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Maximization of the heat sink performance used in the arm solar converter

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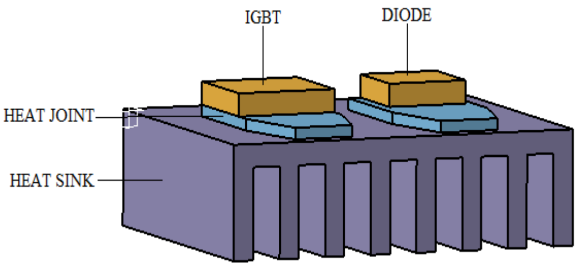
Abstract
This study presents an approach for the optimization of the heat sink; which is used for dissipating the heat generated by high power IGBT modules in the arm solar converter. This could be achieved by minimizing the geometry of the heat sink and choosing a good material; I will design these heat sinks using 2D CAD, then i will test the heat sinks using COMSOL by changing the materials and the parameters of the geometry. An algorithm will be done by MATLAB to minimize the volume and found the suitable parameters.

Keywords: Heat sink, Thermal model, Thermal resistance, IGBT modules, 2D CAD.

Introduction
Heat dissipation of the power components is a function that takes more and more importance in electronic power equipment. Heat sink design goals may vary, but the most frequent concern is minimization of the temperature in order to keep the devices in an acceptable working condition. Many ideas pertaining to cooling methods have been proposed [1]. In order to further enhance the cooling of electronic components, R. Sam and G. Sriharsha have been modelled and analysed of heat sink with rectangular fins having through holes, when it is observed from the results that optimum cooling is achieved by the heat sink design which contains interrupted fins with holes. These heat sink designs promises to keep electronic circuits cooler than standard heat sinks and reduction in cost due to reduction in material [2-3]. In addition, the heat transfer performance of various commonly used fin geometries is compared; the geometries are considered for minimizing thermal resistance at moderate laminar air velocities and pressure gradients [4-5], then Keisuke Horiuchi presented the multi-objective optimization of water cooled pin fin heat sinks [10] and Mehran Ahmad presented the design of high performance naturally cooled heat sinks with vertical rectangular interrupted [11].Up to date, the study of the performance of a surface air–oil heat exchanger for an aero gas-turbine engine having plate- and pin–fin shaped geometries was investigated numerically [12].
The present paper is devoted to maximize the performance of the heat sink used in arm solar converter [13]; in this study, we are talking about the interaction between two solid objects (the heat sink and the chips) and about theconvection, but the radiation will be neglected. In the first place the thermal network model is determinate in order to calculate the thermal resistance of the heat sink. Then an algorithm will be done by MATLAB in order to found sustainable parameters of the geometry; the aim of this model is to optimize the dimensions of the heat sink to minimize its weight. Finally, a 2D finite element model is developed to predict the temperature surface of the heat sink distribution, by the use of three different materials: Aluminium, Copper and Graphite metal. The graphite has an excellent anisotropic thermal conductivitywhich can reach 1500 W/ (m*K) in the c axis direction of the Graphite crystal. The Graphite has also other excellent properties, including low density, low thermal expansion coefficient, good mechanical property [6].

2. Heat sink thermal analysis
A thermal model of arm solar converter is created which's composed of two IGBTs and two diodes. Specifically, it's created for one IGBT and one diode because the study of two others is the same and the simulation will be done in 2-D. All of these devices are fixed in the heat sink as shown in figure 1.To model the dissipated heat from IGBT module; we use the concept of thermal resistance as shown in figure 2.



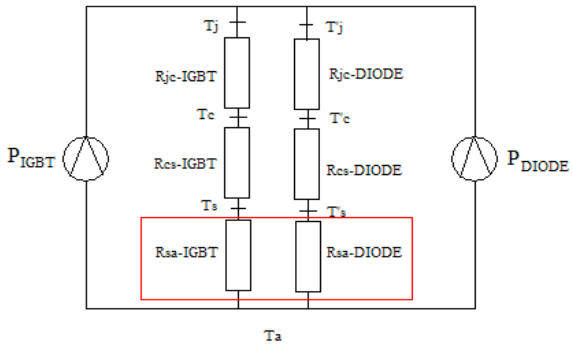


Figure 1:IGBT and Diode model.**Figure 2:**Thermal network of IGBT model.

$$R_{sa\text{-}IGBT}=\frac{(T_{j,IGBT}-T_a)}{P_{IGBT}}-(R_{jc\text{-}IGBT}+R_{cs\text{-}IGBT}) \qquad (1)$$

$$R_{sa\text{-}DIODE}=\frac{(T_{j,DIODE}-T_a)}{P_{DIODE}}-(R_{jc\text{-}DIODE}+R_{cs\text{-}DIODE}) \qquad (2)$$

Where:

R_{sa} is the thermal resistance of heat sink, T_j is the junction temperature, T_a is the ambient temperature, P is the power dissipated, R_{jc} is the thermal resistance between the junction and the case, and R_{cs} is the thermal resistance between the case and the heat sink. These values will be estimated from a reel application [7] and from datasheet [8].

3. The geometry configuration

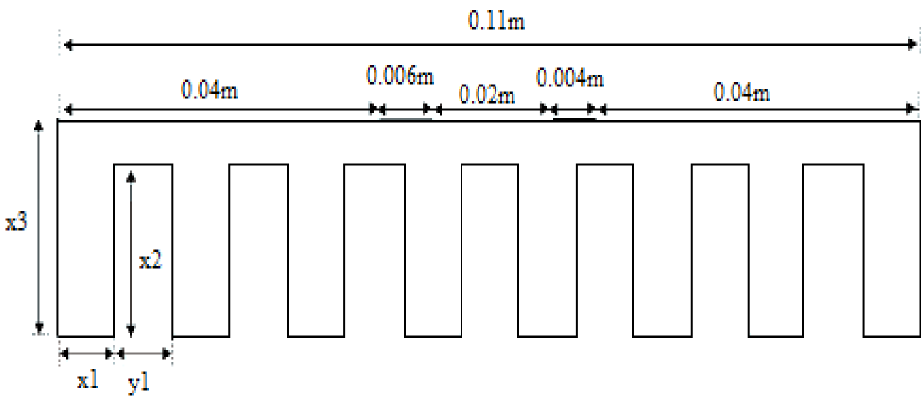


Figure 3: The geometry configuration of the heat sink

As shown in figure 3 the parametery_1 depends on x_1, and the parameter x_3 depends on heat flux.

Where:

$$y_1=\frac{(0.11-8*x_1)}{7} \qquad (3)$$

$$Q_{IGBT}=\frac{P_{IGBT}}{(0.006*x_3)} \qquad (4)$$

$$Q_{DIODE}=\frac{P_{DIODE}}{(0.004*x_3)} \qquad (5)$$

Q is the heat flux (W/m²).

We'll use three cases for each of the three geometric parameters as shown in table 1; taken from profiles Ferraz Shawmut/ Mersen [9], then the number of combinations simulating is seventeen, they will be simulated in COMSOL.

Table 1: The cases chosen for three design parameters

Parameters	Case I (m)	Case II (m)	Case III (m)
x1	0.001	0.005	0.01
x2	0.03	0.045	0.05
x3	0.05	0.055	0.07

4. The property parameters of materials

Usually metals are the materials that have the highest conductivity. That is why all heat sinks are usually made of metals. Aluminium is one of the most common metals used to make heat sinks because of its relatively high thermal conductivity and ease of manufacturing. And also the copper is one of the best materials used for heat sinks; its thermalconductivity is nearly double that of aluminium, however, copper is much heavier (density) than aluminium, and much more expensive. In addition the graphite is the patent material of a company in Shanghai, which has an excellent anisotropic thermal conductivity, and the thermal conductivity can reach 1500 W/(m.K) in the c axis direction of the graphite crystal. The graphite also has other excellent properties, including low density, low thermal expansion coefficient, good mechanical property, so it will become the focus of the emerging heat dissipation materials and have great application and commercial space. The parameters of several common materials are showed in table 2 [6].

Table 2: The materials properties(293K).

Materials	Properties		
	Thermal conductivity W/(m*k)	**Density Kg/m³**	**Specific heat J/(kg*k)**
Copper	398	8930	902
Aluminium	236	2710	386
Graphite	1500 50 ~ 60	700 ~ 210	1400 ~ 1600

5. Simulation results and analysis

5.1. Simulation by COMSOL

The dissipated heat is transmitted by conduction from the top of the base plate to a heat sink through the fins; afterwards this heat is transferred from the heat sink to ambient air by convection. Then, seventeen models have been tested for aluminium material as shown in table 3,with thermal conductivity k = 236W/ (m*k), density ρ = 2710 kg/m³ Cp = 386 J/ (kg.k) and Specific heat to calculate the junction temperature of the IGBT and diode, in the figure 4 only four cases of simulations are shown. The model used in COMSOL is "Heat Transfer in Solids" and Q = 0. The equation model is:

$$\mathbf{\rho Cp.\Delta T = \nabla(k\Delta T) + Q}$$

With boundary conditions:

- Convective heat flux applied in all surfaces except the top surface of the heat sink (is adiabatic) h = 100w/ (m².k);
- Heat flux applied in IGBT chip (calculated with different values of x_3);
- Heat flux applied in Diode chip (calculated with different values of x_3).

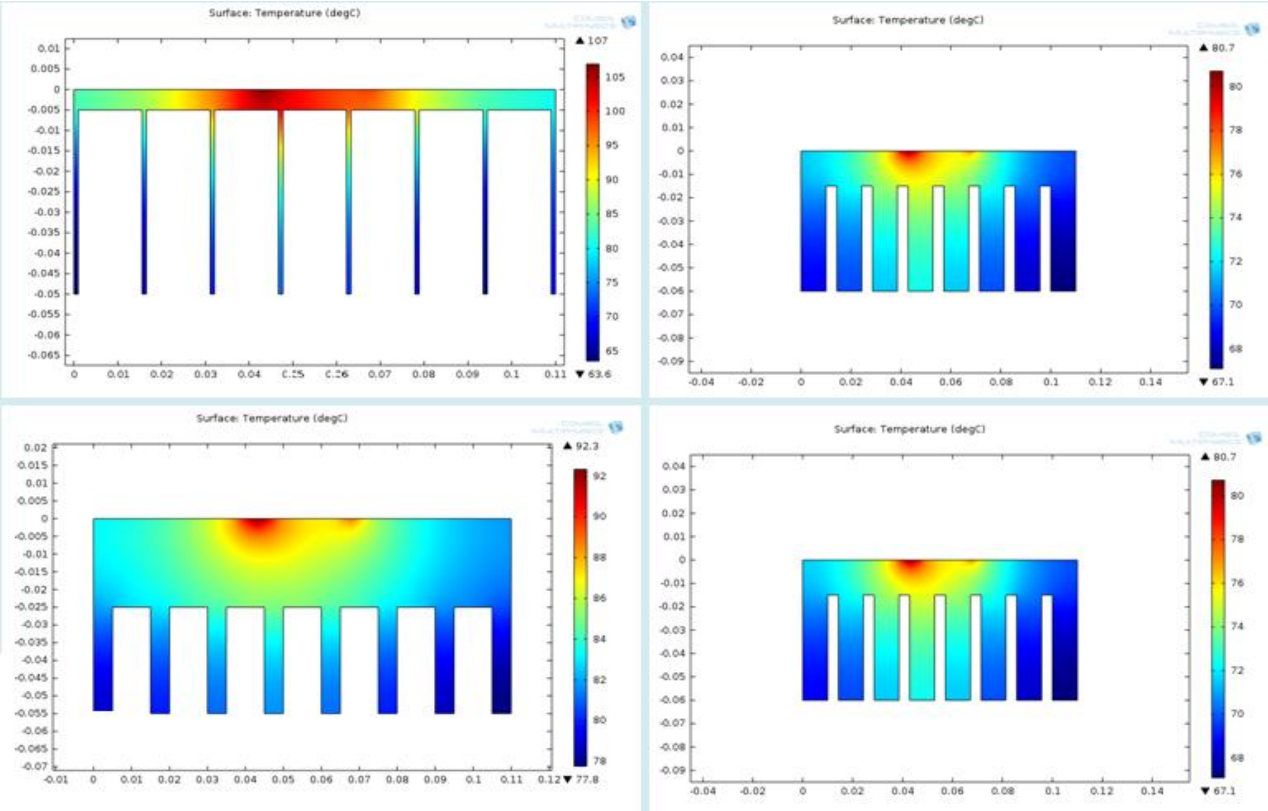


Figure 4: Four examples of simulation by Comsol

Table 3: The simulation by Comsol

x_1(m)	x_2(m)	x_3(m)	$T_{s,IGBT}$(°C)	$T_{s,Diode}$(°C)
0.001	0.03	0.05	103	99
0.001	0.03	0.055	96.7	92
0.001	0.03	0.06	91.8	88
0.001	0.045	0.055	95.2	90
0.001	0.045	0.06	89.2	85
0.005	0.03	0.05	97.8	94
0.005	0.03	0.055	92.3	88
0.005	0.03	0.06	88.1	84
0.005	0.045	0.05	95.6	90
0.005	0.045	0.055	86.9	81
0.005	0.045	0.06	82	78
0.01	0.03	0.05	96.8	92
0.01	0.03	0.055	91.6	88
0.01	0.03	0.06	87.4	84
0.01	0.045	0.05	92.3	85
0.01	0.045	0.055	85	80
0.01	0.045	0.06	80.7	76

5.2. An algorithm to model the thermal heat sink resistance

We consider a real application of IGBT Modules in the arm solar converter [7] with the following data (taken from datasheet [8]): $T_{j,IGBT}$=150°C, P_{IGBT}=100W, P_{DIODE}=50W, $T_{j,DIODE}$=125°C, T_a=25°C, $R_{jc\text{-}IGBT}$=0.125°C/W, $R_{cs\text{-}IGBT}$=0.025°C/W, $R_{jc\text{-}DIODE}$=0.26°C/W and $R_{cs\text{-}DIODE}$=0.025°C/W.

We replace these parameters in equation (1) and (2), and then we found: $R_{sa\text{-}IGBT}$=1.1°C/W and $R_{sa\text{-}DIODE}$= 1.725°C/W. With the same method, we found: $T_{s,IGBT}$=135°C and $T_{s,DIODE}$=111.25°C.

The main idea is based on simulating of an application of the heat dissipation corresponding to the power dissipated over the 2 chips (IGBT, Diode) using COMSOL. The simulation includes 18 different heat sinks that should lower the temperature under $T_{s,IGBT}$ and $T_{s,DIODE}$ for the 2 chips.
After applying a linear regression over the results of the simulation founding in Table 3, we found this two equations between the geometric parameters and the temperatures:

$$\mathbf{T_{s,IGBT} = 0.007657x_1^{-1} - 143.519x_1 - 2.92785x_2^{-1} - 2402.85x_2 + 8.965x_3^{-1} + 1766.667x_3} \quad (6)$$

$$\mathbf{T_{s,DIODE} = 0.007176x_1^{-1} - 189.715x_1 - 3.33375x_2^{-1} - 2795.37x_2 + 9.35x_3^{-1} + 233.333x_3} \quad (7)$$

With good correlation (R^2 = 99.96% for the IGBT's temperature and R^2 = 99.97% for the diode's temperature), we then found the optimum volume for the heat sink by using the fmincon command (Matlab) in maple:
Minimum of S(x1, x2, x3) such that:

$$\begin{cases} \mathbf{T_{s,IGBT} \leq 135°C} \\ T_{s,DIODE} \leq \mathbf{111.25} \\ \mathbf{0.001 \leq x_1 \leq 0.01} \\ \mathbf{0.03 \leq x_2 \leq 0.05} \\ \mathbf{0.05 \leq x_3 \leq 0.07} \end{cases}$$

$S(x_1, x_2, x_3)$ is the section of the heat sink. And we found:
$\mathbf{x_1 = 0.001m}$; $\mathbf{x_2 = 0.045m}$; $\mathbf{x_3 = 0.05m}$.

5.3. Simulation with different materials:

The simulation of the heat sink with the parameters founding and with Aluminiumis shown in figure 5:

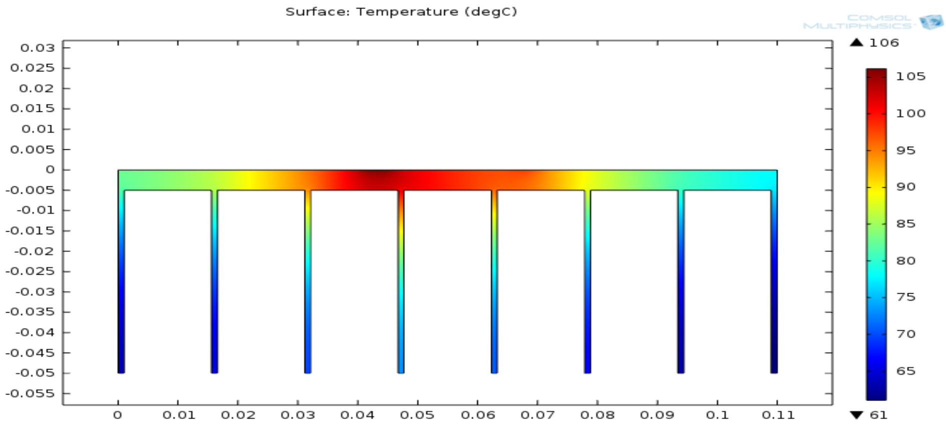


Figure 5: Heat sink with Aluminium.

The simulation of the heat sink with the parameters founding and with copperis shown in figure 6:

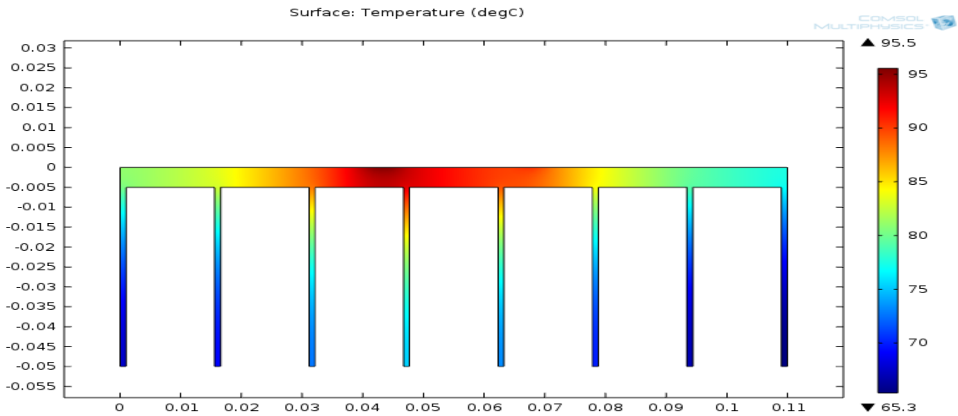


Figure 6: Heat sink with Copper.

The simulation of the heat sink with the parameters founding and with Graphiteis shown in figure 7:

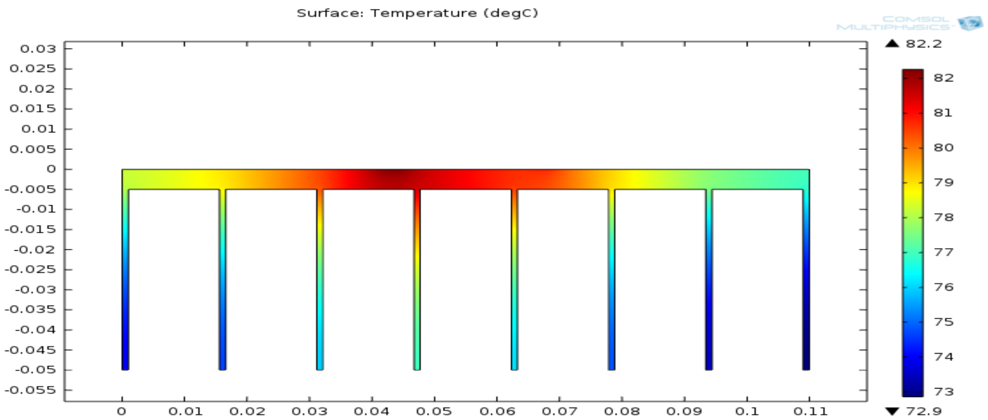


Figure 7: Heat sink with Graphite.

5.4. Results and analysis

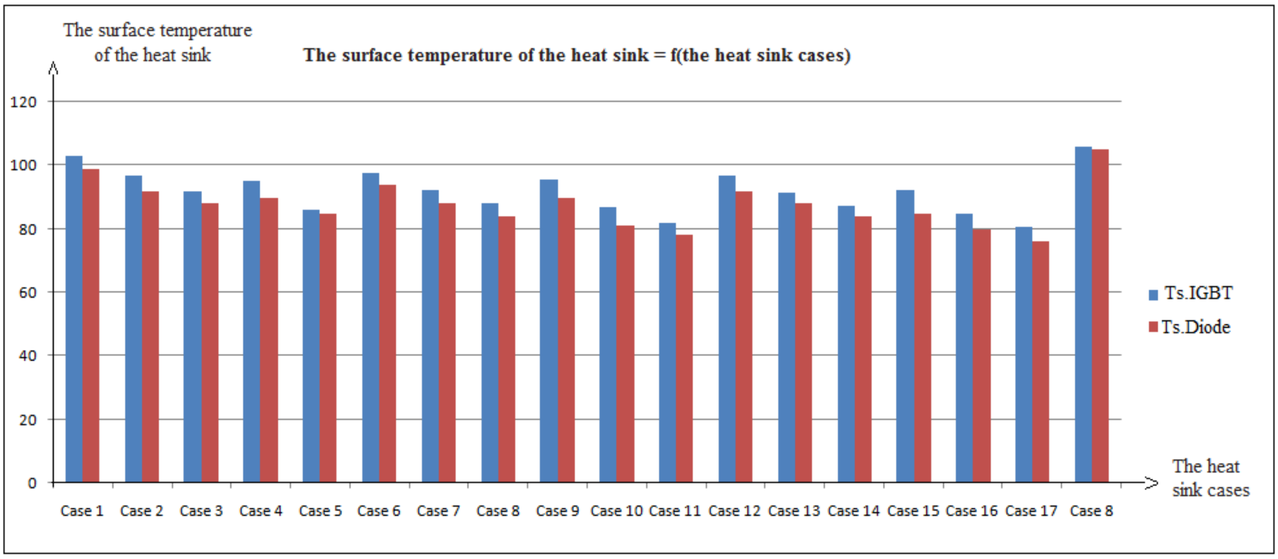


Figure 8: The surface temperature of the heat sink = f(the heat sink cases)

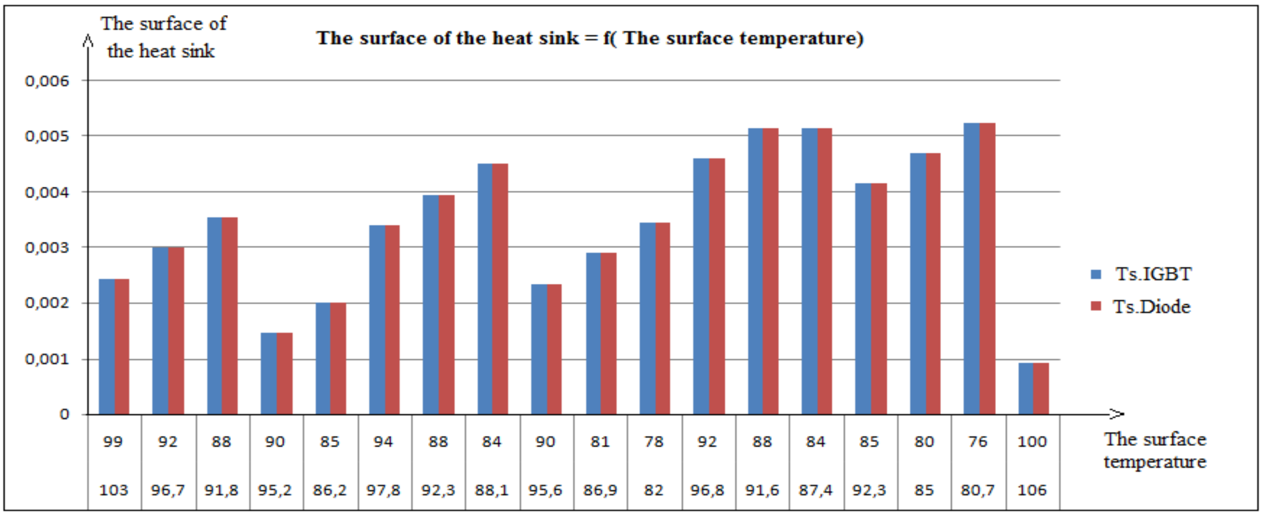


Figure 9: The surface heat sink = f(The surface temperature of the heat sink)

Between the three materials (Aluminum, Copper and Graphite) simulated, we concluded that the Graphite is the most efficient heat dissipating one as shown in figure 7.

The figure 8 shows that all cases meet the thermal condition ($T_{s,IGBT} \leq 135°C$, $T_{s,Diode} \leq 111.25$)c), even the case found by the weight optimizing algorithm. It's true that the temperature implied by our algorithm is the highest of all the other cases; still it satisfies the thermal condition. Moreover it needs less materiel as shown in figure 9.

Conclusion

The choice of the optimum heat sink can be achieved by using a complete simulation of the heat dissipation within it. In our case, we could achieve cold temperature (106°C) by using very small heat sink. Using a different materiel can increase the temperature.

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