An Elliptical Octagonal Phased-Array Head Coil for Multi-Channel Transmission and Reception at 7T

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INTRODUCTION Recent advances in ultra-high field and parallel imaging have spurred new interest in using MRI to visualize fine anatomical structures and reveal brain functions with unprecedented spatial resolution and sensitivity. At 7T, it has been shown that the in-plane resolution of human brain morphological studies can reach 0.12x0.12mm^2 [1], while fMRI with echo planar imaging can produce voxels as small as 1x1mm^2 [2] with drastically improved BOLD sensitivity over 3T. To fully realize the great potential of 7T, the performance of the RF coil must be optimized not only to ensure a high signal-to-noise ratio (SNR), but also to provide uniform image intensity over a large brain region. In this study, we have developed an 8-channel (8-ch) phased-array transmit/receive (Tx/Rx) head coil on a Siemens 7T whole-body MRI scanner. By independently adjusting the B_1-field phase of each channel, this coil improves brain coverage as compared to a commercial head coil. The coil also has a large, unblocked visual stimulation field, which is highly desirable for fMRI experiments.

MATERIALS and METHODS To match the shape of the human brain, the head coil was designed with an elliptical octagonal geometry consisting of eight elements on plexiglass plates as shown in Fig. 1a. The horizontal and vertical inner diameters were 23 cm and 26 cm, respectively. The coil mechanical length was 28 cm. To facilitate fMRI studies with visual presentation, two rectangular windows (185mm by 70mm each) were placed in the upper central portion of the coil, allowing an unblocked visual field for stimulation. Eight identical phased-array surface loops with the size of 20cmx8.5cm were distributed evenly around the coil mould to achieve a uniform transmitting field (Fig.1b). Coupling between the adjacent phased-array loops was minimized via the inter-loop capacitors Ci, Ci' (i=1,2...8) [3,4]. Coupling between the next adjacent and opposite loops was negligible because of the geometric separation. All the elements were tuned to 297.2MHz and matched to 50 ohms with a Siemens 7300ml cylindrical water phantom as a loader. The S11 reflection coefficient of each surface loop was less than -16db, and the S21 decoupling parameter was less than -12db between adjacent loops. The coil was interfaced to a home-built RF sub-system (Fig. 1a) consisting of a 1-to-8 Wilkinson RF power splitter, 8 fast Tx/Rx switches, phase shifters, low-noise preamplifiers (LNAs), RF traps, and other components [5,6,7]. During transmission, the signal from a single RF transmitter on the scanner was divided evenly into eight channels by the Wilkinson power splitter. The divided signals were then shifted independently by the eight coaxial phase shifters to achieve a homogeneous B_1-field. In the receiving mode, the MRI signals detected by the eight phased-array surface loops were input to the LNAs through the Tx/Rx switches, and then sent to the multi-channel receivers for digitization and processing. To address the safety concerns, EM simulations were performed to analyze the coil B_1 and SAR distribution using a Virtual Family human brain model [8] with FDTD-based commercial software, SEMCAD X [9]. To evaluate the coil performance, standard T_1-MPRAGE and BOLD-EPI sequences were employed for image acquisition. The key imaging parameters were: for T1-MPRAGE, TR/TE/TI=2200/3.2ms/1050ms, 25 slices, voxel size=0.7x0.7x0.7mm^3; for BOLD-EPI, TR/TE=3000/22ms, iPAT=3, voxel size=2x2x2cm^3. For comparison, similar images were also acquired using a commercial volume-transmit 24-element receive coil (Nova Medical, Wilmington, MA) [10].

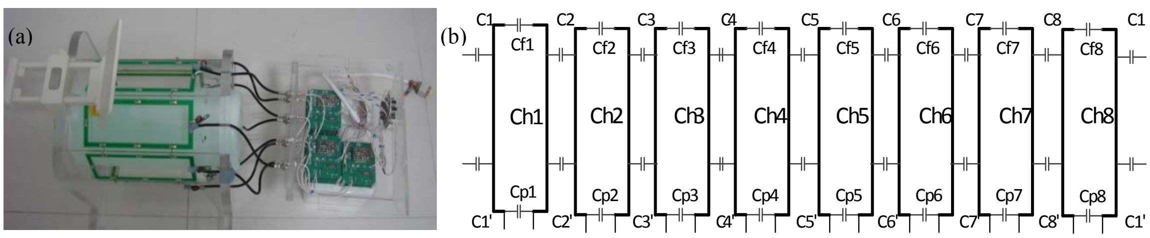

Fig.1 (a) The 8-ch Tx/Rx head coil together with other RF components for interface to the 7T scanner; (b) Circuitry of the 8 phased-array surface loops placed on the octagonal coil mould.

RESULTS The first four images in Fig. 2 display pairs of T1-MPRAGE sagittal and BOLD-EPI axial brain images from a healthy human subject using the 8-ch Tx/Rx head coil (a, c) and the Nova 24-ch head coil (b, d), respectively. In both comparisons, the 8-ch Tx/Rx coil demonstrated improved brain coverage (a vs. b), better image uniformity (a vs. b), or higher signal intensities in specific areas that were not adequately visible using the Nova coil (c vs. d). In particular, our 8-ch Tx/Rx coil expanded the imaging area to the lower portion of the human brain (the red boxes in Figs. 2 (a) and (b)) when compared with the 24-channel Nova head coil. Figure 2e shows a sagittal simulation map of the local 1g SAR, assuming a transmit power of 8W (1W for each channel) [11,12]. The global and local SAR distributions were simulated and confirmed to be within the IEC safety standard. Compared with the Nova coil, our 8-ch Tx/Rx coil also decreased the transmitting RF power by about 25%-35% in both structural and functional experiments, which can be beneficial for studies involving high RF transmitting power levels, such as the MT experiments.

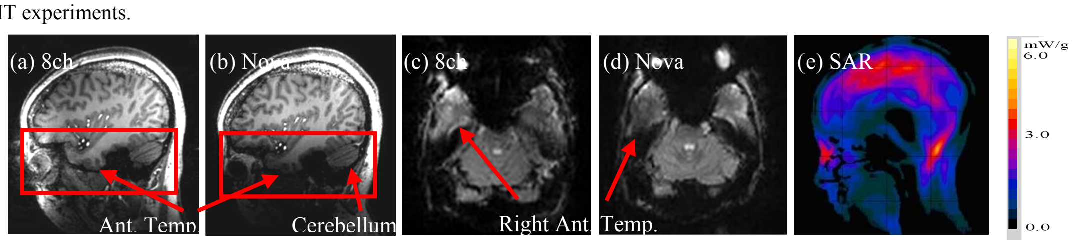

Fig.2 Human brain images acquired with the T1-MPRAGE (a,b) and BOLD-EPI (c,d) sequences using our 8-ch Tx/Rx coil and a Nova 24-ch head coil on 7T. A sagittal 1g-SAR simulation map is displayed in (e) showing SAR distribution within the IEC standard.

DISCUSSION The 24-channel Nova coil offers excellent image quality in the upper portion of human brain including parietal and occipital regions. However, its whole brain coverage is limited because the inner receive elements are designed as a close-fitting helmet, resulting in compromised whole brain coverage especially in the frontal and cerebellum regions. In contrast, our 8-ch Tx/Rx head coil is designed with an elliptical octagonal geometry [13], which places coil elements closer to the temporal area of the brain. Improvement in whole brain coverage can also be attributed to the larger rectangular surface loops used in our design. Additionally, the ability to perform RF shimming with phase shifting is also an important factor for achieving uniform high image intensity in the lower portion of the brain, as observed in this study. In conclusion, by exploiting the advantage of transmit-arrays, the proposed coil design offers a number of desirable features (improved brain coverage, reduced transmit power, and open visual field) for structural and functional imaging at 7T.

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