Efficiency of Single-loop and Quadrature Surface RF Coils in the Human Brain at 9.4 Tesla

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Introduction
NMR spectroscopy, especially in a single-voxel, is commonly performed with surface coils such as single-loop and “quadrature” coils since only a limited field of view is required and higher signal-to-noise ratio is achievable in comparison to single channel volume coils. However, at high magnetic field transmit and receive B1 profiles are significantly distorted as demonstrated previously at 7 T [1]. Here we investigate the impact of these B1 field distortions in the human brain at 9.4 T when using single-loop and quadrature RF coils.

Methods
Home-built single-loop (10cm in diameter) and quadrature (two overlapping loops, each 7cm in diameter) RF coils were used to image the occipital lobe in humans. Healthy human subjects were studied in a 9.4 Tesla/65cm bore magnet [2] interfaced to a DirectDrive 8-Transmit Channel Varian console. |B1| maps were obtained with the two flip-angle technique [3]. To estimate the receive |B1| profiles, the product ρ|B1| was also derived (ρ being proton density). The two loops of the quadrature RF coil were driven by two independent channels, rather than with a classic hybrid (transmit-splitter/receive-combiner), thereby enabling the use of any phase shift between the two loops instead of the fixed 90° phase with a hybrid. RF efficiency maps were obtained for the quadrature RF coil by dividing the actual |B1| by the sum of |B1| of each loop (range: 0–1). Data processing was carried out in Matlab.

Results and Discussion

Single loop. |B1| maps in the human brain at 9.4 T with a single-loop RF coil clearly show two distinct patterns for B1+ and B1− with opposite rotational direction (Fig. 1). Here we use ρ|B1| to approximate the overall |B1| profile. (Note that this lack of overlap between B1 profiles is not observed in small animals where the sample size is smaller than the 1H RF wavelength). Because transmit and receive profiles reach their maximum in different locations, a single voxel used in localized spectroscopy cannot be positioned optimally for both transmission and reception. In principle, higher RF power could be used to obtain higher peak B1− in a voxel located where B1− is maximal. However, power deposition (SAR) becomes a limiting factor at very high field and increasing transmit power is not a favorable option. A classical approach to enhance RF efficiency is to use a 2-loop quadrature coil. However, it has been shown that at high field B1− destructive interferences [4] can reduce RF efficiency between neighboring coils, thereby requiring proper adjustment of their relative phases [5,6].

Two loops ("quadrature coil"). Results show that when the two-loop coil was driven in classic quadrature mode, i.e. with a 90° phase between the loops, the transmit efficiency in a region-of-interest (ROI) located in the occipital lobe (black box in Fig. 2 left) was about 86% (Fig. 2, top). In contrast, when the transmit phase between these loops was locally adjusted using local B1 phase shim [5,6], the transmit efficiency in the same ROI was increased to 98% (Fig. 2, bottom). As a result, the peak RF power was reduced by ~30% for a given excitation flip angle. Experimental measurements in a human head (Fig. 2, left) were highly consistent with simulated data obtained using similar RF coils design and a human head model (Remcom software) (Fig. 2 right). The phase shift calculated for local B1 phase shim was 67° in experiments and 60° in simulations.

Conclusion
Single-loop RF coils do not appear optimal for NMR spectroscopy in human brain at 9.4 T because of limited overlap between transmit and receive B1 profiles. However, "quadrature" surface RF coils may be used as long as the relative phase between the two loops is optimized for a given ROI to maximize B1 transmit efficiency, thereby reducing SAR.

References
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