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Thermal Performance Analysis of Electronic Components on Different Substrate Materials

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Abstract

This study numerically analyzed different substrate board materials, including FR4, silicon, and copper, for electronic component cooling. Ten diverse components were mounted on these boards and subjected to uneven heat distribution. Both natural and forced air cooling were tested at various speeds. Copper cladding significantly lowered component temperatures by 34-54 degrees Celsius compared to FR4 or silicon at 7 m/s. Moreover, copper allowed for lower fan speeds (5 m/s) while keeping component temperatures below 100 degrees Celsius, reducing energy consumption. These results offer valuable guidance for thermal engineers in selecting optimal substrate boards for efficient electronic cooling.

Keywords: *IC Chips, Optimal Arrangement, SMPS Board, Thermal Management*

1.0 Introduction

Many electronic devices fail due to excessive temperature rise during operation. This study focuses on evaluating the effectiveness of heat sinks in dissipating heat from these devices, which is crucial for maintaining optimal operating temperatures. By exploring heat sink-driven cooling strategies, we aim to improve the overall thermal management of integrated circuits. This involves investigating the cooling efficiency and potential temperature reduction achieved through the use of heat sinks. Modern electronic devices face challenges in efficiently dissipating heat due to factors such as increased power density, degrading Thermal Interface Materials (TIMs), and the demands of high-performance computing. Advancements like graphene-enhanced

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TIMs and liquid cooling offer potential solutions to these challenges. Additionally, innovative cooling technologies such as vapour chambers, flexible heat pipes, and Phase Change Materials (PCMs) are being integrated into consumer electronics, batteries, and wearables to manage heat effectively. Furthermore, eco-friendly cooling technologies and AI-driven thermal management systems are emerging to enhance efficiency and performance.

Anant *et al.*[1,2] conducted numerical simulations to assess the effectiveness of different substrate boards in regulating the temperature of Integrated Circuit (IC) chips. They selected the most suitable substrate material and phase change material (PCM) for optimal thermal management. Rahman and Raghavan[3] studied the use of natural and forced convection to cool four heat sources. Dogan *et al.*[4] explored the characteristics of rectangular heat sources and found that optimal heat dissipation can be achieved by placing the maximum heat at the entrance or exit. Yadav and Kant[5] conducted experiments on vertically mounted PCB heat sources and proposed a Nusselt number correlation for heat transfer. Alves and Altemani[6] analyzed laminar forced convection and developed a predictive superposition principle. Yusoff *et al.*[7] used numerical simulations to study the thermal performance of a PLCC mounted on a PCB and found that higher air velocities improve heat dissipation. Narasimham[8] examined heat transfer from IC chips and highlighted the limitations of traditional cooling methods. They suggested alternatives like liquid immersion and heat sinks for enhanced heat dissipation. Pirasaci and Sivrioglu[9] empirically observed improved heat dissipation at lower Reynolds numbers. He *et al.*[10] investigated heat transfer from flush-mounted heat sources on a horizontal channel and found that high emissivity is beneficial. Ajmera and Mathur[11] studied three flush-mounted heat sources and considered both natural and mixed convection to determine the optimal placement for cooling. Bejan *et al.*[12] explored design and thermal optimization techniques for various systems using thermodynamics and heat transfer principles. Anant *et al.*[13-19] focused on numerical thermal control of IC chips. Shital *et al.*[20-23] provided critical reviews on heat transfer enhancement in heat exchangers. Khot Rahul and colleagues[24-28] studied the impact of laser welding parameters on the strength of TRIP steel.

Most research has focused on cooling discrete heat sources using different heat transfer methods (natural, forced, or mixed). Many studies have used similar heat source geometries. Additionally, numerous studies have employed flush or protruding-mounted heat sources with 1D and 2D geometries, suggesting the potential for exploring 3D protruding-mounted heat sources. Numerical analysis and optimization techniques have been widely used, and various hybrid cooling methods have been employed to cool heat sources. This study aims to identify the optimal arrangement of IC chips through numerical simulations, effectively reduce temperature

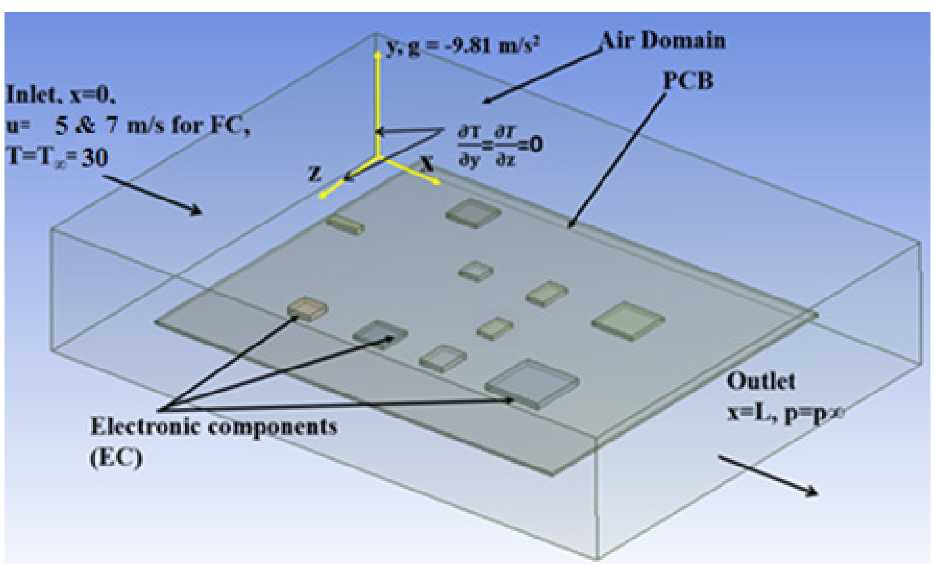

Figure 1. Domain used.

levels, and determine the most suitable substrate board material for specific applications and temperatures. The study will analyze 10 symmetric and non-symmetric electronic components.

2.0 Computational Approach

This study focuses on analyzing the thermal and fluid dynamics of IC chips located at different positions on an SMPS board. ANSYS Workbench Design Modeler software was used to predict the temperature and flow patterns of the IC chips under forced convection cooling with water as the coolant circulating in the cold plate. ANSYS Workbench employed the FLUENT solver to solve the governing equations of thermo-fluid flow using a steady-state laminar multiphase model. The entire numerical model is shown in Figure 1. There are a total of 170,554 possible arrangements for placing ten symmetric and asymmetric rectangular heat sources on a printed circuit board. The actual substrate board, as shown in Figure 1, is made of copper cladding. Each arrangement is assigned a λ value, ranging from 0.28 to 1.9 in this study. A MATLAB code was used to generate these various arrangements and their corresponding λ values. For the current numerical analysis, 30 different positions were randomly selected within the 0.28 to 1.9 range.

3.0 Boundary Conditions

The boundary conditions are mentioned in Table 1.

Table 1. Boundary condition

Position	NC	FC (5 m/s)	FC (7 m/s)
In , x=0	U=0.02 m/s T=T∞ =30 °C	U=5m/s T=T∞ =30 °C	U=7 m/s T=T∞ =30 °C
Out, x=L (Length)	Adiabatic Lateral Boundary conditions		

4.0 Grid Refinement Analysis

This study used quadrilateral elements and focused on high-quality hex-dominant meshes with skewness

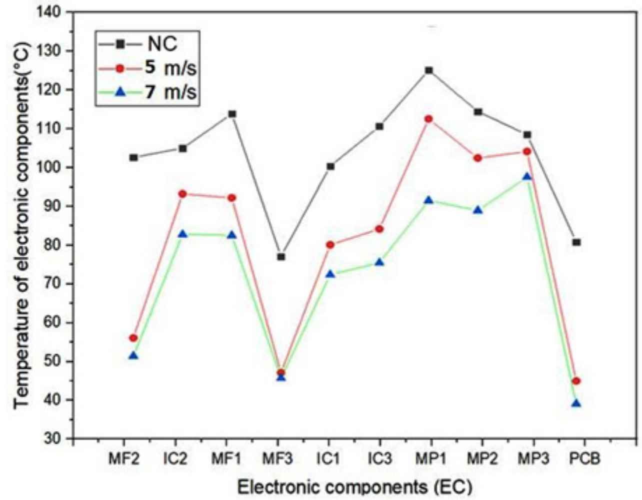

Figure 2. Temperature under different velocities.

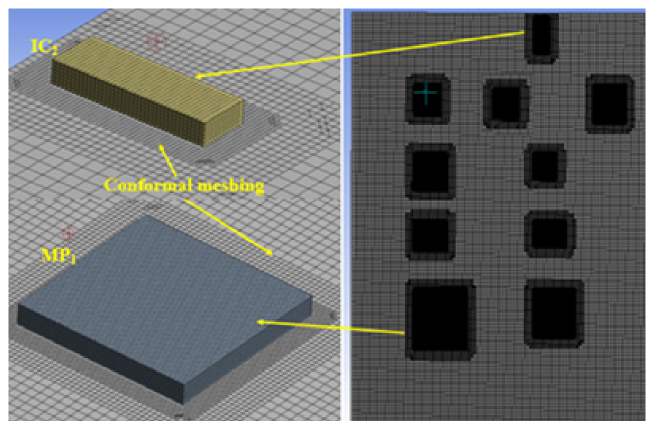

Figure 3. Mesh profile.

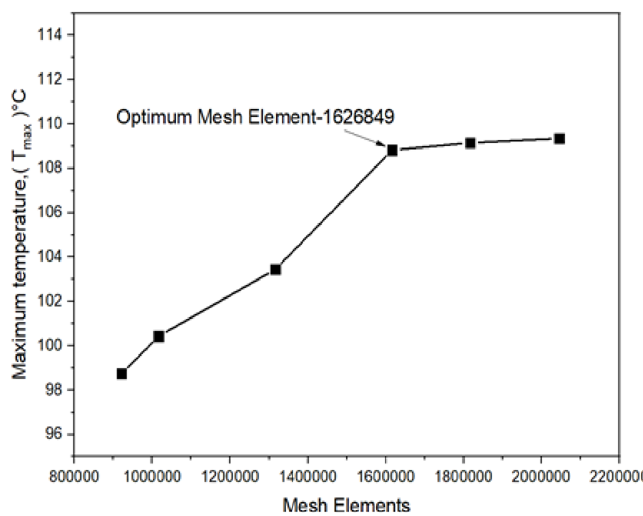

Figure 5. Independency study.

below 0.85. A mesh independence analysis (Figure 2) determined that 1,626,849 elements were sufficient for achieving converged results. Adding more elements would not significantly improve accuracy but could increase computational time. The mesh used is illustrated in Figures 3 and 4.

5.0 Result and Discussion

This study numerically analyzed electronic components under different heat transfer conditions. The components were heated unevenly and mounted on various substrate materials such as FR4, copper cladding, and silicon cladding. The aim was to investigate how heat transfer and substrate materials affect component temperatures. The results provide valuable insights for thermal designers in selecting the most suitable substrate boards for efficient electronic cooling.

5.1 Electronic Components Temperatures

Figure 2 illustrates the temperatures of electronic components (heat sources) under Natural Convection (NC) and Forced Convection (FC) at different air velocities. Natural convection caused temperatures to rise above 100°C due to uneven heating. Increasing air velocity effectively reduced component temperatures, with the lowest temperatures achieved at 7 m/s. The Microprocessor (MP1) consistently remained the hottest component, followed by MP2 and IC1. The FR4 substrate exhibited lower temperatures due to its lower thermal conductivity. The heat from the IC chips was primarily transferred through convection. Forced convection resulted in a more uniform distribution of heat among the components. Copper cladding allowed for a lower air velocity of 2 m/s while reducing IC chip temperatures by 1.50°C to 11.12°C.

5.2 Component Temperatures on Various Substrate Boards

Component temperatures can be reduced by using different substrate materials. This study utilized FR4, copper cladding, and silicon cladding. Copper and silicon cladding layers (0.5 mm each) were added to the FR4 board (total thickness: 1.65 mm). Copper cladding significantly lowered component temperatures by 34°C to

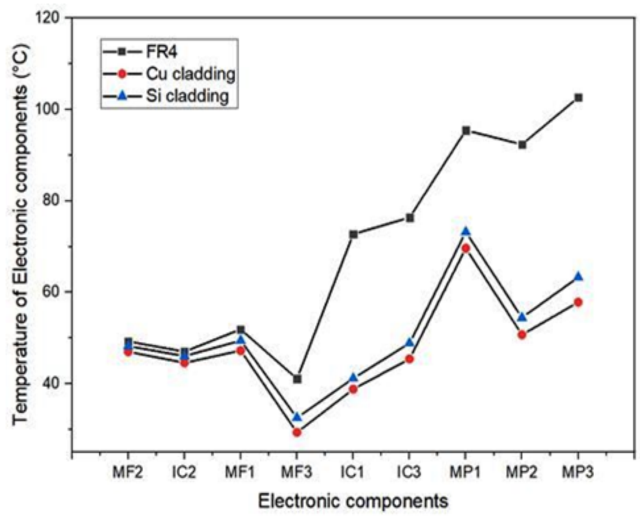

Figure 5. Temperature for substrate board (7 m/s).

54°C (Figure 5). Additionally, copper cladding was 3°C to 11°C cooler than silicon cladding. These results suggest that heat travels through the substrate and then convects to the surrounding fluid.

6.0 Conclusion

This study numerically analyzed electronic components under various heat transfer conditions. Components were heated unevenly and placed on different substrates (FR4, copper cladding, silicon cladding). The aim was to investigate how heat transfer and substrate materials influence component temperatures. Copper cladding was emphasized due to its uniform heat distribution, which reduces air velocity, energy consumption, and component temperatures below critical levels. High-heat-producing components should be positioned at inlets/outlets to minimize thermal interaction and overall temperature. The results showed that copper cladding at 7 m/s significantly lowered component temperatures by 34°C to 54°C compared to FR4 or silicon cladding. Copper cladding also reduced air cooling velocity by 2 m/s and decreased IC chip temperatures by 2.6°C to 12.14°C. Using 3 m/s with copper cladding can minimize fan power consumption and maintain component temperatures below 100°C. These findings are valuable for thermal designers in selecting appropriate substrate boards for effective electronic cooling.

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