Inductive and dielectric tuning techniques for high-sensitivity miniature monolithic surface coils.

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Introduction:

In Magnetic Resonance (MR) Micro-imaging, significant improvements of the sensitivity of the Radio Frequency (RF) detection coil have been achieved using miniature coils that detect both a higher signal coming from a stronger magnetic coupling with the sample and a lower noise coming from a smaller volume of tissue viewed by the coil [1]. In particular, the use of monolithic design such as Multi-turn Transmission Line Resonators (MTLR) has allowed overcoming the miniaturization limit encountered with the conventional surface coils made of discrete elements [2]. However, standard tuning techniques using soldered variable capacitors are not well-suited for small auto-resonant structures such as MTLR: In addition to the problem of capacitor size, that may become larger than the coil size, the electrical performances of the MTLR may be degraded [2]. The objective of the present work is to investigate dedicated tuning techniques, based on inductive and dielectric coupling principles, to perform a precise frequency control of MTLR.

Material & Methods:

The MTLR resonance frequency (F_0) depends on equivalent electrical parameters of the transmission line. F_0 can be modified by inductive coupling varying its equivalent inductance L or by a dielectric coupling effect relying on the modification of the characteristic impedance Z_0 of the media at close proximity to the MTLR. For both tuning technique, experimental characterizations on bench were performed. These investigations were carried out using a 6-turn MTLR (Mean diameter: 14.6 mm) made of micromoulded copper deposited on a 500 µm thick sapphire wafer [3] dedicated to water protons imaging. A micro-translation stage was used to provide a precise positioning (step 2 µm) of the tuning element. F_0 was measured, using the single loop probe method [4] and an E5061A network analyzer (Agilent Technologies), as a function of the distance between the MTLR and the tuning element. In particular, we have focused on an inductive coupling using a circular copper ring (width: 20 µm, height: 20 µm), coaxial to the MTLR, and on a dielectric coupling using the interception of the electrical fringing field lines by a dielectric pad placed against the surface of the resonator windings. A parametric study was conducted to evaluate the influence of the thickness and permittivity of the dielectric pad and the influence of the diameter of the ring. Analytical model combining the induction laws and a calculation of the equivalent inductance of a MTLR [5] was developed for the inductive tuning technique. Moreover, numerical simulations using CST Microwaves Studio (MWS), which have already been used for a precise F_0 prediction [6], were performed for the dielectric tuning.

Results:

Figure 1 displays the measured and calculated variations of F_0 as a function of the distance, obtained with the inductive tuning technique for several ring diameters. A maximum F_0 increase of 10.2 MHz (15.3% shift) was obtained for a 14 mm diameter ring. A mean deviation of 1% was achieved between the measured and calculated F_0. However, a critical quality factor (Q) decrease of about 66% was observed for the same ring. This decrease became smaller than 10% for a distance between the MTLR surface and the ring larger than 5mm, limiting the achievable frequency shift to 0.5 MHz. Figure 2 displays the measured and calculated variations of F_0 as a function of the distance obtained with the dielectric tuning technique for several permittivities and thicknesses. A maximum F_0 decrease of 6.7 MHz of F_0 (9.9% shift) was obtained for a 500 µm thick lanthanate aluminate pad with a Q decrease smaller than 5%. As it is shown, a mean deviation of 2% was achieved.

Discussion & Conclusion:

The feasibility of these two tuning techniques was demonstrated and a good agreement between experimental, numerical and theoretical investigations was obtained. The achieved frequency shifts allow overcoming the variations of F_0 due to the environment during an MRI operation. Besides, combining these two techniques allows as well increasing or decreasing F_0. However, the preservation of Q being essential, the tuning ring has to be located several mm away from the MTLR windings, and thus the achievable frequency shift is limited. A dielectric tuning model, based on transmission line equations taking into account the multilayered structure composed of the MTLR, the air gap and the dielectric pad [7], is under development. Moreover, numerical simulations for the inductive tuning will be performed. According to the results presented here, a micro-displacement device, based on piezoelectric actuators is being realized: When a polarization is applied, the tuning element is displaced. The precise positioning and the large achievable displacement will allow a fine tuning of a MTLR. The whole system will then be implemented in a clinic MRI tool.

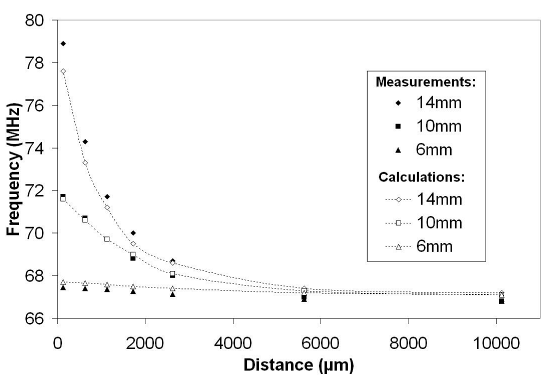

Fig. 1: Variation of F_0 as a function of the distance, for several ring diameters.

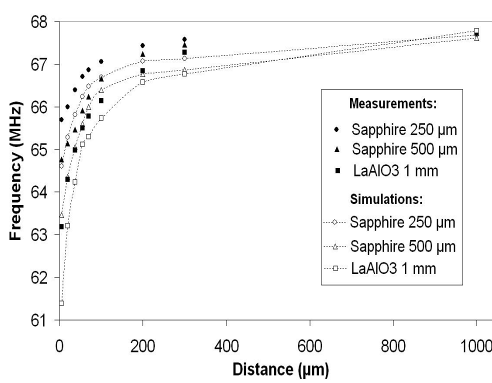

Fig. 2: Variation of F_0 as a function of the distance, for several permittivities and thicknesses.

References:

[1] Darrasse L et al. *Biochimie*, 85, 2003.

[2] Poirier-Quinot M. et al. *11th ISMRM*, Toronto (Canada), 2003.

[3] Woytasik M. et al. *Microsystem Technologies*, 13, 2007.

[4] Ginefri J-C. et al. *Review of Scientific Instruments*. 70, 1999.

[5] Megherbi S. et al. *Journal of Microsystem Technologies*, 12, 2005.

[6] Lambert S. et al. *25th ESMRMB*, Valencia (Spain), 2008.

[7] Kumar R. Et al. *Microwave and Optical Technology Letters,* 49, 2007.