Bent Electric Dipoles: A Novel Coil Design Inspired by the Ideal Current Pattern for Central SNR at 7 Tesla

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

Introduction: Investigations of the Ultimate Intrinsic SNR (UISNR) have revealed that curl-free current modes (corresponding to electric dipoles) make a significant, even dominant, contribution to the UISNR for the center of the object for high frequencies and large objects[1,2]. Coil designs motivated by the ideal current patterns corresponding to the UISNR have been used to boost central SNR at 7T[3,4]. Past research at 3T has suggested that by bending the rungs of a birdcage coil or the arms of a loop array, a V-Cage or V-Array can better follow the phase evolution of current in high field, providing higher central SNR compared to a conventional birdcage or loop array[5]. For a body-sized phantom at 7T the ideal current pattern for curl-free current modes shows V-shaped patterns due to the need for phase evolution along the axial direction (z) to account for propagation delays to the central region of interest[3] (Fig.1). We explored in simulations whether bending the electric dipole into a V, as shown in Figure 1, can better replicate the ideal current phase evolution and provide superior performance compared to a straight dipole.

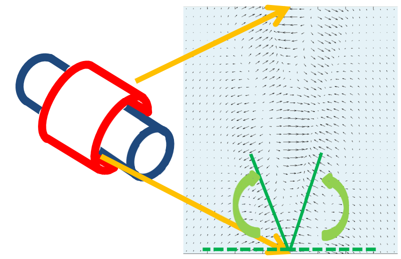

Figure 1: Curl-free Ideal current pattern for 30 cm dia. phantom and 32 cm dia. coil at 7T

Method: FDTD simulations were performed with Microwave Studio (CST, Darmstadt, Germany) Various 8-channel dipole array designs with 7mm conductor width were modeled on a 31 cm diameter cylindrical shell (figure 2), loaded with a cylindrical phantom with uniform electrical properties ($\varepsilon_r = 81.81$, $\sigma = 0.604$), 29 cm in diameter and 80 cm in length. Dipole arrays with various bending angles were simulated, including a straight dipole, and dipoles bent at 35°, 45° and 55°. The 45° bent dipole array simulation setup is shown in Figure 2. The other dipole arrays were bent using a similar approach. The length of each dipole was adjusted to achieve self-resonance at 297.2 MHz. All elements were tuned and matched in the simulation at the proton frequency.

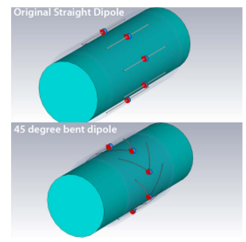

Figure 2: Simulation setup for straight dipole array and bent dipole array

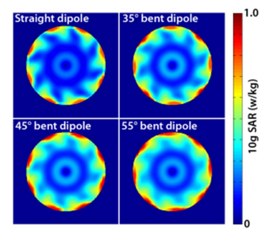

Figure 3: 10g SAR maps for 4 different dipole arrays

Result and Discussion: 10g peak local SAR for original straight dipole, 35°, 45° and 55° bent dipoles were 0.817, 0.964, 0.9652 and 1.046 w/kg respectively. 10g SAR maps of the central axial slice are shown in Figure 3. Bending the dipole resulted in increasing peak local SAR and significantly altered the SAR distribution. B_1^+ and B_1^- maps for different dipole arrays are shown in Figure 4 and Figure 5 respectively. The bent dipole arrays produced more uniform B_1^+ patterns compared to the original straight dipole. The 45° bent dipole generated the highest B_1^+ in the center. If we normalize B_1^+ by the square root of 10g peak SAR for each dipole array, the central B_1^+ benefit by bending the dipole 45° reduces to 3%, compared to the straight dipole.

B_1^- patterns for different dipole arrays were also different. However, the central B_1^- of the 45° bent dipole was *lower* than original straight dipole. The asymmetry between B_1^+ and B_1^- behavior with bending is expected since the phase evolution to optimize B_1^- would be opposite to that needed to optimize B_1^+.To better see the asymmetry between B_1^+ and B_1^-, ratio maps of B_1^+/B_1^- are shown in Figure 6. For the original straight dipole, the central point ratio is one, but for each bent dipole, the ratio in the center is higher. If bending the elements of the dipole array in one direction can help increase B_1^+ in the center, for SNR performance it would be preferable to bend the dipole array in the opposite direction (or turn the coil around in the scanner). In Figure 7 we show the SNR and ratio map for the straight dipole array and the 45° bent dipole array, with the dipoles bent to optimize SNR rather than B_1^+. Bending the dipole by 45° provides 10% higher central SNR.

Conclusion: The simulation results showed the asymmetry of B_1^+ and B_1^- produced by bent dipole array, and confirmed the theory that bending the electric dipole can make it follow more closely the phase evolution of the ideal current pattern, therefore improving either central B_1^+ or SNR. However, the maximum 10% central SNR boost was less than expected. By bending the dipole element away from z direction, the current flowing in the conductor becomes more and more orthogonal to the ideal current pattern, as shown in Figure 8 for a 70° bending tracking the V-shape of the ideal current pattern, limiting the gains to be made by this approach. Nevertheless, B_1^+ efficiency or SNR can be improved, and better uniformity achieved, by bending electric dipoles appropriately.

Reference: [1] Lattanzi R. MRM 68:286–304 (2012) [2] Schnell W. (2000), IEEE Trans Ant Prop 48:418-28 [3] Wiggins G. ISMRM 2012 p541 [4] Wiggins G. ISMRM 2013 p2737 [5] Reykowski A. ISMRM 2005 p950.

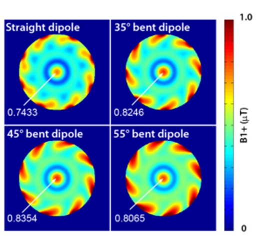

Figure 4: B_1^+ maps for 4 different dipole arrays

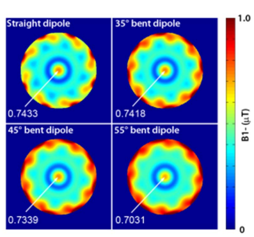

Figure 5: B_1^- maps for 4 different dipole arrays

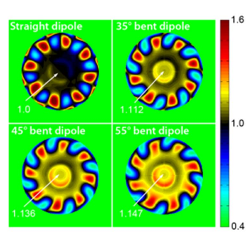

Figure 6: B_1^+/B_1^- ratio maps for 4 different dipole arrays

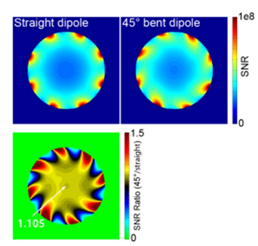

Figure 7: SNR plots for 2 dipole arrays and ratio map

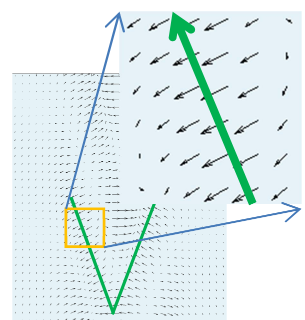

Figure 8: Dipole current (green) vs. ideal current pattern