# Extended Multi-Flip-Angle approach: a 3D B1unit+ mapping method for inhomogeneous fields

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## Introduction

For successful RF coil development and improvement, coil characterization plays an essential role. A quantitative map of the magnetic field produced per unit current (B1unit+) provides information about the coil efficiency as well as its sensitivity distribution [1]. This allows one to predict SNR, homogeneity and sensitive volume. A mapping method with high accuracy over a large dynamic range is required, particularly for surface and array coils with inhomogeneous B1unit+ fields. Most techniques, such as the double-angle method (DA) [2], are based on only a few data points and rely on fixed assumptions about the corresponding signal. This leads to inaccurate results for small flip angles (FA), due to low SNR, as well as for signals which differ from the assumed FA dependency. The latter is the case for an effective B1+ field not orthogonal to the static magnetic field (B0), due to off-resonance effects, for example. The multi-flip-angle approach (MFA) [3] can overcome the SNR problem, but still relies on a fixed signal dependency, such as a sin(FA) course for a gradient echo (GE) image series.

In this study we present an extension of the MFA method (ExMFA) with higher flexibility. As it is not based on a fixed assumption regarding the orientation of the effective B1+ field axis, it can handle complex signal courses as well as data with low SNR. To demonstrate its superiority over the commonly used DA method, especially in the case of inhomogeneous B1+ fields, a comparison between the two is given.

## Methods

To map the B1unit+ field of a surface coil, a series of 80 3D GE images of a doped $H_20$ phantom (T1/T2=250/200 ms) was acquired on a 9.4T BioSpec 94/20 system (Bruker BioSpin, Ettlingen, Germany) (matrix: 32x32x16; FOV: 8x8x6 cm, TE=5 ms, TR=1500 ms; rectangular RF pulse, $\tau$=0.3 ms). For each image, the RF pulse amplitude was increased by a fixed increment. Power values were chosen such that a full period of signal oscillation (corresponding to a FA up to 360°) in the area of highest B1unit+ field was acquired. For analysis, the varying magnitude signal per voxel (*S*) was plotted over the coil current (*I*). The latter has been calculated from the pulse power measured in advance. B1unit+ is derived from the signal oscillation frequency by fitting the signal course with the following equation using Matlab:

$$S(I) \propto \sqrt{(S_x)^2 + (S_y)^2} \text{ with } S_x = \sin\Theta \cdot \sin(\gamma \cdot \tau \cdot B_{1unit}{}^{+} \cdot I) \text{ and } S_y = \cos\Theta \cdot \sin\Theta \cdot (1 - \cos(\gamma \cdot \tau \cdot B_{1unit}{}^{+} \cdot I))$$

Here, $\Theta$ describes the angle between B0 orientation and effective B1unit+ field axis.

## Results

As an example, Fig. 1 displays signal courses and fitting results for voxels at different positions inside the excited volume with varying SNR and signal course slope. Also for very low SNR and stronger deviations from the standard |sin| shape, the data are described by the fitting algorithm with a high accuracy. Black circles mark the data points used for DA evaluation. Fig. 2 a) shows a slice of the resulting ExMFA B1unit+ map. In this plane, the signal courses for all voxels are |sin| shaped, like the ones shown in Fig. 1 a) and b). Besides oscillation frequency, only their SNR varies. The field change corresponds to a FA variation of 63°. With decreasing B1unit+ field the DA results (Fig. 2 b) deviate up to 20% from the ExMFA results. For an orthogonal plane, with signal courses additionally affected by a declined effective B1+ axes, like the one shown in Fig. 1 c), the ExMFA method delivers the typical profile of a surface coil (Fig. 2 c). The corresponding DA profile (Fig. 2 d) is more similar to the intensity profile of a single image (Fig. 2 e). Deviations between the two are up to 50% (Fig. 2 f). ExMFA leads to incorrect results for only a small number of voxels. Further analysis showed that the number of data points can be reduced to 20 to achieve fitting results with similar quality, resulting in measurement times of only a few hours for typical resolutions.

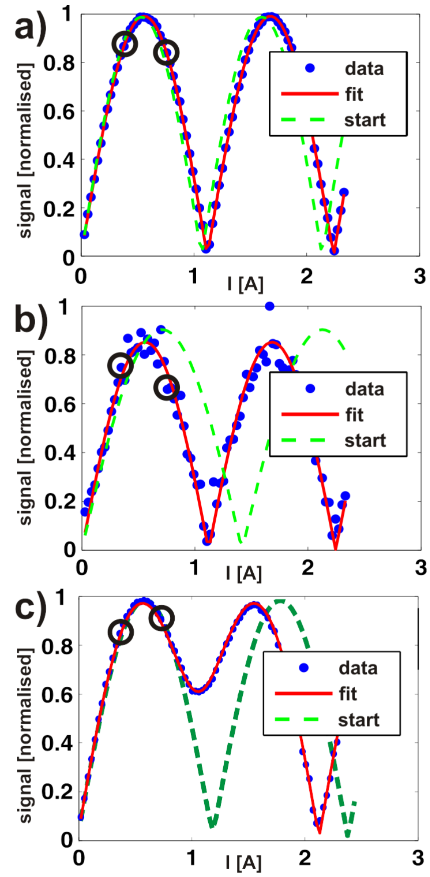


**Fig.1:** Signal courses for voxels for effective B1+ orthogonal to B0 with (a) SNR 150 and (b) SNR 10. Deviating signal course for a declined effective B1+ axis and SNR 150 (c).

## Discussion

Direct comparison of the DA and ExMFA methods shows an increasing difference in resulting B1unit+ strength for decreasing SNR and as the effective B1+ field axis becomes less orthogonal to the B0 field. However, high agreement of fitted and recorded data validates the results of the ExMFA method also for low B1unit+ values and complex signal courses. The recorded data also allows for manual analysis in case of incorrect fitting. For the DA method, neither control nor correction is possible. As demonstrated, the ExMFA method allows mapping of homogenous as well as inhomogeneous B1unit+ fields in three dimensions. As it is designed for coil characterisation, a measurement time of typically several hours is acceptable. In addition, ExMFA can serve as a reference for validating B1 mapping techniques, which allow no internal control as shown for the DA method.

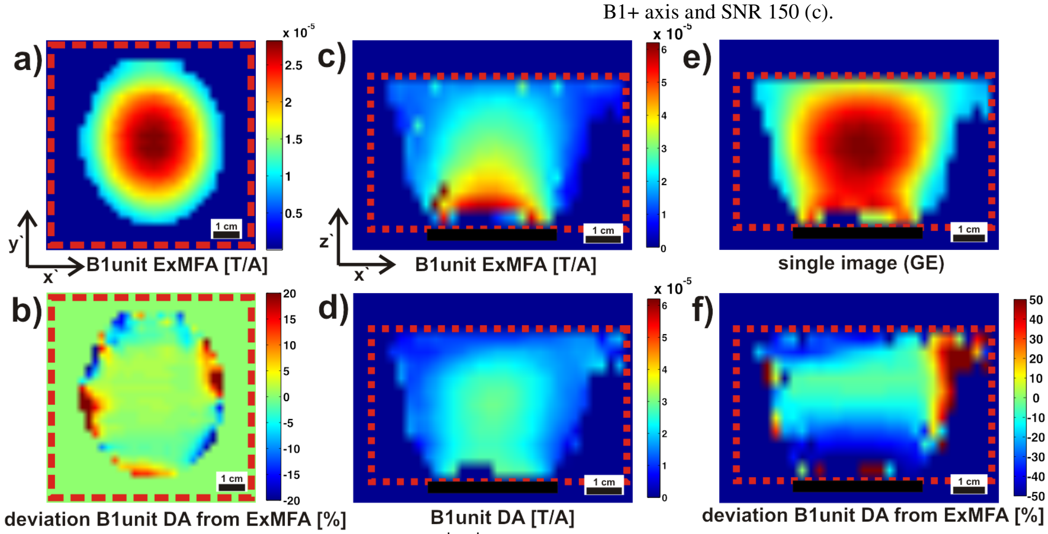


**Fig.2:** B1unit+ ExMFA in a plane with exclusively |sin| shaped signal courses (a) and deviation of the DA result (b). Bunit+ ExMFA (c) and DA (d) for an orthogonal plane corresponding to deviating signal courses. Single image of the series (e) and deviation of B1unit+ DA from ExMFA (f). The shape of the phantom is marked by the dashed red box.

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**References** [1] Hoult et all., JMR 1976, 24:71-85; [2] Hornak et. al, MRM 1988, 6 158-163; [3] Insko et. al., JMR(A) 1993, 103:82-85