A Miniaturized Optical Link for an Active Intravascular MR-Device

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Objective: MRI can provide detailed structural and compositional information of atherosclerotic plaques [1]. However, the high SNR demand limits its current use to superficial vessels as carotids. Intravascular imaging devices greatly enhance SNR, but require special means to avoid RF-induced heating. A prototype device equipped with optical, and therefore, inherently RF safe signal transmission of an intravascular imaging coil has been demonstrated previously [2]. While the basic feasibility of the approach including integration of the system on a catheter tip was demonstrated, MR images showed a loss of 20 dB in SNR compared with a direct electrical transmission. The objectives of this work are to improve the SNR considerably and to further miniaturize the optical MR-probe compared to the previous system.

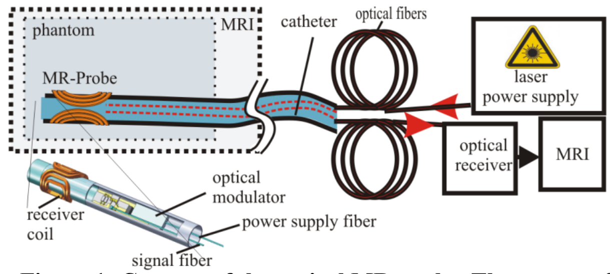

Figure 1: Concept of the optical MR-probe. The output of the tip-mounted optical modulator is transmitted to the external optical receiver by a first fiber. A second fiber is used for the delivery of the required power.

Materials and Methods: Fig. 1 depicts the concept of the optical MR-probe. The MR-signal is acquired with a foil-based miniature Helmholtz coil that is optimized for tracking and imaging performance by providing an azimuthally homogenous sensitivity profile [3]. An optical transmitter on the catheter tip converts to an optical signal, which is directed by a first fiber to an optical receiver (HFBR-2416, Agilent Technologies) located on the patient support. The optical receiver converts back to an RF signal, which is fed to a receiver of the MR scanner (Achieva 1.5T, Philips Healthcare). A second fiber is used for optical power supply of the optical modulator. To allow the integration on a catheter tip, only chip components as bare die are used.

In this work, two different transistors were examined and compared for integration into the optical modulator to achieve maximum SNR. The JFET (2N4393, Central Semiconductor USA, 533 x 457 µm²) had already been used previously [2]. It has a high input gate-source capacitance C_{GS} of about 20 pF and a transconductance g_m of 10 mA/V. The second transistor is a pHEMT (TGF2022-06, 566x530x100 µm3, TriQuint Semi-conductor, USA) with a low input gate-source capacitance C_{GS} of 1.5 pF and a transconductance g_m of 225 mA/V. The output characteristics of both transistors were compared with a spectrum analyzer. A new photo voltaic power converter with reduced size (PPC3FM, 500x500 x150 µm3, JDSU, USA CA) was applied to supply electrical power to the transmitter. A laser diode die (VCSEL ULM850-10-TT-N0101U, 250 x 250 x 150 µm³, Ulm-Photonics) with a low threshold current of 0,55 mA was used as optical source for the optical modulator [2]. Fig. 2a) shows how the fibers are coupled to the laser diode and power converter using an optical micro bench including self-alignment structures and a reflector. Figure 2b) depicts the integrated MR-micro probe. This system was used for active tracking and high resolution MR imaging experiments with subsequent evaluation of SNR.

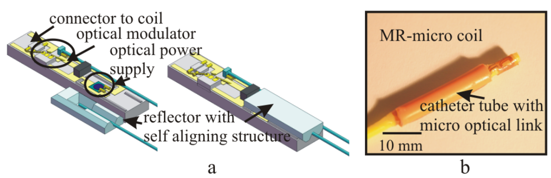

Figure 2: a) Optical modulator implemented on micro optical bench to realize self-aligning structures for coupling to fibers; b) MR-probe inside the catheter tip.

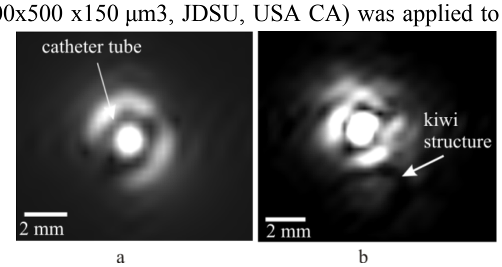

Figure 3: High resolution MR-images acquired using the optical link (a) in a bottle phantom and (b) in a kiwi.

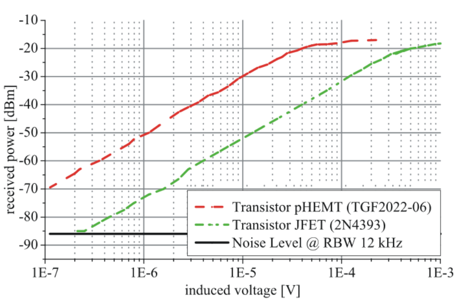

Figure 4: Output power of the optical receiver vs. input voltage using either JFET and or pHEMT as optical modulator (noise level = –86 dBm @12 kHz RBW).

Results and Discussion: The redesign of the optical MR-probe resulted in a further miniaturization which firstly allowed the integration into a catheter (Fig 2b). Active tip tracking with the new probe performed robustly in all experiments. MR images acquired in a homogeneous phantom reveal the distribution of receive sensitivity of the micro-coil, and additional structures are visible inside a kiwi (Fig.3). SNR of the images was improved by +25 dB in comparison to the previously presented system based on the JFET. This improvement was verified by the electrical characterization of pHEMT and JFET shown in Fig. 4. The improvement in SNR is mainly caused by the higher Q-factor and the higher transconductance of the pHEMT-system. Interestingly, the new system showed an SNR gain of about 5 dB compared with a direct electrical transmission. This may be explained by the fact, that the receive circuit is almost unloaded in case of the optical transmission resulting in a high Q, whereas matching to a 50Ohm load is applied in case of the electrical transmission.

Conclusion: Projection-based tip tracking and high resolution MR imaging in phantoms was demonstrated with an improved version of a system for optical signal transmission. The SNR of the system was considerably improved in comparison with the previous system and is now comparable with conventional signal transmission. The miniaturization of the system allows integration in a catheter, which may be used for inherently RF-safe active tracking and intravascular imaging, because any elongated conductors are avoided.

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[3] Fandrey S, Weiss S, Müller J. A Novel Intravascular MRI Coil with optimized Sensitivity, Joint Annual Meeting ISMRM-ESMRMB, May 2008, Toronto.