# The Art and Engineering of EBG Designs for Low Profile Antennas: Recent Developments

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Periodic structures are abundant in nature, which have fascinated artists and scientists alike. When they interact with electromagnetic waves, exciting phenomena appear and amazing features result. In particular, characteristics such as frequency stop bands, pass bands, and band gaps could be identified. Reviewing the literature, one observes that various terminologies have been used depending on the domain of the applications. These applications are seen in filter designs, gratings, frequency selective surfaces (FSS), photonic crystals and photonic band-gaps (PBG), etc. Recently they have been classified under the broad terminology of "*Electromagnetic Band Gap (EBG)*" structures. Generally speaking, electromagnetic band gap structures are defined as *artificial periodic (or sometimes non-periodic) objects that prevent/assist the propagation of electromagnetic waves in a specified band of frequency for all incident angles and all polarization states*.

Discovery of EBG structures has provided promising paradigm for novel antenna designs. Due to the complexity of the EBG structures, it is usually difficult to characterize them through analytical methods. Instead, full wave simulators that are based on advanced numerical methods have been used in EBG analysis. Dispersion diagram, surface impedance, and reflection phase features are revealed for different EBG structures. These analysis tools have been integrated with modern optimization techniques such as genetic algorithms and particle swarm optimization to synthesis unique EBG structures. The applications of EBG structures in antenna designs have become an exciting topic for antenna scientists and engineers. This is the central focus of this presentation.

The perfect electric conductor (PEC) has customarily been used as a ground plane for antenna designs. The imposition of the PEC boundary condition demands that the total tangential electric field to be zero. This boundary condition severely affects the performance of low profile electric-type antennas. Recently, various artificial complex ground planes with different boundary conditions such as soft and hard surfaces, electromagnetic band-gap (EBG) structures, and frequency selective surfaces (FSS) on a grounded slab have been considered to overcome the limitations of the PEC ground plane. In recent years, many innovative antenna designs and various claims have been made. Utilizing several representative antenna examples it will be demonstrated that the implementation of artificial complex ground planes could enhance the performance of low profile antennas; however, considerable care must be exercised to fully understand the advantages and disadvantages.

Horizontal electric-type antennas that cannot radiate efficiently near a PEC ground plane due to the reverse image currents are capable to radiate efficiently near an EBG ground plane. It is revealed that the good return loss is contributed to the quadratic reflection phase of the EBG ground plane and the broadside radiation patterns result from the surface wave band gap. Various wire class antennas will be presented to demonstrate the utility of the concepts. Surface wave antennas with monopole type radiation patterns are also presented. It is noticed that when the vias in the mushroom-like EBG structures are removed, the reflection phase for the normal plane wave incidence remains the same whereas the surface wave band gap disappears. In this case, a well-matched short horizontal dipole or patch excites strong surface waves, and it works more like a transducer rather than a radiator. When the surface waves propagate and radiate, a monopole type radiation pattern is generated. Thus, this antenna can be identified as a surface wave antenna, which is equivalent to a monopole but with a much less antenna height. Some recent trends will be highlighted.