EVALUATION AND CHARACTERIZATION OF PCB SHIELDING EFFECTIVENESS IN NEAR FIELD REGION

by

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Thesis submitted in fulfillment of the requirements for the degree of Master of Science

July 2017

ACKNOWLEDGEMENTS

First, I would like to thank Universiti Sains Malaysia and the School of Electrical and Electronic Engineering for providing me with this postgraduate project and providing fund for test boards fabrication. Besides that, I would like to express my appreciation to my host company, Motorola Solutions Penang for supporting Cadence EDA tools software, Computer Simulation Technology (CST) Microwave Studio software, and Electromagnetic 3D scanner.

Special thanks to my supervisor, Dr. Mohd Tafir Mustaffa, for guiding me throughout my postgraduate research. I am grateful for his support, encouragement, permission, and all the advices given in achieving objective of my research and thesis writing. I sincerely appreciate his contribution and commitment in guidance for me to complete my postgraduate project.

In addition, I would like to address my appreciation to my technical mentors, namely, Mr. Adib Osman and Mr. Khairul Azmy Zakaria for their patience, and their willingness to impart their knowledge and share their experiences. I am really grateful to have their advice and guidance in design of test boards, measurement method, and analysis of the collected data.

Last but not least, I thank my family members, who offered me unlimited moral support. Without them, I could never have completed my project successfully. To those I failed to mention here, I am no less grateful and ask forgiveness for my oversight.

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LIST OF SYMBOLS

μ	Permeability
ε	Dielectric constant
σ	Conductivity
δ	Skin depth
λ	Wavelength
μr	Relative permeability
σr	Relative conductivity
A	Absorption loss
R	Reflection loss
B	Correction factor for multiple reflections
t	Thickness of shield
r	Distance from radiation source to point of measured
E_i	Electric field intensity without shield assembled
E_o	Electric field intensity with shield assembled
g	Longest dimension of the aperture
d	Depth of the waveguide

LIST OF ABBREVIATIONS

ADS	Advance Design System
BLS	Board-level Shields
CAD	Computer Aided Design
CST	Computer Simulation Technology
EMI	Electromagnetic Interference
ERP	Effective Radiated Power
FIT	Finite Integration Technique
FM	Frequency Modulation
FR4	Fire Retardant
HDI	High Density Interconnect
NFC	Near Filed Communication
PBA	Perfect Boundary Approximation
PCB	Printed Circuit Board
RF	Radio Frequency
TEM	Transverse Electromagnetic
VNA	Vector Network Analyzer

PENILAIAN DAN PENCIRIAN KEBERKESANAN PEMERISAIAN PCB DALAM MEDAN BERDEKATAN

ABSTRAK

Perisai tahap PCB telah digunakan dalam industri elektronik secara meluas untuk mengurangkan masalah gangguan elektromagnet dan mematuhi piawai Keserasian Elektromagnet (EMC). Namun, peranti yang nipis, kecil, dan laju, beroperasi pada frekuensi Giga-Hertz telah menyebabkan gangguan elektromagnet antara jalur elektrik dan komponen. Berdasarkan pengetahuan terbaik penulis, kebanyakan penilaian keberkesanan pemerisaian tahap PCB hanya dilakukan dalam medan berjauhan. Oleh itu, kaedah pengukuran keberkesanan pemerisaian dalam medan berdekatan untuk tahap PCB dengan menggunakan pengimbas 3D elektromagnet dicadangkan di dalam tesis ini. Beberapa papan ujian PCB direkabentuk dengan dimensi yang berbeza dan dinilai. Keputusan mengesahkan kebolehpercayaan kaedah pengukuran dalam kawasan berdekatan berdasarkan keserasian antara keputusan pengukuran dan simulasi. Selain itu, penilaian kesan ciri-ciri perisai seperti ketebalan dan ketinggian dinilai melalui simulasi. Keputusan mencadangkan bahawa keberkesanan pemerisaian boleh ditingkatkan dengan mempunyai perisai yang lebih tinggi dengan jarak antara ‘ground via’ yang lebih kecil. Dengan setiap tambahan 0.5 mm pada ketinggian perisai, keberkesanan pemerisaian boleh ditingkatkan sebanyak 1 dB. Sebaliknya, keberkesanan pemerisaian akan berkurang sebanyak 0.5 dB untuk setiap peningkatan 1 mm dalam jarak antara ‘ground via’. Di samping itu, perisai yang lebih tebal boleh meningkatkan keberkesanan pemerisaian pada frekuensi di bawah 300 MHz.

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ABSTRACT

PCB level shield cans had been widely used in electronic industry to mitigate electromagnetic interference and to comply with Electromagnetic Compatibility (EMC) standard. However, the thinner, smaller, and faster, operating up to Giga-Hertz range devices led to electromagnetic interference among traces and components. To the best of author's knowledge, most of the shielding effectiveness in PCB level was done in far field evaluation. Thus, measurement method in near field for PCB level shielding effectiveness by using electromagnetic 3D scanner is proposed in this thesis. Several test boards were designed with different shields' dimension, evaluated for shielding effectiveness. Comparable results between the measurement and simulation justified the reliability of the measurement method in near field. Besides that, the evaluation of the impact of shield's characteristic such as shield's height and thickness, were modeled through simulation. Results suggested that shielding effectiveness could be improved by having greater shield's height with smaller ground via spacing in shielding ground tracks. With every step of 0.5 mm increase in shield's height, shielding effectiveness can be improved by 1 dB. On the other hand, shielding effectiveness would be degraded by 0.5 dB for every step of 1 mm increase in ground via spacing. In addition, greater shield's thickness can contribute better shielding effectiveness for operating frequency below 300 MHz.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Wireless communication becomes basic tool for human to stay connected to the world anytime and anywhere. In recent years, mobile handset market experiencing unprecedented growth. This booming in activity has rewarding rapid growth in semiconductor industry as well. Driven by market demand, electronics technologies improve continuously to deliver innovative capabilities and higher circuit performance. Circuit designed in continuing shrinking size to fit into smaller and thinner PCB, more and more integrated circuit emerged in one piece to provide multiples wireless features in a single device. With these technology improvement, end user becomes the main beneficiary to enjoy several wireless technologies such as Bluetooth, NFC (Near Filed Communication), Wifi, LTE cellular in a single mobile device.

However, implementing such on board wireless modules comprising multi-band antennas make Electromagnetic Interference (EMI) issues on PCB even more complex than ever before. Potentially EMI coupling would occur between on-board digital circuits and on-board antennas (Pissoort, et al., 2013). With several wireless modules operate in frequency up to 2.4 Giga hertz, and bunch of digital switching signals in compact space, potentially each portion of the circuit maybe interfered by other conducted or radiated disruptive energy. This energy can adversely affect circuit performance or even, if high enough, cause damage to human brain cells or other organs (Archambeault, Brench, & Connor, 2010). Thus, the goal in any RF design is to reduce emitted radiation to a level that meets or stays below any mandated industry requirements for operation, safety, and health. Shielding is the common way to resolve electromagnetic interference. It is noninvasive and does not affect high-speed operation, works for both emissions and susceptibility. The use of shielding can take many forms ranging from RF gaskets to board-level shields (BLS) (Lairds technologies, 2010).

Usually shielding can be differentiated by two categories, enclosure level shielding and PCB (Printed Circuit Board) level shielding. Enclosure shield used to be bigger size metal box, covers whole board or a system, which all of six planes of the box made by the metal. On the other hand, PCB level shielding apply small size metal cans to be attached on a portion of the PCB board. Five planes of the conductive shield cans are made by the metal material, while the sixth bottom plane is the PCB itself.

PCB level shielding is capable of dealing with problems of the internal interference and regulatory emissions control at low-cost and providing ease of assembly compared to enclosure shielding. It becomes more effective when dealing with integration of close proximity wireless communication in a product through the isolation of the noisy transmitting or digital processing signal sources (Armstrong, 2004). To achieve promising emission suppression, researcher started to study varies parameters of the tiny shield can, such as its material, shape, thickness, behavior of apertures, and so on.

1.2 Problem Statement

Shielding is good to be implemented by taking the consideration of several critical parameters in the early stage of design to achieve the best shielding effectiveness. Those critical parameters are material, shield’s thickness, height from the source, and most importantly number of apertures, aperture's size, location, and shape. Dealing with PCB shield's design, there are several items that can be improved. At first, most of the study been conducted to date were relevant to the enclosure level shielding. There is lack of knowledge about impact of those critical parameters to PCB level shielding effectiveness. In terms of shield's design, there have no advance guideline to determine the geometry dimension and characteristics of apertures to achieve optimum shielding effectiveness. In addition, energy leakage from the sixth plane of the shield, which is PCB itself often been excluded from consideration. Openings formed between ground vias on the ground track potentially allow significant radiation. Second, PCB level shielding was evaluated in far field in previous study. However, design of small shield cans become more complicated as the electromagnetic radiation hard to be predicted in such small space, impact of design parameters such as thickness, height of the shield and mainly aperture design to the shielding effectiveness become dominant. There should be a way to evaluate shielding effectiveness in near field as interference and coupling of signal always happen in near field region among traces and digital circuits. To improve the shielding effectiveness, there is a need to evaluate those shielding characteristics and the relationship of the shield parameters such as thickness, height of the shield and apertures to the shielding effectiveness. Through analysis of the evaluation, an advance guideline can be created for designer to improve their shielding solution in their particular circuit and operating frequency.

1.3 Research Objectives

This research aims to evaluate the characteristic of PCB level shielding. The specific objectives are as follows:

i. To design, simulate and measure the PCB test board for shielding effectiveness evaluation.
ii. To evaluate and characterize PCB shielding effectiveness in near field by using 3D Electromagnetic Scanner.
iii. To evaluate the impact of ground via spacing, shield's thickness and shield's height with PCB level shielding effectiveness in sweeping frequency up to 2.5 GHz.

1.4 Contributions

The following are the contributions from this research:

i. A way to evaluate PCB level shielding effectiveness in near field.
ii. Knowledge to characterize PCB level shielding for purpose of resolving electromagnetic interference.
iii. An advance shield's characterization guideline to improve electromagnetic interference suppression in particular wireless technologies operating frequency up to 2.5 GHz, such as NFC, Bluetooth, Wifi, and cellular network.

1.5 Scope of Research

This research was separated in three stages. First stage was mainly focused on the study of enclosure level shielding and PCB level shielding theories, consolidating shielding characteristics that had been evaluated. Method of measurement for PCB level shielding will be reviewed to determine the proper method for PCB level shielding effectiveness measurement.

Design and fabrication of the PCB test board and shield can was carried out in stage two. In the design of test board, ADS software tools will be used to simulate

50 ohm transmission line in sweeping frequency range up to 2.5 GHz. Several test boards will be fabricated with different ground via spacing, while the shields will be fabricated with different thickness and different height. By considering most of the interference and signal coupling are happened in close distance among circuits, PCB shielding was suggested with a way to be evaluated in near field. Several shields with different dimension were evaluated to justify the reliability of the measurement result in near field compared to simulation results.

In stage three, key work will be simulation and real measurement of the shields and test boards with different characteristics to figure out the impact of shield's thickness, height and ground via spacing to the shielding effectiveness. Results from simulation and real measurement will be compared to determine the precision and accuracy. Analysis of the results meant to create a guideline for PCB level shielding techniques in particular operating frequency electromagnetic interference mitigation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this chapter, fundamental theory of enclosure level shielding and PCB level shielding are discussed. Definition of the shielding effectiveness is clearly interpreted as well in terms of PCB level. Besides, there are reviews of shielding effectiveness measurement method in PCB level for far field and near field. The study of shield's characteristic impact to the shielding effectiveness is revealed in this chapter as well.

2.2 Overview of Enclosure Level Shielding

A perfect shield should have the ability to fully reject the radiation from external circuit, while prevent internal signal to interfere other circuit. Ability of the enclosure to prevent electromagnetic interference is determined by its shielding effectiveness which is the sum of absorption loss and reflection loss.

Figure 2.1: Enclosure level shield

Enclosure shield generally is a metal box as described in Figure 2.1, which forms a conductive barrier covering an electrical circuit in order to provide isolation from other sensitive signal sources. There are several variable may influence the shielding effectiveness of the enclosure, such as material permeability, conductivity, enclosure geometry and type of field being attenuated. Those described variables are only applicable to enclosure with no aperture. However in real application, there must be apertures placed to allow ventilation, and also input output wire from the circuit inside the enclosure. When taking aperture into account, potentially the opening causing significant signal leakage and decrease overall shielding effectiveness. The following subsection will review shielding theory for those shielding effectiveness factors and also impact of apertures.

2.3 Characteristic of field

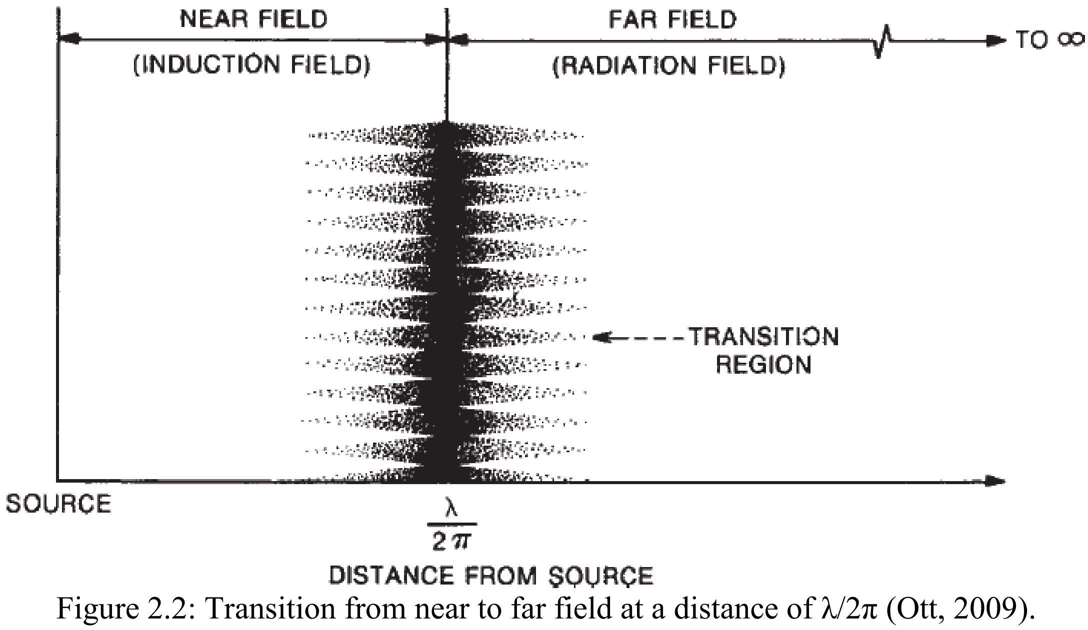

Figure 2.2: Transition from near to far field at a distance of $\lambda/2\pi$ (Ott, 2009).

Figure above shows the characteristic of field determined by the source, distance between the source and the point of observation. If r > wavelength (λ) / 2π , around one sixth of a wavelength, radiation would be far field. On the other hand, radiation is near field if r < wavelength (λ) / 2π, where r is the distance from the source to where the field is observed (Ott, 2009). In far field, determination of electric or magnetic field can be neglected as signal are propagating as plane wave which has constant 377 ohm impedance (Hickman, 2007). However, in near field, ratio of the electric field to magnetic field is key point to determine its wave impedance. Thus, it must be considered separately. If the source has high voltage and low current, near field is predominantly electric, while in the other way near field will be predominantly magnetic (Hitchcock, 2004). With a straight wire antenna in near field, electric field attenuates at a rate of $(1/r)^3$, and the magnetic field attenuates at a rate of $(1/r)^2$ (Ott, 2009). Determination of field's characteristic is important to estimate shielding effectiveness where distance of observation point to the radiation source is key variable in reflection loss.

2.4 Wave Impedance

Wave impedance (Zw) of any electromagnetic wave is defined as ratio of the electric field (E) to magnetic field (H), Zw = E/H. Impedance of a plane wave is a constant with a value of 377 ohm (Hickman, 2007).

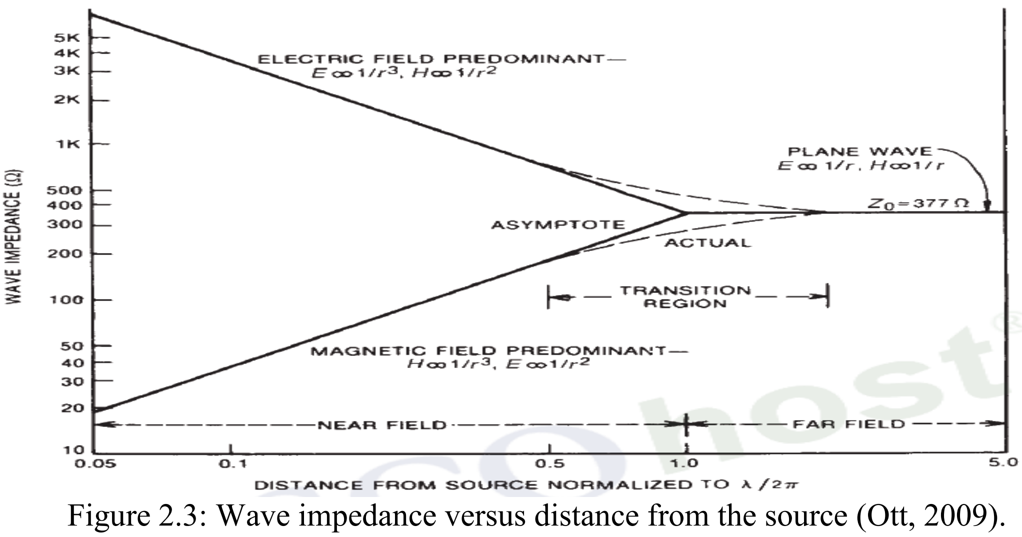

Figure 2.3: Wave impedance versus distance from the source (Ott, 2009).