ELEC 499
Project Design

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Abstract

Overclocking is the process of increasing the CPU clock rate, which allows a greater number of instructions per unit time. This results in an increase in the overall performance of the PC. The increased clock rates cause the CPU to generate more heat internally. The stability of the processor is diminished while operating at high clock rates and high temperatures, which can be corrected by reducing the temperature of the processor.

An Intel Pentium III 600MHz processor was overclocked by increasing the Front Side Bus of the PC motherboard. A cooling system was developed in which a thermoelectric device directly cooled the processor. The temperature of the thermoelectric device is regulated using an electronic proportional controller with temperature feedback. A water circulation system was constructed to remove heat from the hot side of the thermoelectric device and reject the heat into the air. The temperature of the CPU and water were monitored and it was found that the CPU could be maintained to approximately 23°C and the water at 39°C. The CPU was tested for stability and then benchmarked to characterize the improvement in performance. It was found that the computer clock could be increased by 38% before the stability of the processor was compromised.
1 Introduction

With the advent of rising clock rates in personal computers, the requirement for improved thermal management of the microprocessor and other components becomes a necessity. Through improved thermal management, this project aims to extend the boundaries of PC performance.

An understanding of the operational characteristics and limitations of the PC is required before improvements to PC performance can be realized. Enhancements to PC performance can be fulfilled through the use of increased clock rates, which necessitates improved cooling methods on the microprocessor and chipset.

The scope of the project includes:

1. The relationship between computational performance and front side bus speed will be analyzed.

2. The correlation between increased front side bus speed and processor heat dissipation will be examined.

3. The relationship between processor temperature and operational stability will be characterized.

4. Alternative methods for active cooling of the processor and chipset will be studied and employed to further extend thermal stability limitations.

5. Temperature regulation of the processor and its feasibility will be investigated.

6. All designs will minimize the probability of condensation occurring within the PC.

This project achieved its goals through overclocking of the PC combined with active temperature regulation of the processor. The computational performance was increased by increasing front side bus clock speed. The temperature of the processor was regulated using a thermoelectric device and a temperature controller. A water circulation system was utilized to reject the excess heat.

The first section of this report will deal with a detailed explanation of the PC used in this project. An explanation of overclocking is then presented. The cooling system and temperature controller are described followed by the test results.
2 The PC Specifications

This section will introduce the PC that was tested for this report.

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
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<td>Processor</td>
<td>Intel, Pentium III 600E, 256 KB L2 ECC Cache, 100MHz FSB</td>
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<tr>
<td>Motherboard</td>
<td>ABIT, BX6 R2 w/ Intel 440BX chipset</td>
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<td>Hard drive</td>
<td>Maxtor, DiamondMax Plus 40, 40GB, 7200 RPM, ATA66</td>
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<td>Memory</td>
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<td>Video card</td>
<td>ATI, Rage Fury, 32MB, AGP2X</td>
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<td>IDE controller</td>
<td>Promise Technology, Ultra66 IDE controller</td>
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<td>Power Supply</td>
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2.1 Processor

The Intel PIII 600E processor operates with a 100MHz front side bus (FSB) and a 6 times multiplier which clocks internally at 600MHz. The internal 600MHz clock is also applied directly to the 256kB of L2 cache. The Intel PIII 600E comes in an FC-PGA370 package. All these specifications are shown in the following screen capture of WCPUID. WCPUID is freeware that can be found readily on the internet.

Figure 1: WCPUID\(^1\) Showing CPU Specifications
2.2 Motherboard

The ABIT BX6 R2 is designed for use with Intel PIII 450 ~ 700 MHz and PII 350 ~ 450 MHz processors running on a 100 MHz FSB. The motherboard is equipped with a WinBond W83782D IC for the monitoring of fan speed, voltages, and system temperatures. The W83782D is capable of monitoring three separate temperatures. The PIII 600E has an internal temperature diode, which is polled by the WinBond chip. The second temperature is from taken from a thermistor located on the motherboard. The third temperature input is connected to a probe, which the user can place. The probe, in this instance, is used to monitor the 440BX chipset temperature.

A freeware program called Motherboard Monitor II is used to display the temperatures, fan speeds and power supply voltages. The software also alarms on high and low temperature, voltage and fan speed. Figure 2 shows the Motherboard Monitor display.

Figure 2: Motherboard Monitor Showing System Temperatures, Voltages and CPU Clock Speed

The ABIT motherboard allows for control of the clock generator IC through ABIT’s SoftMenu II feature in the BIOS. The clock generator IC clocks the FSB. The FSB is connected to the CPU and to the 440BX chipset. Typically the FSB speed, on OEM motherboards, must be changed through the use of hardware jumpers. The FSB settings allowed are 66, 75, 83, 100, 112, 117, 124, 129, 133, 138, 143, 148 and 153 MHz.

The FSB speed can also be changed by communicating directly to the clock generator IC through a piece of software called SoftFSB III. Shown below are two screen captures of the SoftFSB interface. One shows the FSB at 100 MHz and the other shows the FSB changed to 138 MHz.
The SOFTMENU II interface also allows for the adjustment of the CPU core voltage, which is shown below in Figure 2. The core voltage can be adjusted from 1.30V to 1.85V in 0.05V increments. The core voltage adjustment would normally be accomplished through jumper setting on OEM motherboards.

Figure 4: SOFTMENU II Bios, CPU Voltage Adjustment
3 Overclocking

Overclocking is the process of increasing the CPU clock rate, which allows a greater number of instructions per unit time. The CPU clock rate can be changed by increasing one or both of the following:

- CPU Multiplier Factor (set to 6 times on Figure 4)
- Front Side Bus

The PIII 600E processor is multiplier locked which only allows overclocking through FSB manipulation. It is the aim of this project to maximize PC performance without compromising system integrity. System integrity can be compromised with increasing CPU temperature.

The highlighted portions of the PIII datasheet, shown in Table 1, illustrate the increased thermal requirements with increasing processor core frequency. If the FSB speed of the processor is increased we can extrapolate from this chart that an increased temperature will be experienced within the processor. To maximize system performance, improved thermal management is required.

Table 1: Excerpt from Intel Pentium III Datasheet

<table>
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<tr>
<th>Processor</th>
<th>Core Frequency (MHz)</th>
<th>L2 Cache Size (Kbytes)</th>
<th>Processor Thermal Design Power (W)</th>
<th>Power Density (W/cm²) CPUID up to 068h</th>
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<td>70</td>
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NOTES:
1. These values are specified at nominal VCCORE for the processor pins.
2. Thermal Design Power (TDP) represents the maximum amount of power the thermal solution is required to dissipate. The thermal solution should be designed to dissipate the TDP power without exceeding the maximum Tjunction specification.
3. TDP does not represent the power delivery and voltage regulation requirements for the processor. Refer to Table 6 for voltage regulation and electrical specifications.
4 Cooling System

A cooling system was devised to deal with the increased thermal load on the processor and chipset. The following schematic gives an overview of the components required to regulate the CPU temperature.

The thermoelectric device cools the processor and as a result it heats the water. The water then passes over the chipset and returns to the reservoir. In the reservoir there is a submersible pump that keeps the water circulating. Heat from the water is rejected through the aluminum heat sink, which is cooled by forced air. The temperature of the processor is regulated with a controller using temperature feedback.
4.1 Thermoelectric Device

The thermoelectric device operates by exploiting the Peltier effect, which states that when a direct current is applied to an electric circuit made of two dissimilar materials, then one junction of the circuit becomes cold, the other hot.

The thermoelectric device consists of a number of p- and n-type couples connected electrically in series and sandwiched between two ceramic plates. When it is connected to a DC power supply, the applied voltage causes heat to move from one ceramic plate to the other. The process creates a hot side and a cold side.

A 93 watt thermoelectric device is sandwiched between a cold block on the cold side and a water block on the hot side as illustrated in Figure 6. The cold block’s function is to provide high thermal conductivity to the processor and provide mechanical support. The water block’s function is to remove heat from the hot side of the thermoelectric device.

Figure 6: Thermoelectric Device Between Cold Block (Lower) and Water Block (Upper)
4.2 Copper Water Blocks

Two copper water blocks were constructed, one for the processor and one for the chipset. The cooling blocks were assembled from 2” x ¼” copper bar. Inside each block a serpentine channel was drilled to allow for maximum cooling. ¼” copper pipe was soldered to ¼” holes drilled into the copper block for external connections. Copper pipe fittings and ¼” poly tubing was used for fluid interconnections. Both cooling blocks were pressure tested to 40 psi to assure there was no leakage. Photos of the water blocks are shown below.

Figure 7: Copper Water Blocks for BX Chipset and Pentium Processor

4.3 Water Reservoir and Pump

The water reservoir is composed of a plastic container, which has been fitted with an internal heatsink, which is mated to an external heat sink. The external heatsink is equipped with a fan to provide forced air-cooling.

A Rio 800 submersible water pump is contained within the reservoir. The pump is capable 800 liters per minute and maximum head of four feet. Figure 8 shows the pump, reservoir and heatsink without the fan installed.
4.4 Water Temp Display and Fan Control

A digital temperature display, with high and low alarm outputs, monitors the cooling water temperature. The high temperature alarm runs the reservoir heatsink fan at 25°C. The fan control was used previously to control air temperature in the case and is superfluous in its current use. The min/max temperature recorder built into the display has been useful during testing. A photo of the controller is shown in Figure 9.
4.5 Temperature Controller

A proportional temperature controller capable of 40 watts output was designed to regulate the processor temperature. The controller uses 12V from the computer power supply and outputs a variable 0-9 volt DC to the thermoelectric device. A schematic of the controller, sectioned into three main parts, is shown in Figure 9.

![Figure 10: Schematic of Temperature Controller](image)

The processor temperature control is based on a TL598 Pulse Width Modulator. A functional schematic of the TL598 is shown in Figure 11.

![Figure 11: TL598 Functional Block Diagram](image)
4.5.1 Processor Temperature Control

The TL598 has two built-in error amplifiers used for feedback control. Error amplifier 2 is used for the temperature control section. Temperature feedback comes from a thermistor inserted directly into the cold block located between the processor and thermoelectric device. A bridge circuit and a differential amplifier (Q1D) provide signal conditioning for the temperature feedback. A temperature set point is derived from a potentiometer (R5). The controller increases or decreases its output proportionally to compensate for the difference between temperature set point and the actual measured temperature.
4.5.2 Max Voltage Limiter

Error amplifier 1 on the TL598 is used to limit the maximum output voltage of the controller. Only one of the error amplifiers can control the output at a time. The error amplifier that is in control is always the one that is requesting the smallest output to the thermoelectric device.

Voltage feedback comes from a voltage divider on the output of the power amplifier stage. A voltage set point is derived from a potentiometer (R1). The controller increases or decreases its output proportionally to compensate for the difference between the voltage set point and the controller output voltage. The voltage limiter control includes a capacitor for integrating the error so that the voltage output will equal the set point in steady state.
4.5.3 Power Amplifier

Figure 14: Schematic of Max Voltage Limiter

The power amplifier stage uses the 100 kHz pulse width modulated (PWM) output from the TL598 to switch the Darlington configured power transistors. The switched output from the power transistors (Q4 & Q5) is low pass filtered (L1 & C5) to remove AC content before applying to the thermoelectric device. The switching of Q5 could not be accomplished without the flyback diodes (D1) to supply the L1 current during the transistor (Q5) off period.

The triac (Q3) is used to switch the AC powered water pump on when the computer is turned on.
5 Test Results

A comparison of stability, temperatures, and benchmarks was completed for the PC with stock heat sink and fan versus the active cooling solution. The results follow.

5.1 Stability

The FSB speed was tested at 5 different frequencies: 100, 117, 129, 133 and 138 MHz. The core voltage was changed from 1.45V to 1.8V. The specified core voltage for this PC is 1.65V. Stability was determined by running a piece of software called CPU Stability Test 6.0\textsuperscript{V}, for over 12 hours at each frequency. The software tests the processor using the following algorithms:

- Quicksort
- Whetstone
- Fibonacci
- Prime Test
- Cache Test
- Peripheral Test

5.1.1 Stock Heat Sink and Fan

The PC was found to be stable up to 133MHz at all 3 voltage levels. The PC locked up or went unstable when switched to 138MHz FSB at all 3 voltage levels.

These stability tests showed no computational errors and no other anomalies were observed up to 133 MHz FSB.

5.1.2 Active Cooling

The PC was found to be stable up to 138MHz at all 3 voltage levels. The PC locked up or went unstable when switched to 143MHz FSB at all 3 voltage levels.
5.2 Benchmarks

SiSoft Sandra® 2001 benchmarks were used to measure computational performance at the different clock speeds. The following screen captures in Figure XXX are a combination of results from tests at 100, 117, 124, 133 and 138 MHz. The benchmarks done on the PC are shown in red/blue. These benchmarks are compared to different systems, which are shown in orange/green.

Figure 15: SiSoft Sandra CPU Benchmarks
Figure 16: SiSoft Sandra Multi-Media Benchmarks

![CPU Multi-Media Benchmark](image)

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In all of the benchmarks, an increase in performance was observed due to an increase in FSB speed.
5.3 Temperature Monitoring

5.3.1 Stock Heat Sink and Fan

Temperatures internal to the CPU and the 440BX chipset were monitored for three different FSB speeds. The temperature transition from CPU idle to 100% processor usage is presented in the following graphs.

Figure 18: PIII Internal Temp w/ Stock Heatsink

Figure 19: 440BX Chipset Temp w/ Stock Heatsink

The temperature of the CPU and water were monitored and it was found that the CPU temperature would be approximately 35°C at no-load at all three FSB speeds. At full-load the temperatures began to deviate by as much as 5°C between the 100 MHz FSB and 133 MHz FSB.

The Chipset temperatures increased by 7°C at 100 MHz FSB and by 13°C at 133 MHz.
5.3.2 Active Cooling

Temperatures internal to the CPU and the 440BX chipset were monitored for two different FSB speeds. The temperature transition from CPU idle to 100% processor usage is presented in the following graphs.

Figure 20: PIII Internal Temp w/ Active Cooling

![Figure 20: PIII Internal Temp w/ Active Cooling](image)

Figure 21: 440BX Chipset Temp w/ Active Cooling

![Figure 21: 440BX Chipset Temp w/ Active Cooling](image)

The temperature of the CPU and water were monitored and it was found that the CPU could be maintained to approximately 23°C and the water at approx 39°C.
6 Conclusion

Through improved thermal management, this project aimed to extend the boundaries of PC performance. The report shows that through the use of increased clock rates and improved cooling methods enhancements to PC performance can be realized.

The project achieved its goals through overclocking of the PC combined with active temperature regulation of the processor. Overclocking is the process of increasing the CPU clock rate, which allows a greater number of instructions per unit time. This results in an increase in the overall performance of the PC. The increased clock rates cause the CPU to generate more heat internally. The stability of the processor is diminished while operating at high clock rates and high temperatures, which can be corrected by reducing the temperature of the processor.

An Intel Pentium III 600MHz processor was overclocked by increasing the Front Side Bus of the PC motherboard. A cooling system was developed in which a thermoelectric device directly cooled the processor. The temperature of the thermoelectric device was regulated using an electronic proportional controller with temperature feedback. A water circulation system was constructed to remove heat from the hot side of the thermoelectric device and reject the heat into the air. The temperature of the CPU and water were monitored and it was found that the CPU could be maintained to approximately 23°C and the water at 39°C. Thus, temperatures of the cooling blocks were controlled to a level above the dew point so as to minimize the possibility of condensation. The CPU was tested for stability and then benchmarked to characterize the improvement in performance. It was found that the computer clock could be increased by 38% before the stability of the processor was compromised.

7 References

IV Intel Pentium III Processor for the PGA370 Socket at 500 MHz to 1 GHz Datasheet’, Intel Corporation, October 2000, p.47.