# An optimized insert coil for high-performance delta relaxation enhanced MR imaging of the mouse

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## Introduction

Delta relaxation enhanced magnetic resonance (dreMR) is an emerging method for field-cycled MR imaging, which utilizes a removable electromagnetic coil to modify the strength of the main magnetic field during an MRI pulse sequence. The purpose of these unconventional field shifts is to allow unique contrasts not available with static-field MRI systems. Arguably, the most important application of this method is in the detection and quantification of targeted contrast agents that have become bound to *in vivo* target protein. Figure 1. shows a second-generation, mouse imaging, dreMR insert-coil within a clinical, 3.0 T, Siemens Tim Trio MRI system. Previous publications (1, 2) have described the initial applications of this technology as well as the proof-of-principle hardware used.

This abstract describes major improvements made in a new, high-performance, second-generation dreMR system for mouse and small animal imaging. Comparisons are made between this second-generation dreMR coil and the prototype dreMR coil used in early dreMR studies.

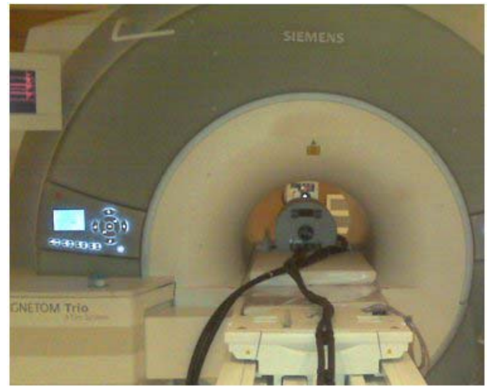


Figure 1. The dreMR electromagnetic insert rests upon the patient bed of an MRI machine. Electrical current is delivered though 4-0 AWG wire and heat is removed through chilled water lines.

## Methods

Important measures of any field-cycled electromagnetic insert coil are: ease of installation (mass), magnetic field efficiency, resistive merit, electromagnetic shielding and cooling method. Magnetic efficiency, $\eta$, is the magnitude of the magnetic field shift per amp of current flow. The resistive merit, $\eta/\sqrt{R}$, is a measure of the magnetic field produced by insert for a given rate of heat deposition, where R is the resistance of the insert. The final measure, cooling method, is a determining factor in the maximum field shift achievable by the coil.

**Reducing the coil size** The 17 cm inner diameter of the prototype dreMR coil was unnecessarily large for mouse imaging. To increase magnetic efficiency, lower electrical resistance and reduced weight, the inner diameter of the second-generation coil was decreased to 8 cm. Reducing the inner diameter allowed the outer diameter to be decreased from 41 to 32 cm and the length shortened from 76 to 42 cm.

**Improving the coil cooling** In order to improve the rate of heat flow out of the insert (cooling), chilled water was passed directly through the electrical windings of the second-generation insert coil. This was achieved by using custom-made, hollow wire (Small Tube Products, Duncansville, USA) with a 5 mm, square outer diameter and a 3 mm, circular inner diameter. Electrical insulation for the wire was achieved with a continuously wound, double layer of 0.125 mm Kapton. While the use of hollow wire increased the electrical resistance of the coil by 30%, it provided a vastly superior cooling mechanism by permitting chilled water to flow directly through the hot electrical conductor. This direct cooling method provides intimate contact between the coolant and the copper windings, enhancing cooling efficiency.

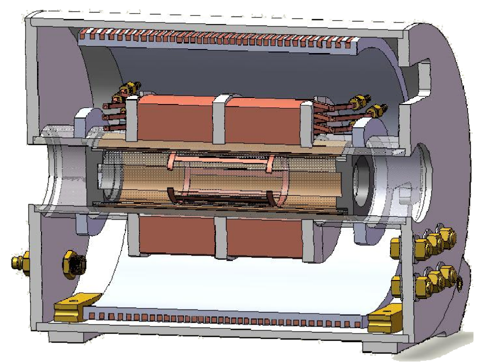

Figure 2. Computer-aided-drawing of the second-generation dreMR insert coil. The primary magnet, for creating the field shift, shield magnet, to reduce magnetic interaction between the insert coil and host MRI system, water manifold are shown.

## Results

The table to the right lists the essential parameters of the prototype and second-generation dreMR system. The most significant improvements over the prototype dreMR system are: a 9-cm reduction in imaging region diameter, 100-kg decrease in mass, 20 % increase in magnetic efficiency, 2.3 fold increase in resistive merit and a 3.9 fold increase in sustained field shift.

| | Prototype dreMR Coil | 2nd-gen. dreMR Coil | Units |
|---|---|---|---|
| **Mass** | 150 | 50 | [kg] |
| **Length** | 76 | 42 | [cm] |
| **Inner Diameter** | 17 | 8 | [cm] |
| **Outer Diameter** | 41 | 32 | [cm] |
| **Inductance** | 7 | 1.2 | [mH] |
| **DC Resistance** | 400 | 120 | [mΩ] |
| **Imaging Region** | 14 | 5 | [cm] |
| **Mag. Efficiency** | 0.7 | 0.85 | [mT / A] |
| **Resistive Merit** | 1.1 | 2.5 | [mT $A^{-1}$ $\Omega^{-1/2}$] |
| **Max. Cont. Field** | 70 (70 °C rise) | 270 (30 °C rise) | [mT] |

## Conclusions

Resizing and redesigning the dreMR insert coil for mouse-sized subjects resulted in a higher efficiency and increased resistive merit. Using hollow conductor instead of regular magnet wire resulted in more effective cooling. Combing these two features, the maximum sustained magnetic field shifting was increased by nearly 4 times to 270 mT. In many applications, this increase will directly result in a four times increase in the contrast to noise ratio.

## References

1. Alford J.K.; et. al., MR Engineering 2009;35B(1):1-10.
2. Alford J.K., et. al., Mag Res Med 2009;61(4):796-802.