

# Protecting Printed Circuit Boards from Harsh Vibration Environment

M.I.Sakri<sup>1</sup>, P.V.Mohanram<sup>2</sup>Professor, Dept. of Mechanical Engineering, BLDEA's College of Engineering & Technology, Vijayapur, India<sup>1</sup>Professor, P S G Institute of Technology and Applied Research, Coimbatore, India<sup>2</sup>

**ABSTRACT:** The printed circuit board (PCB) which forms the basic support structure of all electronic equipment will be subjected to moderate to severe vibration environments during manufacture, transportation, handling and actual use. The severe vibration environment will subject the PCBs to high input acceleration levels and displacements leading to failure of lead wires and solder joints of electronic packages, loosening of PCB fastening screws, cracking of PCB itself and finally malfunctioning of electronic equipment. To reduce the failure rate and enhance the reliability of electronic equipment, it is necessary to minimize the displacement of PCB; stresses and strains induced in solder joints and the lead wires of critical electronic components mounted on it. The dynamic response of the PCB assembly also depends on the material used for supporting the PCB structure. In the present work, the dynamic responses are experimentally determined by mounting the PCB assembly on plastic spacers and rubber spacers. From the experimental results it was found that, the rubber spacers reduced the PCB displacement, peak response acceleration and transmissibility ratio by 28% compared to the responses when the PCB was mounted on plastic spacers. In addition, rubber spacers improved the damping ratio by 32% while the fundamental frequency remained same for both cases. The fatigue life of the lead wires of the electronic package was estimated. Finite element simulation was also done to validate the experimental results.

**KEYWORDS:** PCB, Plastic spacer, Rubber spacer, Transmissibility ratio, Peak acceleration, Peak displacement

## I. INTRODUCTION

Sinusoidal vibrations can induce very high acceleration  $G$  levels in lightly damped structures, when the natural frequency is excited. Transmissibility  $Q$  values can be greatly magnified, resulting in very high displacements, forces, accelerations, and stresses, which often result in electrical malfunctions and failures. High displacements often result in impacting between adjacent structural members such as circuit boards, resulting in cracked components, cracked solder joints, broken electrical lead wires and broken connector pins. High forces can produce high stresses in load carrying elements such as screws, rivets, and ribs, which may become loose or may fracture. High accelerations can cause relays to chatter, crystal oscillators to malfunction, and potentiometers to lose their calibration accuracy [12]. High stresses typically result in very rapid fatigue failures in various electronic elements from aluminium housings to cables and harnesses.

The severe vibration environment will lead to failure of component leads wires and solder joints, cracking of PCB, and finally malfunctioning of the electronic equipment [12]. Eugene D.V [4] described various methods available for reducing the PCB resonant amplitudes and one of the method proposed by him is, the use of rubber pads to reduce resonance amplification. Andy Perkins et.al, [2008] in their paper addressed the prediction of solder joint fatigue life of ceramic column grid array (CCGA) package under sinusoidal loading. Pitarresi [9] addresses the basic modelling issues regarding the mechanical shock and random vibration response of a typical computer motherboard. Pitarresi, et al., [8] studied the response of personal computer motherboards subjected to mechanical shock loads. Du Pingan et al., [3] in their paper, the finite element modelling issues regarding the modal analysis of motherboard was addressed. Yang Q.J et al., [15] have discussed the about the reliability of PBGA solder joints subjected to vibration loading. The failures at the connectors' level between the PCB and the electronic package can be attributed to vibration or fatigue resulting

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

from dynamic loads [2]. Hence, the dynamic behaviour of PCBs is becoming an important issue in determining the reliability of electronic equipment used in applications such as military and aerospace.

## II. RELATION OF DISPLACEMENT TO FREQUENCY AND ACCELERATION G LEVEL

Dynamic displacements that are developed during vibration conditions are often very important since they can be used to determine the dynamic stresses, which are needed for the calculation of the expected fatigue life of the critical electronic structural members [12]. Dynamic displacements are very difficult to observe and to measure. Acceleration levels are easy to obtain with the use of small accelerometers, and frequencies are easy to obtain directly from the electrodynamic shakers performing the vibration. Therefore, if there is an easy way to obtain accurate dynamic displacements, it would reduce the amount of work required to calculate the expected fatigue life of critical electronic members.

The single amplitude displacement  $Y_o$  in meters at the centre of the PCB when subjected to harmonic excitation may be estimated using the following equation.

$$Y_o = \frac{9.81G_{out}}{4\pi^2 f^2} \quad (1)$$

Where,  $G_{out}$  is output peak acceleration measured at the centre of the PCB, and  $f$  is the resonant frequency of the PCB assembly. Alternately, Equation (1) can be written in the following form.

$$Y_o = \frac{9.81G_{in}Q}{4\pi^2 f^2}, \text{ where } Q = (G_{out}/G_{in}) \text{ is the transmissibility ratio} \quad (2)$$

From above equations, it can be seen that, reducing the  $G_{out}$  or  $Q$  ( $G_{in}$  being constant during sine sweep test) will reduce displacement of the PCB, provided the resonant frequency  $f$  is maintained same or increased. Hence, this work aims at reducing  $G_{out}$  by using alternative spacer material for mounting the PCB while the natural frequency maintained at same magnitude.

## III. EXPERIMENTAL PROCEDURE

The experimental setup for conducting the sine-sweep test is as shown in Fig 1. The experimental setup mainly consists of an electrodynamic shaker (DEV-001, 50 kg-f, 12 mm peak-to-peak displacement) for exciting the PCB assembly at constant input acceleration. An aluminium fixture (300 mm x 300 mm x 8 mm) bolted onto the shaker head for mounting the printed circuit board (PCB) made of glass-epoxy material (240 mm x 200 mm x 1.5 mm). Two accelerometers (B&K 4513-001 and B&K 4517) one for controlling and monitoring the input acceleration level ( $G_{in}$ ) and the other for monitoring the output acceleration ( $G_{out}$ ), will be interfaced with a four channel signal conditioner. The first accelerometer placed on the base plate (fixture) will control and monitor the input acceleration level during the test period and the second accelerometer placed near the component will measure the output response. Electrodynamic shaker is excited at constant input acceleration using sinusoidal vibration controller software. The PCB assembly was mounted on the fixture using four fastening screws and plastic spacers placed at the corner of the PCB. The electronic package used for the test is a through-hole mounted 16 pin dual in-line package (DIP-53C539H, 8 pins x 2 rows) mounted at the centre of PCB is as shown in Fig 2. A failure detecting circuit for detecting the failure of component lead wires or solder joints during the test is shown in Fig 3. In case, any of the lead wire or solder joint fails, the LED provided on the circuit will go off.

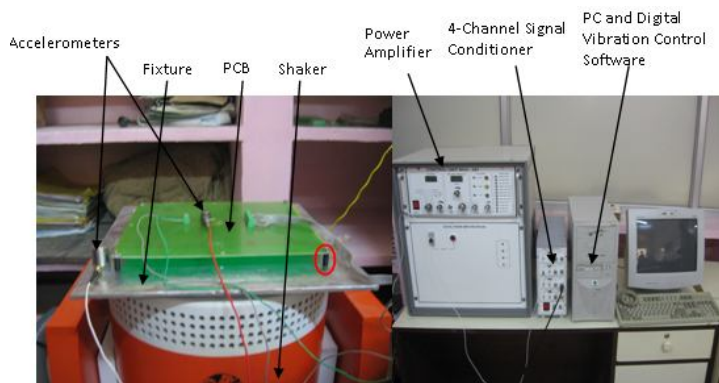


Fig 1 Experimental setup and PCB mounted on plastic spacer

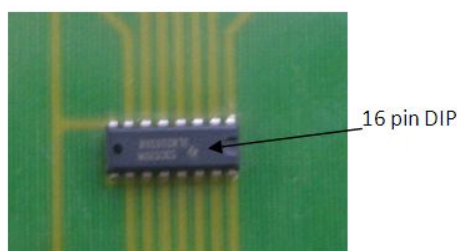


Fig 2 Electronic package mounted on PCB

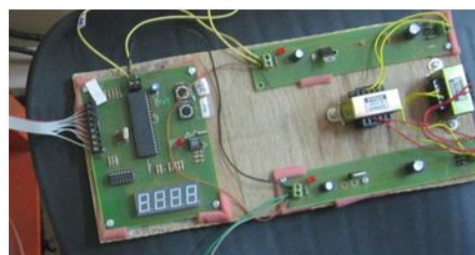


Fig 3 Failure detecting circuit

#### IV. SINE SWEEP TEST WITH PCB ASSEMBLY MOUNTED ON PLASTIC SPACER

The logarithmic sine-sweep at the rate of one octave per minute was programmed using sinusoidal vibration control software. Sine sweep tests were conducted on the PCB assembly by mounting it on four plastic spacers (encircled in Fig 1) placed at the corner of the PCB in the frequency range 20-500 Hz at a constant input acceleration of  $1G$ . The displacement values at predominant natural frequencies were measured using a pen type digital vibrometer (Fig 4) while holding the sweep (software facilitates this feature). The frequency response of the PCB assembly when mounted on plastic spacers is as shown in Fig 5. The natural frequencies of the PCB assembly obtained from the logarithmic sine sweep test at  $1G$  input acceleration level are as tabulated in Table 1. Similarly, the output acceleration levels and displacement values at resonant frequencies are as tabulated in Table 2 and Table 3 respectively. From Fig 5 it is seen that, the first resonant frequency of PCB assembly is 46 Hz and single-amplitude displacement of 2.93 mm with peak acceleration of  $25G$ . Second prominent resonant frequency is at 210 Hz with peak acceleration of  $70G$ . From the data it is clear that, the first resonant frequency of 46 Hz is dangerous, which leads to maximum PCB deflection inducing maximum stresses in component lead wires. This will lead to reduced fatigue life and early failure of electronic packages.

Table 1 PCB assembly resonant frequencies (Hz)

Mode number	1	2	3	4	5	6	7	8	9
Plastic spacer	46	60	105	140	210	240	340	398	460
Rubber spacer	46	60	105	140	210	240	350	410	460

From above table it can be seen that, upto mode 6 the resonant frequencies for the PCB mounted on plastic and rubber spacers are same. After that, for higher modes there is minimum difference.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

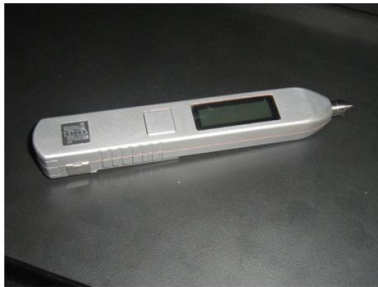


Fig 4 Pen type digital vibrometer

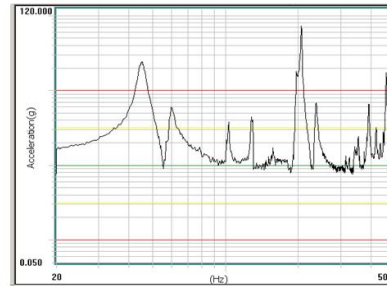


Fig 5 Acceleration response at 1G input using plastic spacer

Table 2 PCB assembly acceleration values (Peak -G)

Mode number	1	2	3	4	5	6	7	8	9
Plastic spacer	25	6	4	4.5	70	7	2.5	7	18
Rubber spacer	18 (28)*	5.5 (8.3)	3 (25)	1.5 (66.7)	50 (28.6)	4 (42.8)	3 (-20)	2.5 (64.3)	12 (33.3)

\* Figures within bracket indicate percentage of variation

From Table 2 it is seen that, there is significant reduction in peak acceleration levels when PCB is mounted on rubber spacers. If peak acceleration levels are minimum then, PCB suffers minimum damage and life of components mounted on it is extended.

Table 3 PCB assembly displacement values (peak-single amplitude in mm)

Mode number	1	2	3	4	5	6	7	8	9
Plastic spacer	2.93	0.41	0.09	0.06	0.39	0.03	0.01	0.01	0.02
Rubber spacer	2.11 (28)*	0.38 (7.3)	0.07 (25)	0.02 (66.7)	0.28 (28.6)	0.02 (42.9)	0.01 (0.0)	0.00 (100)	0.01 (50)

\* Figures within bracket indicate percentage of variation

Table 3 shows the comparison of displacement level of PCB when mounted on plastic and rubber spacers. From table it is observed that, when PCB is mounted on rubber spacers, the displacement magnitudes are less. This again leads to prolonged life of electronic components.

## V. SINE SWEEP TEST WITH PCB ASSEMBLY MOUNTED ON RUBBER SPACER

In an attempt to reduce the output acceleration, displacement and the transmissibility ratio, and enhance the fatigue life of electronic packages, the rubber spacers (Fig 6) were used for mounting the PCB assembly. All the fastening screws were tightened uniformly torque of 1.7 N-m using a torque wrench. The sine sweep test at an input acceleration level of 1G was conducted when the PCB assembly was mounted on rubber spacers. The response of PCB assembly mounted on rubber spacer is as shown in Fig 7. The natural frequencies, output acceleration levels, and displacement values are as tabulated in Tables 1, 2, and 3 respectively.

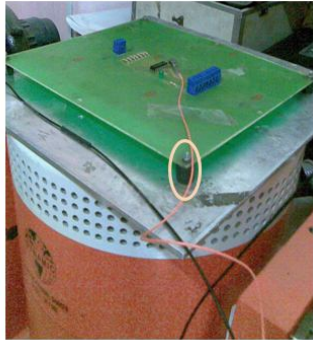


Fig 6 PCB assembly mounted on rubber spacer

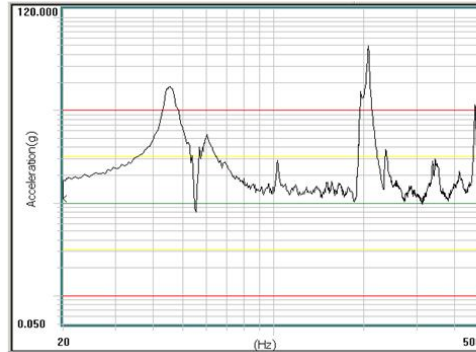


Fig 7 Acceleration response at 1G input acceleration using rubber spacer

### VI. COMPARISON OF PCB RESPONSES

From Table 1 it is observed that, the fundamental frequency and higher mode resonant frequencies are almost same for both the mounting conditions. From Fig 7 it is observed that fourth mode frequency (140 Hz) is not prominent. A reduction of 28% in peak response acceleration (Table 2) and single amplitude displacement (Table 3) at the first frequency are noticed when the PCB assembly is mounted on rubber spacer. The peak acceleration (output) levels for the two types of mounting spacers are as shown in Fig 8. Figure 9 shows the comparison of peak single amplitude displacement values for the two types of mounting spacers.

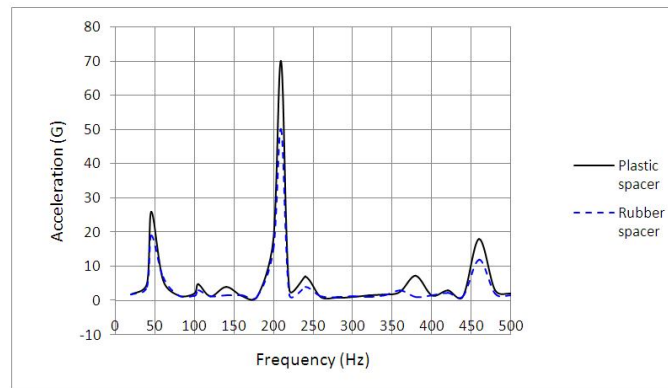


Fig 8 Comparison of response acceleration for plastic and rubber spacers

Similarly, Fig 10 shows the comparison of transmissibility ratios ( $Q$ ) for the plastic and rubber spacer mounted PCB assembly. From the figure, it is seen that there is a reduction of about 28% in the transmissibility ratio at first frequency (46 Hz) and 210 Hz.

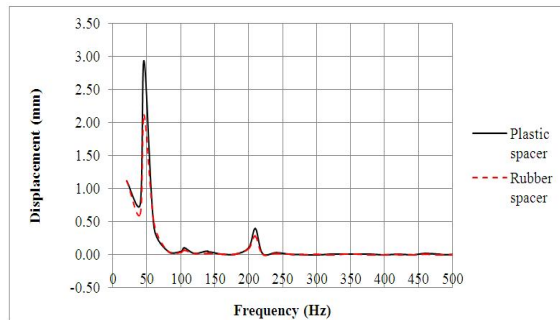


Fig 9 Comparison of displacement for plastic and rubber spacer

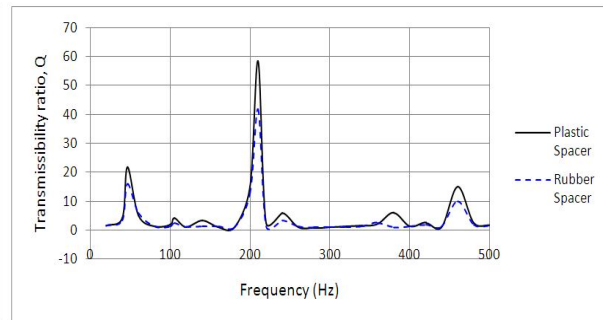


Fig 10 Comparison of transmissibility ratio for plastic and rubber spacer

## VII. CONCLUSIONS

Sine sweep tests were conducted on PCB assembly when mounted on plastic spacers and rubber spacers. The displacement, peak acceleration level and transmissibility ratio of the PCB assembly were reduced by about 28% when rubber spacers were used. Thus, the displacement of the PCB and the stresses induced in the lead wires can be reduced by mounting PCB assembly on rubber spacers and also the fatigue life can be improved to a great extent.

## REFERENCES

1. Andy Perkins, Sures K. Sitaraman, "Analysis and Prediction of Vibration-Induced Solder Joint Failure for a Ceramic Column Grid Array Package," ASME Journal of Electronic Packaging, Vol. 130, pp. 011012-1 – 011012-11, 2008
2. Cifuentes A.O., Shulga N., and Neff C.A., "A Sensitivity Study of Printed Wiring Board Vibrations using Statistical Method", Journal of Sound and Vibration, 181, pp. 593-604, 1995
3. Du Pingan, Yu Yating, Gan Ezhong, Li Bo, "Finite Element Modeling for Computer Motherboard Modal Analysis", International conference on Mechatronics & Automation, Niagara Falls, Canada, 2005
4. Eugene D. Veilleux, "Vibration control of Printed Circuit Boards in a Dynamic Environment", IEEE Transactions on Parts, Materials, and Packaging, Vol. PMP-6, No.3, pp. 100-105, 1970
5. Kun Nan Chen, "Optimal Support Locations for a Printed Circuit Board Loaded with Heavy Components", ASME Journal of Electronic Packaging, 128, pp. 449-455, 2006
6. Ong J.H., and Lim G.H., "Dynamic Finite Element Model Improvement of a PCB Structure", Journal of Vibration Control, 5, pp. 57-74, 1999.
7. Ong J.H., and Lim G.H., "A Simple Technique for Maximizing the Fundamental Frequency of Vibrating Structures", ASME Journal of Electronic Packaging, Vol. 122, (4), pp. 341-349, 2000
8. Pitarresi J, Roggeman. B., Chaparala S., and Gong P., "Mechanical Shock Testing and Modeling of PC Motherboards", Proceedings of the 2004 Electronic Components and Technology Conference, Las Vegas, NV, pp. 1047-1054, 2004
9. Pitarresi J., Geng P., Beltman W., and Ling Y., "Dynamic Modeling and Measurement of Personal Computer Motherboards", Proceedings of the 2002 Electronic Components and Technology Conference, San Diego, CA, pp. 597-603, 2002
10. Pitarresi J.M, and Primavera. A. A., "Comparison of Modeling Techniques for the Vibration Analysis of Printed Circuit Cards" ASME Journal of Electronic Packaging, 114, 00. 378-383, 1992
11. Pitarresi. J.M. and Di Edwardo A.V., "A Design Approach for the Systematic Improvement of Support Locations for Vibrating Circuit Cards", ASME Journal of Electronic Packaging, 115, pp. 118-123, 1993
12. Steinberg D.S., "Vibration Analysis for Electronic Equipment," John Wiley & Sons.
13. Suhir E., 2000, "Predicted Fundamental Frequency of Vibration of a Heavy Electronic Component Mounted on a Printed Circuit Board", ASME Journal of Electronic Packaging", Vol. 122, No 1, pp. 3-5, 2000
14. Wong T.L, Stevens K.K. and Wang G., "Experimental Modal Analysis and Dynamic Response Prediction of PC Boards with Surface Mounted Electronic Components", ASME Journal of Electronic Packaging, Vol. 113, pp. 244-249, 1999
15. Yang Q.J., G.H. Lim, R.M. Lin, F.F. Yap, H.L.J. Pang and Z.P. Wang, , "Experimental Modal Analysis of PBGA Printed Circuit Board Assemblies", Proceedings of the IEE/CPMT Electronic Packaging Technology Conference, Singapore, pp. 290-296, 1997
16. Yücesan E., C.-H. Chen, J. L. Snowden and J. M. Charnes, "Simulation- based analysis of a complex printed circuit board testing process", Proceedings of the Winter Simulation Conference, U.S.A., , pp. 993-998, 2002