Improving Flip Angle Uniformity with Parallel Excitation

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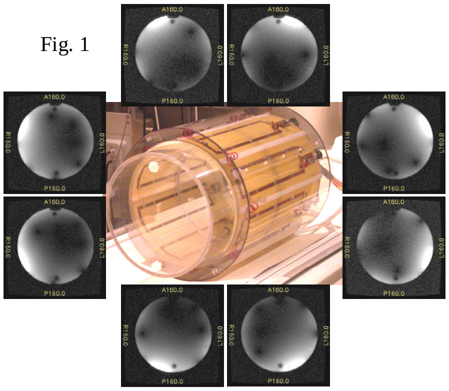
Introduction

The standard approach of RF transmit with a volume coil relies on B_1-field homogeneity to attain flip-angle fidelity and image uniformity. In high-field imaging however, increased wave behavior and source-subject interaction may significantly degrade B_1 homogeneity, causing undesirable flip-angle spatial variations and non-uniform image intensity/contrast. A number of methods have been proposed that adapt the transmit coil geometry and/or the driving mechanism in order to restore B_1 homogeneity. Such methods tend to be limited in effectiveness at high field strength. Even with calibration-guided adjustment of driving port weights (1), or RF shimming, results are often subject to substantial residual inhomogeneity. Use of a parallel transmit array and accelerated multi-dimensional pulses has been recently proposed as an alternative to the field optimization approach (2). With the support of a prototype parallel transmit MRI system, we investigated the feasibility of achieving uniform flip angle with parallel excitation, and conducted a preliminary comparison study of RF shimming and parallel excitation.

Fig. 1



Methods and Results

A cylindrical parallel transmit array, about the size of a standard birdcage head coil, was constructed. The transmit array consists of eight 18x6 cm^2 rectangular elements that are distributed azimuthally on a ∅27cm shell (Fig.1). A T/R switch design was employed that configured the array to be transmit only. The scanner's body coil was configured for use as a receive-only coil. The RF amplifiers' 50Ω impedance seen by the coils (as compared to the few-ohms pre-amplifiers typically seen by an array of receive coils), added to the difficulty of constructing the array, where significant coupling exists between neighboring elements. A transformer-type decoupling scheme was therefore incorporated into the array design to assist tuning and matching.

A recently developed prototype 8 transmit-channel MR scanner was used in the present study. The prototype scanner was built based on integrating 4 sets of Excite II system electronics (GEHC, Milwaukee, WI), each with 2 exciter boards. Effective synchronization measures were implemented to minimize detrimental phase incoherency and timing differences between a total of 8 parallel RF outputs. Augmented with developed software, this scanner enables the use of designed RF pulses to independently control amplitude and phase of the parallel RF outputs, which feed a stack of eight 8-KW RF power amplifiers that in turn drive the cylindrical parallel transmit array. A gradient echo sequence was adapted for loading and running parallel RF pulses on the system, as well as collecting MR data and producing images.

Fig.2a

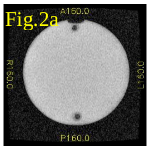
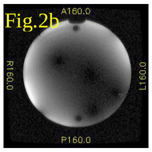


Fig.2b



In one investigation, to facilitate the evaluation of flip-angle uniformity across the A/P-L/R (axial) dimensions, a thin and uniform ∅24cm disc phantom was placed near the array center and used as the imaging object. In applying the parallel excitation approach, we designed parallel RF pulses to achieve accelerated 2D selective excitation that aimed at a flat flip-angle distribution across the phantom's center 14cm x 14cm region. Specifically, with the desired distribution profile as input, the minimum-norm algorithm (2) was used to obtain a 5.7msec-long parallel excitation pulse design. The design reflects a 4-fold acceleration, where an excitation k-space EPI trajectory was shortened to 8 lines with a 4-fold increase in Δ_{kx}, which in effect provides 32 harmonics (L/R direction) for achieving the desired profile. When applying the RF shimming approach, we used non-selective excitation. In this case the 8 transmit elements were driven by 8 RF pulses that are each weighted by a corresponding complex number but otherwise identical. This provided the equivalent function to that of adjusting port weights. The magnitudes and phases of the eight complex weights are determined through least-squares fitting of a weighted sum of calibrated B_1 maps to a flat profile. The B_1 maps used by both approaches were calibrated one at a time, each involving an imaging experiment that uses a single element of the transmit array for transmission (with zero inputs to other elements) and the body coil for reception. Division of the individual results (Fig.1) by a separately acquired body-coil image (Fig.2a) provided B_1 estimates.

Fig.3a

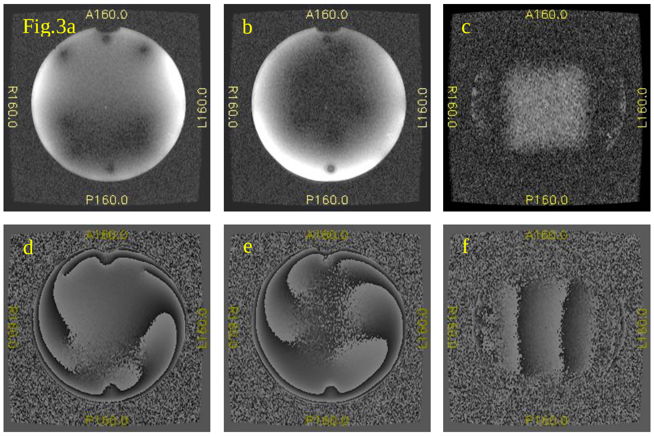


Fig.2b displays the result of a non-selective excitation where 8 identical RF pulses were used to drive the elements. The asymmetric pattern shown reflects the existing gain/phase offsets between the 8 transmit channels as well as the effects of inter-coil coupling. Applying RF shimming over the whole disc region realized an overall uniformity improvement (Fig.3a). When targeting the same center 14cm x 14cm area as the parallel excitation approach did, RF shimming effected further uniformity improvement over this particular region yet at some cost to uniformity elsewhere or overall (Fig.3b). Fig.3c showed the parallel excitation result, which compares favorably to the RF shimming results in terms of uniformity across the target area. However, the 2D profile was less accurate near the phantom boundary, where B_1 mapping error appeared to be a main factor. The corresponding phase images shown in Fig.3d-e further indicate that the parallel excitation approach has the capacity to refocus and achieve uniformity in phase. While further development is clearly required, this study suggests that accelerated multi-dimensional pulses may outperform RF shimming in a practical setting. In a sense, the parallel excitation approach directly targets flip-angle profile and overcomes B_1 inhomogeneity with Fourier harmonics, which should be a more effective way for attaining flip-angle uniformity than attempting to synthesize a homogeneous B_1 field with a handful of fixed B1 patterns.

1. T.S. Ibrahim, et al., *Magn Reson Imag*, 19:1339-1347, 2001. 2. Y. Zhu, *MRM* 51:775-784, 2004.