CHAPTER 4

RANDOM VIBRATION ANALYSIS OF A BOARD
LEVEL ELECTRONIC PACKAGE

4.1 INTRODUCTION

Random vibration 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 (Steinberg 2000). 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.

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.

Random vibration is unique in that all of the frequencies within the bandwidth are present simultaneously at any instant of time for every frequency. When the frequency bandwidth is from 20 to 1000 Hz, every natural frequency of every structural member between 20 and 1000 Hz will be excited at the same time. This includes every fundamental natural frequency, and every higher harmonic of every structural member within that bandwidth.
Under random vibrations, the electronic packages are subjected to low amplitude and high cyclic frequency loads.

Hand held electronic components were subjected to random vibration loads during transportation and during their actual service life. Hence, response of hand held electronic components when subjected to random vibration loads is investigated in this work. In performing random vibration analysis on hand held electronic components, two electronic packages performing similar functions are investigated in order to compare their fatigue lives under random vibration loads. One package considered for investigation is a SOP and the other package is a BGA package. Both the packages were intended to perform the same function as specified by the manufacturer.

In this research, two PCBs custom made as per JEDEC standard (JESD22-B111, 2003) are subjected to random vibration loads. In one PCB, 5 SOP packages are mounted and in the other one, 5 BGA packages are mounted. Initially, FE model of the two PCBs are developed and random vibration analysis is carried out on these PCBs. The results from the FE model are verified by conducting experiments on the actual PCBs. Damage analysis and failure prediction of electronic packages are then carried out using the data from both FEA and experiment and the critical areas which are vulnerable to failure were identified. Once the validity of the FE model is established, the performance of these packages is then compared when subjected to random vibration load conditions specified by JEDEC standard (JESD22-B103B, 2006). Suggestions are given at the end of this chapter to prevent the failure of electronic components under random vibration loads. The methodology adopted in this chapter is shown in Figure 4.1.
Figure 4.1 Methodology adopted in the random vibration analysis of the PCB
4.2 RANDOM VIBRATION ANALYSIS OF PCB BY FINITE ELEMENT METHOD

In this method, two FE models of the PCB are developed as explained in chapter 3 and are used for performing the analysis. Two different electronic packages are considered for investigation. One package is a SOP package which has eight copper lead wires, four on each side which are soldered to the surface of the PCB and the other is a BGA package which is mounted on the PCB using fifteen solder balls. The two packages are shown in Figure 4.2 and the detailed layout of the packages is shown in Figure 4.3 and Figure 4.4.

![Figure 4.2 Packages used for investigation (a) SOP and (b) BGA](image)

Each package is mounted on two different PCBs. One PCB has five SOP package mounted and the other board has five BGA package mounted. The board size is 132 x 77 x 1.6 mm$^3$. The size and the layout of the PCB are based on JEDEC standard (JESD22-B111, 2003). The layout of the PCB together with the mounting locations of the packages and the places where the PCB is supported by mounting screws is shown in Figure 3.2.
Figure 4.3 Detailed layout of SOP Package

Figure 4.4 Detailed layout of BGA Package
The PCBs are made of FR4 epoxy composite material. The properties of the board and the packages used in the FEA model are shown in Table 4.1.

**Table 4.1  Material Properties of board level packages used in FEA (Pecht 1999)**

<table>
<thead>
<tr>
<th>S.No</th>
<th>Component</th>
<th>Material</th>
<th>Young’s modulus, $E$ (Pa)</th>
<th>Poisson’s ratio, $\nu$</th>
<th>Density, $\rho$ (kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>PCB</td>
<td>FR4/Epoxy</td>
<td>$1.7 \times 10^{10}$</td>
<td>0.35</td>
<td>2200</td>
</tr>
<tr>
<td>2.</td>
<td>Package</td>
<td>Plastic</td>
<td>$2.2 \times 10^{10}$</td>
<td>0.29</td>
<td>2100</td>
</tr>
<tr>
<td>3.</td>
<td>Lead wire</td>
<td>Copper</td>
<td>$1.21 \times 10^{11}$</td>
<td>0.35</td>
<td>8400</td>
</tr>
<tr>
<td>4.</td>
<td>Solder ball</td>
<td>63Sn/37Pb</td>
<td>$3.2 \times 10^{10}$</td>
<td>0.38</td>
<td>8440</td>
</tr>
</tbody>
</table>

The FE model of the PCB together with the packages is shown in Figure 4.5.

**Figure 4.5  FE model of the PCB with packages mounted (a) SOP, (b) BGA**
In order to evaluate the dynamic response of the PCB to random vibration loads, initially a simple random vibration excitation is considered for investigation. The excitation given as input is a white noise with input PSD of $0.05 \text{ G}^2/\text{Hz}$ over the frequency range of 100 Hz to 2000 Hz with the root mean square acceleration of $9.75 \text{ G}_{\text{rms}}$ (Steinberg, 2000). The excitation is given at four node points at the four support locations on the bottom side of the board as shown in Figure 4.5. The input random excitation profile is shown in Figure 4.6.

![Figure 4.6](image)

**Figure 4.6** White noise vibration profile used as input in FEA and experiment

The RMS acceleration plot from the FE model of the PCB for the given input excitation was shown in Figure 4.7 and 4.8 for the SOP and BGA packages respectively. The RMS acceleration at the centre of the PCB was found to be $17.64 \text{ G}_{\text{rms}}$ for the SOP package and $12.31 \text{ G}_{\text{rms}}$ for the BGA package.
Figure 4.7 RMS acceleration plot of the PCB with SOP package

Figure 4.8 RMS acceleration plot of the PCB with BGA package
4.3 EXPERIMENTAL RANDOM VIBRATION ANALYSIS

Boards with the same configuration as that of FEA model were fabricated for experimental analysis. The test board was mounted to vibration fixture by bolts of diameter 3 mm at the four locations and the vibration fixture is in turn mounted on an electro dynamic shaker (Dynamic Associates, Model DEV 005). Two accelerometers (B&K 4517C) were used in the experiment. One accelerometer was used to measure the input excitation by placing it in the aluminium base plate fixture and was used for both monitoring and controlling the input. The second one was used to monitor the response of PCB and was mounted near the centre of the PCB. The excitation profile was same as that of FEA input profile shown in Figure 4.6. The system characteristics such as modal frequencies, acceleration response PSD were obtained from the experiment. The schematic layout of the experimental setup is shown in Figure 4.9 and the actual set up is shown in Figure 4.10.

![Schematic layout of the experimental set up for random vibration](image)

Figure 4.9 Schematic layout of the experimental set up for random vibration
In order to determine the failure of the packages during experiments, a dedicated electronic circuit was developed for each package and was used in the actual mounting of the package on the PCB.

Figure 4.10  Experimental setup for random vibration analysis (a) and circuit for checking the package (b) & (c)
A 5 V DC from a voltage regulator was given as input for each of the packages and the output from the packages which was in the form of a square wave signal was captured continuously in using a DAQ card and analysed using LabVIEW 8.6 software. The DAQ card and the LabVIEW software are supported by National Instruments NI PXI-1042Q Chassis. When there was no signal from the package for the given input, it was understood that the package has failed.

4.4 CORRELATION OF FE MODEL WITH EXPERIMENTS

The acceleration response Power Spectral Density (PSD) was obtained at the centre of the PCB for both the FE model as well as from the experiments and was shown in Figure 4.11 and Figure 4.12 for the SOP and BGA packages respectively. The maximum response obtained from FE method for the PCB with SOP package was found to be 70.82 G²/Hz occurring at the first natural frequency (340.74 Hz) of the PCB, whereas the same obtained from the experiment was found to be 70.45 G²/Hz occurring at the first natural frequency (342 Hz). The responses at higher frequencies were found to be less when compared to the fundamental frequency for both experiment and FE methods.

In case of BGA package, the maximum response at the centre of the board was found to 43.79 G²/Hz occurring at the first natural frequency (341.08Hz) by FE method, whereas by experiment it was found to 45.24 G²/Hz occurring at the first natural frequency (340 Hz). The responses at the other frequencies were found to be significantly less compared to the first natural frequency.

The RMS acceleration which was the square root of the area under the acceleration response PSD curves was also computed for both the experiment and FE methods. The RMS acceleration for the FE model of the
PCB with SOP package was found to be 17.64 G$_{\text{rms}}$ and that from the experiments was found to be 16.5 G$_{\text{rms}}$. The result from the FE model was found to correlate with the RMS acceleration contour plot of the PCB shown in Figure 4.7 wherein the RMS acceleration at the centre of the PCB was found to vary between 15.5 G$_{\text{rms}}$ to 20.6 G$_{\text{rms}}$ (154.8 m/s$^2$ to 206.4 m/s$^2$).

In case of the PCB with BGA package, the RMS acceleration was found to be 12.31 G$_{\text{rms}}$ for the FE method and 11.89 G$_{\text{rms}}$ for the experimental method. The G$_{\text{rms}}$ from FE method was found to correlate with the RMS contour plot of the PCB shown in Figure 4.8 wherein the RMS acceleration at the centre of the PCB was found to vary between 9.9 G$_{\text{rms}}$ to 13.2 G$_{\text{rms}}$ (99 m/s$^2$ to 132 m/s$^2$).

The results obtained from both FE and experiment methods for both the packages were tabulated in Table 4.2 and 4.3 respectively.

![Experimental and FE acceleration response PSD of PCB with SOP Package](image)

Figure 4.11  Experimental and FE acceleration response PSD of PCB with SOP Package
Figure 4.12 Experimental and FE acceleration response PSD of PCB with BGA Package

Table 4.2 Comparison of results from FE model and experiments for SOP package

<table>
<thead>
<tr>
<th>Parameters</th>
<th>FE Model</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Natural frequency (Hz)</td>
<td>340.74</td>
<td>342</td>
</tr>
<tr>
<td>Maximum acceleration response at the first natural frequency (G(^2)/Hz)</td>
<td>70.82</td>
<td>70.45</td>
</tr>
<tr>
<td>RMS acceleration(G(_{\text{rms}}))</td>
<td>17.64</td>
<td>16.5</td>
</tr>
</tbody>
</table>

Table 4.3 Comparison of results from FE model and experiments for BGA package

<table>
<thead>
<tr>
<th>Parameters</th>
<th>FE Model</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Natural frequency (Hz)</td>
<td>341.08</td>
<td>340</td>
</tr>
<tr>
<td>Maximum acceleration response at the first natural frequency (G(^2)/Hz)</td>
<td>43.79</td>
<td>42.24</td>
</tr>
<tr>
<td>RMS acceleration(G(_{\text{rms}}))</td>
<td>12.31</td>
<td>11.89</td>
</tr>
</tbody>
</table>
From the above discussions, and from Tables 4.2 and 4.3 it can be concluded that the results from FE model of the PCBs with SOP and BGA packages were found to be in good agreement with the experimental results.

4.5 **CUMULATIVE FATIGUE DAMAGE FOR A RANDOM PROCESS**

A random vibration can be broken up into a series of overlapping sinusoidal vibrations with each vibration having its own frequency and amplitude. Each sinusoidal vibration will have its associated stress cycle. The cumulative fatigue damage ‘D’ for random vibration process can then be defined as (Lee et al 2005)

$$D = \sum_{i=1}^{k} \frac{n_i}{N_{f,i}}$$

(4.1)

where $n_i$ is the total number of cycles in the $i^{th}$ block of constant stress amplitude $S_{a,i}$, $N_{f,i}$ is the number of cycles to failure under $S_{a,i}$, and $k$ is the total number of blocks. Failure of components when subjected to random vibrations, occurs when $D \geq 1$. The relationship between stress amplitude $S_{a,i}$ and the fatigue life $N_{f,i}$ is given by

$$S_{a,i} = S_f (2N_{f,i})^b$$

(4.2)

Equation 4.2 after rearranging results in

$$N_{f,i} = \frac{1}{2} \left( \frac{S_{a,i}}{S_f} \right)^{1/b}$$

(4.3)

where $S_f$ is the fatigue strength co-efficient of the material and $b$ is the fatigue strength exponent. If $m = -1/b$ and $A=0.5 (S_f)^m$, an alternative form of equation 4.3 results in
\[ N_{f,i} = A \times S_{a,i}^{-m} \quad (4.4) \]

In case of random vibrations, the stress amplitude is treated as a continuous random variable. In such a case, the expected value of the \( S_a^m \) is given by

\[ E(S_a^m) = \int_0^\infty S_a^m f_S(a) \, da \quad (4.5) \]

If the distribution of \( S_a \) is assumed to follow Weibull distribution then

\[ E(S_a^m) = \alpha^m \Gamma \left( \frac{m}{\beta} + 1 \right) \quad (4.6) \]

where \( \Gamma(.) \) is the gamma function, \( \alpha, \beta \) are the scale parameters (characteristic life) and shape parameter (Weibull slope) respectively.

In the special case in which \( \beta = 2 \), the Weibull distribution reduces to the Rayleigh distribution. This is an important case, because Rayleigh is the distribution of peaks or ranges or amplitude in a stationary narrow-band Gaussian process that has an RMS value of \( \sigma_s \). Also, it can be shown that

\[ \alpha = \sqrt{2\sigma_s} \quad (4.7) \]

Therefore, if \( S(t) \) is a stationary narrow band Gaussian process and the stress amplitude follows Rayleigh distribution,

\[ E(S_a^m) = \left( \sigma_s \sqrt{2} \right)^m \Gamma \left( \frac{m}{2} + 1 \right) \quad (4.8) \]

\[ \sigma_s = \sqrt{M_o} \quad (4.9) \]
where, $M_0$ is zeroth moment of stress PSD function and is given by,

$$M_0 = \int_0^\infty W_a(f) df \quad (4.10)$$

$W_a$ is the stress PSD of the random process. In such a case, the expected total fatigue damage $D_{NB}$ of a stationary narrow band random process over a time interval $T$ can be written as

$$D_{NB} = \sum_{i=1}^{k} n_i \left( \frac{E[S_a^m]}{A} \right) \frac{E[0^+] \times T}{2M_0} \left( \sqrt{2M_0} \right)^m \left( \frac{m}{2} + 1 \right) \quad (4.11)$$

$E[0^+]$ is the expected rate of zero crossing of the stress PSD curve and can be calculated using equations 4.11 and 4.12

$$E[0^+] = \sqrt{\frac{M_2}{M_0}} \quad (4.12)$$

$$E[0^+] = \sqrt{\int_0^\infty f^2 W_X(f) df} \quad \sqrt{\int_0^\infty W_X(f) df} \quad (4.13)$$

The white noise excitation used in this research is a wide band random process. For wide band random process the fatigue damage can be calculated by

$$D_{WB} = \zeta_w D_{NB} \quad (4.14)$$

$$\zeta_w = a_s + [1-a_s](1-\lambda)^{bs} \quad (4.15)$$
where $a_s = 0.926 - 0.033m$, $b_s = 1.587m - 2.323$ and $m$ is the slope of the S-N curve of the material. $\lambda$ in equation 4.14 is called the spectral width parameter and is given by

$$\lambda = \sqrt{1 - \gamma^2}$$  \hspace{1cm} (4.16)

where $\gamma$ is called the irregularity factor and is given by

$$\gamma = \frac{E[0^+]}{E[P]}$$  \hspace{1cm} (4.17)

where $E[P]$ is the expected rate of peak crossing of the stress PSD function and is calculated using equations 4.17 and 4.18

$$E[P] = \frac{M_4}{M_2}$$  \hspace{1cm} (4.18)

$$E[P] = \sqrt{\int_0^\infty f^4 W_x(f) df}$$  \hspace{1cm} (4.19)

The stress PSD can be obtained from the FE model of the PCB. With the known stress PSD, material properties of the electronic devices and the duration of random vibration testing, the cumulative fatigue damage of the electronic devices can be calculated.

4.6 CUMULATIVE FATIGUE DAMAGE ANALYSIS OF PCB WITH SOP PACKAGE

The RMS stress distribution in the PCB and the area of maximum RMS stress are extracted from the FE model and are shown in Figure 4.13. From this figure it is clear that the maximum stress is acting on the corner
most copper lead wire of the package which is mounted at the centre of the board. Hence the vulnerable element in the entire PCB assembly is the copper lead wire located at the corner of the package at the center of the board. The maximum RMS stress at the corner lead wire for the given input condition is found to be 7.29 MPa.

![Figure 4.13 RMS stress distribution and the area of maximum stress for SOP package](image)

Figure 4.13 RMS stress distribution and the area of maximum stress for SOP package

In order to understand the reason behind the location of the maximum stress at the corner most lead wire, the stress response PSD curve of the copper lead wire at the region of maximum RMS stress is obtained from the FE model and is shown in Figure 4.14.
The stress PSD curve shown in Figure 4.14 is in the form of a narrow band distribution. From this figure it is clear that the stresses in the copper lead wire is primarily because of the fundamental frequency as the stress PSD value at the fundamental frequency is two times higher than the PSDs at the other natural frequencies. The fourth natural frequency also contributes significantly to the stress on the copper lead wire. The first and fourth mode shapes are extracted from the FE model and are shown in Figure 4.15. From these figure it is observed that among the packages mounted at the five different locations, the centre most package is the one that is subjected to maximum displacement relative to the PCB and this maximum displacement occurs at the first natural frequency. Since the first mode of vibration of the PCB is the bending mode, the PCB flexes up and down. In addition to that, the mode shape of the fourth natural frequency indicates that
the PCB is bending with respect to the longitudinal axis of the PCB. This result in the copper lead wires at the corners of the package mounted at the centre being subjected to an axial force and a bending moment as shown in Figure 4.16.

![Diagram of PCB bending](image)

**Figure 4.15** Natural frequencies and mode shapes from FE Model of the PCB

![Mode shapes](image)

**Figure 4.16** Simple representations of first mode shape (a) and fourth mode shape (b) resulting in maximum stress at the corner lead wire

In order to further verify the values of the RMS stress as obtained from the FE model, the area under the stress PSD curve is calculated. The square root of the area under the stress PSD curve should be equal to the RMS stress of the lead wire at the point from which the curve is obtained. The
square root of the area under the stress PSD curve is found to be 6.58 MPa which is very near to the RMS stress obtained from the contour plot which is 7.29 MPa.

Using the stress spectral density shown in Figure 4.14, the rate of zero crossing (equation 4.12) and the RMS stress were calculated. Equation 4.10 was used to calculate the cumulative fatigue damage of the copper lead wire for duration of 30 minutes (JESD22-B103B, 2006). The material properties used for calculating the fatigue damage is given in Table 4.4.

**Table 4.4 Material properties of copper lead wire for fatigue damage (Steinberg 2000)**

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>Fatigue strength coefficient, $S_f$ (N/m$^2$)</th>
<th>Fatigue strength exponent, $b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead wire</td>
<td>Copper</td>
<td>$3.10 \times 10^8$</td>
<td>-0.25</td>
</tr>
</tbody>
</table>

The analysis was continued for various input $G_{rms}$ levels and for each level, the cumulative fatigue damage was calculated using the above equations. The variation in the cumulative fatigue damage for various input $G_{rms}$ levels is shown in Figure 4.17. From this figure it is clear that for a given input $G_{rms}$ level of 14 $G_{rms}$ or more the damage value was found to be more than one indicating that the lead wire has failed. For input $G_{rms}$ values less than 14 $G_{rms}$, the damage was found to be less than one. According to the theory of fatigue failure, any component subjected to vibration loads will not fail if the fatigue damage is less than one (Lee et al 2005). If the factor of safety is to be taken in to account while the components are designed, then for this SOP packages with a factor of safety assume to be of 2, the maximum
fatigue damage would be 0.5. This shows that the SOP packages considered in this research are capable of withstanding up to 11.5 $G_{\text{rms}}$ input.

![Graph of cumulative fatigue damage](image)

**Figure 4.17** Cumulative fatigue damage of copper lead wire for various input $G$ levels

### 4.7 CUMULATIVE FATIGUE DAMAGE ANALYSIS OF PCB WITH BGA PACKAGE

The stress distribution in the PCB and the area of maximum stress are extracted from the FE model and are shown in Figure 4.18. From this figure, it is clear that the maximum stress is acting on the corner most solder ball of the package which is mounted at the centre of the board. Hence the vulnerable element in the entire PCB assembly is the solder ball located at the corner of the package mounted at the center of the board. The maximum stress at the corner solder ball for the given input condition is found to be 4.17 MPa.
In order to understand the reason behind the location of the maximum stress at the corner most lead wire, the stress response PSD curve of the solder joint at the region of maximum RMS stress is obtained from the FE model and is shown in Figure 4.19. The stress PSD curve shown in Figure 4.19 is in the form of a narrow band distribution. From this figure, it is clear that the stresses in the solder ball is primarily because of the fundamental frequency and the PSD value at the fundamental frequency is two times higher than the remaining PSD at the fourth mode of natural frequency (876.5 Hz) and is about two orders of magnitude smaller in the remaining peaks.

The first and the fourth mode shapes are extracted from the FE model and are shown in Figure 4.20. From these figure it is observed that among the packages mounted at the five different locations, the centre most package is the one that is subjected to maximum displacement relative to the
Figure 4.19  Stress PSD of the corner most solder ball

Figure 4.20  Natural frequencies and mode shapes from FE Model of the PCB

PCB and this maximum displacement occur at the first natural frequency. Since the first mode of vibration of the PCB is the bending mode, the PCB flexes up and down. In addition to that, the mode shape of the fourth natural frequency indicates that the PCB is bending with respect to the longitudinal
axis of the PCB. This result in the solder balls at the corners of the package located at the centre is subjected to an axial force as shown in Figure 4.21.

![Figure 4.21 Simple representations of first mode shape (a) and fourth mode shape (b) resulting in maximum stress at the corner solder ball](image)

In order to further verify the values of the RMS stress as obtained from the FE model, the area under the stress PSD curve is calculated. The square root of the area under the stress PSD curve should be equal to the RMS stress of the lead wire at the point from which the curve is obtained. The square root of the area under the stress PSD curve is found to be 4.16 MPa which is very near to the RMS stress obtained from the contour plot which is 4.17 MPa. As in the case of SOP packages, cumulative fatigue damage is calculated for the corner solder ball using equation 4.10. The material properties used for calculating the fatigue damage is given in Table 4.5.

**Table 4.5 Material properties of solder ball wire for fatigue damage (Steinberg 2000)**

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>Fatigue strength coefficient, $S_f$ (N/m²)</th>
<th>Fatigue strength exponent, $b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solder ball</td>
<td>63Sn/37Pb</td>
<td>$4.482 \times 10^7$</td>
<td>-0.16</td>
</tr>
</tbody>
</table>
The analysis is continued for various input $G_{\text{rms}}$ conditions and the resultant cumulative fatigue damage of the corner solder joint is shown in Figure 4.22. From this figure it is clear that for the BGA packages, cumulative fatigue damage is found to be more than one for input $G_{\text{rms}}$ value of 10 or more. Hence, for a factor of safety of 2 which will result in a maximum permitted damage ratio of 0.5 the package will fail even for the initial input $G_{\text{rms}}$ of 9.75.

![Figure 4.22 Cumulative fatigue damage of solder ball for various input $G$ levels](image)

4.8 COMPARISON OF THE PACKAGES FOR THE INITIAL INPUT CONDITION

From Figures 4.17 and 4.22, it was clear that for the same input condition, the cumulative fatigue damage of the SOP package was found to be less when compared to that of a BGA package. This clearly shows that the SOP package has better service life under random vibration loads when compared to the BGA package. In order to verify the above conclusions, tests were carried out on actual PCBs mounted with SOP and BGA packages. From Figure 4.22 it is clear that the BGA package is expected to fail within
30 minutes for an input $G_{\text{rms}}$ of more than 10, but for the same input the SOP package is expected to continue its function even after 30 minutes. Hence an input $G_{\text{rms}}$ of 11.5 was chosen for the testing. The random vibration profile is the same white noise with input PSD of 0.07 $G^2/\text{Hz}$ over a frequency range of 100 to 2000 Hz. Both the PCBs were subjected to the same input load and the PCBs were continuously monitored during testing. After 30 minutes, the signal from the BGA package was distorted while that from the SOP package was found to be clear. After 30 minutes, the experiments were stopped and SEM photographs were taken of both the packages mounted at the centre of the PCB. The photographs are shown in Figure 4.23 and Figure 4.24 respectively. Figure 4.24 clearly shows the crack formation in the corner solder ball of the BGA package indicating that it is about to fail completely which also explains the distorted signal from the BGA package. Figure 4.23 shows no visible cracks at the corner lead wire in the SOP package which indicates that it is capable of withstanding fatigue loads better when compared to the BGA package.

![SEM photograph of SOP package lead wires](image)

**Figure 4.23 SEM photograph of SOP package lead wires**
4.9 COMPARISON OF THE PACKAGES UNDER JEDEC SERVICE CONDITIONS

The validated FE models of the PCB developed in the previous sections were used to evaluate the performance of the SOP and BGA packages under various service conditions specified by JEDEC. JEDEC standard (JESD22-B103B, 2006) has specified 9 different service conditions starting from A to I, which are used to evaluate electronic components working in random vibration environments. The service conditions are shown in Figure 4.25. Service conditions A to C represent the shipping conditions of electronic components, with A being the most severe condition. Conditions D to I represent various levels of application vibrations to which a component can be exposed, with D being the most severe condition.
Figure 4.25 Service conditions specified by JEDEC for random vibration tests

The stresses at the critical copper lead wire and the cumulative fatigue damage of the copper lead wire for the PCB with SOP package when subjected to random vibration loads as specified by various service conditions of JEDEC are shown in Figure 4.26 and Figure 4.27 respectively.

Figure 4.26 Maximum stress at the critical copper lead wire of SOP package for various service conditions
Figure 4.27 Cumulative fatigue damage of the lead wire for various service conditions

From Figures 4.26 and 4.27 it is observed that the packages are vulnerable to failure during shipment rather than in their application environment. The damage calculated even for the severest shipment condition A was found to be 0.023 which is much less compared to the damage index of 1 needed for failure. Except for conditions A and B, for all other conditions, the damage calculated was found to be even smaller and hence was not visible in Figure 4.27.

Similar data was obtained from the PCB with BGA package and were shown in Figure 4.28 and Figure 4.29. Figure 4.29 also indicates that for the same service condition, the BGA package has higher damage index when compared to the SOP package. Even though the fatigue damage of the BGA package was higher, the damage index is quite small even for the severest service condition. The fatigue damage was found to be 0.115 for the service condition A which was much smaller than fatigue damage of 1 needed for failure. Like SOP package, for BGA package also, except for service
conditions A and B, for all other service conditions the fatigue damage was found to be very small that it was not visible in Figure 4.29.

Figure 4.28 Maximum stress at the critical solder ball of BGA package for various service conditions

Figure 4.29 Cumulative fatigue damage of the solder ball for various service conditions
4.10 CONCLUDING REMARKS

In this chapter, the dynamic responses of two different electronic packages which are used to perform the same function in hand held electronic components were compared when they are subjected to random vibration loads. The packages considered were SOP and BGA packages.

FE models of PCBs with the two packages mounted were developed and analyzed using a simple random vibration input in the form of white noise. Experiments were then carried out on actual PCBs with mounted packages using the same random vibration input as that used in the FE method.

In case of the PCB with SOP package, the acceleration PSD measured at the centre of the PCB from experiments was found to be 70.45 $G^2/Hz$ and that from the FE method was found to be 70.82 $G^2/Hz$. The RMS acceleration obtained from the experiment was found to be 16.5 $G_{rms}$ and that from FE method was found to be 17.64 $G_{rms}$. From these values, it can be concluded that the results from the FE method correlated well with experiments. In case of PCB with BGA package also similar data were obtained from both experiments and FE method which revealed good agreement between the two methods.

From the FE models, the critical areas for both the packages were identified. Cumulative fatigue damage was estimated for both the packages. The fatigue damage was found to be 0.27 for SOP package and 0.75 for BGA package. From this data it was concluded that the BGA package was vulnerable to failure under random vibration loads when compared to the SOP package. This conclusion was further verified by conducting experiments on actual PCBs mounted with these packages. The results from the experiment revealed that for a given test duration of 30 minutes, the BGA package has
started failing due to crack formation at the corner solder ball of the package mounted at the centre of the PCB, where no such crack formation was observed for the SOP package.

Using the validated FE models of the PCBs, the performance of these packages were analyzed for the various service conditions specified by JEDEC. Results from the analysis revealed that both the packages were vulnerable to failure during shipment rather that during their service life. The fatigue damage calculated for the SOP package for the severest shipment condition was found to be 0.023 and for the BGA package it was found to be 0.115. The analysis also confirmed the previous finding that the BGA package is more vulnerable to failure because of higher fatigue damage when compared to the SOP package for the same service condition. Even though it was revealed that the packages were vulnerable to failure during shipment, the fatigue damage calculated was found to be very small for both the packages and hence the packages were unlikely to fail suddenly during shipment.