CHAPTER 3

PARAMETERS AFFECTING HEAT CONVECTION OF CHIP MODULES

3.1. Introduction

Most applications of forced convection cooling to electronic circuits involves blowing air over the components on the circuit boards. A lot of studies have been carried out to develop the techniques to predict the heat transfer coefficient which is rather difficult to get the accurate value because the flow is highly complex such as flow separation, reattachment and recirculation and moreover the surface presented to the airflow is irregular. Most of the experiments used heated elements for measurement of the heat transfer coefficient using conventional heat flux (Wirtz and Mathur, 1994), (Fagri et al, 1996), (Wong and Peck, 2001) and (Meinders and Hanjalic, 2002). The heat transfer coefficient in each element could be estimated when the conduction and the radiation effect in the circuit board are neglected as

$$h = \frac{Q}{(T_s - T_r)} \tag{3.1}$$

T_s is the module temperature and T_r is the reference temperature which might be the inlet air temperature (Wirtz and Mathur, 1994), (Fagri et al, 1996), (Wong and Peck, 2001) and (Meinders and Hanjalic, 2002) or the mean fluid temperature (Garimella and Eibeck, 1991) , (Azar, 1997a).

The heat transfer coefficient depends on the flow rate of the coolant, the module geometry and the location in the array (Garimella and Eibeck, 1992). The heat transfer coefficient in the entry region and in the fully developed range are also reviewed by (Faghri et al, 1996) and (Wirtz, 1996), respectively.

This chapter also finds out the effects of some parameters on the convective heat transfer of electronic chips on a printed circuit board, PCB when all modules are heated. The parameters considered are air velocity, air channel height and chip spacing. Visualization of the module temperatures is carried out by an infrared scanner. The heat transfer coefficient could be estimated from the heat release by each module and the temperature difference of the module and the cooling air.

3.2 Data Reduction

Over 80% of heat generated from electronic chip is belong to the air convective cooling. As the heat is released, the temperature of the air after passing the module could be increased. The rate of heat could be calculated from

$$Q = \dot{m} C_p \Delta T \qquad (3.2)$$

where

Q = heat rate from electronic chip (W)

$\dot{m}$ = air flow rate (kg/s)

C_p = specific heat of air (J/kg^{o}K)

ΔT = temperature difference of downstream and upstream air (^{o}C)

The heat rate could also be calculated by

$$Q = h_s A_s (T_s - T_\infty) \qquad (3.3)$$

where

h_s = convective heat transfer coefficient (W/m^{2o}K)

A_s = heat transfer area of chip(m^2)

T_s = average surface temperature(^{o}C).

T_∞ = average bulk air temperature over the module(^{o}C).

The convective heat transfer coefficient at each module could be estimated from eqns. (3.1) and (3.2) when the values of the heat rate, the air velocity and the surface temperature and the air temperature are recorded.

3.3. Experimental Setup

Experimental study is carried out at steady state condition in a small wind tunnel. The chips used are artificial modules of which the dimensions of each are 1.8 cm × 5.8 cm × 0.6 cm. An artificial module is shown in Fig. 3.1 and there is a thermo foil heater generating heat inside. The chip temperatures could be detected by an infrared camera of which the data have been calibrated with those from thermocouples.

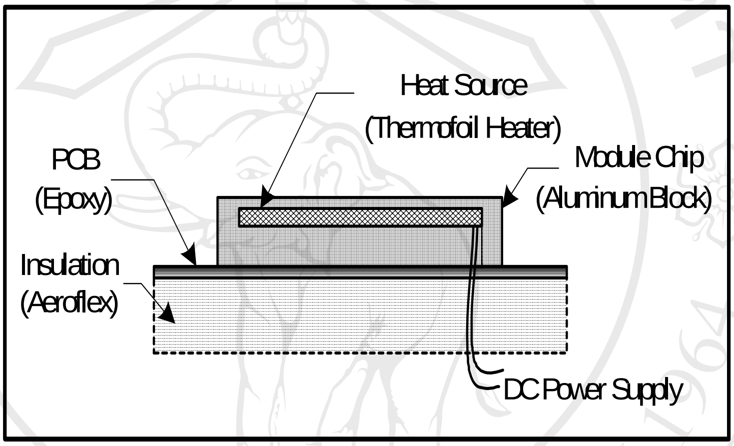


Figure 3.1 Structure of an artificial chip module.

Figure 3.2 The infrared scanner.

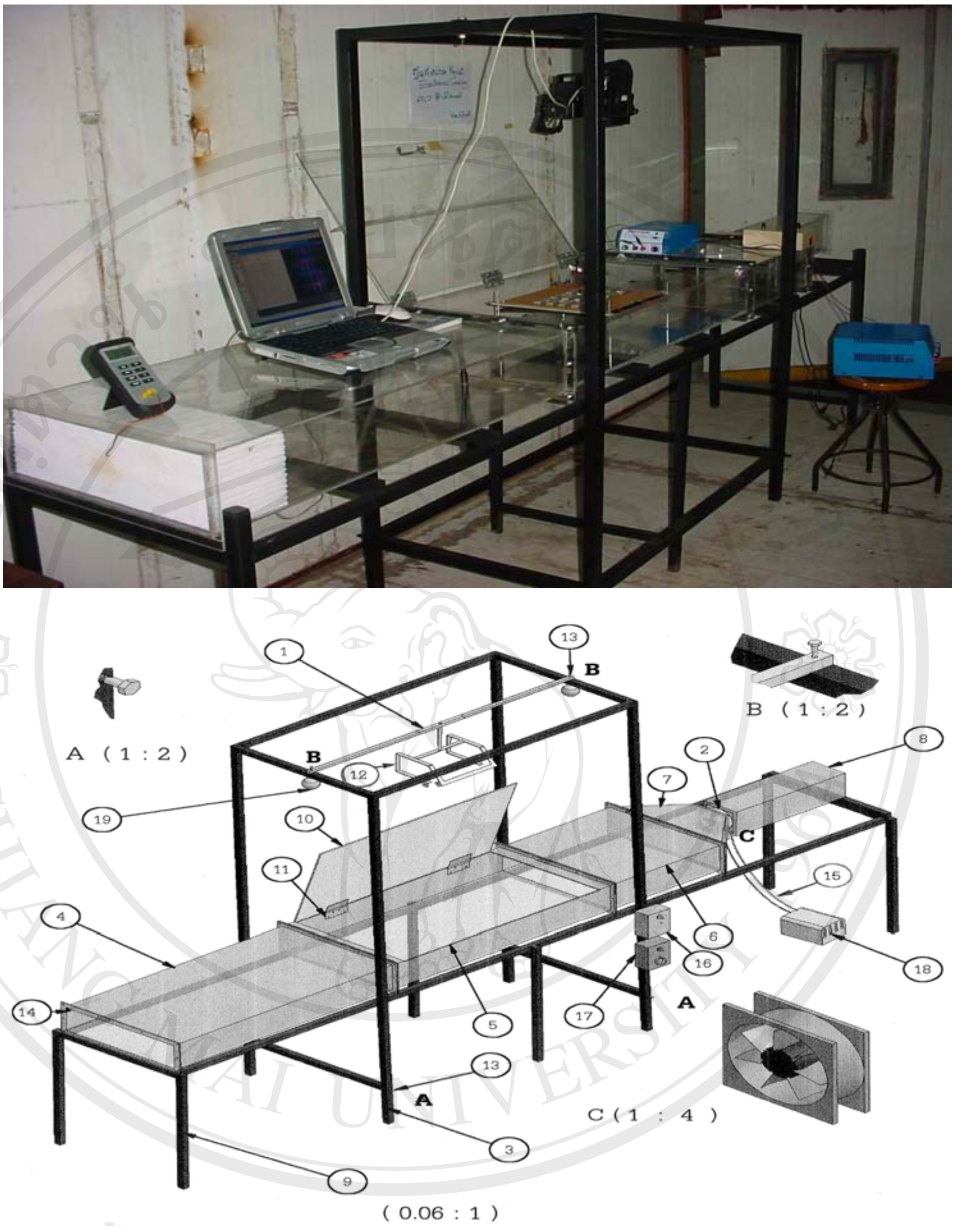


Figure 3.3. The small wind tunnel.

Fig. 3.3 shows the small wind tunnel used in the experiment. The airflow rate could be controlled and the height of air channel could be adjusted. The upstream section (4) has a flow straightener (14) to keep a uniform flow of air. The test section (5) contains the tested PCB with artificial chips. A set of thermocouples are installed to measure the air temperature over the chips. An infrared camera as shown in Fig. 3.2 is used to measure the temperatures of the chip and the PCB. The emissivity of the chip material and that of the PCB have been calibrated and compared with the read temperatures from thermocouples. The temperature levels read from the camera are given by color tones and values. At down stream section, there is a suction fan of which the air flow rate could be adjusted.

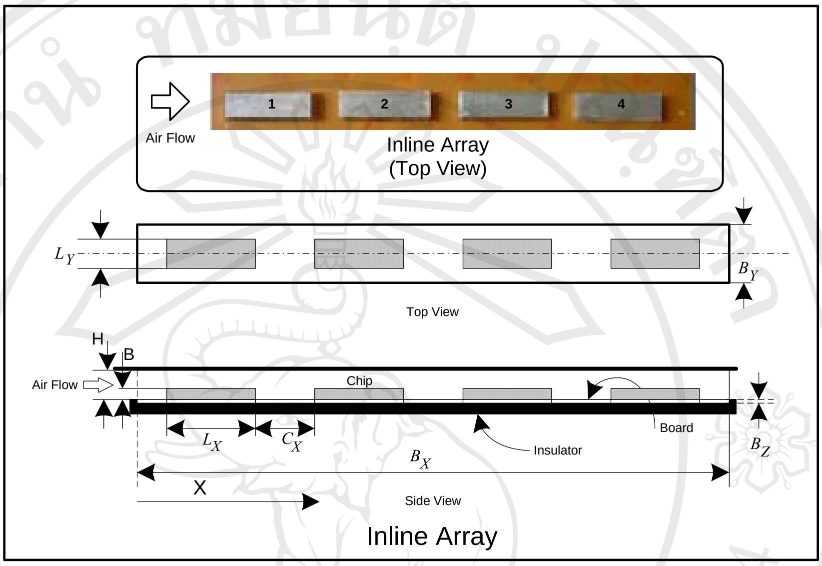


Figure 3.4 The single row modules in the test section.

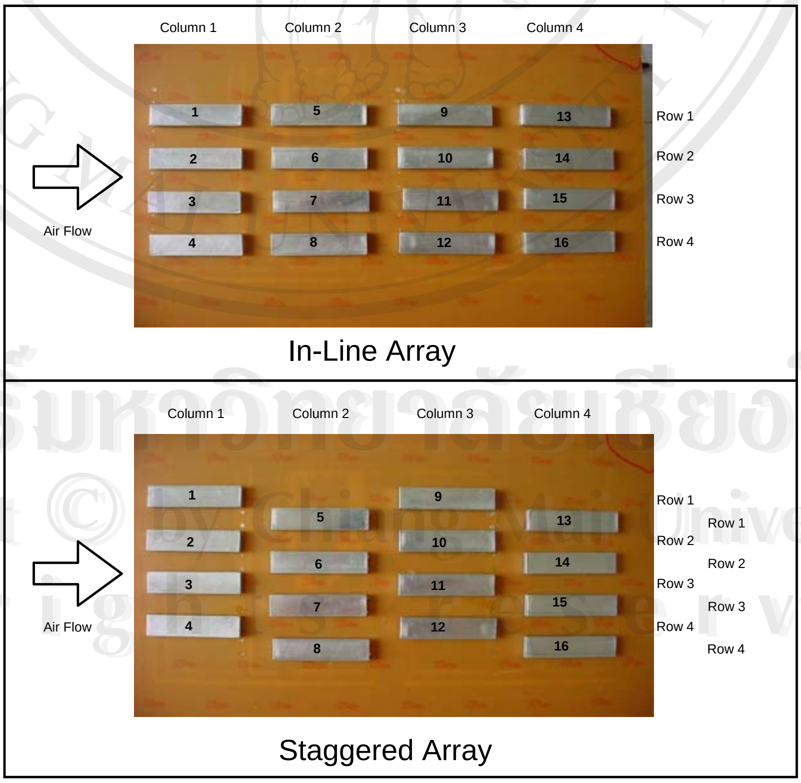


Figure 3.5 In-line and stagger arrays.

The experiments have been carried out into 2 parts. The first one has taken a PCB of 3.6 cm × 36 cm × 0.3cm containing one row of 4 in-line artificial modules as shown in Fig. 3.4. The second part has used the PCB having a set of modules in in-line and staggered arrays as shown in Fig. 3.5. The PCB is assumed to be isothermal its back is well insulated thus the conduction heat in the board is not considered. Since the module is copper block coated with aluminum foil therefore the enabled radiation could be neglected (Rodgers et al., 2003).

3.4 Experimental Results

3.4.1 Single Row Modules

In the experiment, the entering air temperature is keep constant to be 25 ^{0}C. The air speed is controlled to be V_o= 2-4m/s. The heat generated from each chip is 2W. Figure 3.6 shows an example of the temperature reading from the infrared camera.

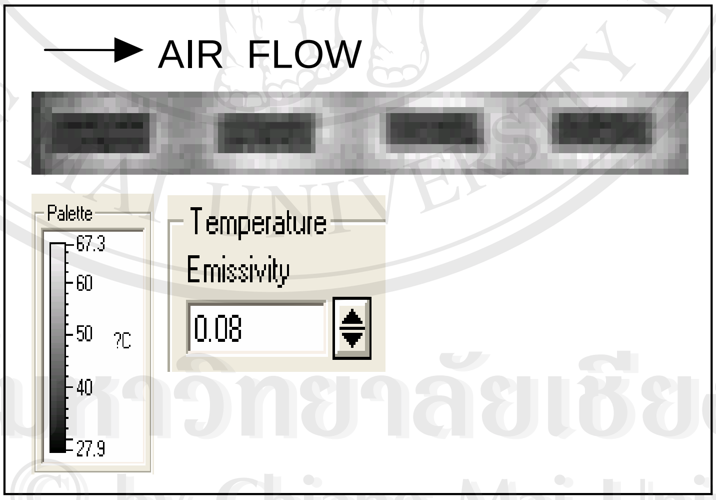
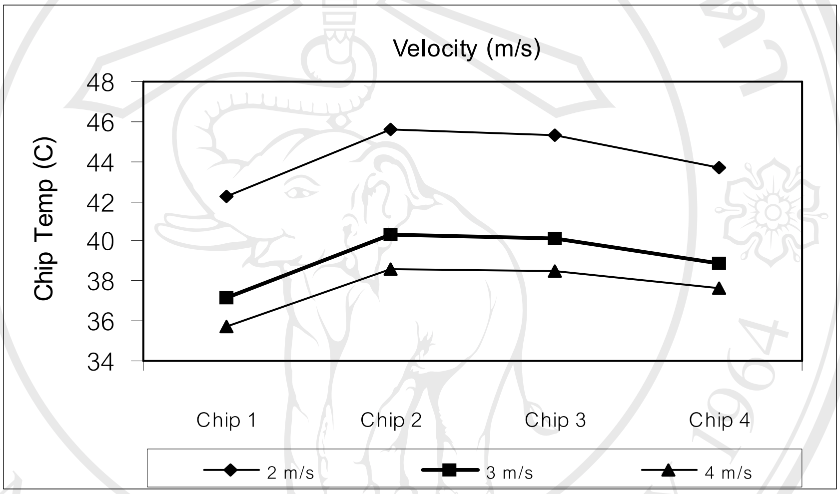


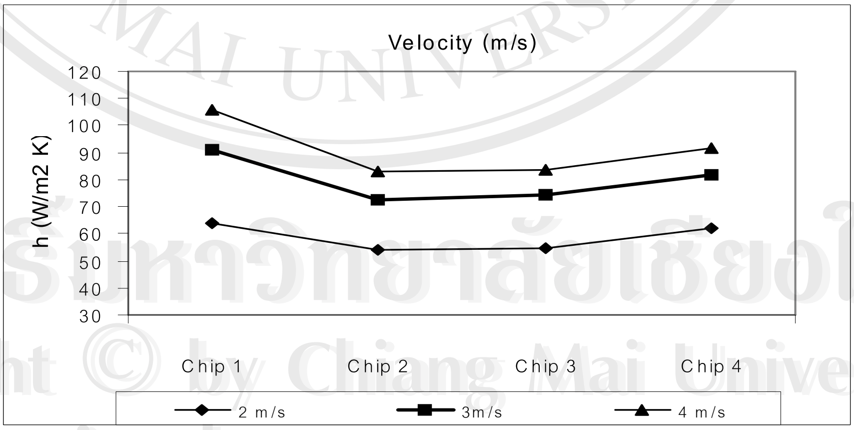
Figure 3.6 Example of the temperature reading from the infrared scanner.

3.4.1.1 Effect of Air Velocity

Figure 3.7a shows the effect of air velocity on the module temperatures. The temperature of the first chip seems to be the lowest since it gets close to the inlet cooling air. The second and the third chips get highest temperatures because the mean temperature of the coolant is raised by the heat release of the upstream module and there is a recirculation perpendicular to flow of the secondary air flow field exists in the inter-block gaps (Wong and Peck, 2001). The last chip temperature is slightly less than those of the second and the third element because the air could move more freely. It could be seen that the temperature decreases with the increase of coolant velocity. However, it seems to have a limit of the augmentation. When the velocity is changed from 3 to 4 m/s, the module temperatures do not drop drastically.



(a)



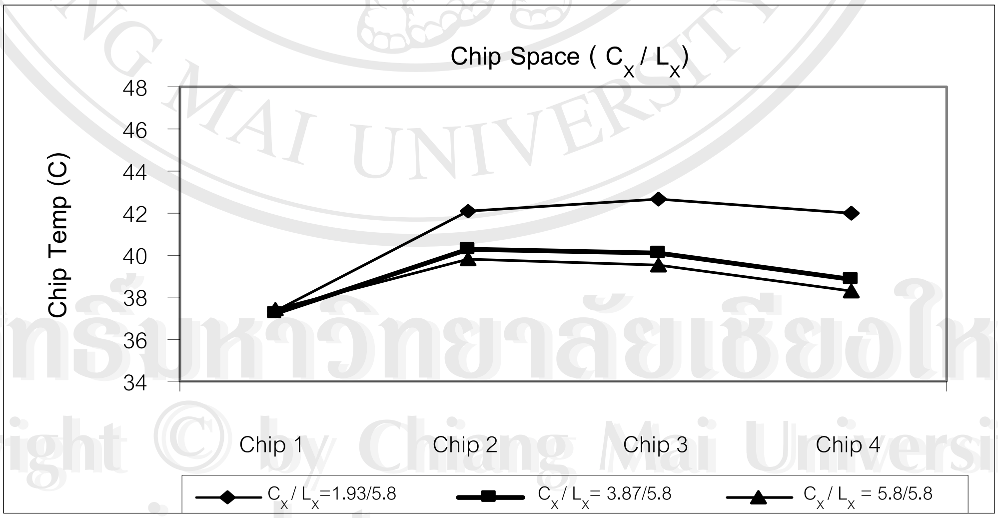
(b)

Figure 3.7 The effect of air velocity on the module temperature and the heat transfer coefficient H/B = 3/0.6 and C_X/L_x = 3.87/5.8.

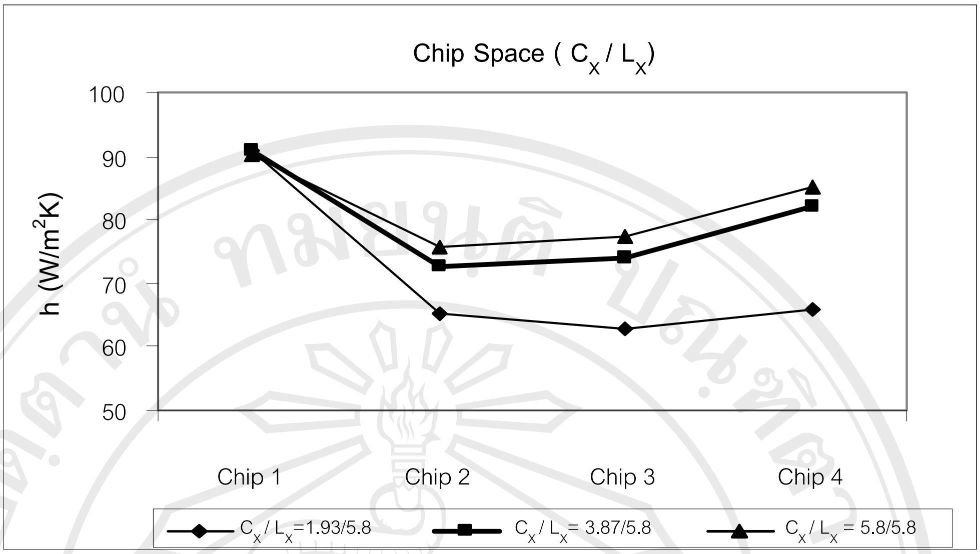
Figure 3.7 b gives the results of the heat transfer coefficients at the modules. The result at the first module is highest and the values at the second and the third elements are lowest due to the poor heat transfer in this region. The last module gets slightly higher heat transfer coefficient compared with the second and the third modules.

3.4.1.2 Effect of Module Spacing

When the module spacing is less, the density of the chips in an area increases thus higher heat generation of that area and the consecutive chips get high temperature air thus higher module temperatures are obtained. Figure 3.8a shows the results of the high module temperatures with the reduction of module spacing. When the spacing is smaller, the recirculation of the flow in the gap between the modules is occurred easily then the heat transfer coefficient is less. When the spacing is bigger such as C_X = 3.87 and 5.8 cm as shown in Figure 3.8b, the recirculation slightly affects the heat transfer therefore the heat transfer coefficients in both conditions are slightly different.



(a)

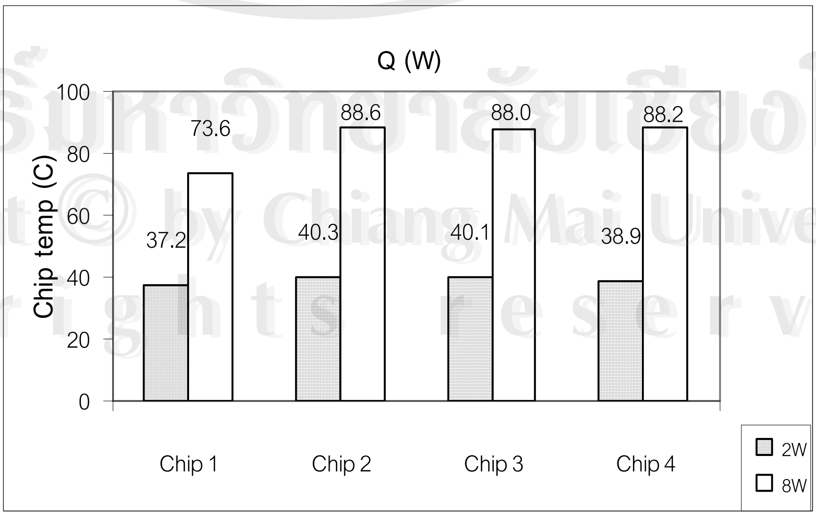


(b)

Figure 3.8 Effect of the module spacing on the module temperatures and heat transfer coefficients. H/B = 3/0.6, air speed = 3m/s.

3.4.1.3 Effect of Heat Generation

Figures 3.9a and 3.9b shows the results of the module temperatures and the module heat transfer coefficients when the heat generation of each chip is changed from 2 W to 8 W. For higher heat generation, the module temperatures are then increased significantly while the heat transfer coefficients slightly change.



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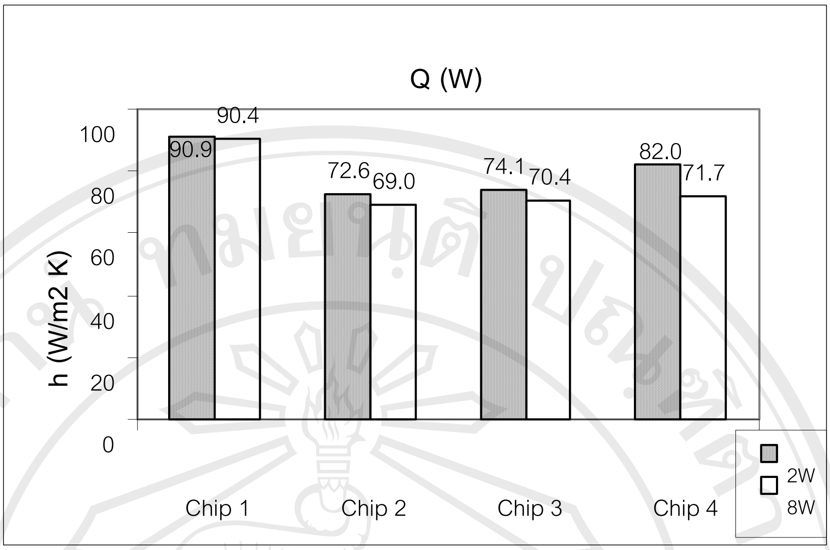
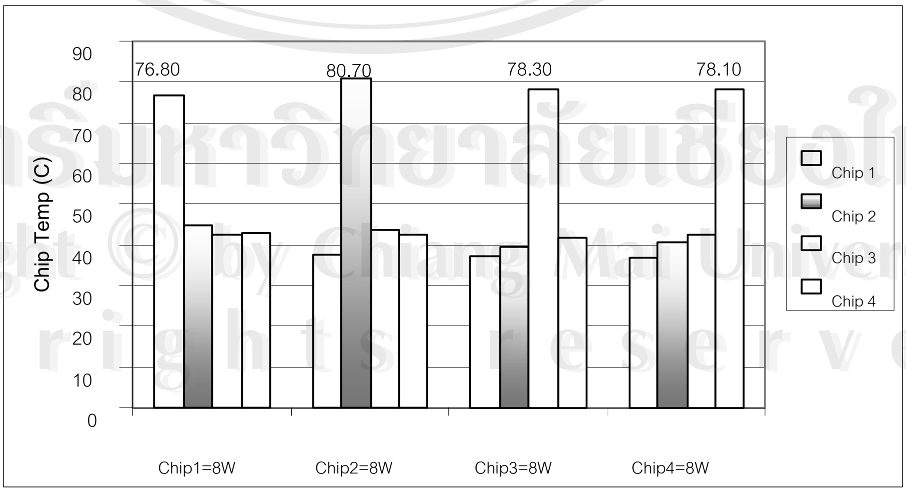


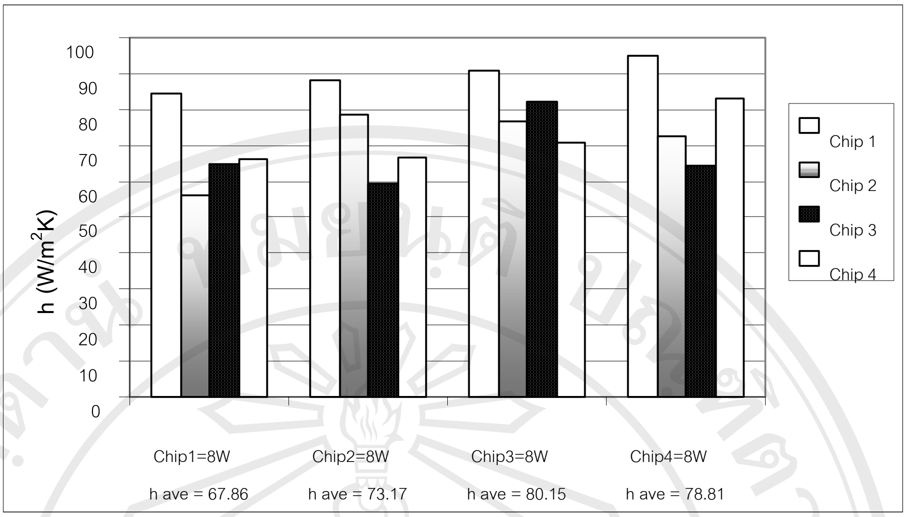
(b)

Figure 3.9. Effect of heat generation on the module temperatures and module heat transfer coefficients.

When the heat rate of each module is different, allocation of the modules are quite important to control the hotspot on the PCB. Figure 3.10 shows an example when one chip has a highest heat flux (8W) compared to the other chips(2W). It could be found that the module having highest heat flux should be positioned closest to the inlet air thus the hot spot temperature is lowest. Figure 3.10 also shows the results on the heat transfer coefficients.



(a)

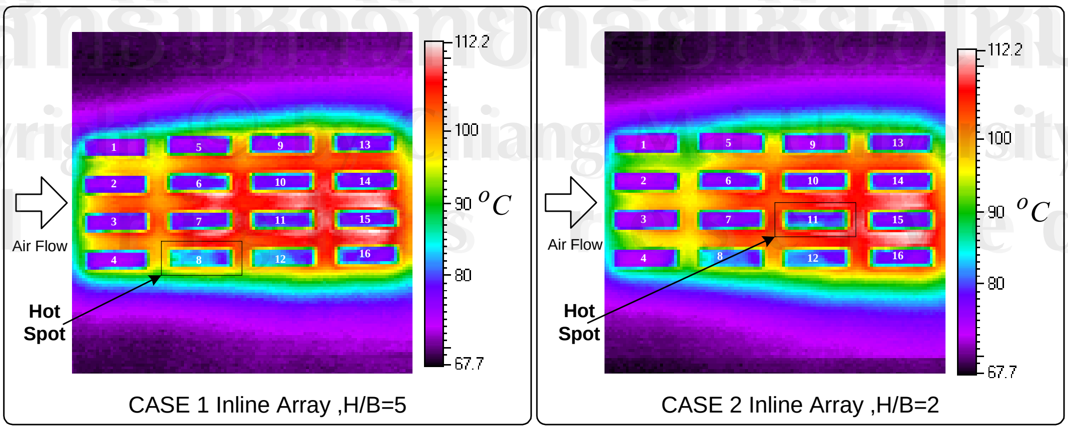


(b)

Figure 3.10. Effect of the position of the highest heat generation module on the module temperatures and the heat transfer coefficients.

3.4.2 Module Arrays

Convective air-cooling for in-line and staggered arrays of artificial modules as shown in Figure 3.5 has been experimentally studied. 16 artificial chips each has dimensions of 18 mm.×58mm.×68mm similar to a 64 pins electronic chip. The wind speed in this study is controlled to be constant at 1 m/s. The ratios of the height of the channel to the height of the module, H/B, are set at 2 and 5. Each chip generates heat 6 W. The ambient air temperature is constant at 25 ^{0}C.



(a) (b)

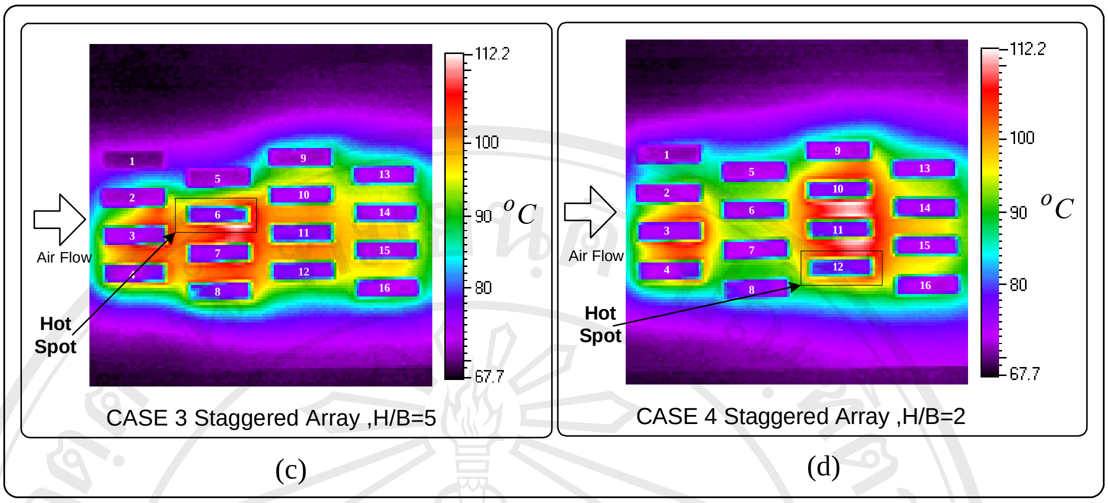


Figure 3.11 Photographs of the module temperatures from infrared scanner.

Figure 3.11 shows photographs of the module temperatures. The color tones show the temperature fields of the modules during cooling. It could be seen that the temperatures of the first column in both in-line and staggered arrangements are nearly uniform and are nearly the lowest because of high heat transfer. At the second row and the rest, the color tones indicate higher temperatures because the air temperatures are higher, which result in lower cooling. For staggered arrangement, the vortex in front of the first module will interacts to the vortex infront of the next off-axis module which causes strong turbulence which subsequently results in higher heat transfer (Meinders and Hanjaloc, 2002). Figure 3.12 shows the results of better heat transfer in terms of temperatures compared with those of the in-line array.

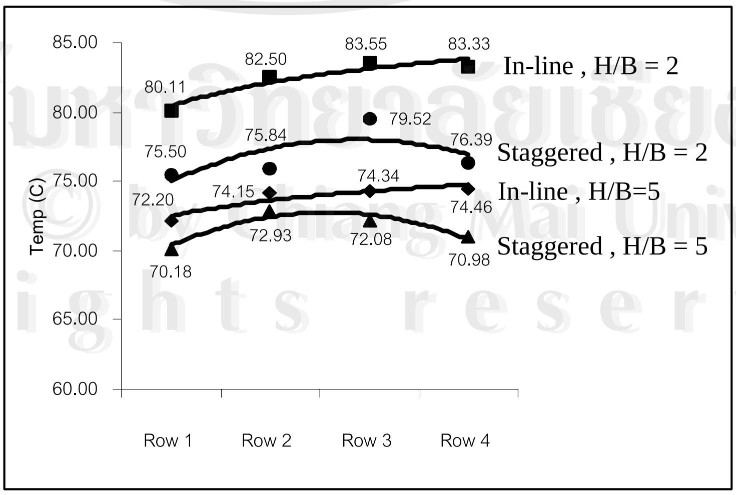


Figure 3.12 Average temperatures in each column of the modules.

3.5 CONCLUSION

This work shows comparative experimental studies of the parameters affecting on convective heat transfer coefficients and temperatures of single row in-line modules on electronic printed circuit board (PCB). The parameters considered are air velocity, chip spacing and heat generation. The experiments are carried out in a small wind tunnel. The experimental modules are made of aluminum with electrical heater embedded inside. The module temperatures are monitored directly with an infrared scanner. For the chips having different heat dissipations, the highest heat flux module should be allocated closest to the entering air to reduce the hot spot on the PCB.

There is a recirculation between the module blocks which reduces the heat transfer to the next module except the last one. Higher the air velocity and increase of the module spacing result in better heat transfer. When the modules give different heat generations, the highest one should be positioned closest to the entering air to reduce the hot spot temperature.

For the arrays of the modules, the staggered arrangement shows better heat transfer than the in-line one. H/B ratio also affects the module temperatures. Higher the ratio results in better cooling.