Design of a 24-Mesh Inductive Birdcage for Imaging of the Head at 500 MHz

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Audience: MR physicists and RF engineers, coil design for high-field MRI

Purpose

Quadrature volume coils for the head and head-size phantoms are often used as transmit coils and provide a measure of baseline performance for high-field systems. When mounted inside a shield, an inductive birdcage is a backward-wave structure that can be tuned to very-high frequency. A 24-mesh version of this resonator has been constructed for imaging of the human head at 7T[1]. A prototype version of the resonator could be tuned to a frequency of 538 MHz, demonstrating feasibility for use at 11.7T [2]. Because the cylindrical shield of the coil is open at both ends, the coil has a propensity to radiate and to couple strongly to connecting cables. To mitigate these problems, direct connection to the resonator was avoided, and planar inductive couplers were mounted in parallel with the struts of the coil. Inductive couplers with single-ended connections at the back end of the coil did not adequately reduce stray fields, so balanced couplers with low-impedance connections at both ends of the coupler were developed. A completed coil utilizing four-port drive is described and is used for power deposition measurements in a custom loading phantom.

Methods: An inductive birdcage with 24 isolated meshes was constructed on a 280 mm diameter cylinder of G-10 material (5 mm wall), as indicated in Fig. 1. Gapped end-rings fabricated from 10 mil, FR-4 were wrapped on the outside of the cylinder with an 18 cm spacing, center-to-center. Rectangular struts, 8 mm wide, 19 cm long, cut from eighth inch thick double-clad Teflon PCB (Polyflon, Norwalk, CT) were attached in the gaps of the end-rings, forming the meshes of the coil. Each strut contained four pairs of capacitor breaks equally spaced along its length, with outer gaps positioned close to the end-rings. The shield of the coil was assembled from four pieces of flexible (10 mil) FR-4 PCB mounted on the inside of a 320 mm diameter cylinder with an inner diameter of 314 mm. Quadrature drive with four-port connection to the coil was made using180° splitters, one λ cables, and planar inductive couplers (Fig 2). A balanced coupler mounted to the coil shield (Fig. 2b) provided the greatest reduction in stray E-fields and stability for tuning/matching. A head-size phantom Fig. 3a (Phantom Labs, Niskayuna, NY) filled with 50% saline was used to load the coil for tuning. The water of the head phantom was imaged with MRI, rendered, and used for Electro-magnetic field simulations of power deposition (Fig. 3). For SAR measurement, a box phantom was fabricated with inner dimensions of 14cm x 14cm x 19cm and filled separately with a sugar-gel mixture (ε_r= 45, conductivity = 0.59 S/m).

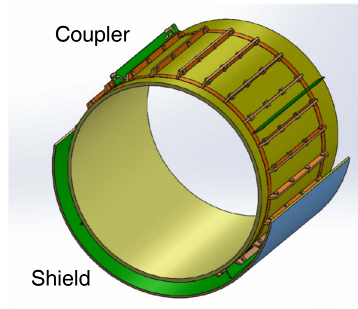


Fig. 1. A 24-mesh inductive birdcage with end-rings gapped at each strut.

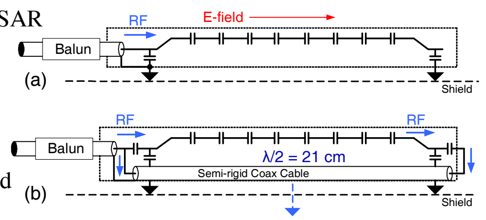


Fig. 2. (a) Planar coupler with single-sided drive and (b) planar coupler with balanced drive (Zin ≈ 25 Ohms).

Results: The coil could be tuned to 495 MHz using mainly 6.2 pF capacitors (176) and 5.6 pF capacitors (16) placed symmetrically in outer gaps. Insertion of a head or the head phantom caused an upward shift in frequency of another 4 MHz. Unloaded Q's of the linear modes measured using S_{21} were 39 and 41. Bench sensitivity (S_{21}) measured with a 3 cm loop (area = 6.6 cm^2, L = 63 nH) was -31 dB for the unloaded coil, equiv. to a B1 of 3.9 μT, CP for100 Watts of input power. Loading by the phantom reduced this by 3.5-4.5 dB. Using the loop, B1 uniformity in the central plane was uniform within 1 dB from the coil center to approximately 80% of the radius. E&M simulations of power deposition in the head phantom (Fig. 3b and c) were performed using the FDTD method with a numerical model of the phantom that was extracted from MRI images using image segmentation techniques. The results illustrate the strong dielectric effects at 500 MHz. Power deposition in the box phantom was measured using 890 Watts total power, 20% DC. Temperature was monitored using optical sensors at the (6cm, -6cm, 0cm) (red) and (6cm, -6cm, 8.5cm) (green) locations (x,y,z) and on an external bottle serving as a reference. In Fig. 4, elevated temperature was observed in the central plane of the sample where RF currents were high (red).

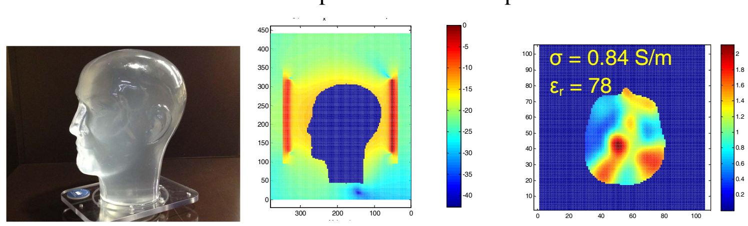
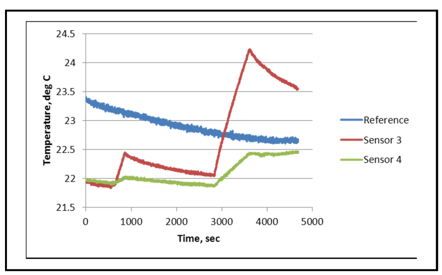


Fig. 3. (a) The head phantom. (b) Simulated B1 field distribution outside the phantom. (c) Simulated temperature map after turning on the coil (100% duty cycle) for 10 min.

Discussion: A head-size, inductively coupled birdcage is capable of resonating at very high MRI frequencies. Isolating the coil by using inductive coupling minimizes coupling of stray electric fields to the head and minimizes coupling to external cables. Balanced inductive couplers maintain a virtual ground at the center of the coil and further reduce external couplings. Induced B1 fields of the unloaded resonator are quite uniform in the coil interior, and loop sensitivity indicates that transmit efficiency should be comparable to that of a 7T copy of the coil.

Fig. 4. Temperature measurement of the box phantom.



References: 1. Murphy-Boesch, J. A Distributed Impedance Model for the Shielded 7T Inductive Head Coil. Proc. ISMRM 2010; 18: 3817.
2. Murphy-Boesch, J., Dodd, S., van Gelderen, P., Koretsky, A., Duyn, J.H. A Prototype Head Coil for 11.7T using the Inductive Birdcage Geometry. Proc. ISMRM 2011; 19: 3986.