Design of a resonant ceramic array for cardiac imaging at high field strengths

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Target Audience MRI coil designers, researchers working in high field cardiac magnetic resonance.

Purpose To design a new ceramic-based transmit/receive coil array for cardiac imaging at 7 Tesla.

Introduction Imaging of the human heart at higher field strengths (7T and higher) is a major challenge due to signal voids introduced by dielectric properties of the body and wavelength effects. Nevertheless, initial results suggest that the high field strength can provide data of higher quality than at lower fields [1]. It has been shown that with multiple transmit / receive coils coverage over the entire heart can be achieved [2,3]. Most cardiac imaging coils for 7T are based on lumped elements and copper strips or transmission line elements with the design goal to be as close as possible to the human body with the coil elements in order to get the highest SNR. Recently an alternative design was presented using dipole antennas mounted on high permittivity non-resonant ceramic blocks in order to force the penetrating wave into the far field region [4]. In this current work a new concept is presented which uses high permittivity ceramic discs which, when coupled to the body, are designed to resonate in the TE_{01} mode.

Methods Eight high ceramic disks were designed with dielectric constant 178, diameter 8.6 cm, and height 3.9 cm. The end of the disc furthest from the patient had a conducting "endplate shield" placed in close vicinity. Inductively-coupled circular loops (30 mm diameter, 35µm thick copper on FR4) with series/parallel capacitors were used for impedance matching. All elements reached at least -15 dB for S11 measurements when placed on the body. Four disks were mounted on the posterior side in a home build housing forming an evenly spaced column with 2.5 cm clear gap between the resonators; the outer elements were elevated 10 degrees towards the body to allow for better comfort. The remaining 4 disks were fitted into home build rapid prototyping housings, allowing each element to be placed independently on the chest (Figure A). The coupling between next nearest elements (S_{21}) was -20 dB or lower. All experiments were performed on a Philips 7T MRI system with independent amplitude and phase modulation for each of the two channels. Using custom-built power splitters each channel was split up four times and connected via custom-built T/R switches to the single elements of the array: thus four elements must have the same phase and amplitude. Cine images were acquired with the following parameters: TE = 1.2 ms TR = 4.5 ms, voxel size = 1.3x1.4 mm^2, slice thickness 8 mm, flip angle 20 degrees, resulting in a single slice per 10 seconds breath hold.

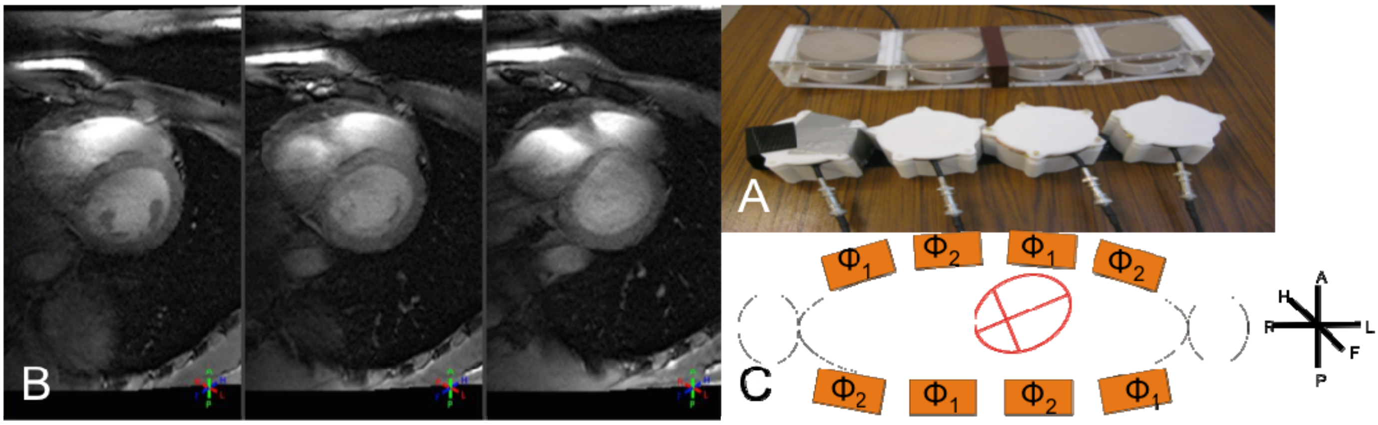

Figure A shows the coil array with the posterior elements in a single housing and the anterior elements in single housings mounted on Velcro for easier positioning on the chest. Figure B shows three two-chamber slices across the heart. Figure C shows the phase setting of the elements in relation to the human chest with Φ_1=0 deg and Φ_2=270 deg.

Results Figure B show a series of two chamber images acquired with the best combination of transmit phases for each set of four elements, shown in Figure C. Coverage of the heart is much greater than obtained in previous studies using a quadrature surface coil, and approaches that using fully operational eight or more channel transmit array systems [2-4]. The images show reasonable contrast between the myocardium and blood pool and a fairly homogeneous signal intensity over the field of view.

Discussion This work presents a new design of body coil for high field MRI based upon high permittivity ceramics which, when coupled to the body, resonate in a particular electromagnetic mode. Although in the isolated resonators, much of the magnetic field is stored within the resonator, the use of a shield and coupling to the high permittivity body produces significant "leakage" of magnetic field into the body. The optimum value of permittivity and performance as a leaky waveguide remains to be determined, but the design adds to a growing field in which high permittivity ceramics form an integral part of resonator design.

Conclusion High permittivity ceramic resonators represent a new and promising approach to high field MRI in humans.

References [1] S.van Elderen et al. Radiology, 257, 254, 2010. [2] C.J.Snyder et al. MRM 61, 517, 2009. [3] L.Winter et al. Eur.J.Radiol. 22, 2211, 2012. [4] A.Raajimakers et al. MRM 66:1488 (2011).