CHAPTER I

INTRODUCTION TO THE RESEARCH PROBLEM

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1.1 Introduction

Mobile and handheld wireless technology, in the contemporary global scenario, has become ubiquitous to say the least. In particular, the field of RF wireless communication is experiencing unprecedented technological advancements and market growth, spurred by the rapid increase in the use of cellular telephony, mobile data and wireless local area network (WLAN) as well as satellite communication [1 - 5]. This growth is only but likely to proliferate in the near future as widespread deployment of wireless networks are revolutionizing the concept of communication and information processing of business, professional and private applications. Furthermore, military agencies deploy high end wireless devices for use in tactical environment including portable devices providing extensive computational powers for soldiers. In this backdrop, it is only but obvious that the world of communication is bound to experience an ever increasing momentum in development of wireless networks and related fields replacing its erstwhile counterpart of wired technology which was the backbone of communication technology until very recently. In this wireless era, the antenna, which acts as the frontends at the transmitting and receiving sides is a critical component.

The device at the transmitting end which launches the signal into free space and at the receiving end which receives the transmitted signals, i.e. the antennas, must have characteristics that conform to the specific requirements of the system. Characteristics of antennas are, therefore, of prime importance in deciding the overall performance of any communication system.

In the microwave region, because of the wavelengths involved, antennas can be designed within a practical size while catering to the performance requirements of a system. In addition, a channel in this frequency range occupying a fixed percentage bandwidth can carry far more data than in the lower frequency range. As a consequence, most long and short range RF wireless communication links operate in this frequency range although higher frequencies are also used nowadays having larger channel capacity.

There are two major aspects that need to be addressed while designing an antenna. First, the bandwidth over which its desired characteristics remain within an acceptable range. This requirement becomes all the more significant in view of the present day broadband and multichannel systems. Multi frequency antenna, on the other hand, can operate at a number of desired frequencies rather than over the whole frequency range, for which it is more difficult to design the antenna with the given characteristics. These
can also eliminate the need for additional space for mounting a number of antennas for different frequencies. Secondly, the shape of the radiation pattern that will determine what part of the total power will be radiated and received in the desired direction. For instance, highly directional radiation patterns with sharp pencil beam can be useful in establishing point to point links and therefore the same frequency can be used at adjacent locations to establish another link, obviating the requirement for additional frequency bands. This also reduces the total power required to be transmitted to establish the link. Another example of shaped beam antennas are the satellite DTH antennas with beam shape designed for particular intended area of coverage, known as the footprint.

Microstrip antennas are well suited for mobile or radio communications, military applications and applications involving aircraft and space craft, where small size, light weight and low profile is a necessity [6 - 15]. Microstrip antennas are also preferred for wireless LAN systems due to their versatility, conformability, mechanical ruggedness, low cost and low sensitivity to manufacturing tolerances. Many of the antenna applications for satellite links, mobile communications, wireless local area networks etc. require broadband, dual/multi frequency operation, frequency agility and polarization control. These can be achieved by suitably loading the simple microstrip antenna and altering the basic antenna structure by introducing slots, structural modifications etc. [16 - 17].

Microstrip antennas began gaining prominence from the year 1970, although the idea of microstrip antenna is reported in the literature way back in 1953 by G.A. Deschamps [18] and was first patented by H. Gutton and G. Bassinot in 1955 [19]. In the years that followed, microstrip antennas received significant attention of the research community and work on different patch configurations, array designs as well as patches with different loading are reported in the literature [20 - 23]. Modelling of antennas for design and analysis has also seen continued development alongside [24 - 27].

The inherent limitation of narrow bandwidth in patch antenna requires to be enhanced for many practical applications, posing a challenge for designers. As a consequence, increasing the bandwidth of microstrip patch antennas has been a major thrust area of research. Some of the approaches for broadband techniques are: (i) lowering the value of Q which involves selection of different radiator shapes, increasing the substrate thickness and using substrates with lower dielectric constant, (ii) using impedance matching techniques which include inserting matching networks, adding tuning elements, slotting and notching of patches, use of aperture and proximity
coupling (iii) introducing multiple resonators which include use of parasitic (stacked or coplanar) elements in combination with (i) and (ii) [28 - 33].

Another limitation is its inherently low power handling capability which is a constraint for use in the transmitting mode. Various techniques, including use of arrays, are employed to overcome this. Surface wave propagation is another limiting factor affecting efficiency, which increases with increase in frequency and cross-coupling among others. Techniques such as use of photonic band gap structures, which are obtained by periodic loading of the substrate, are generally used to suppress this unwanted propagation within the antenna structure [34 - 36].

Size reduction and bandwidth enhancement are also becoming major design considerations for practical applications. Application in present day mobile communication requires smaller antenna size for mobile handheld devices. For this reason, there has been great emphasis on achieving compact and broad band operations of microstrip antennas. With the introduction of new mobile wireless systems such as WiMax 2400 (2595 - 2690 MHz), Wi-Fi (2400 - 2483.5 MHz), WCDMA in 3G mobile telecommunication network etc., a notable change in antenna design approaches has come about. Significant progress in the design of compact microstrip antenna with broad band, dual band-frequency, dual-polarized, circularly polarized and gain enhanced operations has been reported [37 - 42].

The feeding mechanism is another important design consideration for antenna performance characteristics. The microstrip antennas can be exited directly either by a coaxial probe or by a microstrip line. It can be also excited indirectly using electromagnetic coupling, aperture coupling and a coplanar wave guide feed with no direct electrical contact between the feed line and patch. Aperture coupling is often chosen by designers as this type of feed arrangement allows physical separation of the two functions, antenna excitation and radiation, and the freedom to use optimal substrates for radiator and transmission line [43 - 45].

The development of complex antenna structures using inhomogeneous dielectric material, multilayered dielectric structures, periodic loading of the substrate to suppress surface waves, aperture coupling of the feed to the antenna, use of staked configuration to achieve larger bandwidth, loading of the antenna to improve characteristics and integration of the circuit functions to antenna functions has ushered in the development of various modelling and numerical techniques for these complex structures. These include full wave techniques such as the integral equation approach and FDTD technique. Many
commercial softwares such as CST Microwave Studio, HFFS, IE3D which are based on numerical methods such as MoM, FEM are nowadays available for computation of antenna performance. These are widely used by researchers and designers for validation of experimental results as well as for pre fabrication evaluation of proposed antenna performance.

1.2 Literature on tuning and size reduction

A detailed survey of contemporary literature on microstrip antenna research and the aspects that require attention vis-a-vis their current applications in communication has been carried out. It is with this basis and background that the two aspects as mentioned earlier have been taken up for study in the present work.

1.2.1 Tuning techniques

Iskandar Fitri et al. proposed a compact microstrip slot antenna fed by a microstrip line with multi tuning stubs for UWB applications [46]. They reported an acceptable impedance match in the frequency ranges of 1.3 GHz to 5.1 GHz for single antenna element and 1.1 GHz to 6.4 GHz for stub array composed of two antenna elements. Matching condition can be controlled by tuning the stubs under the slot and shorting the tuning stub connected in shunt for bandwidth enhancement. This technique can be used in antenna array for further enhancement of bandwidth. The technique is complex requiring adjustment of many parameters of the tuning arms.

H.K. Ng et al. proposed frequency tuning of a the dielectric resonator antenna using loading cap [47]. Tuning of resonant frequency can be achieved by changing the radius of the loading cap. Exciting the dielectric resonator antenna with its fundamental $\text{TE}_{111}$ mode by a coupling aperture need very careful adjustment as a small parametric variation can generate higher order modes.

J.A Tirado-Mendez et al. reported an alternative to the commonly used tuning techniques such as use of stubs, posts, variable air gap etc. by applying defected microstrip structure in tuning a square patch antenna [48]. Poor matching and lower gain issues are to be tackled in this technique.

P. Blondy et al. developed a wide tuning range MEMS switched patch antenna [49]. The antenna operates at 23.8 GHz without bias and 12.4 GHz with an applied bias of 150 V.

J. Ollikainen et al. proposed a thin dual resonant stacked shorted patch antenna for mobile communications [50]. The antenna was designed with a bandwidth of 10%
necessary for GSM 1800 or GSM 1900 applications. The structure needs a controlled coupling between the driven patch and parasitic patch for impedance bandwidth.

P.J. Rainville et al. fabricated a microstrip patch antenna on a ferrite film which can be tuned by applying a magnetic field bias [51]. The radiation polarization can be varied by application of small in-plane magnetic bias field.

A tunable bow tie radiating element mounted above an artificial magnetic conductor (AMC) with a geometry consisting of a frequency selective surface (FSS) was presented by Fabio Michele Valeri [41]. The FSS was designed on a thin grounded dielectric slab where chip-set varactor diodes were placed between metallic elements and the backing plane through vias. The antenna was tuned over the S-band by varying capacitances through an appropriate voltage. The technique needs larger volume and external voltage source.

A wideband bow-tie slot antenna with tuning stubs was reported by Abdelnasser et al. [52]. Many of the antenna parameters such as width and height of bow tie slot, width of the stub, inner and outer heights of the metal stub, inner slot height were adjusted to improve the bandwidth up to 88% for a centre frequency of 10.0 GHz with a gain of approximately 6.7 dB. The technique involves many tuning parameters in achieving the requisite gain over the operating frequency range.

Peroulis et al. reported a reconfigurable slot antenna which was compact, efficient and electronically tunable [53]. Tuning is realized by changing its effective length, controlled by the bias voltages of solid state shunt switches. An effective bandwidth of 1.7:1 was obtained by using this tuning method without the need for any other additional matching network.

A compact multi-band antenna with broad individual bands consisting of semi-disk radiating elements was presented by Pouhe et al. [54]. Using angular displacement of probe position, operation in the frequency range from 1.71 GHz to 2.55 GHz for 3G mobile communications and in the C-band from 3.78 GHz to 4.38 GHz for satellite TV communication were obtained. The structure is sensitive to off-set positioning of the probe feed leading of excitation of higher order modes.

Sylvain Loizeau et al. presented a reconfigurable antenna with a low tuning range and with an additionally switchable UWB [55]. Two types of reconfigurability components were used; PIN diode for enabling discrete configuration change and a varicap diode which allows continuous tuning of the resonant frequency. Loading extra components poses matching issues in addition to a large volume for integration.
P. Rocc et al. reported synthesis of a quad-band patch antenna [56]. The shape modification was evolved based on fractal-shaped erosion strategy. The antenna was designed to meet the requirements for Galileo frequency bands $E_5$ and $L_1$ ($f_{E5} = 1191.795$ MHz, $f_{L1} = 1575.42$ MHz) and Wi-Max frequency bands ($f_{WM1} = 2.5$ GHz and $f_{WM2} = 2.5$ GHz).

A dual band antenna, using two stacked shorted patches for applications in the GSM 1800 and GSM 1900 cellular system handsets for increased bandwidth has been presented by Gwo -Yun Lee et al. [57]. Two resonant frequencies close to each other were obtained by adjustment of lengths of the stacked shorted patches although the length adjustments affect radiation pattern and the stacked configuration need reasonable precision in packaging for specific application requirements.

A technique for obtaining dual-band operation using a reconfigurable slot antenna has been reported by Nader Behdad et al. [58]. Frequency ratio achieved for the design ranges from $1.3 \leq f_R \leq 2.67$ by changing dc bias voltages of its two varactors in the range of 0.5 V to 30.0 V. This type of antenna needs simultaneous matching at both bands for entire range of bias voltages.

M. Nishigaki et al. proposed an UWB tunable antenna with built-in piezoelectric MEMS variable capacitors [59]. A tuning ratio of 11 and a quality factor of the order of 37 at 650 MHz for bias voltage from 0V to 8.0 V were obtained. Issues such as nonlinearity of using varactor diodes where RF signal also varies the capacitance of the varactors diodes need to be tackled.

N.X. Sun et al. reported an electronically tunable magnetic patch antenna with metal magnetic film between the alumina substrate and the copper patch designed to operate at 2.10 GHz [60]. With appropriate external magnetic biasing perpendicular and parallel to the feed line, an enhanced bandwidth of 50% over the conventional patch antenna with its directivity increasing from 5.58 dB to 6.73 dB was achieved. In this technique, external field applied has a wide range of variations from 20 to 1000 Oe to control the frequency shift and the direction of external field has to be precisely controlled at the same time.

Antennas with metallic magnetic films and self biased magnetic films for electronic tuning have been reported by Guo-Min Yang et al. [61]. One layer just above a ring and another under the ground plane lowers the resonant frequency to 1.7 GHz from 1.72 GHz for the non magnetic antenna. The ferrite film loading effectively changes the geometrical dimensions thereby shifting down the resonant frequency. Fabrication
complexity is of concern as two layers below and above the patch was loaded with magnetic films.

Zammit et al. presented a tuneable microstrip antenna using switchable patches [62]. The design was obtained with 13 different copper strip bridges in place of switch combinations which tunes the frequency from 1.36 GHz to 1.92 GHz. The co-planar parasitic patches acting as capacitive load need large volume posing compactness problem. Combination of switches needs to be precisely controlled for getting uniform current distribution on the patch.

Davor Bonefacic et al. reported a PIFA with slotted PIFA loading for mobile communication devices [63]. Maximum gain of 3.2 dBi was obtained with capacitive loading to the slotted PIFA. The reduction in antenna dimension was made at the expense of bandwidth, gain and efficiency.

Abdelaziz et al. presented a compact microstrip patch antenna designed for application in civilian GPS (1.575GHz) [64]. Reduction in size of up to 24.6% was obtained. Gain was reduced by low radiation efficiency though good circular polarization was obtained for applications in mobile system.

Jing Liang et al. reported a microstrip patch antenna on tunable electromagnetic band-gap substrates [65]. Tuning was achieved by the diode loaded EBG substrate rather than on the antenna itself. A 4-by-4 EBG unit is embedded underneath the radiating patch and proximity coupled by a microstrip line with edged loaded SMA connector.

Carson R. White et al. developed single and dual polarized tunable slot ring antennas [66] for both single and dual polarized frequency tuning. The design achieved tuning range from 0.95 GHz to 1.85 GHz and 0.93 GHz to 1.6 GHz using two varactor diodes for single polarization antenna and four varactor diodes for dual polarization.

Se-Keun Oh et al. designed a varactor tunable slim antenna [67] which covers frequencies for Digital Cellular Systems (DCS: 1710-1880 MHz), Personal Communication Systems (PCS: 1850-1990MHz), Universal Mobile Telecommunication System (UMTS:1900-2200MHz), WiBro (2300-2390 MHz), Industrial, Scientific and Medical band (ISM) and WLAN (5150-5250 MHz and 5725-5850 MHz). The designed antenna combines the use of slots, Planar Inverted -L (PIL) and varactor diode for obtaining frequency tuning. In this technique, the total volume of components is an important issue for applications in portable handheld devices.

A tunable via-patch loaded PIFA with size reduction was presented by Chi Chiu et al. [68] for application in the 2.4 ISM band. In the designed patch, the adjustment of the
height of the via patch was done by turning a screw. Tuning was obtained in the range from 2.5 GHz to 3.3 GHz. An L-Shaped opening was cut on the ground plane under the patch for enhancing the impedance bandwidth. This type of mechanical tuning needs large parametric variations posing a challenge to the designer in catering to specific application requirements.

J.-C Langer et al. proposed a micro machined reconfigurable out of plane microstrip patch antenna using plastic deformation magnetic actuation [69]. Measurement was done for four angular positions of the antenna: 0°, 15°, 45° and 90°. Practical issues that arise for these designs are stress failure at the joints over the life time of the antenna. Moreover, the strength of the external magnetic field necessary to bend the antenna limits the size reduction. Also the presence of magnetic material on the patch causes significant losses.

1.2.2 Size reduction techniques

X.L. Bao et al. presented a miniature wide band patch for portable and cellular applications [70]. A cross-slot was placed in the ground plane which can achieve reduction of patch size and introduction of cross slot-ring provides broadband characteristics. Appropriate adjustment of antenna parameters is essential as the concentric annular ring-patch and the slot ring in the ground plane may generate multiple resonant modes.

W.-L Chen et al. presented a Sierpinski carpet microstrip antenna based on capacitive loading technique and obtained size reduction of 33.9% [71].

Investigations on an H- shaped microstrip patch antenna with inductive loading had been reported by Pradyot Kala [72]. Theoretical calculations were done for adjustment of the H- shaped patch antenna loaded with multiple shorting posts based on the transmission line theory. Optimizing the parameters connecting the two arms of the ‘H’ and other patch dimensions is claimed to have the potential for size reduction.

Shaoqiu et al. presented a method for combining bandwidth enhancement with size reduction for design of ultra low profile antenna [73]. Commercially available Ansoft HFFS software was used for simulation. Results were obtained by using inset fed loaded and slots, for exciting two orthogonal modes, TM_{10} and TM_{01} simultaneously.

B.R. Holland et al. presented a tunable co-planar patch antenna using varactor [74] operating in the frequency range of 4.92 GHz to 5.40 GHz. Possible applications include next generation multi-standard wireless communication systems. The capacitive loading effect introduced by the varactor at the top radiating edge caused phase alteration between top and bottom radiating edges which tilted the pattern.
Ricky Chair et al. proposed a miniature half slot wide-band, half U-slot and half E-shaped patch antennas [75]. U-slot was introduced to improve size reduction compared to that obtained using shorting post. Bandwidth in the range of 20-30% was obtained using relatively thick substrate (=0.08\lambda). The radiation patterns were asymmetrical in the XZ-plane with a strong $E_p$ field in the YZ-plane caused by structural asymmetry of the half U-slot.

Davor Bonefacic et al. proposed small H-shaped antennas [76]. Modifications to the H-shaped antennas were performed for three different cases: shorting the patch, introducing shorting posts and shorting with folded radiating edges of the patch. All the antennas were designed for 2 GHz. Maximum measured gain obtained was in the range from 3.6 dBi to 5.3 dBi. Reduction in size was observed at the expense of bandwidth. Again, shorting influenced cross polarization level when the lengths become larger than the width of the patch.

Yonghoon Kim et al. presented a size reduction technique by elevating the centre of the patch [77]. A size reduction of 53% was obtained at a single frequency of 3 GHz. Further size reduction was obtained by additional notch on the patch. In this approach, impedance and gain were degraded due to radiation from the edges of the notch.

Hang Wong et al. proposed size reduction of a patch antenna using parasitic shorting elements [78]. A symmetrical arrangement was employed to avoid unwanted radiation from vertical shorting pins. The design exhibited 3.25% impedance bandwidth with a gain of 2 dBi. Narrow bandwidth was a limitation in the design.

Korkontzila et al. designed a square patch antenna on top of EBG substrate comprising of two layers, each carrying a biperiodic array of circular patches, which resonate at 2.4 GHz [79]. A size reduction of 24% was obtained. The structure involves several steps which make the design complex and time consuming. Use of adhesives between layers of laminations, proper machining and spacing between periodic structures were required in this design.

Y.J. Wang et al. reported a compact and broadband microstrip patch antenna [80]. An impedance bandwidth of 17.8% was obtained in the frequency range from 1.862 GHz to 2.225 GHz.

E.E.M Khaled et al. proposed a compact patch antenna based on slot matching [81]. Four frequency bands in the range from 2 GHz to 5 GHz were obtained with return loss of about -9.54 dB and a VSWR of less than 2.
A small size broadband microstrip patch with small ground plane was reported by Ji-Hyuk Kim et al. [82]. Broadband characteristics were obtained from 5 GHz to 6 GHz with multiple layers of substrates. The antenna was divided into three segments and each segment was connected to a microstrip line. The fabrication process involved many steps such as thermal evaporation, molding, electroplating, wafer preparation etc. due to which the cost of fabrication becomes a limiting factor.

Michal Pokorny et al. reported a planar tri-band inverted F-antenna using slots and parasitic patches to cover the GSM 900, GSM 1800 and ISM 2400 bands [83]. Multi-objective optimization was chosen for genetic algorithm (GA) for improvement in the impedance matching and the direction of maximum gain. The practical design revealed some shift in resonant frequency ostensibly caused due to manual assembly and soldering of the antenna and metal pins.

J.Vekataraman et al. proposed a small microstrip patch antenna [84]. Three patches were designed for size reduction of up to 70%. In one method, genetic algorithm was used to optimize size and location of the slots on the patch. In another method, the patch was loaded with multiple slots along its edges where particle swarm algorithm interfaced with HFSS has been utilized for optimizing the dimension of the slots. In yet another approach, Complementary Split Ring Resonator (CSRR) has been placed in the ground plane of the patch to create left handed effect that results in negative permittivity.

1.3 Motivation for the present Work

As mentioned earlier, compact and broadband antenna characteristics are two of the prime considerations for present day wireless systems such as Wireless Access Systems (WAS) and Mobile Wireless Systems (MWS) including WLAN, WiMax, RFID, UWB etc. for short, middle and long range communication systems. Antenna designed for these applications should therefore be easily customizable and configurable to cater to different application requirements with minor alterations in the structure; be it at the fabrication stage or after.

One method for size reduction of microstrip antenna is to use high permittivity substrates. However, the difficulty in achieving this is compounded by the fact that one needs to maintain performance characteristics within the acceptable limit for a particular application. Antennas for mobile systems need specific minimum band width, high efficiency, impedance matching and acceptable radiation pattern bandwidth for practical applications. In particular, the excitation of surface waves within the substrate may deteriorate the antenna gain and the shape of the radiation pattern. Again, size
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Chapter I

Miniaturization of normal patch has been accomplished by loading, which may take various forms such as use of high dielectric constant substrates, modifications of basic patch shapes, use of shorting elements and combinations of the above techniques.

Bandwidth enhancement techniques employed for conventional patch antenna include use of a thick substrate with low dielectric constant, using planar and gap coupled multi resonators, stacked electromagnetically coupled or aperture coupled patches, impedance matching techniques, log periodic configurations and use of ferrite substrates. However, these techniques have to satisfy the ever increasing demand for low cost, simple fabrication, ease of integration, reliability as well as multi band antennas that can operate at different frequency bands or cover a wide frequency spectrum. All these existing and widely used designs have some limitations; for instance, use of high dielectric constant material for size reduction exhibits narrow bandwidth, high loss and poor efficiency due to surface wave generation. Major modification of the basic patch structure may also cause inefficient use of the available space.

A tunable antenna on the other hand provides an alternative to a broadband antenna in which an antenna with a small BW is tuned over a large frequency range. Tunable multi-frequency antennas rather than broadband antennas can be a preferred alternative when the system needs to operate only at one frequency in each band at any given time. Thus size reduction as well as tuning the resonant frequency at more than one frequency or one frequency within the band or multiband is two major areas that need attention. An antenna that can operate in more than one band with continuous or discrete tuning is a requirement for present day wireless applications. The challenge here is to evolve an acceptable trade off between these requirements and other antenna performance characteristics.

The motivation for the proposed work is essentially driven by the need for lower cost antennas providing the performance characteristics required without significant increase in weight or compromise on profile.

The thesis presents some new structures which are designed in this work for:

• Size reduction
• Dual/Multi-frequency operation with tuning of the lower and/or higher frequencies or both.

1.4 Thesis Outline

The present work carried out has been organized into 7 chapters covering the different design techniques with measured and simulation results. High frequency
simulation software CST Microwave Studio, based on FDTD numerical technique is used for pre-fabrication assessment of design as well as comparison with measured results. Various new designs such as modifying the conventional planar patch structures, adding new elements to the patch for tuning, bandwidth enhancement and size reduction are highlighted.

Chapter 1 gives an overview of microstrip antenna technology, tuning and size reduction techniques.

Integration of the constituent units and PC automation of a test and measurement setup is described in Chapter 2. The automated system can carry out antenna performance measurements which include S parameters and antenna radiation pattern. System performance evaluation has been carried out using standard antennas.

Chapter 3 details studies on a planar patch antenna with slits near the radiating edge and the effect of electromagnetic coupling through it on antenna characteristics and tuning. The effect of elevation of the cut out patch sections at different angles of elevation was studied in detail. Radiation patterns are also presented and comparison of measured pattern shapes with that of the conventional planar structure is included.

Chapter 4 describes a patch antenna with notionally superposed finite microstrip line section for size reduction. Performance is studied with respect to angular position of the line section near one of the radiating edges.

Chapter 5 presents spike edged microstrip patch antenna (SEMPA) designed for bandwidth enhancement. A detailed study on variation of spike number, position as well as strip line loading of spike vertices is carried out with respect to return loss, bandwidth and radiation pattern characteristics.

Chapter 6 includes the design of a reconfigurable patch antenna with a rectangular air pocket in the substrate layer between the patch and the ground plane. A plunger of the same substrate material with the dimensions of the air pocket is inserted into the air pocket for tuning the resonant frequency.

Chapter 7 summarizes the results on the designed antenna structures; highlighting the major achievements, shortcoming and scope for future work.
References


