Design, Evaluation and Application of a Sixteen Channel Transmit/Receive Surface Coil Array for Cardiac MRI at 7T

C. Thalhammer[1,2], W. Renz[1,3], H. Pfeiffer[4], J. Rieger[1], L. Winter[1], F. Hezel[1], F. Seifert[4], W. Hoffmann[4], R. Seemann[4], and T. Niendorf[1,5]
[1]Berlin Ultrahigh Field Facility, Max-Delbrueck Center for Molecular Medicine, Berlin, Germany, [2]University of Regensburg, Regensburg, Germany, [3]Siemens Healthcare, Erlangen, Germany, [4]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig und Berlin, Germany, [5]Experimental and Clinical Research Center (ECRC), Charité Campus Buch, Berlin, Germany

Introduction: Detrimental effects bear the potential to spoil the signal-to-noise (SNR) and contrast-to-noise (CNR) benefits of cardiac MR (CMR) at ultrahigh (≥7T) fields (1,2). B_1^+-inhomogeneities and signal voids represent the main challenges. Various coil concepts have been proposed to tackle these issues, enabling CMR images at 7 T (3,4,5). Modulating B_1^+ in two directions has been demonstrated to enhance the RF efficiency of a coil array for head imaging (6). Also, parallel imaging benefits from two-dimensional acceleration. For all these reasons, this work proposes a two dimensional 16-channel transceive array using loop elements and demonstrates its applicability for enhanced B_1^+ homogeneity and improved parallel imaging performance for cardiac MRI at 7 T.

Methods: The coil array consists of a planar posterior section (Fig. 1a) and a bent anterior section (Fig. 1b). Both sections comprise 8 rectangular elements (2 x 4 array) with an effective size of 13 cm x 6 cm each (Fig. 1a). The conductors have a width of 2 cm. Adjacent elements have a common conductor with an integrated, adjustable capacitor for decoupling of neighboring elements. To reduce the radiation losses of the array, an RF shield, made of patches of slotted copper foil, was placed at a distance of 2 cm behind the conductors. Unbalanced currents on the coaxial cables were minimized by cable traps. All 16 elements were connected to multipurpose transmit/receive switch boxes with integrated low-noise preamplifiers. Electro-magnetic (EM) field and SAR simulations were performed using CST Studio Suite 2010 (CST AG, Darmstadt, Germany) together with voxel models from the Virtual Family (7). The RF characteristics were measured using an 8-channel network analyzer (Rohde & Schwarz, Munich, Germany). The MR experiments were conducted on a 7 T scanner (Siemens Healthcare, Erlangen, Germany), equipped with an RF amplifier providing a peak power of 8 kW. The amplifier output was split into 16 equal-intensity signals with relative phase offsets of a multiple of $2\pi/16$ by means of a home-built 16 × 16 Butler matrix. These phases modes were slightly modified by phase-shifting coaxial cables to match them to the coil's geometry. Cardiac MR was performed in 6 subjects using single breath-hold 2D CINE FLASH sequences in conjunction with retrospective acoustic cardiac gating (MRI Tools GmbH, Berlin, Germany) and GRAPPA based parallel imaging.

Results: The RF characteristics were below -15 dB for element-coupling, -20 dB or less for reflection and an average of 5 for Q_U/Q_L. The values were measured on different volunteers without subject-specific tuning and matching. Noise correlation of the array was below 0.3 between all elements (Fig. 1c). SAR values, derived from the EM simulations, were well below permitted limits of the IEC guidelines (8) for an average power of 30 W over 6 minutes (Fig. 1d) (including the application of different phase configurations). A set of 3 fixed phase settings was used to avoid RF shading in the cardiac region for all subjects investigated. The acquired images exhibit a rather uniform intensity over a large region with a high myocardium/blood contrast as demonstrated in Fig. 2 for various long axis and short axis standard cardiac views. The overall image quality enabled the visualization of subtle anatomic structures such as pericardium, mitral and tricuspid valves and their associated papillary muscles and trabeculae. Accelerated 2D CINE FLASH provided excellent image quality even for R=4 as demonstrated in Fig. 3.

Discussion: Our results demonstrate that the proposed two-dimensional 16 channel coil array based on loop design is capable of producing highly uniform cardiac/torso images at 7 T. Combining a large number of surface coil elements yielded an excellent SNR and CNR and facilitated the depiction of subtle anatomical cardiac details. The excellent parallel imaging performance enabled the acquisition of high resolution images with satisfactory SNR within one breath-hold (Fig. 2d). We anticipate further improvement in image quality by using more advanced B_1^+ shimming.

References: 1) Niendorf T. et al. Eur. Radiol. 2010; 1-11. 2) von Knobelsdorff-Brenkenhoff et al. Eur. Radiol. 2010; 1-9. 3) Snyder CJ. et al. MRM 2009; 61:517-524. 4) Maderwald S. et al. ISMRM 2009, p. 822. 5)Renz W. et al. ESMRMB 2009, p. 476. 6) Adriany G. et al. ISMRM 2010, p. 3831. 7) Christ A. et al. Physics in Medicine and Biology 2010; 55:N23-N38. 8) IEC 60601-2-33 Part 2-33, Ed. 3.0 2010

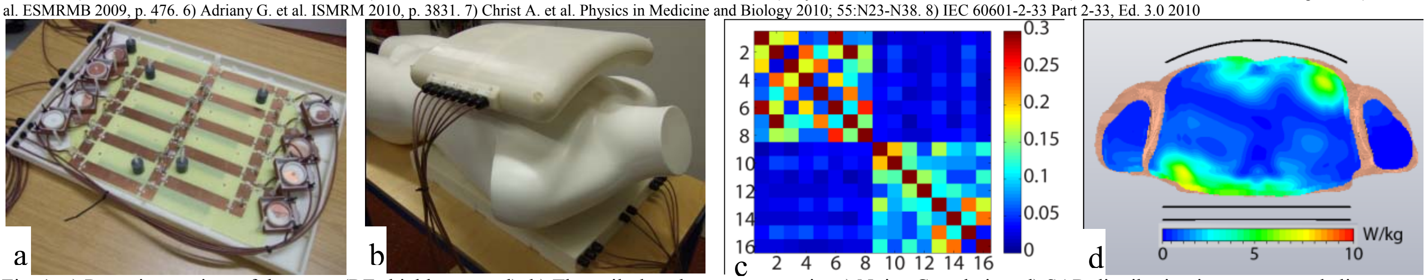

Fig. 1: a) Posterior section of the array (RF shield removed). b) The coil placed on a mannequin. c) Noise-Correlation. d) SAR distribution in a transversal slice.

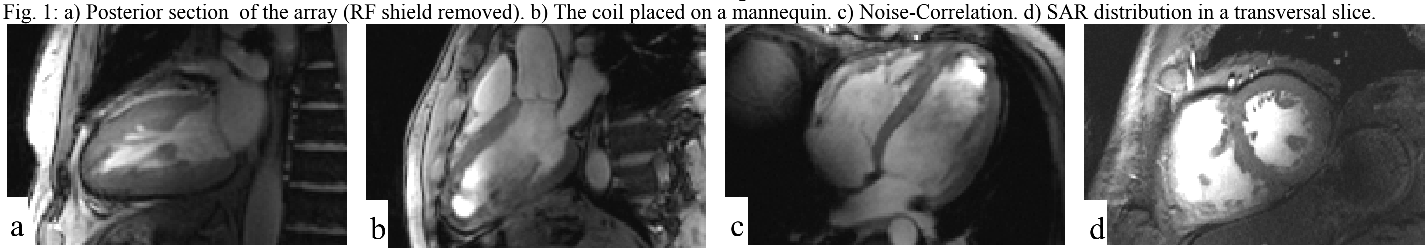

Fig. 2: a-c) 2-chamber, 3-chamber and 4-chamber view, pixel size 1.4x1.4x4 mm^3, TE/TR=2.67/48.7 ms, BW=445 Hz. d) Short axis view, pixel size 1x1x4 mm^3,TE/TR=2.96/56.9 ms, BW=445 Hz, R=2.

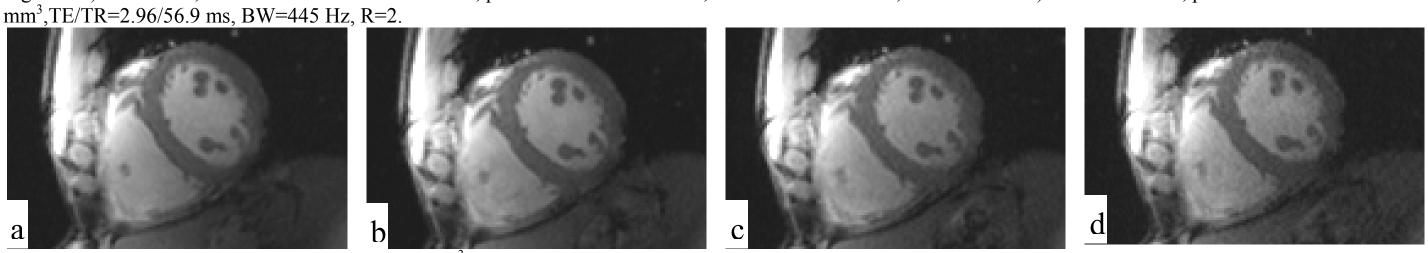

Fig. 3: a-d) Short axis view, pixel size 1.4x1.4x4 mm^3, TE/TR=4.4/80 ms, BW=445 Hz, R = 1, 2, 3 and 4 for a-d, respectively.