Accounting for B1 void using optimized transmit pulses in ultra high field MRI

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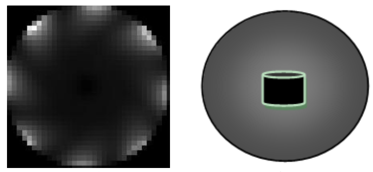
Introduction

Ultra high field MRI offers an unprecedented spatial resolution for anatomical imaging, but the high-frequency RF (B_1) field inhomogeneities may lead to severe signal void in result of shortened wavelength, strong field-tissue interactions and insufficient RF energy delivery/penetration. In this work, an optimized, 3D tailored RF (TRF) pulse has been proposed for compensating the B_1 inhomogeneity based on the parallel transmission technology [1-4]. The RF pulse is designed with optimized stack-spiral trajectory tailored to fit into the 'high-weight' k-space area that is most responsible for the desired excitation pattern. The feature of this pulsing approach is that it dramatically reduces the required RF amplitude in excitation, allowing for the realization of desired flipping of magnetization inside the sample, particularly for central regions. The parallel transmission and the k-space trajectory tailoring technique are adopted to accelerate the excitation, thus ensure the practical application of this method.

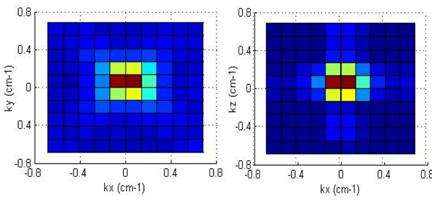
Methodology

To obtain the high-frequency B_1 field profile, an in-house developed FDTD program [5] was used to simulate a transmit array of 8 equidistant active rungs with dimensions: diameter = 36.2 cm, length = 30 cm. The array was loaded with a homogenous spherical phantom whose diameter is 23.4 cm. The dielectric property of the phantom is σ=1.0 *S/m* and ε_r =80. The operating frequency is 470MHz, corresponding to 11.7-T main field strength. The overall B_1 map is shown in Fig.1 (a), and the desired excitation pattern, shown in Fig 1b, is a thin cylinder with diameter of 7 cm and height of 4.2 cm, located in the center of the phantom where RF energy is usually very weak. Bloch simulations without relaxation were implemented to produce the excitation results using the following designed pulse.



(a) (b)

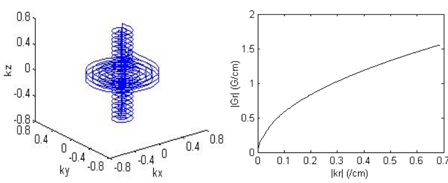
Fig 1 (a) The sensitivity maps of an 8-channel array (on plane *z=0,* inside the ROI). (b) The desired excitation pattern.



(a) (b)

Fig 2 Transverse (a) and cut-away (b) views of the high-weight (in terms of RF energy deposition) area for slab-selective excitation.

K-space trajectory determination Based on the existing Fourier relationship between the RF energy deposition in k-space and the resulting transverse magnetization [6], an optimization problem has been formed and solved for finding a set of k-space grids that highly associated with energy deposition. Based on this set of grids, a 3D boundary-closed area was determined as a k-space "trajectory container". In this case, the interior grids weight 79% of the total energy deposition in the excitation k-space, as shown in Fig 2. In this figure, the high-weight grids densely distributed around the DC point, transversely spread near the plane $k_z=0$, and faded into a fixed width region as deviating from the DC point along k_z axis. To further reduce the size of the "trajectory container", we tailored off the grids in the extension of PSF that is simply estimated by absolute summation of the inverse Fourier transforms of the sensitivity maps.



(a) (b)

Fig 3 (a) Adaptive stack-spiral trajectory (b) Gradient amplitude distribution of stack-spiral trajectory in k_r dimension.

In forming the Fourier relationship, we have $B_1(t) = W(k(t))\cdot\gamma G(t)$, showing that the amplitude of required RF pulse at each k-space grid is implicitly proportional to the weight function and the amplitude of applied gradient in traversing that grid. In most cases, the weight function reaches its peak amplitude around the DC point *k*=0, and fade as it deviates from the DC point along each dimension. Considering its intrinsic distribution of gradient amplitude in traversing the k-space (Fig 3b), we used a stack-spiral trajectory and tailored its range to fit into the "trajectory container", as shown in Fig 3a. In this way, much less RF energy may be needed to excite the anticipated flip angle due to the counteraction of the factors. Here a constant angular rate spiral trajectory was used to optimize the sampling efficiency. To efficiently cover the interior space of the "trajectory container", we chose $\Delta k_{xy}=1/FOV$ as the value of transverse sampling interval.

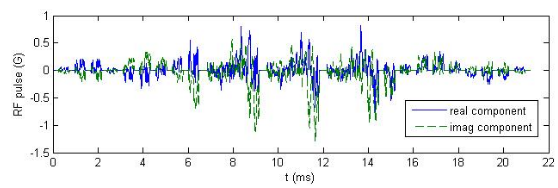
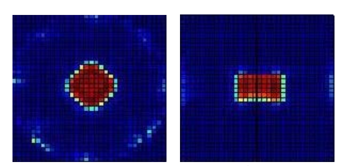


Fig 4 RF pulse to transmit by one of the channels.

RF design The parallel RF pulses are designed based on the small-tip-angle (STA) approach [3] with afore 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 the optimization process [7]. To calculate the actual excitation at each iteration step, the Bloch equation is solved in the spinor domain [8].

Results and discussion

Fig 3a shows the k-space trajectory designed using the above described method, Fig 4 shows the computed RF pulses and Fig 5 shows the consequent excitation pattern. The RF pulse was 21.17 ms in duration. It can also be seen from Fig 5 that even in the area with weakest RF energy, using the optimized TRF pulse it was also achievable to match the desired pattern. By adding appropriate constraints for the reduction of gradient amplitude in traversing near the point *k=0*, other types of k-space trajectory may also be introduced to realize that excitation over any area with weak RF energy coverage. However, stack-spiral trajectory may be the best choice in view of its high efficiency in sampling of the k-space while meeting the constraints. The adopted parallel transmission technique combined with the trajectory tailoring scheme helps to accelerate the excitation, and ensure the practical application of this method. The simulation demonstrated that the designed pulses can effectively upgrade the excitation over the area that is conventionally difficult to cover at ultra high field.



(a) (b)

Fig 5 Transverse (a, on the plane $k_z=0$) and cut-away (b, on the plane $k_y=0$) views of the simulation result of excited magnetization.

Reference

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