Technology development for sub-0.3 mm voxel functional imaging of the murine forepaw barrel subfield at 400MHz (9.4T)

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Target Audience: Engineers involved with designing, testing, and building surface coils for high field strength animal imaging; fMRI / fcMRI researchers attempting to image specific animal brain structures at high resolution.

Purpose: Development of a site-specific surface coil for imaging the rat brain forepaw barrel subfield (FBS) at the highest resolution attainable with current magnet and gradient hardware. In order to significantly improve image quality for MRI, fMRI (functional MRI), and fcMRI (functional connectivity MRI) it is necessary to design and build specific-use coils with geometries chosen to maximize B_1 filling factor. The commercial Bruker (Billerica, MA) 9.4T Surface Coil is overly large compared to the individual structures of the brain and cannot provide the signal-to-noise ratio (SNR) necessary to produce images at high resolutions (sub-0.3 mm cubic voxel). This site-specific coil design provides a smaller, more appropriate reception field to image the FBS at resolutions previously unseen in the field of small-animal imaging.

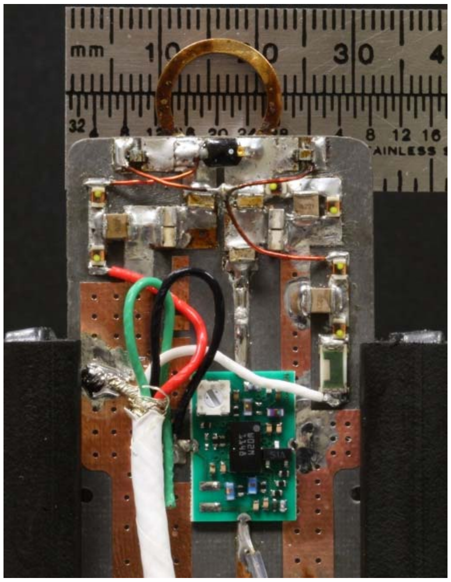

Figure 1 - 10mm ID Coil with LNA

Methods: The coil is a machined copper loop with ID of 10 mm, OD of 13 mm, and a height of 2 mm. An American Technical Ceramics (Huntington Station, NY) 800R series, high-Q, non-magnetic capacitor is soldered directly into a gap cut into the loop. The loop is attached to a Rogers RT/duroid 5880 low-loss circuit board with 1-ounce copper trace on both sides. The PC board is designed in AutoCAD and electronically delivered to Streamline Circuits (Santa Clara, CA) for etching. A WanTCom (Chanhassen, MN) WMA9RA low-noise amplifier (LNA) with an input impedance of 1.5 Ohms and an overall gain of 28 dB, is silver-epoxied to the circuit board at a distance of one inch from the coil. PC board dimensions and LNA ground plane were meticulously designed to meet the specifications for the LNA. The completed coil design is shown in Figure 1.

An electrically balanced circuit design [1] employed with fixed capacitor match circuitry is adjusted to accommodate a rat load of 200 g to 600 g. Tuning is achieved using an Aeroflex (Plainview, NY) MGV125-25 varactor diode in parallel with the coil capacitor. Small values of varactor diode capacitance maximize overall Q-values of the probe. The coil is detuned during the transmit phase of the MRI sequence using two Panasonic (Kadoma, Osaka, Japan) MA2JP02 pin diodes and bench tested to achieve a minimum of 20 dB isolation at 400 MHz under the detuned condition. The output of the LNA connects to the Bruker pre-amplifier by a Coast Wire (Carson, CA) RG-316 double-shielded cable. A typical return loss of 5 dB is seen in experiments from the coil to the pre-amplifier. This signal path loss is negated with an LNA on-board. All coil control voltages (tune, detune, and LNA DC power) are provided through a shielded Belden (St. Louis, MO) 4-conductor cable connected to the standard Bruker coil control port. From the MRI technician's point of view, utilizing this coil for a study is no different in procedure than using the Bruker standard product.

Results: Bruker ParaVision acquisition software is used for echo-planar imaging (EPI) sequence selection and image reconstruction. Table 1 compares the graphically computed SNR of an EPI sequence using half k-space for three different voxel sizes. The SNR from an equivalent scan using the Bruker surface coil is provided for comparison. Signal-to-noise ratio calculations are performed in ParaVision by selecting a pixel equivalent region in the corpus callosum and noise region in a comparable slice.

The new coil design, with LNA on-board, shows a factor of 2.74 increase in SNR over the Bruker coil at 300 micron cubic voxel resolution. Additionally, this increase in SNR allows brain structure to be imaged at a previously unattainable resolution, as low as 200 micron cubic for typical studies. It is possible to discern distinct fMRI BOLD activation of the FBS at the cortical column level at this resolution. Smaller voxel sizes are possible in-plane, though the current gradient coil configuration is unable to accommodate transverse-plane slice thickness of less than 200 micron.

Table 1 - Voxel Size SNR Comparison

	Bruker	10mm w/ LNA
Q_0 with rat load	70	120
	SNR	
300 x 300 x 300 micron	20.42	56.04
200 x 200 x 200 micron	4.84	21.23
150 x 150 x 200 micron	-	11.25
100 x 100 x 200 micron	-	11.04

Conclusion: The standard Bruker Surface Coil does not provide sufficient SNR to image the small structures of the rat brain required for fMRI studies of the forepaw barrel subfield. Developing a site-specific surface coil, utilizing low loss components, and placing an LNA on-board is necessary for these studies to be successful. The result is a nearly three-fold increase in SNR at a typical resolution used in these studies. The increase in SNR has made it possible to routinely image at 200 micron cubic voxel resolution, allowing the researcher to pinpoint fMRI BOLD activation to a specific cortical column.

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[1] Doty, F. D., Entzminger, G., Kulkarni, J., Pamarthy, K. and Staab, J. P. (2007), Radio frequency coil technology for small-animal MRI. NMR Biomed., 20: 304–325. doi: 10.1002/nbm.1149