# CHAPTER VI

# CONCLUSIONS AND FUTURE DIRECTIONS

The thesis focuses on the development of simple, compact frequency and beam reconfigurable planar antennas with stable antenna performance. PIN diode and microfluidic switching techniques are employed to achieve the functionalities. Both the techniques are simple and effective.

For frequency reconfiguration, two meandered cross slots of different dimensions are introduced along the non-radiating edge of a rectangular patch antenna. The effective length of the patch boundary is controlled through strategically placed PIN diodes. The antenna can be reconfigured to four frequency bands using only two diodes. The bands collectively cover a continuous – 10 dB range of 1.80 GHz. The broadside beam pattern of the RMA is conserved during the reconfiguration and the antenna has a directivity of ~ 7.20 dB and gain averaging to 5.20 dBi. The space filling property of the slots forces surface currents to travel a much longer path within a small area. A constant overall physical dimension and minor variations in field distributions across the periphery of the patch results near identical radiation characteristics for all the operating modes. Beam patterns of all the reconfigured frequencies are identical to the broadside beam of a standard RMA. Placement of biasing circuitry to the non-radiating sides of the patch reduces the possible interference caused by it.

A prototype of parasitic element based multi-stepped beam steering reconfigurable antenna, with the capability to scan wide spherical displacement, is developed. The presented reconfigurable antenna consists of a driven antenna with four sets of parasitic elements which are placed in a coplanar configuration. The antenna beam directions are controlled, following Yagi antenna principle. Each parasitic elements is split into four metallic strips controlled by PIN diode switches. A network consisting of PIN diodes and RF inductors toggled the status of each parasitic elements between director and null. With different sequential switching of the PIN diodes attached to the strips, multi-stepped beam steering is obtained. Thus, with 16 such parasitic strips, the antenna reconfigures the beam into 57 different directions. With a sweeping resolution of ~ 10˚, the antenna can scan a spherical distribution up to ~ 40˚ off broadside in both XZ and YZ planes.

The precisely optimized position of the directing elements helps in maintaining the stability of the antenna return loss. The antenna resonates at around 8.00 GHz for all the reconfigured beam directions. A fairly stable directivity of around 8.0 ± 0.6 dB and moderate gain of 4.7 ± 0.5 dBi are observed for the antenna throughout the reconfigured range. The design requires a low-complexity mode selection algorithm to control the beam direction with enhanced resolution, unlike most of the arrayed antennas.

Another switching system studied for frequency and beam tuning is a magnetically controlled contactless microfluidic channel based technique. For frequency reconfiguration, an engineered antenna substrate, housing fluidic channels, is fabricated. The channels contain ISPW (Isopropanol and deionized water solution) and ferrofluid (nanosized magnetite particle dispersed in hexane), which are immiscible and have significantly different dielectric constant values. Being magnetic in nature ferrofluid's position can be controlled electromagnetically. With the interchanged position of two liquids, an alterable spatial variation of the dielectric constant is obtained within the channels. The technique reconfigures the resonating frequency between two values of 7.40 GHz and 8.00 GHz, respectively. The antenna maintains stable radiation patterns with gains 3.20 dBi and 5.80 dBi. The variations in the gain values are due to the lossy nature of one of the liquids used.

The steering of antenna beam pattern is done by using microfluidic channels as directors in a planar rectangular patch configuration. 10 molar solution of NaCl in the channel acts as the conducting fluid. The channelized conducting liquid turned directing element is activated/ deactivated following the Yagi antenna principle. The toggling is done through the selective positioning of ferrofluid within the channel, which is electrically insulating. Control through a pair of electromagnets attached to each directing channel collectively leads to multi-stepped reconfigurations. The beam can be shifted to 19 different directions. The antenna preserves the consistency of its resonating frequency for all the reconfigured beam patterns. Directivity and gain are also fairly stable with values of 8.3 ± 0.3 dB and 4.7 ± 0.5 dBi, respectively.

The presented works focus on the development of reconfigurable antennas for microwave communications. Both the switching techniques can be replicated to other frequencies also, by undergoing the required design related modifications.

For frequency reconfigurable patch antennas, there are scopes to further increase the tuning range with a need to improve the antenna efficiency at lower frequencies. This may require modifications of the feeding networks also, as the frequency of the feeding network (especially quarter-wave transformer) needs to be matched for better input impedance matching. Reconfiguration over a small frequency range is also possible if the bandwidth of each individual resonating notch is further narrowed down.

Fine steering resolution will be required beam scanning antenna, where antennas get misaligned due to wind sway or other accidents, but the connections should not be lost. Enhanced beam scanning resolution and wider coverage area can be achieved with the increased number of parasitic elements. However, issues related to system complexity and increased form factor may arise and are needed to be addressed. Reducing the variation in the antenna operating frequency and enhancing the antenna gain would be another aspect for study in future.

The microfluidic actuation offers a proximately controlled reconfiguration technique for tuning the functionalities of reconfigurable antennas. The technique is simple and contactless and does not require auxiliary biasing units as in case of electrical or optical switching. The method also does away with bulky pump mechanism and complex network of connecting pipelines, mostly used in liquid based tuning techniques. Further fine tunings especially the actuation speed and the lossy behaviour will make it a potential technique to effectively convert a standard patch antenna into a contactless reconfigurable one. Increasing the number of reconfigurable frequencies to more than two could be another interesting future study. Investigation of a highly conductive liquid which conforms to RoHS standards may enhance the efficiency. Future research direction can be extended to investigate and create polarization diverse patterns in addition to directionally diverse patterns.

**Publications:**

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2. R. Baruah and N. S. Bhattacharyya, "A frequency reconfigurable antenna with consistent radiation characteristics," IEEE Conference Proceedings, pp. 177-180, 2017, DOI - 10.1109/IESPC.2017.8071887.
3. Rocktotpal Baruah, and Nidhi S. Bhattacharyya,"Ferrofluid actuation based frequency reconfigurable patch antenna" Progress In Electromagnetics Research Letters, Vol. 79, 71–77, 2018.
4. Rocktotpal Baruah, and Nidhi S. Bhattacharyya,"An electrically switchable single radiator beam scanning antenna in planar geometry" (In process).

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