

# 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  $30^\circ$  to  $60^\circ$ . A more recent method [5], which calculates the flip angle from the signal null at  $180^\circ$ , 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  $180^\circ$ . 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  $\alpha$  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 ( $\alpha$ ) and a moderate resolution of  $64 \times 64$  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  $\alpha$  (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  $\Delta$  and  $Tr - \Delta$  when the longitudinal magnetization is relaxing (see Fig. 1-1),  $Tr$  denoting the repetition time. In the measurements presented,  $\Delta$  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  $90^\circ$  nutation, is also used as an anchor for initializing the fitting procedure.

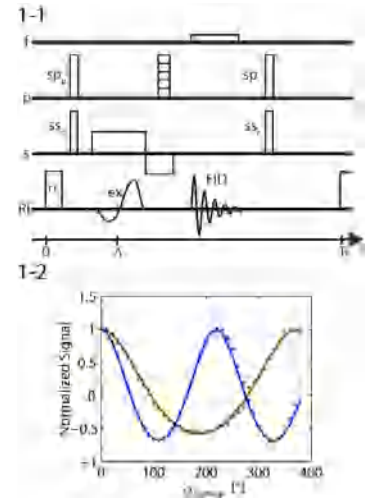


Figure 1: Top: sequence diagram, bottom: measured signal in two distinct voxels (points) with different  $B_1$ ,  $T_1$  and  $B_0$  and the model fits (solid lines)

## 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 ( $T_1 \sim 220$  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).

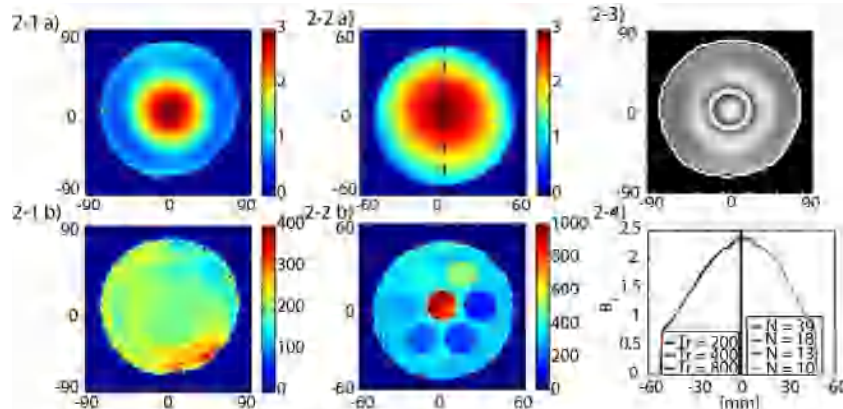


Figure 2: Results and validation of the method: 1 a) and 1 b) show the measured relative  $B_1$  and  $T_1$  [ms] values in phantom A measured with a  $Tr$  of 200 ms. 2 a) and 2 b) show the analogous results for phantom B. The wiggling of the  $T_1$  values coincides with the ringing artifacts seen 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  $90^\circ$ , the white rings show where the signal minimum is expected (1% threshold) according to the measured  $B_1$  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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- [5] N. G. Dowell et al. Proc. ISMRM 14 (2006)