In-vivo Active Catheter Tracking using an RF-Safe Transmission Line

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Objective: The clinical usefulness and the technical robustness of active catheter tracking for MR-guided intravascular interventions has been proven before. However, RF-resonances on the cables required for active techniques may lead to excessive heating during RF transmission, which prohibits their clinical use [1,2]. Previously, coaxial chokes have been proposed to block such RF-resonances, and tip heating was greatly reduced [3,4]. However, such chokes are resonant themselves and provide new localized areas of high electric fields, making the chokes prone to RF-heating.

RF-resonances can be shifted to a frequency range beyond the Larmor frequency by dividing a transmission line into short segments. We propose such a transmission line for interventional instruments, that contains transformers to segment the line. It is the objective of this work to demonstrate that this approach can vastly improve the RF safety of intravascular active tracking devices, and that the approach allows robust active tracking in-vivo.

Material and Methods: Transformers were used as connecting elements between the line segments, because they inductively couple the MR signal, but strongly attenuate any RF currents associated with resonances, since the latter do not generate currents through the coils of the transformers. In order to test the effect of the transformers on RF-heating, two test lines with and without transformers were built for comparative temperature measurements. Both lines were made from coaxial cables (1.5m, 1.05mm ∅, 0.83dB/m loss, SML50, Axon, Germany), and tip tracking coils wound on short sections of a catheter tube were matched to the cables using miniature capacitors. A diode (BAS516, Philips Semiconductors) was connected parallel to the coil for passive decoupling. Three transformers were integrated into one of the lines dividing it into equally long segments. The transformers were realized in PCB technology as symmetric single loop transformers with a loop length of 5cm, a loop width of 500µm, and a distance of 127µm between the loops (Fig.1). Capacitive networks were used to match the transformers to the cable. Temperature measurements were performed with each line immersed in a water bath located at the same position parallel to B_0 in the MR scanner (INTERA 1.5T, Philips). After the application of a balanced FFE sequence for 1min (TR=4.1ms, various α), the temperature was recorded with a fiberoptic probe (Luxtron790, Santa Clara, CA) at and in the tip coil and at various locations of the transformers.

In order to evaluate the approach for in-vivo active tracking, a tracking catheter was built based on a 12F double lumen tube. A micro coil was mounted to the tip, matched to a micro coaxial cable (0.53mm ∅, 1dB/m loss, MMK5001, Elspec, Germany) and passively decoupled as described above. The micro coax was segmented using transformers as in Fig.1 and pulled through one of the lumina, keeping the other one free for medical use. The catheter was used for real-time MR-guided catheterisation of the vena cava, the right atrium and the right ventricle of a swine. In-plane tracking and slice tracking were performed using the standard catheter tracking option of the scanner. Slice tracking projection data were recorded, and the SNR of the projections was evaluated.

Results and Discussion: The temperature increased by at least 10°C for $\alpha \geq 35°$ for the standard line (Fig.2). The measurement with $\alpha = 50°$ was stopped after 20 s, and higher flip angles were not applied in order to avoid extreme heating and a possible damage to the device. The high increase of temperature measured with the standard line confirms that a position within the MR system has been chosen, which is demanding in terms of RF-safety. For the transformer line at the same position, heating was limited to 0.5 °C at all locations of the tip coil and of the transformers, even for $\alpha = 90°$. Further measurements for $\alpha = 50°$ with partial immersion of the transformer device did not result in any noticeable temperature increase. A transmission loss of -1.3dB per transformer and a -3dB-bandwidth of 32 MHz for the complete line was measured with a network analyser. In the in-vivo experiment, the tip coil of the active tracking catheter provided a very strong signal (factor 57±12 wrt blood, hot spot marked by arrow in real-time image in Fig.3). Also, the transformers were well visible as bright bars (factor 3±1 wrt blood, close-up of real-time image in Fig.4), because they act as local receive coils. In-vivo slice tracking and in-plane tracking performed absolutely robust in the vena cava and in the right heart. The SNR of the magnitude projections acquired for slice tracking was 107±13.

Conclusion and Outlook: It has been demonstrated that the RF-safety of intravascular instruments that contain MR signal transmission lines can be vastly improved by the introduction of transformers in the transmission line. Miniature transformers have been designed, that fit the dimensions of such instruments. Comparative temperature measurements in the MR have shown that these transformers can reduce RF heating to the physiologically non-relevant level. Robust active slice- and in-plane tracking with an active tracking catheter equipped with transformers was demonstrated in the beating heart. Since the transformers introduce signal loss only in the order of the loss of low profile miniature coaxial cables, the approach may also be applied to intravascular imaging. Due to the large transmission bandwidth, the approach might also be used to provide RF-safe transmission of non-MR signals.

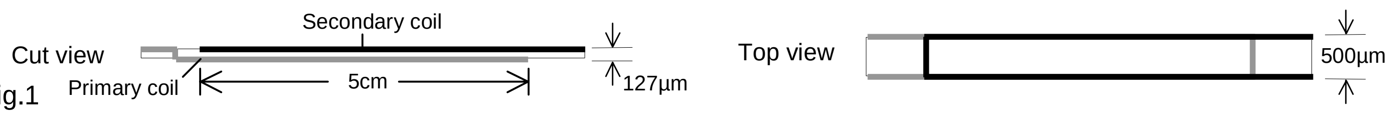

Fig.1

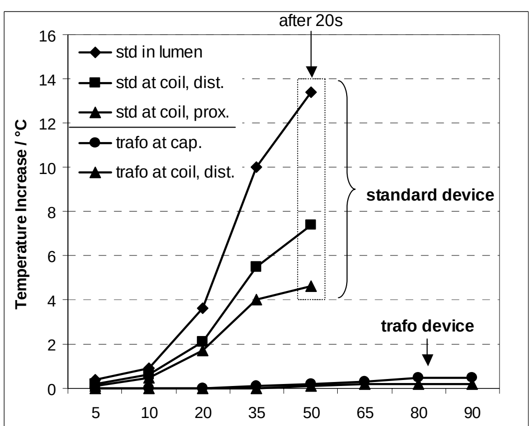

Fig.2

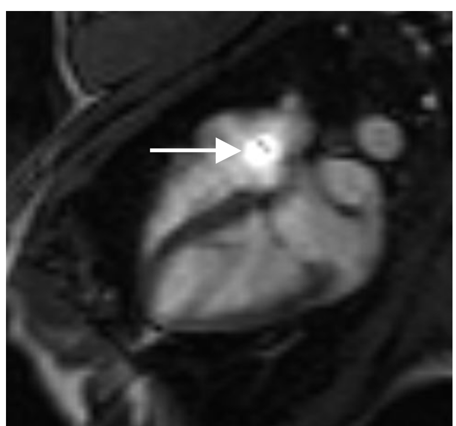

Fig.3

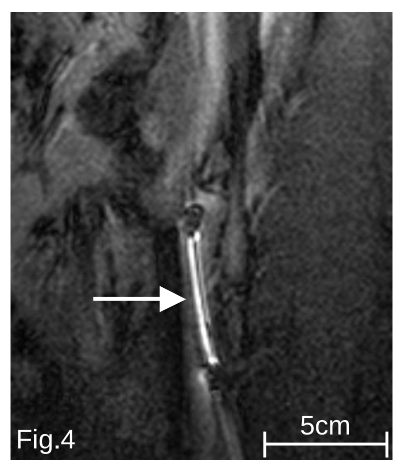

Fig.4

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