Detecting Unsafe Device Coupling using Reversed RF Polarization

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Purpose: Patients with many types of common implants, including pacemakers and neurostimulators, are ineligible for MR scans due to the potential for tissue heating arising from RF coupling between the excitation field and their device. We propose a method for detecting this coupling by reversing the RF polarization in a birdcage coil. This produces strong MR signal around any coupled structures within the excitation volume and no signal everywhere else. We also describe straightforward calibration procedures to ensure perfectly reversed polarization over thick projection imaging volumes. Such a technique could be used to safely detect potentially unsafe coupling conditions before tissue damage occurs.

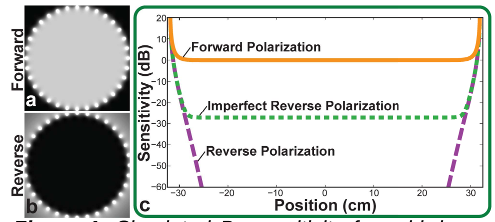

Figure 1: *Simulated B_1 sensitivity for a birdcage coil under (a) forward and (b) reverse polarization. When reverse polarized, the coil neither excites nor detects MR signal (c). However, a coil with 5° of quadrature error retains a small amount of background sensitivity if not properly calibrated.*

Methods: To generate standard MR images, a spatially uniform left circularly polarized RF field is desired for transmission[1,2], $B_L = B_1(a_x + ja_y)$, and a right circularly polarized field is needed for reception, $B_R = B_1(a_x - ja_y)$. Here, a_x and a_y represent unit phasors in the x and y directions. Figure 1 shows that a 32-rung birdcage coil closely approximates this ideal case near its center. If this RF polarization is reversed; i.e., B_R is used for transmission and B_L is used for reception, then MR signal is neither generated nor received.

When a coupled wire is present in the coil, it generates a secondary, linearly polarized field proportional to I, the coupling current: $B_W = \mu_0 I e^{j\phi}(a_y\cos\theta - a_x\sin\theta)/2\pi r$, where ϕ is a temporal phase and (r,θ is the polar position relative to the wire. The forward-polarized component of this induced field results in both excitation and reception of MR signal[3,4]. Thus, a wire in a reverse-polarized birdcage produces localized signal proportional to its coupling, while an uncoupled wire does not generate signal. The wire's coupling to the imaging transmit field (B_L) is of greatest interest, so reversal of the receive field to match B_L provides the greatest accuracy. However, by reversing both the transmit and receive field, the selectivity is squared. This may be preferred if precise quantification of coupling current is not required.

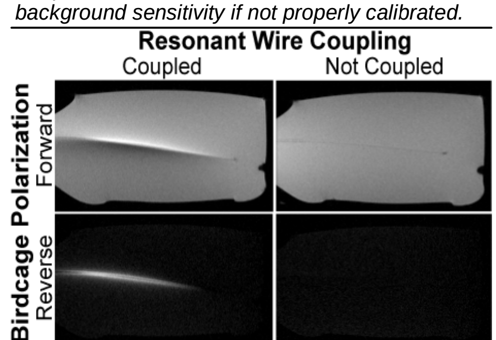

Figure 2: *Images acquired using forward polarization (top) generate tip errors near unsafe currents. When polarization is reversed (bottom), signal is generated only in the vicinity of unsafe currents. When the wire is cut short (right), reverse-polarization signal disappears because coupling is eliminated.*

To ensure that the primary excitation field is perfectly reverse-polarized, the birdcage coil should be calibrated to correct for asymmetric loading of the quadrature channels. Imbalances in the magnitude, phase, and group delay of the channels can vary significantly across subjects due to different loading conditions. To correct these errors in transmit and receive modes, we have modified a birdcage head coil to allow independent control of in-phase and quadrature channels. With this coil and a custom Medusa transmit/receive imaging console[5], we can quickly calibrate both the transmit and receive fields for optimally reversed polarization. Calibration is particularly advantageous in projection imaging, as large background volumes can generate significant erroneous signal even when errors are small.

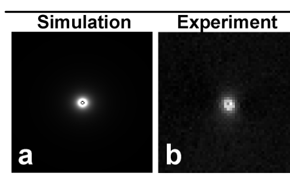

Figure 3: *Simulated reverse-polarization images (a) can be fitted to acquired data (b) to quantify current.*

Results: Sagittal gradient-echo images of a coupled 160-cm guidewire (Fig. 2) show tip artifacts near the device in the forward-polarization image and strong near-wire signal in the reverse polarization image, indicating significant coupling. When the wire was cut short to prevent coupling, the reverse-polarization signal vanished. Simulations of axial wire currents (Fig. 3) verify that reverse-polarization signal increases with wire current with the appropriate relationship. Modeling predicts that axial currents below 10 mA can be reliably detected using this technique, below which level RF burns are unlikely. Projection images (Fig. 4) show that when the coils are properly calibrated, reversing polarization in receive mode alone also adequately isolates wire currents. Similar current magnitudes are seen along the wire in the fully reversed-polarization image, suggesting that bias introduced by using B_R for transmission is not significant in this case. The area of low signal near the center of the image is likely due to a node of zero current in the standing wave.

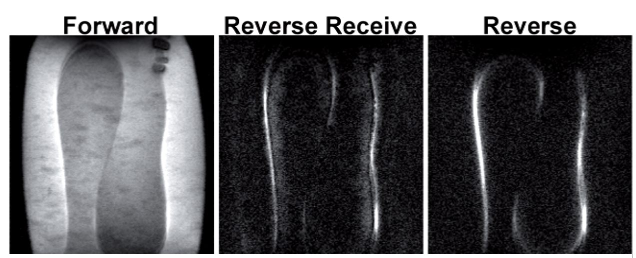

Figure 4: *Projection images of a 85-cm pacing lead in a 36-cm gel phantom. (a): Forward polarization; (b): Reversed receive polarization; (c): Reversed transmit and receive polarization.*

Discussion: We have demonstrated a new technique for rapidly detecting the presence of dangerous B_1 coupling using reversed circular polarization. Imperfections in the birdcage quadrature can be removed through a simple calibration. For fixed implants, such a technique could be integrated into a pre-scan regimen, or reverse-polarization echoes may be reconstructed periodically for dynamic monitoring during interventions. If desired, the tip profile generated by the wire might also be fitted[6] to more accurately quantify wire current from reverse-polarization images.

References:

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