Design Considerations and Coil Comparisons for 7 Tesla Brain Imaging

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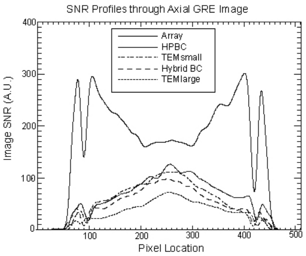
Introduction The development of 300MHz RF head coils analogous to those used at field strengths of 1.5T and 3T is complicated by increased dissipative losses in conductive tissue, effects arising from the short RF wavelength in biological tissue (~13cm at 300MHz), and the constraints imposed by the use of head gradient sets desirable for mitigating increased static field susceptibility effects. In this study, five RF head coils were constructed and tested on a 7T scanner including 2 TEM designs, 2 birdcage designs and a local receive-only array. SNR, coil reception profiles and interactions between the coil and dielectric head were examined. Particular attention was placed on the coil's reception in the neck and shoulders, where the head gradient is unable to unambiguously spatially encode the image.

Methods All imaging tests were performed on a prototype 7T human scanner (Siemens Medical Solutions, Erlangen, Germany). The scanner is built around a 90cm diameter 7T magnet (Magnex Scientific, Abingdon UK) equipped with both whole body gradients (Siemens Avanto) and a high performance 36cm inner dia. head gradient set, both permanently mounted in the magnet bore. All subject studies were performed on healthy subjects after obtaining informed consent under a protocol approved by the institution's Human Research Committee. Four volume coils and 1 eight channel array coil were constructed and tested.

TEM coils: Two TEM coils (designated $\mathrm{TEM}_{\mathrm{large}}$ and $\mathrm{TEM}_{\mathrm{small}}$) were tested. Inner diameters, number of rungs, and lengths were 27cm and 24.5cm, 24 and 32, and 18.5cm and 14cm. The outer shield was 31.5cm diameter for both coils, 1mil copper foil slotted and bridged with 10nF capacitors. The distributed series capacitance in the rungs was formed using the low-loss circuit board material (R03003 Rogers Corp., Rogers CT) as the dielectric and the copper as the capacitor plates. By staggering the overlap of copper on the two sides of the board, up to 7 series capacitors were built into each rung. The large TEM coil was capable of being detuned for use as a transmit only coil in addition to being statically biased "on" for use as a conventional TR coil using PIN diodes placed between the rung and its associated trim capacitor for each rung except for the 4 driven rungs. The 4 driving rungs of the volume coil were matched to 50Ω coax and driven with phases of 0, 90, 180, and 270 degrees.

Two designs of birdcage coil were tested; an endcapped high pass birdcage design (designated HPBC) whose dimensions matched $\mathrm{TEM}_{\mathrm{small}}$, and an open-ended (no endcap) hybrid birdcage coil, 16 rung, 28cm dia, 19.5cm long (designated HybridBC) shielded only by the shield within the 36cm dia. head gradient set. A linear array of 8, 8.5cm dia. circular surface coils designed on a flexible former to wrap tightly around the human head was also tested.(1) The receive coils were actively detuned using a PIN diode across the lattice balun and $\mathrm{TEM}_{\mathrm{large}}$ was used as a transmit coil.

Results Figure 1 shows the SNR profiles measured thru the axial slice for each coil. The array coil showed significantly higher SNR at all depths for this slice. The signal reception profile of the array coil and volume coils are nearly complimentary. Images of the head and shoulders taken with each of the 5 RF coils in the whole-body gradient set revealed a ratio of shoulder muscle to white matter brain signal intensity of: 6.5%, 7.1%, 27%, 31%, 36% for the array, HPBC, $\mathrm{TEM}_{\mathrm{small}}$, Hybrid BC, and $\mathrm{TEM}_{\mathrm{Large}}$ respectively. B1 measured as a function of distance along the center line of the coil with a shielded inductive pick-up probe as the empty volume coil was driven in quadrature at resonance suggested that the birdcage designs possessed a useful null in field in the neck region compared to the TEM design. This is also seen in B1 simulations (2). Figure 2 shows the degree of signal reception in the shoulders for the 5 coils. Ratio of shoulder to white matter signal intensity ranged from 6.5% for the array to 36% for $\mathrm{TEM}_{\mathrm{Large}}$. Residual shoulder signal was seen to be effectively shielded or dephased using a flexible copper shoulder shield or a jacket with small pieces of Ferrous material sewed into the shoulder and chest region. The ratio of shoulder signal intensity to white matter signal was 21% without mitigation and 8% with the RF collar. With the dephasing jacket or jacket plus collar, the shoulder signal was less than the noise level.



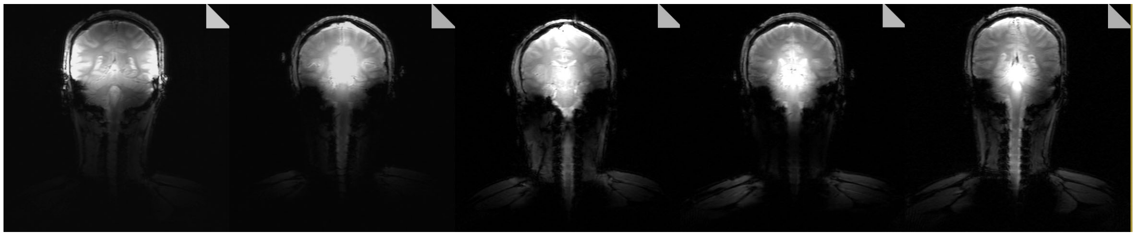


Fig. 1 SNR profiles for the 5 coils measured through an axial slice. **Fig. 2** Images of the head and shoulders taken with each of the 5 RF coils in the whole-body gradient set. From left to right: receive array, HPBC, $\mathrm{TEM}_{\mathrm{small}}$, Hybrid BC, $\mathrm{TEM}_{\mathrm{Large}}$. The ratio of shoulder muscle to white matter brain signal intensity for each of these 5 coils was: 6.5%, 7.1%, 27%, 31%, 36% for the array, HPBC, $\mathrm{TEM}_{\mathrm{small}}$, Hybrid BC, and $\mathrm{TEM}_{\mathrm{Large}}$ respectively

Conclusions All of the 7T coil designs could image effectively with expected increase in sensitivity from the smaller coils, but with subtle differences in field distribution, interaction with the dielectric boundary conditions of the head and detection in the neck and shoulders. In particular, the birdcage and array coils were found to have reduced B1 reception field profiles in the neck and shoulders which helped reduce signal detection outside the linear region of the head gradient coil. Residual artifacts from signal pick-up in the shoulders were effectively mitigated through use of a conductive shield or by small local dephasing shims sewn into the shoulders of a jacket worn by the subject. The volume coil's B1 profile was strongly peaked in the center of the head, rendering them spatially complimentary to that observed in the surface coil array. The image profile of the surface coil array was found to be less dramatically changed from patterns observed at lower field strength.

References 1) Wiggins G, et al Proc. of ISMRM 2004, Kyoto p. 36 2) Wang C. et al Proc. of ISMRM 2004, Kyoto p. 487

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