# Safely Detecting Device Coupling using Reversed RF Polarization and Pre-Spoiled EPI

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**Purpose**: Patients with many types of common implants, including pacemakers and neuro-stimulators, are ineligible for MR scans due to the potential for tissue heating arising from RF coupling between the excitation field and their device. The severity of this coupling can be detected by reversing the RF polarization in the birdcage RF receiver[1]. Ideally, this results in MR signal only around coupled structures within the excitation volume. To exploit this effect for implant safety assessment, total RF power must be kept under a safe limit even in the case of maximum coupling. Here, we show that a four-shot projection EPI image of the region containing the implant can be used safely given some reasonable assumptions. Furthermore, robustness can be improved by adding a pre-spoiler gradient that effectively suppresses signal imperfections due to electrodynamic effects while minimally affecting the desired signal.

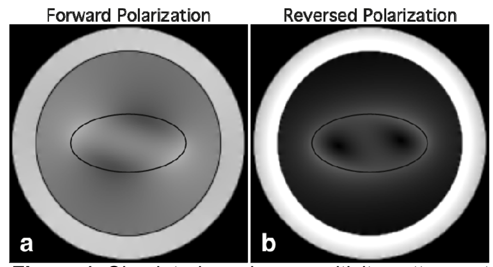


***Figure 1:*** *Simulated receiver sensitivity patterns at 1.5T for an infinite birdcage containing an elliptical load. Scattering fields induced by the load lead to signal inhomogeneity when the coil is phased for forward polarization (a), and regions of undesired sensitivity when polarization is reversed (b).*

**Methods**: A birdcage receiver has outputs that are combined in quadrature to be optimally sensitive to the circularly polarized field generated by precessing magnetization. The circular polarization sensitivity of such a coil can be reversed by inverting the relative phases of its outputs, which ideally makes the birdcage insensitive to MR signal. However, if a coupled wire is placed in the coil, it creates a secondary, linearly polarized field. Through reciprocity[2], this induced field is proportional to the coupling current $I$. It has equal forward- and reversed-polarization components regardless of the polarization of the birdcage receiver. Thus, a wire in a reverse-polarized RF receiver produces signal proportional to its coupling.

To exploit this phenomenon for detecting potentially dangerous implants, heating must be kept within safe limits. Using the bioheat equation[3], the worst-case heating from a single scan is

$$\Delta T \leq \frac{t_{rf} P_{max}}{m C_p},$$

where $C_p$ is the specific heat of the tissue, $t_{rf}$ is the total RF duration, $P_{max}$ is the maximum power of the RF amplifier, and $m$ is the smallest possible mass over which this power could be deposited. For example, if a 2-ms RF pulse is used with a 500-W amplifier delivering its power entirely into 1g of tissue, the maximum possible heating is about 0.27° C. Up to four TRs of such a sequence could be safely played without exceeding established heating limits.

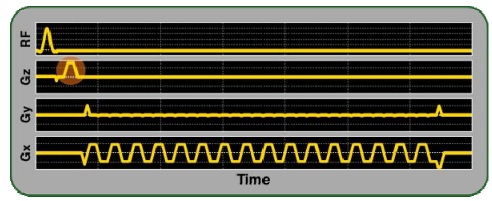


***Figure 2:*** *Pre-spoiled projection EPI sequence for detecting RF coupling. A reversed-polarization EPI readout detects RF wire currents. Signals arising from imperfect polarization reversal are suppressed by an extra z-spoiler (orange circle).*

Ideally, no signal would be generated in the absence of wire coupling, but RF inhomogeneity induced by coil loading can also disturb coil polarization as shown in the finite-difference simulations of Figure 1. In a forward-polarized coil, this loading results in well-known RF shading, while the reverse-polarized case results in regions of non-zero sensitivity.

These slowly varying background signals can be suppressed by adding a spoiler prior to readout (Fig. 2), which conceptually acts as spatial frequency filter. This spoiler also affects the wire signal, but to a lesser degree because of the sharp signal peak at the wire. In the unspoiled case, the projected signal of a wire running parallel to the imaging plane is approximately $S \propto I^2/r$ (after integration along the projection direction), where $r$ is the absolute in-plane distance from the wire. After through-plane spoiling, this signal becomes $S \propto I^2 e^{-kr}/r$, where $k$ is the time integral of the spoiler gradient, $k = 2\pi\gamma\int G_{spoil}(t)\, dt$. Thus, the spoiler adds only an exponential decay term to the wire signal. Figure 3 illustrates the effect of the spoiler; near-wire signal is virtually unaffected, while slowly varying background away from the wire is suppressed.

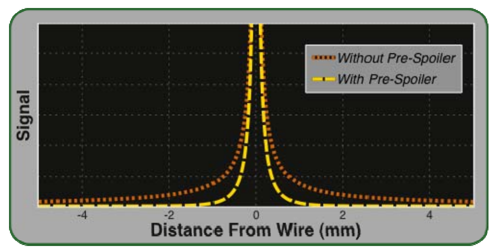


***Figure 3:*** *Wire signal as a function of distance shows that pre-spoiling has little effect near the wire, while signal further away is suppressed.*

We implemented this pre-spoiling in a four-shot projection EPI sequence with $128^2$ matrix and a 38-cm FOV. For polarization reversal, we modified a birdcage head coil to allow independent quadrature control using a custom Medusa imaging console[4].

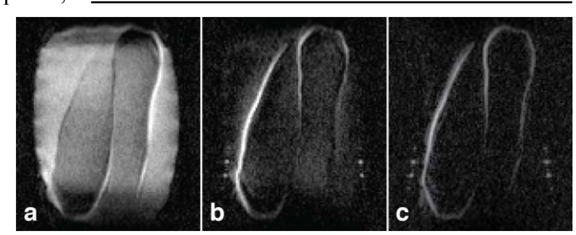


***Figure 4:*** *Projection EPI images of a wire lead in a 36-cm gel phantom. (a): Forward polarization; (b): Reversed polarization without pre-spoiler; (c): Reversed polarization with pre-spoiler. The added spoiler cancels residual background while retaining wire signal.*

**Results**: Sagittal images of an 85-cm wire (Fig. 4) show strong wire signal when polarization is reversed, indicating the presence of coupling. When the pre-spoiler is not used, background signal is reduced by 87%, but wire signal is difficult to distinguish in regions of lower current. Adding a pre-spoiler ($k$ = 0.5 cyc/cm) further reduces background signal to below the noise floor, while reducing near-wire signal by an average of only 25%. Areas of low current (at right in each image) are more easily distinguished from current nulls (near the ends and midpoint of the wire).

**Discussion**: We have shown that polarization reversal can be combined with a small pre-spoiler gradient to safely and reliably detect dangerous currents in an implanted device. The pre-spoiler eliminates background artifacts without suppressing the desired device signal, while the low-RF-power EPI projection ensures patient safety. For dynamic monitoring during interventions, echoes might be reconstructed periodically. Continuing research will develop a framework for quantifying wire current from image data and correlate these current measurements with RF heating.

**References**: [1]. Overall W, et al. Proc. 17th ISMRM: 306, 2009.
[2]. Kales M, et al. Proc. IRE 39(5): 544-549, 1951.
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