IMPROVEMENT OF MAGNETIC RESONANCE IMAGING AT LOW FIELD USING A BIRDCAGE COIL

G. GIOVANNETTI*, M.F. SANTARELLI*, L. LANDINI**, V. POSITANO*, R. FRANCESCONI*, A. BENASSI*

*C.N.R. Institute of Clinical Physiology, Pisa, Italy
**Department of Information Engineering, University of Pisa, Pisa, Italy

Abstract: **The main goal of this research was to demonstrate the utility of using a transmitter-receiver birdcage coil for magnetic resonance imaging at very low static field (0.18 T). As well known, the SNR decreases with frequency, thus reducing the image quality at very low field. Moreover, we would expect that the birdcage coil Q factor reduces with frequency. But, from experimental evidence, we proved that at low frequency (7.66 MHz), the Q factor for a well-designed birdcage coil reverses the trend, reaching unexpected high values. It is a prerequisite to use low static magnetic field in microimaging applications for small animals experiments.**
Keywords: **Magnetic resonance; birdcage coil; microimaging; low magnetic field**

Introduction

In 1985 Hayes et al. described the first application of the birdcage coils in magnetic resonance imaging (MRI) systems, evidentiating its capacity to generate wide field of view (FOV) with elevate radio frequency (RF) magnetic field homogeneity and high signal to noise ratio (SNR) [1], useful for using in transmit/receive mode. However, when a coil is used in MRI scanners at very low static magnetic field (0.18 T), the decrease in SNR with frequency is the principal cause of poor image quality. We also know that in general the coil Q factor decreases with frequency as $Q \alpha \sqrt{\omega}$ [2]. Among the advantages in using low magnetic field, the low cost per examination and the limited environment requirements are the main arguments that make appealing their use in medical and experimental measurements. In this paper, we demonstrated that by a correct choice of the topological and electrical parameters, such as conductor shape and dimension, i.e. wire or strip, and capacitors quality factor, the Q factor can be strongly improved beyond any optimistic prevision, maintaining an elevate degree of homogeneity. We chose to build the birdcage with eight legs to reach an elevate degree of field homogeneity inside the coils volume (the field homogeneity depends on legs number, see [3]).

Materials and Methods

We start from the well-known relationship between the SNR and the Larmor frequency ω_0 for a MRI scanner [4]:

$$SNR \, \alpha \;\; \omega_0^{\,2} / (R_{COIL} + R_{SAMP})^{1/2} \qquad (1)$$

where R_{COIL} is the coil resistance and R_{SAMP} is the resistance due to the induced eddy current losses in the conductive sample. R_{COIL} has a frequency dependence due to the skin effect, as $R_{COIL} = a\,\omega_0^{\,1/2}$ and R_{SAMP} is proportional to the frequency according the law $R_{SAMP} = b\,\omega_0^{\,2}$, where a and b are constant coefficients depending on coil characteristics and sample properties respectively [1]. So, we obtain:

$$SNR \;\alpha\; \omega_0^{\,2} / (a\omega_0^{\,1/2} + b\omega_0^{\,2})^{1/2} \qquad (2)$$

At low RF frequencies the SNR is mainly determined by the coil losses and $SNR \;\alpha (1/a^{1/2}) \cdot \omega_0^{\,7/4}$: we can improve SNR by optimising the RF coil reducing the constant a, i.e., using RF coil with high quality factor (for a RF coil tuned at ω_0, $SNR \alpha \sqrt{Q}$, see [3]).

At high RF frequencies, the sample losses are dominant and $SNR \alpha (1/b^{1/2}) \cdot \omega_0$: this is the situation normally found in a clinical system (>0.5T) (see Fig. 1 for an example).

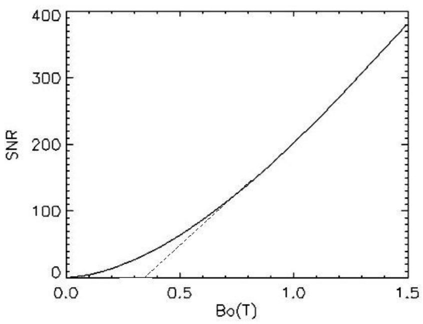

Figure 1: SNR versus B_0

This means that the reduction in SNR due to physical limitations at low magnetic field, such as low magnetization, can be partially recovered taking low the sample losses and by exploiting the lower decrease in SNR with respect to higher field.

The first step in the designing of an optimized birdcage coil was the best choice of the conductor topology. In general, due to the penetration depth concept for current flowing in a cylindrical conductor, the resistance results proportional to $\sqrt{\omega}$ [5]. For a strip conductor the current is not homogeneously distributed inside the con-

ductor volume, but its concentration is enhanced at the conductor edges [2]. In order to maximize the surface where the current flows and to minimize the conductor resistance, the strip thickness should be larger than the penetration depth at that frequency (at 7.66 MHz the penetration depth value is 23µm). On the other hand, in a wire conductor the current has a better volume distribution with respect to the strip one, and the birdcage coil performance should be better.
The second step in the RF coils design concerns the choice of high quality capacitors in order to minimize losses and to obtain good coil performances.
In this research, we constructed two identical birdcage coils of 11cm height and 14cm diameter in low pass version, previously simulated using an home-made software [6], tuned at 7.66 MHz that corresponds to 0.18 T static magnetic field. The first birdcage coil was realised using copper strip of 1cm wide and 800µm in thickness and 2nF high quality capacitors (Q> 10.000 at 1MHz), obtained with the parallel of two 1nF capacitors (ATC 100B - American Technical Ceramics, USA).
The second coil was realised using a wire conductor of 6mm diameter and using the same capacitors as in the first prototype.
The test consisted in the evaluation of the unloaded and loaded quality factor for each coil; the load consisted of a cylindrical homogeneous phantom of saline solution that simulates the knee conducibility (diameter 11cm, length 20cm, constituted of 55mM of NaCl and 5mM of $NiCl_2$).

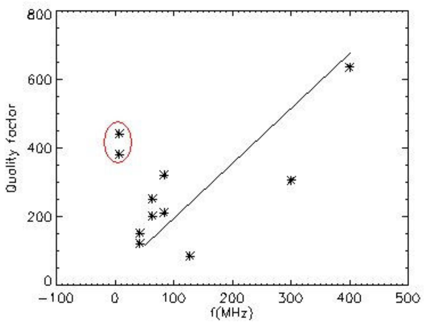

Figure 2: Q versus frequency for birdcage coil described in the literature and, in red circle, the values measured in our laboratory.

Results

Measurements performed on the two birdcage coil prototypes experienced very high unloaded quality factor: 380 for the strip coil and 440 for the wire conductor one. The higher value for the wire version is imputable to a better current distribution inside the conductor with respect to the strip one, as predicted theoretically. It is worth to note that the birdcage coils Q factors are far superior to the expected ones. They are comparable with the ones available in the literature for higher frequencies (see Figure 2). Even the ratios of the unloaded to loaded quality factors (2.8 and 3), are very satisfactory.

Discussion

The high Q factors we obtained with birdcage coils tuned at low RF frequency are probably due to two factors: firstly, at very low frequency, the conductor resistance is low and, secondly, the quality factor of the ATC capacitors is higher with respect to the one experienced at higher frequency [7]. So, the total losses in all components are low and the final coil quality factor assumes high values.

Conclusions

At low frequency two concomitant factors contribute to improve the image quality for MRI applications: 1) the frequency dependence of the SNR that at low field decreases slower with respect to higher field; 2) the high Q factor obtained using optimized birdcage coils. Another advantage is the use of a unique coil for transmission and reception.
In conclusion, the combined use of low field magnetic resonance imaging and a birdcage coil geometrically optimized for animal experiments has potential to develop low cost MRI scanner for microimaging applications.

REFERENCES

[1] C.E. Hayes, W.A. Edelstein, J.F. Schenck, O.M. Mueller, M. Eash, "An efficient, highly homogeneous radiofrequency coil for whole-body NMR imaging at 1.5 T", J. Magn. Reson., vol. 63, pp. 622-628, 1985.

[2] C. Chen, D.J. Hoult, "Biomedical magnetic resonance technology", Bristol:IOP; 1989.

[3] S. Crozier, K. Luescher, L.K. Forbes, D.M. Doddrell, "Optimized small-bore, high-pass resonator designs", J. Magn. Reson., vol.109, Series B, pp.1-11, 1995.

[4] D.I. Hoult, P.C. Lauterbur, "The sensitivity of the zeugmatographic experiment involving human samples", J. Magn. Reson., vol. 34, pp. 425-433, 1979.

[5] H.W. Johnson, M. Graham, "High-Speed Digital Design: A Handbook of Black Magic", Prentice Hall, 1993.

[6] G. Giovannetti, L. Landini, M.F. Santarelli, V. Positano, "A fast and accurate simulator for the design of birdcage coils in MRI", MAGMA, vol. 15/1-3, pp. 36-44, 2002.

[7] ATC 100B Series Porcelain Superchip Multilayers Capacitors Data Sheet.