Simulations on a Transformer based Transmission Line to achieve enhanced RF-safety

P. Vernickel[1], S. Weiss[1], V. Schulz[2], B. Gleich[1]

[1]Philips Research Laboratory, Hamburg, Germany, [2]Draeger Medical AG & Co. KGaA, Luebeck, Germany

Introduction

Active catheter tracking and intravascular imaging using catheter borne wired micro coils have been shown to be very useful during MR-guided intravascular interventions. Possible common mode resonances (CMR) may cause hazardous tissue heating, and hence, active techniques are not applicable to patients up to now [1,2]. The RF-safety can be vastly improved by shifting the lowest CMR frequency of the transmission line far above the MR frequency. This can be obtained by breaking the long conductor structure into short sections, which are weakly coupled with respect to common mode. Here, transformers are introduced to connect the short sections to transmit the MR–signal inductively. It is the objective of this work to examine the effect of transformers on the CMR frequencies and on the local SAR by means of EM- and SAR simulations.

Methods

The simulation model (Fig.1) comprises a catheter inside a patient who is located in a body coil. A dielectric layer mimicking the patient (thickness d_P= 0.3m, ε_r= 80, σ= 0.5S/m) was centred between two perfect electrically conducting layers (PEC) of distance d_b= 0.65m. Two rods were connected to the PEC layers in order to simulate an RF-excitation similar to a body coil. A catheter model in form of a coated wire (length=1.5m, coating ε_r= 4, σ= 0) was placed off centre in the dielectric layer. The transformers, which are placed along the transmission line, are modelled as lumped capacitors with the capacitance C_{stray}, because the residual common mode coupling between the sections is determined by the stray capacitance of the transformers. The lowest CMR frequency was determined for different model configurations by monitoring the wire current. Firstly, the shift of the CMR frequency was observed as a function of the coating thickness of a plain wire. Secondly, a first capacitor was placed in the centre of the wire to examine the influence of the capacitance C_{stray}. Thirdly, up to four capacitors with a fixed capacitance C_{stray}= 5pF were distributed evenly to observe the effect of multiple transformers. Finally, the SAR gain [3] in the tissue along the wire was calculated for up to three transformers. All simulations were performed at 63.87 MHz using the 3D method of moments tool FEKO [4]. Based on the results, a transformer was designed, which matches the spatial requirements of a catheter. Using several of these transformers, a prototype transmission line was built. The transformers were matched to the characteristic impedance of the cable. The properties of signal transmission were measured with a network analyser (HP8753D).

Results and Discussion

The lowest CMR frequency of the plain coated wire was 42MHz (Fig.2). Because the CMR frequency would be at Larmor frequency at some shorter inserted length, the configuration is not RF-safe. To achieve RF-safety, the lowest CMR frequency of the fully immersed wire should already be beyond the Larmor frequency. The CMR frequency could be increased by decreasing the ratio between the conductor radius and the coating thickness, but due the spatial constraints for catheters, this measure alone was not sufficient. Secondly, the CMR frequency could be increased by decreasing the capacitance C_{stray} (Fig2). An enhanced shift effect could be obtained by using more than one capacitor (Fig.2), because the effective capacitance was reduced due to the series connection of several capacitors. The wire without any capacitor caused a local SAR reduction at Larmor frequency, but this configuration is not RF safe as pointed out above (Fig.3). A SAR gain of 9.8 was obtained at the wire ends for one capacitor, because the CMR frequency was shifted to nearly the Larmor frequency. For the models with two and three capacitors, the SAR gain was significantly reduced. For three capacitors, the SAR gain was lower than 1.4 for all immersed lengths. The local maxima of the SAR gain along the wire were caused by the stray fields of the capacitors. Each transformer enhances the CMR suppression, but also introduces some signal loss. By proper matching of the transformers and the cable, an attenuation of 1.3dB per transformer was obtained at the Larmor frequency. A good trade-off between CMR suppression and signal attenuation was found for three transformers. The stray capacitance between the primary and secondary winding of the designed transformer was 4.8 pF.

Conclusion

The simulations for the CMR and the SAR gain indicate that transformers improve the RF safety of transmission lines in active catheters. The introduction of transformers into a catheter transmission line limits the SAR gain to acceptable values. The additional signal attenuation caused by the transformers is acceptable and suggests the use of the approach for active catheter tracking and intravascular imaging.

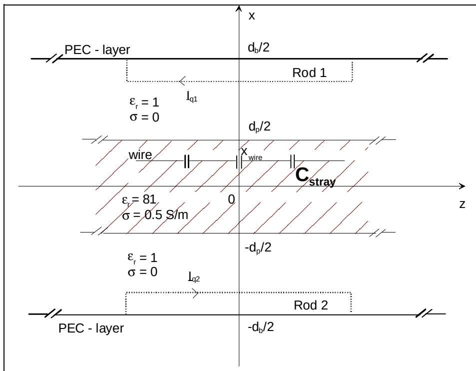

Fig.1 Common mode model for the wire inside in a lossy dielectric mimicking the patient. Here, three capacitors are placed along the wire.

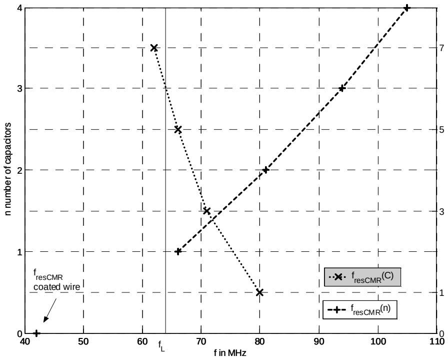

Fig.2 Lowest CMR frequency vs. number of capacitors (dashed) and lowest CMR frequency vs. stray capacitance of one transformer (dotted). The vertical line indicates the Larmor frequency for 1.5T.

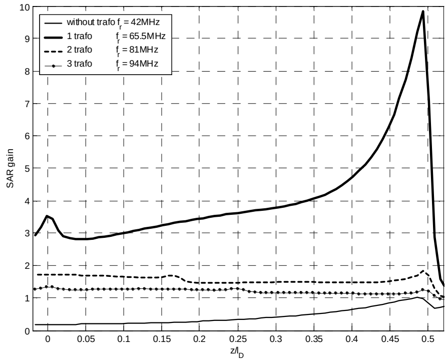

Fig.3 SAR gain along the wire at Larmor frequency. Position z is normalized to the wire length l_D. Because of the symmetry only one half of the SAR gain curve is represented. The lowest CMR frequency for each configuration is listed in the legend.

References

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