A Nested Dual Frequency Birdcage/Stripline Coil for Sodium/Proton Brain Imaging at 7T

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Introduction: Dual tuned sodium/proton coils are valuable for multi-nuclear magnetic resonance imaging and spectroscopy. Due to low sodium content in the body and its low gyromagnetic ratio, the critical design aim for a sodium/proton coil is to maximize sodium sensitivity and homogeneity while maintaining adequate proton sensitivity. This has previously been achieved using a dual-tuned birdcage coil (1) incorporating high-impedance “trap” circuits that permit dual resonance (2,3). Compared to a single tuned coil, this approach has yielded detectors with 80-90% efficiency at the low resonance frequency and 40-50% efficiency at the high resonance frequency. While this design has the benefit of packaging both coils on a single structure, it requires numerous identical traps that can make tuning an arduous task, especially for high field applications. High field is particularly beneficial for sodium imaging because the high field signal-to-noise advantage helps to compensate for the inherently weak sodium signal. Another proposed approach is a stripline array with alternating elements tuned to different frequencies (4).

Rather than implement a dual-tuned coil, we explored a nested-coil configuration for sodium/proton imaging at 7T with the goal of maintaining as much SNR performance as possible at the sodium frequency. A traditional single-tuned birdcage coil was used for sodium excitation and detection and an eight-channel stripline array was used for proton. Striplines have become popular for high-field MRI due to their spatially distinct sensitivity pattern, self-contained E-fields, and relatively low inter-element coupling (5). In this dual frequency application, we hypothesized that the high pass birdcage would have little interaction with the stripline elements. Correspondingly, particular attention was given to the effect of the proton striplines on the performance of the sodium birdcage.

Methods: For the sodium side, a standard high pass birdcage coil with eight 19cm rungs was built on a cylindrical acrylic former with 27.9cm diameter (Fig. 1). The high pass design was selected since the high-order birdcage modes occur at frequencies below the 78MHz uniform mode, and interaction with 297MHz proton coil should be minimized (Fig. 2). Birdcage resonance at 78.6MHz was achieved by inserting 33pF capacitors at 16 locations along the endrings. In transmit mode, the birdcage was driven in quadrature through a 90° hybrid. In receive mode, the signals from each quadrature channel were fed to independent preamplifiers (6). The isolated sodium birdcage was characterized on the bench by measuring the loaded (1890mL water phantom with 7.1g $NiSO_4 \times 6H_2O$ and 9.5g NaCl) and unloaded quality factor (Q) and on a whole-body scanner (MAGNETOM 7T, Siemens Healthcare, Erlangen, Germany) by measuring the RF transmit voltage required for a 90° flip angle with a 500μs hard pulse and the signal-to-noise ratio (SNR) of a gradient echo image in the transverse plane in the center of the coil. Complex k-space signal and noise from both channels were used to generate the combined image with optimal SNR. These measurements were repeated after introduction of the proton striplines.

Fig. 1. Photograph of the sodium/proton coil.

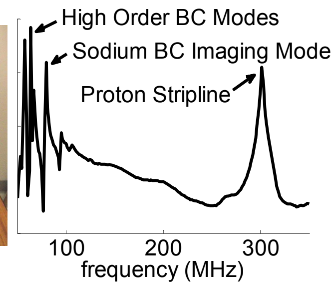

Fig. 2. Coil response.

Eight proton striplines were centered between the birdcage rungs and mounted on the acrylic former. The striplines were built on 15x4x1.3cm^3 teflon bars with ground planes formed using 4cm wide copper tape and sidewalls with 1.3cm height to reduce inter-element coupling (4). The active element was formed using 14x2cm^2 copper tape. Two capacitors of approximately 6.8 pF and 8.2 pF were distributed at opposing ends of the striplines to achieve resonance at 297.2 MHz. Separate baluns tuned to proton and sodium frequencies were utilized to reduce currents on the coaxial cable shields. Excitation was provided via an eight-way power splitter consisting of a three stage cascade of seven Wilkinson power dividers. The stripline array was driven in a birdcage-like manner, with 45° phase delays between each element corresponding to their azimuthal position. Signals received from each element were fed to independent preamplifiers via coaxial cable of appropriate length for preamplifier decoupling (7). The stripline array was characterized by measuring the loaded (7300mL water phantom with 9.1g $NiSO_4 \times 6H_2O$ and 19.1g NaCl) and unloaded Q, RF transmit voltage required to achieve a 90° flip angle with a 1ms hard pulse and the signal-to-noise ratio (SNR) in the center of the phantom. Scanner measurements were repeated using a commercially available quadrature head coil with 28cm diameter (Invivo Corp.)

Table 1. Coil performance.

	Sodium BC (Isolated)	Sodium BC (with Proton Striplines)	Proton Striplines	Commercial Head Coil
Unloaded Q	403	365	320	
Loaded Q	30	31	190	
90° Tx voltage	220	265	125	60
Phantom SNR	12.1	11.1	43.4	63.8

This study was approved by our local institutional review board and healthy volunteers were scanned after obtaining informed written consent.

Results: The resonance frequency of the sodium birdcage increased to 80.8MHz in the presence of the proton striplines due to shielding, requiring an additional 2pF at each location to pull its resonance down to 78.6MHz. This shielding resulted in a 20% increase in the RF voltage needed for the birdcage to create a 90° flip and an 8% reduction in SNR (Table 1). Fig. 3 shows 3-plane phantom images demonstrating the typical homogeneous birdcage sensitivity pattern. In vivo sodium images are shown in Fig. 4. The stripline array provided good coverage and adequate sensitivity for B_0 shimming and anatomical reference imaging (Fig. 5). The SNR of the stripline array was approximately 68% that of the commercial volume coil.

Discussion: The nested sodium/proton coil proved to be a feasible alternative to the standard trap-based method for dual frequency imaging. There was little interaction between the sodium birdcage and proton stripline, resulting in near-maximum sodium sensitivity. This characteristic simplified construction as the sodium and proton coil could be tuned independently. Stripline sensitivity may be improved by up to 30% by optimizing the substrate thickness (8), potentially providing similar sensitivity as the commercial coil.

References: 1) Hayes, et al. JMR 1985. 2) Schnall, et al. JMR 1985. 3) Shen, et al. MRM 1997. 4) Xie, et al. ISMRM High Field MR 2007. 5) Adriany, et al. MRM 2008. 6) Sorgenfrei, Edelstein. MRM 1996. 7) Roemer, et al. MRM 1990. 8) Akgun, et al. ISMRM 2009.

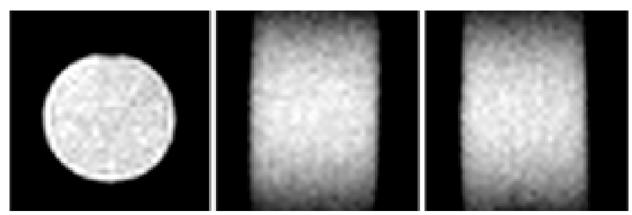

Fig. 3. 3-plane sodium phantom images.

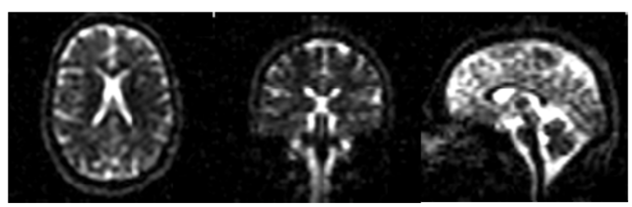

Fig. 4. 3-plane in vivo sodium images. 4mm isotropic resolution, TE/TR/FA=6.6ms/100ms/90°, 3 signal averages, BW=100Hz/pixel, TA=14.5mins.

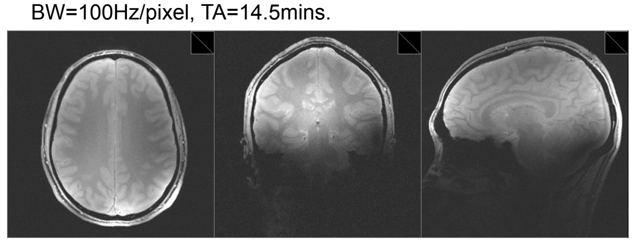

Fig. 5. 3-plane in vivo proton images.