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Design of passive heat sinks to power semiconductor with the cesaro curve

Diseño de disipadores de calor pasivo para semiconductores de potencia con la curva de cesaro

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Luis Carlos Ruiz-Cárdenas [1], Luis Eduardo Llano-Sánchez [1*], Darío Manuel Domínguez-Cajeli [2], Martha Cecilia Melo de Alonso [2], Carolina González-Rodríguez [1]

[1]Facultad de Ingeniería, Programa de Ingeniería Civil, Universidad Militar Nueva Granada, Sede Campus, Km. 2 vía Cajicá – Zipaquirá. C.P. 250247. Cundinamarca, Colombia.
[2]Facultad de Ciencias Básicas y aplicadas, Departamento de Matemáticas, Universidad Militar Nueva Granada, Sede Campus, Km. 2 vía Cajicá – Zipaquirá. C.P. 250247. Cundinamarca, Colombia.

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ABSTRACT: In the design of electronic circuits, stands out the power stage, which is responsible of increasing the signal characteristics, as current and voltage, for an appropriate performance of the device to fabricate. However, this stage is composed of elements like transistors, which may have a low performance, due to the undesired temperature increase, as a result of reaching the desired power. To mitigate the loss of power and with it, the temperature rise, the management of heat sink is proposed, in order to keep the work of the power stage at a stable level and avoid thermal fractures within the circuit. This manuscript presents the obtained results of the thermal analysis in finite elements of the heat sink with fins in the form of a Cesaro curve, for power semiconductors, which evidence the increase in the heat flow, with respect to the commercial ones and so, facilitate the heat evacuation for conditioning the voltage and/or current.

RESUMEN: En el diseño de circuitos electrónicos se destaca la etapa de potencia, la cual se encarga de aumentar las características de una señal, como la corriente y el voltaje, para un apropiado funcionamiento del equipo a desarrollar. Sin embargo, esta etapa está conformada por elementos como los transistores, los cuales pueden presentar un bajo rendimiento, debido al aumento indeseado de temperatura, como consecuencia de alcanzar la potencia deseada. Para mitigar la perdida de potencia y con ello, la elevación de temperatura, se propone el manejo de disipadores de calor, con el propósito de mantener el trabajo de la etapa de potencia en un nivel estable y evitar fracturas térmicas dentro del circuito. En el siguiente trabajo, se exponen los resultados obtenidos del análisis térmico en elementos finitos del disipador de calor con aletas en forma de curva de Cesaro, para semiconductores de potencia, lo cual evidenció el aumento en el flujo de calor, respecto a los comerciales y de este modo, facilitar la evacuación de calor para el acondicionamiento de la tensión y/o corriente.

1. Introduction

The development of electronic circuits require the continuous use of daily tasks, as demand the manipulation of autonomous and teleoperated devices, as also the prolonged use of mobile devices. Thereby, it is possible to infer, that the use of those devices, sometimes requires the use of high levels of voltage and/or current, which could obtain losses by generation of heat energy, therefore it would alter the performance of the device and could show deterioration in the internal circuits [1, 2]. To reduce the heating of the devices inside, the use of heat sinks is proposed, for power semiconductors. These elements have the quality of absorbing the heat and in this way lead it to the outside, avoiding the possible damage of the circuit as of the elements that compose it [3–5].

Other application of heat sinks is in hybrid vehicles, arranged for fluid cooling, where the design is validated from analysis in the finite elements with variables such

* Corresponding author: Luis Eduardo Llano Sánchez
E-mail: luis.llano@unimilitar.edu.co
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as the amount of fluid to cool and the speed of circulation [3]. In lighting devices [6], heat sinks with fins with "T" or "+" shapes are used [7], as well as inclined fins for natural convection [8]. In the same way, alternative to conventional geometries have been developed such as the cookie structure [9], which is coupled to the integrated ones through protuberances on the surface of the semiconductor packing [10, 11]. In the development of printed circuits, heat sinks are integrated into the processors, in order to take advantage of the energy required by each of the elements present on the plate [12, 13]. In the telecommunication area, antennas with fractal geometries have been developed, which can fulfill the function of a heat sink and can also increase communication decibels and amplify Radio Frequency energy [14].

Previous to do the production of the heat sinks, it is necessary to implement the finite elements analysis, in order to analyze the heat flow [3], or the mass flow analysis, to proceed to apply optimization methods to improve results regarding the thermal, physical and electrical characteristics [15, 16]. As a clear example, it can be observed in the development of computers, where it is necessary to predict the behavior of the non-uniform heat inside the CPU (Central Processing Unit), to reduce the temperature in the plates of the CPU [17–19] and favor storage in magnetic mediums with energy assistance [20].

In the present work, the results obtained are presented with the analysis of heat flow by finite elements, of a heat sink with fins in the form of the Cesaro curve, for transistors with packaged TO – 220. This transistor is taken as an example due to its common use in engineering applications to obtain the necessary current for actuators, such as motors. Initially, the methodology that was carried out to perform the analysis of the heat flow of the suggested heat sink is proposed, where the use of the geometry of the Cesaro curve is explained [21], with the aim of increasing the surface of the heat sink and improving the heat evacuation outward.

Then, it is proceeded to explain the result obtained from performing the thermal flow analysis at a stationary state with the finite element software (CAE) ANSYS. There, the heat flux comparison of a commercial fin heat sink is performed with the fractal geometry heat sink by means of natural convection. This work is oriented at advancing the research process to carry out the implementation of geometrical structures of nature or fractal in everyday and engineering applications, with the purpose of improving processes such as heat transfer and thus contributing to the continuous growth of engineering processes.

2. Methodology

With the integration of the engineering with fractals geometries, it has been possible to describe the behavior of heat flow [22], as well as computational algorithms that have been developed for digital image processing [23]. Another clear example is in the area of telecommunications, with the development of antennas to improve wireless communication, increasing the bandwidth and improving the communication efficiency [24, 25], similarly in the area of medicine, it has been used for the purpose of identifying the morphological structure of organs such as the kidney and the brain [26, 27]. Similarly, postsurgical tissue recovery processes have been performed [28] and software development for medical image analysis [29].

In the mechanical engineering field, the analysis of fractures in polycrystalline materials is carried out, based on the fractal dimension, to reduce the fracture behavior and thus reduce it [30, 31]. Another use can be detailed in improving the understanding of ceramic surfaces with respect to metals, where stiffness and texture are taken into account [32].

In order to carry out the thermal analysis by finite elements of the heat sink with fins in forms of a Cesaro curve, initially, the growth procedure of the Cesaro curve is performed, as shown in Figure 1.

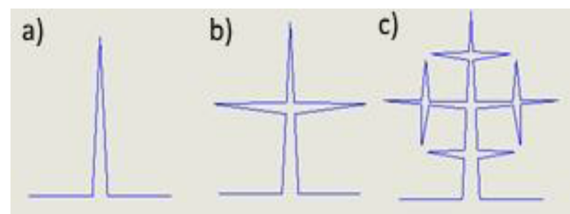

Figure 1 Cesaro curve growth to a) generation 0, b) generation 1, c) generation 2. (Source: own elaboration)

The mathematical analysis of the Cesaro curve is obtained from the Equation 1, which requires knowing the initial length of the main branch (Lo) and the generation to be obtained (n), from it you can get the length (L) of each of the sub-branches that are obtained in each iteration [33].

$$L = Lo * \left(\frac{1}{2}\right)^n \quad (1)$$

In the design of heat sinks, it is necessary to take into account the power to be dissipated (P_t) which is generated during the task of the semiconductors. For this, Equation 2 is taken into account, which requires knowing the power on the load (P_r) and the power supplied (P_{cc})

$$P_t = \frac{P_{cc} - Pr}{4} \quad (2)$$

Where P_r, Equation 3, requires knowing the load resistance (R_L) and the amplitude of the input signal (V_p):

$$P_r = 2 * \frac{V_p^2}{R_L} \quad (3)$$

To found P_{cc}, Equation 4, it is necessary to take into account the power supply by the booster in direct current (E)

$$P_{cc} = \frac{8 * E * V_p}{R_l * \pi} \quad (4)$$

Now, it is the heat sink-air resistance (R_{da}), which is obtained from the Equation 5 and requires knowing the maximum temperature that the transistor (T_j) can reach, the ambient temperature (T_a), the power to dissipate (P_{cc}), the capsule – union resistance (R_{jc}) and the union – sinks resistance (R_{cd}).

$$R_{da} = \frac{T_j - T_a}{P_{cc}} - (R_{jc} - R_{cd}) \quad (5)$$

With the use of the heat sinks in the power transistors, it is possible to maintain its operation at a stable level and prevent the low performance due to the power that dissipates as heat [34]. Then, the commercial heat sink is used for transistors with packaged TO – 220, in order to adjust the fractal geometry of the Cesaro curve to each fin.

Therefore, to do the design of the fins with the Cesaro curve, the generation 2 described in Figure 1 is taken into account, with the purpose of proposing two kind of heat sinks, the first one with longitudinal continuous fins and the second with split fins, as shown in the Figure 2.

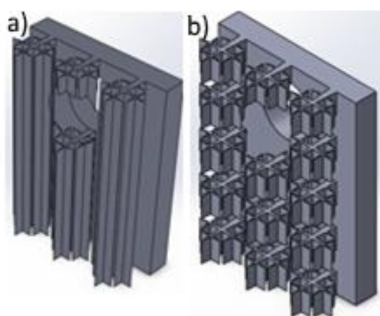

Figure 2 Heat sinks with fins in Cesaro curve form with the second generation, where a) is the continue longitudinal fins and b) is the divided fins (Source: own elaboration)

This is done by stimulating finite elements, with the computational tool ANSYS, to identify the heat flow that would be presented by each of the designs previously proposed. For this, it is considered that the heat sink is passive; it is configured as a natural convection process, without the need to use fans. It will also be simulated by assigning aluminum as semiconductor material and in the middle of the fins air is flowing at room temperature.

3. Results

In order to obtain the heat flow of the commercial heat sink with continuous and split fins and of the sinks designed with Cesaro curve fins, the ANSYS software indicates that the thermal analysis is to be carried out at a steady state (steady - state thermal), then the material corresponding to the heat sink is assigned. In this case, the different materials that are used are taken into account, which are cooper and aluminum. But to have a better consistency with reality, anodized aluminum was chosen, because of its thermal properties and it costs less than copper.

Then, the initial environment temperature (25°C) and the type of fluid that would surround the heat sink are indicated, for this case is air. Finally, it is taken into account that part of the heat sink will be in contact with the power semiconductor and the analysis is carried out, whose results can be appreciated in the Figure 3.

In order to have a better understanding of the results, Figure 4 is presented, indicating how the heat flow can increase by using split and continuous fins for the second generation of the fractal geometry of the Cesaro curve.

4. Result analysis

With the results, it is possible to appreciate the increase of the heat flux in the heat sinks with fins in Cesaro curve of second generation both continous and divided. This can improve the operation conditions of the power semiconductors, increasing the power capacity without damaging the physical structure of both the transistor and the plate where it is installed. In the same way, the results can be reached, because there is a better air flow between the fins and the increase of the sink surface of the heat sink.

With the development of this work, it is possible to increase the heat flux between the heat sink, the junction and the power semiconductor, due to the enlargement of the sink surface, giving the ability to allow a better flow of heat into the environment by the process of natural convection. In the same way, it is possible to deduce that the use of the Cesaro curve, with higher generations is possible to obtain a great increase of the heat flux, giving the capability to the transistors function in desired operating ranges without hainge damage by the high temperature produce.

Conventional rectangular fins are used by normal commercial dissipaters as shown in Figure 4, heat dissipation is lower than that obtained with fractal fins with Cesaro curve. The first proposal is divided into

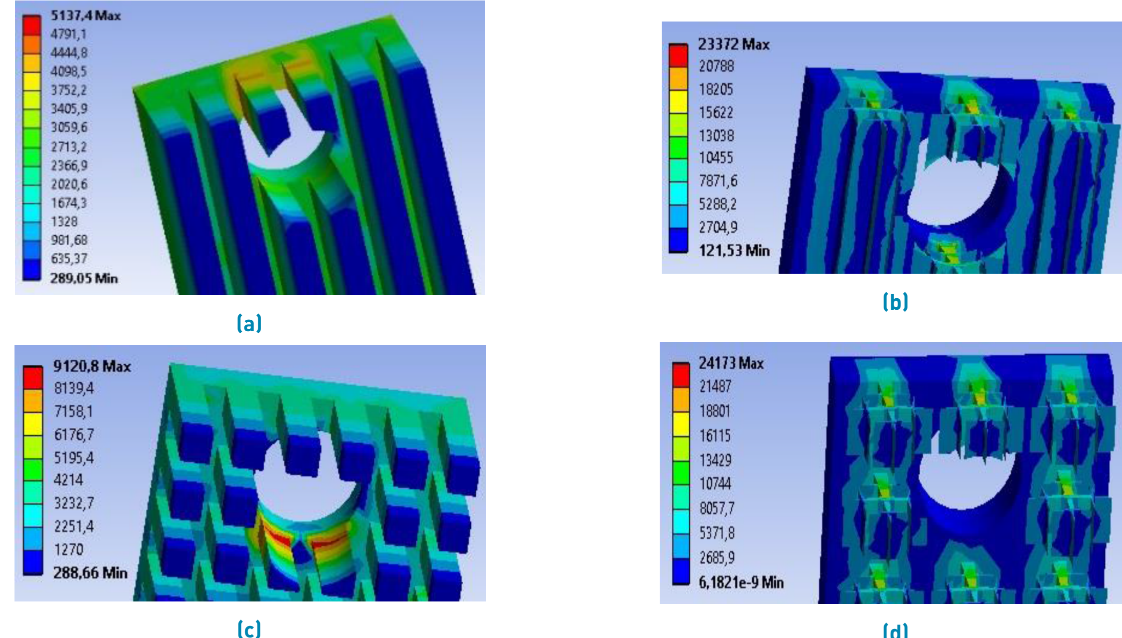

Figure 3 Results obtained of the finite elements analysis of the heat sinks, for longitudinal fins a) commercial, b) fins in Cesaro curve form of second generation, with divided fins c) commercial and d) fins in Cesaro curve form of second generation. (Source: own elaboration)

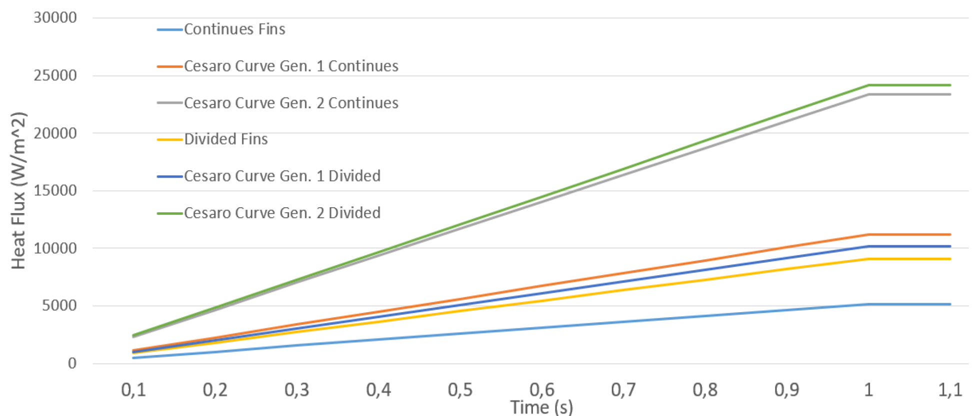

Figure 4 Behavior of the heat flux to each sink both commercials and designed proposed (Source: own elaboration)

rectangular fins which already improve heat transfer, Now, when the fractal fins with Cesaro curve are analyzed, the increase in heat flow in the sink compared to the previous ones is evident.

First and second generation Cesar curves were analyzed (Figure 1), finding that the second generation is the most efficient in continuous fin; however this same split fin is more efficient than continuous.

Cesaro's curve was chosen because the seed of the construction is a classic triangular fin and as fractals have a geometric property of increasing the area significantly with a moderate increase in volume, it is corroborated that the heat transfer in the heat sink is increased due to the increase in the area of convection by the fractal design of the fins. This was verified by the simulation performed with finite elements with ANSYS, which in turn required the construction in CAD of the second generation CESARO curved fins sink.

5. Conclusions

It is possible to conclude with the development of this work, that the heat flux between the heat sink, the junction and the power semiconductor can be increased, due to the enlargement of the sink surface, giving the ability to allow

a better flow of heat into the environment by the process of natural convection. In the same way, it is possible to deduce that with the use of the Cesaro curve, with higher generations is feaseable to obtain a great increase of the heat flux, giving the capability to the transistors function in desired operating ranges without having damage by the high production temperature.

It is possible to conclude that as fractal theory asserts that on any scale physical phenomena such as heat flow behave similarly on any scale. This phenomenon functioned in a similar way at the nano, micro or macro level, which the authors consider the most important contribution of this research, since innovation in engineering designs with fractal geometries can improve the efficiency of different applied engineering phenomena.

Finally, its possible to continue with the analysis of fractal geometries applications in works of engineering at macro level, where it is probable to improve different process that are limited by variation of temperature, humidity, solar radiation among others. Giving way to the development of future works where it could contribute in the improvement of activities to industrial level and personal of the daily life.

6. Declaration of competing interest

None declared under financial, professional and personal competing interests.

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