Investigation of fractal-shaped alternating impedance microstrip coil for 7 Tesla MRI

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Introduction

It is well known that increasing the static magnetic field (B0) strength will significantly improve the signal-to-noise ratio (SNR). However, the wavelength in high dielectric and lossy tissue at ultra high field (7T+) magnetic resonance imaging (MRI) systems is much smaller than human anatomic dimensions [1]. As a result, the radio frequency (RF) excite field (B1+) is highly non-uniform. Nowadays, multi-channel transceiver coil array comprised of transmission line elements is popularly used for NMR signal transmission and reception. The conventional microstrip line produces an inhomogeneous B1+ field along the coil axis, it peaks at the center of the coil and drops substantially at the terminating ends. Recently, novel alternating impedance microstrip transceiver coils are proposed [2]-[3]. By varying impedances along the axis, the current density along the length of the transmission line can be homogenized with multi-section alternating impedance microstrip design, which leads to a uniform B1+ field. In this study, a Koch fractal-shaped alternating impedance microstrip coil for 7T MRI is assessed.

Methodology

Koch fractal-shaped microstrip is widely applied on miniaturized, multi-band antennas design [4]-[5]. Fig.1 shows the configuration of a Koch island, which consists of a Koch curve. HFSS electromagnetic simulations are performed for four types of microstrip coils (one conventional, two alternating impedance and one fractal- shaped) for MRI at 7T. Each element substrate is FR-4 (ε_r=4.4) with height of 3mm. A conventional microstrip line coil of 60mm in width and 246.2mm in length is modeled and simulated for comparison. All the microstrip coils are side fed with a microstrip line, the width of which is calculated by the LineCalc in Advanced Design System (ADS). The conductor widths are alternated at 60mm and 40mm for the first pattern of 7-section (4 thick and 3 thin sections) alternating impedance microstrip coil, whose lengths are alternated at 35mm and 30mm. For the second pattern of 7-section alternating impedance microstrip coil, the alternating parameters is 30mm and 5mm in width and 30mm and 19.8mm in length. Both feed lines is calculated to be 5.73mm in width. The Koch fractal-shaped alternating impedance microstrip coil is constituted by replacing the low impedance sections (thick sections) with first order Koch fractal shapes shown in Fig.1b. The Koch fractal shapes are firstly plotted with MATLAB, and then drawn in HFSS using VBScript file which is created by HFSS-MATLAB-SCRIPTING-API. The zero order Koch island is 60mm in width and 44mm in length, while the width and length of high impedance sections (thin sections) are 10mm and 92mm, respectively.

Results and Discussion

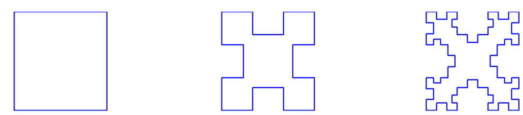
Fig.2. shows the magnetic field along the z-direction of the first pattern and the second pattern of alternating impedance microstrip coil and the Koch fractal-shaped microstrip coil. It is seen that the first pattern of alternating impedance microstrip coil has much more homogeneous magnetic field than the second pattern, but with low magnetic field quantity. By replacing the low impedance sections with fractal shapes, the magnetic field peak is further broadened as shown in Fig.2c, and a more uniform magnetic field distribution is given. The magnetic field and conduction current distributions at the surface of strip conductor for the four resonators are shown in Fig.3. While the left column depicts the magnetic field distributions, the right column shows the conduction current distributions. It is clear that the magnetic field of conventional microstrip coil peaks at the center of coil and drops at the terminating ends. Additionally, the high impedance sections showed greater current than low impedance sections. For all the alternating impedance microstrip line coils, the magnetic field peaks at high impedance sections while decreases in the low impedance sections. Further quantity analysis can be seen in Table 1.

TABLE 1

Maximum values of magnetic field, electric field, the ratio of E/B and the mean value of the magnetic field on the surface of microstrip coils

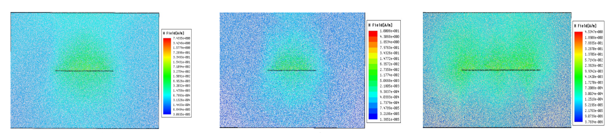
	Max B(A/m)	Max E(A/m)	Max E/B	Mean B(A/m)
7-section first pattern	7.43	164.4	5734	1.544
7-section second pattern	10.0	39.88	838.6	1.509
Koch fractal-shaped	6	45.12	1481	1.138

The maximum magnetic field is improved from 7.43 of first pattern to 10.0 of second pattern alternating impedance microstrip coil by narrowing the width of high impedance sections. These results showed that the magnetic field for the second pattern alternating impedance coil is improved by 34.5% at the surface of the microstrip coil with a reduction in the E/B ratio by 85.3%, which means a less RF-power disposition. Although with 19.2% reduction in magnetic field, the first order Koch fractal shape alternating impedance microstrip coil shows reduction of 72.5% for electric field and 74.1% for E/B ratio. The gradual change of Koch fractal shape alternating impedance coil's width in low impedance sections gives rise to less discontinuous of electric field. Further adjusting the geometry of low impedance sections and lengths of high impedance sections will lead to a more uniform magnetic field distribution with lower electric field.



(a) (b) (c)

Fig 1 Koch island shape whose iteration factor is 1/4: (a) zero order iteration, (b) first order, (c) second order.



(a) (b) (c)

Fig 2 HFSS simulated magnetic field distributions along the z-direction (i.e., in the sagittal plane) of alternating impedance microstrip coils: (a) first pattern, (b) second pattern, (c) Koch fractal-shaped.

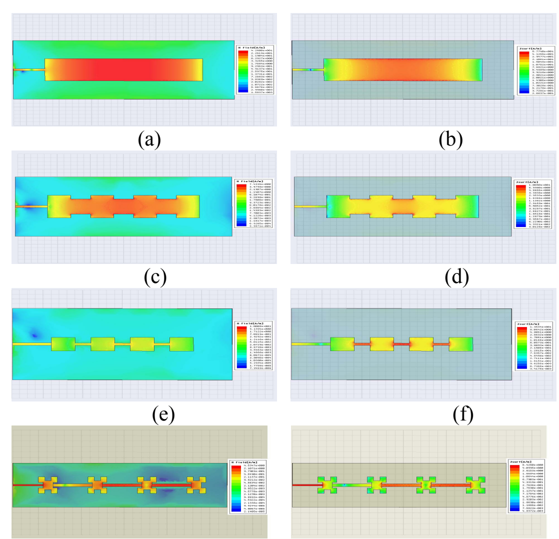


Fig 3 HFSS simulations for magnetic field and conduction currents on the surface of microstrip coils: (a)-(b) conventional microstrip coil, (c)-(d) first pattern of alternating impedance microstrip coil, (e)-(f) second pattern of alternating impedance microstrip coil, (g)-(h) Koch fractal-shaped alternating impedance microstrip coil.

Reference

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