A combined electric dipole and loop head coil for 7T head imaging

Gang Chen[1,2], Karthik Lakshmanan[1], Daniel Sodickson[1], and Graham Wiggins[1]

[1]*Center for Advanced Imaging Innovation and Research (CAI2R) and Center for Biomedical Imaging, Department of Radiology, New York University School of Medicine, New York, NY, United States,* [2]*The Sackler Institute of Graduate Biomedical Science, New York University School of Medicine, New York, NY, United States*

Target audience: Radiofrequency (RF) engineers, anyone interested in high field RF coils, parallel transmit or high field brain imaging.

Introduction: At 7 Tesla the combination of surface coil loops and electric dipole antennas can provide higher central SNR in a body sized object than is possible with loop coils alone[1, 2, 3]. In a head-sized object, similar but more modest gains are expected. An array of dipoles has been demonstrated for head imaging[4], and was shown to provide extended coverage in z compared to a standard birdcage, but suffered from low central SNR compared to loop-based coils. Simulation studies have shown reduced 10g peak SAR vs. excitation fidelity for parallel transmit in a mixed dipole and loop array for 7T head imaging[5], However, the SNR benefit has not been explored. We investigate here the addition of a loop array to a previously constructed dipole array. The dipole array is used for transmit, and although it is typical to detune a transmit coil when using a separate receive array, here the dipole elements remain active during receive to explore the benefits of combining loops and dipoles for increased SNR in 7T head imaging.

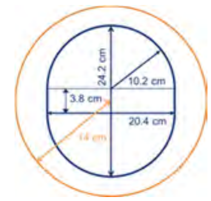

Figure 1: dimensions of 8 channel receive-only loop array (dark blue) and outer dipole array (orange)

Methods: An 8 channel loop array was constructed on an elliptical shell as shown in Figure 1. Each loop element measured approximately 8 × 10 cm, and three 3.9 pF capacitors were placed evenly along the loop conductors for uniform current distribution, as shown in Fig 2(a). One variable capacitor was used for tuning. Preamps and preamp interfaces with impedance matching and active detuning circuits (Siemens Healthcare, Erlangen Germany) were placed at the ports of loop elements, and preamp decoupling for all elements was tuned. Two passive detuning circuits with crossed diodes and resonant inductors were employed on the loop elements conductors parallel to the dipoles to minimize the currents which might be induced by the nearby dipole elements during transmit. Each loop element was tuned to 297.2 MHz and -20 dB or better match was achieved. Adjacent loop elements were overlapped carefully to reduce the inductive coupling. Distal to the preamps two bundled cable traps were used to minimize cable currents.

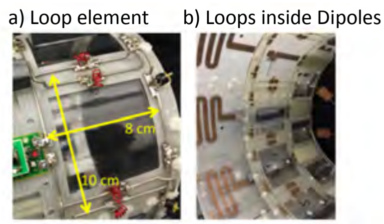

Figure 2: Coil prototype structures

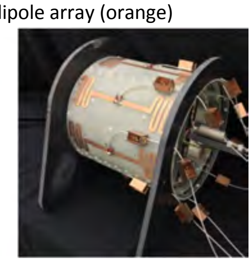

Figure 3: structure of combined dipole and loop array

An 8 channel electric dipole head array [2] was used for transmit and receive. The loop array was carefully placed inside of dipole array so that each dipole element aligned with the center of a loop element to reduce coupling (Fig 2(b)). The combined dipole and loop array can be seen in Figure 3. Dipole elements were retuned and matched in the presence of the detuned loop array. Preamp decoupling was also implemented for the dipole array. The coil was interfaced to a 7T scanner with 8 channel parallel transmit capability (Siemens, Erlangen Germany) using an in-house custom-built transmit-receive interface. Data were obtained on a head shaped gel phantom with uniform electrical properties ($\varepsilon_r = 52$, $\sigma = 0.56$ S/m). Phases to the elements were chosen to create constructive interference at the center of the phantom. B_1^+ maps were obtained by fitting a sine curve to pixel intensities from GRE images with different pulse voltages. SNR was generated based on the same GRE measurements obtained with RF excitation and without (TR/TE/BW=2000/3.26/300, FOV=256mm, Matrix=64, Slice = 6 mm). For dipole-only experiments, the inside loop array was removed, and all the dipole elements were retuned and matched to the gel phantom. For the loop-only experiments, the loop array was placed inside a detunable birdcage resonator (28 cm in diameter, and 20 cm in length), which was used for transmit and detuned during receive.

Results: For the constructed dipole+loop head array, the match for all the elements were -18 dB or better, the average coupling between each dipole and the aligned loop element underneath it was -18 dB, and -8 dB average coupling was observed between each dipole element and adjacent loop elements. The coupling between nearest neighbor dipole elements was about -6 dB when the loop array was present and detuned, degraded from -8 dB when there was no loop array inside. To achieve a 90 degree flip angle in the center of the object with a 500 µs hard pulse required 240 volts on the phantom with the mixed dipole and loop array. For the dipole array alone the value was 158, demonstrating that the presence of the loop array was a considerable perturbation on the dipole array. Nevertheless, the sagittal plots of optimal SNR[6] (i.e. SNR obtained using matched filter combination of elements) in figure 4 (normalized for the B_1^+ excitation profile) show that there is a substantial SNR gain from combining loops and dipoles in receive, in addition to the benefits of extended field of view using excitation with dipole elements. The noise correlation matrix for all the arrays are shown in Figure 5, for the dipole loop head array, the first 8 elements being dipoles and the last 8 loops. The heavy coupling between the dipoles creates additional opportunities for coupling but that most values are still below 0.5.

Discussion: The mixed dipole and loop array provides 17% or 32% higher central SNR when compared to loop array alone or dipole array alone, respectively, while maintaining the extended transmit FOV of the dipole array for whole brain imaging. High coupling between adjacent dipole elements degraded the transmit efficiency of the dipole array. The dipole array seems particularly sensitive to the presence of other coil apparatus inside of it, so effective decoupling strategies are in great need for coil optimization. Compared to Nova 24 channel coil, our mixed dipole loop array achieved comparable SNR in the center. However we were not able to achieve satisfactory whole volume RF shimming using the constructed mixed dipole and loop array in phantom experiments. We attribute this to excessive interaction between dipole and loop array during transmit. Combination of loops and dipoles is essential to capture all of the available SNR at high field and that designs such as the proposed coil will make it possible.

Reference: [1] Lattanzi R. MRM 68:286–304 (2012) [2] Schnell W. (2000), IEEE Trans Ant Prop 48:418-28. [3] Wiggins G. ISMRM 2013 p2737 [4] Chen G. ISMRM 2014 p621 [5] Eryaman Y. ISMRM 2013 p393 [6] Kellman P. MRM 54:1439–1447 (2005)

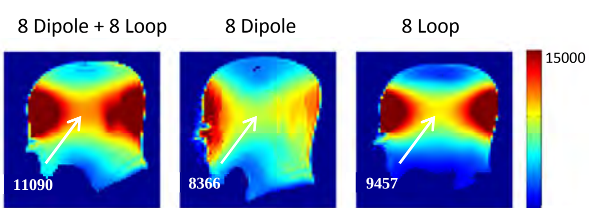

Figure 4: Optimal SNR (normalized for B1+ excitation)

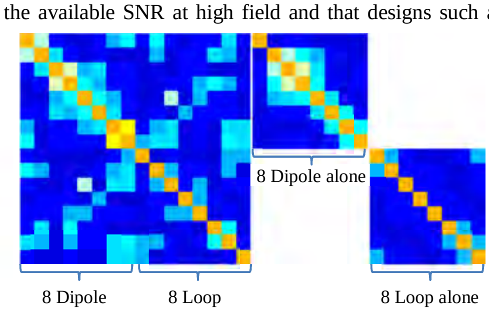

Figure 5: Noise correlation matrix for different coils