Fast mapping of highly inhomogeneous RF fields

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Introduction

Emerging new technologies in human MRI, such as ultra-high-field systems and multiple-channel transmit techniques, such as transmit SENSE [1] or RF shimming [2], call for fast and accurate B_1 mapping. Most of the B_1 mapping techniques presented to date are not suited to the enormous RF field inhomogeneities that are produced by surface transmit coils or that appear in ultra-high-field MRI due to dielectric effects. In these situations, the flip angle can vary up to an order of magnitude across an imaging plane. The calculation of flip angles using double-angle methods ([3], [4]) is well-posed only if the lower effective flip angle is in the range of 30° to 60°. A more recent method [5], which calculates the flip angle from the signal null at 180°, can only be successfully applied in conjunction with a time-consuming 3D sequence, since the excitation pulse must not be slice selective. Furthermore, the method assumes that the range of flip angles used lies in the linear zone of the signal amplitude at about 180°. However, for highly inhomogeneous RF fields, this linear range of nominal flip angles cannot simultaneously be found for all voxels.

In view of these issues, the present work describes an alternative method designed to be both fast and capable of handling highly inhomogeneous RF fields. Besides accurate B_1 maps it yields coarse T_1 maps as by-product, which may be useful for sequence planning purposes.

Method

The sequence consists of a 2 ms block saturation prepulse of varying flip angle α followed by a strong spoiler gradient (sp_p), as shown in Fig. 1. A standard gradient-recalled echo sequence using a small nominal excitation flip angle (ex) and a moderate resolution of 64x64 pixels is then used to image the saturation pattern produced by the prepulse. The number of dummy shots performed in advance of each image was calculated using a block pulse approximation and initial guesses for the T_1 range within the imaging plane. During post-processing, a model using relative B_1 (defined as the ratio between effective and nominal flip angle) and T_1 as parameters is used. This model is fitted to every pixel on the signal strength curve, which depends on α (see Fig. 1-2). The model assumes that the measurement was performed in a steady state and that ideal spoiling was achieved. It accounts for the off-resonance and B_1-dependent saturation of the prepulse, for the B_1-dependent loss of longitudinal magnetization induced by the excitation pulse as well as for the two time periods Δ and Tr-Δ when the longitudinal magnetization is relaxing (see Fig.1-1), Tr denoting the repetition time. In the measurements presented, Δ was kept at 5 ms. The range of nominal prepulse flip angles is chosen such that every point in the slice undergoes a complete saturation at least once. This can be checked on the scanner by verifying the corresponding signal null. This signal null, which approximately corresponds to 90° nutation, is also used as an anchor for initializing the fitting procedure.

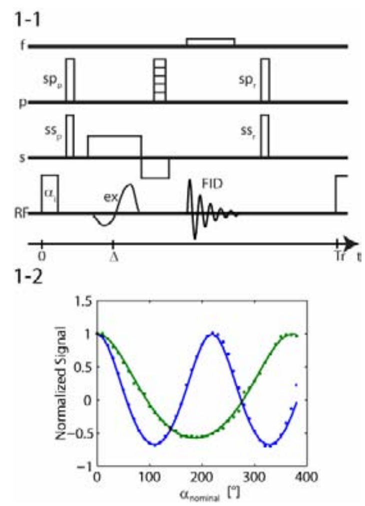

Figure 1: Top: sequence diagram, bottom: measured signal in two distinct voxels (points) with different B_1, T_1 and B_0 and the model fits (solid lines)

Results

The B_1 field and the T_1 distribution were measured using a Philips Achieva 7T system (Philips Medical Systems, Cleveland, OH) and a T/R volume head coil. A 150 mm sphere filled with doped water (T_1 ~ 220 ms) (A) and a cylindrical container with several compartments of varying T_1 (150 - 800 ms) (B) served as phantoms. Both phantoms have a high dielectric constant, creating a highly inhomogeneous B_1 field (see Fig. 2-1 and 2-2). For validating the mapping method the signal null of a non slice-selective 3D FFE sequence was predicted from a measured B_1 map (Fig. 2-3). To verify robustness, the sequence was repeated with several different Tr and a number of nominal flip angles (N) of the saturation pulse (see Fig.2-4 showing results from Phantom B).

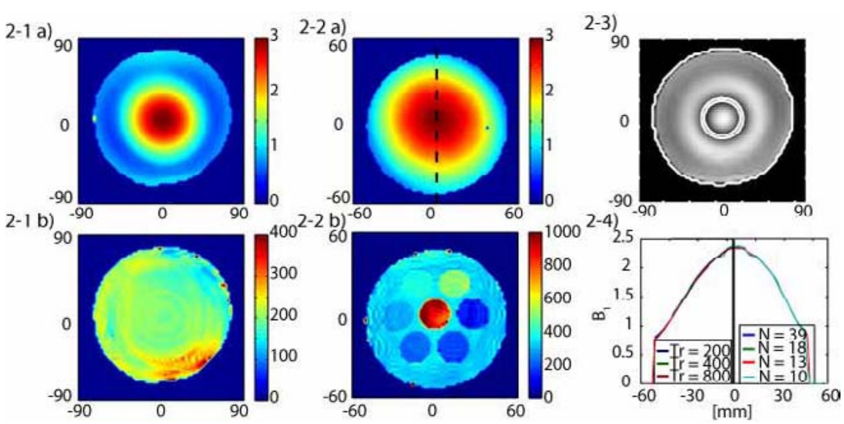

Figure 2: Results and validation of the method: 1 a) and 1 b) show the measured relative B_1 and T_1 [ms] values in phantom A measured with a Tr of 200 ms. 2 a) and b) show the analogous results for phantom B. The wiggling of the T_1 values coincides with the ringing artifacts seen in the images. 3) the grayscale plot shows the result of a validation 3D FFE sequence in phantom A using a nominal flip angle of 90°, the white rings show where the signal minimum is expected (1% threshold) according to the measured B1 map. The excellent agreement reflects the accuracy of the B_1 map. 4) shows a slice profile along the dashed line in 2 a). The left half of the plot consists of the B_1 measured using different Tr in the sequence. The right half shows the dependence of the results on the number of different flip angles taken (N). The slight wiggling of the curves coincides with the signal voids of the PMMA tubes of the containers. This demonstrates the low noise level and the high robustness of the mapping technique.

Conclusions

The proposed method has been shown to yield accurate B_1 maps of the highly inhomogeneous RF fields occurring at 7 T. It does so robustly and within 3 min for a single slice. The T_1 maps produced as a side product of the fitting process showed good agreement with single voxel inversion recovery experiments, but the stability of the fitting was less robust than for the B_1 values.

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