ABSTRACT

To meet the demand of continuously growing RF and microwave technologies, scientists and engineers have developed innovative materials consisting of conducting and dielectric materials that overcome limitations in the properties of natural materials. Over the last decades, the development of these artificial materials has evolved to be a new field. An artificial material is a synthesized material that gains its electromagnetic properties from its structure rather than inheriting them directly from those it is composed of. Planar versions of these artificial materials are often characterized by small periodic conducting patches over a dielectric substrate. In addition to the periodicity, the interaction of these structures with the electromagnetic waves depends on the shape and size of the small patches.

Planar artificial materials pursued in electromagnetics include frequency selective surfaces (FSS), high impedance surfaces (HIS), artificial magnetic conductors (AMC), and electromagnetic bandgap (EBG) materials, which are characterized by periodic unit cells whose lattice constant is comparable with the operational wavelength. One of the very commonly seen geometry is the mushroom structure, which has a patch array with each element connected to the metal on the other side of the dielectric with a via. These metal-backed configurations are used in various antenna applications. Some narrowband absorbers have also been suggested using these configurations. This thesis investigates new artificial materials consisting of one- and two- layer of metal patch arrays that overcome the requirement for vias, and examines their design and analysis for four different applications (i) Circularly polarized antennas (ii) Surface wave suppression of microstrip antennas (iii) In-phase reflection surface and (iv) Thin radar absorbing material.

Artificial materials with square patch arrays with or without vias can be designed as artificial magnetic conductors. Arrays of rectangular patches with vias or square patches with two vias or slots have been proposed for polarization sensitive reflectivity characteristics. In this thesis we propose a simple geometry for polarization sensitive reflection characteristics. This consists of a modification to square patches with variants of fractal Minkowski curves as boundaries on two of its sides, printed over a metal backed dielectric substrate without vias. The structure is compact, and due to its planar nature, it can be fabricated easily using planar technology. Properties and performance of the structure is analyzed numerically through simulations by varying fractal properties of the

sides. The asymmetry in the patch causes the reflection phase of the proposed structure to depend on the polarization state of the incident wave and frequency. A phase difference above 200 degrees between the x- and y-polarized reflected waves has been achieved with small unit cells. Application of the proposed via-less structure to generate circular polarization using simple dipole antenna is also demonstrated in this thesis.

Square patches arrays with vias have been proposed as high impedance surfaces (HIS) with in-phase reflection and as electromagnetic bandgap (EBG) structures for suppressing surface waves in microstrip antenna applications. The second structure proposed in this thesis is an alternative for these mushroom structures, and consists of a periodic array of square metal patches (on the top surface) and square metal rings (embedded within the dielectric substrate). This structure does not require any vias for effective operation and is analyzed extensively by numerical simulations. In-phase reflections due to high surface impedance and surface-wave suppression characteristics similar to the mushroom structure proposed by Sievenpiper have been validated. Application of the structure to reduce mutual coupling between microstrip antennas and to improve the radiation pattern are demonstrated through simulations. The structure is fabricated and experimental measurements have been made to confirm surface wave suppression characteristics. A waveguide-based experiment was done to demonstrate the in-phase reflection characteristics. One of the main advantages of the proposed structure is that it is planar in nature and easily fabricated using planar technology, without the need for any via connections across dielectric layers. Another feature is that it exhibits in-phase reflection and surface wave suppression bands at the same frequency band as in mushroom structure. The scalability of this structure to operate in different frequency ranges is also demonstrated in this thesis.

Modifications to EBG using either resistive patches or surface mounted resistors have been used as absorber. In this thesis, we propose the use of the above ring-patch structure printed on a moderately lossy substrate such as FR4, as a near-perfect electromagnetic absorber. It is demonstrated that input impedance of the structure can be configured to match the free space impedance by varying the width of the ring to result in near-perfect absorption. This configuration causes a concentration of electric fields in the dielectric region between the ring and patch, thereby enhancing the dissipation of the energy.

Monostatic and Bistatic radar cross section measurements have been used to ensure that there are no scattered fields in other directions. The structure is thin, easy to fabricate, and is scalable to operate at different frequencies. This does not use any resistive materials for absorption. It is shown that 99% of the incident power is dissipated by either dielectric or metal losses. The performance of this structure is analyzed using an equivalent circuit approach. A method for improving the bandwidth of this absorber by combining four unit cells and optimizing the dimensions of this sub-array is also proposed here. The performance of this EBG based absorber configuration is similar to the metamaterial based absorbers proposed recently with much smaller unit cells.

To summarize, this thesis investigates electromagnetic behavior of single and stacked two-layer periodic metal patches without any interconnects, which are simple and easy to fabricate using planar approaches. It has been established that the configurations proposed in this thesis are equally effective for various electromagnetic applications as previously reported geometries, often characterized by vias or surface mount components.