Suppression of RF Heating due to Intravascular Devices using Non-resonant In-line Coaxial Choke Baluns

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Introduction: MR guidance and high resolution endovascular imaging using therapeutic devices such as catheters and guide wires involve the use of radio frequency (RF) microcoils located at the distal tip of such devices and connected to the external system via a long coaxial cable. Large transmitted B_1 fields induce large current standing-waves on resonant lengths of the coaxial cable, leading to significant heating, especially in the vicinity of the microcoil. Solutions suggested to suppress RF heating include the use of triaxial sleeve baluns [1], transformer-coupled transmission lines [2] and in-line coaxial chokes [3]. There is some degree of skepticism of the effectiveness of coaxial chokes as it is hypothesized that self-resonant chokes will only shift the problem of RF heating to the chokes themselves. In this work, which is an extension of previous work [3], we demonstrate the effectiveness of the non-resonant coaxial choke in suppressing RF heating not only at the microcoil but also in the vicinity of the chokes themselves.

Methods: Two identical solenoidal microcoils (ID = 2.9 mm, length = 2.6 mm, number of turns = 14) were built at the distal tip of 2 long plastic tubes (OD = 2.9 mm) (figure 1). Both microcoils were tuned to series resonance at 63.86 MHz using series capacitors. One of the microcoils (M1) was connected to a proximal SMA connector via a straight micro-coaxial cable (42 AWG center conductor), while the other microcoil (M2) was connected to a proximal SMA connector via a micro-coaxial cable with coaxial choke baluns placed at three (3) locations along the length of the tube. The baluns consist of 50 tightly-wound turns of the self-same micro-coaxial cable. An inductive reactance of 1.5 kΩ was measured across the balun.

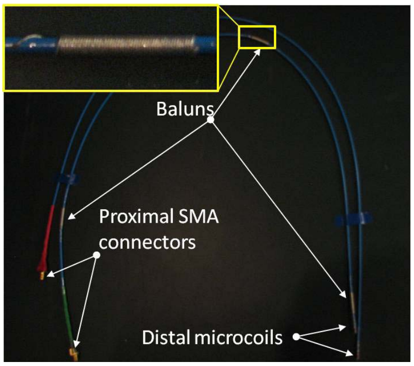

Fig.1 Implementation of catheters with distal microcoils. The inset shows the coaxial in-line balun.

To quantify RF heating, an experimental setup identical to that described in [3] was used (figure 2). A cylindrical phantom (length = 45 cm, ID = 4 cm) with holes drilled along its length at a spacing of 5 cm was filled with 0.9% physiologic saline doped with 0.3% $CuSO_4$. The openings were plugged with acrylic rods with co-axial and cross-axial holes. The tubes containing the microcoils were inserted into the co-axial holes of the acrylic rods along the length of the phantom. Fiberoptic temperature probes (Neoptix) were inserted into the cross-axial openings in the acrylic plugs at points corresponding to the microcoil and five (5) points along the length of the balun closest to the microcoil. The probes were connected to the fiberoptic thermometry system (Neoptix). Extension coaxial cables terminated in 50Ω were connected to the micro coaxial cables of M1 and M2 at their proximal ends and served to extend the total lengths of the coaxial cables to 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 (Signa, GE Healthcare, Waukesha, WI).

The maximum temperature rise at the distal tip of M1 and M2 and five points along the length of the balun as described above were recorded during a 4 minute scan with a 2D multi-slice FSE imaging technique (TR/TE1/TE2 = 2000/16/80 ms, ETL = 8, FOV = 40 cm, slice thickness = 3 mm, slice spacing = 1.5mm, number of slices = 13, matrix = 256 X 128, number of excitations = 4). The transmit gain was increased by 8dB above the level selected by the scanner auto-prescan as reported in [1].

Results: As seen in Figure 3, a plot comparing the temperature rise at M1 and M2 locations clearly demonstrates the effectiveness of the non-resonant balun in suppressing RF heating at the microcoil. Figure 4 shows the temperature measurements at 5 locations along the balun described above. The temperature rise is insignificant and is less than 0.1^{o} at all 5 measurement locations.

Discussion: The in-line RF coaxial choke presents a simple and straightforward mechanism for suppressing RF heating of microcoils used in MRI active device tracking and intravascular imaging applications. Our results corroborate previous work [3], which demonstrates that the use of non-resonant coaxial chokes effectively suppresses RF heating at the microcoil. More importantly, our results clearly show that the balun itself does not result in RF heating, provided that non-resonant coaxial chokes are used. Additional concerns about the in-line choke design are with regard to its bulk. For our work, we have used microcoaxial cable with outer diameter of 400 µm. However, smaller micro-coaxial cable (OD =115 µm) is also available [4], thus reducing the size of the balun. Of course, the question of signal loss will have to be addressed with the use of smaller and therefore lossier microcoaxial cable. In conclusion, our results clearly demonstrate that non-resonant coaxial chokes as in-line baluns are very effective in suppressing RF heating not only at the microcoil but also in the vicinity of the choke itself.

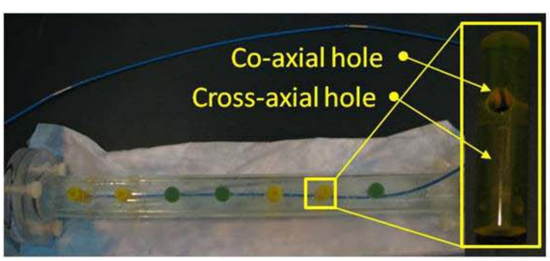

Fig.2 Experimental setup for RF heating measurements is shown.

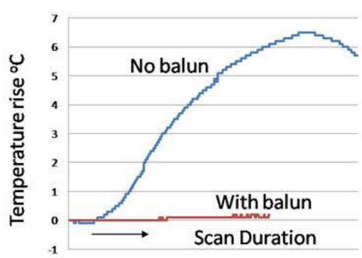

Fig.3 Temperature rise with or without baluns is shown. Effectiveness of the balun is clearly demonstrated

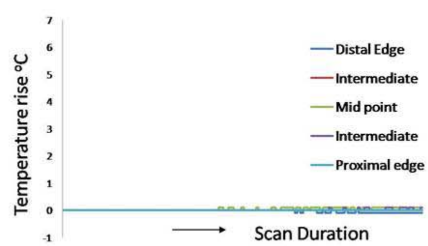

Fig.4 Temperature rise at 5 different locations along the non resonant balun are shown. Note that there is no heating.

References: [1] Ladd ME *et al*, MRM (2000) 615-619, [2] Weiss S *et al*, MRM (2005) 182-189, [3] Kurpad KN *et al*, ISMRM (2009) 4791, [4] Yak N. *et al*, ISMRM (2010) 1851.

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