# Modelling, analysis and comparison of heat sink designs with improved natural convection

Angel Marinov, Anton Georgiev
Department of Electronics and Microelectronics
Technical University of Varna
Varna, Bulgaria
a.marinov@tu-varna.bg, georgiev_an@yahoo.com

Alex Van den Bosshe
Electrical Energy Lab (EELAB)
Gent University
Gent, Belgium
alex.vandenbossche@ugent.be

Borislav Dimitrov
Engineering School
Southampton University
Southampton, UK
B.H.Dimitrov@soton.ac.uk, bdimitrov@processmodeling.org

***Abstract*— The paper presents a finite element modeling based study of various heat sink designs. The main aim of the study is to determine and evaluate solutions with improved heat dissipation by utilization of natural convection. Seventeen different cases both classical and proposed by the authors are studied, where each case is examined under three different heat source (in the case with the proposed study a transistor) powers. Results for temperature of the power source and velocity magnitudes in the studied volume are presented and compared. Experimental verification of the modeling is presented for a number of selected cases.**

***Keywords*— FEM modeling, heat sink design, natural convection**

## I. Introduction

Power losses in electrical and electronic devices are converted to heat, even the most efficient electrical or electronic device will need to dissipate some generated heat into its environment. This dissipation has to be designed so that the device never reaches its critical temperature. Furthermore maintaining a relatively low work temperature in most cases ensures improved efficiencies, better working stability overall reliability [1,2] and device robustness.

Various solution for heat dissipation and temperature regulation exist [3]. They can range from simple once – such as heat sinks and fan air cooling, to more elaborate once such as heat pipes and water cooling. Even active heat dissipation solutions are used, where the generated heat is removed as devices are cooled down by a dedicated refrigeration unit (active cooling). [4,5]

A heat dissipation based of heat sinks usually involves a passive heat exchanger that transfers the heat that builds in the device to a fluid in motion. Many cases, especially once for low to medium power and compact design, use ambient air as "fluid". The air can be moved actively - by a fan – or passively through natural convection. In both cases heat sinks are designed so as a large as possible amount of surface is in contact and in direction to the airflow. This however is not always compatible with device construction specifics, geometric constrains, etc. Thus in those cases specialized heat sink designs might be needed so the device requirements can be met while cooling properties are preserved.

In this context, the current paper presents a study of several heat sink designs that utilize natural convection in order to improve the rate of their heat dissipation and ultimately maintain lower temperatures for the electronic or electrical device, while keeping smallest possible geometric dimensions and weight. In fact a natural convection could be considered as some forced convection, where the chimney effect is responsible for the air flow. Some analytical models for transformers can be found in [6].

## II. Proposed Study

In this paper seventeen different solutions are proposed. They are presented in figure 1, where each case study is given a number. The solutions show a simplified geometrical representation, without supports and fixations. To unify it, the device for all of the presented cases is a power electronics switch (MOSFET, IGBT) in a TO-247 package.

The heat sink geometries proposed for the study include:

- Conventional heat sink (1) with its fins placed in parallel to the airflow (considering natural convection). This design has a maximum surface exposed to the airflow and should show the best heat dissipation properties. The mounting surface of the modeled heat sink is: 90mm wide, 40mm high and 3mm thick. The heat sink has six evenly placed fins, each: 40mm wide, 30mm high and 3mm thick. This solution will be used as a reference.

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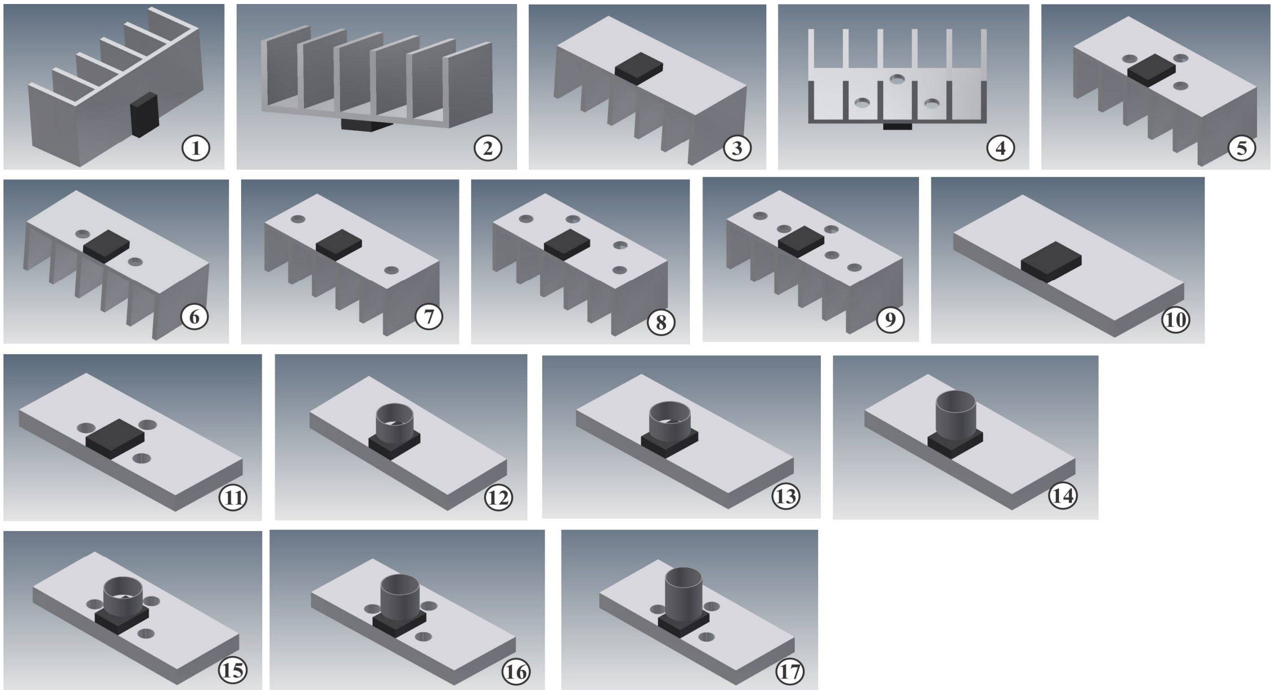


Fig. 1. Studied heat sink designs.

- A conventional heat sink (2 and 3) placed so the airflow is obstructed and does not pass efficiency through the fins.
- Heat sinks (4 to 9) – where the design and placement from 2 and 3 are used but with added holes for improved airflow. The size of the holes is 8mm (the size is selected based on the distance between the fins). Different number of holes and their arrangement is made.
- A compact heat sink (10) with no fins. The size of the mounting surface is: 90 mm wide, 40mm high and 9mm thick – relative volume of the heat sink in comparison to deigns 1 to 9 is preserved.
- A compact heat sink with added holes for improved airflow (11).
- A compact heat sink with added chimney effect for improved natural convection (12 to 14). Three different chimney sizes are used – internal diameter 18mm (this size is selected so the chimney size is close to that of the transistor), height 10mm, 15mm and 20mm.
- A compact heat sink with added chimney effect and holes for improved natural convection (15 to 17) . Three different chimney sizes are used – internal diameter 18mm, height 10mm, 15mm and 20mm.

For each of the studied geometries a dedicated Finite Element Modeling (FEM) based model was developed. For each model a set of three transient analysis for flow and heat transfer were conducted. The sets include studies for three different amounts of losses in the electronics switch - 10W, 20W and 30W.

## III. Simulation Analysis

Results from the studies for the temperature on the evaluated device (MOSFET or IGBT) are presented at figures 2, 3, 4, 5, 6 and 7 where the examined solutions are divided into two groups: (1) Classical solutions with modifications (holes on the heat sink for improved convection) – figure 2,4 and 6; (2) Solutions proposed by the authors in one of their previous works [7] – figures 3, 5 and 7. In both figures proposed solutions are compared to a heat sink with its fins placed so that an optimal air flow can be achieved (design 1, figure 1). Figures 2 and 3 represent a study for a power source of 10W, 4 and 5 for 20W, 6 and 7 for 30W.

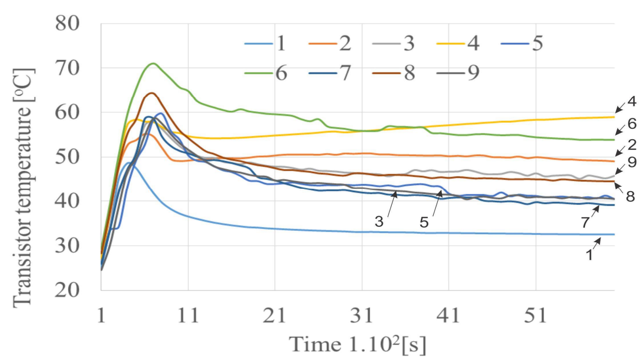


Fig. 2. Simulation results - transistor temperatures for designs 1 through 9 – device power 10W.

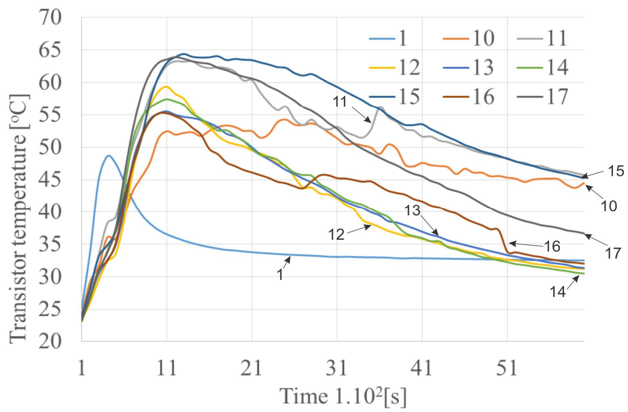


Fig. 3. Simulation results - transistor temperatures for designs 1 and 10 through 17 – device power 10W.

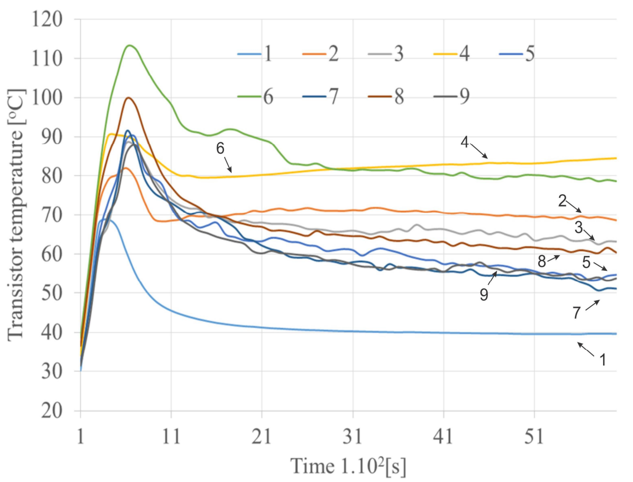


Fig. 4. Simulation results - transistor temperatures for designs 1 through 9 – device power 20W.

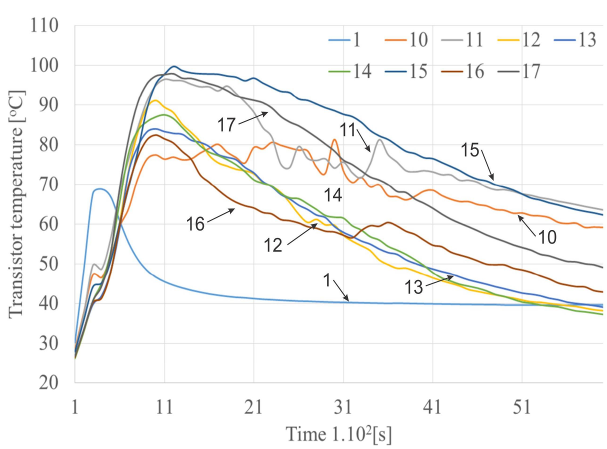


Fig. 5. Simulation results - transistor temperatures for designs 1 and 10 through 17 – device power 20W.

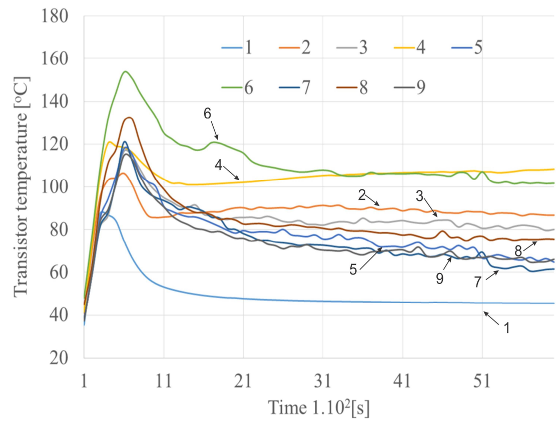


Fig. 6. Simulation results - transistor temperatures for designs 1 through 9 – device power 30W.

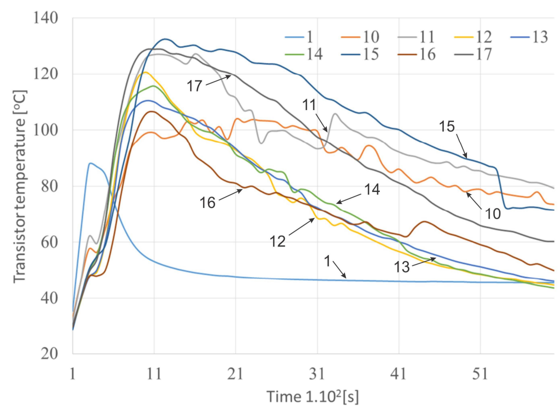


Fig. 7. Simulation results - transistor temperatures for designs 1 and 10 through 17 – device power 30W.

For the set 1 to 9 it can be seen that modifying the heat sink by adding additional holes improves heat dissipation (designs 7,5,9) compared to the same heat sink and placement but without holes (designs 2 and 3), where however the distance of the holes to the device and their placement affect the results and can even worsen heat dissipation (6 and 4).

For the set 10 to 17 it can be seen that adding a chimney effect to the heat sink significantly improves heat dissipation, where the result for the compact design in some cases (12, 13 and 14) is comparable to a optimally placed heat sink with fins (1). The placement of holes for this design however do not improve heat dissipation.

Based on the results of the simulations designs 5 and 13 are selected for further study. Figures 8, 9 and 10 show a planar velocity magnitude and temperature on the heat sink (the observed plane is placed: on the fins for design 1; on the holes for design l5 and on the chimney for design 13) – source power is 20W. By comparing to the reference design (1), it can be seen that: for design 5 the improved heat dissipation is due to the air passing through the holes and effectively increasing the dissipation surface; for design 13 the improved heat dissipation is due to the increased velocity magnitude.

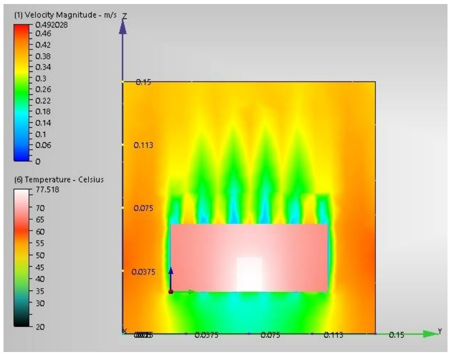

Fig. 8. Simulation results – design 1, source power 20W

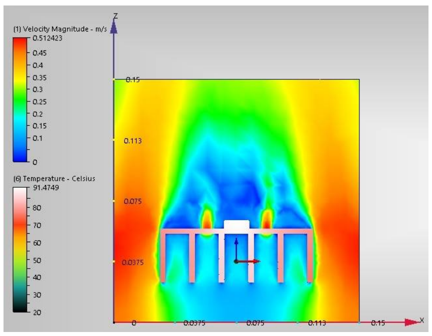

Fig. 9. Simulation results – design 5, source power 20W

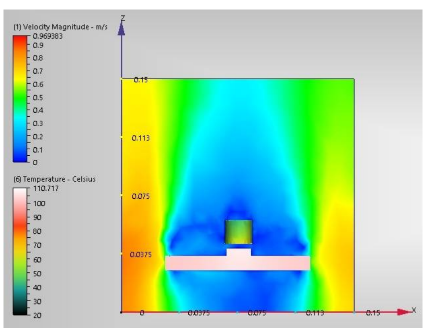

Fig. 10. Simulation results – design 13, source power 20W

## IV. Experimental Results

For the selected cases 5 and 13, as well as for the reference design an experimental setup was developed. Temperature measured on the surface of the devices – through IR temperature sensors – is shown on figure 11. Although measured temperatures differ from the one obtained through simulation (due to simplifications and imperfections in the model boundary conditions), relations between the temperatures in the different designs remains relatively the same. This provides verification for the qualities of the two designs.

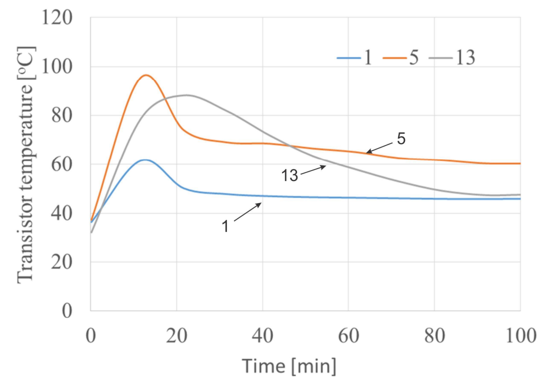


Fig. 11. Experimental results for designs 1,5 and 13

## V. Conclusions

Results in the presented study show that by utilizing various solution to improve the natural convection of a heat sink temperatures on the devices can be lowered to the once of an optimally placed heat sink but for the less amount of space required. A significant improvement can be noted when utilizing a local chimney effect – solutions 12 to 14 and when adding holes to the heat sink designs 5,7,9.

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