B1+ and SNR Optimization of High Field RF Coils Through Offsetting of Transmit and Receive Elements

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Introduction: One of the main challenges for MR imaging at fields above 3 Tesla is the relative lack of available RF coils. In addition, the design of RF coils for high field is complicated by the fact that at the higher RF frequencies required there is a more complex interaction of the RF excitation field with the sample. This leads to excitation inhomogeneity due to wavelength effects and complex twisted B_1^+ and B_1^- profiles which differ significantly from those seen at low field [1]. Predicting the behavior of RF coil designs for high field MR requires full wave simulation of the electromagnetic fields, since low-field quasi-static approximations no longer apply.

One simple RF coil design which is frequently employed for high field imaging is the transmit-receive surface coil. Even at low fields this coil design suffers from transmit and receive profiles which drop off steeply with depth into the sample, but given the complexities of creating a uniform excitation in anything but the smallest volumes at high field, the transmit receive surface coil provides an attractive solution for imaging small regions of interest in the body and for acquiring preliminary data as improved application specific coils designs are developed. With increasing field, however, the efficiency of the transmit-receive surface coil diminishes due to the fact that the B_1^+ and B_1^- profiles twist in opposite directions. We propose a simple improvement in which separate transmit and receive elements are used, which are rotated relative to the imaging region of interest so as to optimize the transmit and receive profiles in that volume. SNR improvements of up to 40% are demonstrated at 7 Tesla.

Methods: B_1^+ and B_1^- fields were simulated using a current mode expansion with a dyadic Greens function formulation [1,2]. A single rectangular surface coil was simulated, wrapped onto a 200mm diameter cylinder, with the element 67mm wide circumferentially and 74mm long. A cylindrical phantom was simulated with diameter 158mm, $\sigma = 0.5$ S/m and $\varepsilon_r = 79$, corresponding to the Siemens large cylindrical phantom. Simulated B_1^+ and B_1^-- maps were generated by calculating the respective quantities for a number of points within the phantom (20 points radially and every 5 degrees around the center for a 20x72 matrix) and then interpolating to create a 1 x 1mm resolution map. Simulated SNR maps were generated for low flip angles (maximum excitation < 10 degrees) by creating an excitation map (sine of the magnitude of B_1^+) and then multiplying that by the magnitude of B_1^-. The respective B_1^+ and B_1^- maps were rotated in Matlab to test the cases of different rotational offsets of separate Tx and Rx coils around the cylinder.

To verify the effect of offsetting the Tx and Rx elements two 7 Tesla RF coils were constructed. The first was a simple T/R surface coil of the same dimensions as the simulated coil, constructed from FR4 circuit board with a 5mm conductor width. The second was a pair of identical elements whose centers were rotated by 50 degrees relative to the center of the cylinder. One of the two elements was configured as a detunable transmit coil, broken with diodes in two places. The second element was a standard receive coil configuration with a resonant detuning trap built around the match capacitor. For the T/R surface coil a T/R switch preamp device was used (Stark Contrast, Erlangen Germany), while for the two element coil two T/R switches were used, one each in the transmit and receive paths. The unloaded to loaded Q ratio of the T/R and Rx only elements was 3.5 and 2.8 respectively and both showed active detuning of better than -30dB. Experimentally measured B1 maps were generated by running a GRE sequence and stepping through a number of different RF pulse amplitudes. Information from the B_1^+ measurement was used to determine the RF pulse amplitude necessary to provide a 10 degree flip at the point of highest B_1^+ near the transmit element. SNR maps were generated from a GRE sequence and an identical acquisition with no RF excitation.

Results: Simulated B_1^+ and B_1^- maps are shown in Figure 1. The pronounced twisting of the B_1^+ and B_1^- fields, in opposite directions, can clearly be seen. Experimental measurements with the T/R surface coil show close correspondence to the simulations, within the limits of the B1 mapping algorithm, which breaks down for regions far from the coil element. Also shown are the simulated and experimental SNR for a low flip angle excitation. Again the correspondence between simulation and experiment is very close. The effect of separating the Tx and Rx functionalities into two elements and rotating them relative to each other was explored through simulations, as seen in Figure 2. The SNR ratios in the lower row show that there is a region of SNR boost of up to 40% which moves deeper into the sample as the angle is increased. Thus for a ROI at a given depth in the phantom there is an optimum offset between the transmit and receive elements. This can be seen more clearly in Figure 3, which plots profiles through the SNR ratio maps. The maximum SNR boost is obtained with a 40 degree offset, providing a 40% SNR boost at a depth of about 40mm into the phantom. Experimental verification of the benefit of offsetting the Tx and Rx elements is shown in Figure 4 for a 50 degree offset. It can clearly be seen how offsetting the Tx and Rx elements steers the B_1^+ and B_1^- fields towards each other, increasing the SNR at depth, while sacrificing SNR closer to the surface. The experimental data again show close correspondence to the simulations.

Conclusions: While a coil with separate Tx and Rx elements has somewhat greater complexity than a simple T/R surface coil, for an ROI deep in the sample this complexity may be well worthwhile for the potential 40% SNR boost that can be achieved. In particular a coil of this design could be particularly useful for imaging the cervical spine at 7T. More generally this experiment is intended to demonstrate that the twisted B_1^+ and B_1^-- profiles should be taken into account in the design of high field RF coils in order to maximize the performance of the coil.

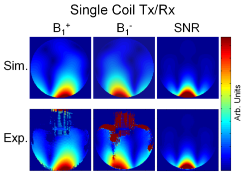

Figure 1

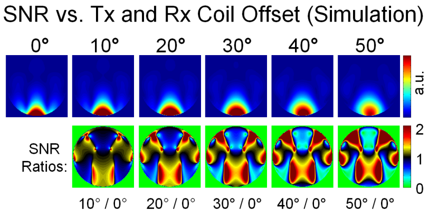

Figure 2

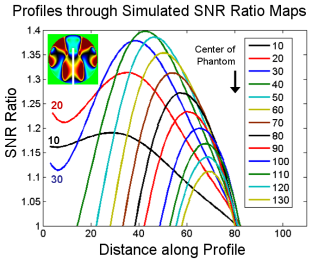

Figure 3

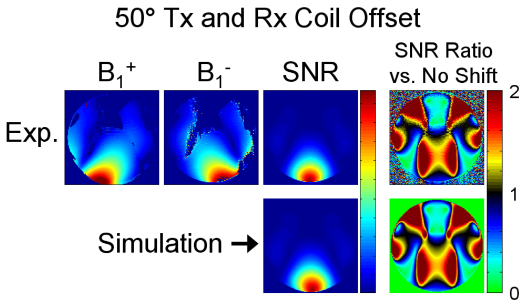

Figure 4

[1] Collins et al, Magn Reson Med 2002, 47:1026-1028