CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The majority of the miniaturized antenna designs need simulation of the paper designs with microwave CAD softwares before trying out for fabrication. This literature review covers the investigations of the previous researchers on the FA, MTM and IA. However, the elaborate discussions and the investigation reports of the previous researchers on the low profile antennas by Gupta and Abdelaziz Benalla (1988), Gupta et al (1996), David Pozar (1995), Rod Waterhouse (2003, 2007), Samuel Liao (2006), John Kraus et al (2010) and Kai Fong Lee and Kwai Man Luk (2011) including advantages, limitations, detailed design aspects and the related issues have been thoroughly overviewed as a starting point for this thesis.

The MSA design is an ever growing area because of the never ending demand. Many researchers took efforts in designing miniaturized antennas with varieties of approaches to overcome the limitations imposed by MSAs. Few of such approaches are FAs and MTM antennas. Hence a preliminary literature survey has been carried out on the topics of FAs and MTM. Later to inculcate the suitability of performance enhanced low profile antennas in implantable device applications, a literature survey on IA has been included. Finally with a view to gain the optimum design structure and performance and to experience the advantage, the MTM based MSAs and MTM based/ANN optimized LPF are also reviewed.

2.2 REVIEW ON THE FRACTAL ANTENNAS

Mandelbrot (1983), the French mathematician introduced the concept of fractals and established ideas for the basis of their applications in engineering including electromagnetic field radiations. He also explained the fractal geometry in nature and how that can be interpreted in real science and engineering fields. Starting from his contributions till date, there have been varieties of FAs designed and studied to aid the tremendous growth in telecommunication requirements and to meet the advancing demands.

Nathan Cohen (1997) reported loop shaped FAs with improved gain, optimized field strength and pointed out the trade-off possibilities and requirements in order to achieve low profile.

Douglas Werner et al (1999) provided the theoretical foundations needed for the design of various FA array shapes including linear, deterministic and self similar fractals, Sierpinski carpet and gascut, concentric circular ring, planar square, triangular and hexagonal types. They demonstrated the advantages such as multi-band behavior, low side lobes and efficient radiation for the increasing iteration orders.

Vinoy et al (2001) proposed a Hilbert curve FA of size measuring 105mm x105mm with lower resonant frequencies compared to other fractal configurations. They used copper strips for antenna which was pasted on a thin transparent substrate sheet and simulated using numerical electromagnetic coding (NEC). The method to convert it as a reconfigurable structure was also suggested.

Liu Ying et al (2002) developed a square MSA for tri-band resonance with good radiation and impedance matching characteristics for a Sierpinski carpet model using Teflon as substrate FEM based simulation.

Wang Hongjian and Gao Benqing (2002) presented FDTD based full wave analysis of Hilbert fractal curves as well as Sierpinski and Bowtie antennas. Experimentally verified performance is also discussed and reported that the resonant frequency points shifted to lower side for their increasing iteration orders.

Song et al (2003) described the poor input impedance matching difficulties at the feeding port in the Sierpinski gascut type fractal antennas and the methods of improving the multiband behavior and bandwidth of the same antennas in a modified feed approach with perturbed shapes. FR4 substrate and HFSS simulation tool were used.

Tsachtsiris et al (2003) developed a work on size reduction with multiple frequency resonance without any compromise over antenna bandwidth or efficiency in a fractal rectangular curve patch antenna using IE3D. Moreover, the geometry provides a freedom to control the bandwidth and the antenna size for any demand.

Douglas et al (2003) reported an overview of contributions of various researchers on FAs including Sierpinski gascut and carpet fractals, Koch snowflake meander and loop curves, Hilbert curves, different types of fractal trees, hexagonal patch fractals, genetically engineered fractal dipole antennas and their arrays. The report also provides an insight into the design aspects and the benefits of novel structures with cited applications.

Noor Asniza Murad and Mazlina Esa (2003) reported the experimental investigation on a FA array fed by a CPW system. They reported the achievement of high directivity of the array where the MSA being the starting point for building the array.

Noor Asniza Murad et al (2003) reported on higher order iteration of a fractal patch antenna design originated from the basic square patch for a specific GPS application. They used GML1000.06 substrate material of 53.8mm x 53.8mm x 1.534mm and simulated using Ensemble SV software.

Jinhui Zhu et al (2004) reported the radiation characteristics of thin wire peano fractal antenna. They also reported the improved performance of the antenna on various parameters and also pointed out the limitations on cross polarization when compared to Hilbert curve FA of the same order. Various peano curve outer sizes such as 70mm x 70mm and 30mm x 30mm were used in the simulation using NEC.

Tae-Hwan Kim et al (2005) worked on the basic square and landed at a CPW fed miniaturized self-affine multi-band fractal antenna and made a study on the fundamental resonant frequency using RT Duroid 5880 substrate and Computer Simulation Technology microwave studio (CST MWS) simulation tool.

Ananth Sundaram et al (2007) reported the results of folded-slot antennas using RT Duriod 6002 substrate for first and second iterations indicating that the down shift of resonant frequency, reduced return loss and decreased bandwidth for higher iterations.

Nicholas Kingsley et al (2007) reported the design aspects of a CPW fed triangular shaped Sierpinski reconfigurable antenna for RF MEMS applications. The antenna was integrated on a flexible organic polymer substrate for attaining the multiband resonance property which was simulated using IE3D.

Rajkumar et al (2007) provided a report on the design of double side fractal edged square patch antenna of 36.08mm x 29.6mm using FR4 substrate and FDTD numerical technique with a discussion on experimental results indicating the ability for controlling the cross-polarization levels.

Niruth Prombutr and Prayoot Akkaraaektharin (2007, 2008) reported the generation algorithm, simulation and experimental performances of the fourth stage of a CPW fed Hilbert curve FA of size measuring 88mm x 88mm on a FR4 substrate. This antenna was simulated using IE3D. The resonance occurred at four frequencies which are lesser compared to the lower iterations.

Mirzapour and Hassani (2008) introduced a new probe fed and slot loaded Koch snowflake MSA which is much miniaturized when compared to the original type of Koch. The simulation as carried out using HFSS on an air/foam substrate to improve impedance bandwidth.

Nicolaescu et al (2008) presented a report on the modified design of Sierpinski and Koch curves and also discussed the experimental results of the same. They used an evolutionary algorithm for optimization, method of moments based software for simulation and FR4 and Rogers substrates in two antennas. Compactness and multiband resonances are the highlights in this discussion.

Kimouche et al (2009) discussed the design of a fractal tree dipole antenna of size 69mm x 30mm on a FR4 substrate whose performance with dual band resonance reported to be suitable for RFID applications.

Joan Gemio et al (2009) reported a work on triangular monopole antenna printed on a fractal based ground plane of 104mm x 104mm with dual frequency resonance found suitable for WLAN applications using FR4 and FEKO software simulation.

Hwang (2009) proposed the performance of a dual band broadband half-Sierpinski FA on a 74mm x 37mm FR4 substrate using CST MWS. This antenna provides multiple resonances with wide bandwidth and nearly omnidirectional radiation pattern. He also proposed a circularly polarized broadband antenna in his another paper in the same year, which was designed as a spidron fractal slot type using a 40mm x 40mm RF-35 substrate. This antenna provides wide bandwidth with bidirectional radiation pattern.

Ghatak et al (2009) proposed a genetic algorithm based MATLAB coded procedure for the Sierpinski fractal antenna design and getting different iterations. They linked IE3D and MATLAB for optimization and simulation and compared the results with CST MWS also. The size of the substrate was 60.01mm x 60.01mm to hold the printed antenna layout. They have claimed that in the absence of closed form formulae for some FA designs, numerical techniques remain the alternative solution.

Wen-Ling Chen et al (2009) presented a report on the design of higher order Koch fractal shaped wide slot for a rectangular MSA for enhancing the bandwidth as compared to that of a conventional square slot antenna. They also reported that this antenna did not require any optimization or tuning for its stated performance.

Rowdra Ghatak et al (2009) presented a method to generate Sierpinski gascut fractal MSA using GA. They reported that this method of generating fractal antenna had been faster and any number iteration could be achieved.

Rowdra Ghatak et al (2009) made a report on the performance of a CPW fed perturbed and modified Sierpinski carpet antenna of 64mm x 44 mm. Its performance was analyzed using IE3D, verified with CST MWS and is reported suitability for dual band WLAN applications.

Rajkumar and Malathi (2009) worked on the backscattering reduction of a fractal square MSA of 36.08mm x 29.6mm with the help of different iterations and FDTD numerical technique. They demonstrated that the size reduction and down shift in resonant frequency are possible with fractal structures.

Eskandari et al (2009) reported the design of a single resonant modified novel square shaped MSA loaded with electromagnetic band gap structure for improvement in VSWR and gain. This antenna of size 15mm x 15mm was printed on a Taconic RF-30 substrate, placed tilted by 90 degrees with trimmed single corner, dual-fed from two sides for attaining circular polarization and simulated using HFSS.

Rajkumar and Jayashree Shinde (2010) studied the effect of fractal electromagnetic bandgap (EBG) on the performance of a square MSA of 28.6mm x 20.6mm on a FR4 substrate. A comparison of the performance of this antenna with the one in the absence of EBG is also found discussed in this report. They stated that the presence of EBG aids size reduction ability.

Siti NuhaShafe et al (2010) reported the performance of the modified Minkowski FA of 24.6mm x 24.6mm size on a Roger RO4003c substrate. This antenna resonated at triple bands whose performance was claimed to support WiMAX, WLAN and HiperLAN applications. They used CST MWS for the simulation.

Lotfi Neyestanak et al (2010) designed a hexagonal slotted FA kept inside a rectangular shaped slotted portion a CPW feed system which provided ultra wide band resonance. This antenna was supported by a 40mm x 30mm substrate and simulated using HFSS.

Chien-Wen Chiu and Yu-Jen Chi (2010) reported a fractal edged loop antenna which is fed by a U shaped tuning element and resonated in hepta band with multiple frequencies. They used a FR4 substrate along with a double side coated antenna of size measuring 65mm x 10mm x 0.8mm. This set up was mounted on a vertical ground plane of size measuring 200mm x 160mm and simulated using HFSS. The performance of this antenna at four resonant frequencies was claimed to be suitable for laptop, WLAN and WiMAX applications.

Vinoy and Pal (2010) reported the multi-resonant performance of an iterated compact sized Minkowski square ring antennas of 100mm perimeter spreading on a double-stacked Rogers RO-3003 substrate separated by an air-gap, aluminum coated ground plane of 20cm x 20cm size and simulated using IE3D. This structure was achieved by modifying the three sides of a square ring antenna to assume fractal shapes while retaining one side unaltered.

Jung-Tang Huang et al (2010) proposed the design of a miniature coaxial probe fed Hilbert curve antenna on FR4 substrate resonating at 2.45 GHz using HFSS simulation. The use of Hilbert geometry reduced the size of the antenna to 77% as compared to the conventional patch antenna of the same size. The overall size of the antenna including substrate and ground plane was 35mm x 6mm x 1.6mm.

2.3 REVIEW ON THE METAMATERIALS

MTMs are new class of artificial materials found attractively useful as substrate materials for antenna designs to provide improved performances. A variety of structures have been introduced by various researchers till date.

Veselago (1968) a Russian physicist has been the pioneer for MTM concept who theoretically speculated the simultaneous existence of both $\varepsilon_r, \mu_r < 0$ in artificial media. He made a complete study on the propagation of EM waves in such substances and concluded the left-handedness of EM waves when incident on such medium.

David Smith and Norman Kroll (2000) experimentally confirmed the presence of negative medium properties with some thin wire radiating structures.

Caloz et al (2001) made a full-wave analysis using HFSS to verify the effects of LHM on the EM wave propagation using two- and three-port waveguide configurations loaded by MTM and realized negative medium properties.

Anthony Grbic and George Eleftheriades (2002) presented a report on the experimental verification of backward wave radiation of a CPW fed small radiating MTM structure on a Rogers RO3203 substrate. They made Bloch analysis to determine the backward-wave propagation from the results of MoM based software simulation from Agilent products.

Underhill and Harper (2003) showed the contradiction of the Q criterion stated by Chu- Wheeler for the impedances of small antenna and provided suggestion to add a logarithmic correction in the Chu limit statement.

Pendry (2004) provided a detailed report on the concept of refractive index after making a thorough study on the theoretical pioneering of Veselago and practical implementation of some MTM structures by Smith.

Christophe Caloz et al (2005) provided a detailed report on the challenges and issues in preparing homogenization MTMs as substrates employed in antenna environment for performance improvement.

Irfan Bulu et al (2005) reported a highly directive far-field radiation pattern of a compact sized multilayered (30 x 15 x 15 layers) circular dual SRR structure laid in 3-dimensions when excited with a monopole source using FR4 substrate. The numerical analysis was made using FDTD.

David Smith et al (2005) explained the procedure of retrieving the negative permittivity and negative permeability from an inhomogeneous medium by making use of dyadic Green's function technique. However it suffers from time consuming recursive calculations but the accuracy is quite appreciable.

Bian Wu et al (2006) presented the results of performance of a microstrip transmission line when a double SRR was etched to form a defected ground structure and showed that the transmission frequency range decreases with the increase in side length of ring, increases with the increase in split gap and ring spacing. They claimed that this structure can be used as a low pass filter for harmonic suppressions.

HU Jun et al (2006) reported the effect of multi-layer grid type MTM covers measuring 35.4mm x 35.4mm size with 43mm spacing between adjacent layers on a 36.8mm x 45.9mm rectangular patch antenna to improve the directivity and reduce resonant frequency. The structures were simulated using HFSS and from the field distribution nature they also described the physical reasons for such high directivity.

Filiberto Bilotti et al (2006, 2008) designed a circular MSA of 20mm radius on a RT Duroid substrate with magnetic inclusions. They used a double split type MSRR and a multi-turn square spiral ring resonator as MNG. The simulation was through CST MWS for demonstrating lower resonance, good matching and radiation.

Filiberto Bilotti et al (2007) provided a new set of accurate analytical formulas based on a quasi-static model for the determination of resonant frequency, magnetic permeability and effective impedance of the magnetic inclusions in terms of physical dimensions of the structures. These are applicable to MTM structures such as MSRR, spiral resonators and Labyrinth Resonators which could provide magnetic inclusions. These Labyrinth Resonators are useful at the sacrifice of miniaturization in situations where anomalous values of permeability are needed for higher microwave frequencies.

Andrea Alu et al (2007) worked on the 50mm x 40mm sized rectangular and 20mm radius circular MSAs along with magnetic MTMs using SRR type and analyzed their radiation properties with cavity as well as numerical models using CST MWS. They demonstrated low resonant frequency with fixed dimensions and also suggested methods for efficiency improvement. The resonance frequency reduction was possible by employing ENG and MNG materials and by varying the core permeability and permittivity.

Shamonia and Solymar (2007) described the newness of MTMs and how that got started influencing them for engineering applications in view of their unusual medium properties.

Alfred Lopez (2008) reported a work on the radiation Q limit of electrically small antennas as compared to the physical limits on the size of antennas proposed by Wheeler and Chu during 1947-48.

Miyamaru et al (2008) reported on results of Terahertz electric response of H shaped fractal metamaterial structures using slicon substrate for providing multi-frequency operaion. For higher fractal levels, the structure resonated at lower THz (nearly around 0.04GHz) frequencies. The resonance results were good with metallic as well as slit type structures leading applications in near field optics.

Marco Antoniades and George Eliftheriades (2009) worked on a CPW fed small rectangular monopole antenna on a 30mm x 22mm FR4 substrate supported by a negative refractive index transmission line MTM and simulated using HFSS. It was reported that the broadband dual mode resonance characteristics suitable for WiFi, WiMax and MIMO diversity systems achieved.

Zhu and Eleftheriades (2009) reported a work on the small MTM inspired and HFSS simulated rectangular monopole antenna measuring 9.2mm x 5.7mm placed in a slot on a 32mm x 24mm FR4 substrate for WiFi applications. They developed a single unit cell of metamaterial with zero index of refraction and CPW feed system.

Dalia Nashaat Elsheakh et al (2009) presented a design and characterization of a compact ultra wideband hemisphere patch antenna occupying 24mm x 12mm area which was microstrip fed and loaded by a 40mm x 40mm ground plane with square spiral shaped artificial magnetic conductor of single and four arms. Using FR4 as substrate, the simulation was performed with HFSS.

Majid et al (2009) used a modified square SRR with two splits on opposite sides for obtaining negative medium substrate material on FR4. A set of capacitance loaded strips was loaded by this MTM to enhance the gain of and also to change the circular polarization to linear polarization.

Merih Palandoken et al (2009) used a modified square spiral ring MTM structure as a 2 x 3 array and made three dipole radiators connected to three sets of MTM unit cells on the FR4 substrate. The numerical analysis was performed using FEM based software. They also demonstrated that the resonance and radiation of electrically small unit cell is the key issue for the design of size reduction of antenna.

Kubota et al (2009) reported simulation results of Terahertz (at 0.4 THz and 1.22 THz) response of a three sided Koch fractal structure adapted by MTMs as SRRs. The resonance frequency shifted to lower side when the fractal order increased. They recommend this type of structure for producing extremely small unit cell MTMs with curves varying towards outside.

Ahmad Sulaiman et al (2010) worked on the simulation of a compact circular patch antenna on a dual square SRR MTM structure for operating it in the C band spectrum. The circular patch on a conventional substrate of 48mm x 48mm was dominated in resonance performance by its reduced size on a 20mm x 20mm MTM loaded substrate.

Ahmad Sulaiman et al (2010) reported the bandwidth enhancement of a rectangular patch antenna using a symmetrical-ring MTM structure with ENG property and proved size reduction ability. MTM loaded antenna on an FR4 was the substrate used by them to simulate in CST MWS.

Ahmad Sulaiman et al (2010) provided a report on the performance of a small patch antenna when loaded with SNG dual as well as array of omega shaped MTM structure and proved the size reduction and better performance properties. Size reduction was the important point in the discussions in all the cases. They used FR4 as substrate and CST MWS for the design and simulation.

Al Naib and Koch (2010) presented the numerical and experimental results of the performance of a modified CPW loaded with dual circular type SRR and CSRR structures where SRR loading a microstrip line and CSRR loading a slot line on a 44mm x 24mm FR4 substrate simulated by HFSS. They found optimum position for these MTM structures by moving them along the CPW structure.

Singh (2010) reported the size reduction possibility of rectangular patch antenna with double negative MTMs using CST MWS. The antenna of 139.16mm x 139.66mm on the conventional substrate with larger permittivity could be reduced to 70.85mm x 70.85mm when loaded with CSRR at a particular resonant frequency.

Cheng Zhu et al (2010) presented a new multi-resonant MTM structure composed of two asymmetrical triangular resonators connected by a thin rectangular strip. They verified the negative medium effect produced by these EM resonators on a Teflon substrate both numerically using HFSS and experimentally by using a parallel plate waveguide system.

Shyam Pattnaik et al (2010) proposed a thin rectangular MSA of 10mm x 0.5mm loaded by a 12 ring MSRR structure for enhancing the impedance bandwidth. The structure was supported by a RT Duroid 5880 substrate and simulated using IE3D. The size of the antenna was designed considering the Chu limit and the efficiency and Q factor were estimated to be high in such a small antenna.

Raoul Ouedraogo and Edward Rothwell (2010) proposed a circular MSA of 20mm radius loaded by a circular CSRR type MTM to improve the return loss performance using genetic algorithm (GA) optimization technique. They used Rogers 5880 RT Duroid substrate and linked HFSS and MATLAB based GA platform for various iterations.

Benjamin Braaten et al (2010) proposed a compact and differently shaped meander line antennas loaded with deformed omega and circular SRR based MTM structures for UHF RFID tags. The analysis results of different parametric variation such as permittivity, substrate thickness and different layouts have also been presented well which gives a useful insight into the designs.

Joshi et al (2010) presented the simulated results of a square slip ring resonator loaded and coaxial fed new electrically small rectangular MSA of size measuring 5mm x 0.5mm on a RT Duroid 5880 substrate using IE3D and established reduction in resonance frequency due to MTM substrate.

Jyotisankar Kalia and Behera (2011) proposed a proximity fed small circular MSA of 8mm radius with inner and outer annular gap rings for enhanced gain and radiation due to double negative MTM substrate by introducing a via for inductance and gap for capacitance effects in the annular rings. The structure was printed on a 26mm x 3mm Duroid substrate and was simulated using HFSS.

Akram Boubakri and Jamel Bel Hadj Tahar (2011) presented a simulation of circular MSA on MTM using HFSS for obtaining size reduction, improved gain, directivity, and reduced back lobe radiation.

Mahdy et al (2011) developed an algorithm for better radiation with multi resonant rectangular MSA of size measuring 50mm x 40mm loaded with single negative medium exhibited by a multi-turn square spiral resonator. This algorithm has been developed for better radiation and is also useful in choosing the relevant antenna design depending on the prepared ENG or MNG material. They established a link between this algorithm coding and CST MWS for optimum design and performance.

2.4 REVIEW ON THE IMPLANTABLE ANTENNAS

From the literature survey, it is found that antennas can be used for many therapeutic applications. For such purposes, the wireless link between implantable devices and exterior devices is required. In view of this the radiation characteristics of the antenna outside the body and modeling implanted antenna in human/animal tissues are required. These antennas are inherently sensitive to their environment, thus becoming good sensors. They deposit large amount of power in near field of the antenna, particularly in the lossy environment when embedded inside body, thus becoming good therapeutic tools. However these are the positive characteristic for therapy and negative characteristic for communication (Pichitpong Soontornpipit et al 2004). Though there are numerous contributions found in the literature on fractal and metamaterial antennas, the combination of them for application in IA is very limited. However, the review on various IAs proposed by investigators are presented below.

Kasevich (1988) proposed EM scale modeling of implantable microwave antennas operated in 100 and 300 MHz for hyperthermia cancer therapy. With this treatment procedure the tumor temperature was made to rise to a desired level by inserting the tip of the monopole antenna beyond the tumor volume for destroying cancerous cells. However, there were limitations on the range of values of dielectric constant and dimensional scale factor of antenna.

Mingui Sun et al (2003) worked on an x shaped less power consuming volume conduction antenna operated in 150 kHz and 5 kHz for implantable devices. They developed an IA which can be either embedded in, or connected to various implantable medical devices and can serve as a good information transferring device between IMDs within the body and the external device worn by patients through the layers of biological tissues.

Pichitpong Soontornpipit et al (2004) worked on the design of implantable MSAs for communication with medical implants in the 402-405 MHz MICS band. They used planar inverted F antenna (PIFA) measuring 26.6mm x 16.8mm between Macor substrate and silicon superstrate materials. The whole antenna was kept inside a human muscle mimicking environment and various antenna parametric variations and SAR for spiral as well as serpentine antennas were studied numerically using FDTD and verified experimentally.

Jaehoon Kim and Yahya Rahmat-Samii (2004) investigated the performances such as return loss and radiation of two co-axial fed low-profile spiral MSA at 402 MHz and spiral PIFA antennas at 402-405 MHz for implantable medical devices by keeping in a body-simulating fluid mimicking high dielectric values and optimizing with FDTD numerical technique.

Suresh Atluri and Maysam Ghovanloo (2005) worked on the design of a wideband power-efficient inductive wireless link for implantable bio-medical devices using multiple carriers with a goal to achieve high transmission efficiency and high data transmission bandwidth at three operating frequencies of 125 kHz, 50 MHz and 2.45 GHz as well as in ISM band. They designed two sets of planar rectangular and circular spiral shaped IAs as data and power coils.

Basset et al (2005) presented a work on the design and experimental results of a $\lambda/4$ ‘chip-size’ MSA measuring 5mm x 4mm on a RT/Duroid 5880 substrate for outside body communication with implantable sensors at 10.3 GHz. They simulated various antenna designs using HFSS to arrive at a reduced size resonating at $\lambda/4$ frequency.

Jaehoon Kim and Yahya Rahmat-Samii (2005) worked on the effect of EM interactions including SAR between biological tissues and implantable biotelemetry systems using small dipole of 50mm length and loop antennas of dimensions measuring 50mm diameter at 402-405 MHz and 1.5 GHz, along with the use of EBG structure and FDTD simulations.

Azad and Ali (2006) presented a work on a miniaturized implantable miniature Hilbert PIFA antenna designed using HFSS with biocompatible superstrate materials macor and silicon at 1.575 GHz for GPS application claiming the use of the antenna for identifying the declining mental capacity (alzhemimers's disease) of patient and also for implanting under the skin of the potential kidnap victims. The antenna has unavoidable backlobe radiation because of the ground plane size being small.

Chien-Ming Lee et al (2006) presented a compact broadband stacked implantable PIFA omnidirectional antenna in 402-405 MHz using HFSS simulator and Rogers 3210 substrate covering SAR test also. For experimental purposes several kinds of tissue simulating fluids were used and found thin substrate produces better performance than the thick one. The authors claim that this antenna can be implanted into other human tissues such as muscle, heart, eye etc.

Xiaoning Qiu and Ananda Sanagavarapu Mohan (2006) investigated the performance including SAR of a CPW-fed printed UWB antenna for wireless body-worn applications with omni directional radiation characteristics using HFSS. The printed CPW-fed UWB antenna was fabricated on Rogers- RO4003C substrate and tested in free space environment and human body mimicking environments.

Kamya Yekeh Yazdandoost and Ryuji Kohno (2007) designed a small multi-turn printed square loop antenna for medical implant communications system and simulated at 403.5 MHz in a medium surrounded by tissue layers. The size of the antenna was 8.2mm x 8.1mm printed on a D59 (NTK) substrate covered by RH-5 superstrate.

Merli et al (2008) designed an implantable circular PIFA antenna using HFSS simulation for biomedical applications in MICS band especially for glucose sensor. The antenna was placed in cylindrical shaped case and experimentally verified in a body simulating solution by using a battery of height 10.8mm and diameter of 11.6mm with 155mAh (31 hours of life time). The communication link was tested in an anechoic chamber.

Yasir Ahmed et al (2008) proposed a 31.5 GHz square MSA design for medical implants. In addition to miniaturized size of 5.68mm x 6mm, it provided reduced return loss and good radiation characteristics essential for reliable communication. A mini rectangular MSA was designed to operate at 31.5 GHz frequency on a Rogers RT6002 substrate and simulated using CST MWS in the lossy body environment. The return loss of the antenna increased with a 1.14% shift in frequency. They suggested that this shift could be suppressed by adjusting the dimensions of the antenna.

Xueyi Yu et al (2008) presented a design and test of a miniature 2.45 GHz antenna for implantable medical devices. They designed a 10mm circular ring MSA on a F4KB335 substrate using shorting pin technique for size reduction which provided 104 MHz impedance bandwidth. They suggested that this antenna could be used for a wireless capsule endoscope system. The simulation was performed with HFSS and animal test was carried out with the fabricated antenna.

Gianluca Lazzi et al (2008) suggested a method on the design of a multi-turn spiral IA for a retinal prosthesis to restore partial vision to the blind. The antenna was operated optimally for frequencies up to a few MHz by first modeling with the Partial Inductance Method without considering lossy human body. The coupling resulted with the internal coil in terms of mutual inductance was later used to increase the bandwidth. The full wave simulation was performed using FDTD method which covered SAR test for large frequency coverage.

Erdem Topsakal (2009) proposed antennas for medical applications in dual bands MICS and ISM (2.4-2.48 GHz). Three different antennas such as implantable, body-centric and ingestible types designed simulated using an FE BI solver with particle swam optimization algorithm (PSO). Measurements were performed between 500 MHz and 20 GHz in tissue mimicking gels and rats. The antenna resonated at 402 MHz and 2.4 GHz.

Tutku Karacolak et al (2009) worked on the study of electrical properties of rat skin and the design of dual band IAs for medical wireless telemetry in monitoring the physiological parameters such as glucose, pressure, temperature etc. The electrical properties (ε_r and σ) of rat skin samples were studied between 200 MHz to 20 GHz. A dual band (MICS and ISM) antenna operating at 402 MHz and 2.4 GHz was then designed with FE-BI solver with PSO algorithm. A serpentine configuration was considered for optimizing the antenna surface area using Rogers RO3210 as substrate and superstrate materials.

Kamya Yekeh Yazdandoost (2009) proposed a 2.4 GHz antenna of 5mm x 4.8mm size for medical implanted communications printed on a D51(NTK) substrate and covered by RH-5 superstrate. The simplified biological tissue was modeled and simulated using HFSS.

Tharaka Dissanayake et al (2009) suggested a capsule-shaped dielectric-loaded implantable UWB antenna for impedance matching. This was printed on a RO TMM 10i high permittivity substrate and etched to possess antenna as well as CPW feed shapes. Performance degradation of antenna due to surrounding dissipative biological tissue and impedance mismatching was analyzed using CST MWS.

Wei Xia et al (2009) worked on optimizing the performances of an implanted H-shaped cavity-slot antenna embedded in the human arm at 2.45 GHz in the ISM band. Many worked on the cavity slot-antenna however, the dimension had been little big to be embedded into human body. As a result of the introduced H-shaped slot, the dimension of the optimized antenna became less (38.5%) measuring 2.8mm x4.0mm than that of the previous antenna measuring 5.2mm x 2.8mm considered for comparison. In addition, since the antenna was too small for fabrication, the performances of the antenna were measured by using a scale model with 180mm x 60mm size to confirm the validity of the numerical calculation made using FDTD. And hence with the 2.5 times larger scale model the resonant frequency of the antenna shifted from 2.45 GHz to 980 MHz.

Carlos Sanchez-Fernandez et al (2010) proposed an implantable spiral antenna short-circuited to SRR covering dual frequencies in MICS and ISM bands with a multi layer configuration where the microstrip feed line and the antenna layers were located at different levels. ARLON 1000 was used as substrate as well as superstrate with high permittivity. In order to validate the entire design of the antenna, the characteristics were studied with four types of simulations such as free space model, single-layer (skin alone), three-layer (skin, fat and muscle) and a realistic human body based voxel model using CST MWS.

Francesco Merli and Anja Skrivervik (2010) presented an investigation results on the design and measurement considerations for an electrically small IAs taking meander, spiral and PIFA shapes for telemetry applications. Considering the interference problem associated with the coaxial feeding the electrically small antenna was carefully designed and analyzed in the 401-406 MHz range.

Sheng-How Chen and Chin-Lung Yang (2010) proposed implantable fractal dental antennas for teeth implanting purposes in low invasive biomedical devices to monitor patient's health condition. A Hilbert-curve miniature (with total area less than 128mm^2) FA was designed on a very high permittivity ceramic denture substrate in MICS band. The design such antennas was very challenging including the miniature size, limited gain and bandwidth, loss of EM wave propagation, bio-compatible materials, isolation from the tissue fluids, the influence of human tissue dielectric constant, the depth of electromagnetic wave penetration, and safety issues. With HFSS simulation the two antennas resonated at 455 MHz and at 403.75 MHz each.

Merli et al (2010) presented a design of a dual band antenna for subcutaneous telemetry applications. This antenna was designed to operate implanted in human muscle tissue/in vivo in a subcutaneous environment in Medical device Radio communication (MedRadio) and ISM bands. A multilayered PIFA structure was designed on a Roger TMM 10 alumina substrate. The necessary biocompatible insulation was made of PolyEtherEtherKetones with ε_r = 3.2, tan δ = 0.01, as it could provide excellent mechanical, thermal and chemical characteristics. They prepared liquid solutions, measured their electrical properties and then used the same for testing the antenna.

Minshen Wang et al (2010) worked on the electromagnetic compatibility issues between vehicular mounted antennas and implantable medical devices. The interactions between these two were investigated as SAR and found that higher electromagnetic energy deposition was found in the vicinity of the devices, bystanders as well as passengers. FDTD method is used for investigating the interactions between these antennas operating in 900 MHz ISM band.

Chien et al (2010) presented a report on the development of implantable ceramic antennas at 404 MHz with no substrate. As IAs fed by CPW were simulated using HFSS and indented for immersing in lossy body environment, the shift in resonant frequency, low radiating efficiency, and mismatch loss became critical. Introduction of superstrate layer to prevent tissue erosion increased the fabrication difficulty and size. For reducing the mismatch loss and absorption loss of the implantable antennas immersed in the lossy tissue, the dielectric constants of the substrate and the superstrate should be equal to or close to that of the surrounding tissue environment. Hence two antennas (one monopole section and the other inductive loading section) were developed without any covered superstrate on the microwave dielectric ceramic MgTa1.5Nb0.5O6 and Aluminum Oxide (Al2O3) ceramic substrates respectively. The characteristics of the proposed implantable antennas were obtained in the phantom tissue fluid, compared with several other IAs and found that maximum power was received exterior at 2m away.

Gupta et al (2010) presented a review report on the development of wearable and IAs in the last decade. The design and utilization of wearable textile materials as antenna substrate has been rapid due to the recent miniaturization of wireless devices. A wearable antenna is meant to be a part of the clothing used for communication purposes, which includes health monitoring tracking and navigation, mobile computing and public safety. This article presents research report on wearable and body mounted antennas designed and developed for various applications at different frequency bands over the last decade. A little on the developmental scenario of implantable antennas for medical applications is also presented.

2.5 REVIEW ON THE MTM/ANN BASED MSA AND LPF

The design of MSA remains complex and time consuming from the analytical point of view. The ANN on the other hand provides quick and accurate solutions to multi-parameters controlling MSA designs. The ANN can be considered to be a multi-layer model consisting of input, hidden and output layers. Depending on the problem at hand the number of neurons for each layer can be decided. The ANN can be trained to grab and handle arbitrary relationship between the input and output parameters to provide any degree of accuracy. The investigations pertaining to the design of MSAs found in literatures are presented below.

Several reports have been presented using various ANN training algorithms to model various microstrip filters. Each has its own uniqueness in the performance. There have been reports marking the advantages of MTMs in microstrip filter designs since they possess frequency selective property as reported by Gil et al (2005).

2.5.1 ANN Based Microstrip Antenna

Lakshmi Narayana et al (2007) provided a general design procedure, synthesis and analysis methods for the accurate design of microstrip antennas using ANN. They reported the advantage of the same for the rectangular microstrip antenna and facilitated the suitable algorithms in term of percentage of accuracy.

Siakavara (2007) worked on the design of ANN trained probe fed dual resonance slotted circular patch antenna. They used MLP ANN to determine the best combinations of various input parameters which would yield desired frequency response in the specified range of 1- 3.5 GHz.

Naser Mohaddasi et al (2007) reported the use of Resilient BPA based MLP ANN for the design and accurate calculation of resonant frequency of a rectangular patch antenna using three, seven and two neurons in the input, hidden and output layers respectively. The characteristics were compared with the experimental results already available in literature.

Thakare and Singhal (2009) proposed an inset feed 10 GHz slotted rectangular patch antenna of size measuring 8.88mm x 6mm on a glass epoxy substrate of 18.4mm x 15.528mm using IE3D for design and simulation and ANN for design and performance optimization. They developed an ANN to analyze the bandwidth of the antenna with and without slots. They claimed that the radial basis function ANN had been fast and more accurate when compared to different variants of training algorithms of multi-layer perceptron feed forward back propagation (MLP FF BP).

Malathi and Raj Kumar (2009) proposed a method to improve the performance of the circular patch antenna using Levenberg-Marquart (LM) algorithm based MLP ANN. They reported that the average percentage of accuracy in the resonant frequency of antenna in the 1-10 GHz range with the proposed ANN model is more and hence this method could replace complicated mathematical formulas or CAD designs. They used multilayers of dielectric materials below and above the antenna to enhance gain and bandwidth. The limitation is that the weight and size corresponding to low profile is forgone.

Abhilasha Mishra et al (2010) used ANN for the design of rectangular microstrip antenna using scale modeling. They reported that the normalized scale modeling helped in reducing the number of epochs in the analysis model of ANN when BPA was used. Also they stated that the maximum accuracy was obtained by changing the neurons of three hidden layers. The model helped in deciding the antenna design with desired resonance occurring between 1 and 20 GHz.

EL Aoufi et al (2011) worked on the design of a rectangular patch antenna of size 45.4mm x 37.2mm fed by a microstrip line at the centre via an inset using Polycorbonate and Polybutylene Terephtalate plastic substrate materials. The structure was simulated using CST MWS and reported that it resonated at a single frequency of 2.45 GHz. They claimed that this antenna would be suitable for RFID applications.

Amit Agarwal et al (2011) worked on the design of elliptical patch antenna design using radial basis function ANN and compared the results with IE3D. The use of ANN resulted in deciding the best values of substrate height, permittivity and eccentricity of ellipse. The resonance between 1 and 3 GHz was targeted. The practical implementation of fabrication with such ANN defined substrate has been a limitation in this work.

Praveen Kumar Malik (2011) used MLP BP ANN for the design of a equilateral triangular microstrip antenna with side length of 4.1cm, 8.7cm and 10cm on a substrate with permittivity flipping between 10.5 and 2.32 and thickness of 0.07cm, 0.078cm and 0.159cm. The antenna was reported to resonate between 1.28 GHz and 4.443 GHz.

Deena Nath Jaiswal and Tripathi (2012) reported the results of various training algorithms for the analysis of microstrip antenna stating that the ANN proved to be simple, accurate and fast compared to the analytical methods. They used LM, scale conjugate gradient and quasi-newton algorithms based on standard numerical optimization techniques.

Gurdeep Singh and Jaget Singh (2012) reported the results of E shaped MSA resulted from basic rectangular type by applying U slot, L probe and MLP ANN modeling with two, fifty and three neurons in the input, hidden and output layers. The designed antenna was verified with IE3D simulation. The size and space needed for the antenna are the limitations in this work.

Vandana Vikas Thakare et al (2012) presented a report on the design of a coaxial fed circular MSA on a epoxy glass substrate using RBF ANN with two, fifteen and one neuron in the input, hidden and output layers respectively. This was verified by IE3D simulation with resonances in the 3.8-8.15 GHz frequency range for various parameter combinations.

2.5.2 MTM /ANN Based Microstrip LPF

Sri Rama Krishna et al (2009) proposed the design and analysis of the three-pole stepped impedance as well as open circuited stubs based Chebyshev type 1 GHz microstrip LPF. MLP ANN model trained by seven different algorithms was used to analyze the magnitude and phase of S-parameters of the filters. They reported that Quasi Newton and Simplex method algorithms were providing better accuracy and faster results when compared to BP, sparse optimization, conjugate gradient scaling, adaptive BP and Huber-Quasi-Newton algorithms.

Sudhakar Sahu et al (2011) proposed a maximally flat 4.5 GHz microstrip LPF of 47.466mm x 17.533mm on a Rogers RT/Duroid 5870 substrate loaded by a hex-omega structure MTM. This was simulated using advanced 3D EM simulation tool based on FEM and verified with experiment. They reported that the filter possessed fast roll-off, size reduction and improved selectivity.

2.6 COMPUTATIONAL METHODS AND MICROWAVE CAD SOFTWARES

The history of computational electromagnetics (CEM) has passed through several phases. In 1960-1970s there had been only primary work on CEM formulations, in 1980s non-specialists also started accepting significantly, in 1990s commercial codes were made available for RF EM problems and from 2000 onwards more computer aided design (CAD) software tools have become available.

Silvester and Ferrari (1996) provided detailed information and methods on the FEM and mentioned that it was a popular method in structural mechanics and thermodynamics and later found applicable in EM problem solving.

Daniel Swanson and Wolfgang Hoefer (2003) provided elaborate discussions on the analytical and numerical methods of solving electromagnetic problems along with microwave CAD softwares. The MoM is the most widely used numerical technique in RF and antenna engineering most MoM codes use the free space Green function. It has strong points such as efficient treatment of perfectly or highly conducting surfaces, only surface meshing excluding the air around the medium, incorporation of the ‘radiation condition’, current density as working variable, possibility of deriving many important antenna parameters (impedance, gain, radiation pattern etc.,). However, there are some weak points such as inability to handle electromagnetically penetrable materials.

IE3D is an integral equation based full-wave electromagnetic simulator using MoM from Zealand. One of the most important applications of the IE3D is for antenna design. It solves the current distribution, provides network scattering parameters, radiation patterns. However, there are some limitations for smart design. Some of the major factors affecting IE3D simulation are meshing frequency, meshing cell size, de-embedding schemes and requirement of large computer memory.

David Davidson (2005) mentioned that either the quasi-static analysis or the full-wave analysis can be performed using the CEM methods depending on the needs.

Mathew and Sadiku (2009) mentioned that the numerical methods generally provide appropriate solutions of sufficient accuracy for engineering applications. Though the analytical methods provide exact solutions, they remain to be time-consuming because of huge calculations. On the other hand, the numerical methods provide faster solutions with the help of methods such as finite difference time domain method (FDTD), Method of Moments (MoM), Finite Element Method (FEM), Method of Lines (MoL) etc. FEM can handle two different types of problems such as Eigen analysis (source-free) and deterministic (driven) problems. There are some strong points in FEM such as very straight forward treatment of complex geometries and material inhomogeneities, very simple handling of dispersive materials with frequency dependent properties. Though it has potentially better frequency scaling it suffers from some weak points such as insufficient treatment highly conducting radiators when compared to MoM.

HFSS is based on FEM and is a high performance full wave EM field simulator for arbitrary 3D volumetric passive device modeling that takes advantage of the familiar Microsoft Windows graphical user interface as found in HFSS user manual from Ansoft. It provides network scattering parameters, VSWR, impedance, resonant frequency, specific absorption rate (SAR), fields and the radiation patterns with boundary / environment setting facility.

Though most problems that can be solved analytically have been solved, there are still a number of EM problems which need solutions. The analytical methods are much time consuming and challenging which appear as a main disadvantage in this fast-faced modern communication world. Reworks or redesigns are becoming obsolete as the available useful time can be spent for catching up the technological growths. Hence, for obtaining fast and accuracy of designs and results, any one or more of the readily available strongly built microwave CAD based numerical simulation softwares can be used.

2.7 CHALLENGES

Most of the antennas designed by various researchers as seen from the above literature review are either large in size, heavy or space occupying in view of acquiring improved performances. In most of the works they used thicker dielectric substrates, stacked antennas, arrays, or larger antennas to meet out the demands in the lower microwave spectrum and the related applications. Hence it is vivid that in small antennas such as MSA, it is not always possible to have complete low profile when the advances in communication increase demand for low profile antennas. These limitations leave antenna designers with lot of challenges as listed below.

1. Change in tissue properties due to physiological reasons from person to person or from time to time has direct impact on the implantable antenna performance.
2. Need for reduction in physical size of antennas is strong to match with the rapid size reduction in wireless devices.
3. Unwanted radiation from CPW feed becomes more serious leading to insufficient bandwidth.

4. Reduction in ground plane size has impact on two issues such as backward radiation thus reducing the forward directivity and rise in resonant frequency.

5. Dimension dependency of antenna characteristics resists in maintaining low profile in a single antenna.

2.8 PROBLEM IDENTIFICATION

It is learnt from the literature survey that the MTMs can elevate the MSA performance and the FAs can provide size reduction and multiple resonances. There are no reports of the MTM loaded FAs in the literatures to the best of knowledge. Therefore combining these two concepts can be innovative since each being hot area of research. Hence exploring novel FAs which can be MTM loaded for providing enhanced performances is the motivation behind this research activity. The resulting miniature antenna would be of new kind with improved performances such as reduced return loss, multiple resonances, 2:1 VSWR and enhanced gain compared to the conventional MSA. This could meet the demand where a single antenna for multiple frequency operations in wireless communication and IMDs is preferred.

2.9 METHODOLOGIES AND OBJECTIVES

Though the investigation can use any experimental, analytical or numerical techniques in solving EM field problems associated with antennas, the experimental method is expensive and time consuming but one can know the real performance of the antenna. This thesis covers the numerical designs simulations and experimental verifications to validate the works. Hence the design and numerical simulation using electromagnetic field solvers IE3D and HFSS, physical implementation by fabrication using photolithography and experimental verification using network analyzer and anechoic chamber are the sequences in the objective.

The main objectives are:

- To explore the designs of a variety of new fractal structures.
- To create MTM structures and verify the negative medium properties.
- To combine both MTM and FAs suitably and to verify the enhanced performance.
- To fabricate the models and to verify the performance through measurements.

The secondary objectives are:

- To use IE3D and HFSS softwares for the antenna and metamaterial designs and simulations.
- To use pattern generation algorithm ANN platform for more Iterations and to link with HFSS for importing patterns and optimizing results of FAs.
- To develop MATLAB coding for designing antennas, filter, MTM and negative medium property verification and also results comparison wherever needed.
- To apply the ANN as well as MTM concepts additionally in microstrip LPF design also in order to verify the performance improvement.

2.10 CONCLUDING REMARKS

In this Chapter the review of research works carried out by various researchers has been presented and the challenges towards antenna profile and performance improvement have been marked. Based on this a research investigation work is proposed to play with the basic microstrip antenna shape for acquiring new compact antennas so as to meet many of the wireless devices requirements providing improved performances without sacrificing the low profile requirements.