An interleaved opposing monopole transmit-receive array for 7T brain imaging

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

Introduction: At high field, electric dipole antennas can provide comparable performance to more traditional loop based RF coils[1-4]. In its simplest form the electric dipole antenna is simply a straight conductor broken at the midpoint along its length and driven from there. It is most efficient in the far field when it is self-resonant, which occurs when its length is $\lambda/2$ in free space. When placed close to a relatively high dielectric material such as the body the self-resonant length shortens somewhat, but for 7T head imaging this still comes out to an inconvenient length of 40 cm or more. Another approach which has been suggested is the use of a monopole antenna, where a conductor $\lambda/4$ long is placed perpendicular to a conductive ground plane. An 8 channel TxRx array based on this design has been demonstrated, but suffered from fast drop-off of transmit and receive efficiency towards inferior brain regions due to rapid drop off in current along the monopole elements [5]. We describe here a modified monopole antenna where the ground plane is replaced by a strip of conductor. These are arranged in an 8 element array which allows alternating monopoles to be driven from opposing ends of the array, which extends excitation into inferior brain regions while also providing diverse B_1 profiles along Z.

Methods: Coil designs were evaluated in simulation before construction of a prototype array. FDTD simulations were performed with Microwave Studio (CST, Darmstadt, Germany). The coil was modeled on a 27.9 cm diameter cylinder, loaded with a head shaped phantom with uniform electrical properties ($\varepsilon_r = 52$, $\sigma = 0.56$). Monopole elements 18 cm in length were arranged similarly to the rungs on a birdcage. Each monopole element was T-shaped, with an 18.6 cm length of conductor extending around the cylinder which acts as a partial shield, with alternating monopoles oriented in opposite directions (Figure 1a). A lumped element inductor of 60.5 nH was included between the monopole element and its shield conductor and it was driven with an 50 Ω port. All elements were tuned and matched in the simulation.

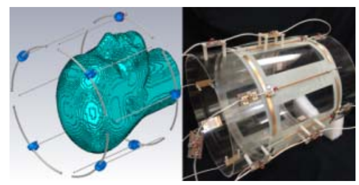

Figure 1: Simulation setup and constructed 8 channel Monopole array

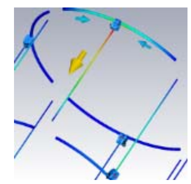

Figure 2: Surface current direction and distribution of a monopole element

An 8 channel array was constructed based closely on the simulated design (Figure 1b). Monopole lengths were extended to 19 cm and 71 nH inductors chosen based on bench measurements. Each element was matched using a parallel capacitor and 2 or 3 cable traps were used in the coaxes feeding each antenna. For elements driven from the patient end of the coil the cables were routed back over the coil through 3 cable traps. The coil was interface to a 7T scanner with 8 channel parallel transmit (Siemens, Erlangen Germany) using an in-house built transmit-receive interface. Data were obtained on a gel phantom with the same shape and properties used in the simulations and with a human volunteer after establishing safe power limits on the gel phantom using MR thermometry. Phases to the elements were chosen to create constructive interference at the center of the phantom. B_1^+ maps were obtained with a turbo-FLASH sequence with preparation pulse [6], and G-factor maps were calculated based on GRE measurements obtained with RF excitation and without (TR/TE/BW=200/4.1/300, FOV=220mm, Matrix=256, Slice = 3 mm). The monopole array was also compared to an 8 channel array of meander-shortened dipoles (Chen G, submitted ISMRM 2014).

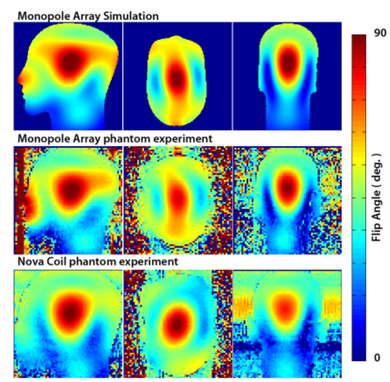

Figure 3: B_1^+ maps of Monopole Array and Nova coil in simulation and experiment.

Results: It was necessary to insert a 60.5 nH inductor between the element and the T-segment to achieve resonance at 297.2 MHz. Figure 2 shows that much stronger current flowing on the monopole element than on the T segment, and confirms that our proposed T-shaped monopole behaves similarly to a monopole with a real ground plane. S_{11} of -16 dB or better was achieved on all elements, and maximum S_{12} coupling was -9 dB. B_1^+ maps for quadrature excitation in simulation and head shaped gel phantom experiment are shown in Figure 3. There is weaker excitation in the region of the cerebellum, but the pattern is comparable to what is seen with the Nova volume coil. 10g peak local SAR for monopole array is 1.352 w/kg, and 1.428 w/kg for the 8 channel array of meander-shortened dipoles.

In the constructed coil each element showed a current maximum at the drive point and gradual current drop off along the length. When loaded with the head shaped gel phantom a 90 degree flip angle could be achieved with the single channel equivalent of a 225v 500 µs hard pulse. This increased to 326v with a volunteer, compared to 235v of Nova coil. B_1^+ maps obtained in the volunteer are shown in Figure 4. The excitation in inferior brain regions is improved compared to the data presented for the single ended monopole array in ref. 5. SNR maps for optimal reconstruction from volunteer data are shown in Figure 5. The long elements of the dipole array provide higher SNR in the cerebellum, but both arrays achieve similar central SNR values. G factor maps for the monopole array and a dipole array are shown in Figure 6. The diversity in Z-profiles for the oppositely driven monopole elements is demonstrated by the lower G-factors for this coil with head-foot acceleration.

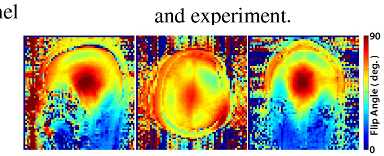

Figure 4: B_1^+ maps of Monopole Array in the volunteer

Conclusions: Transmit efficiency for this first prototype was low compared to other volume coil designs, but work is continuing on optimizations to the design. The use of monopoles allows for a more compact coil design, and the variation of B_1 profiles along Z should be helpful both for G-factors in receive but also for parallel transmit pulse design. SNR could be substantially improved by inclusion of a close fitting receive array.

References: [1] Wiggins GC. ISMRM 2012 p541. [2] Wiggins GC. ISMRM 2013 p2737. [3] Schnell W. (2000), IEEE Trans Ant Prop 48:418-28. [4] Lattanzi R. Magn Reson Med 2012 68:286-304. [5] Suk-Min Hong. MRM 2013 doi: 10.1002/mrm.24844. [6] Klose U, Med. Phys. 19(4), 1992

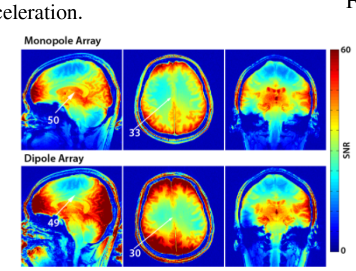

Figure 5: SNR maps of optimal Reconstruction for two coil designs

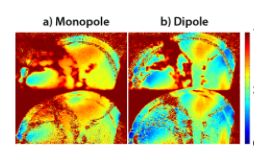

Figure 6: Sagittal plots of 1/g-factor for X2 acceleration along z for the two 8 channel coils