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 (B1) 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 B1 inhomogeneity based on the parallel transmission technology [1-4]. The RF pulse is designed with optimized stack-spiral trajectory to tailored 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 B1 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 ε = 80, σ = 1.0 S/m and, ν = 80. The operating frequency is 470MHz, corresponding to 11.7-T main field strength. The overall B1 field profile, an adaptive stack-spiral trajectory was used to optimize the sampling efficiency. 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_y 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.

In forming the Fourier relationship, we have B1(r,t) = W(k(t))·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. 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 Δk_y=1/FOV as the value of transverse sampling interval.

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 3 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 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.

Reference