A quadrature HEM11 mode resonator as a new volume coil for high field MRI

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Introduction Most RF coils are based on lumped elements and copper strips, or transmission line elements.. Steady increases in static magnetic field strengths make it possible to use simple cavity and dielectric resonator designs which are high frequency devices in which the operating frequency is determined by the geometry and material properties. For example, water can be used to produce dielectric resonators at 4T [1] and 7T [2]. However, no practical design that makes use of the two degenerate, quadrature HEM_{11} resonant modes for human imaging has been presented. In this work a resonator that makes use of this HEM_{11} mode to image the extremities at 7 T was simulated, designed and constructed.

Methods All experiments were performed using a Philips Achieva whole body 7T MRI system. Initial estimates for the dimensions of the RF coil for the HEM_{11}mode were derived from well-known empirical formulae for resonant modes of cylindrical dielectric resonators. A concentric configuration of two plastic tubes was used to form a resonant annulus with dimensions 140 mm outer radius, 80 mm inner radius and a length of 153 mm. The volume between the two cylinders was filled with deionized water. The filled compartment was sealed and two circular loops with a diameter of 30 mm were mounted on the outside of the resonator at 90 degrees to one another to excite the quadrature, degenerate HEM_{11} modes of the resonator. Variable capacitors were used for impedance matching to 50 Ω at 298.1 MHz.. Electromagnetic simulations were performed using the xFDTD package (Remcom, State College, PA, USA).

Results The measured Q for the matched resonator was ~50, with S_{11} and S_{12} measurements of the two modes below -20 dB. Figure 1A shows an image (multi slice gradient echo TR/TE 141/2.1 ms, tip angle 50^o, slice thickness 5 mm) of a mineral oil phantom placed in the HEM resonator. This shows that the field is relatively homogeneous, even with a sample of very low permittivity within the outer annulus.. Figure 1B shows a multi slice gradient echo sagittal image of a healthy human wrist (TR/TE 249.5/3.5 ms, tip angle 50^o, slice thickness 2 mm). Figure C shows a photograph of the resonator with a human wrist inside showing the two impedance matching coupling loops. Figures 1D and 1E show the results of the simulations with the cylinder filled with muscle tissue, demonstrating a homogeneous RF field produced perpendicular to B_0: only one mode of the resonator is shown for clarity, the other mode is identical but rotated by 90^o.

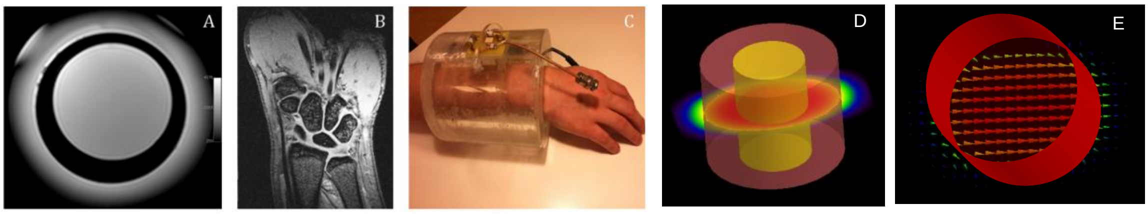

Figure 1. A. Image of an oil phantom inside the HEM resonator. B. Single slice from a 2D multislice data set from the wrist of a healthy volunteer positioned within the resonator. C. Photograph of the setup. D. Simulation of the B_1^+ field within the water cylinder (pink) and muscle tissue (yellow) from one of the degenerate HEM modes. E. Corresponding vector plot of the B-field with the outline of the outer cylindrical surface shown.

Discussion This work shows that dielectric resonators operating in the HEM_{11} mode are promising designs for high field volume resonators. Construction is extremely simple and eliminates the requirement for multiple tuning elements. A number of simple further refinements are being implemented: (i) the resonator itself can be made "MRI invisible" by using D_2O instead of H_20 or by doping with paramagnetic contrast agent, (ii) low-loss, high permittivity ceramics or suspensions can be incorporated to make smaller resonators [3], and (iii) lower permittivity materials can be used for larger designs.

References [1] H.Wen et al. J.Magn.Reson. B, 110, 117-123, 1996. [2] A.G.Webb, J.Magn.Reson. in press, 2011. [3] A.G.Webb, Concepts Magn.Reson 38A, 148-184, 2011.