Optimized transmit pulses for excellent whole-brain excitation homogeneity in high field MRI

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Introduction

Homogeneous whole-brain excitation is increasingly required in high field fMRI applications [1–3]. To achieve homogeneous whole-brain coverage, we propose an optimized 3D tailored RF (TRF) pulse for the compensation of the severe RF field (B_1) inhomogeneity, based on the recently-developed parallel transmission technique [4–7]. The RF pulse is designed with an optimized stack-spiral trajectory tailored to fit into the 'high-weight' k-space area that is mostly responsible for the desired excitation pattern. The feature of this pulsing approach is that it produces optimized pulses that provide homogeneous excitation over the entire brain volume with an optimized pulse duration and lowered RF energy.

Methodology

To obtain the high-frequency B_1 field profile, an in-house developed FDTD program [8] was used to simulate a transmit array of eight equidistant active rungs with dimensions, diameter = 36.2 cm, length = 30 cm. The array was loaded with the head part of the virtual human data obtained from the U.S. Air Force Research Laboratory. The operating frequency is 470 MHz, corresponding to an 11.7-T main field strength. The overall B_1 map is shown in Figure 1. The desired excitation pattern was a single slab covering the whole brain volume, and was blurred by convolution with a Gaussian kernel of *FWHM* = 2.0 cm to reduce the ringing in the resulting excitation pattern. Bloch simulations without relaxation were implemented to produce the excitation results using the following designed pulse.

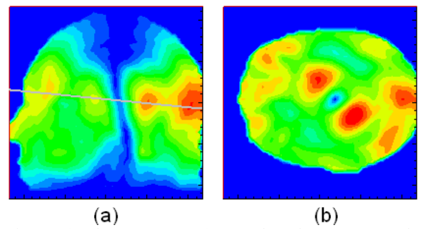

Fig 1 (a) The cut-away (a, on the plane y=0) and transverse (b, on the oblique plane shown as the gray line in a) views of the overall sensitivity map of an 8-channel array.

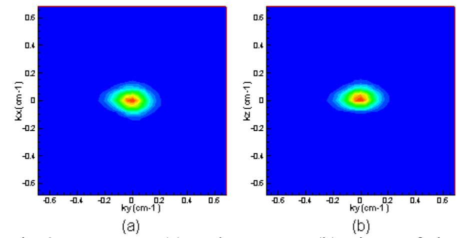

Fig 2 Transverse (a) and cut-away (b) views of the PSF-deconvoluted high weight area for the whole-brain excitation.

K-space trajectory determination. Based on the existing Fourier relationship between the RF energy deposition in the k-space and the resulting transverse magnetization, an optimization problem has been formed and solved for finding an RF weight function that indicates the RF weight or the contribution of each k-space grid for achieving the desired excitation. The PSF effect of the parallel transmission is simply estimated by the absolute summation of the inverse Fourier transforms of the sensitivity maps. Taking the de-convolution of the weight function with the estimated PSF leads to a "tailored" weight function that distinguishes the candidate sub-sampling area or the "trajectory container", see Figure 2. The container's boundaries are then determined using an edge detection technique. Assuming that the detected boundaries form multiple closed regions, that with the highest summation of the weights is chosen as the "trajectory container".

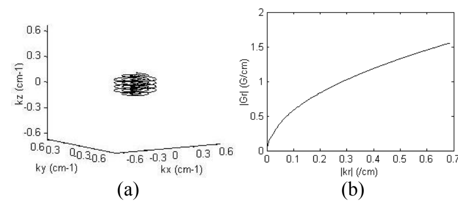

Fig 3 (a) The tailored stack-spiral trajectory (b) Gradient amplitude distribution of the stack-spiral trajectory along the k_r dimension.

After determining the "trajectory container", we use a stack-spiral trajectory and tailored its range to fit, as shown in Figure 3a. As seen from Figure 2, the weight function reaches its peak amplitude close to the DC point k=0, and fades as it deviates from the DC point along each dimension. Meanwhile, as seen in Figure 3b, the gradient amplitude of the stack-spiral trajectory grounds at the DC point and climbs as it deviates from the DC point along the k_r dimension, varying inversely with the weight function. Therefore, according to the formula $B_1(t)=W(k(t))\cdot\gamma G(t)$, the RF energy needed in the excitation would be maximally lowered when using the stack-spiral trajectory. Here, the optimized, slew-limited spiral trajectory was used to optimize the sampling efficiency. To efficiently cover the interior space of the "trajectory container", an acceleration factor of 2 was chosen according to the dimension of the main-lobe of the estimated PSF effect, and hence, $\Delta k_{xy}=2/FOV$ as the value of the transverse sampling interval.

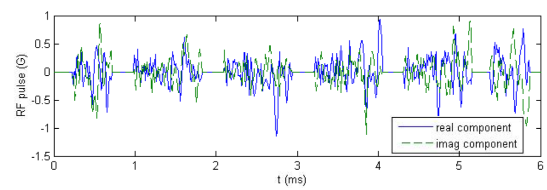

Fig 4 RF pulse to transmit by one of the channels.

RF design. The parallel RF pulses are designed based on the small-tip-angle (STA) approach [6] with the above-determined trajectory. To approach the desired excitation pattern, the resulting pulse is used as an initial guess and an iterative design method is then adopted into an optimization process [9]. To calculate the actual excitation at each iteration step, the Bloch equation is solved in the spinor domain.

Results and discussion

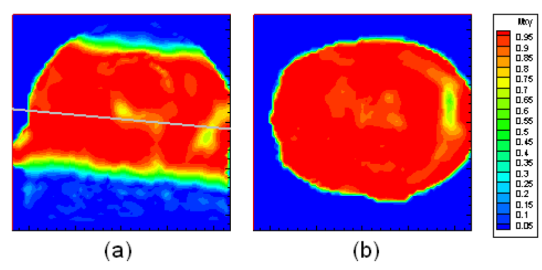

Fig 5 Cut-away (a, on the plane y=0) and transverse (b, on the oblique plane shown as a gray line in a) views of the simulation result of excited magnetization.

Figure 3a shows the k-space trajectory designed using the above-described method; Figure 4 shows the computed RF pulses of one of the channels, and Figure 5 shows the consequent excitation pattern. The RF pulse was 5.97 ms in duration with the peak RF amplitude of 1.6 G; both are acceptable in the whole-brain excitation case. It can be seen that the RF pulse provides homogeneous excitation over the entire brain volume in spite of the inhomogeneous field and insufficient longitudinal coverage, which even hinders the efficiency of the RF shimming technique. The proposed method offers the feasibility of a general multi-dimensional pulse design in parallel excitation where various types of k-space trajectory may be introduced to achieve an optimized excitation. In this case, the stack-spiral trajectory was chosen, because of its high sampling efficiency and the intrinsic distribution of the gradient amplitude in traversing the k-space that meets the optimization requirement of the desired excitation.

Reference

[1] Olman et al., *ISMRM* 2009, #21.
[2] Deichmann, *MRM* 53:1212-1216 (2005).
[3] Talagala, *MRM* 52:131-140 (2004).
[4] Katscher et al., *MRM* 49:144-150 (2003).
[5] Y. Zhu, *MRM* 51:775-784 (2004).
[6] Grissom et al., *MRM* 53:620-629 (2006).
[7] Setsompop et al., *MRM* 56:1163-1171 (2006).
[8] Liu and Crozier, *Phys Med Biol* 49:1835-51 (2004).
[9] Grissom et al., *MRM* 59:779-787 (2008).