RF Image Optimization at 7T & 9.4T

J. T. Vaughan[1], L. DelaBarre[1], C. Snyder[1], G. Adriany[1], C. Collins[2], P-F. Van De Moortele[1], S. Moeller[1], J. Ritter[1], J. Strupp[1], P. Andersen[1], J. Tian[1], M. Smith[2], K. Ugurbil[1]

[1]Center for Magnetic Resonance Research, University of Minnesota, Minneapolis, MN, United States, [2]Radiology, Penn. State Hershey Medical Center, Hershey, PA, United States

Objective: To improve human head imaging at the highest available field strengths (7T-9.4T) by RF field magnitude and phase angle optimization in the multi-channel transmission line resonator.

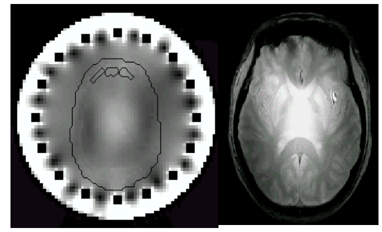
Introduction: While ultra-high head imaging has produced the signal-to-noise sought, image homogeneity has been problematic. Causing this inhomogeneity is a B_1 field gradient peaking in the center of the head when a homogeneous volume coil is used [1]. Figure 1a shows the FDTD head-in-coil model (Remcom) predicting the problem demonstrated in the 7T head image of Figure 1b. Signal loss, contrast loss, flip angle errors, unwanted echoes, and quantification errors are but a few of the consequences of this non-uniform B_1 field due to EM propagation, attenuation and interference of the high frequency waveform in human head tissues. Some of these problems have been modeled in recent years by Collins, Ibrahim and others, [2, 3]. This work includes first examples of solutions successfully described and implemented *in vivo* at field strengths to 9.4T.

Methods: To solve the high field B_1 homogeneity problem, a strip line (micro strip) TEM coil was designed for controlling the magnitude and phase of the B_1 field [4,5]. The baseline B_1 magnitude (field profile) was adjusted by coil symmetry, element-to-shield spacing, and choice of dielectric (Teflon) between the inner elements (rungs) and the outer elements (shield). Figure 2a shows the resultant B_1 field profile from a 16 element coil (2b) with a central sensitivity deficit ΣB_1- , (3b) calculated to compensate for the constructively interfering B_1 field peak ΣB_1+ , (3a) imparted in the center of the head by a homogeneous coil as in Figure 1. The B_1 field magnitude of this baseline profile can be further adjusted by changing the symmetry of the coil (e.g. to elliptical) to better fit the long axis of the Caucasian head. Finally, by controlling the RF impedance (both magnitude and phase) per element, the B_1 field profile can then be dynamically and interactively "shimmed". All of these methods were employed to produce a homogeneous head image at 7T and most recently at 9.4T.

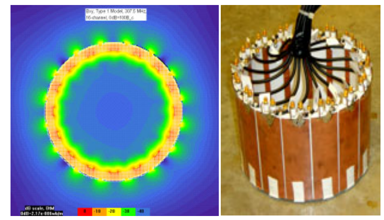
Hardware: A number of coils of various dielectrics (air, Teflon, Duroid), dielectric thicknesses (5mm – 20mm), shapes (circular, elliptical) and element counts (8, 16, 32) have been built and tested on phantom loads and heads at 7T and 9.4T. The coils were dimensioned to fit closely to the human head with a nominal 25cm i.d. x 16cm length. All of the coils were driven (transmit and receive) at every element as shown for the 16 element coil in Figure 2b. Baseline magnitude and phase angles were adjusted per element with phased power splitters and fine tuned with connectors (cable length) and coaxial attenuators. This process is presently being upgraded to a console controlled design. The independent coil elements were individually tuned and matched to the Larmor frequency for ^1H imaging, or to multiple frequencies by the same method used in other TEM volume coils [6]. Each element of the coil can also be PIN switched individually to "steer" the B_1 field profile, or in concert to detune the structure [4]. A broadband amplifier (CPC) was used for the transmitter, and our multi channel receiver was configured from Echotek components. This work was performed with Magnex 7T and 9.4T magnets and head gradient sets, interfaced to a Varian Inova consoles.

Results: Greater homogeneity was achieved with the B_1 profiled coil per Figure 2a, predicted in 4a and validated in Figure 4b, compared to Figure 1b. The FLASH image of Figure 4b was acquired with an eight element coil of symmetric phase distribution (0,45, 90,etc.), by the following parameters: TR 20ms, TE 5ms, FOV $25cm^2$, Thk 5mm, flip 10, matrix 256^2. SNR and SAR were equivalent to results previously reported [1], albeit more uniformly distributed. Homogeneity was improved further by setting new phase angles (0, 25.16, 55.16, 100.16, 175.16, 192.66, 232.66, 290.16) calculated for the head model of Figure 5a [3]. Image 5b acquired by the parameters previously given, shows the improved results. Further improvements can be had in this close fitting coil by increasing the number of elements to 16 or more as shown in Figure 2b, and by reshaping the coil to an elliptical form for equal element spacing from the head. The inversion recovery turbo FLASH image in Figure 6a is an example from 7T, where TR = 14ms, TE 5ms, TI 1.45s, Thk 5mm, matrix 256^2. Figure 6b shows a first 9.4T gradient echo image from an 8 element coil acquired by the parameters: matrix 256^2, 25x25cm, 5mm thick, 2ms sinc pulse, TR/TE = 100/4.5 ms, flip = 15 degrees, NEX = 2. The small hole is from a phase angle error unresolved in this first-of image at time of abstract submission. The strip line TEM coil being effectively an array of decoupled linear coil elements, has proven very useful for parallel imaging applications. Its SENSE performance improves with an increasing element count. A one dimensional reduction factor of approximately 5.2 (considering an geometry factor of 1.4) was achieved with the 16 element coil and 6.3 with the 32 element coil.

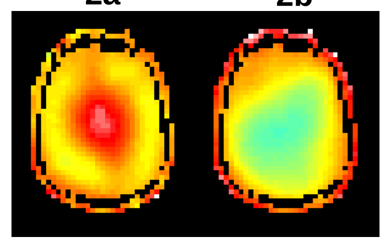
Conclusions: With the advent of 7T, 8T and now 9.4T human dimensioned magnets, RF tissue wavelengths become as short as 8cm for human MRI. B_1 homogeneity at these wavelengths is a challenge to many MR applications. To meet these challenges, the coil and methods described offer full front-end flexibility and interactive control over B_1 magnitude, phase angle, time and frequency for a target region of interest.



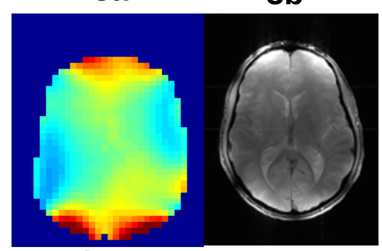
1a 1b



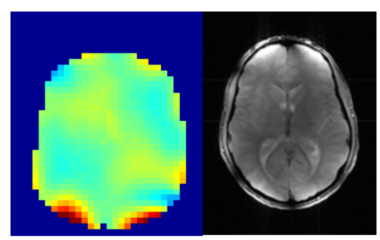
2a 2b



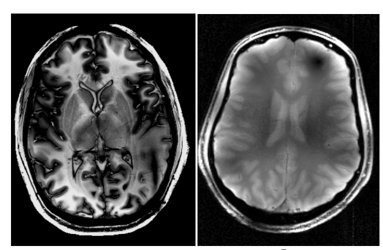
3a 3b



4a 4b



5a 5b



6a 6b

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References: [1] Vaughan JT, et.al., MRM 46:24-30 (2001); [2] Ibrahim et.al, MRI 19:1339 (2001); [3] Collins C, et.al. "Optimal Multiple-element Driving …" 12th ISMRM (2004); [4] US Patent No. 6,633,161 (2003); [5] Boskamp EB, et.al. Proc. 10th ISMRM, 903 (2002); [6] US Patent No. 5,557,247 (1996);