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Microprocessors Fan Speed Control for Dynamic Thermal Management

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Abstract: - This paper presents a methodology for temperature reduction in general purpose microprocessors, based on dynamically thermal control, which is known as dynamic thermal management. This technique can be considered as an effective mechanism for reducing processors temperature and power dissipation.
In the last decade a lot of works have been done during the hardware and software implementation. In this paper a proposed application circuit has been introduced. SPICE simulation program results confirm the theory.

Key-Words: - Dynamic thermal management, Fan speed control, BLDC fan

1 Introduction

In the last decade, microprocessors performance has been improved dramatically, with the new manufacture technology and more advanced architecture innovation [1], and the current computer technology used to make a processor run faster, these leads to increase the power dissipation and temperature, but processors do not perform well at high temperature because the failing rate are doubles every 10°C increase [2], that makes the temperature reduction techniques of processors to be an important design parameter. Figure 1 shows the CMOS Performance vs. processor temperature, and figure 2 shows the Pentium IV temperature versus power consumption [3,4,5]:

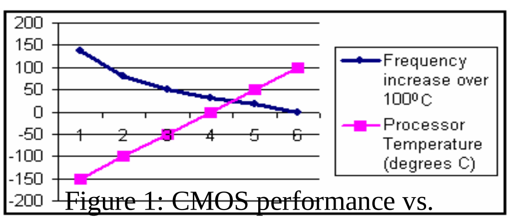
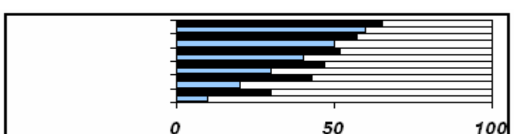


Figure 1: CMOS performance vs. processor temperature



	1	2	3	4	5	6
■ Temperature (degrees Celsius)	30	43	47	52	57	65
□ Power Consumption (W)	10	20	30	40	50	60

Figure 2: Temperature versus power consumption of Pentium IV processor

To keep processors at an acceptable operating temperature, more expensive cooling systems are being used. Failures in the cooling system can result in permanent chip damage. For this manner the following methods of temperature reduction is suitable [5,6]:

1. **Always On:** The simplest method of fan control is not to use any technique; just run a fan of appropriate capacity at full speed 100% of the time. This technique is Simple and low costing design, but it has Lower reliability, Maximum noise, and higher power consumption.

2. **On/Off Control:** Another simple fan control method, the fan is switched on only when the temperature exceeds a predetermined threshold; it is switched off for the remainder of the time. This technique has Maximum noise when fan is on and Noticeable noise when fan switches off.

3. **PWM Control:** This technique is the prevalent method traditionally used for controlling fan speed in PCs. The voltage applied to the fan switches between zero and full scale. This technique is Simple, inexpensive, efficient, and better speed control range than the other methods.

According of these advantages, in this study the PWM control is used for processors dynamic thermal management, by dynamically controlling the fan speed based on the processor temperature monitoring

2 Why Use Speed Control

The general purpose microprocessors will spend most of its time under worst-case conditions. At this point, it should be obvious that under most conditions fan speed can be reduced without adverse effects on the system and increased only when conditions demand it. The points below are the main benefits of the fan speed control [3,7,8]:

1. **Reduced Audible Noise:** Fans running at full speed can be a significant source of annoyance, and then fan speed can be reduced without adverse effects, much to the relief of everyone within hearing distance.
2. **Reduced Power Consumption**: Applications such as laptops will benefit from reduced power consumption. Because the power consumption can be approximated as a square of the fan's speed. Figure 3 shows the typical power consumption versus fan speed for three different fans.
3. **Increased Lifetime:** Reducing fan speed also decreases the wear on the fan. Fan wear is a rough function of the absolute number of revolutions of the fan. Reduced wear translates into increased fan lifetime.
4. **Reduced Clogging**: Dusts is attracted to electronics, especially in systems with fans. As dust collects at the inlet and the exhausts of systems with fans, airflow can diminish or be stopped altogether. This, of course, can result in decreased cooling and higher temperatures. Reduced fan speed can lessen the rate at which systems collect this dust, thus extending the systems' life.

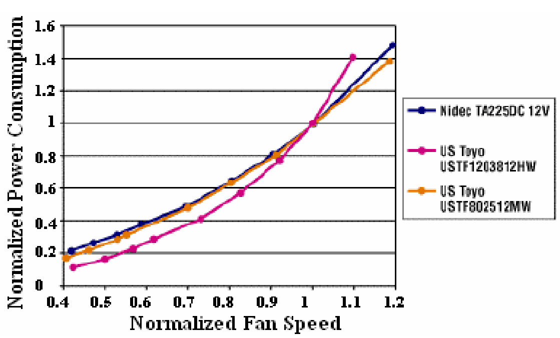


Figure 3: Power consumption versus fan speed for three different fans.

3 The Algorithm

The prerequisite for intelligent fan-speed control within processors is the ability to measure processor's temperature accurately. The temperature monitoring and thermal management techniques have been the subject of many power and thermal management articles [9].Therefore, it can be considered within the hardware implementation of the processors.

The algorithm of the processors fan speed control is shown in figure 4:

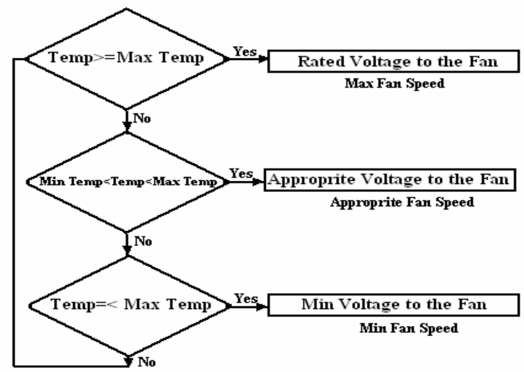


Figure 4: The algorithm used in the study

4 Application Circuit

The block diagram of the application circuit which is used in our study, for processors fan speed control for dynamic thermal management is shown in figure 5:

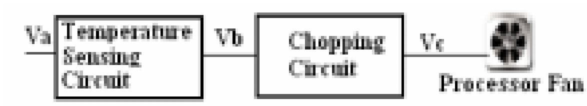


Figure 5: The application circuit block diagram for microprocessors fan speed control

1. The reference voltage Va is applied to the temperature sensing circuit, and is compared with the voltage from the temperature sensor (10 mV/°C), and amplified to (0.5V/10°C). The temperature sensor (LM35) was putted at the centre of the top surface of the processor to measure the temperature.

2. The sensing circuit output voltage Vb, which is in the range of 2-4 V is the input to the chopping circuit to generate the variable duty cycle (PWM) pulses to control the output voltage of the DC-DC converter which controls the processor's fan speed. The chopping circuit output voltage was in the range 6-12 volts depending on the ratings of the processor's fan.

3. The brush less DC (BLDC) motor is widely used as a small horsepower control motor, which is supplied from an inverter to generate a 3-phase AC voltage with frequency corresponding instantaneously to the rotor speed ω_r [10]. The BLDC motor has high efficiency, good reliability,

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light weight, and long life. These advantages make the 12V BLDC fan be the main popular fans used in computer systems today. The steady state torque speed characteristics of BLDC fan can be expressed in equation 1 (for DC equivalent circuit per phase) [11,12]:

$$V = E + IR \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where, V is the DC terminal voltage
E is the counter back emf
I is the phase current

The counter back emf and the fan speed can be expressed in equation 2:

$$E \propto \omega_r \quad \ldots\ldots\ldots\ldots\ldots (2)$$

Where, ω_r is the fan speed in (rad/sec)

The BLDC fans are fairly simple to characterize electrically. As the DC voltage applied to the fan is varied, its speed and current draw also varied. To a first order speed and current are directly proportional to the DC voltage applied.

The characteristic of the used fan in our study is shown in figure 6&7:

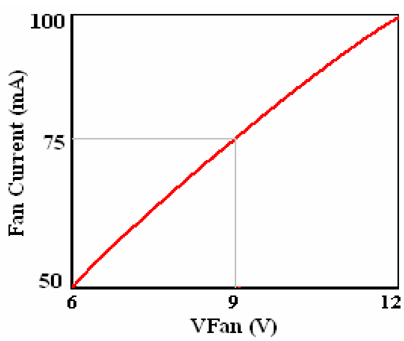

Figure 6: The current vs. supply voltage of the used fan

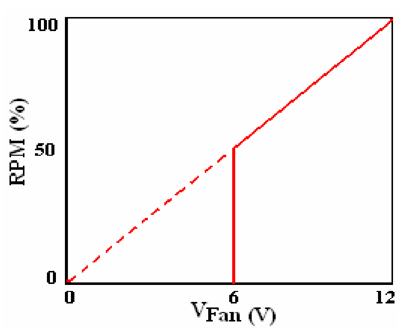

Figure 7: The speed vs. supply voltage of the used fan

Figure 8 shows the schematic diagram of the application circuit, which measures the processor temperature and generates the required voltage to operate the BLDC fan:

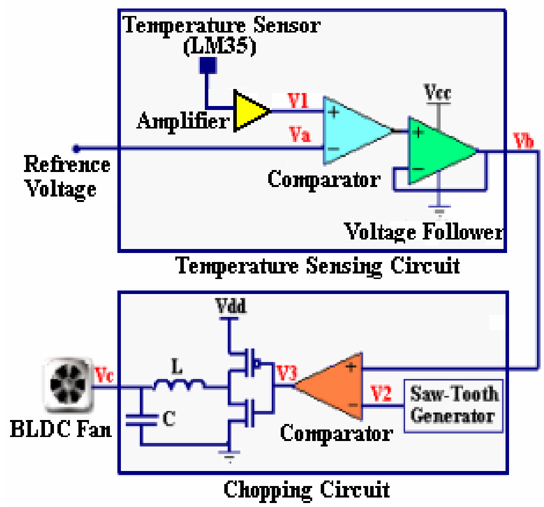

Figure 8: Schematic diagram of the application circuit

5 Results

Case 1: Processor temperature = 36°C, The sensing circuit output V(b), PWM voltage V(3), and the DC-DC converter voltage V(c) are plotted in figures 9&10:

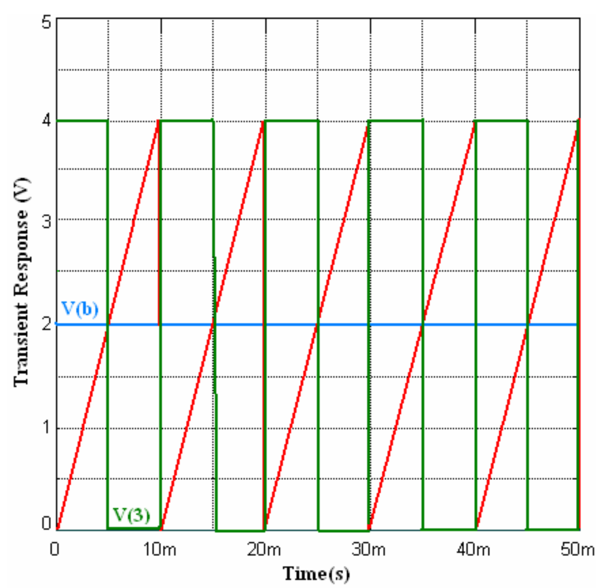

Figure 9: The sensing circuit output V(b) and PWM voltage V(3), when processor Temperature = 36°C

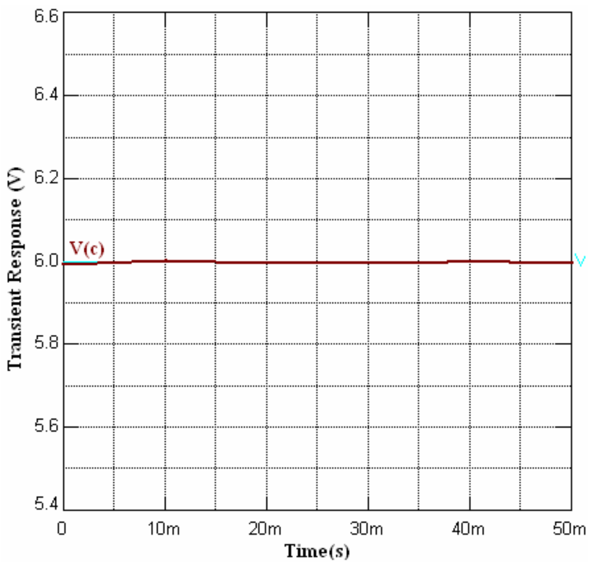

Figure 10: The DC-DC converter voltage V(c), when processor Temperature = 36°C

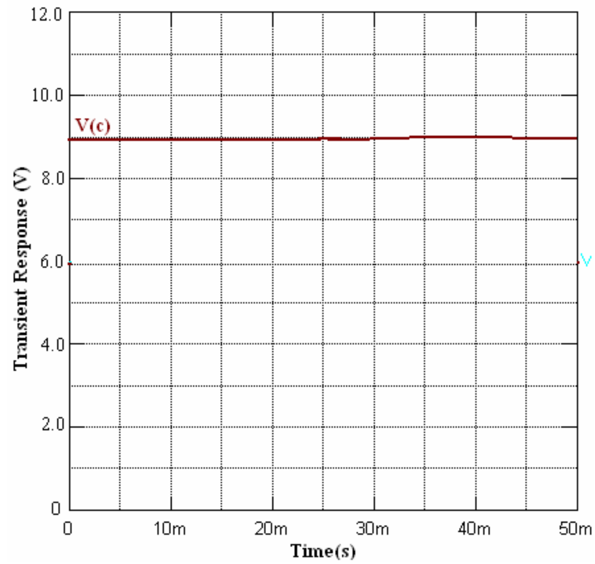

Figure 12: The DC-DC converter voltage V(c), when processor Temperature = 54°C

Case 2: Processor temperature = 54°C, The sensing circuit output V(b), PWM voltage V(3), and the DC-DC converter voltage V(c) are plotted in figures 11&12:

Case 3: Processor temperature = 72°C, The sensing circuit output V(b), PWM voltage V(3), and the DC-DC converter voltage V(c) are plotted in figures 13&14:

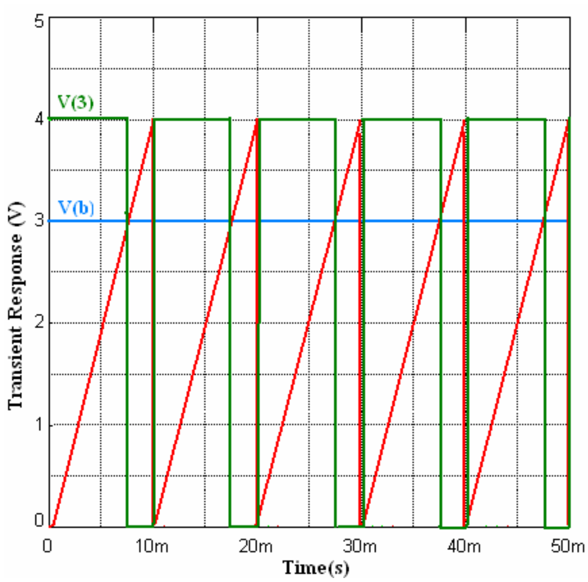

Figure 11: The sensing circuit output V(b) and PWM voltage V(3), when processor Temperature = 54°C

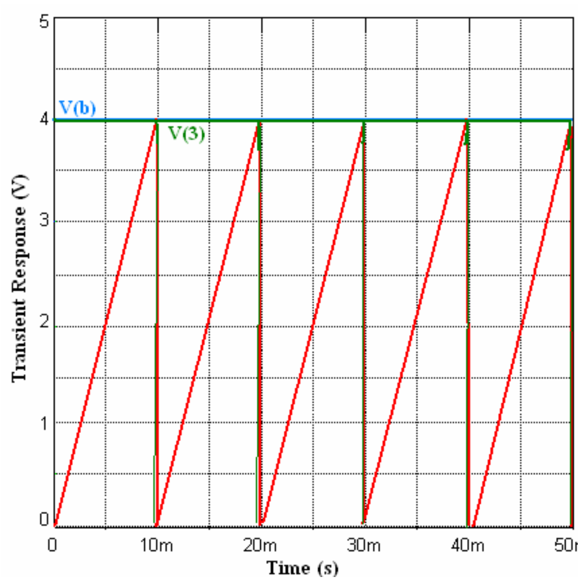

Figure 13: The sensing circuit output V(b) and PWM voltage V(3), when processor Temperature = 72°C

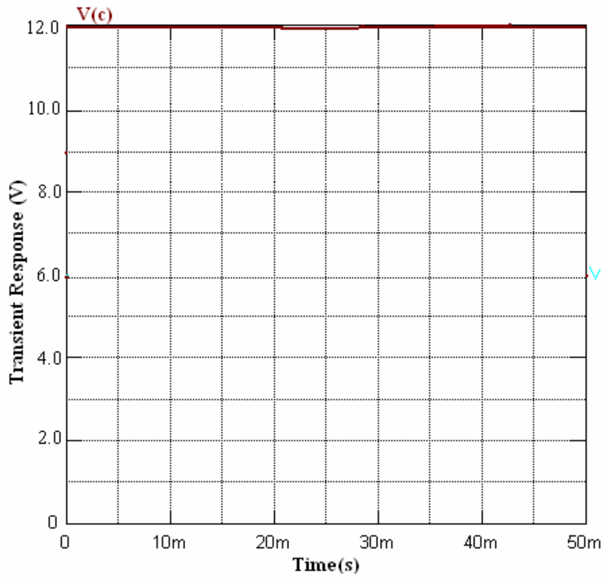

Figure 14: The DC-DC converter voltage V(c), when processor Temperature = 72°C

The results from the figures which are obtained from the Spice simulator program can be tabulated in table1:

Processor Temperature (°C)	Sensing Circuit output (V)	PWM Duty Cycle	DC-DC converter Voltage (V)
36	*2*	*0.5*	*6*
54	*3*	*0.75*	*8.95*
72	*4*	*1*	*11.98*

Table 1: The application circuit results for the three cases

6 Conclusion

The proposed application circuit, for microprocessors fan speed control for dynamic thermal management, which is introduced, designed, and simulated in this paper, is to vary or set the supply voltage of the processor's fan based on the temperature monitoring.

The application circuit has a high performance due to accuracy in progress. Also can significantly improve the energy efficiency, especially for general purpose microprocessors, multimedia interface systems, battery or UPS powered electronic devices.

This technique can changes the processors fan speed at runtime depending on the changing in temperature.

Therefore, this proposed technique can be considered as a critical constraint for the current and future processor's performance

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