AN EASY-TO-MADE DOUBLE TUNED 23NA / 1H, INDUCTIVELY DRIVEN, QUADRATURE BIRDCAGE, FOR SMALL ANIMAL MRI AT 4.7 TESLA

J. Mispelter[1,2] and M. Lupu[1,2]

[1]Institut Curie, Orsay, France, [2]INSERM U759, Orsay, France

Introduction: The construction of a double tuned, inductively coupled, birdcage resonator specifically designed for small animal sodium (53 MHz) MRI at 4.7 T is evaluated and described. The second frequency (proton, 200 MHz) is necessary for tissues localization. A 16 legs birdcage design was considered as a compromise between this constraint and reasonably low loss due to the capacitors [1]. The design is based on a modification of the classical "four-rings" birdcage geometry (Murphy-Boesch et al [2]). This design has the advantages that: a) it decreases considerably the unnecessary power deposition of RF energy at the proton frequency near the extremity of the probe and b) it minimizes the magnetic coupling of resonant modes that simplifies the frequency spectrum of the resonator, hence its adjustment. Furthermore, inductive coupling [3] was chosen in order to simplify the design while quadrature driving [4] improves the sensitivity at least at the lowest frequency.
Building and optimizing a resonator having many resonant modes, like a birdcage, is greatly simplified using numerical simulation tools. These simulators should be able, at least, to calculate the resonance spectrum and the current distribution on all conductive parts of the probe in order to evaluate the RF magnetic field. Simulators have been already proposed for the birdcage design [for example: 5,6], but they appeared to be inadequate for the present design. We have thus implemented our own which is evaluated here at each stage of the construction.
Methods and results: The original four-ring birdcage design of Murphy-Boesch et al. is schematically drawn on Fig. 1a. The low frequency RF field is mainly obtained from a Low Pass birdcage tuned by the central capacitors. The two external High Pass birdcage structures couples through space and through the legs to give the high frequency resonant mode (200 MHz). In the present design, the HP structures are placed in a plane perpendicular to the probe axis (Fig. 1b). In this configuration, the magnetic coupling between the resonant modes is reduced, as shown by the numerical simulation of the resonant spectrum (S11, Fig. 1d). Furthermore, the high frequency magnetic field is reduced at the probe extremities, which are outside the low frequency sensitive region (Fig.1 c).

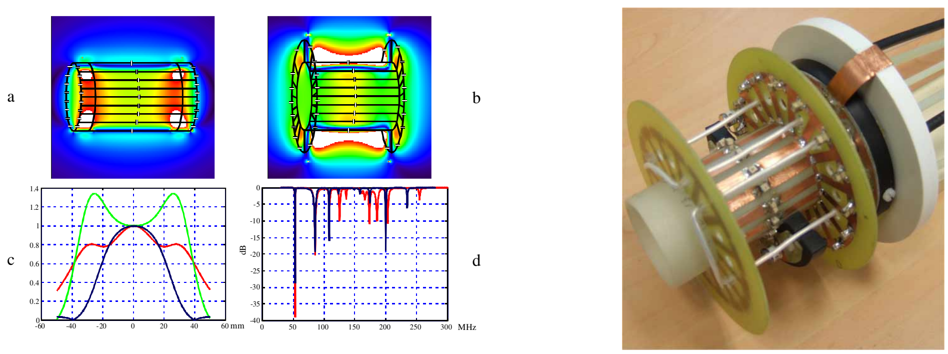

Fig.1. Upper: geometry and field maps at 200 MHz for the basic (a) and proposed (b) designs. Lower : c: RF field profile along the resonator axis z at 200 MHz compared to that at 53 MHz (blue). d: S11 spectrum for design a (red) and design b (blue) when the probe is tuned and matched at 53 MHz. Right: the actual design (shield removed).

The numerical simulation was done by solving the voltages and currents equations in all branches of the electrical circuit, using the full inductance matrix. The self-inductances for all conductive parts were calculated from well known formulae existing in the literature. The off-diagonal elements of the inductance matrix (mutual inductance) were calculated using Grover's formulae for linear section of thin wire. When required, the conductors were decomposed into elementary linear sections. The perturbation of each inductance matrix elements due to the cylindrical shield was estimated from the mutual inductances of the conductive wires with their images. This simulator proved to be accurate enough to predict better than 4% the resonant spectrum of the whole construction (Fig. 2,3), including the shielding. Hence, the (complex valued) currents in all parts may be accurately predicted, from which one deduces the rotating field components b+ and b-, of the RF magnetic field.

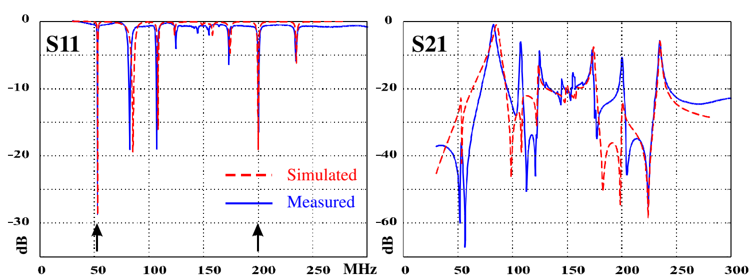

Fig. 3 :

Left : simulated (red) and experimental (blue) reflection coefficient (S11) spectra at one of the driving ports, matched at 53 MHz.
Right : simulated (red) and experimental (blue) transmission coefficient (S21) spectra between the two quadrature driving ports. Port 1 is tuned and matched to 50 Ohms.

As a result, the 90° pulse width expected for a given incident power is well predicted (123 µs for 10 W, measured 100 µs; the proton 90° pulse width was of 300 µs for the same power level), showing that the construction was optimally made. In spite of the mutual inductance between the two coupling loops, the isolation between the two quadrature ports is predicted to be better than -35 dB which was reached easily in practice.
Conclusion: An efficient double tuned resonator for small animal sodium MRI at moderately high magnetic field (4.7 Tesla) has been easily designed and built with the help of a simple, but accurate, numerical simulator. The choice of an inductive coupling greatly simplified the design while introducing no degradation on the performances. The construction proved to be optimum, at least at the sodium frequency, and the performances were close to those expected for such a volume. Improvement of the probe may be still realized by reducing the number of legs (increasing the Q factor) and by driving the proton resonance in a quadrature mode. The latter is very easy to implement and may provide a significant improvement in sensitivity for proton, if required.
Acknowledgments : The authors want to acknowledge "Canceropole Ile de France" for their support.
References: [1] Roffmann *et al. J. Magn. Reson.* 111B, 174-177 (1996) ; [2] J. Murphy-Boesch *et al. J. Magn. Reson.* 103B,103-114 (1994) ; [3] D.I. Hoult *et al. Concepts in Magn. Reson.* 15, 262-285 (2002) ; [4] D.I. Hoult *et al. Magn. Reson. Med.*, 1, 339-353 (1984) ; [5] G. Giovannetti *et al. MAGMA*, 15, 36-44 (2002) ; [6] C.L. Chin *et al. Concepts in Magn. Reson.*, 15, 156-163 (2002)