CHAPTER–7

CONCLUSION AND FUTURE SCOPE

In this thesis design and development of a single band, dual band and wideband metamaterial microwave absorbers have been discussed in detail. The unit cell dimensions of all the absorber structures are optimized to make the design useful for potential RF applications specifically for C and X-band. Different types of unit cell designs consisting of square loop, JCS, and ELC resonator structures have been presented. In all the designs the thickness and compactness of the structures lie in sub-wavelength range, which makes the proposed design not only ultrathin in thickness but also low profile in size. Moreover, all the metamaterial absorber structures have been designed using commercially available 1.6 mm thick copper plated low cost FR-4 dielectric substrate. For all the absorber design the simulation is performed through Ansys HFSS by applying Floquet's periodic boundary conditions.

The single band metamaterial absorbers of different types based on single or multiple square loops with compact size and good absorption rate as compared to the already proposed absorbers have been discussed. Mutual electromagnetic coupling effects in between the two and more square loops have been utilized to achieve the perfect absorption. Based on this approach initially, a single band triple square loop based metamaterial absorber has been discussed. In this, the contribution of each loop in absorption has been thoroughly discussed. The design has been fabricated and tested for its performance under normal incidence of electromagnetic wave. Next, a convoluted square loop structure has been designed in order to increase the FWHM bandwidth as compared to the previous case. The gap in between the loops is optimized in such a way that the absorption frequency falls within microwave X-band frequency regime thereby making it useful for practical applications. After that, another absorber structure based on the combination of different resonator structures has been designed in order to achieve perfect absorption along with wide FWHM bandwidth. This designed absorber is polarization and the incidence angle insensitive and therefore provides nearly perfect absorption for all polarization and incidence angles. The electromagnetic parameters for all single band absorbers have been retrieved and it is observed that their values satisfy the condition of high absorption.

Thereafter, dual band metamaterial absorber based on double square loop has been discussed. The designed structure is polarization insensitive and provides more than 90% absorption at both the bands for the incident angle of 60^0. As compared to the already reported dual band metamaterial absorbers the proposed absorber is compact (λ/4.4) and ultra-thin (λ/26) in its unit cell dimensions. Further, a triple band metamaterial absorber based on ELC resonator has been discussed. The design consists of a combination of three ELC resonators to obtain triple band. The geometric dimensions are optimized to serve C-band, X-band and Ku-band applications such surveillance radar applications. Field and surface current distributions have been studied for the three absorption frequencies in order to investigate the contribution of each ELC resonator in absorption. The absorber design is the incident angle insensitive and therefore provides more than 90 % absorption for incidence angle up to 60^0 under TE polarization. The design shows polarization insensitivity with a negligible deviation of absorption peaks up to polarization angle of 60^0. The electromagnetic parameters have been evaluated to confirm the absorption phenomenon for both the dual band and triple band absorbers.

This thesis has also discussed the low profile wideband metamaterial absorbers in order to fulfil the requirements of complete band absorption especially for defence applications. A wideband wide-angle metamaterial absorber for C-band applications is discussed. The simulation results show two absorption frequencies at 5.34 and 6.33 GHz. The dimensions are optimized in such a manner that the two absorption peaks come closer to give wideband absorption. Although, the structure is polarization sensitive but it provides more than 90% absorption for a bandwidth of 1.94 GHz. Moreover, the absorber structure provides wideband absorption of more than 90% for a bandwidth of 1.22 GHz up to an angle of 40^0. The contribution of various design parameters has been investigated in order to understand the absorption mechanism.

Further, a wideband absorber design based on microstrip bend like structure has been discussed. Instead of using a scaling approach with large unit cell size, multilayer and thicker substrate design configurations, in this thesis a planar single resonator based metamaterial absorber design is presented. The absorber structure provides almost complete X-band absorption with more than 90% absorptivity from 8.60 to 12.35 GHz. The design is low profile with its unit cell size of ~0.16 λ_0 and ultrathin with its thickness of ~λ_0/18 as compared to the already proposed wideband single layer metamaterial absorbers. Essential physical parameters are investigated for investigating their contribution in absorption. Field and surface current distribution have been studied in order to understand the absorption mechanism.

This thesis also discusses a low profile wideband metamaterial microwave absorber for the wide-angles of the incident wave. The unit cell of the absorber structure consists of an inclined hexagonal patch as the top layer separated by the grounded substrate. From the simulated response under normal incidence, it is seen that the absorption is above 90% from 8.81 to 13.83 GHz and the FWHM bandwidth is 7.56 GHz (from 8.17 to 15.73 GHz). The essential geometrical dimensions of the proposed design are varied in order to understand the origin of absorption peaks. The proposed design is fabricated and experimentally verified for different oblique incident and polarization angles. In comparison to the already proposed wideband metamaterial absorbers, the proposed structure is simple in design, low profile (with unit cell size 0.21 λ_0), ultra-thin (only $\lambda_0/17$ thick) and it exhibits wide angle absorption with absorptivity of more than 70 % up to incident angle of 60^0 of the electromagnetic wave.

Thereafter, a novel design of ultrathin ($\lambda_0/17$ thick) metamaterial microwave broadband absorber has been presented. In this two resonator structures are combined in a single unit cell in such a way that without increase in unit cell size three absorption peaks are observed and when gets merged it gives enhancement in bandwidth. The simulation results show that the proposed absorber provides full wave at half maximum bandwidth of 7.75 GHz (from 7.55 to 15.30 GHz) for wide angle of incidence up to 60^0. The contribution of essential design parameters in absorption bandwidth has been studied. A prototype of the proposed absorber has been fabricated and experimentally verified for normal incidence as well as oblique angles. The experimental results are observed to be in good agreement with the simulation results. In comparison with the existing metamaterial-based absorber, the proposed absorber is low profile, ultra-thin and broadband in its bandwidth. Therefore, the proposed absorber can be used in defence for stealth technology, cloaking, thermal imaging and electromagnetic interference.

At the last of the thesis an ultra-wideband ultra-thin, low profile and wide-angle metamaterial based microwave absorber has been discussed. The unit cell of the absorber consists of two diagonally placed 'microstrip bend' like metallic patches. The simulation response under normal incidence shows more than 90% absorption in the frequency range from 10.45 to 17.64 GHz and the FWHM absorption bandwidth is 11.43 GHz (from 9.61 to 21.04 GHz). The mechanism of absorption has been analyzed using electromagnetic field and current distributions. The absorption response of the proposed absorber under different oblique and polarization angles has been studied both theoretically and experimentally. It provides more than 50 % absorption for wideband even for incident angle of 60^0.

Future Scope

Although, different types of single band, dual band, triple band and wideband designs for potential RF applications have been discussed and analyzed in this thesis, but there are certain issues listed below that can be taken up for future work in this area:

(a) In chapter 3 single band metamaterial absorbers have been discussed. Although the designs are polarization and incidence angle insensitive, but their FWHM bandwidths are limited. The simple polarization insensitive designs with the single layer configuration, but with enhanced bandwidth can be considered.

(b) In chapter 4 dual and triple band absorbers are discussed. Although the designs are polarization insensitive, but more compact structures with almost perfect absorption should be designed to make them more effective for practical applications.

(c) In chapter 5 wideband absorbers are discussed. Although the designs cover large bandwidth, but they are polarization sensitive. Polarization and angular insensitivity with large bandwidth coverage is still a bottleneck. Therefore, symmetrical structures with low profile and single layer design configurations should be developed to effectively serve more potential RF applications.

(d) At last but not the least it is observed that the although many researchers have proposed equivalent circuits of the simple metamaterial absorbers but the general concept of equivalent circuit modelling of metamaterial absorbers which covers dielectric losses, inductive and capacitive effects of dimensional parameters and mutual coupling effects of structural elements are still missing. Moreover, the equivalent circuit modelling of bandwidth enhanced and wideband absorbers should also be considered for future work.