X-BAND METAMATERIAL ABSORBER FOR ANTI-MOTION DETECTOR

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To my lovely mother, who gave me supports, assistance and encouragement from before I start doing this project until the end.

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ABSTRACT

A motion detector is a device designed for sense motion, particularly humans for security and surveillance purpose. The counter-product of a detector is an absorber. Applied for various modern military and civil technologies, the study of absorber has been expanded to a very wide area, including in metamaterials. This report will discuss on an X-Band Metamaterial Absorber (MMAb) designed for anti-motion detector operating at 10.525 GHz. The proposed MMAb is aiming to achieve a maximum absorptivity that at least 90% of the electromagnetic radiation absorbed. It is expected to have wider operating angle that can be extended at least 60º. The design is aspired to reach a very high degree of insensitivity involving polarization through a series of simulation. By using CST Software, the absorber is designed from an orthodox pattern of annulled circle per unit block, which consists of textile-based substrate in between a metal-based ground plate and a top structure. The structure is then simulated in unit cell to determine the maximum absorptivity through a simple design. Through a series of calculation and observation, the parametric study of the structure is implemented, and from that point, the complication of the pattern is increased so that the maximum absorptivity can be accomplished. Some of the parameters concerned are width of the circle, size of a unit cell and angle of operation. As to consider the flexibility of the absorber, the bend factor of the MMAb is also applied in the simulation. The final design will be decided from the highest absorptivity attained in the series of simulation. The MMAb is expected to be flexible enough to be applied as wearable electromagnetic absorber that is sustainable in terms of absorbing electromagnetic wave from most of the definite directions.

ABSTRAK

Alat pengesan gerakan adalah peranti yang direka untuk mengesan pergerakan manusia untuk tujuan keselamatan dan pengawasan. Peranti bertentangan dengan pengesan adalah penyerap. Digunakan untuk teknologi ketenteraan dan sivil moden, kajian tentang penyerap semakin diperluas, di antaranya adalah di dalam bidang metamaterial. Laporan ini akan membincangkan mengenai penyerap metamaterial dalam band X (MMAb) yang direka untuk menyah-kesan gerakan dikendalikan khusus pada frekuensi 10.525 GHz. MMAb ini direka bertujuan untuk mencapai penyerapan maksimum yang sekurang-kurangnya sehingga 90% daripada radiasi elektromagnet yang diserap. Ia dijangka mempunyai sudut operasi yang lebih luas yang boleh dilanjutkan sekurang-kurangnya 60º. Struktur yang direka ini dengan tujuan agar ianya tidak sensitif terhadap polarisasi. Dengan menggunakan Perisian CST, penyerap direka daripada corak bulatan ortodoks dalam unit blok yang terdiri daripada substrat berasaskan tekstil di antara plat bumi yang berasaskan logam dan struktur di atas. Reka bentuk ini kemudiannya disimulasikan setiap reka bentuk untuk menentukan penyerapan maksimum melalui reka bentuk yang mudah. Melalui siri pengiraan dan pemerhatian, kajian parametrik struktur dilaksanakan, dan dari sudut itu, komplikasi corak meningkat supaya penyerapan maksimum dapat dicapai. Antara parameter yang diambil kira adalah seperti lebar bulatan, saiz sel unit dan sudut operasi. Faktor lengkungan penyerap turut dipertimbangkan untuk mencapai tujuan fleksibiliti. MMAb dijangka cukup fleksibel untuk digunakan sebagai penyerap elektromagnetik yang boleh dipakai, yang mampan dari segi menyerap gelombang elektromagnet dari pelbagai arah.

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LIST OF ABBREVIATIONS

MMAb	-	Metamaterial Absorber
ENG	-	Epsilon Negative Media
DNG	-	Double Negative Metamaterial
MNG	-	Mu Negative Media
SNG	-	Single Negative Metamaterial
TE	-	Transverse Electric
TM	-	Transverse Magnetic
et. al.	-	and others
FWHM	-	Full-width Half-maximum
EMC	-	Electromagnetic Compatibility
EM	-	Electromagnetic

LIST OF SYMBOLS

λ	-	Wavelength
ε	-	Dielectric Permittivity
μ	-	Dielectric Permeability
R(ω)	-	Reflectance
T(ω)	-	Transmittance
A(ω)	-	Absorbance
Z_M	-	Impedance of Metamaterial
Z_O	-	Impedance of Free Space
ε_0	-	Permittivity of Free Space
μ_0	-	Permeability of Free Space
$R_{TE}(\omega)$	-	Reflectance of TE Mode
$R_{TM}(\omega)$	-	Reflectance of TM Mode
λ_0	-	Resonant Wavelength
f_0	-	Resonant Frequency
c	-	Velocity of Light
W	-	Width of Unit Cell
L	-	Length of Unit Cell
ε_r	-	Relative Permittivity
ε_{eff}	-	Effective Permittivity
r_i	-	Inner Radius
r_o	-	Outer Radius
Φ	-	Phi
Θ	-	Theta

CHAPTER 1

INTRODUCTION

1.1 Introduction

Motion detector is a device that can detect the movement of objects, particularly humans within a near-range distance by the application of electromagnetic radiation. The fundamental mechanism operating on motion detector is based on the mechanism applied on radar. The common purposes of radar are to detect the presence of an object from a definite distance, to detect the speed of a moving object and to map the surface of an object from a very far distance, such as topographic mapping of planets. As radar uses echo from the signal it has transmitted to detect the object, motion detector also applies the same principle to spot moving objects [1]. Based on recent market study, many of motion detectors operate at X-Band frequency of 10.525 GHz, functioning in the range of three to seven meters from the detector. However, this project focuses on how to 'sneak away' from being detected by motion detector. This means that being invisible from the electromagnetic radiation emitted by motion detector. The common device that serves this purpose is microwave absorber. Since the project focuses on the design of an absorber specially devised to conceal its presence from motion detector, the term of anti-motion detector has emerged as for highlighting the absorber's functionality.

Electromagnetic absorber that functions to absorb all incident radiation at the operating frequency is also called a near unity absorber. There are two types of electromagnetic absorber; resonant and broadband absorber [25]. As for resonant absorber, the material interacts with the incident radiation through resonance that extracted from the operating frequency. On the other hand, broadband absorber relies on properties of the materials that are frequency-independent so that it can absorb over a huge bandwidth [25]. Some famous resonant absorbers were introduced, such by W.W. Salisbury and J. Jaumann. The very classic electromagnetic absorber used at least a quarter of operating wavelength to match the electromagnetic wave to the free space [26]. For instance, Salisbury screen that was designed by W.W. Salisbury consisted of a resistive sheet placed in front of a metal ground plane by $\lambda_0/4$ and separated by lossless dielectric [26]. The Jaumann absorber that was quite like Salisbury screen, except that it has two or more resistive sheets that operate at distinct wavelength respectively. The increase of layer has made the bandwidth to be increased, however, the absorber becomes bulky and inconvenient for some applications.

The introduction of metamaterials was a ground-breaking in electromagnetic research field. Researchers began to adapt the material into the design of electromagnetic devices such as antenna, superlens, absorber, filter, etc. Utilizing metamaterial as the base material of an absorber have lots of advantages such as being compact and light-weight, tunable for different range of frequency, applicable for a very high frequency band, flexibility in design and acquire huge possibility in designing new structure for specific purposes [6]. Some of applications of metamaterial absorber (MMAb) that were developed in times are invisibility cloak, bolometer spectroscopy, sub-wavelength imaging and thermal emission.

1.2 Problem Statement

As discussed in 1.1, MMAb functions to absorb electromagnetic radiation, thus conceals its presence from sensor or precisely for this project, a motion detector. In other word, MMAb has lots of similarity to an invisibility cloak. However, working mechanism of MMAb requires all incident radiation to be absorbed at the operating frequency by using the concept of transmission line theory. In that theory, metallic plate functions as short circuit and the placement of other metallic layer with the certain distance relating to the operating wavelength will act as a load, therefore an open-circuit scenario is established [1]. As an absorber that absorbs all the electromagnetic radiation, a very minimal reflectance is required because the incident wave can only see the metallic patch as admittance. When the load impedance matches the free space, the reflectivity will be zero, therefore high absorptivity can be realized. To design a structure whose load impedance matches the free space is one of the challenges in designing a MMAb. There were some researches that worked on MMAb structural design and some analysis that were made from the works [6-14]. However, most of them using FR-4, which is hard and not flexible, as substrate materials. To create a MMAb that function against a motion detector means that it needs flexibility to operate against all incident wave, including some bending effects on no matter polarization it might be. The most suitable material to operate on is textile. However, since the design MMAb operates in X-Band, a unit cell is predicted to be very small and inapplicable to textile, based on equation in sub-chapter 3.2.2. This project will study on how MMAb can be designed on a textile, despite of all the challenges it might confront.

On the other hand, MMAb research field occupies a very large possibility as infinite designs of structure are yet to be discovered. The design is not only focusing on the functional values of the MMAb, but also the aesthetic value. There were lots of interesting structure of MMAb that are highly capable in absorbing electromagnetic radiation [6], [10], [11], [13]. The characteristics of MMAb from previous works and their differences are studied in Chapter 2. Some of the MMAb are reviewed to construct the “best structure” to achieve the objectives stated in sub-Chapter 1.3.

1.3 Objectives of Study

MMAb is an ideal device for anti-motion detector, however, there are also some impediments that need to be solved so that it can function as what it is aimed to be. The objectives of this research are to design, simulate, fabricate, measure, and analyze an X-Band MMAb based on textiles for anti-motion detector. The MMAb should have all three properties as mentioned below;

(1) Achieve absorptivity at least 90% of the incident electromagnetic wave

(2) Achieve wide operating angle which at least 60^{o}

(3) Achieve perfect polarization insensitivity

1.4 Scope of Works

Scope of work is the field in which the limitation of the work can be performed as describe. As for this project, variety of designed MMAb are studied in Chapter 2, for instance MMAb that focus on operating for single band or wideband, and also flexible MMAb that works fine for either single, multi- or wideband. Despite of the differences, the mechanism in designing the MMAb is overall the same. For every design, a unit cell dimension is constructed and simulated by using Radio Frequency software such as CST software and HFSS. Since the targeted frequency of operation is in X-Band, the size of a unit cell is not outside the range of 15 mm. However, from the literature review in Chapter 2, there are some MMAb designed at C-Band, so a unit cell is larger compared to ones designed at X-Band. This makes a point that for all the designs, the thickness and the compactness of the structures depending on the sub-wavelength range.

1.5 Key Contribution and Novelty

Prior research has shown that metamaterial is a vast field of study that it is endless to dive into its research field. The development of EM absorber has also widened from the orthodox Salisbury absorber to absorber based on metamaterial. As to progress towards the main goal, which is discovery of the world of metamaterial, the research of the diversity of the field is essential.

Designing a flexible MMAb that based on textile is one of the diversity for metamaterial. Not only it is practical wise, it is suitable for safety and intelligence purposes. Although this project emphasizes on the theoretical part of the study, it is not an impossible project to make it come true if chances were given. Adding some additional features like bending factor, contributes to the question of flexibility. How flexibility can be perceived by just deforming the structure of the MMAb, and if it is possible, to what extent? How absorptivity is affected by tilting and bending the MMAb? All those questions are the first step towards finding out the path of the project. From the review journals, articles, and academic papers, textile-based MMAb is not that popular however, when there is any, it did discuss on flexibility. In other words, flexibility is not studied. This project will discuss thoroughly on designed structures of textile-based MMAb and detailed analysis of the simulations executed.

1.6 Report Organization

This report is divided into five chapters. In this chapter, that is the first chapter of the report, contains a brief introduction of motion detector and MMAb. Then, the necessity of completing this project is explained in problem statement. The research objectives are stated in number form as a benchmark whether the MMAb fulfil the targets of research. The scope of work is specified to show the limitation of the works and the whole project report is summarized in this sub-chapter.

In chapter 2, literature review is done by studying what is metamaterial and the theory of MMAb, including some equations related to the theoretical value of the subject. Previous works on single- and wideband MMAB are included and compared in this sub-chapter. As the proposed MMAb aims to be flexible, few examples of works related to flexible MMAb are presented. The chapter is concluded by comparing the reviewed MMAb.

In chapter 3, methodological part of the research is shown including, the usage of simulation software and the schedule of the whole project. Some of additional methodological procedure such as bending factor, is explained in the process.

In chapter 4, the designs are shown with the analysis for the designs. The analysis consists of reflectance, transmittance and absorbance of MMAb, the absorptivity of the MMAb for different incident angles, the simulated current distribution and surface current and the effects on the absorptivity from changing the bending factor. It will be summarized in the end of the chapter by comparing both designs.

Chapter 5 concludes the whole project, whether or not the objectives stated in sub-Chapter 1.3 are achieved. Some additional findings are stated and future works related to this project are explained at the end of the chapter. References used for this project are listed at the end of this report.

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