CHAPTER I

INTRODUCTION TO THE RESEARCH PROBLEM

1.1 Reconfigurable antenna – an introduction

Escalated uses of communication services have necessitated the use of multiple wireless standards. Increased functioning of wireless protocols have also crowded the regime and caused hindrance in trans-reception of the signal. Functioning at multiple wireless protocols requires reconfiguring antenna parameters of interest. Antennas with manoeuvrability in-terms of the direction of transmission, operational frequency and the plane of propagation have always been of concern for solving such issues. Realization of these adaptive features in a conventional single element antenna with static radiation characteristics is generally difficult and usually multiple antennas with varying geometries or phased array structures are used to achieve these functionalities [1, 2]. Conversely, the presence of multiple radiators, in such an antenna system, have the drawbacks of increased system complexity, size and cost [3]. Considering the demands for low profile, simple and cost-effective devices, antennas with reconfigurable radiation characteristics are projected as an alternative to their complex, inflexible and bulky counterparts [4-6].

The ability to dynamically adjust the operational characteristics, with inclusive reconfiguration mechanism is one of the major benefits of reconfigurable antennas (RAs) [7-9]. Alterable parameters are operating frequency, beam pattern and polarization [10, 11]. A frequency reconfigurable antenna has the ability to modify its operating frequency between multiple band positions. Beam sweeping type antennas can steer the radiation pattern towards an intended direction while with the polarization reconfiguration feature, the antenna can change the plane of polarization.

The ease in modifying the topology along with their low form factor and simplicity of integration makes planar radiators the most preferable choice [12]. One of the earliest investigations to achieve alterable antenna features in a planar structure was patented by D. Schabert in 1983 [13]. From late 90s planar reconfigurable antennas have gained considerable attention and have been studied extensively for their potential applications in devices like cognitive radios, MIMO systems etc. [2, 10, 14, 15].

Geometry and functioning of planar reconfigurable antennas are specific to its reconfiguration category and targeted performance [16]. Different reconfiguration mechanisms are used to control and reverse the changes of antenna operating characteristics [10, 14]. In planar structure, the mechanisms are mostly used to redistribute the surface current density for possible reversible changes in antenna radiation properties. One of the most common ways of modifying the current distribution is by using RF switches. The control can be carried out by either applying voltage in electrical switching elements, like PIN diodes [17-20], RF-MEMS [21-23], varactors [24, 25] or by optical illumination on photoconductive elements [26]. Structural modifications of the antenna radiating parts through some movable joints can also tune the antenna properties [27]. Altering some constitutive property of antenna substrate can also bring about the desired reconfiguration. Substrates made up of liquid crystals or ferrites can change their relative permittivity or permeability upon the application of electric or magnetic fields [28-31]. In past decade, fluidic channels are being employed to reconfigure antenna parameters and are either used as parasitic elements in a coplanar design or as the main radiator [32-37].

The extensive investigations on antenna reconfiguration techniques reveal that each of the techniques possesses certain strengths and shortcomings. Electrical switching, provide a reliable, fast and easily attachable way of reconfiguration but most of them are non-linear and some require high biasing voltages [10, 14]. Additionally, they require a biasing network which may cause interference with the antenna performances [38]. The effects of the biasing line, however, can be reduced by strategically placing them. In spite of the linear behaviour of optically controlled switches, they are not so common because of their bulky controlled mechanism. Most of the reported work on optical switching requires a laser source and a network of optical fibers [10, 26, 38]. Physically actuated reconfiguration methods have some benefits as they do not rely on any switching mechanisms or biasing lines/optical fiber integration. But the technique possess some limitations as it has to depend on mechanical actuators and movable joints which increases the overall antenna form factor and have some issues related to the repeatability and switching speed [14]. Moving on to the material based reconfiguration, the major advantages of the techniques is their integration into the system thus reducing the size, however, the main disadvantage is their low efficiency [10]. The fluidic channels have also gained popularity because of their linearity and resilience to wear and tear [39]. The fluids used are mostly liquid metals like mercury which is highly toxic [39] or metallic alloy Galinstan which use is limited due to its relatively high melting point of ~ 10°C [40]. The movements of the liquids inside the channels are generally controlled by a bulky pump mechanism [32, 35, 39, 41, 42].

The switching mechanism choice is a trade-off in functionality, complexity, upkeep, system lifetime and cost. An effective reconfiguration requires a switching mechanism that should be fast, reliable, easy to integrate, low profiled, and preferably have a linear response [2, 10, 14, 37]. None of reconfiguring technique, discussed above, completely satisfies all the criterions. The most widely used technique is electrical switching. Apart from its non-linear response, electrical switches gain popularity due to their fast response time, easy control mechanism and higher reliability. The three most commonly used electrical switches are RF-MEMS, varactor and PIN diodes. A detailed listing of characteristics of these switching elements is given for comparison in Table 1.1 [14].

Low operating voltage, the wide frequency range of operation and ease of integration are the factors which make PIN diodes more suitable than the other two types [16]. Numerous works have been reported for PIN diode based reconfiguration to achieve frequency and beam pattern adaptations. Frequency alternation is mostly done by controlling the surface current distribution using structures like slots, fragmented patches, fractals, nested radiators etc. In nested structures, the antenna patch dimension increases with the tunable frequency range as observed in references [43-45]. Slotted structures, however, offer more versatility in shifting the operational frequency than the nested configuration.

Table 1.1 Attributes of electronic switching elements

Electronic Elements	Advantages	Limitations
PIN Diode	• Provides discrete tuning • Low bias voltage • Fast switching speeds • Inexpensive • Easy integration • Commercially available • Low insertion loss	• May require complex biasing network • Low to moderate power handling
RF-MEMS	• Provides discrete tuning • High isolation • Low insertion loss • Low power consumption • High linearity	• Requires high activation voltages • Requires hermetic packaging • Relatively expensive • Lower reliability • Limited commercial availability
Varactor Diodes	• Provides continuous tuning • Easy to integrate • Low power consumption • Moderate insertion loss	• Moderately high bias voltage • May require complex biasing network • Lower working band width

Simply altering the slot configuration can cover a large frequency range without much change in its physical dimensions [46, 47]. In [48], a slot antenna with nine reconfigured bands (1.98 GHz – 3.59 GHz) is presented. A switchable multiband operation over a wide range of about 4.60 GHz is reported in [18]. However, variations of radiation patterns at different frequencies are noted. A continuously tunable antenna is proposed in the approach [49], where a single PIN diode and varactor is used. This investigation offers a continuous tuning, covering a range from 0.42 GHz – 1.48 GHz with a consistent radiation pattern over the whole tuning range. Conversely, the relatively high value of biasing voltage used for tuning makes it less suitable for some operations with limited power source [10].

Similar to the frequency reconfiguration, beam pattern reconfiguration in planar antennas are also extensively investigated. Commonly, electrically or mechanically controlled parasitic elements are used for the beam sweeping [1, 50-55]. A single feed beam switching antenna with the ability to steer the beam in both E-and H-plane is reported in [3], with the main beam capable of switching in four different directions. Jusoh *et al.* [56] have presented a parasitic planar patch antenna that can redirect the beam to nine different directions in both azimuthal and elevation planes.

In conjunction with electrical switching, works based on fluidic channels are also reported. Liquids are being integrated with antennas for various applications such as frequency tuning, pattern reconfiguration etc. [34, 39, 42, 57-60]. Approaches made for reconfiguration of antenna frequency using liquid metal as shorting elements are reported in [36, 61]. These microfluidic RF switches are used to short various slots present in the antenna structure. Liquid metals are also being used as antenna radiating patch in frequency tuning applications. In [58] fluidic actuation based frequency reconfigurable antenna is presented. Here, a mechanical pump (syringe) is used to change the position of the liquid metal to alter the operating frequency. A reconfigurable liquid monopole antenna with a tuning ratio of 5.2:1 and driven by electrochemical actuation is reported in [60]. A colloidal dispersion with changeable height is used as a frequency tunable dielectric resonator antenna in [33]. An annular slot antenna with surface-integrated fluidic channels for independent control of multiple resonating notches is reported by Murray *et al.* [59]. A maximum tuning range of about 3 GHz is offered in the design. Single axis variation of beam direction in a pressure-driven five-element liquid-metal monopole array antenna is presented in [35]. Rodrigo *et al.* in their work describe a beam reconfigurable antenna with mechanically controlled liquid metals as parasitic elements [39]. The antenna provides a beam steering of 360° in E – Plane.

1.2 Problem formulation and objectives

The work focuses on two techniques to reconfigure frequency and beam pattern in a planar antenna geometry. Importance is given for simplicity and compactness of the overall system. Stability of antenna performance is also emphasized. At first, an electrical switching technique is investigated for frequency and beam reconfiguration. The objective is to achieve maximum level of reconfiguration with minimum possible complexity of the system. Secondly, a microfluidic channel based reconfiguration technique developed for the alteration of antenna characteristics. Usability of the technique for both frequency and beam tuning is also studied. Thus, the current work aims at:

1. Development of a frequency reconfigurable planar antenna using PIN diodes, with stable radiation characteristics for all the reconfigured frequencies with minimum switches to alleviate biasing issues.
2. Realization of beam steer-ability in patch antenna through a network of PIN diode controlled parasitic elements.
3. Development of a magnetically controlled contactless microfluidic actuator for frequency reconfiguration by varying the material property of the substrate in planar geometry.
4. Magnetically controlled fluidic switches as parasitic elements for beam reconfiguration in planar antenna.

As the aim of the work is to demonstrate frequency and beam reconfiguration with simple and low form factored techniques. C-band is chosen as:

- Comparatively, large antenna size provides more room for design manipulation.
- No known commercial and industrial frequency bands for the current working range of 6.00 GHz to 8.00 GHz. So there is a better possibility to do interference free measurements without anechoic chamber.

1.3 Thesis structure and outline

The thesis is structured into six chapters focusing the design and development of frequency and beam reconfigurable low profiled antenna in C – band. An introduction to the reconfigurable antenna, its background research, applicability, challenges and issues to be targeted are discussed in the current Chapter.

In Chapter II, design and development of frequency reconfigurable planar antenna using PIN diodes is presented. A meandered slot patch antenna is designed and evaluated for its performance as a reconfigurable antenna. The design is optimized to enhance the reconfigurable frequency range.

Electrically controlled sets of parasitic elements are designed to steer the beam direction of a patch antenna. PIN diodes are used to reconfigure the beam pattern of the antenna and performance of the designed antenna is tested. This is included in Chapter III.

A magnetically controlled contactless reconfigurable technique for antenna frequency reconfiguration is developed. Chapter IV describes the design, development and testing of the technique.

Chapter V discusses the work on beam pattern reconfiguration of patch antenna using microfluidic channels as directing elements. Details of the design scheme and testing of the developed antenna are presented.

Chapter VI summarizes the suitability of the developed reconfigurable technique and antenna for potential application in C-band. The limitations and possible future direction of the work that can be carried out are also included.

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