Finite Element Modeling and Analysis of a Heat Sink

-Kunal V. Shinde

Department of Mechanical Engineering

University of Colorado Boulder.

Abstract: Heat sinks are often required by Power transistors to keep junction temperatures below the recommended limit by dissipating thermal energy. The reliability and durability of any semiconductor device depends on their heat sinks ability to dissipate energy. With the increasing complexity of electronic components and their systems, their cooling solutions become an important issue. This paper presents Finite Element Analysis of Heat sinks in *ABAQUS* with varying parameters such as number of fins and geometries as well as with different materials. Heat Flux and temperature distribution for various models is analyzed. Finally, a comparison with numerical analysis for verification is provided.

Keywords: Heat sink, conduction, convection, Transistor.

1. Introduction

The main purpose of heat sink is to reduce the temperature of the electronic component attached to it. The excess heat is transferred into another medium, typically air. In this way heat-related failures of electronic components are prevented. There are several design aspects which are important in order to ensure the effective heat emission from heat sink. Some of them are related to operating conditions, such as artificial air circulation, choice of thermal interface materials, or a proper attachment to the heat-emitting component. However, most of the factors which determine the efficiency of heat sink are related to its construction, e.g. larger active surface area, type of material it is manufactured of, overall shape or shape of separate elements of heat sink. [1]

[2]In modern industry the efficiency of a heat sink is typically determined using numerical modelling techniques; in relatively rare cases theoretical calculations are used. Computer software based on FEM is an irreplaceable part of heat sink design and is used in different stages of development, e.g. modelling, performance optimization or analysis of their characteristics.

Figure 1 TO-126 A transistor package

This paper focuses on the heat sink that deals specifically with a TO-126A package, one of several common types used in the industry.

Project Overview

The following heat sinks would be considered for Heat transfer analysis. A general TO-126 A has a power rating of 12.5W. The heat generated in the transistor was transferred to the heat sink alone through conduction between the two surfaces and not to the surrounding air for dissipation. This can be considered as a surface heat flux to the heat sink, which would dissipate through the heat sink by conduction and convection to the surrounding air. Transistors work in a definite temperature range and the temperature between the transistor and heat sink is considered to be 333K (60° C). Ambient air temperature for convection is set at 313K This paper examines the following factors: 1) Effect of Material Selection on Heat sink 2) Effect of different geometries on Heat Sink 3) Effect of Mica plate on Heat Flux.

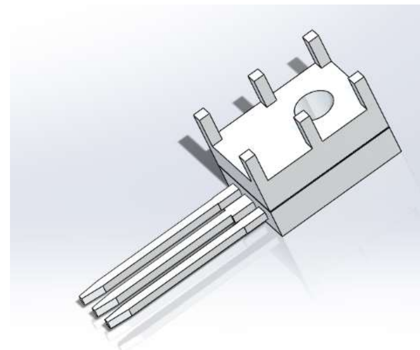


Figure 2 Heat sink attachment with Transistor

Technical Approach for Material Selection

Part

A heat sink with three fins is considered. The geometry is shown in the figure().

Materials

The following materials will be considered for the heat sink:

Material	Thermal Conductivity (W/m K)	Specific Heat (J/K)
Aluminium Alloy 1050	237	0.440
Aluminium Alloy 6060	264	0.440
Tungsten	167	0.134
Copper	401	0.390

Load and Boundary Condition

A load of 12.5 W in the form of surface flux is provided to the heat sink. The temperature of the base is set to be 333K (60 C). Ambient air temperature is set at 313K.

Interaction

An interaction is set with the faces for convection. The external heat coefficient (h) is set to be 21 J/K with the ambient air at 40C.

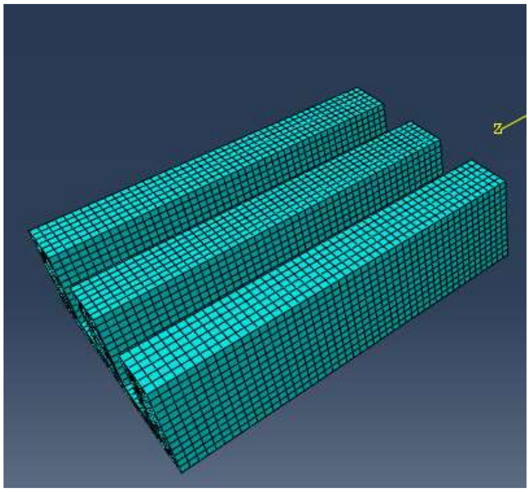


Figure 3 Meshing of Heat Sink

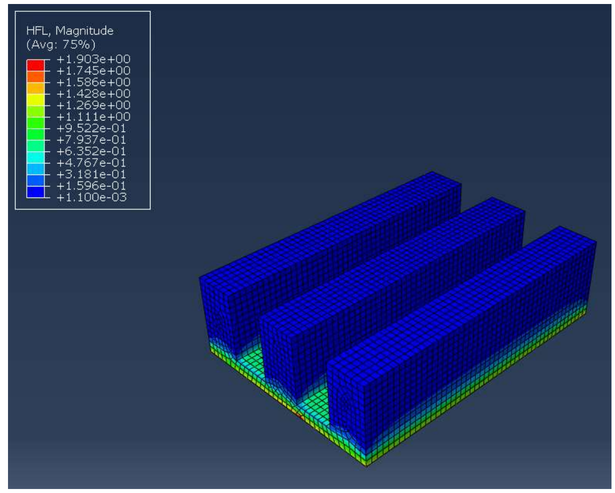


Figure 4 Heat Flux Variation

Meshing

An 8-node linear heat transfer brick- DC3D8 is used for meshing as shown in Figure 3. Total number of nodes are 19992. Total number of elements: 16224. Element type is set to Heat Transfer.

Results

Figure 5 shows the variation of heat flux along the height from base to the tip of the fin. It can be seen that copper dissipates the maximum heat, followed by Aluminium 6060, Aluminium 1050 alloy and Tungsten. The heat flux dissipation is maximum near the base and gradually decreases. The reason for copper dissipating the maximum heat flux is due

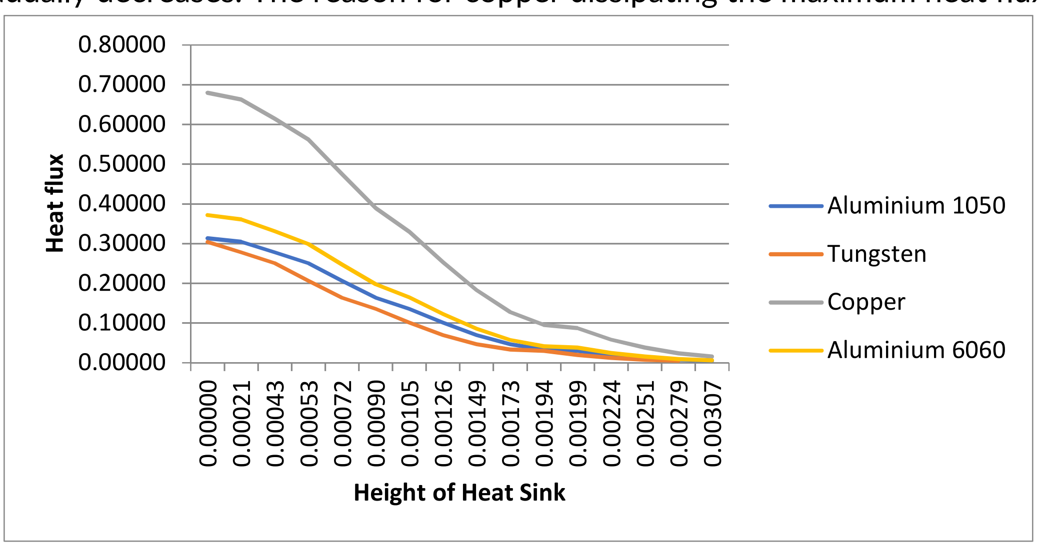
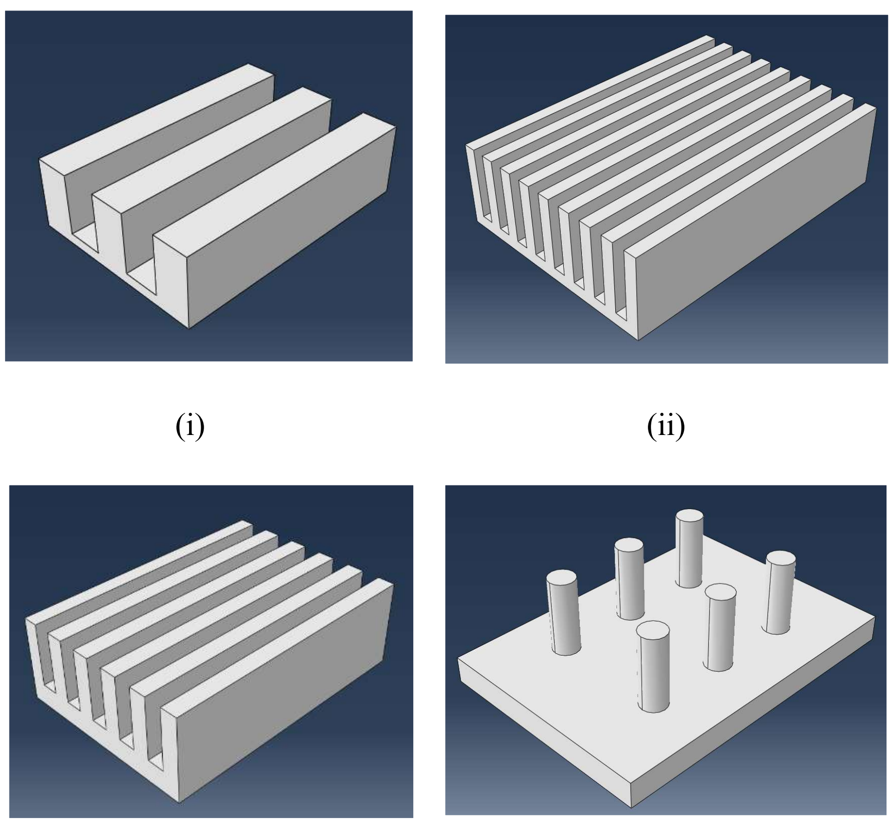


Figure 5 Heat Flux variation with different materials

to its greater thermal conductivity. Despite this, Copper is not the most favorable material for heat sink. Copper is not the commonly used because Aluminium is lighter and does not oxidize. Moreover, Copper is more expensive than aluminum. Copper is also denser than aluminum. This means that the same volume of copper is heavier than aluminum. A heavy heat sink will pull at the transistor and may cause structural issues based on how it's mounted on a transistor. This is also the reason why the long high voltage wires are made of aluminum instead of copper (this is for electrical conductivity, not thermal). Even though aluminum is more lossy for electricity transfer, it is much lighter and cheaper, so the wires do not sag as much, and you can buy more of it.

Technical Approach for Fin geometry selection

Under similar conditions as for the previous example, four types of heat sinks are evaluated for maximum heat dissipation. The temperature profile of the fins along its length is checked to check its efficiency. Fins are varied by shape and number as shown in fig.6.



(i) (ii)

(iii) (iv)

Figure 6 Different fin geometries

Results

It can be seen from the fig. 6 that the heat sink with 3 fins dissipates the heat at a faster rate than the other geometries. It is followed by the one with 6 fins, 9 fins and lastly with 6 circular fins. It might appear that as the number of fins increase, there must be an increase in the heat dissipation. That may not always be the case. Closely spaced fins require a higher pressure to move heated air away from the fins than natural convection can provide. If fins are closely placed, especially in natural convection, the heatsink will have as much usable surface area as a brick [1]. As a result, heat sink with 3 fins performs the best in this case. The heat sink with circular fins have less overall area and thus dissipates heat at a much slower rate. In addition, it can be stated that **a fin length of 2 mm should suffice the cause, as temperature remains steady after that length.**

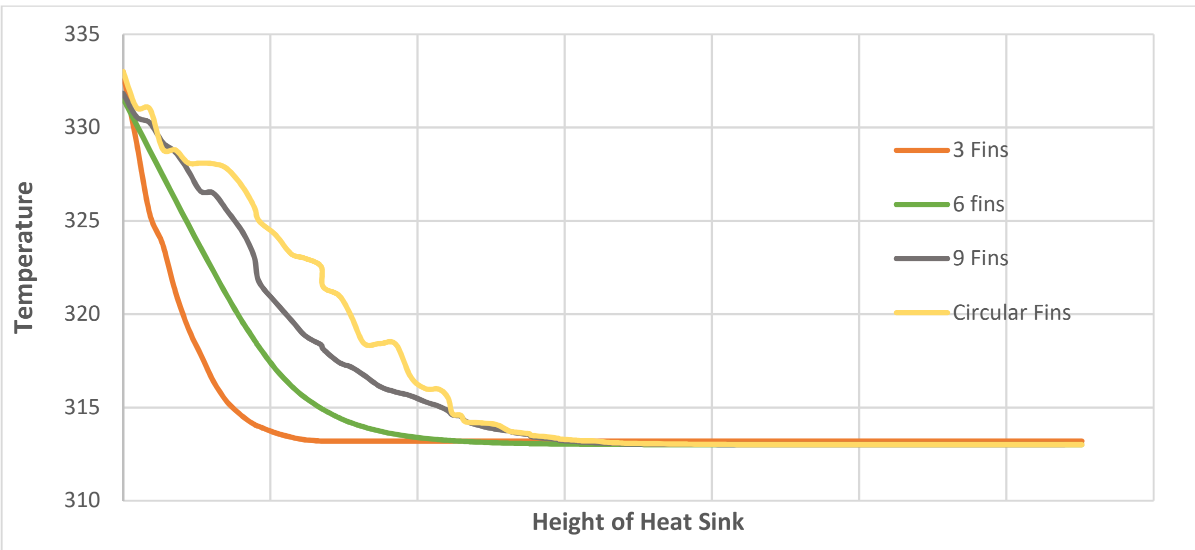


Figure 7 Temperature Variation of different Geometries.

Effect of Mica plate

In practical applications, an insulator is required to be placed between the heat sink and the transistor to prevent a short circuit. Mica is a good electrical insulator at the same time a good thermal conductor. As this study revolves around the efficiency of the heat sink, the insulating layer has not been considered in my previous iterations. However, in most applications there exists a Mica plate between the heat sink and the transistor to prevent a short circuit. Hence, effects of having a Mica plate in between on heat flux is tested below.

Modelling

A heat sink model with three fins was analyzed with the one containing a Mica plate of 1/10mm. This can be considered as a film between the transistor and heat sink. An interaction was defined between the two with the Mica plate being the master surface and the Aluminium base being the slave surface, other conditions remaining the same.

Results

The heat dissipation as a function of height can be seen in the fig. 9. Since Mica plate has a conductivity of 71 W/m K, as compared to the 234 W/m K of Aluminium, the heat flux at first is less but eventually reaches 0 at fin tip.

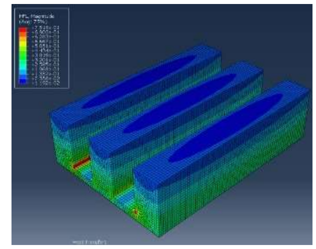


Figure 8 Mica Plate heat flux variation

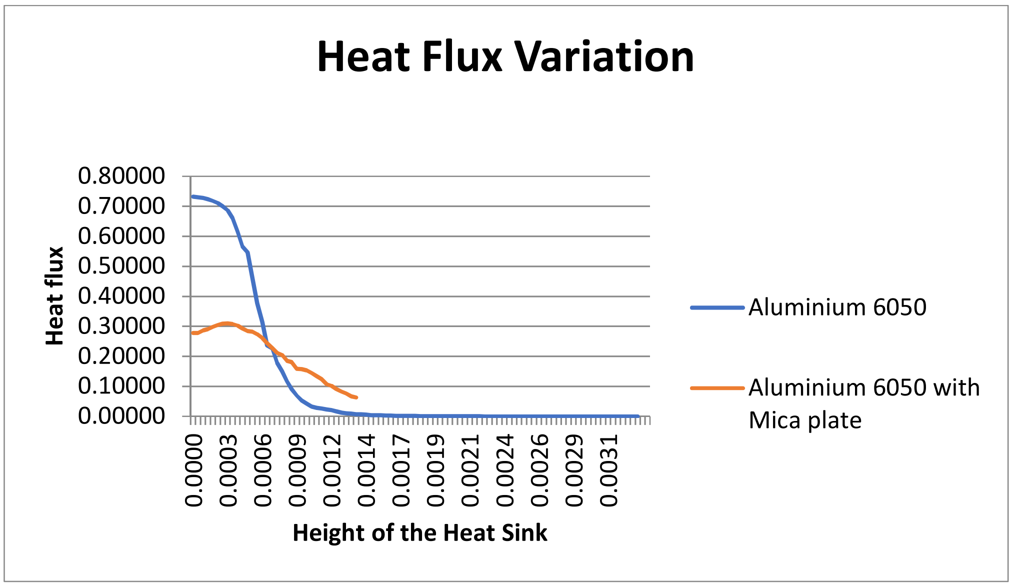


Figure 9 Mica plate effect on heat flux

Numerical Analysis

A quasi-approach was taken, in which the temperature in the fin was be assumed to be a function of x only. The heat flux generated from the Transistor was 12.5 W, which needs to be dissipated from the heat sink. With a fin cross-section equal to A and a perimeter P, the characteristic dimension in the transverse direction is A/P. The regime of interest will be taken to be that for which the Biot number (ratio that determines the variation of temperature within the body is much less than unity, Bi = h(A/P)/k<<1, which is a realistic approximation in practice as the heat sink is much smaller in size and hence, uniform temperature fields inside the body are assumed.

$$Q = Qcond + Qconv = 12.5W$$

$$Qcond = kA(x)\frac{dT}{dx}$$

$$Qconv = A\,h(Tb - Tf) = w\,x\,s(N-1)h(Tb - Tf)$$ where N is no. of fins;

Tf is fin temperature;

Tb is base temperature;

A is cross sectional area;

w is width; s is spacing;

h is external heat transfer coefficient.

$$Q = kA(x)\frac{dT}{dx} + hdA(x)(Tb - Tf)$$

$\frac{dT}{dx} = \tanh(ml) * m * (Tb - Tf)$ where $m^2 = \frac{hP}{kAc}$ and A_c is the cross-sectional area

The above equations are calculated in the MATLAB code attached in the appendix.

T_f= 316.1K

This confirms with the temperature at the fin tip which equals to 313.094K in the ABAQUS model. This result can be seen in fig. 7, in which fin temperature reaches 313.09K at its tip.

Conclusion

Heat sinks with different geometries and materials were analyzed. Following are the outcomes of the analysis:

1) The Heat sink with 3 fins followed by 6 fins, 9 fins and lastly circular fins were found to be the most effective in this case. This is because there is less spacing between the fins and pressure required for heat dissipation increases. This may not always be true.
2) Copper has the best heat dissipation properties among the considered materials. However, it is quite heavier than Aluminium and is prone to corrosion.
3) Mica reduces the heat dissipation rate of the heat sink but is necessary to prevent short circuit.

References

[1] S. Lee, "Optimum design and selection of heat sinks.," *IEEE Transactions on Components, Packaging, and Manufacturing Technology,* Vols. 812-817., p. Part A 18.4 , 1995.

[2] P. e. a. Gunnasegaran, " "The effect of geometrical parameters on heat transfer characteristics of microchannels heat sink with different shapes."," *International Communications in Heat and Mass Transfer,* vol. 37.8, pp. 1078-1086., 2010.

[3] R. e. a. Romero-Méndez, ""Effect of fin spacing on convection in a plate fin and tube heat exchanger."," *International Journal of Heat and Mass Transfer,* vol. 43, pp. 139-51, 2000.

Appendix

```
%Temperature Calculation at Fin tip

k=237; %Thermal conductivity of Aluminium

Af=3*21.90*(10^(-4));%Area of Finned region

Au=278.24*(10^-6);%Area of unfinned region

h=21;%convection coefficient

L=0.0038;%Length of Fin

Tb=333;%Base Temperature

m=10.91;%constant

Q=12.5%Total heat Fluz

A=Au+Af; %Total cross sectional Area

%Equation for Total Heat Flux

%Q=(k*Af*(tanh(m*L/2))*m*(Tb-Tf))+(Au*h*(Tb-
Tf)*tanh(m*L/2))

Tf=Tb-(Q/((k*A*(tanh(m*L)*m))+(A*h*tanh(m*L)))) %Tf is
Fin tip temperature
```

Output

```
Tf= 316.1001
```