Calculation of B1 pulses for RF shimming at arbitrary flip angle using multiple transmitters

J. L. Ulloa[1], M. Callaghan[2], M. Guarini[1], J. V. Hajnal[2], P. Irarrazaval[1]

[1]Department of Electrical Engineering, Pontificia Universidad Catolica de Chile, Santiago, Chile, [2]Robert Steiner MRI Unit, Imaging Scienes Department, MRC Clinical Sciences Centre, Hammersmith Hospital, Imperial College London, London, United Kingdom

Introduction

MRI at high field (≥ 1.5T) improves SNR, spatial resolution and real-time imaging. But, also at high field, B_1 inhomogeneity increases causing artefacts including spatially varying contrast and non-uniform intensity across the field-of-view (FOV) [1]. To address this issue there are compensation methods that use spatially varying RF pulses (RF shimming), designed in the small-tip-angle (STA) regime [2] which require long excitation times. The concept of parallel excitation [3, 4] makes spatially selective excitation feasible in practice, combining the excitation produced by each coil in an array of transmitters to reduce the excitation time or the RF peak power. However, for larger flip angles both the STA and the parallel excitation model fail. In this work we propose a model to correct B_1 inhomogeneity for large angle excitation, based on optimisation and numerical solution of the Bloch equation.

Theory and Methods

The inhomogeneity correction problem is equivalent to solving the optimisation problem:

$$\min_{\text{RF pulse}} \quad \|P_{des} - P_{act}\|_n \qquad (1)$$

where P_{des} is the uniform desired magnetisation profile, P_{act} is the actual magnetisation profile calculated from the B_1 field and $\|\cdot\|_n$ denotes the *n*-th norm. Assuming a set of *R* transmitters coils acting simultaneously, each one produces a sub-profile $P_r(\mathbf{x})$ which is weighted by its sensitivity $S_r(\mathbf{x})$, the actual profile is $P_{act} = \sum_r S_r(\mathbf{x})P_r(\mathbf{x})$ and there is a reduction in the excitation time of ~*R* times. The STA makes the B_1 field the Fourier transform of the magnetisation profile, so (1) can be solved by finding the Fourier coefficients of $P_r(\mathbf{x})$ [6]. However, for larger angles, the Fourier relationship is not valid and it has to be replaced by the Bloch equation itself, which is efficiently solved in the spinor domain [7]. In this case, each coils applies an RF pulse $B_1^r(t)$, that is distorted by its spatial sensitivity, the effective (or total) RF field experienced by the object is

$$B_1^E(\mathbf{x},t) = \sum_r S_r(\mathbf{x})B_1^r(t) \qquad (2)$$

Which is used in (2) as the input to the Bloch equation to generate P_{act}, required for solving (1). As suggested in [8], an adequate metric to measure the error is the norm n=1.

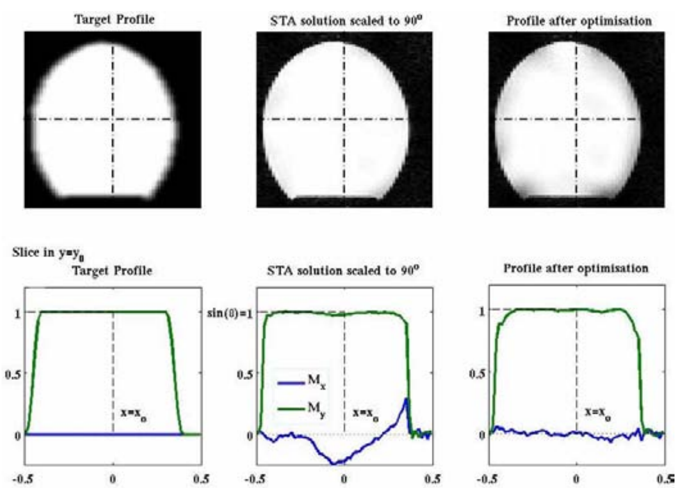

Figure 1: Simulation for a 90° 3D excitation. *Top row:* Transverse slices in *z*=0. *Bottom row:* Slice profiles along *x* in *z*=0 and *y*=y_0. Desired uniform magnetisation (Target profile). Predicted magnetisation by Bloch simulation from the parallel transmission model in the STA regime. Magnetisation from the Bloch optimisation. Note the phase profile improvement across the FOV.

Results

Simulations for 90° were performed considering two transmitters (1.66-fold reduction) and an EPI like trajectory in 3D [9]. The slice selection is achieved with a conventional sinc pulse in the longitudinal (k_z) direction. Therefore, only the pulse samples in the $k_x - k_y$ directions are calculated during the optimisation, 5x5 which become 5x3 per coil considering the parallel transmission acceleration factor. Variations across the FOV due to B_1 inhomogeneity are smooth; therefore, the profile is well defined with only the central part of *k*-space. This also requires that transmitters have a smooth sensitivity profile (i.e. with no abrupt changes within the FOV). In order to solve the Bloch equation with a spatially varying B_1 field transmitter, the desired tip angle is defined at a specific location, $\mathbf{x}_0$ (e.g. the centre of the FOV) and the RF pulse is then scaled respect to the integral at this point.

Figure 1 shows a comparison between the STA approximation (starting solution) and the profile achieved with the optimisation. It should be noted that after the optimisation the magnetisation in the centre of the FOV (where the desired tip angle was defined) has zero phase and is, in general, flatter than the STA solution, although there is a small amplitude decay at the edges. Bloch simulations did not include T_2 relaxation or off-resonance effects, so the predicted magnetisation profile amplitudes do not show their influence.

Conclusions

In this work we proposed a method to find the RF pulses required to correct B_1 inhomogeneities for applications requiring large tip angles beyond the STA approximation scope. The method is computationally efficient and the results show good performance with considerable less phase variation across the FOV. The approach naturally includes the case of undersampling in k_x - k_y as used in Transmit SENSE with multiple coils. In the future, it will be necessary to include relaxation and off-resonance effect in the Bloch equation to represent more accurately the excitation performance of longer pulses, as required for large angle excitation.

Acknowledgement. We thank Philips Medical Systems for grant funding support.

References: [1] C. Collins et al. *JMRI*, vol.21, pp. 192–196, 2005. [2]S. Saeko et al. *MRM*, vol.53(2), pp. 479–484, 2005. [3]U. Katscher et al. *MRM,* vol.49(1), pp. 144–150, 2003. [4]Y. Zhu, *MRM*, vol.51(4), pp. 775–784, 2004. [5]J. Pauly et al. *JMR* vol.81, pp. 43–56, 1989. [6]W. Grissom et al. in *Proc. ISMRM 13,* 2005, p. 19. [7]J. Pauly et al. *IEEE-TMI*, vol.10(1), pp. 53–65, 1991. [8]J. Ulloa, et al. *IEEE-TMI*, vol.23(11), pp. 1445-1452, 2004. [9]J. Ulloa et al. in *Proc. ISMRM. 13*, 2005, p. 21.