Effect of Distributed Capacitance on the Performance of Birdcage Type RF Coil for ^{1}H MRI

Hyeok Woo Son[1], Sheikh Faisal Ahmad[1], Jin Young Choi[1],
Hyun Deok Kim[1], #Young Ki Cho[1]
[1] School of Electronics Engineering, Kyungpook National University
1370, Sankyuk-dong, Buk-gu, Daegu, 702-701, Korea, ykcho@ee.knu.ac.kr

Abstract

This paper analyzes the effect of distributed leg capacitance of a hybrid type birdcage RF receiver coil on the performance of NMR imaging at 1.5T MRI systems. The NMR images obtained by triple leg capacitor RF coil are found superior to NMR images of the single leg capacitor coil.

Keywords: NMR, 1.5T Birdcage Coil, Hybrid Coil, Detuning Circuit, Small Animal MRI, Receiver Coil,.

1. Introduction

RF Coil design is a most important and sensitive issue in the preparation of the MRI (Magnetic Resonance Imaging) system. It plays vital role in the production of magnetic resonance based imaging in the MRI system. Along with the other factors the quality of an NMR (Nuclear Magnetic Resonance) image strictly depends upon the noiseless NMR signal detection property of the RF coil. The RF coil must have the ability to produce the stronger magnetic field and weaker electric field.

Birdcage type RF resonator is considered to be the best choice because of their inherited strong magnetic field property [1]. A lot of efforts have been made in the preparation of the birdcage type RF coils with different configurations [2, 3, 4]. The hybrid type birdcage resonators contain lumped capacitors in the end rings and the coil legs. The coil legs are either cylindrical conducting wires or rectangular copper strips which provides distributed inductance. It has been investigated [5, 6] that the quality of NMR image improves when the capacitance and inductance are distributed along the legs of the birdcage coil. TEM type resonator is a realization of this idea [7]. However it is difficult to make a TEM type resonator for small animal imaging because of its dimensions.

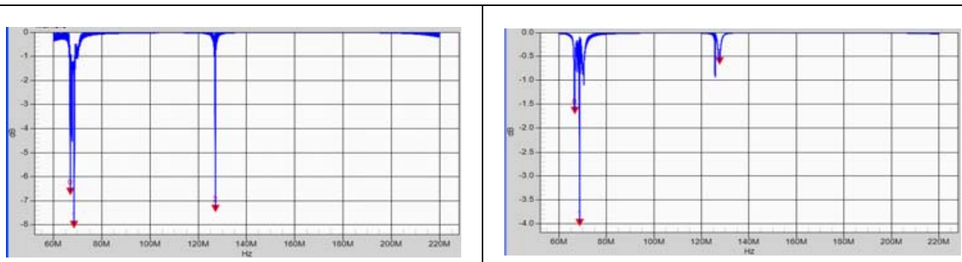
Here we are presenting a method of preparing a birdcage type RF receiver coil for small animal imaging by using flexible dielectric etched copper conductors. We are also describing a comparison on the basis of distributed leg capacitance between two different configurations of a birdcage coil which are capable to detect the nuclear magnetic resonance of ^{1}H nuclei at 1.5T magnetic resonance scanners. The coil is a whole body volume coil in band pass configuration for small animal imaging. The conducting elements of the RF coil are copper strips which are etched on a flexible epoxy material. Coil leg currents are responsible for 64 MHz resonance frequency which is required to detect the NMR signal of ^{1}H element in 1.5T MRI system. Because of receive only coil, a passive type detuning circuit has also been used in the end rings of the RF coil. Simulation via SEMCAD X 3D provided the optimized dimensions to prepare the prototype of the coil. The NMR scans of small mouse using the designed coil was taken on 1.5T MRI systems.

2. Material and Method

2.1 **Coil Simulation**

FDTD based 3D EM simulation tool SEMCAD X 3D [8] was used to simulate this RF Coil. The RF coil has eight legs shorted on both ends by the end rings. There are present capacitors in the coil legs and end rings to make it a band pass type LC resonator. The best dimensions of the coil are optimized with the help of the simulation software. A hollow cylinder of acrylic material with 40 mm internal diameter, 5 mm thickness and 220 mm of length was used to hold the coil structure.

The optimized width of 0.5 ounce thick copper conductor was found to be 5mm for the coil end rings, legs (rungs) and parallel feed lines. The length of each coil leg (for single leg capacitor and triple leg capacitor coils) including capacitor gaps are 162.5mm while each capacitor gap for coil leg and end rings is of 2mm. Each end ring capacitor is 123.2 pF and each leg capacitor is 100 pF. Two different configurations of RF coil are prepared and simulated. First configuration contains a single position for capacitor in the centre of each coil leg and second configuration contains three equally spaced positions for the capacitors in each coil leg. In case of triple leg capacitor coil the equivalent capacitance of the lumped capacitors of each coil leg is also 100 pF. The return loss graphs for the simulation models as acquired by the SEMCAD X are shown in Figure 1.



(a) (b)

Figure 1: Simulation Results of Return loss for (a) Single leg capacitor RF coil, (b) Triple leg capacitor RF Coil.

Figure 1 shows that the return loss graphs for single leg capacitor and triple leg capacitor RF coil are obtained by SEMCAD X 3D are similar to each other. Both coil configurations have the lower resonance frequencies due to coil legs currents and higher resonance frequency due to coil end rings current. For both coil configurations, the resonance frequency due to coil legs can be adjusted at 63.85 MHz for NMR signal detection in1.5T MRI system.

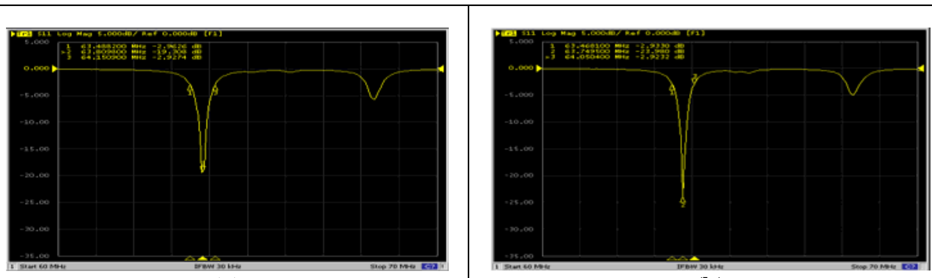
2.2 **Coil Prototype Implementation**

Usually in the birdcage type RF coil the conductors of coil legs and end rings are directly attached around the dielectric cylinder. However in our case we etched the copper strips for end rings, coil legs and feed line on a flexible epoxy dielectric material of 0.23 mm thickness. The solder paste of 1mm width which was required to accommodate the surface mount type diodes of the detuning circuit was also been etched on the flexible epoxy material. For the RF coil which carries only one 2 mm gap for the leg capacitor, each coil leg is composed of two 80.25 mm long and 5 mm wide copper strips. Similarly for the RF coil which carries three gaps of 2 mm size for leg capacitors, each coil leg is divided into four copper strips of 39.125 mm length 5 mm width. The feed line has a total length of 30mm. The copper etched epoxy is then pasted to the acrylic cylinder. The internal diameter of the prepared coil is 40 mm with an overall length of 220 mm. There are present total four passive type detuning circuit (2 in each end ring). Detuning circuits are connected in parallel to the alternate capacitors in the both end ring. The inductor of the detuning circuit is simple air core type while the PIN and switching diodes is surface mount. Four switching diodes and a PIN diode are connected in a limiter circuit configuration in each of the detuning circuit. Feed line for birdcage coil consists of two parallel copper conductors with 5 m width and 30 mm length. They also accommodate a series a parallel variable capacitor for impedance matching of the coil at 50 ohm.

3. Results and Discussion

3.1 **Coil Measurement**

The impedance matching of both FPCB RF coils was achieved with the help of non-magnetic variable capacitors which are present in the feed line. The impedance matching of the designed FPCB RF coils at 63.85 MHz was checked by performing the return loss measurement on the network analyzer. The images of return loss graphs are shown in Figure 2. It is quite visible by the return loss graphs of Figure 2 that the single leg capacitor RF coil has a return loss of -19.30 dB at 63.80 MHz and triple leg capacitor RF coil has a return loss of -23.98 dB at 63.75 MHz resonance frequency. The detuning circuit was also included in the RF coil before taking these measurements.



(a) (b)

Figure 2: 1.5Tsmall animal receive only FPCB RF coil return loss measurement graphs for (a) Single leg capacitor coil, (b) Triple leg capacitor coil.

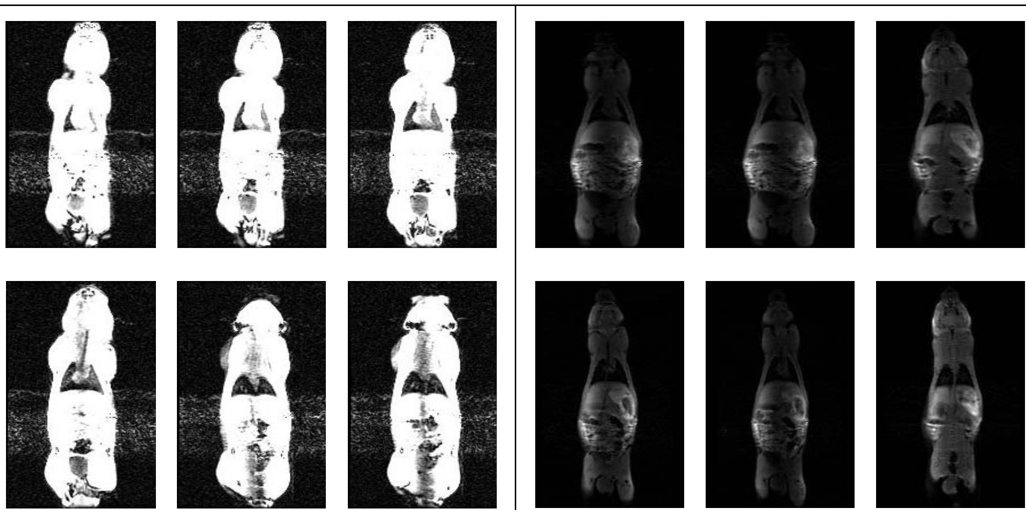
3.2 **Coil NMR Image**

The NMR images of ^{1}H in a small mouse on GE Company 1.5T MRI system were acquired with the help of single leg capacitor FPCB RF receiver coil and triple leg capacitor FPCB RF receiver coil. The parameter setting and the found SAR of the FPCB RF coils are given in Table 1 below.

Table 1: Parameter setting on MRI systems for NMR images acquisition

Parameters	1.5T	
	Single Leg Cap	Triple Leg Cap
Pulse Sequence	FSPGR	FSPGR
Imaging Frequency (MHz)	63.85	63.85
TR (msec)	9.072	8.8
TE (msec)	2.14	2.004
Slice Thickness (mm)	1.5	1.5
SAR	0.173186	0.177522

The NMR images of small mouse found by single leg capacitor FPCB RF receiver coil and triple leg capacitor FPCB RF receiver coil on 1.5T MRI system are shown in Figure 3.



(a) Single Leg Capacitor Coil (b) Triple Leg Capacitor Coil

Figure 3: Coronal NMR images of whole body of a small mouse at 1.5T MRI System.

4. Conclusion

RF receiver coil was designed and implemented as a birdcage type coil by using flexible PCB etched copper conductors which are not commonly used to prepare birdcage coils. The designed RF coil has an ability to detect the NMR signal of ^{1}H in a small mouse 1.5T MRI system. This RF receiver coil was tested by concentrating and distributing the coil leg capacitance. In both of cases the RF receiver coil successfully performed the NMR imaging of whole body of a small mouse with remarkably low value of SAR. The NMR images obtained by using triple leg capacitor FPCB RF coil has batter image contrast level as compare to the single leg capacitor FPCB RF coil. It has been found in the NMR images that noise immunity of the coil increases and image quality also improves when we distribute the capacitance along the coil legs. At the same time efforts are required to improve the magnetic field inside the RF coil so that the image quality can more improve.

References

[1] Hayes C, Edelstein W, Schenck J, Muller O, Eash M. “An Efficient Highly Homogeneous Radio Frequency Coil for Whole-Body NMR Imaging at 1.5T ”, Journal of Magnetic Resonance, vol. 63, pp. 622-628, 1985.

[2] Enzo A. Barberi, Joseph S. Gathi, Brian K. Rutt, Ravi S. Menon, “A Transmit-Only/Receive-Only (TORO) RF System for High-Field MRI/MRS Applications”, Magnetic Resonance in Medicine, vol. 43, pp. 284-289, 2000.

[3] Benard J. Dardzinski, Shizhe Li, Christopher M. Collins, Gerald D. Williams, Michael B. Smith, “ A Birdcage Coil Tuned by RF shielding for 9.4T”, Journal of Magnetic Resonance, vol. 131, pp. 33-38, 1998.

[4] S.E. Solis, G. Cuellar, R.L. Wang, D. Tomasi, A.O. Rodriguez, “Transceiver 4-Leg Birdcage for High Field MRI: Knee Imaging”, Revista Mexicana de Fisica, vol. 54, no. 3, pp. 215-221, 2008.

[5] Hayes C, Edelstein, “Radio Frequency Field Coils for NMR”, US Patent #4694255, 1987.

[6] Boguslaw Tomanek, Vyacheslav Volotovskyy, Marco L.H. Gruwel, Eilean Mckenzie, Scott B. King. “Double~Frequency Birdcage Volume Coils for 4.7T and 7T”, Concepts in Magnetic Resonance Part B: Magnetic Resonance Engineering, vol. 26B, no. 1, pp. 16-22, 2005.

[7] Vaughan J, Adriany G, Snyder C, Tian J, Thiel T, Bolinger L, Liu H, DelaBarre L, Ugurbuil K, “ Efficient High-Frequency Body Coil for High Field MRI”, Magnetic Resonance in Medicine, vol. 52, pp. 851-859, 2004.

[8] “SEMCAD X by SPEAG”, www.speag.com .

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