Thermal Analysis of Power Amplifier Chassis

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Abstract - Power electronics is an enabling technology and widely used in computers, automobiles, telecommunications, motors, lighting, and alternative energy. With its importance in performing in our daily life functions, it is crucial to have high-reliability power electronic systems. Higher temperatures make the electronic components unreliable and more likely to fail. Therefore, keeping the power electronics components within the operating temperature range is essential. More importantly, good thermal management not only can reduce the thermally-induced failures but also enhance the performance of the power electronics components. Consequently, reliability, durability, and cost become very crucial issues in power electronics. Overheating of electronics can cause severe catastrophes in our daily life. For all these factors thermal analysis of electronic components is necessary. Power amplifier is used in avionics equipment such as Transreceiver (R/T) to amplify and transmit the Radio Frequency (RF) signals. During this transmission heat is dissipated on the chassis by various electronic components. By this temperature is raised and is affecting the performance of the power amplifier. The main aim of the project is to find the maximum temperature of the power amplifier with and without fins of the chassis under steady state and natural convection conditions and also to compare the results obtained with those of practical readings are within working condition of -40°C to 100 °C. Thermal analysis is carried out by using Nastran and Patran finite element package, and compared with pure conduction case.

Keywords: Power amplifier, Thermal analysis, finite element package.

1. INTRODUCTION

Whenever electrical current flows through a resistive element, heat is generated in that element. An increase in the current or resistance produces an increase in the amount of heat that is generated in the element. The heat continues to be generated as long as the current continues to flow. As the heat builds up, the temperature of the resistive element starts to rise, unless the heat can find a flow path that carries it away from the element. If the heat flow path is poor, the device junction temperature may continue to rise and exceeds the maximum safe operating temperature specified by the manufacturer which in turn stops the current flow. Consequently, semiconductors performance, life, and reliability are drastically reduced. If the heat flow path is good, the temperature may raise until it stabilizes at a point where the heat flowing away from the element is equal to the heat generated by the electrical current flowing in the element.

Heat is generated in electronic component parts such as resistors, diodes, integrated circuits, hybrids, transistors, microprocessors, relays, dual inline packages, very high scale integrated circuits, pin grid arrays, leadless ceramic chip carriers, and plastic leaded chip carriers. Electronic components and electronic systems are rapidly shrinking in size while their complexity and capability continue to grow at an amazing rate. In addition, the power has been increasing while the volume has been decreasing which has produced a dramatic increase in the power density, resulting in rapidly rising temperatures and a large increase in the number of failures. These factors have challenged the mechanical engineers to design and analyse electronic components.
Figure 1.1 causes of avionics failures

The life of an electronic component reduces by half for every rise in 10°C rise in its operating temp.

Thermal management is very much necessary in the power amplifier due to the followings factors.
1. Increase in density of packaging.
2. Use of high heat dissipating components.
3. Excessive heat affects the performance of electronic equipments.
4. Use of advanced computer chips.
5. With developments in technology of miniaturized microprocessors.
6. To increase Reliability of the system

To prevent premature failure of the electronic component

2. PROBLEM DESCRIPTION

Avionics are electronic equipments used in aircraft and the demand a great deal of the mechanical design skill for achieving sound and reliable products. The use of the avionics in the strategic or military applications is rapidly increasing and these equipments are becoming more and more sophisticated. Today communication among pilots of various aircrafts and between aircraft and ground stations is a major necessity. Power amplifier is used in the Transmitter to amplify the generated signal.

Power amplifier is used to amplify the Radio Frequency signals that are generated in the Transceiver (R/T). The input power of 0.1mW is given at stage 1 and output power of 20W comes at stage 4. Power amplifier works during transmitting and don’t work during receiving of signals. The material used for this is Aluminium alloy 1060.

Figure 2.1 Power Amplifier Chassis

It consists of 4 stages at each and every stage there is some projected area on which electronic PCB’s are mounted respectively. The efficiency of power amplifier is 40% and the working conditions are in between -40°C to 100°C. In the Transceiver maximum heat is dissipated by power amplifier. In power amplifier heat is dissipated at these four stages which are shown below.

Stage 1
Operating temperature = -40 degree C to 100° C
Total power dissipation = 14 Watts @ 25 °C
Actual power dissipation = 7 Watts @ 25 °C
Efficiency=25%
Heat dissipation=5.25 Watts
Power at the end of this stage= 1Watts

Stage 2
Operating junction temperature=200°C
Total power dissipation= 11 Watts @ 25 °C
Actual power dissipation= 6 Watts @ 25 °C
Junction temperature= 16 °C /w
Efficiency = 40%
Heat dissipation=3.6 Watts
Power at the end of this stage= 5 Watts

Stage 3
Operating temperature=200 °C
Total power dissipation= 116 Watts @ 25°C
Actual power dissipation= 30 Watts @ 25°C

Figure 2.1.1 Top View Describing Various Stages of a Power Amplifier
Junction temperature=1.52 °C /w
Efficiency=35% to 40%
Heat dissipation= 18 Watts
Power at the end of this stage= 25 Watts

Stage 4
Operating temperature =200 °C
Total power dissipation= 389 Watts @ 25 °C
Actual power dissipation= 140 Watts @ 25 °C
Efficiency =35% to 40%
Heat dissipation=84 Watts
Junction temperature=0.45 °C /w
Power at the end of this stage= 20 Watts

The total heat dissipation at the end of each and every stage is given by adding the dissipated heat at the end of each and every stage i.e. \( Q = 5.25 + 3.6 + 18 + 84 = 110.85 \) Watts.

The main aim is to find the maximum surface temperature of the power amplifier chassis. As the power amplifier dissipates heat only when it is transmitting signals at various stages, time required is not considered and uses free convection for cooling of chassis so therefore
1. Steady state heat transfer is considered.
2. Natural convection is done has the cooling is done by air.

The convective heat transfer coefficient is determined for power amplifier with and without fins from which maximum surface temperature is found by thermal analysis and verified with practical values.

2.2 SOLUTION METHODOLOGY

Scope of the project focuses in Modelling a Power Amplifier Chassis with and without fins as per the already existing design, selecting the mode and type of heat transfer and then analysing the results obtained and concluding. In designing stage, Transmitter box and power amplifier chassis is modelled and assembled by using SOLID WORKS software and thermal analysis is carried out through MSC NASTRAN/PATRAN software. The obtained results are compared and verified.

The steps involved in the project can be listed out as
- Modelling of the Power Amplifier chassis interface in SOLID WORKS.
- Calculating the heat transfer coefficient.
- Thermal Analysis of the Power Amplifier Chassis with and without fins interfaces in MSC Nastran.
- Finding the surface temperature with and without fins.
- Comparing the Results with practical Values and conclusion.

2.3 PROBLEM ANALYSIS

There are various types of analysis been done in MSC Nastran which includes structural, vibration, fatigue and thermal analysis and these are described below. In this we have discussed in detail about thermal analysis as our project is confined to it.

- **Structural analysis** consists of linear and non-linear models. Linear models use simple parameters and assume that the material is not plastically deformed. Non-linear models consist of stressing the material past its elastic capabilities. The stresses in the material then vary with the amount of deformation.
- **Vibration analysis** is used to test a material against random vibrations, shock, and impact. Each of these incidences may act on the natural vibration frequency of the material which, in turn, may cause resonance and subsequent failure.
- **Fatigue analysis** helps designers to predict the life of a material or structure by showing the effects of cyclic loading on the specimen. Such analysis can show the areas where crack propagation is most likely to occur. Failure due to fatigue may
also show the damage tolerance of the material.

- Thermal analysis models the conductivity or thermal fluid dynamics of the material or structure. This may consist of a steady-state or transient transfer. Steady-state transfer refers to constant thermo properties in the material that yield linear heat diffusion.

2.3.1 Thermal Analysis

A thermal analysis calculates the temperature distribution and related thermal quantities in a system or component. Typical thermal quantities of interest are

- The temperature distributions
- The amount of heat lost or gained
- Thermal gradients
- Thermal fluxes.

Thermal simulations play an important role in the design of many engineering applications, including internal combustion engines, turbines, heat exchangers, piping systems, and electronic components. In many cases, engineers follow a thermal analysis with a stress analysis to calculate thermal stresses.

Nastran supports two types of thermal analysis:

1. A steady-state thermal analysis determines the temperature distribution and other thermal quantities under steady-state loading conditions. A steady-state loading condition is a situation where heat storage effects varying over a period of time can be ignored.

2. A transient thermal analysis determines the temperature distribution and other thermal quantities under conditions that vary over a period of time.

2.3.2 Steady-State Thermal Analysis

If an electronic system is turned on and left running for a very long period of time, and if the power requirements remain constant during that period, the temperatures of the electronic components and their mounting structures, such as PCBs, will usually become stable. Minor fluctuations in the line voltages, small changes in the physical properties of the individual components, and slight variations in the outside ambient conditions may have some small effects on the temperatures within the electronic system.

For all practical purposes, however the heat gained by the electronic components is equal to the heat lost. So that the system has reached thermal equilibrium. The internal heat has found one or more thermal paths from the heat source to the ultimate heat sink. Usually, all three methods of heat transfer-conduction, convection, and radiation-are involved. When the thermal equilibrium condition has been reached, the rate of heat being transferred by each of the three methods remains constant.

The temperature gradients are now fixed with the heat flowing from the hotter parts of the system to the cooler parts of the system, until the heat finally reaches the ultimate sink. These characteristics indicate that the system has reached the steady state heat transfer condition. Steady state conditions may develop in a matter of minutes for small components such as transistors and diodes. However for large electronic consoles, it may take a full day of operation before steady state heat transfer conditions are reached.

MSC Nastran products support steady-state thermal analysis. A steady-state thermal analysis calculates the effects of steady thermal loads on a system or component. Engineer/analysts often perform a steady-state analysis before performing a transient thermal analysis, to help establish initial conditions. A steady-state analysis also can be the last step of a transient thermal analysis has performed after all transient effects have diminished.

You can use steady-state thermal analysis to determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time. Such loads include the following:

- Convections
- Radiation
- Heat flow rates
- Heat fluxes (heat flow per unit area)
- Heat generation rates (heat flow per unit volume)
- Constant temperature boundaries

A steady-state thermal analysis may be either linear, with constant material properties; or nonlinear, with material properties that depend on temperature. The thermal properties of most material do vary with temperature, so the analysis usually is nonlinear. Including radiation effects also makes the analysis nonlinear.

The steady state heat balance equation is

\[ [K] \{u\} + [R] \{u + T_{
\delta_S}\}^4 = \{P\} + \{N\} \]

[K] = a heat conduction matrix
[R] = a radiation exchange matrix
[P] = a vector of applied heat loads that are independent of temperature
[N] = a vector of nonlinear heat loads that are temperature dependent
[u] = a vector of grid point temperatures
[T] = the absolute temperature scale adjustment required for radiation heat transfer exchange or radiation boundary conditions when all other
temperatures and units are specified in deg-F or deg-C.

3 THERMAL ANALYSIS OF A POWER AMPLIFIER CHASSIS WITHOUT FINS

The power amplifier after modelling in solid works 2008 is saved as parasolid file format (*.x_t). In MSC Patran 2005 a new file i.e. (*.db) is created and the parasolid format of power amplifier is imported. The power amplifier after importing is shown in wireframe model.

![Figure 3.a Power Amplifier Assembled In Transreceiver Box](image)

After generating solid models (*.prt, *.sldprt) in Solid Works are converted into the Parasolid files (*.x_t) of the same are imported to Analysis software MSC Nastran.

In the Pre-processing stage the model is fed with the required data such as material specification and material properties, element property specification, meshing parameters and application of the constraints.

In the solution stage, the meshed model with constraints is subjected to steady state analysis. In the Post-Processing stage, once the analysis is completed, the post process data is retrieved to view the Surface temperature and temperature gradient values of the power amplifier chassis with and without fins. For power amplifier chassis material used is Aluminium alloy and its composition is discussed in the table below.

<table>
<thead>
<tr>
<th>Aluminium Alloy</th>
<th>Composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>3.8-5.0</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.2-0.8</td>
</tr>
<tr>
<td>Silicon</td>
<td>0.5-1.2</td>
</tr>
<tr>
<td>Iron</td>
<td>0.7</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.3-1.2</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Remainder</td>
</tr>
</tbody>
</table>

Table 3.b Composition of Aluminium Alloy (ISO 2473)

3.1 Meshing Of Power Amplifier

In Patran after importing then meshing is done. The inputs given for meshing are solid mesh, in that Tet4 mesh is selected and the mesh size of 0.1. Meshing details are

- No of elements generated are 1, 32,608.
- Type of the mesh : Tet mesh (Tet4 mesh is selected)
- Mesh size of 0.1 is defined for refine mesh

![Figure 3.1.1 Meshing of Transreceiver](image)

![Figure 3.1.2 Meshed view of power amplifier](image)
3.2 MATERIAL PROPERTIES

After meshing is done then material properties are defined. The type of material used is Aluminium alloy and its material properties are defined in the table below.

<table>
<thead>
<tr>
<th>Material Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Conductivity</td>
<td>300 W/m-K</td>
</tr>
<tr>
<td>Specific Heat</td>
<td>900 J/kg/K</td>
</tr>
<tr>
<td>Density</td>
<td>2700 kg/m³</td>
</tr>
</tbody>
</table>

Table 3.2 Properties of Aluminium Alloy (ISO 2473)

After applying convection on the selected surface of the power amplifier chassis the model looks like below manner. Convection needs to be applied on the areas which in contact with atmosphere. From the calculations of heat transfer coefficient for without fins is \( h_{\text{conv}} = 6 \text{ W/m}^2\cdot\text{K} \). Ambient temperature = 25°C

4 RESULTS OBTAINED IN THERMAL ANALYSIS

The results obtained by analysis the (*.bd) file using analysis manager from which (*.bdf) file is generated. Then generated file is again given into MSC Nastran to get (*.xdb) file which is attached to view the results. In results the Temperature distributions on the power amplifier chassis is shown in below figure.
In Figure 4.1b Temperature distributions on the Transreceiver box

From the results the temperature distribution on the Trans receiver from power amplifier is shown in the figure below and temperatures obtained are

Maximum temperature on the power amplifier $T_{\text{max}} = 104^\circ\text{C}$

Minimum temperature $T_{\text{min}} = 40.3^\circ\text{C}$

4.1 Thermal Analysis of a Power Amplifier Chassis with Fins

The power amplifier with fins after modelling in solid works 2008 is saved as parasolid file format (*.x_t). In MSC Patran 2005 a new file i.e. (*.db) is created and the parasolid format of power amplifier is imported. The power amplifier with fins are importing is shown in wireframe model.

4.1.2 Meshing of power amplifier with fins

In Patran after importing then enter into element tab. The input given for meshing is solid mesh, in that Tet4 mesh is selected and the mesh size i.e. global edge length 0.1.

- Total no of elements = 175507
- Type of mesh = Tet10
- Mesh size = 0.1

After applying convection on the selected surface of the power amplifier chassis the model looks in this manner. Convection needs to be applied on the areas which in contact with atmosphere. From the calculations of heat transfer coefficient for with fins is $h_{\text{conv}} = 6.5\ \text{W/m}^2\cdot\text{K}$

Ambient temperature = 25°C

4.2 Analysis and Results of Power Amplifier with Fins

The results obtained by analysis the (*.bd) file using analysis manager from which (*.bdf) file is generated. Then generated file is again given into MSC Nastran to get (*.xdb) file
which is attached to view the results. In results the Temperature distributions on the power amplifier chassis is shown in the figure.

Temperature distribution of Transreceiver box from the fins is shown below. From the results it is clear that the temperature is distributed from the power amplifier to the Transreceiver box.

Maximum temperature on the power amplifier $T_{\text{max}} = 94^\circ$C  
Minimum temperature on the power amplifier $T_{\text{min}} = 30.1^\circ$C  

5 CONCLUSIONS

<table>
<thead>
<tr>
<th>Temperature readings</th>
<th>Power amplifier without fins ($^\circ$C)</th>
<th>Power amplifier with fins ($^\circ$C)</th>
<th>Practical readings of power amplifier with fins ($^\circ$C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum surface temperature $T_{\text{max}}$</td>
<td>104</td>
<td>94.1</td>
<td>87.4</td>
</tr>
<tr>
<td>Minimum surface temperature $T_{\text{min}}$</td>
<td>40.3</td>
<td>30.1</td>
<td>37</td>
</tr>
</tbody>
</table>

Table 5.1 Comparison of Results

The maximum temperature obtained on the power amplifier chassis by thermal analysis is found out and is within in the power amplifier working condition i.e. between $-40^\circ$C to $100^\circ$C. The results are within $10^\circ$C tolerable range when compared with practical readings. From this it is concluded that the results obtained from both finite element analysis and practical testing proves that the temperatures are within the working temperature range of the power amplifier.

6 FUTURE SCOPE

With rapid development in electronic industry the electronic components with multi functionality and intermittently dissipating different ranges of temperatures while under operation hence a steady state analysis may result in over design of the mechanical package, so further transient analysis dependent on time scale definitely beneficial for the optimization of the design.

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