CHAPTER 1

INTRODUCTION

1.1 ELECTRONIC PACKAGING (EP)

Electronic equipment continues its relentless expansion into virtually every area associated with commercial, industrial, and military applications throughout the world. Exotic technology has become commonplace in medicine, entertainment, communication, travel, transportation, aerospace, manufacturing, education, and commerce. All this was possible because of the development of new integrated circuits (IC) also known as electronic packages which are smaller in size and have multiple functionalities built in them.

As per the McGraw Hill dictionary of Scientific and Technical terms, an electronic packaging is “the technology of packaging electronic equipment” which includes the interconnection of electronic components into printed wiring boards (PWBs) and the interconnection of printed wiring boards to electronic assemblies (Lapedes 1978).

In this chapter, a brief introduction to the electronic packaging configurations and functions, electronic packaging levels, types of printed circuit boards (PCBs), package mounting methods, types of electronic packages, the failure of electronic equipment due to vibration environments and the methods to control the vibration levels are provided.
1.1.1 Typical Electronic Packaging Configuration

An electronic packaging configuration typically consists of component packages containing silicon die (chips), and other components such as capacitors and resistors, mounted on printed wiring boards. The printed wiring boards 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. A typical electronic packaging configuration is shown in Figure 1.1.

![Typical Electronic Packaging Configuration Diagram](image)

Figure 1.1 Typical electronic packaging configuration

1.1.2 Functions of Electronic Packaging

An electronic packaging serves manifold functions; some of which are listed below.

- A structure (usually the PCB) to physically support the chip
- A physical housing to protect the chip from the environment (encapsulate)
An adequate means of removing heat generated by the chips or systems

Electrical connections to allow signals and power access to and from the chip (copper traces)

A wiring structure to provide interconnection between the chips of an electronic system

1.1.3 Levels of Electronic Packaging

Over time, the trade-off in requirements has divided electronic packaging into: component (device) level packaging, module (board) level packaging, and chassis (system) level packaging. Although separation into these levels is not absolute, they reflect a common method used to organize the electronic circuitry and categorize electronic packaging requirements. Each level of packaging provides similar functions but has a distinct purpose and design. The three levels of electronic packaging are discussed in the following sections.

1.1.3.1 Component Level Packaging

The first or lowest level of packaging is semiconductor device packaging. Not long ago, the selection of package style was limited. The dual-inline package (DIP) dominated the semiconductor market and represented the majority of electronic packages sold. Today, with the drive toward miniaturization, combined with the lack of a clearly superior miniature package, many distinct package styles are available, ranging from traditional DIP to chip-on-board (COB).
The primary motives for packaging the device before assembly onto a circuit board are to allow for complete testing and to protect the device from contamination. Without packaging, testing of bare devices is expensive and difficult because of the tiny dimensions involved. When packaged, a device has far less stringent handling requirements than a bare device. Bare silicon devices must be handled cautiously in a clean-room environment. Soldering and normal handling during assembly leave contamination that often causes corrosive failure of unprotected devices. Improper handling easily damages the tiny wire interconnections on devices. For these reasons devices are usually packaged before testing and further assembly.

The design of the device packages is driven by many factors, including the number of leads and their routing on the substrate as well as the ability to dissipate the heat generated by the device. The external lead geometry must meet the customer’s circuit board design constraints, assembly needs, and cost requirements. To conserve the space on a circuit board, customers frequently want the device in the smallest package possible. Smaller packages permit significant system miniaturization. However, miniaturization of packages frequently results in increased costs.

1.1.3.2 Module Level Packaging

Module-level packaging interconnects components to the next level of packaging. Components are mounted on a platform known as PWB or PCB. PWB mechanically provides support to the components. Specifics of module packaging configuration vary if through-hole or surface-mount technology is used. A through-hole technology module typically uses DIP for the microcircuits. The leads on these components are soldered into holes in a printed wiring board to provide interconnection to other components and the
chassis (via wires or connectors). These mounting technologies are discussed in section 1.1.4.2.

In designing PCB, shock and vibration environments of the application must be accommodated. Because components are small, damage from shock and vibration forces usually is not an issue in device packaging. With larger PCBs, both mass and moment increases, thereby increasing the potential for damage. To reduce the damage due to shock and vibration, stiffeners are added to PCB, and it will be mounted on extra points. A typical module (board) level packaging is shown in Figure 1.2.

Figure 1.2 A typical board level electronic packaging

1.1.3.3 Chassis Level Packaging

Chassis-level packaging connects the circuit boards and mounts them into a chassis, forming a system or subsystem. For many systems (personal computers), this is the level of packaging seen by the user. In satellites, this chassis-level package is connected to a structural frame and electrically connected with other chassis having different functions. The
design phase of chassis packaging has similar mechanical, thermal, and materials considerations found in device and circuit board packaging.

All the three levels of electronic packaging configurations are as shown in Figure 1.3. The device is packaged into a component, the component is mounted on the board, and the board is installed into the subsystem chassis.

![Figure 1.3 Levels of Electronic Packaging](image)

**Figure 1.3 Levels of Electronic Packaging**

### 1.1.4 Printed Circuit Board / Printed Wiring Board

A printed circuit board in its simplest form 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 components together. Component leads are soldered to lands, which are also known as pads. Lands may have holes drilled through the board to facilitate component mounting (through-hole technology) or the
component may be placed on the land (surface-mount technology). In early times this description would have been sufficient, however in recent years electronic equipment for all types of applications has seen major advances in performance, size and cost. PCBs now play an important role in determining the active functioning of electronic circuits and may no longer be regarded as a passive interconnection panel.

1.1.4.1 PCB Materials

A variety of materials are used to fabricate the PCBs with different combinations such as epoxy-glass, polyimide-glass, epoxy-kevlar, polyimide-kevlar, epoxy-quartz, polyimide-quartz and many different types of ceramics. Epoxy fiberglass, FR-4 (fire retardant, grade 4) appears to be the most popular material used by many different commercial, industrial, and military organizations for the fabrication of PCBs (Steinberg 2001).

Circuit board technology has moved from the traditional flat, rigid boards to flexible substrates and rigid-flex boards, a hybrid of the rigid and flexible technologies. Flexible boards are made from sheets of polyimide (Kapton), laminated with copper foil to form traces. These may have several layers like rigid substrates. Flexible boards permit rolling and folding to fit the space available, which has many advantages in the packaging of electronics in constrained areas or in areas with odd shapes. Many consumer electronic products such as cameras and watches contain such flexible boards.

1.1.4.2 Methods of connecting components to PWB

Following are the some of the techniques used for attaching or mounting electronic components on to the printed circuit board. The method
of attaching the component depends on the type of component; whether it is through-hole or surface mount type.

1.1.4.2.1 Through-Hole Joints

Through-hole joint configurations refer to package types in which the component leads are inserted and soldered into predrilled holes in the PWB. Metallization may be located on one side of the board only. This type of architecture is considered to be single-sided. Double-sided and multilayer constructions use holes that are plated through such that the metallization is not only on both the top and bottom sides of the board but also forms a barrel on interior hole wall. The device leads are usually made of copper or one of several iron-base alloys that are typically coated in a protective tin-lead solder finish, which is either plated, hot dipped, or plated and fused. Components like, Dual-in-line packages, capacitors, resistors, transistors etc., are attached to PWB using through-hole technology. The different types of through-hole configurations are shown in Figure 1.4.

![Figure 1.4 Through-hole configurations](image-url)
1.1.4.2.2 Surface Mount Joints

The main problem with through-hole devices is their size. The trend in printed circuit board manufacturing was to increase density while decreasing board area. Through-hole devices did not easily allow this to happen. In the 1980’s, through-hole devices began to give way to a new packaging technology called Surface Mount Technology, or SMT. The leads from these packages mount directly to rectangular pads on the surface of the printed circuit boards. They did not require holes to be drilled into the PWBs. As a result, the width of the leads could be smaller and the spacing between the leads (lead pitch) could be decreased. This allowed for a package with the same number of pins as a traditional through-hole device to be significantly smaller. These devices were made with the same materials as the through-hole devices. Common surface mount devices are the Plastic Leaded Chip Carrier (PLCC), and Small Outline Integrated Circuit (SOIC). In recent years, the Quad Flat Pack (QFP) has become a predominant Fine Pitch, high lead count package solution. A typical surface mount configuration is shown in Figure 1.5.

Figure 1.5 Typical surface mount technology
1.2 FAILURES IN AN ELECTRONIC PACKAGING

Electronic equipment can be subjected to many different environments during their service life. They will be subjected to thermal cycling, thermal shock, harsh vibrations, sand and dust, salty atmosphere, humidity, and high altitudes. The operating environment will have great influence on the life of the electronic equipment. Thermal cycling events and high acceleration levels will induce mechanical failures in electronic equipment.

Field failures in electronic equipment hardware compiled by the U.S. Air Force over a period of about 20 years show that about 40% of these failures are related to connectors, 30% to interconnects and 20% to component parts (Steinberg 2001). Failures in these areas can be due to handling, vibration, shock, and thermal cycling. Field failures related to operating environments show that about 55% of the failures are due to high temperatures and temperature cycling, 20% of failures are related to vibration and shock, 19% are due to humidity, and 6% are due to dust. These failures are shown with the help of a pie chart in Figure 1.6.

![Figure 1.6 Major sources of failures in electronic packaging](image-url)
From Figure 1.6 it is obvious that, the temperature is one of the important factor which leads to a variety of failures in an electronic packaging. Other environments which equally contribute to the failure of electronic packages are vibration and humidity.

As per MIL-810-F, the electronic equipment are subjected to different types of vibration environment during their service life. They may be subjected to road shock, road vibrations (random), rail shock (humping), rail vibrations, in-flight vibrations, lancing shock and wave induced vibrations during road transportation, rail transportation, air transportation and water transportation. During handling also, the electronic equipment are subjected to different vibration environments.

As the present research work is related to the experimental investigations on the board level electronic packaging subjected to dynamic loads, the sources and effects of vibrations on electronic equipment only are presented in the following section.

1.2.1 Effects of Shock and Vibration

Electronic equipment can be subjected to many different forms of vibration over a wide frequency ranges and acceleration levels. It is probably safe to say that all electronic equipment are subjected to some type of vibration at some time in its life. If the vibration is not due to an active association with some sort of a machine or a moving vehicle, then it may be due to transporting the equipment from manufacturer to the customer. Vibrations encountered during transportation and handling can produce many different types of failures in electronic equipment. Table 1.1 shows the vibration frequency spectrum and acceleration levels to which the electronic
equipment used in different type of transportation vehicles and other systems are subjected to.

Table 1.1 Operating frequency range and acceleration levels (Steinberg 2001)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Frequency range (Hz)</th>
<th>Acceleration level (G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ships and Submarines</td>
<td>1-50</td>
<td>1-3</td>
</tr>
<tr>
<td>Automobiles, trucks and tanks</td>
<td>15-40</td>
<td>15-19</td>
</tr>
<tr>
<td>Airplanes</td>
<td>3-1000</td>
<td>1-5</td>
</tr>
<tr>
<td>Helicopters</td>
<td>3-500</td>
<td>0.5-4</td>
</tr>
<tr>
<td>Missiles</td>
<td>5-5000</td>
<td>5-30</td>
</tr>
</tbody>
</table>

Vibration environments can often involve millions of stress reversals because natural frequencies in electronics can range from 50 Hz to well over 1000 Hz. Stress raisers and stress concentrations can be very severe when millions of cycles are accumulated. Electrical lead wires loaded in tension or bending will fail very often in vibration events because a large number of stress cycles can be accumulated in a short period of time. Testing has shown that thermal cycling events typically produce many more solder joint failures than lead wires for surface-mounted and through-hole-mounted PCB components. Vibration events tend to produce many more electrical lead wire failures than solder joint failures in surface-mounted and through-hole-mounted PCBs.

As the electronic equipment are subjected to vibration, connections can fail, the substrate of microelectronic parts can fracture, and work hardening can occur in mechanical components. Vibration can be caused mechanically and acoustically and is either random or sinusoidal. Through
proper design, vibration effects can be avoided (avoiding resonant frequencies through stiffening, orientation) or reduced (use of vibration isolators).

Vibrations cause high cycle fatigue and failures usually occur after many cycles. Problems caused by vibrations include lead fracture caused by fatigue, solder joint fracture caused by fatigue and fretting corrosion of connector contacts. The sudden or violent application of a force to equipment causes mechanical shock. The equipment is subjected to rapid acceleration, and the resultant forces can destroy connections, fracture structures, and break loose particles that can contaminate electronic components that incorporate a cavity in their design. Shock can occur when a mechanic drops the equipment as it is removed for maintenance or when an aircraft makes a hard landing. Table 1.2 summarizes the sources and effects of vibration and mechanical shock on electronic components and systems.

Table 1.2 Effects of Vibration on components and systems

<table>
<thead>
<tr>
<th>Environment</th>
<th>Sources</th>
<th>Principal effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibration</td>
<td>Excitation of natural frequencies, other nearby periodic exciting forces. Random vibrations.</td>
<td>• Intermittent electrical contacts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Touching/shorting of electrical parts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Wire chafing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>•Loosening of hardware</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Component/material fatigue</td>
</tr>
<tr>
<td>Mechanical Shock</td>
<td>The sudden application of force, measured in Gs of acceleration and milliseconds duration. Can be caused by handling, transportation, gunfire, explosion and/or propulsion</td>
<td>• Interference between parts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Permanent deformation due to overstress</td>
</tr>
</tbody>
</table>
1.3 TEST STANDARDS

Many organizations like defense, NASA, Electronic Industry Alliance and JEDEC have developed the various standard methods for manufacturing, assembling, and testing of electronic packages and related devices. Some of the standards available and used in the thesis are mentioned in the subsequent sections.

1.3.1 Military Standards

Military standards and specifications cover materials, test standards, and standard board layout procedures. Following list includes some of the applicable military standards used in electronic packaging industry for testing.

MIL-STD-275 Printed Wiring for electronic Equipment
MIL-P-55110 Military Specifications for Printed Wiring Boards
MIL-E-5400 Vibration tests
MIL-P-13949 General Specifications for Plastic Sheet, Laminated, Metal Clad (for Printed Wiring Boards)
MIL-STD-883 Constant Acceleration Test, Mechanical Shock Test
MIL-STD-810 F Military Standard Test Methods for Electronic and Electric Component Parts

1.3.2 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
JESD22-B113  Board Level Cyclic Bend Test Method for Interconnect Reliability

1.4  STANDARD VIBRATION TEST PROCEDURES

The purpose of vibration tests is to determine whether the item being designed (electronic equipment) is rugged enough to withstand the shock and vibration environment in which it will be placed to work. In general, vibration testing is based on the interpretation of data obtained from measurements of service conditions. The reproduction of actual service conditions, such as proving-ground tests of vehicles is not usually used except for aerospace applications. In actual working environment, the electronic equipment may be subjected to pure sinusoidal vibrations, random vibrations, combination of sinusoidal and random (sine on random), and mechanical shock loads.

Vibration testing can provide an understanding of a product’s sensitivity in this regard early in the design cycle. Some test options include transportation simulation, resonant frequency determination (e.g. which frequencies are most likely to damage the product) and comparison testing with existing designs. Vibration is also an integral component of highly accelerated stress testing (HAS) used to reduce lengthy test times while
ensuring high field reliability. Hence, following are the some of the tests which are conducted in laboratories on newly designed electronic packages or assemblies to weed out latent defects and to test the survivability of the equipment in the harsh vibration environment.

1.4.1 Sine Sweep Tests

The sine sweep test involves a logarithmic frequency sweep usually through a range of 5-1000 Hz, holding a specified acceleration constant at the base of the test article or its mounting bosses on the fixture. A control feedback accelerometer is mounted in the desired position on the fixture and the level is maintained as the frequency of vibration is swept. This method ensures excitation at all frequencies between the sweep end frequencies. This type of testing usually will cycle up and down repetitively between frequency limits for a specified time or number of sweep cycles to ensure that adequate reliability levels are attained.

By comparing the acceleration, usually measured in G’s, to frequency one can determine the natural frequencies of the test item. When the acceleration is plotted against the frequency one might observe large peaks at certain frequencies. The frequencies where these peaks occur are the natural frequencies. One would need to either re-design to change the natural frequencies of the test item or design the tested item to withstand the increased accelerations due to experiencing resonance.

1.4.2 Resonance Dwell Tests

Another qualification test done by electronic equipment manufacturers is the resonance dwell test. From sine-sweep test, the resonant frequencies of the test article are determined. Now, the test article will be
subjected to a sine sweep in the frequency range $\pm 5\%$ around the first resonant frequency at constant input acceleration level. The idea behind this test is to accelerate the test by subjecting the test article to lowest natural frequency at usually higher input acceleration levels. Any latent defects in the assembly can be uncovered by doing this test, and also the ability of the test article to withstand high acceleration levels at low frequencies will be tested.

1.4.3 Random Vibration Tests

The random vibration test is a test that puts the test item through a wide range of frequencies that might be experienced during operation of the equipment. Instead of limiting the vibration to one frequency at a time, the test item is subjected to a range of frequencies applied at the same time. The frequencies can be applied at the same time by stacking the frequencies on top of each other, similar to how a radio signal works. The frequencies are applied on a random basis and natural frequencies are usually notched out so the test item will not experience resonance during the test. The test is defined with a random vibration profile in which the Power Spectral Density (PSD), measured in $G^2/Hz$, is plotted against the frequency. Another important part of the random vibration profile to be noted is the area under the curve. The square root of the area under the curve is the $G_{rms}$, or the root mean squared of the $G$ accelerations, of the vibrations. The test is performed on a shaker table which induces the random set of vibrations to the test item. Once completed, thorough examination and tests are conducted to expose any failures that may have occurred. These weaknesses are then corrected and the test is re-run until no failures are observed.

1.4.4 Mechanical Shock Tests

Mechanical shock testing is done to ensure the test item can withstand instantaneous vibrations, usually due to sudden impacts, explosions
which will be experienced during operation. This test is analogous to indirectly hitting the test item with a hammer. This test is similar to the random vibration because a plot of PSD to frequency is used to define the test parameters. This test is usually done by mounting the test item to a plate or structure that will induce the “shock” to the test item. The structure is then subjected to the instantaneous vibration, or shock, through a hammer device. The hammer device is usually a heavy piece of metal that is dropped along a guide and hits the structure inducing the vibrations. The vibration is controlled by changing the way the hammer strikes the structure through height released and dampening mechanisms.

1.5 CONTROL OF VIBRATIONS

In many practical situations, it is possible to reduce but not eliminate the dynamic forces that cause vibrations. Several methods can be used to control vibrations, among them the following are the important (Singiresu Rao 2004):

1) By controlling the natural frequencies of the system and avoiding resonance under external excitations.

2) By preventing excessive response of the system, even at resonance by introducing a damping or energy-dissipating mechanism.

3) By reducing the transmission of the excitation forces from one part of the machine to another, by the use of vibration isolators.

4) By reducing the response of the system, by the addition of an auxiliary mass neutralizer or vibration absorber.
1.6 THESIS ORGANIZATION

The remainder of the thesis is broken into eight chapters and the content of these is summarized below:

Chapter 2 reviews the work done by past researchers in the area of analysis of electronic package subjected to dynamic loads. Papers related to the analysis of board level electronic packaging subjected to sinusoidal vibrations, random vibrations and mechanical shock loads using experimental procedures, numerical procedures or combination of both methods are reviewed. Also, the literature related to the methods of increasing the natural frequency of the PCB assembly, methods of reducing PCB deflection in vibration environments, and methods of fatigue damage analysis due to dynamic loads are reviewed. This chapter also highlights the objectives and methodology of the present research work.

Chapter 3 discusses with the dynamics of plate structure in brief and experimental and numerical investigations on the influence of PCB mounting methods on its dynamic response using free vibration tests (impact hammer test) in detail.

Chapter 4 discusses about the series of experiments conducted on electronic assemblies to investigate the influence of mounting the PCB assembly on plastic spacers, rubber spacers and rubber pads on its dynamic behavior i.e. in reducing the vibration amplitudes when subjected to sinusoidal vibrations.

Chapter 5 presents the results of random vibration tests conducted on electronic assemblies. The influence of using plastic and rubber as spacer
material on the behavior of the PCB responses in a random vibration environment is discussed in this chapter.

Chapter 6 presents the results of mechanical shock tests conducted on electronic assemblies. The electronic assemblies are subjected to mechanical shock pulses (in terms of $G$) using electrodynamic shaker. The responses of the PCB assembly due to shock load are investigated by mounting it on plastic spacers, rubber spacers and rubber pads. The advantages of using rubber spacer as a PCB support material are discussed.

Chapter 7 presents the experimental results of sinusoidal, random and mechanical shock tests conducted on PSOP-PCB assembly. This chapter also discusses about the experimental investigations on the response of PSOP-PCB assembly when mounted on plastic, rubber spacer and rubber pads.

Chapter 8 presents the procedure for estimating the fatigue damage ratio of DIP and PSOP lead wires subjected to sinusoidal and random vibration loads. The influence of using rubber spacers to support the PCB on the fatigue damage ratio of package lead wires is discussed.

The conclusions on the experimental investigations and the scope for the future work are presented in chapter 9.