

The Looppole Antenna: Capturing Magnetic and Electric Dipole Fields with a Single Structure to Improve Transmit and Receive Performance

Karthik Lakshmanan¹, Martijn Cloos¹, Ricardo Lattanzi¹, Daniel Sodickson¹, and Graham Wiggins¹

¹Department of Radiology, The Bernard and Irene Schwartz Center for Biomedical Imaging, New York University School of Medicine, New York, New York, United States

Introduction: Electric dipole fields show an increasing contribution to Ultimate Intrinsic SNR (UISNR) at high fields^{1,2}. Substantial SNR boosts have been shown in a body sized phantom at 7.0 T by using a combination of loop and electric dipole elements³. A mixture of element types may also improve the performance of parallel transmit array designs⁴, but with most parallel transmit systems currently limited to 8 channels design options are limited. We describe here a novel array element design which can capture magnetic and electric dipole fields in a single antenna structure, and demonstrate improved performance compared to conventional surface coil loops at 7T.

A circular surface coil with uniform current is equivalent to a magnetic dipole. However, if the current is not uniform, the field created by the surface coil can be deconvolved into a magnetic dipole and an electric dipole component⁵. It is standard practice in RF coil design to try to maintain a uniform current distribution in a surface coil using an appropriate amount of distributed capacitance. We have turned this practice on its head and designed surface coil loops with a highly non-uniform current distribution in order to capture both magnetic and electric dipole fields in a single structure, which we call the “looppole”. Through the appropriate choice of capacitors in the loop we can concentrate current near the drive point, and control the degree of current asymmetry.

Methods: Full wave electromagnetic simulations were performed with the FDTD method (CST Microwave Studio). A cylindrical phantom was modeled with $\epsilon_r=81.81$, $\sigma=0.604$, 29.5 cm diameter and 1.4m long. 8 overlapped rectangular coils with 12 capacitors each were modeled on a cylindrical surface 31.5cm diameter which were 20cm along z and 16 cm wide (Fig.1). All capacitors in the balanced coil were 6.8pF. The unbalanced elements had two 10pF capacitors in the long feed leg, three 1.5 pF in the opposite long leg and three 6.8pF capacitors in each of the short legs. The coils were tuned, matched and driven with 50 ohm ports in simulation. For experimental verification, two eight channel arrays were constructed with identical dimensions and capacitance values as the simulation (Fig. 2). The balanced array was driven at the service end to maintain the current balance and the unbalanced array was driven at the side to enhance the current unbalance. $\lambda/4$ lattice baluns were used to match the coil arrays to coaxial cables. The constructed arrays were used in transmit receive mode on a 7T scanner with 8 channel parallel transmit (Siemens, Erlangen Germany). Transmit phases were chosen to align all phases at the center of the phantom. Excitation was calibrated at the center of the phantom using a turbo flash scan with preparation pulse⁶. B_1^+ maps were obtained with the AFI method⁷ and individual coil B_1^+ maps were obtained using a low flip angle GRE. SNR was calculated using the Kellmann method⁸ from GRE acquisitions both with and without RF excitation (TR/TE/Flip/BW = 2000ms/3.6ms/90°/300Hz per pixel, Matrix = 64, FoV = 320mm, Slice = 5mm).

Results Simulations: The CST simulations achieved better than -25dB of match and a worst isolation of -14dB for the balanced and the unbalanced loops. Due to inconsistencies in the display of surface current in the simulation software, we show instead a plot of current density in the phantom in figure 3 to illustrate the current unbalance, which was 3.4:1 for the unbalanced loops. B_1^+ maps for a single balanced loop, unbalanced loop and an electric dipole element are shown in figure 4. The electric dipole element was 36 cm long in Z. The balanced loop exhibits an asymmetric B_1^+ with a strong null, whereas the electric dipole exhibits nearly symmetric B_1^+ . The unbalanced loop shows hybrid behavior, with excitation focused near the stronger current side, but with a small side lobe and weak null. Simulated B_1^+ and SNR maps for the 8 channel balanced and unbalanced array are shown in figures 5 & 6. The B_1^+ and SNR maps were generated in two orientations where in orientation 2 the coil was flipped end to end with respect to orientation 1. The balanced loop array and electric dipole array showed almost the same B_1^+ and SNR between orientations. However, the unbalanced array showed an optimal B_1^+ in orientation 1 but with low SNR, whereas it had less than optimal B_1^+ and the highest SNR in orientation 2. This asymmetry is to be expected given the configuration of the ideal current patterns⁵. The best unbalanced loops B_1^+ was 18% better than the balanced loops, and 10 % better than the dipole array, while the best unbalanced loops SNR was better by 22% and 13% respectively.

Experiments: The Unloaded and Loaded Q values for the constructed balanced and unbalanced elements were 80 & 6 and 55 & 6 respectively, with Q ratios of 13 and 9, indicating sample noise dominance. All elements were matched to better than -20dB with isolation between elements better than -15 dB. Experimentally acquired B_1^+ maps for the three arrays are shown in figure 7. There is a small deviation between the B_1^+ values for the balanced array between the two orientations, but there is still a very marked increase in central B_1^+ with the unbalanced array in orientation 1, 35% higher than the average balanced array value. The overall B_1^+ distributions are very similar to simulation, with improved uniformity for the unbalanced array in the first orientation. Central SNR values are summarized in figure 8, which shows the small dependence on orientation for the balanced array, but SNR boost of 37% for the unbalanced array compared to the average balanced SNR value.

Conclusions & Discussion: With the array of large elements examined here it was possible to achieve substantial improvements in B_1^+ or SNR through the counter-intuitive strategy of deliberately creating an unbalanced current distribution on the loops. If these elements are truly capable of capturing magnetic and electric dipole fields we would expect a maximum performance for a particular amount of unbalance, but so far we have found that increasing the unbalance only improves the performance. The dipole array we compared to is substantially longer than the loop elements, and hence does not represent the logical endpoint of transition from a loop to a pure dipole. Other configurations will be tested to confirm how much benefit can be gained from capturing magnetic and electric dipole fields in a single element.

References: [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] Eryaman Y. ISMRM 2013 p393 [5] Horner F. Properties of Loop Aerials, The Wireless Engineer, Vol. 25, Aug. 1948 p254-259 [6] Klose U, Med. Phys. 19 (4), 1992 [7] Yarnyk V. MRM 57:192–200 (2007) [8] Kellman P. MRM 54:1439–1447 (2005)

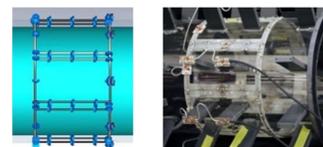


Figure 1: Array layout
Figure 2: Constructed coil

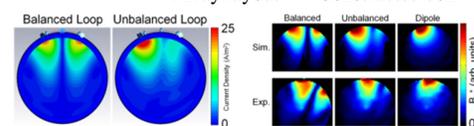


Figure 3: Current density
Figure 4: B_1^+ for single elements

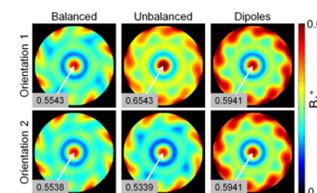


Figure 5: B_1^+ maps, simulation

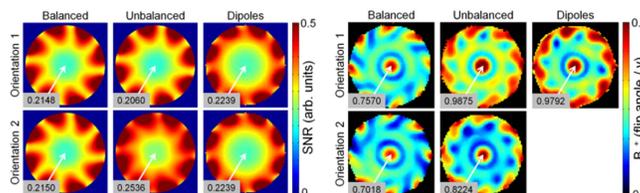


Figure 6: SNR maps, simulation

Figure 7: B_1^+ maps, experiment

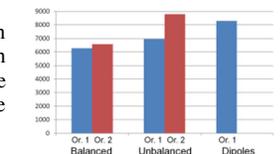


Figure 8: Central SNR, experiment