CHAPTER 1

INTRODUCTION

1.1 ELECTRONIC PACKAGING (EP)

Electronic components are being used extensively now-a-days in varied applications like automotive, aerospace, machine tools, consumer goods etc. In particular the use of electronics in consumer goods industry has exploded in the recent years. The popularity of the electronic components in this segment is due to the fact that the electronic components like mobile phones, PDAs, digital cameras etc. are smaller in size and are easily portable. Due to the increasing demand of convenience in handling and the need to capture and maintain market share in this segment, portable electronic product manufacturers tend to miniaturize their products together with increasing their functionalities. This miniaturization with the increased functionalities leads to the design of electronic packages with very high packaging density. High packaging density in turn leads to smaller solder joints and finer pitch between the joints. These fine solder joints of IC packages are susceptible to failure when the products are subjected to vibration loads or when the products are suddenly dropped. So the reliability of these packages and their board level interconnections when subjected to vibration loads or drop impacts has become a vital issue.

Electronic packages provide the medium for electrical bridges or interconnections as well as the mechanical support and protection of the delicate electronic circuitry. An electronic packaging configuration typically
consists of component packages containing silicon die (“chips”), and other components such as capacitors and resistors, mounted on printed circuit board (PCB) or also called as printed wiring boards (PWBs). These PCBs with components (called modules) are then mounted in a chassis which provides protection from the environment, cooling, mechanical support, and a method of interfacing to the outside world.

1.2 ELECTRONIC PACKAGING LEVELS

Because of differences in materials and configuration requiring a different analytical approach, electronic packages are typically classified into the following levels based on the number and sophistication of the electronic elements of which they are comprised:

1. Component (level 1)
2. Module (level 2)
3. Chassis (level 3)

Although the above packaging levels are frequently used, they are not universal.

Increasing packaging density and the use of novel packaging approaches (such as multichip modules and chip on board) have often clouded the distinction between the packaging levels.

1.2.1 Component (First) Level Packaging

Component-level packaging involves packaging of a chip or a set of chips in a functional and protective chip carrier. The chip carriers can range from a single chip carrier such as the common Dual In-line Package (DIP) to very sophisticated multichip modules such as the Thermal Conduction
Module from IBM. The connections between the chip and the outside world in case of single chip carriers are usually through a metalized pattern commonly referred to as lead frame. Electrical interconnections are then established between conductor pads formed on the chip and the lead frame through wire bonding, direct solder bonding or tape automated bonding processes. In multichip packages, several chips are mounted directly onto a multilayer substrate which contains metalized patterns which interconnect the chips and connect to external leads. A typical component level electronic package is shown in Figure 1.1.

![Typical Component Level Electronic Package](image)

**Figure 1.1 A typical component level electronic package**

The specific function of the IC package is to protect the chip from mechanical stress, environmental stress (such as humidity and pollution), and electrostatic discharge during handling. In addition, the package provides mechanical interfacing for testing, burn in and interconnection to the next level of packaging. The packages must meet all device performance requirements, such as electrical (inductance, capacitance, crosstalk), thermal (junction temperature, power dissipation), quality, reliability, as well as fabrication interval and cost objectives. Until recently, the packaging and interconnecting technologies have not been limiting factors in the performance of most silicon devices in high volume production. But, as
circuit and system demands are increasing, more attention is needed in selecting packaging technologies, materials and design that will meet these challenges.

1.2.2 Module (Second) Level Packaging

Module-level packaging interconnects components to the next level of packaging. The second level packaging is sometimes referred to Electronic Circuit Assembly (ECA) or board level packaging. At this level, the individual chip carriers are mounted on a common base, usually a PCB. The PCB may be composed of an organic material, a polymer or glass coated composite material, a flex film or an injection molded polymer. It provides a mounting surface on which the chip carriers may be positioned, a medium for chip carrier to chip carrier interconnections, electrical test sites, and off-board power and signal connections. To facilitate interconnections, metalized conductor paths for signal and power transmission, footprints for mounting the chip carriers and vias for signal propagation and heat transfer between the board surfaces are formed on the PCB. A typical second level packaging is shown in Figure 1.2.

![Figure 1.2 Typical module level electronic package](image-url)
1.2.3 Chassis (Third) Level Packaging

The third level of packaging typically involves the interconnection of circuit boards and power supplies to a physical interface such as a chassis, a control or a electro mechanical device or system. Typical example of this level of packaging is the personal computers in which the PCB is mounted on to a chassis commonly called cabinet. This level of packaging may also involve the connection of several PCBs with in a supportive structure or cabinet. PCB to PCB interconnections are commonly made on another larger PCB which is commonly referred to as back plane. In other designs, the backplane may be omitted as several PCBs are mounted in a rack and cabled together. Several racks may then be mounted and cabled together in a single cabinet. The three levels of packaging are clearly shown in Figure 1.3.

Figure 1.3 Typical example of three levels of electronic package
1.3 PRINTED CIRCUIT BOARDS (PCB)

A Printed Circuit Board (PCB) is an electronic structure which consists of a thin board of insulating material that supports the components in a circuit and conducting tracks, usually copper on one or both sides of the board material connecting the other circuit components together. Component leads are soldered to lands, which are also known as pads (i.e.) parts of the track with space for a soldered joint between the component and the track. Lands may have holes drilled through the board to facilitate component mounting or the component may be placed on the land.

The essential components of a printed circuit board are as follows:

- The base, which is a thin board of insulating material, rigid or flexible, which supports all conductors and components; and

- The conductors, normally of high purity copper in the form of thin strips of appropriate shapes firmly attached to the base material.

The base provides mechanical support to all copper areas and all components attached to the copper. The electrical properties of the completed circuit depend upon the dielectric properties of the base material and must therefore, be known and appropriately controlled. The conductors provide not only the electrical connections between components but also solderable attachment points for the same. When the completed board provides mechanical support and all necessary electrical connections to the components, it is essentially a Printed Wiring Board or Printed Circuit Board. The term printed became popular because the conductive areas are usually
generated by means of a printing process like screen printing or photo-engraving, which are commonly used to print drawings or inscriptions.

The rectangular printed circuit board is the most common shape used by the electronics industry. Epoxy fiber glass is the most common material used, with laminated layers of copper on one or both sides of the board to form the electrical conductors. PCBs are divided into four types: (1) Single sided boards, (2) Double sided boards and (3) Multi-layer boards.

‘Single-sided’ means that wiring is available only on one side of the insulating substrate. The side which contains the circuit pattern is called the ‘solder side’ whereas the other side is called the ‘component side’. These types of boards are mostly used in case of simple circuitry and where the manufacturing costs are to be kept at a minimum. Nevertheless, they represent a large volume of printed boards currently produced for professional and non-professional grades. Figure 1.4 shows the arrangement of a single-sided board.

![Figure 1.4 Single sided PCB](image)

‘Double-sided’ printed circuit boards have wiring patterns on both sides of the insulating material, i.e. the circuit pattern is available both on the components side and the solder side. Obviously, the component density and the conductor lines are higher than the single-sided boards. Two types of double-sided boards are commonly used. They are:
- Double-sided board with plated through-hole connection; and
- Double-sided board without plated through-hole connection.

Figure 1.5 shows the constructional details of the two types of double-sided boards.

![Diagram of double-sided PCB with plated through-hole connection](image1.png)

**Figure 1.5** Double sided PCB with (i) non plated through hole connection and (ii) plated through hole connection

The multi-layer board makes use of more than two printed circuit boards with a thin layer of what is known as ‘prepreg’ material placed between each layer, thus making a sandwich assembly as shown in Figure 1.6. The printed circuit on the top board is similar to a conventional printed circuit board assembly except that the components are placed much closer to avoid having many terminals, which necessitates the use of additional board layers for the required interconnections. The electrical circuit is completed by interconnecting the different layers with plated through-holes, placed transverse to the board at appropriate places. Multi-layer boards have three or more circuit layers, while some boards have even as many as 50 layers.
The base or the substrates of most PCBs are made from FR-4 epoxy resin impregnated F-glass cloth. Rolls of glass cloth are coated with liquid resin. Then the resin is partially cured to a semi stable state (prepreg). The rolls are cut into large sheets and several sheets are stacked to form the desired final thickness. If the laminates are to be copper clad, then copper foils form the outside of the stack. The stack is then laminated and cured irreversibly to form the final resin state. The single-sided boards typically use phenolic or polyester resins with random mat glass or paper reinforcement. The double-sided boards are usually made of glass-reinforced epoxy. Most multilayer boards are also made of glass-reinforced epoxy.

The overall PCB thickness can vary from about 0.15 to 3.175 mm. Board sizes can vary from about 50 to 400 mm. Many different shapes can be found, ranging from small squares to large circular plates and triangles, depending on the shape of the electronic box used to support the circuit boards. The rectangular shape is the most commonly used PCB in electronics industry. PCBs may be supported in the electronic box in many different ways, depending on factors such as the environment, weight, maintainability, accessibility, and cost. The manner in which the PCBs are supported in the electronic box can be an important factor in determining how the boards will respond to vibration and shock. The transmissibility developed by a PCB during resonance will depend on many factors, such as the board material, number and type of laminations in a multilayer board, natural frequency, type
of mounting, type of electronic component parts mounted on the circuit board, acceleration G levels, type of conformal coating, type of connector, and shape of the board. A loose circuit board will often develop high acceleration loads which will lead to high deflections and stresses in the electronic component parts mounted on the circuit boards. The edges of the printed-circuit boards should be supported if they will be subjected to severe vibration or shock environments. A firm grip can reduce deflections due to edge rotation and translation, which will increase the natural frequency of the circuit board.

1.4 METHODS OF MOUNTING OF ELECTRONIC PACKAGES ON PCBs

The electronic packages are mounted on PCBs using two different technologies. They are;

- Pin Through Hole Technology
- Surface Mount Technology

1.4.1 Pin Through Hole Technology

Pin Through Hole (PTH) or Through Hole Technology (THT) refers to the mounting scheme used for electronic components that involves the use of pins on the components that are inserted into holes which are drilled in the PCBs. These pins are then soldered to the PCBs on the opposite side. Through-hole mounting provides strong mechanical bonds when compared to other mounting techniques but the additional drilling required makes the boards more expensive to produce. A typical PTH mounting configuration is shown in Figure 1.7.
1.4.2 Surface Mount Technology

Surface Mount Technology (SMT) is a method for constructing electronic circuits in which the components are mounted directly onto the surface of PCBs. The PTH-type packages not only use more surface area but also consume circuit density because holes must be fabricated through all layers of the board that otherwise could accommodate inner circuitry. These drawbacks are overcome in SMT technology. The clear benefits of SMT have allowed this style package to capture more than half of designs. SMT has advanced over the years to reduce size and accommodate more leads. It should be noted that feed-through packages are still used, and this will continue. In fact, SMT and feed-through packaging can be complementary, and there are assembly processes for connecting both types in one operation.
A few advantages of Surface Mount Technology are as follows:

- Smaller, lighter components
- Fewer holes need to be drilled through the PCBs
- Simpler automated assembly
- Small errors in component placement are corrected automatically (the surface tension of the molten solder pulls the component into alignment with the solder pads).
- Components can be fitted to both sides of the circuit board.

There are many types of surface mount packages available in the market. The prominent among them are Quad Flat Package (QFP), Small Outline Package (SOP), Chip On Board (COB) package and Ball Grid Array (BGA) package. Among these packages, SOP and BGA packages are quite popular in hand held electronic products market.

1.4.3 Plastic Ball Grid Array Package

The Plastic Ball Grid Array or PBGA package is the industry description of what is sometimes referred to as Motorola’s Over Molded Pad Array Carrier (OMPAC) package. PBGA package has several advantages for its electrical, mechanical and thermal characteristics and these characteristics can come from its outstanding structure. By using the PCB board and solder ball array for the interconnection material between the semiconductor and board instead of lead frame, PBGA package can get powerful advantages such as

1. High area density of I/O design.
2. Small area occupation of board on which the package attached.
3. High degree of freedom of design.
4. Low handling problem by self alignment of solder ball when reflowed.
5. High thermal dissipation efficiency.

The cross-section of a typical BGA package is shown in Figure 1.9.

![Figure 1.9 Cross-section of a BGA package](image)

PBGAs are widely used in Flash Memory, Micro controller, Chip-Set, CPUs, Mobile Communications, Network Systems, Engine Control Unit, Sensors and Opto-electronics.

1.4.4 Plastic Small Outline Package

Plastic small-outline packages (PSOP) are a type of surface mount IC packages. They are notably very low-profile (about 1mm) and have tight lead spacing. Some PSOPs are shown in Figure 1.10.

![Figure 1.10 Typical examples of Plastic Small Outline Packages](image)
Key features of the Plastic Small Outline Package (PSOP) include,

- Two side leaded for routing simplicity.
- Simplicity and ease of use.
- Gull wing formed leads for improved SMT manufacturing.
- Supports future flash density and feature growth.
- Outstanding in any temperature application.

1.5 FAILURE OF ELECTRONIC COMPONENTS

Electronic components are available in a large variety of types, sizes, and materials for leaded and leadless mounting and for through-hole or surface mounted applications. Most of these components will end up on PCBs for use in everything electronic from cameras and washing machines to telephones and space shuttles. Some types of electronic equipment will be used in homes and offices that are air conditioned with very quiet environments. Other types of equipment will be used in military programs with high vibration and shock levels.

Most electronic failures are mechanical in nature. Many of these mechanical failures occur in the component lead wires and solder joints. Extensive military testing experience over a period of many years has shown that about 80% of the electromechanical failures are due to some type of thermal condition and about 20% of the failures are due to some form of vibration and shock (Steinberg 2000).

1.5.1 Failure of electronic components due to vibrations

Electronic component parts can be mounted on PCBs in many different ways. The ability of these components to survive a severe vibration
environment will depend on many different factors such as component size, resonant frequency of the circuit board, acceleration G forces, method of mounting components, type of strain relief in the electrical lead wires, location of the component, and duration of the vibration environment (Steinberg 2000). Most component failures in a severe vibration environment will be due to cracked solder joints, cracked seals, or broken electrical lead wires. These failures are usually due to dynamic stresses that develop because of relative motion between the electronic component body, the electrical lead wires, and the PCB. This relative motion is generally most severe during resonant conditions that can develop in the electronic component part or in the PCB. Resonances may develop in the component part when the body of the component acts as the mass and the electrical lead wires act as the springs. These resonances are usually not too severe if the body of the component is in contact with the PCB, since this contact will sharply reduce the relative motion of the component. If resonances of this type do develop, it is an easy task to tie or cement the component part to the circuit board. If resonances develop in the circuit board, large displacements can force the electrical lead wires to bend back and forth as the circuit board vibrates up and down. If the stress levels are high enough and the number of fatigue cycles is great enough, fatigue failures can be expected in the solder joints and the electrical lead wires.

1.6 FAILURE OF HAND HELD ELECTRONIC DEVICES

Even though electronic equipments are used in variety of fields and applications, the primary focus of this research work is the electronic equipments used in hand held electronic devices. The handheld electronic devices fit into the consumer and portable market segments. Some of the handheld electronic devices are cameras, calculators, cell phones, palm size
PCs and PDAs. These electronic devices are conveniently stored in a pocket and are used while held in user’s hand.

The handheld electronic products are subjected to random vibrations and are prone to being dropped during their useful service life because of their size and weight (JESD22- B103B 2006, JESD22- B111 2003). These random vibrations and dropping events can, not only cause mechanical failures in the housing of the device but also create electronic failures in the PCB assemblies mounted inside the housing due to transfer of energy through the PCB supports. The electronic failures may result from various failure modes such as cracking of circuit board, cracking of component lead wires used in the IC packages mounted on the PCBs or cracking of solder joints used to mount the IC packages on the PCBs.

Random vibration testing is being specified for acceptance tests, screening tests, and qualification tests by commercial, industrial, and military manufacturers of electronic equipment; because it has been shown that random vibration more closely represents the true environments in which the electronic equipment must operate. This includes airplanes, missiles, automobiles, trucks, trains, and tanks as well as chemical processing plants, steel rolling mills, foundries, petroleum drilling machines, and numerically controlled milling machines. Random vibration has also proved to be a very powerful tool for improving the manufacturing integrity of electronic equipment by screening out defective components and defective assembly methods, which results in a sharp improvement in the overall reliability of the system.

Electronic packaging designers and engineers must understand the fundamental nature of random vibration and fatigue in order to design, develop, and produce cost-effective and lightweight structures that are capable of operating in the desired environments with a high degree of
reliability. The path that the dynamic load takes as it passes through the structure must be examined to make sure there are no weak links that can cause catastrophic failures. It is also necessary to examine the load-carrying capability of the structural elements, to make sure they will not buckle under the expected dynamic loads. Designers and engineers must constantly be on the alert for major structural resonances that can magnify dynamic loads and stresses. If two major structural resonances occur close to one another, they may produce severe dynamic coupling effects that can produce rapid fatigue failures.

The mechanical shock resulted from mishandling during transportation or customer usage may cause PCB or solder joint failure of IC package, which leads to malfunction of product. It is important to know the location of the critical solder joint (where failure first occurred) within a package of the PCB during drop impact.

Because of the variety in the size and shape of the products available in the hand held electronics market segment, it is practically impossible to generalize the failure mechanisms of electronic components used in this segment. Elements identified to be vulnerable to failure under mechanical loads for a particular type of product may not be the same for other type of products in this segment. JEDEC has suggested that the failure mechanism of electronic components under this category can be identified more easily under board level conditions. A board level condition involves a PCB with a standard size and shape as specified by JEDEC, populated with packages mounted at specific locations on the PCB. Board level random vibration and drop tests are convenient to characterize the solder joint performance, because it is more controllable than product level test.
1.7 TEST STANDARDS

Many organizations like defense, NASA, Electronic Industry Alliance and Joint Electron Device Engineering Council (JEDEC) have developed the various standard methods for manufacturing, assembling, and testing of electronic packages and related devices. Among these standards, JEDEC standard is used in this thesis as it specifies testing conditions for hand held electronic products.

1.7.1 Joint Electronic Device Engineering Council (JEDEC) Standards

JEDEC is the semiconductor engineering standardization body of the Electronic Industries Alliance (EIA), a trade association that represents all areas of the electronic industry in the United States. Following JEDEC test standards provide procedures and guidelines for performing laboratory tests on electronic packages.

JESD22-B103B Vibration, Variable Frequency
JESD22-B104C Mechanical Shock
JESD22-B111 Board Level Drop Test of Components for Handheld Electronic Products

1.7.2 JESD22-B103B Vibration, Variable Frequency

This test standard is intended to determine the ability of electronic components to withstand moderate to severe vibration as a result of motion produced by transportation or field operation. This test is a destructive test intended for component qualification.
1.7.3 JESD22-B104C Mechanical Shock

The Mechanical Shock Test Method is intended to evaluate component(s) for use in electrical equipment. It is intended to determine the compatibility of the component(s) to withstand moderately severe shocks as a result of suddenly applied forces or abrupt change in motion produced by handling, transportation or field operation. Mechanical Shock of this type may disturb operating characteristics, particularly if the shock pulses are repetitive. This is a destructive test intended component qualification.

1.7.4 JESD22-B111 Board Level Drop Test of Components for Handheld Electronic Products

The Board Level Drop Test Method is intended to evaluate and compare free fall drop performance of surface mount electronic components for handheld electronic product applications in an accelerated test environment.

The primary focus of this research is to analyze the dynamic response characteristics of board level electronic packages used in hand held electronic devices under dynamic loads. Hence, JEDEC standards described above are used in this research.

1.8 ORGANISATION OF THE THESIS

The thesis is divided into six chapters and the contents of each chapter are summarized below:

In chapter 2, detailed literature surveys carried out in the area of analysis of electronic packages under dynamic loads are reviewed. Literature on modal analysis of electronic components by experimental and Finite Element (FE) methods, analysis of electronic components under harmonic and
random vibration loads, analysis of electronic components under free fall drop impact loads by experiment and FE methods are collected and reviewed. Literature related to the optimization of support locations of plate structures and PCBs are collected and reviewed in chapter 2. At the end of the chapter, the important objectives identified for the present research work are listed and methodology adopted for this research is also shown.

In chapter 3, dynamic system characteristics of a PCB used in hand held electronic products are determined using modal analysis technique. The dynamic system characteristics extracted from the PCB are its natural frequencies, mode shapes and damping ratios. The modal analysis is carried out using both FE method and experimental method. Results from both the methods are compared to validate the FE model.

In chapter 4, two different electronic packages used in hand held electronic products but performing the same function are mounted on two PCBs and the dynamic responses of the PCBs when subjected to random vibration loads are investigated. Both FE and experimental methods are used in the analysis. Critical elements in the electronic packages that are prone to failure under random vibration loads are identified using FE method and the same are validated by experiments. The dynamic responses of the PCBs when subjected to random vibration levels defined by JEDEC are analyzed and compared.

In chapter 5, the dynamic responses of a PCB similar to the ones used in previous chapters are analyzed when the PCB is subjected to free fall drop impact loads. Vulnerable elements in the electronic packages mounted on the PCB are identified by FE method and the same are validated by experiments. Two different FE methods proposed in the literature are compared to determine the suitability of these methods to analyze drop impact tests.
In chapter 6, the support locations of a typical PCB used in PCs having important components like cooling fans, memory slots etc. mounted on it are optimized in order to increase the fundamental natural frequency of the PCB. Modal analysis technique is used to determine the fundamental natural frequency of the PCB when supported at its original support locations. The support locations are then optimized using FE method and the results are validated by experiments.

In chapter 7, the major conclusions arrived in this investigation are listed together with suggestions to improve the life of the PCBs when subjected to dynamic loads. Scopes for further work that can be carried out in this area are also listed.

1.9 CONCLUDING REMARKS

In this chapter, a brief introduction was provided about the application of electronic components in various industrial segments like defense, automotive, aerospace and consumer industries. Different levels of packaging that constitutes electronic equipment were detailed and the various types of PCBs used in electronic equipments were explained. The methods of mounting IC packages on PCBs were also described. The need for analyzing the effect of vibration loads on electronic equipments particularly in the hand held electronic product segment was brought out. Various test standards used in this research were described. A comprehensive literature review carried out in the area of dynamic analysis of hand held electronic products is described in chapter 2.