A 7 Tesla Gradient Mode Birdcage Coil for Improved Temporal and Occipital Lobe SNR

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Introduction B1 inhomogeneity is a persistent problem for high field imaging. Using a standard birdcage or TEM volume coil at 7T yields flip angles which are 42% lower in the periphery of the brain compared to centrally, due to dielectric effects [1]. Areas with low transmit efficiency (and also, by reciprocity, low receive efficiency) commonly include the temporal lobes, parts of the occipital cortex and the cerebellum. Various approaches have been proposed to mitigate B1 inhomogeneity at high field. These include B1 shimming [2], spiral birdcage designs [3], the use of dielectric pillows [3] or detuned surface coils [4], and shaped RF pulses, which may become practicable with the use of transmit SENSE [5]. Birdcage and TEM volume coils are almost invariably used in the so-called uniform mode, where the currents in the rungs vary as sine(ϕ), where ϕ describes the position around the circumference of the coil in cylindrical coordinates. This creates, in the absence of a sample, a highly uniform B1 field. Other modes of oscillation also exist for these coils, including the first "gradient mode", where the rung currents vary as sine(2ϕ), creating a B1 field which is zero at the center and increases towards the outside of the coil [6]. This mode has been used in MRI imaging previously by shifting its frequency to coincide with the uniform mode to allow phased array type reception from a volume coil [7] [8]. We describe the use of a birdcage coil tuned exclusively to the first gradient mode for increasing the SNR in the temporal lobes, occipital lobes and cerebellum and compare its sensitivity to that of an identically sized birdcage coil in the uniform mode.

Methods The coils were developed and tested on a prototype 7T human scanner (Siemens Medical Solutions, Erlangen, Germany). Two birdcage coils were constructed on identical acrylic formers using routed FR4 circuitboard to lay out the conductors for the rungs and endrings (fig 1). The coils were an open-ended, hybrid birdcage design, with a diameter of 28cm, 16 rungs of 20cm length, four segments to each rung and a conductor width of 1cm. The 36 cm diameter gradient shield provided a unconnected but close-fitting shield for the birdcage. The first coil was tuned to the uniform mode by attaching capacitors of 10pF in the endrings and 4.2pF in the rung capacitor positions. Coaxial cables were connected via match circuits across endring capacitors at two points 90 degrees apart on the coil with a cable trap in each coax to reduce common mode currents. The second coil was tuned to the first gradient mode by attaching capacitors of approximately 16pF in the endrings and 6.7pF in the rung capacitor positions. For this coil, because of the sine(2ϕ) current distribution of the modes, cables were attached at two points 45 degrees apart to drive the two orthogonal modes. In both cases the two ports were driven and received with a 90 degree phase relationship. Loaded and unloaded Q values were obtained with an S12 measure between two shielded probes loosely coupled to the coil, with the coil empty or loaded with a head shaped loading water phantom.

To confirm the scanner transmit voltage calibration, a series of low resolution gradient echo scans (TR/TE = 2000ms / 3.6ms , 64x64, FOV = 250mm) were performed with flip angles varying from 60 to 110 degrees in 10 degree steps. Image intensity in a particular ROI was measured and compared across scans to look for the maximum signal intensity, and hence the image with closest to 90 degrees flip angle in that ROI. For SNR comparison, images were made with identical parameters with the two coils on a human subject. SNR maps were obtained from gradient echo images (TR/TE/flip = 200 / 4.03 / 20, 256x256, FOV = 220mm). SNR profiles were generated from the SNR maps.

Results The unloaded to loaded Q ratio was 3.6 for the uniform mode coil and 8.6 for the gradient mode coil. An S12 measure between the two ports of the loaded coils showed quadrature isolation of -17dB for the uniform mode coil and -14.5dB for the gradient mode coil. Both coils could be tuned and matched to a human head. With a human subject in the scanner, a transmit voltage calibration was performed for each coil as usual, yielding 229 volts for the uniform mode coil and 288 volts for the gradient mode coil. Examination of a series of gradient echo images with varying flip angles revealed that for both coils the scanner's automatic transmit adjustment produced its target flip angle in the region of highest transmit and receive efficiency (near the thalamus in the case of the uniform mode coil and in the occipital cortex for the gradient mode coil).

The SNR maps (fig 2) show the usual center brightening for the uniform mode coil, with significantly lower SNR in the temporal lobes and cerebellum. While the low SNR at the apex could be addressed by incorporating an endcap in the coil design, this would prevent easy presentation of visual stimulus in functional experiments. The gradient mode coil shows the expected signal null down the center of the coil, but shows the highest sensitivity in the occipital cortex and temporal lobes, almost the inverse of the uniform mode coil. The SNR gain with the gradient mode coil is about 3.3 fold in the temporal lobes, 1.5 fold in the occipital cortex and approximately a factor of 2 in the cerebellum. The SNR distribution through the temporal lobes can be seen more clearly in the SNR profiles (fig 3).

Conclusions A 7 Tesla gradient mode birdcage coil has been constructed and compared to an identically sized uniform mode birdcage in human brain imaging. While the gradient mode does not solve the problem of B1 inhomogeneity in high field brain imaging, it provides a complimentary spatial pattern, and thus offers a way to get substantial SNR gains in particular regions of the brain that are normally poorly served by the standard coil designs. A detuneable gradient mode coil, used in conjunction with a phased array receiver, would make it easy to achieve the target flip angle in the temporal lobes without the use of excessively high transmit voltages, and thus provide extremely high SNR images of the temporal and occipital lobes. Work is underway to pursue this approach.

Fig. 1 Gradient mode birdcage coil, formed from machined circuitboard on an acrylic former. Uniform mode coil is almost identical

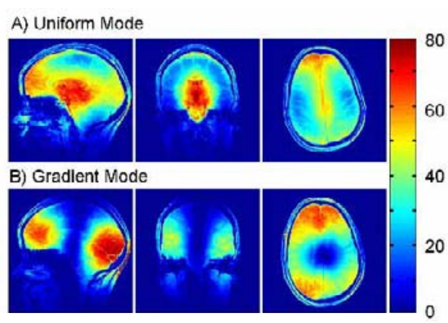

Fig. 2 SNR maps for the two different birdcage coils. Areas typically problematic for uniform mode coils (e.g. temporal lobes) are improved with the gradient mode coil

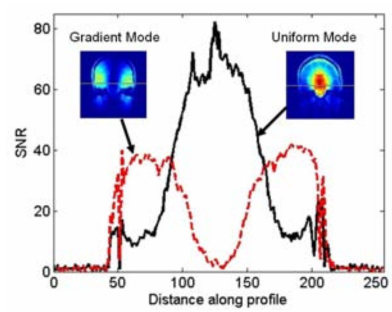

Fig. 3 SNR profiles through the temporal lobes from a coronal image. The gradient mode coil provides 3.3 fold SNR improvement in most of the temporal lobe

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