Highly Distributed RF Transmission with a 32-Channel Parallel Transmit System

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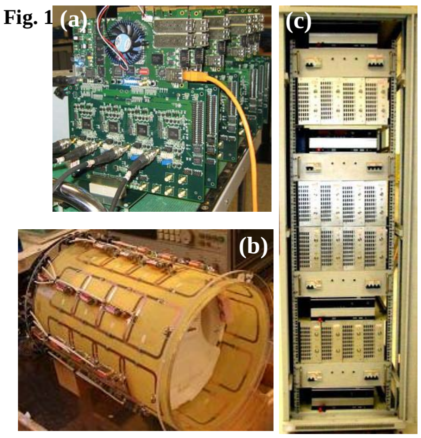
Introduction: When RF signal gets transmitted (Tx) / detected (Rx), the $B1^+$ / $B1^-$ fields interact with the spin system of the imaged object, forming the basis of MR signal induction / detection. The concomitant E field meanwhile gives rise to RF loss in the object and dictates SAR / noise. An MR system implements / optimizes the RF electromagnetic fields for MR via the currents in an RF coil structure, by controlling their magnitudes, phases, temporal modulation and spatial distribution. Conventional Tx actively controls the temporal modulation only, with a single source driving a volume coil structure. Parallel Tx supports flexible spatiotemporal current pattern control with multiple sources driving a distributed RF coil structure, and promises to address major challenges facing conventional Tx in high field MR, including excitation profile degradation and SAR exacerbation. This study explores substantially distributed parallel Tx, aiming at its applications in reducing RF power dissipation in the subject / the coil structure, as well as in B1 shimming / accelerated parallel excitation of an arbitrarily oriented target slice or volume. We developed a cost effective 32-channel exciter module, RF coil arrays that support 32-channel parallel Tx and Rx, and 32 current-source amplifiers that facilitate coil current control. In the following we describe the development efforts and present initial phantom imaging results.

Methods and Results: While conventional Tx has supported well clinical MR at a B0 field strength of up to 1.5T, it has room to improve. To achieve a circularly polarized uniform B1 field, an RF power amplifier on a modern scanner commonly splits its output into two and drive a birdcage coil in quadrature. This tends to create, in the coil's azimuthally distributed rungs, a current pattern that is with a phase offset equaling to a rung's azimuthal angle but a magnitude uniform among all the rungs. Internally the amplifier contains an array of sub-kW amplifier modules that combine at the output stage to provide a capacity of tens of kW. One possible improvement is to have the modules drive the rungs directly, as opposed to combine the power inside the amplifier and then redistribute it. This is expected to support circular polarization better in practice – such factors as asymmetric patient loading could be compensated for if desired. From an RF loss perspective, eliminating the combination and redistribution step helps. A recent study also suggested that increasing the number of rungs tends to reduce coil loss (1), e.g., a factor of two increase allows a decrease of each rung's required current by the same factor, giving a factor of two reduction in total power loss in the coil (assuming a rung's resistance remains the same).

Fig. 1



More significantly, from the perspective of excitation profile and patient SAR control for high field MR, parallel Tx research suggest that one is better off targeting the excitation profile directly instead of attempting to approximate a uniform B1 field. The present investigation intends to push the envelope of distributed RF Tx by developing a 32 channel parallel Tx prototype system and further pursue applications as enabled by the system.

A multi-port coil array defines individual RF field profiles that, under the control of B1 shimming coefficients or parallel RF pulses, are weighted and superimposed to create the actual RF field in the object. The array thus plays a central role in the induction of a temporally/spatially varying B1 field that effects excitation profile control and a concomitant E field that dictates SAR. Guided by previous studies that analyzed SAR and coil current patterns (2,3), we chose a geometry that has 32 properly sized individual coils populated in 8 columns on a ∅27cm cylindrical shell (Fig.1b). This geometry supports comparatively flexible control of current pattern over a surface enclosing the imaging volume. It also facilitates significant contributions from multiple element coils to any region within the volume and is therefore suited for B1 shimming or 2D/3D accelerated parallel excitation of an arbitrarily oriented target slice or volume. Given a target region, SAR reduction may be realized with a down-selected set of elements near the region or a prioritized use of the elements (4), which in effect reduces the footprint of the E field and avoids unnecessarily high RF power absorption beyond the region. The 32 ports of the finished array are connected to the rest of the system through 32 T/R switches. A shielded version of the coil was also built, which assumes the same array geometry and supports both parallel Tx and parallel Rx.

Control of current pattern and support for parallel Tx rely on a module comprised of 32 independent exciters (Fig.1a) and an array of 32 1kW narrow-band current-source RF power amplifiers (Fig.1c). The exciters were implemented with eight sets of boards. They fetch from a PC RF pulse definitions calculated with a Matlab program. During Tx they operate off two reference signals: a clock signal (for forcing phase coherence with Rx) and a trigger signal (for timing alignment). The two signals are derived from the scanner which is responsible for everything else except Tx, and are distributed to the boards through a backplane. On each set a 4-channel DAC board along with an off-the-shelf Altera PCIe EVM board and custom FPGA code perform synchronized synthesis of 4 independent RF waveforms at a pre-specified center frequency. The DAC boards were developed in-house and each uses four AD9779 (16-bit interpolating DAC). The modulating, mixing and interpolating all take place in digital domain, with an internal sample rate of up to 1 GHz. The current-source power amplifiers were developed based on the ultra-low output impedance concept (5). They are placed in the equipment room and are connected to the array through 8.5m-long coax cables. In a study carried out previously under practical imaging conditions, prototypes of the same design showed superior control over coil currents (6), rendering the currents largely independent of coil load change / coupling between array elements. Although the present arrays' geometry design was fine tuned to avoid excessive coupling conditions, residual coupling between non-overlapped neighbors remain significant. With the present 32-channel system the decoupling effect associated with the current-source amplifiers is leveraged during Tx, and an analogous effect associated with the scanner's low input-impedance preamplifiers is leveraged during Rx. Cost per Tx chain (exciter + amplifier + power supply) of the present system is less than $1K.

Initial 3T phantom MRI experiments were conducted to evaluate the coil arrays and the amplifiers. One experiment tested Tx with 12 elements of the unshielded array (8 and 4 from the two middle rings respectively). A spoiled gradient echo sequence was used (TE=4.8ms, TR=34ms, 256x160 matrix and 24cm FOV). Comparisons of an image acquired with one of the twelve active elements transmitting with an image acquired with that same element transmitting in isolation show excellent agreement (Fig.2), which suggests that the present system can overcome significant coupling effects and achieve excellent current control. Further bench testing indicated that the current-source amplifiers improved decoupling by 10dB compared to conventional amplifiers. Full integration of the system with a 3T scanner is underway. Its success may facilitate experimental assessment of parallel Tx performance limit and enable exploration of new applications.

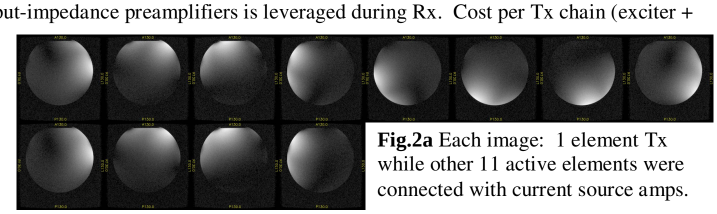


Fig.2a Each image: 1 element Tx while other 11 active elements were connected with current source amps.

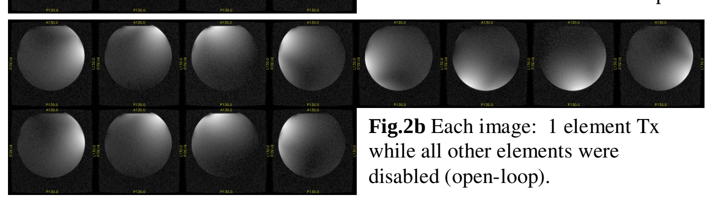


Fig.2b Each image: 1 element Tx while all other elements were disabled (open-loop).

1. E. Boskamp, et al., *16th ISMRM* p 1094, 2008. 2. Y. Zhu, *14th ISMRM*, p 599, 2006. 3. R.Lattanzi, et al., *16th ISMRM*, p 614, 2008. 4. Y. Zhu, *MRM* 51:775-784, 2004. 5. X. Chu, et al., *15th ISMRM*, p 172, 2007. 6. X. Chu, et al., *MRM* (in press).