Optimization of an 8-channel receive-only surface array for whole brain MRI of marmosets

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Target audience:
MR Physicists, Engineers, basic/translational neuroscientists.

Purpose:
Experimental autoimmune encephalomyelitis (EAE), an induced condition that is pathologically and immunologically similar to human multiple sclerosis (MS), is well established in the common marmoset *(Callithrix jacchus)* [1], a New World primate of strong interest to translational neuroscience. High-resolution MRI of the marmoset brain plays a fundamental role in EAE studies, in providing both anatomical and functional data that can be used to learn about the formation of lesions in cerebral white matter [2]. Here we compare three different designs of 8-channel receive-only phased arrays specifically built to provide whole brain MRI coverage of marmosets with high sensitivity.

Methods:
Three different 8-channel receive-only arrays designs were built, characterized on the workbench and compared in the MRI. The first array (Fig. 1a) was built using 1.5mm wide CuFlon (Polyflon Inc., Norwalk, CT, USA) with 2 oz/ft^2 of copper deposited in a 0.25 mm thick PTFE dielectric. Rectangular 15 mm x 28 mm coil elements were arranged in 2 x 4 configuration, overlapped in the z-direction and gapped (~1mm) in the x-direction. The second array (Fig. 1b) consisted of circular 22 mm ID loops overlapped in both z- and x-directions in a 2 x 4 configuration using 0.8 mm gauge copper wire. The third array (Fig. 1c) was made of 1.8mm thick wire and consisted of one central 40 x 35 mm elliptical element surrounded by 7 overlapping 25 mm ID loops. The coil circuitry for each element in all three designs consisted of a matching network and a PIN diode controlled blocking circuit for active detuning during transmission. Decoupling between non-nearest neighbors elements was achieved by connecting the elements to homebuilt low input impedance preamplifiers [3, 4] through a π-network phase shifter, combined with 22 cm of RF cable adjusted to provide an equivalent $\lambda/2$ cable at the input of the preamplifier. The isolation provided by preamp decoupling was better than 18 dB, and better than 30 dB by active detuning. Cable traps inserted between the matching network and the preamplifiers minimized common modes in the cables. SNR maps and noise correlation matrices were obtained for all three designs. High resolution T1- and T2-weighted anatomical MRI of marmosets (125µm in plane, 600µm thickness) were acquired in a 7T/30 cm USR magnet (Bruker-Biospin, Inc,) connected to an AVIII console running ParaVision 5.1, resulting in a total acquisition time of 21 min 59 sec.

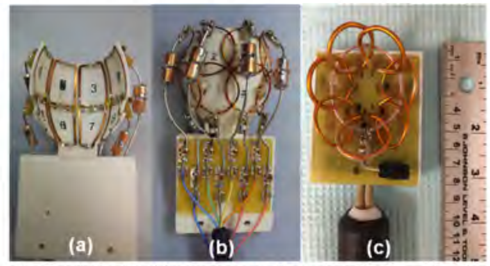

Figure 1: (a) Coil-1: 8-Channel array with rectangular elements using flat conductor. (b) Coil-2: 8-CH array with circular elements using 0.8 mm round wire arranged 2 x 8. (c) Coil-3: 8-CH array with one big elliptical element partially overlapped with 7 circular elements using 1.8 mm round wire.

Results and Discussion:
SNR maps obtained in axial, coronal and sagittal orientations for each of the three coils (Fig. 2) show that coil 3 provided higher sensitivity and better brain coverage than coils 1 and 2. A gain up to 60% in SNR was achieved in the frontal cortex, 40% in the occipital cortex, and 20% in the center of the brain compared to coils 1 and 2. The highest noise correlation coefficients obtained for coils 1, 2 and 3 were 0.41, 0.25 and 0.14, respectively. A major reason for the better performance of coil 3 is that all nearest neighbors were decoupled from each other by partial overlapping, while in both coils 1 and 2 the elements were arranged such that the decoupling with nearest neighbors was achieved only in the z-direction or in both x- and z-directions, respectively. In addition, the use of thicker round wire in coil 3 decreased resistive losses when compared to coils 1 and 2, which used flat conductors or 0.8 mm round wire, respectively. The higher sensitivity of coil 3 was confirmed in high-resolution anatomical brain images obtained from a healthy marmoset (Fig. 3), and from an EAE animal (Fig. 4). These images clearly show high sensitivity throughout the brain. White-matter EAE lesions are clearly visible in both T1- and T2-weighted images, as indicated by the arrows.

Conclusions:
We built and compared three different 8-channel receive-only arrays designs for in vivo MRI of the marmoset brain at 7T. The SNR maps indicate that coil 3 provides extended coverage with high sensitivity throughout the entire brain, allowing easy identification of multiple white matter lesions in the EAE marmoset. The combination of partial overlapping between all coil elements with preamplifier decoupling minimized the noise correlation. Additionally, the use of thicker wire gauge minimized resistive losses, resulting in improved SNR.

References:
[1] Gaitán, M. et al. *Perivenular brain lesions in a primate multiple sclerosis model at 7-Tesla magnetic resonance imaging.* Mult Scler 2014 20(1): 64-71
[2] Maggi P et al., *The formation of inflammatory demyelinated lesions in cerebral white matter.* Ann Neurol. 2014 76(4):594-608
[3] Nascimento, G.C., et al. *Inductive Decoupling of RF Coil Arrays: A Study at 7T.* Proc 14th ISMRM, Honolulu, 2590, 2006.
[4] Dodd, S.J., et al. *Modular Preamplifier Design and Application to Animal Imaging at 7 and 11.7T.* Proc 17th ISMRM, Seatle,3141, 2009.

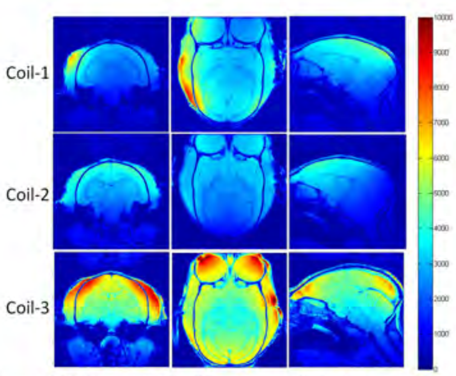

Figure 2: SNR maps obtained from an anesthetized marmoset in the axial coronal and sagittal orientation using coil-1 (top row), coil-2 (middle row) and coil-3 (bottom row).

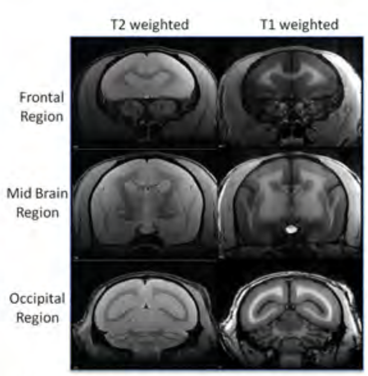

Figure 3: 125 µm in plane resolution and 600 µm slice thickness axial brain images from an anesthetized marmoset with different contrast mechanisms: T2 weighted (left column), T1 weighted (right column).

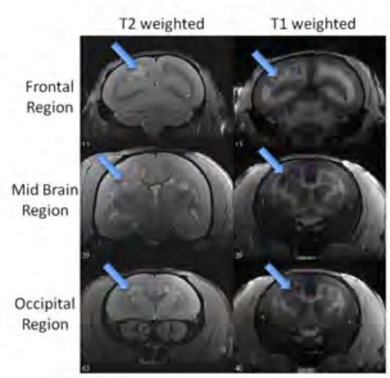

Figure 4: T2W (left column) and T1W (right column) axial brain images from a MS induced marmoset. The arrows indicate white matter lesions.