This chapter sums up the results and highlights the achievements of the research work carried out. This is followed by few suggestions for future work. The results presented in the thesis have been published by the author in different international journals and conferences.
5.1 Thesis Summary and Conclusions

The aim of the thesis was to investigate the design requirements of compact planar antennas for ultra wide band applications. Two types of antennas belonging to this class were identified: monopole and slot antennas. Three novel compact antennas were designed, namely ground modified monopole, serrated monopole and triangular slot antenna. The evolution of the designed antennas were investigated in detail to have an insight into their wideband behavior.

The design aspects, based on the geometrical parameters of the antenna, were first investigated. The simulation studies, in terms of their return loss and current/field distribution on the antenna at different resonances, reveal their dependence on the antenna dimensions. Dimensional parameters, critically determining the resonances and wideband impedance matching of the antenna, were identified and simple relations were deduced. This can help the antenna designer to design the antenna on any substrate for the desired frequency range of operation. The deduced geometry can act as a precursor to the final design optimized using any of the simulation softwares.

The designs also incorporate thin slot resonators inscribed within the radiator to reject narrow frequency bands. Such embedded filters avoid the use of additional filters in the circuits which may not be desired for portable wireless systems with space constraints.

A brief summary of the different antennas designed are;

1. **Ground modified monopole antenna**

This antenna has a wide band of operation (3.1GHz to 12GHz), simple structure and an omnidirectional radiation patterns especially at the lower end of the spectrum. This UWB monopole design is arrived from an
existing narrow band design by a geometric manipulation of the ground plane, whose design aspects are presented in Chapter 3. As mentioned in the detailed literature review of monopole antennas, there are several design practices to realize UWB in such antennas, which may even complicate the antenna design. In the present work a novel method is proposed which include removing quarter circles from the ground plane which can be mathematically accounted to design the ground modified Monopole antenna on laminates with any permittivity.

2. Serrated monopole Antennas

A microstrip fed serrated monopole antenna is designed first which has a reduced size of 20x22mm$^2$ and wide band of operation(3.09 GHz to 11.6 GHz) is developed. The UWB response is achieved by a microstrip fed staircase patch with an identical inverted ground plane. Antenna appears to be perfectly ideal for UWB hand held applications with compact size, stable & omnidirectional antenna pattern. The antenna gain averages around 2.5dBi and an average efficiency of 85% is noted in the operating band. A band notched antenna to notch out the 5.8GHz WLAN band by etching an inverted U slot from the patch is also presented. Electronic reconfiguration of the notch band by integrating a PIN diode across $\lambda/2$ inverted ‘U’ slot is also demonstrated. A CPW version of the antenna is also developed and studied at the end of the chapter.

3. Triangular slot Antennas

A triangular slot antenna having the size of 26x26mm$^2$ overcomes the disadvantage of pattern deterioration at higher frequency region found in the case of ground modified and serrated monopoles is also presented. The antenna features all the desirable characteristics demanded by UWB
communication systems such as adequate impedance bandwidth and stable radiation patterns throughout the ultra-wide band. This design also include an open ended slots inscribed on the tuning stub to notch out the 5.8GHz WLAN band.

The antennas designed for UWB operation from 3.1 to 10.6GHz has been further analyzed for their time domain response in the final section of the chapters to confirm their suitability for pulsed UWB applications. The transfer function measurements are performed for the azimuthal planes and their impulse responses are deduced. The band-notched antenna designs record a clear increase in ringing. The antenna effects on nano-second pulses are measured in terms of the fidelity factor and values > 90% in the azimuth plane is recorded for all antennas. The triangular slot antenna gives a superior performance with a fidelity >95% in the azimuth.

All of the designs proposed in this thesis can be conveniently used for ultra wide band systems. However, in the case of ground modified monopole and serrated monopoles, a distortion in the pattern is observed at higher frequencies since the region of radiation does not remain constant. This distortion in the frequency domain gets reflected in the transient response of the antenna and the performance varies with azimuth angle.

The triangular slot antenna, by virtue of their near omnidirectional pattern over the whole bandwidth, exhibits relatively uniform transient response for different space coordinates. The performance of all the designed UWB antennas is, however, within tolerable limits which makes them suitable for pulsed UWB applications.
5.2 Suggestions for Future Work

The following are some of the prospects for future work:

The transfer functions are determined from the measurements. But they can also be found from simulation by placing virtual probes around the antennas. For better understanding of the 3-dimensional antenna radiation properties, an automated measurement setup may be devised in future to measure at different spherical coordinates of the antenna.

A direct time domain measurements may also be performed in future for all the designed antennas using the pulsed power measurements available in PNA’s. The antenna can be designed on low temperature co-fired ceramic (LTCC) substrates in future which have the advantage of direct integration with monolithic microwave circuits.

Further miniaturization of the antennas designed is a feasible future prospect, the techniques to achieve ground-independent UWB antenna performance may be stressed in order to enhance their prospect of adoption in practical applications. Diversity UWB antenna may also investigated for the same reasons. When the antenna is built on a portable device, the impact from human body may also be considered.

UWB systems operate at extremely low power level which limits its transmission range. In order to enhance the quality of the communication link and improve channel capacity and range, directional systems with high gain are required. Therefore, research on UWB directional antenna and antenna array may be carried out.
Due to the low power level operation of UWB systems, a typical UWB receiver requires a low-noise amplifier. Antenna integration with low-noise amplifier may be investigated in future.