

ASSEMBLY AND PRINTED CIRCUIT BOARD (PCB) PACKAGE

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Summary

The design of electronic systems on single and multiple printed circuit boards (PCB) has advanced the integration of complex electronic systems dramatically in the past few decades. In this chapter we present the basics in electronic system packaging and integration. In addition, we go over the basics of modeling and verification of PCBs.

The various layout configurations and types of transmission lines used in modern PCBs are discussed. The area of signal integrity and high speed digital board design is highlighted. The problems of reflection, crosstalk and ground bounce are illustrated. Several examples are given to illustrate the ideas discussed.

1. Introduction

The rapid advancements in the electronics systems industry is due to several factors, two of which are component integration and assembly. Since the introduction of the integrated circuit (IC) in the late 1950's [1], the electronics industry started moving at a very high speed rate. These days, we can have a simple electronic board that can perform faster than a computer that occupied a whole room back in the 1940's.

The reduction in size and high performance of electronic systems is due to electronic circuits' integration and packaging as well as device assembly. ICs can have millions of transistors that can perform a large set of functions in an extremely small area. The interconnection between different ICs on a common substrate is called a printed circuit board (PCB) or a printed wired board (PWB). A PCB will provide the mechanical, thermal support as well as the electrical interconnection between various ICs and discrete components to allow them to function as a single system unit. PCBs can be found in almost all electronic systems and devices these days, from your computer down to your cell phone or even watch.

This chapter will touch upon the various aspects of PCB design and manufacturing, along with electronic system packaging and assembly. Each one of these topics is a science by itself and several references have been published in each category. The chapter will start with some basics in IC packaging and system level integration. Then it will start describing PCB structures, materials, design and fabrication processes as well as assembly. Finally, electrical modeling of PCB is presented and signal integrity issues are highlighted and discussed. Several examples are presented to show the steps of PCB design as well as signal integrity simulations factoring in the package and PCB effect on the signal flow. The chapter ends with some current enabling technologies that are suggested by the research community to overcome some of the limitations of current copper based PCBs.

2. Basics of IC Packaging

Any electronic system or device is composed of several sub-systems or modules. Each module consists of several integrated circuits (ICs) that perform a certain task. For example, a personal computer motherboard contains a large amount of subsystems, such as the memory card (dual in line main memory – DIMM) sub-system, the input-output (I/O) sub-system, etc. Figure 1 shows the hierarchy of a motherboard example. A sub-system will contain several electronic components in discrete and integrated forms. ICs are widely used these days in sub-systems where a single or multiple ICs perform a certain function within the sub-system. Consider the Memory module as a sub-system of the motherboard system, the memory module contains several ICs, some of them are pure memory storage ICs such as the dynamic random access memory (DRAM) ICs, and others perform the controlling functions needed by the memory module. Discrete components such as termination resistors and decoupling capacitors are always used to enhance the signal flow.

ICs consists of the die which is the silicon chip that contains the actual circuit (made of transistors) and the package which is the case that hold the die and allows it to connect

to other sub-system components. Figure 2 shows an IC with its package sliced from the middle to show its internal structure. Note the size of the die with respect to the overall package. The pads on the die are so small that they cannot be used to connect directly to the outside world, thus the package provides this interface as well as the protection and support, any cooling functionality as well as powering mechanisms.

IC packaging is denoted as *Level 1* packaging since it is the first level of interfacing with the actual silicon chip. After the die is sliced from the silicon wafer, it gets placed in the center of the package and its pads are connected to the pads of the package. Several kinds of packaging exist; the most widely used ones are the bond wire technology and the flip-chip technology. In the bond wire technology, the pads of the die are connected to the pads of the package via very thin wires. Bond wires are metallic interconnects that have diameters around 1 mils (0.0254 mm) and with lengths ranging from 50-500 mils. Bond wires are made of gold or aluminum. In the flip-chip technology, the die is connected to the package center via metallic balls after flipping it up-side-down. The package itself acts as a multilayered printed wired board (PWB) and the final package has a ball grid array (BGA) type of package.

The type of packaging determines the final shape of the package frame and surrounding pins. Dual in line packaging (DIP) has two rows of pins on both sides of the rectangular shaped package. While the quad flat package (QFP) has pins covering all four sides of the square shaped package. Figure 3 shows several well known packaging types of ICs. The type of package has several impacts on the final system design such as the cost, the level of integration, the impact on signal flow and quality as well as the size and cooling mechanisms. While DIP is widely used in the laboratory environment because of its ease of use with prototyping boards and breadboards, it is rarely used in actual products that are integrated on a printed circuit board (PCB) or printed wired board (PWB). This is because the leads of this type of packaging need to penetrate all the PCB layers to get mechanical support compared to surface mount packages that are only placed on the TOP or BOTTOM layers of the PCB. Not to mention the electrical and thermal issues that accompany the use of DIP in bigger systems. That is why they are rarely used. So far the discussion has assumed that there is only one die in a single package. Another scenario exists where more than one die are encapsulated within a single package, this is called multi-chip package. This type of IC packaging is also used in industry, but single chip packaging is more widely used.

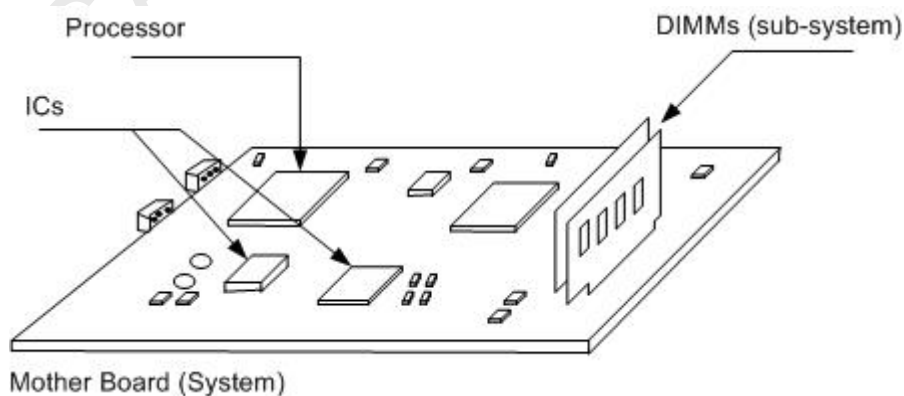


Figure 1. Hierarchy of a Motherboard.

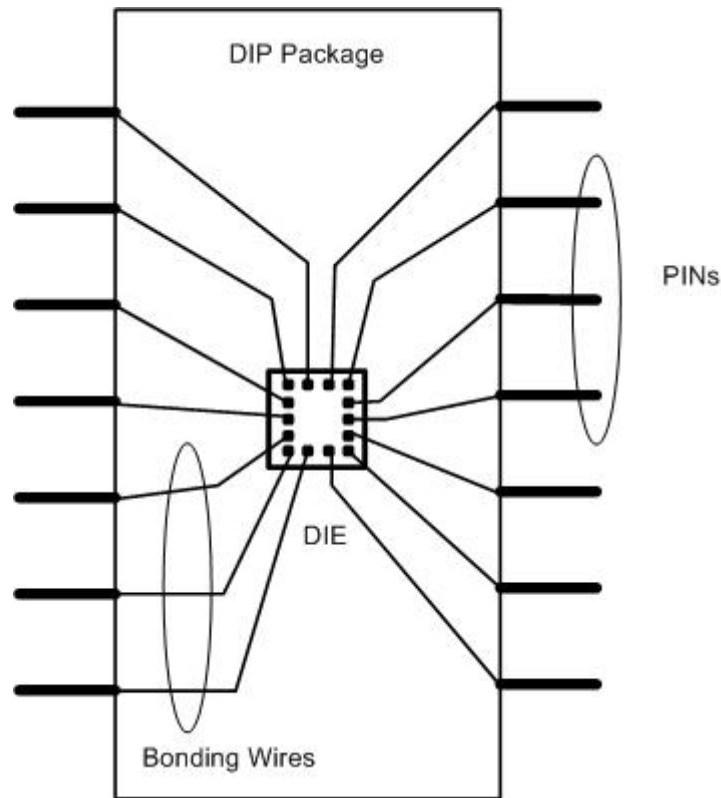


Figure 2. Sliced Chip to Show the Die and Inside Wires

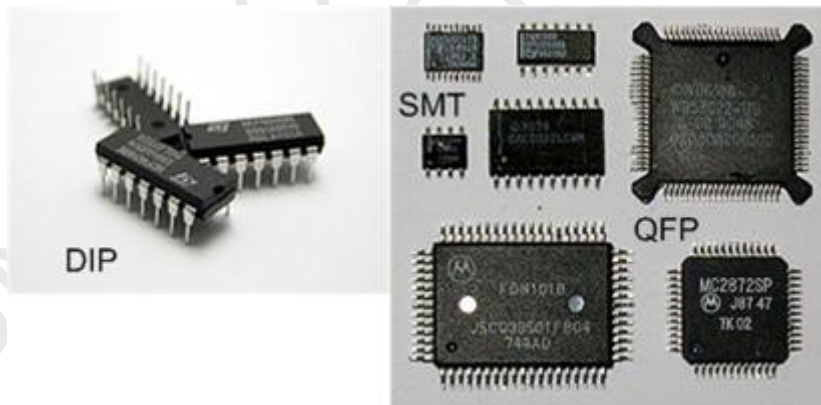


Figure 3. Several Types of Packaging, Dual in Line Package (DIP), Surface Mount Technology (SMT) and Quad Flat Package (QFP).

3. Electronic Systems Integration

Innovations in electronic system integration have resulted in a significant decrease in the sizes of most electronic devices and equipment. Integration refers to the interconnection of the various sub-systems to give the final system. This interconnection can be via a single PCB or via cables and connectors.

Referring back to the computer motherboard example, the interconnections between the different sub-systems is realized via the use of a multi-layer PCB. Thus you can see that the processor is connected to the memory controller, as well as the I/O chipset among other sub-systems on a single board. While other components such as hard drives are connected to the motherboard via cables. Dual in line main memories (DIMMs) are built on separate boards, and are placed on the motherboard as daughter cards as shown in Figure 1 via edge connectors. All other components in a standard computer are connected to the motherboard via an interconnect media. This interconnection leads to an integrated system that can function as one unit. The interconnection and interfacing on a single board such as the mother board is referred to as *level 2* packaging (system packaging). Cabling and daughter card interconnection that builds the complete system is referred to as *level 3* packaging. The interconnection between the various sub-systems requires proper interfacing. This means that the information or electrical signals being transferred between the sub-systems should be compatible. For example, proper interfacing circuitry is needed to transform the analog signals that a dial-up modem uses into digital signals that the computer understands. This is also the case with the screen, mouse among a wide variety of I/O devices connected to the computer motherboard.

Another example of electronics system integration would be the cell phone. The cell phone has analog sub-systems, digital sub-systems and radio frequency (RF) sub-systems. The integration of these various sub-systems is critical for the proper operation of a cell phone. Several interfacing circuits are used to interconnect and glue these sub-systems. The three levels of electronic systems packaging are evident in every single electronic device or equipment. This covers simple devices such as your digital watch, up to the most complicated ones such as your cell phone or computer system.

4. Basics of Printed Circuit Boards (PCBs)

PCBs are used widely in almost all electronic sub-systems. Any electronic device or equipment that uses several discrete components along with a single or multiple ICs uses a PCB to interconnect these components together. In this section we will present some detailed description of the structure of some widely used PCBs along with their applications and materials used to manufacture them, then we will touch upon some design and verification methods and tools for PCBs.

4.1. Structure of PCBs

A PCB consists of a rigid substrate material that has a predefined thickness, and that can hold the electronic components and connect them together. The components are placed on the TOP or BOTTOM sides of this substrate, and the interconnection between them is performed by etching metallic wires (also called traces) between the components. Figure 4 shows a two layer PCB with components placed on TOP and BOTTOM sides and the interconnections are also placed on the TOP and BOTTOM sides. This is the simplest PCB layout configuration. The wires are most of the times etched using copper (Cu). The width of the wires used is chosen to satisfy certain electrical criteria and impedances as will be discussed in the signal integrity section. But in general, we want to make the wires as thin as possible, to be able to shrink the size of the board and interconnections as much as possible.

Multi-layer PCBs are widely used (more than 2 layers). In a multi-layer board, the layers are placed in a certain configuration according to the application at hand and according to the electrical characteristics needed. This configuration of the multi-layered board is called the *board stackup*. The board designer defines the board stackup, and then starts the interconnection (or so called routing) between components using copper traces. In simple boards, the power supply and ground lines are represented by wires traces on the TOP or BOTTOM layers of a 2 layer PCB. In multi-layered boards, a complete metallic layer (sometimes multiple layers if multiple voltage levels are needed) is designated as the power supply or ground planes. An example of a 6-layer board stackup is shown in Figure 5.

While the components are placed only on TOP and BOTTOM layers of a multi-layered board, the interconnections can be made on other layers. When a trace transfers from one layer to another, a via is needed. A via is a conductive hole that allows a trace to go from one layer to another. A through-hole via is a via that goes from the TOP layer all the way to the BOTTOM layer of a PCB. Vias are extensively used in PCB layout because the continuity of traces might be blocked by a component if only routed on TOP or BOTTOM layers. Thus board designers utilize middle layers to route signal traces with ease.

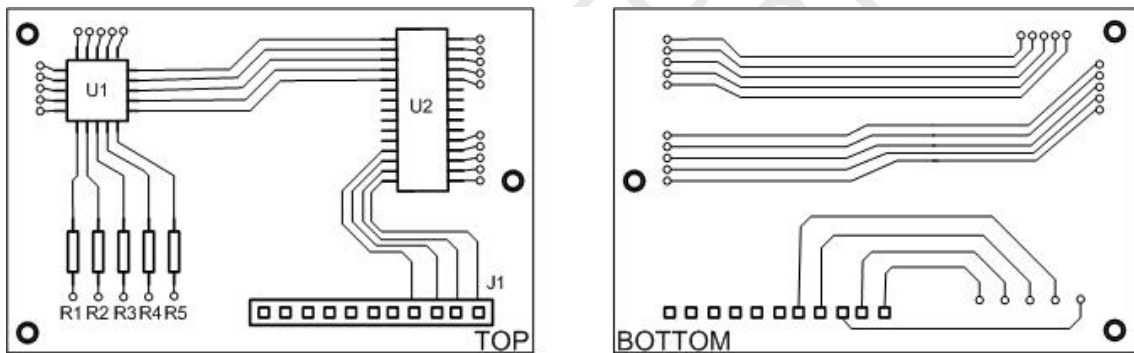


Figure 4. TOP and BOTTOM Sides (Layers) of a Sample PCB with Components and Traces.

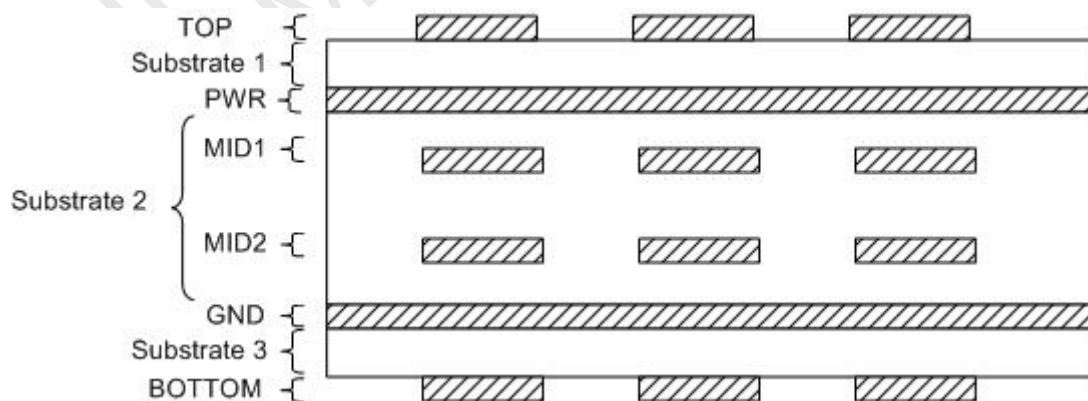


Figure 5. A 6-layer board stackup. Signals are routed on Top, Bottom, Mid1 and Mid2 layers.

4.2. Types of PWBs

There are basically 4 types of PWBs,

1. Printed Circuit Boards (PCBs): These boards are the most widely used to interconnect ICs and discrete components in electronics equipment. The board is made of glass epoxy, and have thicknesses starting from 0.4 mm and up according to the number of layers used. These PCBs can be seen in calculators, computers, cell phones, etc.
2. Chip Carriers: These are single chip substrates that hold the die in flip-chip technology and carry the wires that map the die pads into the package pins. Polymer (glass epoxy) and ceramic based substrates are used for this application. Chip carriers are encapsulated within the chip package.
3. Flexible Circuit Carriers: these PWB are made of flexible polymer based thin films than can be conformal to device shapes. A thin film metal is deposited to act as the conducting wire.
4. Metal based boards: these types of boards use metal as their core. Insulating material is deposited on top of the metal core. Such boards are used in applications where high temperatures are to be dealt with such as in automotive applications.

4.3. Materials (Digital/Analog/RF)

The material type of the PCB substrate has an impact on its electrical, thermal and mechanical properties. Usually, materials are chosen according to the type of the system being considered. For example, most digital boards use a commercially cheap and available glass epoxy substrate called FR-4. This material has a dielectric constant (ϵ_r) of approximately 3.8 - 4.4, and a loss tangent ($\tan(\delta)$) of 0.017. It can withstand temperatures up to approximately 140 °C with a rigid structure. The electrical properties of the traces are altered by changing their widths or by changing the thickness of this material.

For RF applications, usually the substrate material used varies according to the application, the amount of miniaturization and the cost. A widely used material for RF applications is Duroid with a dielectric constant of 2.2 - 2.9 (also from 3.2 – 3.8 as well as 6.2 - 6.8 depending on the manufacturer and range of dielectric constant needed) and loss tangent of 0.0012. It can withstand temperatures in excess of 100 °C and has good mechanical rigidity. This material is used because it has lower losses through it (i.e. lower loss tangent) at high frequencies compared to FR-4. It is more expensive of course. Table I shows a list of the most widely used substrate material for the three types of applications; Digital, Analog and RF.

Digital	Analog	RF
FR4 (Glass Epoxy) Polyimide/Glass	FR4 Polyimide/Glass Duroid	FR4 Polyimide/Glass Duroid Ceramics

Table 1. Widely used substrate material in various fields

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Biography Sketch

Mohammad S. Sharawi is an Associate Professor of Electrical Engineering at King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia. He was a Research Scientist with the Applied Electromagnetics and Wireless Laboratory in the Electrical and Computer Engineering Department, Oakland University, Michigan, USA, during 2008-2009. Dr. Sharawi was a faculty member in the Computer Engineering Department at Philadelphia University, Amman, Jordan, during 2007-2008. He served as the Organization Chair of the IEEE Conference on Systems, Signals and Devices that was held in Jordan in July 2008. He obtained his Ph.D in Systems Engineering from Oakland University,

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