ROBUST MODELLING AND EXPERIMENTAL VALIDATION OF ELECTRONIC PACKAGES IN RANDOM VIBRATION PERSPECTIVE

Submitted in partial fulfilment of the requirements for the award of the degree of

DOCTOR OF PHILOSOPHY
in
Mechanical Engineering

by

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NATIONAL INSTITUTE OF TECHNOLOGY
WARANGAL–506004
2018

Thesis Approval Sheet

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CERTIFICATE

This is to certify that the thesis, entitled **"ROBUST MODELLING AND EXPERIMENTAL VALIDATION OF ELECTRONIC PACKAGES IN RANDOM VIBRATION PERSPECTIVE"** submitted by **JAGADISAN KRISHNAMOORTHY (Roll No: 701243)** to **Department of Mechanical Engineering, National Institute Of Technology (Deemed University) Warangal 506 004,** for the award of the degree of **DOCTOR OF PHILOSOPHY** is the bonafide record of research carried out by him under our supervision. The contents of thesis in full or in parts have not been submitted to any other University or Institute for the award of any degree or diploma.

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DECLARATION

This is to certify that the work presented in the thesis entitled "**ROBUST MODELLING AND EXPERIMENTAL VALIDATION OF ELECTRONIC PACKAGES IN RANDOM VIBRATION PERSPECTIVE**" is a bonafide work done by me under the supervision of Dr. P. Bangaru Babu, Professor Mechanical Department and was not submitted elsewhere for the award of any degree. I declare that this written submission represents my ideas in my own words and where others' ideas or words have not been included. I have adequately cited and referred the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/sources in my submission. I undertake that any violation of the above will be a cause for disciplinary action by the institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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DEDICATION

I wish to dedicate this dissertation to my beloved father Mr. K R Krishnamoorthy (Late) and my beloved mother Mrs. K Rajalakshmi and offer this work at the lotus feet of the Universal Spirit.

ACKNOWLEDGEMENTS

It is said, that if strong thoughts about doing something is seeded in the mind, the Universe would conjure to give effect to that thought. Hence, it would only be right to tell the world, the factors that lead to the seeding of the thought and the facilitating factors that brought me to the situation of being able to write my doctoral dissertation.

The greatest of motivation factors for the thought to be seeded began at my home where, my Parents desired that I should continue in Pursuit of Knowledge (Academic or otherwise) no matter what age I was in. In fact, I registered for PhD at an age of 54 years. My family consisting of my wife (a teacher), my two children (a son and a daughter- both from IIT's), have all been a great source of encouragement and Moral booster. Particularly, when I was encapsulated between the official pressures and requirements of academics, and the various experiments that was needed for this work. I wish to thank my wife as she did all the proof reading and ensured that the dissertation is as perfect as possible.

I wish to thank Prof. L. Krishnanand, who was Head, Dept. of Mechanical Engineering at the time of my selection for Phd candidature, who inquired about the time left for my Superannuation and asked if I would be able to complete the work before that event. This triggered in me a sense of time consciousness thoughout the course of my work. I am extremely grateful to my entire doctoral Committee comprising of Dr. P.Bangaru Babu, Prof. and Head Dept. of Mechanical Engg., Chairman DSC, Dr.S.Srinivasa Rao, Associate Prof. Electrical and Electronics Dept., Dr. V. Hari Kumar, Asst. Prof. Dept of Mech Engg. and Dr. K. Srikanth, Asst. Prof. Mech Engg. Dept., who have been critically examining the progress of the work and have given timely advice and guidance which is responsible for enabling me to complete the project work.

My Advisor, Prof. P Bangaru Babu has been a source of great inspiration, encouragement and guidance all through the Project. Apart from being an advisor, he took on the mantle of Academic parenting and I am not just thankful to him but indebted to him.

I am grateful to Mr. P Anil Kumar, who has taught me the art of academic swimming right from teaching me the various credit courses, conducting day to day classes, helping me with various tests that have been conducted a part of the Project work in the Environmental Test facilities of Research Centre Imarat, Hyderabad and by his companionship all through.

I wish to profoundly thank my organisation Research Centre Imarat (RCI), Hyderabad (DRDO), the Director of the Laboratory, Dr. B H V S Narayana Murthy and all departments, from where I received ample encouragement & support, and for the permission that RCI has me given for doing this work.

I wish to place on record, the guidance and advice I received from my Co-supervisor Dr. P. Ramachandran, Scientist 'G', DRDL, Hyderabad.

Last, but not the least, I am grateful to all the well-wishers for their continuous and unswerving support.

Date: , 2018 Jagadisan Krishnamoorthy

ABSTRACT

Electronic packages used in aerospace are sensitive, mostly mission critical and are in the form of printed circuit boards, which populates critical components, processor, relays, switches, crystal oscillators and the like. The packages are subjected to adverse conditions like climatic and dynamic environments during their life time and are expected to perform under the adverse conditions with an extraordinary level of reliability. Among the dynamic environments, vibration is a condition under which many failures have been reported. The failures could either be due to the higher level of vibration and due to fatigue. Hence designing of electronic packages for the aerospace industry is a challenge, since any failure could lead to an irreparable catastrophic event.

There is also a challenge to be the first to introduce a technology especially in the context of taking the lead among similarly aspiring industry. This gives an edge over other competitors from many aspects. Designing for meeting desired environment, fabricating the PCB, populating the components and testing with the final package for the simulated vibration environment in a vibration test lab, could often spring surprises and could lead to failures, due to various assumptions made in the design. At this stage to go back to the design table and redo the entire process causes lot of delay in the cycle of development.

It becomes pertinent in the above context that the designer is armed with sufficient tools which could help in estimating the response of the package to the desired random vibration input.

Finite element method (FEM) could form an excellent tool towards this end. However, this method is highly sensitive to the model and the modeling approaches. It is sensitive to the mechanical properties, to the end conditions, to the type of element formulation etc. Hence it is imperative that all the variables in the modeling approaches be optimized and standardized so that the results of the FEM for the random vibration response of the package to the various input vibration are consistent and precise, so that the designer can say with a great degree of confidence that the response levels are acceptable, or he needs to change the design to meet the prevailing conditions of input vibration.

Thus, timely prediction of the vibration response on the electronic packages would give a reasonable idea about the capability of the systems to withstand the vibration inputs, without affecting the functionality. However, the degree of confidence in these predictions should be significantly high, to make this a dependable tool for decision making.

In this work, an attempt is made to address the major challenges of the modeling and consistencies in the modeling parameters. A systematic approach has been made to quantify all the properties to be used in the modeling for performing the finite element analysis. Various techniques have been studied from literature, and the technique giving better result, consistently and precisely has been adopted with suitable justification and modifications. It has also been endeavored to remove the various limitations and shortcomings in the previous research works. Real-life aerospace systems have been considered for the random vibration analysis, so that the utility of the outcome of this research is felt directly on such systems. The method has been qualified with experimental verification on many samples.

A novel approach is evolved to extract shear modulus of PCB. A method to define the rotational spring element for the PCB fixing etc. is evolved with the help of experimentation and tuning approaches. A database is established consisting of rotational stiffness and damping values for various mounting configurations of PCB and is validated with experiments as well.

The entire modelling approach has been dealt with modularly, i.e. at PCB, PCB with components, Chassis, and integrated system level. At each level the principles of the modelling have been applied and the validation was done on many samples to assess the efficacy.

It is expected that this work would be an excellent guide towards random vibration response predictions for aerospace electronic packages.

Keywords: Electronic packaging, Finite element analysis of PCB, PCB boundary conditions

CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE AND ABBREVIATION

AVF	Anti-vibration fixture
CMR	Composite modelling region
CCGA	Ceramic column grid array
DOF	Degree of freedom
DIP	Dual in line package
EMA	Experimental modal analysis
EMI/EMC	Electromagnetic interference/Electromagnetic compatibility
FEM	Finite element method
FEA	Finite element analysis
FCOB	Flip chip on board
g	Acceleration due to gravity
g_{rms}	root mean square of acceleration due to gravity
GMS	Global mass smearing
GSS	Global stiffness smearing
K	stiffness
LSS	Local stiffness smearing
MAC	Modal assurance criterion
MEMS	Micro electro mechanical systems
PBGA	Plastic ball grid array
PWB	Printed wire board
PTH	Plate through holes
SMT	Surface mount technology
UTM	Universal testing machine

CHAPTER 1

INTRODUCTION

1.1 MOTIVATION

Electronic packages for aerospace consists of sensitive systems like the navigation system, the control system, the telemetry system and are all mission critical. Failure of any system or underperformance in their functioning could cause mission failures involving huge financial losses and are also of serious safety concern.

Most critical components come with their own capabilities in terms of the vibration levels to which they can withstand and perform functionally without any deterioration. These are known as the qualifying limits of the component. Such limits for typical electronic components (In terms of g_{rms}) are given in Appendix-'I'.

When the vibration levels in the PCB's exceed these qualifying limits there is failure of the subsystem. Hence packaging the system which includes the PCB (With various components mounted on them) mounted on a chassis, the various inter connecting cables and connectors needs to be such that for the vibration inputs the package is likely to get during its operation, the responses are below the qualifying limits of the components.

Hence if the designer is armed with a tool which could accurately predict these levels he could ascertain the margins available and establish the reliability of the designed system. If required suitable modifications and ruggedization can be made at the design stage itself.

For the tools of FEM to be effectively guiding the designer, precise modelling at each level of the package viz, PCB, components on PCB, interconnectivity, mounting on chassis, chassis mounting in the airborne vehicle, is essential, for the FEM to be able to do justice and give out the correct responses to the input vibration.

Extensive literature survey carried out in this particular context indicates that research carried out so far is confined to the extent of individual component modelling only. Literature does not speak about the holistic modelling approach for an electronic package as a whole giving considerations to all subsystems down to solder pin level. Lack of information about modeling practice for electronic packages is the reason behind many assumptions being resorted to during FE modeling. Electronic packaging engineer needs to understand thoroughly whether a particular subsystem gives stiffness influence or mass influence before framing the model, as the modeling approach needs to be different for each of these. Improper consideration of these two factors (Stiffness and mass influence) may yield erroneous judgements about the design and further makes the model unsuitable to carry out structural modification studies in order to provide solution for high vibration responses if necessary. These problems negatively impacting, the correct assessment of accurate vibration responses using finite element analysis is the main inspiration in carrying out this profound study. The current research is motivated by the organization goal of devising a precise modelling practice for evaluating the design adequacy of PCB in random vibration environment with finer degree of accuracy and a greater degree of confidence.

1.2 OBJECTIVES

The objectives of the present research work is to develop a robust and precise modeling approach for electronic packages for air borne vehicles with the aid of experimental tools available. The following sequential steps were followed in the development of the precise model.

(a) The first step to achieve this objective is to understand the behaviour of different packaging configurations considered, implementing the limited information available using FEM.

(b) The second step is to develop a PCB level modeling methodology. The methodology identified from literature is taken as a reference and further extended for different mounting configurations of the PCB by fine tuning the modeling parameters i.e., rotational stiffness for the spring elements, types of mounting methods and number of mounting configurations involved. The deviations observed in the manufacturer specified material properties to the actual properties took the study a step ahead in deriving the material properties for the PCB through various experiments. Developed dynamic models are validated by comparing vibration responses and frequencies calculated from the analytical results with experiments. Further, to support the analysis performed, consistency studies will also be carried out to gain confidence in the obtained results.

(c) The third step is to spin out the simulation studies with the validated PCB modeling approach extending to Component level. The simulation studies are also carried out for three cases (Three different component population schemes) with regards to variations in different component modeling approaches identified from literature and further extending the study for different components and different mounting conditions.

(d) Cultivating a well-tuned model for the chassis level, by application of the steps evolved from steps ‘a’ through ‘c’ and applying certain established influences of other parameters like the number of mounting lugs etc. on the chassis.

(e) Establishing a holistic modeling approach for the whole package level and to achieve very close correlation with the experimental results. Finally establishing consistencies with the database and the principles developed from ‘a’ to ‘e’.

Thus, the scope of this research work is to:

Evolve accurate FE modeling approach for random vibration response analysis of electronic packages and validation of the same with experiment, and establishing consistencies for different packages using the same principles.

1.3 ORGANISATION OF THESIS

The thesis is organized as follows.

Chapter-1 : Deals with introduction to problem statement, information about PCBs, electronic Components, scope and layout of the project- motivation and objectives.

Chapter-2 : Deals with the literature survey on vibration analysis of printed circuit boards and electronic components and information with regard to modeling of electronic components and printed circuit board.

Chapter-3 : Deals with the constituents which makes up an electronic package and the problem definition.

Chapter-4 : Deals with the PCB level modeling and analysis, the experimental evaluation tools and accessories.

Chapter-5 : Deals with FEM analysis of PCB with single and multiple electronic components.

Chapter-6 : Deals with results and discussion related to the FE analysis at chassis level and the experimental test results and consistency checks.

Chapter-7 : Deals with the complete package level analysis, the experimenatal validation and consistency checks. It also deals with real life packages as a case study for testing the efficacy of the developed approach, summary and conclusions.

Chapter-8 : Deals with the summary and conclusions, followed by scope for future work.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

Electronic packages are meant for meeting various vital functional requirements like guidance, control, navigation,etc. in any airborne vehicle. During the course of application these packages will experience adverse environment like vibration which will influence the functionality of electronic components mounted on printed circuit boards (PCBs), which are in turn mounted in these packages. Maximum vibration response experienced by critical electronic components needs to be predicted in the design stage itself so as to ensure that it is well within limits. If the levels are not within limits, corrective action can be initiated to eradicate the possibility of failure of any electronic component at a later stage. Finite element method (FEM) is generally used as a tool to accomplish this. Closeness of vibration response predicted by FEM with that of reality will enable a proper judgment and this is dictated by the accuracy of the FE model which in turn depends on correct modeling methods. In this chapter, the published literature in the area of modeling practices for electronic packages and the research work carried out by various investigators on finite element modeling of electronic packages is presented. The learnings and their limitations are also brought out.

2.2 CONSTITUENTS OF AN ELECTRONIC PACKAGE

The basic elements of a typical electronic package are shown in Figure 2.1.

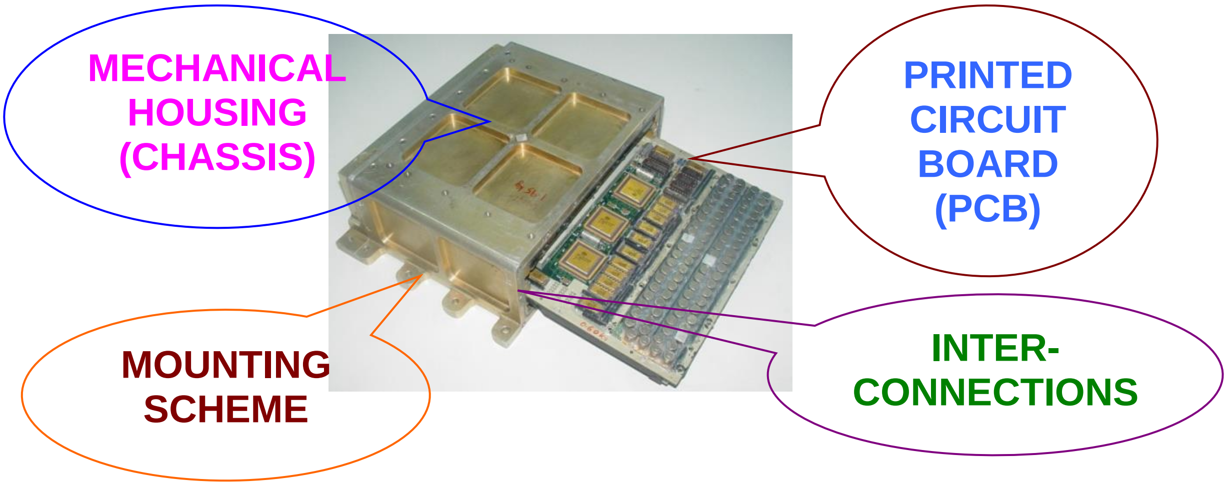


Figure 2.1 Basic elements of a typical electronic package

Levels of electronic packaging analysis can be broadly classified as follows:

- PCB level
- PCB with components
- Chassis level
- Package level

Accordingly published literature on electronic packaging analysis has been classified into four sub groups. The work carried out in each group is presented below.

2.2.1 PCB LEVEL

Numerous modeling techniques are discussed by **Pitarresi (1990)**. Smearing concept is one such technique for evaluating stiffness/mass characteristics of PCB. It is not uncommon, however, for a detailed model of a PCB to have many thousands of elements. A computer model of this size requires extensive expertise in modelling and large amounts of computer time to solve. A technique that is used to dramatically reduce the size and complexity of the model is to 'smear' or homogenize the material properties of the PCB into a representative Composite regions of the structure. However this concept calls for physical bisection of PCB, adopting the smearing, and evaluating the properties experimentally which becomes destructive evaluation and is not convenient. This is possible only after making the PCB physically available involving time and effort. Since a PCB resembles a structural plate in bending, plate bending elements are most commonly used to model the cards and modules, and beam elements for the Leads.

Plate elements were used to model PCB by **Artro (1993)** Optimization of support locations was carried out to increase the stiffness of PCB. It is stated that the frequency of PCB can vary by a factor as large as three or four depending on the location of the supports and hence becomes very sensitive to the locations of supports.

Importance of consideration of geometric nonlinearity when displacement is more than thickness is addressed by **Artro (1994).** It is also stated that frequency estimation is more sensitive to error in mass estimation than that of stiffness. But neglecting shear deformation of PCB is not justified. Further the damping considered i.e. 5% for prediction of vibration response is far from reality. The paper tries to address issues that are important while the PCB's dynamic responses are evaluated:

- How accurate could the estimates be, if they are based just on the basis of the first natural frequency.
- The importance of accounting for geometric nonlinearities when estimating the response of a PCB.
- The relative importance of errors in the mass and stiffness in the computation of the dynamic characteristics of a PC board.

Block Lanczos algorithm has been considered for carrying out modal analysis in FEM software by **Xie *et al* (2006)**. Huge mismatch in random vibration response has been noticed on high frequency side between FEM and test. There are two basic problems that need to be addressed while modeling the PCB's for a random vibration analysis. The first arises from simplification of the model. The geometrical shape of the PCB is too complicated to model it exactly. Secondly, one has to identify the stiffness and density, which are two key parameters for dynamic response analysis. Some principles were followed in order to simplify the model in ANSYS. Firstly, circle angle has been changed to the right angle. Secondly, tiny hole in the PCB has been ignored. Thirdly, the component that has bigger mass and bulk has been treated as simple, homogenous, rectangular block. Fourthly, the influence of soldering tin has been neglected.

Simplified modeling approach has been adopted for PCB by **Chen *et al* (2006)**. Discretization of the PCB is done using 2D solid elements. A meshing method called the "mapped meshing" is implemented. The paper restricts itself to estimations of the PCB's modal charachteristics alone. The modal analysis of the PCB was performed by the block Lanczos method. The eigenvalue extraction using block Lanczos method is used for large symmetric eigenvalue problems. The first four frequencies are compared with that measured by test. It can be found that the first and second modes have a bowing of the PCB. The location and the grade however, differ. The first mode's bowing is located in the middle right section and more gentle. The second mode's bowing is located in the middle left section and severe. However, the third and forth modal shapes are more complex.

Import of a solid model in to the ANSYS software often involves loss of geometry data like connectivity along the edges, and the various inter relations between the components of the model as per **Tang *et al* (2007)**. The paper describes the validation of the analysis results with the test data. The paper also describes the problems associated with modelling for a random vibration analysis, like the issues arising out of large variation in the stiffness of the bigger components and the size of the PCB itself, when compared to the minute details of the solder joints and the smaller components which result in the size of the elements becoming very large which demands a much larger computation time.

Shell elements are used to model PCB by **Lee *et al* (2008)**. Further it has been stated that mid surface modeling approach yields accurate results for PCB like structure whose thickness is much less compared to the width.

Aytekin and Ozguven (2008) uses experimental modal analysis and gets the material properties of the electronic circuit boards. Linear hexahedral solid elements were used to mesh PCB. Modal frequencies were extracted by comparing the model shapes obtained using FEM and test. PCBs can be assumed as sandwich plates. The PCB considered in the numerical case study is a 7 layered rectangular composite plate composed of copper and FR4. For a slender plate having a small thickness it would be acceptable to believe that the normal lines to the mid surface would remain normal even during the vibration. Thus, the theory applicable to homogenous plates would be applicable for these slender plates as well, with regards to the fundamental frequencies..

Two-DOF model has been proposed by **Steinberg (1988)** for vibration analysis of electronic packages. However its scope is limited to sine vibration environment only. Further formulae for evaluating the first natural frequency of PCB are presented which are useful for standard end conditions like simply supported, free-free and clamped. Methodology is discussed to estimate random vibration response of a PCB which confines its applicability to the first natural frequency only but in reality PCB will have so many natural frequencies and random vibration response needs to be estimated over the entire band.

Three point bend test set up is used to evaluate the elastic bending moduli by **Pitarresi and Primavera (1992)**. Sub structuring technique has been used for modeling PCB in FEM. Frequencies of PCB obtained using FEM are compared with that of the test. In addition, the coefficients pertaining to modal assurance criteria were also compared.

Effectiveness of smearing concept in estimating modal parameters is investigated by **Pitarresi *et al* (2002)**. Modal frequencies and mode shapes so obtained are compared with that of test. Degree of correlation is represented in the form of modal assurance criterion.

Typical motherboard of a personal computer is considered for dynamic modeling and measurement by **Pitarresi *et al* (2002)**. Elastic modulus for locally stiffened regions are estimated through three point bend test. Modal parameters predicted with the aid of FEM are correlated with test. White noise random excitation is given with in a band of 5–1000 Hz and acceleration responses are measured and the same is used to validate the outcome of FEM. Further, same approach is extended to shock response analysis.

A methodology to estimate the fatigue life of electronic components through joint approach of FEM and testing is presented by **Yu *et al* (2011)**. This methodology has been demonstrated in random vibration environment. Base excitation is given to the PCB with components with the help of an electro dynamic shaker.

Amy *et al* (2010) stated that for achieving accurate prediction of natural frequencies the first major challenge is to model the boundary conditions of the PCB accurately. Incorrect consideration of boundary conditions will influence vibration response prediction to a greater extent. However, it is found that the translational DOF are to be simulated using rigid link and the rotational DOF are to be simulated using rotational spring elements, stiffness of which has to be tuned, until the first natural frequency predicted using FEM, matches with that of test results. The second major challenge is consideration of material properties of PCB accurately. It is shown that significant amount of deviation exists between measured and those specified by the manufacturer. Further, the risk associated with using material properties given by manufacturer is quantified in terms of percentage discrepancy noticed in frequencies obtained using FEM and test. Based on these inputs, the material properties of a PCB are evaluated experimentally and the rotational stiffness values necessary for modeling boundary conditions in FEM are established with the aid of random vibration testing.

Yoshihara (2012) used a four point bend test set up using which material properties of PCB like shear modulus are evaluated. Using this test set up the above mentioned material properties are evaluated for a wooden sample.

2.2.2 PCB WITH COMPONENTS

Pitarresi (1990) stated that the properties of the smeared PCB can be estimated either experimentally, if the hardware of PCB having components exists, or computationally, if the design is still in the conceptual stage. The smeared material properties for the different Composite Modeling Regions (CMRs) contain the necessary information, i.e., equivalent elastic moduli and mass density, so that dynamic analysis can be performed with reasonable accuracy. The degree of accuracy may be controlled to some extent by the designer's choice of CMRs. For example as a 'first cut', the entire card may be smeared into a single CMR to get an overall feel for the PCB's Performance. Then, as the design is refined, a single CMR is replaced by numerous CMRs, chosen so as to reflect the particular structural aspect characterizing the various regions of the card. CMRs are often chosen wherever there is an abrupt change in the PCB packaging, for example, where the type and/or density of modules change. Such Composite modelling regions greatly reduce the complexity, and thereby the cost, of the dynamic Analysis. Experimental determination of the CMR properties can be obtained by means of either a three/four point static bending test for the equivalent stiffness in the principle directions of the CMR. For example, in the three-point bending test, the CMR is literally cut from the PCB and then supported on two opposite sides while a known load is applied parallel to the supported sides, along the center of the CMR. The slope of the resulting load deflection plot represents the effective spring stiffness of the CMR. As a final step, the effective spring stiffness is converted to appropriate material properties (Typically the elastic moduli).

Artro (1994) mentioned that finite element representation of a PCB reduces to an assembly of plate elements. As far as the components are concerned there is a wide variety of possibilities. These range from rather simple models in which the presence of a component is ignored or represented as a concentrated mass if the mass of such component exceeds a certain value to more elaborate models in which each component is modeled in detail using an assembly on thick plate, beam and possibly solid elements. In this study, the presence of a component is modelled by considering an equivalent mass density (and sometimes stiffness) for the plate elements located in the area where a component is situated. The approach descibed above is validated by experiments. Any approximation of the dynamic response of a PCB with components based on the fundamental mode (especially at a point other than the center) can be very misleading unless the fundamental mode accounts for approximately 90% of the total vibrating mass. This result is known for quite some time to civil engineers working in earthquake-resistant design. Similarly, where ever semi empirical formulae are used for the estimation of the maximum deflections of an electronic board, for a given load, the results could be as misleading. The paper also describes that when ever the supports are symmetrical and the PCB has components faily distributed as uniformly distributed, the fundamental frequency would be more influenced by the mass. However, in a PCB having a nonsymmetric support layout or a nonsymmetric distribution of components this will certainly not be the case. In such cases, the designer must rely on an estimate that incorporates higher modes.

Xie *et al* (2006) has built finite element model of PCB having components with the data on the dimensions, layout, and material properties. It contained only mechanically significant components, such as integrate circuit, aluminium frame, ICO and crystal vibrator. PCB was discretized using plate elements where as electrical connectors are discretized with solid elements. About 5000 elements were used. In ANSYS coupling degree of freedom were used to connect PCB and the electronic components. First of all, the number of jointing points used to fix the component were identified. Then the same number coupling points were used in ANSYS model in order to simulate the actual condition.

Chen *et al* (2006) has ignored stiffness of small components, and added their mass into PCB. Critical electronic componets are modeled as regular geometric shapes like cuboids. Where ever a cluster of small components are found, they are considered as a single component and modeled accordingly. The detailed FEMtures of PCB or aluminium frame are ignored. The paper brings out that a over simplified model, which ignores the details would result in a big gap between the experimentally derived natural frequencies and those obtained by FE analysis.

PCB considered by **Tang *et al*** (2007) for study consists of ICs and crystal oscillators which are significant with respect to their stiffness and mass contribution for PCB. Additional mass and stiffness imposed by these components will alter the modal parameters. Elastic moduli of PCB are obtained using strain measurements. Conventional universal testing machine is used for conducting the test and for measuring strains. FEMtures in the geometry of PCB like sudden change in cross section are ignored for FE modelling as they can influence the accuracy of results to a greater extent. However stiffness and mass lost due to such ignorance is added to the model through smearing technique. The model tests gives the modal parameters, i.e. the modal frequencies, the mode shapes and the modal damping. The modal parameters are estimated by curve fitting algorithms on the data obtained through experimental modal analysis. The measurements are made by exciting the structure, usually by way of an electro dynamic shaker or an instrumented impact hammer, and measuring the responses with an accelerometer. Correlation is done between the experimentally obtained modal frequencies with those from analysis and validated with the modal assurance criteria (MAC)..

Lee *et al* (2008) has estimatd the modal parameters of a populated PCB. To start with modal test was done on the said PCB in unsupported condition (free-free) and the natural frequencies were extracted. From the equations available in literature for estimating natural frequency of rectangular plate like structure (As the geometry of PCB is close to rectangular plate), Young's modulus of PCB is back calculated. However density is estimated from the physical weight of PCB. Using these material properties FE analysis is carried out for service mount condition of PCB i.e. clamped edges. PCB was discretized using solid elements and accelerometers used during modal test are considered as lumped mass elements. Convergence study is carried out to identify the optimal element size which yields accurate results.

Aytekin and Ozguven (2008) suggested a simple analytical model for a PCB with electronic components to avoid expensive finite element modeling in order to meet the expectations of the aerospace experimental approaches in preliminary design stage. The model suggested makes it possible to study the vibratory systems. Several studies are performed to analyze and isolate responses of critical elements on a PCB for different design alternatives in the preliminary design stage. A PCB of dimension 100 mm x 70 mm x 1.6 mm is considered as simply supported with an electronic component at the PCB centre. Analytical and empirical methods are applied on the above model. The two DOF springmass model which is suggested for the PCB-component system, has been used to obtain the random vibration response for a given vibration profile.. Acceleration spectral density and root mean square value of acceleration are calculated for the electronic component. The results are compared with the FE analysis and the correctness of the proposed model is established. The discrete model suggested represents the first mode of the printed circuit board and the vibration of a component on the PCB. The equivalent spring and mass constants which are applicable to the first mode are calculated. This is combined with the model of the component. The point of maximum displacement at the first mode is emphasized in the PCB modelling. Amount of static displacement is calculated for simply supported PCB. The displacement is used for calculating equivalent spring constant. Then, equivalent mass of the simply supported printed circuit board is derived by assuming a velocity profile for the PCB displacement during vibration and by calculating the corresponding kinetic energy. During the modeling, the components are considered rigid and the lead wires are considered to be flexible and the equivalent stiffness is compiled. The following assumptions are made:

- The electronic component itself is rigid.
- Lead wires of an electronic component are beam structures and can be modeled with beam elements.
- The printed circuit board is a composite structure and can be modeled with shell elements, considering each layer with isotropic properties.
- The stiffness which the solder can introduce is ignored
- Loss factor of the PCB and the component can be taken as 0.01.

In order to study the vibration of a component itself, it is necessary to model the electronic component with its connection to the PCB. The lead wire deflections gives the stiffness coefficients for the leaded components. When the flexibility of the component body is comparable with that of the lead wires, it can be considered as a rigid body. In that case it only has inertia effect. Modal and spectral analyses are performed by using the finite element analysis, and natural frequencies and root mean square value of acceleration are obtained. Random vibration responses got from the analytical model and the finite element model are given, while also comparing the the natural frequencies obtained by the two models. The results bring out that the modal density is fairly large and the power spectral density (PSD) match reasonably though limited to 1000 Hz.

Pitarresi *et al* (2002) build a model of a motherboard. Components which are considered to have mechanical significance, like contributing to mass or stiffness are modeled. These regions included the AGP and PCI connector slots, memory connector slots, CPU (including socket, processor, and heat sink) and chipset. The I/O connector region was modeled as a block but only the density was modified; the stiffness was taken as that of the FR-4 scaled for the connector geometry. PCB was discretized using plate elements where as electrical connectors are discretized with solid elements. Fewer than 2,000 total elements were used. The actual boundary condition used during testing was used on the standard ATX 10-point support layout. Flat-head screws were used to attach the motherboard to the rigid fixture plate. Each screw connector was set to a torque of 777 mm-N. In the model, fixing two corner nodes at each of the ten support points simulated this boundary condition. There were no video, extension, or memory cards installed in the sockets. (However, the CPU block includes the stiffness and mass effects of the socket, processor, and heat sink as discussed previously). It is stated that there could be problems arising due to large variations found in the stiffness of large components along with their sockets, which are mounted on relatively flexible mother board or PCB. These locally stiffened regions can have a considerable affect on the dynamic response and limit the use of simple homogenous flat plate approximations. The size of the mother board/PCB in comparison to the nitty gritties of the entire PCB, arising out of the minute FEMtures of the solder joints and components, necessitates a very large number of element, which could result in enormous time taken for the solution. The model is thus simplified with a view to reduce the number os elements in order to reduce the overall computation time. The paper describes one such simplified modeling approach for capturing the dynamic responses of PC motherboards. The first step in the modeling approach is to identify regions of the motherboard that exhibit significant concentrations of stiffness and/or mass. Examples include the CPU (including the socket, heat sink and retention clip), connectors (PCI, AGP, and memory), chipset, and so forth. Next, the region is idealized as a simple homogenous, rectangular block. It contains many geometric details that would be difficult to model. Using the proposed approach, the connector is modeled as a simple block. The stiffness and mass density of these simplified block regions are required. The finite element representations of these block regions are then arranged and assembled to the motherboard. The attachment of the components, the solder joints etc. introduce reasonable flexibility. This is however not considered and the attachments are assumed to be rigidly connected with the motherboard / PCB.

Cinar *et al* (2013) has discretized PCB using solid elements having only rotational degrees of freedom i.e. three per node. Piecewise modelling is attempted in this work in which entire PCB is divided into different regions. Initially, the total PCB is modelled and FE analysis was done to estimate the displacements. In the later stage each region of the PCB is modelled separately and the displacements thus obtained from integrated analysis are defined at boundaries for sub regions. The reason for adopting this approach was stated to be the complexity associated with meshing areas like component-PCB interconnections which needs very fine element size. However this approach has a fundamental limitation that it cannot be attempted to areas with sudden changes in the cross-section. The local model has the same element type as the global model, with 233,168 total elements. Pre-test results also showed that the packages near the fixed boundary where maximum relative displacements are encountered are the ones which failed the most. Sub modeling concept was implemented where vibration response predicted for one subsystem is considered for other subsystem located at symmetric location. It was concluded from the analysis that interconnection between component and PCB is experiencing more sterss concentration.

Perkins and Tian (2004) measured the properties of components with the help of strain gauge by de-soldering the components from PCB. This is laborious and a destructive method. This paper discussed vibration experiments and modeling for a 42.Smm X 42.5mm x 4" 1089 YO Ceramic Column Grid Array (CCGA) component with 1089 UO's on a 1.27mm pitch. Out of plane sweep sinusoidal test were conducted at lg, 3g, 5g, and 10g. In-situ resistance monitoring was done to determine solder joint failure. Crosssectioning of the failed components was done to ensure that the failure was at the solder joints and to compare the vibration-induced failures with thermal-cycling failures. Along with the experiments, an analytical model was derived from a power balance formulation for a conservative system with no extemal forces. Influence of PCB-component interconnection in terms of stiffness is investigated on modal parameters of PCB using the said model. Finite-element models were also developed to predict the failure location and behavior of the failed solder joints. A finite-element model of electronic packages for vibration and mechanical environments that avoids a local-global or submodeling approach was developed. In order to capture all mode shapes; to account for inertial forces, and to account for possible plasticity in the solder joints, a full 3D model is necessary. A hybrid 3D model that consists of 3D solid elements for solder joints of interest and equivalent beam elements for other solder joints was developed. The board and the ceramic substrate were represented using solid elements. The rotational degrees of freedom of the beam elements were constrained.

Che and Pang (2009) addressed modeling issues considering solders as equivalent beams. An analytical method was presented for predicting the natural frequencies but its scope was limited to the first mode only. Experimental characterization of PCB was carried out and vibration responses were measured on PCB in terms of transmissibility. Sine excitation has been considered as the objective was to evaluate the fatigue life of the PCB. Functionality of the electronic compoents was monitored through a special arrangement for the sake of life evaluation. Simultaneosly free vibration response analysis was carried out for PCB to estimate its modal parameters. PCB was discretized using shell elements. Fixed boundary conditions were considered in FE model so as to simulate test conditions. Initially, the PCB with out components was considered for study to understand the influence of element size on results. Later the analysis was extended for populated PCB. Four different modeling approaches were adopted for components. Initially components were considered as lumped masses and then modeling of components with smearing approach, shell elements and solid elements is attempted. Components were discretized with beam elements in approach where PCB was discretized with shell elements.

Chen *et al* (2008) used shell elements to model PCB. Stresses experienced by component-PCB interconnections were computed with the aid of FE method. FE model of PCB is constrained while replicating the test boundary conditions. Part of PCB alone was considered for analysis based on dynamic symmetry. It was noticed that element size influences natural frequencies to a greater extent. Results obtaine using FE analysis are validated with that of test. However no criteria is implemented in identifying true natural frequencies from peaks appearing in transfer function plot (Imagniary). Further analysis is extended for response prediction. However analysis is confined to harmonic excitation only while ignoring random vibration environment.

Francois (2010) has discussed different levels of modeling simplifications that were possible and then later summarized his ideology of modeling approaches for various types of electronic components present on a PCB.

2.2.3 CHASSIS

Chen *et al* (2006) presented on modal analysis of electronic devices by finite element analysis (FEM). The model used, consists of a frame, a PCB with its various components populated on it. The modeling was done on Solid Works and imported into the Ansys for analysis. The properties of the PCB were obtained experimentally and used. There was a good agreement of the natural frequency values between the FE analysis and the experiment.

Amy *et al* (2010) has modeled walls of chassis using shell elements and ribs with beam elements.

Francois (2010) mentions that when a subsystem is considered for analysis, dynamic coupling with respect to its mounting strucuture (Another subsystem in assembly to which the first subsystem is connected) needs to be studied. Mounting structure can be ignored for modeling only when it has no freqeuncy in the frequency range of excitation. Indeed, in reality, the PCB is fixed on the chassis. So, to obtain accurate results, it is a current practice to attach the PCB on this structure during experimental tests. Thus, the boundary conditions are identical to the ones encountered during the lifetime of the PCB and the obtained dynamic response is more accurate.

Zampino (1995) has estimated vibration response on a housing i.e. chassis using FE method for a random vibration load. The results which are obtained for various modeling methods, which includes the effects due mass distribution and mess size are compared. He has used shell elements for discretizing chassis.

Aglietti *et al* (2004) has modeled chassis using shell elements whilst the supporting structure has been modeled using beam elements.

2.2.4 PACKAGE LEVEL

Chen *et al* (2006) modeled interconnections between PCB & housing by coupling displacement DOF alone. Package level fixity is modeled by constraining displacement DOF alone. Similarity between FEM & test mode shapes are not considered while comparing frequencies.

Zampino (1995) stated that, as more engineers turn to finite element analysis (FEM) to solve tough problems, there is the need for practical knowledge of efficient and accurate modeling practices. Easy availability of computational power and FEM softwares are being immensely exploited by engineers. Moreover severe limitations in knowledge relating to proper modeling results in wrong and unreliable results. This was discussed by doing a vibration analysis of a power supply packaged in a rectangular enclosure. FE analysis reported was performed using NISA. Chassis consists of an aluminium base plate and a cover lid. Chassis was secured to a frame by a wedge-lock at each end. A FR-4 PCB was mounted inside the chassis directly to the base plate on 14 stand-offs. An EMI filter was mounted on top of PCB using 6 standoffs. Hence, an analysis was needed to find the natural frequencies of each part, and then for assembly. Each part will have its own dynamic response, however, the assembly of PCB & chassis will have a combined dynamic response different than the two independent responses. More importantly, it must be determined if the two parts couple dynamically. To determine if the two parts would couple, the octave rule is employed which states, if the natural frequencies of one part lies within a range of one-half to twice the other part's natural frequency then the two parts will couple dynamically. The effect of the wedge lock is considered in calculating the thickness. Nodes located at the end flanges under wedge-locks were fully constrained in all DOF. Then PCB level analysis was done for which constraint u = v = w = 0 was applied at locations where the standoffs held the board. From the analyses it was concluded that dynamic coupling doesn't exists as frequencies of PCB & chassis are well separated. Based on this observation, approach for modeling interconnections for package level analysis was formulated. For assembly (Package level) analysis interconnections between PCB & chassis are modeled with rigid links. Fixity of the package was modeled by fully constraining the nodes located at end flanges under wedge lock for all DOF. Then random vibration response analysis was done for PCB level and package level. Deflection was estimated and found with in limits and hence package configuration was declared as safe. Requirement of the power supply was that it had to withstand exposure to a random vibration environment which was defined and provided by the customer. Relative displacement between PCB and component influences survivability of mounted electronic components to a greater extent.

Aglietti *et al* (2004) modeled interconnections between enclosure & PCB with rigid elements.

2.3 SCOPE OF THE PRESENT RESEARCH

To carry out research to develop a robust modeling approach for electronic packages for air borne vehicles with the aid of conventional tools available which yields accurate results. The total execution of this research programme is planned in three stages.

- In the first stage a set of electronic packages which covers the different packaging configurations (Stacked and wedge guide) is considered and preliminary models are established using FEM. During this stage limited information available on modeling practices for some components in literature is implemented.
- In the second stage experiments are conducted for the corresponding hardware.
- Finally, in the third stage the modeling is fine-tuned until the results (Random vibration response levels for a prescribed random vibration input) matches with that of experiments.

The end goal of this research work is to bring out the converged modeling practices with respect to all types of electronic packages for consideration of electronic packaging community for ensuring accurate prediction of design adequacy of any electronic package. The modelling practice so evolved would be extremely useful to carry out structural dynamic analysis of any electronic package followed by structural modification studies confidently as and when situation demands and clear the design of a package for fabrication at the earliest thereby reducing the lead time in the total product development cycle.

2.4 SUMMARY

Extensive literature survey carried out in this particular context brought out that research carried out so far is confined to the extent of individual component modeling only. No literature speaks about a holistic modeling approach for an electronic package covering all subsystems down to solder pin level. Lack of sufficient literature covering all the aspects of modeling for complete package and an analysis methodology giving a generic solution to the problem of estimating the random vibration response for aerospace electronic packages forces many assumptions to be made during the FE modeling and analysis. This results in inconsistencies in the results and the confidence on the results to be significantly low. The situation forces the designer to develop the package and wait to ascertain its effectivenss and the ability to perform intended functions until it is tested and in case of problems, implement changes and again wait for the test results. This results in enormous development time adversely impacting schedules and costs.

CHAPTER 3

ELECTRONIC PACKAGES AND THEIR CHARACTERIZATION

3.1 INTRODUCTION

Electronic Packaging is "the technology of packaging electronic equipment", which includes the population of electronic components into Printed Circuit Boards (PCBs) and the interconnection of PCBs to electronic assemblies, in such a way, that it is protected against all the environments that the system encounters during its lifetime and service requirements. Because of the increased use of computers and electronics in all aspects of flight vehicle development programmes, increasing performance of electronic packaging configurations without increasing the cost is becoming a major thrust for the electronic packaging designers. This increased use of electronics in conjunction with reduced size and weight and the designer's need to introduce products rapidly has led to increased use of analysis instead of 'build and test' to determine if equipment can meet the appropriate requirements. Electronic packaging analysis aims at ensuring the best performance of the package against different environments viz., Dynamic, Thermal and EMI/EMC.

The rapid pace at which electronics is developing and the fast rate at which obsolescence sets in, warrants that the development cycle time is reduced to the minimum, lest, the competitors get an edge over us. Hence, using tools that help in this faster evolution needs to be resorted to. The finite element analysis helps in analyzing the effects of various inputs on these packages particularly in terms of vibration response which is the topic of this research work. It helps in estimations, without having to fabricate the systems, PCB, chassis, interconnections etc. However, if we need to estimate with great degree of accuracy, it is essential that the best modeling practice is used and all the assumptions that are usually made are plugged with more realistic data.

3.2 PROBLEM DEFINITION

Electronic packages are meant for meeting various cardinal requirements like guidance, control, navigation, etc. in any airborne vehicle. A typical electronic package is shown in Figure 3.1

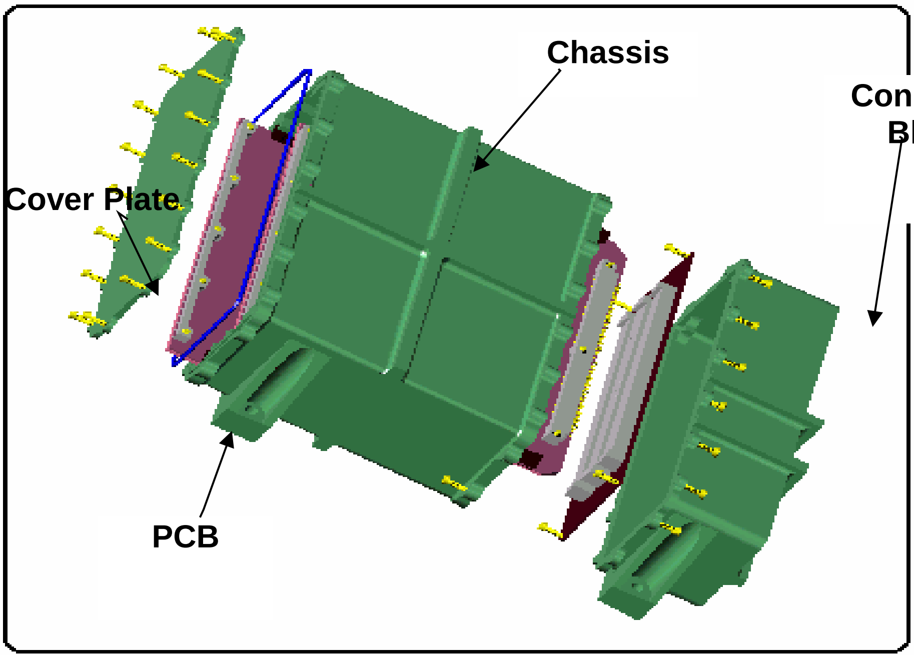


Figure 3.1 Typical electronic package

Any failure results in catastrophic effects, involving failure of the mission involving huge costs and safety. An electronic package consists of a mechanical housing (Chassis) in which Printed Circuit Boards (PCB's) having critical electronic components like IC's are mounted. During the life cycle of the air borne vehicle it will experience harsh environments like vibration, shock, temperature, etc. which inturn will get transferred to PCB's and hence to electronic components. When the vibration levels experienced by these components exceed their respective qualification limits which they have been designed for, either they malfunction or fail (i.e.., either soft failure or hard failure) which ultimately leads to a catastrophic mission failure.

Most such electronic failures are mechanically induced. Many of these mechanical failures occur in the component lead wires and solder joints. Extensive military testing experience over a period of many years has shown that about 40% of the electromechanical failures are due to thermal, 27% of the failures are due to vibration, 2% of the failures are due to shock and remaining are due to other environments as shown in Figure 3.2. (Courtesy MIL-STD)

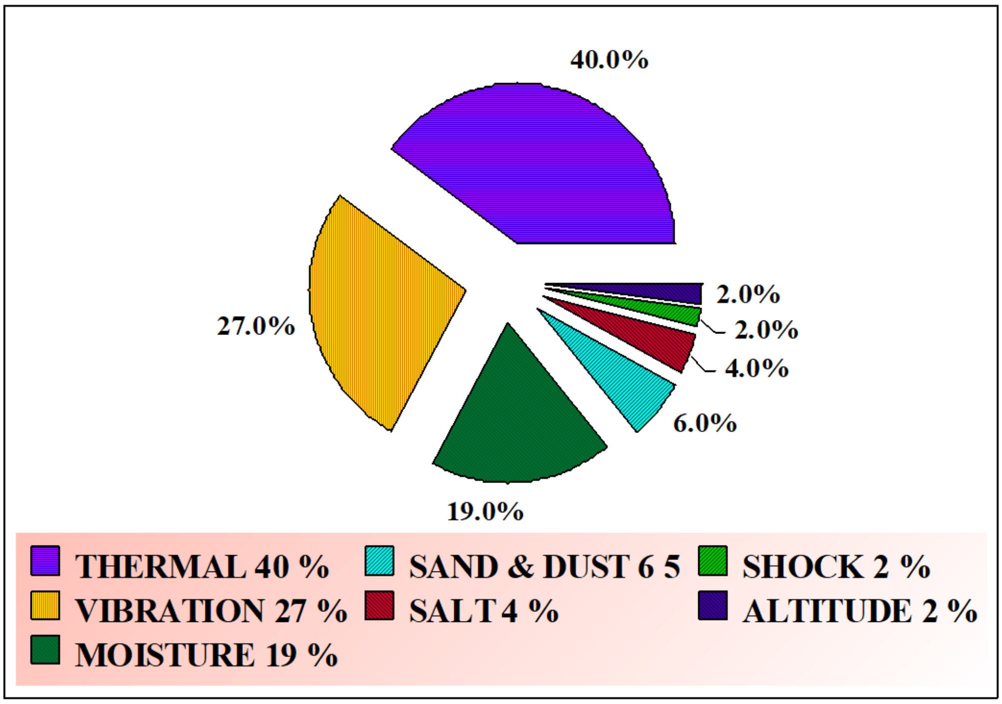


Figure 3.2 Failures in Electronic Packages

Acceleration levels experienced by the air borne vehicles range from about 5g to about few hundreds of g's peak, with the maximum levels occurring during maximum dynamic pressure flight condtions. The vibration environment in air borne vehicles is actually more random in nature than it is periodic. The forcing frequencies present in air borne vehicles will excite many resonant modes in every package, all at the same time.

As the electronic components are very sensitive to vibrations, they must be properly and accurately analyzed for their sustainable vibrational limits, to avoid problems during their operation. Analysis of these PCBs with electronic components prior to their fabrication is ade possible through Finite Element Techniques and are used to simulate the actual real-time scenarios. In order to achieve the accurate results in analysis and to maintain the consistency of these results the PCB's, Components, Chassis and their interconnections must be modelled properly i.e., their influencing parameters such as stiffness, mass, damping and their mounting methods have to be simulated accurately. The accuracy depends on the modelling methods adopted for simulating their effects in FEM software's. Literature in this area suggests that piece wise modelling approaches are tried and results documented. However a holistic approach to the complete package which includes, the PCB, chassis, interconnecting cables and connectors is not available, that too which could be adapted for the aerospace required frequencies of upto 2000 Hz. Hence the problem for this work is defined as under "To develop a robust modelling technique, for all the elements of electronic packaging from random response perspective in order to minimize assumptions and to get consistent and accurate results in predicting the random responses to various vibration inputs".

3.3 ELECTRONIC PACKAGING CONFIGURATION

An electronic package generally consists of various component packages which contain silicon dies or chips combined with components such as capacitors and resistors which are together mounted on a PCB. These PCBs with components (modules) are mounted on a chassis, and this provides the necessary protection from the adverse environments

Electronic packaging configuration is divided into following levels

- Component (Level 1)
- PCB (Level 2)
- Chassis (Level 3)

Although the above packaging levels are frequently used, they are not universal. Increasing the packaging density and the use of novel packaging (such as multichip modules and chip on board) has often clouded the distinction between the packaging levels.

3.3.1 COMPONENT LEVEL PACKAGING

Component level of packaging provides a method to join and interconnect a silicon microcircuit to the next packaging level, and protecting the microcircuit from the adverse environment. The design of the component-level package and material selection depends upon the choice of the use of hermetic (ceramic) or non-hermetic (plastic) packaging to be used.

For a hermetic packaging configuration, the silicon die is bonded into the cavity of a ceramic package and the configuration is sealed with a lid that closely matches the expansion rate of the package. Typically, small wires are used to inter connect the pads on the silicon die to the leads. In some cases the leads are not used and interconnection to the printed circuit board is made through metallized areas on the outside of the package (Lead less chip carriers).

In a non-hermetic configuration, the silicon die is bonded to a heat spreader, which is typically part of a lead frame. Interconnection is made either with small wired connection between the die pads and the lead frame or directly between leads and the pads. Once the interconnection is made, the whole assembly is encapsulated in an epoxy material which provides protection from the environment.

Because ceramic is a brittle material, the package lid and leads must match the expansion of the ceramic. Typical materials used in the component packaging are summarized in Table 3.1.

Table 3.1 Typical component level packaging materials

Item	Hermetic	Non- Hermetic
Package body	Aluminium oxide	Epoxy
Package lid	Nickel iron alloy*	-
Leads	Nickel iron alloy*	Copper

Heat spreader	-	Copper
Die bond	Solder/Epoxy	Epoxy
Die	Silicon	Silicon

3.3.2 PCB LEVEL PACKAGING

PCB level packaging provides a method for attaching and interconnecting the components to the next level of. Specifics of the module-packaging configuration vary if through hole or surface mount technology is used.

A through- hole technology typically uses dual in line packaging (DIP) for the micro circuits wherein the leads on the components are soldered into holes of the Printed Circuit Board (PCB) and this provides the interconnection to the other components and to the chassis (via the wires and the connectors). In cases where thermal performance needs to be enhanced, a heat sink is attached to the PCB directly beneath the component.

Surface Mount Technology, (SMT**)** solders the components directly on to the pads, on the surface of the PCB since the leads are not inserted into the holes in the PCB and may be mounted on the back of the module without any concern for the location of parts on the front. Since the leads are not inserted into the holes, the SMT parts are typically smaller than the DIP parts and components may be mounted on both sides of the module, an increase in the packaging density approximately a factor of 3 has been realized. Thermal performance in a SMT module is typically accomplished by bonding a heat sink in between the two surface mount PCBs or by laminating a heat sink as a part of the PCB fabrication process. In some cases, through holes (PTHs) which are plated are used to enhance the thermal conduction between the component and the heat sink. Typical materials used in the module level packaging are summarized below.

Table 3.2, enumerates the typical PCB level packaging materials.

Table 3.2 Typical PCB level packaging materials

Item	Through-hole And SMT	Hermetic SMT
PWB	Glass/epoxy Glass/ polyimide	Glass/polyimide glass/epoxy with CMC or CIC planes Aramid/epoxy
Heat sink	Aluminium Copper	Copper-invar-copper

3.3.3 CHASSIS LEVEL OF PACKAGING

Typically, the chassis level of packaging has support rails to which the modules are mounted, and to a motherboard which has connectors. Modules may be mounted to the chassis by springs, mechanically actuated clamps, bolts, or similar methods. Chassis cooling may be enhanced by fins, tubes, or cooling plenums. Materials used for chassis- level packaging include aluminium, steel, plastics, and composites depending upon the cost and weight considerations.

3.4 SUB-SYSTEMS OF AN ELECTRONIC PACKAGE

3.4.1 CHASSIS

A typical housing of an electronic package shown in Figure 3.3 protects all of the vital internal equipment such as Printed Circuit Board (PCB) from dust, moisture, etc. PCB is mounted inside the chassis and chassis in-turn is mounted directly on the surface of air borne vehicle through bolted joints.

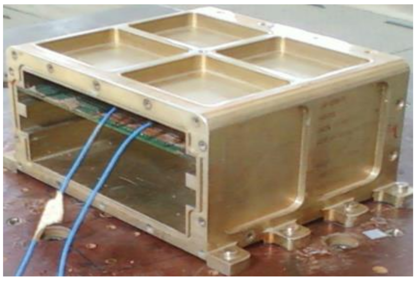


Figure 3.3 Chassis

3.4.2 PRINTED CIRCUIT BOARD (PCB)

A printed circuit board, or PCB, shown in Figure 3.4 is used to mechanically support and electrically connect the electronic components by using pathways, which are conductive tracks, etched from copper sheets and laminated onto a non-conductive substrate. Printed circuit boards are used in allmost all commercially produced electronic devices. Many different types of PCBs are manufactured by the electronics industry. Epoxy fiberglass is the most common material used, with laminated layers of copper on one or both sides of the board to form the electrical conductors. The overall PCB thickness can vary from about 0.006 to 0.125 inches. Many different shapes can be found, ranging from small squares to large circular plates and triangles, depending on the shape of the electronic box used to support the circuit boards. Since electronic equipments are packed into every available space in most airplanes, air borne vehicles, and even domestic electronics, the shape of the circuit board are dictated by the geometry of the space available. The rectangular PCB is the most common shape used. PCBs with many high-power-dissipating components will run very hot unless the heat is removed. Therefore aluminum and copper, which have high thermal conductivities, are often bonded to the epoxy fiberglass circuit boards to act as heat sinks.

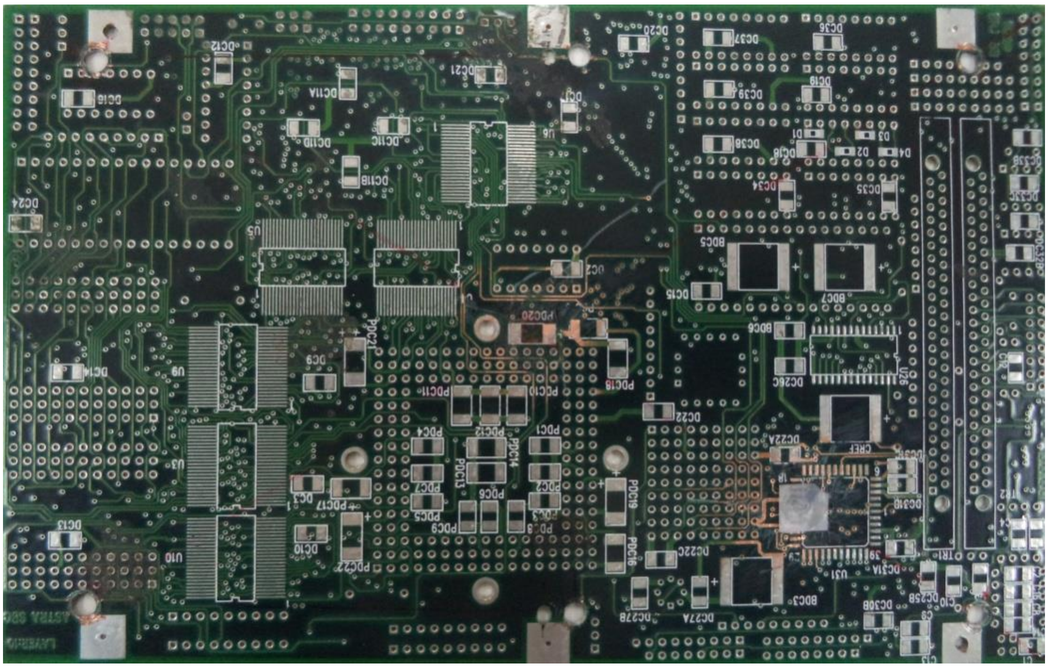


Figure 3.4 Printed Circuit Board

PCBs are supported in the electronic package in many different ways, depending on factors such as the environment, weight, maintainability, accessibility and cost. In general two types of mounting configurations are being used for PCBs. They are shown in Figure 3.5.

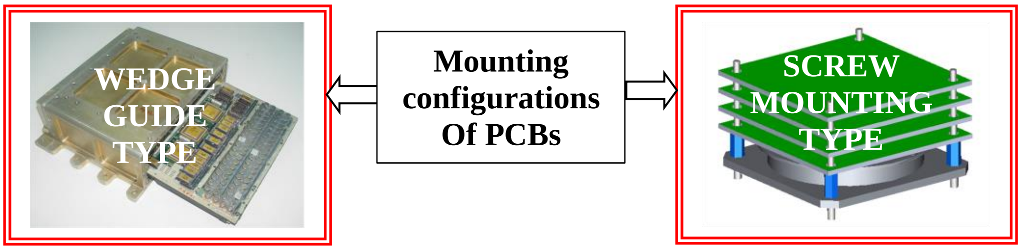


Figure 3.5 Mounting configurations of PCBs

3.4.2.1 Wedge Guide Configuration

In this configuration rectangular shaped guides known as wedge guides are provided integral to the side walls of the chassis as shown in Figure 3.6.

Figure 3.6 Chassis with wedge guides

PCBs are provided with wedge locks integral to them. PCBs are then inserted from front side along the chassis wedge guides. Once the PCB is fully inserted wedge lock is tightened by which the wedge lock will be in contact with chassis wedge guides and remain in contact with PCB. PCBs having male connectors are connected to female connectors provided on mother board located in rear side of the chassis. Merits of wedge guide configuration are as follows.

- Maintenance of PCBs is easier as faulty PCB can be removed independently and repaired and inserted back into the chassis without disturbing other PCBs.
- As the type of contact between PCBs and chassis is frictional in nature, vibration energy will be dissipated across the wedge guides which imparts more damping to this type of configuration.
- As the PCBs are held rigidly between wedge guides lateral vibration levels experienced by them will be comparatively less.
- In general, side walls of the chassis are much stiffer compared to top and bottom walls. So when the PCBs are mounted to side walls of the chassis, forcing frequencies will be less in number and overall vibration response on the PCB will be less compared to other configurations.
- The thermal resistance across wedge guides is least compared to other interfaces which will lead to better heat dissipation and results into lesser temperatures.

3.4.2.2 Screw Mounting Configuration

In this configuration PCBs are mounted one over another in stacked fashion and long screws are used to connect all the PCBs with chassis as shown in Figure 3.7.

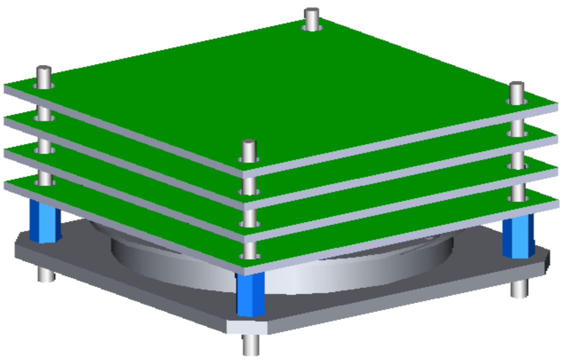


Figure 3.7 Screw mounting configuration of PCBs

However one would not recommended to mount PCBs with the help of long screws. Because long screws are slender in nature and they impart cantilever (One end fixed and other end free) type bending modes which will cause high vibration levels. Typical cantilever mode which commonly appears in screw mounting configuration of PCB is shown in Figure 3.8.

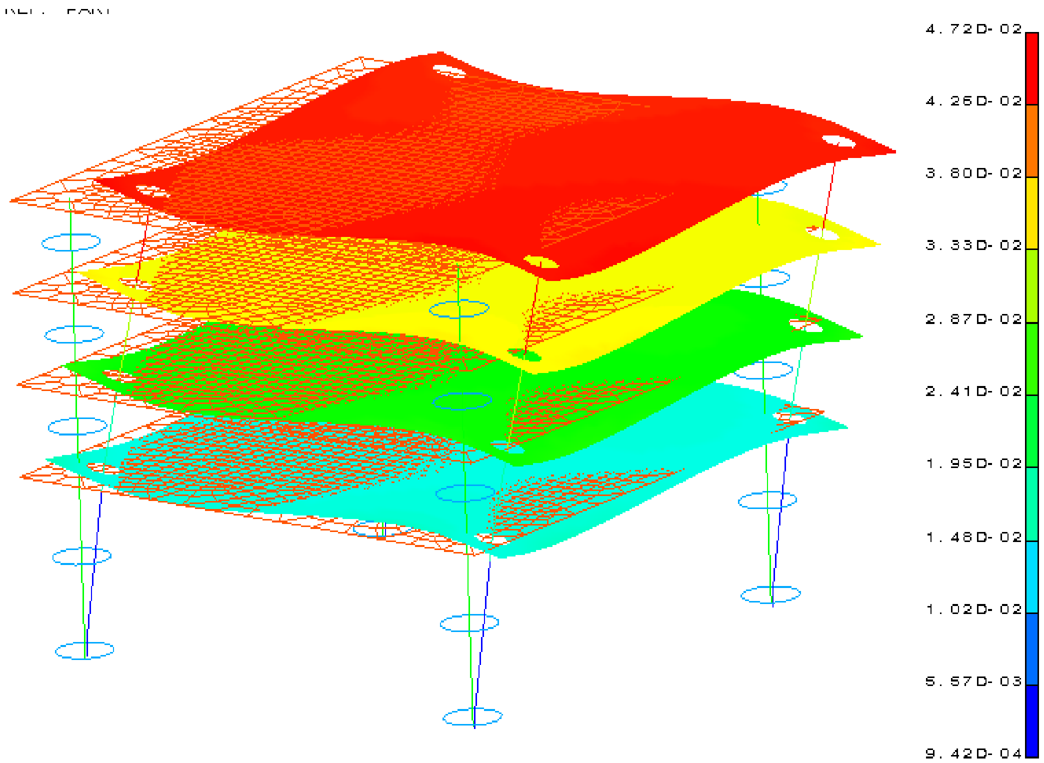


Figure 3.8 Cantilever mode of screw mounting configuration

3.4.3 ELECTRONIC COMPONENTS

Electronic components have two or more electrical terminals (or leads). These leads are soldered to a printed circuit board, to create an electronic circuit for performing a particular function. Printed circuit boards (PCBs) are composed of a variety of complex electrical elements, including resistors, capacitors, diodes, transistors and fuses. For the PCB to function properly, each component must play its part. If any one component fails, the PCB may fail in its functionality. Usually these electronic components are classified into various types. They are:

- Light weight Components
- SMT Components

- Heavy Components

3.4.3.1 Light weight components

These components are usually the smallest components that can be seen on any printed circuit board. Some of the examples for light components consist of resistors, capacitors, diodes, etc., and are shown in Figure 3.9 and Figure 3.10.

Figure 3.9 Resistor

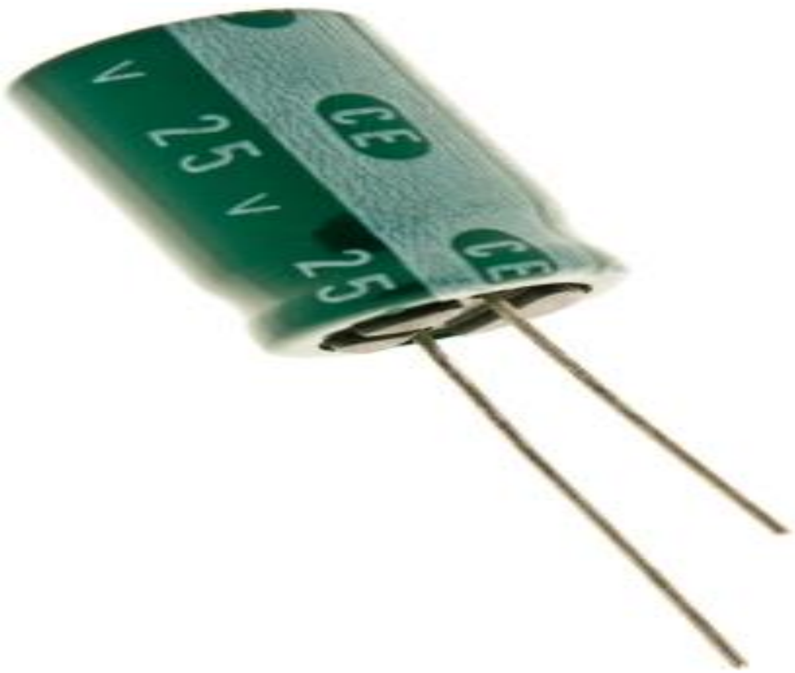


Figure 3.10 Capacitor

Normally light weight components are mounted in Dual In-line Package (DIP) configuration. In microelectronics, DIP is an electronic package having a rectangular housing and two parallel rows of electrical pins. The package may be mounted to a printed circuit board through a hole or inserted in a socket. DIPs are commonly used in integrated circuits (ICs). Resistor packs, DIP switches, LED segmented and bar graph displays, and electromechanical relays are some of the other devices in DIP packages.

3.4.3.2 SMT components

These components are usually seen flush mounted onto the printed circuit board. These surface mount technique (SMT) components are of different types as shown in Figure 3.11 and Figure 3.12.

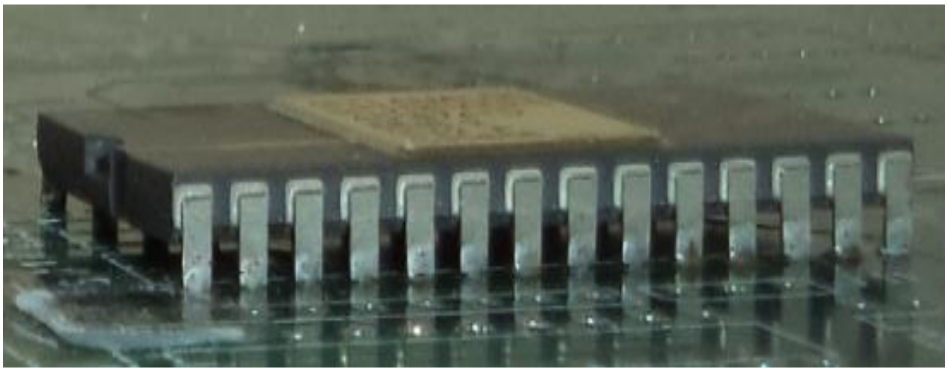


Figure 3.11 SMT with Gap

Figure 3.12 SMT without gap

Surface Mount Technology (SMT) solders components directly to pads on the surface of the PCB since the leads are not inserted into the holes. PCB components may be mounted on the back of the module without concern for the location of parts on the front. Since the leads are not inserted into the holes, SMT parts are typically smaller than the DIP parts and components may be mounted on both sides of the module, an increase in the packaging density approximately a factor of 3 is realized. Thermal performance in SMT module is typically accomplished by bonding a heat sink in between the two surface mount PCBs or by laminating a heat sink as a part of the PCB fabrication process. In some cases additional plated-through holes (PTHs) are used to enhance the thermal conductivity between the component and the heat sink.

3.4.3.3 Heavy components

Heavy components are usually the large components identified by their size and by their weight present on the PCB. DC-DC converters, hybrid components as shown in Figure 3.13 are examples of heavy components.

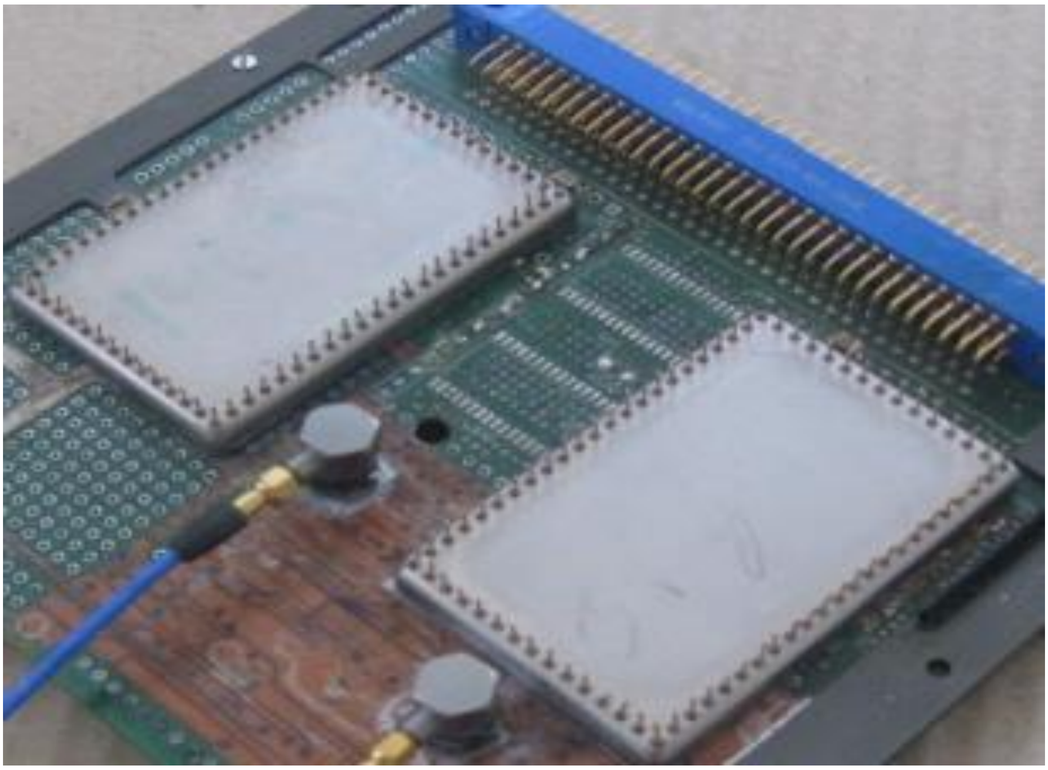


Figure 3.13 Heavy Components.

3.5 ANALYTICAL TOOLS FOR CHARACTERIZATION OF ELECTRONIC PACKAGES

The sophistication, complexity and packaging density of electronic equipment follow an established trend of circuit and device development. This evolution in technology, materials and techniques has dramatically improved the capability, performance, reliability and availability of systems that perform tasks bounded only by the limits of the human imagination. New uses for compact sophisticated equipment, meeting a variety of requirements of the user and the environment emerge continually .The diversity of human designs and service conditions coupled with the necessity to demonstrate equipment integrity as a condition of acceptance have increased the importance of the design engineer. This is placing an additional emphasis on his abilities of designing electronic packages to withstand vibration environments.

Typical tools used in the analysis of electronic packaging include:

- Hand calculations
- Symbolic equation solver
- Spread sheets
- Custom programs
- Finite element analysis

3.5.1 HAND CALCULATIONS

Hand calculations include the derivation of governing equations for a system with specific loading condition. Most PCBs can be approximated as flat rectangular plates with different edge conditions and different loading conditions. General plate equations can then be used to find out the strain energy and the kinetic energy of the vibrating plate. This leads to the natural frequency equation. One very convenient method for analysing plates is the Rayleigh method. A deflection curve which satisfies the geometric boundary conditions, is assumed, which gives the deflections and the slope for the plate. Once these boundary conditions are satisfied, the assumed deflection curve is used to obtain the strain energy dissipated, the strain energy will be equal to the kinetic energy and the approximate natural frequency can be determined. The Rayleigh method results in a natural frequency that is slightly higher than the true natural frequency for a given set of conditions, unless the exact deflection curve is used.

Consider a flat rectangular plate with four simply supported edges and uniformly distributed load, being vibrated in a direction perpendicular to the plane of the plate. Using the Rayleigh method the natural frequency for the PCB can be written as

$$f_n = \frac{\Omega}{2\Pi} = \frac{\Pi}{2}\sqrt{\frac{D}{\rho}\left(\frac{1}{a^2} + \frac{1}{b^2}\right)} \qquad (3.1)$$

Where

D: Flexural rigidity of PCB

ρ: Density of PCB

a: Length of PCB

b: Breadth of PCB

Numerical calculation can be performed to find out the resonant frequency of any PCB using the above expression.

3.5.2 SYMBOLIC EQUATION SOLVER

It is a software product like MATLAB that allows the user to solve algebraic equations, conduct integration and differentiation symbolically instead of numerically. It is a typical computer based method. This can be thought of as a computer based hand calculations. Since equation, representation can be made in a manner that is very much similar to those written and derived by hand.

3.5.3 SPREAD SHEET

It is a software product, which provides a tabular work sheet, which performs rapid numerical calculations. A spread sheet is typically broken up into cells with columns designated by letters and rows represented by a numbers. Equations can be developed with in the spread sheets that use the values contained in other cells to determine the results of the equation. Typically spread sheets also include the ability to graph results and iteratively solve for a particular problem. To some extent, spread sheets may be considered as the backbone of electronic packaging analysis.

3.5.4 CUSTOM PROGRAM

A custom program is developed by the analyst to solve a particular problem or class of problems. Since the custom program is developed for a specific application, the limitations noted in some of the other analytical tools may not exist in this tool but the only limitation in a custom program are capabilities of the hardware or the software.

3.5.5 FINITE ELEMENT METHOD

This is the method in which we can easily solve the complex geometries instead of analyzing a continuum, as it is often found in solid mechanics and thermal problems a finite number of simple geometries called the "elements" are used and these are connected to adjacent elements at fixed points called the "nodes". The finite element software varies from vendor to vendor but most include the capability to analyze the following areas.

- Static
- Dynamic
- Thermal
- Fatigue life
- EMI/EMC

3.5.5.1 Static analysis

Considering the various static loads coming on to the chassis, PCBs and power supplies etc., adequate design margins are given with suitable factor of safety to limit the maximum static stresses and static displacement within the allowable limits. Static analysis is carried out to ascertain the design margin by estimating the maximum stress and evaluating the factor of safety by comparing with that of allowable stress. Information regarding the maximum displacement and reaction forces are additional outcome of static analysis. Shear force and bending moment diagrams also can be obtained from static analysis. Maximum stress plot for a typical electronic package is shown in Figure 3.14.

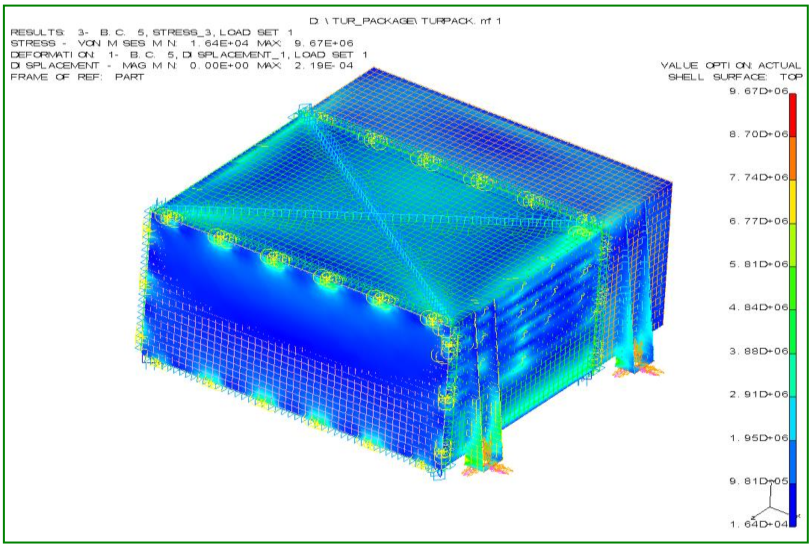


Figure 3.14 Maximum stress plot of a typical electronic package

3.5.5.2 Dynamic analysis

The package with its subsystems are analyzed to get the natural frequencies of subsystems individually and combined package as a whole to detune the coincident natural frequencies so that resonance under the given boundary conditions is avoided. Mode shape of a typical package is shown in Figure 3.15.

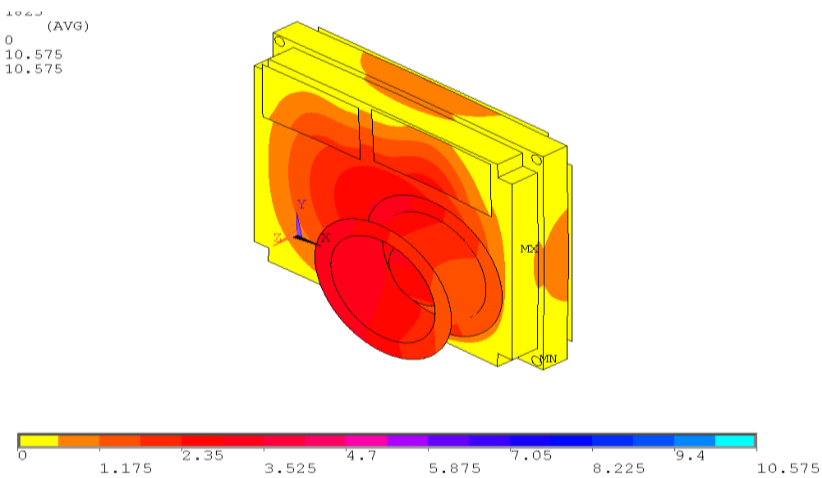


Figure 3.15 Mode shape of a typical electronic package

Altering the mass and stiffness properties is helpful in this case. For the specified random vibration and shock inputs the response at critical locations on the subsytems of the package is analyzed. The damping values obtained from the modal tests are used for this purpose. Suitable vibration control methods are employed to limit the vibration levels in case of excessive amplification. Modal test and vibration test on realized hardware are done to validate the analysis results. Random response of a typical electronic package is shown in Figure 3.16.

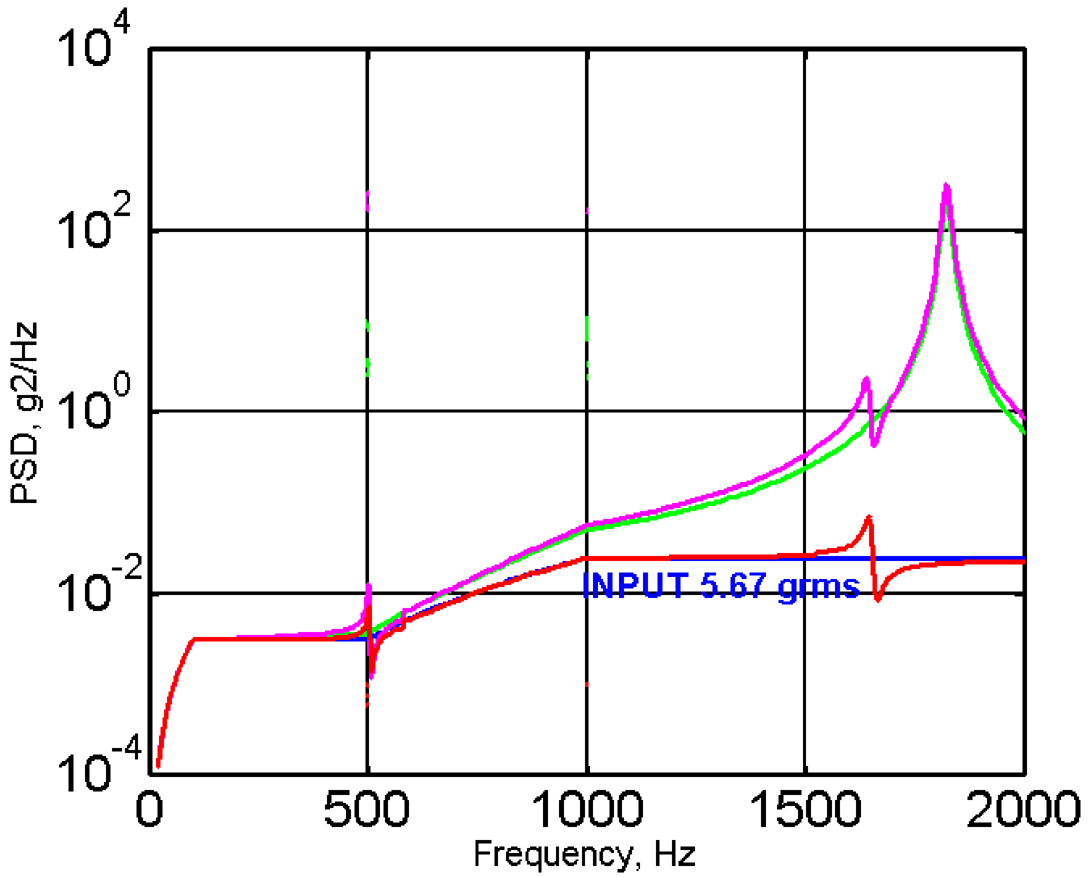


Figure 3.16 Random vibration response of a typical electronic package

3.5.5.3 Thermal analysis

By considering the thermal environment and the individual wattage of the components, the power supply and auxiliary units, the temperature profile for a given duration is obtained to ascertain that the junction temperatures are within limits. Different cooling techniques can be employed to ensure the safe functioning of the package in high temperature environment. Bonding a thin aluminium layer to the PCB will enhance structural stiffness and also act as a heat sink. Cooling fins are provided for high heat dissipating components. Temperature distribution plot of a typical PCB is shown in Figure 3.17.

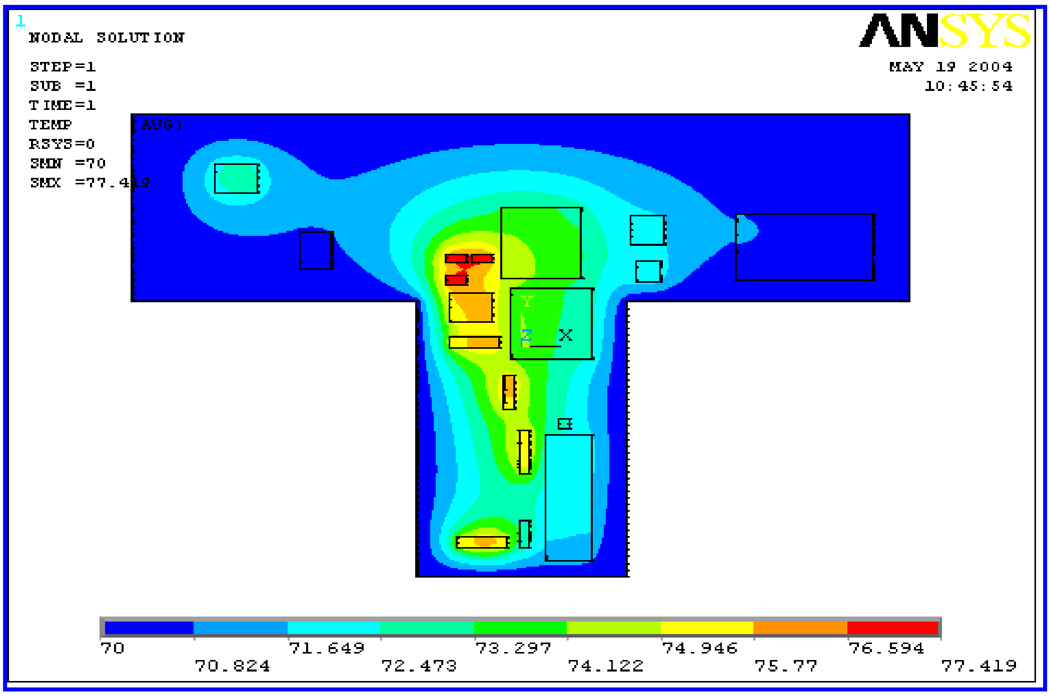


Figure 3.17 Temperature distribution plot of a typical PCB

3.5.5.4 Fatigue analysis

For units with long duration of operation, the accumulation of stress poses serious threat to the functionality of the unit. Fatigue life prediction based on the stresses developed in the unit under different dynamic loading conditions ensures the life of the packages.

3.6 MERITS AND DEMERITS

The merits and demerits of analytical tools are summarized in Table 3.3.

Table 3.3 Merits and demerits of analytical tools

Tool	Merits	Demerits
Hand calculations	• No specific tools are required. • Familiarity with the software is	• Difficult to check. • Manual unit conversions.

	not required. • Concepts can be developed rapidly.	• Subject to human errors. • Large volume of the data can be tedious and time consuming.
Symbolic Equation solver	• Changes can be made easily • Eliminates hand calculation errors • Units can be included	• Extremely large equations cannot be solved • Importing/Exporting may be limited
Spread sheets	• Changes can be made easily • Many calculations can be performed simultaneously • Data can be Imported/Exported	• Familiarity with the software is required • Manual unit conversions
Custom Programme	• Portability if standardized code is used • Multiple - letter variables allow Greek and other special characters to be spelled out • May be more efficient for some applications	• Development may be time consuming • Manual unit conversions • Must be developed for each typical case separately.
Finite Element method	• Applicable to many geometries • Can be used where closed form solutions are not possible/practical • Can import CAD data	• Familiarity with the software is required • Manual unit conversions

3.7 SUMMARY

In this chapter, typical electronic packaging configuration along with its subsystems has been presented. Further, problem definition pertaining to the present research work is also discussed.

CHAPTER 4

MODELING PRACTICE FOR PCB LEVEL ANALYSIS

4.1 INTRODUCTION

In the previous chapter, electronic packages and their individual sub-systems have been discussed elaborately. This chapter deals with deriving the fundamentals for simulating accurate practical physical effects of printed circuit boards in the dynamics involving random vibrations. Material properties which form the essential inputs to the FEM are validated with the help of experimental data. Scope of present research work in this chapter is to establish robust modeling practice for performing PCB level random vibration response analysis.

4.2 MODELING STRATEGY

Accuracy of random vibration response predicted by Finite Element Analysis (FEA) depends on accurate prediction of natural frequencies during first stage of analysis i.e. modal analysis and also on consideration of proper value of damping during second stage of analysis. Both these stages together form the random vibration response analysis. For achieving accurate prediction of natural frequencies, the first major challenge is to consider correct material properties for FE model. Normally the manufacturer specified material properties are considered, in order to save time. However significant amount of deviation exists between measured properties and those specified by manufacturer. Second major challenge is to model the boundary conditions of the PCB accurately. Incorrect consideration of boundary conditions will influence vibration response prediction to a large extent. For ease of modeling rigid links are used to simulate the securing of the PCB to the chassis and constrain both the translational and rotational degrees of freedom. This is not the real condition.

The following iterative steps are followed in finalizing the modeling strategy for universal application.

(i) Experimentally evaluate the material properties of the PCB for inputs into the FE model.

(ii) Random vibration test on PCB simulating the exact boundary conditions, to evaluate the response characteristics both in terms of the frequencies (modes) as well as the vibration levels in terms of g_{rms}.

(iii) Modeling the boundary conditions, as rigid links, flexible links etc.

(iv) Implementing a damping value to match the vibration response.

(v) Changing the parameters of the screws, size, height and number of screws.

Finally, at the end of the iterative cycle, establishing the typical damping, stiffness of mounting and influence of the screw parameters on the results.

4.3 EXPERIMENTAL EVALUATION OF MATERIAL PROPERTIES FOR PCB

Figure 4.1 shows PCB considered for experimental evaluation of material properties for the present research work.

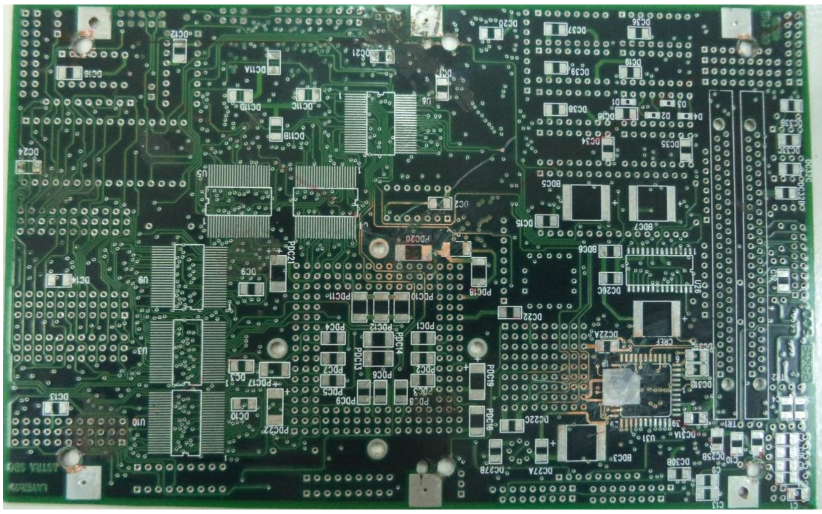


Figure 4.1 PCB-1 considered for evaluation of material properties

Details of PCB-1 are given below.

- Length: 216 mm
- Width: 150 mm
- Thickness: 1.6 mm
- Weight: 102 grams

Material properties of this PCB are evaluated experimentally by conducting tensile test with the help of strain gauge based universal testing machine (UTM). Load range used is 4.69 to 6.88 KN and strain components measured were 0°/90°. Figure 4.2 shows the test setup. Size of test sample considered is 120 mm x 25 mm.

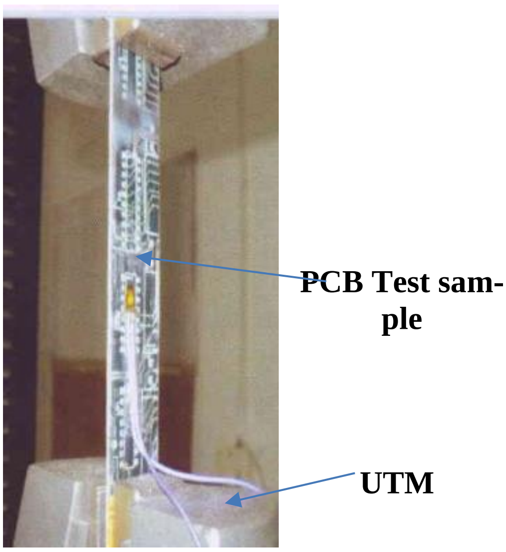


Figure 4.2 Test Setup

Figure 4.3 shows strain gauge bonded on test sample

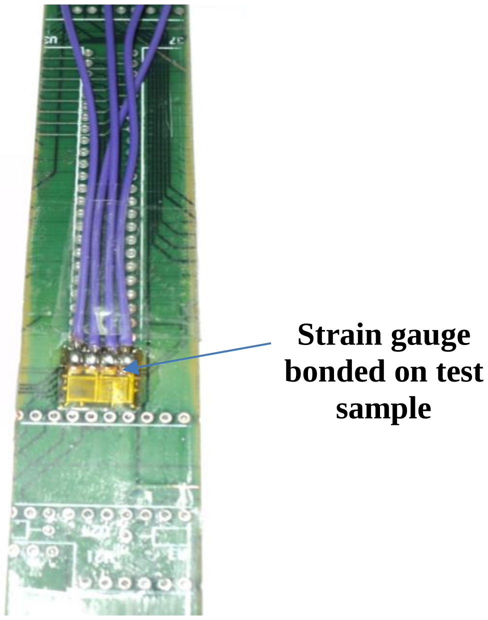


Figure 4.3 Test sample with strain gauge

Tensile strength-strain graph obtained from tensile test is shown in Figure 4.4.

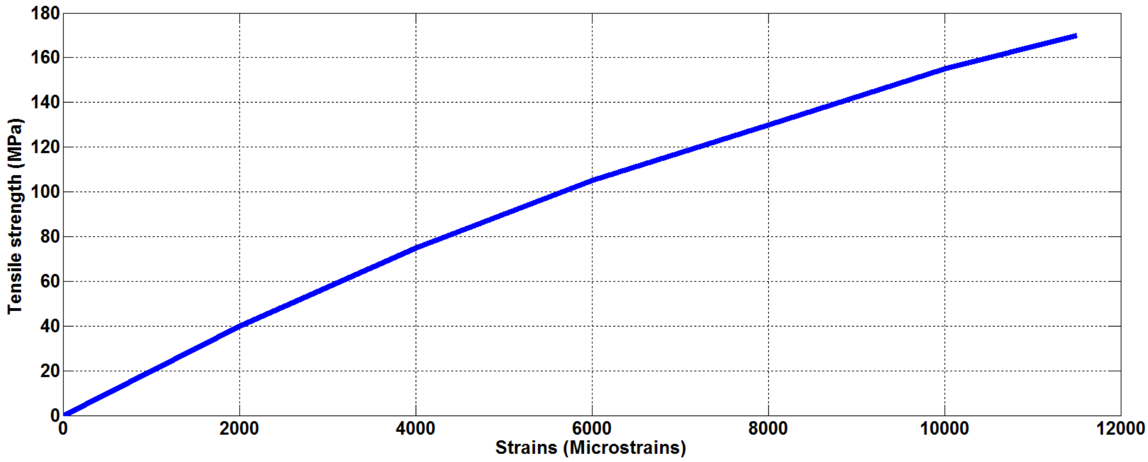


Figure 4.4 Tensile strength - strain graph obtained from tensile test

Material properties are listed in Table 4.1 (Young's modulus and Poisson's ratio) obtained through tensile testing for which specimen preparation and testing has been done as per standard ASTM D3039. PCB-1 specimens were tested for density as per standard ASTM D792.

Table 4.1 Material properties derived experimentally

Sl. No.	Property	Value
1.	Young's modulus	19 GPa
2.	Poisson's ratio	0.22
3.	Density	2190 kg/m^3

However, it is not possible to evaluate shear modulus using UTM. **Amy** [14] proposed four point bend test scheme as shown in Figure 4.5 for evaluating shear modulus.

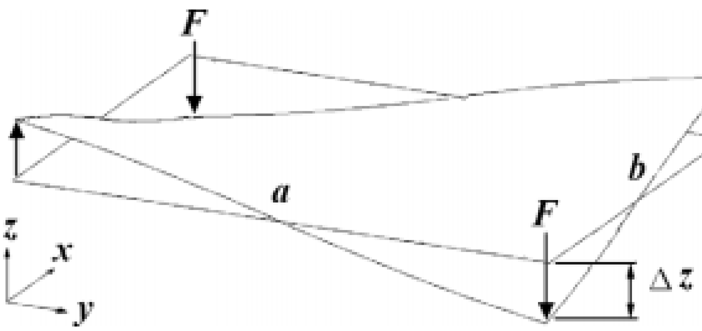


Figure 4.5 Four-point bend test scheme proposed in reference

Based on this an in-house test setup has been devised in the laboratory for evaluating shear modulus. PCB-2 which is identical to that of PCB-1 with respect shape and size is considered for evaluating shear modulus. Figure 4.6 shows the test setup.

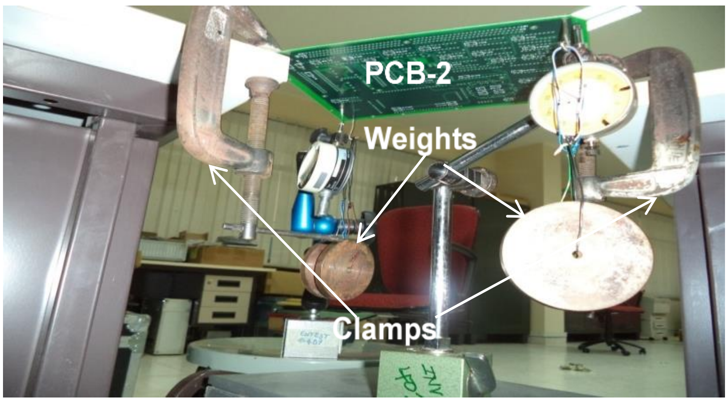


Figure 4.6 Laboratory test setup for evaluating shear modulus

In this setup diagonal corners (opposite) of the PCB were clamped and other diagonal corners were gradually loaded equally. Then the deflection is measured at loaded corners for each load set. By varying the load, the variation observed in deflection has been plotted. Slope of this curve gave torsional stiffness from which, shear modulus has been estimated using the following relation

$$G_{xy} = \frac{3K_t ab}{4t^3} \quad \text{................4.1}$$

Where:

K_t: Torsional stiffness (Nm/rad)

a: Length of PCB (m)

b: Width of PCB (m)

t: Thickness of PCB (m)

Figure 4.7 shows the load vs. deflection graph.

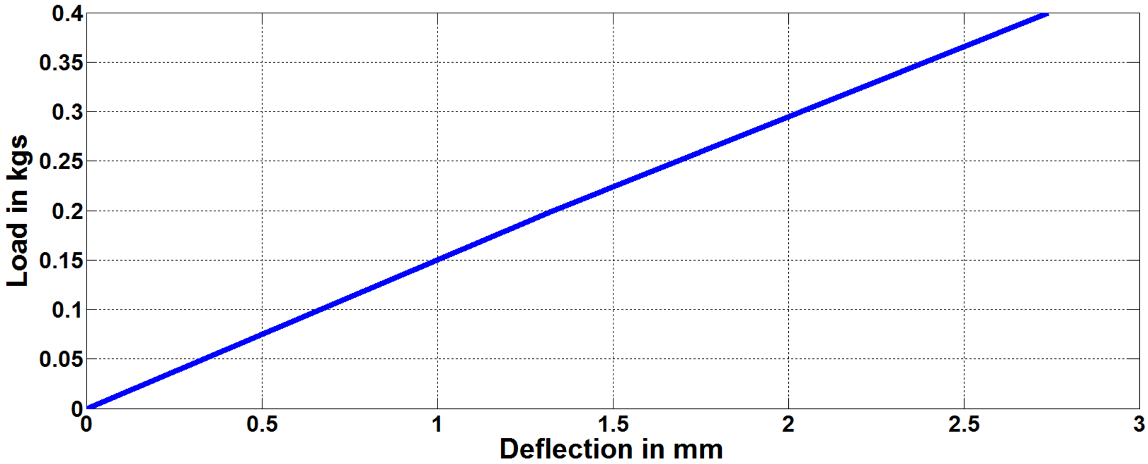


Figure 4.7 Load vs. deflection graph

Shear modulus thus evaluated for PCB-2 is 6 GPa. Consistency of the proposed test method has been checked for two other PCBs (PCB-3 and PCB-4) and the shear modulus values were observed to be identical as given in Table 4.2.

Table 4.2 Shear modulus values

Sample No.	**PCB size**	**Value obtained**	**Actual value as per literature**
1	210 mm x 140 mm x 1.6 mm	6 GPa	6 GPa
2	205 mm x 130 mm x 1.6 mm	6 GPa	

Every Method proposed comes with its own limitations, in terms of feasibility, or range etc. To establish the limitations of this method, another PCB , PCB-5 with a size of 160 mm x 60 mm x 1.6 mm thickness is considered. Shear modulus obtained for this PCB is 9 GPa which is far from reality i.e. 6 GPa. This highlights the limitation of using the proposed method for relatively stiffer PCBs. From this exercise we can say four-point bend test can be used effectively for evaluating shear modulus of PCBs having stiffness up to 2.5 N/m, with reasonable accuracy.

4.4 RANDOM VIBRATION TEST ON PCB

Details of key elements of test set up are given below

- Electro-dynamic shaker
- Accelerometers
- Fixture

4.4.1 ELECTRO DYNAMIC SHAKER

The electro-dynamic shaker used for carrying out present project work is shown in Figure 4.8.

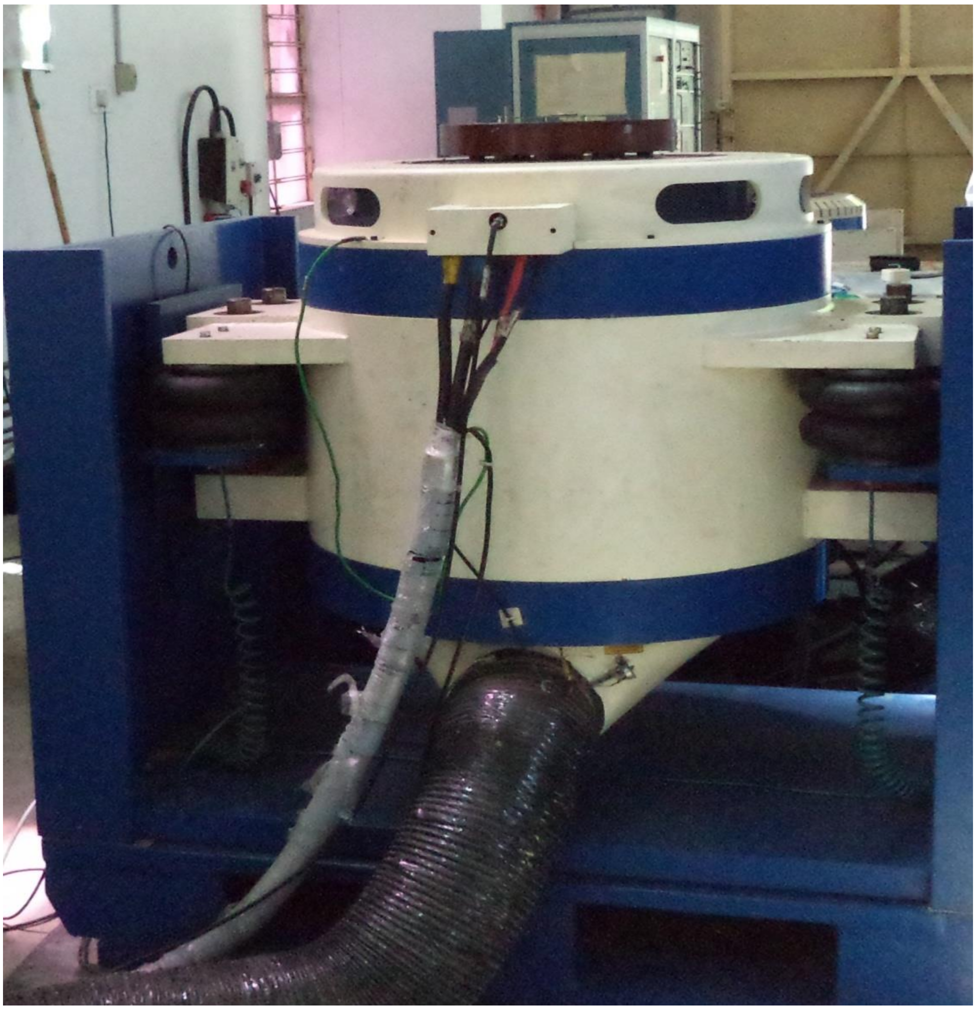


Figure 4.8 Shaker used in the present research work

The detailed specifications of the shaker used for this work is described in a tabular format as shown in table 4.3.

Table 4.3 Specifications of the shaker used in the present research work

Parameter	**Specifications**
Model	SEV 200
Armature Diameter	300 mm
Rated Force	2000 kgf peak SINE 2000 kgf rms RANDOM 4000 kgf, Peak SHOCK

Maximum Acceleration	Above 60 ‘g’ Peak
Velocity (0-p) (p=peak)	1.70 m/sec
Displacement (p-p)	51 mm with over travel inter lock (continuous duty)
Effective mass of Armature	34 kg
Useful frequency range	5 Hz to 2000 Hz
Armature Resonance	Above 2800 Hz
Pay Load Capacity (with Pneumatic ILS)	400 kg
Working Ambient Temperature Range	5-45^0 C
Stray Magnetic Flux	<5 gauss at 150 mm

4.4.2 ACCELEROMETERS

Miniature uniaxial accelerometers with built in signal conditioners are used during experiments. Figure 4.9 shows the miniature accelerometer used for the test. The accelerometers are mounted at different locations on the PCB to measure the response.

Figure 4.9 Accelerometer used in the test.

The specifications of the accelerometers are given in Table 4.4

Table 4.4 Specifications of the accelerometer used

Model No.	**340A15 (Make: PCB)**
Performance	**SI**
Sensitivity	10 mV/g
Measurement Range	± 500 g peak
Frequency Range (± 5%)	1 to 12000 Hz
Frequency Range (± 3dB)	0.35 to 25000 Hz
Resonant Frequency	≥50000 Hz
Environmental	
Overload Limit (Shock)	±10k g peak
Temperature Range (Operating)	-55 to +125^{0}C
Electrical	
Excitation Voltage	18 to 30 VDC
Constant Current Excitation	2 to 20 mA
Physical	
Sensing Element	Ceramic
Sensing geometry	Shear
Housing Material	Titanium
Sealing	Hermetic
Size	8.0 X 10.9 mm
Weight	2.0 gm
Electrical Connection	M3 Coaxial
Electrical Connection Position	Side
Mounting Thread	M3 X 0.5 Male
Mounting Torque	90 to 135 N-cm

4.4.3 FIXTURE

A vibration fixture is essentially an interface between the shaker and the unit under test. This interface becomes essential because the shaker comes with a standard set of mounting patterns. This pattern may not be inter faceable with the units under test. The Units Under Test (UUT) has its own mounting provisions as would be required as per its service conditions or requirements. The fixture helps in forming this interface. The fixture is mounted on the shaker and the UUT is attached to the fixture using appropriate screws / bolts. It is endeavored to transfer the vibration from the shaker to the UUT faithfully without much amplification or attenuation. The vibration controller ensures, this requirement. However, for this to happen, the fixture design needs to be professionally done while ensuring certain essential requirements as described below.

A vibration fixture needs to have the following characteristics.

(i) Must be light weight, so that the available shaker force is not unproductively utilized.

(ii) Must be stiff enough to have a higher natural frequency, so that the number of vibration modes within the frequency band of testing would be minimum. This will ensure little or no amplification as it would be within the dynamic range of the controller.

(iii) The fixture must have enough damping, so that even if a vibration mode is present the peaks are limited, to fall within the controller dynamic range. Hence, Aluminium or Magnesium (having higher damping coefficient) is the preferred choice.

(iv) It is essential to design the fixture to exactly simulate the service mounting condition of the equipment's under test. This is necessary because the vibration modes are entirely dependent on the end conditions.

(v) Sometimes, it may so happen that the size of the test article is larger. In such cases it is required to ensure that there is no overhang of the test article from the base of the fixture. Hence an expanding fixture is to be designed to ensure this.

(vi) The fixture must be so designed that the center of gravity of the fixture along with its mounted test article is as close as possible to the axis of the shaker armature. This would avoid any eccentricity and moment loads on the bearings of the shaker.

A fixture has been selected meeting all the above requirements and used for the present work and is shown in Figure 4.10.

Figure 4.10 Fixture used for the present research work

Random vibration test has been conducted on the PCB-6 which has been mounted on a shaker with the help of four M3 screws (Standoffs) of 7 mm height.

Details of PCB-6 are given below.

- Length: 216 mm
- Width: 150 mm
- Thickness: 1.6 mm
- Weight: 102 grams

Figure 4.11 shows two accelerometers mounted on PCB-6 for measuring the vibration response.

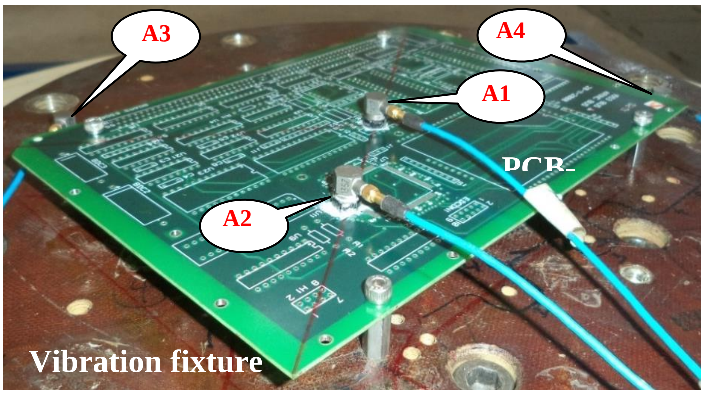


Figure 4.11 Test set up

Where:

A1 (Accelerometer-1): To measure the response at location 1 on PCB

A2 (Accelerometer-2) : To measure the response at location 2 on PCB

A3 (Accelerometer-3) : Input to the PCB coming from fixture } average control

A4 (Accelerometer-4) : Input to the PCB coming from fixture } is used

Test results are discussed in the later section.

The input vibration spectrums as given in Table 4.5 was considered for the test.

Table 4.5 Vibration input for case-1

FREQUENCY, Hz	**ACCELERATION, g^2/ Hz**
20	0.0002
100	0.005
1000	0.005
2000	0.00125

Vibration input mentioned in the above table is fed to the vibration shaker and the same is shown in form of graph in Figure 4.12, which is as per MIL-STD-810G .

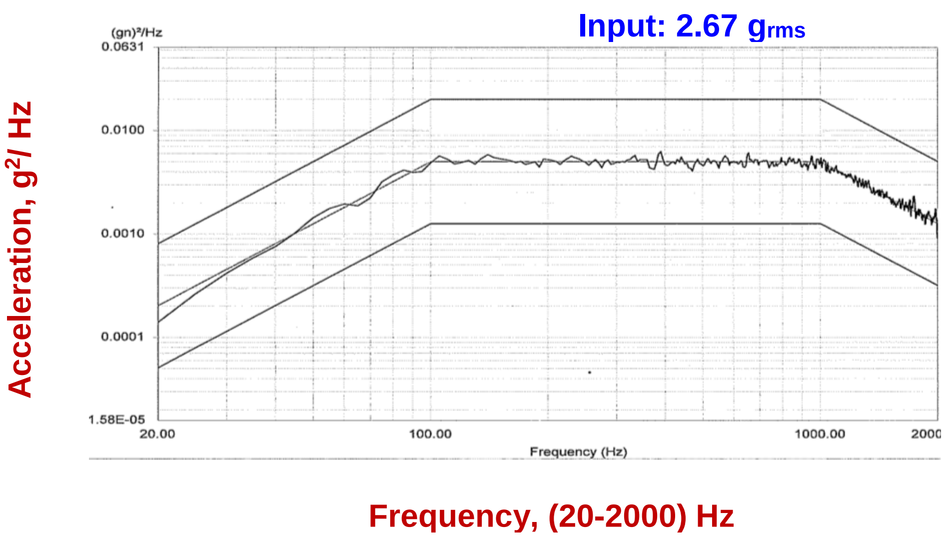


Figure 4.12 Vibration input spectrum graph

4.5 FINITE ELEMENT ANALYSIS

Various commercial software packages are available for carrying out Finite Element Analysis (FEA). Following steps are involved in FE analysis.

- Preprocessing
  - Geometry modeling, Meshing, Boundary conditions, Loads ,etc
- Solution
  - Solving the model
- Post processing
  - Viewing the results

Out of all these steps preprocessing takes more time. Accordingly, software should have appropriate graphic features to accomplish preprocessing quickly and with ease. NX-IDEAS software has such features, which meets above mentioned requirement. Further different softwares use different algorithms to perform analysis during solution process. Accuracy of the predicted results is also influenced by mathematical competence of the algorithm. Block Lanczos algorithm is renowned with respect to accuracy which is possessed by ANSYS software. NX-IDEAS software is good at preprocessing capabilities but makes use of normal Lanczos algorithm for solution which is relatively less accurate compared to that of Block Lanczos algorithm. ANSYS software is good at accuracy but very inferior with respect to preprocessing capabilities. No single software offers optimal solution for addressing both ease of use and accuracy. Based on this experience all preprocessing was done in NX-IDEAS software and then the model was exported to ANSYS software for analysis.

PCB-6 was discretized with four nodded quadrilateral shell elements (SHELL 63), which exhibit both bending and membrane capabilities. Both in-plane and normal loads are permitted. SHELL 63 is an element having 6 DOF at each node constituting, translations in the x, y, and z directions and rotations about the x, y, and z-axes, about the nodes. Thickness needs to be keyed in as real constant. The model is verified to ensure that the influence of the mass of the accelerometer is negligible by comparing the frequencies obtained with and without the mass of the accelerometer. The density of this PCB is increased until the weight of FE model matched with that of physical weight of PCB with accelerometers used for test. Thus, the effect of accelerometer got nullified by including it in the mass of PCB. Measured material properties mentioned in Table 4.1 were considered for the analysis. All three translational DOF were fixed. Rotational DOFs were modeled using rotational spring elements. Two types of spring elements are available in NX-IDEAS software [13] as shown in Figure 4.13 and Figure 4.14.

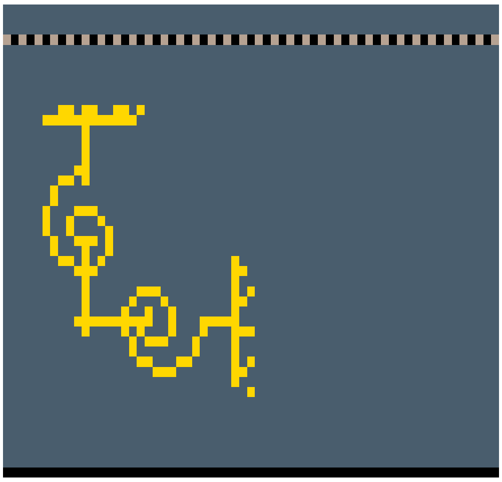


Figure 4.13 Ground to node type spring element

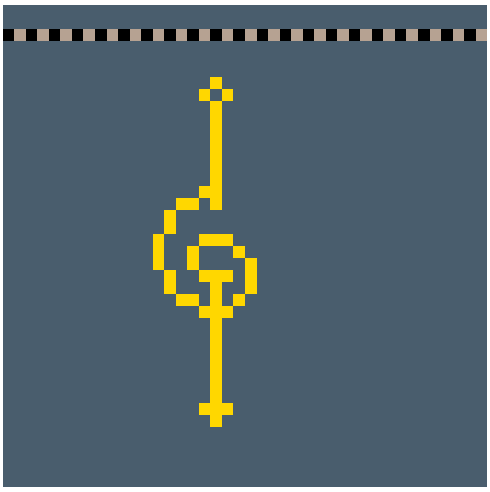


Figure 4.14 Node to node type spring element

Desired attributes for the present research work along with respective compatibility of these two elements is given in Table 4.6

Table 4.6 Comparison between Ground to node & Node to node type rotational spring element

Sl. No.	**Desired attribute for present research work**	**Ground to node type rotational spring element**	**Node to node type rotational spring element**
1.	Option to key in three rotational stiffness values (Rot-x, Rot-y and Rot-z)	Meeting	Not meeting
2.	Tuning feature with which frequency should change by changing rotational stiffness value	Meeting	Meeting
3.	Compatibility with ANSYS software when imported from NX-IDEAS	Not meeting	Meeting

As the above table implies none of the two spring elements meet the present requirement. To overcome this problem node to node type spring element which is supported by ANSYS is custom modified to ground to node type which suits for present requirement (By having coincident nodes and grounding one node).

Rotational stiffness of the spring elements was continuously tuned until the first natural frequency obtained using FEA matched with that obtained from random vibration test. Initial value and final values of spring rotational stiffness are 60 and 48 N-m/rad respectively. Values chosen for performing mesh quality check for the FE model is shown in form of screen shot in Figure 4.15 and no element failed the mesh quality check.

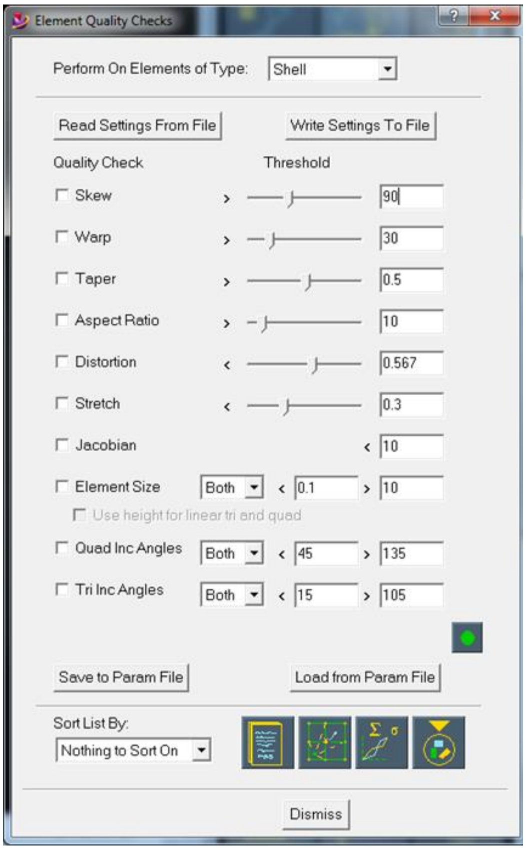


Figure 4.15 Values chosen for performing mesh quality check for the FE model

Figure 4.16 shows the FE model of PCB

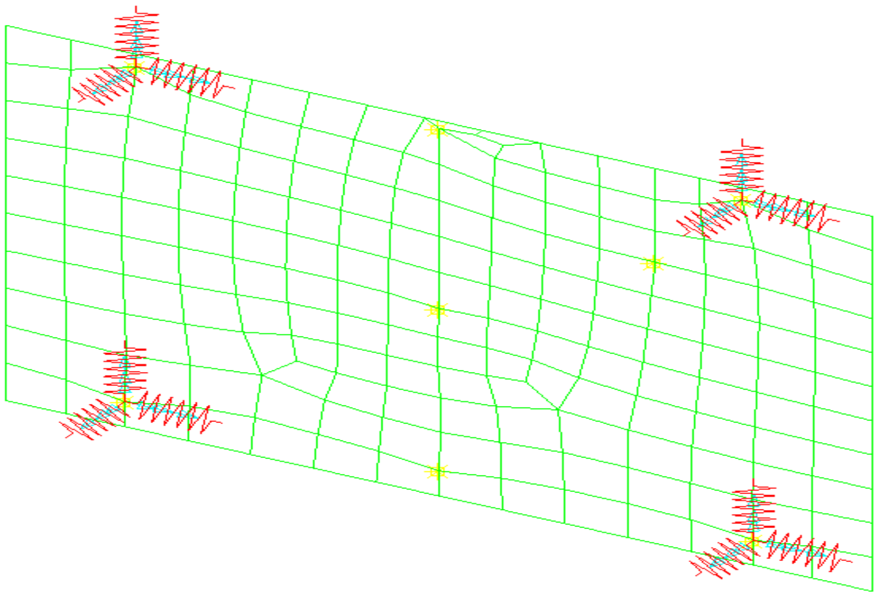


Figure 4.16 FE Model of PCB

Influence of mesh density on first natural frequency is shown in Table 4.7.

Table 4.7 Influence of mesh density

Number of Elements	First Natural Frequency	Second Natural Frequency
128	133 Hz	215 Hz
140	132 Hz	210 Hz
160	130.5 Hz	207 Hz
170	130 Hz	206 Hz
210	130 Hz	206 Hz

As shown in Table 4.7, mesh density has less influence on first natural frequency and in general it is seen that it has more influence on stress result in static analysis. Having matched the natural frequency, analysis has been extended for predicting random vibration response. Vibration input considered for test is also considered for analysis. Damping has been tuned until random vibration response obtained using FEA matched with that of test in the range of 1 to 1.5% respectively based on past experience. Even though damping as a function of frequency is more relevant, it would need elaborate experimentation to arrive at the values. Moreover, if we need to get an idea of the random response before the actual fabrication of PCB or the packages, which is the main objective of FEM, and this work, we need empirical values to be used which gives fairly accurate results in terms of the responses. Hence an equivalent flat damping value from measurement, which makes both test and FEA process simpler, is adopted. Figure 4.17 shows the typical random vibration response.

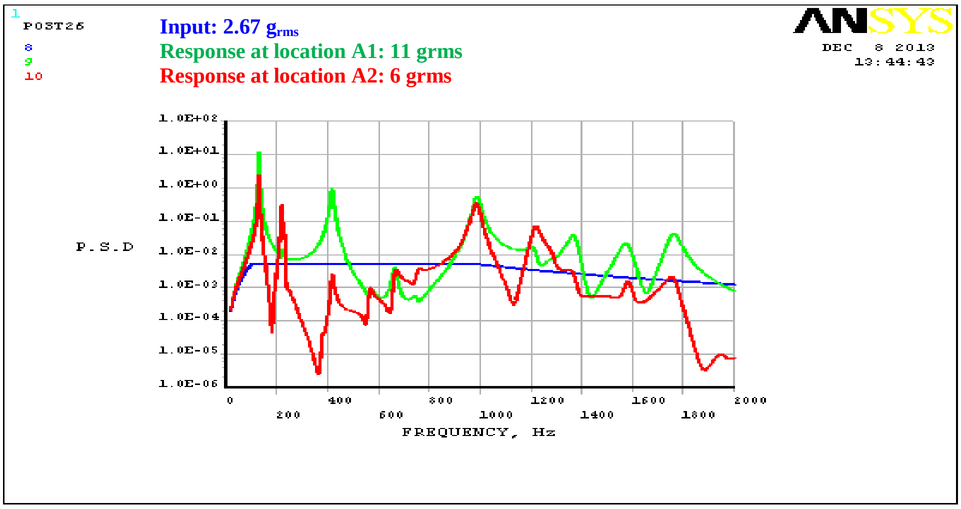


Figure 4.17 Typical vibration response

In practical scenario mounting configuration of PCBs (Height, size and number of screws) will vary from case to case, based on individual components heights. Accordingly, M3 screw (Stand-off) with 7 mm height, M4 screw with 7 mm height and 15 mm height (Different screw lengths are required depending on component height) are used for mounting PCBs as shown in Figure 8.1-8.3 at appendix respectively at page numbers 120 -121.

Exercise has been done to generate the data base consisting of tuned values of rotational stiffness and damping for different length of the screws used for mounting PCBs. Table 4.8 gives the outcome of the exercise.

Table 4.8 Comparison of results for PCB-6

Screw details			**Frequency (Hz)**		**Response Accelerometer- A1 (g_{rms})**			**Response Accelerometer- A2 (g_{rms})**			**Rotational stiffness (Nm/rad)**	**Damping**
Size	**Height**	**Number**	**Test**	**FEA**	**Test**	**FEA**	**% error**	**Test**	**FEA**	**% error**		
M3	7 mm	4	130	130	10.6	11	3.7	7	6	14	48	1.5 %
M4	7 mm	4	130	130	11.3	11.4	0.8	7.7	6.3	18.2	48	1.4 %
M4	15 mm	4	135	135	9.8	10	2	5.4	5.7	5.5	100	1.75 %
M4	15 mm	6	205	205	10.7	10.5	1.8	7.5	7.1	5.3	115	1.75 %

From the above-mentioned exercise the two major challenges in developing a good modeling practice for PCB have been addressed by establishing tuned values of rotational stiffness and damping for various mounting configurations of PCBs. This data is extremely useful in carrying out PCB level random vibration response analysis accurately.

Typical vibration response comparison between FEA and vibration test for PCB-6 with M4 screw having height 15 mm is given in Figure 4.18.

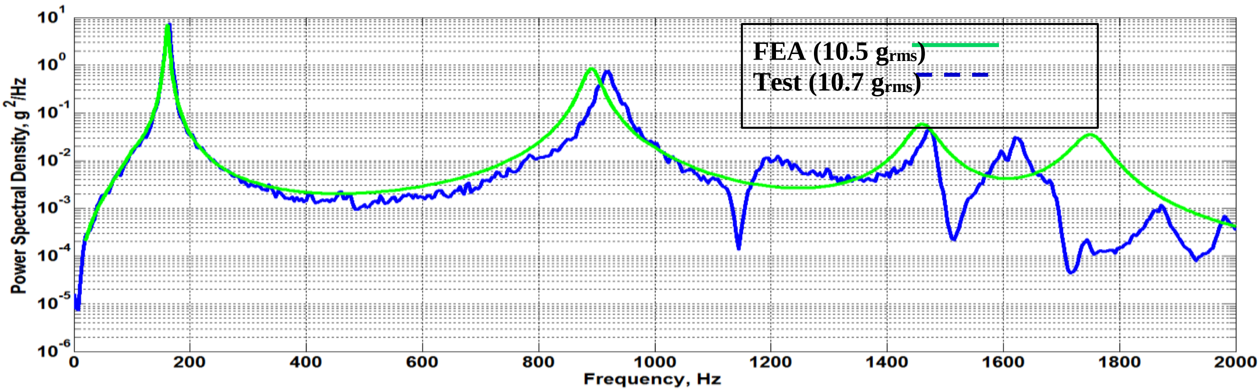


Figure 4.18 Typical random vibration response comparison between FEA and Test

Study has been extended further to exhibit the consistency associated with the rotational stiffness and damping values established. To accomplish this task, two more PCBs (Different in size but same in geometry) have been considered and FE analysis has been carried out to obtain the random vibration response by incorporating the rotational stiffness and damping values established previously, where in, measured material properties were considered for the analysis. Further random vibration test has been conducted on the same PCBs. Response locations are same as that of PCB-6. PCB-7 is shown in Figure 4.19.

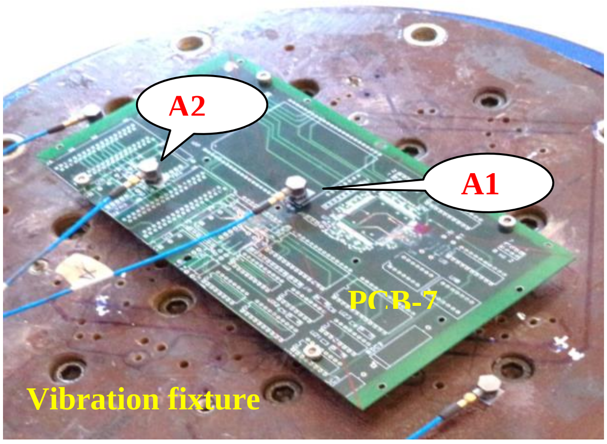


Figure 4.19 PCB-7

Where:

A1 (Accelerometer-1): To measure the response location 1

A2 (Accelerometer-2): To measure the response location 2

Details of PCB-7 are given below.

- Length: 216 mm
- Width: 117 mm
- Thickness: 1.6 mm
- Weight: 80 grams

Table 4.9 gives the comparison of results between FEA and test for PCB-7.

Table 4.9 Comparison of results for PCB-7

Screw details			Frequency (Hz)		Response Accelerometer- A1 (g_{rms})			Response Accelerome-ter- A2 (g_{rms})			Rotational stiffness (Nm/rad)	Damping
Size	Height	Number	Test	FEA	Test	FEA	% error	Test	FEA	% error		
M3	7 mm	4	150	150	9.2	10.2	10.8	5.7	5.7	0	48	1.5 %
M4	7 mm	4	150	150	9.8	10.5	7.1	6.2	6	3.2	48	1.4 %
M4	15 mm	4	155	155	10.6	9.6	9.4	6	5.2	13	100	1.75 %
M4	15 mm	6	305	304	15	14	6.6	7.6	7.8	2.6	115	1.75 %

PCB-8 is shown in Figure 4.20 which was used to check for consistency further.

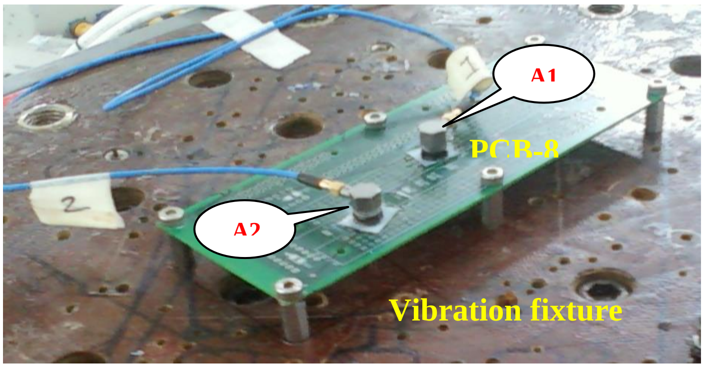


Figure 4.20 PCB-8

Where:

A1 (Accelerometer-1): To measure the response at location 1

A2 (Accelerometer-2) : To measure the response at location 2

Details of PCB-8 are given below.

- Length: 161 mm
- Width: 60 mm
- Thickness: 1.6 mm
- Weight: 34 grams

Table 4.10 gives the comparison of results between FEA and test for PCB-8.

Table 4.10 Comparison of results for PCB-8

Screw details			**Frequency (Hz)**		**Response Accelerometer- A1 (g_{rms})**			**Response Accelerometer- A2 (g_{rms})**			**Rotational stiffness (Nm/rad)**	**Damping**
Size	**Height**	**Number**	**Test**	**FEA**	**Test**	**FEA**	**% error**	**Test**	**FEA**	**% error**		
M3	7 mm	4	156	156	12.2	11.3	7.3	9.7	8.3	14.4	48	1.5 %
M4	7 mm	4	152	152	9.7	11.6	19.5	7.5	8.6	14.6	48	1.4 %
M4	15 mm	4	164	164	11.5	10.5	8.6	7.4	7.8	5.4	100	1.75 %
M4	15 mm	6	540	304	8.8	7.3	17	16	18	12.5	115	1.75 %

- Random vibration response obtained from FEA and test are observed to be in good agreement indicating the closeness associated with the modeling practice established in the current research work.

4.6 SUMMARY

The Material properties like Young's modulus, density and Poisson's ratio are experimentally evaluated with the aid of Universal testing machine. The shear modulus was evaluated using the four-point bend test. Use of the rotational spring elements in the modeling to replace the mounting of PCB with screws gave more accurate results with respect to the random vibration response. A data base consisting of tuned values of rotational stiffness and damping for various mounting configurations of PCB was established. With the model so developed consistency checks were done on more packages.

CHAPTER 5

MODELING PRACTICE FOR PCB WITH ELECTRONIC COMPONENTS ANALYSIS

5.1 INTRODUCTION

The modeling methodology for PCB level analysis was addressed in earlier chapters. The material properties of PCB were considered without the component population. Rotational spring element was used to simulate rotational degrees of freedom (DOF) of PCB. Rotational stiffness has been extracted from experimentation. Later damping was tuned until random vibration response predicted using FEA matched with that of random vibration testing and the typical values of rotation stiffness and damping for different conditions were generalized with the help of statistical data base and validated for similar other PCB's and the components and utility of the data base was established, for universal applicability (Within certain limits). Integrating the rotational stiffness and the damping, a model was developed and methodically validated with that of experimentation and its consistency was established. The next step in the development of the model is the inclusion of the components into the PCB and establishing the influence of different types of components, the population density on the PCB etc. The details of the work in this direction is documented in this chapter, finally bringing out an optimal model, yielding accurate and consistent results in terms of the frequency and the random vibration response with a comparative ease in the efforts involved in modelling.

5.2 MODELING STRATEGY

To begin with, PCB without components had been considered for the study in the earlier part. Material properties of the PCB were evaluated experimentally. Translational DOF were simulated using boundary conditions and rotational DOF using rotational spring elements. Stiffness of these elements was tuned, until the first natural frequency predicted using FEA, matched with that of test results and thus established rotational stiffness values necessary for modeling rotational boundary conditions in FEA. In the later stage damping was tuned until random vibration response predicted using FEA matched with that of random vibration testing. Exercise has been done to generate the data base consisting of tuned values of rotational stiffness and damping for various mounting configurations of PCBs. From the exercise it was clearly evident that random vibration response obtained from FEA and test were in good agreement indicating a good confidence that data base consisting of rotational stiffness and damping values established for various mounting configurations of PCBs is consistent in yielding accurate prediction of random vibration response. In order to study the effects of different types of components that are generally populated on the PCB, a step by step approach is followed.

The basic classification of components is

a) SMT
b) DIP

SMT'S are further mounted in two configurations on the PCB

a) With gap
b) Without gap

For this study three basic cases were considered.

Case 1: PCB with SMT without gap.

Case 2: PCB with SMT without gap and with DIP component

Case 3: PCB with combination of SMT without gap and with gap.

For the populated PC, the properties as established by the four-point bend test cannot be used. Hence a different approach was essential to be followed. In this context, the following logical approaches were considered and studied to find out which approach could result in precision modeling.

(i) Global mass smearing (GMS): In this approach the weights of the components mounted on the PCB are smeared on to the PCB as uniformly distributed. The mass density of the PCB is calculated taking into the consideration the weights of all the components.

(ii) Local stiffness smearing (LSS): To work out composite Young's modulus and density based on the relative volume fractions of components and PCB and to impart the same locally at respective component mounting locations. Which means entire PCB is divided into two regions. One is the bare PCB portion where no component exists for which Young's modulus and density of PCB material is considered. Second, where component is mounted on PCB for which composite properties are calculated as follows and same are considered for analysis.

Composite Young's modulus, $E = E_{PCB} \times v_{f\ PCB} + E_{component} \times v_{f\ component}$

In which

$V_{f\ PCB}$: Volume fraction of PCB in that region

$V_{f\ component}$: Volume fraction of component in that region

For example, If thickness of PCB is 2.4 mm and height of component in a particular region is 3 mm then total thickness will be 5.4 mm and volume fraction of PCB becomes 0.44 (2.4/5.4) and that of component becomes 0.56 (3/5.4).

Composite density is calculated in the similar lines using above mentioned relation and volume fractions.

(iii) Global Stiffness Smearing (GSS): To work out composite Young's modulus and density based on the overall relative volume fractions of components and PCB and to impart the same globally for the entire PCB. Which means volume fractions of PCB and components are calculated globally rather than dividing the whole PCB into two regions as mentioned earlier. For this the total volume of PCB with components is calculated and volume fractions are obtained by dividing individual volumes (Of PCB and all components together) with that of total volume.

(iv) Component modeling with solid Elements (SOLID)

(v) Component modeling with shell Elements (SHELL)

(vi) Component modeling with mass Elements (MASS)

This study is now extended for PCB having single electronic component which is SMT without gap (Case 1) to understand the dynamics associated and a better modelling approach without major complexity. The same material properties and rotational spring stiffness values along with damping established during PCB level study presented in the earlier chapter were also considered for PCB with electronic components. The approaches as listed out above from (i to vi) were considered for modeling electronic components.

In the later stage, the approach out of those stated above which yielded closeness in FE analysis results compared to that of test was considered for case 2 (PCB with three components out of which two were SMT without gap and third one is DIP) and case 3 (PCB with three components out of which two were SMT without gap and third one is SMT with gap).

5.3 RANDOM VIBRATION TEST ON PCB WITH ELECTRONIC COMPONENTS

As mentioned earlier, study has been carried out for PCB with electronic components. Random vibration test was conducted on PCB-7 having single electronic component which is SMT without gap (Case 1) which has been mounted on a shaker with the help of four M3 screws of 7 mm height.

Details of PCB-7 are given below.

- Length: 216 mm
- Width: 117 mm
- Thickness: 1.6 mm

Further experimentation has been extended for the same PCB with two additional components (case-2 and case-3). Figure 5.1 shows accelerometers mounted on PCB for measuring the vibration response for case-1.

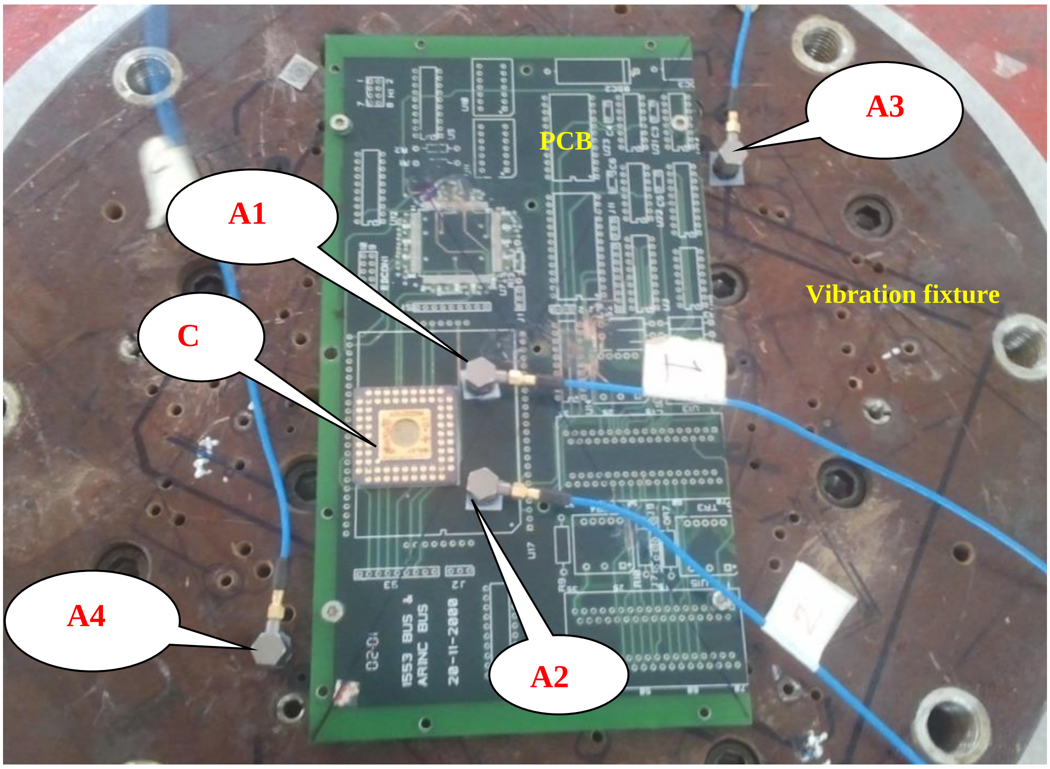


Figure 5.1 Test Setup for Case-1

Where:

C: Electronic Component

A1 (Accelerometer-1): To measure the response at location 1

A2 (Accelerometer-2): To measure the response at location 2

A3 (Accelerometer-3): Input to the PCB

A4 (Accelerometer-4): Input to the PCB

Details of accelerometer used for all the tests both control and responses are given in appendix. Page number 122.

Figure 5.2 shows accelerometers mounted on PCB for measuring the vibration response for case-2.

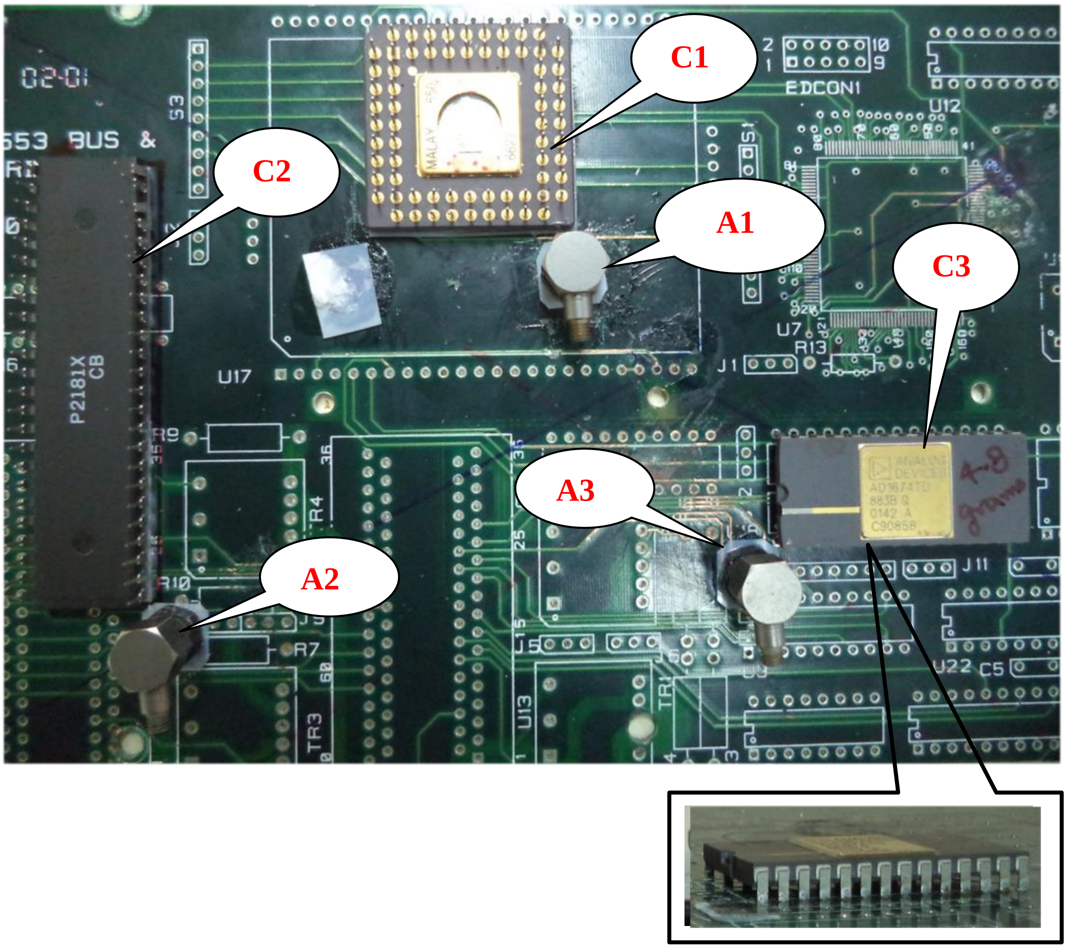


Figure 5.2 Test Setup for Case-2

Where:

C1: Electronic Component (SMT without gap)

C2: SMT component without gap

C3: DIP component

A1 (Accelerometer-1): To measure the response at that specific location

A2 (Accelerometer-2): To measure the response at that specific location

A3 (Accelerometer-3): To measure the response at that specific location

Figure 5.3 shows accelerometers mounted on PCB for measuring the vibration response for case-3.

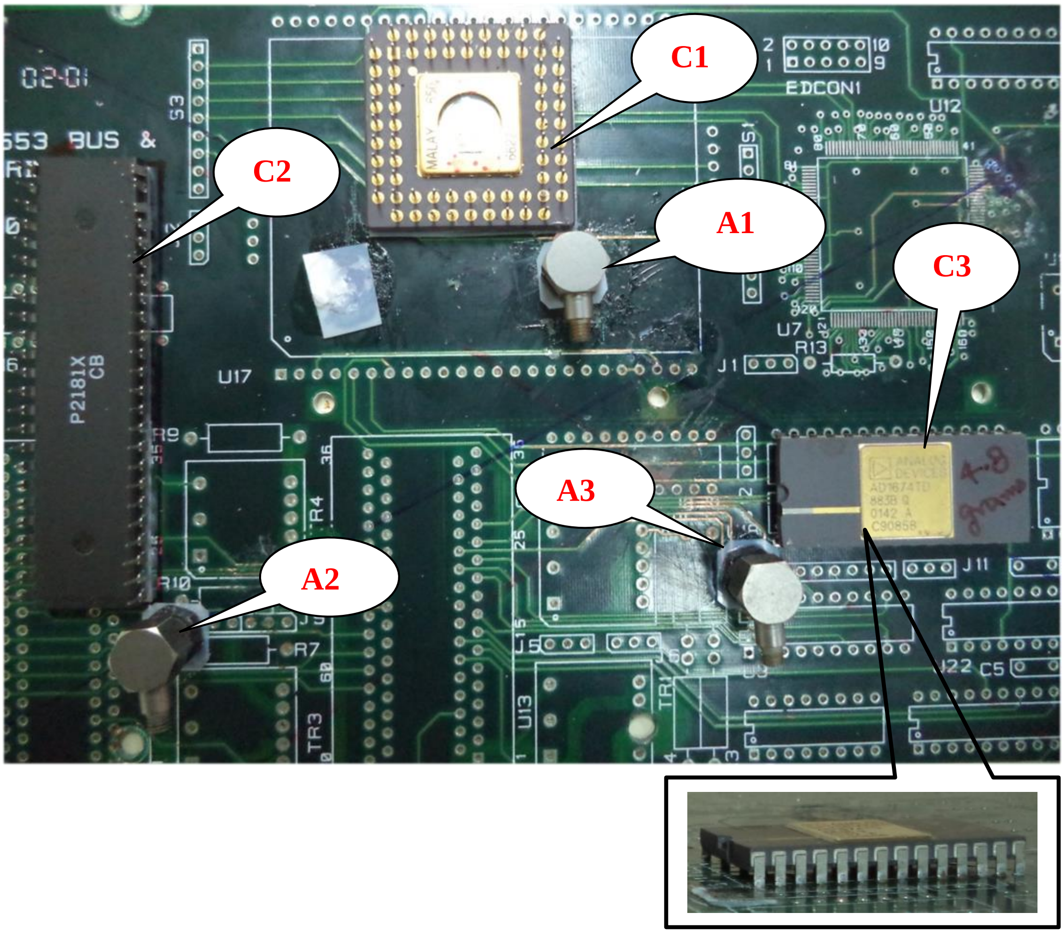


Figure 5.3 Test Setup for Case-3

Where:

C1: Electronic Component (SMT without gap)

C2: SMT component without gap.

C3: SMT component with gap.

A1 (Accelerometer-1): To measure the response at location 1

A2 (Accelerometer-2): To measure the response at location 2

A3 (Accelerometer-3): To measure the response at that specific location

The input given in Table 8.1 as shown in Appendix, at page number 122 and the corresponding spectrum in figure 8.4 .is the vibration input given to the shaker.

Test results are discussed in a later section.

5.4 FINITE ELEMENT ANALYSIS OF PCB WITH ELECTRONIC COMPONENTS

FE analysis is also carried out for the same 3 cases as that of the experimental work. As mentioned in earlier chapter all preprocessing was done in NX-IDEAS software and then the FE model of the PCB was exported to ANSYS software for analysis. PCB was discretized with four noded quadrilateral shell elements (SHELL 63). Initially, the six modeling approaches mentioned in section 5.2 were attempted for case-1. Experimentally evolved material properties for the PCB along with that of component given in Table 5.1 were used in the present work. However density of this PCB is increased until the weight of FE model matched with that of physical weight of PCB with accelerometers used for test. Thus the effect of accelerometer got nullified by including it in the mass of PCB.

Table 5.1 Material Properties of Components

Properties	**Electronic Components**		
	C1	C2	C3
Young's Modulus (E), GPa	16	1.9	1.9
Poisson's Ratio (ν)	0.3	0.3	0.3
Density (ρ),kg/m^3	3255	2425	2425

As mentioned earlier tuned values of rotational stiffness were incorporated for the rotational spring elements used to represent boundary conditions of PCB.

FE model of the PCB for case-1 is shown in Figure 5.4.

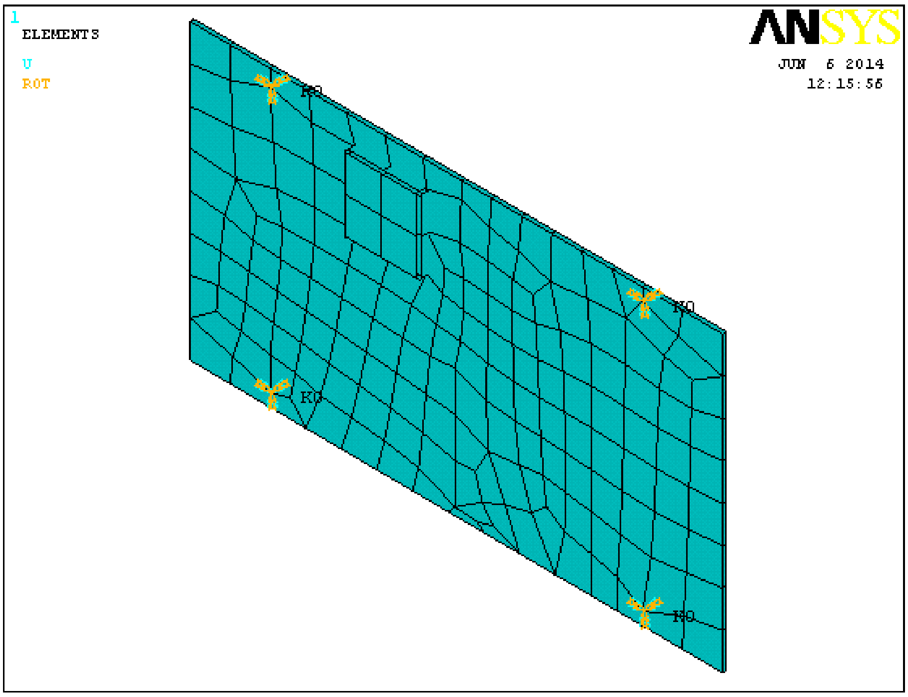


Figure 5.4 FE model of the PCB for case-1

Similarly tuned values of damping were implemented for carrying out random vibration response analysis.

5.5 COMPARISON OF FEA AND TEST RESULTS

Results obtained for all the 6 modelling approaches in FE analysis were compared with that of test with a view to evolve the best approach for PCB with components populated in it for predicting the random vibration response accurately.

Vibration response spectra corresponding to vibration test and FEA (GMS for all) for locations A1 and A2 for case-1 are shown in Figure 5.5 – Figure 5.8 respectively.

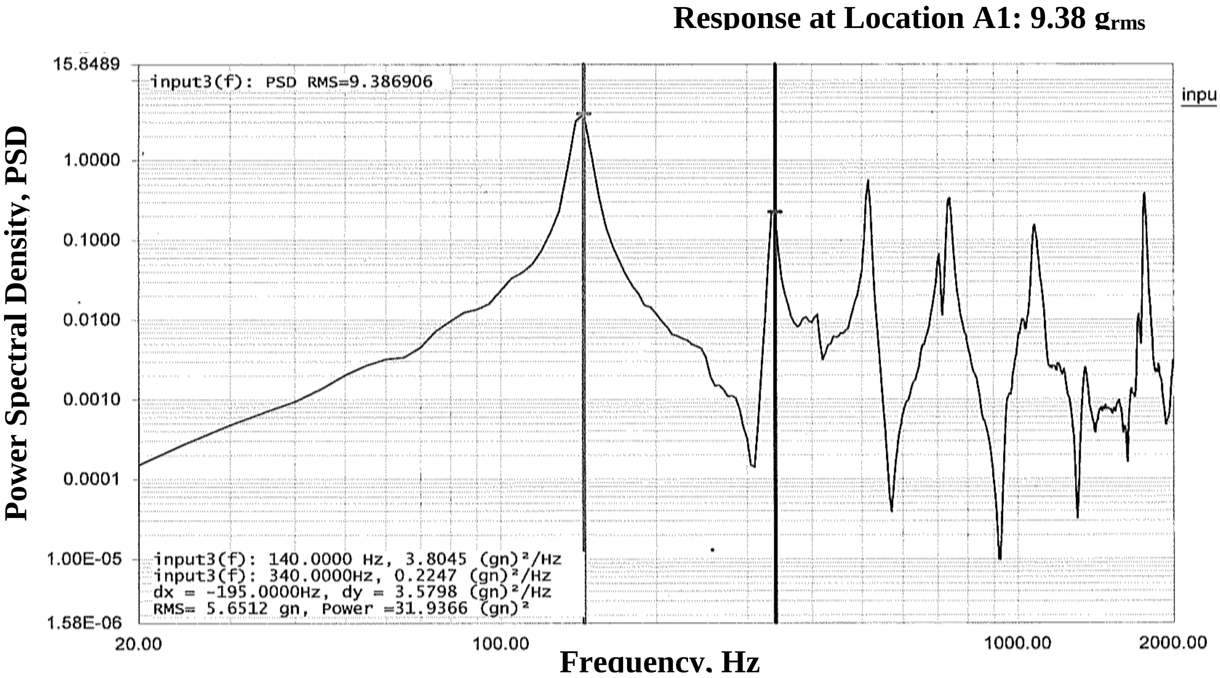


Figure 5.5 Vibration response spectrum: Case-1 (Measurement location A1-Test)

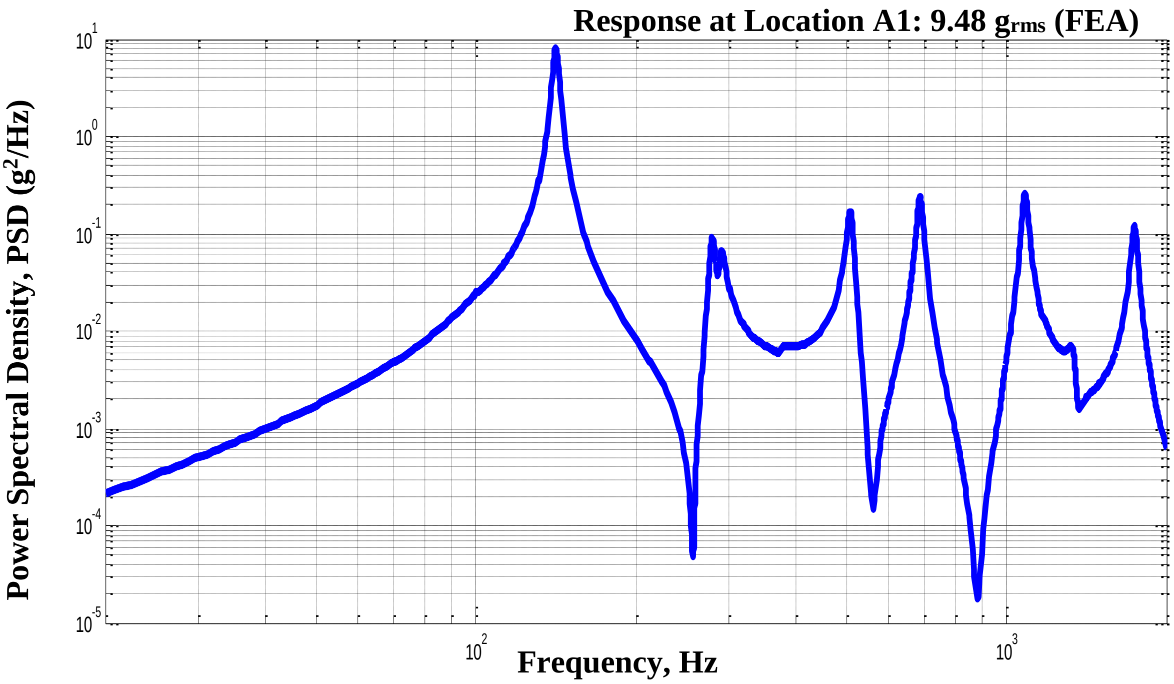


Figure 5.6 Vibration response spectrum: Case-1 (Measurement location A1-FEA)

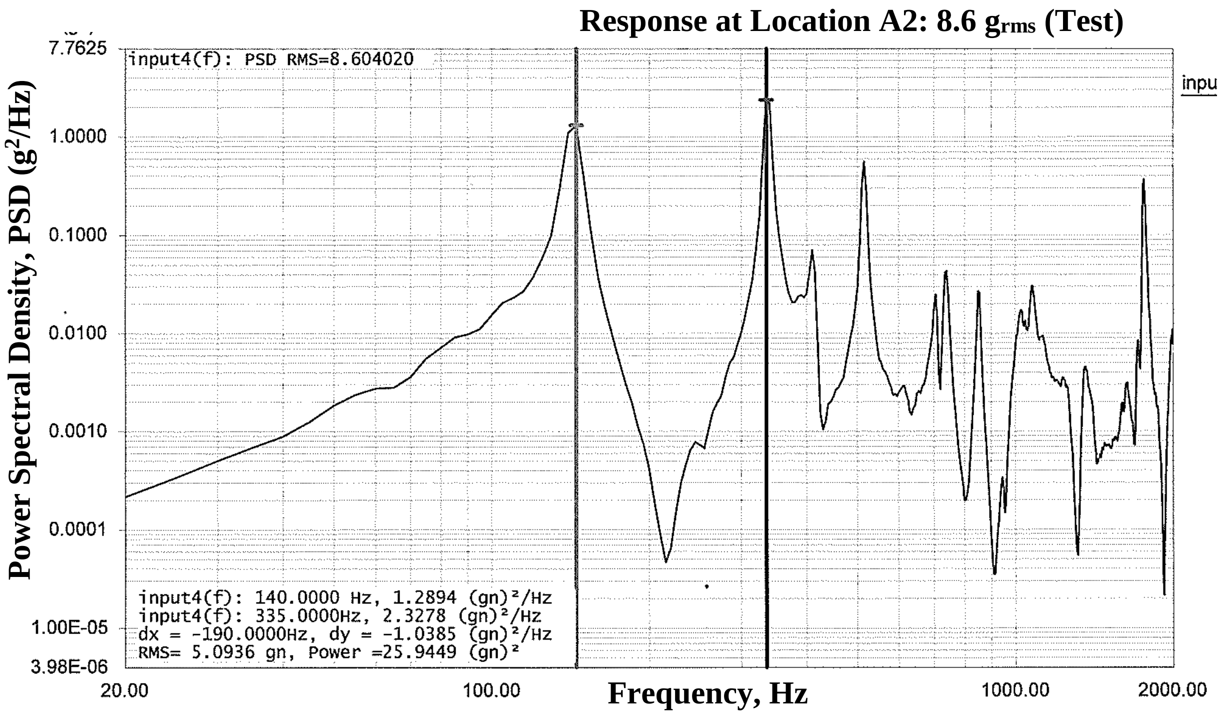


Figure 5.7 Vibration response spectrum: Case-1 (Measurement location A2-Test)

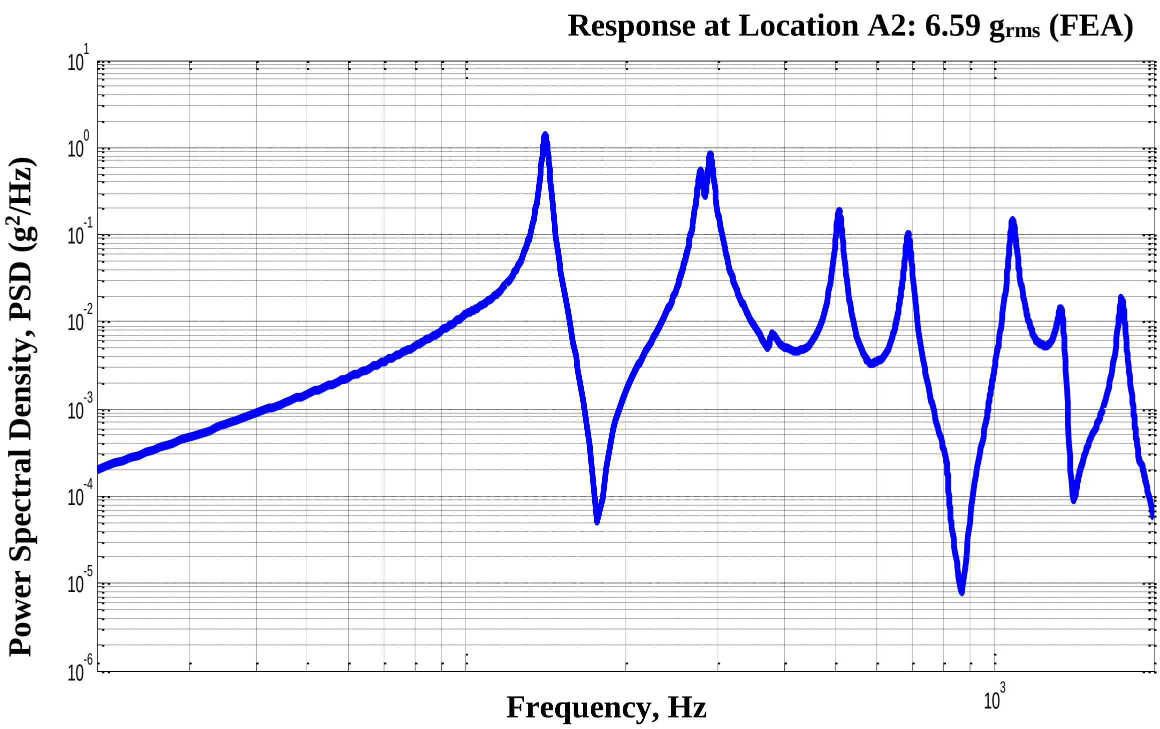


Figure 5.8 Vibration response spectrum: Case-1 (Measurement location A2-FEA)

Comparison of the results of the random vibration responses for case 1 (where the PCB is populated with SMT without gaps) is presented in Table 5.2.

Table 5.2 Comparison of FEA and test results for Case-1 (PCB with SMT's without gap)

Method	**Frequency (Hz)**	**Vibration response (g_{rms})**	
		A 1	**A 2**
Test	140	9.38	8.6
LSS	151	-	-
GSS	166	-	-
MASS	133	-	-
SOLID	139	9.19	6
SHELL	142	9.17	5.9
GMS	141	9.48	6.59

An analysis of the results in Table 5.2 highlights that local stiffness smearing; global stiffness smearing and the method of modeling components as mere mass are all resulting in the normal mode analysis (Step 1 in any random response analysis) itself yielding in-accurate frequencies of the normal modes with respect to the test. Hence it is concluded here itself that these three methods could be safely discarded as they would not be forming a model yielding accurate results, for a random vibration analysis. In further understanding of the reasons for this inaccuracy it could be concluded that in LSS (Local stiffness smearing) method and the GSS (Global stiffness smearing) the stiffness of components though considered completely, ignores the effects of the mass resulting in the frequency of analysis being higher than the actual test result. Similarly in the method where the components are being modeled as a mass, the effects of the stiffness is totally ignored and only the predominant mass effect is resulting in the analysis frequencies being lower than that of the test.

In the process of reduction LSS, GSS and the mass methods were not further subjected to random vibration analysis as obviously it wouldn't result in accurate results.

In case 2 and 3, two other components were added to the existing PCB having a single component. Out of these, the first and second components (C1 and C2) were modeled using GMS approach as it was found to be the best as can be seen from the fact that the responses obtained by GMS approach are relatively closer to the test values (As shown in the table 5.2). The third component (C3) which is mounted as DIP configuration in case-2 and SMT with gap in case-3 is modeled using SOLID, SHELL and GMS approaches so as to address case-2 and case-3 commonly. Thus, change in mounting configuration of third component alters experimentally obtained results alone but not FEA results.

Vibration response spectra corresponding to vibration test and FEA (GMS for all) for locations A1, A2 and A3 for case-2 are shown in Figure 5.9 – Figure 5.14 respectively.

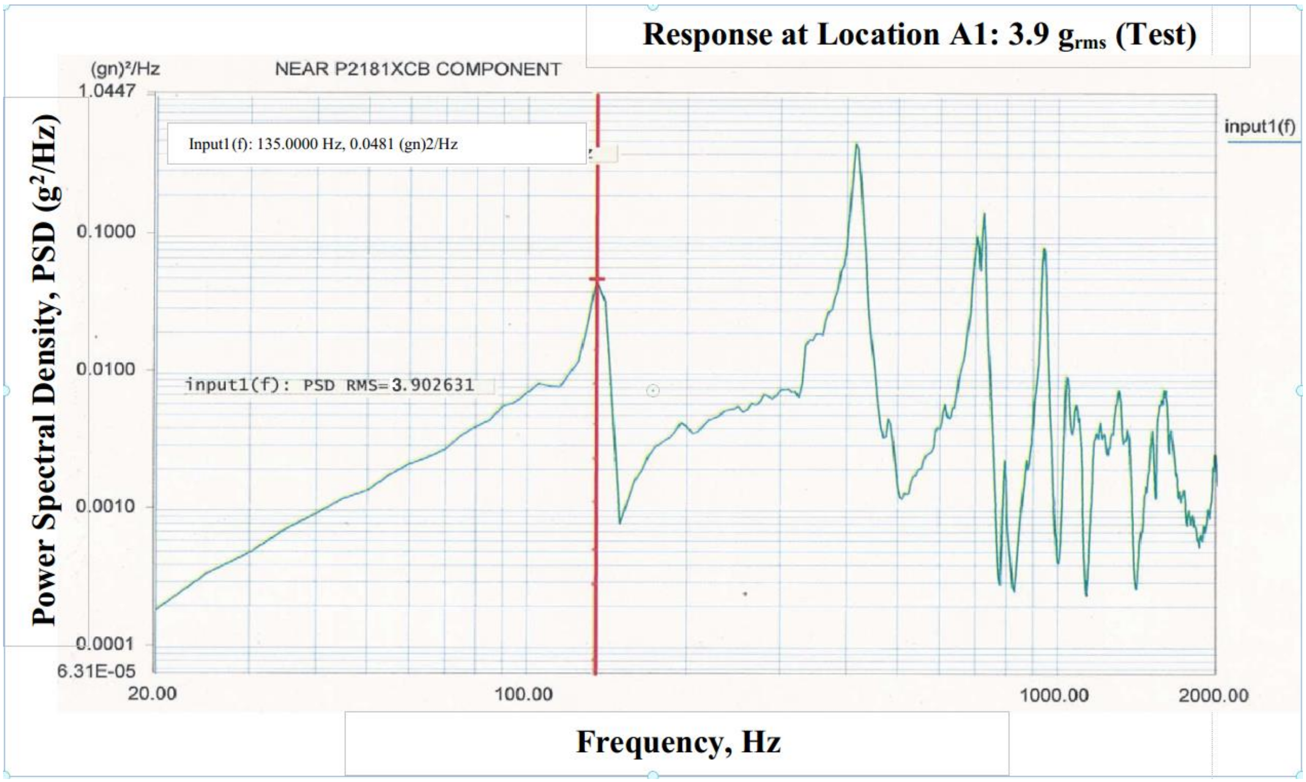


Figure 5.9 Vibration response spectrum: Case-2 (Measurement location A1-Test)

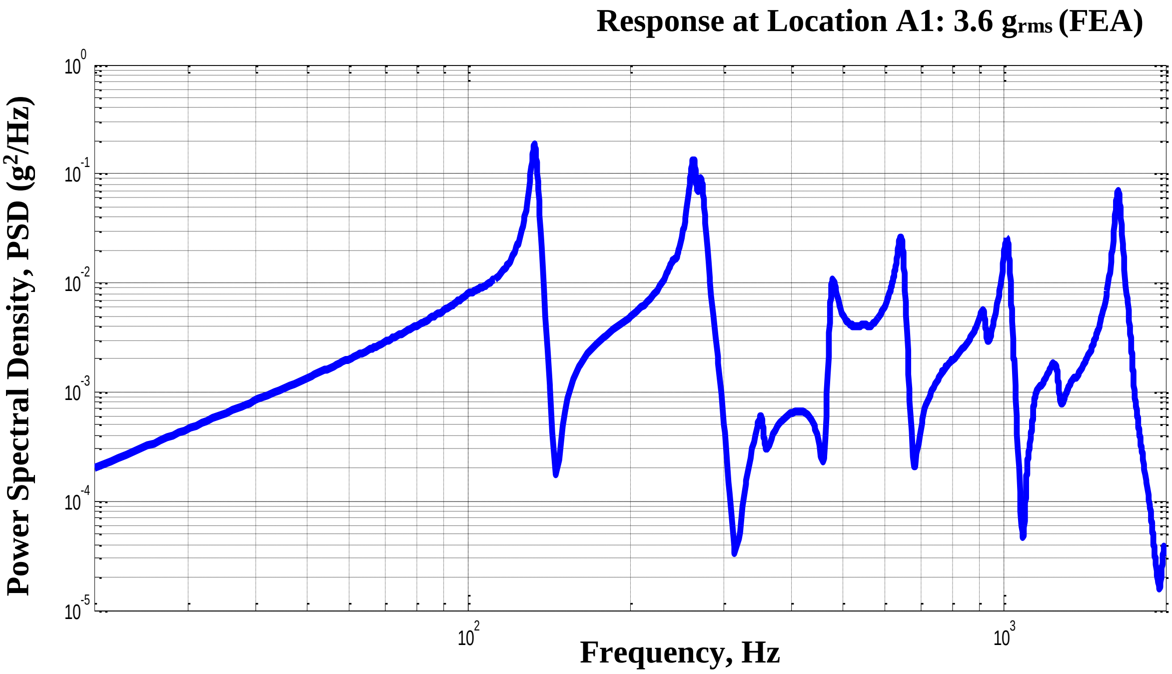


Figure 5.10 Vibration response spectrum: Case-2 (Measurement location A1-FEA)

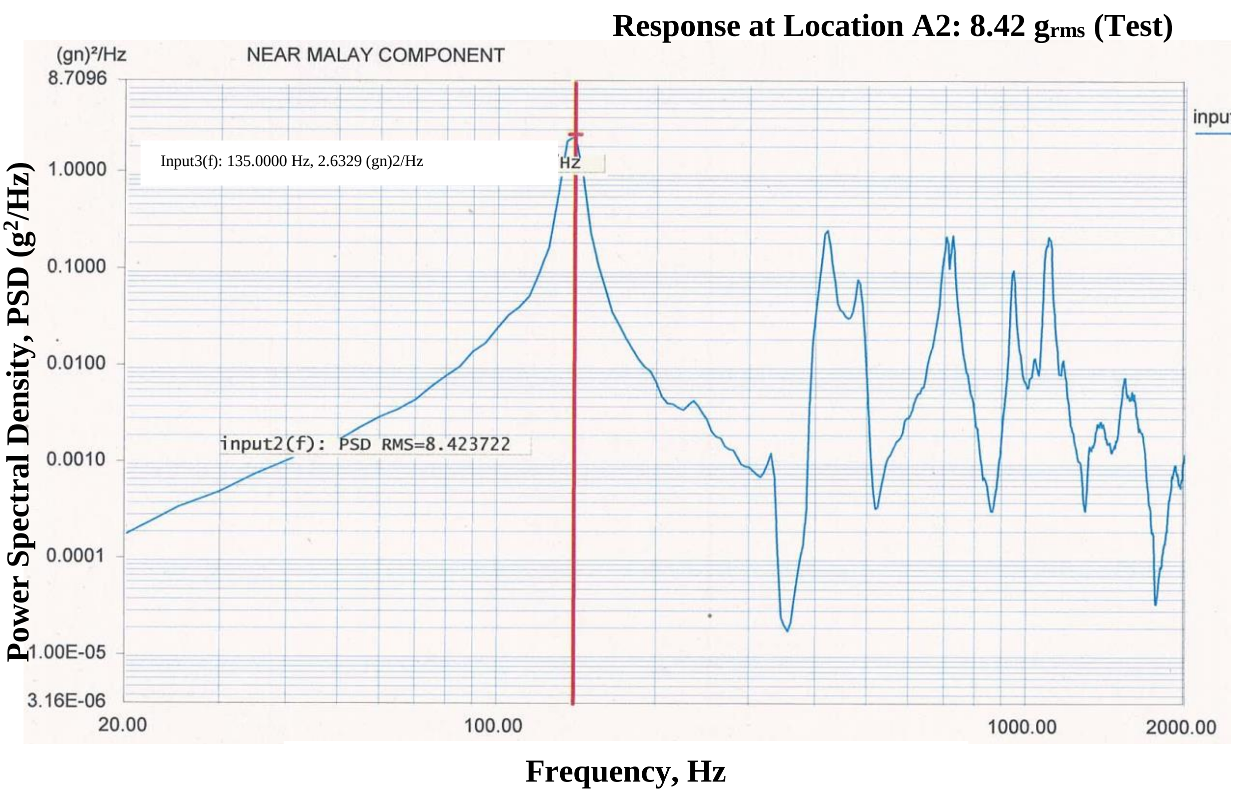


Figure 5.11 Vibration response spectrum: Case-2 (Measurement location A2-Test)

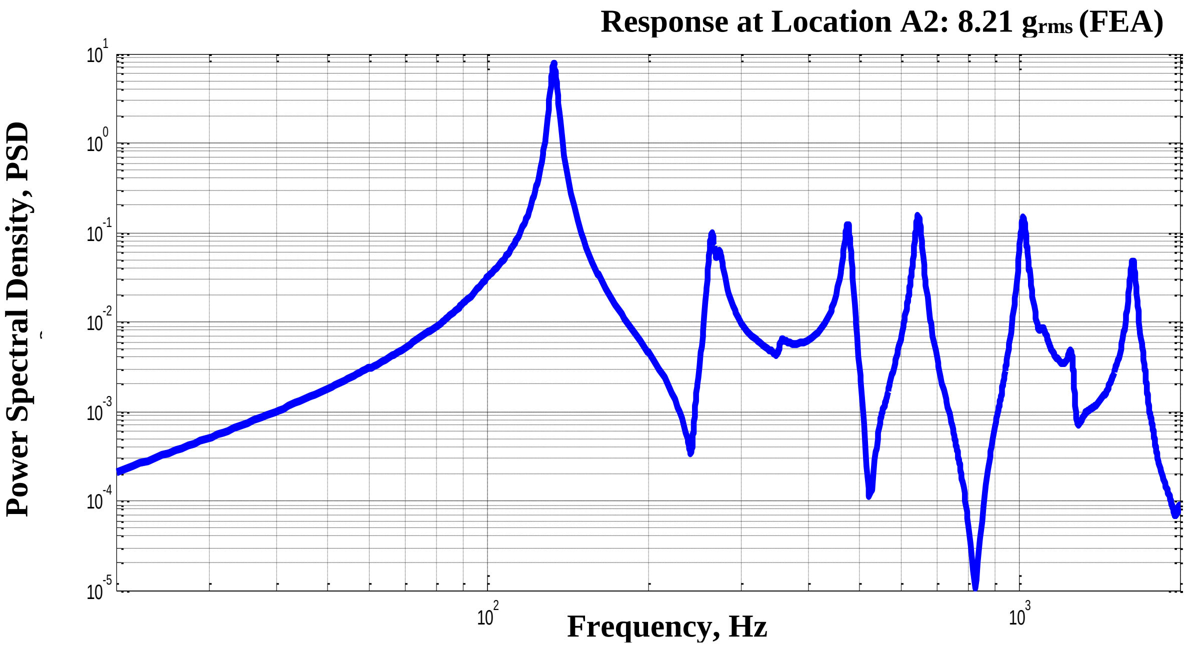


Figure 5.12 Vibration response spectrum: Case-2 (Measurement location A2-FEA)

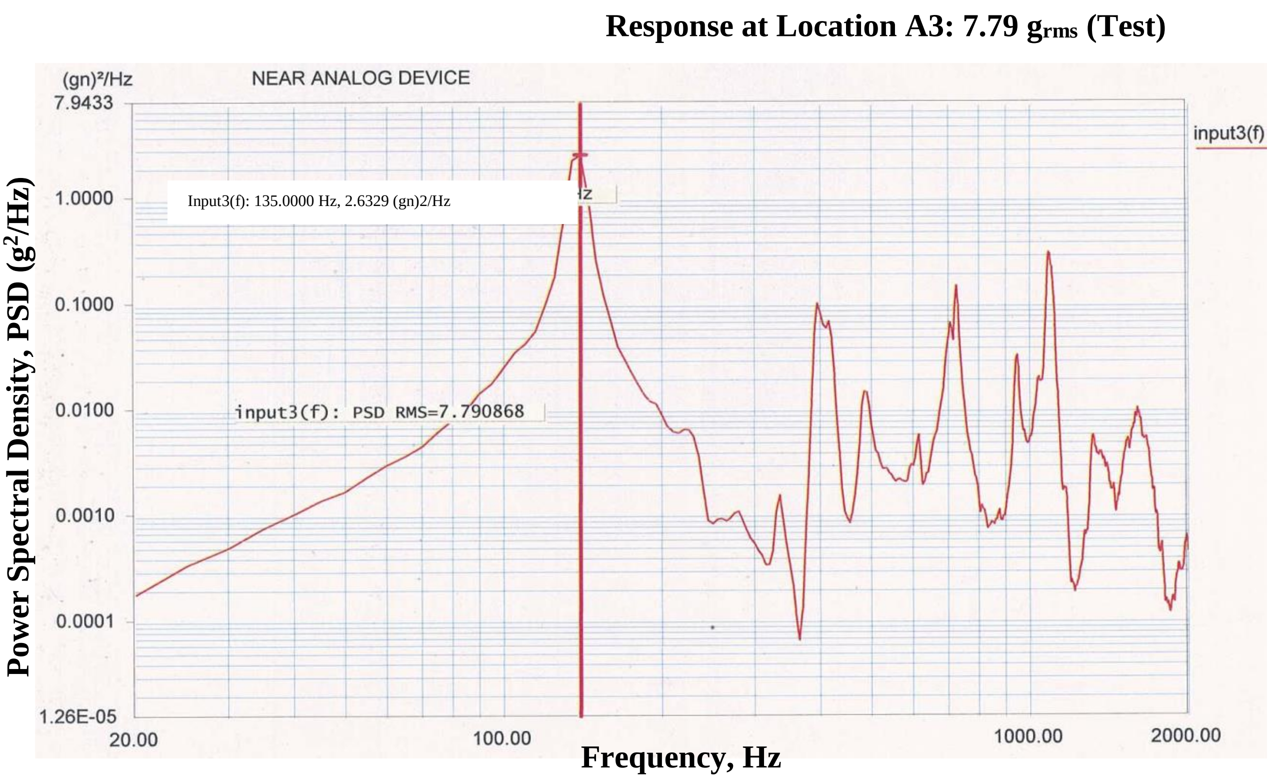


Figure 5.13 Vibration response spectrum: Case-2 (Measurement location A3-Test)

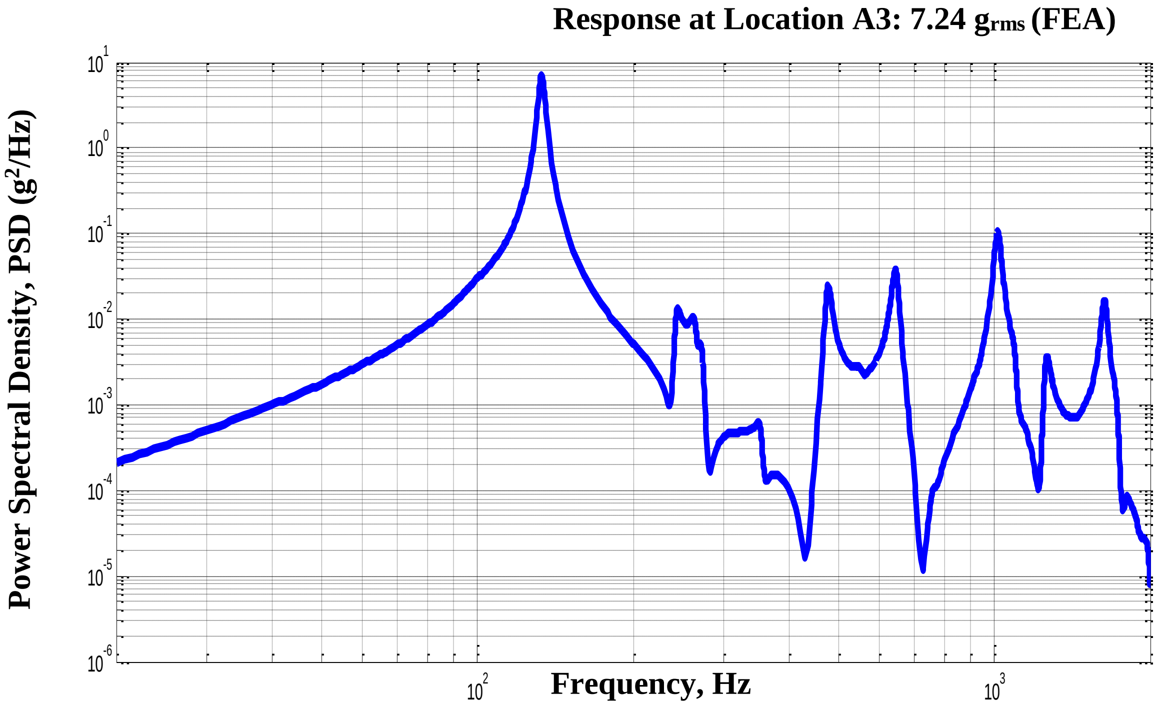


Figure 5.14 Vibration response spectrum: Case-2 (Measurement location A3-FEA)

The comparison of FEA and test results for case-2 is shown in Table 5.3.

Table 5.3 Comparison of FEA and test results for Case-2 (PCB with SMT without gap and with DIP)

Method	**Frequency (Hz)**	**Vibration response (g_{rms})**		
		A 1	**A 2**	**A 3**
Test	135	3.9	8.42	7.79
GMS for SMT and SOLID for DIP	133	3.36	8.37	7.69
% error	1.4	13.8	0.6	1.2
GMS for SMT and SHELL for DIP	134.69	3.42	8.54	7.49
% error	0.2	12.3	1.4	3.8
GMS for all	133	3.6	8.21	7.24
% error	1.4	7.7	2.4	7

Vibration response spectra corresponding to vibration test and FEA (GMS for all) for locations A1, A2 and A3 for case-3 are shown in Figure 5.15 – Figure 5.20 respectively.

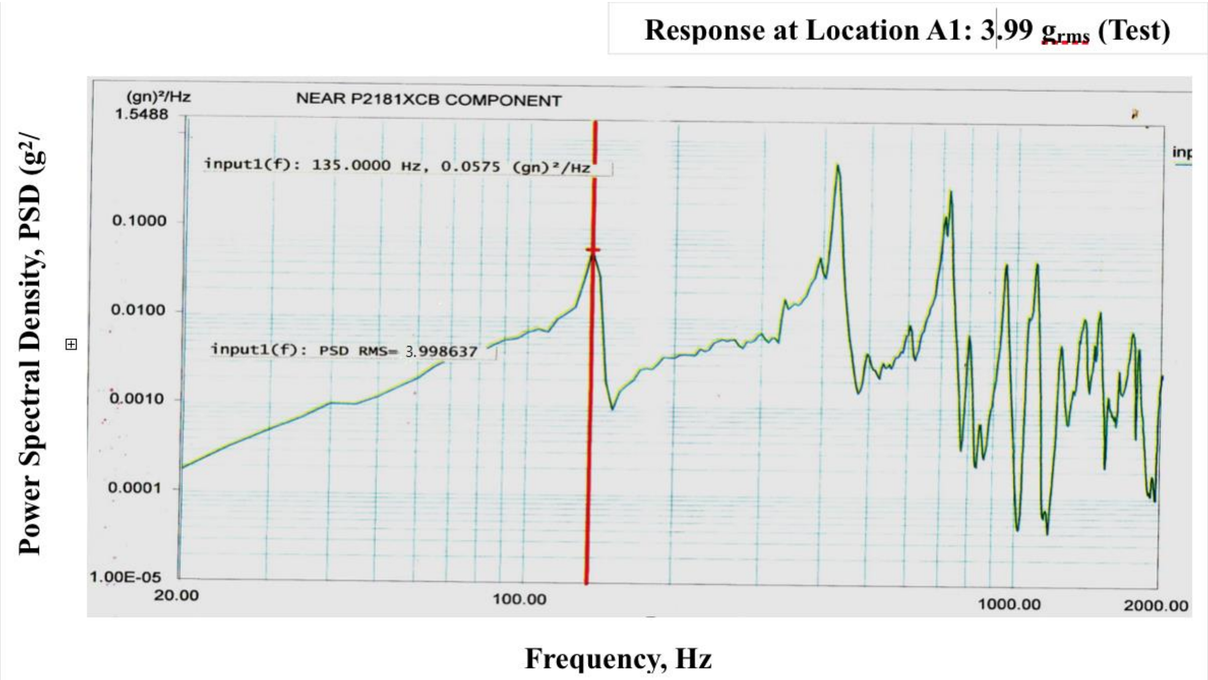


Figure 5.15 Vibration response spectrum: Case-3 (Measurement location A1-Test)

Figure 5.16 Vibration response spectrum: Case-3 (Measurement location A1-FEA)

Response at Location A2: 9.58 g_{rms} (Test)

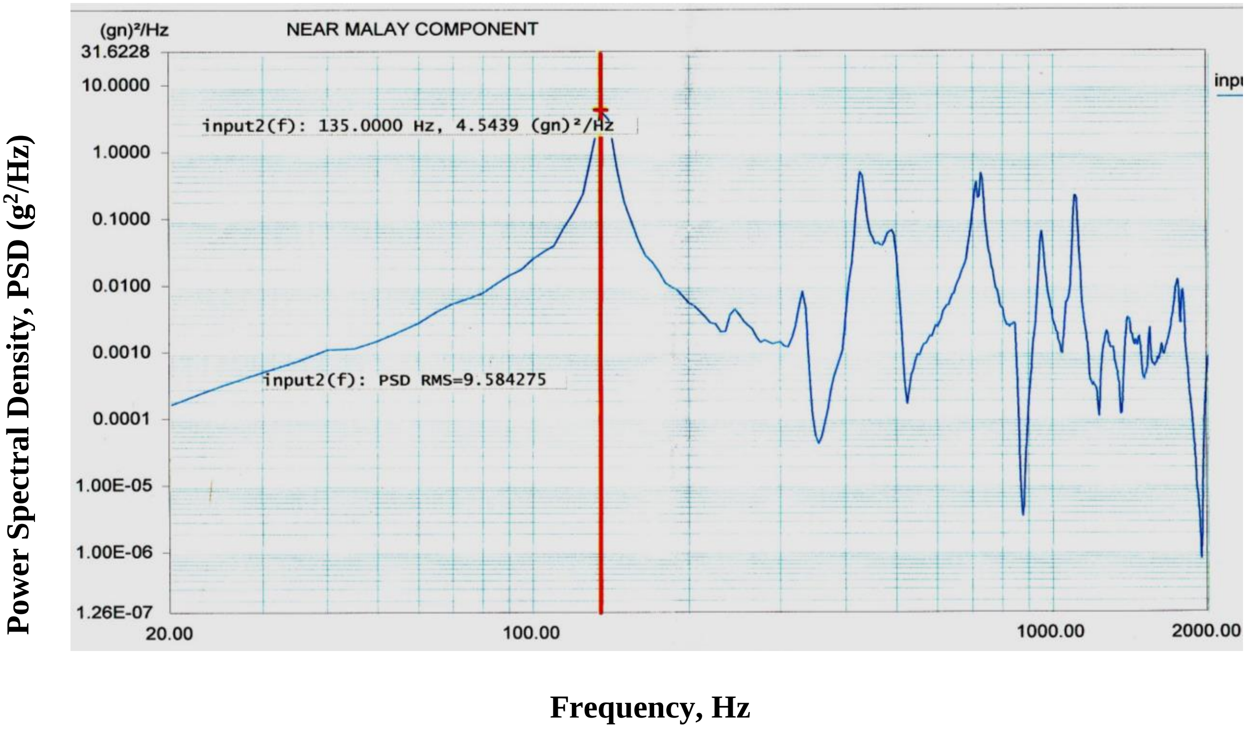


Figure 5.17 Vibration response spectrum: Case-3 (Measurement location A2-Test)

Response at Location A2: 8.21 g_{rms} (FEA)

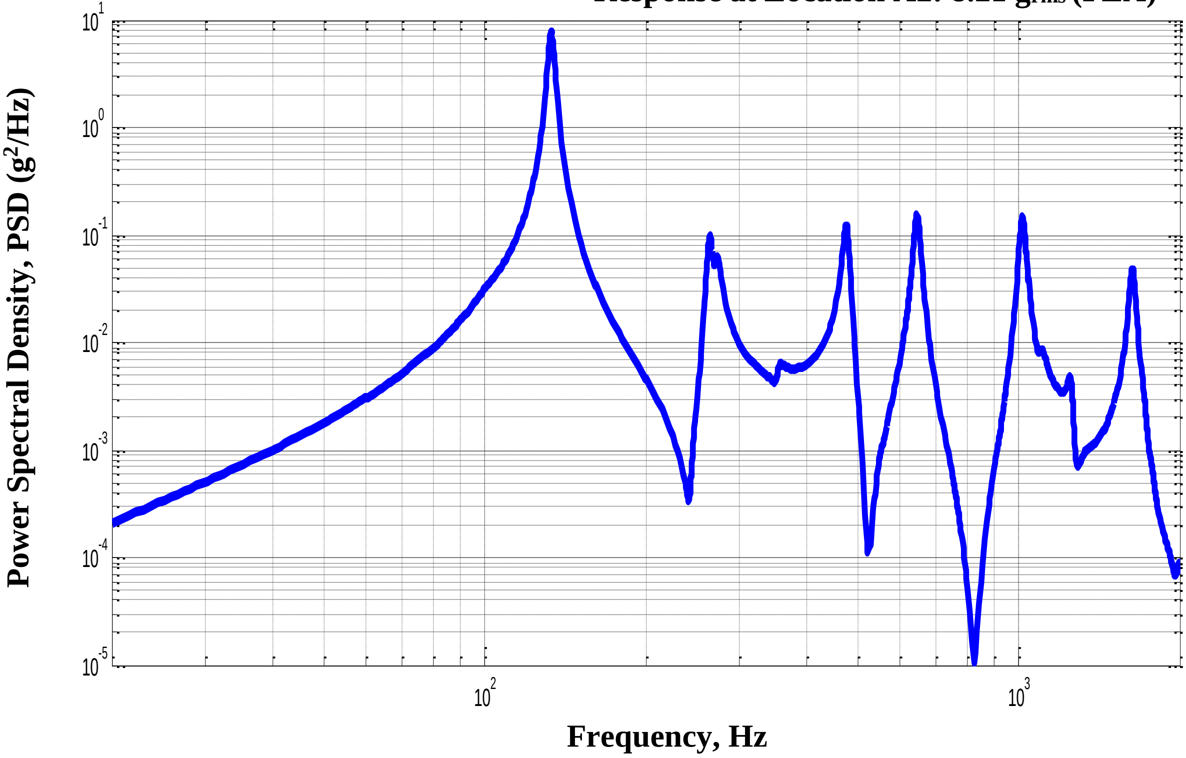


Figure 5.18 Vibration response spectrum: Case-3 (Measurement location A2-FEA)

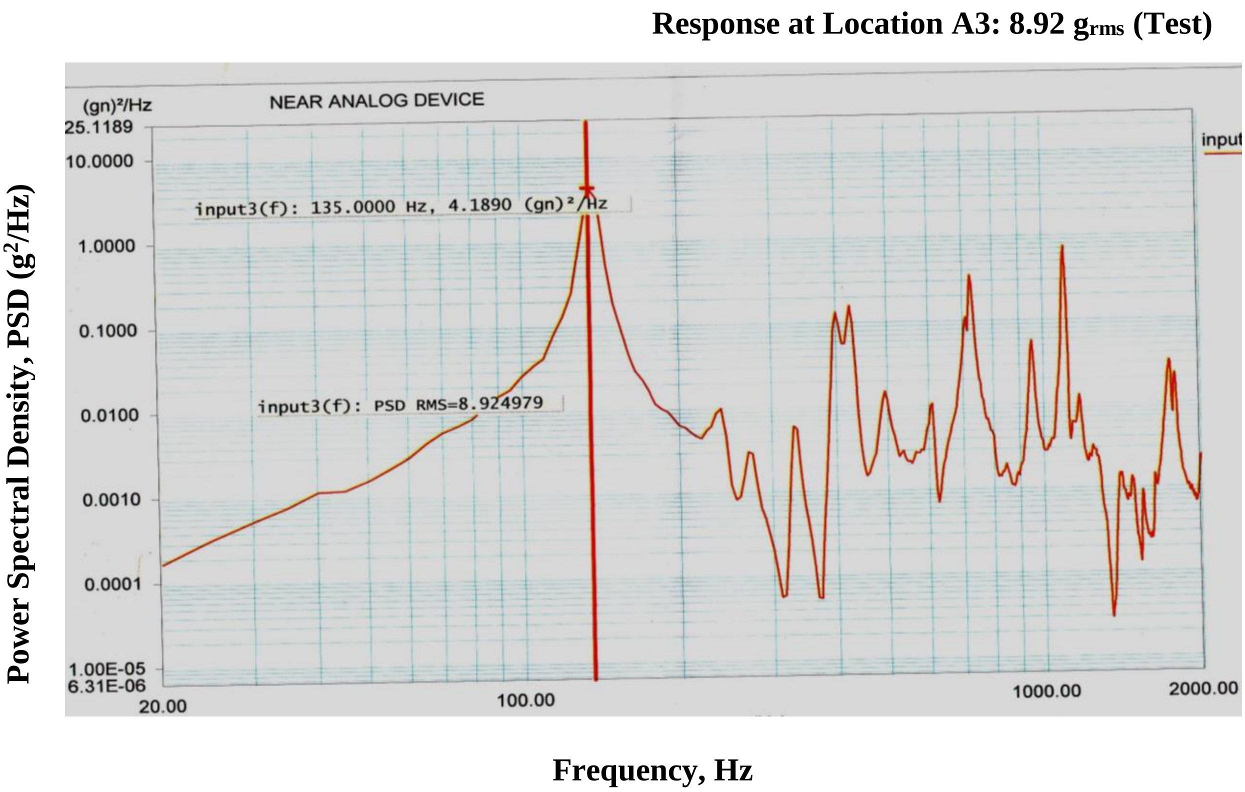


Figure 5.19 Vibration response spectrum: Case-3 (Measurement location A3-Test)

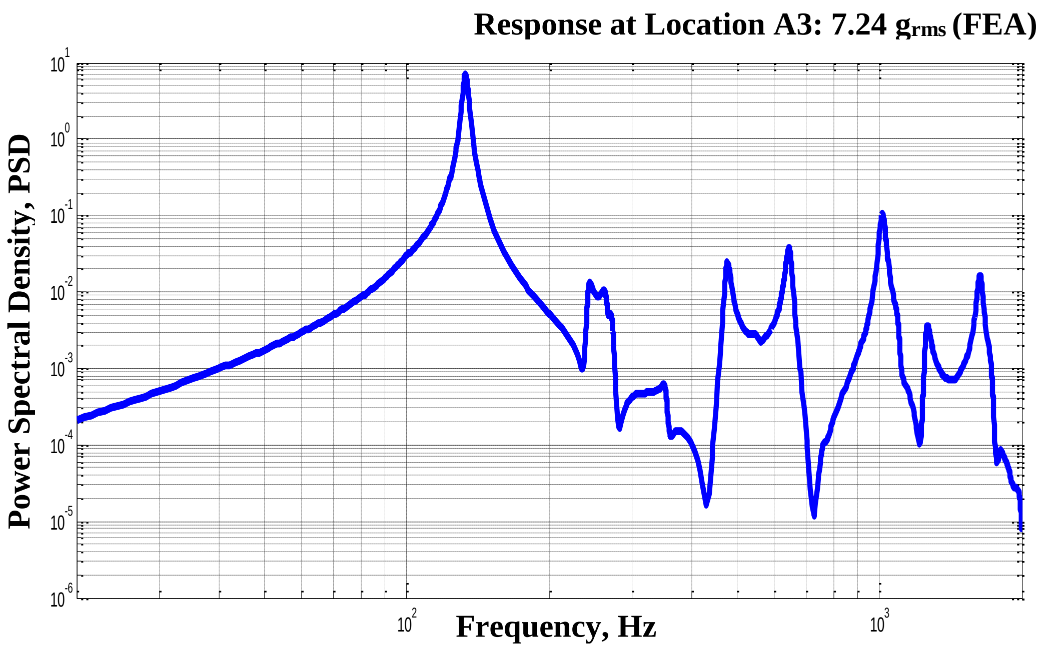


Figure 5.20 Vibration response spectrum: Case-3 (Measurement location A3-FEA)

The comparison of FEA and test results for case-3 are shown in Table 5.4.

Table 5.4 Comparison of FEA and test results for Case-3 (Combination of SMT without gap and with gap

Method	**Frequency (Hz)**	**Vibration response (g_{rms})**		
		A 1	**A 2**	**A 3**
Test	135	3.99	9.58	8.92
GMS for SMT and SOLID for DIP	133	3.36	8.37	7.69
% error	1.4	15.7	12.6	13.7
GMS for SMT and SHELL for DIP	134.69	3.42	8.54	7.49
% error	0.2	14.28	10.8	16
GMS for all	133	3.6	8.21	7.24
% error	1.4	9.8	14.3	18.8

- Based on quantitative assessment of accuracy associated with modeling approach, all three (SHELL, SOLID and GMS) appears to be identical for both case 2 and case 3.
- However keeping in view the complexity associated with SHELL and SOLID approaches which need modeling for each and every discrete component taking its dimensions, location, material properties, etc, GMS method is identified to be a reasonably accurate modeling practice for PCB with components for all practical purposes like ease of modeling and modeling time.

5.6 SUMMARY

The various modeling approaches to the electronic components mounted on the PCB'S are discussed. The effect of each type of modeling on the result of the random vibration analysis is discussed. The general ways of mounting of the components on the PCB'S are also brought out. It is found that the local stiffness smearing, global stiffness smearing and the mass modeling approaches to the components aren't yielding good results. However, the general mass smearing, modeling the components as SHELL elements and modeling the components as SOLID elements are more or less giving similar and consistent results.

However, the modeling ease in terms of time and effort for the global mass smearing (GMS) approach makes it a model of choice without any compromise on the quality and accuracy of the result.

CHAPTER 6

CHASSIS LEVEL ANALYSIS

6.1 INTRODUCTION

The objective of this chapter is to establish modeling practices for chassis level analysis. Further these modeling practices are validated through experimentation. Consistency also has been established.

6.2 RANDOM VIBRATION TEST

A chassis alone with out any internal subsystems like Printed Circuit Boards (PCBs), electronic components is considered for study. This chassis is made of aluminium and it has two parts namely main housing and top cover which are fastened with the help of screws.

Chassis is shown in Figure 6.1.

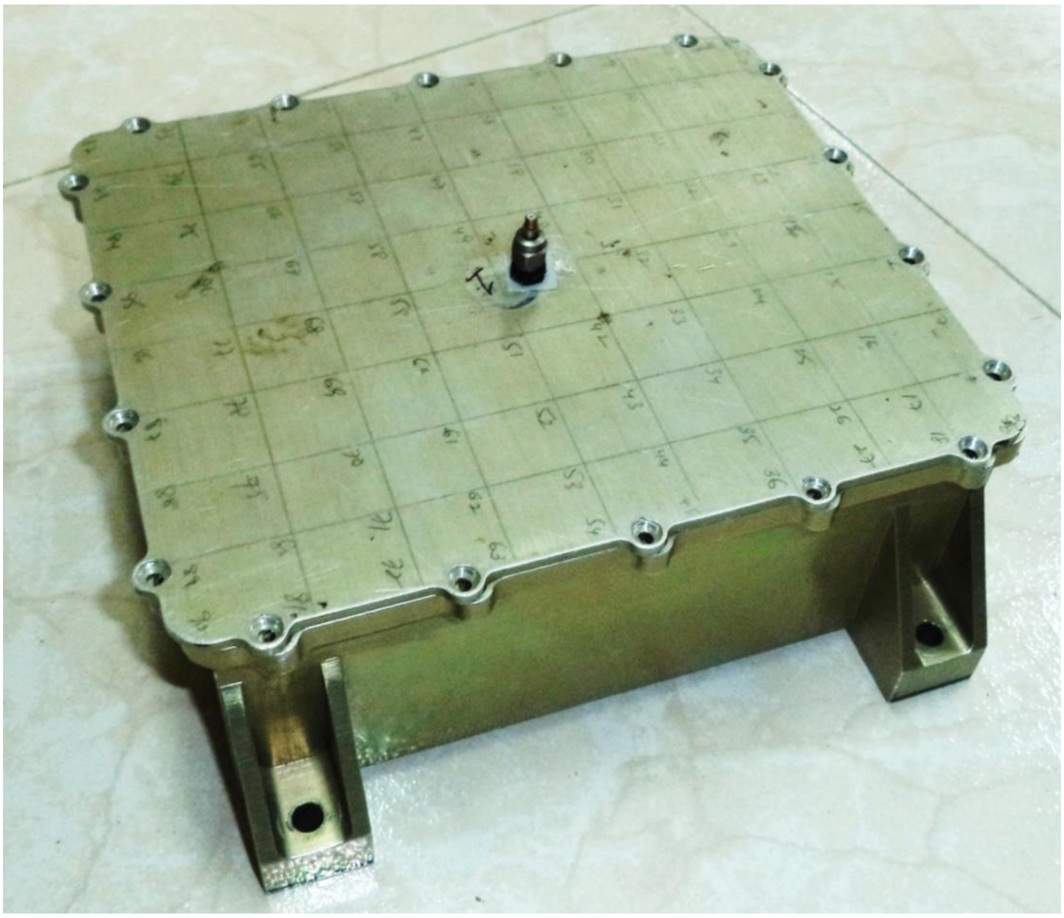


Figure 6.1 Chassis-1

To start with random vibration test has been conducted on this chassis and the response has been measured at two locations using accelerometers as shown in Figure 6.2 and 6.3. Details of accelerometer used are given in appendix at page 122.

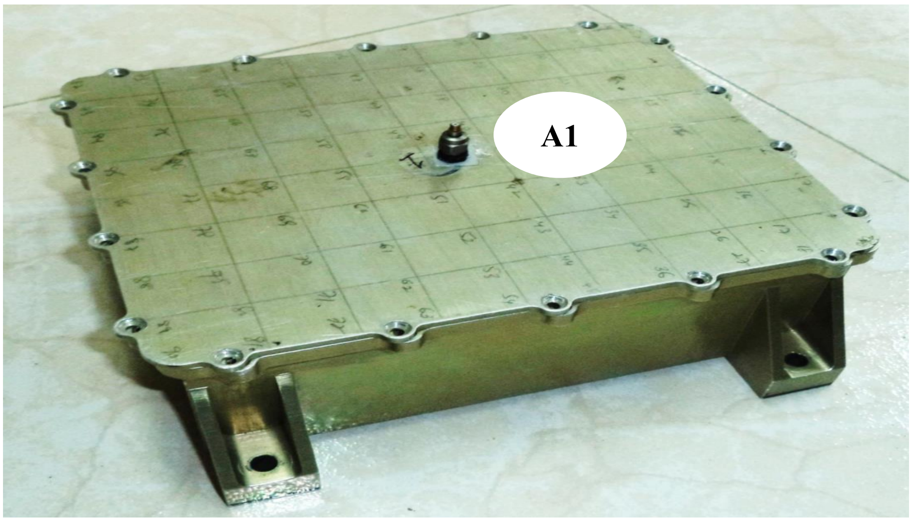


Fig 6.2 Response Locations

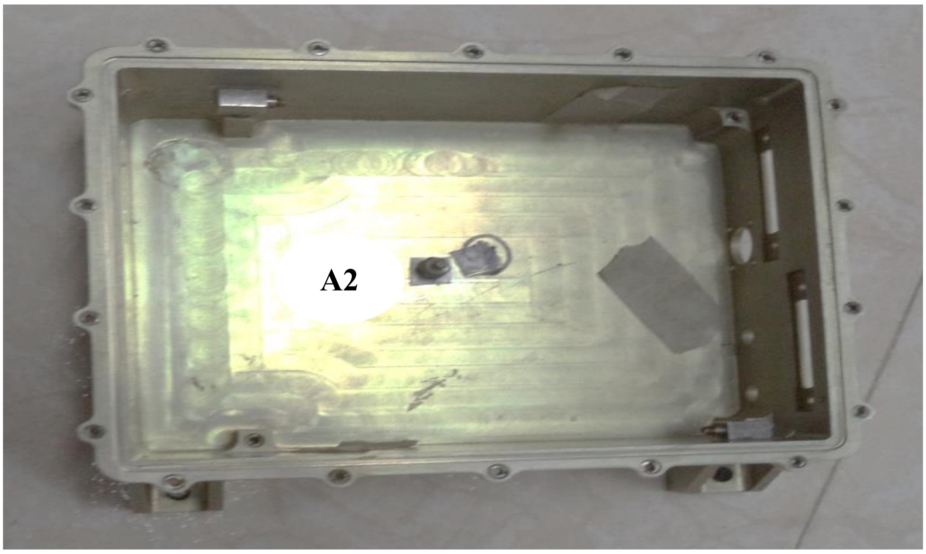


Fig 6.3. Response Locations

Where:

A1 (Accelerometer-1): To measure the response at specific location 1

A2 (Accelerometer-2): To measure the response at specific location 2

The input vibration is as per MIL-STD-810G as given in table 8.1 and as per the spectrum shown at figure 8.4 both of which are at appendix, page 122.

Response details are given in Table 6.1.

Table 6.1 Response details

Location	Input: 2.67 g_{rms}	
	Frequency	**Vibration response**
A1	710 Hz	39 g_{rms}
A2	905 Hz	47 g_{rms}

6.3 FINITE ELEMENT ANALYSIS

As discussed in earlier chapter all preprocessing was done in NX-IDEAS software and then the model was exported to ANSYS software for analysis. Both main housing and top cover of chassis-1 have been discretized with four nodded quadrilateral shell elements

(SHELL 63). Wall thicknesses of both top cover and main housing were fed to the FE model as real constants. As chassis is made of aluminium its material properties are considered for FE analysis and the same are given in Table 6.2.

Table 6.2 Material properties of chassis (Aluminium)

Sl. No.	Property	Value
1.	Young's modulus	70 GPa
2.	Poisson's ratio	0.3
3.	Density	2700 kg/m^3

Chassis was fixed at four locations. Accordingly, all 3 translational DOF were fixed. Whereas rotational DOF were simulated using spring elements. Rotational stiffness of the spring elements was continuously tuned until the first natural frequency obtained using FEA matched with that obtained from random vibration test. However, density of this chassis was increased until the weight of FE model matched with that of physical weight of chassis with accelerometers used for test. Thus, the effect of accelerometer got nullified by including it in the mass of chassis. FE model is shown in Figure 6.4.

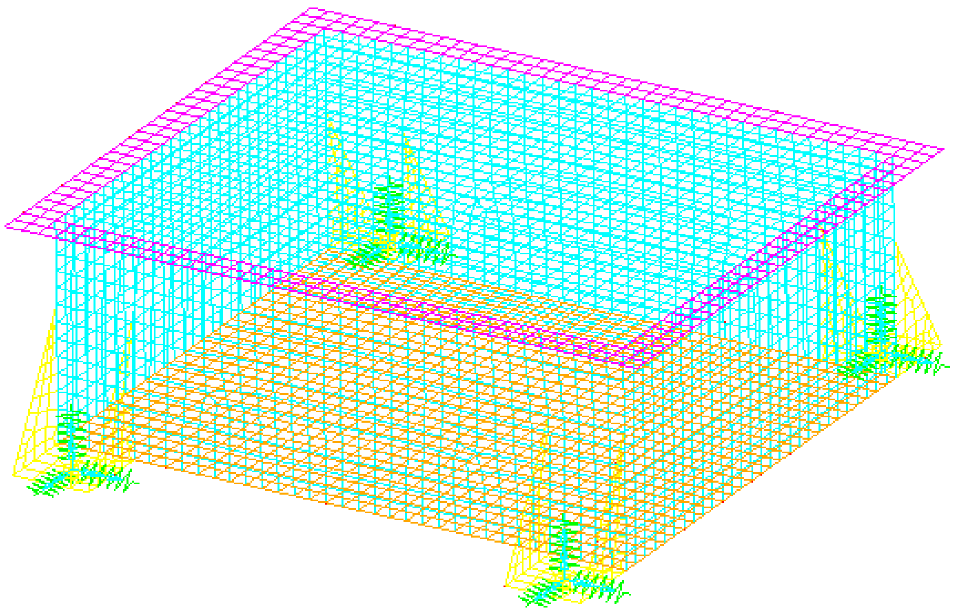


Figure 6.4 FE model of chassis-1

Results obtained using FEA are compared with that of test in Table 6.3.

Table 6.3 Summary of results

Configuration	Frequency (Hz)			Response at A1 (g_{rms})			Response at A2 (g_{rms})			Rotational stiffness (Nm/rad)	Damping
	Test	FEA	% error	Test	FEA	% error	Test	FEA	% error		
Chassis-1	710	711	0.1	39	35	10.2	47 (905 Hz)	49 (906 Hz)	4.2	10000	0.75 %

6.4 CONSISTENCY CHECKS

In order to establish the consistency associated with the proposed approach another chassis (Which is shown in Figure 6.5) has been considered for the study, where the rotational stifness and damping as established in table 6.4 for the chassis 1 was used.

Figure 6.5 Chassis – 2

To start with random vibration test has been conducted on this chassis-2 and the response was measured at two locations using accelerometers as shown in Figure 6.6.

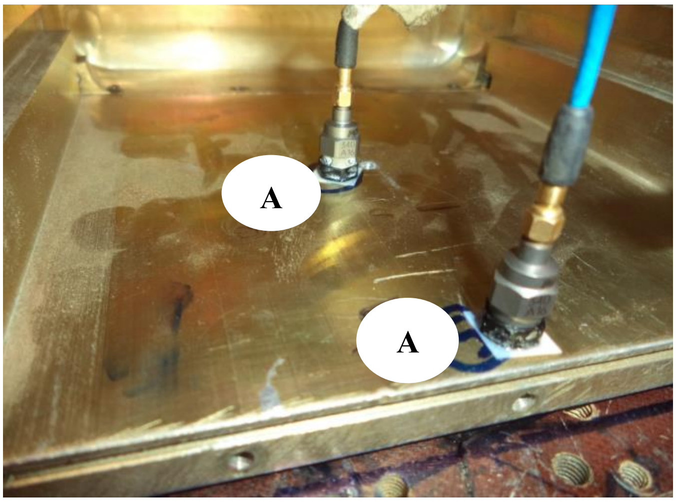


Figure 6.6 Response locations

Response details are given in Table 6.4.

Table 6.4 Response details

Location	**Input: 2.67 g_{rms}**		
	First Frequency (Hz)	**Second Frequency (Hz)**	**Vibration response (g_{rms})**
A1	1265	1485	31.5
A2	1265	1485	27.7

FE modeling details are same as that of previous case. FE model is shown in Figure 6.7.

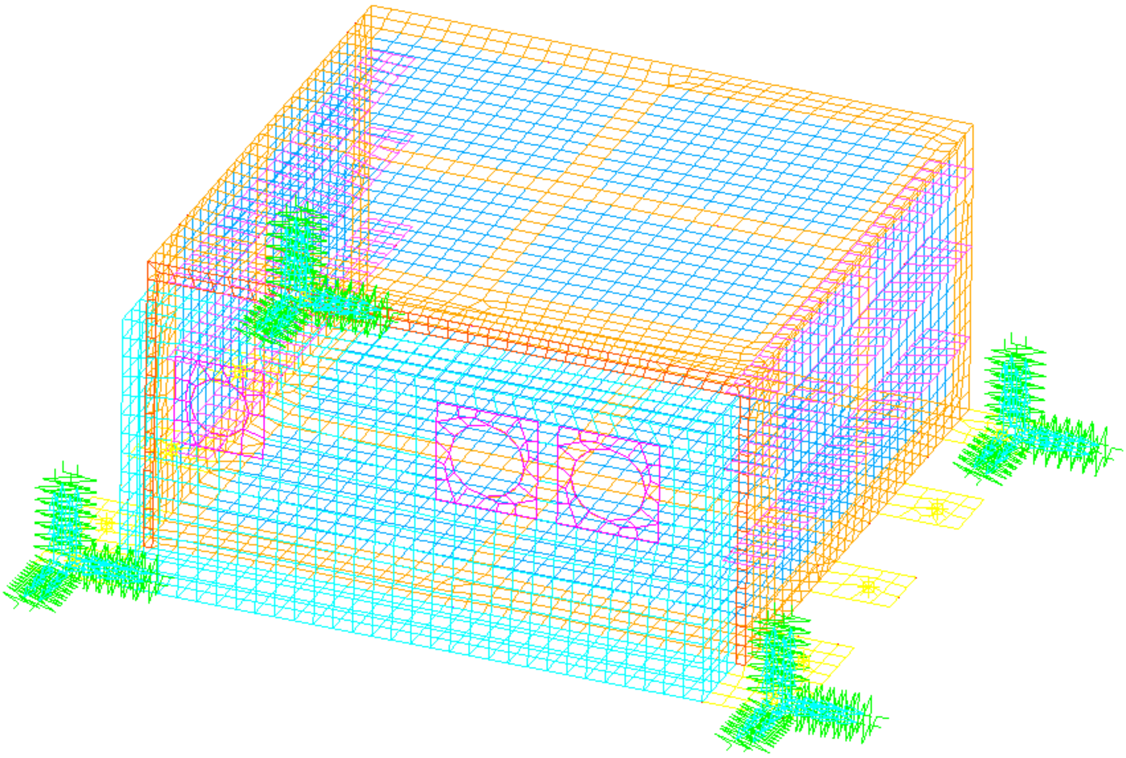


Figure 6.7 FE model of chassis 2

Results obtained using FEA are compared with that of test in Table 6.5.

Table 6.5 Summary of results – 1

Configuration	**Frequency (Hz)**			**Response at A1 (g_{rms})**			**Response at A2 (g_{rms})**			**Rotational stiffness (Nm/rad)**	**Damping**
	Test	**FEA**	**% error**	**Test**	**FEA**	**% error**	**Test**	**FEA**	**% error**		
Chassis-2	1265 (First)	1266 (First)	0.07	31.5	33	4.7	27.7	29	4.7	10000	0.75 %
	1485 (Second)	1520 (Second)	2.3								

Further to study the influence of number of mounting lugs the above-mentioned exercise has been extended for chassis-2 with 6 and 10 lugs and the results are given in Table 6.6.

Table 6.6 Summary of results – 2

Configuration	Frequency (Hz)			Response at A1 (g_{rms})			Response at A2 (g_{rms})			Rotational stiffness (Nm/rad)	Damping
	Test	FEA	% error	Test	FEA	% error	Test	FEA	% error		
4 lugs	1265 (First)	1266 (First)	0.07	31.5	33	4.7	27.7	29	4.7	10000	0.75 %
	1485 (Second)	1520 (Second)	2.3								
6 lugs	1340 (First)	1342 (First)	0.1	34.8	36	3.4	33.9	35.2	3.8	18200	0.75 %
	1532 (Second)	1555 (Second)	1.5								
10 lugs	1380 (First)	1381 (First)	0.07	28	30	7.1	28.7	26	9.4	38750	1.1 %
	1775 (Second)	1801 (Second)	1.4								

- From Table 6.6 it is evident that rotational stiffness values obtained for various mounting configurations of chassis are very high
- This conveys a message that mounting scheme of the chassis is very rigid and close to fixed boundary condition
- Hence consistency studies are not carried out with respect to rotational stiffness values established.

6.5 SUMMARY

The mounting of the PCB and the modeling of the PCB with the mountings represented by the rotational stiffness was extended to the mounting of the chassis represented by rotational stiffness of the element. The properties of the material of chassis were used in the model. The results bring out the tuning values of rotational stiffness and the damping for the different number of lugs and would form a good data base, which can be used for the full package level analysis.

CHAPTER 7

PACKAGE LEVEL ANALYSIS

7.1 INTRODUCTION

In the previous chapters, the PCB, populated PCB and chassis level analysis has been discussed along with experimental validation. The package level consists of the populated PCB's mounted on the chassis either in a stacked configuration or in a wedge guide configuration. It also consists of all the interconnections either between the PCB's and/ or the connections between the PCB's and the chassis in the form of typical connectors. In this chapter, modeling and analysis details are presented for such an overall configuration which is the ultimate form in which the subsystems are mounted in an aerospace vehicle. The analysis is done with the same approach as presented up to the chassis level and the results are verified with the experiments. Consistency of the approach is checked with many packages for the efficacy of the method.

The following two basic configurations are considered for analysis.

- Stacked configuration
- Wedge guide configuration

7.2 STACKED CONFIGURATION

Typical stacked configuration package is shown in Figure 7.1.

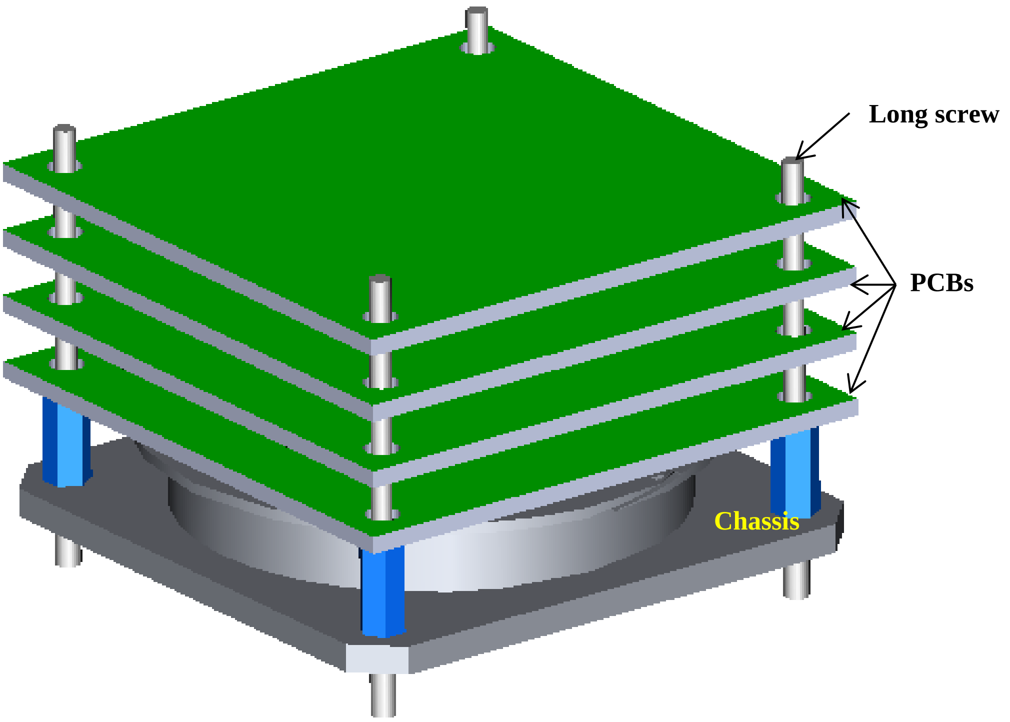


Figure 7.1 Typical stacked configuration package

In this configuration PCBs are mounted one over another in stacked fashion. Long screws are used to connect all the PCBs with chassis. Desired interspacing between PCBs are provided based on height of tallest components mounted on adjacent PCBs. Spacers are provided in hollow circular shape between any two adjacent PCBs to cater for this desired interspacing. Long screws that have threads only in the bottom portion which are engaged with chassis after passing through all the spacers. Sometimes hybrid spacers (Shown in chapter 4) are used which acts as spacer and screw. Further in the case of the stacked configuration, euro connectors are provided integral to PCBs for ensuring electrical interconnections. Euro connectors from two adjacent PCBs will mate together.

7.2.1 PACKAGE – 1

Package in stacked configuration considered for the study is shown in Figure 7.2.

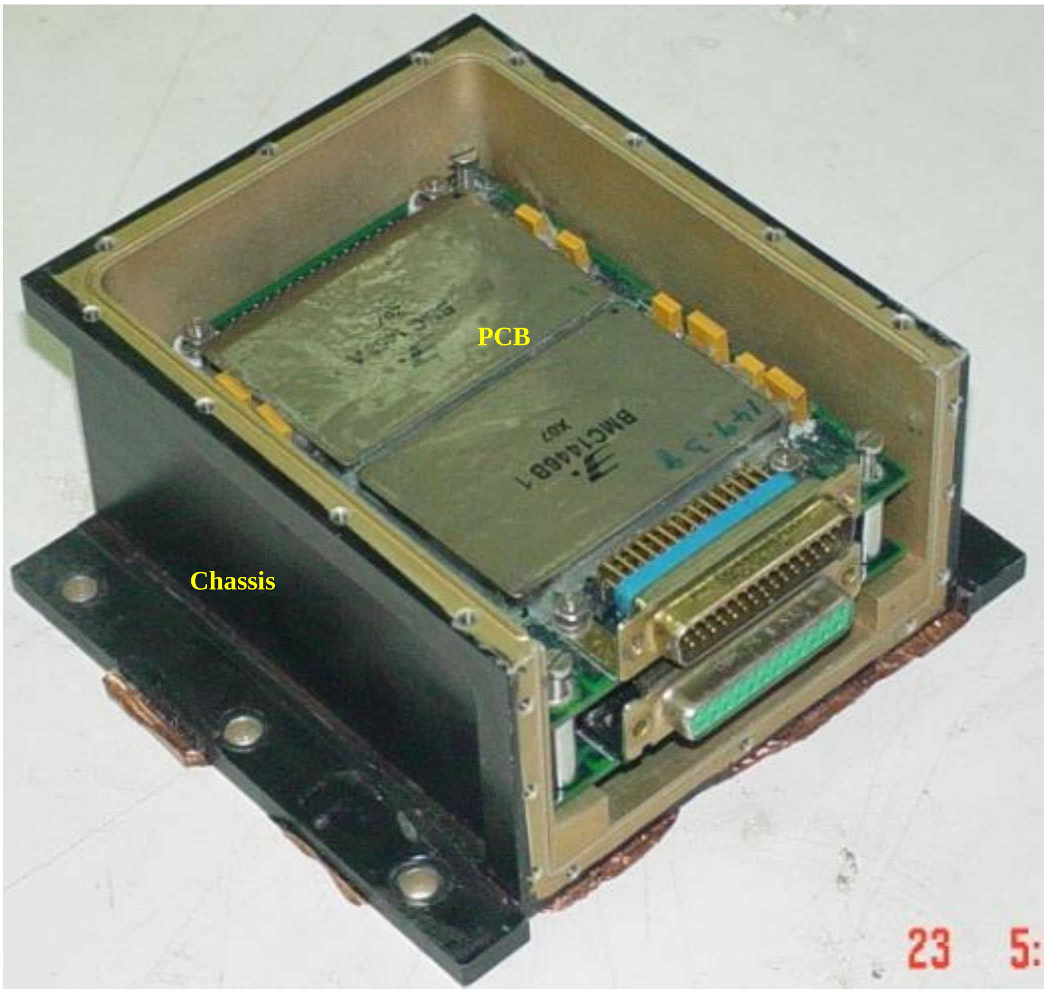


Figure 7.2 Package-1

To start with random vibration test has been conducted on this package and the response has been measured at six locations using accelerometers as shown in Figure 7.3.

Details of accelerometer used are given in appendix at page 122.

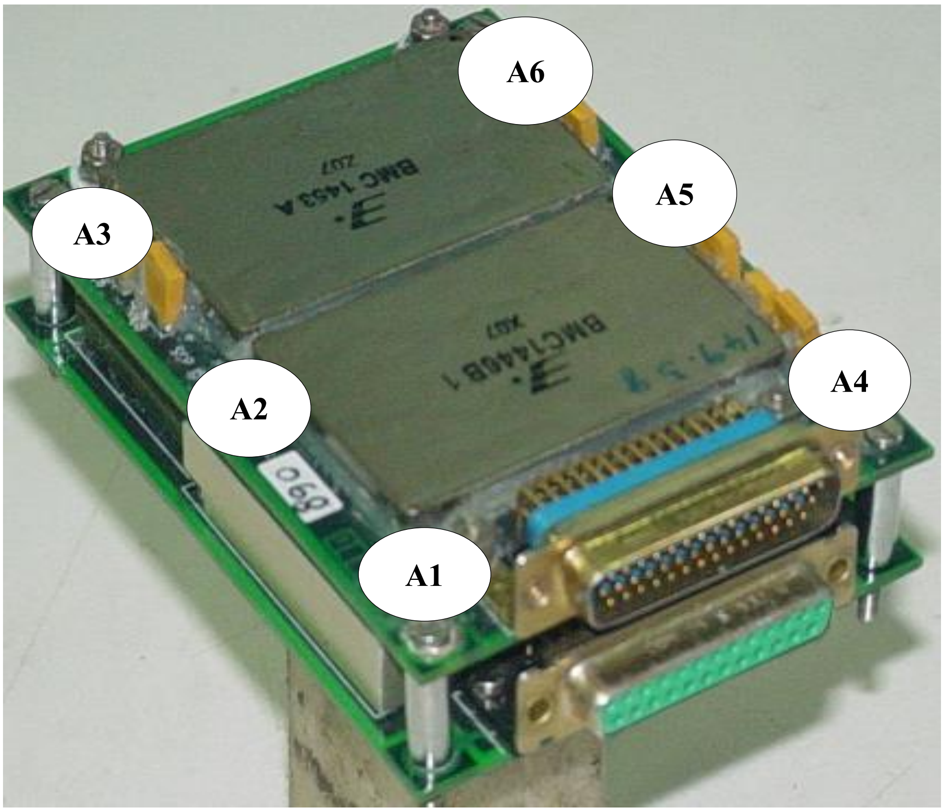


Figure 7.3 Response locations on package-1

Where:

A1 (Accelerometer-1): to A6 (Accelerometer-6) are accelerometers to measure the vibration responses at the respective locations.

The input vibration to the shaker table is as given in Table 8.1 and the corresponding vibration spectrum in figure 8.4 at appendix at page 122 and was considered for all the test cases.

Response details are given in Table 7.1.

Table7.1 Response details of package-1

Location	A1	A2	A3	A4	A5	A6
Response, g_{rms}	3.2	10	4.5	3.5	10.2	4
Frequency, Hz	311					

As discussed in earlier chapter all preprocessing was done in NX-IDEAS software and then the model was exported to ANSYS software for analysis. Chassis and PCB have been discretized with four nodded quadrilateral shell elements (SHELL 63). However, density of this PCB is increased until the weight of FE model matched with that of physical weight of PCB with accelerometers used for test. Thus, the effect of accelerometer got nullified by including it in the mass of PCB. Global mass smearing approach is implemented for electronic components. Experimentally evaluated material properties given in Table 7.2 were considered for PCB.

Table 7.2 Material properties considered for PCB

Sl. No.	Property	Value
1.	Tensile elastic modulus	19 G*Pa*
2.	Poisson's ratio	0.22
3.	Density	2190 kg/m^3

Various connectors of a typical electronic package are mentioned below.

In stacked configuration, PCBs are connected using Euro connectors to ensure electrical interconnectivity as shown in Figure 7.4.

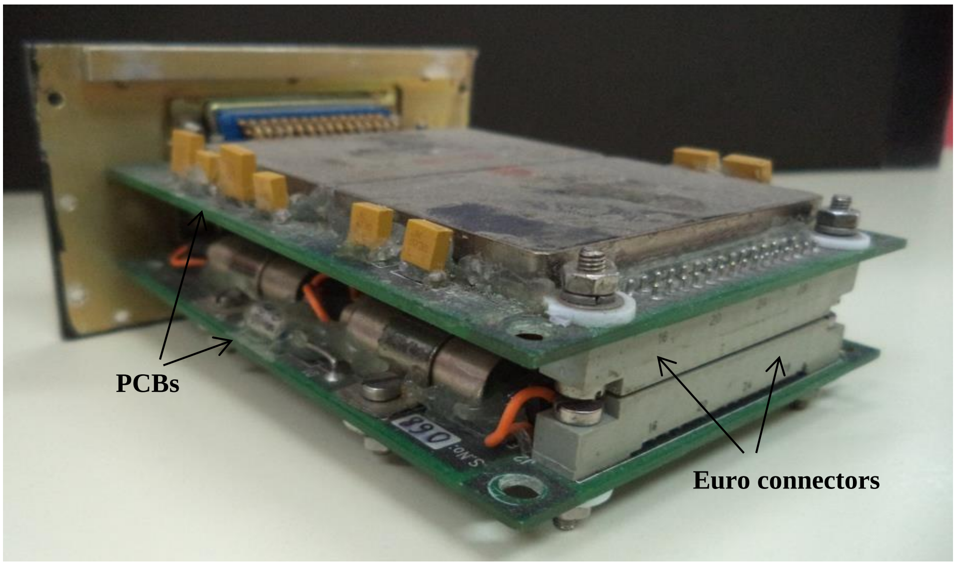


Figure 7.4 PCBs connected using Euro connectors

Further PCBs are connected to mating cables which are positioned outside the package with the aid of external connectors which in turn is firmly mounted on chassis as shown in Figure 7.5.

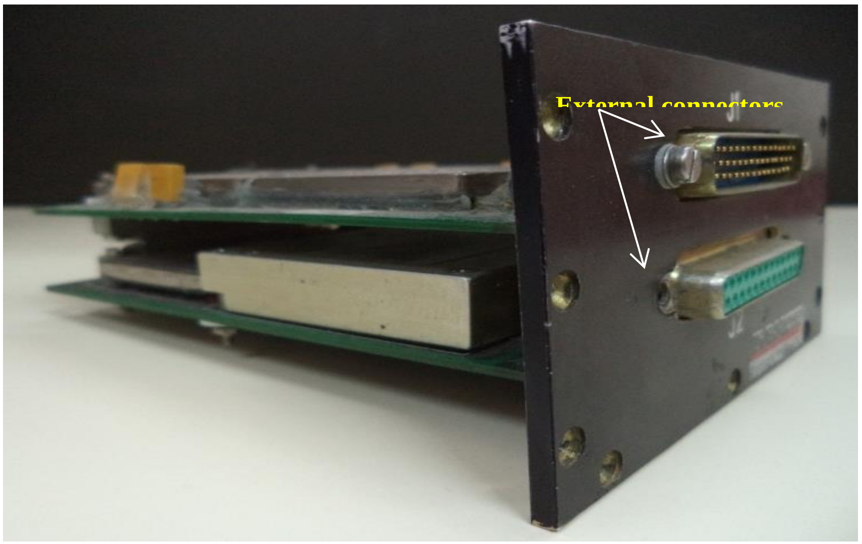


Figure 7.5 External connectors

In addition to these, PCBs are connected to chassis with the help of screws as shown in Figure 7.6.

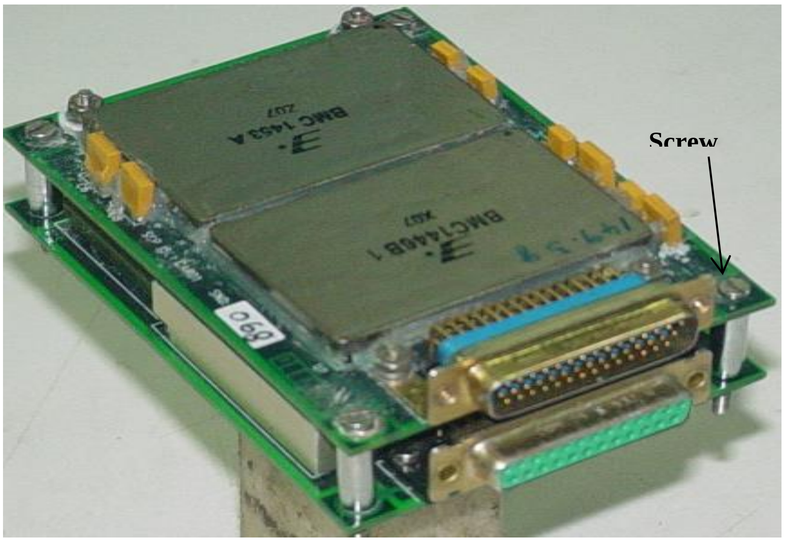


Figure 7.6 Screws for connecting PCBs with chassis

Approach adopted for above mentioned interconnections are mentioned below.

a) Between adjacent PCBs (Euro connectors)

- Connector area on PCB is modeled with shell elements.
- Mass of connectors is lumped.
- Interconnections are modeled with rigid links.

b) Between PCB & chassis (Connectors)

- Connector geometry is modeled (Projecting out) on PCB and discretized with shell elements.
- Screw connections between connector & chassis are modeled with beam elements (Size identical to screw).

c) Between PCB and chassis (Screws)

- Modeled with beam elements (Size identical to screw).

FE model is shown in Figure 7.7.

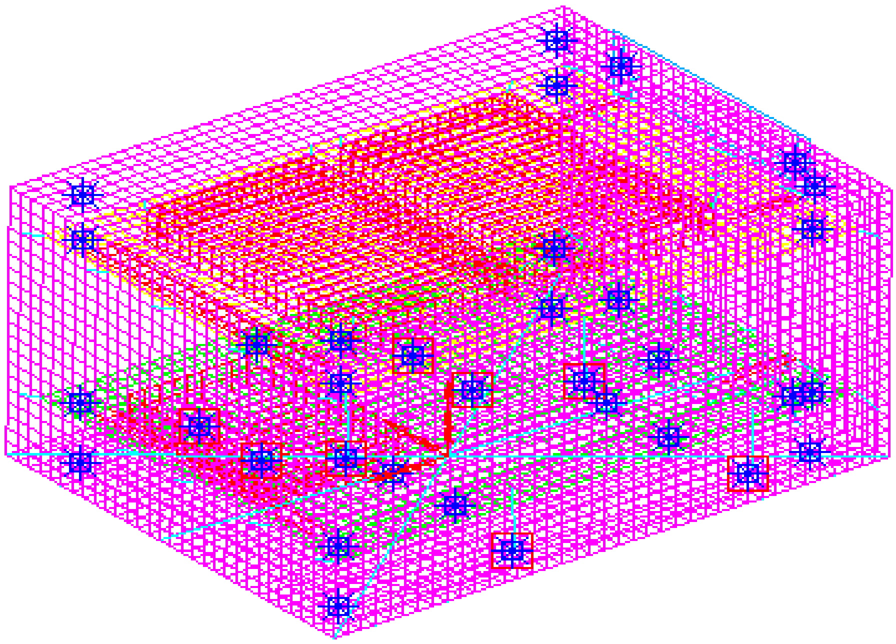


Figure 7.7 FE model of package-1

Results obtained using FEA are compared with that of test in Table 7.3.

Table 7.3 Summary of results of package-1

Location	A1	A2	A3	A4	A5	A6
Response (Test), g_{rms}	3.2	10	4.5	3.5	10.2	4
Response (FEA), g_{rms}	3.15	11.4	4.9	4	10.4	4.2
% error	1.5	14	8.88	14	1.96	5
Frequency (Test), Hz	311					
Frequency (FEA), Hz	312					
% error	0.32					

7.2.2 PACKAGE – 2

In order to establish the consistency associated with the proposed approaches, another package in stacked configuration (shown in Figure 7.8) has been considered for the study.

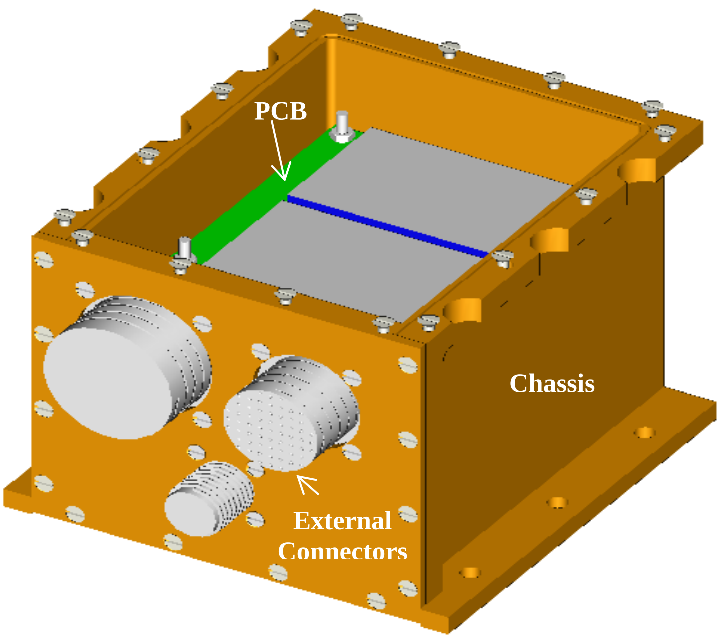


Figure 7.8 Package-2

Package-2 has four PCBs mounted in stacked configuration in a chassis. Chassis is made of three parts namely top cover, front plate and main housing. However top cover of the package is not shown in Figure 7.8. Front plate is meant for housing external connectors. All the three individual parts are connected to each other, with the help of screws. Three external connectors are provided on chassis which has electrical interface with PCBs on one side and with external mating cables on other side.

PCBs along with their mounting scheme without chassis is shown in Figure 7.9.

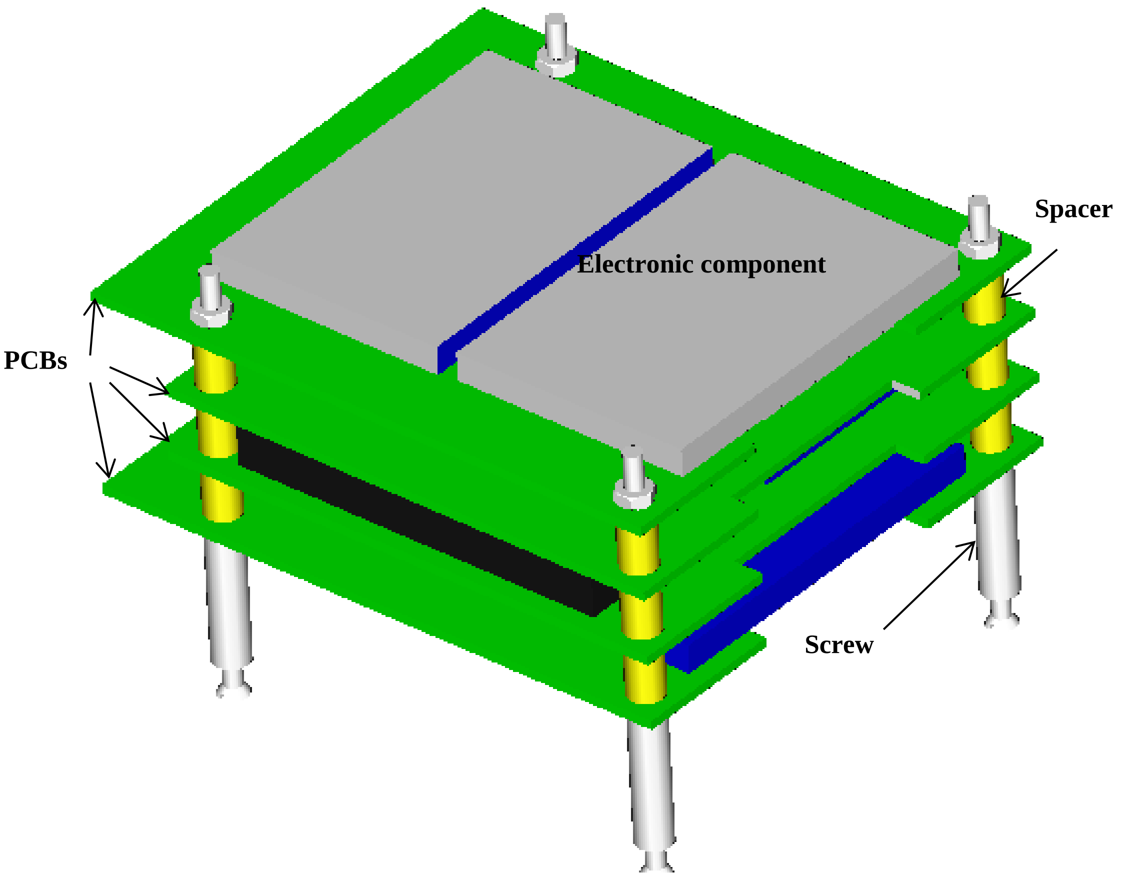


Figure 7.9 Mounting scheme of PCBs without chassis

Top PCB has two critical electronic components mounted on it. As mentioned earlier spacers were used to maintain desired interspacing between adjacent PCBs. To start with, random vibration test has been conducted on this package and the response has been measured near one of the critical components using accelerometer as shown in Figure 7.10.

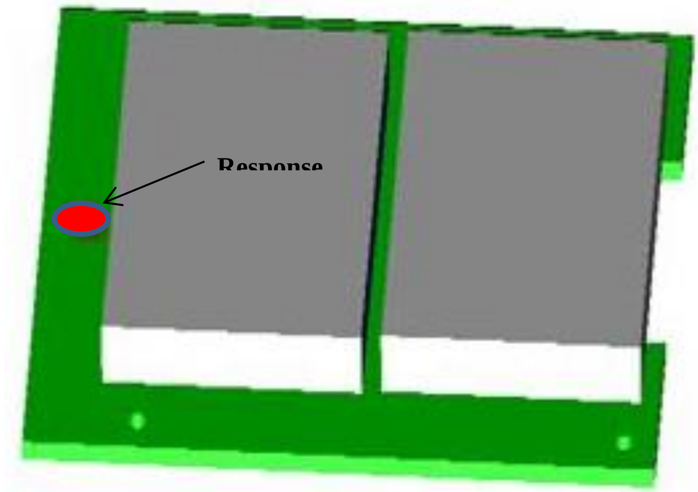


Figure 7.10 Response location

Formally, the package is analyzed in FEA using the proposed modeling approach and the finally obtained FE model is shown in Figure 7.11.

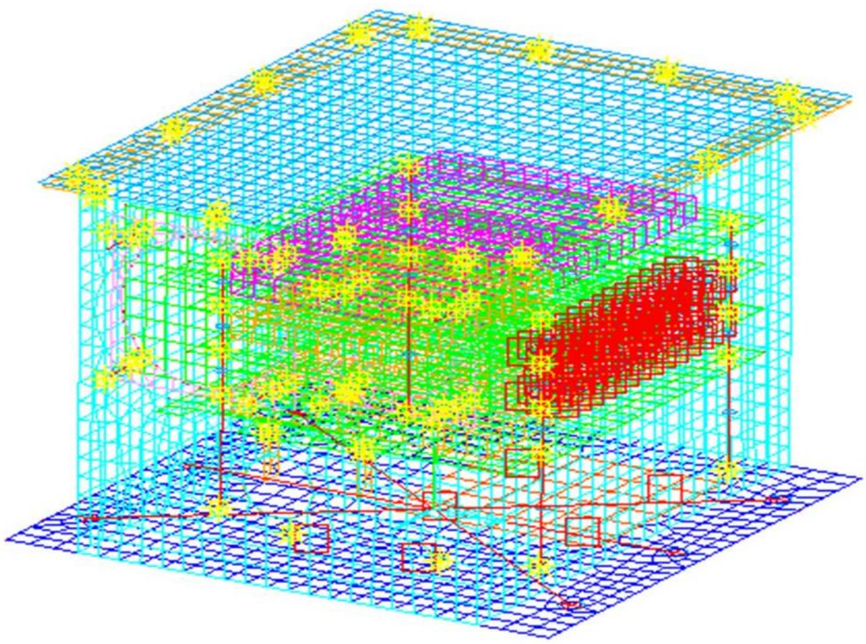


Figure 7.11 FE model of Package-2

Figure 7.12 shows the vibration response plot obtained using FEA and the response plot of test result is shown in Figure 7.13.

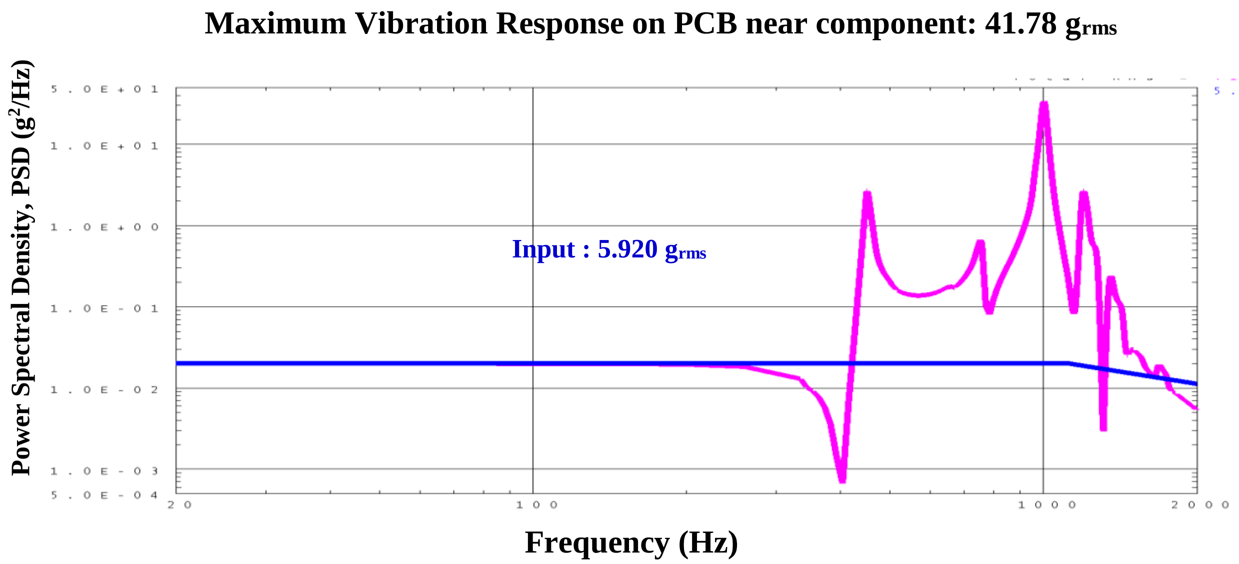


Figure 7.12 FE results plot of Package-2

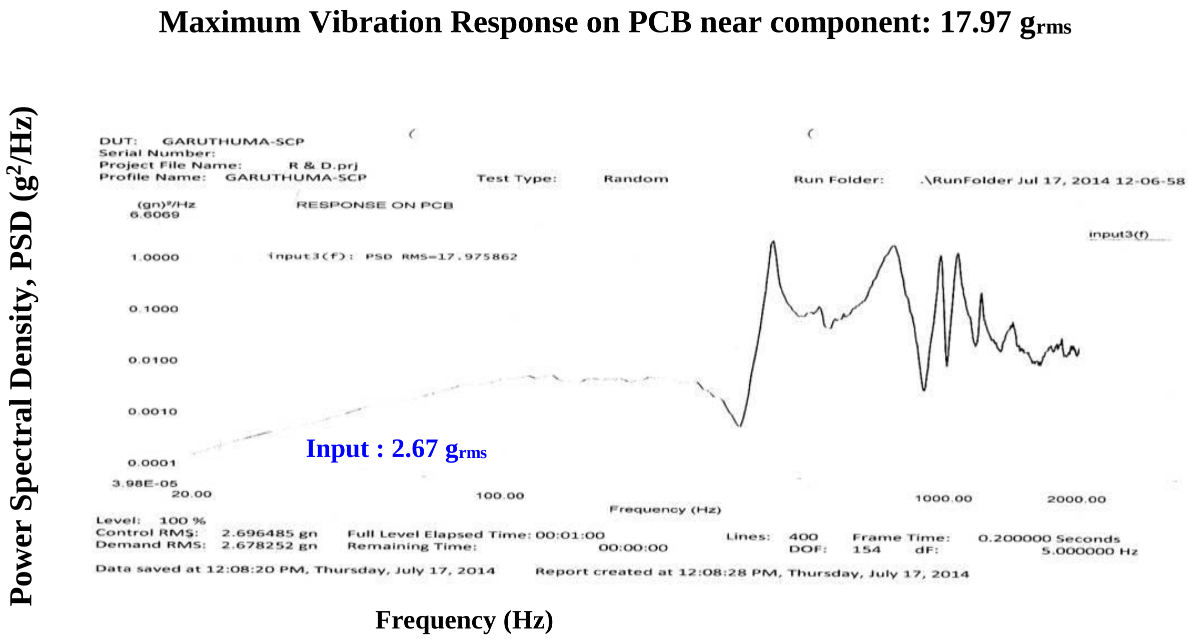


Figure 7.13 Test results plot of Package-2

To ascertain the applicability of the proposed Universal modeling approach, the test results obtained are compared with the FE results in Table 7.4. As the test is done at low level input i.e. 2.67 g_{rms}, response measured is scaled up for higher input considered in FE analysis for the sake of comparison.

Table 7.4 Comparison of vibration response for package-2

	Response, g_{rms}
FEA	41.78
TEST	39.84
% error	4.8

7.2.3 PACKAGE – 3

Package-3 consists of 2 PCBs as shown in Figure 7.14. Inner details without chassis are shown in Figure 7.15.

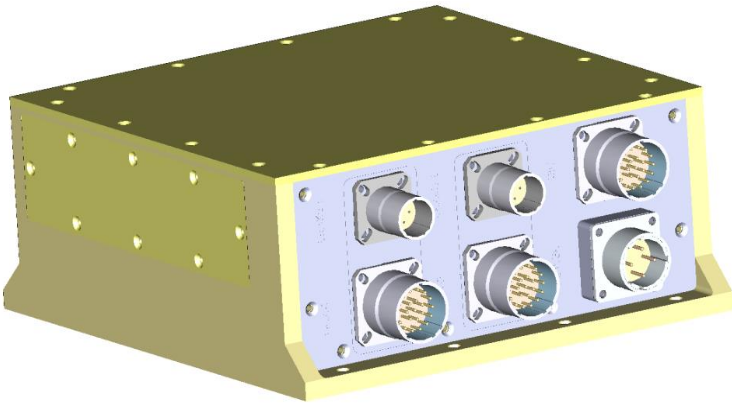


Figure 7.14 Package-3

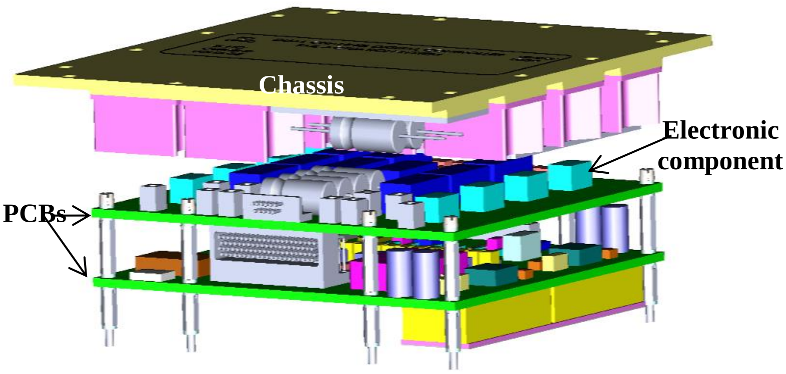


Figure 7.15 Inner details of Package-3

To begin with random vibration test has been conducted on this package and the response has been measured at four locations near critical components as shown in Figure 7.16.

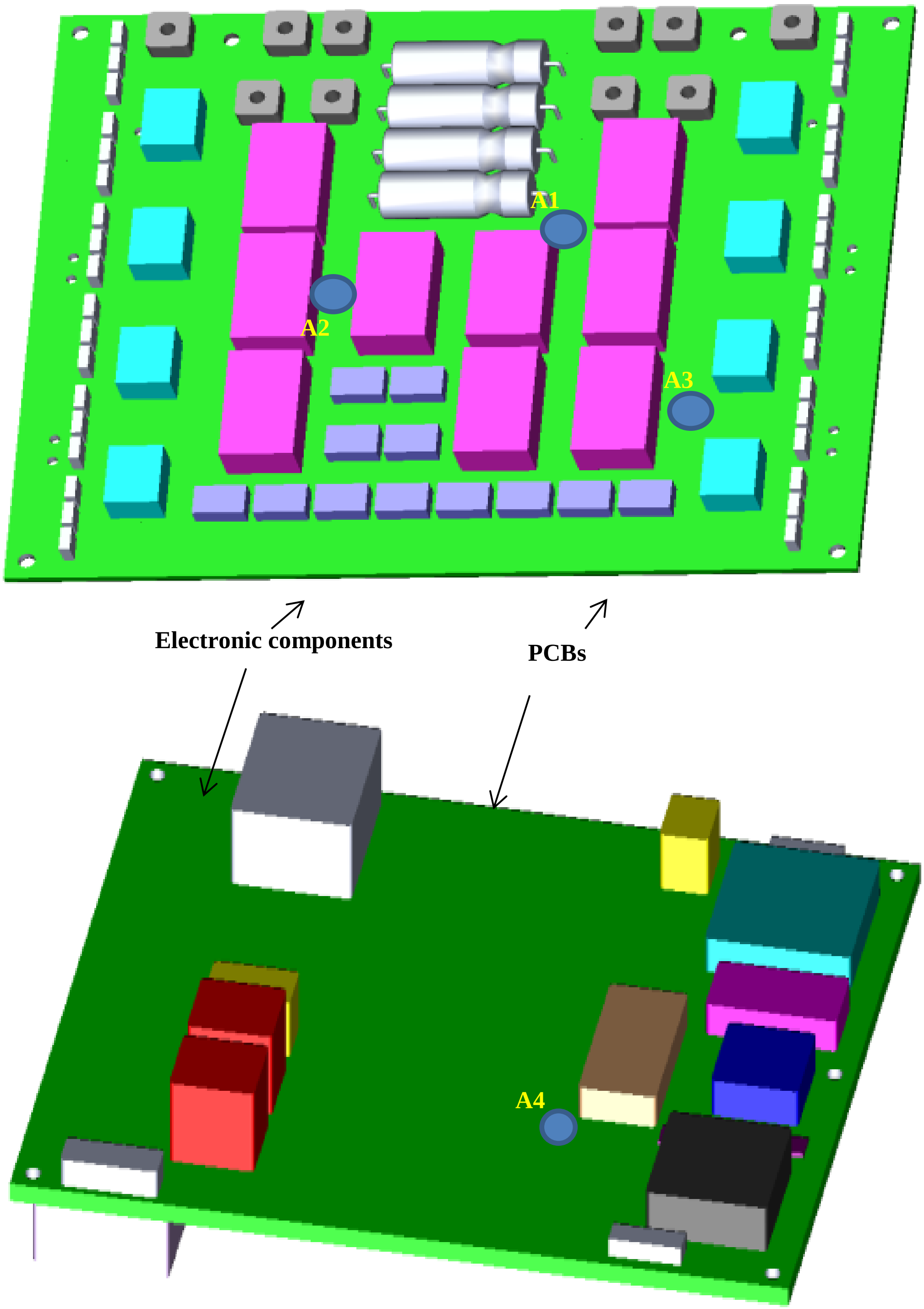


Figure 7.16 Response locations

The package is then analyzed in FEA using the proposed universal modeling approach and the finally obtained FE model is shown in Figure 7.17.

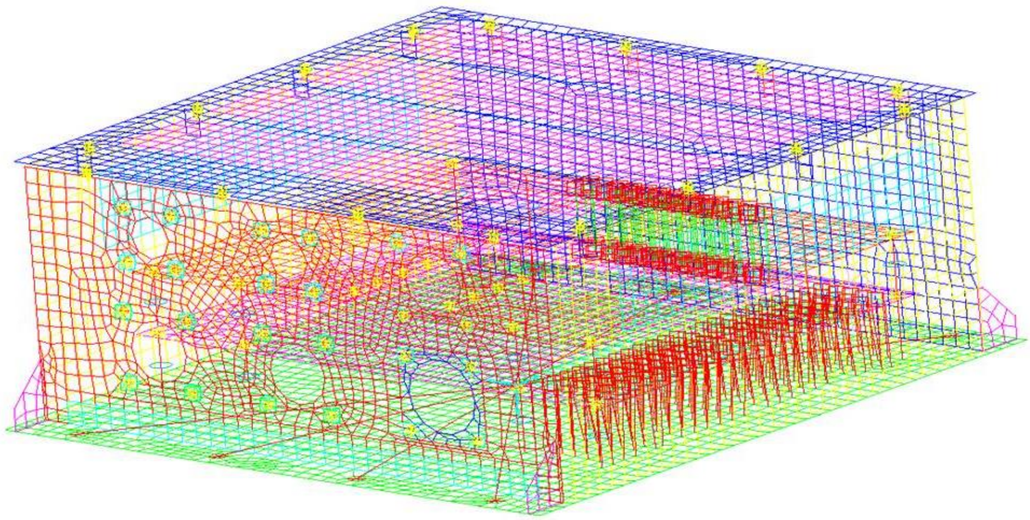


Figure 7.17 FE model of Package-3

Comparison of FEA and test results is shown in Table 7.5.

Table 7.5 Summary of results of package-3

Location	A1	A2	A3	A4
Response (Test), g_{rms}	12.8	9.24	13.7	18.2
Response (FEA), g_{rms}	11	9.1	11.3	15.9
% error	14	1.5	17.5	12.6

7.2.4 PACKAGE – 4

Similar attempt to verify the applicability of the proposed approach has been made on package-4 which consists of 2 PCBs as shown in Figure 7.18. Inner details without chassis are shown in Figure 7.19.

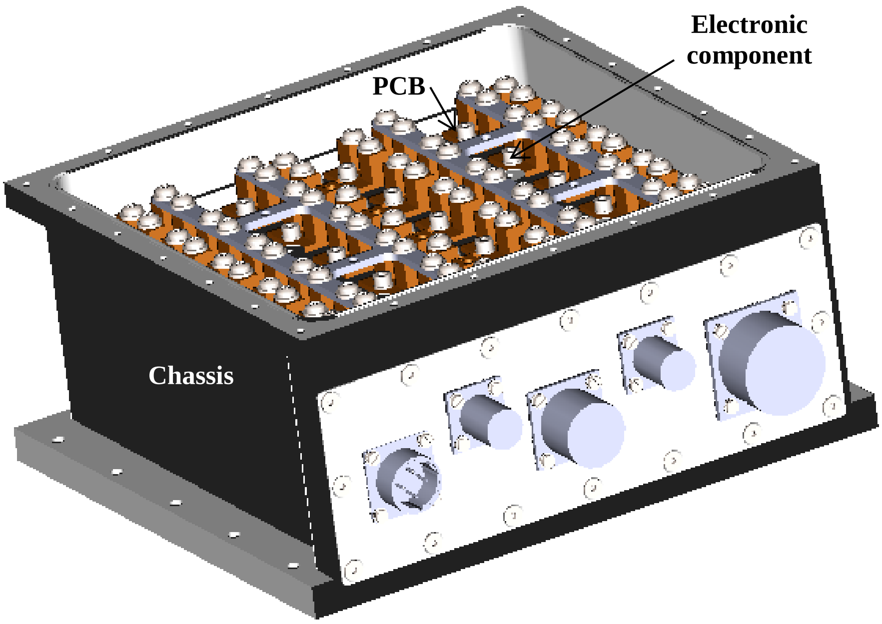


Figure 7.18 Package-4

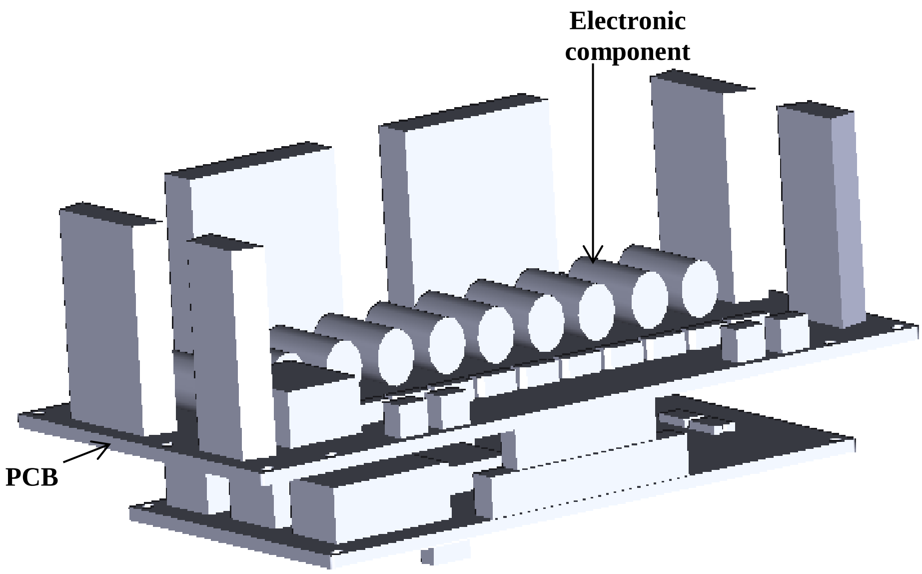


Figure 7.19 Inner details of Package-4

Formally, the package is analyzed in FEA using the proposed universal modeling approach and the finally obtained FE model is shown in Figure 7.20.

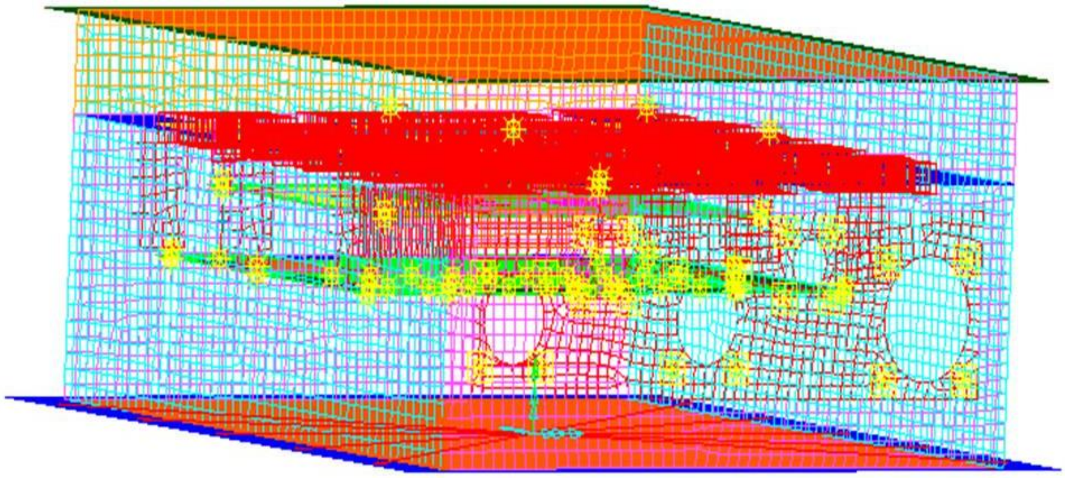


Figure 7.20 FE model of Package-4

Figure 7.21 shows the response location.

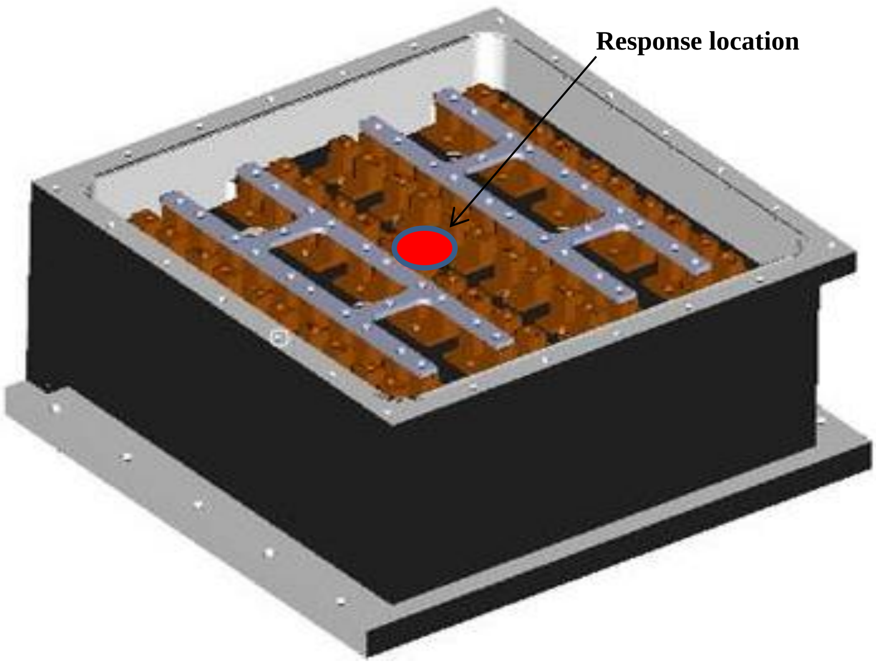


Figure 7.21 Response location

Comparison of FEA and test results is made shown in Table 7.6.

Table 7.6 Summary of results of package-4

Response (Test), g_{rms}	65
Response (FEA), g_{rms}	70
% error	7.6

7.3 WEDGE GUIDE CONFIGURATION

In this configuration rectangular shaped guides known as wedge guides are provided integral to the side walls of the chassis as shown in Figure 7.22.

Figure 7.22 Chassis with wedge guides

PCBs are provided with wedge locks integral to them. PCBs are then inserted from front side along the chassis wedge guides. Once the PCB is fully inserted, wedge lock is tightened by which part of the wedge lock will be in contact with chassis wedge guides and remaining will be in contact with PCB. PCBs are provided with male connectors which connects to female connectors provided on mother board located in rear side of the chassis.

7.3.1 PACKAGE – 5

Package considered for the study is shown in Figure 7.23.

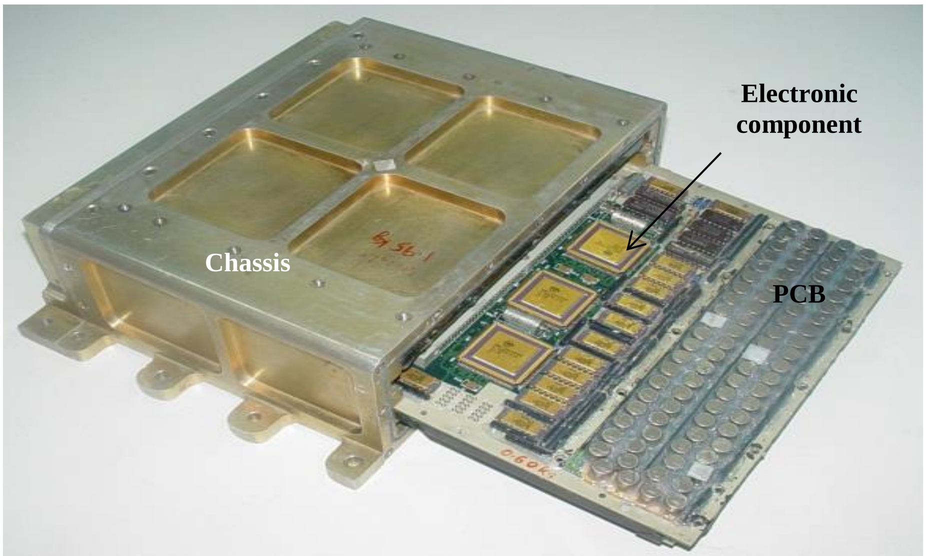


Figure 7.23 Package – 5

Random vibration test has been conducted on this package also and the response has been measured at four locations using accelerometers as shown in Figure 7.24.

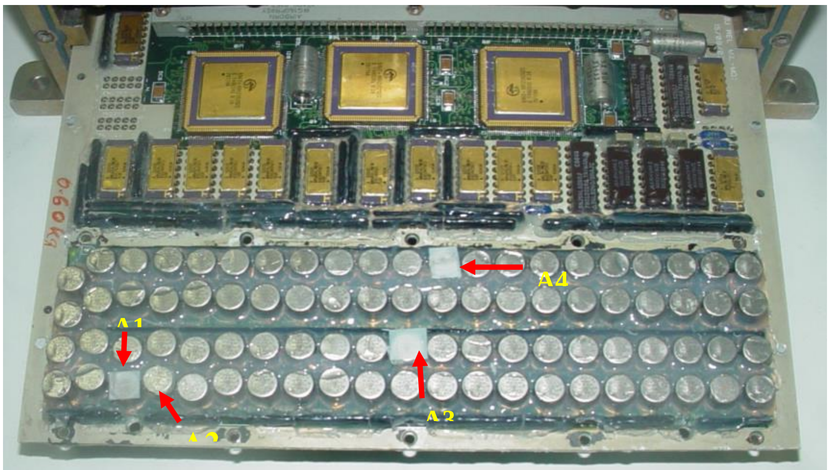


Figure 7.24 Response locations

Response details are given in Table 7.7.

Table 7.7 Response details of package-5

Location	A1	A2	A3	A4
Response, g_{rms}	34	33	45	32
Frequency, Hz	180			

Following methodologies were used to find the optimal one for modeling wedge guide interconnections.

1. Beam elements
2. Rigid links

and it was found that the option number 2 (i.e. Modelling the wedge lock as a rigid link) was an optimal one, as the FEA frequency was the closest to that of the test. Results obtained using FEA are compared with that of test in table 7.8.

Table 7.8 Summary of results of package-5 for an input of 8.9 g_{rms}

Location	A1	A2	A3	A4
Response (Test), g_{rms}	34	33	45	32
Response (FEA), g_{rms}	32	30	43	30
% error	5.8	9	4.4	6.2
Frequency (Test), Hz	180			
Frequency (FEA), Hz	181			
% error	0.5			

7.3.2 PACKAGE – 6

Further to study and examine the consistency of the stated modeling approach in case of wedge guide configuration, the proposed FE modeling procedures has been adopted on another chassis shown in Figure 7.25.

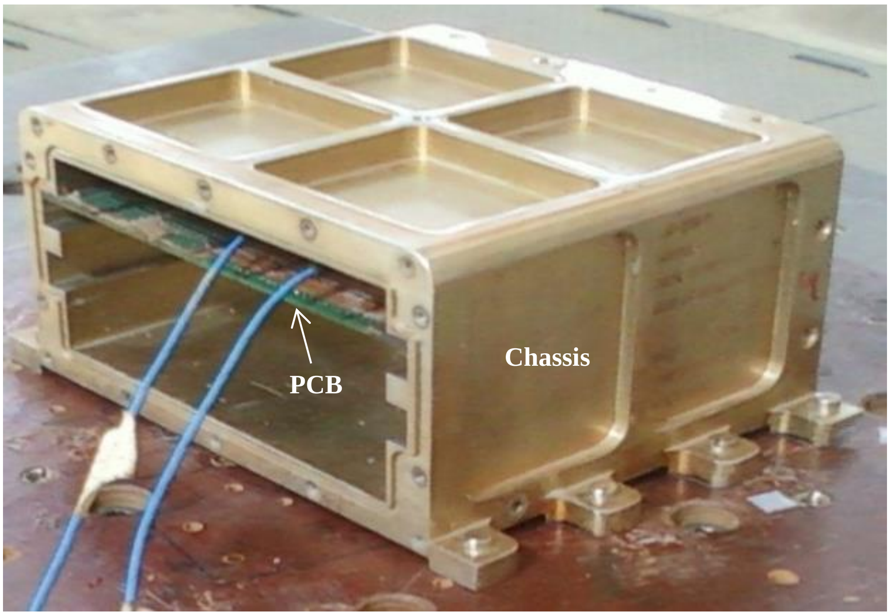


Figure 7.25 Package-6

The response is measured at two locations on the PCB as shown in figure 7.26.

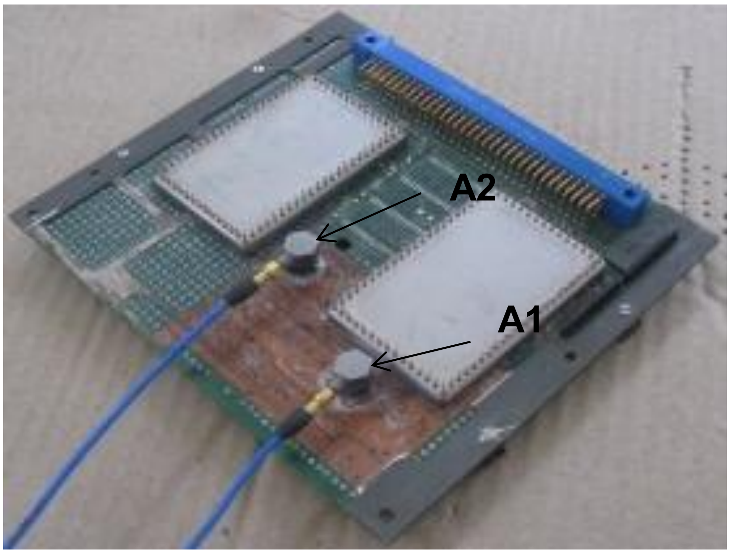


Figure 7.26 Response locations on package-6

Results obtained using FEA are compared with that of test in table 7.9

Table 7.9 Summary of results of package-6

Location	**A1**	**A2**
Response (Test), g_{rms}	47.8	13
Response (FEA), g_{rms}	48.1	15
% error	0.62	15.4
Frequency (Test), Hz	90	
Frequency (FEA), Hz	92	
% error	2.2	

After ascertaining consistencies associated with proposed modeling practices in predicting random vibration response of electronic packages, an attempt has been made to compare the outcome of current research work with that in literature. From extensive literature survey it is found that one paper addressed comparison of vibration response predicted using FEM with that of test [1]. Authors of this reference have considered a package consisting of one PCB mounted on Anti Vibration Frame (AVF) for study as shown in Figure 7.27 [1]. Measured material properties were considered for analysis. PCB has been discretized with shell elements and the AVF has been discretized with beam elements. Screwed connections between PCB and AVF were simulated using rigid links. Mass of components was added to the mass of PCB.

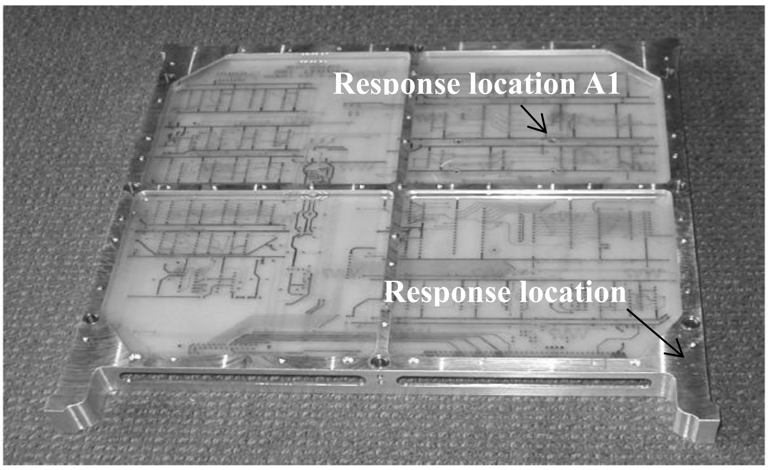


Figure 7.27 Package considered for study

Random vibration response analysis has been carried out using FEM and subsequently vibration test was also done. Outcome of the approach in terms of vibration response as stated in the above-mentioned reference is compared with that of current research work in Table 7.10.

Table 7.10 Comparison of outcome of current research work with that of literature

Location	**Random vibration response (g_{rms})**					
	Reference			**Current research work**		
	Test	**FEM**	**% error**	**Test**	**FEM**	**% error**
A1	52	41	21.1	3.2	3.15	1.5
A2	35	23	34.3	10	11.4	14
A3				4.5	4.9	8.88
A4				3.5	4	14.3
A5				10.2	10.4	1.9
A6				4.0	4.2	5.0

- From Table 7.10 it is seen that the degree of closeness between prediction and that of test is far better in case of modeling approach proposed in current research work than that of the one stated in reference, found in literature.
- Reason for high error in vibration response estimated in reference could be due to two reasons. First one being modeling screwed connections between PCB and AVF using rigid links which doesn't account for the flexibility associated with screws. Instead screws would have been modeled using beam elements. Second reason for high error could be consideration of damping estimated from free-free modal testing for performing response analysis. Instead damping estimated from vibration test would have been considered.

7.4 SUMMARY

Two basic configurations are considered for package level analysis. Approaches adopted for various interconnections are discussed. In order to establish the consistency associated with the proposed approaches, various other packages have been considered for the study. Efficacy of proposed modeling approach is far better than that seen in literature, particularly the match of g_{rms} for a larger frequency band of up to 2000 Hz and in terms of variation of results of the numerical approach with that of experimentally obtained results.

CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1 SUMMARY

Primary scope of the current research study is to establish a meticulous modeling practice for carrying out random vibration response analysis for electronic packages. The defined problem is systematically divided into various stages of modeling/ analysis.

a) PCB level
b) Populated PCB level (PCB with components)
c) Chassis level
d) Integrated sub system level which forms the practical system level configuration for any aerospace system.

To begin with PCB without components is considered for the study. Material properties of the PCB are evaluated experimentally. Rotational DOF of PCB at screw mounting location are modeled using rotational spring elements. Stiffness of these elements is tuned, until the first natural frequency predicted using FEA, matches with that of test results and thus established rotational stiffness values necessary for modeling rotational boundary conditions in FEA. In the later stage damping is tuned until random vibration response predicted using FEA matched with that of random vibration testing. Exercise has been done to generate the data base consisting of tuned values of rotational stiffness and damping for various mounting configurations of PCBs. Then the study has been extended for PCB having electronic components. Various approaches are considered for modeling electronic components. Based on quantitative assessment of accuracy associated with modeling approach, all three (SHELL, SOLID & GMS) appears to be identical. However, keeping in view, the complexity associated with SHELL and SOLID approaches which need modeling each and every discrete component taking its dimensions, location, material properties, etc., GMS method is identified to be accurate modeling practice for PCB with components for all practical purposes like ease of modeling and modeling time. Later study has been extended for chassis level analysis. The package level consists of the populated PCB’s mounted on the chassis either in a stacked configuration or in a wedge guide configuration. It also consists of all the interconnections either between the PCB's and/ or the connections between the PCB's and the chassis in the form of typical connectors. In this stage modeling and analysis details are presented for such an overall configuration which is the ultimate form in which the subsystems are mounted in an aerospace vehicle. The analysis is done with the same approach as presented up to the chassis level and the results are verified with the experiments.

8.2 CONCLUSIONS

The following are the conclusions drawn from the present work:

- Material properties like Young's modulus, density, Poisson's ratio and shear modulus are experimentally evaluated.
- Approach for modeling mounting screws of PCB using rotational spring elements is presented. Data base consisting of tuned values of rotational stiffness and damping for various mounting configurations of PCB has been brought out.
- The various modeling approaches to the electronic components mounted on the PCB'S are discussed. The effect of each type of modeling on the result of the random vibration analysis is discussed.
- The mounting of the PCB and the modeling of the PCB with the mountings represented by the rotational stiffness was extended to the mounting of the chassis represented by rotational stiffness of the element.
- By extending the methodology to the final subsystem level the analysis has been carried out on many packages and the experimental verification of the random vibration levels are made, which gives confidence that the approaches followed are giving results close to the test results.
- By following a similar modeling approach, it can be said that anyone would be able to predict the vibration response levels in terms of the g_{rms} for any package with a great degree of accuracy for up to 2000 Hertz. Of course, the g2/Hz values would be closely matching with the first few modes. At higher frequencies, there would be mismatch. However, the g_{rms} is an indication of the total energy level in the susceptible frequency band entering into the system and would reasonably be a measure of the damage it could impact. Most of the component specifications therefore restricts the g_{rms}. Typical component specifications are attached in figures 8.5 and 8.6 at appendix pages 123-124. It has been seen that mostly this could form a decision-making tool for proper

packaging of electronic systems, largely because failures are displacement predominant and displacements at higher frequencies are much lower.

8.3 SCOPE FOR FUTURE WORK

The following future work is proposed

- Application of major outcome of the present research like modelling approach for boundary conditions, experimentally evaluated material properties for sections of air borne vehicles.
- Evolution of precise modelling practices for other environments like inertial acceleration and shock
- Formulation of modelling approach for component level to address issues related to pins.

Figure 8.1 M3 screw with 7 mm height

Figure 8.2 M4 screw with 7 mm height

Figure 8.3 M4 screw with 15 mm height

ACCELEROMETER DETAILS:

Details of accelerometers used for all the tests both for control and the responses are given below:

- Make: PCB
- Model number: 340A15
- Sensitivity: 10 mV/g
- Measurement range: $\pm$ 500 g
- Frequency range: 1 Hz to 12000 Hz
- Type: Shear
- Weight: 2 grams

Table 8.1 Vibration input (Common for all cases)

FREQUENCY, Hz	ACCELERATION, g^2/ Hz
20	0.0002
100	0.005
1000	0.005
2000	0.00125

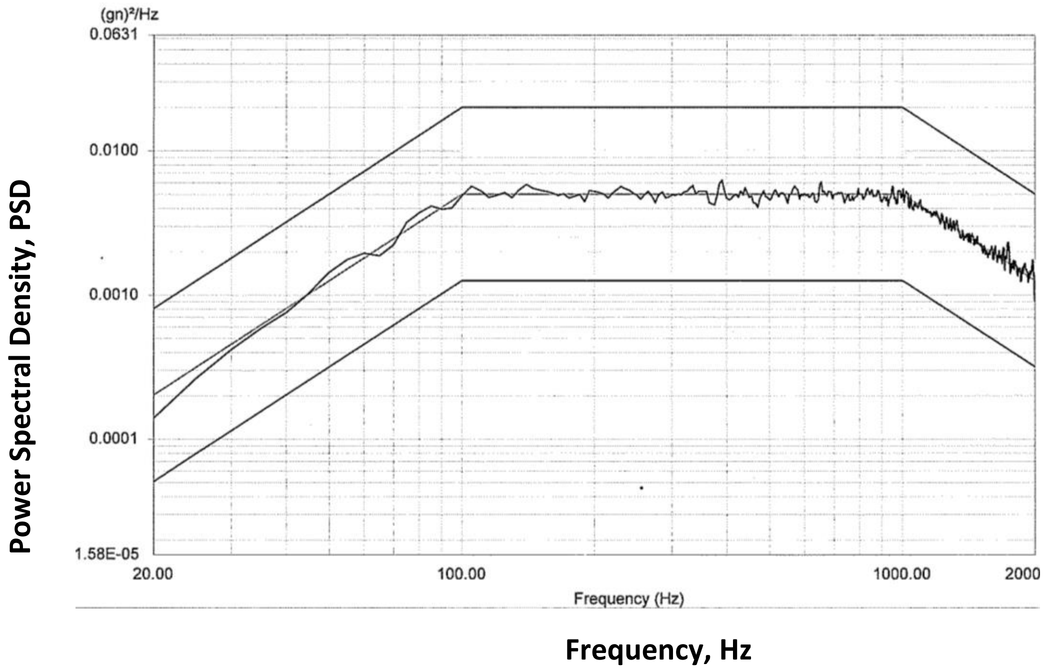


Figure 8.4 Vibration input spectrum graph

VIBRATION QUALIFICATION LIMITS FOR CRYSTAL OSCILLATORS

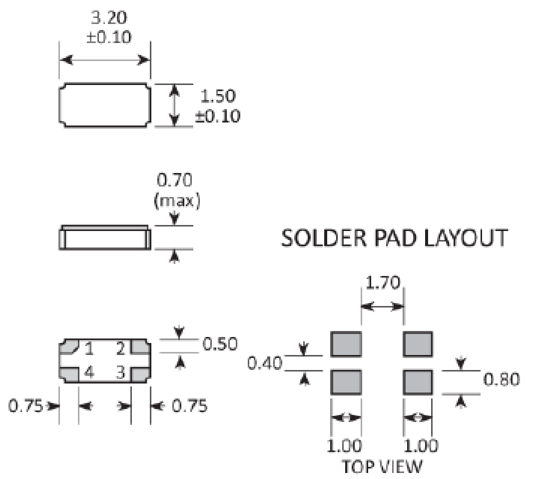
Golledge

OM7604C7 2/5

SPECIFICATIONS

Frequency	32.768kHz
Dimensions	3.2 x 1.5 x 0.7mm
Turnover temperature (T_O)	+25°C ±5°C
Frequency / temp coefficient	-0.035ppm/°C² ±10%
Storage temperature range	-55 to +125°C
Supply voltage (V_{DD})	Operable from 1.2 ~ 5.5V
Supply current (backup mode)	0.3µA typ, 0.5µA max (V_{DD} 3.0V, output disabled)
Logic levels	'0' level = 0.4V max '1' level = V_{DD} - 0.4V min
Driving ability	10pF CMOS
Voltage coefficient	±1.5ppm/V max
Rise / fall time	70ns typ, 100ns max
Start up time	400ms typ, 800ms max
Enable / disable function	Control via pad 3
Ageing	±3ppm max first year @ 25°C
Shock resistance	±5ppm, 5,000g, 0.3ms ½-sine
Vibration resistance	±5ppm, 20g rms 10.0 ~ 2,000Hz
Soldering condition	Reflow, 260°C, 20 sec max

PACKAGE DRAWING



PAD	CONNECTION
1	Output
2	Ground
3	Enable/Disable
4	Supply

Dimensions in mm

Figure 8.5 Cited from M/s Golledge Crystal oscillators catalogue

VIBRATION QUALIFICATION LIMITS FOR INERTIAL SYSTEMS

General | **Technical Specifications**

Gyro Channels Performance

Parameter	units	1 σ / max	Value	
			Grade A	Grade B
Dynamic Range	°/sec	max	1000	
Scale Factor Accuracy	ppm	1 σ	50	100
Bias Accuracy	°/hr	1 σ	0.1	0.5
RW	°/ √hr	max	0.03	0.1
Magnetic sensitivity	°/hr/ gauss	max	0.1	

Accelerometers Channels Performance

Parameter	units	1 σ / max	Value	
			Grade A	Grade B
Dynamic Range	g	max	25	40
Scale Factor Accuracy	ppm	1 σ	200	750
Bias Accuracy	mg	1 σ	0.2	1
RW	m/sec/√Hr	max	0.05	0.1
Vibration sensitivity	$\mu g / g^2$	max	50	100
Linearity	$\mu g / g^2$	max	20	50

Environmental Conditions (MIL-STD-810F)

Parameter	Value
Temperature, operating	-40°C to +71°C
Temperature-Altitude	–40°C @ altitude of 70,000 ft
Vibration, random	8 grms 20 to 2000 Hz
Shock, operating	25 g, 11 msec
EMI/RFI	per MIL-STD-461F

Additional Characteristics

Parameter	units	
Dimensions (LXWXH)	mm	100 x 100 x 115
Weight	kg	< 1.7
Voltage Supply	Vdc	+15, -15, +3.3
Power Consumption	Watts	typ. 10, max. 12
Communication	Kbits/sec	UART,RS 485, Baud Rate 460.8, SDLC optional

ALL INERTIAL SYSTEMS

ADNAV - Small INS/GPS

NFS - North Finding

RNAV-IPON INS/GPS

Figure 8.6 Cited from M/s Tamam sensor specification from internet.

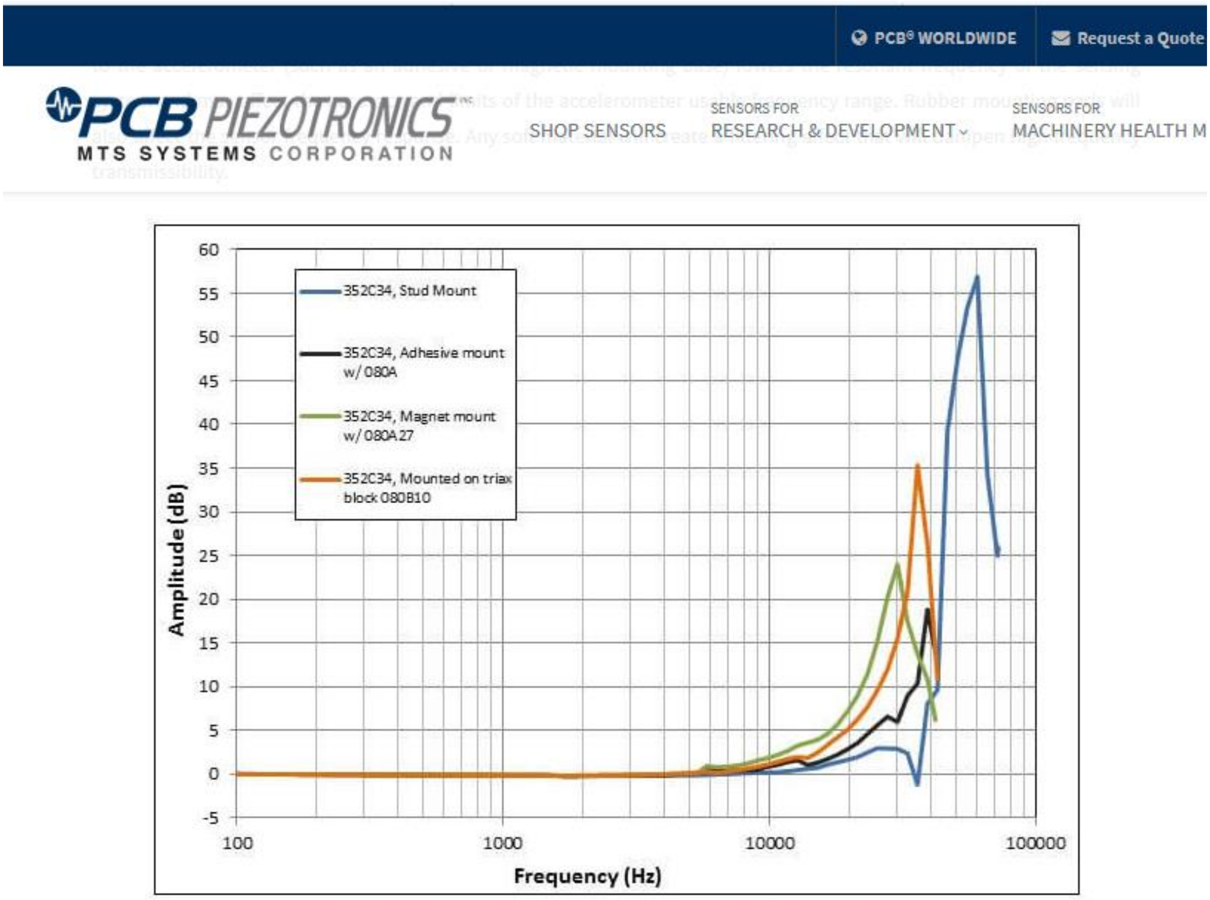


Figure 1: Approximate frequency ranges of mounting techniques

Figure : 8.7	Frequency response for different adhesive used for mounting accelerometers.

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OUTCOME OF THE PRESENT WORK

Part of the work is published as the following papers:

1. K.Jagadisan, Bangaru Babu P, Anil Kumar P. **Precise Modeling Practice for Avionics PCB in Random Vibration Environment. Journal of Experimental & Applied Mechanics**. 2016; 7(1): 51– 59p.
2. K. Jagadisan, P. Bangaru Babu. **Evolution of Structural Dynamic Modeling Technique for Airborne Chassis. Journal of Mechatronics and Automation**. 2016; 3(3):
3. K. Jagadisan, P. Anil Kumar & P. Bangaru Babu (2017): **Finite element modeling technique for avionics PCB with electronic components in random vibration environment, Australian Journal of Mechanical Engineering**, DOI: 10.1080/14484846.2017.1372030

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He acquired his BE (Mech.) from Regional Engineering College, Bhopal (Presently NIT, Bhopal) in 1980 and completed his MTech (Heat transfer) from Regional Engineering College, Nagpur (Presently NIT, Nagpur) in 1994. He joined DRDO in 1986 in the Environmental testing division and is presently an outstanding Scientist (Scientist 'H'). Innumerable vibration testing been conducted with him as a team leader. He has around 20 Publications of which tree are related to the present work.