Multi-channel Hexagonal Surface Coils for 1.5T MRI Scanner

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***Abstract*—Radio-Frequency coil is the major component used in the detection of Nuclear Magnetic Resonance Signal. Usually the Radio Frequency coil is designed for operation on a specific Magnetic Field strength based Magnetic Resonance Imaging system. Multi-element phased coils, offers the high signal-to-noise ratio (SNR) and Resolution of a small surface coil over field of view (FOV) normally associated with body imaging with no increase in imaging time. Multi-channel phased array coil Imaging is an advanced method for obtaining high Resolution Images with enhanced signal-to-noise ratio (SNR) and large field of view (FOV) compared to single loop surface coil. This paper describe the method of Implementing a Hexagonal Surface type Receive only Radio Frequency coil which has ability to detect the Nuclear Magnetic Resonance Signal of ^{1}H Nuclei at 63.87 MHz Resonance Frequency for 1.5T Magnetic Resonance Imaging scanner. The RF coil in MRI is used for excitation of the Magnetization and to receive the Signal from the excited spins. A surface coil is usually a loop of conducting material designed specifically for localized body regions. These coils have high SNR and uniform sensitivity. The Return loss of fabricated surface coil is 24.521 dB and bandwidth is 0.188 MHz.**

Keywords*— *1.5 Tesla MRI, RF coil, Surface Coil, Hexagonal Coil, Quality Factor, Multi-element Coil, Electromagnetic Simulations.

I. INTRODUCTION

MRI is based on the principles of nuclear magnetic resonance phenomena. Magnetic resonance imaging (MRI) is an imaging technique that produces images of biological tissue based on the nuclear magnetic resonance (NMR) phenomenon. The NMR phenomenon occurs when nuclei with non-zero spin interact with an external magnetic field B_0 [1] .MRI allows Non-Invasive Imaging without Ionizing Radiation and provides detailed images of the body in any plane. RF coil is a RF detector which has the ability to detect the very weak RF signal produced in the object present in MRI system due to Nuclear Magnetic Resonance phenomenon. The most important factor in designing of the RF coil is the strong Magnetic Field which the RF coils must have to produce in its desired observed area. This Magnetic Field must be produced at the same Resonance Frequency as of the Nuclear Magnetic Resonance signal [2].

RF Array coils is used to have Improved SNR and better Image Resolution over the Imaging FOV. Array coils are Multi-channel coils that are designed to Image different parts of the body. Multi-channel RF array coil is composed of Multiple surface coils which are overlapped in such a way that the Mutual coupling between the neighboring coils is minimum, An array of receiver coils that encompasses an area of interest is called a phased array coil. For this to occur, each receive coil must be connected to its own Preamplifier and Receive channel. In a Multi-channel array coil, individual coil signals are generally combined to obtain a uniform image. In a MRI system RF coils are used for the purpose of Transmission and Reception [3]. A Transmitter excites the Magnetization vector while the Receiver detects the signal that arises from Relaxation of Magnetization and Image encoding. The basic demands in the design of RF coil are the Magnetic Field Homogeneity inside the coil along with the high SNR and Filling Factor at the desired Resonance Frequency. A surface coil has high B_1 Sensitivity compared to other volume coils due to the small size of the RF coil and Filling Factor. Surface coil are generally used as Receive-only types for receiving the B_1 signal efficiently in extended field of view (FOV). Surface coil are commonly used in MRI as their close proximity to the patient limits the volume from which noise is detected thus providing good SNR for superficial tissue.

II. SURFACE COIL MODEL

Surface coil usually are used to receive only, because of the Inhomogeneous Reception Field. However this type of coils is good for detecting signals near the surface of the patient. Surface coil have the advantage that they are smaller and can be made of various shapes to fit the contour of the sample to be imaged. Thus, the measured SNR of the surface coil is more than that of the volume coil, since the surface coil is in close proximity to the sample. These coils have high SNR and unifrom sensitivity although the uniformity is less. Since they are typically smaller then volume coils, they sacrifice Image unifomity for high SNR. In general, they are mostly used as Receiving only coils [4] .

An RF coil is simply an R-L-C circuit . The R represent a Resistance, the C represent a Capacitance, and the L represents an Inductance of the coil. RF coil is used for both series and parallel resonance circuit [5]. A series Resonance circuit acts

like a short circuit at the Resonance frequency and parallel resonance circuit acts like an open circuit at the Resonance Frequency. RF coil has one or more loops of conductive wire with defined wavelength [6-7] .

III. Designing Of surface Coil

Steps for Designing of Surface Coil:-

A. Larmor Frequency :-

Each Hydrogen Nucleus that makes up the net Magnetization vector is spinning on its axis; the influence of B_o produces an additional spin, or wobble of the net Magnetization vector around B_o. This secondary spin is called Precession and causes the Magnetic Moment to follow a circular path around B_o. This path is called the Precession path and the speed at which the net Magnetization vector wobbles around B_o is called the Precession Frequency.

$$\omega = \gamma \beta_{\circ} \tag{1}$$

Where, ω = Precessional or Larmor Frequency in (MHz)
γ = Gyro magnetic ratio (MHz/T)
β_o = strength of magnetic field (T)

We have a MRI system of 1.5T and the Gyro-magnetic ratio of hydrogen atom is 42.56MHz/T then the Larmor or Precessional Frequency is, 42.56× 1.5 = 63.87 MHz.

B. Induction of Coil

Most RF coil is designed around the concept of Resonance. Imaging coil are composed of Inductive and Capacitive elements. Since the Magnetic field is directly proportional to the magnitude of the current, RF coils operating at Resonance Frequency produce maximum Magnetic field strength at a relatively low input voltage. Then the Inductance of hexagon is

$$L = \frac{3\mu_{\circ} S}{\pi}\left[\ln\left(\frac{S}{R}\right) + 0.09848\right] \tag{2}$$

Where, S = Side Length of Hexagonal coil
R = Wire Radius
μ_o = Permeability of the free space
L = Inductance of Hexagonal coil.
Obtained L = 267.8431 nH

C. Capacitance of Coil :-

The relation between Angular Resonance Frequency, Inductor and Capacitor values is given by the Thompson formula from equation (3).
The Resonance Frequency (Fr) or Precessional Frequency for 1.5T MRI system is 63.87 MHz and Inductance of coil (L) is 267.8431 nH then from equation (4) we get the value of Capacitance

$$\omega = \frac{1}{\sqrt{LC}} \tag{3}$$

or

$$Fr = \frac{1}{2\pi\sqrt{LC}} \tag{4}$$

where, Fr is the Resonant Frequency
C is the Capacitance
Then value of C = 23.18281 pF

D. Quality-Factor of Coil :-

Another important parameter of Resonant circuit is its Quality Factor Q. It is a measure of the loss of a Resonance circuit, and is affected by parameter such as the strength of the Magnetic Field, the SNR of the Image, and the sensitivity of the RF coil. MRI coil is a Magnetic Energy storage device and Q-factor measures this storage performance. The Quality Factor of a coil is defined as:

$$Q = 2\pi \frac{\text{maximum energy stored}}{\text{total energy dissipated per cycle}} \tag{5}$$

IV. Design Model

A. Hexagonal Coil :-

RF coils are responsible for Transmission and Reception and therefore can be thought of as the MRI's antenna. This is achieved via an electrical circuit containing a Capacitor (C) and Inductors (L). The Software of Ansoft HFSS 2015 is used for the analysis of the EM distribution of the Hexagonal surface coil.

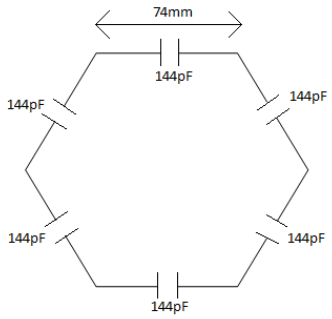

Figure 1. Design of Hexagonal surface coil

B. Designing of Balun :-

A Balun is a device which convert balanced impedance to unbalanced and vice versa. Balun can also provide impedance transformation. A Balun is used as a type of transformer. It is used to convert a balanced signal to an unbalanced one or vice versa. Balun Isolate a Transmission line and Provide a balanced output.

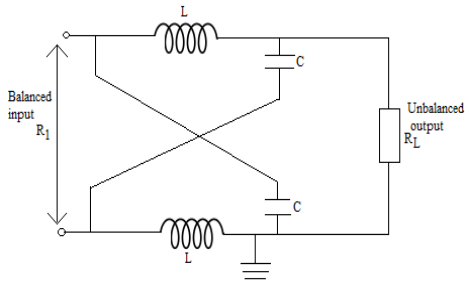

Figure 2. Balun Equivalent Circuit [4].

At the Resonance Frequency the desired values of L and C are chosen in such a way that the Balun is resonate at the Resonance Frequency then values of L = 124.59287 nH and C = 49.83715 pF.

C. Multi-channel :-

Multi-channel surface coil is formed by overlapping the surface coils which are tuned to the same Resonant Frequency. When the coils are placed adjacent to each other then there is Mutual coupling between the two coils. Due to Mutual coupling, split in Resonance peak of coils and is also be caused by the next nearest neighboring coil, that is a coil placed in proximity but which does not overlap with the coil. This split in their Resonant Frequency causes a loss in sensitivity of the both coils. Hence during the building of a phased array coil, a number of loops are in close proximity to each other, it is important that Mutual coupling between the loops be kept as low as possible. This can be done by placing the two coils over each other (overlapping the coils) at a position such that Mutual induction between them is zero. Varied the separation between the coils is such that the coil is resonant at the Resonance Frequency and by giving the gap to provide the Isolation between the coils. Array are Multi-channel coils that are designed to Image different part of the body, this type of coil has higher rounded quality factor (Q_L) and the combined set of surface coils also provide uniform sensitivity over a large field of view.

V. Simulated And Experimental Result

A. Single Surface Coil:-

The Simulation of coil was carried out in 3D full wave Electromagnetic Simulation Software HFSS 2015.The FEM is probably the most popular numerical method used to solve different boundary-value problems and its geometrical modeling capability is unmatched by any other numerical method. The Return loss graph of the designed RF coil clearly indicates the presence of Resonance Frequency near the desired Resonance Frequency at 63.87MHz. The purpose of Simulation was to optimize the coil parameters so that the coil can produce Resonance near the desired Resonance Frequency. The RF coil is able to produce the Resonance for ^{1}H Nuclei NMR imaging at 1.5TMRI system. The RF coil is loaded by phantom and the Return Loss graphs obtain from Simulation that is, when loading the RF coil with phantom does not shift the Resonance Frequency.

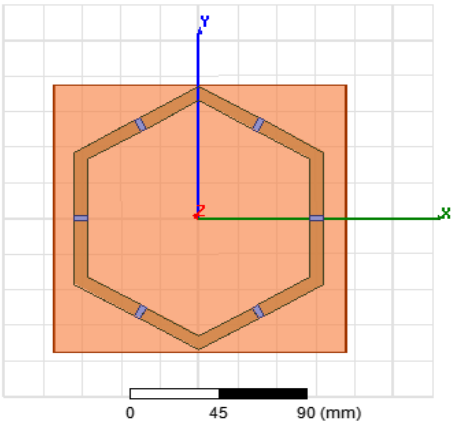

Fig. 3. Simulation Model of Surface Coil for 1.5T MRI

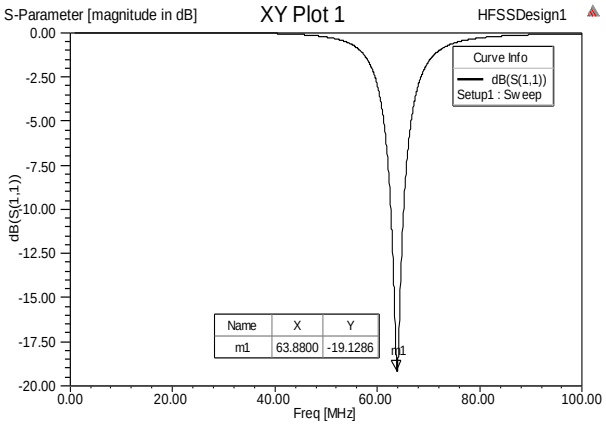

Fig. 4. RF Coil Simulation Result

The Fabricated RF coil is tested by the Network Analyzer at the Resonance Frequency of 63.87MHz and the Quality Factor of Fabricated RF coil is 339.61.

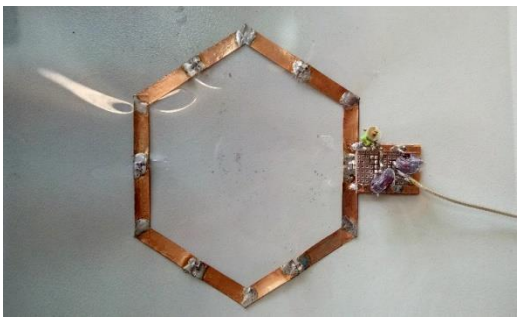

Fig. 5. Fabricated RF Coil

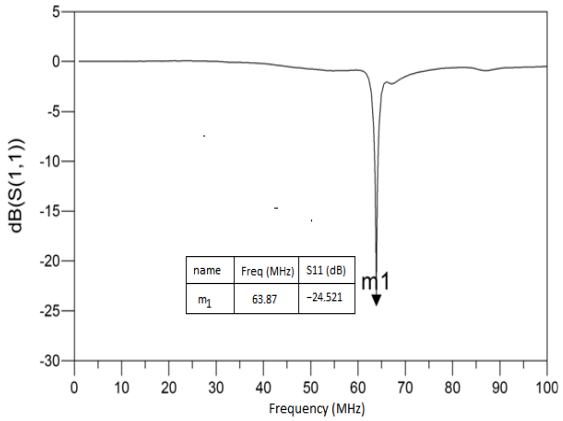

Fig. 6. RF Coil Fabricated Result

The Frequency Responses of the coils from Simulation and from Network Analyzer at the Resonance Frequency 63.87MHz as shown in fig. 7 we can see that there is good match between Simulation Result and Experimental data.

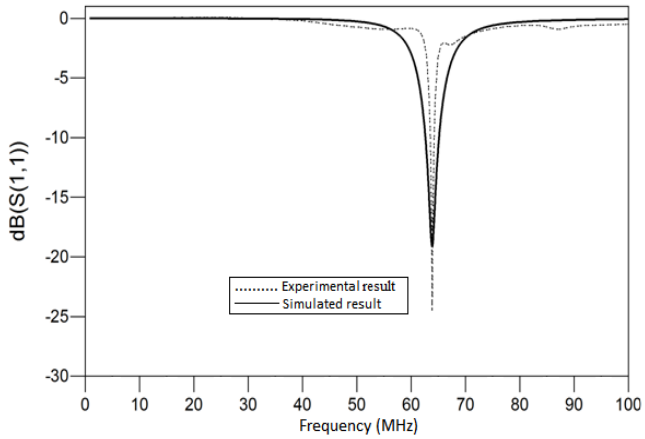

Fig.7. Comparison of Simulation & Experimental Result

Simulated and Fabricated Result Comparison Table:-

Parameters	Simulated	Fabricated
Return loss (dB)	19.1286	24.521
VSWR	1.24	1.17
BW (MHz)	0.9	0.188

Table-1

B. Multi-channel Surface Coil:-

When one coil is overlapped to the other, then signal is coupled from one coil to another due to Inductive coupling. Improved the performance of the coils by limiting Inductive coupling between the coils. The Inductive coupling depends on the distance between each planar coil. The optimized overlapping distance between two planar coils is determined by the relative ratio of the diameter and distance from the center of the two coils. By varying the overlapping area between the two coils there is Frequency shift in the Signal has been observed.

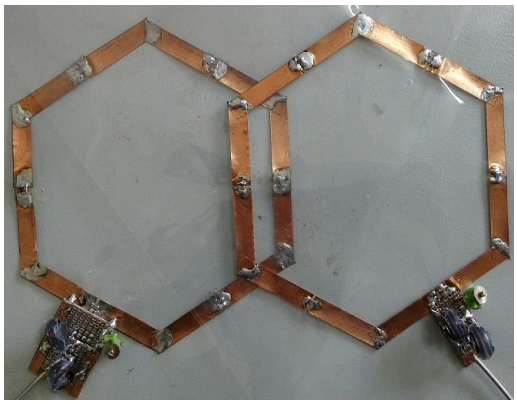

Fig 8. Fabricated Hexagonal Surface Coil Array

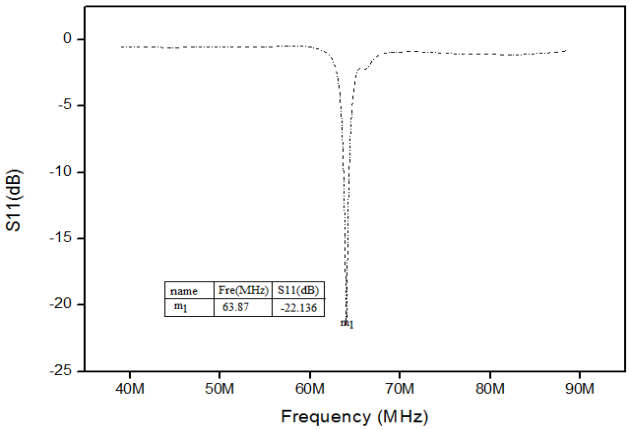

Fig 9. Return Loss of Hexagonal Surface Coil Array

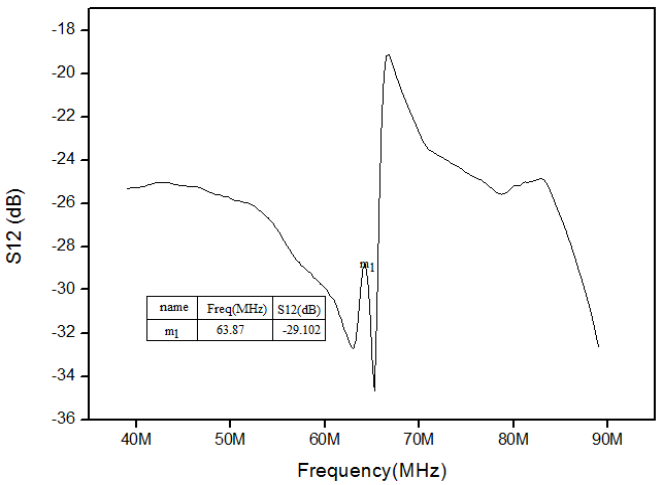

Fig 10. Reverse Isolation of Hexagonal Surface Coil Array

VI. Conclusion

RF surface coil is a most important and simple approach to designing the MRI coil to detect the NMR signal of the ^{1}H Nuclei of human body which is excited by the RF pulse Transmitted by the Transmitter coil. The coil has been tested by using the Simulation Software HFSS and it is resonating at the Resonance Frequency of 1.5T MRI systems. Surface coils, the most common RF coil, offer high local SNR however intensity quickly decreases as you move away from the surface. Matching is also an important criterion when designing RF circuit, when the load impedance is differs from source impedance; a matching network is used to obtain the delivery of maximum power from source to load. Both Simulation and Experimental Results clearly demonstrate the advantages of proposed surface coil configuration. RF coil should ideally be able to provide a Homogenous B_1 field throughout the sample but surface coil is not Homogenous. Then typically uses a surface coil for receive only coil. Overlapped area of the two phased array coils is changed or by proper overlapping we achieve good Return Loss, good Isolation and low coupling. Return loss of the Multi-channel coils is 23.136 dB and reveres Isolation is 29.102 dB.

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