Parallel transmit with integrated toroidal transceive device visualization

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Introduction: An important concern in interventional MRI is the effective visualization of guidewires and ablation devices in a manner safe from unintended RF-induced heating. Previous work has shown that transmit-receive toroid-coupling enables high SNR and positive contrast visualization of conductive structures such as guidewires and EP ablation devices [1]. Unlike typical visualization and safety methods involving embedded micro-coils and cable traps, the transceive toroid can potentially be used with standard interventional devices, with minimal (if any) modifications. For RF safety, the transceive toroid can be integrated with a parallel transmit system employing power and optically coupled current sensing [1, 2] to monitor, control, and minimize RF coupling. In this work, we investigate this transceive toroid approach for safe and effective visualization of interventional devices within an integrated parallel transmit platform.

Methods: An EP catheter model (~9F insulated wire with 5mm of exposed conductor at the tip) with toroid coupling was inserted into a saline gel phantom (Fig. 1). The transceive toroid inductively couples to the catheter, making the catheter and toroid combination behave like an elongated coil [1]. We integrated this device with a Medusa parallel-transmit system [4] using a transmit-receive (T/R) switch, which converts the transceive toroid into a transmit array element. During receive, the T/R switch directs the toroid signal to a surface coil port of a GE Signa 1.5T scanner, allowing high SNR visualization of the catheter. Image reception could instead be performed with a volumetric receive array, when better visualization of the surrounding phantom volume is required [1, 2].

To determine the power levels needed for effective visualization of the catheter tip when transmitting and receiving with the transceive toroid, GRE images and Bloch-Siegert B1 maps [5] (TR/TE = 50/6ms, coronal/axial FOV = 40/15cm, 256x256, 1cm slice) were acquired using different peak slice-select RF transmit pulse amplitudes. An optically coupled toroidal current sensor [3] was used to measure the magnitude and phase of induced catheter current when transmitting hard pulses of the same amplitude as the Bloch-Siegert slice select pulse. The forward and reverse powers delivered to the transceive toroid were recorded from the bi-directional coupler inserted in the transmit chain.

Results: As shown in Fig. 2, power levels as low as 12mW are sufficient for visualizing the catheter clearly to the tip, with SNR exceeding 40. The corresponding current sensor measurements are consistent with these power levels; an increase in power by a factor of 25 corresponds to an increase in current by a factor of $\sqrt{25} = 5$.

The B1 maps in Figs. 3-4 give us an image-based method to determine the level of induced current. As the toroid is driven with increasing levels of power, greater amounts of current are induced, as indicated by the increase in B1 along the catheter in Fig. 3 (a-c). Increased background excitation and different wire current levels are induced when the additional surface coil elements of the transmit array are also excited (Fig. 3d). From the axial B1 map in Fig. 4 and the relation $B1 = \mu_0 I / (4\pi r)$, we can estimate the amount of induced current. We find that we are only inducing approximately 10mA of current when we transmit with 12mW, the power level needed for effective visualization.

Conclusion: A transceive toroid requires very low transmit power levels to achieve high SNR visualization of conductive interventional devices such as EP catheters and guidewires. When integrated within a parallel transmit platform employing current and power monitoring, it is a promising approach to RF safety and interventional device visualization.

References: [1] Etezadi-Amoli et al., Proc. 19th ISMRM, p1749, 2011. [2] Etezadi-Amoli et al., Proc 18th ISMRM, p777, 2010. [3] Zanchi et al., IEEE Trans. Med. Imag. 29:169-178, 2010. [4] Stang et al., Proc 15th ISMRM, p925, 2007. [5] Sacolick et al., MRM 63:1315-1322, 2010.

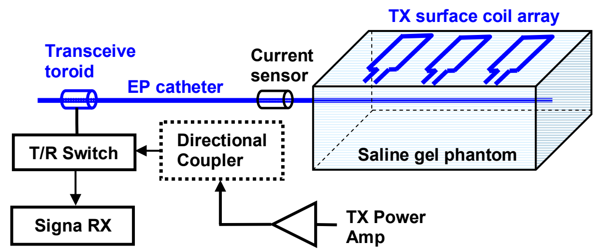

Figure 1: The elements in blue (3 surface coils, plus the conductive EP catheter and transceive toroid) form a 4-element transmit array, where each element can be individually excited. The T/R switch allows the toroid to also be used as the receive coil for imaging and high SNR visualization of the catheter.

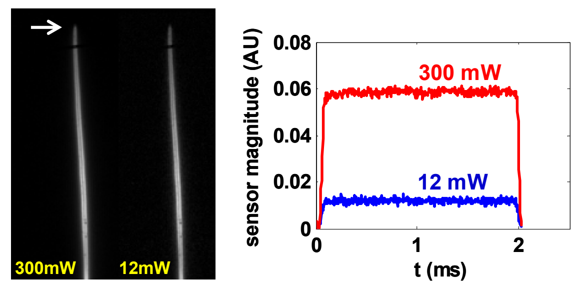

Figure 2: Catheter visibility (left) for 300mW (SNR = 190) and 12mW (SNR = 45) power delivered to toroid. Images are each windowed for optimal contrast. White arrow shows location of tip, black lines are markers in phantom. Current sensor measurements (right) for 2-ms hard pulse at these transmit power levels.

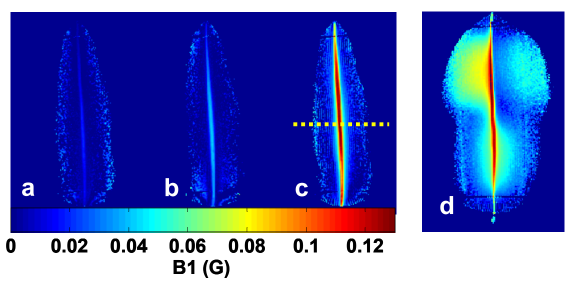

Figure 3: Coronal B1 maps for increasing transmit power levels on transceive toroid: 300mW (a), 1.2W (b) and 19.4W (c). More background B1 is available when the surface coils are also transmitting in addition to the toroid (d).

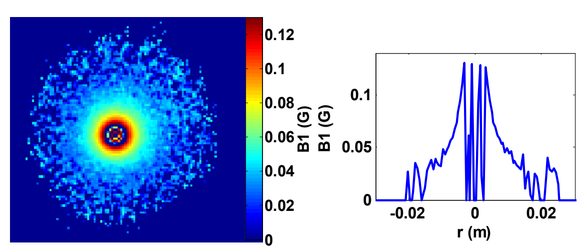

Figure 4: Axial B1 map at slice location indicated by dotted yellow line in Fig. 3c for the 19.4W transmit case and cross section through center of axial map showing ~1/r falloff of B1 with distance from the wire center. From this cross section, we compute a current value of approximately 414mA. For tip visibility, only 12mW of power is required, which from linearity is only ~10mA of current.