DESIGN OPTIMIZATION OF MICROWAVE ABSORBERS USING WASTE MATERIALS FOR ELECTROMAGNETIC COMPATIBILITY APPLICATIONS

By

MUHAMMAD NADEEM IQBAL

(1140810704)

A thesis submitted in fulfillment of the requirement for the degree of

Doctor of Philosophy (Communication Engineering)

School of Computer and Communication Engineering
UNIVERSITY MALAYSIA PERLIS

2014

UNIVERSITI MALAYSIA PERLIS

DECLARATION OF THESIS

Author's full name : Muhammad Nadeem Iqbal

Date of birth : 25th January, 1977

Title : Design Optimization of Microwave Absorbers Using Waste Materials for Electromagnetic Compatibility Applications

Academic session : 2011/2012-2014/2015

I hereby declare that the thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed in the library of UniMAP. This thesis is classified as:

☐	**CONFIDENTIAL**	(Contains confidential information under the Official Secret Act 1972)
☐	**RESTRICTED**	(Contains restricted information as specified by the organization where research was done)
☑	**OPEN ACCESS**	I agree that my thesis is to be made immediately available as hard copy or online open access (full text)

I, the author give permission to the UniMAP to produce this thesis in whole or in part for the purpose of research or academic exchange only (except during the period of ___ years, if so requested above).

Certified by:

_____	_____
SIGNATURE	**SIGNATURE OF SUPERVISOR**
(GS1333072)	Dr. Mohd Fareq Bin Abd Malek
(NEW IC NO. / PASSPORT NO.)	**NAME OF SUPERVISOR**
Date: _____	Date: _____

ACKNOWLEDGEMENT

In the name of Allah, Most Gracious, the Most Merciful. All praise to the Allah the almighty, for the blessing that lead to my success in completing my research.

I would like to express my gratitude to my PhD supervisor, Prof. Dr. Mohd Fareq Bin Abd Malek for his continuous encouragement, extensive support, freedom and trust that enabled this research to run smoothly. Special thanks to Dr. Muhammad Iqbal Husain (Senior Lecturer) from the School of Manufacturing Engineering, UniMAP, who motivated me to opt this opportunity. I would like to thank, all of my colleagues at Advanced Microwave Research Laboratory (AMREL), UniMAP, Perlis for the help, guidance and friendly environment including Fikri, Solahine, Rubail, Wee, Hasliza and Nazri. I also appreciate Mr. Yeng Seng Lee for his help and friendly discussions.

I would like to acknowledge here, late Dr. Nasir Ahmed Ex-DG (R&M), May Allah SWT rest his soul in peace, who granted me the permission and encouraged to correspond with the foreign universities for PhD studies. Special thanks to all of my office colleagues, especially, Mr. Israr Muhammad (Sr. Scientist) who always encouraged, support and guide the juniors. At the last but not least, I would like to thank to my parents who looked after my family and also my family members who suffered a lot during my studies. It is all due to their prayers, patience and understanding that have driven me to this extends.

At the end I want to thanks all of my Paksitani friends here in Perlis especially, Humayoon and Kashif from nano lab.

Muhammad Nadeem Iqbal

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

2-D	Two Dimensional
A-1	Arrangement 1
A-2	Arrangement 2
BL	Back Layer
CNC	Computer Numerically Controlled
CNT	Carbon Nanotubes
DUT	Devide Under Test
EM	Electromagnetic
EMC	Electromagnetic compatibility
EMI	Electromagnetic Interferenc
EMP	Electromagnetic Pulse
ESD	Electrostatic Discharge
EU	European Union
EW	Electronic Warfare
FCC	Federal Communications Commission
FD	Frequency Domain
FEM	Finite Elemnt Method
FF	Far Field
FIT	Finite Integration Technique
FL	Front Layer
FSA	Free Space Arch
FSS	Frequency Selective Surfaces
GHz	Giga Hertz

GI	Galvinized Iron
GT	Geometrically Tapered
HARP	Halpern Anti Radar Paint
HFSS	High Frequency Structure Solver
HIS	High Impedance Surfaces
IFF	Identification of Friend or Foe
IL	Insertion Loss
MEKP	Methyl Ethyl Ketone Peroxide
MIL-STD	Military Standard
MS	Mild Steel
MUT	Material Under Test
NEMP	Nuclear Electromagnetic Pulse
NP	Null Point
NPF	Null Point Frequency
NPF	Null Point Frequency
OA	One Antenna
OATS	Open Area Test Sites
PCB	Printed Circuit Board
PEC	Perfect Electric Conductor
PVA	Poly Vinyl Acetate
RADAR	Ranging and Detection
RCS	Radar Cross Section
RH	Rice Husks
RHC	Rice Husk clad
SOLT	Short Open Load Thru
SR	Scrap Rubber
SRC	Scrap Rubber composite

TE	Transverse Elecetric
TM	Transverse Magnetic
TRL	Thru Reflect Load
UPR	Unsaturated Polyester Resin
UWB	Ultra Wideband
VNA	Vector Network Analyzer
WG	White Glue
WLAN	Wireless Local Area Network

LIST OF SYMBOLS

$\varepsilon_r^{'}$	Real Part of Complex Permittivity
$\varepsilon_r^{''}$	Imaginary Part of Complex Permittivity
γ	Wave propagtion constant
α	Attenuation constant
β	Phase constant
t	Thickness
Z_{in}	Input impedance
f	Frequency
dB	Decibel
Γ	Reflection coefficient
T	Transmission coefficient
Γ_1	Reflection coefficient at first interface
λ	Wavelength
l	Length of single layer absorber
θ_i	Angle of incidence
θ_r	Angle of reflection
θ_t	Angle of transmission
μ_r	Reletive permeability
ε_r	Reletive permittivity
n_1	Refractive index of medium one
n_2	Refractive index of second medium
Z_L	Load impedance
η	Charateristic impedance
η_0	Charateristic impedance of air
η_d	Charateristic impedance of dielectric medium

ω	Angular frequency
σ_{eff}	Effective conductivity
S_{21}	Transmission S-parameter

Reka Bentuk Pengoptimuman Hentak Ketuhar Gelombang Mikro Yang Menggunakan Bahan-Bahan Buangan Untuk Aplikasi Keserasian Electromagnetic

ABSTRAK

Penggunaan bahan-bahan yang dibuang dalam produk-produk tambah nilai sejak Amalan kebiasaan lama. Terbaru, dua sisa telah belajar untuk kegunaan mereka berpotensi dalam ketuhar gelombang mikro yang menyerap aplikasi. Salah satu daripada sisa-sisa nasi hampas (RH) dari sawah padi dan sumber semulajadi karbon, manakala satu lagi adalah getah sekerap (SR) dari tayar kereta dibuang (sumber sintetik karbon hitam). RH yang mempunyai ketumpatan pukal yang rendah (70-110 kg/m³), dan dengan itu memerlukan jumlah yang besar untuk menyimpan. Begitu juga, proses kitar semula yang sangat mahal dan kompleks diperlukan untuk guna semula SR sintetik. Pembakaran sisa-sisa, melepaskan sejumlah besar toksik karbon oksida mono (CO) dan gas karbon dioksida (CO2) di udara. Tambahan pula, buih dielectric yang tersedia secara komersil hentak Khas menurun dalam penyelesaian karbon (grafit penggantungan) sebelum, mereka boleh digunakan dalam Dewan-Dewan anechoic. Walau bagaimanapun, kedua-duanya daripada sisa-sisa mempunyai kandungan karbon yang sudah lossy, yang telah menjadikan mereka menarik bahan-bahan mentah untuk pembuatan hentak microwave kos rendah. Dalam tesis ini keserasian elektromagnet (EMC) berorientasikan kajian ketuhar gelombang mikro hentak terdiri daripada sisa-sisa dua dalam satah dan geometri tirus bentuk rongga (GT) dibentangkan. Inovatif penggunaan sisa ini dua, di hentak EMC boleh membuat sumbangan penting dalam usaha untuk menangani masalah-masalah yang berkaitan dengan pencemaran alam sekitar dan pelupusan sisa. Sebagai langkah pertama dalam kajian ini, sampel telah dicipta dalam Borang Komposit oleh mencampurkan berbeza tambahan (wt. %) daripada sisa-sisa dua, dengan kedua-dua jenis pelekat iaitu, resin poliester tak tepu (UPR) dan gam bukan toksik yang tersedia secara komersil. Sampel yang telah disediakan pada skala makmal pada suhu bilik dengan menggunakan salah satu kaedah pembuatan komposit yang paling mudah iaitu, kaedah bengkalai tangan. Dalam langkah kedua, sifat-sifat dielectric sampel diukur menggunakan sensor himpuan jalur lebar yang mudah ke atas dalam julat 2 hingga 20 GHz frekuensi. Sifat-sifat ini maka, digunakan untuk mengkaji dan menentukan ciri-ciri galangan, gelombang pelemahan hidrologi malar, fasa malar, dan kedalaman penembusan gelombang kejadian sisa lossy. Hentak microwave satah yang terdiri daripada lapisan tunggal, galangan-diberi gred dua dan reka bentuk tiga lapisan telah belajar berangka dan digunakan bagi melaksanakan eksperimen keberkesanannya dalam menumpaskan kekerapan diskret (jalur sempit) dan jalur lebar elektromagnet menekankan. Nilai-nilai pembalik yang didapati berada di bawah-20 dB pada frekuensi-frekuensi yang diskret dengan prestasi sempit jalur, dalam kes hentak lapisan tunggal. Prestasi jalur lebar di bawah dB -15 telah dicapai dengan menggunakan Reka bentuk impedans-kecerunan. Hentak hollow GT telah belajar untuk menyelesaikan isu-isu yang berkaitan dengan pemasangan hentak pepejal yang sangat besar. Hentak ini direkabentuk berdasarkan gelombang pelemahan Hidrologi dan kulit kedalaman data dan prestasi EMC mereka dinilai dari segi prestasi pembalik bi-statik. Keputusan membuktikan bahawa, walaupun, hentak ini mempunyai berat badan 58% kurang dan 15% kurang ketinggian daripada penyerap pepejal, mereka disediakan standard prestasi, iaitu <-20 dB. Nilai optimum dalam pecahan RH untuk hentak hollow berat badan didapati berada dalam lingkungan 35 hingga 60%, komposit keseluruhan, yang mana kerosakan struktur yang kurang diperhatikan. Prestasi penyerap yang dijumpai di bawah dB-10 walaupun pada 100 °C di dalam jalur frekuensi X. Dua lapisan Papirus Reka bentuk yang berasaskan konsep pelapisan juga dikaji bagi meningkatkan prestasi EMC frekuensi rendah hentak pepejal yang terdiri daripada getah sekerap dari tayar kereta.

Design Optimization of Microwave Absorbers Using Waste Materials for Electromagnetic Compatibility Applications

ABSTRACT

Use of discarded material in value-added products has been a common practice since long. Recently, two wastes have been studied for their potential use in microwave absorber applications. One of these wastes is rice husk (RH) from the paddy fields and is a natural source of carbon, while another is scrap rubber (SR) from discarded automobile tires (a synthetic source of carbon black). The RH has a low bulk density (70-110 kg/m^3), and thus requires large volumes for storage. Likewise, a very expensive and complex recycling process is required to reuse the synthetic SR. Burning of these wastes, releases a large amount of toxic carbon mono oxide (CO) and carbon dioxide (CO_2) gases in the air. Furthermore, commercially available dielectric foam absorbers are specially dipped in a carbon solution (graphite suspension) before, they can be used in anechoic chambers. However, both of the wastes have already lossy carbon contents, which has made them attractive raw materials for the fabrication of the low cost microwave absorbers. In this thesis electromagnetic compatibility (EMC) oriented study of the microwave absorbers composed of these two wastes in planar and geometrically-tapered (GT) hollow shapes is presented. Innovative use of these two wastes, in EMC absorbers can make significant contributions in our efforts to cope with the waste disposal and the problems associated with the environmental pollution. As a first step of the study, the samples were fabricated in composite form by mixing different loadings (wt. %) of these two wastes, with the two types of adhesives i.e., unsaturated polyester resin (UPR) and a commercially available non-toxic glue. The samples were prepared on laboratory scale at room temperature by using one of the easiest composite fabrication methods i.e., hand lay-up method. In the second step, dielectric properties of the samples were measured using an easy to use broadband co-axial sensor over the frequency range of 2 to 20 GHz. These properties were then used, to study and determine the characteristic impedance, wave attenuation constant, phase constant, and depth of penetration of the incident wave in the lossy wastes. Planar microwave absorbers composed of a single layer, impedance-graded two and three-layer designs were studied numerically and experimentally for their effectiveness in suppressing the discrete frequency (narrowband) and broadband electromagnetic echoes. The values of the reflectivity were found to be well below the -20 dB at discrete frequencies with narrowband performance, in case of single layer absorbers. Broadband performance below -15 dB was achieved by using impedance-gradient design. The GT hollow absorbers were studied to solve the issues related to the installation of the bulky solid absorbers. These absorbers were designed on the basis of the wave attenuation and depth of penetration data and their EMC performance was evaluated in terms of bi-static reflectivity performance. The results proved that, while, these absorbers had 58% less weight and 15% less height than the solid absorbers, they provided standard performance, i.e., < -20 dB. The optimum value of the weight fraction of the RH for hollow absorbers was found to be in the range of 35 to 60 %, of the overall composite, for which less structural damage was observed. The performance of the absorbers was found to be below -10 dB even at 100 °C in the X band of frequencies. A two-layer pyramidal design based on the cladding concept was also studied to improve the low frequency EMC performance of the solid absorbers composed of scrap rubber from automobile tires.

CHAPTER 1

INTRODUCTION

1.1 Background

With the dawn of state-of-the-art microelectronics based modern era, various types of man-made electromagnetic interference (EMI) sources in the environment have emerged (Al-Ghamdi & El-Tantawy, 2010; Kim, Kim, & Choi, 2007). Rapid advances in microprocessor-based technology, which is the backbone of today's military and civil communication systems have brought a variety of serious un-intentional EMI concerns. EMI is the unwanted coupling of electromagnetic (EM) energy which takes place among the unprotected sensitive electronic circuits and systems. The least effect experienced by the receptor circuit or system, as a consequence of this intersystem coupling, might be the performance degradation. However, the worst effects may include the temporarily malfunction or permanent damage of a sensitive component which can lead to the failure of the mission critical systems. Irrespective of the adverse EMI effects, its origin is believed to be the time varying currents and voltages which can be found in the diverse nature and closely packed electronic circuits within any active electronic device or system.

In real life, the systems have to work within the shared EM environment and need to be compatible with each other without causing or suffering from EMI (Tong, 2009). The control of EMI at source level or minimization of its adverse effects on the receptor or victim enhances the electromagnetic compatibility (EMC) and results in better performance of the integrated electronic systems and sub-systems in mission critical military and civil equipment. It should be noted that the biological systems can also be the victims of EMI and this area is dealt under the name of bio-EMC. The effects of the EM radiations emitted from

the mobile phones on the human body are investigated in this area. Intersystem radiated EMI can be controlled by confining the sources or receptors within specially designed EM shields which in most of the cases are fabricated using metallic sheets. These shields act as external barriers and enhance the intersystem EMC; however, intra system or self-EMC of a system degrades due to the presence of these shields. These metallic shields reflect back any EM signals that impinge on them internally and augment the internal echoes resulting in a noisy environment.

In order to evaluate the compatibility of the electronic equipment, indoor EMC test facilities are used as an alternate of the open area test sites (OATS) (Williams, 2001). The radiated and conducted EMC testing is performed on the military and civil electronic and electrical systems for the levels of their emission and susceptibility or immunity against the EM ambient radiations. These facilities are specially equipped with the microwave absorbers working in a broad frequency range of 30 MH to 18 GHz (Trautnitz F. W., 2007).

1.2 EMC Oriented Study of Absorbers

There are two types of tests which are performed within the EMC test facilities for the compatibility of the electronic equipment and these are known as conducted and radiated EMC tests. These tests are performed in accordance with the internationally well known standards in military and civil domains such as MIL-STD-461 and CISPR series standards (Holloway et al., 1997). Active electronic components and devices in electrical, electronics and communications systems can be evaluated for their levels of emissions and susceptibilities. However, microwave absorbers are passive components and are used to enhance the EMC of the electronic systems along with the other techniques such as filtering of common mode and differential mode conducted EMI, grounding and shielding of radiated EMI. To date, no standard is available for the EMC testing of the absorbers but there are certain performance requirements which are considered to have fulfilled before the absorbers

can be used in EMC test facilities. These performance requirements will be discussed in detail in the next chapter.

The EMC performance of a device, system or even anechoic chamber strongly depends on the performance of the microwave absorbers (Chung & Chuah, 2003). Whereas, the performance of the microwave absorbers depends on many factors, including frequency, angle of incidence, the geometry of the absorber. Therefore the EMC-oriented study of the microwave absorbers involves the investigations of all those factors that can affect its ability to control radiated EMI. The knowledge of the complete response of the absorbing material exposed to high frequency EM radiations is very crucial at different weight fractions of the lossy filler.

1.3 Problem statement

Recently rice husks (RH) and powder of scrap rubber (SR) from discarded automobile tires have been identified as microwave anechoic wastes. These were studied for their reflection loss performance in 7 to 13 GHz (Malek et al., 2011; Nornikman et al., 2011). However, there were two important issues related to their practical applications. One of the issues was related to the installation of these absorbers due to their bulkiness. In order to solve this issue, a hollow pyramidal design is presented and evaluated.

The other issue was related to the design, shape i.e., pyramidal, which was investigated, but is impractical to be used in the general purpose EMC applications which includes the suppression of electromagnetic echoes from the flat reflecting surfaces other than chamber walls. To date, no study has been conducted to investigate the effectiveness of the RH and SR based microwave absorbers in planar geometries which are more robust design shapes and have wide EMC applications. An impedance-graded technique has been used in this thesis to design the flat absorber for the 4-8 GHz band. The thickness of the