A Four-Channel Transceive Phased-Array Helmet Coil for 3 T

Wolfgang Driesel[1], Timm Wetzel[1], Toralf Mildner[1], Christopher J. Wiggins[2], Harald E. Möller[1,3]

[1]Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany;
[2]A.A. Martinos Center for Biomedical Imaging, MGH, Charlestown, MA, USA;
[3] Department of Radiology, University Hospital Münster, Münster, Germany

MAX PLANCK INSTITUTE FOR HUMAN COGNITIVE AND BRAIN SCIENCES LEIPZIG

Introduction

A wide-spread strategy to improve the sensitivity in MRI is to use a phased-array receiver [1] in combination with a volume-coil transmitter, typically the body coil. With the advent of parallel imaging, this concept has become even more popular. However, for dedicated head scanners or ultrahigh-field systems (operating above 3 T), whole-body transmit RF coils are currently not available due to design challenges and specific absorption rate (SAR) issues. It would, hence, be desirable to have a single head coil that combines the advantages of a transmitter of sufficient homogeneity and a multi-channel receiver.

GOAL

Design of a 4-channel transceiver array for human brain MRI at 3 T with minimal crosstalk between the individual coil elements.

Coil Design

Recently, the helmet coil concept introduced by Merkle et al. [2, 3] has been re-engineered based on a pure strip-type transmission-line (SL) design [4]. This concept yields improved RF field homogeneity and low out-of-volume sensitivity. The 3T transceiver helmet array, which was constructed based on this concept, may serve as a prototype for higher frequencies. Specific features include:

- High filling factor achieved by an open, dome-like shape (Fig. 1).
- 4 SL resonators consisting of 10-μm thick, 70-mm wide, self-sticking Cu tape over a Cu ground plane separated by a 15-mm thick polypropylene layer and terminated by a short.
- Electrical length of each SL resonator set to ¼ wavelength generating standing waves with a current maximum at the position of the short (sinusoidal excitation).
- Use of a 180° power splitter combined with two 90° splitters to produce equal amplitudes and phases of 0°, 90°, 180°, and 270° for the transmit power of the 4 SL resonators to obtain circular polarization (Stark Contrast, Erlangen, Germany).
- Power control by a T/R switch for each channel using actively switched PIN diodes to provide sufficient isolation between transmitter and receiver.
- Preamplifiers with high input impedance for each channel to minimize mutual coupling between array elements during reception.
- Each segment tuned by a parallel capacitance and matched to 50 Ω by two series capacitors.
- Suppression of common-mode currents by quarter-wave baluns between match capacitor and T/R-switch.

1

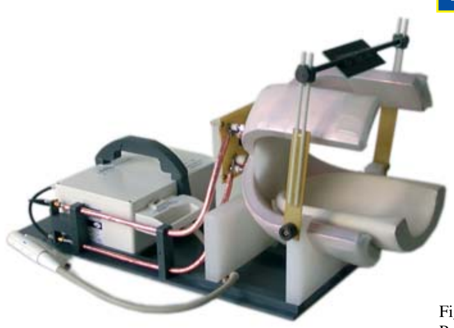

Figure 1.
3T transceive four-channel helmet array.

2

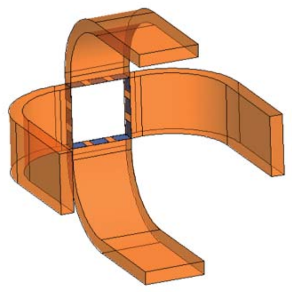

Figure 2.
Parametric coil design used for RF field modeling under consideration of material properties, capacitors, and excitation ports.

Numerical Results

For optimizing the design (Fig. 2), and in order to investigate the distribution of the RF field, B1 (Figs. 3, 4), computer-aided calculations were performed with HFSS (Ansoft, Pittsburgh, PA), which employs a finite-element method with adaptive meshing to solve numerically Maxwell´s Equations in the frequency domain.

3

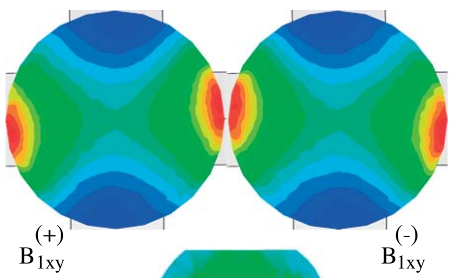

Figure 3.
Magnitude of the RF transmission and reception fields inside a cylinder phantom upon exclusive excitation of two opposite coil elements. The numerical results are indicative of a subtle polarization effect at 3 T similar to observation at higher field [5].

4

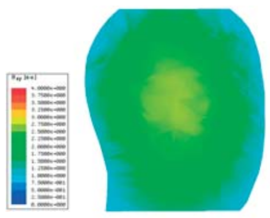

Figure 4.
Numerical results of the B1 simulation inside an unstructured human head model at 3 T indicating a high degree of homogeneity.

Experimental Results

Workbench measurements

- Reflected power measurements indicated a balanced coil design (small frequency shifts upon loading, low dielectric losses, dominating magnetic losses).
- Transmission coefficient measurements indicated good electronic decoupling between different channels.

3T MRI measurements
(Bruker MedSpec S 300 & Siemens MAGNETOM Trio)

Quadrature receive mode (*i.e.* signals of the four channels are combined after appropriate phase correction)

- Experimental B1-maps and signal distributions (Figs. 5, 6) agreed well with simulations including polarization effects (Fig. 3, 4).
- Due to the high rotational symmetry, a nearly perfect circularly polarized RF field is achieved (Fig. 7).

Phased-array receive mode (sum-of-squares combination).

- Nearly the same signal distribution was observed for the different channels (Fig. 8).
- Due to the use of semi-open SL resonators, mutual coupling between coil elements is low leading to very low noise correlation:

$$\Psi = \begin{pmatrix} 1 & 0.1705 & 0.0736 & 0.1525 \\ 0.1705 & 1 & 0.0482 & 0.1457 \\ 0.0736 & 0.0482 & 1 & 0.0122 \\ 0.1525 & 0.1457 & 0.0122 & 1 \end{pmatrix}$$

- No significant noise amplification was observed with parallel imaging and acceleration factors between 2 and 4 (Fig. 9).

5

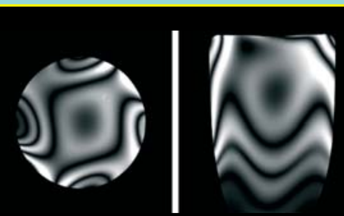

Figure 5. Qualitative B1 maps obtained with FLASH following a 720° prepulse [6]. Adjacent bright areas correspond to a 25% difference in field strength.

6

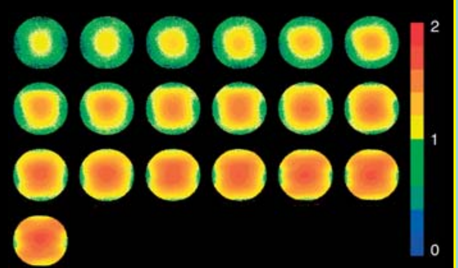

Figure 6. Quantitative B1 maps [a.u.] (double-angle method) at different z-positions (slice thickness 5 mm; distance 10 mm; input power 4.5 kW).

7

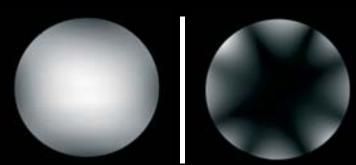

Figure 7. Experimental signal distributions in clockwise (left) and counter-clockwise (right) modes.

8

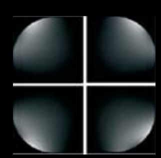

Figure 8. Signal distribution measured for the different channels

9

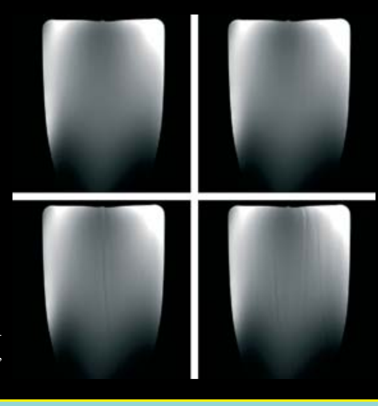

Figure 9. Images obtained without (top left) and with GRAPPA reconstruction and acceleration factors of 2 (top right), 3 (bottom left), and 4 (bottom right).

Conclusions

The transceive SL-helmet array permits imaging in both a conventional 4-channel phased-array mode as well as a parallel-imaging mode without the need of an additional large-volume transmit coil. Extension of this priciple to eight or more channels is straightforward. The open design provides sufficient space for use of common audiovisual stimulation devices for fMRI.

Acknowledgements

We are grateful to Hans Post, Sven Junge, and Ralf Weber from Bruker BioSpin, Hubertus Fischer from Siemens Medical Solutions, and Helmut Stark from Stark Contrast for helpful comments and hardware support. Appreciation is extended to Fa-Hsuan Lin from MGH-MIT-MMS, Charlestown, USA, for assistance in ICE programming, using MatLab, and to Markus Laudin from Ansoft Germany for helpful remarks on HFSS.

REFERENCES:

1. P.B. Roemer et al. The NMR phased array. Magn. Reson. Med. 16: 192-225 (1990).
2. H. Merkle et al. Dedicated circularly polarized surface coil assemblies for brain studies at 4 T. SMRM, 12th Ann. Meeting, New York, 1993. p. 1358.
3. W. Driesel et al. Reengineered helmet coil for human brain studies at 3 tesla. Concepts Magn. Reson. B: Magn. Reson. Engineering 27B: 64-74 (2005).
4. W. Driesel et al. A new helmet coil concept using strip lines. Proc. ISMRM 13: 948 (2005).
5. J. Wang et al. Polarization of the RF field in a human head at high field: A study with a quadrature surface coil at 7.0 T. Magn. Reson. Med. 48: 362-368 (2002).
6. A. Haase et al. NMR probeheads for in vivo applications. Concepts Magn. Reson. 12: 361-388 (2000).

email:driesel@cbs.mpg.de