Hybrid TEM/Loop Coil Array for Parallel High Field MRI

J. Paska[1], and C. Leussler[2]

[1]Institute for High-Frequency Technology, Technical University of Hamburg-Harburg, Hamburg, Germany, [2]Sector Medical Imaging Systems, Philips Research Europe Hamburg, Hamburg, Germany

Introduction

As B_0 field strengths increase, there is an almost linear increase in SNR. However, new problems arise at higher field strengths, such as a higher SAR and B_1-field inhomogeneity. To counteract these problems, multiple transmit channels are necessary to improve the image homogeneity, this can be achieved with static RF-shimming [1]. In this work, a new transceive surface coil array is investigated made up of hybrid coil elements [2]. The single hybrid coil element consists of a TEM and a loop coil, which are geometrically decoupled, and locally produce a circularly polarized field. Because each hybrid coil element has its own shield, the hybrid coil array is configurable and acts as a building block for coil arrays to image different parts of the body.

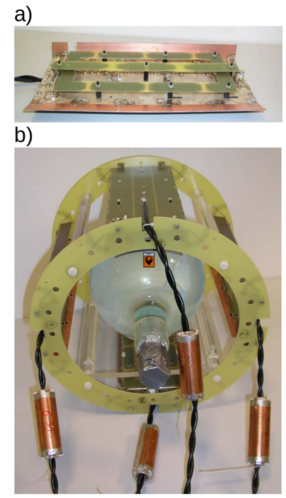

Fig. 1: Single Hybrid coil element (a), and 4-element Hybrid head coil array (b), for head imaging at 3T.

Experiments & Methods

A 4-element hybrid coil array was designed and constructed for the imaging of the head at 3T. Because the TEM and loop coil on this hybrid coil element are geometrically decoupled, additional decoupling circuitry is not necessary. The TEM coil has a lower sensitivity and is placed above the loop coil. To reduce coupling between neighboring hybrid coils, additional copper side shields were added to the RF-shield.

Each hybrid coil element has its own RF-shield to reduce radiation loss. The unloaded Q-factor, measured with a network analyzer, was 360 for the TEM coil and 400 for the loop coil. 50Ω-matching was performed by inductive coupling to reduce cable currents. Remaining cable currents at the Larmor frequency were successfully reduced using cable traps. The side-shields were optimized to reduce the maximal coupling to −12 dB (occurring between neighboring TEM coils). The hybrid coil array was matched to a spherical phantom and successfully tested on a Philips 3T Achieva scanner with eight independent transmit channels developed at the Philips Research Laboratories in Hamburg [3]. The spherical phantom had a radius of 10 cm, ε_r=50, and σ=0.5S/m. The complex transmit sensitivities in the transversal plane were computed from the experimental data. The measured complex transmit sensitivities were consistent with the simulated results using a MoM solver. Therefore, we can use the simulations to further investigate the coil array. The excitation voltages for the homogeneous drive (minimizing the normalized standard deviation s_n of the B_1^+-field, with input power of unity) were computed with an optimization program in MATLAB based on optimizations described in [4], and compared to the homogeneous drives of a 4-TEM and 4-loop array with the same dimensions (Fig. 3). Fig. 3a shows the simulated homogenized transmit fields of the 4-element head coil array prototype using hybrid coil elements (1st row), TEM elements (2nd row), and loop coil elements (3rd row). The use of a 6-element body coil array for body imaging (elliptically cylindrical phantom, short axis 23 cm, long axis 50 cm, length 1m) was investigated in the same way, see Fig. 3b. Here the coil elements were placed 7 cm away from the phantom for a more homogeneous transmit field. Additionally, the hybrid coil array for head imaging was optimized in the simulation by varying the height of the TEM and the loop coil above the RF-shield. Shown in Fig. 4 are the normalized standard deviation s_n, the input power needed to achieve a 90 degree flip angle in the center, the minimum intrinsic transceive SNR, and the maximum and average noise amplification factors for SENSE imaging with reduction factor of R=3 as a function of distance coil to the RF-shield h_{TEM} and h_{loop}. The intrinsic transceive SNR is computed as:

$$SNR = \left|\sin\left(\sum_{i=1}^{N} V_i \hat{B}_{1i}^{+} \gamma\tau\right)\right| \underbrace{f^2\sqrt{S^T \Psi^{-1} S^*}}_{Rx}$$

with V_i representing the complex voltages in homogeneous drive, normalized for a 90° flip angle in the center voxel. Ψ is the noise covariance matrix, and S a vector containing the complex receive sensitivities. Rx is the SNR when the coil array is used only for reception.

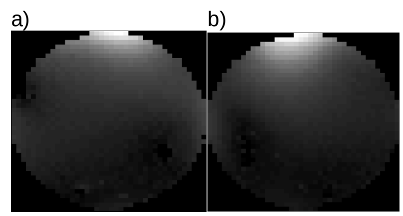

Fig. 2: Measured Tx-sensitivities of the TEM coil (a) and loop coil (b).

Discussion & Conclusion

Hybrid TEM/loop coils are able to locally produce a circularly polarized B1-field. In a hybrid coil array the orthogonal fields of the TEM and the loop coil provide the hybrid coil array with additional degrees of freedom to produce a considerably more homogeneous transmit field as compared to similar TEM-coil arrays or loop-coil arrays. Furthermore, it was shown that the hybrid coil array can be used for the imaging of different parts of the body. For a spherical, head-sized phantom, optimal distances between the shield and the TEM and loop coil elements can be found with the help of parametric simulations in order to obtain a homogeneous transmit field or the maximum intrinsic SNR. The actual coil array properties depend on the phantom that is used, but a trend can however be derived.

References

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[3] I. Graesslin et al., Proc. ISMRM, 15:1007, 2007.

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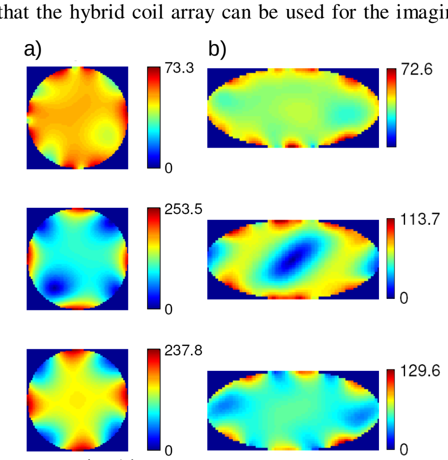

Fig. 3: | B_1^+ | [nT] of the homogenized drives of the 4-element head coil array (a), and the 6-element body coil array (b).
First row: hybrid elements, second row: TEM elements, third row: loop elements.

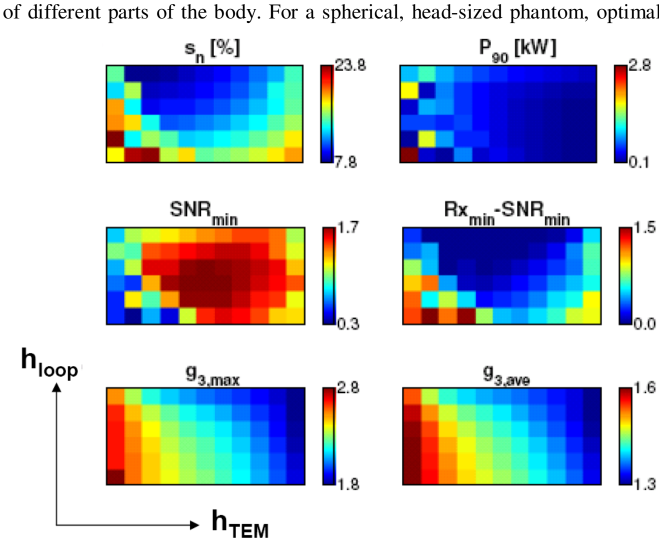

Fig. 4: Simulated properties of the 4-element Hybrid head coil array. h_{TEM}=10,15,…,60mm, h_{loop}=10,15,…,60mm.