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ENDOLUMINAL MR RECEIVER COIL BASED ON ELECTRO-OPTICAL CONVERSION AND ACTIVE OPTICAL DECOUPLING

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Target audience: Researchers working on endoluminal receiver coils for MRI.

Introduction: The use of endoluminal coil in magnetic resonance imaging (MRI) located close to the region of interest enhances image spatial/temporal resolution using the local signal-to-noise ratio (SNR) gain. Wall bowel analysis could be then performed and wall layer could be distinguished for a better diagnosis and characterization of inflammation and lesions [1]. Conventionally, coaxial cables connecting the MRI console and the receiver endoluminal coil are used to transmit the NMR signal and the DC bias current used for active decoupling. However, patient safety can be compromised by heating of tissues located in proximity of these cables. In fact, the electric field accompanying the radiofrequency (RF) magnetic field B_1 induces high-frequency currents along the metallic wire and thus increases the specific absorption rate (SAR) by the tissues lying nearby [2]. To ensure full patient safety, an optical fiber was chosen as an alternative solution to transfer optically the RMN and the DC decoupling signal. Both electrical signals are converted into optical signals: the conversion of NMR signal is based on Pockels effect ensured by an electro-optical (EO) crystal which its refractive indexes change according to an applied electric field. While DC signal is converted by the use of optoelectronic devices. The electro-optical (EO) conversion and the active optical-base decoupling were demonstrated and proven separately in previous works [3], [4]. In the following, the results of these previous works are presented and a novel type of endoluminal receiver coil combining both optical transmission and active optical decoupling was designed.

Methods: The conversion of NMR signal is ensured by associating the endoluminal coil to an EO Ti:LiNbO₃ waveguide. Figure 1 illustrates the experiment performed on an optical bench. Firstly, the body coil generates a RF electrical power P_{in} ranging from -101 dBm to 14 dBm. The B_1 of RF waves is detected by the endoluminal receiver coil. This coil was designed to resonate at a frequency of 128.2 MHz corresponding to the proton's resonant frequency at 3T. Therefore, an electromotive force ϵ is applied to the waveguide and in turn induced an electrical field E_z lying between the electrodes and proportional to B_1 . The refractive indexes of the waveguide vary linearly with the induced E_z (Pockels effect). At the same time, a linearly polarized laser beam (pigtailed DFB laser, $\lambda = 1550 \mu\text{m}$) is emitted toward the waveguide. Hence the polarization state of the laser beam varies according to E_z . Then the modulation of polarization state is treated, converted into an electrical power by a fast photodiode and amplified. The output power P_{out} is visualized on a spectrum analyzer.

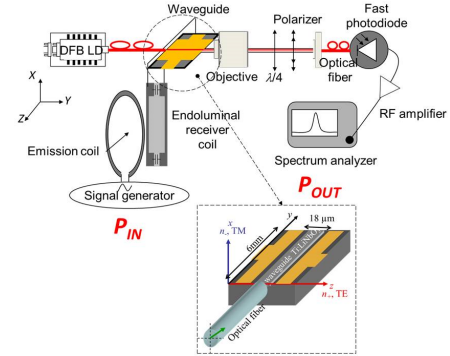


Figure 1. Schematic set up for the experiment of EO conversion and optical transmission.

An active optical-base decoupling system was designed and built. Once illuminated, photodiodes provide a sufficient DC current that ensure coil decoupling during RF transmission phase. The basic idea is to ensure a DC current to the PIN diode by using photodiodes (Figure 2b). Decoupling efficiency was evaluated by inserting into a cylindrical phantom filled with a 5 g/L of saline water solution three different endoluminal coils : reference coil , optically-decoupled endoluminal coil and a non-decoupled endoluminal coil (without a PIN diode).Then images taken by the body coil were compared (Figure 4). The body coil was used as a transceiver so endoluminal coil were considered to be constantly decouple.

Results: The graph in the figure 3 indicates that the experimental and the theoretical values are matching. This graph shows a good linearity of the results and a dynamic range of the input power exceeding 100 dBm. And the magnetic field is ranging between 0.3 pT at -104 dBm (electronic noise) to 2.10⁵ pT at 14 dBm. In addition, the optical decoupling was verified. The figure 4 shows that both reference and optical decoupled coils have a comparable behavior. While the coil without decoupling circuit shows a clear artifact due to B1 concentration.

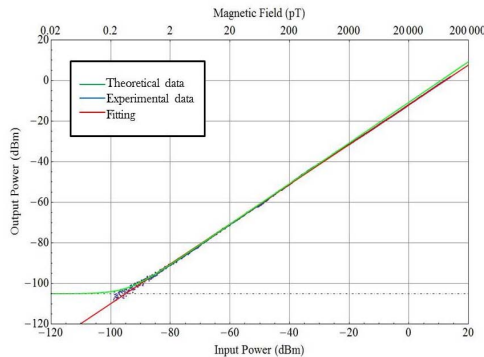


Figure 3. The output power in function of the input power and the corresponding magnetic field (top axis). The dotted line represents the electronic noise threshold.

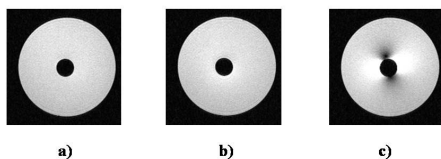


Figure 4. Axial images of a phantom obtained using GRE sequence with: a) A galvanic-decoupled coil. b) An optically-decoupled coil. c) A coupled coil.

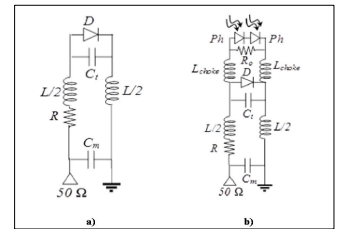


Figure 2. Equivalent circuit of the interventional receiver coil. a) Galvanic-decoupled coil circuit. b) Optically-decoupled coil circuit.

Discussion: Using a Ti:LiNbO₃ waveguide, the NMR signal detected by the receiver coil was converted into an optical signal and measured after being optically processed. Results demonstrated both an excellent linearity and sensitivity. Besides, the concept of optical decoupling was demonstrated without SNR or B_1 uniformity penalties. Based on these results, a fully optical endoluminal receiver coil was designed by combining the two described systems (Figure 5). Such a coil may provide very useful information about bowel diseases and human gastrointestinal wall layers without the fear of heating biological tissues.

References:

- [1] O. Beuf, et al. , *Journal of Magnetic Resonance Imaging*, vol. 20, p. 90-96, 2004. [2] V. Detti, et al. , *Magnetic Resonance in Medicine*, vol. 66, p. 448-455, 2011. [3] R. Aydé, et al. , *IEEE Photonics Technology Letters* , vol. 26, p. 1266- 1269, 2014.[4] R. Aydé, et al. , *ESMRMB*, Toulouse, France, 2013.

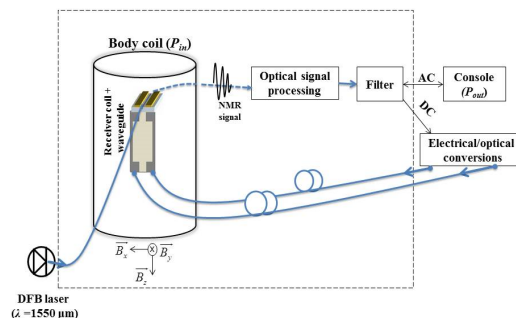


Figure 5. Schematic set up for a fully optical endoluminal receiver coil. The blue link represents the optical fiber.