# 6
# Conclusions and Future Scope of The Work

## 6.1 CONCLUSIONS

Metamaterials are artificial composites of periodic or aperiodic arrays of sub wavelength unit cells designed to achieve electromagnetic properties not available in nature. One of the prominent applications of metamaterials is in the field of stealth technology. For the stealth applications, the primary goal is to reduce significantly the backward scattered waves from the objects under surveillance such as missile, aircraft etc. The RCS reduction is basically achieved by (i) shaping, (ii) absorbing, (iii) cloaking and (iv) phase cancellation. However, all of these approaches are limited with losses and tolerances associated with them. In addition to this, as the direction and frequency of the incoming wave in unpredictable, oblique incidence performance and broad bandwidth are two necessary factors in the stealth technology.

In this Thesis, these issues are addressed using metamaterial based structures; the two different approaches for the RCS reduction i.e. absorption and phase cancellation were considered. In the first part of the Thesis, disordered patch resonator based metamaterial absorbers were illustrated targeting the absorption technique for the RCS reduction. In the subsequent part of the Thesis metasurface based structures were proposed for wide band RCS reduction using the phase cancellation approach. The proposed structures were different from the earlier reported metamaterial based structures and have significantly improved responses both in the terms of absorption/reflection characteristics and fabrication tolerances.

In **Chapter 3**, disordered patch resonator metamaterial-based absorbers were investigated. The proposed absorbers were extensively studied using numerical simulations. The quality factor approach, along with an equivalent electric circuit model, was used to deduce the optimal period for the perfect absorption condition of the periodic unit cell. Further, a controlled degree of position disorder was introduced in the initial periodic setting, and the resulted disordered structures were investigated for different disorder parameters. Moreover, the effect of increasing filling fraction and oblique incidences on the disordered absorber structures were explored.

Later, a different patch configuration, i.e. square patch-based absorber structure was investigated for both the periodic as well as disordered setting. It was observed that the patch shape does not have much effect on the absorption characteristics of the disordered metamaterial absorbers. The absorption characteristics were directly dependent on the effect of coupling among the neighboring resonators in the disordered setting. The proposed disordered patch resonator based absorbers had absorption bandwidth enhancement of roughly four order compared to the initial periodic structure. They also had a stable absorption response even for large oblique incidences for both TE and TM polarization.

In **Chapter 4**, the proposed disordered patch resonator based absorbers were fabricated and experimentally characterized. Two different type of random structures were fabricated i.e. non-overlapping and overlapping resonators based absorbers. It was experimentally demonstrated that these fabricated random absorbers have enhanced absorption bandwidth compared to their periodic counterpart. Effect of increasing filling fraction and oblique incidences were also investigated experimentally. It was observed that the random patch resonator based absorbers have stable absorption response even for oblique incidences for both the polarization. It was observed that the overlapping random absorbers support further lower frequency modes due to the formation of clusters. These clusters were then studied using numerical simulations. The experimental results and simulation results were compared and a good degree of agreement was found even tough the two approaches were quite different. It was deduced that for random patch resonator based absorbers the absorption properties were mainly dependent on the coupling among neighbouring resonators.

In **Chapter 5**, two different metasurfaces based on different design concepts have been proposed for wideband polarization-insensitive RCS reduction. The first metasurface was comprised of different supercells distributed randomly inside a checkerboard configuration. This random distribution of variable phase difference results in the diffused scattering of the reflected wave in a wide frequency band. Further, 3D scattering patterns were also provided, and it was evident from the 3D scattering patterns that the incident wave was diffused in various directions. More than 10 dB RCS reduction was achieved in a wide frequency band ranging from 6.5 GHz to 21 GHz for both TE and TM polarization under normal incidence.

The proposed second metasurface was based on the phase gradient principle. Three different random metasurfaces were designed by randomly distributing the phase gradient supercells in a checkerboard pattern. Each supercell had a specific phase gradient direction. A total of eight different phase gradient supercells were selected for the two-unit cells having four different phase gradient directions. The simulated results demonstrated that the designed metasurface significantly reduces the backward scattering within the frequency range 10 GHz to 20.5 GHz under normal incidence for both the TE and TM polarized waves.

## 6.2 FUTURE SCOPE OF THE WORK

The proposed structures overcome the limitations of the earlier reported structures in many aspects. However, there remains some scope of improvement in the reported designs. The future scope can be illustrated in the following points.

1. Random patch resonator based absorbers exhibiting both size as well as position randomness can be explored for further enhancing the absorption bandwidth. The effect of different ratios, along with different filling fractions, can be considered. The structures can be investigated numerically as well as experimentally for different ratio configurations for achieving optimal absorption response.

2. The proposed disordered patch resonator based absorbers were designed for a planar environment only, thus limiting their practical applications. Random absorbers with a flexible substrate can be considered for non-planar environments, where flexibility and stability are of a prime concern.

3. The proposed metasurface designs are yet to be realized experimentally, as they have shown excellent potential for the wideband RCS reduction. Further, oblique incidence absorption characteristics are also needed to be obtained both numerically and experimentally.

4. The metasurface designs can be further optimized for the better response by employing algorithms for unit cell selection such as particle swarm optimization algorithm, genetic algorithm, etc. These algorithms allow one to achieve active phase cancellation by optimizing the phase differences among the selected unit cells.

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