TRIPLE-BAND DIPOLE ANTENNA WITH ARTIFICIAL MAGNETIC CONDUCTOR FOR RADIO FREQUENCY IDENTIFICATION

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Specially dedicated to my beloved husband, Musa Abdullah and my children; Muhammad Hakim, Adam Fakhri, Izzat Ibrahim, Sayyidah Akma and Akma Huda for their love

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ABSTRACT

The radiation characteristics and input impedance of the dipole antenna will be distorted when the antenna is placed on a metal object. The electromagnetic wave of the antenna is reflected almost entirely by the metallic surface and a 180° phase shift is occurred. In addition, a common dipole antenna has low gain which is about 2.15 dBi. Owing to the high impedance, surface structure called Artificial Magnetic Conductor (AMC) is developed as a ground plane for the dipole antenna to prevent the performance degradation of the antenna caused by metallic objects and to increase the antenna's gain. Due to the reflected wave of the AMC is in-phase with the antenna current (reflection phase equals to zero), it improves the radiation efficiency and subsequently enhances the gain of the dipole antenna. Thus, due to the great demand in multiband antenna, this research has developed a triple-band dipole antenna with straight and meander structures at Ultra-high Frequency (UHF) and Microwave Frequency (MWF) Radio Frequency Identification (RFID) frequencies; 0.92 GHz, 2.45 GHz and 5.8 GHz respectively. Firstly, the single-band square-patches AMCs are investigated. Then, to obtain a smaller structure of AMC and suitable for RFID applications, two new structures of AMC-HIS are developed. They are single-band AMC called zigzag dipole and dual-band AMC called rectangular-patch with slotted rectangular and I-shaped slot. The parameters that affect the AMC performance are discussed and the performances of the antenna with and without the AMC GP are investigated in terms of return loss, total gain, total efficiency and directivity. From the results gained, in general the power received of the dipole antenna with AMC GP is higher than the power received of the dipole antenna with the absent of AMC GP. Furthermore, a longer reading distance is recorded for the dipole tag antenna backed by AMC structures. For instance, the reading distance for the UHF meandered dipole tag antenna with the 2x2 rectangular-patch with slotted rectangular and I-shaped slot has achieved two times higher compared with the dipole antenna without the AMC GP. While at MWF, its reading distance is increased from 0.8 m to 1.25 m. The performance of the dipole tag antenna with AMC GP attached to the metallic plate size is also tested to verify the dipole tag antenna with AMC GP can be used for metallic object detection in RFID applications.

ABSTRAK

Ciri-ciri radiasi dan galangan masukan antena dwikutub akan terganggu apabila ia diletakkan ke atas objek logam. Ini kerana, hampir keseluruhan gelombang elektromagnetnya akan dipantulkan oleh permukaan logam dan berlaku anjakan fasa sebanyak 180°. Tambahan lagi, antena dwikutub biasanya mempunyai gandaan yang rendah di mana nilainya sekitar 2.15 dBi. Oleh itu, struktur permukaan galangan tinggi yang dikenali sebagai Konduktor Bermagnet Buatan (AMC) telah dibangunkan sebagai satah bumi kepada antena dwikutub untuk menghalang kemerosotan prestasi antena yang disebabkan oleh objek logam dan untuk meningkatkan gandaan antena. Disebabkan gelombang pantulan bagi AMC adalah sama fasa dengan arus antena (fasa pantulan bersamaan sifar), ia meningkatkan kecekapan radiasi dan seterusnya meningkatkan gandaan antena. Maka sehubungan dengan permintaan yang tinggi dalam antena pelbagai jalur, penyelidikan ini telah membangunkan antena dwikutub tiga-jalur yang mempunyai struktur yang lurus dan berkelok pada frekuensi amat-tinggi (UHF) dan pada frekuensi gelombang mikro (MWF) frekuensi Pengenalan Frekuensi Radio (RFID); 0.92 GHz, 2.45 GHz dan 5.8 GHz. Mulanya, segiempat sama-tampal jalur-tunggal AMC dikaji. Kemudian, untuk mendapatkan struktur AMC-HIS yang lebih kecil dan sesuai untuk aplikasi RFID, dua struktur baru AMC-HIS telah dibangunkan. Ia adalah jalur-tunggal AMC yang dipanggil dwikutub zigzag dan dwi-jalur AMC yang dipanggil segiempat-tampal dengan alur segiempat dan bentuk-I. Parameter-parameter yang memberi kesan ke atas prestasi AMC dibincangkan dan prestasi antena dengan satah bumi AMC dan tanpa satah bumi AMC dikaji dari segi kehilangan balikan, gandaan keseluruhan, kecekapan keseluruhan dan penumpuan. Daripada keputusan yang diperolehi, secara keseluruhannya penerimaan kuasa oleh antena dwikutub dengan satah bumi AMC mempunyai penerimaan kuasa yang lebih tinggi berbanding antena dwikutub yang tidak mempunyai satah bumi AMC. Selain daripada itu, jarak bacaan yang lebih panjang telah direkodkan bagi antena label dwikutub yang dibelakangi oleh struktur AMC. Sebagai contoh, jarak bacaan bagi antena label UHF dwikutub dengan Konduktor Bermagnet Buatan segiempat-tampal dengan alur segiempat dan bentuk-I 2x2 telah mencapai dua kali ganda berbanding antena dwikutub tanpa satah bumi AMC. Manakala pada MWF, jarak bacaannya telah meningkat dari 0.8 m kepada 1.25 m. Prestasi antena dwikutub dengan satah bumi AMC juga telah diuji di mana ia telah diletakkan ke atas kepingan logam untuk mengesahkan bahawa antena label dengan satah bumi AMC boleh digunakan untuk mengesan objek logam di dalam aplikasi RFID.

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LIST OF SYMBOLS

Z_s	-	Surface impedance
ε_r	-	Substrate permittivity
h	-	Substrate thickness
δ	-	Tangent loss
d	-	Separation distance between dipole antenna and metal surface
λ	-	Operating wavelength
Z_0	-	Characteristic impedance
ε_{eff}	-	Effective dielectric constant
hg	-	Height of the ground plane
ht	-	Distance between the ground plane and the branches
l_b	-	Length between the port and branch dipole elements
b_r	-	Length of the branch dipole
$P_{tag\text{-}chip}$	-	Tag power
R	-	Reading distance
$P_{reader\text{-}tx}$	-	Reader output power
$G_{reader\text{-}ant}$	-	Reader antenna gain
$G_{tag\text{-}ant}$	-	Tag antenna gain
χ	-	Mismatch polarization coefficient
$P_{tag\text{-}threshold}$	-	Threshold power
τ	-	Power transmission coefficient
Γ	-	Reflection coefficient
$G_{realized}$	-	Realized gain
μ_{total}	-	Total radiation efficiency

D	-	Directivity
f_r	-	Operating frequency
L	-	Inductance
C	-	Capacitance
W	-	Patch width
g	-	Gap between the patches
f_U	-	Upper frequency
f_L	-	Lower frequency
ε_0	-	Free-space permittivity
μ_0	-	Free-space permeability
η_0	-	Free-space impedance
λ_0	-	Free-space wavelength
λ_g	-	Guided wavelength

LIST OF ABBREVIATIONS

HIS	-	High Impedance Surface
AMC	-	Artificial Magnetic Conductor
UHF	-	Ultra-high Frequency
MWF	-	Microwave Frequency
GP	-	Ground Plane
RFID	-	Radio Frequency Identification
ASIC	-	Application Specific Integrated Circuit
RF	-	Radio Frequency
PMC	-	Perfect Magnetic Conductor
PEC	-	Perfect Electric Conductor
CST	-	Computer Simulation Technology
PIFA	-	Planar Inverted-F Antenna
CAD	-	Computer Aided Design
FSS	-	Frequency Selective Surface
FR-4	-	Flame Retardant-4
SMA	-	Sub Miniature Version A
RL	-	Return Loss
VSWR	-	Voltage Standing Wave Ratio
UV	-	Ultraviolet
VBA	-	Visual Basic for Applications
RCS	-	Radar Cross -Section
TE	-	Transverse Electric
TEM	-	Transverse Electromagnetic
GUI	-	Graphical User Interface

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CHAPTER 1

INTRODUCTION

1.0 Research Background

Printed dipole antennas have been actively studied since they are simple, easy to fabricate, and easy to integrate with the Application Specific Integrated Circuit (ASIC) microchip. It is also comes with wide variety of shape. However, it is categorized as a low gain antenna where it is fundamentally limited by the size, radiation patterns and the frequency of the operation [1-2]. In addition, the radiation characteristics and input impedance of the dipole antenna will be distorted when the antenna is placed on a metal object [3-5]. This is because, the electromagnetic wave is reflected almost entirely by the metallic surface and a 180° phase shift may be occurred. By nature, the conventional ground planes exhibit the property of phase reversal of the incident currents resulting destructive interference of both dipole antenna and image currents. The same scenario happens when the dipole tag antenna is attached to a metallic object, the tag cannot be powered up by the field strength emitted by the Radio Frequency Identification (RFID) reader since the metallic object reflects Radio Frequency (RF) wave. The impedance of the tag antenna, resonant frequency of the antenna and radiation efficiency will be changed due to the parasitic capacitance between the tag antenna and the metallic object. To overcome this problem, the antenna must be placed at a quarter-wavelength above the metallic ground plane, making the antenna bulky at low frequencies [6]. Another way to minimize effects of the parasitic capacitor between the dipole antenna and metallic object and the effect of the reflection of the RF wave by metallic object, a gap between tag antenna and the metallic object is placed and dielectric material between them is added [7].

Thus one way to reduce the size of the antenna, the high-impedance surface (HIS) structure is introduced to act as Perfect Magnetic Conductor (PMC) which does not exist in nature [8-11]. Its structure can be realized by artificially engineered, thus it is called as Artificially Magnetic Conductor (AMC). The AMC or PMC condition is characterized by the frequency or frequencies where the magnitude of the reflection coefficient is +1 and its phase is 0°. It has high surface impedance (Z_s) and it reflects the external electromagnetic waves without the phase reversal. In contrast, the Perfect Electric Conductor (PEC) has a reflectivity of -1 and has electromagnetic waves out of phase with the incident waves. As the metallic plate, the AMC also can be used as a ground plane to redirect the back radiation and provide shielding to the antennas.

This research involves the design and development of a triple-band dipole antenna employing HIS structure called AMC at 0.92GHz, 2.45GHz and 5.8GHz in order to prevent the performance degradation of the dipole antenna caused by a metallic surface and at the same time to increase the gain of the antenna. The approach of designing multi-band antenna and AMC is considered in order to get a versatile antenna and AMC that can operate at multiple frequency bands which have attracted much attention today. All the design simulations are done using Computer Simulation Technology (CST) Microwave Studio software. Based on the optimum simulation results, the designed antenna and AMC are fabricated. The experimental validation of the antenna and tag prototypes with and without the AMC ground plane (GP) is carried out to verify the performance of the designs. Furthermore, the read range of the tag with and without AMC GP and metallic plate attached to them are also recorded to ensure that the developed tag antenna can be used for metallic object identification in RFID applications.

1.1 Research Benefits / Applications

The research benefits/applications are:

i. The High Impedance Surface structure called Artificial Magnetic Conductor prevents the performance degradation of the antenna and tag caused by a metallic object.
ii. The AMC offers good radiation efficiency and high gain to the antenna and tag antenna, thus achieving longer reading distance.
iii. A versatile antenna and AMC can operate at multiple frequency bands.
iv. The designed tag antenna can be used for metallic and non-metallic object identification.

1.2 Problem Statements

Printed dipole antennas have been actively studied since they are simple, easy to fabricate and integrate with the Application Specific Integrated Circuit (ASIC) microchip. However, these antennas which do not have a ground plane cannot work when the antenna and tag is directly attached to a metallic surface. The electromagnetic wave is reflected almost entirely by the metallic surface and a 180° phase shift occurs. The reflected wave cancels the incident wave of the antenna and tag and this causes changes in the radiation properties of the antenna. The radiation efficiency and gain will be decreased and the resonant frequency will be poor. Microstrip patch [12-13] and Planar Inverted-F Antenna (PIFA) [14-16] antennas are presented as RFID tags for working in metal environments because their designs consist of metallic ground planes. However, their performance as tag antennas is still dependent on the dimensions of the metallic planes close to them [7].

Next, the performance of the RFID is evaluated in terms of reading or communication distance where it is highly dependent on the tag and the RF reader design. Depending on the specific antenna configuration and RF power of the reader, the communication distance may vary. The reader antenna with higher gain and power will be able to read tags from a greater distance. But, in many cases, a UHF reader will be operated at the legal limit, normally a watt of power of the reader [17]. So, the gain of the reader antenna and tag is another important parameter for the reading distance. The range is greatest in the direction of maximum gain, which is fundamentally limited by the size, radiation patterns and frequency of operation. For a small omni-directional dipole antenna, the highest gain is about 2.15dBi which is considered a low gain antenna. Therefore, a new tag antenna needs to be designed and developed which is able to read tags mounted on metalic objects without any performance degradation.

1.3 Research Objectives

The main purpose of this research is to develop a dipole antenna and tag for metallic object identification by employing High Impedance Surface structure called Artificial Magnetic Conductor. By applying the AMC as a ground plane for the dipole antenna, the performance degradation of the antenna and tag caused by the metallic surface can be prevented and the gain of the antenna can be increased. Thus, the research objectives are:

i. To design and fabricate the triple-band dipole antenna (at 0.92GHz, 2.45GHz and 5.8GHz).
ii. To design and fabricate the single-band and dual-band AMC-HIS.
iii. To measure the performance of the antenna and tag with and without the AMC and dipole antenna with AMC ground plane attached with metallic surface.

iv. To test and validate the tag prototypes by measuring the reading distance of the tag with and without the AMC ground plane and dipole antenna with AMC ground plane attached with metallic surface.

1.4 Scope of Research and Limitations

The scope of the research is as follows:

i. Review the technique used for multiband printed antenna, the theory and design of Artificial Magnetic Conductor - High Impedance Surface (AMC-HIS) and study the RFID systems and other material related to the research work.
ii. Design, simulate and optimize a multiband dipole antenna and AMC-HIS at 0.92GHz, 2.45GHz and 5.8GHz.
iii. Design, simulate and optimize a triple-band dipole antenna with AMC-HIS GP.
iv. Fabricate the antenna, tag and AMC-HIS.
v. Measure the antenna and tag properties with and without AMC-HIS structures.
vi. Validate the designed tag by measuring the reading distance with and without AMC GP attached to a metallic plate.
vii. Finalize the designs, compile reports and cite regional/international conference and journal papers.

Two factors are identified which impeded the progress of the research. First, the designed triple-band dipole antenna can only be matched at 50Ω impedance in spite of the value difference of tag impedance applied at different RFID frequencies. In this case, for the UHF RFID tag, the Monza® 3 tag chip requires an antenna's impedance of 32 + 216j Ω and the 2.45GHz RFID tag requires antenna's impedance of 60Ω (see Appendix 1 and 2). Second, the passive 5.8GHz MWF RFID systems is required in this research to validate the tag antenna prototypes. However, the passive 5.8GHz RFID system is not available in the market and therefore, it is not possible to test or record the reading distance of the dipole tag antenna working at 5.8GHz.

1.5 Thesis Organization

Chapter 1 presents the research background, research benefits, problem statements, objectives and scope of research and limitations.

Chapter 2 reviews multiband printed antenna technique, Artificial Magnetic Conductor and tag antenna for metallic object identification. The applications of AMC by other researchers are reviewed too. This chapter also presents an overview of the RFID system including its operation, bands and the effect of metallic surface on the dipole antenna and tag performance.

Chapter 3 investigates the wire dipole placed on or near to a metallic surface. Then new designs of triple-band printed dipole antennas used for RFID tag are presented. The dipole antenna with straight and meander structure are designed to operate at three (3) different frequencies (0.92GHz, 2.45GHz and 5.8GHz). The simulation and measurement results of the antenna properties are discussed such as return loss, bandwidth, gain, and radiation pattern at each operating frequency. The performance of the RFID tags (when the dipole antennas are connected to the ASIC microchip) in terms of reading distance is also presented using the UHF SDK Gen2 Module RFID and Microwave readers.

Chapter 4 gives a detailed explanation of the designed single-band and dual-band AMCs. The AMC characteristics in terms of reflection phase, reflection coefficient magnitude and surface impedance are discussed in this chapter. A detailed analysis of the single-band and dual-band AMCs including the new structure of 0.92GHz zigzag dipole AMC-HIS, and 0.92GHz and 2.45GHz AMC-HIS with rectangular-patch with rectangular and I-shaped slot are elaborated too.

Chapter 5 presents the performance of the designed triple-band straight and meandered dipole antennas with and without the AMC ground plane. It is the main important chapter that aim to demonstrate the simulation and measurement of the dipole antennas with single-band and dual-band AMC-HIS GP. The study parameters include return loss, realized gain, total efficiency, radiation pattern and directivity of the antenna.

Finally, Chapter 6 draws some conclusions including the findings of the research, key contribution and recommendation for future research work.

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