Chapter 6

Conclusions and Future Scope

6.1. Major Discussion

- ☐ Many forms of the metasurface (MS) structures have been discussed for the design of various metasurface antennas (MSA) with radiating elements such as patch antennas, slot antennas, CPW-Fed antennas, dual-band antennas, etc. The antenna performance in terms of impedance bandwidth, gain, radiation characteristics, and radiation efficiency have been greatly improved with the use of MS.
- ☐ The first chapter examined the design and analysis of various metasurface antennas for different practical applications, as well as the benefits and drawbacks of each. This section also covers the operation principles of single-layered and multi-layered antennas.
- ☐ In the second chapter, the design and analysis of a miniaturized, dual, and wideband MSA have been studied in which the slotted radiating patch and the MS are printed on the same dielectric. The partial ground concept has been introduced in this design. The MSA is made of a slotted patch antenna and a 4×5 periodic MS in the bottom of the dielectric adjacent to the partial ground. Each unit cell consists of a regular pattern of two L-type patches and a cantered C-type patch. The antenna has dual-band operation and a significantly enhanced gain of 7.16 dBi at 10.92 GHz, operating at two separate operating frequencies of 2.6 GHz and 10.60 GHz, respectively, with

fractional bandwidths of 150 % and 5.09 %. From 1.8 to 5.7 GHz, the antenna radiates nearly omnidirectional characteristics, while, the antenna exhibits a unidirectional radiation pattern from 10.38 GHz to 10.92 GHz.

- In the third chapter, a multi-layered MSA has been proposed for gain enhancement in which the dielectrics are stacked in a superstrate manner. Teflon dielectric plays an essential part in the design as it has excellent electrical and mechanical properties. Dielectric via, slots in the ground surface and array of patches improve the impedance characteristics of the antenna. The 5×5 periodic metasurface along with the slotted radiating patch improves the gain characteristics in the operating frequency band. The incorporation of an MS to a simple conventional patch improves the gain of the developed antenna by 7.57 dBi in the frequency range 10.14 -10.94 GHz.
- The detailed circuit model analysis of the MSA has been sequentially developed in chapter four to validate the impedance behavior of the proposed metasurface antenna configuration. In that part, the design study of two separate MSAs was presented. The first MSA is a single-layered structure, while the second is a multi-layered one. In comparison to the first MSA, the radiation properties of the second MSA are significantly improved. The first prototype operates over dual frequencies with impedance bandwidths of 4.02% and 28.24% at 9.20 GHz and 11.65 GHz, respectively. The multi-layered MSA achieves the bandwidths of 6.1% and 35.15% at 4.26 GHz and 8.62 GHz, respectively.
- The design and analysis of the MSA employing an artificial magnetic conductor (AMC) surface have been explored in the fifth chapter for gain enhancement and increased impedance bandwidth. The AMC-based MSA has been created by stacking

a CPW-fed slotted patch antenna and a 7×7 order MS. This antenna operates at two distinct frequencies of 2.34 GHz and 8.94 GHz, with fractional bandwidths of 6.8 % and 53.8 %, respectively. The antenna offers a peak gain of 9.1 dBi and a radiation efficiency of 91.2 % at 11.51 GHz.

- All the designed prototypes have been fabricated and the experimentally measured results offer good agreement with the simulated ones. Based on the study and analysis of the above-mentioned different metasurface antennas, the metasurface antennas possessing more than one operational frequency band are promising candidates for integration into modern communication systems. The compact and low-cost single, dual or multi-band antennas can generate more attention to the researchers and engineers due to their frequency versatility and enhanced bandwidth.
- Additionally, the investigation of single-layered or multi-layered metasurface antenna topologies can lead the way for antenna designers who are working in the field of multifunctional metasurface devices. The metasurface antennas have fulfilled all types of requirements based on applications in medical, wireless communications such as WLAN/WMAX, as well as modern civil and military applications compared to other antennas. Moreover, by adopting MS antennas, the constraint on the relative position between transmitting and receiving antennas can be relaxed, preventing unreliable wireless disturbances.

6.2. Research Proposals for the Future

- Nonlinear metasurfaces have created new opportunities for researchers and designers, enabling the development of highly efficient, stable, and compact antenna systems. The surface impedance of the non-linear MS can be modified using active electronic components such as diodes, transistors, and varactors. By adopting a full-wave rectifier, transistor-based MSA offers manual gate control, which can make the surface programmable, or allow to create a sharp directive radiation response. Additionally, active nonlinear self-tunable MSA widens the frequency bandwidth beyond the limits of passive MSA.

- The manipulation capability of metasurfaces can be extended to nonlinear optics, opening up new possibilities for creating antennas in the THz or optical domain. The design and performance of the MSA can be extended in the THz domain by using graphene surface, as graphene possesses exceptionally high tensile strength, electrical conductivity, and transparency, in addition to being the world's thinnest two-dimensional substance. Further, the researchers can take the challenge of fabrication and the performance measurement of the graphene-based MSA in the THz region.

- Solar cell metasurface-integrated antennas are expected to become a major research topic in the field of self-powered antennas for sensors and Internet of Things applications. The MSA structures can reduce the size of solar structures and can be used in a variety of applications when space is limited. The MSA harvests microwave receiving energy and channels it to a single resistive load. This process is initiated by this new mechanism, which controls all received power to a single load.

☐ Reconfigurable and active metasurfaces are an exciting new platform for 5G/6G communications, remote sensing, and radar. Metasurfaces can overcome the fundamental limitations of passive and static systems by incorporating active elements.

☐ For researchers and designers, controlling the interaction of waves with the metasurface is difficult. As a result, greater symmetries metasurfaces can overcome the fundamental restrictions. The researchers can look at the possibility of combining several layers of the metasurface to achieve greater symmetry.

☐ The research can be extended to address recent advancements and future problems in analyzing and synthesizing metasurfaces through the use of circuit models, analytical solutions, and computational methods.