Dual Tune MRI RF Receiver Coil for ^{31}P and ^{1}H NMR Imaging at 4.7T

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Abstract

A dual tune birdcage type whole body MRI RF coil is designed to acquire the NMR imaging of ^{31}P and ^{1}H elements at 4.7T MRI system for small animal. The resonance frequency of the coil was observed via simulation and measurement of resonance frequency of the prototype was performed on network analyzer.

Keywords: Birdcage Coil, ^{31}P, ^{1}H, Dual Tune, FPCB Coil, MRI, 4.7T.

1. Introduction

Among the currently existing medical imaging techniques, MRI (Magnetic Resonance Imaging) is considered to be the best technique which is able to provide the detailed information about the metabolisms existing inside the human and the animal bodies. The basic purpose of the MRI is to image the proton (^{1}H) which abundantly exists in the human and the animal bodies. Even after the invention of the MRI efforts are always been there to improve the image quality. With the growing needs the trend in the MRI research has now being shifted towards the high Tesla MRI system with the capability of multi-element nuclei imaging for human and the animal bodies.

The dual tune RF coils have the ability to perform the imaging of the proton of ^{1}H element and that of the other element which also exist in the human and the animal bodies [1, 2]. As phosphorus ^{31}P is also a relatively available element in the human and animal bodies so it has also been tried to prepare the RF coil which can also detect the nuclear magnetic resonance of ^{31}P nuclei along with ^{1}H [3, 4, 5]. Usually it is constructed as surface coil [6]. It is a very difficult task to prepare ^{31}P/^{1}H dual tune volume type RF coil using birdcage coil configuration because of the coil dimensions optimization and field homogeneity issues [7].

In this paper we are presenting a method to prepare dual tune RF receiver coil for 4.7T MRI system. This is a volume type band pass birdcage RF coil for the small animal whole body imaging application. The coil has eight legs which are shorted by the end rings on each side. The end ring and the rungs of the coil are copper conductor etched on a flexible printed circuit board. Due to receive-only operation the RF coil also carries the detuning circuit. For dual tune operation of the coil at 4.7T, 81 MHz is the required resonance frequency for ^{31}P and 200 MHz is the required resonance frequency for ^{1}H respectively. As there is present the multiple resonance frequencies in the birdcage coil due to coil legs and the end ring. So the 81 MHz resonance frequency to detect the ^{31}P NMR signal is caused by the coil legs and the 200 MHz resonance frequency to detect ^{1}H NMR signal is caused by the coil end rings. The coil structure was simulated in SEMCAD X 3D and the measurement of the prototype of the coil was performed on the network analyzer.

2. Coil Simulation and Design

2.1 Simulation Setup

RF coil is receive-only band pass type birdcage coil for whole body NMR imaging of small animal. The coil was simulated in FDTD based 3D EM simulation software SEMCAD X 3D [7]. Simulation software helped to optimize the best dimensions of the coil and the capacitor values for which the RF coil can simultaneously resonate at 81 MHz and 200 MHz. The RF coil was simulated in the absence of mouse phantom. The RF coil is a band pass type LC resonator. The inductance in the end rings and coil legs is due to the copper conductor material while the lumped capacitors in the end rings and the coil legs provide the capacitance. The simulation model of RF receiver coil is shown in Figure 1. Coil legs end rings and feed line are represented by yellow colour strips. End rings and coil leg capacitors are shown by Blue colour arrows while flexible printed circuit board is shown in green colour circular cylinder which is wrapped on a grey colour hollow cylindrical acrylic cylinder. The optimized dimensions used to prepare this simulation model for the RF coil are given in the following Table 1.

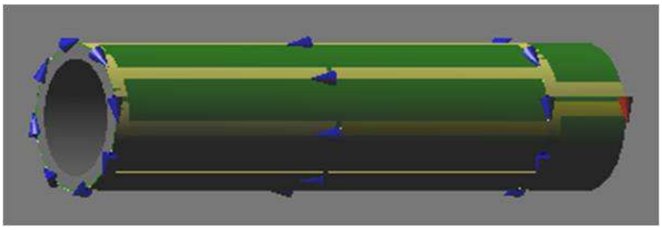


Figure 1: Simulation Model of RF receiver Coil.

Table 1: RF Coil parameters for Simulation model

Acrylic	Thickness	5 mm
	Diameter	40 mm
	Length	216 mm
Flexible Epoxy	Thickness	0.23 mm
Copper	Thickness	0.5 oz
	Width	5 mm
	(Each) Leg Length	162.5mm (Including Capacitor Gaps)
	Feed Line Dimension	30 mm
Capacitor	Gap Size	2mm
	End Ring	47 pF
	Leg	82 pF

2.2 **Simulation Results**

To view the Impedance matching of the RF coil the return loss and smith chart graphs taken by SEMCAD X 3D are given in Figure 2.

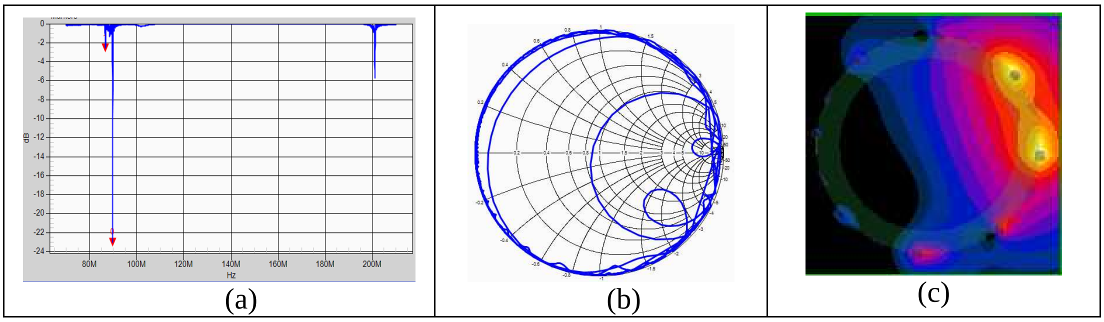
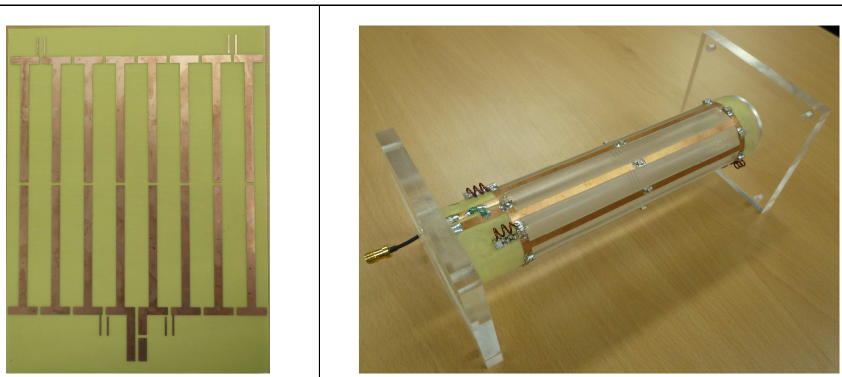


Figure 2: Simulation Results of Return loss for (a) Return Loss graph of RF coil, (b) Smith Chart graph of RF Coil, (c) Transvers Magnetic Field Distribution inside the RF coil.

The return loss graph of Figure 2 verifies the existence of multiple resonance frequencies in the simulated FPCB RF coil. Lower resonance frequencies are caused by the coil legs. One of the leg current resonance frequencies is strengthened for the detection ^{31}P in the animal body. The higher resonance frequency is caused by the coil end rings current and is responsible for the detection of ^{1}H in 4.7T magnetic field. The smith chart graph points that the impedance matching is required for the RF coil. The main purpose of RF coil is to produce the magnetic field inside the RF coil. The transverse view of the magnetic field of the simulation structure taken by SEMCAD X 3D at the centre of the RF coil is shown in Figure 2.

3. Implementation and Measurements of the RF Coil

The actual prototype of the RF coil was implemented by etching the copper conductor on flexible epoxy dielectric material. The coil carries eight legs and two rings with the dimension according to the simulation model. The gaps for the leg capacitors divide the each coil leg into two parts of equal length. Each end ring capacitor is placed in the centre of the gap between the two consecutive coil legs. A 0.23mm thick flexible epoxy material was used to etch the copper conductor according to the same manner as adopted in the simulation and was attached on the acrylic cylinder. There is present a feeding line composed of two parallel copper conductor which also carries a series and a parallel capacitor for the sake of impedance matching. All the capacitors in the RF coil are non-magnetic type. As the coil is a receive-only band pass type birdcage RF coil, so it must require the detuning circuit. This helps to neutralize the effects of induced current due to RF transmission coil in the RF receiver coil during the time interval when the nuclei of ^{31}P and ^{1}H are energized at Larmor's frequency. Four passive type detuning circuits with two in each end ring were used in RF receiver coil at the alternate positions. The detuning circuit is composed of limiter circuit which contains four switching diodes in parallel with a PIN diode which is connected in series with the inductor. This detuning circuit is connected in parallel to the end ring capacitors. The switching and PIN diodes are also non-magnetic type. The value of inductor is best optimized so that it could not change the resonance frequency. The switching and the PIN diodes are surface mount type. There are present 1mm conductor strips as the solder paste for these diodes at the respective positions. The flexible printed circuit boards with single and triple leg capacitors along with the solder paste for the diodes and the final prototype of the RF coil are shown in Figure 3.



(a) (b)

Figure 3: (a) Copper etched flexible Epoxy, (b) Prototype of FPCB RF Receiver Coil for ^{31}P and ^{1}H MRI at 4.7T.

The results of the return loss and smith chart of the RF coil as shown in Figure 4 are obtained at the Agilent network analyzer. For dual tune operation at 4.7T MRI system the resonance frequencies should be 81MHz for ^{31}P and 200 MHz for ^{1}H respectively. It can clearly be seen in Figure 4 that the coil has ability to resonate at 81.81 MHz and 200.28 MHz simultaneously with return losses of -19.64dB and 24.27dB respectively. The return loss values are little different as compare to the simulation result of return loss values which is shown in Figure 2. However these return loss values are more batter. This is because of the impedance matching which was performed with the help of non-magnetic impedance matching capacitors present in series and parallel to the feed line. These capacitors were not included in the simulation model only for the sake of reducing the simulation time. After performing the impedance matching and acquiring the appropriate resonance behaviour of the RF coil, the variable capacitors were replaced with the fixed value non-magnetic chip capacitors before performing the NMR imaging.

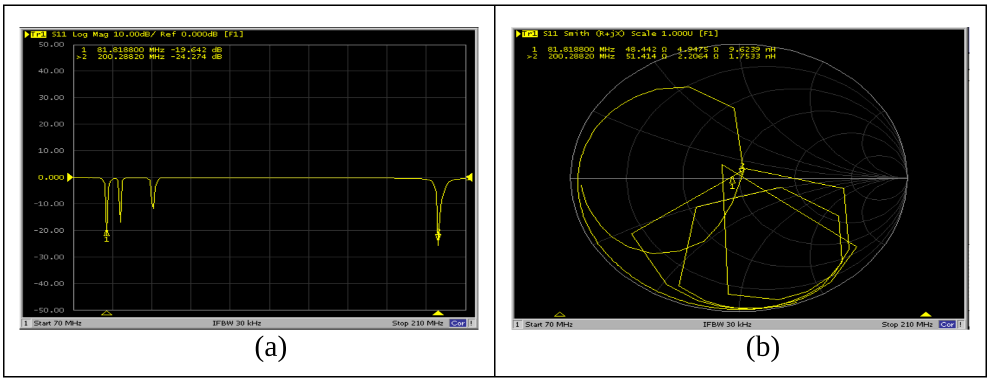


Figure 4: 4.7T dual tune RF receiver Coil for small animal with (a) Return Loss, (b) Smith Chart.

4. Conclusion

The simulation of a dual tune birdcage type RF receiver coil using FPCB technology for the NMR imaging of ^{1}H and ^{31}P nuclei in the whole body of the small animal at 4.7T is performed in SEMCAD X 3D EM simulation tool. The prototype of the simulated coil is also implemeted and tested on network analyser. It has been found that there exist a good compromise between simulated structure and the prototype of the RF coil. In the future the designed dual tune FPCB RF coil will be tested via NMR imaging at 4.7T MRI system.

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Acknowledgments

This work was partially supported by the Grant of the Korea Ministry of Education, Science and Technology (The Regional Core Research Program/Anti-aging and Well-being Research Centre) and the Korea Ministry of Education, Science and Technology under BK21 Program. We are also thankful to the SPEAG for providing free license of SEMCAD X used in this study.