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$^{11}_{11}$ resonant modes for human imaging has been presented. In this work a resonator that makes use of this HEM$^{11}_{11}$ 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$^{11}_{11}$ 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$^{11}_{11}$ modes of the resonator. Variable capacitors were used for impedance matching to 50 $\Omega$ 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°, 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°, 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°.

Discussion  This work shows that dielectric resonators operating in the HEM$^{11}_{11}$ 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$_2$O instead of H$_2$O 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.