A two-dimensional 16 Channel Dipole Transceiver Array for Cardiac MR at 7.0 T: Design, Evaluation of RF Shimming Behavior and Application in CINE Imaging

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Target audience: This work is of interest for engineers, basic researchers, clinical scientists and clinicians interested in the progression of cardiac MR (CMR) at ultrahigh fields (UHF). Technological progress towards a clinically useful RF coil setup is presented.

Purpose: Notwithstanding its tremendous progress UHF-CMR applications development is heavily linked to improvements in radio frequency (RF) technology, since transmission field (B_1^+) non-uniformities and RF power deposition constraints bear the potential to offset some of the sensitivity gain and other benefits inherent to UHF-CMR. Serious efforts have been devoted to the development of multi transmit surface RF coil arrays tailored for UHF-CMR including strip line elements and loop elements [1,2,3]. Recent publications introduced dipole antennas as an alternative approach to provide uniform B_1^+ field distribution and to improve transmit efficiency in the short wavelength regime [3,4]. It was demonstrated that a large number of transmit elements - preferably distributed in two dimensions - enable multi-dimensional B_1^+ modulations to improve B_1^+ shimming performance and to enhance RF efficiency [5,6]. Realizing the capabilities of two-dimensional arrays together with the characteristics of radiative elements this works proposes a 16-channel transceiver dipole array and examines its applicability for UHF-CMR in a volunteer study.

Methods: For the dipole elements a building block (Figure 1a) with the dimensions (w, l, h) 75x155 x40 mm was designed [7,8]. The Dipole structure is laid out in a Bowtie shape. The box is filled with Deuterium oxide (D_2O) (ε_r=81, σ=0.02S/m) to shorten the length of the dipole, while exhibiting low losses and negligible spin excitation at 300MHz. The coil array consists of 16 dipole elements, distributed in two rings around the upper torso (Figure 1b). RF characteristics were measured for five subjects (4male, 1female; BMI 19 – 24) without subject-specific tuning and matching.
Electro-magnetic (EM) field and SAR simulations were performed using CST Studio Suite 2012 together with the voxel model Duke from the Virtual Family (ITIS Foundation, Zurich, Switzerland). The heart tissue pixels of the voxel model were used to mask the slices used for phase setting adjustments and B_1^+ optimization in MATLAB. A nonlinear optimization algorithm was used to compute the phase setting for optimal B_1^+ efficiency, based on simulated absolute B_1^+ maps. The merit function was chosen to minimize the pixel wise squared deviation from the sum of squares of the individual B_1^+ fields of the elements. With this numerical approach, the slice-by-slice (4mm slice thickness) B_1^+ transmission field performance of the dipole array was examined.
The MR experiments were conducted on a whole body 7.0 T scanner (Siemens Healthcare). The amplifier output (peak power 8 kW) was split into 16 equal-intensity signals by means of home-built power splitters. Phase adjustments were implemented by phase-shifting coaxial cables. All 16 elements were connected to multipurpose transmit/receive switch boxes with integrated low-noise preamplifiers. Cardiac MR was performed in healthy subjects using single breath-hold 2D CINE FLASH in conjunction with retrospective acoustic cardiac gating (MRI.TOOLS GmbH, Berlin, Germany) without subject-specific tuning and matching. For the in-vivo study a fixed phase setting (see Figure 1c) tailored for B_1^+ efficiency across a four chamber view was used.

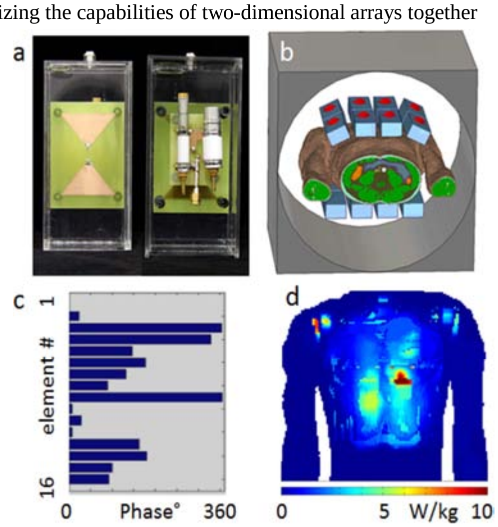

Fig. 1: a) Dipole building block b) Simulation model showing the coil placement. c) Phase setting used for imaging and SAR calculation. d) 10g averaged local SAR maximum projection plot for 40W input power.

Results: Measured over all subjects and elements reflection coefficients of -19±7 dB were observed, coupling was always below -13 dB, proving the RF characteristics being sufficiently subject independent for the regarded BMI range. SAR values, derived from EM simulations using the phase settings of the *in vivo* study were well below the limits permitted by the IEC guidelines (8) (Figure 1d).
Slice-by-slice B_1^+ efficiency optimization for a stack of short axis views of the heart revealed very smooth phase transition, with numerous phase settings being almost identical for a set of slices as demonstrated in Figure 2. The acquired standard views demonstrated uniform intensity across the entire heart - if not for the entire upper torso- with a high myocardium/blood contrast as illustrated in in Figure 3. The overall image quality and the high spatial resolution of (1.4x1.4x4) mm³ enabled the visualization of subtle anatomic structures.

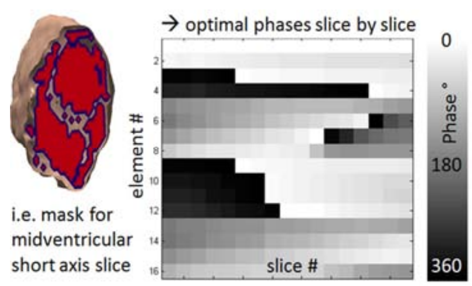

Fig. 2: Efficiency optimized phase settings calculated for a set of short axis view slices covering the entire heart. Only minor slice-to-slice changes were observed, which affords a universal phase setting for whole heart coverage.

Discussion: Our results demonstrate that, once phase-optimized for a certain body geometry/BMI, the proposed 16 channel dipole array supports the acquisition of uniform long and short axis views of the heart at 7.0 T using a fixed RF shim setting derived from EMF simulations without the need for patient specific coil or transmission field mapping/adjustments. This behavior can be attributed to the characteristic symmetric B_1^+distribution with a slow varying phase of the individual dipole elements. The uniform B_1^+distribution and efficiency obtained for 2D CINE FLASH imaging at 7.0 T is heartening and the driving force for further explorations into SSFP and fast spin-echo imaging of the heart at 7.0 T.

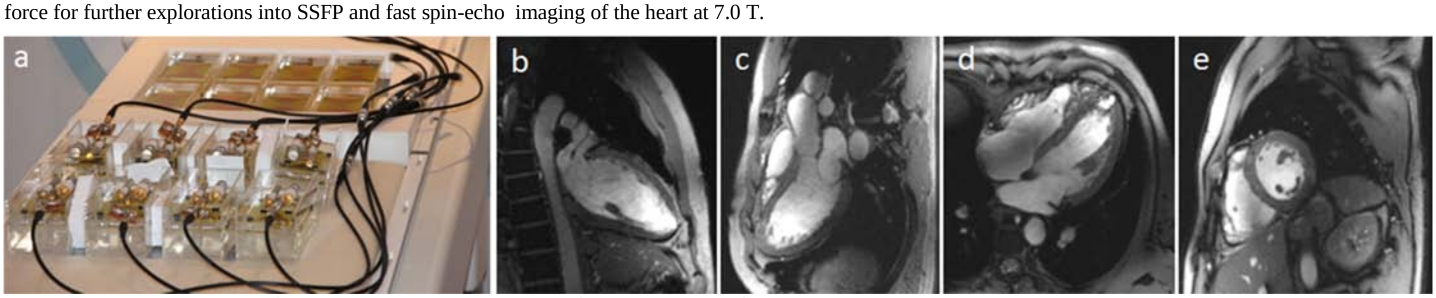

Fig. 3: a) Final coil setup used for the in vivo study. b-e) Images of the heart derived from 2D CINE FLASH imaging within a single breathhold using the proposed 16 channel transceiver coil design together with the universal transmit phases shown in Figure 1c (voxel size (1.4 x 1.4 x 4) mm^3, TE/TR=2.7/5.7 ms, BW=444 Hz/Pixel, 7 views per segment GRAPPA R=2): b) 2 chamber view. c) 3 chamber view, d) 4 chamber view, and e) short axis view.

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