Chapter 6

Conclusion and Future Work

This chapter summarizes the contributions presented in this dissertation and proposes future work to enhance the existing research.

6.1 Outcome of the Thesis

The main focus of the thesis was to design and develop RA capable of realizing independent pattern, beamwidth, and polarization reconfiguration. The RA designs presented in this thesis provide diversity in terms of pattern, polarization, and beamwidth reconfiguration at an operating frequency of 2.45 GHz.

Chapter 1 gives a general introduction and motivation to design pattern and polarization RA. This introduction provides an initial description of the concept of antenna reconfiguration. The benefits offered by RAs in wireless communication applications are discussed with particular emphasis on pattern and polarization reconfiguration. This chapter also presents details related to the proposed antennas simulation, fabrication, and measurement. The main objectives of this thesis are detailed and a description of the structure of this document is provided.

In Chapter 2, a detailed literature survey on the linearly polarized and circularly polarized PRA is presented. Descriptions of the various methodologies employed for achieving antenna reconfiguration are explored. The PRA designs reported in the literature are classified as 1-D beam steering, 2-D beam steering, beamwidth RA, and beam steering and beamwidth RA. The pattern and polarization RA designs are classified according to the radiation pattern characteristics.

Limitations and drawbacks of the existing pattern and polarization RA designs are discussed in detail.

The next three chapters presented newly developed antenna designs realizing independent pattern, beamwidth, and polarization reconfiguration. The proposed RA designs consist of a square-shaped driven element surrounded by tunable parasitic elements. The dual-band behavior of tunable parasitic elements allows a continuous change in the effective electrical size, as compared to the size of the driven element. The tunable parasitic patch size method provides efficient control on the mutual coupling and gives a clear insight into the behavior of tunable parasitic elements.

In Chapter 3, PRA design is proposed to achieve continuous beam scanning from -40° to 40° in the H-plane. In contrast to the previously reported PRA designs based on the microstrip Yagi principle the proposed antenna offers improved and symmetrical 1-D beam scanning without the use of any impedance matching network. Initially, a reconfigurable dual-band antenna consisting of a hexagonal slot loaded with varactor diodes is proposed. This antenna is used as a tunable parasitic element in the proposed three-element PRA. The operating frequency of the tunable parasitic element can be continuously tuned above and below the driven element center frequency of 2.45 GHz. Main beam direction of the antenna is determined by the phase difference between active patch and tunable parasitic elements, and phase differences are influenced by the resonant frequency of tunable parasitic elements. The effect of distance between the antenna elements and size of the parasitic element on reflection and beam scanning characteristics is analyzed in detail. It is shown that for spacing less than 3 mm, strong currents are induced on the parasitic elements, and it is difficult to obtain good impedance matching at 2.45 GHz for all the capacitance values. It is also shown that 1-D electronic symmetrical beam scanning with low SLL is obtained by placing two parasitic elements around the driven element serving as a reflector, director, or neutral element. Performance of the proposed antenna is measured in three operating modes namely RD, DR, and broadside.

In Chapter 4, PRA is proposed to realize 2-D continuous beam scanning and beamwidth reconfiguration in both the principal planes. The simulated and measured results prove antennas reconfigurability of the main beam in eight directions with 45° steps in azimuth plane and continuous beamwidth tuning in the E-plane and H-plane. The proposed cross parasitic antenna consists of a square-shaped driven element and tunable parasitic elements placed in the E-plane and H-plane. This antenna has the advantage of achieving both pattern and beamwidth reconfiguration in a single antenna structure with a low profile, simple biasing circuit, and less number of active components. The mutual coupling is analyzed in detail for different configurations of parasitic elements. It is shown that for a square-shaped antenna elements coupling between the non-radiating edges is stronger as compared to the coupling between radiating edges. It is also found that to achieve complete 360° azimuth coverage the parasitic elements need to be placed in the cross configuration. The simulated and measured results show that the main beam of the antenna is continuously scanned from 0° to 32.4° and 0° to 40° in ϕ = (45°, 135°, 225°, 315°) and (90°, 270°) plane respectively. The difference in coupling levels of E-plane and H-plane affects the beam scanning capabilities in ϕ = (0°, 180°) plane and the maximum scanned angle gets limited to 10.8°. It is observed that by physically changing the size of the parasitic element from 21 to 41 mm, the 3-dB beamwidth in the E-plane and H-plane can be varied from 44° to 166° and 58° to 140° respectively. It is demonstrated that reflector and director properties of the tunable parasitic element can be used to achieve continuous beamwidth tuning in both the principal planes. The simulated and measured results show that the 3-dB beamwidth of the cross antenna is continuously tuned from 65° to 152° and 64° to 116° respectively.

In Chapter 5, RA design is proposed to achieve independent pattern and polarization reconfiguration along with beamwidth reconfiguration. The proposed antenna provides the highest level of diversity by realizing polarization reconfiguration along with pattern and beamwidth reconfiguration in a single antenna structure. To achieve pattern reconfiguration with CP is a difficult task, and the challenge is to maintain polarization purity in each main beam scanned direction. This RA is capable of scanning the main beam in the elevation plane for each polarization state and provides complete 360° coverage in the azimuth plane. The LP (LVP, LHP) and CP (LHCP, RHCP) reconfiguration are realized by developing RFN consisting of a 3-dB quadrature hybrid coupler and RF switches. The effect of single-feed and dual-feed configuration on CP beam scanning characteristics is discussed in detail. The single-feed corner truncated driven element has an advantage of low profile and simple design. However, it is challenging to maintain CP purity when the main beam of the antenna is scanned at higher angles in the elevation plane. The dual-feed antenna configuration provides excellent CP performance, and AR is less than 3 dB over the complete beam scanning range. In LP operating mode, main beam of the antenna is continuously scanned in the elevation plane from θ = 0° to 11°, 0° to 32° and 0° to 40° in $\phi = \pm 0°$, ±45° and ±90° plane respectively. In CP operating mode, beam is continuously scanned from 0° to 30° for $\phi = \pm 0°$, ±45° and ±90° plane respectively. The 3-dB beamwidth of the antenna can also be continuously tuned either individually or simultaneously in the broadside direction for LVP and LHP configuration.

6.2 Future Work

Following are some of the topics which can be explored further in the context of work carried out in this thesis.

- **Array design** : The proposed RA designs can be utilized into planar 2×2 phased array to realize an increased gain, lower SLL, and minimum gain fluctuation. The number of phase shifters can be reduced in phased array design since parasitic elements provide an extra degree of freedom in controlling amplitude and phase of the mutually coupled field. The lower SLL can be achieved by changing the power distribution of the driven elements through a feeding network.
- **Compound RA** : RA designs presented in this thesis achieve independent pattern and polarization reconfiguration at a fixed operating frequency of 2.45 GHz. The proposed RA design can be further extended to realize independent frequency, pattern, beamwidth and polarization reconfiguration.
- **Wideband pattern and polarization RA** : The sequential rotation technique can be used to design a wideband pattern and polarization RA. The RFN used in this thesis performs satisfactorily over a narrow bandwidth. The wideband RFN can be designed using cascaded branch-line coupler, Schiffman phase shifter, and diversity switches.
- **System analysis** : One of the most important continuations of this work is the study of system-level benefits derived from the use of pattern and polarization RAs in wireless communication systems. Efficient algorithms should be proposed for optimum mode selection in pattern and polarization RA.