Doctoral Dissertation
Doctoral Program in Electrical, Electronics and Communications Engineering
(31.th cycle)

Experimental and computational EM analysis of MRI RF coils and of their interaction with implanted conductive objects

Umberto Zanovello

* * * * * *

Supervisors
Prof. Carlo Ragusa, Supervisor
Dr. Michele Borsero, Co-supervisor
Prof. Mario Chiampi, Co-Supervisor

Doctoral Examination Committee:
Prof. Carlo Carobbi, Referee, Università degli Studi di Firenze, Italy
Dr. Matt Hall, Referee, National Physical Laboratory (NPL), England
Dr. Fabio Baruffaldi, Istituto Ortopedico Rizzoli, Italy
Prof. Luca Giaccone, Politecnico di Torino, Italy
Dr. Marta Parazzini, CNR - IEIIT, Italy

Politecnico di Torino

I hereby declare that, the contents and organisation of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

Umberto Zanovello

Summary

Radio frequency (RF) coils are employed in Magnetic Resonance Imaging (MRI) to excite and detect the signal from nuclear spins at Larmor frequency. The intrinsic complexity of the phenomena involved inside an MR scanner leads to strong requirements on the magnetic field $\boldsymbol{B}_1$ generated by the RF coil which should be fulfilled to ensure reliable results. Nevertheless, the presence of an external conductive object, such as a metallic implant, strongly interacts with the $\boldsymbol{B}_1$ field and potentially affects the performance of an even ideal RF coil.

Whereas the $\boldsymbol{B}_1$ magnetic field prevalently impacts on the quality of the MRI result, the electric field generated by the RF coil has important safety consequences and should be accounted for as well.

This thesis is developed in the framework of the evaluation of the electromagnetic fields generated by MRI RF coils and of their interaction with conductive passive objects.

In this context, the third chapter of the thesis describes the realization of a dosimetric experimental set-up, able to generate and measure RF electromagnetic fields in a "tissues mimicking" phantom. The generation equipment consists of an RF synthesizer whose amplified signal is used to supply suitable antennas. The acquisition system is based on two power meters (connected to a directional coupler to measure the incident and reflected power), an electromagnetic field acquisition station and a tri-axial automatic system for specific field probes positioning.

The first characterization of the set-up is described and has been obtained employing a self-made shielded loop antenna. Its validation has been performed both in terms of magnetic and electric fields by comparing the experimental measurements with numerical simulation results. In such a context, an uncertainty budget has been studied and it has been associated to the relevant dosimetric set-up.

A second activity is presented in the same chapter and involved a double-tuned (23Na/1H) loop coil specifically designed for a 7 T MRI scanner and provided by the IMAGO7 foundation, Pisa. The experimental electromagnetic measurements have been compared to the numerical results carried out by the IMAGO7 research group by means of the same simulation codes they use for coil design routine evaluations.

The plan for the implementation of a realistic scaled-down 3 T MR body coil, conceived to increase the versatility of the dosimetric set-up, led to the design of a 16-leg high-pass

birdcage coil. A detailed theoretical study of the coil structure represents the topic of the second chapter, whereas the coil design and fabrication become part of the chapter devoted to the experimental set-up.

The distortion of the RF coil sensitivities due to the presence of elongated passive implants, which leads to RF inhomogeneity artefacts, is evaluated through numerical simulations and represents the subject of the fourth chapter. The simulation set-up includes a birdcage volume resonator and a proper phantom inside which the metallic objects (i.e. a metallic cylinder and a realistic hip prosthesis stem model) are plunged. Special attention is given to the achievement of an easy but reliable description of the physical phenomenon. On the basis of these results, a solution is hence proposed to reduce the impact of RF artefacts in MRI exams. This proposal consists in covering the metallic objects with a suitable dielectric coating to make them invisible to the radiating antenna. The optimum coating parameters and the general effectiveness of the coating are studied using different commercial electromagnetic numerical codes both at 64 MHz and 128 MHz.

Finally, following a specific request from an MRI medical staff, the possible interactions between body-art tattoos and MRI electromagnetic fields are evaluated. The study is developed especially from a safety point of view. The tattoo inks and pigments electrical and magnetic properties experimental characterization is performed to assess electromagnetic and thermal simulations. The results are reported and discussed in the fifth chapter of the thesis.