

THERMAL NUMERICAL ANALYSIS IN TELECOMMUNICATIONS RACKS

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Abstract. *This work shows the validation of a numerical simulation model through experimental test. The power dissipated by electronic components was measured experimentally through the wind tunnel test and application of analytical models of heat conduction and convection. Then a numerical test was accomplished with aid the Software ANSYS. It was considered laminar flow model in numerical simulation because in the experimental test the speed used were low. The temperatures observed in experimental and numerical tests are very close to a higher speed, longer for lower rates that did not happen. This fact can be explained by errors considerations involved in the model of experimental test. It was adopted as the heat transfer occurred in one direction, it simplifies the calculations and the experimental apparatus, however, what it happens is a three-dimensional heat conduction. For lower speeds the heat transfer of heat conduction is more significant than by convection and therefore the calculation involved in the conduction heat transfer have larger errors. However, for higher speeds, conduction heat transfer are lower and then it is possible obtain results considerable closer.*

Keywords: *heat transfer, CFD, turbulent flow*

1. INTRODUCTION

With the development of the electronic industry it was possible to develop other important branch of the industry, the telecommunications. The customers were becoming increasingly demanding, and to remain in the market, industries of telecommunications had to offer other types of services. Since then, this industry started to look for smaller components so they could consolidate a greater number of functions in a single rack of telecommunication. The components decreased and at the same time the problems increased. The temperature began to be an important variable to be observed at these racks, because with the miniaturization, the components started to dissipate heat at a higher rate.

A solution for this problem would be to simulate numerically the phone rack to find the speed and temperatures fields, thus discovering the critical areas of the system. For that it would be necessary to know the power of each component. But how could it? The data sheet would be the first answer. In this case, these data does not exist in the data sheet of these components. It is the purpose of this work. To find these dissipated power in an experimental way and soon afterwards using numeric simulation models, to validate the numeric data with the experimental results.

For the numerical simulation proposed it will be used mathematical models for laminar regime. This regime was chosen, because on the experimental tests the velocities used are relatively lower.

Besides the principle of momentum conservation, represented by the Navier Stokes equation, for the solution it is necessary also to observe the principle of entropy increase in the amount of energy and mass conservation. Experimentally, as would be expected, the same physical principles must be observed.

In this work a wind tunnel was built to create a flow around printed circuit board. It was collected the temperatures of each component to thereby calculate the dissipated power by each component from the equations of heat transfer and fluids mechanics. This calculated power served as input for the numeric model. From the numerical simulation, it was obtained the temperature value for each component and then, both temperatures were compared, experimental and numerical.

For the calculation of the generated heat by the electronic components of the boards MMA and MCC were considered the conduction and convection heat transfer. The heat transfer by the radiation was neglected because it was a problem of forced convection. Thus:

$$Q_{Total} = Q_{convection} + Q_{conduction} + Q_{radiation} \quad (1)$$

Where Q_{total} represents the total dissipated heat quantity, $Q_{convection}$ the dissipated heat convection and $Q_{conduction}$ dissipated heat conduction.

1.1. Calculation of the convection heat transfer

$$Q_{convection} = h \cdot A \cdot \Delta T \quad (2)$$

Where:

h is the convection coefficient between the component and the air;

A is the area of heat transfer (area of the component);

ΔT is the temperature variation between the air and the component.

The area of each component and the temperature variation of the air with the component are known, so it is necessary to determine the coefficient h .

1.1.1. Calculation of the heat transfer coefficient by convection

$$h = \frac{Nu \cdot k}{L} \quad (3)$$

Where:

Nu is the Nusselt number;

k is the heat transfer coefficient by conduction of the air;

L is the component length along the flow.

The conduction coefficient of the air and the component length along the flow are known, so it is necessary to determine the Nu .

1.1.2. Calculation of Nusselt number

One of the correlations of Nusselt accepted for laminar flow is:

$$Nu = 0,664 \cdot Re^{\frac{1}{2}} \cdot Pr^{\frac{1}{3}} \quad (4)$$

Where:

Re is the Reynolds number;

Pr is the Prandtl number of the air at 300 K.

The Prandtl number is a tabled value. Need to determine the Reynolds number.

1.1.3. Calculation of the Reynolds number

$$Re = \frac{V \cdot L}{\nu} \quad (5)$$

Where:

V is the velocity of the air flow;

L is the component length along the flow;

ν is the kinematic viscosity of the air at 300 K.

The flow velocity and the length of the component along the flow are measured experimentally. The kinematic viscosity is a tabled property. So the Reynolds number can be calculated and the heat flow by convection.

1.2. Calculation of the heat transfer by conduction

$$Q_{cond} = \frac{\Delta T}{\sum R_T} \quad (6)$$

Where:

ΔT is the temperature variation between the component and the board as showed in Fig. 1;

$\sum RT$ is the sum of the thermal resistances (component and board).

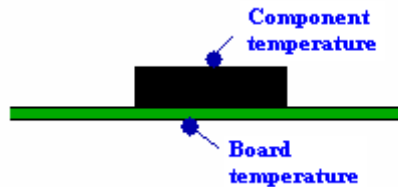


Figure 1- Points of temperature measured.

As the temperature variation between the component and the board is measured experimentally, just need to determine the sum of thermal resistances.

1.2.1. Calculation of the thermal resistances sum.

$$\sum R_T = \frac{L_c}{q_{ss} \cdot k A_s} + \frac{L_p}{k_p \cdot A} \quad (7)$$

Where:

L_c is the component characteristic length (Incropera et al., 2007);

q_{ss} is the dimensionless conduction heat rate (Incropera et al., 2007);

k is the thermal conductivity of the component;

A_s is the surface area of the component (Incropera et al., 2007);

L_p is the board thickness

k_p is the thermal conductivity of the board;

A is the heat transfer area of the component with the board.

As the q_{ss} , k and k_p are tabled values and, L_p and A are experimentally measured, just need to determine the characteristic length and the active area of the component.

The terms q_{ss} and L_c are described in details in the Conduction Shape Factor and the Dimensionless Conduction Heat Rate where the same are selected by system. For example, in this job it was selected the case 15 (Incropera et al., 2007).

1.2.2. Calculation of the characteristic length

$$L_c = \left(\frac{A_s}{4\pi} \right)^{\frac{1}{2}} \quad (8)$$

Where A_s is given by (Incropera et al., 2007):

$$A_s = 2L^2 + 4L \cdot E \quad (9)$$

Where:

L is the component length along the flow;

E is the component thickness.

2. PROCEDURES AND METHODS

2.1. Experimental Methodology

To estimate the dissipated power by each component it was carried out an analysis of the flow around the printed circuit board, and through the aid of thermocouples collected in the temperature of each component and then obtain the dissipated power by the component. The experimental test was conducted in the laboratory of software quality (LSQ) of CPqD located in Campinas in June 2008. The experimental apparatus was developed and built at “Universidade Estadual Paulista Júlio de Mesquita Filho”, Campus of Ilha Solteira.

For this work the following equipments were necessary:

- Wind Tunnel;
- Module of Data Acquisition;
- Controllable tension sources;
- Source of Tension (JIGA DE ALIMENTAÇÃO);
- Digital Thermal Anemometer;
- Board MMA.

The wind tunnel was designed to allow a fully developed flow and uniform. A sketch of the project is shown in the fig. 2:

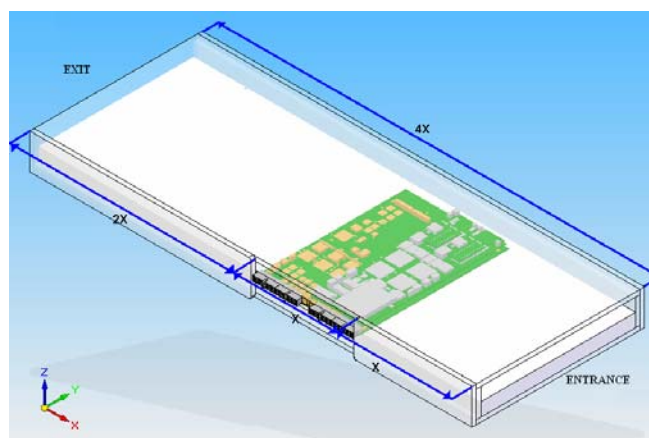


Figure 2 – Wind Tunnel design.

To measure the temperatures thermocouples were fixed on the most critical components.

In the wind tunnel, the printed circuit board (PCB) was connected to the power source and the entrance air velocity was stabilized at 0.59m/s. After the system enters into steady state it was made four temperature measures for each component. Then the speed was varied to 1.06, 1.79, 2.52 and 3.05 m/s repeating the procedure above for each speed.

2.2. Numerical Methodology:

The numerical test was performed on a reverse experimental way, or from the values of the thermal dissipated power and geometries properties of the board. The figure 3 shows the wind tunnel modeled on the software.

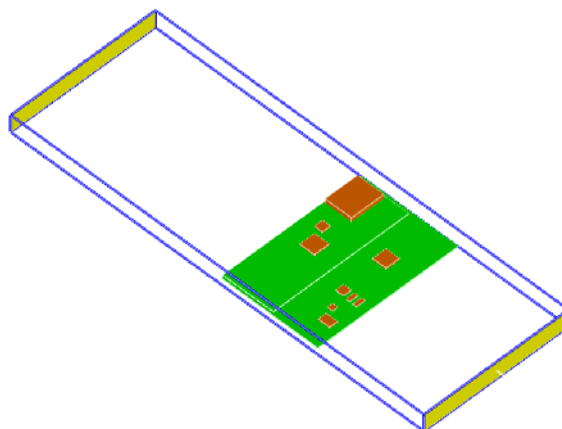


Figure 3 – Wind Tunnel modeled at ANSYS software.

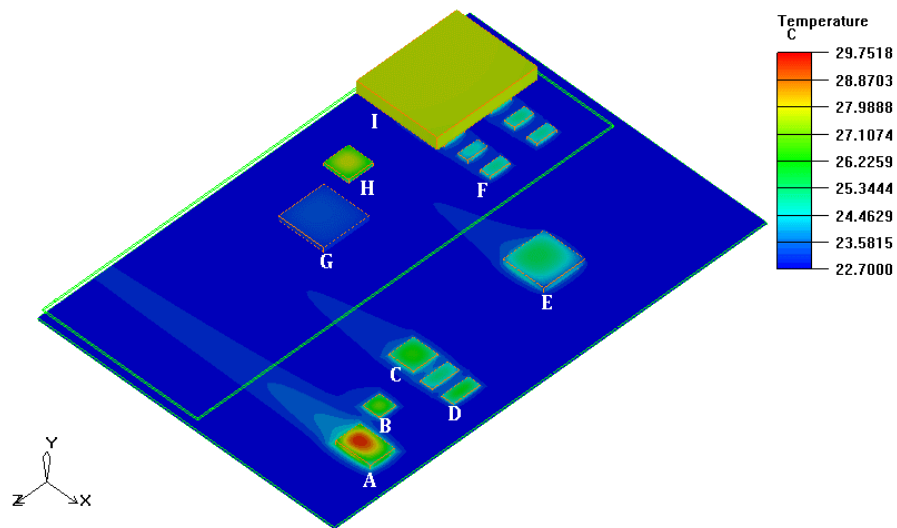


Figure 4 – Temperatures field with the respective components

The figure 4 shows all components of the board. To simplify, only the board components that generates heat were modeled. This entails a small error, but by limits of computer processing power this simplification had to be adopted. The blowers also were not modeled according to the limits of computational processing, but some contours conditions were used.

2.3. Experimental Results

The values of the medium temperature measured for each component are shown in Tab. 1. The dissipated power values were found using the equations described in this article introduction. The result can be observed in Tab. 2.

The dissipated power of the components was calculated for each velocity, where the Q value of Tab. 2 is the sum of the dissipated power by conduction and convection.

Table 1 – Experimental temperature of each component with variable air entrance velocity. $T_{amb} = 22.7^{\circ}C$.

Average Temp [$^{\circ}C$]	Velocity (m/s)				
	0.59	1.06	1.79	2.52	3.05
A	35.5	33.7	31.7	30.7	30.0
B	30.0	28.4	27.3	26.6	26.4
C	31.9	29.5	27.9	27.2	26.7
D	29.0	27.6	26.4	26.0	25.4
E	27.4	26.5	25.7	25.7	25.6
F	27.3	26.2	25.7	25.8	25.4
G	28.0	26.9	26.1	26.3	26.0
H	31.1	29.4	28.3	27.7	27.9
I	30.9	29.0	28.4	27.8	27.4

Table 2 - Experimental values of the thermal dissipation of each component.

Dissipated Power (Q) [W]	Velocity (m/s)				
	0.59	1.06	1.79	2.52	3.05
A	0.23	0.24	0.23	0.24	0.24
B	0.04	0.04	0.04	0.04	0.04
C	0.08	0.06	0.06	0.06	0.06
D	0.05	0.04	0.04	0.05	0.04
E	0.14	0.13	0.13	0.15	0.16
F	0.03	0.02	0.02	0.03	0.03
G	0.04	0.04	0.04	0.05	0.05
H	0.13	0.13	0.12	0.13	0.14
I	3.4	3.07	2.55	2.79	2.67

2.4. Numerical Results

The numerical simulations were performed using the software ANSYS. It was adopted the following parameters:

- Ambient Temperature of 22,5 °C;
- Laminar flow model;
- It was used 1.603.686 elements;
- Unstructured hexagonal mesh-type;
- The radiation was despised;
- Degrees of freedom: Temperature, Velocity, Pressure, Flow, and Heat flow.

The choice of the elements number was performed using a convergence test of the results according to the number of elements. The figure 5 shows this convergence of the entrance and exit air velocity.

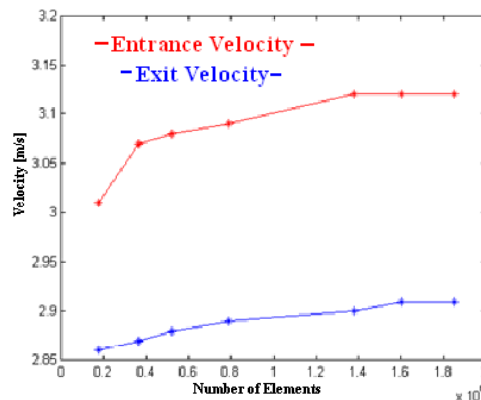


Figure 5 – Mesh convergence

The software was supplied with thermal dissipation of each component to obtain the temperature of each point experimentally measured. Then the simulation was performed. The Table 3 shows the results of the component temperature depending of the flow velocity of the air in the board entrance.

Table 3 – Numerical temperature of each component with the entry variable air velocity. $T_{amb} = 22.7^{\circ}\text{C}$

Average Temperature [°C]	Velocity (m/s)				
	0.61	1.05	1.68	2.34	2.9
A	38.8	33.2	31.1	30.5	29.8
B	28.6	26.8	26.6	26.9	27.1
C	31.8	27.3	26.3	26.7	26.5
D	29.8	26.8	25.9	25.9	25.3
E	30.1	26.6	25.7	25.8	25.6
F	28.4	26.0	25.3	25.9	25.4
G	23.8	23.4	23.3	23.4	23.4
H	30.4	28.6	27.9	27.8	27.9
I	43.0	32.5	29.0	28.5	27.8

2.5. Comparison of the Numerical model with the Theoretical:

The following figures are shown for comparison between the results obtained experimentally and the results calculated from the numerical simulation. The error was calculated based on the Equation 10 and the numerical temperatures were calculated for the experimental velocity to obtain the Tab. 4:

$$err = \left(\frac{T_{Exp} - T_{Num}}{T_{Exp}} \right) \quad (10)$$

Table 4- Numerical temperature for the experimental velocities for each component. Tamb = 22.7°C.

Average Temperature [°C]	Velocity(m/s)				
	0.59	1.06	1.79	2.52	3.05
A	39.1	33.1	31.0	30.2	31.3
B	28.6	26.8	26.6	27.0	28.5
C	32.0	27.3	26.3	26.6	27.9
D	29.9	26.8	25.9	25.7	26.6
E	30.3	26.6	25.7	25.7	26.9
F	28.5	26.0	25.4	25.8	26.7
G	23.8	23.4	23.3	23.4	24.6
H	30.5	28.5	27.9	27.8	29.4
I	43.5	32.4	28.9	28.3	29.2

The table 5 shows the error values for each component in each exit flow velocity.

Table 5 – Error values for each component in each exit flow velocity.

Error	Velocity(m/s)				
	0.59	1.06	1.79	2.52	3.05
A	10.2%	1.8%	2.4%	1.4%	4.5%
B	4.6%	5.6%	2.3%	1.4%	8.0%
C	0.4%	7.5%	5.5%	2.1%	4.5%
D	3.1%	2.9%	1.8%	0.9%	4.8%
E	10.5%	0.6%	0.1%	0.2%	5.5%
F	4.4%	0.7%	0.9%	0.3%	5.3%
G	15.0%	13.0%	10.7%	11.0%	5.6%
H	1.8%	2.8%	1.5%	0.4%	5.1%
I	41.0%	11.6%	2.0%	1.6%	6.5%
Average	10.1%	5.2%	3.0%	2.2%	5.5%

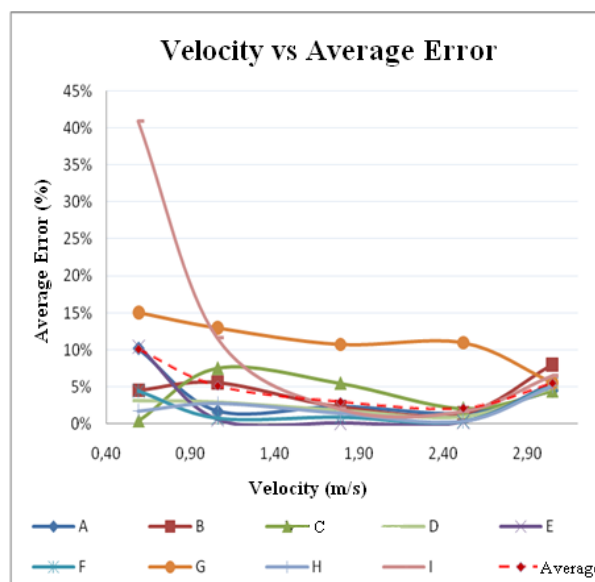


Figure 6 – Velocity versus Average Error

3. DISCUSSION

The thermal dissipation measures found experimentally may be considered reasonable because they were based on the dissipation of this kind of components. It is observed in the literature that when there is such experiment, the thermal dissipation to higher speeds are more relevant because involves less approximation errors. The modeling of heat conduction used was for only one dimension, to simplify the calculations and experimental measurements. But is fact that the dissipation occurs in more than one direction, this way you can get better approximations for higher speeds. This effect can be observed in the Fig. 6, where the errors decrease as the velocity increase, however the velocity can not be increased indefinitely, because the modeling errors start to show up, and this can be observed at the same figure when the velocity go from 2.4 m/s to 3 m/s or more. This error is associated to the adopted flow model.

For the dissipation measured and for the estimate temperature by the numerical model, it was considered laminar flow, which becomes inappropriate as the velocity increase. Thus, a model consistent with the flow type for the dissipated calculation by convection must be used, because turbulent and laminar models differ much in the value of Nu. The Nusselt number, obtained experimentally, is restricted for each flow type even when it is the same flow state.

A suggestion to improve the data estimative would be the use of turbulence models for low range velocities.

4. CONCLUSION

The type of dimensional conduct addressed in modeling can mean considerable errors of measurement when conducting the experiment to lower speeds. To reduce this error and increase the accuracy of the data must be used because higher flow rates, thus reduces the dissipation by conduction at the expense of increasing the convection heat transfer.

5. ACKNOWLEDGEMENTS

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