AN EVALUATION ON THE CONTRIBUTION OF DIFFERENTIAL MODE AND COMMON MODE CURRENTS IN RADIATED EMISSION OF DIGITAL CIRCUITS

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For my beloved parents and family.

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ABSTRACT

Electromagnetic Compatibility (EMC) is an issue that has rapidly increased in importance in recent years, driven by legal, and commercial demands. The EMC compliance requires the implementation of a total EMC approach to the development of electric and electronic circuitry such as in product manufacturing, with compliance being an integral part of the product life-cycle. Radiated emission test is one of the EMC criteria with a purpose to ensure that other products are protected from the emissions generated by it. This project is focused on the contribution of Differential Mode Current (I_d) and Common Mode Current (I_c), that occur in electric and electronic circuitry which definitely affects the overall radiated emissions level. A standard test circuit was designed and implemented as the reference circuit. Several of the test circuits were designed and developed using appropriate layout design techniques such as loop area control and appropriate grounding techniques to ensure signal quality and functional performances due to EMC. The value of I_d exhibited significantly much higher values than I_c for frequency ranges between 30 MHz to 1000 MHz throughout all the measurements. Despite the significantly different values between I_d and I_c , the total radiated emissions over the frequency ranges exhibited consistent results. This indicate that although the values of I_c were noticeably lower than I_d, I_c still dominated the radiated emission in electric and electronic circuitry. The effects of loop area and grounding techniques on radiated emission were also studied. There was a 0.3 % of reduction regarding loop area technique using double-sided PCB compared to the standard test circuit. The average value of radiated emission produced by the test circuit due to I_d exhibited a reduction of 3.42 % from the standard test circuit, while the average value of radiated emission produced by the test circuit due to I_c exhibited a reduction of 2.17 % from the standard test circuit. Future work should focus on improving the circuit design and development using multilayer PCB for optimal performance. Furthermore, effort can

also be made on expanding the circuit design by implementing noisy sources such relays and motors, and improve the circuit with higher density and more traces.

ABSTRAK

Keserasian elektromagnet (EMC) adalah satu isu penting yang meningkat dengan begitu cepat pada kebelakangan tahun ini, yang disebabkan oleh permintaan terhadap undang-undang dan permintaan komersial. Kepatuhan terhadap keserasian elektromagnet memerlukan pendekatan perlaksanaan keserasian elektromagnet sepenuhnya ke atas proses pembangunan sesebuah litar elektrik dan elektronik seperti di dalam penghasilan produk di mana kepatuhan terhadap keserasian elektromagnet adalah salah satu kitaran hidup produk tersebut. Ujian terhadap sinar pancaran merupakan salah satu kriteria di dalam keserasian elektromagnet, di mana ia khususnya bertujuan memastikan sesuatu produk dilindungi dari pancaran sinar yang terhasil. Projek ini memfokus terhadap sumbangan mod berbeza arus aliran elektrik (I_d) dan mod biasa arus aliran elektrik (I_c), yang wujud di dalam sesebuah litar elektrik dan elektronik, yang mana ia semestinya memberi kesan terhadap paras sinar pancaran yang terhasil. Sebuah litar ujian piawai telah direkabentuk dan diaplikasikan sebagai litar rujukan. Beberapa litar ujian telah direkabentuk dan dihasilkan menggunakan teknik-teknik rekaan yang baik seperti teknik mengawal keluasan litar dan teknik pembumian bagi memastikan penghasilan isyarat yang berkualiti dan bermutu terhadap keserasian elektromagnet. Di dalam setiap ujikaji, nilai I_d mempamerkan bacaan yang sangat tinggi berbanding nilai I_c bagi julat frekuensi di antara 30 MHz ke 1000 MHz. Akan tetapi, di sebalik terdapatnya perbezaan nilai yang besar antara I_d dan I_c, sinar pancaran yang terhasil menunjukkan bacaan keputusan yang konsisten antara satu sama lain. Ini menunjukkan yang walaupun nilai I_c adalah lebih rendah berbanding nilai I_d, I_c tetap mendominasi sinar pancaran yang terhasil dari litar elektrik dan elektronik. Kesan terhadap keluasan litar dan teknik pembumian juga telah dikaji. Terdapat pengurangan sebanyak 0.3% terhadap teknik keluasan kawasan yang digunakan pada PCB dua-belah berbanding litar ujian piawai. Nilai purata sinar pancaran yang terhasil oleh litar ujian yang disebabkan oleh I_d, menunjukkan pengurangan

sebanyak 3.42 % berbanding litar ujian piawai, manakala purata sinar pancaran yang terhasil oleh litar ujian yang disebabkan oleh I_c, menunjukkan pengurangan sebanyak 2.17 % berbanding litar ujian piawai. Kajian lanjutan seharusnya memfokus kepada penambahbaikkan rekabentuk dan pembinaan litar menggunakan PCB berbilang lapisan untuk perlaksanaan yang optimum. Focus juga boleh dilakukan ke atas mengembangkan rekabentuk litar dengan menggunakan sumber yang mempunyai nilai hingar yang tinggi seperti motor, dan menambahbaik litar dengan kepadatan yang lebih tinggi dan laluan yang lebih banyak.

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LIST OF SYMBOLS AND ABREVIATIONS

B	-	Magnetic Flux Density (Wb/m^2)
E	-	Electric Field Intensity (V/m)
f	-	Frequency (Hz)
I	-	Current (A)
jX	-	Resistance (Imaginary Value) (Ω)
R	-	Resistance (Real Value) (Ω)
s	-	Spacing (m)
t	-	Thickness of Strip (m)
V	-	Voltage (V)
w	-	Width (m)
Z	-	Real and Imaginary Value of Resistance (Ω)
ε_r	-	Relative Permittivity of Material (dimensionless)
ε_r'	-	Effective Relative Permittivity
ω	-	Angle Frequency (rad/s)
λ	-	Wavelength (m)
$E_{,max}$	-	Electric Field Intensity (dBuV/m)
$E_{c,max}$	-	Electric Field Intensity Due To Common Mode Current (dBuV/m)
$E_{D,max}$	-	Electric Field Intensity Due To Differential Mode Current (dBuV/m)
I_c	-	Common Mode Current (dBuA)
I_d	-	Differential Mode Current (dBuA)
I_{rf}	-	Radio Frequency Current (dBuA)
V_{probe}	-	Voltage of Probe (V)
V_{rf}	-	Radio Frequency Voltage (V)
Z_c	-	Characteristic Impedance of a Copper (Ω)
Z_0	-	Characteristic Impedance (Ω)

EMC	-	Electromagnetic Compatibility
EUT	-	Equipment Under Test
emf	-	Electromotive Force
FCC	-	Federal Communications Commission
GTEM	-	Gigahertz Transverse Electromagnetic Mode
PCB	-	Printed Circuit Board
RF	-	Radio Frequency

CHAPTER 1

INTRODUCTION

1.1 General

In many countries, the necessities to meet up with the EMC requirements of digital devices are in great demand. The continued market growth in portable electrics and electronics, advanced control systems for transportation and computerized factories have flooded the Radio Frequency (RF) spectrum. The increases in RF noise make EMC of digital devices essential in insuring continued expected operation. Generally, EMC indicates the capability of electrical and electronic system, equipment and devices to operate in its intended electromagnetic environment within a defined margin of safety, and at design levels or performance, without suffering or causing unacceptable degradation as a result of electromagnetic interference [1]. A system is electromagnetically compatible with its environment if it satisfies these three criterions; it does not cause interference with other systems, it is not susceptible to emissions from other systems and it does not cause interference with itself [2].

The field of EMC consists of two distinct areas which are emissions and susceptibility as shown in Figure 1.1. Emissions are the propagation of electromagnetic interference from noncompliant devices (culprits), in particular, radiated and conducted electromagnetic interference. On the other hand, susceptibility is the detrimental effects on susceptible devices (victims) in the form that include radiated and conducted electromagnetic interference. Consequently, EMC subproblems comprise of radiated emission, conducted emission, radiated susceptibility and conducted susceptibility. However, this experimental study will only focus on one of those subproblems which are radiated emission. On the whole, the role of current sources, I_c and I_d in electric and electronic circuitry towards radiated emission level is investigated.

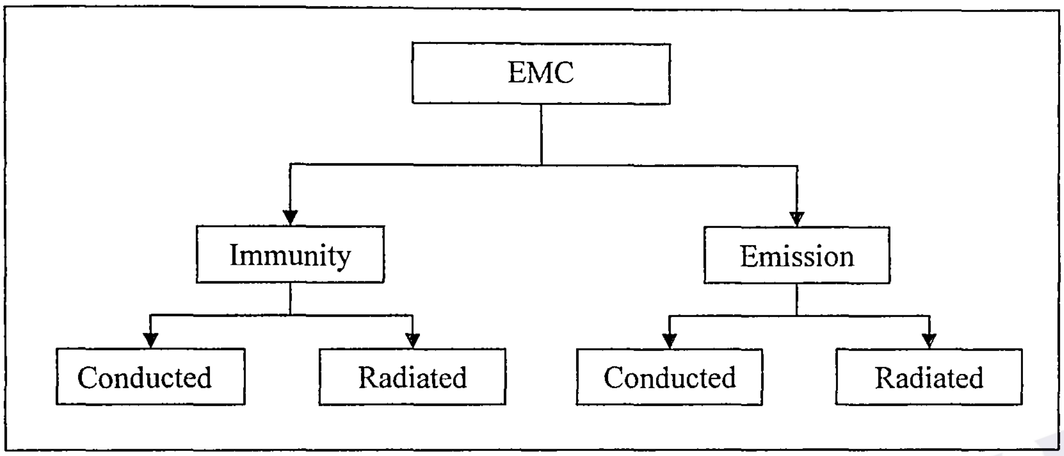

Figure 1.1: The field of EMC.

Radiated emission occurs when the component of RF energy is transmitted through a medium as an electromagnetic field. This RF energy is usually transmitted through free space; however, other modes of field transmission may occur [1]. Radiated emission from an interface cable is usually called common mode radiation, which caused by ground-noise voltage and asymmetries; the non-ideal ground plane creates voltage drops throughout the circuit acting as an antenna driver to the externally connected cables or Printed Circuit Board (PCB) traces from which electric fields radiate [3]. On the other hand, radiated emission from a current flowing on well-defined circuit loop is usually called differential mode radiation. Hence, Figure 1.2 and Figure 1.3 illustrate both of these differential-mode radiation and common mode radiation respectively.

Generally, in all electric and electronic circuits, both types of currents, which are I_c and I_d, determine the amount of RF energy propagated between circuits or radiated into free space. I_d signals carry data or information which is important for functional performance for the circuitry, while I_c is an undesired signal that is present in every practical system. The significance of I_c and I_d identification within electric and electronic circuitry is to verify to which current source contributes to the RF emission power which might cause the circuit to pass or fail the radiated emission test, which will be conducted in GTEM cell. Despite of being the undesired and not inconsequential in typical electric and electronic circuitry, I_c is often produced larger radiated emission than do the I_d [2].

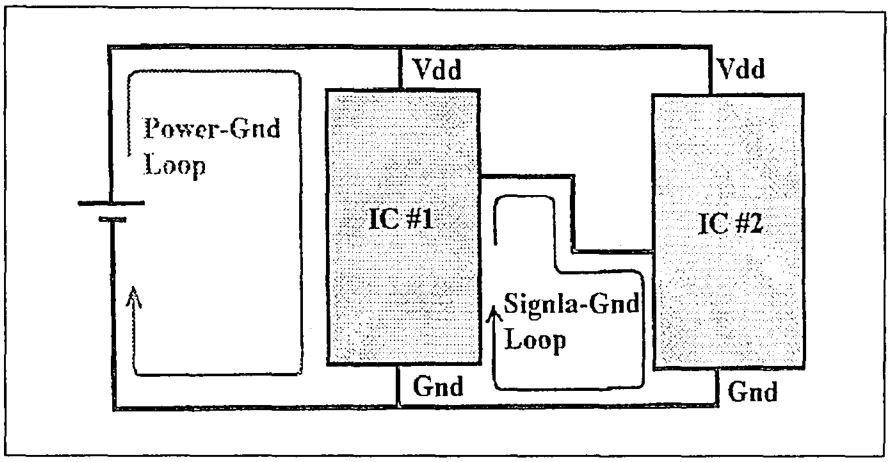

Figure 1.2: Radiated emission from an interface cable is usually called differential mode radiation.

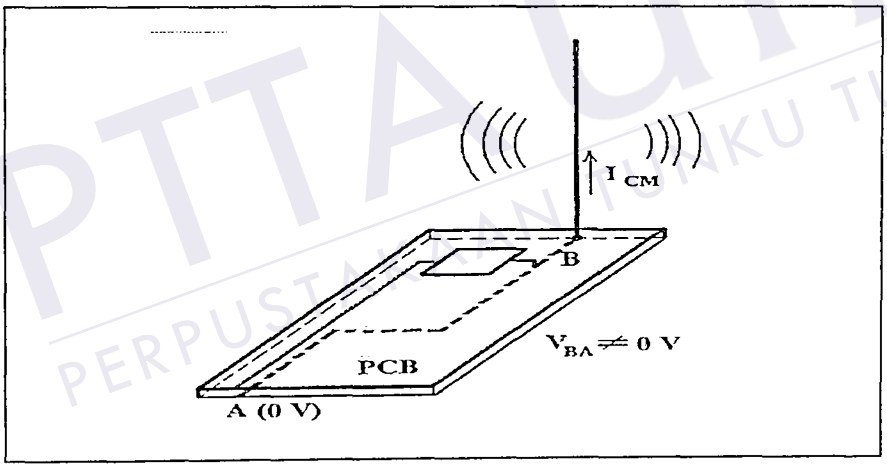

Figure 1.3: Radiated emission from on well-defined circuit loop is usually called common mode radiation.

1.2 Problem Statement

With the rapid, global transportation and communications, the market workplace today encompasses the entire world. Therefore, it is important for the designer manufacturers of electric and electronic equipments to embrace the EMC requirements to all countries, for the purpose of ensuring reliable, quality product and assure customer satisfaction. Basically, the EMC regulatory requirements of all countries are divided into two sectors; those mandated by the governmental agencies and those imposed by the product manufacturers [2]. Hence, it will be an excruciating challenge for the designer manufacturers to come out with the best designed of electric and electronic circuitry, so that the equipment complies satisfactorily with EMC requirements, for it to be functioning properly in a wide variety of field installations.

With the intention to achieve the EMC compliances, it is compulsory to control the emissions level produced by the electric and electronic circuitry as well as its level of immunity to such emissions. In essence, radiated emission is one of the most prominent forms of electromagnetic interference. This is the most regulated EMC requirements because of the excessive electromagnetic interference generated by one product may affect the operation of another product. The European Union, United States, and numerous other countries enforce radiated emissions limits on every digital device [4]. However, to fulfill those EMC requirements is a thoroughly tough and challenging task.

The most effective way of complying with EMC requirements within an electric and electronic circuitry, system, or end product, is to consider the requirements at the earliest stages of design, as shown in Figure 1.4 [5]. These critical stages initiate from the product definition, circuit design, PCB layout till the product launch at the completion stage. Early and continuous attentions to the effect on EMC will also give the product the best possible chance for minimum cost and schedule delay resulting from EMC [2]. Every designer manufacturer diagnoses these critical stages of electric and electronic circuitry, system, or end product accordingly, to ensure its complying with the EMC requirements, so that no additional cost and time will arise at the end of the product development.

Consequently, this thesis investigates the circuit design and PCB layout, which specifically concentrates on the contribution of I_c and I_d in radiated emission. It is expected that the results from this research will assist the circuit designers to improve on their circuit design to ensure restricted radiated emission for compliances with EMC regulations.

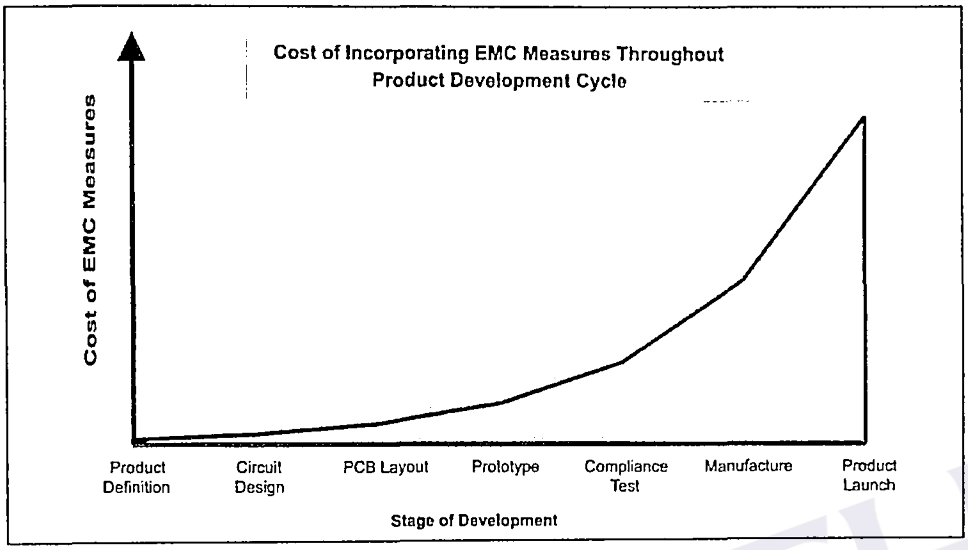

Figure 1.4: Graph of incorporating EMC measures throughout product development cycle.

1.3 Aim of Study

The aim of this experimental study is to develop test circuits capable of evaluating and demonstrating the contribution of differential mode current (I_d) and common mode current (I_c) in radiated emission of digital circuits.

1.4 Objectives

The objectives of this experimental study are as follows;

(i) To study the contribution of I_c and I_d in radiated emission by experimental measurement.

(ii) To determine a good circuit layout design that is capable of characterizing I_c and I_d.

(iii) To investigate the mechanism of radiated emission upon circuit, and to study how to overcome the emissions, in order to comply with EMC requirement.

1.5 Significance of Study

The significance of this experimental study is that it will assist EMC engineer involving in high speed circuit design to introduce a design technique that will ensure radiated emission which will comply with international EMC requirement. This definitely will support local electrical and electronic manufacturer in marketing their product in countries where EMC has been enforced.

1.6 Outline of the Report

Generally, this thesis report consists of five chapters relating to the developments of the experimental study regarding the evaluation on the contribution of common mode and differential mode currents in radiated emission.

Chapter 1 presents the introduction and conception of this experimental study as a whole, including the background of study, problem statement, aim of study, objectives, and significance of the study.

Chapter 2 discusses on the basics of PCB, EMC towards PCB levels, grounding concepts and grounding on PCB levels. It also signifies the characteristics and features of I_c and I_d in electric and electronic circuitry. Besides that, some preceding research papers related to this experimental study are also deliberated within this chapter.

Subsequently, Chapter 3 dicusses the project methodology including the review of standard test circuit, as well as the design and development stages of eight test circuits in order to study and quantify the contribution of I_c and I_d in electric and electronic circuitry. These test circuits are developed using single-sided PCB and double-sided PCB along with several techniques of good design practice towards EMC requirements. This is followed by the experiment procedures and the measurement techniques for the radiated emission test using GTEM cell. Plus, the project flow chart of the entire project development process are also presented.

Chapter 4 presents the results and findings regarding the standard test circuit and the new fabricated test circuits. Accordingly, the evaluation and discussions on the contribution of I_c and I_d in radiated emissions are also deliberated.

Finally, the conclusions and the suggestions for the future planning regarding this experimental study are discussed in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Within this chapter, the general ideas of PCB structures and grounding concepts, as well as the characteristics of radiated emission and essential features of I_c and I_d in electric and electronic circuitry are deliberated. Besides that, some preceding research papers related to this experimental study are also discussed.

2.2 PCB Basics

With today's high technology products and faster logic devices, PCB transmission line effects become a limiting factor for proper circuit operation. Other than choosing component technologies and packages that offer lower radiation levels, the designer has very few electromagnetic interference reduction options at the device level. In contrast, the PCB, as a building block, offers the first area in which a strong design action is possible [6].

The common PCB configurations regarding the cross-dimensions of lines composed of rectangular cross-section conductors are illustrated in Figure 2.1 and Figure 2.2. The PCB configuration in Figure 2.1 has two lands of width w placed on one side of a board and separated edge to edge a distance s. This is referred to as a coplanar strips configuration which represents two lands on the outer surfaces of a

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