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EFFECTIVE ARRANGEMENT OF OPTIMUM NUMBER OF TEM COILS FOR THE IMPROVEMENT OF B1 FIELD HOMOGENEITY AROUND THE HEAD OF HUMAN PHANTOM AT 7 TESLA

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***Abstract**-The radio frequency (RF) coil, often ignored, is an important part of Magnetic Resonance Imaging. It is able to perform most important function in high-field for Magnetic Resonance Imaging (MRI) to obtain higher sensitivity for human brain imaging and hence generating clear images. In this paper, the performance of different coil is compared based on number of channel and the generation of homogeneous B1 field in the head. The number of channel (4, 6, 8, 10 and 12) of Tx/Rx coil will be varied in order to compare SNR, signal intensity (SI) and B1 field homogeneity utilizing B1 mapping sequence. The simulation will be performed on human head phantom by using REMCOM XFDTD. This paper compares different number of channels and finally proposes a reliable TEM coil of optimum number for imaging brain at ultra-high field.*

Keywords: TEM coils, MRI, B1 Field Homogeneity, Ultra-high field, Imaging Brain.

1. INTRODUCTION

Magnetic Resonance Imaging has become famous and one of the most significant technique available for diagnosis of medical conditions and treatment. It is a non-invasive process and is safe from harmful radiations in comparison with other imaging techniques (X-rays, Positron Emission Tomography and Computed Tomography). Other processes utilizes harmful ionizing radiations to generate an image. However, the ability to diagnose is limited by signal to noise ratio and the resolution of the current medical systems [1, 2]. It has another advantage of generating images in sagittal and coronal plane in addition to axial plane without having to move a patient. It is also able to provide information about important metabolic activities as well as significant organ function in addition to anatomical information.

Ultra-high field imaging (>7T) is now being researched vigorously for its application in clinics as it provides an advantage of increased signal-to-noise ratio and hence better spectral resolution and finally helps in generating better quality of images [3, 4].To remove the challenges prevalent due to the use of high field scanners, dedicated RF coils are used. For example: micro strip transmission line (volume coils) [5] and transverse electromagnetic Coils [6]. TEM coils have a capability to be more efficient at high field. Both TEM and micro strip transmission line have been used previously at high field ($\geq$3T) [7-9]. Phased array coils [10] and birdcage coils [11] are other commonly used RF coils for imaging. Currently, the intensity of magnetic field that is being used commonly in hospitals are 1.5T and 3T respectively. But, it is highly likely that ultra-high field imaging technique will be quite common in the medical field because of its high spectral and spatial resolution. These days, two methods are commonly used to generate good SNR. The first method is to increase a static magnetic field (B0) as the number of nuclear spins (hydrogen) increases with the increase in the static magnetic field. The second method is to increase the magnetic fields (B1+) generated by radio frequency coils [12]. It is relatively easier to obtain better SNR by second method as it is easier to design an effective radio frequency coil for enhancing radio frequency magnetic field at a desired location. The second method also has an advantage of low cost in comparison with the first method. There are many types of coil used in clinic in modern day: Transmit only coil, Receive only coil and transmit-receive coil. Each configuration has its own advantage as well as disadvantage. This paper deals with the design of transmit-receive coil to increase the RF magnetic field at the desired location in order to generate high SNR and hence high quality image.

TEM coil has an advantage of improving transmit B1 field homogeneity in comparison to conventional volume coils. Homogeneity is another important factor to be considered while designing a RF coil. The magnetic field does not change uniformly with increasing depth from the coil. With ultra-high field, homogeneity becomes challenging. While designing RF coils to operate at high field (7T and above), it is required for the designer to fight against the increasing inhomogeneous magnetic field caused by different types of tissues of human body, the decreasing electromagnetic wavelength and increasing specific absorption rate (SAR) with increasing fields. The value of SAR depends upon the type of tissues through which the RF magnetic fields have to pass. The designer needs to consider all these factors while designing an appropriate RF coil.

In this study, 4, 6, 8, 10 and 12 channel TEM coil is constructed, designed and compared around human phantom at ultra-high field (7T). B1 field homogeneity, SAR, reflection coefficient and dissipated power were evaluated. Numerical simulations which was based on FDTD (Finite-difference time domain) algorithm was utilized with the help of REMCOM software.

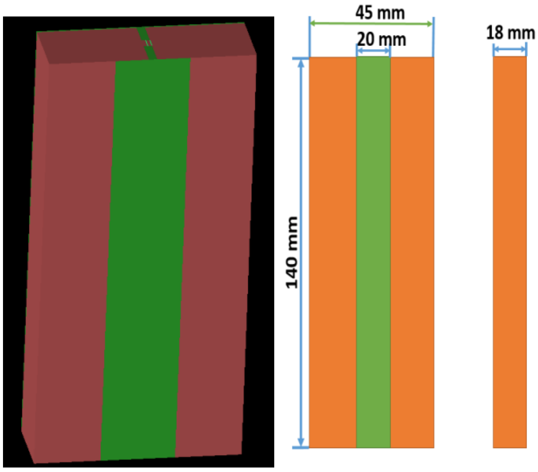

Fig. 1a Fig. 1b

Fig.1: A single TEM Coil

2. MATERIALS AND METHODS

In this research, a model of RF coil was constructed in REMCOM XFDTD (a commercially available software) as shown in figure 1. Figure 1a shows the 3D model of a single TEM coil along with the feed and capacitance position. On the other hand, figure 1b shows the detail dimension of a single TEM RF coil. The overall length of the TEM coil is 140 mm while the overall width of the coil is 45 mm as shown in figure 1b.The width of the copper strip is 20 mm and the length is again 140 mm. Each of the RF coil consists of two capacitors. The first capacitor which is placed adjacent to the feed is called matching capacitor while the other capacitor is called tuning capacitor. Two types of materials are used in this coil: Substrate and Copper. The substrate is brown in color in figure 1 while the copper is green in color. Teflon material is assigned to the substrate while PEC is assigned to the copper. The same materials are assigned to the remaining TEM RF coils as well. The Teflon has a permittivity of 2.08 and permeability of 1 while the electrical conductivity of this material is 0.000462 σ/m.

The coils used in this research is for both transmitting and receiving purpose which has an advantage of simplicity in structure. All the coils operate at ultra-high field (7T) for imaging the brain. The axial planar sensor is placed in the head at the region of interest where the measurement of B1 field along with other component takes place as shown in figure 2.

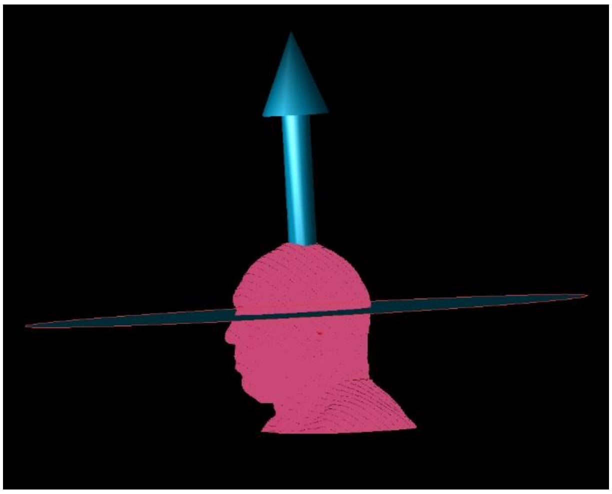

Fig.2: Axial Planar Sensor showing the position for measurement.

The coil is arranged in a circle with a diameter of 255 mm as shown in figure 3. Figure 3a shows the full view of an arrangement of 12 channel coil. Other coils are also placed similarly in a circular arrangement around the head of human phantom. Due to limited space, it is not possible to show all the arrangement in this paper. In this study, electromagnetic simulations were performed with the help of human phantom model with the help of FDTD (finite-difference time-domain) method by utilizing a commercially available software (REMCOM xFDTD, RemcomInc, State College, PA, USA). The different number of coils were arranged in varying number of channel around the human head in order to produce homogeneous uniform RF magnetic field in the human phantom. The three-dimensional human head model was divided into 25 different types of tissues by assigning appropriate dielectric and conductive properties to each of the tissue. All the coils were tuned to 298.2 MHz (7T) by varying the tuning and matching capacitors. The tuning and matching takes some time and the time for each simulation depends upon the power of the computer's GPU. The simulation was performed on a computer having a core of i7 and 32 GB of RAM. Each simulation took about 14 hours to complete. So, computational burden is one of the major factor that influenced for taking long time in order to complete this research.

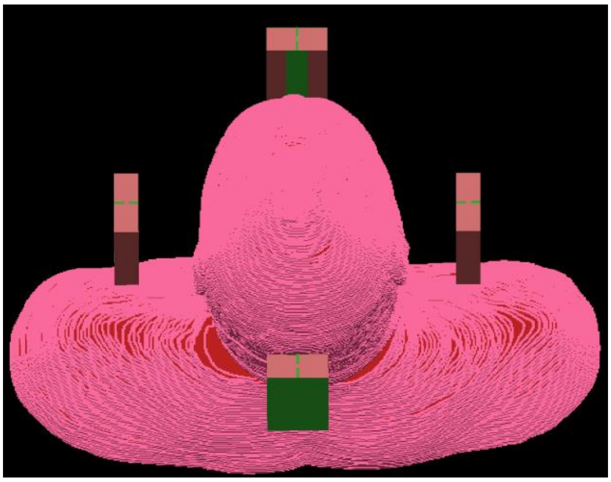

Fig.3a: Four channel TEM Coil

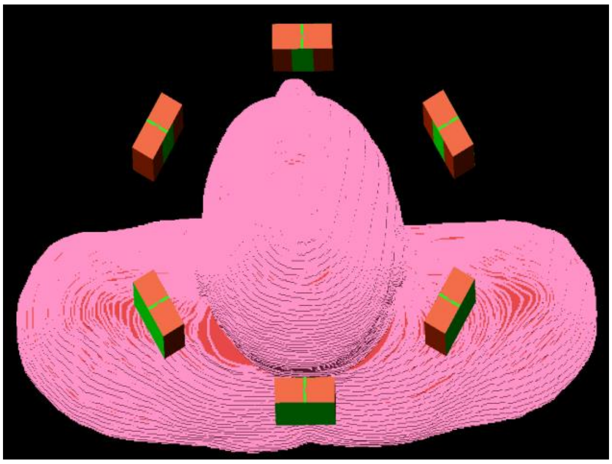

Fig.3b: Six channel TEM Coil

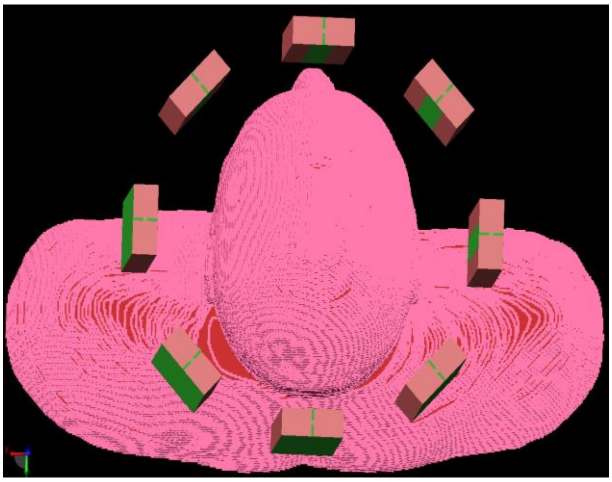

Fig.3c: Eight channel TEM Coil

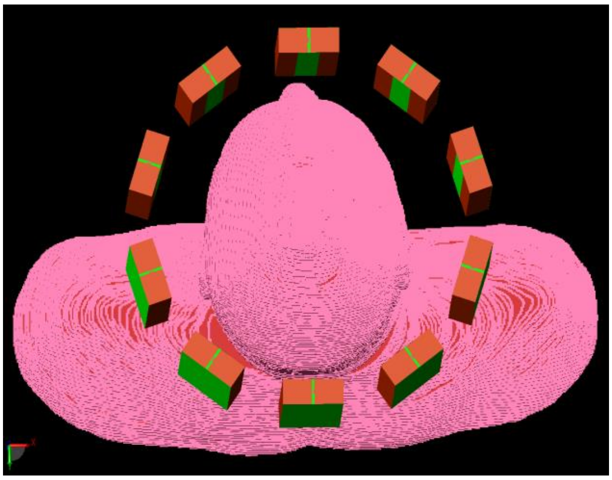

Fig.3d: Ten Channel TEM Coil

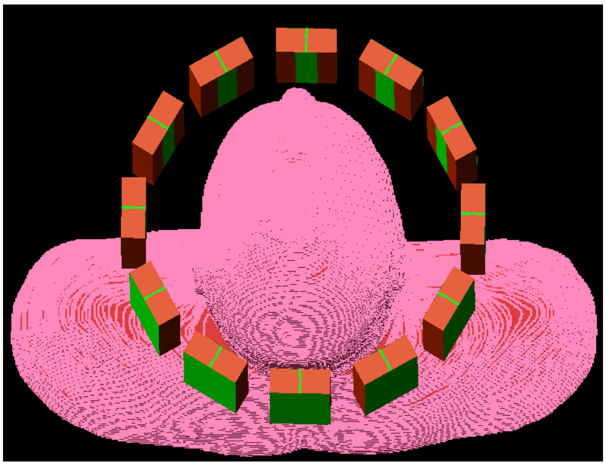

Fig.3e: Twelve channel TEM Coil

Figure 3a, 3b, 3c, 3d and 3e shows the arrangement of four channel, six channel, eight channel,ten channel and twelve channel TEM coil around human phantom. The human mesh size for all the simulations is 1 mm in order to get accurate measurement. The signal to noise ratio was calculated by using Hoult's principle of reciprocity with the help of Remcom xFDTD. Remcom makes it easier to calculate signal to noise ratio as it makes the visualization of B1 field effectively easy. Hoult's principlple was used to measure the strength of a signal in Nuclear Magnetic Resonance (NMR). The reciprocity theorem states that if a direct current is applied to a receiving coil and the B1 field generated were to be measured, the signal induced in the coil would be directly proportional to the strength of the hypothetical field.The SNR is finally given by:

$$SNR = \frac{Signal}{Noise}$$

Or, $SNR = \frac{-\frac{d}{dt}\int \frac{B_1}{I} . MdV}{\sqrt{4kTR\Delta f}}$ (1)

Where, M is magnetization per unit volume, B1/I is the magnetic field produced at volume dV by a surface coil carrying unit current, k is Boltzmann constant, T is absolute temperature, R is resistance. The integral is considered over a small volume. So, B1 is assumed constant, M, k, T and Δfis constant. Thus, equation 1 can can be written as:

$$SNR = \frac{B_1/_I}{\sqrt{R}} = \frac{B_1}{\sqrt{P_{dis}}} \qquad (2)$$

Where, P_{dis} is dissipated power.

As dissipated power is constant, equation 2 finally shows that SNR is directly proportional to B1 field. REMCOM xFDTD made it easier to calculate S11, dissipated power, B1 magnetic field and SAR which led us to calculate SNR. All of the simulations were performed on a computer having specifications: Intel(R) Core (TM) i7 workstation with 3.40 GHz Central Processing Units and 32 GB of Random Access Memory (RAM). The simulations were finally accelerated with the help of graphics NVIDIA Tesla C2075 GPU of 4GB.

3. RESULTS

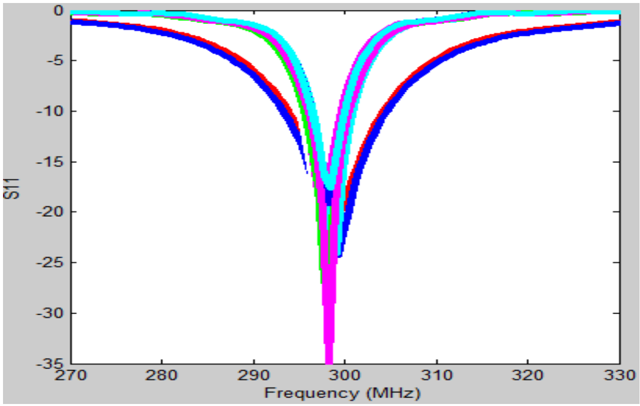

Fig.4: S11 of TEM Coils

Figure 4 shows S11 (also known as, reflection coefficient) of 8 channel TEM coil in order to demonstrate that the reflection coefficient is optimum for all the coils. In the figure, it can be seen that the reflection coefficient varies between -17dB to -35dB. It also determines how much power is delivered to the load. The above mentioned figure shows that value of S11 for all the coils is below -15 dB which is optimum for RF coils in order to transmit RF magnetic field. As shows in figure, all the coils are tuned to the same resonant frequency i.e. 298.2 MHz (7T).

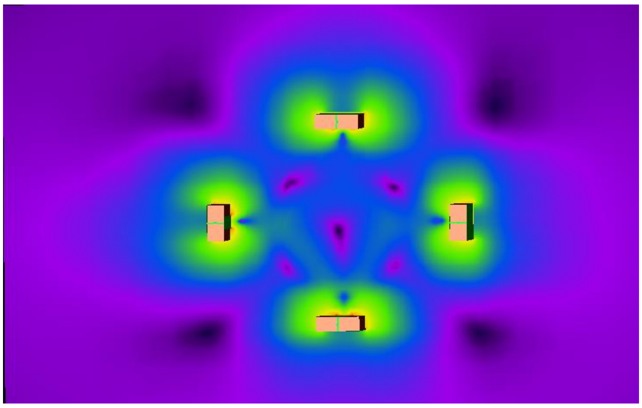

Fig.5a: B1 field of Four Channel TEM coil

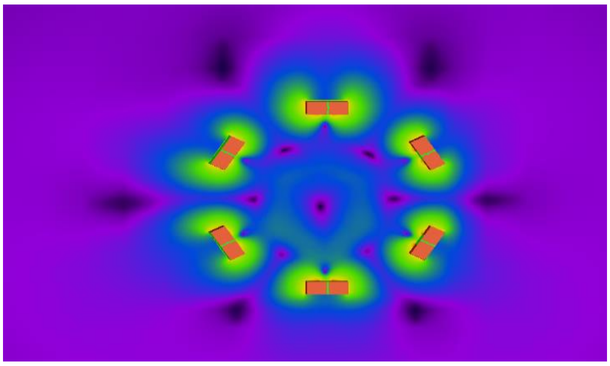

Fig.5b: B1 field of six channel TEM coils

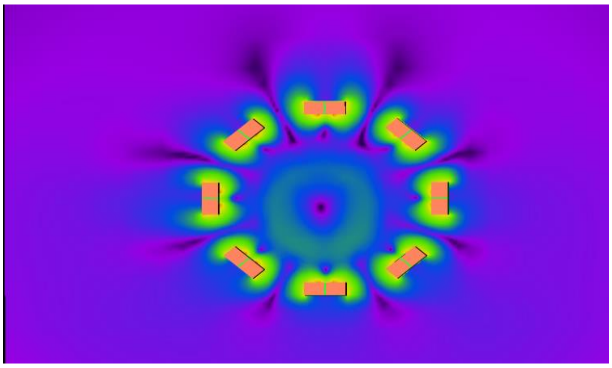

Fig.5c: B1 field of eight channel TEM coils

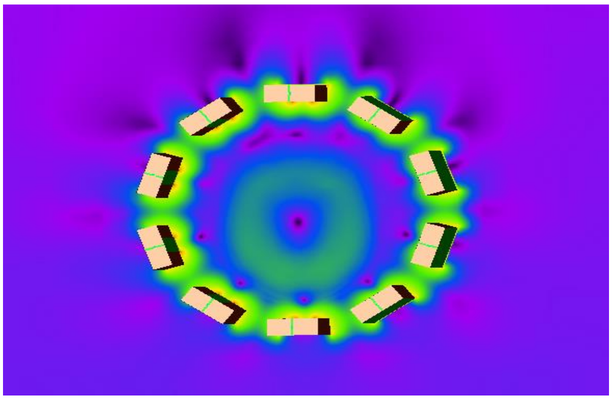

Fig.5d: B1 field of ten channel TEM coils

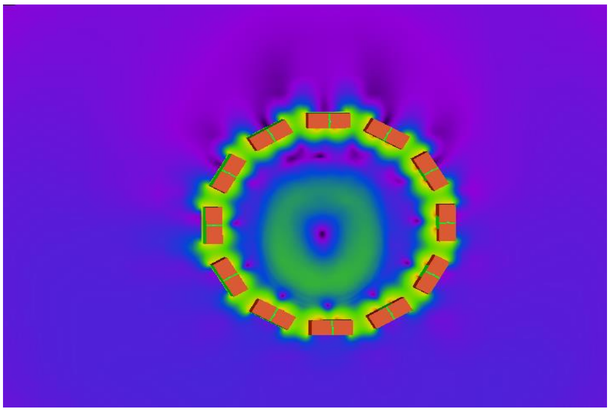

Fig.5e: B1 field of Twelve channel TEM coil

Figure 5 shows the TEM coil arrangement as well as the B1 field map around human head for different configuration of coils. The human head is not shown for better visibility of magnetic fields. Figure 5a, 5b, 5c, 5d and 5e shows the penetration of magnetic field inside human head phantom for four channel, six channel, eight channel, ten channel and twelve channel arrangement of RF TEM coils respectively.

Figure 5a shows the arrangement of four channel TEM coil and weak magnetic field penetration than all other arrangement inside the human phantom. The penetration of magnetic field increases as the number of channels is increased as shown in figure 5. Also, it is notable that the strength of magnetic field is higher near the coil and it goes on decreasing as it moves away from the coil. But, it can be seen that, eight, ten and twelve channel coil has relatively homogeneous magnetic field distribution throughout human head and hence higher SNR. Though, in order to select a specific number of channels is a challenging task and it would depend on the requirement of imaging as well as the condition where it is going to be used. Before implementing, it is to be understood that with higher magnetic field, specific absorption rate (SAR) is increased. In this research, for all coil arrangements, SAR was under the limit. The maximum value of SAR that was found for 10g was 0.0346W/kg and for 1g was found out to be 0.05349 which is under the safety limit of SAR which further determines the feasibility of the coil arrangements.

4. DISCUSSION AND CONCLUSION

In this research, a four, six, eight, ten and twelve channel TEM coil was designed and simulated under different configuration and SNR was evaluated. The SNR is based on magnetic field. The magnetic field from RF coil is higher near the TEM coil and decreases as it goes away from the TEM coils. This research showed that the TEM coils with twelve channel had higher sensitivity in comparison to other coil configurations. The effective arrangement of different number of coils allowed us to improve the sensitivity of the coils. The transceiver approach has an advantage of simplicity in design in comparison with other coil arrangements. This research shows that as the number of channels is increased, the homogeneity of magnetic field is increased and hence, the SNR is increased. The S11 was found out to be less than -15 dB for all coils and SAR of the coils followed the safety conditions. Hence, it is concluded that twelve channel TEM coil arrangement provided better homogeneity of magnetic field but with higher SAR.

7. REFERENCES

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