Quadrature RF Coil and Phased Array Operation at 21.1 T

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Introduction: The use of ultra-high magnetic fields for magnetic resonance imaging has the ability to increased signal-to-noise ratios (*SNR*s), higher spatial resolution and/or reduced imaging times. The highest of field currently available for imaging pursuits is 21.1 T. Increased wavelength effects and radiation and component losses caused by high operating frequencies at 21.1 T (900 MHz for ^{1}H) make efficient radio frequency (RF) coils difficult to design. The ability to overcome potential B_1 inhomogeneities resulting from such effects while maintaining high *SNR* is critical for the successful acquisition of *in vivo* data from pre-clinical animal models. The goal of this effort is to construct custom RF coil arrays that will provide improved *SNR* and parallel imaging functionality at 21.1 T. A transmit-receive quadrature driven saddle pair design is discussed as well as its extension to additional multi-channel configurations.

Methods: Experiments were performed using an ultra-widebore (105-mm) 21.1 T magnet. Two quadrature driven saddle pairs have been constructed for mouse and rat imaging *in vivo*. The mouse coil consists of a saddle pair fabricated from 27.40 x 25.25-mm copper tape on 14.5-mm inner diameter polypropylene tube. The rat coil was constructed from a custom built 60-µm thick copper-clad laminate (DuPont Pyralux, Wilmington, DE, USA), which consist of copper foil (32.02 x 30.25 mm) adherent to a Kapton polyimide film. The laminate was placed on top of a cylindrical G10 fiberglass epoxy cylinder with a 36-mm outer diameter that can accommodate the rat head (Fig. 1). The coils of both saddle pairs were decoupled across a common conductor leg using a Giga-Trim variable capacitor (Johanson, Boonton, NJ, USA). A hybrid coupler (R&D Microwaves, East Hanover, NJ, USA) was used to achieve a 90-degree phase shift between channels. Quadrature performance was assessed using water phantoms to measure signal homogeneity and *SNR*. Rat brains also were imaged to investigate homogeneity across biological relevant samples.

Results: Network analyzer measurements conducted at 900 MHz demonstrated S11 and S22 reflection attenuations below -21 dB whereas the isolation between channels ranged from -3 to -7 dB. In order to evaluate the enhancements in *SNR*, a single RF saddle coil was run as a single linear coil in comparison to the operation of both coils driven in quadrature (Fig. 2). The enhancements in quadrature operation over linear operation are expected to yield an improvement in *SNR* by a factor up to $\sqrt{2}$. With a region of interest enclosing the entire water sample, quadrature coil tests show an improvement in *SNR* by a factor of 1.34, a value close the theoretical yield. With quadrature drive, there is a 50% drop in signal intensity at approximately 5 mm from the surface of the saddle pair. The results indicate that this mouse coil configuration provides the penetration depth necessary to image a whole mouse head or an excised rat brain. The configuration mentioned above with the larger coil dimensions is currently being tested with a modulate probe body that incorporates monitoring apparatus for *in vivo* imaging. Fig. 3 displays *ex vivo* data of a rat brain injected with iron oxide nanoparticles.

Discussion: This work shows the feasibility of implementing a transmit-receive quadrature coil with a common conductor for ultra-high field applications. Coil tests show a homogeneous B_1 profile with up to a 34% increase in *SNR* when operated in quadrature. This *SNR* increase was observed by Gareis *et al*. (2006) when comparing a quad surface coil with a similarly sized birdcage at 17.6 T [1]. The *ex vivo* images show a homogeneous distribution in signal (left image), which supersedes even potential *SNR* gains in importance for imaging applications at high fields. Additionally, this coil has been operated as a two-element array, achieving acquisition time improvements through PI techniques. Current efforts are directed at expanding this effort into a four element transceive array for 21.1 T.

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[1] D. Gareis, at al. 2006. Concepts Magn Reson Part B. 29B:20-27.

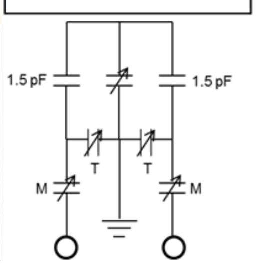


Fig 1: Quadrature saddle pair alongside the lumped element circuit design.

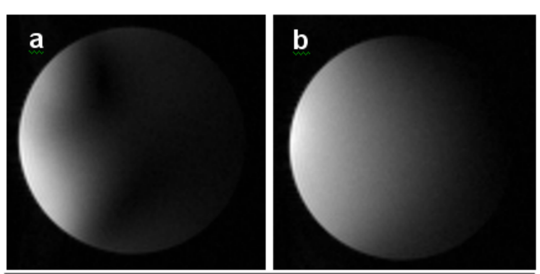
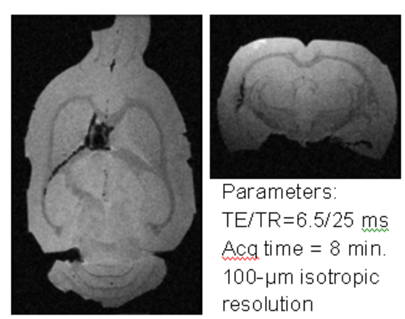


Figure 2: Gradient echo images of water phantom using linear (a) and quadrature (b) modes; TE/TR = 4/350 ms; 2 x 2 cm FOV.



Parameters:
TE/TR=6.5/25 ms
Acq time = 8 min.
100-µm isotropic resolution

Figure 3: 3D gradient recalled echo images of an excised rat brain.