This chapter highlights the conclusions drawn from numerical, simulation and experimental investigations of broadband and high gain microstrip antennas. The important inferences of the strip loading and offsetting techniques are also presented along with some of the future directions in this area.
6.1 Thesis highlights and Key contributions

This chapter describes the closing stage of the thesis by summarizing the important conclusions drawn from the experimental and simulation studies of the broadband and high gain strip loaded slotted square patch antennas.

An overview of the antenna research along with the state of art technologies in planar antenna designs are highlighted in chapter 1.

A broad literature review regarding the development of microstrip antennas and the different technologies used to enhance the bandwidth of microstrip antennas are included in chapter 2. The motivation behind the present work regarding the bandwidth enhancement technique persistent towards the current technological developments is explained in detail in this chapter.

Experimental, numerical and simulation studies towards the development of a broadband strip loaded slotted square patch antenna are the core of chapter 4. Investigations are carried out on tilted square slot and polygonal slot loaded patch antennas and the resonant mechanism is explained in detail. Simple design equations are formulated and are validated on different substrates. Finally, L-strip feed mechanism is successfully implemented to broaden the bandwidth of the polygonal slotted patch antenna further.

Investigations on the gain enhancement technique for single band square patch antenna and two broadband configurations discussed in chapter 4 are discussed in chapter 5. Stacking is successfully implemented and the upper parasitic patch is offsetted to enhance the gain of the structure. The technique
effectively reduces the overall volume of the stacked antenna configurations considerably.

6.2 Inferences from the wideband strip loaded slotted patch antenna

The interferences drawn from the experimental and simulation analysis of the strip loaded broadband patch antennas are summarized below.

- By properly optimizing the strip dimensions, the resonances caused by the patch antenna can be effectively matched and can be merged with the resonance offered by the patch and the strip.

- The antenna has a 2:1 VSWR bandwidth of 38% for the tilted square slot structure and 45% for the polygonal slotted structure, making it suitable for 5.2/5.8 GHz WLAN, HIPERLAN2 and HiSWaNa communication bands.

- The impedance matching strip is incorporated on the same plane of the antenna structure and hence it is devoid of spacers required to support the impedance matching strip as in conventional designs and the design reduces fabrication complexities.

- The added metal strip overcomes the high capacitive reactance offered by the lower resonances and it is found that increase in the strip length shifts the imaginary part to the inductive side. The strip acts like a series LC circuit connected in series with the slotted patch antenna.

- The design equations formulated can be used for the validation of the antenna on different microwave substrates.
6.3 Inferences from the offset stacked single band and broadband high gain designs

The interferences drawn from the offset stacked single band and broadband high gain microstrip antennas are summarized below.

- Principle of stacking is effectively applied and the position of the upper patch is offset without deteriorating the impedance matching performance of the antenna for single band and broadband designs.

- In conventional stacked high gain antennas, gain enhancement is achieved by stacking the parasitic patch at a height equal to the half wavelength of the resonating frequency. The offsetting technique greatly reduces the volume of the antenna without deteriorating the impedance matching performance of the antenna.

- In conventional stacked patches, when the separation between the patches is very less, then the space between the patched acts like a strong cavity and it resonates at the \( \text{TM}_{01} \) mode of the patch antenna and the electric field between them contains mainly \( E_z \) component. When the separation between the patches is equal to half wavelength of the resonating frequency of the patch, the space between the patches acts like a leaky cavity, and \( E_x \) component dominates and it aids radiation. The offset in the position of the stacked upper patch without increasing the stacking height, in effect, makes the space between the patches as a leaky and hence it enhances the fringing electric fields from the patches and the antenna exhibits high gain performance.
Conclusion and future perspective

- The single band design working around 2.3 GHz has a stacking height of the order of $0.025\lambda_g$, where $\lambda$ is the guided wavelength corresponding to the resonant frequency of the antenna and gain of the antenna is found to be 4.8 dBi.

- The offset stacked tilted square slotted and polygonal slotted broadband designs exhibits a bandwidth of 34.9% and 32.56% respectively and shows a maximum gain of 8.07dBi and 8.9dBi respectively.

6.5 Suggestions for future work

The strip loaded broadband patch antenna can be configured for much compact mode of operation by increasing the strip length. It is found from the experimental and simulation studies that the increase in the strip length lowers the resonant frequencies offered by the patch. But the impedance matching performance deteriorates. This is due to the fact that increase in the strip length increases the real part of the impedance and the imaginary part shifts towards the inductive side. The impedance mismatch can be overcome by loading a parasitic patch over the antenna. This is because, the placement of the upper patch lowers the input impedance and it suppresses the high inductive reactance and hence a much compact mode of operation can be achieved.

The strip loaded antennas can be made in the form of an array to enhance the bandwidth of the antenna to meets the requirements of ultra wide band radio which uses 3.1 GHz to 10.5 GHz frequency spectrum in the frequency band. Here the patches can be fed with Wilkinson power divider and the distances between the patches can be adjusted so that the resonances offered by each of the strip loaded patch antenna can be merged to give an
extra large bandwidth. Here the number of patched required will be lesser as compared to the existing Ultra Wide Band log periodic designs available in the literature.

The main design concern regarding the implementation of high gain antennas is their suitability in urban environment. We have checked the radiation patterns of the antenna within the anechoic chamber and outside the chamber and no predominant variation in the radiation characteristics is observed. The existing antenna designs used for indoor wireless application have a gain in between 2 dBi and 9 dBi and the antenna is practically grown along with the wireless communication module. So for indoor application, the gain and bandwidth reported by our design is sufficient. The reported antenna can be easily grown with the wireless module, provided that the antenna should be detuned against the near field coupling effects of the RF circuitry. But in a noisy street, signal fading effects will be predominant. In such a situation, we have to go for array designs of the existing antenna for getting improved gain characteristics. In a normal closed array design, the mutual coupling effects will be present and hence steps should be taken to minimize the mutual coupling effects. It includes implementation of broadband PBG ground planes for the entire array structure for the operating band of interest.