Design and Development of Reconfigurable Antennas with Single and Hybrid Reconfigurability Functions

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By

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5

Conclusion and Future Scope

The summary of this thesis is to design the antenna with single and multi-functionality for the modern communication system, catering to the ever-evolving demands of connectivity, flexibility, and efficiency. To facilitate this goal, some reconfigurable antennas with single and multi-reconfigurability are designed in chapter wise works having different wireless applications fulfilling the requirements of the modern communication systems. This chapter reflects the enormous work done on the reconfigurable antennas in this dissertation. Therefore, this chapter discussed about the key findings, contribution, and conclusion of the present research work in the field of reconfigurable antennas. The scope of future research work is also presented in this chapter.

5.1 Summary and Conclusion

In today's modern world, wireless communication is an essential entity where data transfer, internet, and visual communication are important parts of one's daily life. In any communication system, the antenna is an essential element for transmitting or receiving signals in the form of electromagnetic waves. Traditionally, antennas are optimized for fixed frequency, pattern, and polarization characteristics. However, due to the several limitations faced by traditional antennas in a changing environment where the antenna characteristics (frequency, polarization, and pattern) need to be adapted to the environment, the concept of antenna design has changed drastically. The concept of antenna reconfigurability has become the preferable choice for such requirements. It is an excellent candidate for increasing the system's performance and efficiency. The reconfiguration of an antenna can be achieved by tuning the three main output characteristics (frequency, polarization, and pattern) of the antenna, and to accomplish this, several techniques and design concepts are proposed in the literature. However, some notable drawbacks still exist that limit the functionality and applicability of the design. These existing limitations are overcome by proposing some new design concepts in the preceding chapters to accomplish the research goal. Some of the research contributions are summarized as:

1) Design and development of a compact, planar, low profile, and symmetrical pattern reconfigurable array antenna with beam steering functionality by utilizing the simple, low loss, and easy-to-control reconfiguration mechanism.
2) Along with designing the pattern reconfigurable antenna, the design of a hybrid reconfigurable antenna (simultaneous pattern reconfigurability with polarization agility) is also included in this thesis.
3) Another concern that is associated with these reconfigurable antennas is the placement of the switching elements and the DC biasing circuit to avoid

interference with the antenna radiation property. Therefore, in later chapters of the thesis, different reconfigurable feed networks are designed as a separate layer containing all the switches and biasing circuits to preserve the antenna radiation performance.

4) Design and investigation of a multi-polarized beam switching antenna with quad polarization agility and 2-D beam switching for 5G sub-6GHz application, which can operate in diverse climate conditions and free from antenna orientation due to its circular polarization changing capability.

All the contributions aforementioned along with the introduction, motivation, and rigorous literature review, are arranged from Chapter 1 to Chapter 4, starting with the introduction, design of an antenna with single reconfigurability and then progressing towards the development of multi reconfigurability antennas and with the discussion as the last chapter of this thesis.

Chapter 1 discussed the introduction and motivation to perform this research work. it gives an insight into the historical background of how antenna reconfigurability was discovered to meet the requirements of the present communication system. Further, the design techniques, applications, limitations, challenges, and a detailed literature review on pattern reconfigurability, polarization reconfigurability, and hybrid reconfigurability, along with their limitations, are also presented in this chapter. Based on the literature review, some research problems are identified, and to amend these, some new design techniques are presented.

In **Chapter 2**, a 2x1 pattern reconfigurable antenna with switchable beams is presented for WLAN applications. The concept of pattern reconfigurability is implemented using a very simple and effective technique by employing the transmission line-based phase switchable power divider. Sixteen PIN diodes were inserted to bridge the gaps on the

transmission line, and based on the several switchable excitation paths to feed the two antenna elements, the resultant main beam of the array can be switched in different directions.

The designed antenna achieved the measured -6 dB overlapped impedance bandwidth of 5.5% from 5.12 GHz to 5.41 GHz, covering the WLAN frequency band. The main beam of the antenna is switched into five different directions of 0°, ±24° and ±36° within the overlapping bandwidth.

In **Chapter 3**, a circular polarization agile and beam switching enabled reconfigurable cavity-backed array antenna with the ability to steer its radiation beam in different directions is presented. Two E-shaped patch antennas, a phase switchable feed network designed in chapter 2, and four switchable feed probes were used to realize the hybrid reconfigurability with polarization agility and radiation pattern switching.

The designed multifunctional array antenna achieved satisfactory performance with measured overlapped impedance bandwidth (S_{11} < -10 dB) of 26.4% from 4.6 GHz to 6 GHz and 3 dB axial ratio bandwidth of 17% from 4.7 GHz to 5.6 GHz. Two circular polarization states with left hand circular polarization (LHCP) and right hand circular polarization (RHCP), along with upto ±30° beam switching, were achieved based on the proposed reconfigurable concept.

In **Chapter 4**, a multifunctional quad-polarized array antenna with 2-D beam steering and quad polarization agility is presented for 5G sub-6GHz application. Initially, a single antenna element with four reconfigurable polarization states is proposed. A 2-bit polarization tuner is designed using the three switchable feed probes integrated with PIN diodes to achieve polarization reconfigurability. The individual excitation or the combination of the three feed probes excitation generated the quad polarization states of HLP, VLP, RHCP, and LHCP in the antenna element. The designed antenna element is further utilized to design the 2x2 array antenna and fed through the 1x4 power divider

integrated with the designed phase switchable feed network in Chapter 2 for beam steering and the tunable 2-bit polarization tuner for polarization switching.

The proposed antenna array achieved satisfactory performance with measured overlapped impedance bandwidth (S_{11} < -10 dB) of 29.2%, ranging from 3.5 GHz to 4.7 GHz and 3 dB axial ratio bandwidth of 13% ranging from 3.6 GHz to 4.1 GHz. Four switchable polarization states with vertical linear polarization (VLP), horizontal linear polarization (HLP), left hand circular polarization (LHCP), and right hand circular polarization (RHCP) along with up to ±28° beam switching is achieved based on the proposed reconfigurable concept.

5.2 Future Scope

Although some research and design concepts have been performed in a systematic way to design some promising antenna designs with single and multiple reconfigurability parameters, and some promising results have been reported in this thesis, there are still some concerns that need to be further addressed and continued the present research in the area of reconfigurable antennas. Some of the possible future research that can be further explored are:

1) The designed reconfigurable antennas still have limited beam switching capability, which can be further enhanced. Additionally, maintaining the stable gain and good radiation performance are also a great challenge. Tunable metamaterial-based structures can be further explored for increasing the gain and achieving enhanced beam steering performance with a smooth gain characteristic.
2) Reported design concepts can be further optimized to realize the array configuration with all three tunable characteristics of wide frequency tuning, pattern switching, and polarization tuning, which is not reported in this thesis.
3) Utilization of an automated control circuit can be explored to design the fully automated antenna design with some digital circuits for automatic antenna

operation control. To execute this, a software-based on-chip software command control circuit can be integrated into the antenna PCB to control the antenna operation as per the system requirements while carefully preserving the antenna radiation characteristics and without increasing the weight and volume of the antenna.

4) This research work can be further explored in designing the phased array antennas where the traditional antennas can be replaced with reconfigurable antennas to design the multifunctional phased array antennas.