

Fast B1+ mapping with a function fit using a reduced number of support points

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Introduction: Parallel transmission techniques in MRI have sparked new interest in measuring the B1+ field, the component of the radiofrequency field concerned with spin excitation. A precise measurement over a large range of B1+ values can be performed by fitting a function to data acquired with different flip angles [1]. However a large number of support points are necessary, making this measurement time-consuming. If the function used for the fit matches the measured data closely the number of support points can be reduced as proposed in this study. The shortened acquisition time allows the application of B1+ mapping with a function fit for routine B1+ measurements.

Methods: The B1+ mapping method proposed by Brunner et al. [2] is based on saturation pulses with varying flip angle and imaging of remaining longitudinal magnetization with a gradient echo sequence. In this approach equally spaced flip angles are used for the saturation pulse, starting with 0°, and making sure that complete saturation is accomplished at least once. The B1+ reconstruction technique involves fitting of a simulation to the measured data, incorporating T1 and off-resonance. While B1+ and T1 are determined in the fit, off-resonance is measured in a separate scan.

If the simulation fits very closely to the measured data (see fig. 1) the number of different flip angles used for saturation

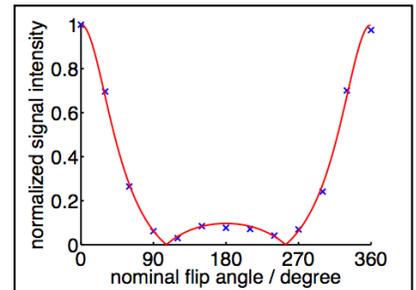


Fig. 1: Intensity of the gradient echo signal depending on the flip angle of the saturation pulse. The illustration shows measured data with saturation flip angles 0°, 30°, 60°, ..., 360° and the fitted simulation.

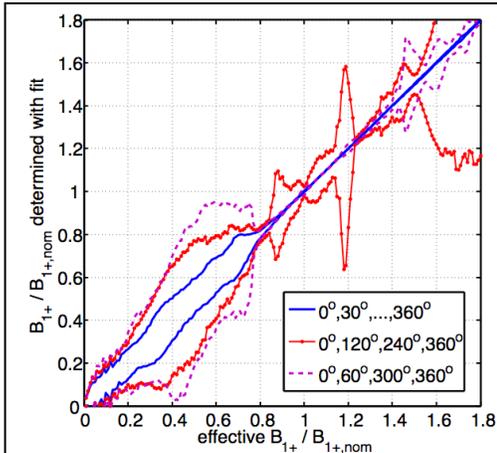


Fig. 2: Simulations of B1+ values determined with a function fit for different sets of saturation pulses. The calculated data is influenced by noise. The 3σ neighborhood is visualized which includes 99.7% of the cases.

can be reduced. A better selection can be made than applying equally spaced saturation flip angles. Deviations in B1+ change the oscillation frequency of the cosine-like progression of signal intensity over saturation flip angles. The oscillation frequency of this curve is best defined by support points where this curve has a large slope. Therefore saturation flip angles where the signal intensity is significantly influenced by changes in B1+ are used: 0°, 60°, 300°, and 360°.

The dynamic range of the new set of saturation flip angles is examined in simulations. For the simulations the data is calculated for different effective B1+ values. It is then influenced by additive normally distributed noise with $\sigma = 0.01$. The B1+ values are determined with the function fit to this noisy data. The proposed method is also applied in experiments, which are realized on a 9.4 T Bruker BioSpec system (Bruker BioSpin MRI GmbH, Ettlingen, Germany) using a linear birdcage resonator.

Results: For the simulations of fitting different sets of saturation flip angles the same parameters as in the experiment in fig. 3 are used. The simulations show that using equally spaced saturation flip angles 0°, 120°, 240°, 360° results in inaccurate measurements in the whole examined range of B1+ values (see fig. 2). The improved set of 0°, 60°, 300°, 360° leads to correct measurements in a dynamic range between $0.79 < B_{1+} / B_{1+,nom} < 1.43$ roughly.

In experiments different sets of saturation flip angles were applied (see fig. 3). The application of 13 saturation flip angles in 30° steps resulted in an exact B1+ map. Using only four equally spaced saturation flip angles between 0° and 360° resulted in a B1+ measurement with errors. The saturation flip angles 0°, 60°, 300°, 360° gave a B1+ field map with only small errors compared to the precise measurement. This is in agreement with the simulations in fig. 2. The reduction of the number of saturation flip angles was also successfully applied in-vivo (see fig. 4).

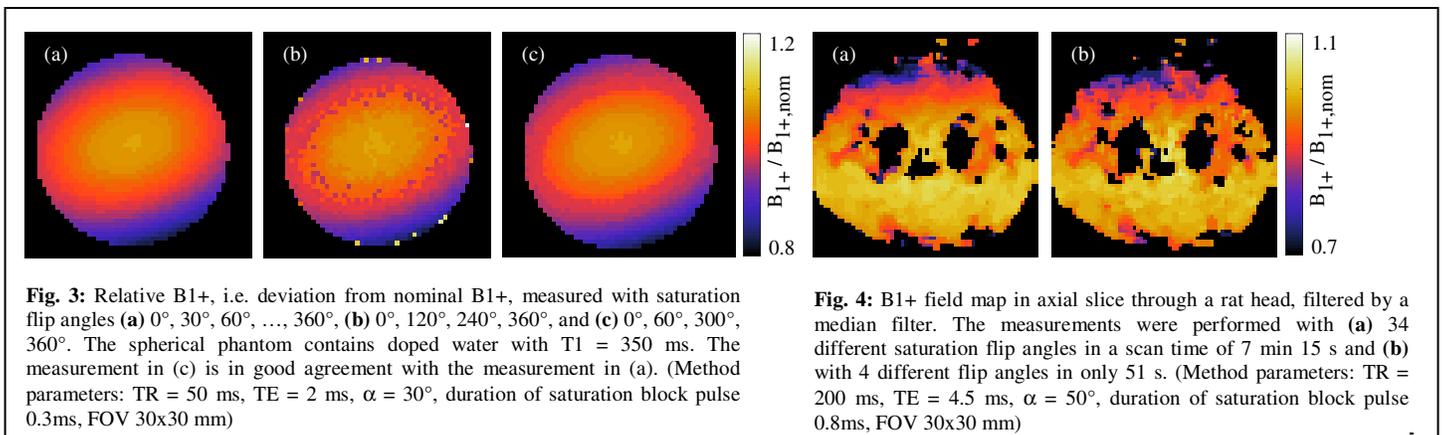


Fig. 3: Relative B1+, i.e. deviation from nominal B1+, measured with saturation flip angles (a) 0°, 30°, 60°, ..., 360°, (b) 0°, 120°, 240°, 360°, and (c) 0°, 60°, 300°, 360°. The spherical phantom contains doped water with T1 = 350 ms. The measurement in (c) is in good agreement with the measurement in (a). (Method parameters: TR = 50 ms, TE = 2 ms, $\alpha = 30^\circ$, duration of saturation block pulse 0.3ms, FOV 30x30 mm)

Fig. 4: B1+ field map in axial slice through a rat head, filtered by a median filter. The measurements were performed with (a) 34 different saturation flip angles in a scan time of 7 min 15 s and (b) with 4 different flip angles in only 51 s. (Method parameters: TR = 200 ms, TE = 4.5 ms, $\alpha = 50^\circ$, duration of saturation block pulse 0.8ms, FOV 30x30 mm)

Discussion and Conclusions: Due to the generally large agreement between the simulation and the measured data for the B1+ mapping method proposed in [2] a good precision in measuring B1+ is still obtained with a smaller number of support points for the function fit. In general it is better to apply saturation pulses where the signal intensity is very sensitive to changes in B1+, i.e. where the progression of signal intensity over saturation flip angles has a large slope. The resulting smaller dynamic range for precise measurements was examined in simulations. If the B1+ inhomogeneity ranges between $\pm 21\%$ from nominal flip angle the saturation flip angles 0°, 60°, 300°, 360° lead to precise measurements. Compared to using a large number of equally spaced flip angles the scan time is reduced significantly, while a similar precision is obtained. The proposed method was successfully applied in a spherical phantom and in the head of a rat. In vivo a 64x64 B1+ map was measured in only 51 s. The reduced scan time obtained with the proposed technique allows using this B1+ mapping method for fast calibration scans necessary for example in Transmit SENSE.

References: [1] J.T. Vaughan et al. MRM 46:24 (2001) [2] D. Brunner et al. Proc. ISMRM 15:353 (2007)

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