CHAPTER 6

STUDY OF COMPACT HILBERT CURVE FRACTAL ANTENNAS FOR IMPLANTABLE MEDICAL APPLICATIONS

Summary- This Chapter proposes two miniaturized compact fractal shaped implantable antennas. The objective is to design two miniaturized HCFAs for communication with implantable medical devices in the ISM band and test its performance using Ansoft HFSS 3D electromagnetic simulation software. The simulation has been carried out in air as well as human muscle tissue environments in order to analyze the behavior of antennas for air-to-air communication and when embedded inside the body environment respectively. The antennas need to be small enough so that it can rest on the metal plane of the battery supplying energy, while embedding inside the body. Copper is used to construct the first antenna called HCFA 1 which occupies a small area on a dielectric slab of 20mm x 20mm and the second antenna called HCFA 2 which measures 18mm x 16.5mm size. Two layers of FR4 dielectric material of 0.5mm thickness are used as substrate and superstrate. In the air environment the HCFA 1 resonates at 1.1 GHz, 2.11 GHz, 3.05 GHz and 5.396 GHz. In the human tissue mimicking environment it provides dual resonances at 4.83 GHz and 5.73 GHz with comparatively broader bandwidths. Investigation of CPW fed HCFA 2 has also been performed in both the environments and found resonating at 10.18 GHz in a wide band of 3.4 GHz in air environment and at 2.99 GHz, 5.5 GHz and 7.1 GHz frequencies in a broadband of 3.04 GHz in

human muscle tissue environment. Both performances are appreciable with good bandwidth, low return loss and VSWR values indicating well-matched conditions. The analysis reports recommend that the antennas are suitable for wireless as well as IMD applications.

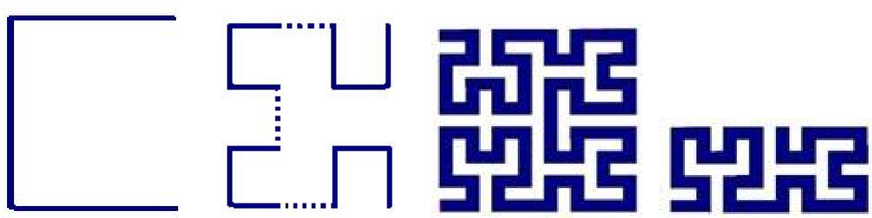
6.1 INTRODUCTION

Though there are many antennas designed and investigated for the air-to-air wireless applications, designing antennas for body embedded applications is extremely challenging because of the reduced antenna efficiency, impact of the body environment and high losses etc. Small sized embedded medical devices for health monitoring purposes need miniaturized antennas to work in lossy body environments (Kamya Yekeh Yazdandoost and Ryuji Kohno 2007). Many investigators Azad and Ali (2006), Xueyi Yu et al (2008), Kamya Yekeh Yazdandoost (2009) have reported the performances of various fractal shaped implantable antennas whereas Vinoy et al (2001), Tsachtsiris (2003) and Niruth Prombutr and Prayoot Akkaraaektharin (2007, 2008) provided report on the performance of Hilbert curve fractal antennas.

In such antenna designs the feed mechanism plays a vital role. For the ground plane laid at the bottom of substrate either the coaxial feed system or the microstrip feed method is preferred. The microstrip feeding the antenna should also be a fraction of the wavelength, say approximately $\lambda/10$ size for better performance. The CPW has been widely used recently as feeding system. Varieties of CPW fed miniature antenna designs have been reported (Shanmuganatham and Raghavan 2009, Xiaoning Qiu et al 2006, Dau-Chyrh Chang et al 2008) indicating many advantages such as negligible radiation leakage, less dispersion, little dependence on the characteristic impedance on substrate height and uni-plane structure. This Chapter provides a report on the improved performance of miniature Hilbert curve fractal antennas using microstrip and CPW feed systems suitable for implantable applications.

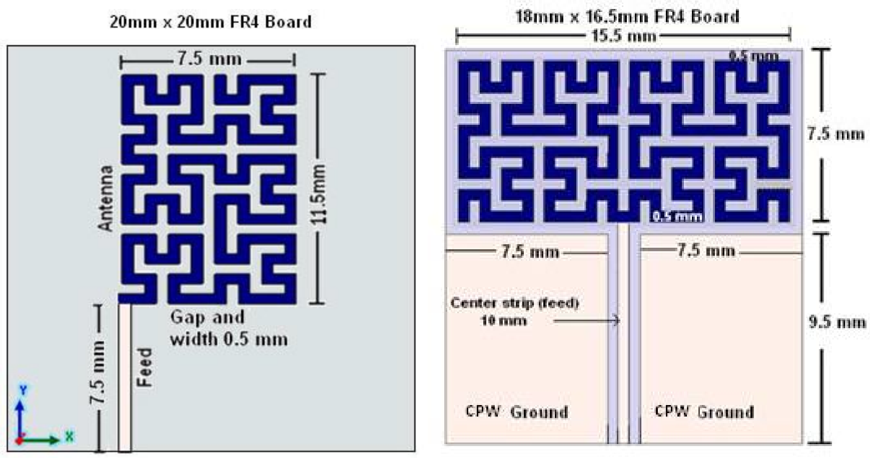
6.2 METHODOLOGY AND ANTENNA DESIGN

The presence of multiple square curves in the Hilbert antenna is the main reason to make the antenna resonate at multiple frequencies. It can be noticed that the length of the antenna is increased without having to increase its overall dimensions because of the fractal geometry. Compared to other fractal shapes, the Hilbert curve (Niruth Prombutr and Prayoot Akkaraaektharin 2008) can pack longer curves in a given area. The Hilbert curve dimensions for the work described in this Chapter have been obtained using the method outlined in Chapter 3 under the Section 3.3.2 for the third iteration. The steps involved in getting the third iteration of Hilbert curve are depicted in Figure 6.1. However, the truncated third iterated structure appearing in Figure 6.1(d) is combined with the third iteration unit as shown in Figure 6.1(c). This results in a new antenna structure as depicted in Figure 6.2(a). This is hereinafter called Hilbert Curve Fractal Antenna 1 (HCFA 1) in this Chapter.



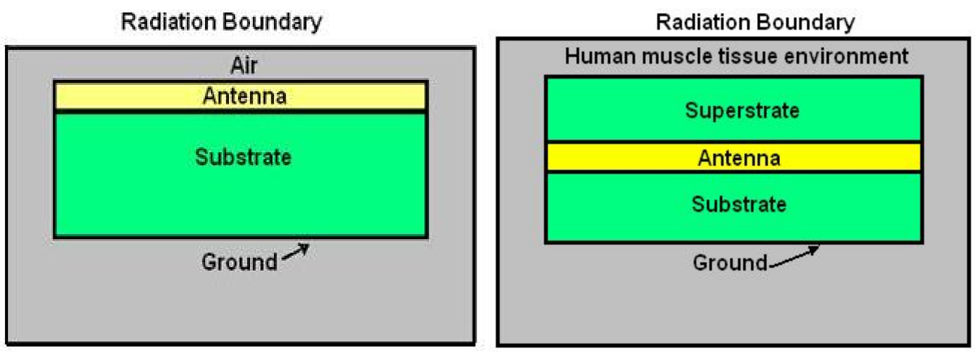
(a) (b) (c) (d)

Figure 6.1 HCFA Antenna Structures (a) Basic Structure (b) Second Iteration (c) Third Iteration (d) Truncated Portion of Third Iteration



(a) (b)

Figure 6.2 Proposed Antenna Structure (a) HCFA 1 (b) HCFA 2



(a) (b)

Figure 6.3 The Different Material Layers of HCFA 1 (a) Different Layers in Air Environment (b) Different Layers in Human Muscle Tissue Environment

The HCFA 1 of size measuring an area of 11.5mm x 7.5mm is designed whose strip width and spacing are 0.5mm each. This is placed on a substrate of size measuring 20mm x 20mm. A microstrip feeding is arranged to feed the HCFA 1. The strip feeding the HCFA 1 measures a size of 0.5mm x 7.5mm. The structure of HCFA 2 is shown in Figure 6.2(b). Two of third iterated structures are attached together using a small microstrip feed of size 0.5mm x 10mm in the CPW system.

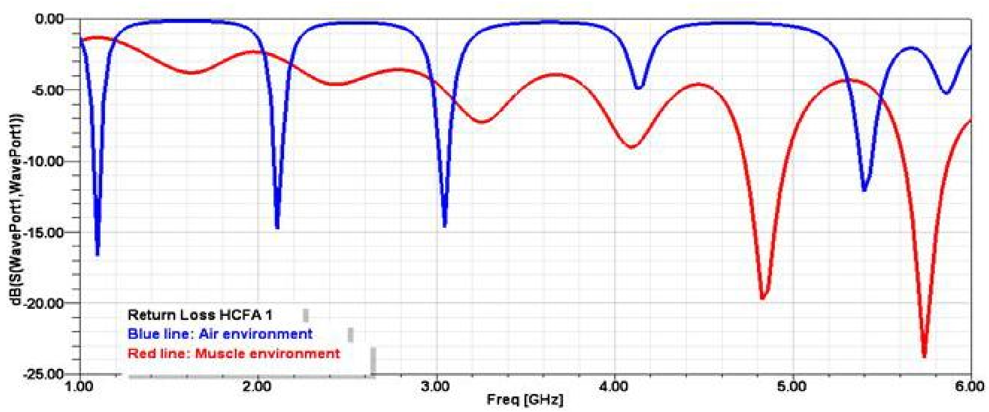
The HCFA 2 is designed to fit an area of 15.5mm x 7.5mm with a small microstrip connecting line whose width and spacing are 0.5mm each. The antenna is laid on an FR4 substrate of 18mm x 16.5mm and thickness of 1.6mm. However a superstrate layer is also required to protect antenna from being shorted while placing it in the muscle tissue environment. Because the human muscle tissue has ε_r of 42.807 and conductivity of 0.6463 S/m. Hence, two 20mm x 20mm sized FR4 board with ε_r=3.2 and thickness h=0.5mm were used as substrate and superstrate materials. The thickness is so chosen that the overall thickness of the entire structure in air and muscle environment remains the same. The different layers of materials used in air environment and in human muscle tissue environment are shown in Figure 6.3(a) and (b).

6.3 SIMULATION

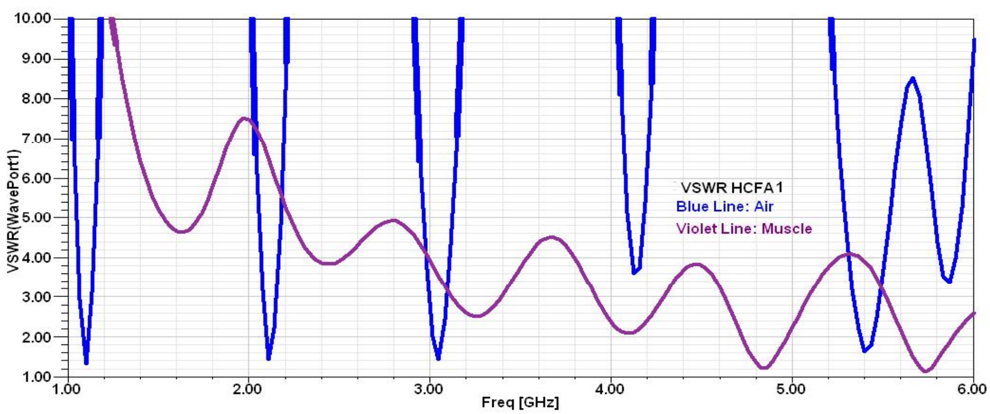
Both HCFA 1 and HCFA 2 have been designed using HFSS electromagnetic 3D simulation software. The sweep frequency ranges of 1-6 GHz and 1-12 GHz have been set in the simulation for investigating HCFA 1 and HCFA 2 respectively. The antennas have been arranged as seen in Figure 6.3 for the simulation. Firstly the whole structure consisting of HCFA 1 and substrate has been placed in air environment and simulated. Later it has been placed between the substrate and superstrate layers. Then, the air has been replaced by human muscle tissue property. A 40mm x 40mm x 15mm block is considered as human tissue mimicking lossy environment in this simulation. Secondly the simulation for the HCFA 2 has been performed following the same procedure.

6.4 RESULTS AND DISCUSSIONS

The investigations involved the study of resonance, return loss levels at resonant frequencies, active frequency bands, VSWR and the radiation patterns. The simulation results of HCFA 1 in the air and muscle tissue environments are shown in Figure 6.4. In air medium, the HCFA 1 resonates at four resonant frequencies 1.1 GHz, 2.11 GHz, 3.05 GHz and 5.396 GHz demonstrating the property of fractal with low return loss levels. The return loss values exhibited by the antenna at four resonances are satisfactorily low and can be seen to be -16.66 dB, -14.76 dB, -14.63 dB and -12.17 dB respectively. The corresponding VSWR values at all the resonant frequencies are 1.34, 1.44, 1.46 and 1.65 respectively and all are well below value 2 indicating the well matched conditions. The bandwidths corresponding to the respective resonant frequencies are 40 MHz (3.9%), 60 MHz (3%), 40 MHz (1.4%) and 100 MHz (1.9%) which are good enough for air-to-air wireless communications.



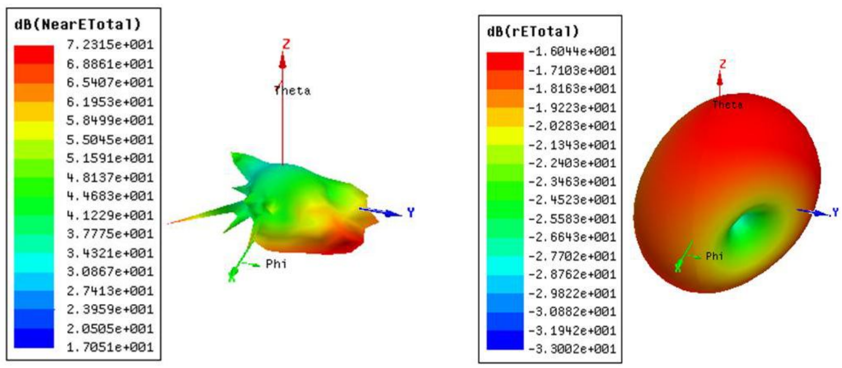
(a)



(b)

Figure 6.4 Simulation Results of HCFA 1 (Air and Muscle Environments) (a) Return Loss (b) VSWR

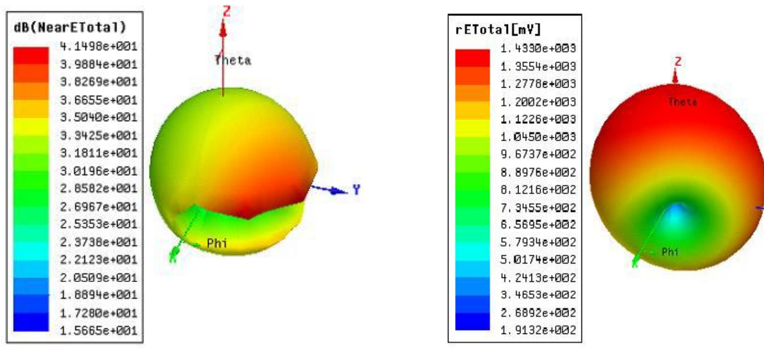
In the simulation results of HCFA 1 with human muscle tissue environment the resonance occurs at two shifted points. The antenna resonates at 4.83 GHz and 5.73 GHz providing return loss of -19.7 dB and -23.9 dB with bandwidths of 260 MHz (5.4%) and 280 MHz (4.9%) respectively. The VSWR values are 1.23 and 1.14 at the respective resonances indicating matched conditions.



(a) (b)

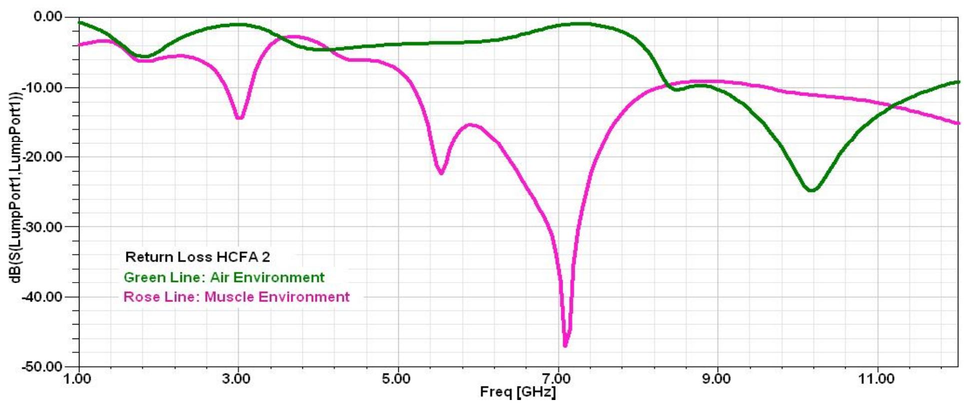
Figure 6.5 Radiation Patterns of HCFA 1 (Air Environment- Total E Field and 3D Polar Plot) (a) Near Field (At Distance of 10mm) (b) Far-Field

The radiation patterns of HCFA 1 in the air medium are shown in Figure 6.5. The total radiating E field in the near field measured at 10mm distance is 72 dB but it becomes reduced to -16 dB in the far-field case. From the 3D polar plot it is noticed that radiation is fair and directional. The far-field pattern is broader compared to the near field pattern since the near field is dominating near the antenna and the radiation is maximum towards X-Z direction, while the antenna is resting on the X-Y plane. The radiation properties of HCFA 1 in the muscle medium is depicted in Figure 6.6. The near and far-field magnitudes of HCFA 1 in the muscle medium is improved. This is because of the presence of the substrate and superstrate layers. The patterns are appearing good showing radiation maximum in the X-Z direction.

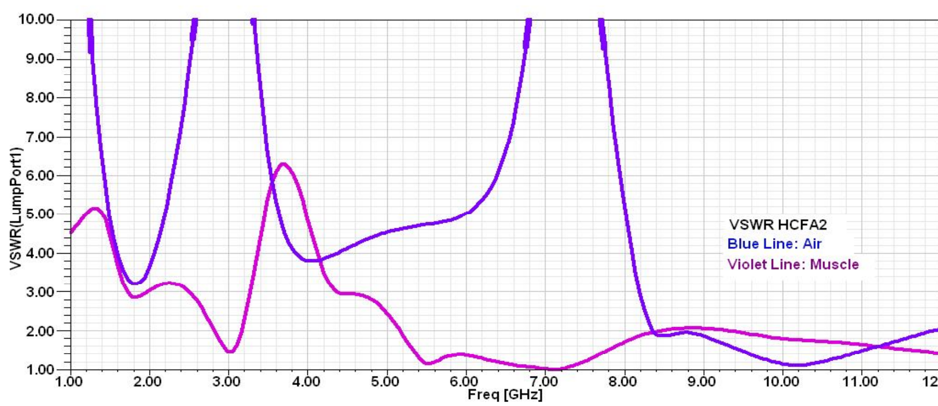


(a) (b)

Figure 6.6 Radiation Patterns of HCFA 1 (Muscle Tissue Environment-Total E Field and 3D Polar Plot) (a) Near Field (b) Far-Field



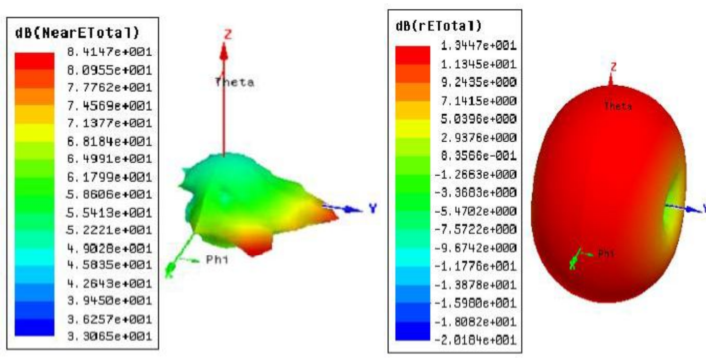
(a)



(b)

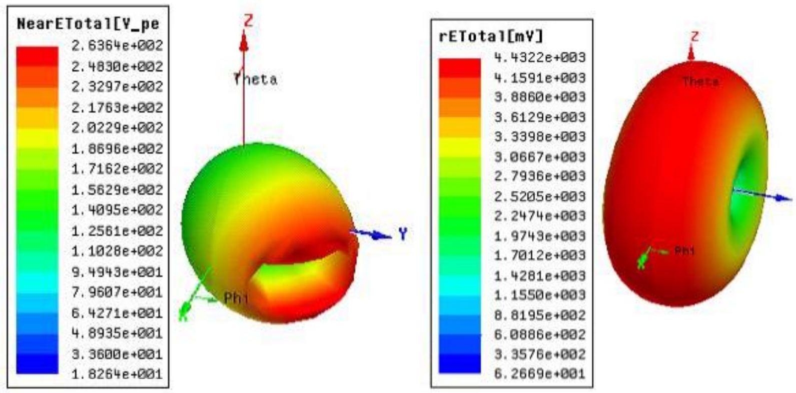
Figure 6.7 Simulation Results of HCFA 2 (Air and Muscle Environments (a) Return Loss (b) VSWR

The results of simulation of HCFA 2 are presented in the Figure 6.7 for air and muscle environments. From the simulation in air environment, it is found that the resonance occurs at 10.18 GHz with a low return loss of -24.86 dB. A broad bandwidth of 3.4 GHz (56 %) is achieved with a VSWR of 1.12 which is much lower than 2. The same antenna resonates at three down shifted frequencies when simulated in the human muscle tissue environment. The resonances occur at 2.99 GHz , 5.5 GHz and 7.1 GHz with much lower return loss of -14.44 dB, -22.4 dB and -47 dB respectively. The second and third resonances occur in a single broad bandwidth of 3.04 GHz (5.7 % and 26.8 %). The well-matched conditions are noticed with VSWR values of 1.1 and 1.16.



(a) (b)

Figure 6.8 Radiation Patterns of HCFA 2 (Air Environment – Total E Field and 3D Polar Plot) (a) Near Field (At Radius 10mm) (b) Far-Field



(a) (b)

Figure 6.9 Radiation Patterns of HCFA 2 (Muscle Tissue Environment-Total E Field and 3D Polar Plot) (a) Near Field (At Radius 10mm) (b) Far-Field

The E fields radiating from the HCFA 2 in the air medium are shown in Figure 6.8. The E fields are at 84 dB and 13.4 dB for the near and far-field radiations respectively. Their respective patterns are fair and good proving unifrom radiation in the Y-Z and X-Z directions. The radiation patterns of the HCFA 2 in the muscle environment are shown in Figure 6.9. The E fields radiated by the antenna in this medium is still greater leading improved broad radiation patterns.

6.5 CONCLUDING REMARKS

The investigation on the performance of two Hilbert curve based fractal implantable microstrip antennas (HCFA 1 and HCFA 2) have been carried out using HFSS numerical simulation tool. The use of CPW feed system with two layers of substrates and superstrates resulting in broader bandwidth is remarkable. The antennas have been simulated in the air as well as human muscle tissue environments and found resonating in the recommended ISM band with nominally good antenna characteristics. Also the near and far filed characteristics are satisfactorily good.

The main difference between the design presented by Azad and Ali (2006) and this work is that the proposed HCFA 1 is slightly larger in size along with inclusion of additional truncated part of third iteration with itself and the structure of HCFA 2 is wholly different. Also, the need for coaxial feed at the bottom of the structure is avoided and a lumped port set up has been used at the end for feeding. No shorting pin is used in this proposed model. Selection of thin substrate serves this purpose also. Though theoretical analysis by Ahmad Sulaiman et al (2010) shows that increasing the substrate thickness can broaden the impedance bandwidth, the HCFA 2 in this Chapter uses very thin substrates with a view to reduce the overall size and weight. The HCFA 1 and 2 proposed in this Chapter provide all features that are expected in IMDs.