Simulation and Modification of Microwave Package for Space Communication Payload

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Abstract--**The purpose of a microwave package is to integrate all the components of a sub-system in such a way to minimize size, mass, complexity and cost. It should provide electrical interfaces between the components in the spacecraft system and ensure high reliability. The packaging of integrated circuits for satellites is a challenging task, as the package has to withstand space environment. The design of a microwave package must integrate the skills of electrical, mechanical, manufacturing, industrial, material and systems engineers.**

This paper thoroughly reviews the mechanical design of channel amplifier tray for GEOSAT communication payloads. The entire tray with machining and assembly aspects has been simulated using 3D CAD model. The assembly has been modified for mass reduction using structural analysis meeting all electro-mechanical constraints. The tray has been reviewed for Design or Manufacturing and Assembly (DFM & A). The CAD model has been analyzed using Altair HyperMesh software for modal as well as linear static analysis.

The theoretical analysis results and effect of mass reduction on geometrical tolerance of the tray have been verified by fabrication of the simulated tray hardware and by carrying out vibration testing. The results obtained will be useful for future design of space microwave payload subsystems.

Index Terms--**Microwave Integrated Circuit (MIC), Channel Amplifier Package, Design for Manufacturing and Assembly (DFM & A), Computer Aided Engineering (CAE), Finite Element (FE) simulation**

I. INTRODUCTION

MICROWAVE electronic packaging is the art and science of creating a physical electronic product - the art being the development of new unique electronic products whose concepts are born through human activities and the science representing the sum of human knowledge in the spacecraft engineering disciplines employed in creative process. Satellite complexity increases with large number of transponders, more power requirement and very short time for development of spacecraft as per user agency delivery schedule. Microwave packaging for space covers a broad range of activities, all of which involve grouping MIC, carrier plates & packaging elements into a functional unit.

CAE is used for virtual prototyping and analysis. Sufficient confidence level is made by using CAE software for the product performance, prior to prototype testing. While this is a welcome step and can result in substantial reduction in development time, further improvement is still possible by ensuring that, the initial design chosen is closer to the optimal design.

The packaging of microwave integrated circuits for satellites is a challenging task, as the package has to withstand space environment. A typical MIC package consists of Aluminum box, Kovar carrier, alumina Substrates and other electronics devices. Realization efforts for Ku-Band Channel Amplifier with FE analysis and experimental tests are described in this paper. The modification of tray with FE analysis is also described in this paper.

II. DESIGN REQUIREMENTS FOR MICROWAVE PACKAGE FOR SPACE USE

Packages should fulfill following design criterions for expendable launch vehicles.

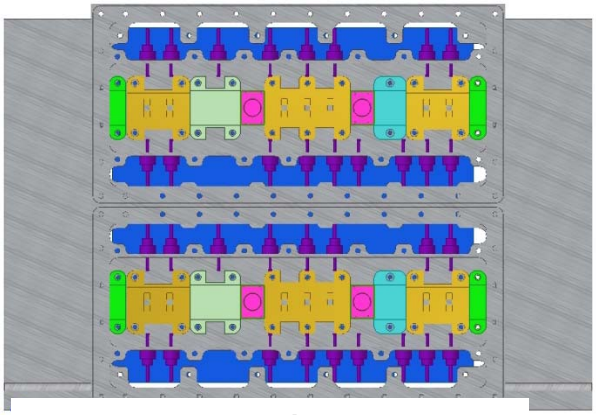
- Low weight and high strength to withstand environmental and launch loads.
- The natural frequency should not couple with spacecraft structure to avoid resonance. Hence, it should be above 100 Hz.
- The margin of safety should be positive (Considering yield strength of material at the end of life).

The mechanical design considers minimum weight, volume, foot print area without affecting the electrical performance & reliability during various phases of testing and integration. The package is designed to withstand specified vibration with accessibility, reliability, interchangeability, and protection against corrosion, humidity and temperature. Tight tolerances are to be achieved in the fabrication to achieve electrical specifications.

III. DEVELOPMENT FOR KU-BAND CHANNEL AMPLIFIER

Different assembly configurations were prepared to minimize size, mass, ease of harness and assembly while meeting electrical connectivity and performance requirement. Each Carrier plate assembly, PCB, Feed throughs, fasteners and other components have been CAD modeled for interconnection and assembly. Requirement of any special cutters and fixtures has also been worked out. [1]

The assembly of Ku-Band Channel Amplifier is shown in fig. 1. The overall size of the package is 222.9 mm x 47.7 mm x 152.2 mm (height). The package is of vertical mounting configuration with 4 no. of socket head cap screws of size M4 x 12 long. The vertically mounting provides less foot print area.



Front view without cover

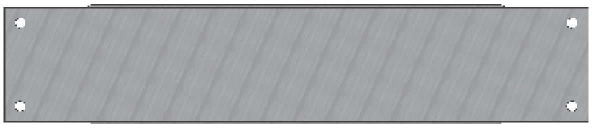


Fig. 1. CAD Layout of Ku Band Channel Amplifier

The package is of two tier and houses MIC devices (carrier plates) at one side and two PCBs at back side. The box is made from aluminum alloy 6061-T6. The aluminum alloy has good machinability, low weight and high strength and desired surface finish can be achieved. The carrier plates made from Kovar (Fe-Ni-Co low expansion alloy) are designed symmetrical to avoid warpage and ease of fabrication.

Special Features of Ku-Band Channel Amplifier

1. Package & carrier plate (CP) design to meet functional requirement with 100% track alignment, minimum 50 micron to maximum 100 micron clearance between CP to CP, CP to wall or devices, 1D engagement of screw threads, 3 mm corner radii meeting all QA guidelines along with fabrication and assembly aspects from given specifications. [2]
2. Complete 3D modeling for simulation of package with carrier plates, covers and devices. The same has been used for generating requirement of any tool or torque attachment in advance. This helped in providing proper torque to feed throughs and other devices.
3. Feasibility of torque application of RF feed-throughs in package and soldering of DC wires using CAD simulation.

IV. SIMULATION AND DESIGN VALIDATION THROUGH FE ANALYSIS

HyperMesh has been used for FE analysis. HyperMesh is a high performance finite element pre and post-processor that allows building finite element and finite difference models, view their results, and perform data analysis. [3]

Material Collectors

Material collectors are made for FE Analysis as shown in Table 1.

TABLE 1
MATERIAL AND ITS PROPERTIES USED FOR FE ANALYSIS IN HYPERMESH

Material	Modulus of Elasticity N/mm^2 (*)	Poisson Ratio	Density Ton/mm^3 (*)
Al. Alloy 6061-T6	70000	0.33	2.7 x 10-9
Glass Epoxy	27500	0.24	2.1 x 10-9

(*) These units are generally used in HyperMesh.

V. FE MODEL OF KU-BAND CHANEL AMPLIFIER

Various component collectors are made with actual thickness and material. Shell elements have been taken for all the components. Combination of auto mesh and manual mesh has been taken with "tria" and "quad" elements. Total no. elements are 28100 with 28418 nodes. Total no. of quad elements is 27368. Total no. of tria elements is 56. So, no. of tria elements is less than 5% of total elements. Total no. of rigid elements is 52 which are screwed joint between cover and box. The small parts are considered as a concentrated mass. Total no. of "conm2" elements is 676. Actual loads are applied at appropriate locations to simulate the actual condition. Final meshed model ready for analysis is shown in fig. 2. Quality index is checked for accurate results and errorless FE analysis.

The mass of FE model closely simulates that of actual model of Ku-Band Channel Amplifier which is 971 gm.

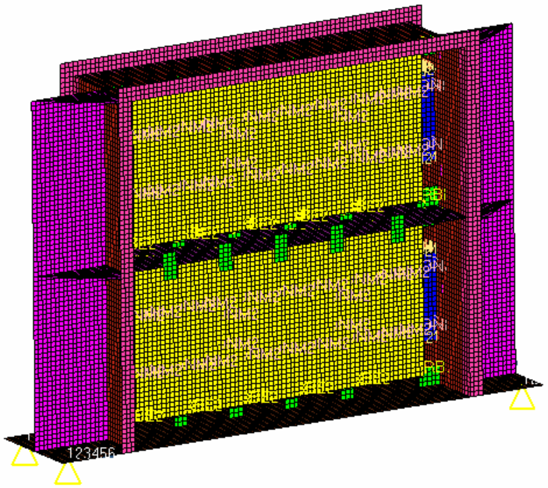


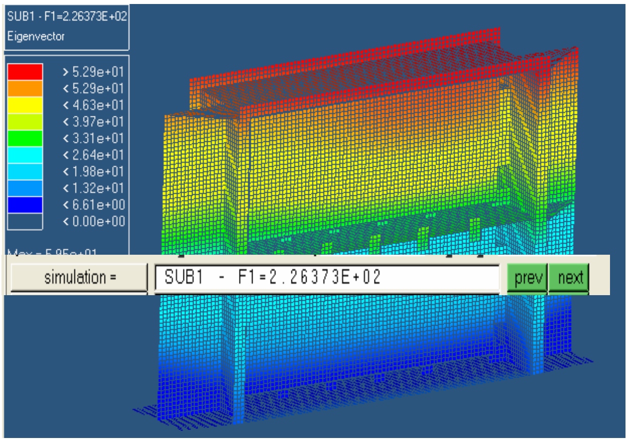
Fig. 2. Meshed Model of Ku Band Channel Amplifier

VI. FE ANALYSIS, RESULTS AND COMPARISON WITH EXPERIMENTAL RESULT

The package is mounted by 4 no. of M4 Soc. Hd. Cap screw with 1.4 N-m torque. All four lugs have been defined as fixed boundary condition (constraint) for FE analysis. FE Analysis is done by the solver Optistruct. Results for frequency, stresses are discussed. [4]

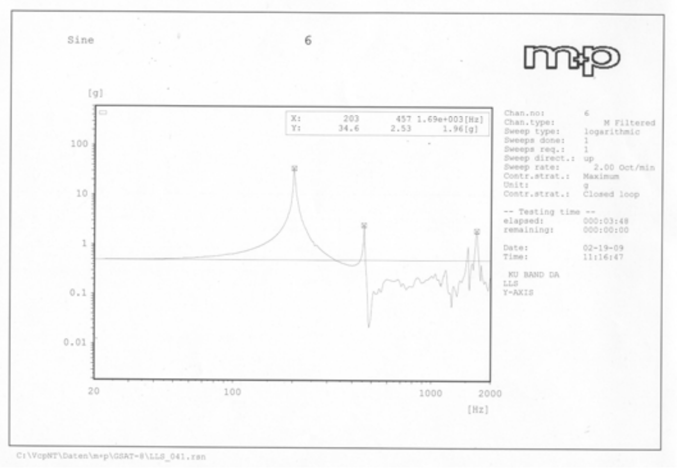
The package has been vibrated at Vibration Test Facility.

FE analysis gives first mode at 226 Hz as shown in figure 3. The graph for resonance search test is shown in figure 4.


SUB1 - F1=2.26373E+02
Eigenvector

simulation = SUB1 - F1=2.26373E+02

Fig. 3. FE Analysis Natural Frequency First Mode (226 Hz)



X: 203 457 1.69e+003 [Hz]
Y: 34.6 2.53 1.96 [g]

Chan.no: 6
Chan.type: M Filtered
Sweep type: logarithmic
Sweeps done: 1
Sweeps req.: 1
Sweep direct.: up
Sweep rate: 2.00 Oct/min
Contr.strat.: Maximum
Unit: g
Contr.strat.: Closed loop

-- Testing time --
elapsed: 000:03:48
remaining: 000:00:00

Date: 02-19-09
Time: 11:16:47

KU BAND DA
LLS
Y-AXIS

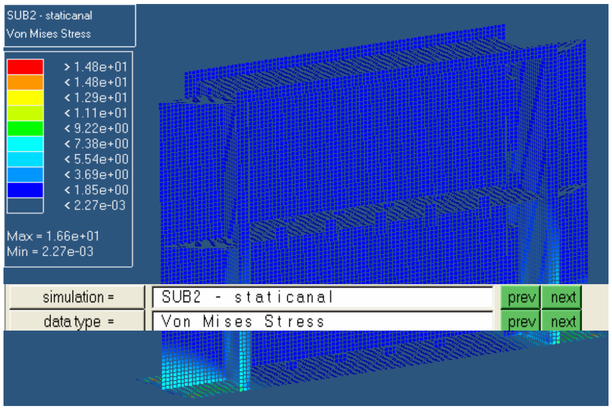
C:\VcpNT\Daten\m+p\GSAT-8\LLS_041.ran

Fig. 4. Experimental Result Natural Frequency First Mode (203 Hz)

The natural frequency estimate matches reasonably well with test results. This validates the FE Model for analysis.

Stresses

The Ku-Band Channel Amplifier structure is most severe in Y direction for stiffness and stress because of the vertical mounting configuration. 15g load has been given in this direction as per the vibration specifications. The results for stresses have been shown in figure 5.


SUB2 - staticanal
Von Mises Stress

Max = 1.66e+01
Min = 2.27e-03

simulation = SUB2 - staticanal
data type = Von Mises Stress

Fig. 5. Stress Analysis (Maximum Stress 16.6 N/mm^2)

VII. IMPROVISATION OF KU-BAND CHANNEL AMPLIFIER

From the above FE Analysis as well as experimental simulation, certain design changes have been implemented for further mass reduction by engineering judgment. During optimization, DFM and DFA aspects have been considered to minimize the machining time & cost, ease of machining. Following changes have been incorporated in FE model as well as in fabricated package by additional precision milling. [5] The design changes are given below.

Box

a. Base thickness reduced to 6.5 mm from 7 mm at outer side.
b. Base thickness reduced to 6.9 mm from 8.2 mm at inner side near cavity.
c. Mid wall thickness reduced to 0.5 mm from 1.2 mm
d. Total removal of mounting lugs for inside cover.
e. Total removal of cantilever wall for mounting of isolator.
f. The position of feed through is horizontal from vertical.

Top Cover

a. Thickness is reduced to 1 mm from 1.8 mm
b. Thickness is reduced to 2 mm from 2.2 mm

Bottom Cover

a. Thickness is reduced to 1 mm from 1.8 mm
b. Thickness is reduced to 1 mm from 2.2 mm

After machining the final package is shown in figure 6, the mass has been reduced by 350 gram.

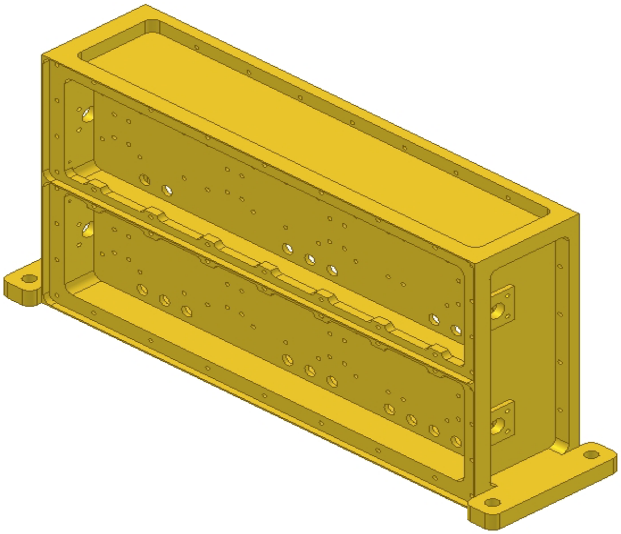


Fig. 6. Final Ku Band Channel Amplifier after modification

Comparison of FE Model and Actual Model for Improvised Package

Modification in required component collectors has been incorporated and the new component collector has been generated. The mass of FE model closely simulates that of final package of Ku Band Channel Amplifier after improvisation which is 710 gm.

VIII. FE ANALYSIS OF IMPROVISED PACKAGE

The modified Ku Band Channel Amplifier design has been checked by FE analysis. For FE analysis same methodology has been adopted as in previously. Shell elements have been taken for all the components. Manual mesh has been generated with “quad” elements. Total no. elements are 22414 with 22824 nodes. Total no. of quad elements is 22167. Total no. of rigid elements is 81 which are screwed joint between cover and box. For simplification, the small parts are considered as a concentrated mass. Total no. of “CONM2” elements is 247. So, total degree of freedom becomes 136920. Actual loads are applied at appropriate locations to simulate the actual condition. Final meshed model ready for analysis is shown in figure 7.

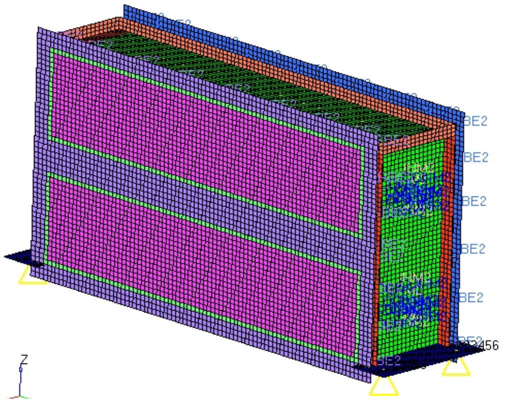


Fig. 7. Meshed Model of Improvised Package

FE analysis result for the improvised package is 561 Hz as shown in figure 8.

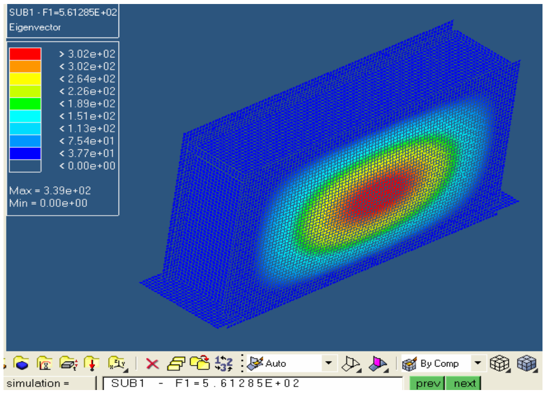


Fig. 8. FE Analysis Natural Frequency First Mode (561 Hz)

Stresses for Improvised Package

The Ku Band Channel Amplifier structure is most severe in Y-axis (perpendicular to mounting surface) direction for stiffness and stress because of the vertical mounting configuration. 15g load is given in this direction as per the vibration specification.

The results for stresses are shown in figure 9. There is marginal increase in stress, which is well within permissible limit.

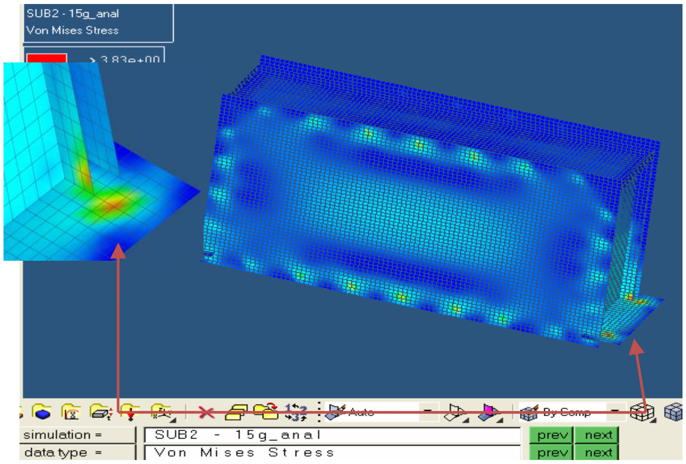


Fig. 9. Stress Analysis (Maximum Stress 43.1 N/mm^2)

IX. CONCLUSION

The Ku Band Channel Amplifier tray and assembly has been modeled and analyzed. The same has been fabricated and realized to validate the analysis results.

The experimental analysis proves the validity of FE analysis. The analysis results are coming within ±10 % of the experimental results. This establishes that FE analysis is an important tool for design and development of complex and costly components. The modification resulted in a compact and dense packaging with 30% foot print reduction and 37% mass reduction.

The Ku-Band Channel Amplifier package analysis can be used as a reference for generating guidelines for mechanical package design of forth coming satellite communication payloads.

X. ACKNOWLEDGEMENT

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XI. REFERENCES

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[4] Dhaval Shah, V. R. Iyer, A. V. Pathak, "*FE Simulation and Experimental Validation for A Space Microwave Package*" at Vaigyaniki'09, IIT, Bombay, March 2009.

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