ELECTRO-OPTIC RF MAGNETIC RESONANCE SIGNAL BASED ON A TI:LINBO3 WAVEGUIDE

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Introduction: The benefit of MR endoluminal coil was demonstrated for imaging of internal tissue layers such as colon walls [1]. However, the use of metallic coaxial cables in MRI could induce local high Specific Absorption Rate (SAR) in the vicinity of the coaxial cable [2]. In fact, during a MRI experiment, the radiofrequency (RF) B1 magnetic field is accompanied by an electric field E which induces currents (at the same frequency) in the metallic. In the case of endoluminal coils, deeply introduced in the patient, cable isolation and circuit commonly used with external coil such as traps are difficult to achieve. Optical fiber link could be a promising alternative to coaxial cables in transmitting directly the MR signal from the receiver endoluminal coil to the data cabinet of MR system. This method could solve definitively the electromagnetic issues and ensure patient safety. Here, the conversion of the Radio-Frequency (RF) magnetic field into an electric signal by electro-optic (EO) effect was demonstrated and characterized.

Methods: In order to validate and characterize the conversion of the RF magnetic field into an electric signal by electro-optic (EO) an experiment illustrated in Fig.1, was performed on an optical bench. A RF magnetic field B_1 is generated using an emission RF coil excited with a function generator. The electrical power P_{in} of the generator ranges from 14 dBm down to -101 dBm at a frequency of 128.2 MHz (proton resonance frequency at 3T). The receiver coil, (resonating at 128.2 MHz), is located in front of the RF emission coil to probe the magnetic field B_1. Thus an electromotive force ε is induced and applied on an electro-optical micro-chip. This latter, consists of a 6 mm length and 7 μm diameter of a Ti-diffused LiNbO3 waveguide confined between two coplanar electrodes lying on YZ plane and separated by 18 µm.

A linear polarized optical probe beam (pigtailed DFB laser, λ=1550 μm) is injected into the waveguide. The Eigen refractive indices of the crystal vary linearly with the induced E_z lying in between the electrodes. Hence, a modulation of the laser polarization state appears [3]. A quarter wave plate and a polarizer convert this modulation into a variation of optical power. Finally, this latter is converted into an electrical signal using a fast photodiode. A spectrum analyzer states the output signal power P_{out}.

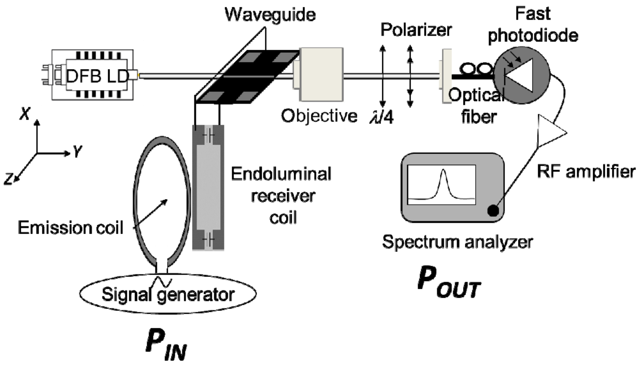

Figure 1: Schematic set up for the characterization experiment of EO conversion for RF magnetic field into an electric signal by EO effect.

Results: The linearity of the EO conversion was established. In figure 3, the measured P_{out} (dBm) versus input power P_{in} (dBm) values closely fit to the expected theoretical values (including noise contributions). The measured dynamics of the EO waveguide exceeds 100 dB and the minimum detectable electromotive force (EMF) induced in the coil is of the order of 10^{-8} V (top X axis). In figure 4, P_{out} is represented versus magnetic field generated by the emission coil and versus the corresponding induced electric field E_z between the two electrodes respectively on bottom and top X axis of the graph. The associated minimum calculated RF magnetic field corresponding to a signal equalizing electronic noise value (-104 dBm) reaches 3 pT, and the minimum corresponding detectable field is 0.1 $V.m^{-1}.Hz^{-1/2}$. Previously, the same experiment was performed using a bulk crystal instead of a waveguide [4]. Results comparison clearly shows that decreasing transducer dimension from mm order down to µm increases the sensitivity three orders of magnitude (from nT down to pT).

Discussion: EO signal conversion using a Ti:LiNbO3 waveguide mounted on an endoluminal RF coil was experimentally demonstrated. A very good linearity, dynamic and sensitivity were measured. The minimum RF magnetic field detected appears compatible with MR experiments, knowing that if needed, it is possible to go further in sensitivity by reducing electrodes separation distance. The next step will be to build a fibered probe to perform first MR images in a phantom at 3T.

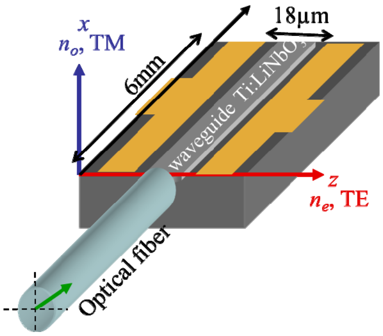

Figure 2: Schematic presentation of the waveguide confined between two gold electrodes. An optical fiber drives the linear polarized optical wave into the waveguide.

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References:

[1] O. Beuf and al., JMRI, 2004, Vol. 20.
[2] V. Detti et al., Magn. Res. Med., 66 (2), 2011.
[3] L. Duvillaret et al., JOSA B, 19 (11), 2002.
[4] R. Ayde et al, ESMRMB, 437 , Toulouse, France 2013.

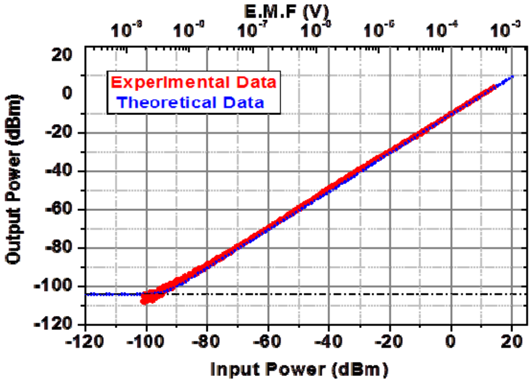

Figure 3: EO response as a function of the transmit input power and the corresponding magnetic field (top axis). The horizontal dashed dotted line represents the electronic noise.

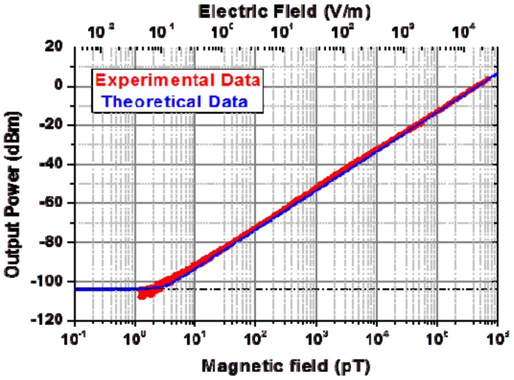

Figure 4: EO response as a function of the input magnetic field generated by the emission coil and the corresponding ElectroMotive Force (EMF) induced in the coil (top axis).