary the voltages of the Fermi pulse with more steps to expand the dynamic range. However, this will come with the expense of more SAR depositions.

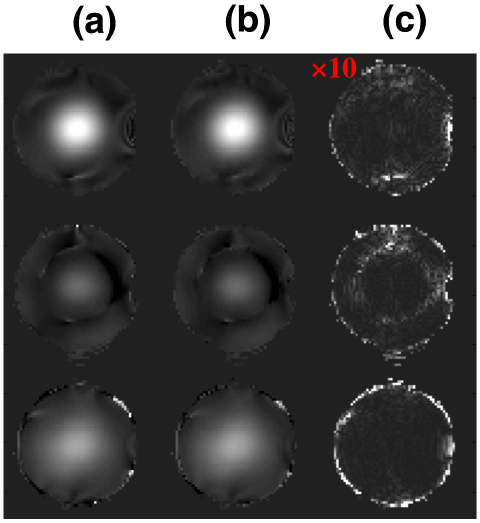

Fig. 2 Phase images (~B1 maps). (a)Conventional multi-slice method, (b) maps from MB accelerated sequence, and (c) the difference between the two methods (x10).

Conclusion We demonstrated that MB can be applied to Bloch-Siegert B1 mapping sequence to reduce the SAR deposition and increase the slice coverage at the 7T.

References: [1] Sacolick, L., *et al.*, MRM 2010. [2] Moller et al ., MRM 2009. [3] Setsompop et al., MRM 2012.