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Determination of the heat transfer coefficient distribution

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Abstract

In this paper determination of convective heat transfer coefficient distribution method is presented. The method is based on infrared thermography measurements. Investigations were done in the low speed wind tunnel for the air speed range 1-4 m/s. In order to determine convective heat transfer coefficient, PCB (printed circuit board) with the linear heat source has been used (Fig. 1). It has occurred that simple analytical model is sufficient for determination of heat transfer coefficient distribution.

Introduction

Power density dissipated by electronic devices grows. It takes place mainly because for electronic devices integration scale rise. The number of transistors in microprocessors increase more or less according to Moore's Law. The other reason is change of operating frequency change.

Because the electronic devices requirements grow, it results in development of many efficient methods of heat dissipation from electronic devices. Nevertheless convective heat transport is still one of the most important methods for power dissipation in electronic devices. Even if efficient cooling systems (for exapmle phase change cooling systems) are used the heat has to finally be spread into surrounding air. Further progress in of electronics will depend on ability to dissipate the heat from devices. In the literature a lot of approaches to determine the heat transfer coefficient can be found, both for natural and forced convection [1-4].

Usually overall heat transfer coefficient is determined, while electronic devices are complex and heat transfer varies on the surface of the electronic systems. Overall heat transfer coefficient depends on many factors like air velocity, density, shape/size, surface emissivity, thermal conductivity of the materials taking part in heat exchange etc.. The greater the coefficient is the better heat is taken off from the cooled device. Heat transfer coefficient needs to be determined not only in electronic systems but also in many other fields like building industry, flow engineering. Also a lot of industrial processes are based on heat exchange. It makes that determination of heat transfer coefficient is crucial for example in power production, air conditioning systems, chemical processing. Heat transfer is quite often very complex phenomenon. There are three ways to transfer heat: convection, conduction and radiation. Usually all of them can occur at the same time and place. This makes that characterisation of heat exchange using heat transfer coefficient is not always easy. Nevertheless in many applications it is reasonable to use the overall heat transfer coefficient. It can be determined for example with simple experimental methods like LMTD (Logarithmic Mean Temperature Difference) or theoretically for example using NTU method (The Number of Transfer Units) [6]. This methods are often used for heat exchangers design. In electronic applications more sophisticated methods can be used. From the Frequency Analysis of the Thermal Transient Response heat transfer coefficient can be determined [8].

Measuring setup

In the paper measurements were done in a low speed wind tunnel. The tunnel was designed and build especially for electronic devices cooling investigations. The contraction nozzle ensures laminar flow in the test section. The air speed range in the tunnel is 0-5 m/s [1].

The wind tunnel was equipped with small germanium window. It enables to perform temperature measurements using infrared Cameras.

Germanium has good transmissivity in MWIR (Mid-Wavelength Infrared) as well as in LWIR (Long-Wavelength Infrared) which are typical for the infrared measurements. Infrared QWIP (Quantum Well Infrared Photodetector) camera Cedip Titanium was used to measure the temperature distribution on the measured object. For the measurements microbolometer infrared camera could also be used. The negative drift effect could be eliminated using shutterless method of thermal drift compensation [8].

The camera calibration according to germanium transitivity was performed. The measured substrate was painted using high emissivity e = 0.95 flatting in order to provide possibly uniform emissivity for infrared measurements.

Both faces of the PCB (printed circuit board) were cooled by the air stream. The substrate was placed in the wind tunnel test section. The tunnel is equipped with three-phase motor with frequency driver. It enables to change the air speed. The measurements were done for the air speed range from 1 to 4 m/s. Using thermo-anemometer Airflow TA-35 the velocity was measured.

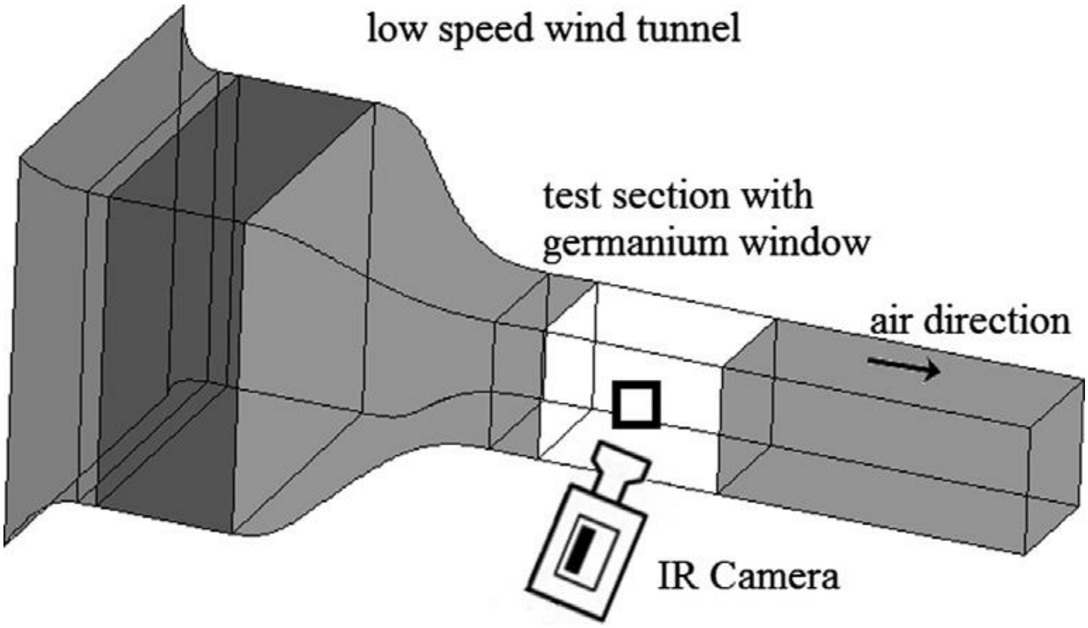

Fig. 1. *Measuring setup*

Heat source is a copper track placed along the PCB leading edge. Temperature distribution of th PCB is on the Fig.3., while Fig. 4. presents temperature distribution along the white line (Fig. 3 and 4).

The printed circuit board is a rectangle 60x150 mm. Its thickness is equal to 1 mm. Witdh of the copper track used as the heat source equals to 0.4 mm. Thickness of the copper layer equals to 0.036 mm.

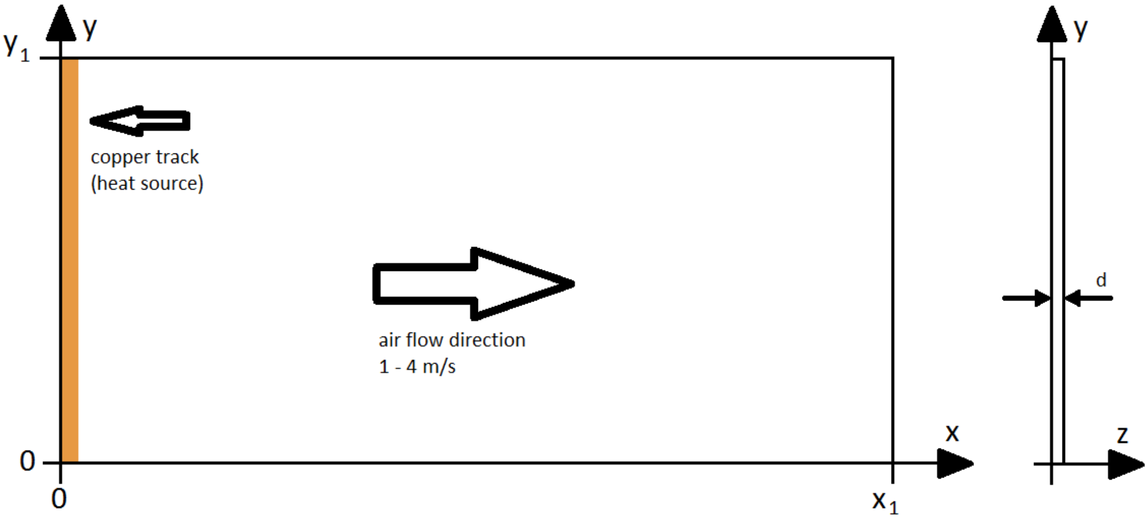

Fig. 2. *Printed Circuit Board with heat source (x1 = 150 mm, y1 = 60 mm, d = 1 mm)*

The Reynolds number is defined as:

$$R_e = \frac{v \cdot l}{\eta} \quad (1)$$

where:

v – velocity of the fluid (air)

η – cinematic viscosity

l – characteristic length

If we calculate the Reynolds number taking into account air parameters

$$\eta = 15 \cdot 10^{-6} \frac{\mathrm{m}^2}{\mathrm{s}}, \tag{2}$$

$$\mathrm{l} = 0.15\mathrm{m} \tag{3}$$

and the largest air velocity used in the measurements ($4\frac{\mathrm{m}}{\mathrm{s}^2}$) the Reynolds nuber equals to 40 thous.. which is still far from the turbulent regime for the flat plate.

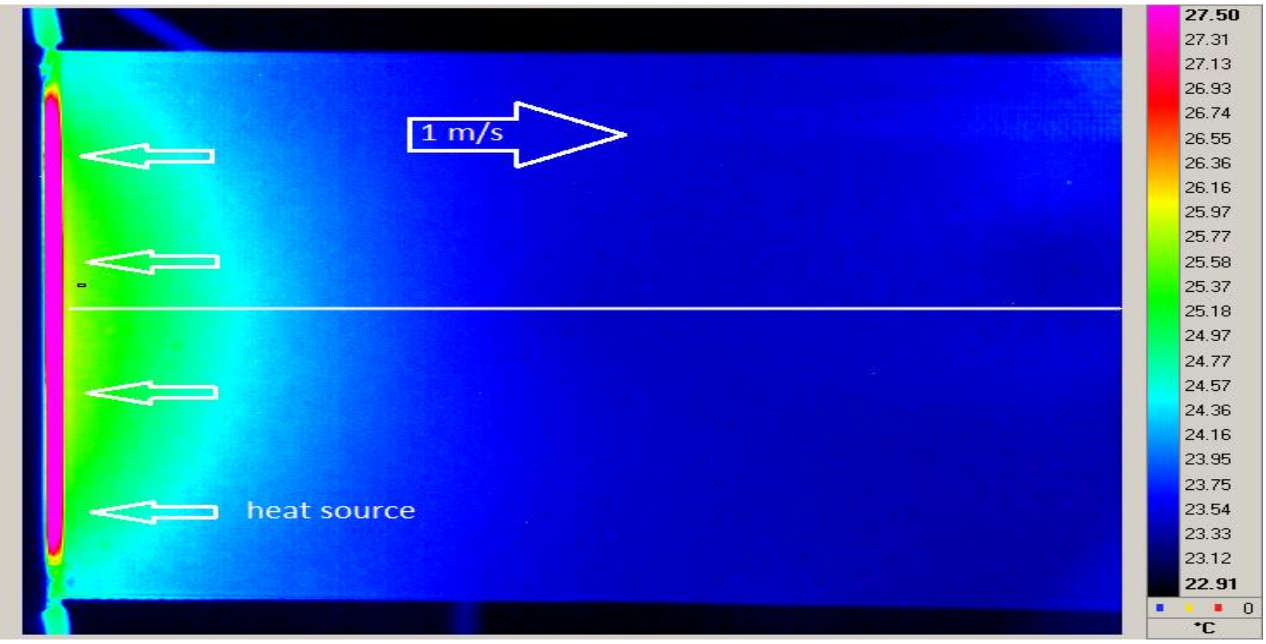

Fig. 3. *Heat source, temperature distribution*

In the first approach measurements were done with microbolometer infrared camera The temperature distribution was very noisy. In the second approach Measurements were done using Cedip Titanium IR camera which has a QWIP detector.

Nevertheless the temperature distribution was still quite noisy. This made that heat transfer coefficient distribution determination using original plot was not acceptable. Because of that the temperature distribution was approximated with the logarithmic function. Approximation as well as the convective heat transfer coefficient determination were done for the part of the temperature distribution excluding heat source. The result of heat transfer coefficient calculations is presented in the plot below (Fig. 3). It is well visible that approximated curve fits very well to the measured temperature distribution.

In the paper we decided to determine distribution of the heat transfer coefficient in one dimension. For that purpose the temperature distribution along the line in the centre of the PCB was chosen (Fig. 3,4).

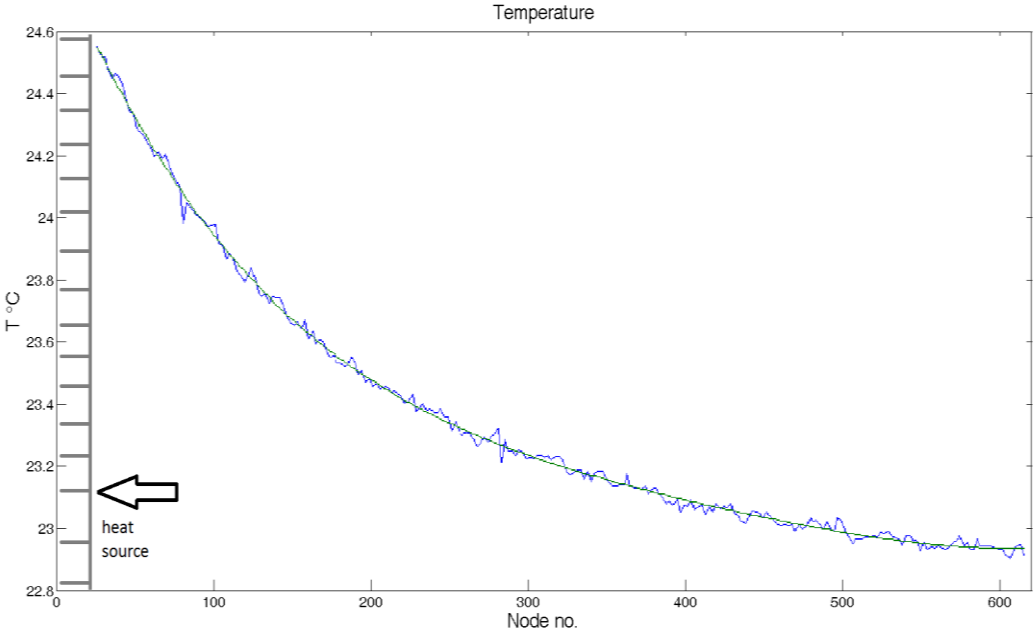

Fig. 4. *Heat source, temperature distribution along white line (fig.1.)*

The convective heat transfer coefficient determination bases on the simple thermal model (eq. 4):

$$\mathrm{kd}\nabla^2 T - 2\mathrm{hT} = 0 \qquad (4)$$

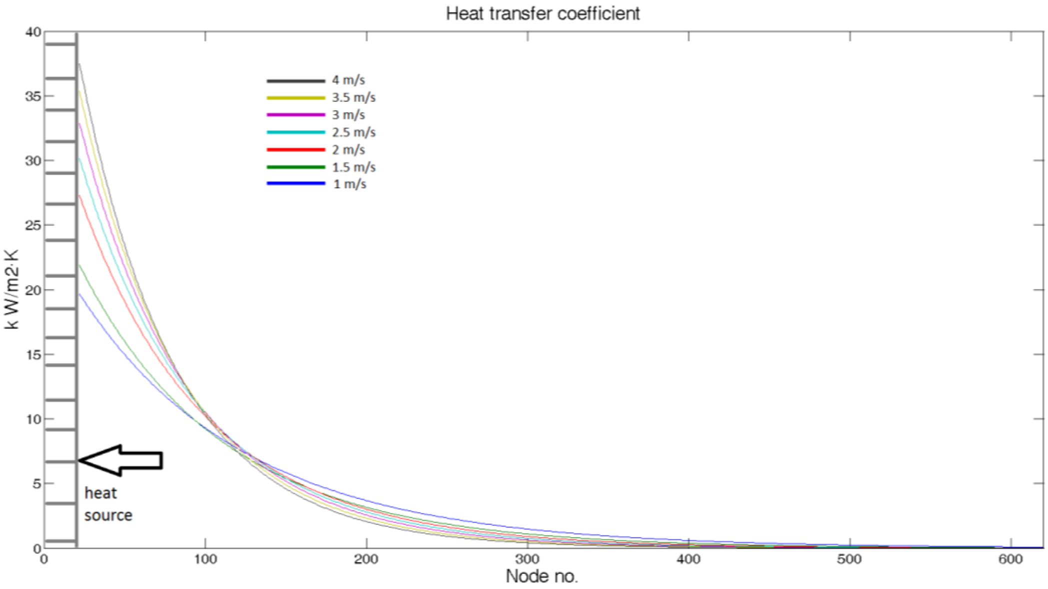

Fig. 5. *Convective heat transfer distribution*

where:

k – PCB thermal conductivity $\frac{W}{m \cdot K}$

d – PCB thickness m

T – temperature °C

h – convective heat transfer coefficient $\frac{W}{m^2 \cdot K}$

Apart from the convective heat transfer coefficient it is also possible to estimate radiation heat transfer coefficient. The investigated substrate was painted with high emissivity flatting what has increased the heat transfer coefficient which can be determined using Stefan-Boltzman equation:

$$q = \varepsilon \cdot \sigma \cdot (T_o^4 - T_a^4) \qquad (5)$$

Where:
q – heat transfer
T_o *– object temperature*
T_a *– ambient temperature*
ε *– emissivity*
σ – The Stefan-Boltzmann Constant 5.6703 10^{-8} $\frac{W}{m^2 \cdot K^4}$

If we transform equation we can obtain:

$$q = \varepsilon \cdot \sigma \cdot (T_o^2 - T_a^2) \cdot (T_o^2 + T_a^2) \qquad (6)$$

and after further transformation:

$$q = \varepsilon \cdot \sigma \cdot (T_o - T_a) \cdot (T_o + T_a) \cdot (T_o^2 + T_a^2) \qquad (7)$$

If we use the formula:

$$q = h_r \cdot (T_o - T_a) \qquad (8)$$

Than we can using equation (7) and (8) obtain formula for the radiation heat transfer coefficient:

$$h_r = \varepsilon \cdot \sigma \cdot (T_o + T_a) \cdot (T_o^2 + T_a^2) \qquad (9)$$

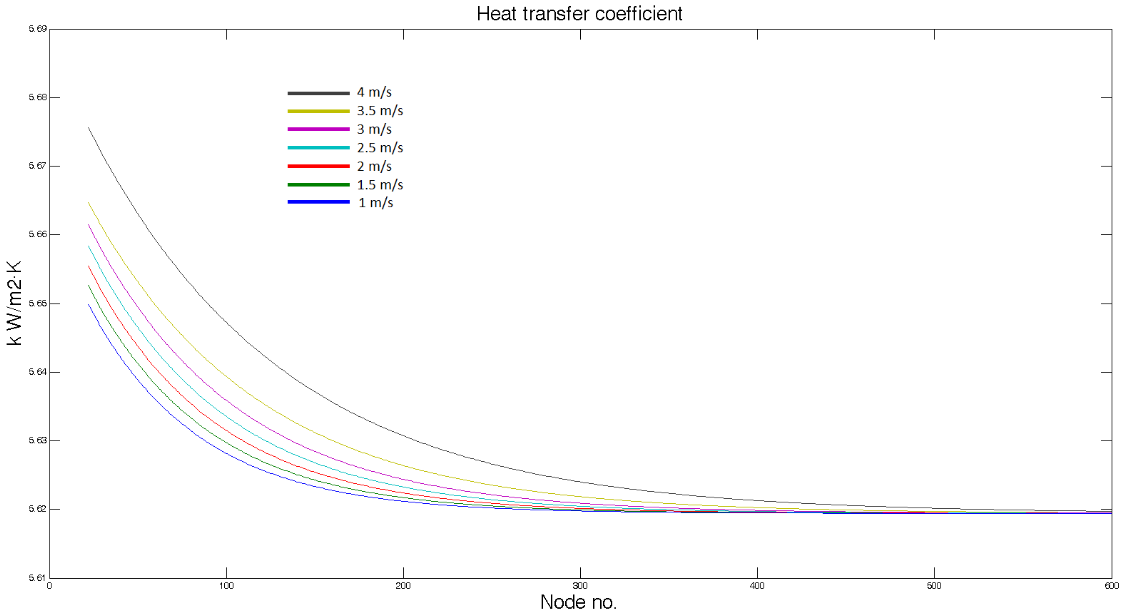

Fig. 6. *Radiation heat transfer distribution*

It can be observed that in the investigated case radiation heat transfer coefficient is a few times smaller than convection one (fig. 5 and 6).

Conclusions

In the paper infrared measurements of the simple linear heat source placed in the printed circuit board were conducted. Using temperature distribution and simple analytical model it was possible to determine the convectional and radiation heat transfer coefficient distribution in one dimension. Determination of the heat transfer coefficient can be considered as inverse heat conduction problem. Thanks to infrared temperature measurements this boundary condition can be determined.

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