Parallel Excitation on an Eight Transmit-Channel MRI System

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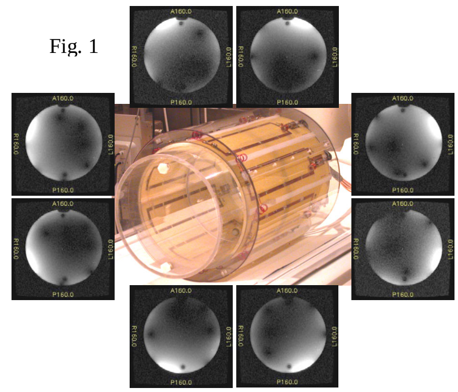
Introduction

Parallel excitation has the potential to accelerate spatially selective excitation, manage flip angle profile, and reduce RF power absorption (1-3). Investigations to date however have been largely confined to numerical simulations or partial testing on conventional scanners. The limitations of theses indirect approaches in modeling the actual B_1 spatiotemporal variations during parallel transmit or the spin system's responses to the varying gradient and RF fields have hindered validation/development of parallel excitation methods. Quantification of transmitted RF power and characterization of the mutual coupling between the transmit elements, for example, represent some of the challenges that indirect studies face. In order to facilitate full-fledged investigations of parallel excitation, we have built a prototype MR scanner with fully independent 8-channel parallel transmit capability, as well as two parallel transmit coil arrays of, respectively, cylindrical and planar geometry. We describe below the key aspects of our development effort and further present results demonstrating 4-fold acceleration of 2D selective excitation.

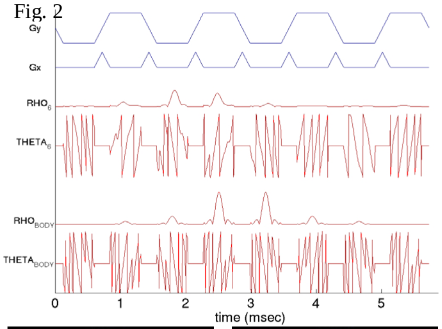
Methods and Results

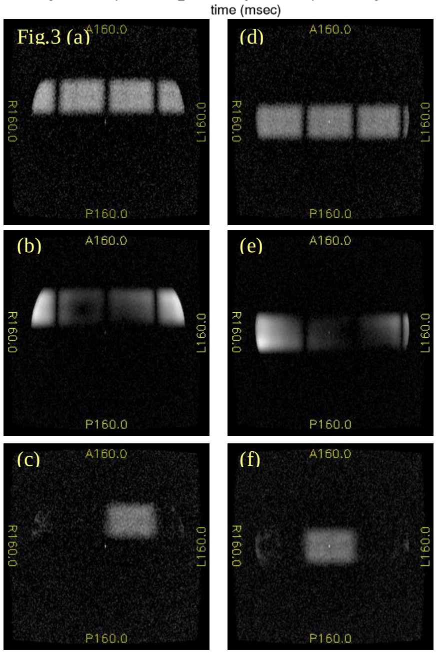
Fig. 1



True parallel excitation with an array of RF coils to create the proper B_1 spatiotemporal variations requires driving each coil with a devoted transmit channel that consists of an RF pulse synthesizer and an RF power amplifier. Robust parallel excitation further requires maintaining high quality inter-channel synchronization, as gauged by the level of control over the timing and phase coherency between parallel RF pulses. The present 8-channel parallel transmit MRI system was built based on integrating 4 sets of Excite II system electronics (GEHC, Milwaukee, WI), each hosting 2 exciter boards. A harmonization scheme was used to synchronize internal state machines as well as scan triggers across all 4 sets, which effects sub-usec precision in parallel RF pulse alignment. To minimize detrimental phase incoherency that may be introduced during digital or analog stages of parallel RF pulse synthesis, additional architectural modifications were made that force the running of 8 exciter boards off a single clock and the sharing of proper carrier signals among multiple mixers. Augmented with developed software, the new system allows the use of designed RF pulses to independently control amplitude and phase of 8 RF outputs, which feed a stack of eight 8-KW RF power amplifiers that in turn drive in parallel an array of transmit coils.

Fig. 2





Two parallel transmit coil arrays were constructed for use with the system. The first is a cylindrical head-coil array consisting of eight 18x6 cm^2 elements distributed azimuthally on a ∅27cm shell (Fig.1). The second is a flat array consisting of six 18x6 cm^2 elements linearly lined-up on a 40x40 cm^2 former. For both arrays, a T/R switch design was employed that configured the arrays to be transmit only. The RF amplifiers' 50Ω impedance seen by the coils (as compared to the few-ohm pre-amplifiers typically seen by an array of receive coils), added to the difficulty of constructing both arrays, where significant coupling exists between neighboring elements. A transformer-type decoupling scheme was therefore incorporated into the array designs to assist tuning and matching.

Acceleration of 2D pulses with parallel excitation, or transmit-SENSE, was investigated. Several sets of pulses designed to induce various flip-angle profiles over the A/P-L/R dimensions were particularly evaluated by using the cylindrical 8-elelemt array for transmission, a uniform ∅24cm disc phantom placed near the array center as the object, the scanner's body coil for receive, and an adapted gradient echo sequence for execution. Required B_1 maps 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 transmit-receive image provided B_1 estimates. The parallel RF pulses were calculated using the minimum-norm design method described in (2).

In one experiment, focused excitation of an arbitrarily located rectangular ROI was carried out with 2D pulses designed for 4-fold acceleration (EPI trajectory shortened to 8 lines with a 4-fold increase in Δ_{kx}). Fig.2 shows a design for selective excitation of an off-center ROI (the amplitude and phase of the RF pulse for the 6th array element are illustrated). Fig.2 (bottom) also shows a reference RF pulse design that represents a conventional 2D pulse but with a 4-fold k_x-direction decimation. Use of this reference RF pulse to drive the scanner's body coil (Fig.3a) or to drive in parallel all 8 elements of the cylindrical array (Fig.3b), produced profiles with prominent aliasing side lobes and/or flip angle non-uniformity, as expected. In comparison, simultaneous driving of the 8 elements with corresponding designed parallel RF pulses (Fig.3c) produced a profile with a main lobe matching the desired profile and side lobes substantially suppressed (>90% suppression at most places; somewhat less near the phantom boundary where B_1 mapping error appeared to be a main factor). Fig.3d-f summarizes results from another case where a centrally located ROI was targeted. Similar experiments using 6 of the 8 elements and additional experiments with the 6-element linear array also provided validations of other parallel pulse designs. Finally we note that the present B_1-calibration and pulse design methods appear to be capable of compensating for residual inter-element coupling and unknown inter-channel phase offsets (due to imperfect synchronization) without requiring any extra calibration or processing steps.

1. U. Katscher, et al., *MRM* 49:144-150, 2003. 2. Y. Zhu, *MRM* 51:775-784, 2004. 3. Y. Zhu, *12th ISMRM*, p 331, 2004.