Eight-channel Tx/Rx Helmet Coil for Human Brain Imaging with Improved RF Homogeneity

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INTRODUCTION Recently, an anatomically shaped helmet coil consisting of four curved microstrip transmission-line (MTL) elements was introduced (1). The MTL elements were combined either as a circularly polarized (CP) transmit/receive (Tx/Rx) coil (*Type A*) or as a CP transmit, four-channel receive array (*Type B*). Both types provided an almost perfect circular polarization in the central region and a linear polarization near the MTL elements. However, a transmission field ($\mathbf{B}_1^{(+)}$) with opposite rotation sense is generated between adjacent MTL elements causing reduced signal intensity and image contrast in peripheral head regions. To overcome this problem, a more advanced design with eight MTL elements was developed. To maintain a sufficiently open coil with ample space for audiovisual stimulation, the geometric length of three of the MTL elements was reduced, whereas the electric length was maintained by proper termination.

METHODS The design (Fig. 1) consisted of self-adhesive strip conductors (Cu, thickness 12 µm, strip width 28 mm; ground width 50 mm) mounted on curved low-loss polypropylene (15 mm thick) to yield an overall dome-like structure (i.d. 23 cm, length 18 cm). Five elements were terminated by a short to the ground to obtain a current maximum at the caudal end. To provide space for audiovisual stimulation, three elements were shortened (red arrows in Fig. 1) and terminated by an inductor of 44 nH to obtain a current distribution equivalent to the other elements. Goals of this strategy was to maximize the RF-field amplitude and to minimize the RF-field gradient inside the circumscribed volume of the coil.

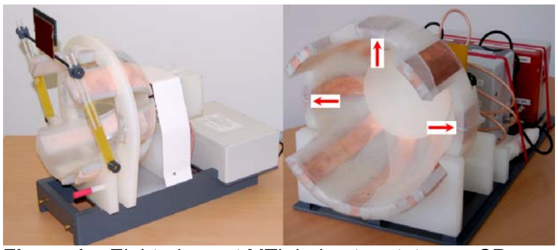

Figure 1. Eight-element MTL helmet prototypes: CP-Tx/Rx coil (left) and CP-Tx/8-channel-Rx array (right).

To obtain a CP-Tx/Rx coil (*Type A*), the two channels were connected to a four-way power divider (consisting of a two-way power splitter followed by a 45° phase shifter and two hybrids) generating the transmit phases (0°, 45°, 90°, 135°) to produce a circularly-polarized field. Opposite coil elements were connected with a 180° phase shift. To obtain an eight-channel array (*Type B*), an eight-way power divider was used to produce transmit phases of 0°, 45°, …, 315°. Alternatively, a Butler matrix (2,3) may be used. Each pair of coil elements (*Type A*) or each coil element (*Type B*) was connected by a short semi-rigid cable to a tune capacitor. Both types were matched to 50 Ω using two series capacitors. Power was controlled by two Tx/Rx switches arranged between the two-way power splitter and the hybrids for *Type A* whereas eight Tx/Rx switches and preamplifier decoupling were used for *Type B*. Actively switched PIN diodes were used for both types to provide sufficient insulation between transmitter and receiver.

RESULTS Numerical results of the transmission field magnitude, $B_1^{(+)}$, and its polarization ratio, β_t, are shown in Fig. 2. They were obtained with HFSS 11 (Ansoft, Pittsburgh, PA) and an unstructured human-head model with average values of the relative permittivity (ε_r = 63.4) and conductivity (σ = 0.46 S/m) of brain tissue at 125 MHz. Workbench measurements were used to characterize the tuning and matching state of the channels and to quantify their residual coupling (*Type A:* <17dB for Tx/Rx*; Type B:* <17dB/<30dB for Tx/Rx). Imaging experiments were performed at 3 T on a MedSpec 30/100 (Bruker, Ettlingen, Germany) with *Type A* and on a TIM-Trio (Siemens, Erlangen, Germany) with *Type B*. The polarization ratio obtained by simulation (Fig. 2g-l) was verified experimentally by comparing images obtained with counterclockwise and clockwise rotation sense of the RF transmission field. The transmission-field magnitude obtained by simulation (Fig. 2a-f) agreed well with experimental results obtained with the double-angle method. The average standard deviation of $B_1^{(+)}$ was 4.2% in axial planes with a profile comparable to that of a birdcage coil. The extent of areas of poor signal intensity at peripheral positions between adjacent MTL's was significantly reduced in the eight-element coils relative to the four-element coils (Figs. 2c & 2f), whereas the gradient of $B_1^{(+)}$ along the *z*-axis was similar. Parallel-imaging experiments (GRAPPA) indicated good image quality with that acceleration factors up to 4. *In vivo* experiments (Fig. 3) demonstrated that the eight-element design permits imaging of the entire brain with good tissue contrast. Improved image quality due to improved RF homogeneity when using eight instead of only four MTL elements was especially evident for RARE-type sequences (Fig. 3 right hand side). There were no indications of signal loss in areas near the MTL elements of reduced length.

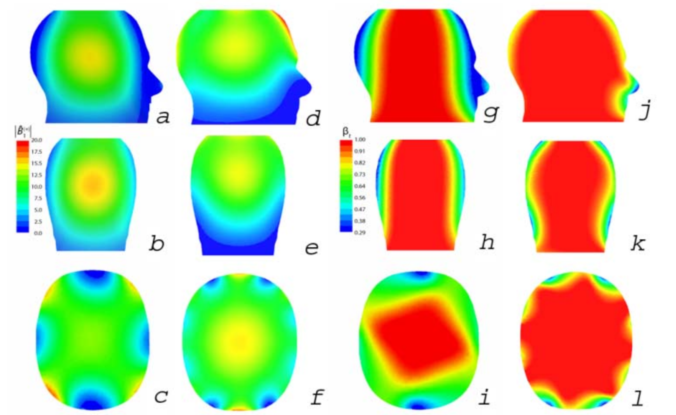

Figure 2. Transmission-field magnitude at 125 MHz **(a-f)** and polarization ratio **(g-l)** computed for the a four-element **(a-c,g-i)** and an eight-element CP-Tx/Rx coil **(d-f,j-l)** in sagittal **(a,d,g,j)**, coronal **(b,e,h,k)**, and axial **(c,f,i,l)** planes through an unstructured human head model.

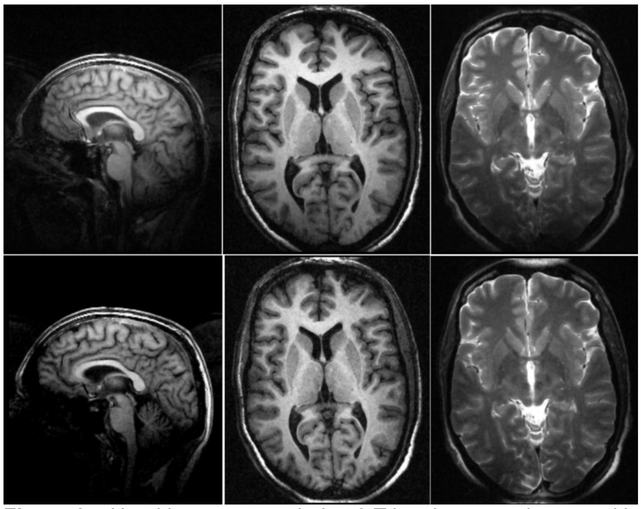

Figure 3. Head images recorded at 3 T in a human volunteer with a four-element (upper row) and an eight-element (bottom row) *Type A* helmet coil (left and middle columns: MDEFT; right column: RARE).

CONCLUSIONS By doubling the number of MTL elements, an improved $B_1^{(+)}$ homogeneity was obtained with eight-element MTL helmet coil prototypes. Shortening three of the eight MTL's to obtain sufficient space for headphones and visual stimulation devices as used for fMRI did not degrade the image quality. Initial experiments with the CP-Tx/8-channel-Rx array indicated good performance for parallel imaging with moderate acceleration factors.

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REFERENCES [1] Driesel W, Concepts Magn Res 33B, 98 (2008). [2] Vester M, ISMRM 14, 2024 (2006). [3] Alagappan V, MRM 57, 1148 (2007).