Six Channel Transmit-Receive Coil Array for Whole Body Imaging at 4T

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Introduction: A typical coil-setup for Parallel Imaging consists of a volume transmit coil in combination with receive-only array coils. For high-field MRI on humans the power requirements and the global specific absorption rate restrict the usability of large volume transmit coils (body coils). In addition, in whole-body imaging at field strengths higher than 2T, B_1-inhomogeneities caused by wave phenomena play an important role in the design of the RF-system. According to recent studies Transmit SENSE has been found appropriate to overcome these B1-inhomogeneity problems [1]. One basic hardware requirement of Transmit SENSE, the availability of multiple independent transmit coil elements, can be fulfilled by the usage of conventional transmit/receive (TxRx) loop arrays which have been reported [2,3] for specific applications such as for head or spine imaging. In this study we demonstrate the applicability of a novel TxRx coil array for whole-body as well as cardiac imaging at 4T.

Methods: All measurements of this study were performed on a 4 Tesla whole-body MedSpec® 4T-System (Bruker BioSpin MRI GmbH, Ettlingen, Germany) equipped with 8 receive channels and a 4kW transmit amplifier. The TxRx coil array is made up of two formers positioned at opposite sides of the object under investigation, e.g. at its top and bottom. Each former is equipped with two identical rectangular TxRx CSA-antennas (dimensions: 16 x 8 x 2,5 cm^3) [4] and one circular Rx-only loop coil (diameter 20 cm) which is mounted centrically on the former (35 x 25 cm^2) between the laterally positioned CSA elements (see figure 1). The coil positions were optimized by numerical calculations performed with Concept II (TU-Hamburg-Harburg, Hamburg, Germany) and CST MWS (CST, Darmstadt, Germany). These calculations not only served to optimize the positioning of the TxRx coil elements but also to investigate how the $B_1^{(+)}$-field distribution in the region of the human heart is affected by the variation of the amplitudes and phases of the RF waves driving the four TxRx coil elements.

Because the system is so far driven with one transmitter the TxRx coil elements were fed by splitting the single transmitter signal to four signals which provided the input for four independent TxRx switches with integrated preamplifier (NF=0.5 dB, gain 27 dB). Applying a conventional 2-stage signal splitting technique we first used a power splitter to generate two signals with 0° and 90° phase shift with respect to the driving signal. Then the second stage based on two 90° power splitters with correctly adjusted cable lengths results in four ports with equal RF magnitudes and phases of 0°, 90°, 180° and 270°, respectively, for driving the array's 4 transmit-elements in a so-called birdcage mode. During the Rx operating mode the 4 transmit-receive switches ensure a separation of the Rx-path from the power amplifier by at least 45dB. The two circular Rx coils are equipped with an active-decoupling circuit and are decoupled from the CSA-array elements only via preamplifier decoupling using low input-impedance preamplifiers (R_{input}=2.6 Ω, NF=0.5 dB, gain 27 dB). The coil array was matched and tuned stationary for a medium-sized human body and first bench tests and MRI experiments were performed with a body loader (ε=76 and δ=2.2S/m).

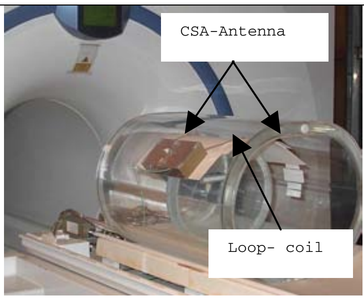

Fig.1: CSA coil setup with test phantom and body loader at the 4T whole-body MedSpec-System

Fig.2: Cardiac retrospective pulse-triggered CINE FLASH image using breath-hold with 40 ms temporal resolution (TE/TR5.3/88.8 ms, in-plane resolution: 2.2x1.77x5mm³)

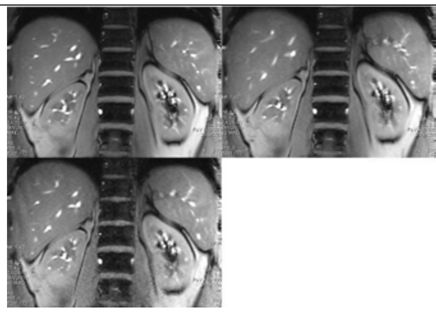

Fig.3: Comparison of standard (upper left) and PI applications with factor 2 (upper right) and factor 3 (bottom) using breath-hold FLASH (TE/TR 5.3/88.8 ms, in-plane resolution: 1.4x1.4x5.0 mm³)

Results:

Using the body-loader setup including a circular phantom the loaded Q-values of the CSA-elements and the circular coil elements were determined to 45 and 25, respectively. The decoupling of all CSA-elements was measured to a minimum value of -21dB for loaded conditions and the preamplifier decoupling isolation was found to be better than 20 dB between the circular coil and the CSA-antennas. The phantom MRI experiments confirmed the predicted sensitivity distribution for a 4-element RF coil driven in birdcage mode. In addition, the technology was investigated in-vivo using retrospective pulse-triggered CINE cardiac and routine abdominal imaging protocols (see Fig. 2&3). The resulting images show good RF penetration and were obtained with low power requirements of only 2.9kW for a 1ms block inversion pulse. Consequently, the strongly reduced energy deposition allows large volume coverage together with high spatial resolution of 1-2 mm^2 in-plane even at the high field strength of 4T and its corresponding SAR limitations.

In addition, the Parallel Imaging (PI) capabilities of the multi-coil array setup were evaluated using GRAPPA with acc. factors of up to 3. Image comparisons showed only minor artefact contaminations and high PI quality (see Fig 3) allowing a total scan time reduction from 10.1s (standard) over 5.6s (factor 2) to 4.5s (factor 3).

Discussion and conclusions: The presented coil-setup proved to be a first successful implementation of a novel multiple transmit/receive coil-array technology appropriate for whole-body imaging at 4T. It allows high field abdominal and cardiac imaging at high quality levels and low RF power levels and significantly reduced energy deposition when compared to large whole-body volume transmit-coils. Furthermore, the coil-setup is well suited for Parallel Imaging applications (e.g. GRAPPA) enabling acc. factors up to 3 without significant image quality reduction. As next step in addition to parallel imaging the multi transmit architecture will also enable new imaging applications, e.g. Transmit SENSE.

References: [1] P. Ullmann et al., Magn. Reson. Med. 54:994-1001 (2005); [2] S.B. King et al., 13th Int. ISMRM 2005, No. 30; [3] H. Nam et al., 13th Int. ISMRM 2005, No. 81; [4] S. Junge et al., 12th Int. ISMRM 2004, No. 42