ELSEVIER
CrossMark
Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 144 (2016) 1469 – 1476
Procedia Engineering
www.elsevier.com/locate/procedia

12th International Conference on Vibration Problems, ICOVP 2015

Response Spectrum Analysis of Printed Circuit Boards subjected to Shock Loads

Jayaraman S[a*], Manish Trikha[b], Somashekar[c], Kamesh D[d], M.Ravindra[e]

[abcde]*ISRO Satellite Centre, Old Airport road, Bengaluru-560017, India*

Abstract

A spacecraft consists of a number of electronic packages to meet the functional requirements. An electronic package is generally an assembly of printed circuit boards placed in a mechanical housing. A number of electronic components are mounted on the printed circuit board (PCB). A spacecraft experiences various types of loads during its launch such as vibration, acoustic and shock loads. Prediction of response for printed circuit boards due to shock loads is important for mechanical design and reliability of electronic packages. The modeling and analysis of printed circuit boards is required for accurate prediction of response due to shock loads. The validated finite element model of the PCB can be adopted to perform response spectrum analysis. Shock response spectrum analysis of printed circuit boards subjected to a half-sine pulse excitation is carried out using finite element method. The objective of this paper is to predict the shock response spectrum of a printed circuit board due to launch environment. The analysis results are validated by conducting experimental tests of PCB.

Peer-review under responsibility of the organizing committee of ICOVP 2015

Keywords: Printed Circuit Board (PCB); Shock Response Spectrum Analysis; Spacecraft

---

* Corresponding author Tel: +91-80-25084345
E-mail address: sjayaram@isac.gov.in

Peer-review under responsibility of the organizing committee of ICOVP 2015
doi:10.1016/j.proeng.2016.06.710

1. Introduction

A spacecraft experiences various types of loads during its launch such as vibration, acoustic and shock loads. Mechanical shock can induce highly dynamic loads on PCBs, causing cracking and fracture problems. It also can cause damage due to severe motions of portion of the assembly, which may lead to mechanical and/or electrical failure. Electronics packages are subjected to shock testing to establish adequate margins before being assembled to the spacecraft. PCBs have to be designed to survive severe environments such as shock and vibration encountered during launch phase. Electronic devices such as integrated circuits, resistors, capacitors and FPGAs demand high quality and reliability. A reliable and accurate analytical model is essential for the PCB with components to predict the system response due to loadings such as shock and vibration. Package component failures due to shock loads have been observed in the past (1995). The four basic failure modes of components mounted on PCB due to random vibration environment are the results of the following conditions: high acceleration levels, high stress levels, large displacement amplitudes and electrical signals out of tolerance. It is possible to predict the probability of mechanical failure by a two stage Physics of Failure (POF) approach (2000). Pitarresi (1990), Pitarresi, et al. (1991), and Pitarresi and Primavera (1992) provided the solutions for issues encountered in modeling the PCB assembly that includes wide variety of components. Tsung-Yueh Tsai et al (2007) developed the analytical solutions for undamped single degree of freedom systems subjected to half-sine impact accelerations of magnitude 1g for duration of 0.5ms. Fabio Botta et al (2007) studied impulse response of the Reissner-Mindlin plates and generated Shock Response Spectrum (SRS) using the modal analysis technique.

Detailed finite element models are built by modeling the PCB and the components. The component effects are included by increasing the Young's modulus and density of the PCB FE model, so it effectively behaves as if components were present. Sensitivity analysis of PCB finite element models was carried out by Amy et al (2009). They determined the factors of safety by using different simplification methods of modeling the PCB. The dynamic characteristics of damped PCB subjected to half sine excitation are studied by E.H.Wong et al (2009). Mihai Vladimirescu et al (2010) used two different methods to derive the loads acting on the reed switch during pyroshocks. In this paper, shock response spectrum analysis of a typical PCB used for space applications is carried out. First, the modal analysis of the PCB is performed to obtain structural modal parameters, i.e. natural frequencies and mode shapes. This work includes the procedure of model verification by the adoption of vibration tests to validate the finite element (FE) model developed using commercially available software package. Dynamic tests are widely used in the engineering design of structures and can be extended to study PCB assembly. FEA is an effective and efficient tool but demands careful validation procedure to ensure the results are reasonably accurate. The analysis is done for a bare PCB (PCB without components) and next, the analysis is carried out for a PCB with components. Subsequently, shock response spectrum analysis of the PCB is carried out for half sine pulse of typical magnitude and time duration. The peak or maximum response at different locations on the PCB is determined. The analysis results are validated through experimental tests of PCB.

2. Finite Element Model and its Validation

Modal analysis is frequently adopted to extract the modal parameters of a structural system, including natural frequencies, mode shapes, and modal damping ratio, etc. Since these parameters depend only on the system itself but dominate the response of the entire system to various kinds of excitations, modal analysis is the fundamental of response analysis and has therefore gained increasing attentions.

2.1 Modal Analysis using FEM

In this study, a six layer PCB used for space applications is considered. The PCB is modeled as isotropic plate with equivalent material properties such as Young's modulus, Poisson's ratio and mass density. FEA simulations of PCB dynamics are made using PATRAN 2014 as pre and post-processor and MSC.NASTRAN as solver for bare PCB and PCB with components. In the second case for component PCB, the effects of components are accounted locally on the PCB by simulating appropriate mass and stiffness distribution. Finite Element model consists of 12364 quadrilateral shell elements with appropriate thickness and 10 rigid elements to simulate fixed boundary condition as shown in Figure 1 and Figure 2. Young's modulus of elasticity for PCB with components is estimated as 34 GPa from the iterations of modal analysis.

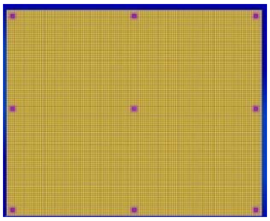

Fig.1 FE Model (bare PCB)

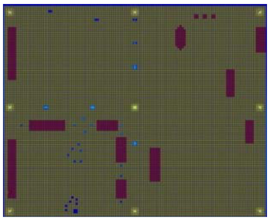

Fig.2 FE Model (component PCB)

Details of the PCB are summarized in Table 1. Normal mode analyses were conducted on FE model to extract first three fundamental natural frequencies for bare PCB as well as PCB with components. The calculated first three natural frequencies are 317 Hz, 343 Hz, 368 Hz and 236.7 Hz, 255.4 Hz, 282.0 Hz for bare PCB and PCB with components respectively. Mode shapes for the two cases are shown in Figure 3 to Figure 6.

Table 1. Details of PCB

Parameter	Value
PCB size	250×200×2.1 mm
Mass of bare PCB	208.4 g
Mass of PCB with components	388.4g (=208.4+180)
Young's modulus of Bare PCB	20 GPa
Young's modulus of Component PCB	34 GPa
Poisson's ratio	0.12
Boundary Condition	Fixed/clamped

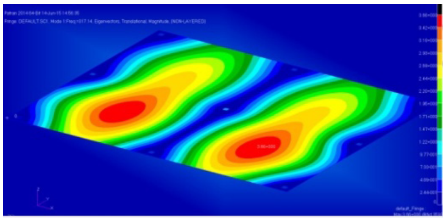

Fig.3 Mode shape of bare PCB for first frequency

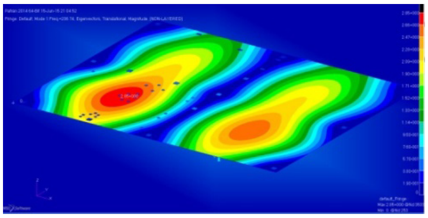

Fig.5 Mode shape of PCB with components for first frequency

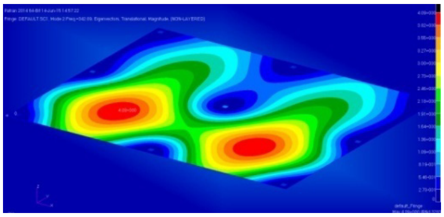

Fig.4 Mode shape of bare PCB for second frequency

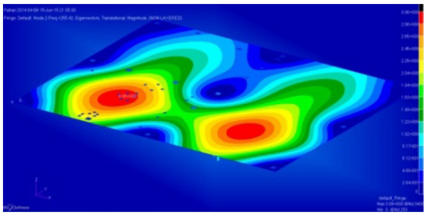

Fig.6 Mode shape of PCB with components for second frequency

2.2 Sine Sweep Vibration Test

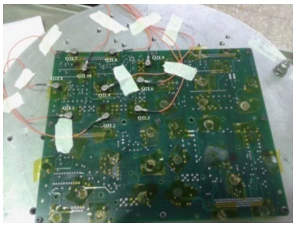
Fig.7 Bare PCB on vibration table

The objective of vibration test is to obtain the modal parameters of the PCB by testing directly on the physical system, and the results can be used to correlate with those from FEA and validate the FE model. The test was conducted by mounting the PCB with screws at nine locations on vibration table. The bare PCB is mounted on the vibration table as shown in Figure 7. The PCB with components is shown in Figure 8. Accelerometers are mounted at various locations of the PCB to measure the responses. The sine sweep vibration test was carried out in the vibration test facility consisting of electro-dynamic shaker, control system, signal conditioners and data acquisition system.

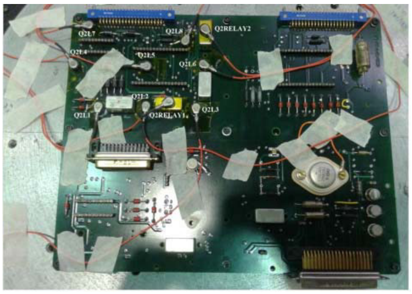

Fig.8 Different measurement locations on component PCB

2.3 Comparison of results

In this section, the FEM simulation results and the experimental test results are compared. Simulation and test results for fundamental frequencies of the bare PCB are compared in Table 2 and for PCB with components (the effects of components are accounted locally on the PCB) are compared in Table 3. The simulation and test results of bare PCB and that of PCB with components are matching well within the acceptable limits.

Table 2. Comparison of Fundamental Frequencies for Bare PCB

Frequency (Hz)	Simulation Results	Test Results	% Difference
1	317.0	311.0	1.9
2	343.0	351.0	-2.3
3	368.0	379 .0	-2.6

Table 3. Comparison of Fundamental Frequencies for Component PCB

Frequency (Hz)	Simulation Results	Test Results	% Difference
1	236.7	236.0	0.3
2	255.4	255.0	0.2
3	282.0	285.0	-1.0

3. **Shock Response Spectrum Analysis**

Shock loading is characterized by a sudden transfer of energy to the system. This transfer results in a significant increase in the stress and strain on the system. The critical parameters in a shock environment are the amplitude and duration of shock load, the type of shock (i.e., shape of the pulse), and the modal characteristics of the system.

3.1 Response Spectrum Analysis using FEM

Response spectrum analyses are the methods used by many engineers to estimate the maximum dynamic response of a structure subjected to severe shock loads. The only major calculation step is determining a sufficient number of normal modes to represent the entire frequency range of the input excitation and resulting response. Applied loads or base excitations are converted in a modal transient response solution (SOL 112) into a spectrum table consisting of peak response accelerations for a set of single degree-of-freedom oscillators. The validated FE model was used to perform the shock response analysis by subjecting it to half sine base excitation of 100g for duration of 3ms. The half sine acceleration pulse is shown in Figure 9. In this study, a structural damping coefficient of 2% is incorporated in the model.

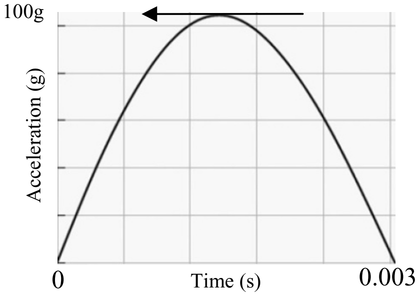

Fig.9 Half-sine acceleration pulse

The maximum transient acceleration response at different locations of the PCB was computed. The transient acceleration response was given as input for calculation of the SRS at the desired locations. The absolute acceleration method and damping of 2% is used for the calculation of shock response spectrum. The shock response spectra (SRS) at three different locations of the bare PCB are plotted in Figures [10] to [12]. These values are then compared with test data obtained from shock tests using vibration shaker.

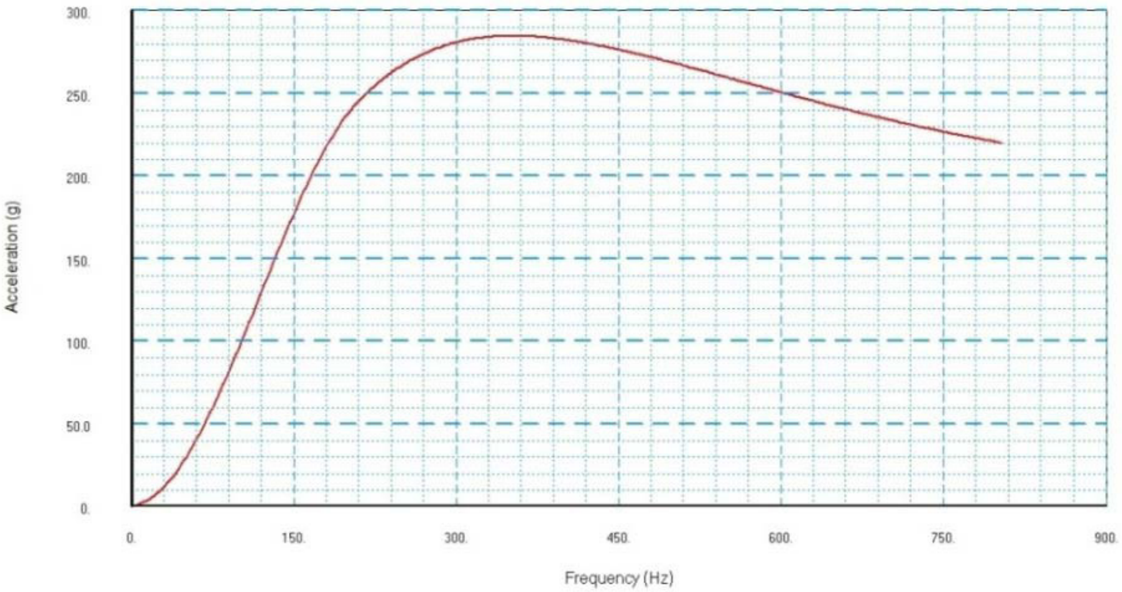

Fig.10. Predicted SRS for location-1

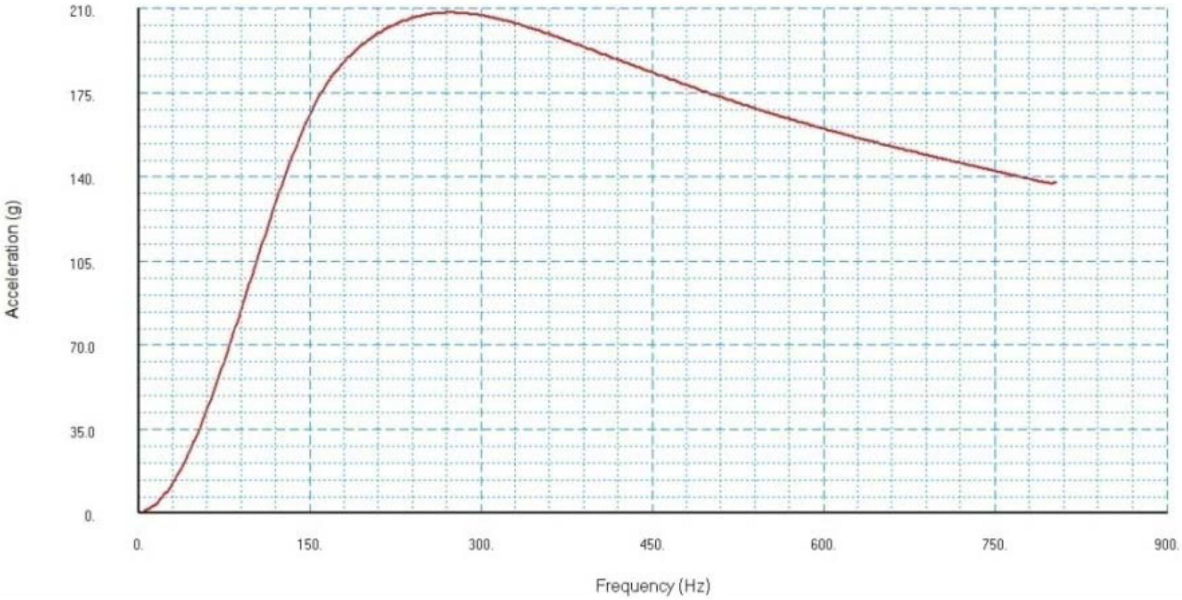

Fig.11 Predicted SRS for location-2

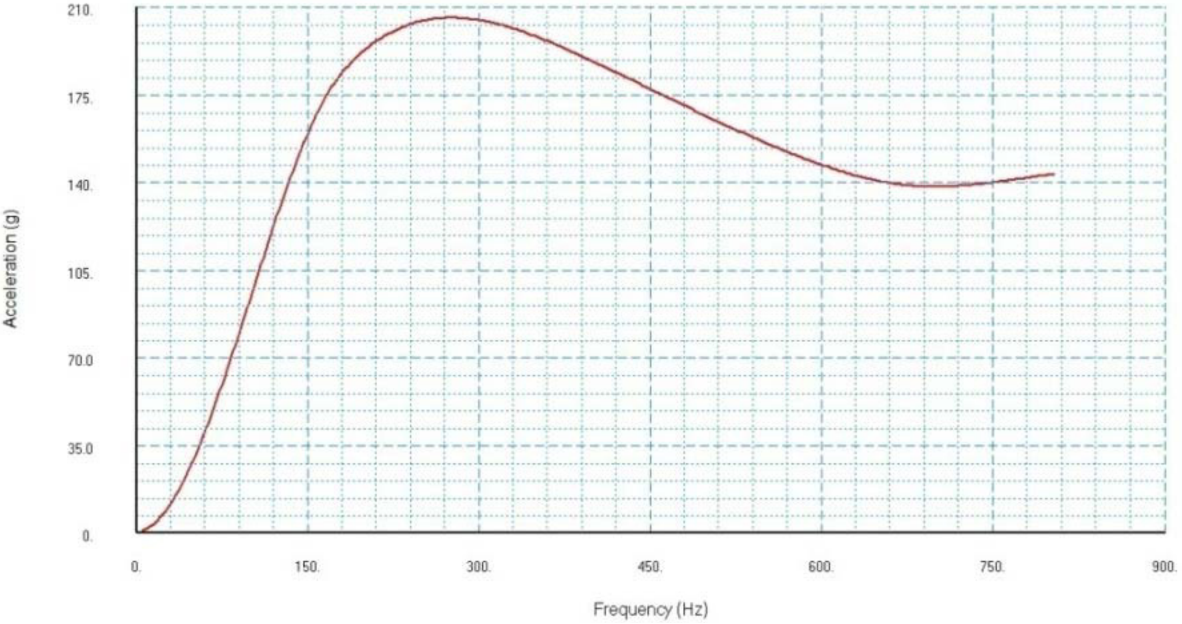

Fig.12 Predicted SRS for location-3

3.2 Shock test

An electrodynamic shaker is used to perform half-sine acceleration shock test on the PCB. The test fixture for shock testing of the PCB assembly is shown in Figure 7. Common load durations for electronic packaging tests range from a few milliseconds to about ten milliseconds with amplitudes from a few tens to hundreds of g's. The shock test is conducted for half sine base excitation of 100g for duration of 3ms. The SRS plots from the test are shown in

Figure [13] and Figure [14] for bare PCB.

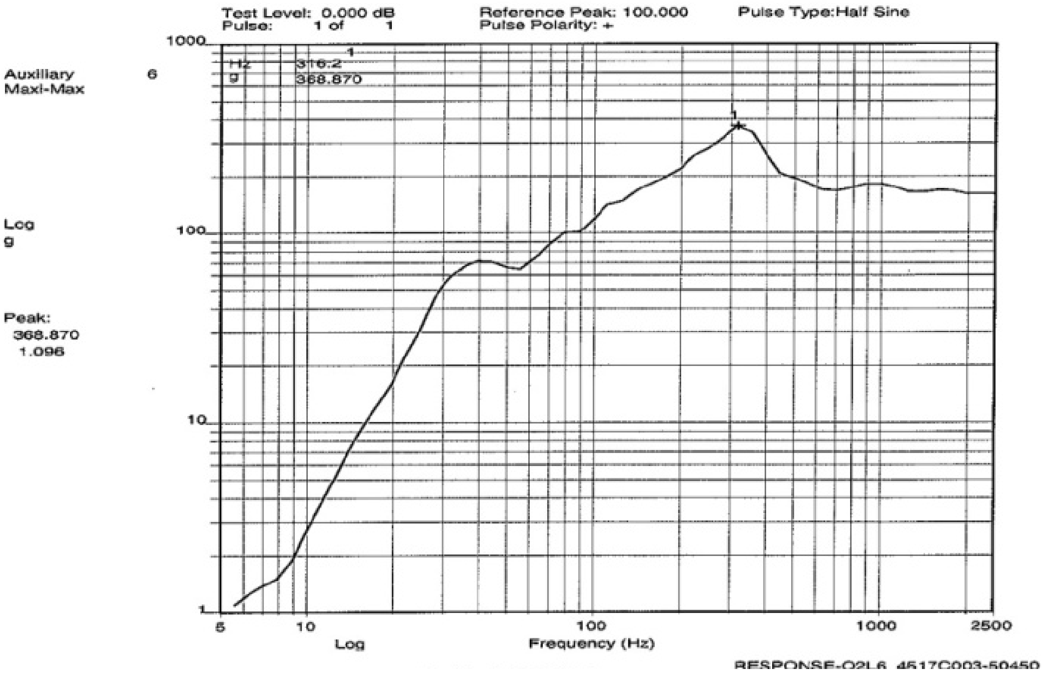

Fig.13 SRS from test for location-1

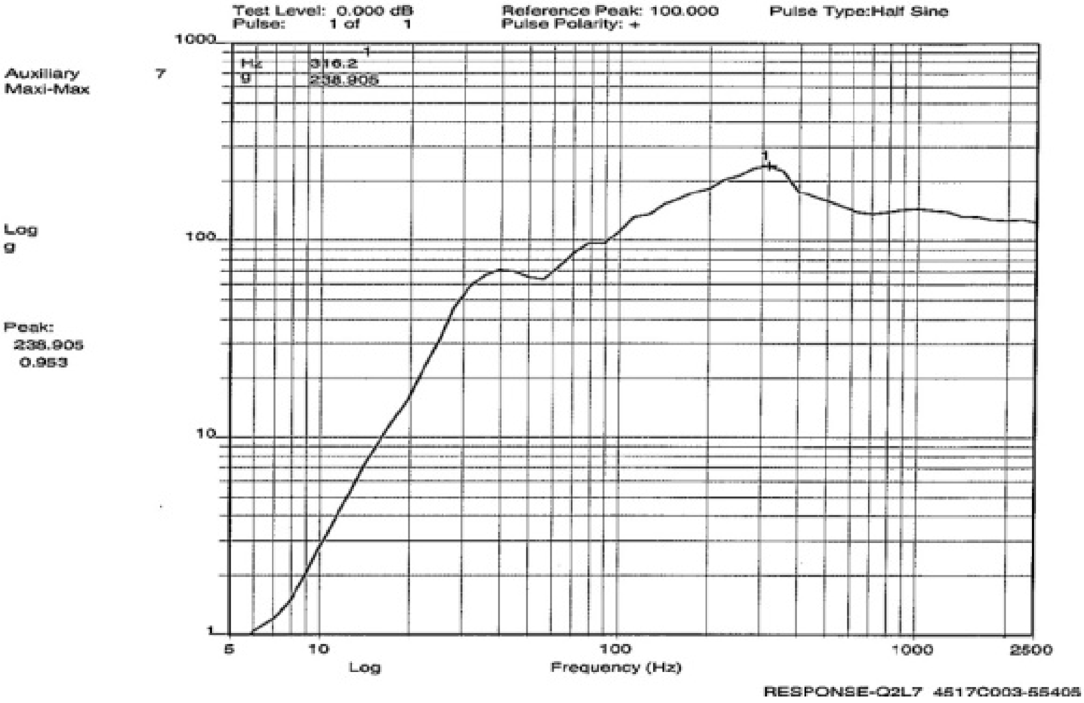

Fig.14 Transient response from test for location-2

3.3 Comparison of results

The acceleration response was typically measured at three locations on the PCB assembly. Both the predicted SRS accelerations from FE model and the measured SRS accelerations are listed in Table 4. From the table, it is observed that the simulation results are below the measured values. However, predicted peak transient response for location-2 is 124g which is very well agreeing with test value of 123-g. In the case of component PCB, the calculated peak SRS response, 450g at 245 Hz is well below the measured SRS response, 699-g at 281 Hz. A possible reason for the discrepancy is the presence of holes near the locations of accelerometers and detailed modeling of components is required for accurate SRS prediction.

Table 4: Comparison of predicted peak SRS values vs. measured SRS values for bare PCB

Location	Measured		Simulation	
	Frequency (Hz)	Amplitude (g)	Frequency (Hz)	Amplitude (g)
1	316	369	320	285
2	316	239	280	209
3	316	229	280	206

4. Conclusions

In this paper, shock response spectrum analysis for a PCB assembly is presented. An equivalent FE simulation model for a standard PCB with components has been established based on experimental test results corresponding to fixed/clamped boundary conditions. Shock tests are conducted on the PCB to understand the response behavior of the PCB assembly. The FE simulation results are compared with shock test results. Simulation and test results for fundamental frequencies as well as shock response spectrum of the bare PCB are matching well within the acceptable limits. In the case of component PCB, a detailed modeling of components is required to obtain reasonably good match between simulation and test data.

References

[1] Amy, R. A., Aglietti, G. S.,Richardson, G.: Sensitivity analysis of simplified Printed Circuit Board finite element models. Microelectronics Reliability. 49 (2009) 791-799.
[2] Fabio B, Giovanni C.: Shock response spectrum in plates under impulse loads. Journal of sound and vibration, 308 (2007) 563-578.
[3] Harris.C.M. Shock and Vibration Handbook. McGraw-Hill, New York, 1995.
[4] Mihai Vladimirescu, Andre Zybura et al.: 3D Finite Element Analysis of the Glass Encapsulated Magnetic Reed Switches Under Pyroshock Environment. IEEE, 978-1-4244-8177-4/10, 2010.
[5] Pitarresi, J.M.: Modeling of Printed Circuit Cards Subject to Vibration. IEEE Proceedings of the Circuits and Systems Conference, New Orleans, LA, May 3-5, 1990, pp.2104-2107.
[6] Pitarresi, J.M., Celetka, D., Coldwel,R. and Smith, D.: The Smeared Properties Approach to FE Vibration Modeling of Printed Circuit Cards. ASME Journal of Electronics Packaging, Vol.113, September, 1991, 250-257.
[7] Pitarresi, J.M. and Primavera, A.: Comparison of Vibration Modeling Techniques for Printed Circuit Cards. ASME Journal of Electronics Packaging, 113, December, 1992, pp.378-383.
[8] Steinberg, D. S.: Vibration Analysis for Electronic Equipment 3rd Ed., John Wiley & Sons, New York, 2000.
[9] Tsung-Yueh Tsai, Chang-Lin Yeh et.al : Response spectra analysis for undamped structural systems subjected to half-sine impact acceleration pulses. Microelectronics Reliability. 47, 2007, pp.1239-1245.
[10]Wong. E.H., Yiu-Wing Mai.: The damped dynamics of printed circuit board and analysis of distorted and deformed half-sine excitation. Microelectronics Reliability. 49, 2009, pp.916-923.