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Static and dynamic simulation of printed circuit boards

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Abstract - *The A printed circuit board is an electronic unit consisting of various electronic components connected with the help of circuits. Circuit boards have different applications such as signaling, processing, execution, etc. Electronic components such as resistance, capacitor, transistor, inductor, integrated circuits, processors are used as per the application. PCB's are made up of different layers as per the application. Now a days a printed circuit board has to overcome numerous test analysis before the final product is delivered. As per the increase in demand in automation industry the circuit boards have to be compact, more efficient and more rigid. To cope with high demand and increasing technological advancement the PCB has to undergo test like its structural capabilities, thermal efficiencies, flow pattern etc.*

It is a well-known fact that vibration is one of the most important loading conditions in electronic systems. The vibration study deals with dynamic analysis of a printed circuit board (PCB) with a component on it under vibratory loading. The objective is to develop an analytical model for common PCB configurations and electronic components on them in order to predict dynamics of the assembly under vibratory loading, and thus to study the effects of component location. [4]

The vibration characteristics of printed circuit boards are related to the reliability of electronic components installed on their surface. Finite element software is a powerful tool to analyze the vibration characteristics of printed circuit boards. [8] This report deals with the study of static and dynamic conditions of a PCB taking two different support conditions and analyzing them.

1. INTRODUCTION

Modern electronic equipment has been widely used in almost all aspects of people's lives. The functions of electronic equipment are gradually varied, and the degree of integration of them is increasing rapidly. These electronic devices may be exposed to many different forms of broadband, multi-level vibration acceleration effect. For example, avionics and aerospace electronic equipment have to experience the effect of sinusoidal vibration, random vibration and transient impact, which are mainly introduced by the engine of the aircraft or spacecraft and the air surround it. Under the effect of above acceleration, the PWAs in the electronic equipment may have flexural displacement, which can cause many kinds of failure or damage of the electronic equipment. [7]

Electronic equipment in use process inevitably subject to vibration and impact, in such a harsh environment, the reliability of electronic equipment will be affected by a lot. According to statistics, in the environmental cause of airborne electronic equipment failure, vibration factors accounted for about 27%. [3]

As per the increase in demand in industry the circuit board have to be compact, more efficient and more rigid. To cope with high demand and increasing technological advancement the PCB has to undergo test like its structural capabilities, thermal efficiencies, flow pattern etc. Following are the analysis types a PCB undergoes for testing. Following are the different types of analysis which are carried out on a PCB.

- Static linear structural analysis
- Deflection analysis
- Static nonlinear analysis
- Natural frequencies
- Lower frequency analysis
- Higher frequency analysis
- Random vibration analysis
- Shock/Impact analysis
- Thermal conductive analysis
- Thermal convective analysis
- Flow pattern and heat carried away
- Drop test analysis
- Electromagnetic analysis

2. Literature Review

2.1 PCB materials

There are total twenty-four different materials such as copper, zinc, aluminum, FR4, steel, etc. that are used in PCB assembly. [6] Thus it is very difficult to apply material properties to each & every component or bonded assembly. The PCB is modeled as isotropic plate with equivalent material properties such as Youngs modulus, Poisson's ratio and mass density. [1]

The PCB is considered as one homogeneous material. Following are its isotropic material properties.

Property	Value
Density	1.5 gm/cm3
Youngs Modulus	24 GPA
Poisson's ratio	0.13
Tensile strength	310 MPA

Table 1. Shows the isentropic material properties of PCB

3.2 PCB manufacturing process

The post process works before manufacturing a PCB is deciding the routing diagram. Once the routing is finalized, the design is sent for manufacturing. The routing diagram is first imprinted on a thin layer of copper which is mounted on FR4. The material apart from route is removed from the copper plate. To support the copper route, prepreg is added to the remaining part. The topmost and the bottom most part is covered with mask.

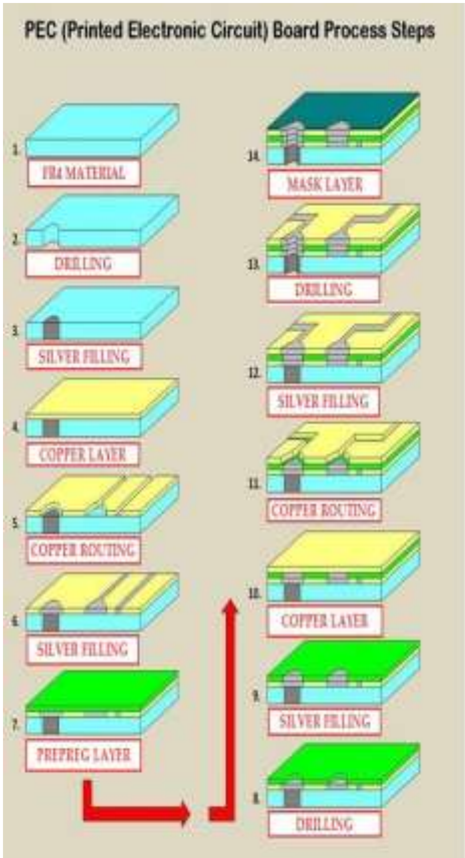


Figure 1. Shows the different steps involved in manufacturing of PCB

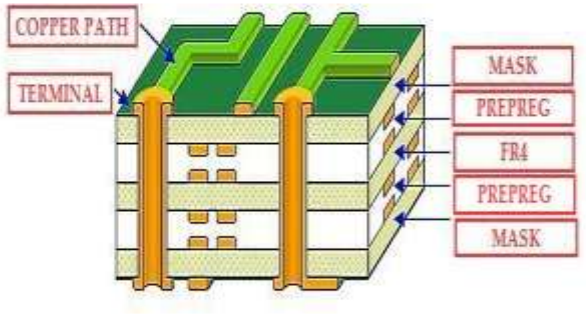


Figure 2. Cross sectional view of PCB

Once the board is raw board is manufactured, the auxiliary devices such as resistors, transistors, etc are soldered. Units such as processors, integrated circuits are plugged in. The board is then sent for testing.

2.3 Different components and their functionality used in PCB: -

- Capacitors - A capacitor is a passive two-terminal electronic component that stores potential energy in an electric field. The effect of a capacitor is known as capacitance. Capacitor consists of semiconductor material surrounded by ceramic. Few capacitors have electrolyte encased in as per application. The weight of the capacitors ranges from 50mg to 500mg.
- Inductors – An Inductor is a passive device that stores energy in its Magnetic Field and returns energy to the circuit whenever required. They are made up of miniature coils embedded in plastic or ceramic. Their weight ranges from 20mg to 200mg.
- Transistors - A transistor is a semiconductor device used to amplify or switch electronic signals and electrical power. It is composed of semiconductor material usually with at least three terminals for connection to an external circuit. The most important material silicon and it is covered in high density plastic. They weight from 50mg to 10gm
- Resistor - A resistor is a passive two-terminal electrical component that implements electrical resistance as a circuit element. In electronic circuits, resistors are used to reduce current flow, adjust signal levels, to divide voltages, bias active elements, and terminate transmission lines, among other uses. They are made from carbon wrapped in ceramic. They weigh from 10mg to 200mg.
- Diodes - A diode is a two-terminal electronic component that conducts current primarily in one direction; it has low resistance in one direction, and high resistance in the other. Silicon is used to make diodes. They from 10mg to 200 mg.
- Radio Frequency devices - Radio frequency refers to an oscillation rate of an alternating electric current or voltage or of a magnetic, electric or electromagnetic field or mechanical system in the frequency range from around

twenty thousand times per second to around three hundred billion times per second. They are a set of small units such as capacitors, resistors, etc. They weigh from 10gm to 100 gm

- Integrated Circuits - An integrated circuit or monolithic integrated circuit is a set of electronic circuits on one small flat piece of semiconductor material, normally silicon. They weigh from 50mg to 2 gm.
- Processors - A processor is the logic circuitry that responds to and processes the basic instructions that drive a computer. The four primary functions of a processor are finding, decode, execute and writeback. They weigh from 90 gm to 300gm.

2.4 Simulation techniques

The most important module of simulation is post processing which involves geometry preparation, meshing and boundary conditions. There are various constraints for PCB simulation such as material, supports, thickness, etc. These parameters have an impact on the mode results of the PCB.

A] M. Mary Thraza, Somashekar V N, Modelling and simulation of effect of component stiffness on Dynamic behavior of Printed Circuit Board, Volume 118 No. 17 2018, 75-89, January 5, 2018. [1]

In certain studies, the PCB is simulated to two ways, one assuming a bare PCB without its components and the other condition is by taking its component weight.

The vibration analysis of a typical PCB mounted with a component is carried out using two different approaches: detailed component modelling approach and local smearing approach. For local smearing approach, the effect of the component stiffness to the PCB is calculated in terms of stiffness coefficients of the PCB based on static analysis. The results of detailed modelling approach and the local smearing approach are matching well for the natural frequencies. Hence local smearing approach is appropriate for determination of natural frequencies, since detailed component modelling approach is time consuming. Detailed component modelling approach is required for determination of stresses/strains for the component or at the PCB-component interface. The maximum stresses and strains at PCB-terminal interface occur for the outer terminals of the component. [1]

B] Banu Aytekin, Vibration Analysis of PCBs and Electronic Components, April 2008.

Effect of design and mounting of the electronic box is investigated. Importance of box rigidity in terms of vibration transmission to the PCB is observed. The effects of cover in electronic box design are examined and the effect of cover mounting on the dynamics of the system is presented. It is observed that vibration of front cover may affect PCB indirectly by lead wires of the connector. [3]

One of the most important issues in finite element modeling of printed circuit boards is defining boundary conditions. The identification of PCB edge condition is very critical to have a reliable solution. Another important issue about PCB vibrations is component addition. Depending on vibration modes of a PCB, the location of component may affect the dynamics of the PCB. Especially, addition of large and heavy components may alter the dynamics, and therefore such cases should be analyzed in detail. Finite element solutions showed that attaching a component on a PCB decreases natural frequency and increases stiffness of the board in that region. Also, it is observed that small components may have very little effect on PCB dynamics depending on their location. Therefore, they can be ignored which results in simplification in modeling.

C] Ren Guoquan, Li Ben, Li Dongwei, Jiao Yingqi, Modal Analysis of the Printed Circuit Board Based on Finite Element Method.

The thickness of the plate plays a significant effect on the dynamic response of the PCB. The thickness of the plate is decided depending upon the functions that it has to carry out

Each order natural frequency of PCB thickness increases with the increasing of the plate, and with higher order time, frequency increases, the more obvious. Would be based on this, by increasing the thickness of the circuit board to improve its natural frequency, to ensure the reliability of electronic equipment. In addition, also can through the circuit boards to other metal materials, to improve the natural frequency, by increasing the stiffness is limited by space, should not be discussed here [3].

2.5 Few applications of PCB

- Used in computers
- Medical devices
- Used in automated machineries
- Consumer electronics
- Used in cell phone and communication systems
- Used in defence systems
- Aerospace applications

3. Methodology

3.1 Geometry preparation

There are total six layers of copper hence called six-layer PCB. Each copper layer is sandwiched between FR4 material. FR4 materials acts as an insulator. Thus, the PCB is made is total 6 layers. The thickness of copper layer ranges from 0.035-0.04 mm. The thickness of FR4 material ranges from 0.4-0.45 mm. The thickness of Prepreg and mask material ranges from 0.02-0.021 mm. Considering all the thirteen layers the total length of the PCB 62.5 mm. The geometry is modelled in solidworks.

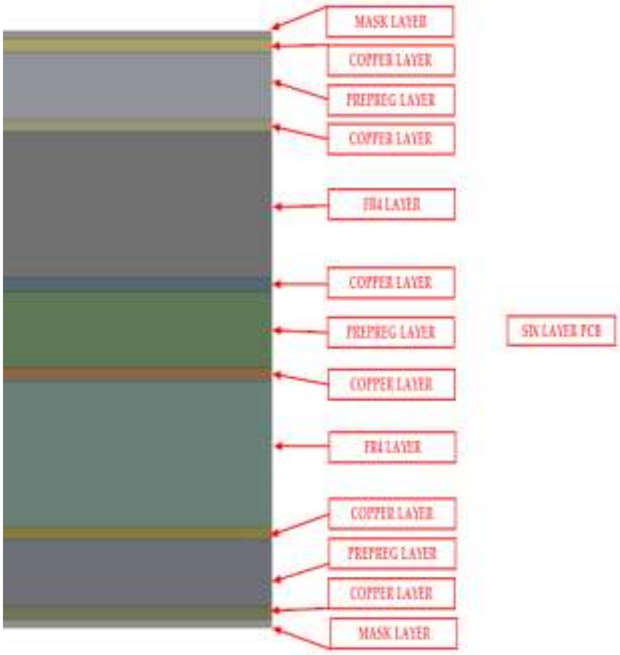
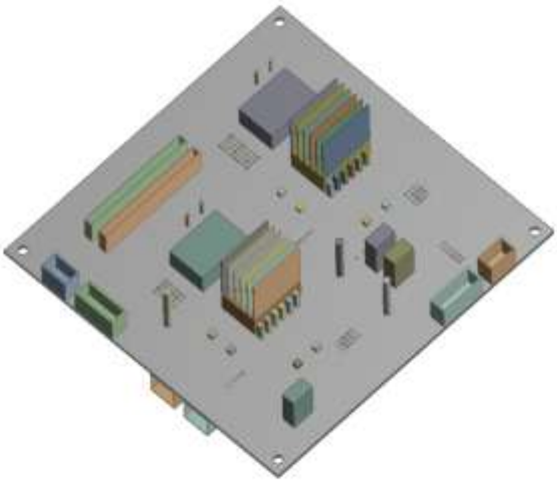


Figure 3. Shows the different layers of PCB

<u>Considering two different geometries as per our study. One of the geometries has holes to support on bolts and the other geometry is supported by two sides of PCB</u>

<u>Geometry 1 – With holes for mounting</u>



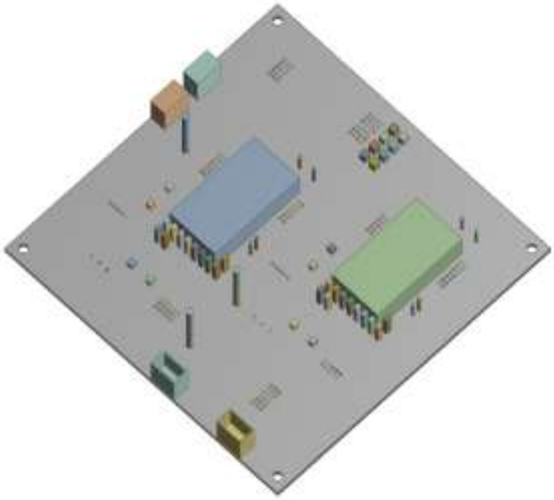


Figure 4. First geometry with holes for mounting

<u>Geometry 2 – Mounted by two sides</u>

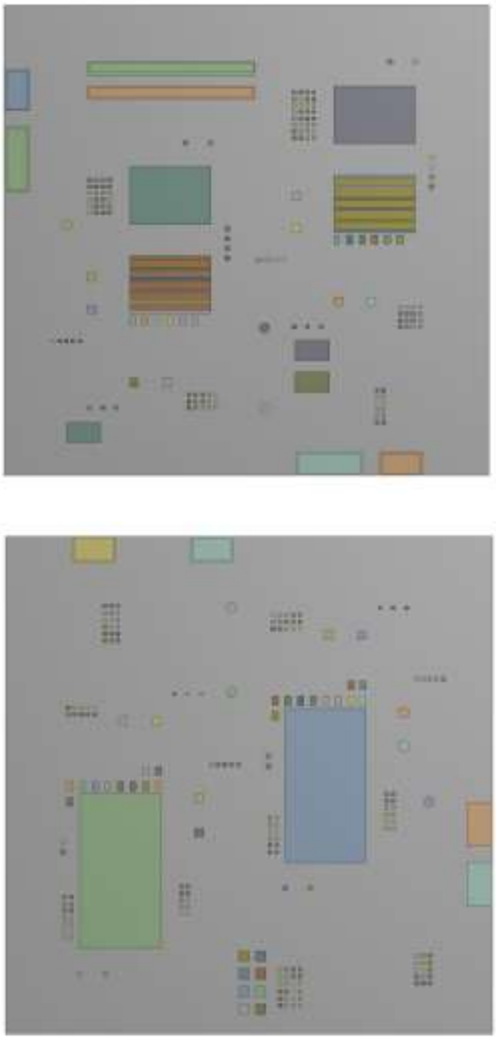


Figure 5. Second geometry without holes

3.2 Mesh model

After the model is prepared, it needs to be meshed. Meshing involves breaking the entity into small elements. The solver solves the equations of the element thereby giving the stress and deflection plots using shape function algorithm.

Thus, meshing is an important process in any simulation technique. Different techniques such as sizing and adaptive controls are used for refinement in meshing. Used solid elements for 3D objects and shell elements for surface objects

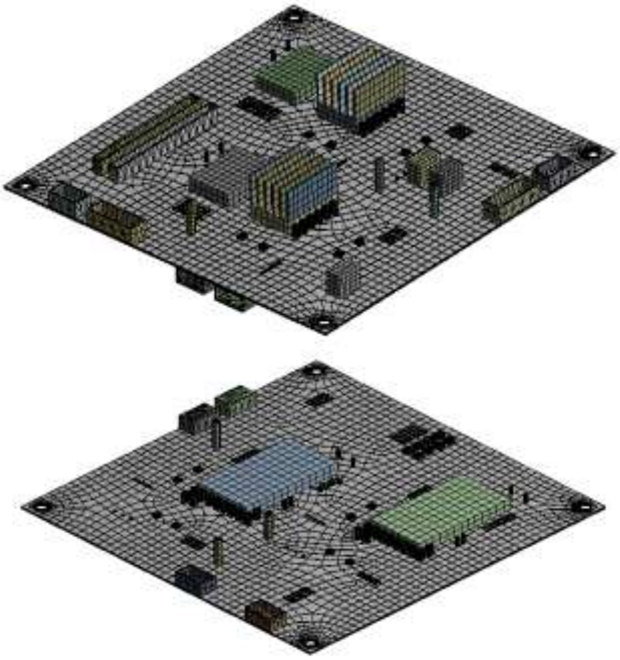
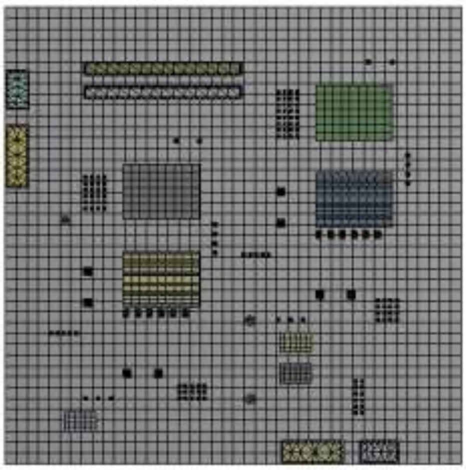


Figure 6. Shows 3D meshed model of first geometry



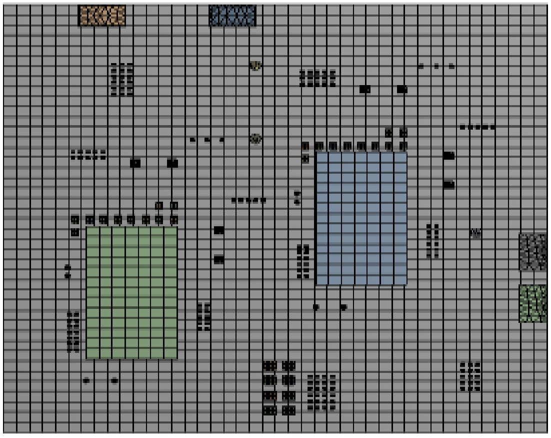


Figure 7. Shows top & bottom meshed model of second geometry

<u>We are considering two different support conditions with two different models and three mesh models for each support condition. Calculating the percentage changes in the models and then performing dynamic modal analysis on them.</u>

Case 1 – Elements – 113779, Nodes - 262728

Case 2 – Elements – 116923, Nodes - 274653

Case 3 – Elements – 123396, Nodes – 291350

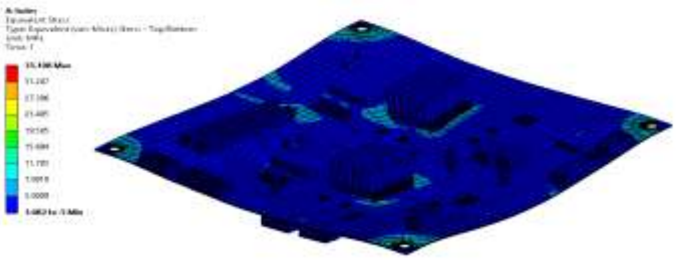
3.3 Static linear structural analysis

Static linear analysis deals with the analysis of the PCB in static condition. In such type of analysis, the structural stability of the board is studied. The PCB board is made of copper routings sandwiched between FR4 layer. Fixed supports are added as per the physical condition. Weight of each component and the self-weight of the board is taken for static calculations. In case of multilayer of larger boards, additional supports are provided in the PCB. Supports such as bolted connection or fixture support at sided might be provided. Simulation is carried out in ANSYS 18.1 version

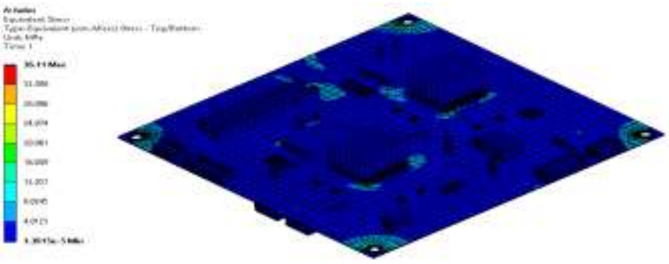
Static analysis of the component mounted on PCB is carried out to determine the contribution of component stiffness to the PCB. The effect of the component stiffness to the PCB is calculated in terms of stiffness coefficients of the PCB based on this analysis. [1] The first geometry is PCB fixed at four corners using bolts and the second one is PCB fixed at two sides. The loads considered are the dead weight of the layers and live loads of the components pinned on the PCB.

4.3.1 Stresses on PCB fixed at hole region

1) Case 1



2) Case 2



3) Case 3

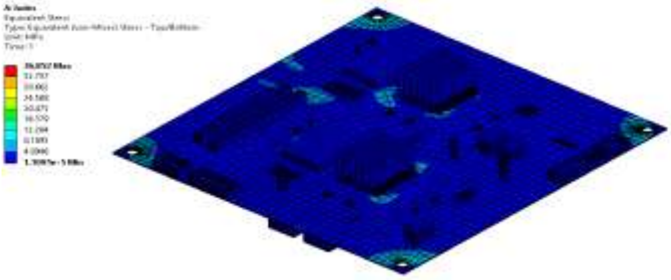
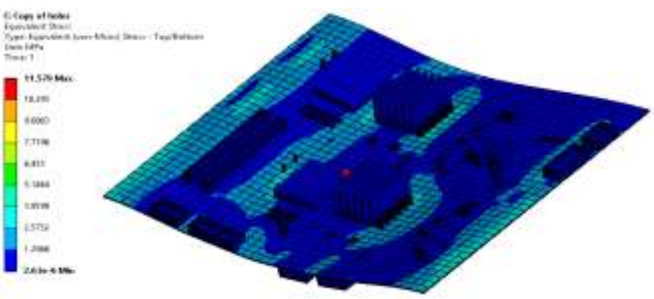


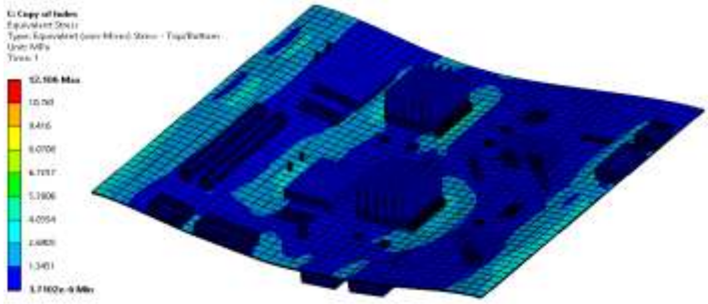
Figure 8. Shows stress values of first geometry

4.3.2 Stresses on PCB fixed at two sides

1) Case 1



2) Case 2



3) Case 3

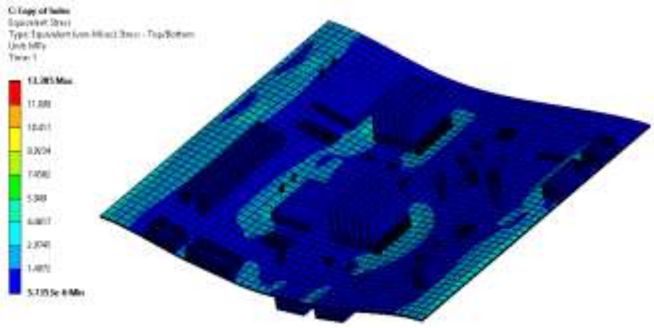


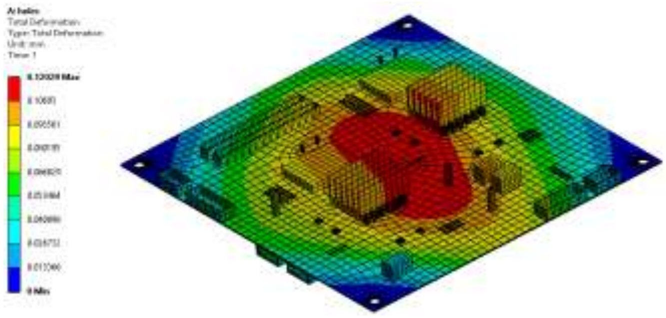
Figure 9. Shows stress values of second geometry

4.3.3 Static deflection analysis

This analysis is used to check the deflection caused due to self and live weights on the PCB. In this analysis the PCB is checked for the nonlinear function. The major materials used in PCB design are non-ferrous, thus the board needs to be sturdy and can move to nonlinear/ plastic zone.

4.3.4 Static deflection analysis fixed at hole region

1) Case 1



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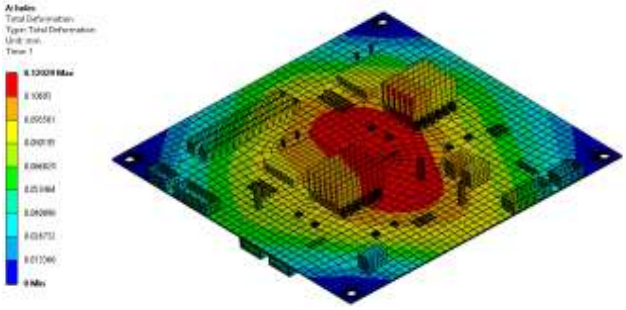
2) Case 2



3) Case 3

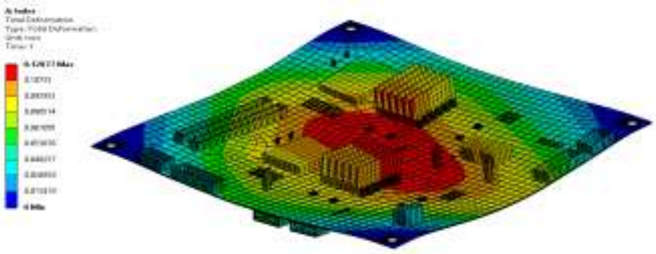
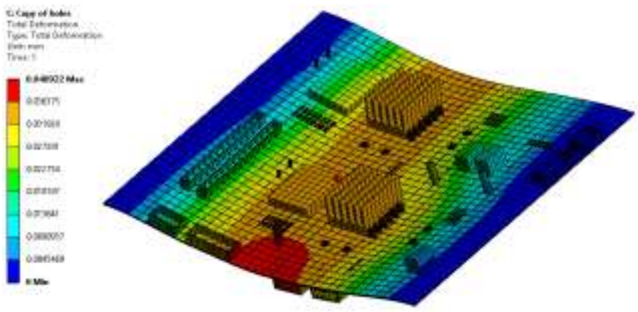


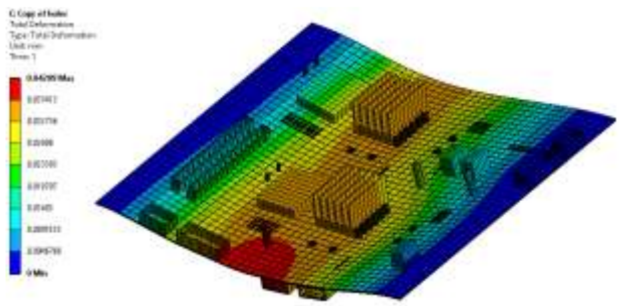
Figure 10. Shows deflection values of first geometry

4.3.5 Static deflection analysis fixed at two edges

1) Case 1



2) Case 2



3) Case 3

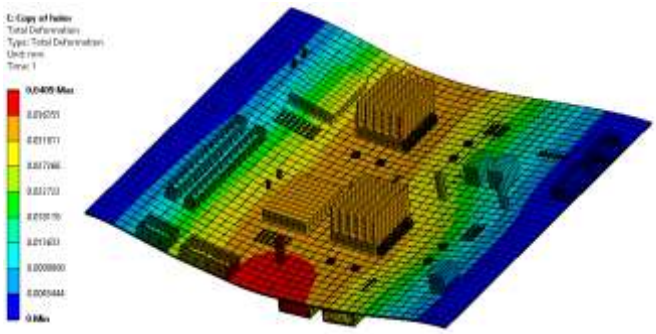


Figure 11. Shows deflection values of second geometry

PCB with fixture at hole region			Case 2 to Case 1 percentage change		Case 3 to Case 2 percentage change
	Case 1	Case 2		Case 3	
Stress	35.108	36.11	2.8 %	36.852	1.9 %
Deflection	0.12	0.12	0	0.12	0

Table 2. Shows percentage change in stress

As per the simulation results, the incremental cases have very less percentage change in error and thus it can be taken forward for further simulations.

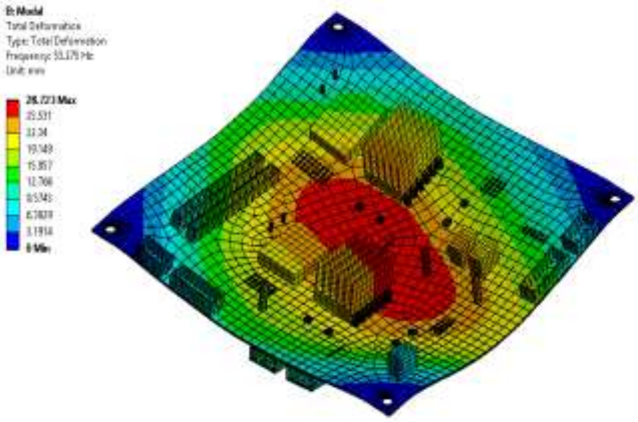
4.4 Natural frequencies

This is the most widely used analysis in PCB testing. Determining the natural frequencies in very important in all applications. Each and every unit has its own natural frequencies. This this analysis helps to determine the mode shape as per each natural frequency.

In few applications there are various auxiliary units installed within the vicinity of the PCB. Some of these applications produce vibrations. Thus, determining natural frequencies of the PCB helps to check for clashing of frequencies which reduces the percentage of damage due to vibrations.

4.4.1 Case one, entity with hole region fixed

1) Mode 1



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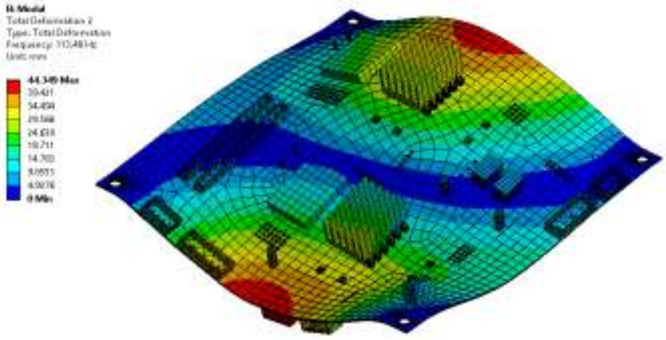
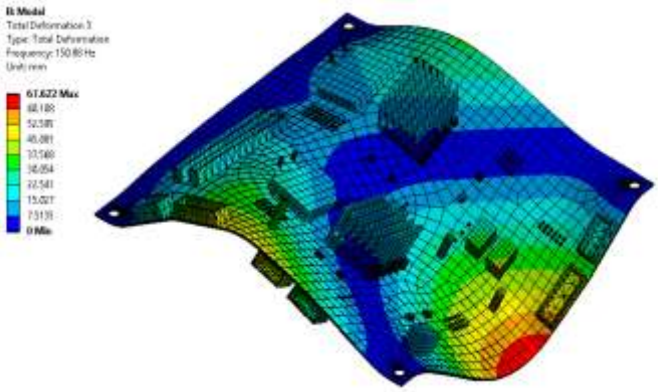
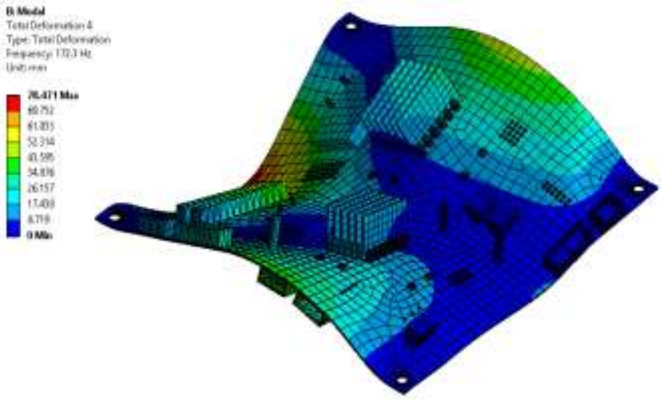


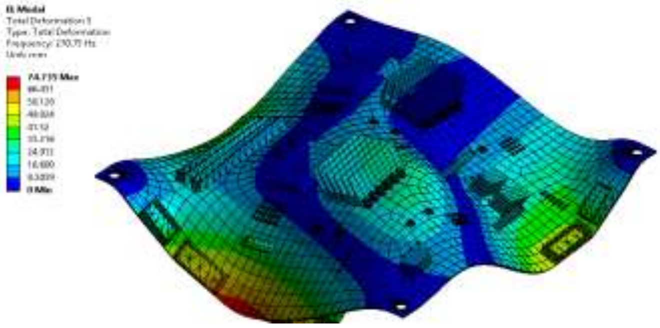
3) Mode 3



4) Mode 4



5) Mode 5



6) Mode 6

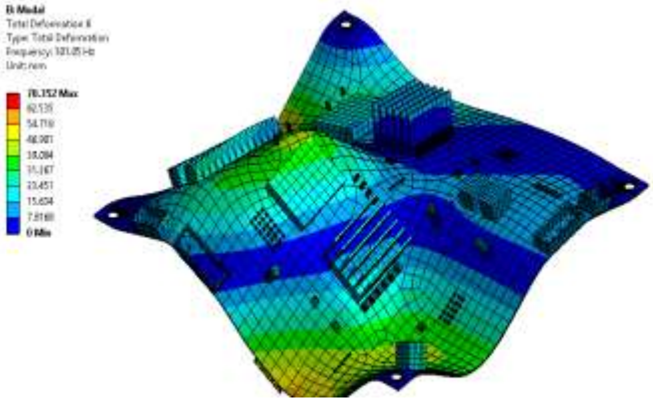
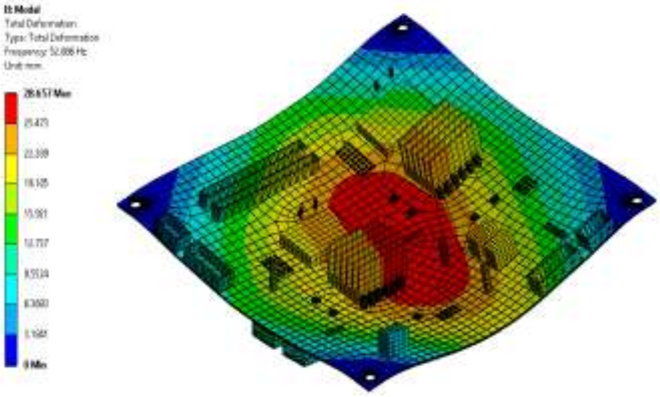


Figure 12. Shows modal values of first geometry case 1

4.4.2 Case two, entity with hole region fixed

1) Mode 1



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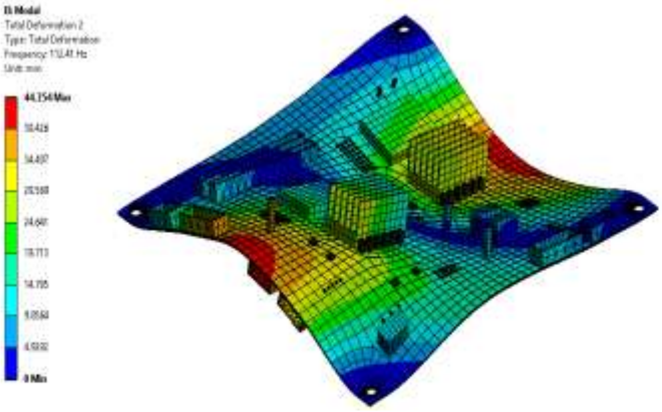

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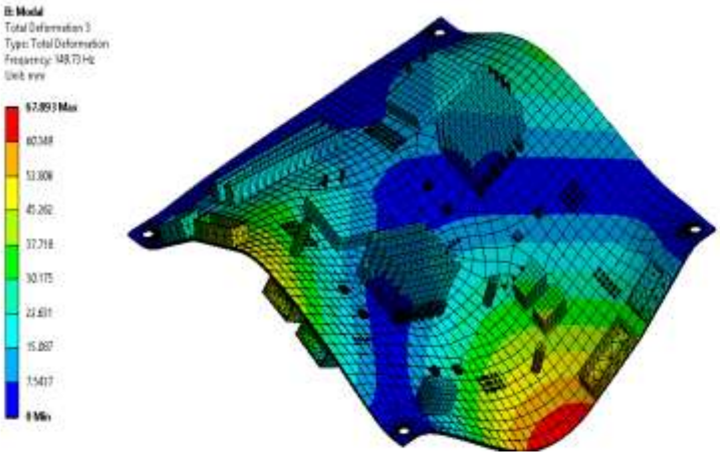
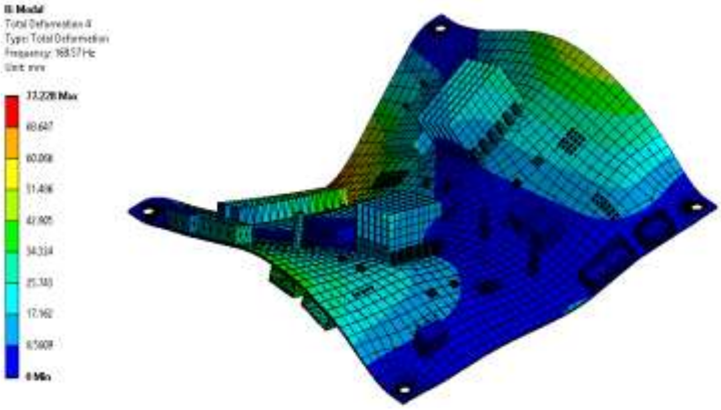


4) Mode 4



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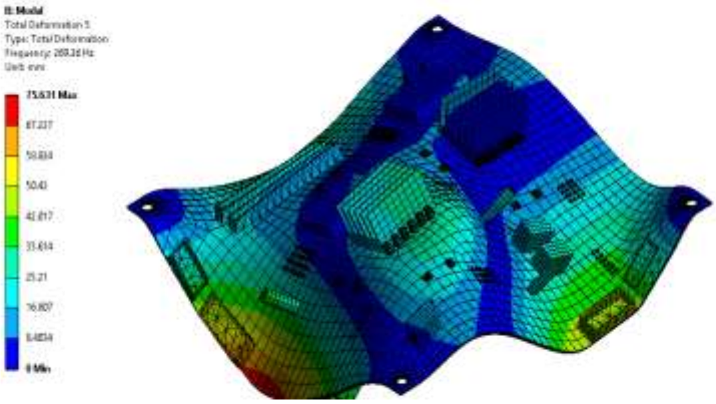


6) Mode 6

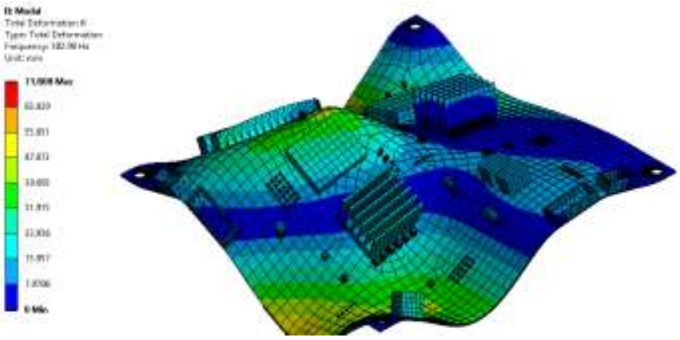
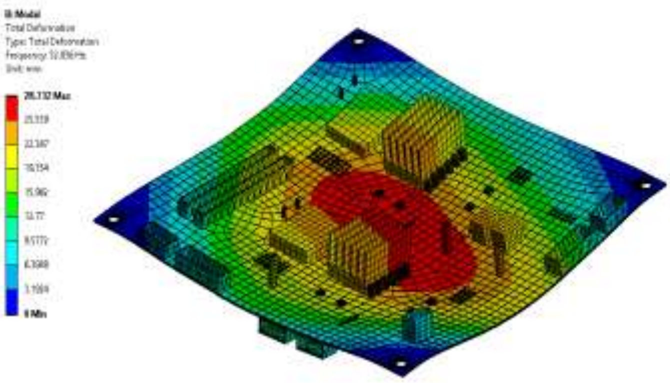


Figure 13. Shows modal values of first geometry case 2

4.4.3 Case three with entity with hole region fixed

1) Mode 1



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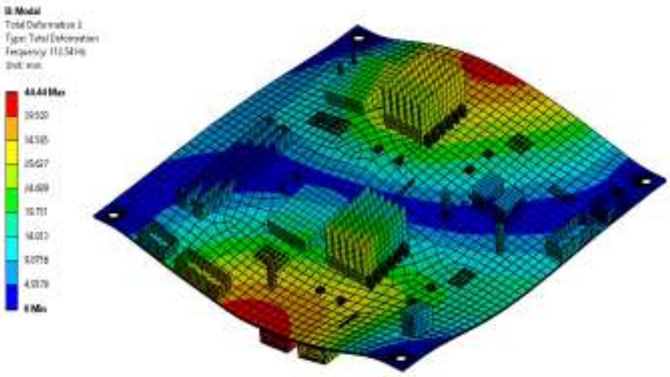
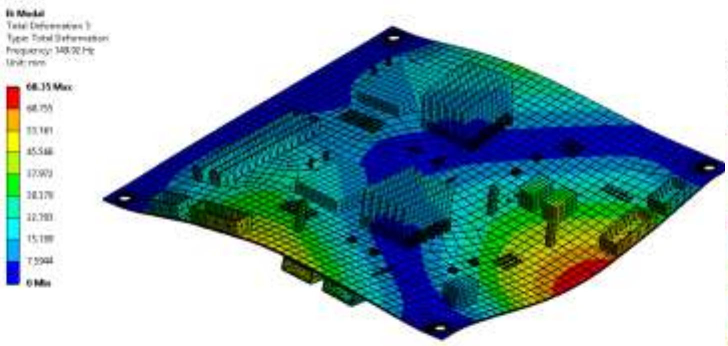
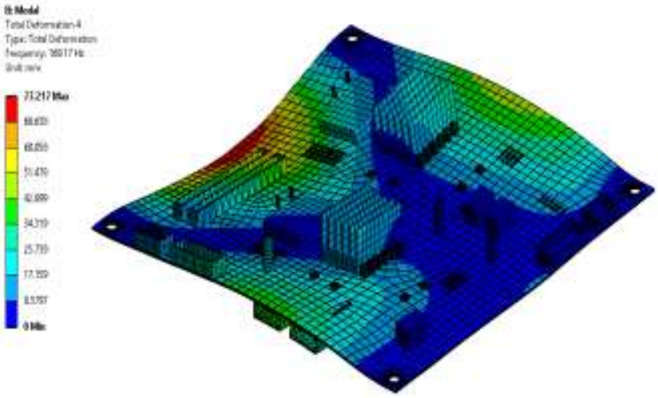


3) Mode 3



4) Mode 4



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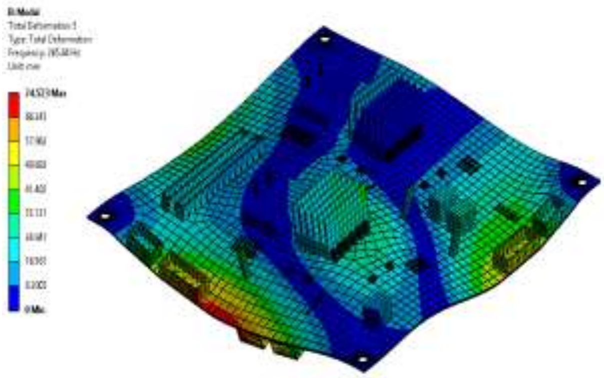


6) Mode 6

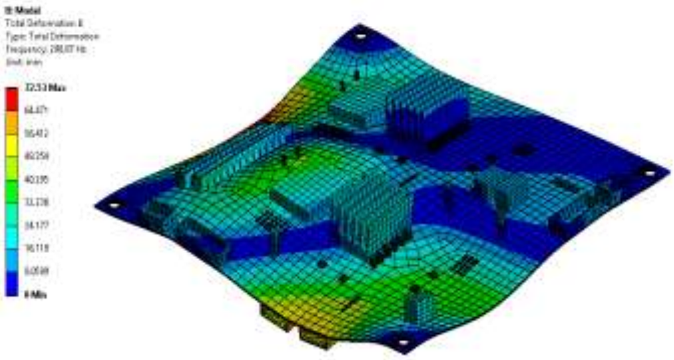
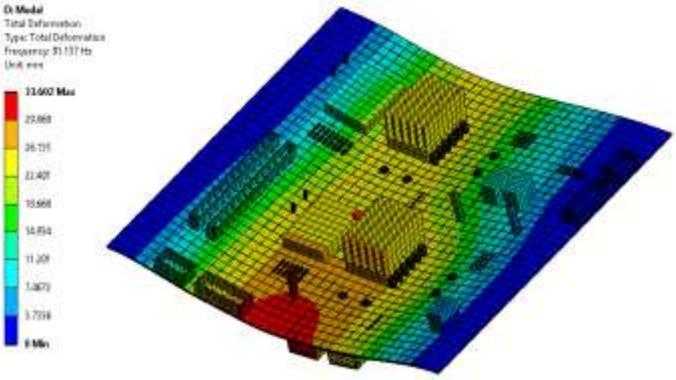


Figure 14. Shows modal values of first geometry case 3

4.4.4 Case one with entity fixed at both sides

1) Mode 1



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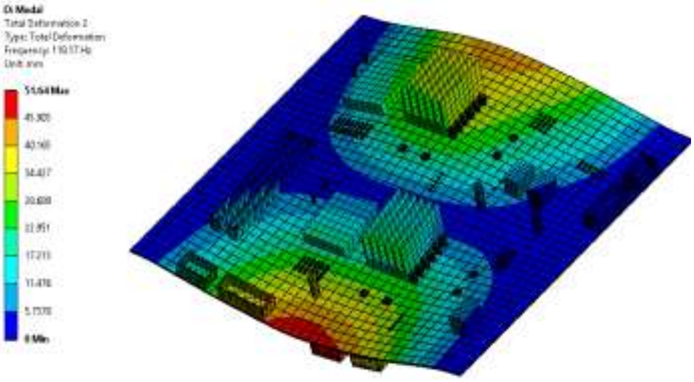
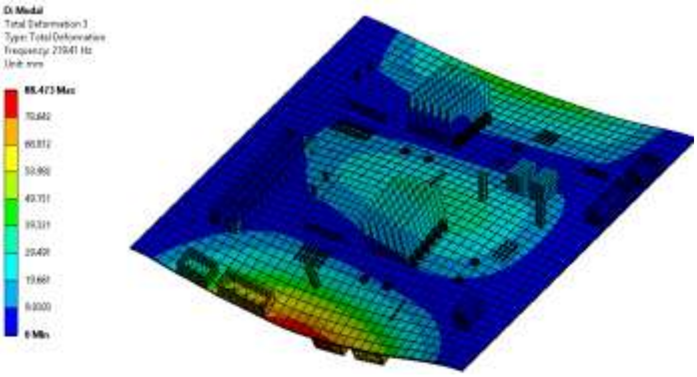
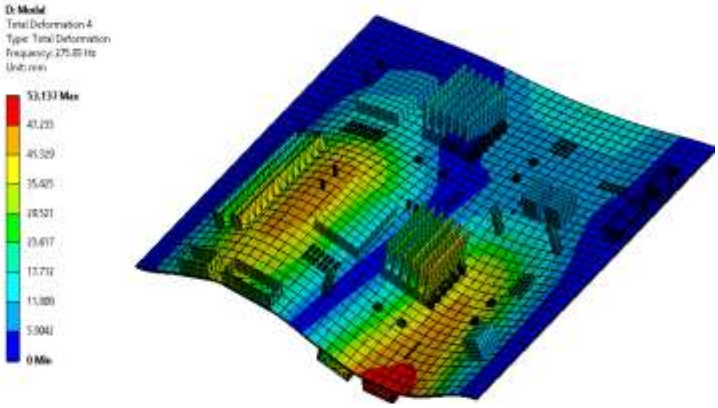


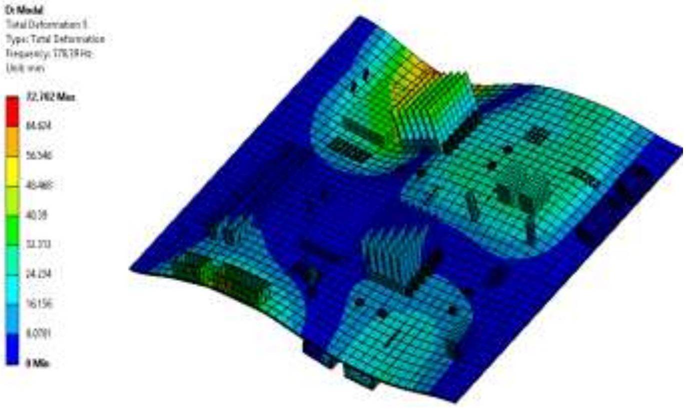
3) Mode 3



4) Mode 4



5) Mode 5



6) Mode 6

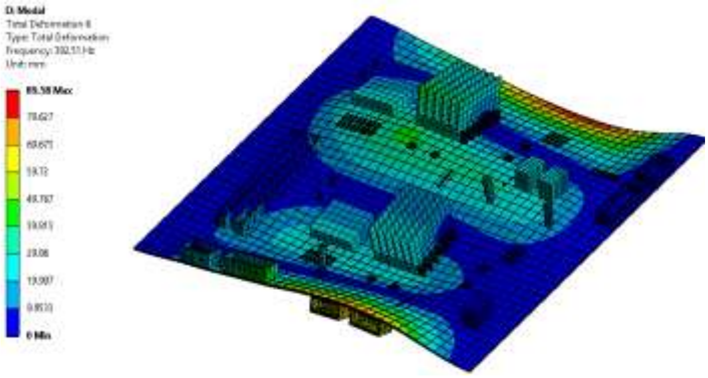
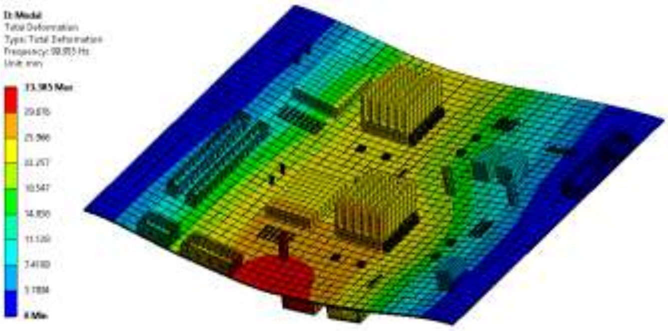


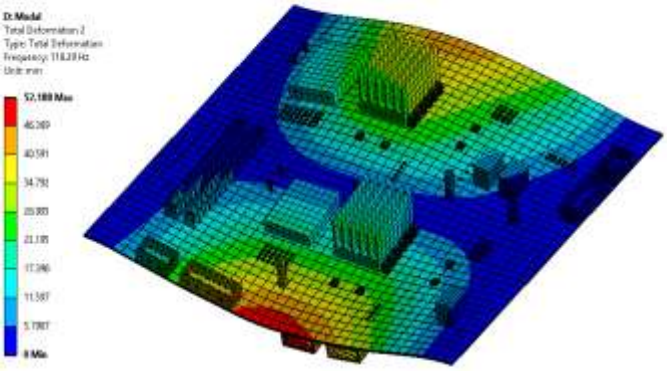
Figure 15. Shows modal values of second geometry case 1

4.4.5 Case two with entity fixed at both sides

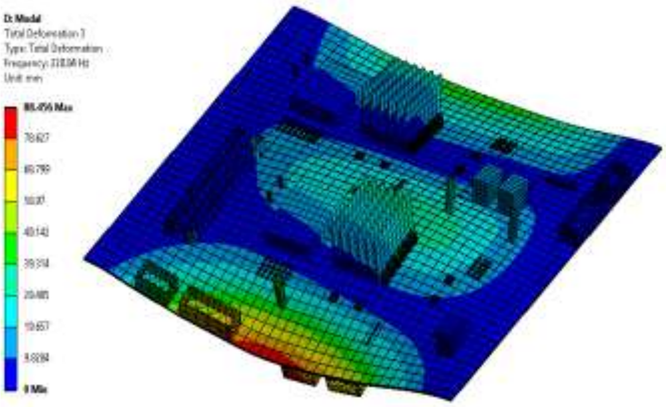
1) Mode 1



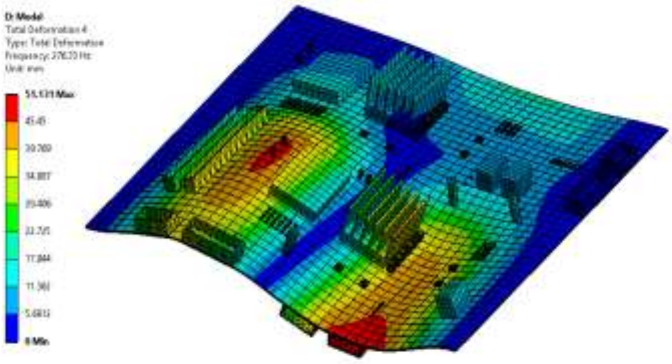
2) Mode 2



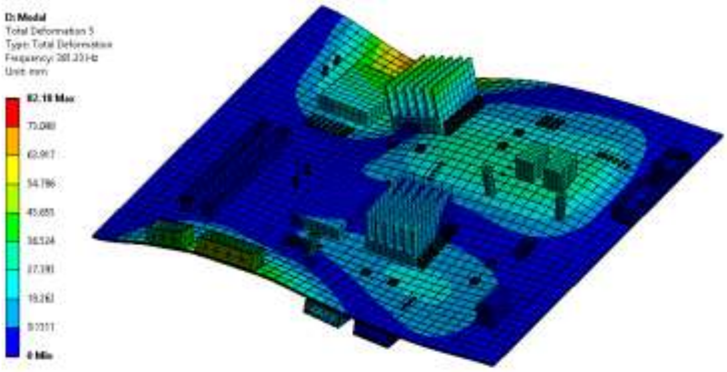
3) Mode 3



4) Mode 4



5) Mode 5



6) Mode 6

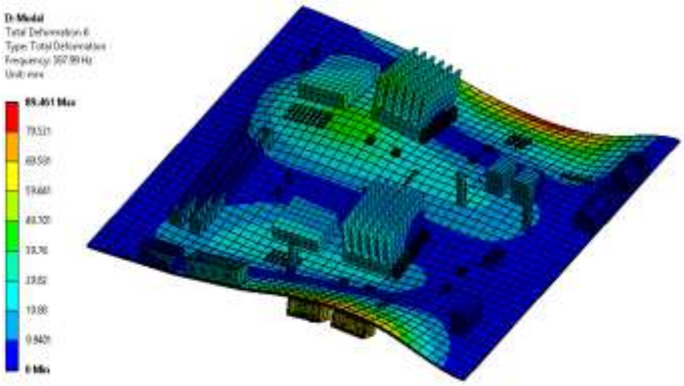
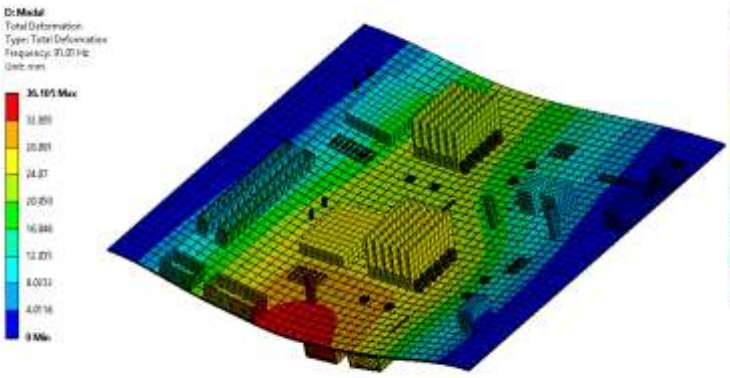


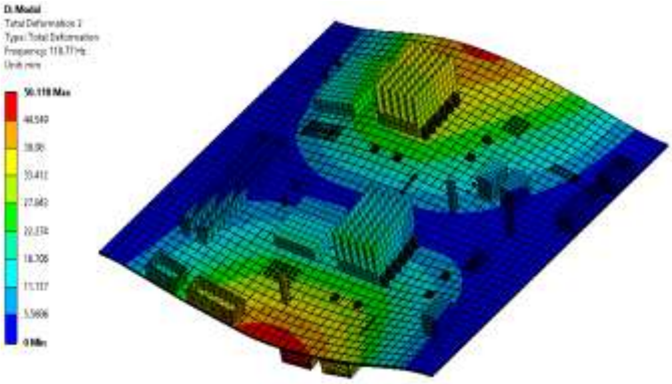
Figure 16. Shows modal values of second geometry case 2

4.4.6 Case three with entity fixed at both sides

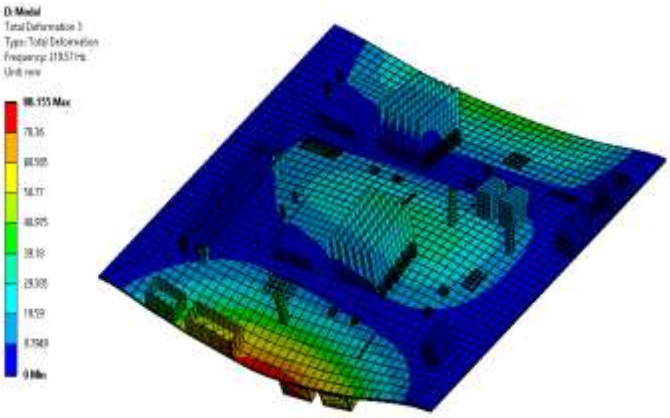
1) Mode 1



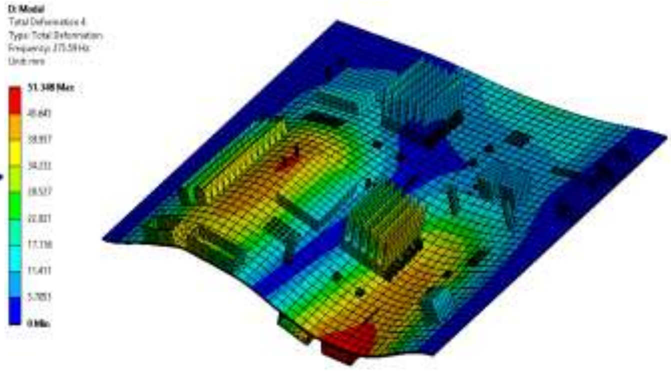
2) Mode 2



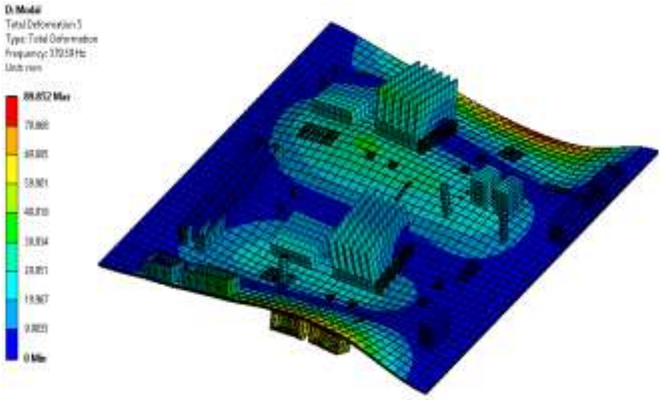
3) Mode 3



4) Mode 4



5) Mode 5



6) Mode 6

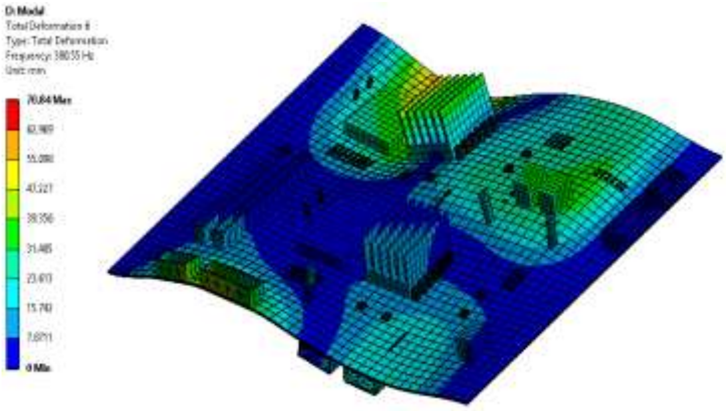


Figure 17. Shows modal values of second geometry case 3

5. Results and conclusion

5.1 Results

PCB with fixture at hole region			
	Case 1	Case 2	Case 3
Stress	35.108	36.11	36.852
Deflection	0.12	0.12	0.12
Mode 1			
Frequency (Hz)	53.275	52.866	52.836
Deflection (mm)	28.723	28.657	28.732
Mode 2			
Frequency (Hz)	113.48	112.41	112.54
Deflection (mm)	44.349	44.354	44.44
Mode 3			
Frequency (Hz)	150.88	149.73	149.92
Deflection (mm)	67.622	67.89	68.35
Mode 4			
Frequency (Hz)	172.3	169.57	169.17
Deflection (mm)	78.471	77.228	77.217
Mode 5			
Frequency (Hz)	270.75	269.26	265.44
Deflection (mm)	74.735	75.631	74.523
Mode 6			
Frequency (Hz)	301	302.98	298.87
Deflection (mm)	70.352	71.808	72.53

PCB with 2 sides fixed			
	Case 1	Case 2	Case 3
Stress	11.579	12.106	13.385
Deflection	0.04	0.04	0.04
Mode 1			
Frequency (Hz)	91.137	90.955	91.01
Deflection (mm)	33.602	33.385	36.105
Mode 2			
Frequency (Hz)	118.17	118.29	118.77
Deflection (mm)	51.64	52.188	50.118
Mode 3			
Frequency (Hz)	219.41	220.84	219.57
Deflection (mm)	88.473	88.456	88.155
Mode 4			
Frequency (Hz)	275.93	276.33	273.59
Deflection (mm)	53.137	51.131	51.348
Mode 5			
Frequency (Hz)	378.39	381.23	379.59
Deflection (mm)	72.7	82.18	89.85
Mode 6			
Frequency (Hz)	382.51	387.99	380.55
Deflection (mm)	89.58	89.461	70.84

Table 3. Shows results of analysis

5.2 Conclusions

For this study, two different PCB geometries have been taken. One geometry has four holes and is fixed at the hole region. The other geometry is fixed at two sides. Both of the models are simulated with same boundary conditions.

The stress values for the second geometry is lower than the first one. The natural frequency values of first PCB start with 58.275 Hz whereas the modal values of second PCB starts with 91.137 Hz. Thus, the model with two sides fixed has better load bearing capabilities for dynamic response. Also, the stress values are very less in magnitude compared to the yield point of the material (310 MPA). The area with maximum deflection during modal study is less in second geometry as compared to the first one.

From the above study we can conclude that the geometry with 2-sided fixed support has better static and dynamic load bearing capacities.

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