Design Decoupling Methods of Multichannel Phased Array Receive Only RF Coil for Different Structures of 1.5T MRI

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Abstract — **Magnetic Resonance Imaging (MRI) system is based on magnetic field and pulses of radio wave energy to obtain detailed image of internal structures of the body. Use of RF surface coils in MRI is for better signal reception as they are more sensitive to signal as they are close to the body. Hence, for improvement in the performance of the coil, multiple coils are combined together for better signal reception. Multiple small coils are arranged in such a way that it can efficiently cover a specific anatomic region and obtains high resolution, high SNR images of a larger volume. When more than single surface coils are closely situated there will be mutual coupling between the coils, which causes splitting in response at desired resonant frequency. Decoupling is the method to cancel the mutual coupling of the coils such that it will resonate at our desired resonant frequency. Thus decoupling plays a major role in MRI coil.**

Keywords- MRI; RF coil; Surface coil; Decoupling

I. INTRODUCTION

I. Magnetic Resonance Imaging(MRI):

Magnetic Resonance Imaging (MRI), also known as nuclear magnetic resonance imaging is a scanning technique for obtaining detailed image of internal body structure and also to identify the nature of variety of disorders.The human body contains 75% of water. Water molecules contain hydrogen protons which are very sensitive to magnetic field. MRI produces very strong magnetic field because smaller the magnetic field, fewer the excess of protons which gives poor SNR. So, MRI uses a very strong magnetic field. This strong magnetic field arrange the spinning of protons. This magnetic field is produced by radio frequency current. When RF energy is turned ON, these protons absorbs energy from magnetic field and flips at high state at certain resonant frequency F_r and when RF energy is turned OFF, then high energy nucleus returns back to its low energy state. This resonant frequency F_r is called as Larmor frequency .The returning process produces a radio signal that can be measured by receivers in the scanner and can be converted into an image[1].

Principle of MRI: Computer-constructed image of body can be obtained based on the response of hydrogen protons from water molecules when placed in strong magnetic field [2].

- Protons align in the direction of a magnetic field.
- Protons are temporarily dislodged and wobble when RF waves are directed at them.
- Protons emits measurable signal that used to construct an image.
- Intensity of signal depends on water content of tissues, strength and duration of RF pulse.

II. Larmor Frequency for 1.5 Tesla:

The Larmor or precessional frequency in MRI, mentions the precession rate of the magnetic moment of the protons located around the external magnetic field[3]. The frequency of precession of protons of a substance placed in primary magnetic field β_0 which is calculated from the Larmor equation as,

$$\omega_0 = \gamma \times \beta_0 \tag{1}$$

Where, β_0= magnetic field strength (MHz)
γ = gyro-magnetic ratio(MHz/T)
ω_0 = Larmor Frequency (T)

For MRI system of 1.5T, gyro-magnetic ratio for hydrogen is 42.6MHz/T, so Larmor frequency becomes 1.5×42.6 = 63.87MHz.

Short periods of high intensity radio waves at a frequency which is closer to Larmor frequency is called β_1 field, is oriented in direction to β_0 and rotating about β_0 [1].

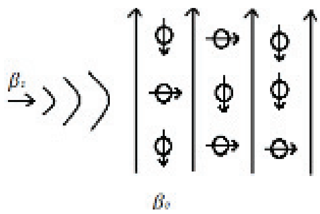

Fig.1. β_1 field applied perpendicular to β_0.

III. Radio Frequency(RF) Coil:

Radio Frequency (RF) coils acts like an antenna in MRI system. When human body is placed in large magnetic field, the hydrogen protons are aligned in parallel and in antiparallel manner to the applied magnetic field.

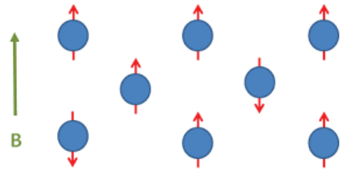

Fig.2. Alignment of protons in parallel and anti-parallel manner[4].

When RF signal is applied in perpendicular to β_0, this RF pulse frequency which is near to Larmor frequency causes net magnetic movement to tilt away from β_0.There is a greater portion aligned parallel than antiparallel protons to applied primary magnetic field β_0 i.e. the net magnetic moment. This RF signals are transmitted towards the patient and receives back the return signal[1]. Basically, there are two types of RF coils: volume coil which behaves as both transmitter and receiver and other is surface coil which behaves only as receiver coil.

IV. Surface Coil

A surface coil is nothing but a loop of conducting material. This RF receiver coils are placed directly on or over the region of interest for increased magnetic sensitivity. The surface coil loop can be designed in various shapes.

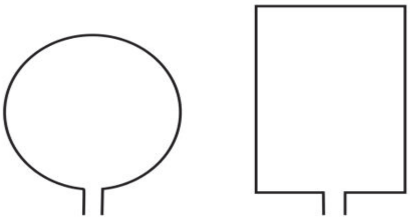
Fig.3. Circular and Square coil

Surface coils have a good SNR for tissues which are close to coil. Signal decreases as distance between the organ and coil increases. So, the rule of thumb which is, sensitivity of surface coil decreases considerably beyond a distance equal to the diameter of the coil[3].

For increasing SNR of surface coil, many of surface coils are combined together. This type of RF coil is combination of multiple smaller coils, which can be used individually or combined according to requirement of system[5]. The multiple coils are arranged efficiently to cover a specific body region, to obtain high SNR and high resolution of image.

II. Decoupling

Creating an array is not as simple as putting together a number of surface coil elements. When coils overlap to each other, their coupling reduces the spatial uniqueness of the signal acquired from the coils due to signal crosstalk and introduces correlation in the noise between channels[5].

Consider two loop coils which are operated at same resonant frequency. If this coils are placed close to each other, the mutual inductance between coils split at their resonant frequency. Due to this splitting, sensitivity will decrease at resonant frequency[6] which is shown in fig 4. To avoid or minimize mutual inductance, adjacent coils are overlapped in such a way that mutual inductance will be zero. This method is known as geometric decoupling. This is a standard method between nearest neighbors[7]. Coils are overlapped at a distance where mutual inductance become zero.

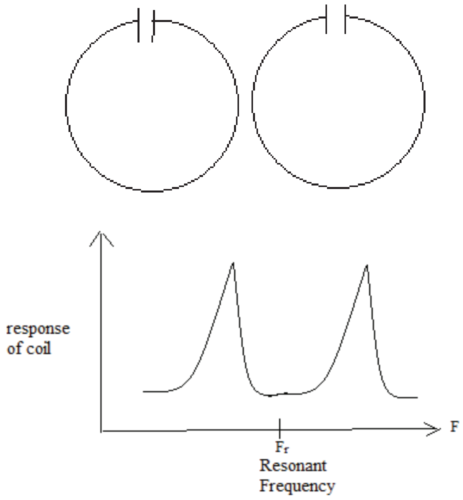

Fig.4.Two coils which are operated at same resonant frequency are placed near to each other, splitting the response at F_r.

To avoid mutual inductance of overlapped coils, distance between the diameters of coil will be in specific manner. Fig 5 shows overlapped coils with specific distance between diameters of overlapped coils[8]. For circular coil, centre of circular coils are separated by 0.75 times their diameter. Similarly, for square coil, centre of square coils are separated by 0.9 times their diameter [5][7].

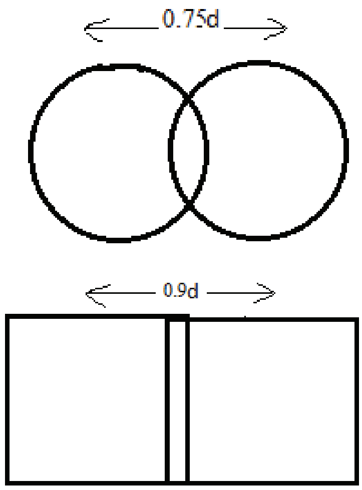

Fig 5.Overlapped Circular and Square coil to set their mutual inductance to zero to avoid the splitting of response at F_r.

III. Designing Of Circular Coil

A. Define the diameter of coil:

Diameter of coil depends on human body part for which coil is going to be designed[3]. Diameter of single circular coil is 94.4mm. As wire width is 1.21mm, inner diameter of coil becomes 92.99mm.

B. Inductance of Coil:

For capacitance of RF coil, inductance of coil is to be determined[9]. To determine the inductance value for circular coil following equation is used,

$$L_{circle} = N^2 \mu_0 a\left[\ln\left(\frac{8a}{R}\right) - 1.75\right] \quad (2)$$

Where, N = number of coil turns

μ_0 = relative permeability of material

a = Loop radius of circle

R= radius of wire coil

L_{circle} = Inductance of circular coil

Then, value of L_{circle}= 0.277 μ H

C. Capacitance of Coil:

Capacitance value can be found from following equation,

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

Or

$$F_r = \frac{1}{2\pi\sqrt{LC}} \quad (3)$$

Where, F_r = Resonance Frequency

C = capacitance of coil

Then, value of C=22.416pF

IV. Circular Coil Model

A. Single Coil

The single loop circular surface coil is simulated in CST 2016 and the geometry of coil is shown in fig.6. While designing coil, capacitor value can be optimized to achieve desired response[7-8].

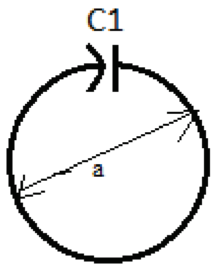

Fig 6.Geometry of circular coil with capacitor value

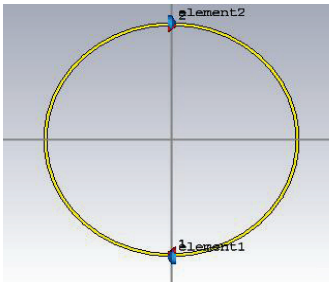

Fig 7. Simulated single loop circular coil.

B. Overlapped Coils:

Two circular coils are overlapped on each other to operate both at same resonant frequency[8-9].

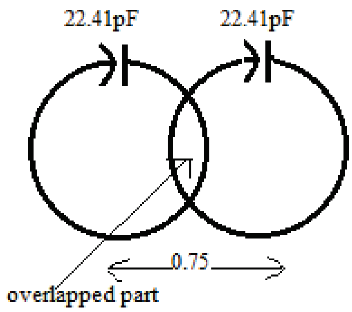

Fig 8. Two overlapped circular coils

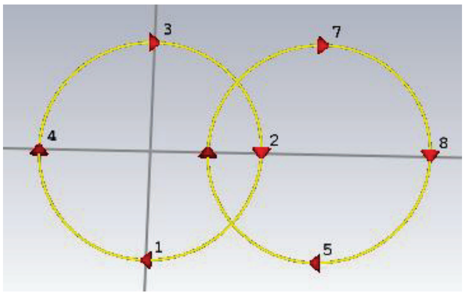

Fig 9. Simulated two overlapped circular coil.

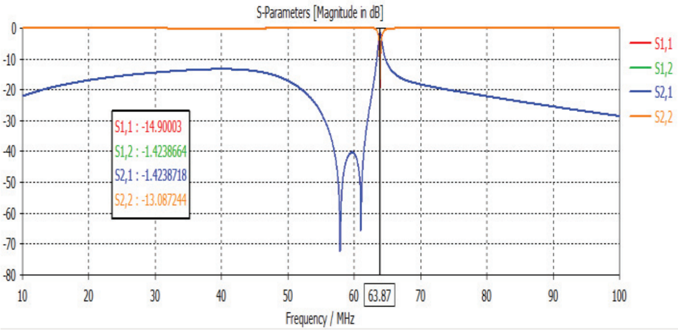

Fig 10. Results of two overlapped circular coil

V. Designing Of Square Coil

A. *Define the Length of Coil:*

Length of coil depends on human body part for which coil is going to be designed[3]. Length of single square coil is 94.2mm. As wire width is 1.21mm.

B. *Inductance of Coil:*

For determining capacitance of RF coil, inductance of coil is to be determined[9]. To determine inductance value for square coil following equation is used,

$$L_{square} = \frac{2\mu_0 D}{\pi}\left[\sinh^{-1}\left(\frac{D}{W}\right) - 1\right] \tag{4}$$

Where, μ_0 = relative permeability of material

D = Length of square coil

W = Wire width

L_{square} = Inductance of square coil

Then value of $L_{square} = 0.357\,\mu$ H.

C. *Capacitance of Coil:*

Capacitance value can be found from following equation,

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

Or $$F_r = \frac{1}{2\pi\sqrt{LC}} \tag{5}$$

Where, F_r = Resonance Frequency

C = capacitance of coil

Then, capacitance C = 17.38pF.

VI. Square Coil Model

A. *Single coil*

The single square surface coil is simulated in CST 2016 and geometry of coil is shown in Fig.11. While designing coil, capacitor value can be optimized to achieve desired response.

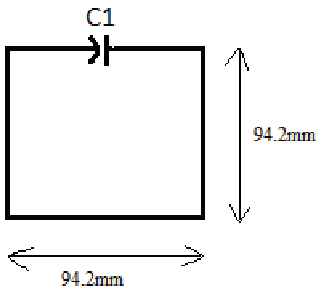

Fig 11. Geometry of square coil with capacitor value

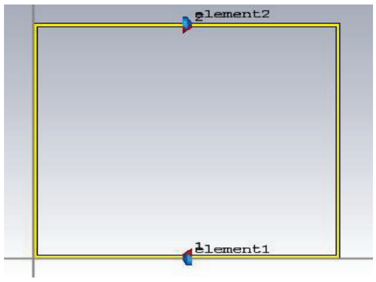

Fig 12. Simulated single loop square coil.

B. *Overlapped Coils:*

Two square coils are overlap to each other to operate both at same resonant frequency[8-9].

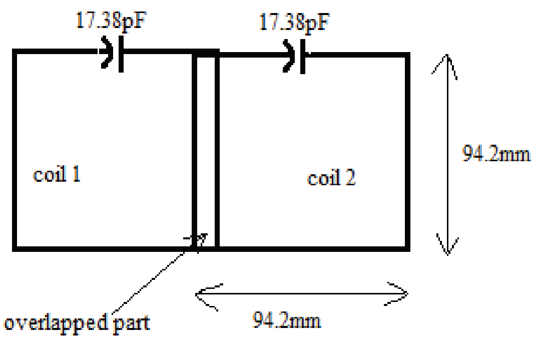

Fig 13.Geometry of two overlapped square coils

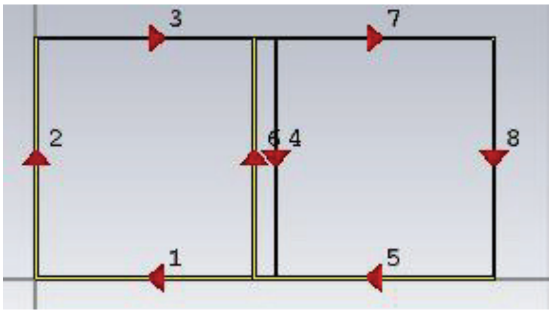

Fig 14.Simulated two overlapped square coil.

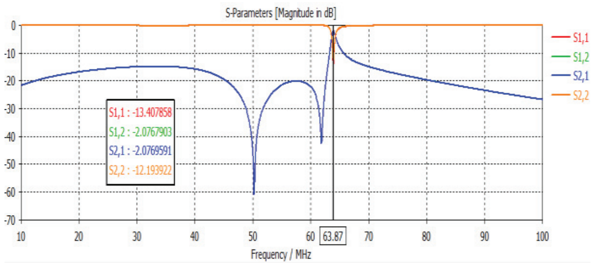

Fig 15. Results of two overlapped square coil.

VII. Discussion

When coils are overlapped, because of mutual inductance, response is splitted over the resonant frequency. To minimize mutual inductance between coils,geometric decoupling is used to minimize or almost nullify the mutual coupling between the coils. The simulated structures having different geometry are modelled and analyzed. The structure and the position of the overlapped coils can be optimized and signal intensity can be improved. The modelling of the different geometric structures have different mutual coupling but it is minimized by geometric decoupling which is shown here.

VIII. Conclusion

While desiging the MRI coil, RF surface coil is important to detect NMR signal of hydrogen protons while pulses of RF energy transmitted on human body from transmitter coil. In order to improve SNR, multiple coils are overlapped to each other. When coils are overlapped ,there is mutual coupling between coils, causing splitting of response at desiered resonant frequency that is loss in sensitivity of both the coils. To avoid this splitting, two coils are placed over each other (overlapping of coils) in such a manner that both will operate at desired frequency. Geometric decoupling is used to minimize or almost nullify the mutual coupling between the coils. The return loss obtained for two overlapped circular and square coil is -14.90dB and -13.40dB.

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