Interference Bloch-Siegert B1 Mapping for Parallel Transmit

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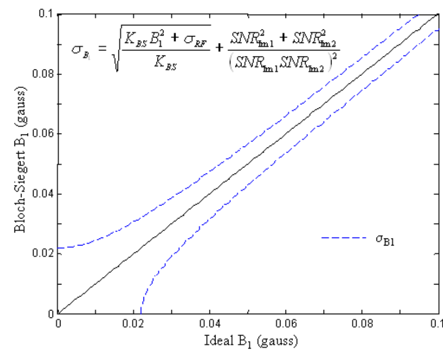
INTRODUCTION: Recently, a novel method of B_1 mapping has been developed based on the Bloch-Siegert shift. Previous works have described application of the method for single-channel RF transmission (1). Here we describe the extension and optimization of the method for B_1^+ amplitude and phase for high-channel count parallel transmit. While the Bloch-Siegert B_1 measurement method is accurate over a wide range of B_1 fields, the SNR increases with B_1^2, so in practice this method is better suited to higher B_1 fields. The B_1 field produced by any single coil element in a high channel count parallel transmit system would typically fall in the noise level of a Bloch-Siegert B_1 map as one moves into areas with low B_1 field away from the coil. The standard deviation of the noise of a Bloch-Siegert B_1 map is dependent on the base image SNR, phase stability of RF chain (with standard deviation σ_{RF}), B_1 field, and Bloch-Siegert shift constant K_{BS}. Figure 1 shows the standard deviation of the noise of a Bloch-Siegert B_1 map over a range of B_1, for a K_{BS} corresponding to an 8 msec, 4 kHz Fermi pulse, an RF phase stability of $\sigma_{RF} = 1.5°$, and image SNR = 25. This measurement would have a minimum detectable B_1 of $\sigma_{RF} = 0.022$ gauss.

For this reason, the method is here combined with the B_1 interferometry method introduced by Brunner and Pruessmann (2). The off-resonance RF pulse used to generate the Bloch-Siegert shift is played sequentially on all but one transmit channel. In this way, small B_1 fields from individual transmit coils can be measured in the high SNR regime of Bloch-Siegert B_1 mapping. This is demonstrated on a 3 Tesla General Electric parallel transmit system, for an 8-channel Tx/Rx head coil, and an 8 channel integrated body Tx coil.

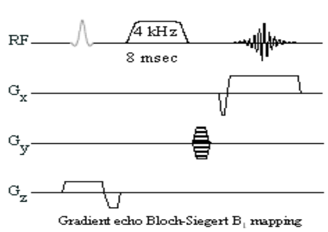


METHODS / RESULTS:

Two separate scans were used to determine the phase and magnitude of the composite 7-channel B_1 fields. The full experiment consists first of a scan to calculate the phase of the composite B_1 field produced by each set of N-1 channels. A circularly polarized phase configuration was used to generate the baseline B_1^+ field for both scans. B_1 phase of the 7-channel composite fields was determined by taking the phase difference (relative to the phase of one of the composite images) between N gradient echo images with all but one channel used for excitation. This simple gradient echo pulse sequence with TR = 30 msec is not shown here.

B_1 magnitude was measured in a second set of 2 x N scans with the sequence shown below. A simple gradient echo Bloch-Siegert B_1 mapping sequence is shown, but the same method can be applied to a wide variety of sequences. The Fermi pulse(s) were played at +/- 4 kHz sequentially on each set of N-1 channels. The excitation RF pulse was played on all channels, with a circularly polarized phase configuration. The TR of this sequence was SAR limited to 70 msec for our head coil, and 100 msec for our body coil.

The B_1 magnitude and phase from these two separate scans were combined into a set of complex B_1 field data for each set of 7 coils. This measured complex B_1 field for the composite N-1 channel image where coil m is left out is called $B_{1,m}$, and is the linear sum of all B_1 fields from each individual channel n. With N coils, and N measurements, we can solve the system of equations $B_{1,m} = \sum_{1}^{N} B_{1,n}, n \neq m$ for the complex $B_{1,n}$ field produced by each single channel. In a typical parallel transmit system, the coils have spatially distinct transmit profiles giving a well-conditioned solution.



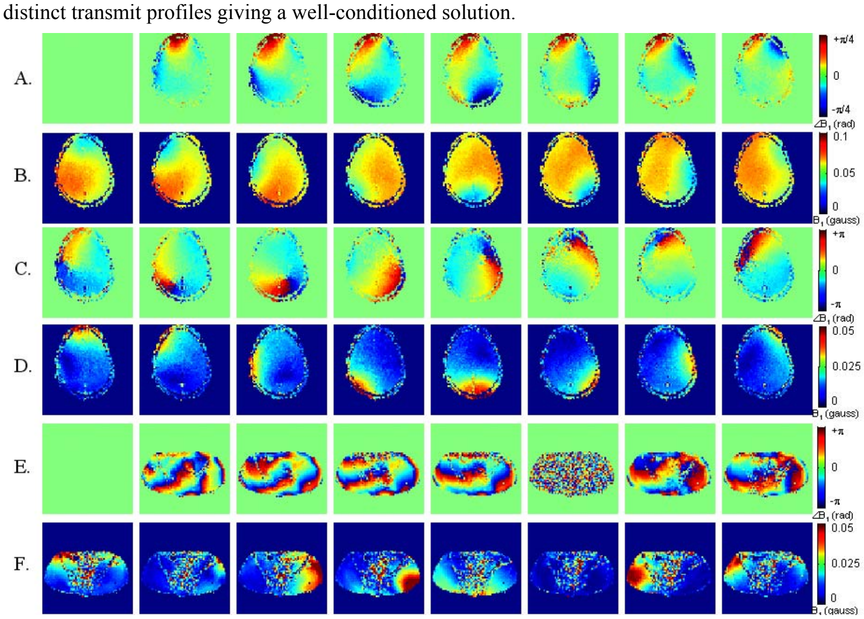


Figure 2: a. 7 composite channel B_1 phase $\angle B_{1,m}$ (relative to channel 1) **b.** 7 composite channel B_1 magnitude $|B_{1,m}|$ **c.** individual coil B_1 phase $\angle B_{1,n}$ (relative to channel 1). **d.** individual coil B_1 magnitude $|B_{1,n}|$. **e.** individual coil B_1 phase, abdomen in an 8 channel body coil. **f.** individual coil B_1 magnitude, 8 channel body coil. (Channel 6 is dead.) Total scan time (B_1 magnitude + phase scans) = 10.2 sec/channel (head), 14.1 sec/channel (body).

DISCUSSION:

The low B_1 from individual coils in a parallel transmit setup presents a challenge for most B_1 mapping methods, including double angle and AFI. The Bloch-Siegert B_1 mapping method can be used to measure the small B_1 fields of individual coils of high channel count parallel transmit systems by measuring the composite field patterns from the off-resonance pulses on N-1 channels. Since this B_1 mapping scan relies on having a good base composite B_1 field, an iterative process may be necessary >3 Tesla where the base starting B_1 inhomogeneity may be very poor.

ACKNOWLEDGEMENTS AND REFERENCES:

1. Sacolick LI, Wiesinger F, Hancu I, Vogel MW. Magn Reson Med 2010; 63:1315-22. **2.** Brunner DO, Pruessmann KP. Magn Reson Med 2009;61:1480-1488.