Simultaneous Excitation of Distinct Electromagnetic Modes using a Tx Array

Yujuan Zhao[1], Sossena Wood[1], Tiejun Zhao[2], Narayanan Krishnamurthy[1], and Tamer of Ibrahim[1]
[1]*University of Pittsburgh, Pittsburgh, Pennsylvania, United States,* [2]*Siemens Medical Solutions, Pittsburgh, Pennsylvania, United States*

Introduction: The inhomogeneous distribution of the magnetic field B1+ at ultrahigh field imaging (≥7T MRI) is a significant challenge for the ultrahigh field RF coil design. Various methods have been explored: the parallel RF excitation approach uses spatially tailored RF pulse design [1]; however, it is sensitive to the measured B1+ maps, the B0 field shimming quality and gradient field performance [2]. There are several works suggesting the use of two modes to increase the homogeneity of the image [2], but it is not easy to simultaneously excite several modes of a coil [3]. In this work, a new excitation paradigm is presented utilizing 20-channel Tic-Tac-Toe (TTT) based RF transmit array design where the 20 elements are combined into 5 different groups in order to excite 20 distinct modes with longitudinal (z direction) spatial selectivity, including zero phase, opposite phase, quadrature and anti-quadrature. Any 5 of these modes can be simultaneously excited. The optimization shimming method has been used to find a uniform excitation pattern with manipulating the amplitude and phase of each excitation modes under SAR constraints. The results are successfully tested on a 7T MRI scanner using phantoms and in-vivo (7 human subjects.)

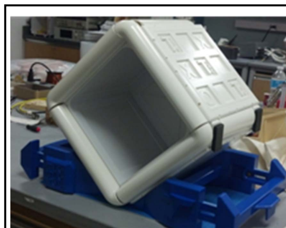
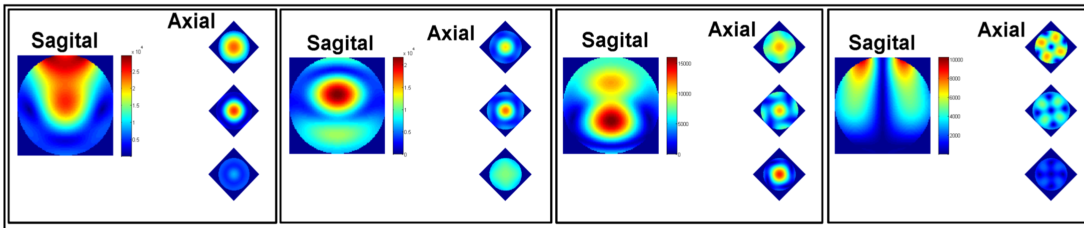


Fig1 20-ch Tx array.

Methods: ***Theory:*** The current distribution on the array elements could be described as a linear combination of EM modes; also each single EM mode is determined by a current distribution on the array elements [4]. The TTT array can readily excite different patterned modes with fixed amplitudes and 4 sets of phases through different array element combinations since there are 20 channels composing 5 sets of coils that could be decoupled. ***Simulation:*** The simulation results of the head model and the phantoms are acquired from the in-house FDTD full wave simulation package which is verified by the experiments.



(a) (b) (c) (d)

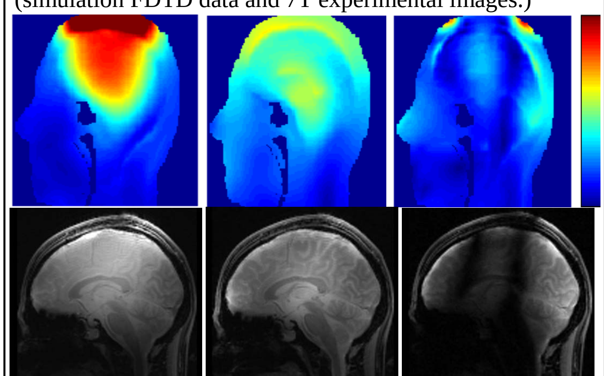
Fig2: Sample modes from 2 levels (total of 5 levels) of the 20-ch Tx TTT array. The array can simultaneously excite 5 different modes from the 5 different levels, if properly combined using B1 shimming, homogenous & efficient B1+ field can be attained (see Fig. 4)

Coil and Experiments: A 20-channel TTT array was constructed and five sides head-long rectangular copper RF shielding ere positioned around the Tx/Rx coil to increase the SNR. The assembled coil is shown in Fig1. The RF copper shielding is slots with specific pattern to reduce eddy current and maintain RF performance [5]. All experiments are done using 7T Siemens Magnetom scanner equipped with 8 channel parallel transmission capability.

Results and Discussion:

The top side array has four different modes, Fig.2 a, d shows 2 of them. Mode 1 (Fig 2 a) excites the center area of the phantom and modes 2, 3, 4 (Fig 2 d) excite the periphery areas. Other array elements could be combined to generate different patterns. Since all coil elements are physically distributed along the direction of the static magnet field (Z), they could be used to excite different regions in the load along Z direction (two of them are shown in Fig.2 b, c. Fig. 3 displays three different modes comparison in the simulation of the human head model and in-vivo low-flip angle GRE images. These comparisons are done in all human subjects in-vivo scan cases. The modes are also optimized with in-house optimization GUI tool box and highly uniform (verified with B_1^+ field measurements with around two maximum over minimum across the imaging regions of human head.) GRE images are acquired (sample shown in Fig.4.)

Fig.3: Modes that can be simultaneously excited (simulation FDTD data and 7T experimental images.)



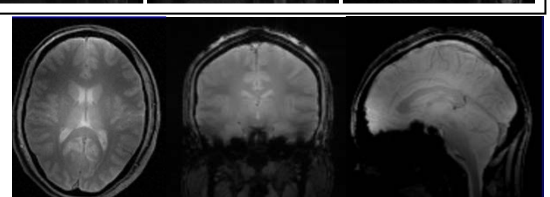


Fig4: GRE images of axial, coronal and sagittal views of the optimized modes (in-vivo at 7T.)

Conclusions: With 20 different distinct modes of 20-ch TTT array, any 5 of which could be excited simultaneously. These modes could excite different regions inside the human head. The 20 Channel TTT coil's modes are consistent with different human subjects. The images acquired by B1+ shimming of these modes are uniform (maximum and minimum inside the whole brain area, including the skin/bone are less than 2.1). The uniform field distributions are validated across different human subjects.

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References: [1] Alagappan, V., et al. MRM, 2007. 57(6): 1148-1158; [2] Orzada, S., et al., MRM, 2010. 64(2): p. 327-333; [3] P. Yazdanbakhsh, ISMRM2009.[4] M. Vester, ISMRM 2006. [5] Zhao, Y., et al, ISMRM 2012 p536