# PACKAGE POWER DELIVERY ANALYSIS FOR UNMERGED AND MERGED POWER RAILS

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To my beloved Wife – Ee San, Daughter -Samantha, Son -Rui Zhe & family members

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# ABSTRACT

Power delivery design has become important and critical nowadays especially at the package level, interconnect between silicon and motherboard. It is not an easy task to perform power delivery analysis at package level as it could have more than 30 power rails and it is very time consuming to validate each of them one by one at a time. Resonance frequency of power delivery network is critically important to understand the design risk from power delivery perspective. Inaccuracy of resonance frequency may result in over design and lead to increase of decoupling solution cost. This thesis presents a study of modeling extraction for single and multiple power rails by using Sigrity PowerSI (2.5D field solver) through frequency domain analysis, focuses on the changes in resonance frequency within each modeling case and recommends the appropriate way of extracting multiple power rails. The criterion of modeling extraction methodology in power rails modeling especially for multiple power rails extraction has been proposed for unmerged power rail and merged power rail designs. Time domain analysis was carried out to understand the performance of power delivery network base on the design target and the impact of resonance frequency of power delivery network. Coupling noise effect has shown significant impact in merged package design through time domain analysis. The thesis also reports the comparison of RL network with extracted model for unmerged and merged power rails design. The generated RL model is correlated with extracted model in frequency and time domain analysis for unmerged package design. It is also a good enough model to replace the extracted model of merged package design by justifying through time domain analysis.

# ABSTRAK

Reka bentuk penghantaran kuasa telah menjadi penting dan kritikal pada masa kini terutamanya di peringkat pakej, sambung antara silikon dan *motherboard*. Ia bukan satu tugas yang mudah untuk melaksanakan analisis penghantaran kuasa pada pakej kerana ia boleh mempunyai lebih daripada 30 landasan kuasa dan ia adalah sangat memakan masa untuk mengesahkan setiap daripada mereka satu demi satu setiap masa. Frekuensi resonans rangkaian penghantaran kuasa adalah amat penting untuk memahami risiko reka bentuk dari perspektif penghantaran kuasa. Ketidaktepatan frekuensi resonans boleh membawa kepada kesilapan reka bentuk dan peningkatan kos penyelesaian nyahgandingan. Tesis ini mengemukakan kajian pemodelan pengekstrakan bagi landasan kuasa tunggal dan berbilang dengan menggunakan Sigrity PowerSI (2.5D field solver) melalui analisis domain frekuensi, memberi tumpuan kepada perubahan dalam resonans frekuensi dalam setiap pemodelan kes dan cara yang sesuai untuk mengeluarkan pelbagai landasan kuasa yang disyorkan. Kriteria pemodelan pengekstrakan dalam landasan kuasa pemodelan terutamanya bagi berbilang landasan kuasa pengekstrakan telah dicadangkan bagi landasan kuasa berasingan dan landasan kuasa bergabung. Analisis domain masa akan dijalankan untuk memahami prestasi penghantaran kuasa pangkalan rangkaian, sasaran reka bentuk dan kesan frekuensi resonans rangkaian penghantaran kuasa. Gandingan kesan bunyi bising telah menunjukkan kesan yang ketara dalam reka bentuk pakej bergabung melalui analisis domain masa. Tesis juga melaporkan perbandingan RL rangkaian dengan model yang diekstrak bagi landasan kuasa berasingan dan bergabung. Tidak ada perbezaan di antara model RL dan model diekstrak dalam landansan kuasa berasaingan. Ia juga mencukupi untuk menggantikan model diekstrak dalan landasan kuasa bergabung melalui justifikasi dalam analisis domain masa.

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# LIST OF ABBREVIATIONS

AC - Alternating Current
C4 - Controlled Collapse Chip Connection
DC - Direct Current
EM - Electromagnetic
FEM - Finite Element Method
GND - Ground
IC - Integrated Circuit
ICC - Instantaneous Collector Current
I/O - Input & Output
PCB - Printed Circuit Board
PDN - Power Delivery Network
PKG - Package
PLL - Phase Lock Loop
PTH - Plated Through Hole
PWL - Piece Wise Linear
S-parameter - Scattering parameter
VRM - Voltage Regulator Module

# LIST OF SYMBOLS

A - Ampere
C - Capacitance
D - Dimension
e.g. - example
F - Farad
G - Giga
Hz - Hertz
H - Henry
k - kilo
L - Inductance
M - Mega
m - mille
n - nano
R - Resistance
V - Volt
w - Omega
Z - Impedance
μ - micro
Ω - Ohm

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of the Problem

Cost-effective power delivery design has become an important determinant influencing designs nowadays, which can be achieved through comprehensive power delivery design. Power delivery design has becomes critical and important in silicon, package and board application [1]. The market nowadays opt for novel power delivery design which are affordable and competitive in cost, which is a major challenge faced by the silicon and packaging industry. Designing a cost effective and optimized power delivery design at package level is no easy task [9].

The primary function of package is to provide mechanical support and electrical interconnects between silicon and motherboard. It acts as an interconnect for transmitting I/O signals from the silicon to the motherboard and it also supplies clean power and reference voltage to the active devices on the die. Figure 1.1 shows the cross section of a flip chip package which consists of bump, micro-via, plated through holes (PTH) and solder ball.

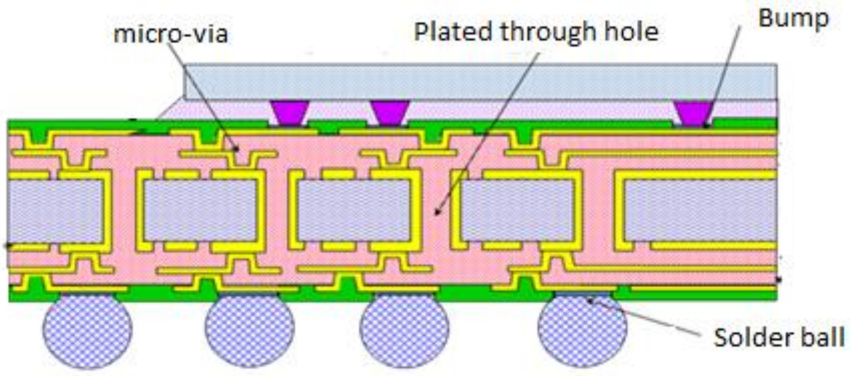

**Figure 1.1** Cross section of flip chip package

There are many analog and digital power rails at package level, in order to support different features set of product segments. The package size is mainly determined by the number of signals, power and ground pins. Package size and cost have increased to accommodate new analog and digital power rails by adding power/ground bumps, package power/ground pins and power planes at the package layers. Package power rails are routed separately, depending on interfaces and voltage level, with the reason of minimizing coupling noise from other interfaces, which may act as aggressor.

Power delivery analysis is required to determine the quality of power delivery network. Power delivery modeling plays an important role in the overall power delivery analysis flow [8]. Commercial 2.5D solver is commonly used to simulate package power rail modeling. Impropriate extraction methodology will result in inaccurate of power delivery network behaviour [2]. The quality of power delivery modeling is verified through frequency and time domain analysis. Impedance profile and noise content are the key elements to determine the quality [11].

Power delivery network contains all electrical and physical elements that form the electrical interconnect between the supply source and the individual IO buffers in a chip. It comprises of the die capacitance, flip chip bumps, package power planes, decoupling capacitors on the package, micro-vias and PTHs that connect the different power planes together. The power and GND package pins, the mother board planes, mother board decoupling capacitors and voltage regulators are shown in Figure 1.2.

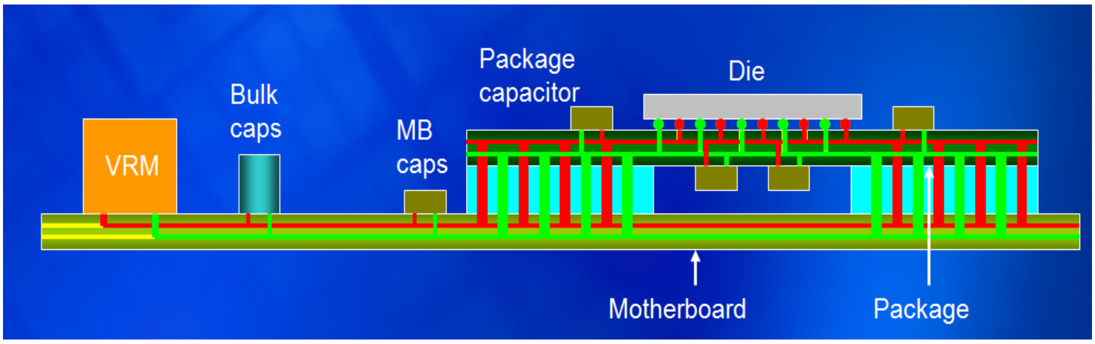

**Figure 1.2** Common physical components of power delivery network

## 1.2 Problem Statement

There are many approaches which aim to enable good power delivery design at package level. However cost optimized design is difficult to achieve and needs a lot of analysis to validate it [7]. As mentioned, there are many power rails at package level and designers are required to perform the analysis individually, which is not efficient in term of the design and time to market cycle due to market competitiveness. It is time consuming to perform 2.5D model extraction and to go through the frequency and time domain analysis on all power rails [12]. Thus, a simple model which is more efficient and has similar result is needed to be developed to represent the extraction model.

Nevertheless, knowing the most efficient way of extracting power rails is important during power delivery analysis [4]. It is important to understand what the required criteria are, while extracting power rails from package design. Neglecting these criteria will cause inaccuracy in frequency and time domain analysis. Thus, any optimization design based on this power delivery model may not be valid. To date, there is no proper guide for extracting single or multiple power rails in single model [10]. Behaviour change in impedance profile is unknown if multiple power rails are extracted as a single model, which may create risk to the power delivery performance. Nevertheless, there are many merged power rail designs nowadays [1]. Coupling effect, behaviour change in frequency and time domain are not straight forward as compared to single and isolated design power rail [6].

Modern electronic devices such as tablets and smartphones are getting more powerful and efficient. The demand in feature sets, functionality and usability increase exponentially and this has posed a greater challenge to the design of a power distribution network (PDN). Power rails merging is a popular option adopted today in a PDN design as the provision of numerous power rails is no longer feasible due to form factor limitation and cost constraint [39]. High performance smartphones and tablets products cycle has been shorten from one year cadence to six months or even three months cadence. It also leads the new product cycle especially derivative product cycle is even shorter although comes with less feature and lower cost. In order to deliver product in short cycle to gain more market share, cost effective power delivery solution where power rail merging is one of it. Nevertheless, due to short schedule an efficient analysis method is required to analyze power rail merging.

The purpose of merging power rails at package level includes

- Improving the package design efficiency by reducing the number of power rails
- Enabling smaller packages and lower number of package layers through lesser micro-via, PTH and package ball for cost saving opportunity
- Potential decoupling sharing at silicon, package and board levels for cost saving.
- Reducing possibility on adding extra voltage regulator at board level.

There are many benefits of merging power rail design; undeniably, but more challenges are expected more as compared to single power rail design. There are risks of violating the noise target and introducing bad coupling noise to sensitive power rails.

## 1.3 Objectives

The objectives of this project are to determine the selection criteria of power delivery modeling for both unmerged and merged power rails design at package level, and propose an efficient method for performing power delivery analysis for single and multiple power rails through RL model. In this study, the RL model was verified through frequency and time domain analysis and was correlated with the extracted model. The proposed method is hoped able to help create awareness and serve as a reference guideline to the power delivery community in power delivery modeling at package level, especially for merged power rails design.

## 1.4 Scope of the Study

The project scope included the understanding on the current power delivery methodology at package level. It involved the background of package design as well. Two different package power rail designs were designed, which were unmerged and merged power rail design.

There were three major stages in this project, starting with package power rail design, followed by modeling/extraction, and then performing the frequency and time domain analysis based on the models that has been created. An improved modeling methodology was also established which would be used to determine the criterion of modeling for both single and multiple power rails. RL model was also generated for comparison with the extracted model for both unmerged and merged power rail design. Nevertheless, three commercial software were needed in this thesis, for example: Sigrity PowerSI 2.5D solver is used to extract power rail model, Allegro is used to design power rails layout and HSPICE is used to perform frequency and time domain analysis.

Literature review is discussed in Chapter 2, which discusses the general overview of power delivery network, impedance profile, existing power delivery flow and tools that were used in the power delivery analysis. Chapter 3 discusses the power delivery analysis flow that includes frequency and time domain analysis. This chapter also covers the power delivery modeling cases. Chapters 4 and 5 discuss the results of the frequency and time domain analysis, which contained the impedance profile and noise content, compared between the extracted and RL model. The frequency domain contained the resonance frequency, which is a critical element in power delivery analysis. The findings from this study deliver the importance of the selection criteria that determine the accuracy of the resonance frequency during power delivery modeling; neglecting it will result in inaccuracy of resonance frequency. Time domain analysis was also performed to verify if the proposed RL model is sufficient to represent the extracted model. Finally, Chapter 6 presents the conclusion of this study.

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