

High-order B_0 shimming with compensating RF pulses enables efficient and uniform flip angles

Vincent Oltman Boer¹, Irene M.L. van Kalleveen¹, Peter R Luitjen¹, Robin A. de Graaf², and Dennis W.J. Klomp¹

¹Radiology, UMC Utrecht, Utrecht, NL, Utrecht, Netherlands, ²Department of Diagnostic Radiology, Yale University School of Medicine, New Haven, CT, United States

Introduction

In high field MRI, the B_1 field strength and efficiency is limited when volume or body coils are used. Especially with multi-transmit coils, B_1 efficiency is traded off for homogeneity, resulting in elevated SAR values. Local transmit coils offer the advantage of a much higher efficiency, however the resulting flip angle distribution is very non-uniform (fig 2a), resulting in non-uniform contrast and signal loss. However, recent developments in dynamic shimming allow for the switching of higher order shim coils [1]. Here we propose to use an RF pulse with a defined frequency profile, in combination with a B_0 offset field to generate a uniform flip angle. A combination of a quadrature surface coil with the compensating RF pulse and 3rd order B_0 offsets provides a relatively uniform flip angle with a high B_1 strength and low SAR.

Methods

An RF pulse with a specific frequency profile was designed [2] where the resulting flip angle (fa) is a function of the offset frequency; $fa \sim 1/freq$ (fig 1). By offsetting the local frequency with the shim coils, the spatial flip angle distribution can be shaped. Actual flip angle imaging (AFI) [3] was obtained of the human brain while transmitting with a quadrature surface coil using a conventional RF pulse hence reflecting a B_1 map. The B_1 field distribution was fitted with 3rd order spherical harmonic shim fields, and applied during the compensating RF pulse (3ms) in the AFI sequence, hence reflecting the flip angle distribution with the compensating pulse. To illustrate the performance, flip angle sensitive spin echo images (TE/TR=60/3000ms, $1 \times 1 \times 4 \text{ mm}^3$) were made of the human brain with a quadrature surface coil using the compensated excitation pulse and calculated shims while using adiabatic refocusing pulses to provide slice selection.

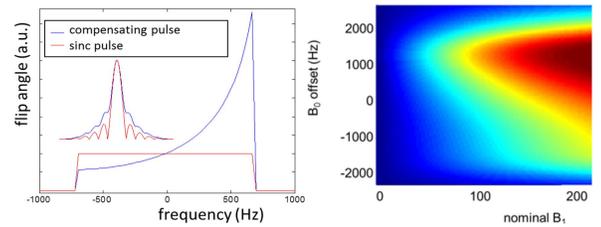


figure 1, the compensating RF pulse shows a $1/freq$ response (left). Therefore for high B_1 and high negative offset frequencies, a similar flip angle is reached as with low B_1 and high positive offset frequencies (right). The duration of the RF pulse determines the bandwidth, and therefore the required B_0 offset field for compensation.

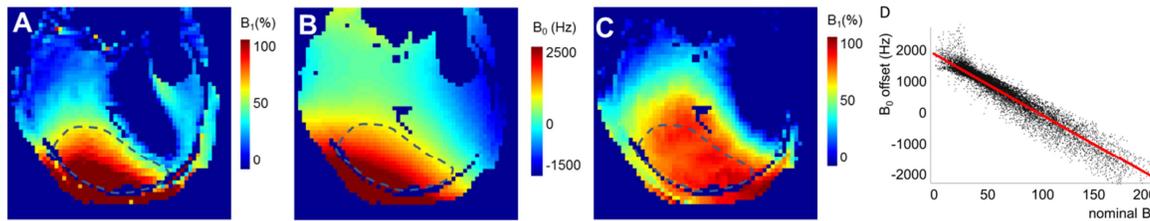


figure 2, measured flip angle map obtained with a quadrature surface coil close to the human brain (a), the fitted B_0 shimfields to the flip angle distribution for compensation (b), the homogeneous flip angle distribution after application of the offset shimfields and the compensating pulse (c). The local B_1 field and fitted B_0 offset field show an almost 1-1 correspondence, indicating a good fit with third order spherical harmonic fields.

Results

The B_1 map of the quadrature surface coil shows a very high, but very not-uniform flip angle distribution (fig 2a). The fitted B_0 field distribution in a ROI (fig 2b) shows an almost 1-1 correspondence (fig 2d) with the applied B_1 field. By applying the compensating pulse, the resulting flip angle is compensated in the ROI (fig 2c).

Using the compensated excitation in a spin echo imaging sequence (fig 3) resulted in a homogeneous excitation with the surface coil, although the actual B_1 varied for more than a factor 3 in the region of interest.

Discussion

By shaping the B_0 field to the B_1 distribution, a compensating RF pulse can be used to mitigate flip angle inhomogeneity, thereby enabling the use of highly efficient surface coils for homogeneous imaging. While multi-dimensional RF pulses using spherical gradient trajectories may be considered as an alternative, here only a static B_0 shim setting is required during the RF pulse, enabling faster, more efficient and uniform flip angles.

References: 1. Juchem *Conc Magn Reson B* 2010 2. Van Kalleveen *ISMRM* 2011 0641; 3. Yarnick *MRM* 2007

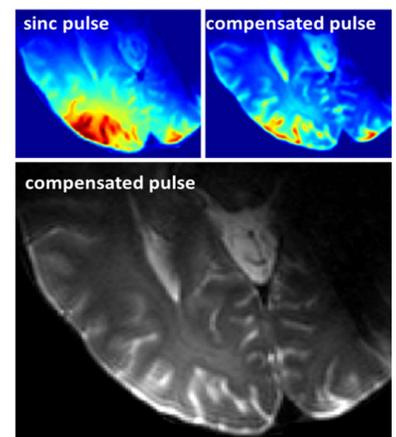


figure 3, A traditional sinc pulse leads to large signal variations due to the inhomogeneous B_1 field of the surface coil, a compensated excitation results in uniform image contrast in the human brain