INTEGRATED ANTENNA ARRAY WITH ARTIFICIAL MAGNETIC CONDUCTOR FOR IEEE802.11A APPLICATION

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INTEGRATED ANTENNA ARRAY WITH ARTIFICIAL MAGNETIC CONDUCTOR FOR IEEE802.11A APPLICATION

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To my beloved mother, ROSE BTE. HJ. SAHARI,
father, DEWAN BIN LEK @ ABDUL RAHMAN BIN MADLI,
family and friends.

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ABSTRACT

Microstrip antenna is a preferable choice for antenna due to low profile, low weight, ease of fabrication, inexpensive to manufacture, and adaptable to design at non planar and planar surfaces. However, the drawbacks of designing antenna using microstrip technology are low gain, narrow bandwidth, low efficiency and low power. Many research works were carried out to improve the performance of microstrip antenna. One of the techniques that increasingly attractive nowadays is the integration of metamaterial to microstrip antenna. Metamaterial is a material that not existed in nature and designed artificially. But, due to some useful characteristics of the material, metamaterial is designed as to mimic the non-naturally occurring material to improve performance of devices such as microstrip antenna. Metamaterial that is used in this research is Artificial Magnetic Conductor (AMC). AMC is designed to mimic the unique behaviour of Perfect Magnetic Conductor (PMC). PMC provides phase reflection properties in a limited frequency band. AMC acts as a modified ground plane and in-phase superstrate when positioned at the bottom substrate and top substrate of the antenna respectively. A technique of Defected Ground Structure is implemented in the AMC unit cell, enhancing its bandwidth up to 94%. An array of antenna is developed as the reference antenna at 5.8 GHz operating frequency. The array antenna is integrated with AMC ground plane and in-phase superstrate. An analysis was carried out on the performance improvement to array antenna made by the two distinguishable structures. The developed array antenna with AMC ground plane achieves bandwidth enhancement of 287% while improves efficiency up to 12%. On the other hand, the developed array antenna with in-phase superstrate successfully improves the bandwidth and efficiency of the antenna by 44% and 6%. Additionally, the integration of in-phase superstrate improves the directivity of the array antenna. It is discovered that the existence of air gap limits the gain of the array antenna with AMC ground plane. Furthermore, the air gap improves the gain of the array antenna with in-phase superstrate

ABSTRAK

Antena mikrojalur merupakan antena yang digemari kerana berprofil rendah, ringan, senang dihasilkan, berkos rendah untuk dihasilkan, dan rekaan yang mudah diadaptasi kepada permukaan mendatar atau bukan mendatar. Walau bagaimanapun, kekurangan rekaan antena menggunakan teknologi mikrojalur ialah kegandaan rendah, lebar jalur sempit, kecekapan dan kuasa yang rendah. Banyak kerja penyelidikan dijalankan untuk meningkatkan prestasi antena mikrojalur. Salah satu teknik yang semakin mendapat perhatian ialah aplikasi *metamaterial* kepada antenna mikrojalur. *Metamaterial* ialah bahan yang tidak wujud secara semulajadi dan dihasilkan secara buatan. Oleh sebab ciri-ciri berguna pada bahan itu, *metamaterial* dihasilkan untuk meniru ciri-ciri bahan bukan semulajadi untuk meningkatkan prestasi antena mikrojalur. *Metamaterial* yang digunakan dalam kajian ini ialah Pengalir Magnetik Buatan (AMC). AMC direka untuk meniru tindakan unik Pengalir Magnetic Sempurna (PMC). PMC memberikan pantulan fasa selari di dalam jalur frekuensi terhad. AMC bertindak sebagai satah bumi termodifikasi dan *superstrate* fasa selari yang terletak di bawah dan atas daripada lapisan *substrate* antena mikrojalur masing-masing. Teknik *Defected Ground Structure* digunapakai dalam sel unit AMC meningkatkan lebar jalurnya sebanyak 94%. Antena susunan dibangunkan sebagai antena rujukan beroperasi pade frekuensi 5.8 GHz. Antena susunan diintegrasikan dengan satah bumi AMC dan *superstrate* fasa selari. Analisis terhadap prestasi dijalankan untuk mengenal pasti peningkatan prestasi pada antenna susunan oleh dua struktur tersebut. Antena susunan dengan satah bumi AMC mencapai peningkatan lebar jalur sebanyak 287% dan pembaharuan kecekapan sebanyak 12%. Antena susunan dengan *superstrate* fasa selari pula mencapai lebar jalur dan kecekapan sebanyak 44% dan 6%. Tambahan pula, *superstrate* fasa selari meningkatkan kearahan antena mikrojalur. Didapati bahawa kewujudan ruang udara menghadkan kegandaan bagi antena susunan dengan satah bumi AMC. Disamping itu, ruang udara meningkatkan kegandaan bagi kes antena susunan dengan *superstrate* fasa selari.

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LIST OF ABREVIATIONS

4G	-	Fourth Generations
AAMC	-	Array Antenna with AMC Ground Plane
AIPS	-	Array Antenna with In-phase Superstrate
AMC	-	Artificial Magnetic Conductor
BW	-	Bandwidth
CPW	-	Coplanar Waveguide
CST	-	Computer Simulation Technology
D	-	Directivity
dB	-	Decibel
DCS	-	Digital Communication Services
DGS	-	Defected Ground Structure
DNG	-	Double Negative
DUT	-	Device Under Test
EBG	-	Electromagnetic Band Gap
FR4	-	Flame Resistant 4
G	-	Gain

GPS	-	Global Positioning System
HIS	-	High Impedance Surface
ILSMA	-	Inverted L-Shaped Monopole Antenna
LCPAA	-	Large Coupled Patch Antenna Array
LH	-	Left- Handed
MMIC	-	Monolithic Microwave Integrated Circuit
NRI	-	Negative Refractive Index
PBC	-	Periodic Boundary Condition
PCS	-	Personal Communication Services
PEC	-	Perfect Electric Conductor
PMC	-	Perfect Magnetic Conductor
RF	-	Radio Frequency
RFF	-	Far-field Distance
RFID	-	Radio Frequency Identification
RL	-	Return Loss
Rx	-	Receiver
SMA	-	Subminiature Version A
Tx	-	Transmitter
U	-	Radiation Intensity
UC-PBG	-	Uniplanar Compact Photonic Bandgap
UMTS	-	Universal Mobile Telecommunications System

UV	-	Ultra Violet
VMA	-	Vertical Monopole Antenna
VNA	-	Vector Network Analyzer
VSWR	-	Voltage Standing Wave Ratio
WCC	-	Wireless Communication Centre
WiMAX	-	Worldwide Interoperability for Microwave Access
WLAN	-	Wireless Local Area Network

LIST OF SYMBOLS

%BW	-	Bandwidth Percentage
+z	-	In the direction of positive z axis
a	-	Air gao
c	-	Speed of light
C_j	-	Junction capacitance
Cs	-	Slot capacitance
d	-	Diameter of screw hole
D	-	Diameter of core of coaxial connector
E	-	Screw hole
f_c	-	Centre frequency
f_H	-	High frequency
f_L	-	Low frequency
f_{lower}	-	Lower frequency of AMC without DGS
$f_{lower(D)}$	-	Lower frequency of AMC with DGS
f_r	-	Resonant frequency
f_{upper}	-	Upper frequency of AMC without DGS
$f_{upper(D)}$	-	Upper frequency of AMC with DGS

h	-	Height of subsrate
k_o	-	Plank constant
L	-	Length of patch
L_{eff}	-	Effective length
P_i	-	Power supply
P_r	-	Reflected power
s	-	Gap between AMC unit cells
t	-	Conductor thickness
V_o	-	Speed of light in vacuum
W	-	Width of patch
y_o	-	Length of inset feed
Z_o	-	Characteristic impedance
Ω	-	Ohm
ΔL	-	Delta length

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Microstrip technology is preferable and attractive technique to fabricate antenna and microwave devices such as coupler, phase shifter, power divider and filter. Antenna fabricated using microstrip technology possess several advantages such as low profile, ease of fabrication, low weight, and simplicity in integration to other millimeter-wave integrated circuits and microwave devices. However microstrip antenna imposes various shortcomings such are narrow bandwidth, low gain, and low efficiency. Various researches were done in the past until recently to solve the shortcoming of the microstrip antenna. One of the techniques is by integrating the antenna with metamaterials.

Metamaterials mimics the characteristics or properties of material that not exist in nature. Metamaterial is design to utilize unique properties of that material. Artificial Magnetic Conductor (AMC) is a one type of metamaterial. AMC mimics the behavior of Perfect Magnetic Conductor (PMC). Microstrip antennas typically use Perfect Electric Conductor (PEC) as the ground plane. The uses of PEC have produce shortcomings of reducing antenna efficiency. PEC introduces the image current that is 180^{o} out of phase from the current source which is the original current. This image current cancel out the original current or cause destructive interference with the original current, this will reduce the antenna radiation efficiency.

PMC in contrast with PEC due to its unique properties when use as a ground plane will introduce image current same like PEC does, but is in phase with the original current. The image currents will undergo constructive interference with the source current thus improving radiation efficiency. However, PMC is not exist in nature, thus Artificial Magnetic Conductor (AMC) is designed. In limited frequency band, AMC behaves like PMC while in the remaining band it acts just like a typical PEC.

In this research, AMC can be integrated to microstrip antenna to potentially solve the aforementioned shortcoming such as narrow bandwidth, low radiation efficiency and low gain. The bandwidth widening effect of AMC ground plane and in-phase superstrate can improve the versatility of antenna to support several services in one single antenna. The increase in radiation efficiency improves the utilization of input power to the antenna.

1.2 Problem Statement

Microstrip antenna is a popular trend of antenna design in recent years due to various such advantages such as low profile, light weight, easily conformable to surface. However, the inherent general disadvantage of microstrip antenna is the narrow bandwidth of typically 5% percentage bandwidth. There is abundance of antenna that is design to operate at single narrowband operating frequency. However, wideband antenna is in increasing demand due to its capability in operate at multiple frequencies in order to accommodate more wireless communication services.

AMC integrated into microstrip antenna can improve the shortcoming of using microstrip technology such as narrow bandwidth, low radiation efficiency and low gain. AMC can be included to the microstrip antenna as AMC ground plane or in-phase superstrate. There is no study conducted on similar design AMC ground plane and in-phase superstrate to the microstrip antenna. Apart from that, integrating AMC structure into array antenna can be challenging compare to single radiating patch antenna, which consist of several antenna elements and feeding network. The antenna elements and feeding network can affect the performance of the integrated structure of the antenna. However, the low gain of typical microstrip antenna can be improves with array configuration.

1.3 Objectives

The main objective of the research is to design an Artificial Magnetic Conductor (AMC) for IEEE 802.11a band suitable for wireless communication services such as Wireless Local Area Network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX).

The project involves antenna designing, fabrication process, and performances measurement in order to develop the optimum type of antenna that can achieve bandwidth enhancement with the use of AMC ground plane and in-phase superstrate. The objectives of the research project are:

(i) To design and simulate Artificial Magnetic Conductor (AMC) that operates at 5.8 GHz.

(ii) To design, simulate, fabricate and develop the array antenna that operates at 5.8 GHz.

(iii) To integrate AMC with array antenna and investigate the performance of the Antenna with and without integration of AMC.

(iv) To analyze the effect of AMC ground plane and in-phase superstrate to the array antenna.

1.4 Scope

The scope of study is specified to provide border to which extent the study will be covered. The AMC unit cell is designed and developed for IEEE 802.11a operation. This frequency is useable for WLAN and WiMAX operations. There are various scopes in completing the research which are designing Artificial Magnetic Conductor (AMC) unit cell, to design an array of antenna and to integrate the array antenna with AMC. Array antenna consists of 4 radiating elements that are able to work in dual band. All the design will be fabricated using inexpensive FR-4 Substrate with thickness 1.6mm and dielectric permittivity of 4.5. The software that is used to design the devices is Computer Simulation Technology (CST). Instrument used to determine the degree of agreement between the measurements with the simulated results were Agilent E5071C network analyzer and anechoic chamber. Measurement result and simulation result will be compared and analyzed.

1.5 Significance of research

There are two significance of the research. Firstly, the artificial magnetic conductor (AMC) unit cell is design at 5.8 GHz. AMC operate at 5.8 GHz band has been designed by previous researcher. However, a technique will be implemented to widen the typically narrow bandwidth of AMC.

Secondly, the significance of this research is the use of AMC as a modified ground plane, namely AMC ground plane for the microstrip array antenna. The conventional ground plane for the antenna is Perfect Electric Conductor (PEC). Apart from that, another significance of the study is the implementation of in-phase superstrate to the microstrip antenna. Performance improvement in terms of bandwidth, gain, and efficiency of the microstrip antenna will be observed by the two structures.

1.6 Organization of Thesis

The thesis is divided into five chapters. The organization is as follows:

Chapter 1 introduces on advantage and disadvantage of microstrip antenna. Artificial Magnetic Conductor (AMC) is used to solve the shortcoming in microstrip antenna in term of narrow bandwidth. Additionally, chapter 1 also covers the problem statement research objective and scopes, and lastly the significance of the research.

Chapter 2 provides the theoretical and principle of operation related to Artificial Magnetic Conductor (AMC). Brief introduction and parameters of performance also describe on microstrip antenna. Subsequently, literature review is done on design of AMC and microstrip antenna. This is carried out to seek the possible contributions of the research project with respect to the previous research.

Chapter 3 discusses about the methodology of research used to carry out the research. Flow chart is used to explain the step by step procedure in achieving the objective of the research. After that, detail explanation design specification, simulation procedures, fabrication and measurement is provided. Firstly, the AMC design is discussed, followed by the design of array antenna design. Finally the design of array antenna with AMC ground plane and array antenna with in-phase superstrate is explained.

Chapter 4 presents the result and discussion of the research project. The performance of each of the devices in the research project is explained. The related parametric studies are included in each of the sections. The first part discuss the results of AMC design, the second part discusses the related result on the array antenna while the final part discusses on the result concerning array antenna with AMC ground plane and array antenna with in-phase superstrate. The initial design of AMC up to the finalized design is discussed. Parametric studies, simulation result and measurement results are analyzed. For AMC design, the reflection phase, size reduction, and related result are analyzed and discussed. Brief study also is conducted on the array antenna. Finally, analysis is made on antenna integrated with

AMC. The simulated results are compared with the measured results to verify the reliability of the simulation data.

Eventually, the research is concluded in Chapter 5. The research outputs are presented. Suggestion for future work is provided to further improve the projects.

REFERENCES

[1] S. R. Saunders and A. Aragon-Zavala, *Antennas and Propagation for Wireless Communications Systems*, 2nd ed.: John Wiley & Sons Ltd, 2007.

[2] K.-L. Wong, "Compact and broadband microstrip antennas," *Wiley-Interscience,* 2002.

[3] N. b. Ismail, *et al.*, "Design and analysis of microstrip yagi antenna for wi-fi application," *IEEE Asia-Pacific Conference on Applied Electromagnetics,* pp. 283-286, 2012.

[4] D. Segovia-Vargas, *et al.*, "Quad-frequency linearly-polarized and dual-frequency circularly-polarized microstrip patch antennas with CRLH loading," *Progress in Electromagnetics Research,* vol. 133, pp. 91-115, 2012.

[5] M. S. Alam, *et al.*, "A novel compact split ring slotted electromagnetic bandgap structure for microstrip patch antenna performance enhancement," *Progress in Electromagnetics Research,* vol. 130, pp. 389-409, 2012.

[6] H. F. Abutarboush, *et al.*, "A Reconfigurable Wideband and Multiband Antenna Using Dual-Patch Elements for Compact Wireless Devices," *Antennas and Propagation, IEEE Transactions on,* vol. 60, pp. 36-43, 2012.

[7] Y.T.Lo and S.W.Lee, "Antenna Handbook Antenna Theory," *Van Nostrand Reinhold,* vol. 2, 1993.

[8] A. Foroozesh and L. Shafai, "Application of combined electric- and magnetic-conductor ground planes for antenna performance enhancement," *Electrical and Computer Engineering, Canadian Journal of,* vol. 33, pp. 87-98, 2008.

[9] Y. Huang and K. Boyle, "Antennas from theory to practice," *Wiley-Interscience,* 2008.

[10] A. M. Kordalivand and T. A. Rahman, "Broadband Modified Rectangular Microstrip Patch Antenna Using Stepped Cut At Four Corners Method," *Progress in Electromagnetics Research,* vol. 137, pp. 599-619, 2013.

[11] R. Dewan*, et al.*, "Improved design of tapering and through element series antenna," in *Wireless Technology and Applications (ISWTA), 2012 IEEE Symposium on*, 2012, pp. 202-205.

[12] X. Chen*, et al.*, "A genetic metamaterial and its application to gain improvement of a patch antenna," *Journal of Electromagnetic Waves and Applications,* vol. 26, pp. 1977-1985, 2012/10/01 2012.

[13] C. A. Balanis, "Antenna Theory Analysis and Design," *Wiley-Interscience,* p. 811, 2005.

[14] T. S. Bird, "Definition and Misuse of Return Loss [Report of the Transactions Editor-in-Chief]," *Antennas and Propagation Magazine, IEEE,* vol. 51, pp. 166-167, 2009.

[15] A. P. Saghati, "Antenna and Propagation for Wireless Communications Systems," pp. 214-215, 2007.

[16] V. J.M., "Antenna Engineering Handbook," *Australia & New Zealand. McGraw Hill,* 2010.

[17] R. Dewan*, et al.*, "X-Polarization array antenna with parallel feeding for WiMAX 3.55 GHz application " *IEEE International RF and Microwave Conference,* pp. 368-372, 2011.

[18] D. M. Pozar, "Microwave Engineering," *Wiley-Interscience,* 2005.

[19] T. L. Yim*, et al.*, "Reconfigurable wideband and narrowband tapered slot Vivaldi antenna with ring slot pairs," *Journal of Electromagnetic Waves and Applications,* vol. 27, pp. 276-287, 2013/02/01 2012.

[20] W. L. Stutzman and G. A. Thiele, "Antenna theory and design," *Wiley-Interscience,* 1998.

[21] D. G. Fang, "Antenna theory and microstrip antennas," *Taylor and Francis Group,* 2010.

[22] G. Zhao*, et al.*, "Compact ring monopole antenna with double meander lines for 2.4/5 GHZ dual-band operation," *Progress in Electromagnetics Research,* vol. 72, pp. 187-194, 2007.

[23] S. Behera and K. J. Vinoy, "Microstrip Square Ring Antenna For Dual-Band Operation," *Progress in Electromagnetics Research,* vol. 93, pp. 41-56, 2009.

[24] D. D. Krishna, *et al.*, "Compact Dual Band Slot Loaded Circular Microstrip Antenna with A Superstrate," *Progress in Electromagnetics Research,* vol. 83, pp. 245-255, 2008.

[25] C. Qing-Xin and Y. Liang-Hua, "Design of Compact Dual-Wideband Antenna With Assembled Monopoles," *Antennas and Propagation, IEEE Transactions on,* vol. 58, pp. 4063-4066, 2010.

[26] V. P. Sarin, *et al.*, "Wideband Printed Microstrip Antenna for Wireless Communications," *Antennas and Wireless Propagation Letters, IEEE,* vol. 8, pp. 779-781, 2009.

[27] C. Yikai, *et al.*, "Bandwidth Enhancement Method for Low Profile E-Shaped Microstrip Patch Antennas," *Antennas and Propagation, IEEE Transactions on,* vol. 58, pp. 2442-2447, 2010.

[28] X. Q. Zhang, *et al.*, "Compact wide tri-band slot antenna for WLAN/WiMAX applications," *Electronics Letters,* vol. 48, pp. 64-65, 2012.

[29] A. Khidre, *et al.*, "Wide Band Dual-Beam U-Slot Microstrip Antenna," *Antennas and Propagation, IEEE Transactions on,* vol. 61, pp. 1415-1418, 2013.

[30] A. Pradeep, *et al.*, "GA optimized SRR calculator," in *Recent Advances in Microwave Theory and Applications, 2008. MICROWAVE 2008. International Conference on*, 2008, pp. 800-802.

[31] R. C. Hadarig, *et al.*, "Novel bow-tie antenna on artificial magnetic conductor for 5.8 GHz radio frequency identification tags usable with metallic objects," *IET Microwaves, Antennas and Propagation,* vol. 5, pp. 1097-1102, 2011.

[32] Nasimuddin, "Microstrip antennas," *InTech*, 2011.

[33] D. Sievenpiper, *et al.*, "High-impedance electromagnetic surfaces with a forbidden frequency band," *Microwave Theory and Techniques, IEEE Transactions on,* vol. 47, pp. 2059-2074, 1999.

[34] N. A. Abbasi and R. Langley, "A wideband printed monopole antenna over dual-band AMC," in *Antennas and Propagation Conference (LAPC), 2010 Loughborough*, 2010, pp. 221-224.

[35] A. Vallecchi, *et al.*, "Low Profile Fully Planar Folded Dipole Antenna on a High Impedance Surface," *Antennas and Propagation, IEEE Transactions on,* vol. 60, pp. 51-62, 2012.

[36] D. J. Kern, *et al.*, "The design synthesis of multiband artificial magnetic conductors using high impedance frequency selective surfaces," *Antennas and Propagation, IEEE Transactions on,* vol. 53, pp. 8-17, 2005.

[37] D. J. Gregoire, *et al.*, "Wideband artificial magnetic conductors loaded with Non-Foster negative inductors," in *IEEE International Workshop on Antenna Technology*, 2012, pp. 237-240.

[38] A. Foroozesh and L. Shafai, "On the Scattering Analysis Methods of and Reflection Characteristics for an AMC/AEC Surface," *Antennas and Propagation Magazine, IEEE,* vol. 52, pp. 71-90, 2010.

[39] F. Costa and A. Monorchio, "Multiband electromagnetic wave absorber based on reactive impedance ground planes," *Microwaves, Antennas & Propagation, IET,* vol. 4, pp. 1720-1727, 2010.

[40] Y. Li, *et al.*, "A dual-band planar compact artificial magnetic conductor," *Antennas and Propagation Society International Symposium, 2005 IEEE* pp. 451 - 454, 2005

[41] F. Costa, *et al.*, "An Active High-Impedance Surface for Low-Profile Tunable and Steerable Antennas," *Antennas and Wireless Propagation Letters, IEEE,* vol. 7, pp. 676-680, 2008.

[42] N. A. Abbasi and R. J. Langley, "Multiband-integrated antenna/artificial magnetic conductor," *Microwaves, Antennas & Propagation, IET,* vol. 5, pp. 711-717, 2011.

[43] E. Carrubba, *et al.*, "AMC-based low profile antennas for 4G communication services," in *Antennas and Propagation Society International Symposium, 2007 IEEE*, 2007, pp. 3364-3367.

[44] M. E. de Cos, *et al.*, "Flexible uniplanar artificial magnetic conductor," *Progress in Electromagnetics Research,* vol. 106, pp. 349-362, 2010.

[45] Y. Zhang, *et al.*, "Planar Artificial Magnetic Conductors and Patch Antennas," *IEEE Transactions on Antennas and Propagation,* vol. 51, pp. 2704-2712, 2003.

[46] M.T.Xie, *et al.*, "Design of a Novel Artificial Magnetic Conductor Plane and Its Application for Low Profile Dipole," *ICMMT Proceedings, IEEE,* pp. 2085-2087, 2010.

[47] A. Foroozesh and L. Shafai, "Improvements in the performance of compact microstrip antennas using AMC ground planes," in *Antenna Technology and*

Applied Electromagnetics & the American Electromagnetics Conference (ANTEM-AMEREM), 2010 14th International Symposium on, 2010, pp. 1-4.

[48] A. Foroozesh and L. Shafai, "Investigation Into the Application of Artificial Magnetic Conductors to Bandwidth Broadening, Gain Enhancement and Beam Shaping of Low Profile and Conventional Monopole Antennas," *Antennas and Propagation, IEEE Transactions on,* vol. 59, pp. 4-20, 2011.

[49] L. Qi, *et al.*, "Tunable multiband antenna with an active artificial magnetic conductor ground plane," in *Microwave Conference (EuMC), 2010 European*, 2010, pp. 461-464.

[50] F. Yang and Y. Rahmat-Samii, "Electromagnetic Band Gap Structures in Antenna Engineering," *Cambridge University Press,* p. 24, 2009.

[51] R. Dewan, *et al.*, "Design of triple band Artificial Magnetic Conductor," in *Applied Electromagnetics (APACE), 2012 IEEE Asia-Pacific Conference on*, 2012, pp. 253-256.

[52] J. J. Tiang, *et al.*, "Circular microstrip slot antenna for dual-frequency RFID application," *Progress in Electromagnetics Research,* vol. 120, pp. 499-512, 2011.

[53] M. Wang, *et al.*, "Uniplanar single corner-fed dual-band dual-polarization patch antenna array," *Progress In Electromagnetics Research Letters,* vol. 30, pp. 41-48, 2012.

[54] N. A. Abbasi and R. J. Langley, "Multiband-integrated antenna/artificial magnetic conductor," *IET Microwaves, Antennas and Propagation,* vol. 5, pp. 711-717, 2011.

[55] L. Akhoondzadeh-Asl, *et al.*, "Influence of Element Shape on the Bandwidth of Artificial Magnetic Conductors," *Journal of Electromagnetic Waves and Applications,* vol. 21, pp. 929-946, 2007/01/01 2007.

[56] M. E. de Cos, *et al.*, "Novel SHF-Band Uniplanar Artificial Magnetic Conductor," *Antennas and Wireless Propagation Letters, IEEE,* vol. 9, pp. 44-47, 2010.

[57] D. N. Elsheakh, *et al.*, "Ultrawide Bandwidth Umbrella-Shaped Microstrip Monopole Antenna Using Spiral Artificial Magnetic Conductor (SAMC)," *Antennas and Wireless Propagation Letters, IEEE,* vol. 8, pp. 1255-1258, 2009.

[58] R. C. Hadarig, *et al.*, "Microstrip patch antenna bandwidth enhancement using AMC/EBG structures," *International Journal of Antennas and Propagation,* vol. 2012, 2012.

[59] Y. Li and K. P. Esselle, "Small EBG resonator high-gain antenna using in-phase highly-reflecting surface," *Electronics Letters,* vol. 45, pp. 1058-1060, 2009.

[60] L. Li*, et al.*, "Ultra-Low Profile High-Gain Fabry-Perot Resonant Antennas With Fishnet Superstrate," *Journal of Electromagnetic Waves and Applications,* vol. 26, pp. 806-816, 2012/04/01 2012.

[61] M. E. De Cos*, et al.*, "Enhancing patch antenna bandwidth by means of uniplanar EBG-AMC," *Microwave and Optical Technology Letters,* vol. 53, pp. 1372-1377, 2011.

[62] F. Mohamadi Monavar and N. Komjani, "Bandwidth enhancement of microstrip patch antenna using Jerusalem cross-shaped frequency selective surfaces by invasive weed optimization approach," *Progress in Electromagnetics Research,* vol. 121, pp. 103-120, 2011.

[63] R. Dewan*, et al.*, "The improvement of array antenna performance with the implementation of an artificial magnetic conductor (AMC) ground plane and in-phase superstrate," *Progress in Electromagnetics Research,* vol. 140, pp. 147-167, 2013.

[64] J. Gye-Taek*, et al.*, "Dual-Band Wi-Fi Antenna With a Ground Stub for Bandwidth Enhancement," *Antennas and Wireless Propagation Letters, IEEE,* vol. 11, pp. 1036-1039, 2012.

[65] K. K. Gebril*, et al.*, "Bandwidth enhancement and miniaturization of dielectric resonator antenna for 5.8 GHz WLAN," *Progress In Electromagnetics Research C,* vol. 19, pp. 179-189, 2011.

[66] A. Kumar and D. Kumar V, "High-performance metamaterial patch antenna," *Microwave and Optical Technology Letters,* vol. 55, pp. 409-413, 2013.