Flip Angle Taxonomy: Measuring Transmit (B1) profile distribution without imaging.

R. Fleysher[1], L. Fleysher[1], J. A. Tang[2], and D. Sodickson[1]

[1]Radiology, New York University, School of Medicine, New York, New York, United States, [2]Chemistry, New York University, New York, New York, United States

INTRODUCTION. Despite careful transmit coil manufacturing and NMR scanner tuning the radiofrequency transmit field (B_1) remains non-uniform over the sample volume in part due to coil geometry and sample size. Such issues are especially pronounced in close-fitting coils, such as micro coils (1). This non-uniformity precludes certain analyses and interpretations of the data especially those where signal cancellations at specific flip angles are expected such as in parahydrogen induced polarization experiments (2). To overcome this difficulty in imaging experiments a flip angle mapping is often employed (see for example 3-5). The data in each pixel is then processed separately taking into account the actual flip angle experienced by the spins at that location. However, in spectroscopic and certain other quantitative applications the spatial localization is not available, nor is it required. It would be sufficient to know the distribution of actual flip angles within the sample volume. The procedure proposed in this work that leads to classification of spins according to the flip angle they experience is dubbed Flip Angle Taxonomy (FAT). It is based on sinusoidal dependence of the signal detected after excitation of spins at thermal equilibrium. The procedure can be used to alleviate systematic errors in data analysis or employed for a quick evaluation of transmit (micro-) coil performance.

THEORY. The amplitude of the signal detected after application of the excitation pulse with nominal flip angle α is given by the volume integral (Eq.[1]) where $B_1(x)$ is the ratio of the actual to nominal flip angle at location x and $m(x)$ is 3-dimensional spin density. Rearranging the order of integration in such a way that all spins experiencing the same actual flip angle are summed over first, we arrive at Eq.[2]. Here $\rho(B_1)$ is the number of visible spins (number of spins weighted by the receive coil profile) whose excitation deviates from nominal by a factor of B_1. In other words, $\rho(B_1)$ is the histogram of B_1's in the sample. According to Fourier theorem, $\rho(B_1)$ can be obtained from the experimental data $S(\alpha)$ by performing sine transform (Eq.[3]). The number of terms in the sum provides the number of independent bins in the histogram $\rho(B1)$.

$$S(\alpha) = \int_V m(x) \sin\left(B_1(x)\alpha\right) d^3x \qquad [1]$$

$$S(\alpha) = \int_0^{B_1^{\max}} \rho(B_1) \sin(B_1\alpha)\, dB_1 \qquad [2]$$

$$\rho(B_1) = \frac{2}{B_1^{\max}} \sum_n S(\alpha_n) \sin(B_1\alpha_n), \qquad \alpha_n = \frac{\pi n}{B_1^{\max}} \qquad [3]$$

METHODS. Experiments were performed using a 11.7T Bruker scanner, with 5mm NMR tube filled with 0.5cc of water doped with $CuSO_4$ (to reduce T_1) and with 2cc hydrogen gas. The transmit power was calibrated using standard procedure of finding the one delivering maximum signal and assigning this excitation to 90°. In the water experiment the flip angles were incremented uniformly every 90°, in the hydrogen gas – every 120° until excitation of nominal 9000° was reached. Flip angle was varied by changing pulse width, maximum duration 1.2ms.

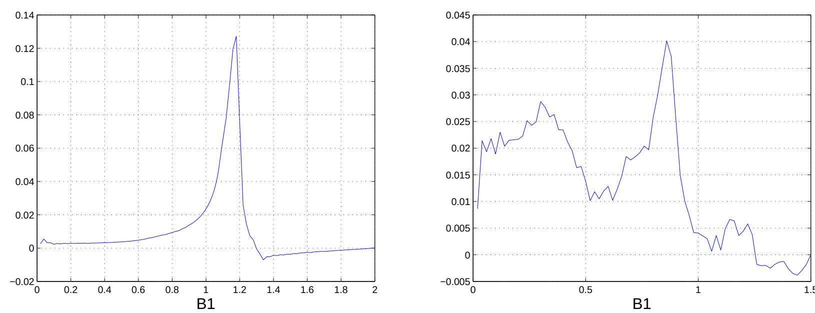

Fig. 1 *Normalized distribution of B_1 obtained in 0.5cc of water (left) and 2cc of hydrogen gas (right). Excitation over the small volume of water is rather uniform, however not so over the entire tube.*

RESULTS. Presented in Fig.1 are the obtained B_1 distributions. Excitation over the small volume of water is rather uniform and shows the scanner to be 18% out of tune. The hydrogen experiment shows that the coil is not uniform over the entire volume of the tube and that despite three orders of magnitude smaller spin density, the distribution is well reproduced.

CONCLUSION. The proposed FAT method does not rely on spatial encoding and thus may be used in spectroscopic and other quantitative applications where imaging is not available. The proposed scheme requires $B_1^{max}/\Delta B_1$ excitations to reach ΔB_1 resolution in B_1 which is often much less than would be needed in traditional mapping approaches. The procedure can be used to alleviate systematic errors in data analysis caused by transmit field non-uniformity or can be employed for a quick evaluation of transmit (micro-) coil performance. To the extend of the validity of the receive-transmit profile reciprocity, the histogram can also be used to correct the receive side and obtain true number of spins experiencing certain B_1: $d(B_1) = \rho(B_1)/B_1$. Distributions of the true number of spins will be much wider than those presented in Fig. 1.

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