The 13th ISAV2023 International Conference on Acoustics and Vibration
20, 21 Dec 2023 Tehran - Iran
Iranian Society of Acoustics and Vibration

Optimizing Printed Circuit Board Assembly Mounting Support Through Experimental Modal Analysis, Finite Element Verification, and Vibration Testing

Amirmohammad Vahedi[a], Aghil Yousefi-Koma[a], Adrian Gharibkhanian[a]
Ali Barahimi[a] and Sina Bakhtiary[a]

[a] *Center of Advanced Systems and Technologies (CAST), School of Mechanical Engineering, University of Tehran, 1417935840, Tehran, Iran.*

**Corresponding author e-mail: aykoma@ut.ac.ir*

Abstract

Vibration analysis of printed circuit boards (PCBs) plays a pivotal role in ensuring the reliability and performance of electronic devices exposed to mechanical stress and vibrations during their operational lifespan. This paper delves into the intricate interplay of mounting configurations on the natural frequencies and vibrations of a microcontroller component strategically positioned at the center of a printed circuit board (PCB). The study commences with a detailed finite element analysis simulation of the PCB using ANSYS software, further refining the physical properties of the Printed Circuit Board Assembly (PCBA) to optimize its performance. This optimization process hinges upon the insights derived from experimental modal analysis facilitated by modal hammer testing. Subsequently, a comprehensive sinusoidal sweep test is meticulously executed on the PCBA, employing three distinct mounting configurations. The velocities of various critical points on the PCBA are judiciously measured using a Doppler laser. The selection of the safest mounting configuration for the PCBA is predicated upon the discerned local and global frequency response functions, thereby bolstering the PCB's reliability and performance under mechanical stress and vibrations. The sweep test is conducted with an electrodynamic shaker, ensuring precise and controlled excitation throughout the experimental process.

Keywords: Finite element analysis; Modal analysis; printed circuit board; mounting configuration.

---

1. Introduction

Vibration analysis of printed circuit boards (PCBs) is crucial due to the reason that PCBs are integral components of electronic devices, and they are often subjected to various mechanical stresses and vibrations during their operational lifespan. These vibrations can result from factors such as automotive electronics (dynamic load of the vehicle tire[1]), aerospace (random vibration during flight operation[2]), smartphones (the acoustic noise related to vibration of the PCB[3]) or other industrial applications such as Railway Electronics[4].

Engineers often make assumptions about a PCB's behavior under vibration conditions during the design phase. Finite element analysis (FEA) allows them to validate these assumptions and ensure that the board's structural integrity and performance meet specified criteria. Hui Wei et al. [5] studied using the FEA to analyze the vibration characteristics of PCBs under different boundary conditions. In [6], a simplified method using FEA to analyze PCB under shock loading is proposed, considering effective constants in place of detailed heavy models. Karthiheyan et al. [7] employed FEA simulation with ANSYS to determine the natural frequencies of a PCB with a Ball GridArray package, facilitating subsequent fatigue life estimation under random vibration conditions, and these results were experimentally validated. One method for determining natural frequencies is analyzing an empty board and adding components one by one, which can increase Young's modulus and density of the whole package[8-10].

Using experimental modal analysis (EMA) alongside FEA is necessary because it provides real-world validation of FEA simulations and offers insights into the actual dynamic behavior of structures, including PCBs. In [11], operational modal analysis (OMA) using Frequency Domain Decomposition (FDD) and Enhanced Frequency Domain Decomposition (EFDD) and EMA is done with free-free conditions examining the dynamic behavior of single-layer PCB. In [12], Lindstrom developed a predictive model for assessing the mechanical behavior and lifetime of BGA components on PCBs under vibration-induced fatigue, using calibration based on experiments; however, predicting lifetimes, especially for new designs without historical data, remains challenging due to variations in results.

In this study, the dynamic characteristics of PCB are initially extracted through EMA. Subsequently, a microcontroller component is mounted on the board, and the effects of the added component are investigated using EMA and simulation in the ANSYS software. Subsequently, by installing the printed circuit board on an electrodynamic shaker and examining various mounting arrangements, we investigate the natural frequencies and vibrations of the microcontroller component.

2. Method

The designed PCB has a rectangular layout, and a microchip N80C188XL20 is installed in its central portion. The designed PCB is depicted in Figure 1 using SolidWorks software. Additionally, to accommodate PCBs with various layouts, a number of symmetrically positioned M5 holes have been created along the length and width of the board and labeled. The board thickness is 1.55 millimeters and is composed of FR-4 material, which makes it suitable for industrial applications.

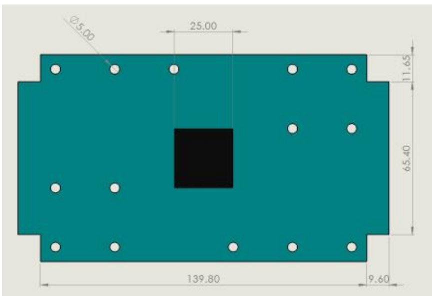


Figure 1. CAD Model of PCB, with Microchip assembled to the PCB

To perform FEA, the designed CAD model with the desired dimensions was imported into the ANSYS software, and simplifications were made to create a computationally efficient model. Furthermore, the solder connections of the ICs were omitted, and the entire IC component was assembled as a homogeneous plate in the central part of the PCB. Since 4 piezoelectric accelerometers are connected to the board in experimental modal analysis, in the simulation, these sensors are added to the structure as concentrated masses in their designated positions. The simulation employed a tetrahedron element type, and the modal analysis process was conducted independently of the mesh. The entire assembly, consisting of the PCB and IC, was simulated with 56474 elements. The simulated PCB Assembly is shown in Figure 2.

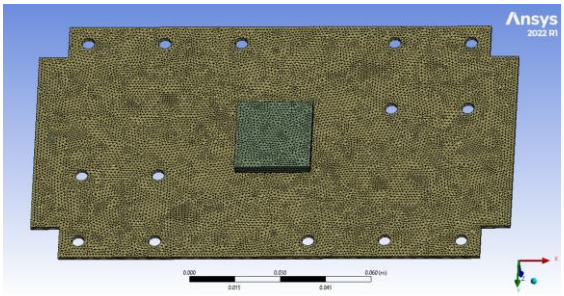
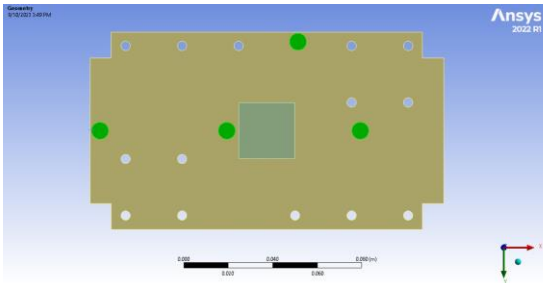
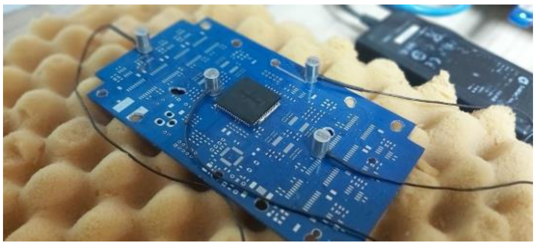


Figure 2. FEA Model of PCB Assembly in ANSYS 2022R1

. Material calibration has been performed to account for potential geometric deviations and uncertainty of material properties between the CAD model and reality. In this process, the Young's modulus of the PCB, microchip, and the mass of the accelerometers were adjusted. This calibration necessitates physical testing to determine the natural frequency values and mode shapes in two scenarios: an empty PCB and a microchip mounted on it. To obtain the Frequency Response Functions (FRFs), four piezoelectric accelerometers, as depicted in Figure 3, are securely attached to the PCB using wax. The accelerometer locations have been strategically chosen to facilitate the extraction of the first three mode shapes. To place the PCB in free-free conditions, foam is utilized as shown in Figure 3. For exciting the vibration modes, the PCB is discretized with a 28-node mesh, and impacts from a hammer with an average of 5 hits and an exponential windowing are applied to the PCB.



(a)

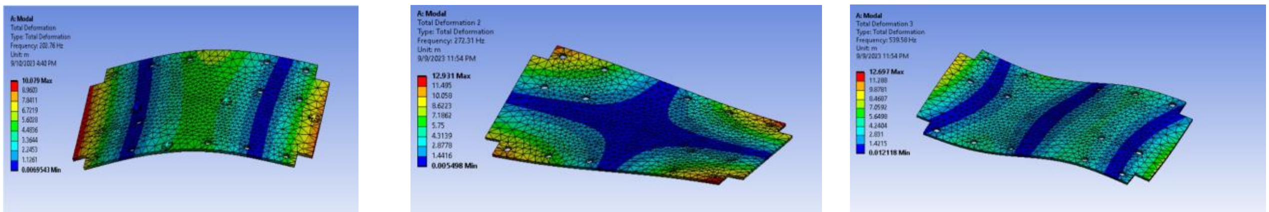


(b)

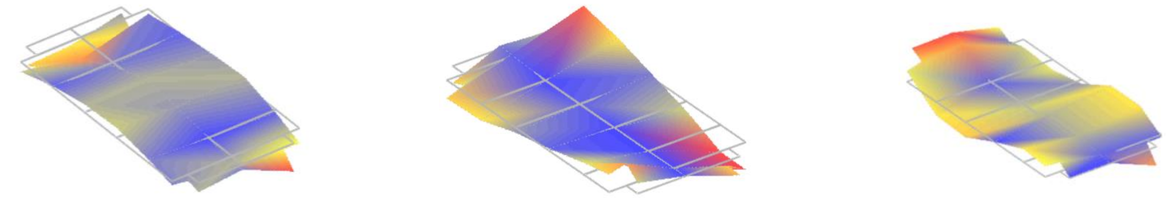
Figure 3. (a) Four Piezoelectric accelerometers location **(b)** Modal Analysis of PCBA in Free-Free Boundary Condition

In the finite element model, the density of the printed circuit board and microchip is determined by physically measuring their weight and volume based on the CAD model. Additionally, a mass of 1.6 grams is considered for each of the accelerometers; however, since each accelerometer is connected by a cable, its mass is also taken into account as a parameter. Through an assessment of experimental natural frequencies and MAC (Modal Assurance Criterion) plots, various parameter combinations for the PCB and microchip have been examined, and the optimal parameters have been selected. Considering the numerical simulation results, it was found that Young's modulus of the microchip had minimal influence on the natural frequency values. Therefore, the PCB and microchip assembly have been modeled as a homogeneous material. The results of experimental modal analysis and numerical simulation are presented in Figure 4. Additionally, the selected values for Material properties and natural frequencies in the assembled PCB configuration are listed in Table

1. Since the mode shapes in PCBA closely resemble those of the empty board, the repetition of mode shapes has been omitted.



(a)Eigenfrequency=202.76Hz (c) Eigenfrequency=272.31Hz (e)Eigenfrequency=539.581Hz



(b)Eigenfrequency=202.87Hz (d)Eigenfrequency=222.8Hz (f)Eigenfrequency=537.17Hz

Figure 4. The First three natural frequencies extracted experimentally and computationally

Table 1. Natural Frequencies of PCB Assembly extracted numerically and experimentally

Row	Numerical Analysis	Experimental Modal Analysis
1st Mode	202.76 Hz	202.84 Hz
2nd Mode	272.31 Hz	229.7 Hz
3rd Mode	539.38 Hz	533.35 Hz

The designed setup for conducting vibration tests comprises various equipment, and its schematic is depicted in Figure 5. The primary vibration testing equipment is an electromagnetic shaker, the ETH-140 shaker, which can excite the PCB with various vibration patterns. The ETH-140 shaker is controlled through a power amplifier and the EDM software, equipped with a Vibration Control System module. The EDM software defines the desired vibration pattern, and the data acquisition card adjusts the power to enable the electromagnetic shaker to maintain its vibration pattern. To achieve this, the data acquisition card requires feedback from an accelerometer to measure the responses of the shaker's head expander vibrations.

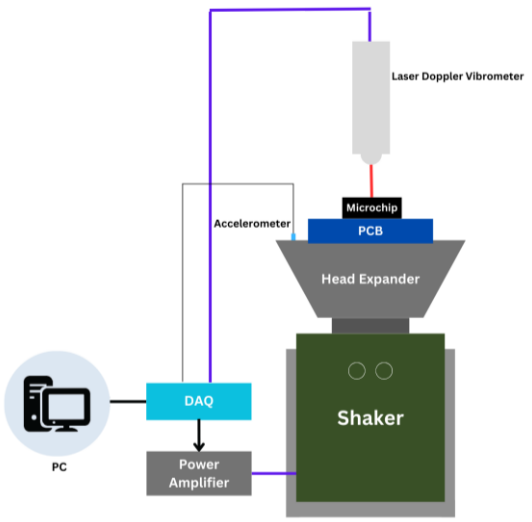
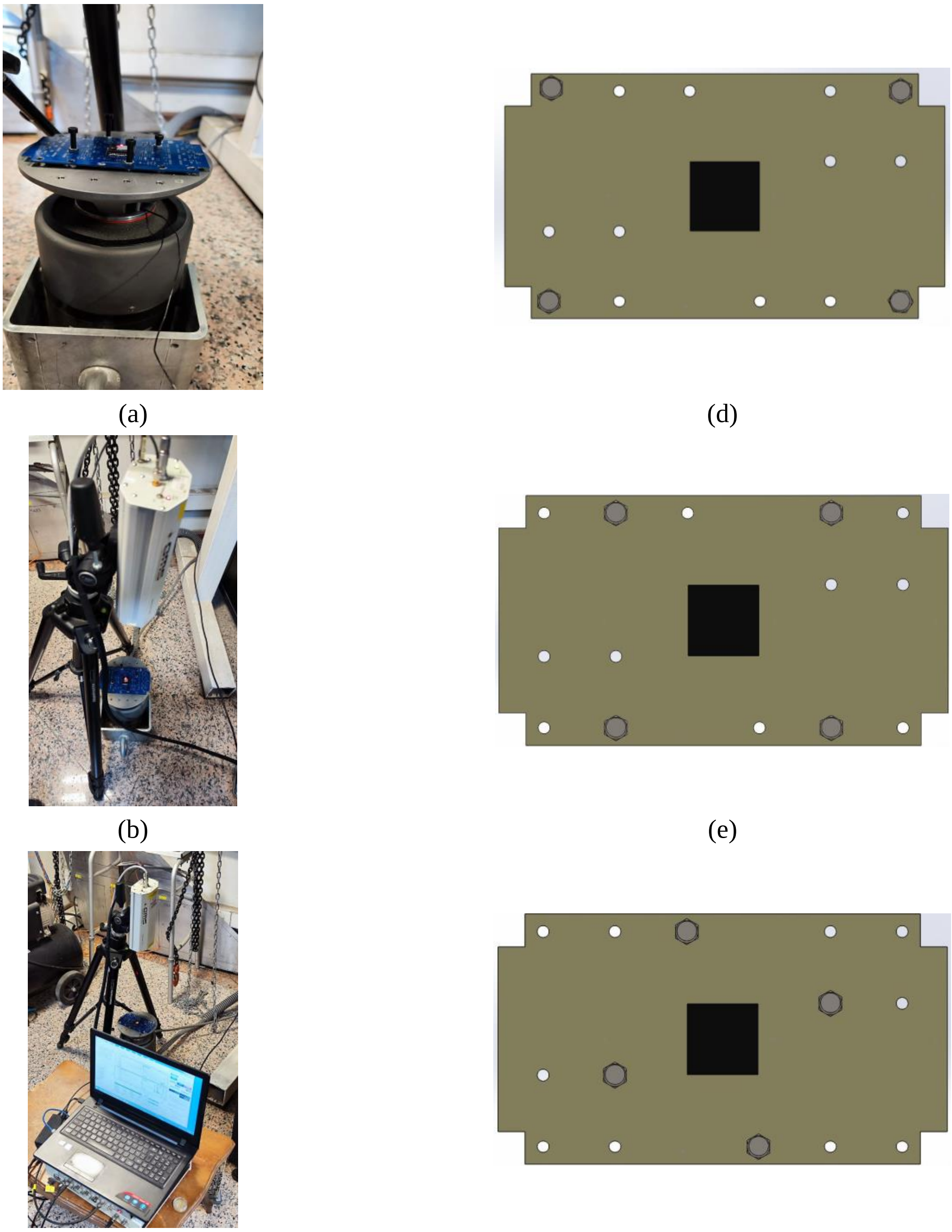


Figure 5. Schematic of vibrational Setup

The purpose of using the head expander for the shaker is to establish a connection between the electromagnetic shaker and the PCB. The chosen head expander possesses a high natural frequency and sufficient rigidity for conducting vibration tests on the PCB. To measure the vibration responses of the microchip without altering the structural dynamics, an OMS Laserpoint Lp01 laser velocimeter is utilized. The use of a non-contact sensor enables the examination of mounting effects. Three mounting arrangements with four screws have been considered to investigate the frequency response and microchip vibrations through sinusoidal sweep tests. The vibration test setup and the three mounting arrangements are shown in Figure 6.



(a) (d)

(b) (e)

(c) (f)

Figure 6. Experimental Setup for testing PCB under 3 mounting conditions: **(a)** PCB Assembly mounted on electrodynamic shaker head expander; **(b)** Measuring vibration with laser velosimeter; **(c)** Experimental Setup with DAQ and EDM Software; (d) Installation with four external points; **(e)** Installation with four internal points; **(f)** Installation with central points

To apply more precise boundary conditions in the configurations presented in Figure 6, M5 screws with a GRADE 10.9 rating are used. All screws and nuts are torqued to 9 N.m. to prevent PCB damage. For calculating natural frequencies and vibration effects, a sinusoidal sweep test is conducted in the frequency range of 5 to 1500 Hz with a base acceleration of 1g. In order to extract the PCB Assembly's global frequency response function, data was collected from 9 points as shown in Figure 7. Data acquisition from a single point provides a local frequency response function and may not encompass comprehensive information about the structure. Additionally, considering the black surface of the microchip, a reflector was attached to it for data acquisition using a laser velocimeter.

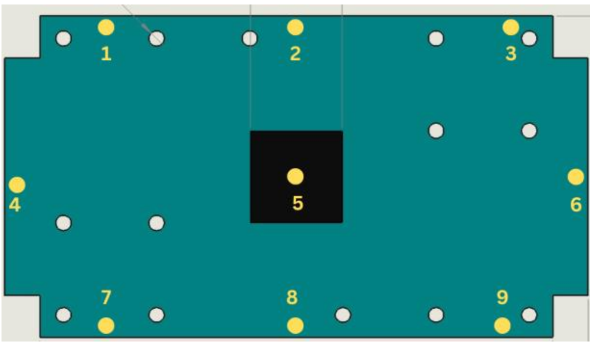


Figure 7. Measurement points on PCB Assembly

3. Result and conclusion

In this article, a series of vibration tests were conducted with two separate objectives. Initially, finite element simulations of the PCB along with the microchip and accelerometers were validated against experimental modal analysis data. Optimal values for parameters such as the elastic modulus of the PCB, microchip, and accelerometer mass were selected. Based on the experimental modal analysis, the natural frequencies do not change significantly when the IC is added to the PCB. Furthermore, Young's modulus value was explored from very low to very high in the simulation process, and its impact was observed. The optimal values for the physical parameters of the system are provided in Table 2.

Table 2. Optimum Material Properties

Material Properties	Printed Circuit Board	Microchip
Density (Kg/m^3)	2095	1756
Young's Modulus (GPa)	22.5	22.5
Accelerometer Mass (gr)	1.6	

The second set of vibration tests was conducted to examine the spacing of mountings and its effects on the frequency response functions. Analyzing the frequency response functions at 9 selected points makes it possible to extract the natural frequencies of the global structure. Three examples of the frequency response function plots with different mounting configurations are shown in Figure 8.

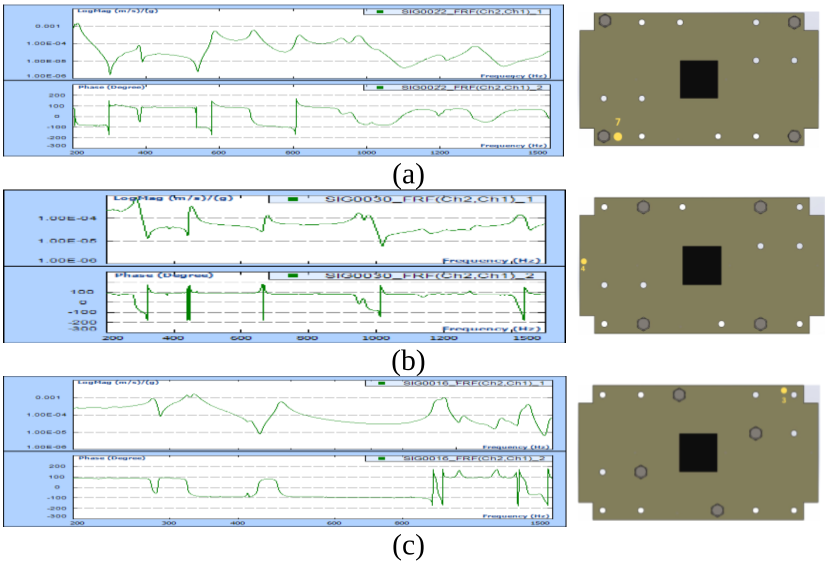


Figure 8. Frequency Response Function with different mounting configurations**: (a)** FRF of PCBA with four external mountings at point 7; **(b)** FRF of PCBA with four internal mountings at point 4; **(c)** FRF of PCBA with four central mountings at point 3

By examining the characteristics of the global PCB Assembly's global FRF, the first 3 natural frequencies have been extracted and are presented in Table 3. Due to the symmetry of the structure and mountings, some modes are repeated with very small intervals and omitted from the table.

Table 3. The natural frequency of PCB assembly with three different configurations

Natural Frequency	External Mountings	Internal Mountings	Central Mountings
1st Mode	207.4 Hz	287.4 Hz	279.9 Hz
2nd Mode	380.72 Hz	384.76 Hz	322 Hz*
3rd Mode	585.92 Hz	451.74 Hz	478. 92 Hz

The natural frequencies and maximum velocity levels have been investigated for each configuration by examining the frequency response function plots for the microchip. In the Central mounting configuration, the central region of the electronic board assembly exhibited lower vibrations in the frequency range of 5 to 1000 Hz, behaving similarly to the nodal region, and it has higher safety margins.

REFERENCES

1. Lin, Shan & Luo, Mi & Niu, Jun & Xu, Hongke. (2022). Research on the Reliability of a Core Control Unit of Highway Electromechanical Equipment Based on Virtual Sensor Data. Sensors. 22. 7755. 10.3390/s22207755.
2. Braz, B.D.C. and Bussamra, F.L.D.S., 2017. An enhanced random vibration and fatigue model for printed circuit boards. *Latin American Journal of Solids and Structures*, *14*, pp.2402-2422.
3. Wang, Y.Q., Ko, B.H., Jeong, S.G., Park, K.S., Park, N.C. and Park, Y.P., 2015. Analysis of the influence of soldering parameters on multi-layer ceramic capacitor vibration. *Microsystem Technologies*, *21*, pp.2565-2571.
4. Zhao, Z., Hu, C. and Yin, F., 2018, August. Failure analysis for vibration stress on ball grid array solder joints. In *2018 19th International Conference on Electronic Packaging Technology (ICEPT)* (pp. 486-490). IEEE.
5. Wei, H. and Xu, L., 2017, August. Research on dynamic model of printed circuit board based on finite element method. In *AIP Conference Proceedings* (Vol. 1864, No. 1). AIP Publishing.
6. Burmitskih, A.V., Lebedev, A.P., Levitskiy, A.A. and Moskovskih, M.S., 2013, September. Printed Circuit Board vibration analysis using simplified finite element models. In *2013 International Siberian Conference on Control and Communications (SIBCON)* (pp. 1-4). IEEE.
7. Karthiheyan, S.G.S., Verma, V.K., Saravanan, S., Ayyappan, V.P., Sathiyaseelan, K. and Gopinath, U., 2020. Dynamic response characteristics and fatigue life prediction of printed circuit boards for random vibration environments. *Journal of Failure Analysis and Prevention*, *20*, pp.920-929.

8. Pitarresi, J.M., 1990, May. Modeling of printed circuit cards subject to vibration. In *IEEE International Symposium on Circuits and Systems* (pp. 2104-2107). IEEE.

9. P K Dash, M Thraza, and Babithakodavanla. “Modelling and simulation of effect of component stiffness on dynamic behaviour of printed circuit board”. In: *International Journal of Mechanical and Production Engineering Research*

10. Amy, R.A., Aglietti, G.S. and Richardson, G., 2009. Sensitivity analysis of simplified Printed Circuit Board finite element models. *Microelectronics reliability*, *49*(7), pp.791-799

11. Anuar, M.A., Mat Isa, A.A., Zamri, A.R. and Said, M.F.M., 2013. Ambient Response Modal Analysis on a CEM-1 Single-Layer Printed Circuit Board. *Applied Mechanics and Materials*, *393*, pp.683-687.

12. . Casen, A. and Lindström, F., 2023. Modeling vibration of printed circuit board assembly to predict component damage.