Rapid Slice-Selective B1 Mapping for Transmit SENSE

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Introduction: Parallel RF excitation is a novel technology that can significantly accelerate multidimensional selective excitation and reduce SAR [1-3]. One caveat however is that the transmit array B1 sensitivity profiles must be known. Previous experimental demonstrations [4-5] have relied on having a uniform transmit reference but this cannot generally be assumed. We have previously described a general approach that provides robust estimation of volumetric B1 maps in ~40s/coil [6]. Here we describe an extension of our method to a slice-selective approach, as well as an extension of the magnetization preparation technique of [7]. Both techniques include careful compensation for B0 off-resonance and acquire B1 maps in less than 3s/coil.

Method: Figure 1a shows a multi-tip extension of the slice-selective B1 mapping sequence of [8]. The sequence includes two 8-ms BIR4 non-selective adiabatic pulses transmitted in parallel from multiple coils and followed by gradient spoilers in order to effectively “reset” the longitudinal magnetization to a fixed state. The relative transmit phases to achieve a quasi-uniform excitation for the RESET pulse is estimated from small-tip single-coil images. The spectral-spatial RF pulse is stepped on the coil under test by factors of γ from 0 to γN-1 between TRs, with the whole process being repeated enough times to acquire N images. Figure 1b shows a similar RESET preparation, but in this case a magnetization-preparation pulse (a hard pulse) [7] is stepped through multiple tip angles on the coil under test. A common zero-amplitude hard pulse result can be shared for all coils. A gradient spoiler follows the preparation, and then a spectral-spatial excitation is transmitted in parallel similar to the RESET pulse, and finally a gradient-echo readout. As Fig. 1 illustrates, the multi-tip excitation of (a) is appropriate for multislice acquisition, however T1 recovery during the first acquisition in the hard-pulse preparation approach (b) will introduce errors in the B1 estimation if, as we assume, T1 is unknown.

The imaging sequence uses a 3-interleaf spiral acquisition with 8-ms readouts providing 64x64 resolution over a 40-cm FOV (GE Signa HD 3T system, 23 mT/m, 77 T/m/s). An additional single image acquisition with a 2-ms delayed echo is used to calculate a B0 off-resonance map.

The multi-tip excitation data for each pixel is fitted using a least-squares nonlinear optimization to the complex signal model (Fig. 2) of the spectral-spatial excitation for the given B1. This determines the absolute transmit B1 amplitude and relative phase maps. In the case of the multi-tip preparation model, the signal is fitted to a model that includes the effect of B0 variations on the prepared longitudinal magnetization Mz. This determines the absolute transmit B1 amplitude maps. The relative B1 phases are obtained from separate small-tip images acquired from single coil excitations.

Results: An eight-channel frequency and phase-locked multi-transmit platform [4] based on an integrated set of four GE HD system electronics was used for our experiments. A 16-element TEM body array was configured with opposite elements being driven in tandem but 180° out of phase by each channel. Figure 3 presents the B1 magnitude profiles measured using the multi-tip excitation and preparation schemes. Each approach used 4 tip-angles with a scale factor of 2. With a TR of 180 ms (T1~600ms), the total acquisition time for measuring all 8 channels was less than 24s for each approach. Figure 3 shows good agreement between the two methods where the B1 transmit amplitude is over 2μT. At lower values, the multi-tip excitation is very sensitive to SNR as the excitation is in the small-tip linear regime. The preparation approach is much more robust in contrast.

Figure 4 presents further validation of the multi-tip preparation scheme when mapping B1 in a large ex vivo meat sample. In this case, the RESET approach could not be used, as insufficient B1 was available for the BIR4 pulse. This is due to the current experimental setup running in a reduced power mode and is not deemed to be a serious shortcoming. As a result, a TR of 2s was used (total acquisition time ~3.3 min for 8 channels). Validation of the acquired B1 maps was obtained by using them to design a parallel-transmit 3D slice-selective excitation similar to that in [9-10].

Discussion: Two slice-selective approaches for rapid estimation of B1 maps over a large dynamic range, including careful compensation of slice-profile and off-resonant effects were presented. The multi-tip excitation method is potentially more appropriate for a multislice acquisition but is more sensitive to regions of low B1 compared to the multi-tip preparation approach. A validation of the B1 maps was obtained by performing a successful demonstration of a parallel excitation design.