Miniature Optical Signal Transmission System for an Active Intravascular Device

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Objective: Active devices with wired receive coils enable very fast and robust catheter tracking and also intravascular imaging, but potential RF heating of such active devices has so far prevented their clinical use. Recently, a transformer-based cable was presented that efficiently reduces RF heating for active devices [1]. Similar results were obtained with an approach based on diodes [2]. Whereas those approaches rely on the segmentation of the cable to reduce RF heating, here, the feasibility of optical signal transmission is evaluated, which completely avoids any long conductors and makes the devices inherently RF safe. Moreover, it is the objective to design a transmission system with as few miniature components as possible to allow the integration into active devices.

Materials and Methods: An optical signal transmission was designed to be applied to an active tracking catheter. A foil-based Helmholtz coil pair was structured by photolithography [3], tuned with a capacitor and passively decoupled with anti-parallel diodes (Fig. 1b). This circuit was wire-bonded to a plain chip transistor (JFET 2N4393, Central Semiconductor, 530x460 µm) to modulate the output of a fiber-coupled chip laser diode (VCSEL, ULM850, Ulm Photonics, 250x250 µm) with the MR signal. The optical fiber was coupled to an optical receiver (HFBR-2416, Agilent Technologies) at the proximal end of the device, where the electrical MR signal was recovered. The optical receiver was directly connected to a pre-amplifier of the MR system (Achieva 1.5T, Philips Medical Systems). In this initial set-up, the power for the laser diode was supplied by an electrical cable that will be replaced shortly by a miniature optical power supply (PPC-3ME, JDS Uniphase, CA). Active tracking experiments were performed in a phantom with this device, and high resolution images of the catheter tip were acquired. To evaluate the SNR loss due to the optical signal transmission, phantom images were acquired with a 2cm loop coil with and without the optical transmission system.

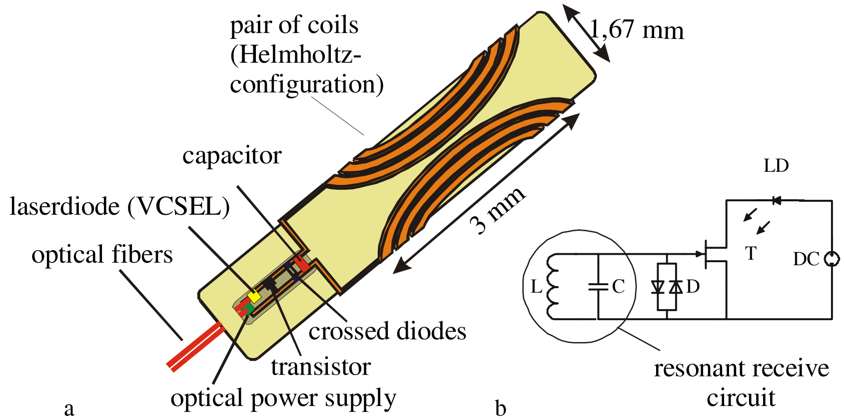

Figure 1: a) Foil-based Helmholtz-coil at device tip connected to the electro-optical conversion circuit and b) equivalent circuit plot.

Results and Discussion: The foil-based Helmholtz coil (Fig. 2) provided sufficient signal in tracking projections for all orientations, so that active tip tracking performed robustly. The photolithographic coil manufacturing process with subsequent wrapping of the coil around the catheter has the advantage over conventionally wound coils, that the foil-based coils can be prepared reproducibly and in large batches, and that they can be integrated with the electro-optical conversion circuit on the foil. High resolution images of the catheter tip resemble the structure of the Helmholtz coil (Fig. 3a,b). The SNR evaluation of the images acquired with the 2cm loop coil (Fig. 3c) indicated an SNR loss of 20dB due to the optical transmission system. Further measurements revealed, that this SNR loss is partly due to the low Q-factor combined with the high gate capacitance of the JFET, which causes a low overall Q of about 5 of the receive circuit. To improve the SNR, a MESFET transistor (TGS1350-SCC, TriQuint, TX) with a gate capacitance of 0.2pF will be used. Additionally, the operating point of the laser diode will be chosen at a higher DC current to improve its noise figure.

Conclusion: It can be concluded that electro-optical conversion of the MR signal at the tip of an intravascular device with few miniature components is feasible. Projection-based tip tracking was achieved with the presented set-up, and high resolution images were obtained in a phantom, but the noise figure of the conversion circuit still has to be improved to be useful for intravascular imaging. Together with an optical power supply, that is currently realised, this all-optical signal transmission has the potential of enabling the design of inherently RF safe active devices in the future.

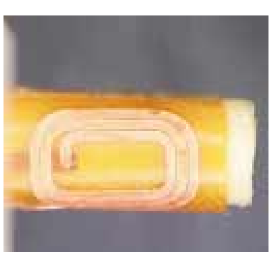

Figure 2: Foil-based miniature Helmholtz coil.

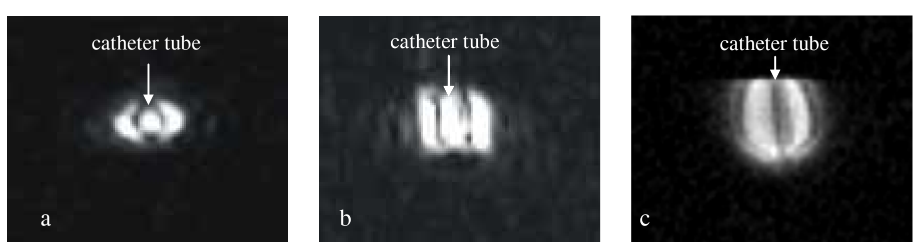

Figure 3: MR images of a) the micro Helmholtz coil with the catheter axis through plane and b) in plane, and c) images acquired with the 2cm loop coil in the image plane.

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[3] Uelzen Th, Fandrey S, Müller J: Mechanical and electrical properties of electroplated copper for MR-Imaging Coils, Journal of Microsystem Technologies, Volume 12, Number 4 / March, 2006. p343-351