ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 1, Issue 7, November 2016

Thermal analysis on Power Amplifier used in Military Tank

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Abstract:-- **Power amplifier is a device which amplifies the signal of communicating device. Thermal analysis was done on the key Componentsof the power amplifier in orderto dissipate maximum heat from the device. The heat input was given to keyComponents i.e. MR (TRANSISTOR) PA COMPONENT of the amplifier ,located on the PCB with a capacity around 195W .Remaining amount of heat distribution was on other components and analysis was done to measure the maximum temperature ofthe components through "SOLID WORKS SOFTWARE ". Three analyses were done in order to achieve optimum operating temperature of maximum heat dissipatingcomponents. First, each part of the power amplifier device was modeled and then assembled. After the assembly, thermal analysis was done on the device with 25 fins. Themaximumtemperature of heat dissipating component was around 225 Degree Celsius much higher than the operating junction temperature of the component which is 150 Degree Celsius;hence this design was not acceptable. During second analysis, in order to minimize the temperature of maximum heat dissipating device less than the operating junction temperature number offins were increased from 25 to 30 .Analysis done with this modification gave the resulting temperatures as165.417Degree Celsius. During third analysis, in which the number of the fins remained samebuta cutout given to the PCB and device mounted on inner surface of the housing. As a result the thermal resistance(K/ L) reduced which allowed more heat dissipation and resulted in minimizing the temperature under the given operating conditions.The temperature measured was around 126.7 Degree Celsius. Hence, design was acceptable. This helps the device to runefficiently for definite time period.**

I. INTRODUCTION

We define the concept of thermal analysis as it relates to product design and also discuss the principles of conduction, convection, and radiation using real-life products as examples and described different ways to perform thermal analysis, specifically how to use design validation software to simulate thermal conditions. To reduce cost and time of product development, traditional prototyping and testing has largely been replaced in the last decade by a simulation-driven design process. Such a process, which reduces the need for expensive and time-consuming physical prototypes, allows engineers to successfully predict product performance with modified computer models.

Thermal intricaciesare very common in electronics products. The design of cooling fans and heat sinks must balance between small size and adequate heat removal. At the same time, tight component packaging must still ensure sufficient air flow so that printed circuit boards (PCB) do not deform or crack under excessive thermal stress.

Thermal challenges like temperature, heat dissipation, and thermal stresses are bound to be in traditional machine design. Obvious examples of products that must be analyzed for are engines, hydraulic cylinders, electric motors or pumps—in short, any machine that uses energy to perform some kind of useful work.

Thermal analysis is to be conducted on material processing machines where mechanical energy turns into heat, affecting not only the machined piece but also the machine itself. Finally, all electrical appliances such as stoves, refrigerators, mixers, irons and coffee makers in short, anything that runs on electricity should be analyzed for thermal performance to avoid over-heating. This applies not only to consumer products that run off AC power, but also to battery-operated devices such as remote-controlled toys and cordless power tools.

Validation for thermal analysiscan be performed on all thermal design problems by simulating with design validation software. Most design engineers are familiar with this approach for structural analysis.So expanding its scope to thermal analysis requires very little additional training.

Emissivity is defined as the ratio of the emissive power of the surface to the emissive power of a blackbody at the same temperature. Materials are assigned an emissivity value between 0 and 1.0. A blackbody, therefore, has an emissivity of 1.0 and a perfect reflector has an emissivity of 0.σ is known as Stefan's constant. Because heat transfer by radiation is proportional to the fourth power of the absolute temperature, it becomes very significant at higher temperatures.

Thermal stresses:Heat flowing through a solid body will cause a change in temperatures in this body. Consequently the body will expand or shrink. Stresses caused by this expansion or shrinkage are called thermal stresses.

Considering the typical problems briefly introduced here, thermal analysis design validation software used in a product-design process must be able to modelHeat flow by conduction, convection and radiation.

The Equations involving Heat transfer are as follows

Conduction:
Q = K* A(Thot -Tcold)/ L
Where K= Thermal Conductivity (W/m-k)
A = heat transfer area of the surface (m2)
(Thot -Tcold) = temperature difference between the surface and the bulk fluid (K or ^{o}C)

Convection :
Q= $\mathbf{h_c}$ A dT where
Q = heat transferred per unit time (W)
A = heat transfer area of the surface (m^2)
h_c= convective heat transfer coefficient of the process (W/(m^{2}K) or W/(m^{2o}C))
dT = temperature difference between the surface and the bulk fluid (K or ^{o}C)

Radiation:
Q = $\sigma\varepsilon$ (T^{4}_{2-} T_{1}^{4}) ,Where **σ** is known as Stefan's constant {**5.67×10E-6(W/m^2-k4)**}.

The thermal resistance layereffects the time-dependent processes such as heating or cooling (transient thermal analyses),temperature dependent material properties, heat power, convection coefficients, and other boundary conditions .There are also other requirements that a validation program, used as a design tool should satisfy that are not only specific to thermal analysis, but apply to structural or electromagnetic analyses. Since new products are universally designed on CAD, the efficient use of any type of validation software as a design tool also places the following requirements on CAD software.

II.FEATURES OF SOLID WORKS SOFTWARE

- A feature-based, parametric, fully associative solid-modeler
- Able to create all geometry, both manufacturing specific and analysis specific
- Able to move between design and analysis representations of the model while keeping geometries linked
- The above requirements call for an advanced simulation system which combines ease of use with high computational power, such as the DS Solid Works simulation program integrated with Solid Works CAD software (a leading 3D parametric, feature-based CAD system).
- State-of-the-art integration allows users to run thermal and structural analyses using the same familiar Solid Works software interface, thus minimizing the need to learn analysis-specific tasks and menus.

Factors considered during thermal analysis:

Climate model, Heat equation, Lumped system analysis The following sections present some examples of design problems solved using the thermal and structural analysis capabilities of Solid Works software.

1) Sizing the cooling fins of a heat sink.
2) Redesign of a heating element.
3) Finding thermal stresses in a flexible pipe
4) Suppose that a corrugated pipe while free to deform is subjected to different temperatures at its two ends. The question of interest is whether it will develop any thermal stresses due to these differences. Using the temperature results in a static analysis.
5) The software calculates the pure effect of non uniform temperature in the absence of any structural loads or supports.

III.POWER AMPLIFIER USED FOR THE ANALYSIS[3]

An amplifier receives a signal from a transducer and amplifies it to a larger version of the signal. A voltage amplifier provides voltage amplification to increase the voltage of the input voltage to a desired output voltage.

Power amplifiers on the other hand primarily provide sufficient power to an output load to drive a power device, typically ranging between few watts to ten watts. The main features of a Power amplifier is the circuit's power efficiency. The main objective is to dissipate the maximum heat out of the power amplifier for better efficiency.
Applications of power amplifier

a) It is used in airplanes for communication.
b) It is used as radio frequency amplifier in Military Tank.
c) It is used in satellite communication.
d) It is used in Magnetic Resonance Imaging (MRI).

***Material Properties of Components*:**
i) ***Silicon Carbide (Sic)*** is used in transistors and integrated circuits of the power amplifier. The main properties of Sic are:-
a) Low density.
b) High strength.
c) Low thermal expansion.
d) High thermal conductivity.
e) Superior chemical inertness.
f) High thermal shock resistance.

ii) Aluminum 6061(Al6061)is the material for the casing &includes the housing and manifolds. It requires
a) Excellent joining characteristics.
b) Good acceptance of applied coatings.
c) High strength.
d) Good workability
e) High resistance to corrosion

Meshingis a practice of generating rectangular mesh that approximates a geometric domain. Meshing is done for simulations such as Computational Fluid Dynamics (CFD) or Solid Works. Three dimensional meshes are created for Finite Elements Analysis need to consist of tetrahedral or prisms. There are two types of meshing i.e. 2D and 3D meshing. We use 3D meshing for this power amplifier.

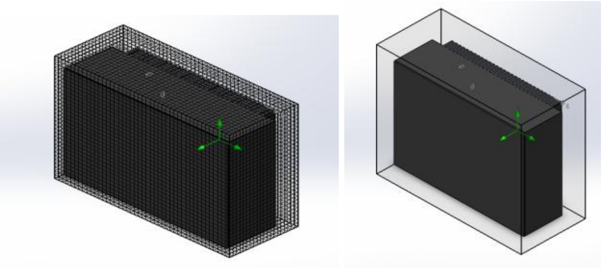
Figure 3.1 Meshing of Amplifier

Computational Domainis of two types i.e. 2D or 3D. For the thermal analysis of power amplifier used, 3D computational domain is used as it is more accurate but takesmore time to run than 2D computational domain. In this z and y axis represents the horizontal directions whereas x axis represents the vertical direction. The resolution parameter determines the volume of the reactor and hence, the size of the system being simulated. It is also necessary to define the behavior at the boundaries of the computational domain i.e. 3D computational domain requires six boundary conditions. It defines a grid point which exist just outside the boundary itself and the parameter vector out represents the planar normal vector.

IV.MODELLING OF COMPONENTS[7]

Description of housing:
Length = 50mm. Breadth = 250mm. Depth = 90mm. Material thickness = 10mm.
Fins description:
Length = 250mm
Thickness = 6mm
Height = 24mm
Material used –Aluminum 6061

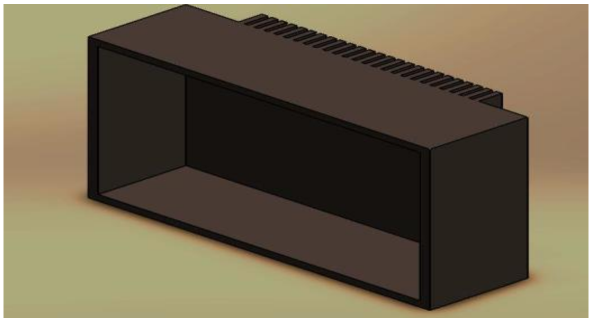
Figure 4.2 Isometric view

Description of PCB:
Length = 220mm, Breadth = 130mm. Thickness = 1.6mm Chamfer length = 10mm

Material used- Non isotropic, PCB-8 layer.
Filter PCB:Length = 220mm. Breadth =130mm. Depth = 35mm. Thickness of material =10mm
Material used –Aluminum 6061

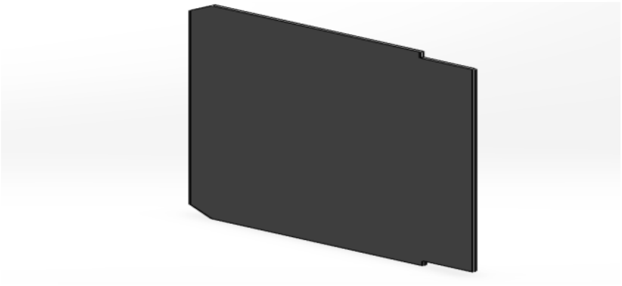

Figure 4.3 Isometric view of top cover

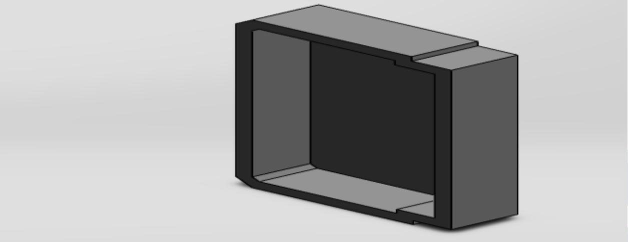

Figure 4.4 Isometric view of bottom part

MR (Transistors) PA Component:

Description of Transistors: Length = 25mm. Breadth = 13mm. Thickness = 1.14mm. Transistors are made up of silicon carbide and total heat dissipation is 195W (Q2).

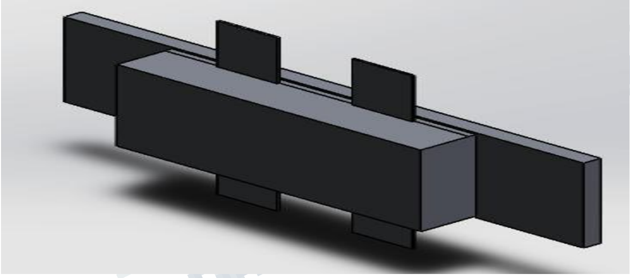

Figure 4.5 Isometric view

MA Filter Components (Integrated Circuit):

Description: Length =9 mm. Breadth =9 mm. Thickness = 0.90 mm. Integrated circuits are made up of silicon carbide. Each component dissipates around 5W of heat (U1).

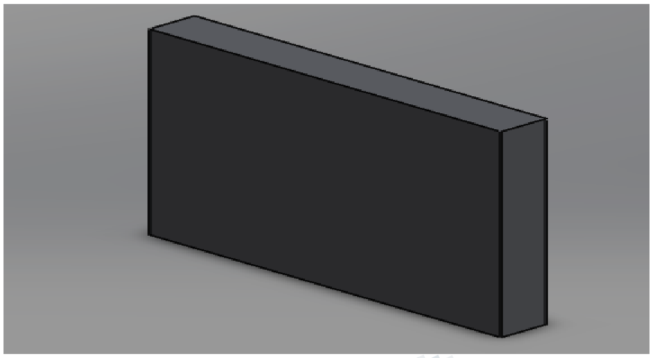

Figure 4.6Isometric view

MAS Filter Components(integrated circuit)

Description Length and Breadth = 12 mm. Thickness = 1.50mm Integrated circuits are made up of silicon carbide. Each component dissipates around 2W of heat.

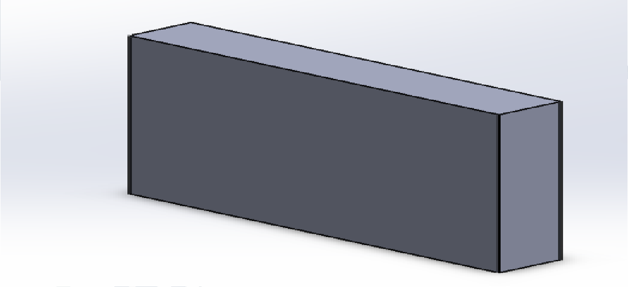

Figure 4.7Isometric view

T2 - PA Components (Transistors)

Description of T2: Length = 8 mm. Breadth = 7.50 mm. Thickness = 2.38mm. Length of leg = 2.92mm. Breadth of leg = 0.64mm Transistors are made up of silicon carbide. Each component dissipates around 1.2W of heat

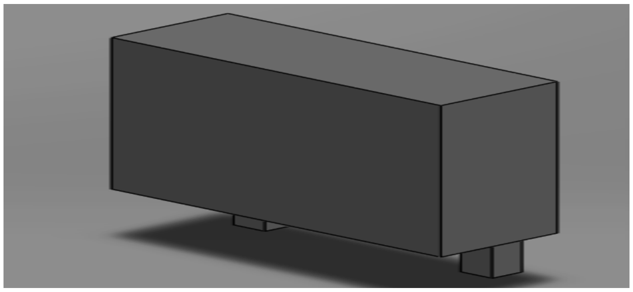

Figure 4.9 Isometric view

V. ASSEMBLY OF THE MODELLED COMPONENTS

Assembly of Harmonic Filter PCBconsists of MR, T2, LT mounted on the PCB.

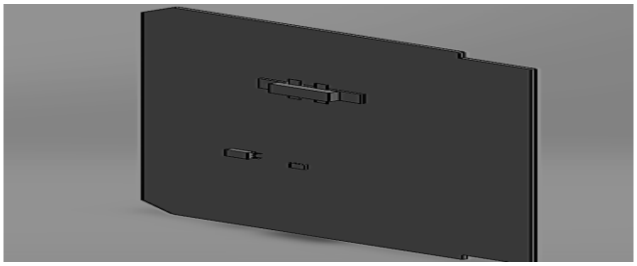

Figure 5.10 Isometric view of assembly of Harmonic Filter

Assembly of Power Amplifierconsists of MASFilter, MAS-55_Filter mounted on filter PCB

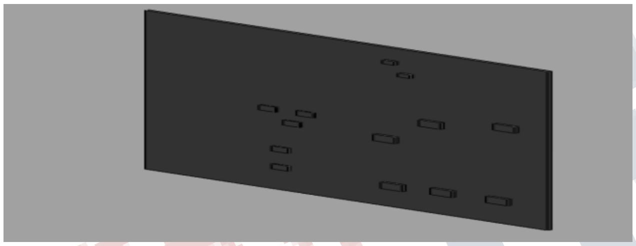

Figure 5.11 Isometric view of Assembly of Power amplifier

Full assembly consists of Power amplifier PCB, Filter PCB, top manifold, PCB module on main housing.

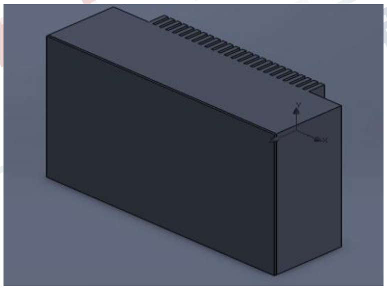

Figure 5.12 Isometric viewof full assembly

VI. THERMAL ANALYSIS[5]

General information, Meshing Details Initial Mesh Settings Automatic initial mesh: Off

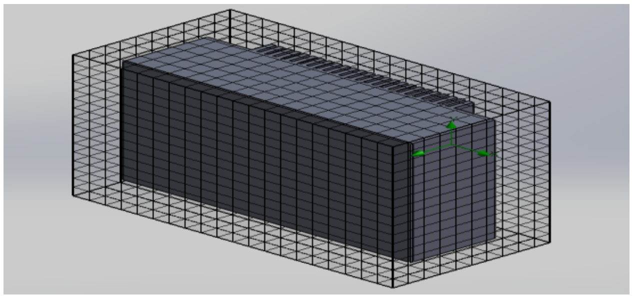

Figure 6.13 Isometric view of Meshing

Basic Mesh Dimensions Table 6.1

Number of cells in X	20
Number of cells in Y	16
Number of cells in Z	10

Number of cells : Table 6.2

Total cells	14428
Fluid cells	4652
Solid cells	2342
Partial cells	7434

VII.COMPUTATIONAL DOMAIN

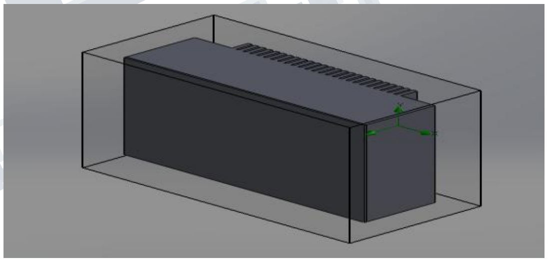

Figure 6.14 Isometric view of Computational Domain

Table 7.13

X min	-80.841 mm
X max	308.056 mm
Y min	40.169 mm
Y max	337.834 mm
Z min	187.667 mm
Z max	378.876 mm

- Size Details of Domain :
- Physical Features of power amplifier during analysis:
- Heat conduction in solids: On,
- Radiation: Off Time dependent: On,
- Gravitational effects: On,

- Flow type: Laminar and turbulent, Gravitational Settings:

Default outer wall condition: Heat transfer coefficient: 5 W/-K, External fluid temperature: 55 °C, Initial Conditions Fluids, Air, Solids, Aluminum 6061, PCB 8-layers, Silicon Carbide

Component details:

a)PCB 8-layers Solid Material 1

Components	Printed Circuit Board, Filter PCB
Solid substance	PCB 8-layers

b) Silicon Carbide Solid Material 1

Components	MAS-55,MA,MAS,LT, T2
Solid substance	Silicon Carbide

c) Aluminum 6061 Solid Material 1

Components	Housing, Power amplifier lid, PCB and filter manifolds
Solid substance	Aluminum 6061

VIII.RESULTS

Analysis- 1

Design Details:

Device fixed directly above PCB.Number of fins is 25. Maximum Value of Temperature of selected component after eachiteration:

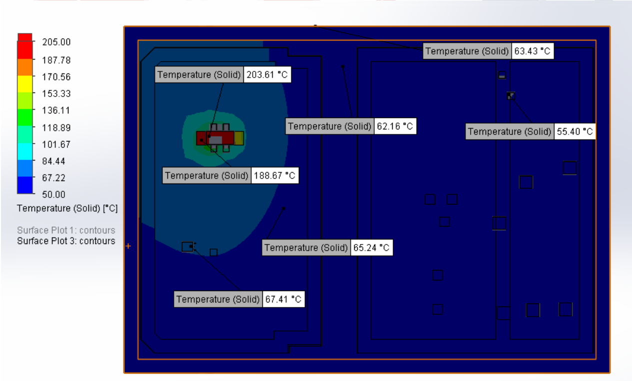

Figure 8.15 Front View of Power amplifier

Fluid Flow Simulation on components responsible for more heat generation:

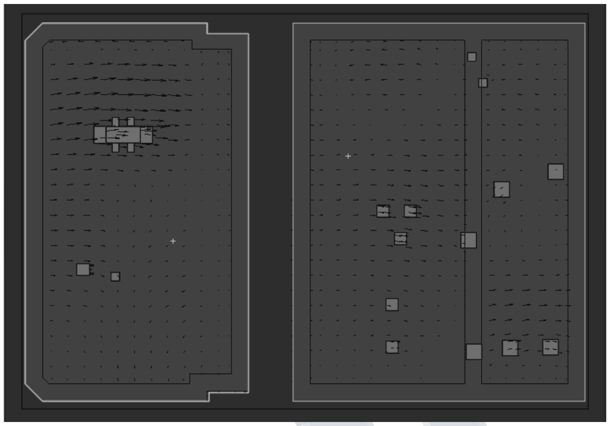

Figure 8.16 Fluid flow over components

Result based on Analysis 1:

Maximum Temperature of device is 225.3^{o}c & Maximum Temperature of Power Amplifier is 225.3 ^{o}c.

Conclusions based on Analysis 1: Maximum temperature in the device was found to be 225.3 ^{o}c.But maximum operating junction temperature is 150 ^{o}c. Hence this design is not acceptable. The following design modification is discussed to reduce device temperature.

Increase number of fins to 30.

Note-Based on above conclusion design is modified and Analysis-2 is done.

Analysis- 2

Design Modificationemployed: Increase number of Fins to 30. Maximum Value of Temperature of selected component after each iteration:

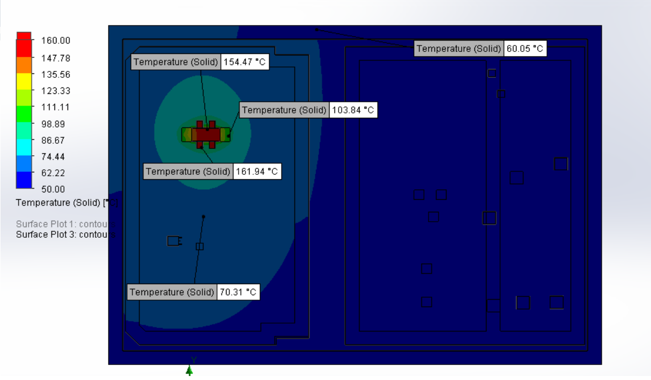

Figure 8.17 Front View of Power amplifier

Result based on Analysis 2:

a) Maximum temperature of the device is 165.417 ^{o}c

Conclusion based on Analysis 2:

Maximum temperature in the device is found and it is 165.417^{o}c Maximum operating junction temperature is 150 ^{o}c . Hence this design is not acceptable.

The following design modification is discussed to reduce device Temperature in Analysis-3.

Device to be fitted directly on the housing inner surface. Number of fins remains same as in Analysis-2 & make a cutout on PCB.

Analysis-3

Design Modification made : i) Make cutout on PCB.

ii) Device to be fitted directly on the inner surface of the housing with same number of fins.

Cut out description: Length = 25 mm,Breadth =13 mm.

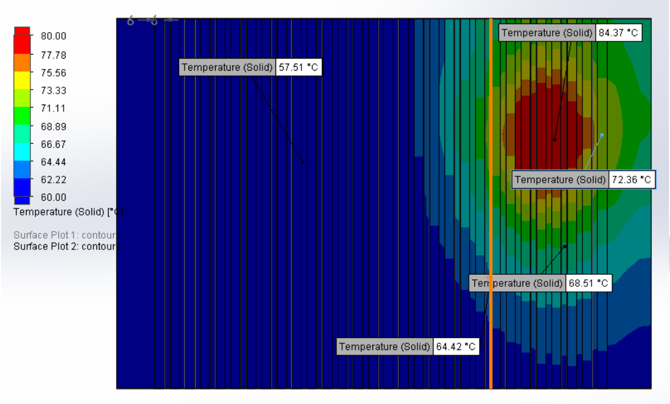

Figure 8.18 Rear View of Power amplifier

Conclusions based on Analysis 3: Maximum temperature in the device is found to be 126.70°**c.** Maximum operating junction temperature is 150°**c.** Hence this design is acceptable. Based on above Analysis, we achieved the optimum temperature of the device.

IX COMPARISON OF THE DESIGN APPROACHES OF POWER AMPLIFIER

Table 9.1

case	**Maximum temperature obtained**	**Maximum Operating Temperature**
25 Fins	**225.41**	**150**
30 Fins	**165.417**	**150**
30 fins Device mounted on inner surface	**126.7**	**150**

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