A three-layered coil arrangement for sodium imaging of the human brain at 9.4T

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Target audience: RF engineers, researchers interested in ultra-high field MRI and Sodium MRI.

Purpose: Sodium imaging benefits from the availability of ultra-high field (7T and above) MRI scanners due to the proportional increase in sensitivity with respect to the static magnetic field (B_0). An important design aspect of a sodium imaging setup is to maximize the sensitivity at the sodium frequency while providing proton signal from the whole brain for anatomical localization, B_0 mapping and off-resonance correction. To achieve this, we developed a coil combination consisting of three coils for combined sodium and proton imaging of the human brain at 9.4T: a 27-channel receive-only sodium array, a 4-element sodium transmit array and a 4-element proton dipole transceiver array.

Methods: Experiments were performed on a Siemens 9.4T whole body MR scanner. The 27 sodium receive elements were arranged in 4 rows on a helmet (L/R – 185mm, A/P – 220mm, S/I – 200mm). The top 2 rows had 9 elements each, forming a complete ring. The 3rd and 4th row had 6 and 3 elements, respectively. The adjacent elements within each row were geometrically decoupled. Each element of the lower row geometrically overlapped with 2 elements of the upper row. The receive elements comprised 2 capacitors in series, one of which was split further in series for matching and active detuning circuit. A series capacitor was used before the preamplifier to adjust preamplifier decoupling. A protection fuse was included in each receive element. Fig.1 shows the sodium receive array.

The presence of a 16-rung sodium transmit birdcage heavily influenced the performance of the proton dipole array. Hence, an actively detunable sodium transmit array with 4-large (15cm x 18cm) loops was constructed on a cylinder with 26cm inner diameter. Adjacent elements were inductively decoupled. Coupling between the opposite elements was high due to the large loop size. Inductive decoupling was implemented between the opposite elements and the decoupling network was connected with a long coaxial cable. To drive the array in CP mode, a 1x4 power splitter was custom-built using a combination of three quadrature hybrids, which provided four outputs with a phase shift of 0°, 90°, 180° and 270°. A double tuned cable trap [1] was installed at the input of each transmit element.

Each element of the proton dipole array was placed 3cm above the center of each sodium transmit loop. Each dipole element was connected to a TR switch through a shielded cable trap. The physical length of the dipole elements were shortened using inductors [2]. The interface to the scanner consisted of 27 sodium receive elements, 4 proton channels. 1 channel was reserved for the combined signal from the sodium transmit array in the receive mode to obtain a homogeneous reference image. Fig. 2 shows the complete setup.

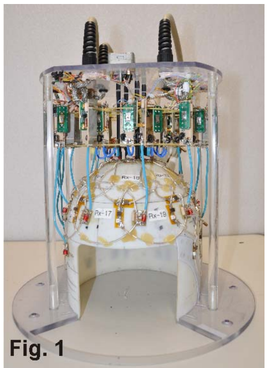
Fig. 1

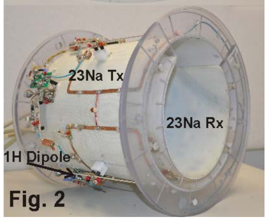

Fig. 2

Results: The elements of the sodium receive array were tuned and matched to 105.7MHz using a head and shoulder phantom filled with tissue equivalent solution. The unloaded Q of the receive element reduced from 240 to 185 with the addition of the protection fuse. The loaded Q varied from 50 to 115 depending on the separation between the loading phantom and the coil element. The adjacent elements of the helmet were decoupled by at least -12dB. Preamplifier decoupling provided -20dB. Inductive decoupling in the sodium transmit array provided at least -20dB decoupling between neighboring elements and -15dB between the opposite elements. Fig. 3 shows B1 field maps of the sodium transmit array, with the actively detuned receive helmet in place, using a 3L, 155 mm diameter phantom filled with 75mM NaCl solution. The large size of the sodium transmit elements reduced the B1 field drop-outs in the gap between the transmit elements. The SNR was compared to a birdcage coil [3] using the same phantom. Fig. 4 shows the SNR comparison in a normalized scale. As expected, significant increase in SNR was observed close to the receive elements and also in the helmet dome (where the large phantom doesn't fit). Fig 5 shows a FLASH image of a head and shoulder phantom acquired with the 4-element proton dipole array in CP mode in the presence of the actively detuned sodium transmit and receive arrays.

Conclusion: We have presented initial results, using phantom studies, of a sodium imaging setup which maximizes the receive sensitivity at the sodium frequency. The next step includes study of transmit efficiency of sodium and proton array and in-vivo SNR comparison.

References: [1] Avdievich NI Appl. Magn Reson. (2011) 41, [2] Lakshmanan K et al. Proc. ISMRM 2013 p2754 [3] Mirkes C et al. Proc. ISMRM 2013 p1982.

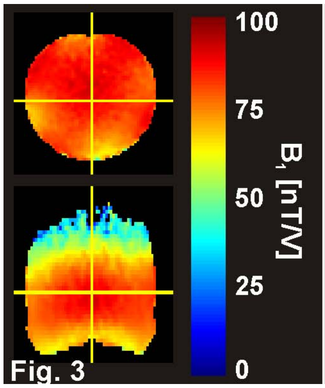

Fig. 3

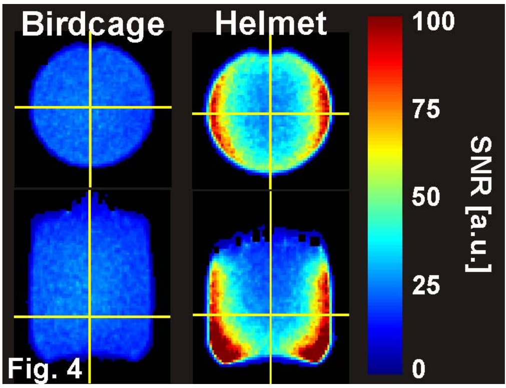

Fig. 4

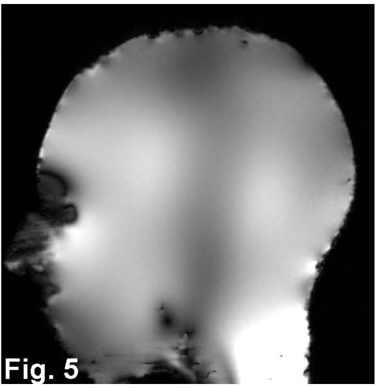
Fig. 5

Fig. 3: B1 field map of sodium transmit array. Fig. 4: Comparison of sodium receive performance. Fig. 5: demonstrates that the proton dipole array is capable of providing relatively homogenous large field-of-view images