PERFORMANCE ENHANCEMENT BY NOVEL COOLING TECHNIQUE IN NETWORK-ON-CHIP(NoC)

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ABSTRACT

This paper proposes a progressive persuasion of alternative cooling system through turbulent flow of high velocity air in multi-channels that is proved to cool the temperature rise in network-on-chip which needs turbo cooling due to high dense packed subsystems in a chip. Based on the inference from various literatures, this method of cooling stays high efficient to the conventional cooling methods like fans, Heat sinks. Initially, the proposed method of cooling has been validated through Noxim and HotSpot simulators in Linux environment and the outcomes of simulation shows that the proposed system can provide average temperature difference of about 10.27 units in NoC. This novel cooling methodology is verified through the experimental setup and the temperature decrease of about 10 units is achieved in both experimental and simulation could increase the life of any electronic systems twice as per Arrhenius equation.

Keywords: Network-on-Chip; NoC; Multichannel Turbulent flow; cooling in NoC; performance; electronic systems.

NOMENCLATURE

PC - Personal Computer
CPU - Central Processing Unit
ΔT - Temperature Difference
DC -Direct Current

HIGHLIGHTS

- Simulating model caters significant temperature decrease when exposed to Network-on-Chip simulating environment.
- Experimental results value-added the simulating model and derives the superior cooling effect.

- Both the experiment and simulation results brought 10 degrees temperature dip in NoC with high dense packed systems which could double the lifetime as per Arrhenius equation.
- This system avoids creation of new infrastructure to adapt with the conventional cooling system.

INTRODUCTION

Modern electronic systems like Personal Computer (PC) need highly sophisticated end user applications like gaming, multimedia and in order to incorporate the high end functionalities, NoC as communication medium in on-chip circuits is required for such systems. Today, the performance of NoC has been decided by various factors like speed, Heat dissipation and so on. Higher levels of heat dissipation may lead to system failure in the incorporated electronic components used for a computer including chip. The techniques employed for cooling of on-chip system have been vital part in achieving the high efficiency. Particularly, sophisticated High end systems dissipates more heat than conventional systems, an efficient solution is required to work with the system in safe zone. Hence, various temperature mitigation techniques and cooling methodologies are the crucial part in designing such systems. This is because of the reality that any of the electronic components fail when heat dissipation exceeds 70°C. Conventional cooling methods like fans, heat sinks have its own drawbacks and high need of finding good choice of cooling method is mandated. This paper provides a novel alternative for cooling of systems under heavy loaded.

SCOPE AND MOTIVATION

The governing law of all thermal aware systems is the 1st law of Thermodynamics which stated that the incoming energy of any system is equal to the energy released from the system at steady state. The energy that is released from any electronic systems is dispersed as heat, released from the systems which are proportional to power used by the systems. Here, the heat dissipation from any electronic systems happens in resistive elements due to its current flow, the heat dissipation is equivalent to its power consumption by equation (1) as shown below.

$$\textbf{Heat dissipation = Power consumption} \Rightarrow Q = V * I \text{ ---(1)}$$

Q→ Heat Dissipation

V→ Voltage

I →Current

Equation (1) and Fig.1 shows that the CPU power is directly proportional to the temperature of the working unit. If the CPU power increases with the high end systems obviously the temperature rise in the system also increases. Intel 32nm and 22 nm core i5 CPU cores have provided different power and proportional temperature rise. Hence, the cooling of sub micron system is highly needed in sophisticated systems.

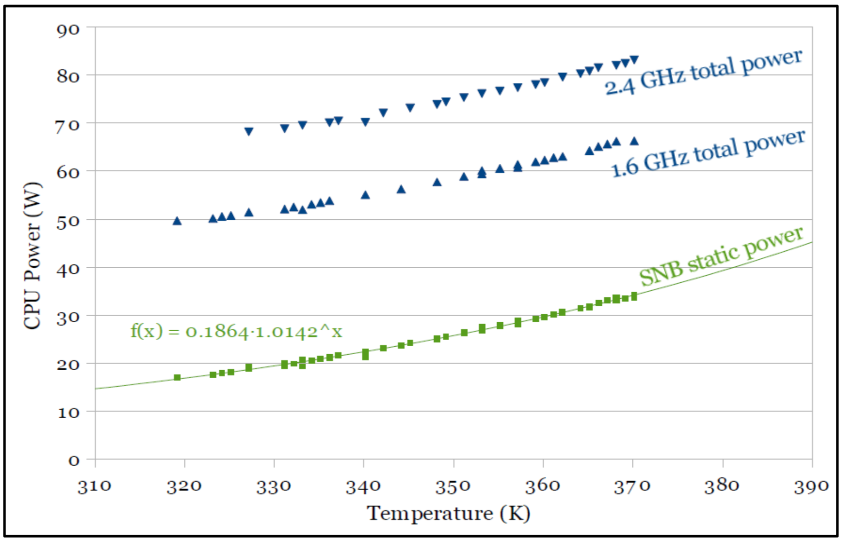

Fig.1 Comparison of Intel's 32nm and 22nm Core i5 CPUs as in [1]

The practice of employing cooling fan, Heat sinks and liquid cooling are used for cooling the electronic systems. [2] Provides the constraint of using air cooler and there is no great significant impact on providing air cooler in working unit as given in Fig.2. [2] Provided the inefficiency of computer fan for the removal of heat when it is fully loaded. The paper [2] stated that only meager temperature can be detached from any systems using cooling fan. This low difference in temperature will not be sufficient for even normal systems.

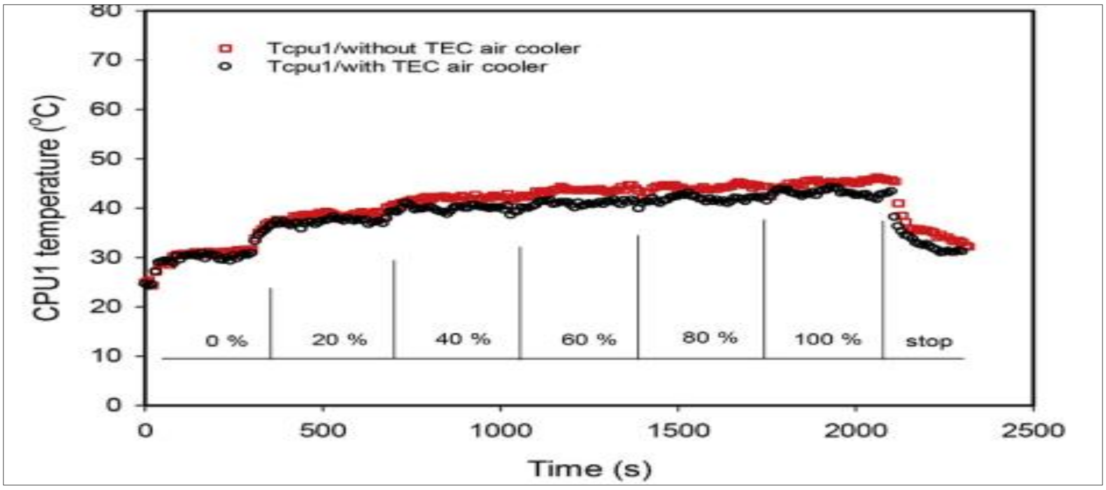

Fig.2 Illustration of non-performance of conventional air cooling as in [2]

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The paper [3] ,[4]-[6] illustrated the effect of failure models on chip power, server power and fans speed Next, liquid cooling attracted drastically among the designers of sophisticated high end systems as they provide better results of cooling in high dense systems. Alkharabsheh in paper [4] also provided the failures of liquid cooling. Some of the reasons are malfunctioning of pump used which includes blocked micro channels in the water block and Kink in the tubes of liquid cooling infrastructure.

SIMULATION MODELING

The simulation is carried out using Linux based tools; Noxim and Hotspot are used to examine the usefulness of the proposed novel system. Noxim simulator simulates the behavior of high dense systems by placing various sub blocks within a single chip. The derived model is described in Fig.3 with the partition of sub-components within the system. Metrics like routing, placement method, number of cores etc., are given as user inputs. Noxim Simulator derives the model of the system with the given user inputs after placement of cores within the chip.

Greater rise of temperature happens with the sub blocks or cores when it is highly densed than the other sub blocks or cores in a single chip. Natural convection of heat is not possible with the congested areas and hence forced convection has to be employed at the particular hotspot in order to prevent malfunctioning or serious disruption due to overheating. In Fig.3, sub-block "IntReg" is highly congested among the other blocks and the heat dissipated in this region is obviously high.

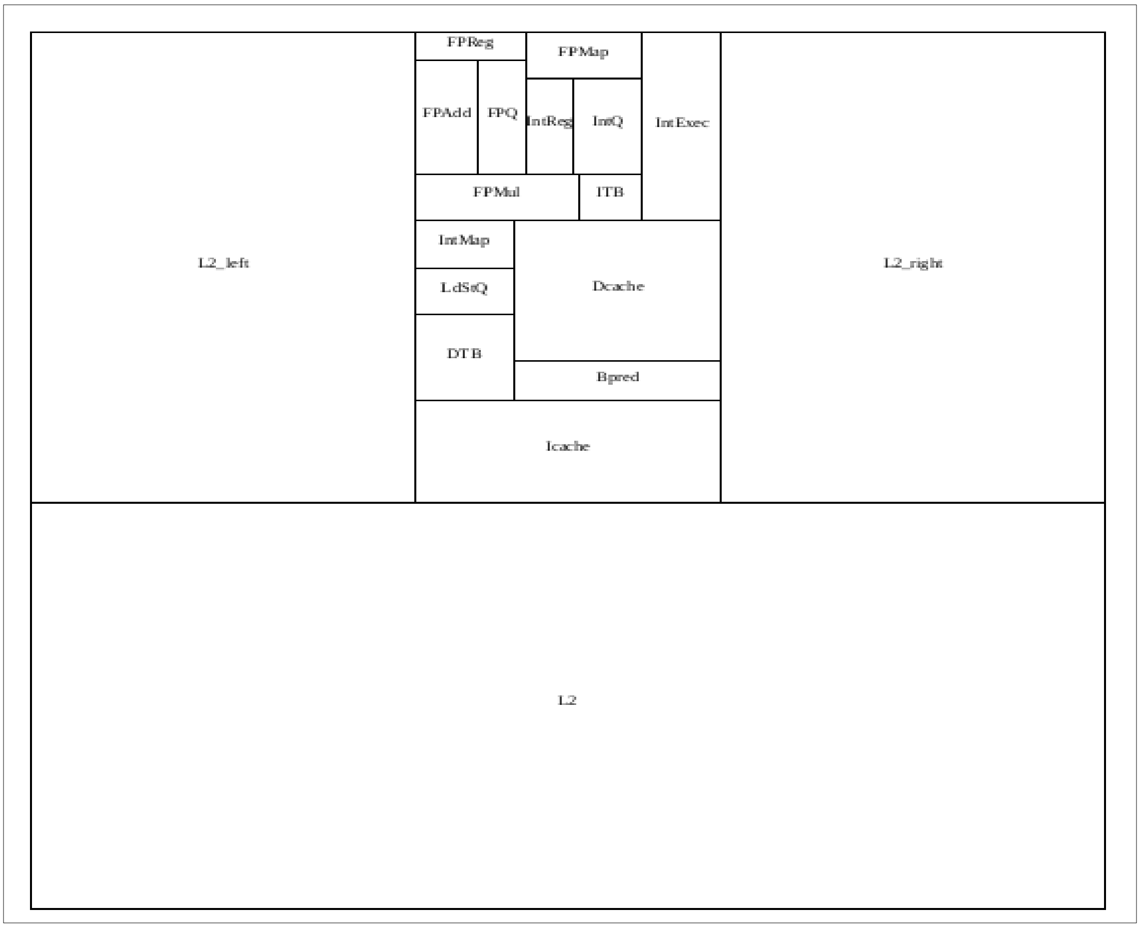

Fig.3 simulating working model with various sub blocks or cores in a single chip

The derived model from Noxim has been fed to the thermal simulating software, Hotspot-6.0. The simulator renders the outcomes like temperature of the system, temperature of individual sub blocks and the temperature of sub blocks after specific hotspots after the coolant blown to the system etc., The results shown in Fig.4 (a) and (b) illustrates the temperature of the named sub-blocks in the simulating model before and after the application of coolant in specific hotspots of the system. Here, pressurized air is used as the coolant to mitigate the extreme heat dissipated from high dense system.

The simulating model provides the significant decrease of temperature when coolant is blown to the system. Initial temperature in Fig.4 (a) gives the clear picture of temperature grown when air as coolant has not applied initially and Final Temperature in Fig.4(a) shows the temperature of named sub blocks after the coolant is blown to the system. In particular, Fig.4(b) depicts the significant temperature decrease (ΔT) of the high dense sub blocks in the simulating environment. Both figures Fig.4 (a) & Fig.4 (b) shows that about 10.72K decrease in temperature has been derived from the simulated cooling system.

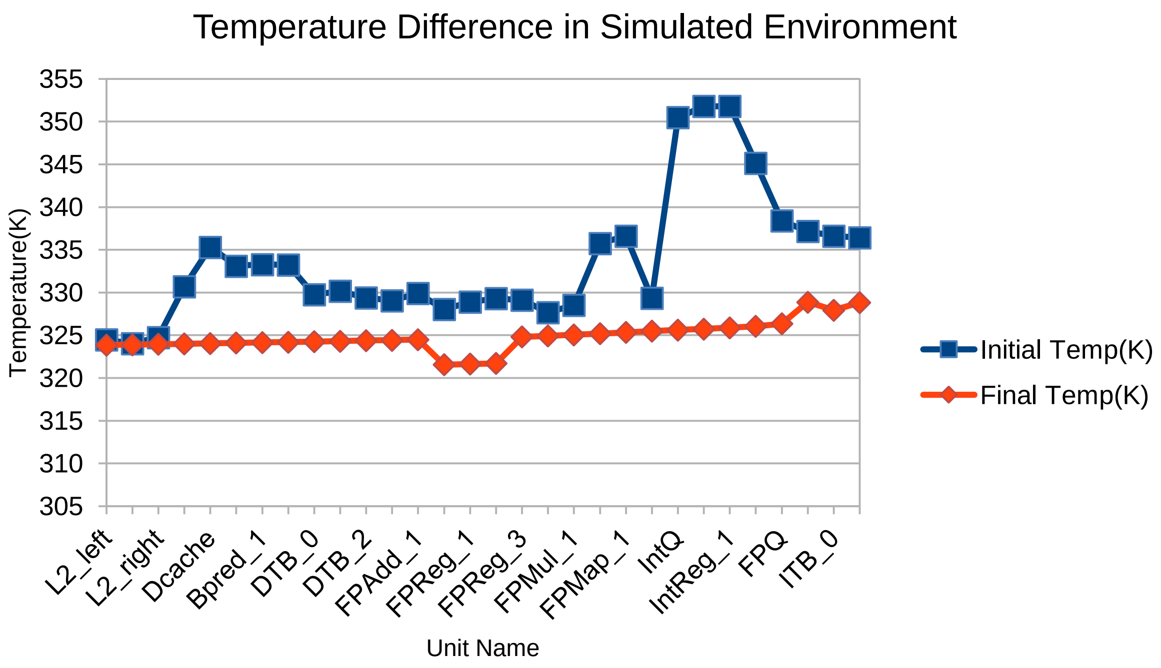

Fig.4.a Demonstration of ΔT of the overall system.

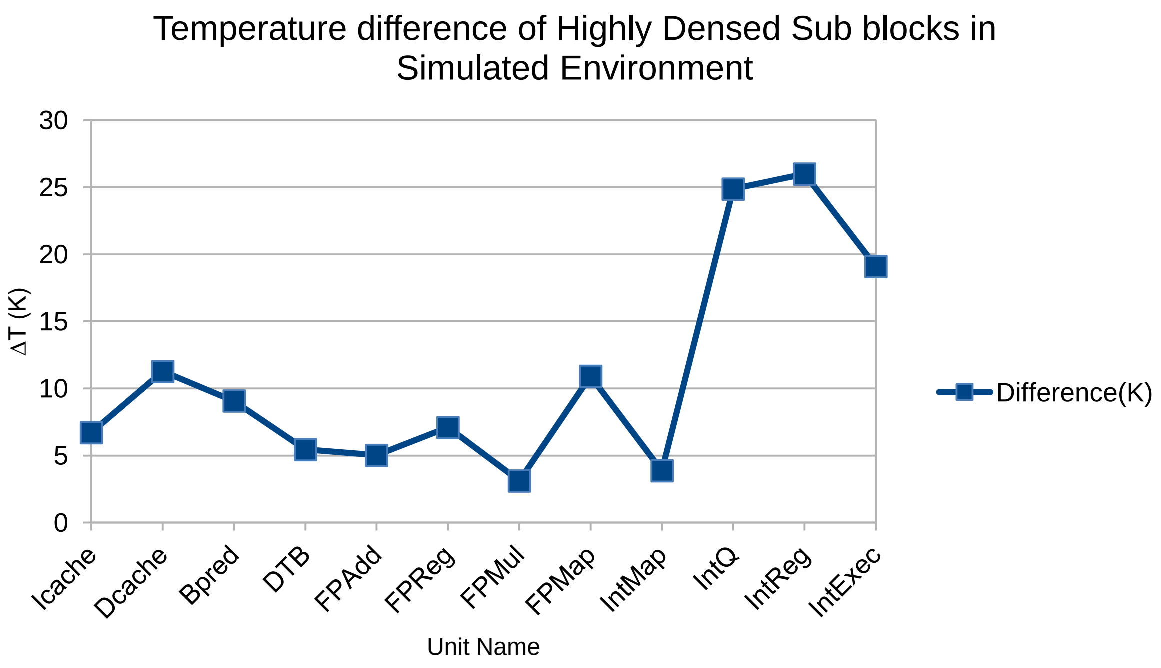

Fig.4.b Demonstration of ΔT of specific hotspots

Experimental Setup

Methods of reducing the heat generated from the electronic components plays the most exploring domain among recent researchers. In this manner, various cooling strategies were utilized as mentioned in papers [7- 11]. From the knowledge gained from these research papers, the proposed system is designed to suit any electronic systems with high dense systems in a single chip. The experimental arrangement of various components is shown in Fig.6.

The working unit as shown in the Fig.6 exhibits the customized model of the chip which behaves like dense systems. External DC supply applied to the customized working unit and accordingly the working unit was heated up over time. Since, power of the DC system can be calculated from the DC current and Voltage applied in the unit.

The controller unit controls the sensing equipment. The power lines, control signals from the controller unit and coolant flow are lucubrated in Fig.6. Various real time factors like temperature, flow rate of the coolant, working voltage, working current were sensed and recorded using the embedded sensors of the controlling/sensing unit.

The system has exposed to operate in various flow modes like Laminar flow in a single channel and multiple channels, Turbulent Flow in a single channel and multiple channels. The coolant flow of the system is well depicted in Fig. 5 .

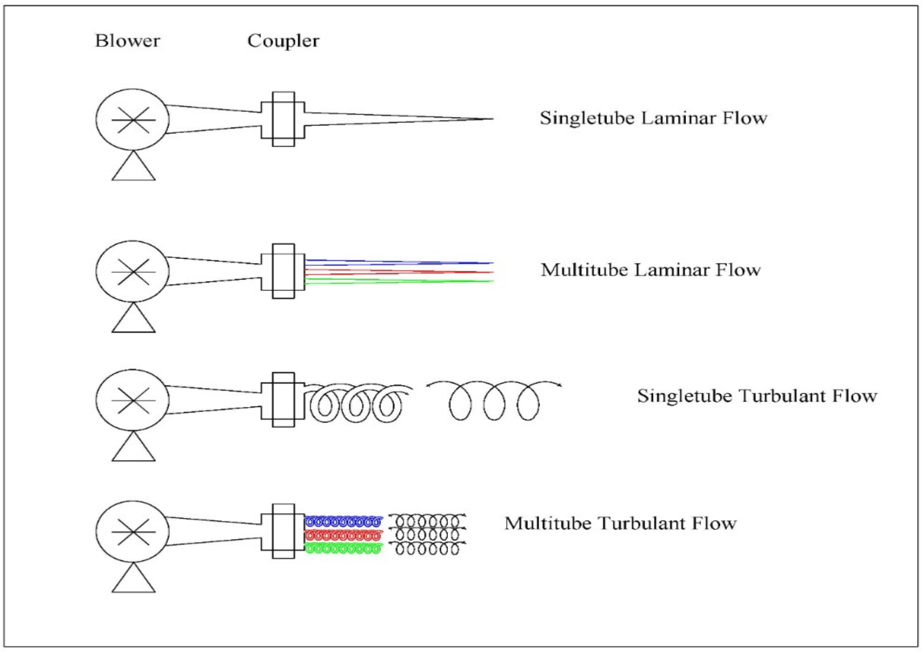

Fig.5 Modes of Coolant blown to the working unit

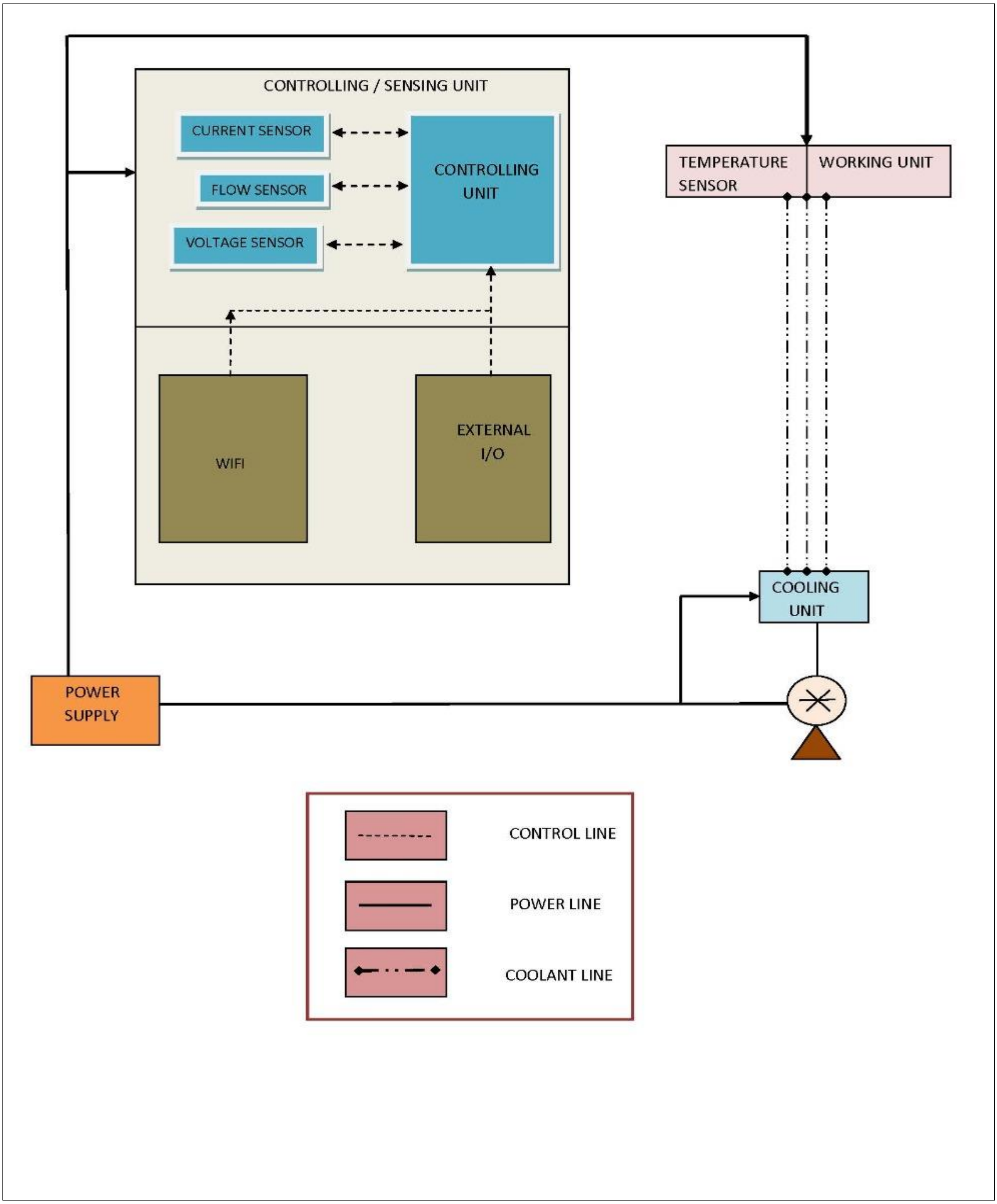

Fig.6 Schematic Diagram of Experimental Setup

Results and Discussions

Table 1: Experimental Examination on various types of cooling methodology

Methodology	Average Drop in temperature per minute (°C)
Single channel Laminar flow	2.3
Single channel Turbulent flow	7.6
Multi channel Laminar Flow	8.5
Multi channel Turbulent Flow	10.1

Among four modes of coolant flow, turbulent flow of coolant blown in multiple channels provide the higher cooling effect in the working unit as shown in Table 1. The multiple channeled turbulence can provide nearly 10.1°C of temperature difference which is the prevailing approach of cooling systems than the conventional methods. In order to ensure the reliability, multiple iterations of cooling has been derived and is shown in Fig.7 which shows initial and Final Temperature of the unit when multiple channeled, turbulent flow approach is executed in numerous . This high degree of ΔT is nearly equals the highly attracted Liquid Cooling method and far better than Fan and Heat sinks employed in Conventional Cooling methods.

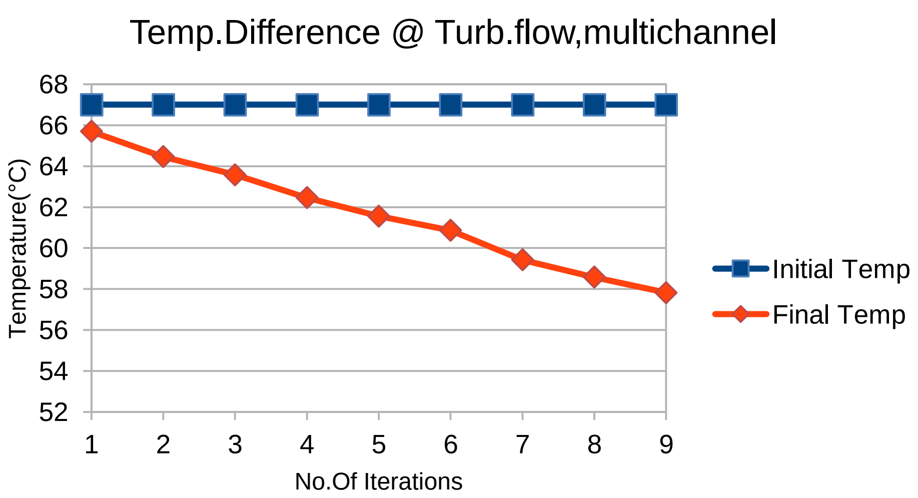

Fig.7 Temperature variation of the experimental working unit

Estimation of Percentage Error

The experimental results provide 10.1°C temperature dip and the simulated outcomes provide 10.72K decrease in the temperature. The temperature decrease in simulating and working experimental unit could be correlated as the difference in units does not change the value of the metrics. The error or deviation between the experimental results and simulated results can be obtained by the formula

$$\textbf{Error (in \%)} = \frac{\textbf{Actual Value} - \textbf{Approx. Value}}{\textbf{Actual Value}} \times 100$$

The experimental analysis provides the actual value of 11.1 units in temperature difference in employing the proposed method (Multi Channel- Turbulent flow) in the high dense systems and the simulated environment gives the approximate value of 10.72 units in temperature difference.

Conclusion

This paper portrays a novel and innovative method to mitigate the thermal outbreaks of the highly sophisticated systems that are embedded in a single chip with heterogeneous sub blocks. The simulation model and the experimental setup validate the proposed novel cooling methodology of multi-channeled turbulent flow of coolant with nearly 10 units of temperature decrease. This is well proven by comparing both the outcomes of model and experiments. The results of multi-channel turbulent flow provide the superior effect of cooling for any electronic systems which suffer from heat dissipation constraint. As per "Rule of Thumb" inferred from Arrhenius equation that 10 degrees of temperature decrease doubles the reliability of any electronic system. This paper recommends the multichannel turbulent flow of high velocity air as the compromising solution for the systems that suffers from thermal imbalances. This may be used as an alternative for conventional cooling systems with little modification in physical structure like incorporating micro channels for passing of high velocity air.

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