CRITICAL PREDICTION MODELING FOR INTEGRATED CIRCUITS (ICs) ELECTROMAGNETIC COMPATIBILITY (EMC) IN SMART AUTOMOTIVE INDUSTRY

BY

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ABSTRACT

Driven by the UN 9.4 Sustainable Development Goal (SDG), by 2030, all industries and infrastructures are to be made sustainable with sound technology and industry. Automotive industry, especially the smart vehicle, is facing design challenges like susceptibility towards Electromagnetic Interference (EMI). EMI is a disturbance caused by an external source that affects an electrical circuit through Electromagnetic induction, electrostatic coupling, radiation, or conduction. Any device is said to have Electromagnetic Compatibility (EMC) if its performance is not deteriorated, and it functions error free in its intended Electromagnetic environment and at the same time does not affect the operation of other devices in the Electromagnetic environment. Electronic control devices calculate incorrect outputs because of EMI, and sensors give misleading values. It becomes more severe with double scaling down of the Integrated Circuits (IC) for every two years. Malfunctioning of the IC due to EMI problem can lead to loss of human life and catastrophic accidents as smart vehicle is highly dependent on electronic systems. Many techniques have been used over the years to check the EMC of ICs including both experimental measurement methods and EMC modeling methods. Effective modeling methods have been recently proposed that could predict the EMI situations in the IC. This research aims to develop an optimum modeling methodology for conducted EMI in an IC using the IBIS (Input/Output Buffer Information Specification) models of the test ICs. The objective is to investigate conducted emissions from the IC, develop corresponding noise models using “Total voltage” method and use the built noise source model for a test IC in system-level simulations and obtain the radiation patterns. The proposed methodology is verified by extracting noise sources and developing noise models using “Thevenin equivalent voltage” method and then obtaining the radiation patterns of the IC. The radiation patterns obtained from both Total voltage method and Thevenin equivalent method are compared, and they are found to be in good agreement with a relative difference of around 5% for the best-case scenario and a relative difference of less than 20% for all the cases considered. Apart from considering the Conducted Emissions from an IC, Signal Integrity (SI) issues of the DUT have also been considered in this research. Signal Integrity analysis of the ICs is carried out using IBIS models. This research will be a significant development in investigating the effect of the Conducted Electromagnetic Interference and assessing Electromagnetic Compatibilities at an early stage and also to tackle the Signal Integrity issues at an earlier stage to reduce overall design cost and time-to-market, as well as to improve durability and reliability. However, in future further investigations need to done on the Radiated Electromagnetic Interference.

خلاصة البحث

جميع الصناعات والبنى التحتية;(SDG) بحلول عام 2030 وبناءً على هدف الأمم المتحدة 9.4 للتنمية المستدامة يجب أن تصبح مستدامة .صناعة السيارات خاصة الذكية منها تواجه تحديات متعلقة بالتصميم مثل القابلية للتداخل على أنه اضطراب ناتج عن مصدر خارجي يؤثر على دائرة كهربائية EMI يتم تعريف .(EMI) الكهرومغناطيسي من خلال الحث الكهرومغناطيسي أو الاقتران الكهروستاتيكي أو الإشعاع أو التوصيل .الجهاز الذي لديه توافق هو الجهاز الذي لديه القدرة على العمل في بيئة كهرومغناطيسية دون أن يتدهور أدائه و (EMC) كهرومغناطيسي أن يعمل دون أخطاء في بيئته الكهرومغناطيسية ,بالاضافة إلى عدم تأثيره على الاجهزة الأخرى التي تعمل معه بنفس EMI الوقت وبنفس البيئة الكهرومغناطيسية .أجهزة التحكم الإلكترونية تقوم بحساب المخرجات الغير صحيحة بسبب .كل عامين تصبح هذه القيم أكثر حدة (IC) وتعطي المجسات قيمًا مضللة ,ومع التصغير المزدوج للدوائر المتكاملة والذي بدوره من الممكن أن يؤدي إلى خسارة في الأرواح البشرية IC من الممكن أن تؤدي إلى خلل في عمل EMI والحوادث الكارثية وذلك بسبب أن السيارة الذكية تعتمد بشكل كبير على الأنظمة الإلكترونية .خلال السنوات السابقة EMI من أجل فحص EMC تم استخدام العديد من التقنيات التي تتضمن طرق القياس التجريبية وطرق نمذجة في EMI تم مؤخراً طرح طرق النمذجة الفعالة والتي لديها القدرة على التنبأ بحالات .(IC) الخاصة بالدوائر المتكاملة وذلك بإستخدام IC في EMI هذا البحث يسعى إلى تطوير منهجية النمذجة المثلى من أجل إجراء اختبار .IC)مواصفات معلومات المخزن المؤقت للإدخال /الإخراج .(يهدف هذا البحث إلى التحقيق في الانبعاثات IBIS نموذج وباستخدام طريقة الجهد الكلي تطويرنماذج الضوضاء المقابلة ,واستخدام نموذج مصدر الضوضاء ,IC التي أجريت من من خلال عمليات المحاكاة على مستوى النظام والحصول على أنماط الإشعاع .تم التحقق من IC المدمج لاختبار Thevenin" المنهجية المقترحة وذلك من خلال استخلاص مصادر الضوضاء وتطوير نماذج الضوضاء باستخدام طريقة أنماط الإشعاع التي تم الحصول عليها من طريقة .IC ومن ثم الحصول على أنماط إشعاع "equivalent voltage وتم التوصل إلى أنه من أجل الحصول على اتفاقية ,Thevenin الجهد الكلي تم مقارنتها مع طريقة الجهد المكافئ جيدة مع اختلاف نسبي يصل إلى حوالي 5 %وذلك لأفضل سيناريو وفرق نسبي يصل لأقل من 20 %لجميع الحالات تم النظر أيضاً في القضايا ,IC الأخرى التي تم النظر فيها .في هذا البحث أيضا وبعيداً عن الانبعاثات التي أجريت من تم إجراء تحليل سلامة الإشارة للدوائر IBIS وباستخدام نموذج ,DUT الخاصة ب (SI) المتعلقة بسلامة الإشارة المتكاملة .هذا البحث سيكون تطوراً ملحوظاً في التحقيق في تأثير التداخل الكهرومغناطيسي وتقييم التوافق الكهرومغناطيسي في مرحلة مبكرة ,بالإضافة إلى معالجة القضايا المتعلقة بسلامة الإشارة في مرحلة مبكرة ,وذلك من أجل تقليل تكلفة التصميم الإجمالية والوقت اللازم للتسويق ,بالإضافة إلى تحسين المتانة والموثوقية.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion; it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Computer and Information Engineering).

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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LIST OF ABBREVIATIONS

ADS	Advance Design System
BCI	Bulk Current Injection
BGA	Ball Grid Array
CACS	Crosstalk Avoidance Codes
CDM	Charge Device Model
CW	Continuous Wave
DPI	Direct Power Injection
DUT	Device Under Test
EMC	Electromagnetic Compatibility
EME	Electromagnetic Emissions
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
FEM	Finite Element Method
HV	High Voltage
HBM	Human Body Model
IA	Internal Activity
IB	Internal Behavior
IBC	Internal Block Coupling
IC	Integrated Circuit
ICEM	Integrated Circuit Emission Measurement
ICIM	Integrated Circuit Immunity Measurement
IMIC	Interface Model for Integrated Circuits
IBIS	Input Output Buffer Information Specification

LISN	Line Impedance Stabilization Network
LV	Low Voltage
MOM	Method of Moments
MM	Machine Model
PCB	Printed Circuit Board
PDN	Power Distribution Network
RFI	Radio Frequency Interference
SI	Signal Integrity
SSC	Simultaneous Switching Current
SSN	Simultaneous Switching Noise
TE	Transverse Electric
TEM	Transverse Electromagnetic
TLP	Transmission Line Pulse
TM	Transverse Magnetic
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio

LIST OF SYMBOLS

Ω	OHM
S_{11}	Reflection Coefficient
S_{31}	Power transferred from Port 1 to Port 3
S_{41}	Power transferred from Port 1 to Port 4

CHAPTER ONE

INTRODUCTION

1.1. OVERVIEW

This introductory chapter lays down a foundation and discusses the background of this thesis, describes broadly the problem statement which this thesis will deal and identify objectives to be solved. Detailed methodology is discussed at the end of this chapter.

1.2. BACKGROUND

TWA Flight 800, heading for Paris from New York, crashed over the ocean shortly after take-off in 1996. The most likely cause of the explosion was a spark in the center wing fuel tank that ignited the air/fuel mixture, according to a thorough inquiry that included salvaging and recreating key components of the aircraft. This spark was certainly caused by a high voltage transient, such as a power line transient or an electrostatic discharge (Hosseinbeig et al., 2017). When in the radio frequency spectrum, Electromagnetic Interference (EMI), also known as Radio-Frequency Interference (RFI), is a disturbance caused by an external source that affects an electrical circuit through Electromagnetic induction, electrostatic coupling, or conduction (Chung, 2020). EMC can be categorized in two directions: Electromagnetic emission, which can disrupt the working of other systems, and Electromagnetic susceptibility, which basically describes how efficiently the system will work if it is subjected to disturbances from other systems (Tsukioka et al., 2017). Furthermore, the Device Under Test (DUT) should be free from both conducted and radiated emissions, i.e., Electromagnetic noise should not be conducted or radiated from the device. At the same time, the DUT should be immune to conducted and radiated emissions from the environment i.e., conducted or radiated Electromagnetic noise from other devices should not affect the working of the DUT.

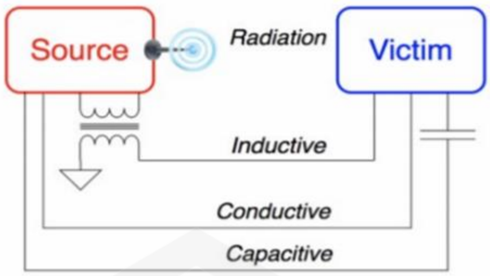

Figure 1.1 Different paths for EMI

The EMI could damage the circuit's performance or perhaps cause it to fail. These consequences can range from an increase in error rate to the complete loss of data in the case of a data path. In today's smart automotive sector, multiple electronic components are used in the system. An IC is a small wafer, typically made of silicon, that can carry transistors, resistors, and capacitors anywhere from hundreds to millions. Using either digital or analog technology, these extremely small circuits can perform calculations and store data. The amount of semiconductors in each automobile is continuously increasing, and by 2030, it is projected that electronic systems would account for half of the overall vehicle cost. Automobiles are getting more intelligent, capable of self-diagnosis, and able to communicate with one another. Electromagnetic Compatibility (EMC) compliance is becoming more important as the number of ICs on electronic modules in the smart automotive industry grows. Preventing Electromagnetic Interference (EMI) faults within a vehicle drives this EMC. Failure to do so could result in financial loss and, in the worst-case scenario, human life (Deutschmann et al., 2018).

Circuits like High Voltage (HV) and Low Voltage (LV) circuits on the same smart power IC are highly susceptible to EMI. Moreover, reduction in size and high functionality of device performance are reasons for increase in number of components on an IC. Eventually, this will result in increasing EMI in electronic system. In addition, high intensity of electric field will be induced with or without shielding. This electric field is one of the EMI parameters that will damage and interrupt the IC, thus, degrading the IC performance. The safety of the passenger of a smart car can be guaranteed by passing the EMC test so that it is immune to any kind of EMI. Consequently, the intensity of the electric field and the frequency range should be identified so that the EMI immunity of the IC of smart automotive industry can be improved (Wiles, 2009).

Recently, EMC of ICs has been attracting more attention as shown by the broad body of work on this subject (Afewerki et al., 2017; Kibaroglu et al., 2017; Kim et al., 2018; Pissoort et al., 2016; Qu et al., 2018). There are a lot of measurement standards available to check the EMI in ICs. However, the efficient modeling of ICs to check the parasitic effects is still a very challenging task. Because of the size of Integrated Circuits, conducted susceptibility and emission are essential than radiated susceptibility and emission. Both measurements and modeling can be used to construct noise models for conducted emissions. Modeling methodologies are essential for generating successful conducted emission models when some IC knowledge is available from the IC vendor. However, most IC knowledge is proprietary, and PCB/system design engineers do not have access to it. Then, techniques for extracting models from measurements are extremely desirable. Inspired by different modeling methodologies used so far for IC EMC, Modeling-based methods like those used for noise-source extraction from measurements will be used in this research.

For I/O pins, IBIS models for the I/O pins of the IC under study will be investigated. The IBIS model is a behavior model. It is used to define the behavior of the ICs input and output. IBIS is a buffer that stores a variety of Voltage to Current (V/I) and Voltage to Time (V/T) curves that can be used in Signal Integrity (SI) and EMI simulations. The specification of the IBIS model is implemented to extract noise source from it.

1.3. PROBLEM STATEMENT

The safety of the passenger of a smart car can be guaranteed by making sure all the electronic units used have passed the EMC test so that it is immune to EMI. The extensive use of Integrated Circuits in the automotive industry makes it extremely important to make sure that the Electromagnetic Compatibility of the ICs has been considered. Some level of feat has been achieved in this field by using various standard experimental methods like 1/150 Ω method (Rotigni et al., 2017), the Bulk Current Injection method (Tan et al., 2018), the Direct Power Injection method (Huynh et al., 2016) and the modeling methodologies like ICEM (Integrated Circuit Emission Measurement), ICIM (Integrated Circuit Immunity Measurement) (Capriglione et al., 2018) and so on. Nevertheless, the system does not remain unencountered by various difficulties faced by researchers, which include expensive test set ups with limited applications, non-availability of IC models from the vendors as most of the models simulate the Integrated Circuit's real silicon or transistor-level circuitry, and the vendors do not want the proprietary knowledge about the IC to be released. Even if the transistor level models like SPICE models of an IC are obtained somehow, time-consuming simulations owing to the simulation of IC transistor level circuitry remains a major concern.

1.4. RESEARCH OBJECTIVES

The main aim of this research is to predict the Electromagnetic Compatibility of ICs used in Smart automotive industry. The overall objectives of this work are:

1- To develop a Behavioral Modeling simulation methodology for extracting noise sources and noise models for conducted emissions of ICs.

2- To obtain the radiation patterns for four different ICs used in automotive industry by carrying out Near/Far field simulations.

3- To perform Signal Integrity analysis of four different ICs used in automotive industry by comparing signals at the driver and receiver end of the circuit.

1.5. RESEARCH METHODOLOGY

Both measurements and modeling can be used to construct noise models for conducted emissions. The proposed framework endeavors to use IBIS models for prediction of the Conducted Emissions and Signal Integrity analysis of an Integrated Circuit. The proposed methodology involves modeling of the interconnects and extracting S-Parameters for them in HFSS. This structure is the configuration that links each part on the board in real design. After this, the S-Parameters are related with IBIS models of the Device Under Test in ADS, and transient simulations are carried out to extract the noise sources from the DUT. These noise sources are extracted in the form of voltage at the output of the IBIS model of the IC, and it contains all the necessary information about the conducted emissions from the IC. After the Noise Sources have been extracted, system-level simulations are carried out in HFSS to obtain the radiation patterns from the IC. For this, the voltage obtained at the output of the IBIS model in

ADS is applied to the port in HFSS, simulations are run, and radiation patterns are obtained. To verify the results obtained from this method, “Thevenin Equivalent Voltage Method” is used. For the first step of this method, the IBIS model is imported into ADS and used with two different loads. Voltages at the output of IBIS model are calculated for these different loads. Thevenin’s theorem is then used to calculate the equivalent voltage. In the second step of this method, equivalent source is applied in full-wave simulation. The radiation patterns are generated and then compared with the pattern obtained in “Total Voltage Method”. Various automotive ICs from leading manufacturers like Maxim Integrated, Analog devices have been tested. As mentioned, this extracted noise contains rich information about the conducted emissions in an IC. Therefore, the main idea is to study the extracted noise and generate radiation patterns for ICs based on the work by (Capriglione et al., 2018) and (Jin et al., 2014b).

For the approach taken for Signal Integrity analysis, the IBIS model of the Device Under Test (DUT) is imported into ADS. The output pin of the DUT is made to drive a high impedance node. The PCB trace between the pin and the load is a strip line and its length is set to as per the requirement. Also, practically the pin may drive any other digital receiver rather than just a high impedance load. Signal Integrity analysis is carried out in ADS, and the results for the simulations are noted. The main idea here is to compare the signals at driver pins and load and check whether the integrity of the signal is maintained or not (*Quick-Start Methods in Simulating the DAC38RF8x Input/Output Buffer Information Specification (IBIS) Model Application Report Quick-Start Methods in Simulating the DAC38RF8x Input/Output Buffer Information Specification (IBIS) Model*, n.d.).

1.6. RESEARCH SCOPE

Electromagnetic Interference is one of the biggest reasons for device malfunctions. ICs are usually both the major cause as well as the victims of EMI in a system. Conducted emissions (i.e., the noise emitted by Integrated Circuit pins) have a significant impact on system-level EMC performance. This research intends to study various behavioral models for the EMC of ICs and develop a critical prediction modeling technique for conducted emissions of ICs used in automotive industry based on the IBIS model of an IC. Noise source models for automotive ICs will be developed in ADS and accordingly, Near/Far-field radiation patterns will be obtained in HFSS using two different approaches (i.e., Total Voltage Method and Thevenin Equivalent Method). Signal Integrity of various automotive ICs will be checked in ADS.

1.7. THESIS OUTLINE

The rest of the report is organized as follows. Chapter 2 is the literature review and discusses the main parameters and research conducted related to Electromagnetic Interference issues and various methods to predict Electromagnetic Compatibility in Integrated Circuits. Chapter 3 is the design and implementation of the research. The results and discussion are presented in Chapter 4. Finally, a conclusion is drawn, and future work is presented in Chapter 5.

CHAPTER TWO

LITERATURE REVIEW

2.1. INTEGRATED CIRCUIT EMC

Integrated circuits (ICs) play a critical role in an electronic system's Electromagnetic Compatibility (EMC). Generally, ICs are both the ultimate source of interference-causing signals and the victim. The proper operation of an IC in an obstructive Electromagnetic environment has always been a serious challenge. Electromagnetic interference (EMI) can cause an IC to malfunction or produce incorrect results. This is considerably more of a worry for ICs used in the automotive industry. The automotive industry, in particular the smart vehicle, is confronted with design issues such as Electromagnetic Interference susceptibility. EMC compliance is becoming more important in the smart automotive industry as the number of ICs on electronic modules grows. Preventing EMI faults within a vehicle drives this EMC. Failure to do so could result in tragic collisions. The EMC problems in an IC can be generally classified into two types, namely Intra chip EMC and Externally coupled EMC.

2.1.1. Intra Chip EMC

Intra chip EMC refers to the situation when Electromagnetic disturbances from some part of the IC interrupt with the working of some other parts of the same IC. There are usually two types of Intra chip interferences namely Crosstalk (J. Wang et al., 2020) and Simultaneous Switching Noise (Shringarpure et al., 2016), which are basically Signal Integrity issues. Signal Integrity in electronics refers to the signal's functionality being unaffected.