# Chapter 5: CONCLUSION AND FUTURE SCOPE

The thesis focuses on design and development of frequency reconfigurable and ultra-wideband antennas with high isolation for cognitive radio applications. With a growing need for efficient spectrum utilization, the development of adaptive systems has become important. The proposed antenna designs address critical challenges such as limited spectrum availability, mutual coupling between antenna elements, and the need for multi-functionality within compact structures. To achieve this, frequency reconfigurable antennas for cognitive radio have been designed and represented in different chapters. This chapter highlights the extensive research conducted on reconfigurable antennas in this dissertation. It discusses the key findings, contributions, and conclusions of the study, along with the scope for future work in this field.

## 5.1 Summary and Conclusion

In todays' modern world, wireless communication is essential entity for enabling data transfer, internet access and visual communication. In any communication system, the antenna plays a crucial role in transmitting and receiving in the form of electromagnetic waves. Traditionally, antennas are optimized for fixed frequency, pattern and polarization characteristics. However, in dynamic environments where these characteristics need to adapt, traditional antennas face several limitations. As a result, the concept of antenna design has evolved significantly, leading to the development of reconfigurable antennas. This approach has become the preferred choice, offering enhanced system performance and efficiency. A frequency reconfigurable antenna is key component of cognitive radio and it enables the dynamic spectrum access by adaptive frequency tuning and fast switching. While operating in wideband or multiband operations, it is essential to maintain the isolation between antenna ports. To accomplish this, various design techniques and design concepts have been proposed in the literature. However, certain notable gaps limits the functionality and applicability of these designs. To overcome these limitations, new design concepts are introduced in the following chapters to achieve the research goals. Some of the key research contributions are summarized as follows:

1) Design and development of a compact, planar and low profile frequency reconfigurable antenna for cognitive radio application.
2) Along with the frequency reconfigurable antenna, a compact ultra-wideband antenna for channel sensing is also included in this thesis.

3) When operating as interweave cognitive radio, maintaining isolation between the antenna ports is crucial. To achieve this, an extended ground plane is designed for improved isolation and bandwidth.
4) Furthermore, the design and investigation of multifunctional antenna capable of operating in both underlay and interweave CR modes while maintaining good isolation between ports are explored.

The contributions mentioned above, along with the introduction and a rigorous literature review, are systematically arranged from Chapter 1 to Chapter 4. The thesis begins with the introduction, followed by the design of a frequency reconfigurable antenna with good isolation between antenna ports for interweave cognitive radio. To explore the underlay cognitive radio, UWB antenna with band notch characteristics is explored. It then progresses towards the development of a multifunctional antenna capable of operating in both underlay and interweave cognitive radio modes while maintaining good isolation between ports. Finally, the thesis concludes with a comprehensive discussion in the last chapter.

Chapter 1 discussed the introduction and motivation to perform this research work. This chapter provides insight into the historical background of the antenna reconfigurability and its evolution to meet the requirements of modern communication systems. Additionally, it presents design techniques, applications, and challenges associated with frequency reconfigurable antennas for cognitive radio. A detailed literature review, key research problems are identified, and new design techniques are proposed to address these challenges.

In Chapter 2, a compact ultra-wideband (UWB) antenna and a frequency reconfigurable antenna with improved impedance matching and isolation is presented for interweave cognitive radio (CR) application. The proposed antenna consist of a UWB antenna for sensing the UWB spectrum and a frequency reconfigurable antenna for communication, both integrated on a compact substrate area of 0.22 $\lambda_0$ × 0.32 $\lambda_0$ (where $\lambda_0$ at 2.7 GHz) with a shared ground plane. A PIN diode was inserted in frequency reconfigurable antenna to achieve two different states of operations. The resultant frequency covers WLAN and ISM bands. To enhance impedance bandwidth and isolation between the two antenna elements, a T-shaped stub is integrated into the ground plane. The designed antenna achieves less mutual coupling of -21 dB over communication frequency range of frequency reconfigurable antenna and most of the UWB spectrum. The impedance bandwidth of 7.3 GHz (2.7 GHz to 10 GHz) for UWB antenna. The impedance bandwidth for frequency reconfigurable antenna for PIN diode ON and OFF states are obtained 1.2 GHZ (4.3-5.5 GHz) and 1.7 GHz (5.1- 6.8 GHz), respectively. The realized gain of both antennas are moreover positive and follows similar trend to the simulated results.

In Chapter 3, an ultra-wideband monopole antenna with dual-band notches is presented. To enhance impedance bandwidth performance, a rectangular slot is introduced in the ground plane. The proposed antenna achieves -10 dB impedance bandwidth from 2.2 GHz to 15 GHz, except the dual notched frequencies. Dual-band notches are implemented using a U-shaped slot etched in the monopole antenna for Wi-MAX band and a U-shaped parasitic resonator integrated on backside of the substrate for WLAN band. These notch bands effectively suppress interference in two frequency ranges: 3.1 GHz to 3.9 GHz and 4.6 GHz to 6.2 GHz. The antenna demonstrates good impedance bandwidth and closely matched simulated and measured results. This antenna is good candidate for underlay cognitive radio.

In Chapter 4, a multifunctional antenna with high isolation for interweave and underlay operation in cognitive radio is presented. The proposed antenna consists of two elements: an ultra-wideband antenna and a frequency reconfigurable antenna. The UWB antenna achieves -10 dB impedance bandwidth ranging from 1.8 GHz to 12 GHz. To enable a reconfigurable notch for underlay cognitive radio operation, a U-shaped slot with a PIN diode $D_1$ is introduced in the UWB antenna. For interweave cognitive radio operation, a frequency reconfigurable antenna with PIN diode $D_2$, the switchable frequency ranges of (3 GHz - 3.7 GHz) and (3.8 GHz - 5.6 GHz) is obtained. To enhance impedance bandwidth and isolation between the two antenna elements, an extended ground plane is proposed. The designed antenna operates in both interweave and underlay modes maintaining mutual coupling less than -17 dB across the entire operating band.

The comparative analysis of different antenna configurations, including reconfigurable notched bands, the number of PIN and varactor diodes, demonstrates that the proposed design achieves improved performance in terms of bandwidth and isolation, and makes it suitable for cognitive radio and UWB applications.

## 5.2 Future Scope

Although some research and design concepts have been systematically implemented to develop antenna designs for underlay and interweave cognitive radio, and some promising results have been reported in this thesis, there are still some concerns that need to be addressed. Therefore, continued research in this area of reconfigurable antennas is necessary. Some possible directions for future exploration include:

1) Wideband and multiband notch reconfigurability: The designed reconfigurable antennas have limited band-notched capabilities. This can be further improved by incorporating tunable band-notched features across a wider frequency range by including varactor diodes. Additionally, maintaining stable gain and good radiation performance remains a significant challenge.
2) Multi-standard operations and enhanced isolation: The reported design concept can be further enhanced by incorporating multiple reconfigurability parameters, such as pattern and polarization. Although improved isolation was achieved in the current design, future research aim for even higher isolation using novel decoupling structures, methods or meta-surface based design.
3) Miniaturization and the integration of multiple reconfigurable antennas can be explored to achieve a compact design and ensure full coverage of the UWB.
4) System level co-design with CR transceivers: The co-design of these antennas with cognitive radio hardware and software will be explored. This approach will ensure the optimal performance of CR system and practical deployment, allows the better management between sensing and transmission functionalities.
5) Reconfigurable beam steering antennas for CR: Introducing beam reconfigurability in addition to frequency reconfigurability could further enhance system performance by directional spectrum sensing.
6) Integration with artificial intelligence and machine learning: Future research could explore AI/ML based dynamic control mechanism for antenna reconfiguration. This

will help in optimizing spectrum sensing, switching, and frequency selection in real time thereby enhancing the performance of the cognitive radio.