Micro Resonant Marker for Endovascular Catheter Tracking in Interventional MRI: In Vitro Imaging at 3T

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Target Audience: This paper is addressed to physicians and scientists who are interested in interventional magnetic resonance imaging (iMRI). Clinical applications include MR guided procedures such as endovascular interventions, percutaneous biopsies or deep brain stimulation.

Purpose: The promise of magnetic resonance (MR) guided endovascular procedures remains largely unrealized, as a safe and appropriately sized method for catheter tracking has yet to be described to date. While markers have been previously described [1,2], size, efficacy and safety shortcomings preclude them from clinical application. The purpose of this study was to create a miniature resonant structure for use as a bright marker on endovascular catheters for use in interventional MR procedures.

Materials and Methods: The resonant marker prototype was constructed on a 1.69 mm clinical grade endovascular catheter. Insulated copper wire with a diameter of 0.160 mm was wound at 45° around the catheter to create a double helix and was soldered to a custom single plate capacitor (Fig. 1). The capacitor is comprised of one 25.4μm thick polyimide sheet sandwiched between two 12.7μm copper sheets. The resonant markers were initially fabricated to resonate at a lower frequency than desired. The capacitor is trimmed to reduce capacitance until the assembly resonates at the desired frequency. A polyurethane layer is applied to waterproof the assembly and prevent coil movement (Fig. 2). The protective coating was applied and cured at 110°C. Coils were immersed in water and tuned with a network analyzer (Agilent Technologies 300kHz-1.5GHz ENA Series) and custom H-filed probe that coupled wirelessly to the resonant structure (Fig. 3). Experiments were performed at 3T (Discovery MR750w 3.0T, General Electric, Fairfield, CT) using a spoiled gradient echo sequence with a 2° flip angle (TE/TR=1.8/5.6ms, square 32mm FOV, slice thickness 5mm, matrix 256x128). The resonant markers were positioned parallel with B_0 in a water phantom. The contrast-to-noise ratio (CNR) was calculated using OsiriX Viewer.

Results: The micro resonant marker was clearly visible with a bright and highly localized signal enhancement (Fig. 4). The signal did not contaminate adjacent tissue. The complete resonant structure had a maximum diameter of 1.95 mm (<6 French) and a length 8 mm. The coil had a calculated Q of 106.11 (Fig. 3) and a CNR of 45.427 (Fig. 4).

Discussion: These findings validate the micro resonant structure as a viable marker for MR guided clinical applications. While we have a high CNR of 45, we feel this can be improved. Hand made resonant markers are effective but labor intensive to fabricate. Further development of manufacturing methods would reduce fabrication time and improve consistency. A catheter-integrated design, reduced thickness and orientation independent capabilities are feasible with only slight modifications to the marker design.

Conclusion: We have developed and tested the micro resonant marker for endovascular catheter navigation under MR guidance. The passive structure allows for tracking of sub 6 French endovascular catheters. The micro resonance marker provides an opportunity for safe and accurate catheter tracking and the ability to capitalize on the wealth of physiologic and structural information afforded by the interventional MRI environment. The marker's flexible structure and localized resonance make it a viable marker for MR guided catheter navigation.

References:

1. Titus Kuehne, et al. Pair of Resonant Fiducial Markers for Localization of Endovascular Catheters at All Catheter Orientations. J. Magn. Reson. Imaging 2003;17:620-624.

2. Mandy Kaiser, Markus Detert, et al. Self-Resonant Swiss Roll Structures as Semi-Active Device Visualization Method for Interventional MRI. Proc. Intl. Soc. Reson. Med. 21 (2013).

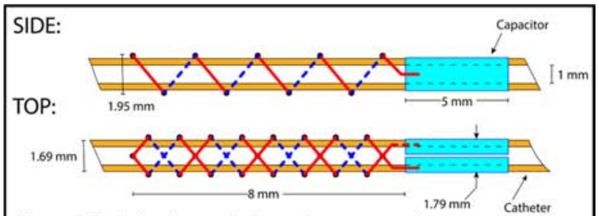


Figure 1: Sagital and coronal views of resonant marker concept Solid and dashed lines indicate wire in front of catheter and behind catheter, respectively.

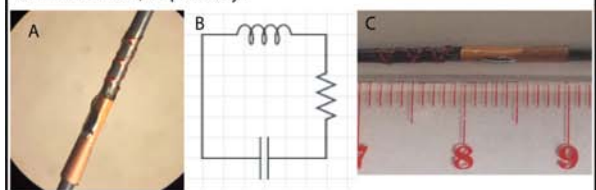


Figure 2: (a) Completed resonant marker viewed through microscope (b) Schematic of first order resonator (c) Resonant marker with scale.

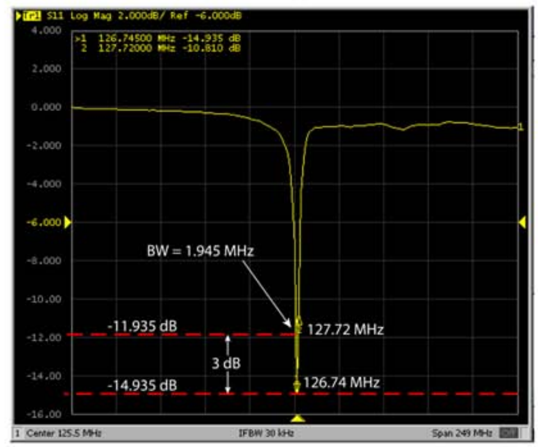
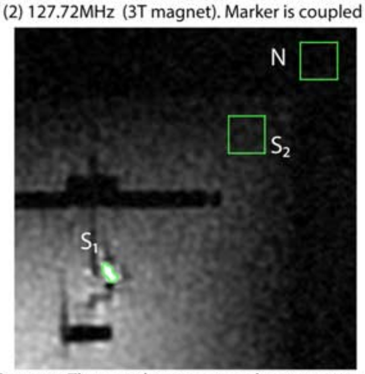


Figure 3: Tuned marker resonating at (1) 126.74 MHz, close to B_1 frequency of (2) 127.72MHz (3T magnet). Marker is coupled to custom H-field probe.



$$CNR = \frac{|S_1 - S_2|}{\sigma_o}$$

Figure 4: The tuned resonant marker resonates at 3T. Contrast to Noise Ratio (CNR) is calculated from resulting images.