Transmit array concepts for improved MRI safety in the presence of long conductors

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Introduction: The MRI RF body coil transmit field can couple to conductive metal structures such as guidewires and implant leads. This can induce currents along the wire, which can cause heating and safety hazards [1, 2]. In this work, we take preliminary steps in investigating the potential of using an array of transmit surface coils to minimize the current induced on guidewires. We also consider the possibility of generalizing the concept of a transmit array to drive the guidewire with a source of chosen magnitude and phase, as if the wire were an additional array element, in order to null out undesired current induced in it by the imaging protocol.

Methods: In the first experiment, we measured how the coupling between a surface coil and wire varies with coil position. The experimental setup is shown in Figure 1. We used an optically-coupled toroidal current sensor [3] to measure the current induced on 122 cm of 22 AWG uninsulated copper wire immersed in a saline phantom. For each coil location on top of the phantom, a 5ms duration hard RF pulse was transmitted by a 6x3 inch surface coil and the reading from the current sensor recorded. The surface coil was also equipped with a current sensor of its own, and the wire current data was normalized by the coil current to account for variations in coil loading at different positions. The pulse transmit and data receive were synchronously controlled by our MEDUSA USB console [4].

In the second experiment, we investigated the feasibility of using a conductive guidewire as an additional element of a transmit array. One method for driving the wire is to use a toroid, which inductively couples energy to the wire without direct electrical connection or modification of the wire. We created a single turn toroid cavity from Teflon tubing and copper foil as in [3]. We used series 25Ω resistors to limit the maximum power that could be coupled to the guidewire. A copper wire was inserted into a gelled saline phantom, and the power toroid was placed on the wire external to the phantom (Figure 2). Initially, we included the optical current transducer, and validated that we could induce current levels comparable to those induced by our surface coils. We then collected MRI SPGR images (1.5T, FOV 32cm, TR 25ms, TE 7ms) with a quadrature head coil, while driving the toroid with various magnitude and phase values. The severity of the wire artifact is an indication of the amount of current in the wire, so the goal in this experiment was to demonstrate that varying the drive signal to the toroid could control the amount of artifact (and thus the current) on the wire.

Results: Figure 3 shows the current sensor readings for various coil locations. The current induced along the wire reaches a minimum magnitude with the coil centered on the wire, as minimal net flux is coupled to the wire, and increases to a maximum value if the edge of the coil is placed just off the wire axis. Current values with the coil at a fixed distance on either side of the wire have comparable magnitude, but differ in phase by approximately 180°. This sign change is consistent with coupling by mutual inductance.

Figure 4 shows scan images from the driven toroid experiment. Current artifact is maximized by driving the toroid with a signal that causes the coupled current to enhance the current already induced on the wire by the imaging protocol. Shifting the phase by 180° minimizes the artifact, which should correspond to minimum current induced on the wire.

Discussion: Coil coupling measurements as in Figure 3 could be used along with linearity of coil excitations to drive a transmit array of several surface coils with magnitude and phase values that give a desired excitation, while causing minimum current to be induced on a guidewire or implant lead. Driving a guidewire with a power source generalizes the concept of a transmit array to include the guidewire as an additional coil element that can be driven with a chosen magnitude and phase to cancel out currents induced on the wire by imaging. However, much remains to be investigated. The exact resonant nature of the wave phenomenon inside and outside the phantom needs to be determined, and the effect of nulls in the standing wave pattern on both the coil coupling measurements and the drive toroid experiment should be examined. A water-proof version of our current sensor could measure the current on the wire in solution, yielding insight into potential wave behavior.

Conclusion: We have performed preliminary measurements of surface coil coupling to metallic guidewires. The goal is to incorporate such measurements in parallel transmit pulse design to use the degrees of freedom inherent in a transmit coil array to cancel out induced currents on guidewires and implant leads and thus potentially increase patient safety in MRI. The feasibility of generalizing the transmit array concept to include the guidewire itself as an active drive element has also been demonstrated.

References: [1] Nyenhuis et al., IEEE Trans Dev Mat Rel, 5:467-80, 2005. [2] Konings et al., JMRI 12 :79-85, 2000. [3] Zanchi et al., Proc 16th ISMRM, p897, 2008. [4] Stang et al., Proc 15th ISMRM, p925, 2007.

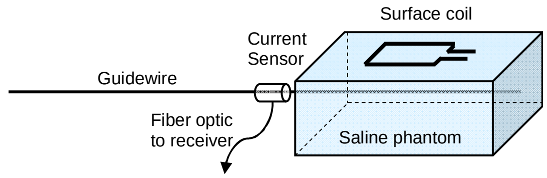

Figure 1: Setup for coupling measurements. By scanning the coil over several surface locations, we can synthesize the reaction that individual transmit coil elements could create.

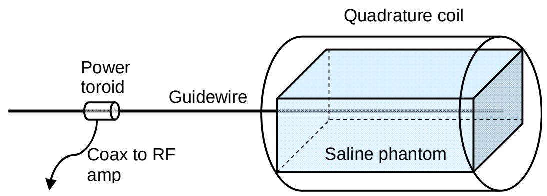

Figure 2: The actively driven guidewire can act as an additional transmit array element. It uses a power toroid cavity as a driver, and can retain the optical current sensor.

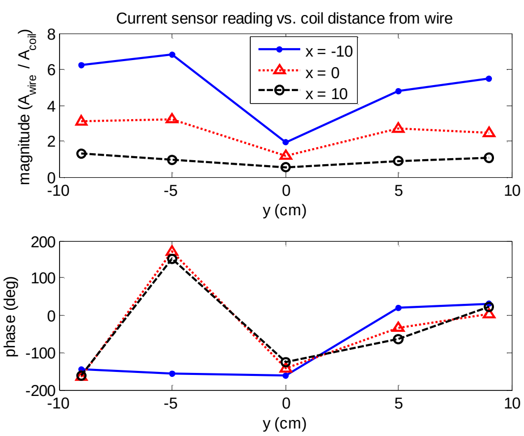

Figure 3: Coil coupling measurements (x = location of coil along wire length in phantom, y = perpendicular distance from wire to coil center) indicate that coupling is via coil-wire mutual inductance and not by electric field mutual capacitance.

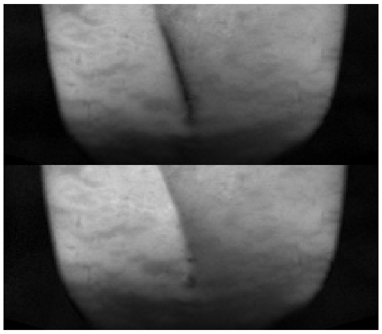

Figure 4: A drive toroid can deliberately induce large current artifacts (top), while a 180° phase reversal of the drive signal nearly minimizes the artifact (bottom) with head coil coupling.