METHODOLOGY FOR ACCOMPLISHMENT OF THERMAL PROJECTS OF ELECTRONIC EQUIPMENTS IN SPACE ATMOSPHERE

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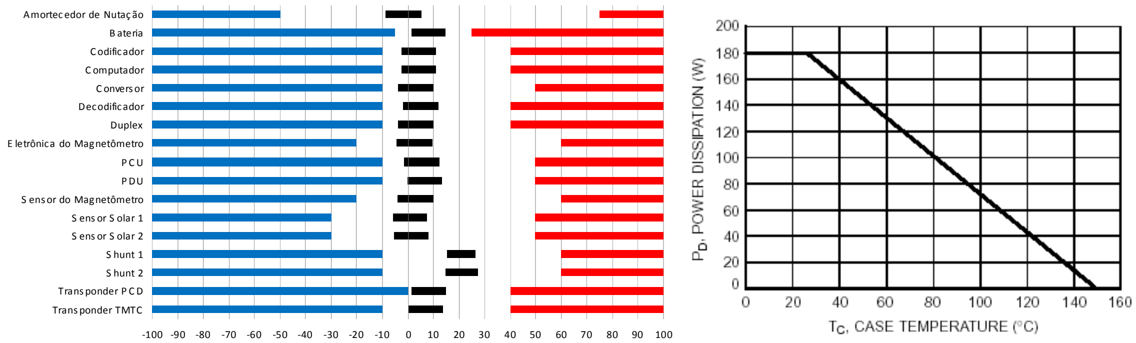
Abstract: *The present work has for objective to present a methodology for accomplishment of the thermal project of the electronic equipments that will compose ITASAT, academical satellite that is being developed by the Technological Institute of Aeronautics (ITA). the proposed methodology uses the software SINDA/FLUINT, that due to their private characteristics, it supplies simulations with a good degree of reliability of the thermal behavior of the electronic equipments embarked in the statement satellite. Those equipments suffer influence of external parameters to the satellite, such as solar radiation, albedo (solar radiation contemplated by the Earth) and terrestrial radiation, and the intensity of these external loads depends on the parameters that describe the orbit of the satellite. The program ITASAT is developed by ITA together with other Brazilian universities, with the technical support of the National Institute of Space Researches (INPE) and financial support of the Brazilian Space Agency (AEB). The presented results and discussed in the present work can serve as initial model for projects of equipments, and other devices that have to answer to the requirements of projects of the aerospace section.*

Key-words: *ITASAT, Thermal project, Electronic Equipments, Academical Satellite.*

1. INTRODUCTION

The project of a space vehicle, in the present case, a satellite, is an activity that involves several areas of the knowledge and, besides, it can be approached in different levels. Then, inside of the project of a satellite we have the subsystems that nothing else is the agglutinating of the activities that they are ruled in a given area of the knowledge, being examples of those the subsystems of attitude control (ACS), supply of energy (EPS) and thermal control (TCS). For the due analysis, it is chosen the subsystems of interest, in other words, the one of thermal control. Such subsystems can be approached in two different levels, being the first of system and the second of equipment. The system level has as his/her mark to maintain the equipments inside of nominal strips of temperature, as presented in the located image to the left in Fig. (1), and the equipment level has as purpose to guarantee that the equipments are below the limit of operation of the components that you/they compose him/it, as willing in the image positioned to the right in Fig. (1). In spite of, those two levels are complemental amongst themselves, since the thermal project of a satellite will only be complete if the problems be solved in those two levels and among the interrelations among the other present subsystems in the satellite. A demonstration that such a veracious statement is the simple fact that given of exit of the thermal project in equipment level, the potency dissipated in form of heat, it is an entrance die to accomplish the thermal swinging of the satellite in the system level, since the sum of the potencies dissipated by all of the equipments composes the load thermal intern of the satellite.

Usually the thermal project in equipment level is linked to the subsystem that is projecting the equipment, in that way imputing to the subsystem of thermal control just the responsibility for the project in system level. It is believed that starting from the moment in that there is demand in the project of the complete satellite the wisest posture is the one of TCS to assume the function and to also accomplish the work in the system level, because no there is the need of each subsystem to have to provide a thermal planner for itself, because that would burden the project due to the request of a great amount of professionals of such area. The proposal here done should be applied in ITASAT, that is an academical satellite developed by ITA (Technological Institute of Aeronautics) together with other Brazilian universities, with the technical support of INPE (National Institute of Space Researches) and financial support of AEB (it Negotiates Space Brazilian).



(a) (b)

Figure 1. (a) Example of the output for the project in system level, obtained for of Silva (2009) for ITASAT (Permanent Regime, with Angle Beta of 1,6 ° and 48,4 °); (b) Example of characteristic curve of derating of energy for transistors MJL0281A (NPN) and MJL0302A (PNP) manufactured by ON Semiconductor.

2. THE SUBLEVELS OF THERMAL PROJECT IN LEVEL OF EQUIPMENT

In what it concerns to the thermal project in the equipment level, this can be fragmented in three sub-levels, being them:

- Component sub-level: it is studied the heat generated by the component and his/her dissipation;
- Plate sub-level: it is studied the transfer of heat in the plate;
- Structure sub-level: it is studied the transfer of present heat in the carcass and in the frame.

In the subsections the details are had below of each one of those sub-levels.

2.1. Component sub-level

As mentioned above, in this sphere it is studied the thermal behavior of the components, being more specific the focus in the analysis of generation of heat of the component and his/her dissipation. In that point it is done necessary to present a first delimitation, which is exactly on what he/she is considered how being a passive component and assets.

In electronics, usually, it is defined as a passive component an element dissipative that don't have possibility to control the flow of energy in a circuit (GRAY,1974), being examples of that category of components the resistors, capacitors and inductors, already in what it concerns the components assets are examples the transistors and diodes. But when the sphere of mute analysis for thermal considerations, then appears to the dimension of the devices that you/they are active thermally, and in that analysis being active or liability presents different meaning. To avoid confusion, the binomial active/passive will be reserved to refer to the behavior of the device in the extent of the electronics and the binomial significant/insignificant will be used for the contribution given by the component for the load thermal total of the equipment. Therefore, the insignificant components are the components that don't contribute significantly in the intensity of the thermal load generated by the equipment, in such a way that such components are those that dissipate less than 1x10-5 Watts. The general expression for the dissipated potency is given by Eq. (1):

$$P_d = V \cdot I \tag{1}$$

where:

P_d = Dissipated potency (W)

V = Tension in the device (V)

I = Current through the device (A)

But in the case of there being a variation frequency in the current or tension, then the potency dissipated raisin the being a potency measured dissipated, given by Eq. (2):

$$P_{dm} = \frac{1}{t}\int_{t_1}^{t_2} V(t)I(t)dt \tag{2}$$

where:

P_{dm} = Potency measured dissipated (W)

t = Wave period (s)

V = Tension in the device (V)

I = Current through the device (A)

A point to be pointed out is that specific expressions are had for several types of components, be them assets or passive. Tab. (1) it presents the expressions for active components.

Table 1: Expressions for active components.

Type	Expression	Details
CMOS	$P_d = \frac{CV^2}{2} f$ Potency dissipated by commutation	C = entrance capacitance (F) V = tension pick - the - pick (V) f = commutation frequency (Hz)
CMOS	$P_d = N_{tot} N_{on} qf$ Potency dissipated by gate short-circuited	N_{tot} = nº total of gates N_{on} = Percentage of gates on (%) q = potential loss (w/Hz for gate) f = commutation frequency (Hz)
Junction FET	$P_{d_{on}} = I_D^2 R_{DS(ON)}$ Potency dissipated by transport	I_D = drain current (A) $R_{DS(ON)}$ = drain resistance for the source (Ω)
Junction MOSFET	$P_c = I_D^2 R_{DS(ON)}$ Potency dissipated by transport	I_D = drain current (A) $R_{DS(ON)}$ = drain resistance for the source (Ω)
Junction MOSFET	$P_S = f_S \left(\int_0^{t_{s1}} V_{DS}(t) I_D dt + \int_0^{t_{s2}} V_{DS}(t) I_D(t) dt \right)$ Potency dissipated during the commutation	f_S = keying frequency (Hz) V_{DS} = tension between drain and source (V) I_D = drain current (A) t_{S1} = time of the first transition (s) t_{S2} = time of the second transition (s)
Junction MOSFET	$P_G = V_{GS} Q_G \frac{R_G}{R_S + R_G}$ Potency dissipated by the gate of the MOSFET	V_{GS} = voltage between the gate and the source (V) Q_G = pick load in the gate capacitive (coulombs) R_G = resistance of the gate (Ω)
Junction MOSFET	$P_{G(TOT)} = V_{GS} Q_G f_S$ Total potency dissipated by the structure of the gate	V_{GS} = voltage between the gate and the source (V) Q_G = pick load in the gate capacitive (coulombs) f_S = keying frequency (Hz)

The expressions for the passive components are given in Tab. (2).

Table 2: Expressions for passive components

Type	Expression	Details
Interconnects	$P_D = I^2 R$ Potency dissipated by the joule law Where: $R = \rho \frac{L}{A_c}$	I = current in stationary state (A) R = resistance in stationary state (Ω) ρ = resistividade for length (Ω/m) L = length of the connector (m) A_c = area of the traverse section (m^2)
Resistors	$P_D = I^2 R$ Potency dissipated by the joule law	I = current in stationary state (A) R = resistance in stationary state (Ω)

Resistors	$P_D = I^2(t)R$ Potency dissipated instantly due to variation of the current, for the joule law Where: $I(t) = I_M sen(\omega t)$	$I =$ current in stationary state (A) $R =$ resistance in stationary state (Ω) $I_M =$ sinusoidal current of pick (A)
Capacitors	$P_D(t) = 0{,}5\omega C_M^2 sen2\omega t$ Potency dissipated by excitement through sinusoidal current	$C =$ capacitance (F) $V_M =$ sinusoidal voltage of pick (V) $\omega =$ frequency radiana, $2\pi f$ $f =$ frequency (Hz)
Capacitores	$P_D = \frac{1}{T}\int_{t_1}^{t_2} I^2(t)R_{ES}dt$ Potency dissipated equivalent resistiva of a capacitor in a circuit AC	$R_{ES} =$ equivalent resistance in it serializes (Ω)
Inductors and transformers	$P_D = I^2 R_L$ Potency dissipated by the joule law	$R_L =$ resistance to the direct current of the inductor or of clearance sale (Ω)
Inductors and transformers	$P_D(t) = 0{,}5LI_M^2\omega sen2\omega t$ Total potency dissipated by the sinusoidal resistance of an inductor	$L =$ Inductance $(Henry)$ $I_M =$ sinusoidal current of pick (A) $\omega =$ frequency radian $(2\pi f)$
Inductors and transformers	$\dot{P}_{D(CORE)} = 6.51 f^n B_{MAX}^m$ Potency dissipated in the presence of nucleus ferromagnetic	$P_{D(CORE)} =$ Dissipated potency (W/Kg) $n, m =$ constant of the material of the it blushes $f =$ commutation frequency (Hz) $B_{MAX} =$ maxim flow density $(Tesla)$
Inductors and transformers	$P_D = \dot{P}_{D(CORE)}M$ Potency dissipated in the presence of nucleus ferromagnetic	$M =$ mass of the it colors mass of the it colors ferromagnetic (Kg)

As evidenced above, in Tabs. (1) and (2), for each component type there is an appropriate expression to calculate the potency dissipated by the same. In such a way that just with those expressions and with the list of components that you/they compose a circuit it is possible if it calculates an initial forecast of the total potency dissipated by the equipment, and in that way to infer if it will be necessary a more refined thermal project for the same. An analysis of that will be seen in the section 3, I study of case.

2.2. Plate sublevel

In this sub-level he/she is considered the interaction between the components and the plate, and it is in this level that makes sense if it discusses the temperature reached by the components. This is due to the fact that the dissipated potency will be transformed in heat and the amount of heat that it will be driven for the plate is that it will determine the final temperature of the component, and this phenomenon is governed by the equation of the transport of heat or law of Fourier.

$$q(r) = -k\nabla T \tag{3}$$

Where:
q = flow of heat
∇T = temperature gradient
$k =$ thermal conductivity

For the case of the flow of heat spreading radially is had:

$$\frac{1}{r}\frac{\partial}{\partial r}(rq(r)) = 0 \tag{4}$$

Substituting (3) in (4) and doing $\nabla T = \frac{\partial T(r)}{\partial r}$, it is had:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(-kr\frac{\partial T(r)}{\partial r}\right) = 0 \tag{5}$$

Considering constant is obtained:

$$T(r) = C_2 + C_1 Ln(r) \tag{6}$$

Delimiting the outline conditions:

$$q(r)\big|_{r=r_0} = q_0 = \frac{Q}{A} = \frac{Q}{2\pi r_0 \delta} \tag{7-a}$$

and

$$T(r)\big|_{r=r_1} = T_1 \tag{7-b}$$

It is obtained:

$$T(r) = T_1 + \frac{Q}{2\pi k\delta}\ln\left(\frac{r_1}{r}\right), \quad \text{para} \quad r_0 \le r \le r_1 \tag{8}$$

Where represents the temperature in the surface of the component, it is the temperature in the point more distant radially of the plate, and any arbitrary point among those two points, as presented in Fig. (2):

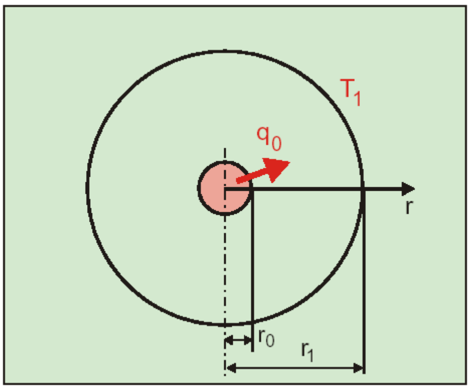


Figure 2. Representation for Eq. (8).

The resolution of such equation can be executed through numeric methods implemented in softwares, facilitating the calculation work a lot. Fig. (3) it presents a simulation accomplished with the software SINDA/FLUINT (www.crtech.com), where the entrance data are:

$Q = 0{,}2W$

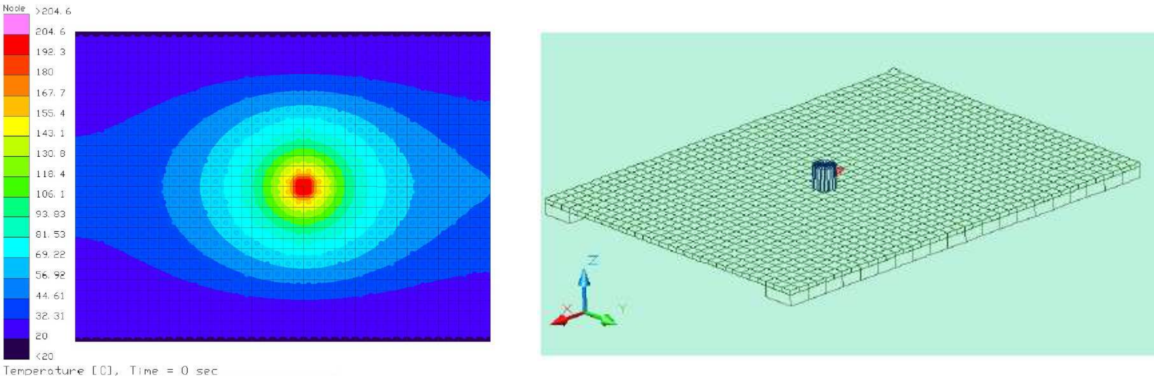
$\delta = 0{,}002m$

$k = 0{,}27\frac{W}{mC}$

$r_0 = 0{,}002m$

$r_1 = r_0 + 0{,}05m = 0{,}052m$

$T_{frame} = 20C$



(a) (b)

Figure 3. (the) temperature Field generated by the dissipation of just a component (b) outline of the assembly of the component on the plate.

In the figure 3(a) that the temperature reached by the component above is something around T0=Tcomp=205 ºC and that is due to the efficiency with that the component accomplishes transfer of thermal energy for the middle his turn and considering that in our case of interest, half space, the predominant form is the transfer through the transport, then we can affirm that:

$$\Delta T_{01} = T_0 - T_1 \quad or \quad \Delta T_{comp/frame} = T_{comp} - T_{frame} \tag{9}$$

Taking into account that temperature component/frame and relating she with the heat transferred then arrived to the concept of thermal resistance:

$$R_{01} = \frac{\Delta T_{01}}{Q} = \frac{\Delta T_{comp/frame}}{Q} \tag{10}$$

That in the cultured case, in the illustration 3, we supply a thermal resistance of 790 C/W, if we catch the case above it is just vary the area of contact of the component, expressed through the ray, that had implicated that the temperature reached by the component will be smaller as adult is the contact area and the thermal resistance is directly proportional the contact area, table 3:

r_0 (m)	$d_{diameter}$ (m)	T_0 (C)	R (C/W)
0,002	0,004	205	790
0,005	0,010	161	706
0,010	0,020	125	526
0,015	0,030	106	432
0,020	0,040	94	369
0,025	0,050	85	324

It is noticed in the illustration 3(a) that the temperature reached by the component above it is something around T0=Tcomp=205 ºC and that is due to the efficiency with that the component accomplishes transfer of thermal energy for the middle his/her turn and considering that in our case of interest, half space, the predominant form is the transfer through the transport, then we can affirm that:

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With that it is noticed that a good joining between PCB and the component allows that he/she stoops down the temperature of the same in way to maintain him inside of the strip of acceptable temperature for operation of the same or going more they haul to accomplish an increase of the reliability

2.3. Structure sub-level

In this sub-level the focus of the project goes back to the interaction between the binomial plates/components and the adjacent structures, best saying, in this phase of the project is studied as the structural interactions between plates/components and fixatives (screws, granpos, pins...), racks, carcass alters the gradient of temperature of the equipment and consequently if the final temperature of the components doesn't cross his/her operational limit that is materialized in one analyzes of how ideal is the contact among the pcb and the rack, illustration 4.

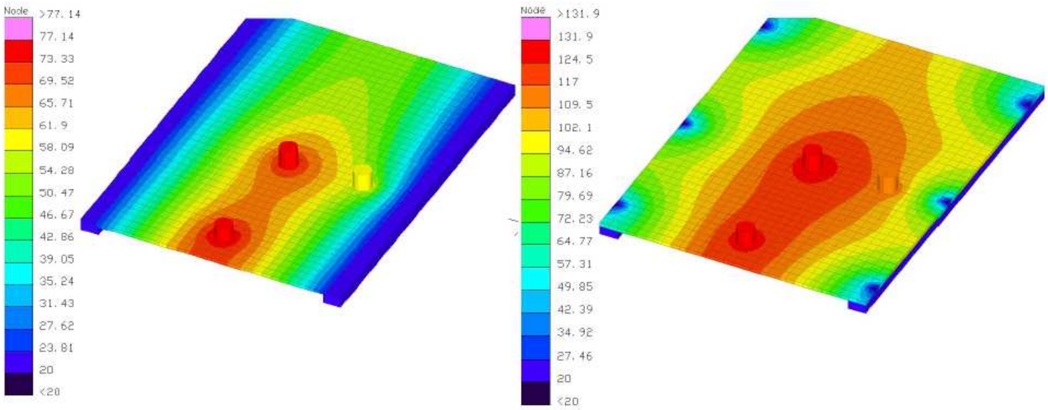

Figure 4. Temperature difference for the same equipment being the first ideal approach and Monday a realistic approach.

In one it analyzes complemental if it analyzes the contact among the rack and box, figure 5

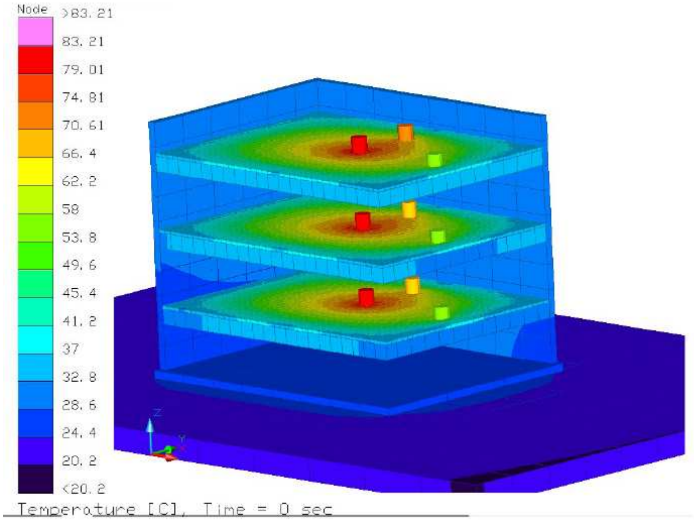

Figure 5. All of the apprenticeships of thermal interactions involved in an equipment developed for satellites.

In that way we closed all of the interactions of change of heat that it happens in an employed equipment in satellites.

3. CONCLUSIONS

In the present article we aimed at to describe the interactions of change of heat that it happens in an equipment that will be used in the space. But such description doesn't turn disposable a deeper approach in each one of the striped levels above, therefore, it is done necessary a research for all of the interactions described so that a deep description of the dynamics is gotten that happens in equipments inserted in such context.

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