An Actively Segmented Transmission Line for Improved MR Safety of Interventional Devices

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Introduction

For many MR-guided interventional procedures rapid and reliable tracking of instrument position is desirable. For intravascular applications active tracking catheters with micro coils at their tips have been designed, where the MR signal is guided to the receiver using long transmission lines over the full length of the devices. As long conductive structures are potentionally dangerous due to excessive tissue heating, their clinical use in interventional MRI is prohibited. Alternative approaches make use of fibre optics to completely avoid conducting structures, however, this technology still needs to be refined to be integrated into small devices such as catheters or guide wires.

Alternatively, methods have been developed which divide extended conducting structures into short segments either using resonant coaxial chokes [1] or miniature transformers [2]. Disadvantages of these technologies are the required increase in size, insufficient common mode suppression, signal attenuation or technological expense. In this work we propose an alternative segmentation approach, where the transmission line is electronically divided into several sections by RF switches. The lengths of the sections are small compared to the wavelength of the scanner's RF and are well isolated from each other during transmit phase so that resonant coupling and thus, excessive tissue heating, is avoided. In receive phase the integrated switches reconnect all segments to a full length low loss transmission line.

Materials and Methods

To demonstrate the concept of active transmission line segmentation a coaxial cable (Suhner K01152-07, length 1.2 m) was cut into four 30cm-long segments. PIN diodes (Philips BAP 51-03, SOD323 package) connected the inner conductors and the braiding as shown in Fig. 1. A direct current of $I = 50$ mA was applied during signal reception to electronically connect the individual segments, whereas a voltage of $U = -30$ V was used to open the transmission line during rf excitation.

To initially characterize the performance of the transmission line at 50 Ω termination both transmission loss and isolation were measured at $\nu = 63.685$ MHz using a network analyser (Advantest R 3765 CG). Then, a micro coil (coated copper wire, $Ø_w = 0.2$ mm, 6 turns, $Ø_c = 5.8$ mm, $l = 6$ mm) was connected to one end of the transmission line to simulate an active catheter. Immersed in physiologic saline solution the transmission line was positioned in a clinical 1.5 T whole body MR system (SIEMENS Symphony, Erlangen, Germany) at a distance of 30 cm from the isocenter, with the tip coil close to an end ring of the body coil. To assess the influence of the switches on the heating properties of the transmission line temperature measurements were performed both close to the tip coil and the RF switches with a fibre optic thermometer (LUXTRON 3100) and a trueFISP sequence ($\alpha = 70°$, TR = 3.5 ms, TE = 1.77 ms, reference voltage = 253 V). For comparison, temperature measurements were also performed with an identical transmission line assembly without rf switches.

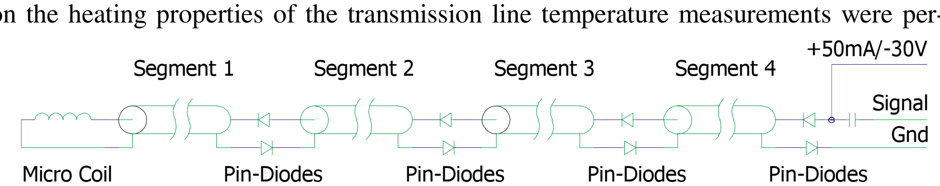

Fig.1: Schematic of the actively segmented catheter. The PIN diodes act as RF switches cutting the transmission line into segments when open (-30V) and reconnecting them to a full length transmission line when driven by a common DC current (+50mA).

Results and Discussion

Neglecting pure cable loss the excess insertion loss caused by the PIN diodes was 0.46 dB during signal reception mode, whereas an isolation of 80 dB was measured during rf transmission. In the MR scanner a temperature increase of $\Delta T = 58$ K was found at the tip for the unsegmented transmission line after only 1.5 min, while the actively segmented catheter showed an increase of $\Delta T = 7.2$ K after 6 min in steady state.

The proposed setup is thus capable of reducing the risk of RF heating in MRI devices with extended conductive structures. The additional rf switches provide an almost perfect isolation during rf transmit and acceptable insertion loss during signal reception. This temperature increase is expected to be significantly smaller in miniaturised devices and transmission lines with typical catheter diameters of 2 mm and less. In the future, integration of the rf switches into small coaxial cables could be accomplished using the most recent generation of PIN diode packages (0603), so that cable diameters of 0.8 mm or less could be achieved over the whole length of the active catheter.

References

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