ANTENNA RADIATION CONTROL USING ELECTROMAGNETIC BAND GAP

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A Thesis Submitted to the University of Sheffield for the Degree of
Doctor of Philosophy in Electronic and Electrical Engineering

September 2013

ABSTRACT

The ever growing wireless technologies pose new challenges for the design of antenna systems. The challenges can be related to the mechanical and electrical properties of the antenna, such as dimensions, compactness and low profile with the improvement of power directivity, gain and efficiency. The antenna design have experienced enormous advances in the last decades and still undergoing massive developments. Many new technologies have emerged including the development of the metamaterial structures. Electromagnetic band gap (EBG) structure can be considered as a metamaterial that possesses some interesting properties of high impedance and artificial magnetic conducting surface.

This work is focused on developing EBG structures to control the surface wave propagation around the antenna. The sectorized EBG has been utilized to steer the beam around the microstrip patch antenna. The flexible beam directive antenna with an operating frequency of 2.2GHz has been achieved by integrating a TM01 mode microstrip patch antenna with an EBG. The circular EBG elements are arranged in six sectors with group of pin vias. Switching pin vias in and out from each sector has steered the beam into that sector. The flexible beam scanning antenna with a stable reflection coefficient has been achieved.

In modern wireless communication, compact systems with high gain and efficiency are always needed. To achieve these requirements, a compact array utilizing the miniaturized capacitive loaded EBG with a total period of λ/36 has been developed. Pin vias been used to alter the EBG surface impedance, which controls the propagation of surface waves within the array elements. Switching pin vias on has increased the surface impedance to be infinite, which suppress the surface waves, whereas switching the pin vias out has reduced the surface impedance and altered the surface to become the artificial conductor. These EBG have

isolated and propagated the signal within the array elements accordingly. The application of EBG to control and channel the signal within the array elements has been demonstrated.

The other EBG application to control the radiation has been described for the phased array antenna. Large array of microstrip phased array antenna with a high gain and a directive beam has the problem of scan blindness with losses of power at a certain direction. This is due to the surface waves, which is bound to the array surface, which stores some of the energy. The array return loss near 0dB at the angle has demonstrated the severity of the problem. Miniaturized EBG which is placed within the array elements has efficiently suppressed the surface waves and improved the scan blindness problems. The simulation results using CST software has illustrated the EBG characteristics on controlling the antenna and array radiation. The novel finding of EBG characteristics in controlling the antenna radiation pattern by suppressing and propagating of surface waves is the main contribution of this research.

ACKNOWLEDGEMENTS

First of all, thanks to Almighty Allah for all His mercy, kindness and guidance and giving me the wisdom and strength to finish my thesis. Heartiest gratitude to my supervisors: Professor Richard Langley and Dr. Salam Khamas for their kind advices, guidance, encouragements and supports during my doctoral research and study. The achievements and completion of the thesis will be very hard to be possible without their valuable, sincere and relentless supervision. Unforgettable acknowledge to Government of Malaysia and Universiti Teknikal Malaysia Melaka for funding my PhD. I also would like to thank Dr. Alan Tennant, Dr. Wei Liu, Dr. Jonathan Rigelsford, Dr. Lee Ford, Dr. Greg Cook, Dr Lester Low, Steve Marsden and all the staffs in the workshop for their helps and supports. I also would like to mention my fellow PhD Liu, Nisar, Tarik, Ismail, Najib, Hassan and Redzuan for their helps and supports and making my time enjoyable during my study and completing my PhD. The discourse is incomplete without mentioning my beloved wife Mahnon Suria and daughters Nur Ayuni Farzana and Nur Ayna Farzana for their love and patience throughout the course of my study. Finally I would like to thanks all my families and friends in Malaysia who always remember me and praying for my success. Thanks you very much.

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LIST OF ACRONYMS

1D	One dimensional
2D	Two dimensional
3D	Three dimensional
AMC	Artificial magnetic conductor
BAN	Body area network
CAD	Computer Aided Design
CPW	Coplanar waveguide
CST	Computer Simulation Technology
DFT	Discrete Fourier transform
DNG	Double negative
EBG	Electromagnetic band gap
E-field	Electric field
EM	Electromagnetic
ETSI	European Telecommunications Standards Institute
FDTD	Finite difference time domain
FEM	Finite elements method
FIT	Finite Integration Technique
FSS	Frequency selective surface
H-field	Magnetic field
HIS	High impedance surface
IEEE	Institute of Electrical and Electronics Engineers
LH	Left-handed

LWA	Leaky wave antenna
MOM	Method of Moment
MPAA	Microstrip patch array antenna
MWS	Microwave Studio
NRI	Negative reflective index
PAA	Phased array antenna
PBG	Photonic band gap
PCB	Printed circuit board
PEC	Perfect electric conductor
PMC	Perfect magnetic conductor
RFIC	Radio frequency integrated circuit
S	Scatter
SWA	Surface wave antenna
TE	Transverse electric
TM	Transverse magnetic
UWB	Ultra wideband
WiFi	Wireless fidelity

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Chapter 1

INTRODUCTION

1.1 Motivation

In modern communications, rapid growths of the wireless technologies have made the antenna design more challengeable. Antenna arrays significantly improve the gain and efficiency of the wireless application systems. Recent research has focused on the miniaturized wireless system with low profile and light weight which mainly depends on the compact antenna with high performance. The study on the antenna's physical limitation can be traced back to Chu's work published in 1948 [1]. Chu limit has derived the trade-off between antenna size and its performance with minimum possible quality factor (Q-factor), maximum gain, and the maximum ratio of gain to Q-factor for an omni-directional antenna using a spherical wave function. Considerable number of related studies have been published since then [2-9] which introduced some new theories and antenna design limits.

Antenna design have experienced enormous advances in the last decades and still undergoing massive developments. Many new technologies have been emerged in the modern antenna design including the development of the metamaterial structures. The ancient Greek prefix "meta", which means "beyond", describes the composite materials with unique feature not readily available in nature. Various names have been introduced, such as, left-handed (LH) material, double negative (DNG) material, negative reflective index (NRI) material, soft and hard surface, artificial magnetic conductor (AMC) and high impedance surface (HIS). The applications of metamaterial structures in the antenna design have become an exhilarating topic among the antenna designers. Based on the metamaterial properties, novel characteristics of antenna designs, which possibly going beyond the Chu limit, have been reported [10-13] .

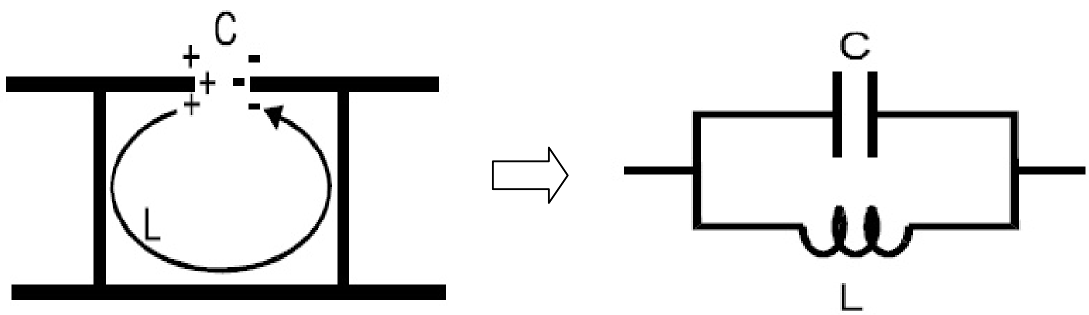
Electromagnetic band gap (EBG) structures with unique band gap features can be regarded as metamaterials. Besides the band gap feature, EBG also possesses some other interesting properties, such as AMC and high impedance surface. For instance, the mushroom-like EBG structure demonstrates high surface impedance for both TE and TM mode. When the surface is illuminated with a plane wave, the conducting surface with in-phase reflection coefficient is obtained which resembles artificial conductor characteristics. These interesting features have been applied to wide range of antenna designs, from linearly to circularly polarized antennas, from wire to microstrip antenna and from conventional to novel surface wave antennas [14-18]. The main challenge of the EBG design is to improve the antenna performance and compactness to meet the modern wireless communication requirements. The antenna compactness can be realized with closer and miniaturized techniques which might cause some degradation in performance due to the surface wave. The control on surface wave suppression and propagation is the focus of this thesis.

1.2 Electromagnetic Band Gap

Recently, there has been a growing interest in utilizing the electromagnetic band gap (EBG) structures in the antenna design. The EBG structure can be classified as an artificial material that operates in a specified frequency range and manipulates the propagation of electromagnetic waves. The research on the EBG can be traced back to the earlier development of the photonic band gap (PBG) materials in the optical spectrum. The typical PBG structures proposed in [19, 20] have been realised by drilling holes in the dielectric structure, which prevent the propagation of the electromagnetic waves within a certain frequency range. The terminology of the suppressing surface wave has been suggested in [21], which is based on the photonic band-gap (PBG) phenomena in optics and realised by a periodical structure that has been found to be effective in improving the performance of an antenna placed on top of that structure. The front-to-backward ratio of the antenna has been enhanced by introducing PBG under or around the antenna. However, due to the manufacturing difficulties and bulky size, the development of periodic band gap materials based on the PBG concept was limited.

A planar EBG structure , which is also known as the unipolar compact photonic band gap (UC-PCB), has been proposed by Fei-Ran on 1999 [22]. It has been constructed using a two dimensional square lattice cells that consist of a metal pad with four connecting lines and etched on the grounded dielectric substrate. The UC-PBG structure has demonstrated a 180° phase difference compared to a PEC at the stop band frequency which demonstrates its' characteristic as an artificial magnetic conductor of EBG. The main advantage of this type of structure is the simpler fabrication process whereas the main drawback is introduced by the bulky unit cell period, which is approximately half wavelength.

The pioneer planar based mushroom-like EBG has been invented in 1999 by D. Sievenpiper [23, 24]. The EBG structure is composed of a metallic EBG patch with a grounded dielectric substrate and a metallic pin via connecting both metals. In several publications [25-27], it has been demonstrated that the mutual coupling within the array antennas can be reduced by integrating the EBG structure into the design.



(a) (b)

Figure 1.2.1 : Equivalent circuit model for the high impedance surface [24]

The two-dimensional array of the EBG elements can be illustrated as an electrical band stop filter and could be modelled using a basic LC circuit as shown on Figure 1.2.1. The capacitance, ***C***, is distributed by the coupling effect of the top metal patches, while the inductance, ***L***, is produced by the current loop within the structure through the pin via as shown on Figure 1.2.1 (a). The values of capacitance and inductance in the equivalent circuit depend on the EBG cell dimensions and the thickness of the substrate, respectively.

For wireless communication applications, compactness and low profile is always a challenge to the antenna engineers. To meet the required demands, compact convoluted geometries of the EBG have been designed which has increased the equivalent capacitance with a reduction in size, as reported in [28-31]

Miniaturized EBG structures that utilize the lumped elements have also been realised, for instance a miniaturized EBG has been developed using a parallel capacitance and inductance [32]. Alternative design that uses loaded of capacitor elements within adjacent patch with series of loaded inductors and vias has been proposed [33]. In both of those studies, the size of EBG structure has been greatly reduced by up to $\lambda/20$. The miniaturized EBG utilizing only capacitive lumped elements is one of the focuses in this research.

1.3 Diversity Antenna

Antennas are key components of any wireless communication system since they allow the transfer of a signal (in a wired system) to waves that propagate through space and can be received by another antenna. The receiving antenna is responsible for the reciprocal process, which is turning an electromagnetic wave into a signal or voltage at its terminals so that it can subsequently be processed by the receiver.

Antenna diversity is among the popular technique used to improve the wireless link performance especially when the line-of-sight between transmitter and receiver is unclear. Signal might be reflected and bounced back, which can introduce phase shift, attenuation, distortion, interference, signal fading, and sometimes a total loss of the signal. The diversity system with multiple antennas at the receiver makes several observations for the similar signal. Each antenna will receive a different quality of signal. Thus, in some cases, one of the antennas receives a weak signal, while other antennas might receive a stronger signal. Collectively, the whole system would be able to provide a better quality of the received signal with more robust link. Diversity antennas have attracted major interests among researchers