Improved RF safety of Interventional Devices using Cable Traps

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Introduction: Radio frequency (RF) micro-coils built at the distal tips of therapeutic devices such as catheters and connected to the external system using one or more coaxial cables enable accurate tip tracking and small field-of-view, high resolution imaging to perform MRI-guided interventions. Large RF magnetic fields generated during the transmit cycle induce large-current standing waves in the coaxial cable shield that result in RF heating. Under certain conditions, temperature rise of as high as 55° C has been reported in RF microcoils. Techniques to suppress RF heating include quarter-wave sleeve baluns implemented using micro triaxial cables [**1**] and transformer-coupled transmission lines [**2**]. In this study, we have investigated the use of simple coaxial cable-traps to suppress RF heating.

Methods: Two multi-mode coils [**3**] were implemented at the distal end of a 3.175 mm (O.D) flexible plastic tubes (box 1, figure 1). One of the coils (coil A) was connected to a proximal external connector via a straight length of micro-coaxial cable. On the other (coil B), three coaxial cable-trap baluns (box 2, figure 1) were formed using 70 tightly-wound turns of the coaxial cable around the catheter. The measured shield impedance of each balun was 510 Ω. The baluns, which that were placed approximately 20 cm (λ/15) apart, were not resonant at 64 MHz, but simply presented a high inductive reactance to currents induced on the coaxial cable shield.

To quantify RF heating, two cylindrical phantoms (length: 45 cm, ID: 4 cm) were constructed with circular openings drilled along their lengths at center to center spacing of 5 cm as shown in figure 2(a). The openings were plugged with acrylic rods with co-axial and cross-axial holes as shown in figure 2(b). Catheters A and B were placed in the cylindrical phantoms filled with 0.9% physiologic saline as shown in figure 2(c). Fiberoptic temperature probes (Neoptix) were inserted into the co-axial openings in the acrylic plugs at points corresponding to the tip tracking coil and matching network of the multimode device (Figure 2(c)). The probes were connected to the fiberoptic thermometry system (Neoptix) as shown in figure 2(d). Open ended extension coaxial cables that were cut to equal lengths (500 cm) and connected to the micro coaxial cables of catheters A and B at their proximal ends served to extend the total lengths of the coaxial cables beyond their respective resonant lengths. The phantoms were placed parallel to the z-axis and 25 cm off-center in the bore of a 1.5 T MRI scanner (GE Signa).

The maximum temperature rise at the distal tip of coils A and B were measured at the end of a 3 minute scan with a 2D multi-slice SSFP imaging technique (TR/TE = 4/1.3 ms, Flip = 90°, FOV = 48 cm, slice thickness = 5 mm). The scan was repeated several times for various extension cable lengths.

Results: A plot of the temperature rise as a function of cable length shown in figure 3 clearly demonstrates that simple coaxial cable trap baluns can effectively eliminate RF heating. In this plot, P1, 3P1 and P2, 3P2 correspond to the active tip-tracking coil and matching network locations of the multimode coil with and without baluns respectively.

Conclusion: Our preliminary results suggest that 1) the maximum temperature rise at the coil tip-tracking coil and matching network locations occurs when the cable length is close to nλ/2, 2) coaxial cable traps can effectively eliminate RF heating at the tip-tracking coil and matching network locations, and 3) RF heating for all other cable lengths is negligible.

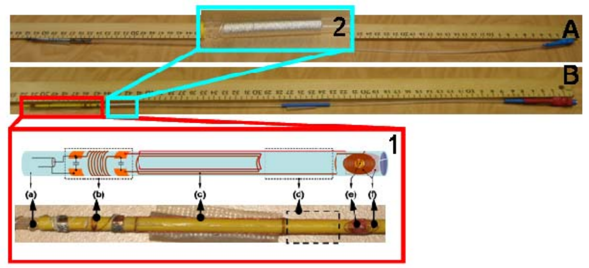

Figure 1: Multimode coil implementation without (A) and with (B) coaxial cable trap baluns. The multimode device is magnified and shown in box 1 along wih a schematic of the multi-mode coil showing (a) the flexible plastic tube, (b) the π matching network, (c) the 2-turn imaging loop, (d) the region of signal cancellation, (e) the tuning capacitor (yellow rectangle) and (f) the tip tracking Helmholtz pair. A magnified picture of the coaxial cable trap is shown in box 2.

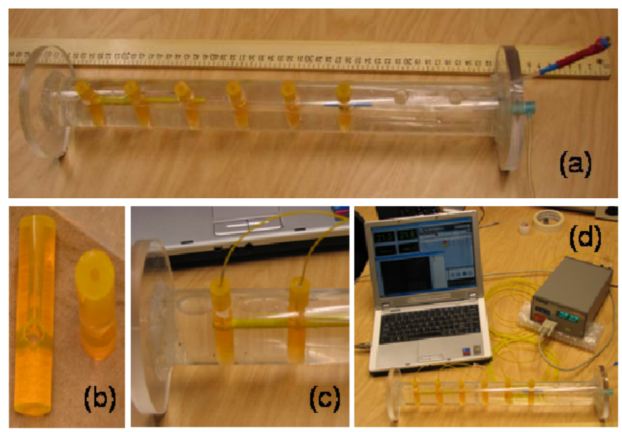

Figure 2: The cylindrical phantom (a) was used to measure the RF heating caused by placing a multimode coil in an external RF magnetic field. The plugs (b) have co-axial and cross axial holes into which, are inserted, respectively the temperature probes and multimode coil (c). The fiberoptic temperature probes are connected to a thermometer that is interfaced with a computer (d).

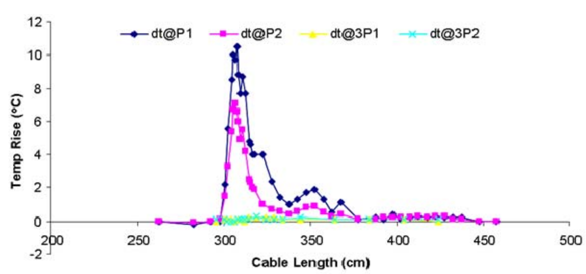

Figure 3: A plot of the temperature rise vs. the resonant cable length reveals 1) RF heating is a problem only at some resonant length of the cable and 2) the coaxial cable trap balun effectively eliminates RF heating even in the worst case of a static phantom. In this plot, P1, 3P1 and P2, 3P2 correspond to the tip and matching network regions of the multimode coil with and without baluns respectively.

References

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Acknowledgements

This work was supported in part by the National Institutes of Health Grant HL86975, Coulter Foundation, DRAPER, and IEDR funds.