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A HEXAGON SHAPED 24 CHANNEL PHASED ARRAY RF SURFACE COIL FOR 1.5 TESLA MRI APPLICATIONS

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ABSTRACT

In this article a new phased array structure is proposed to act as a receive only surface type radiofrequency (RF) coil for 1.5 Tesla Magnetic Resonance Imaging (MRI) applications. Initially a single channel hexagon shaped RF coil structure is designed and it is implemented in FR4 (Flame retardant Type 4) substrate having a height of 1.6 mm. The RF coil resonance is achieved at 63.87 MHz by using a proper matching network. The workability of the single channel RF coil has been verified using Advanced Design System (ADS) S-Parameter simulation. This single channel design is extended to construct 24 channel phased array RF surface coil. The spacial distance between each channel is adjusted in successive simulations to analyze the performance of 24 channel phased array RF coil and the results were also presented.

KEYWORDS: *Phased array, return loss, RF Coil, resonance, Smith chart, matching network.*

I. INTRODUCTION

In recent years, Magnetic Resonance Imaging (MRI) is one the most extensively used medical imaging technique to obtain the clear image of the anatomy, especially those of high-water-content tissues [1]. The introduction of MRI technique into clinical practice gives a new dimension to the radiological study. The basic principle behind MRI is to radiate the high-power RF energy towards the object of the body and to capture the Nuclear Magnetic Resonance (NMR) induced signals emitted by the body. The whole action of RF energy radiation and reception is performed by RF coil under high-magnetic field intensity called static magnetic field (B_0) [2]. The efficient way of signal transmission and reception at these high fields can also be achieved by using multi element RF transceiver coils [3].

The entire MRI system consists of RF coil, gradient coil, magnet, power amplifier, low noise amplifier, pulse programmer, RF source and computer. There are several types of RF coils such as saddle coil, surface coil, volume coil and birdcage coil. Surface coils are better in producing high-signal-to-noise ratio of the reconstructed image and able to perform multichannel operation in comparison with volume coils [4]. The operating frequency of the MRI RF coils is decided by the static magnetic field strength [5]. If the static magnetic field strength of MRI system is selected as 1.5 Tesla, the desired Larmor frequency (42.58 MHz/Tesla for 1H protons) of operation is 63.87 MHz. The signal to noise ratio of the reconstructed image can also be improved by selecting high static field strength coils. These high resonance frequency RF coils are dimensionally small and consequently produce less field of view for imaging. That is the reason to concentrate on low field RF coils.

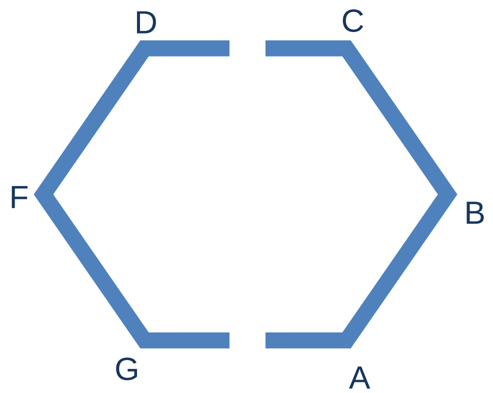
There are many number of phased array RF coil structures were addressed for high field MRI applications [6-9]. But due to the requisite of high field strength and large sized magnets makes the availability of very few array coils with higher costs. This demands a low field MRI system (1.5 Tesla) competent to work under phased array operation. Therefore the objective of this paper was to design a 24 channel phased array RF surface coil operating at 63.87MHz (1.5T) for human spine imaging.

The remainder of this paper is organized as follows. In Section 2 materials and methods is discussed in details which consist of hexagon shaped RF surface coil, matching network design and implementation using ADS 2011. Simulation results are discussed in section 3. Section 4 concludes the proposed work.

II. MATERIALS AND METHODS

2.1 Single channel hexagon shaped RF coil

The specialty of hexagon shape compared to other shapes is, the given area can be covered by placing the hexagons one after the other without any overlap of hexagons. It is also possible to keep equal spacing between the hexagons. Figure.1(a) shows the geometry of hexagon shape. The side length of hexagon is 36 mm. In between edges G and A, a feeding end circuit will be connected. A tuning capacitor Ct is connected in between edges C and D. Similarly a decoupling capacitor Cd is connected between edges G and A. A 2mm gap is provided to connect the capacitors Ct and Cd in between the sides CD and AG respectively.



(a)

(b)

Figure .1 Hexagon shaped RF coil a) Full section (b) Optimized half section

2.2 Matching network design

The proper matching network will make the RF coil to act as near field radiator for the designed frequency of 63.87 MHz. Smith chart based matching network design is in existence over several decades [10-11].The matching network proposed in this work consists of a shunt and series connected Capacitors C1 and C2. Figure.1(b) shows the half section of the Hexagon shaped RF coil. The inductance (L) of the half section is evaluated from the input impedance of the structure [12]. The tuning capacitor is obtained from the relation (1).

$$C_t = \frac{1}{2\pi f_0 \sqrt{L}} \tag{1}$$

Where resonance frequency f_0 = 63.87 MHz.

The input impedance (Zin) of the un-matched hexagon coil is evaluated from ADS S-parameter simulation. The source impedance (Rs) is selected as 50Ω.

In resonance circuit the quality factor is related with source (Rs) and load resistance (Rin) as,

$$R_S = \left(1 + Q^2\right) R_{in} \tag{2}$$

$$Q = \sqrt{\frac{R_S}{R_{in}} - 1} \tag{3}$$

The shunt Capacitor (C1) is in parallel with source resistance. So for parallel resonance,

$$C_1 = \frac{Q}{2\pi f_0 R_S} \tag{4}$$

Inductor L is in series with RF coil input resistance. So for series resonance,

$$Q = \frac{\text{Reactance}}{\text{Resistance}} = \frac{X_L}{R_{in}} = \frac{L2\pi f_0}{R_{in}}$$

Series inductor L is given by

$$L = \frac{QR_{in}}{2\pi f_0} \tag{5}$$

$$X_2 = X_{in} - X_L \tag{6}$$

$$C_2 = \frac{1}{X_2 2\pi f_0} \tag{7}$$

2.3 Design Calculations:

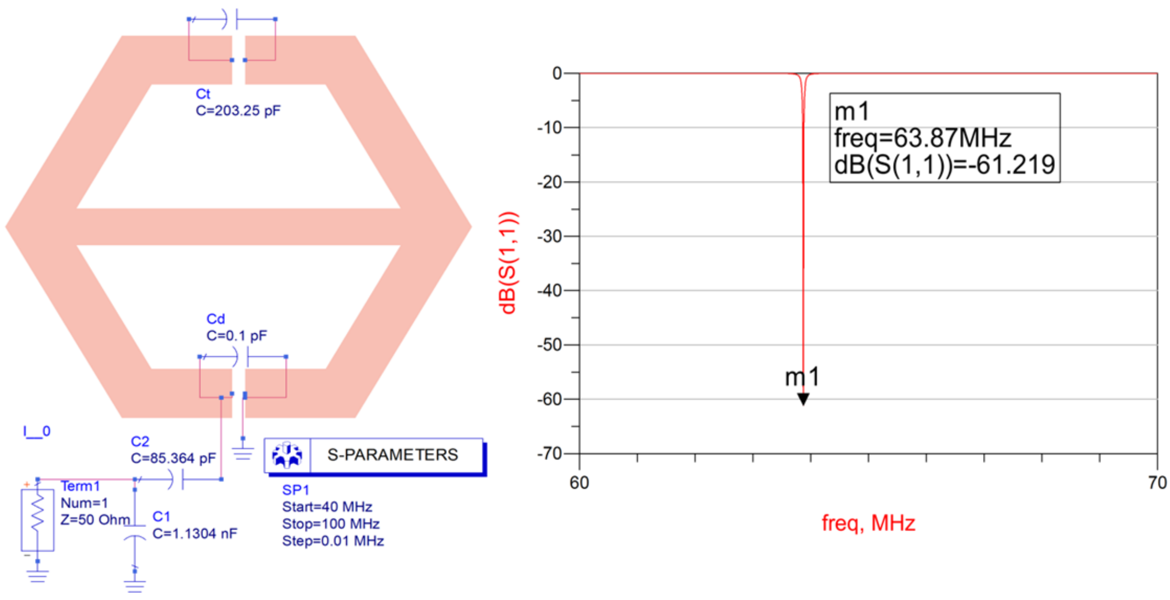
Input impedance of Half section RF coil from S Parameter simulation,

$$Zin = Z0*(2.2748e\text{-}5 + j0.1226)\ \Omega$$

Inductive Reactance Xin = 50*0.1226, Inductance of Half section L_H= 15.275nH
Total inductance of Single channel Hexagon structure L =2*L_H=30.550 nH.
From equation, (1) Tuning capacitor Ct = 203.25pF
Input impedance for full section Zin = Z0*(0.00194 + j0.62782) Ω
From equations (2) – (7). The shunt capacitance C1=1.1304 nF and series capacitance C2 = 85.364pF.

III. IMPLEMENTATION

The phased array implementation will be obtained by verifying the performance of single channel RF coil. The Single channel Hexagon shaped RF coil is implemented in ADS 2011 schematic option as shown in Figure 2.(a). FR4 dielectric substrate of thickness 1.6 mm is used in all the simulations presented in this work. At the top surface of the substrate 35µm copper conducting transmission line of 8mm width is made and the bottom side is fully coated by a copper layer of thickness of 35µm for grounding purpose. A gap of 2mm is created between transmission lines to insert the capacitors.



a) ADS Schematic Structure b) Return loss graph

Fig. 2 Single Channel Hexagon RF coil

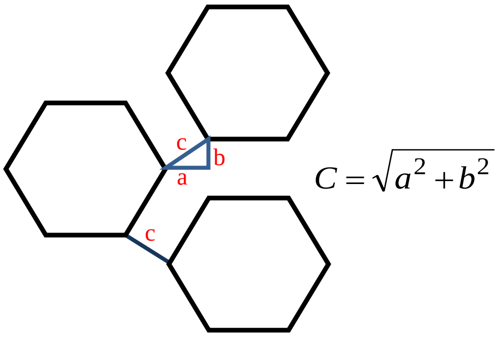


Figure.3 Distance calculation between nearby hexagons

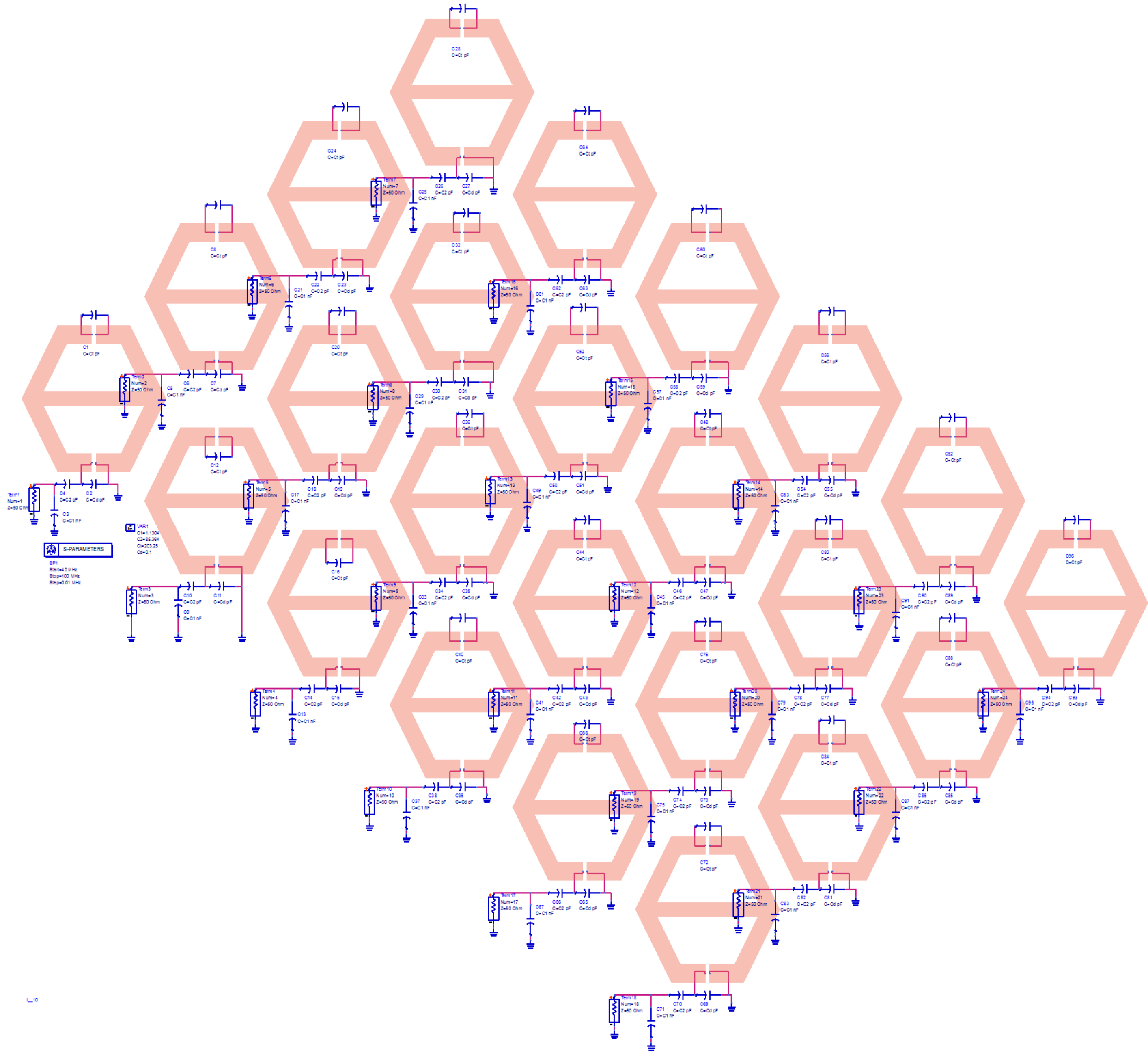


Figure.4 Schematic structure of 24 channel RF surface coil

The matching network capacitors are inserted at the appropriate places in the schematic design. S Parameter simulation is performed to obtain the return loss (Figure. 2(b)) behaviour of single channel RF coil. Single channel Hexagon shaped coil is placed in an array of 6x4 configurations to obtain a 24 channel phased array RF coil. The spacing C between nearby Hexagons is decided from Pythagoras' theorem as indicated in Figure 3. A 24 channel phased array RF coil with parallel spacing C =14 mm (a=7mm, b = 12.1244mm) is shown in Figure.4.

IV. RESULTS AND DISCUSSION

A single channel Hexagon shaped RF coil of 8 mm width is simulated in ADS 2011 and the return loss result is presented in Figure.2 (b). Usually for an RF circuits return loss of less than -20dB is considered to be the optimal design. The simulation result shows S_{11} of -61.219 dB, therefore this single channel hexagon structure is giving appropriate return loss result. This is extended to construct 24 channel RF surface coil as shown in Figure 3. The parallel spacing (C) between the two channels is adjusted to verify the return loss performance of all the 24 channels. The geometrical parameters of 24 Channel RF coil for different parallel spacing is illustrated in Table.1. The variation of return loss with respect to spatial distance parameter is indicated in Tables.2 &3. This table shows that, if parallel spacing between nearby channel increases the return loss for all the 24 channel’s decreases.

Table.1 Geometrical parameters of 24 Channel Phased array RF Coil

Case	Distance in mm			Length x Width mm^2	Area mm^2
	Horizontal a	Vertical b	Parallel spacing C		
1	7	12.1244	14	436 x 286	124696
2	6.5	11.2583	13	432 x 284	122688
3	6	10.3923	12	427 x 281	119987
4	5.5	9.5263	11	422 x 278	117316
5	5	8.6603	10	418 x 276	115368

Table .2 Return loss variations of ch1 to ch12 for various spatial distances

Case	Return loss values from channels 1 to 12 (dB)											
	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8	Ch9	Ch10	Ch11	Ch12
Case1	-33.4	-32.3	-27.6	-27.7	-27	-32.3	-33	-27	-27	-27.6	-27.1	-27.1
Case2	-30.5	-29.3	-24.8	-24.8	-24.2	-29.3	-29.3	-24.2	-24.2	-30.1	-29.3	-24.2
Case3	-26.4	-25	-21	-21	-20.3	-25	-25	-20.3	-20.3	-26	-25	-20.3
Case4	-23.1	-21.6	-17.9	-18	-17.3	-21.6	-21.6	-17.3	-17.3	-22.7	-21.6	-17.3
Case5	-20.1	-18.5	-15	-15.1	-14.5	-18.5	-18.5	-14.5	-14.5	-19.5	-18.5	-14.5

Table .3 Return loss variations of ch13 to ch24 for various spatial distances

Cases	Return loss values from channels 13 to 24 (dB)											
	Ch13	Ch14	Ch15	Ch16	Ch17	Ch18	Ch19	Ch20	Ch21	Ch22	Ch23	Ch24
Case1	-27.1	-27.7	-27.7	-27.6	-27.6	-33.1	-27	-27	-32.3	-32.3	-27.6	-33.3
Case2	-24.2	-29.3	-30.1	-24.2	-24.2	-29.3	-29.3	-24.2	-24.8	-24.8	-29.3	-30.5
Case3	-20.3	-25	-26	-20.3	-20.3	-25	-25	-20.3	-21	-21	-25	-26.4
Case4	-17.3	-21.6	-22.7	-17.3	-17.3	-21.6	-21.6	-17.3	-18	-17.9	-21.6	-23.1
Case5	-14.5	-18.5	-19.5	-14.5	-14.8	-18.5	-18.5	-14.5	-15.1	-15.1	-18.5	-20.1

V. CONCLUSION

A new hexagon shaped 24 channel phased array RF surface coil is proposed for human spine imaging needs at 1.5 Tesla. Initially a single channel RF coil design is verified for its return loss performance. Afterward the same single channel RF coil is extended for 24 channel phased array operation at 63.87MHz (1.5 T). In both single channel as well as 24 channel operation return loss value of less than -20 dB is achieved. This shows the appropriateness of simplified matching network and Hexagon shaped RF coil geometry for multichannel operation. The solitary factor which controls the performance of multichannel phased array RF coil is the spacing between nearby channels. After investigating the results of 8mm width 24 channel RF coil, a parallel spacing of greater than 14 mm gives a lesser value of return loss. This gives the total RF coil dimension as 43.6 cm x 28.6cm which is compatible with practical spine RF coil dimensions ranges.

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