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A liquid-based system for CPU cooling implementing a jet array impingement waterblock and a tube array remote heat exchanger

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ABSTRACT

A liquid CPU cooler has been designed and tested with the aim to achieve a cooling capacity of 200 W for a surface area of 8.24 cm^2, commensurate with the integrated heat spreader dimensions of an Intel® Pentium® 4 Processor. The primary aim of the design was to develop thermal hardware components that can be manufactured simply and cost effectively. To this end, a miniature jet array waterblock and a tube bundle remote heat exchanger were employed since the bulk of their housings could be manufactured using low cost injection molding techniques which could significantly reduce the total system cost compared with conventional units. The system was capable of dissipating the required heat load and exhibited an overall thermal resistance of 0.18 K/W requiring approximately 1.5 W of hydraulic power. At maximum power the chip-to-air temperature difference was 45 °C which is adequately close to typical design thresholds. The influences of power loading and liquid volumetric flow rate are also discussed.

1. Introduction

During operation all electronic devices generate heat that must be dissipated effectively in order to ensure proper functioning and reduce the risk of failure. In devices such as microprocessors, temperature thresholds (typically ~85 °C at present) are imposed to reduce leakage currents. From a reliability standpoint, elevated temperatures and cyclic temperature excursions can induce failure mechanisms which will cause premature component failure [1]. The proper functioning and reliability of electronic components hinges on adequate thermal management. However, advances in micro-fabrication of electronic circuitry have lead to continual decreases in dimensions ostensibly allowing more circuit components per unit surface area. This has lead to severe increases in power densities and have strained existing air based board level thermal management hardware, such as the low-tech fan-finned heat sink, to their operational limits.

It is accepted that chip heat fluxes will continue to escalate in the coming years. Current fan-fin cooling techniques will not be a viable solution at board level primarily due to fin efficiency and heat spreading bottlenecks and the fact that air is a poor thermal transport medium. One of the main conundrums is that the heat transfer coefficient generally increases asymptotically with air velocity ($h \propto u^{0.8}$) whereas the pressure drop penalty increases as $\Delta P \propto u^2$ and acoustic noise at somewhere in the region of $U \propto u^5$. This being the case there are disproportionately large increases in penalties with modest gains in heat transfer.

Liquid based cooling of electronics is an obvious choice due to their superior thermophysical properties compared with air. Liquid based heat sinks extract the heat with very reduced form factors at board level since the heat is released to the air by a remote heat sink, typically where there is sufficient real estate that form factor constraints are not as severe. Furthermore, the liquid flow in the remote heat exchanger precludes the need for advanced heat spreading technologies.

Over the past 20 years there has been very aggressive international research effort regarding single and two-phase microchannels [2,3]. Single-phase channel flow affords reasonable heat transfer coefficients whilst offering the enticing possibility of a very high heat transfer surface areas per unit volume. One drawback, however, is the singular direction of the flow which can result in large temperature gradients from inlet to outlet which are undesirable [4]. A possible solution to this is two-phase convective flow which should ideally be more isothermal. However, two-phase flow in microchannels has proven to be extremely complex, both with regards to the overall heat transfer coefficient and the dryout limit [3], and it is not likely that a reliable and affordable two phase heat sink will be available in the near future.

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