Design and Implementation of an Instantaneous Turning-on Mechanism for PCs

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Abstract-In recent years, the "digital home" has created a need for many electronic home appliances. Some of them are redesigned from PCs and have made the physical PC invisible everywhere in our living environment. Thus "system standby all the time" has become an important feature for turning on a PC instantly. In this paper we use the "Suspended to RAM" method to replace the "System off" method to perform instantaneous turning-on just like some other consumer electronics have done, and we redesign the circuit to reduce the standby power consumption of a PC. First, we use CMOS as the current switch, thus avoiding the static current consumption between chips or modules, and we turn off the USB, PS/2 and network controller power supply with the USB, PS/2 and LAN waking-up function disabled. Second, we turn off the termination resistor power supply for the memory modules. Third, we use the high-efficiency pulse width modulation power regulator to replace the linear power regulator. Fourth, we enlarge the value of the divider resistors for the reference voltage to reduce the leakage current. Overall, these improvements reduce the standby power consumption to 0.7 watts from 2.4 watts. In addition our design shows that the PC can be turned on within 3 seconds by reloading the OS in the DRAM.

I. INTRODUCTION

It has become much harder to differentiate between PCs and electrical home appliances in recent years. Structurally speaking, the digital electrical home appliance is, in fact, a PC. Many major worldwide information technology (IT) industry leaders have aimed at the digitization of electrical home appliances, and this goal has finally been achieved. For example, Windows MCE (Windows Media Center Edition) in software and ViivTM technology in hardware have already integrated electrical home appliances and PCs.

These major IT leaders believe that the concept of the "digital home" is not only a PC, they promote the idea of a connected home, whereby multiple devices can access and share multimedia content stored on a PC or a central server [1]. We can utilize a wired or a wireless network linking the PC to a large TV screen in the sitting room, and then the whole family can not only watch TV and movies, play games, listen to music, surf the Internet, receive but also dispatch e-mail on one amusement platform which has a complete set of information applications for home living.

For a long time the course of booting a PC has been the key problem. Since we are promoting the idea of a digital home, electrical home appliances must be made so that they can be instantaneously turned on. Therefore, for electrical home appliances we must increase the speed of the machine to meet the demands of the consumer. This paper proposes a design to shorten the booting time and to improve the existing PC design in the hope of achieving an instantaneous start of the machine.

There are several kinds of method for shortening such a long loading or booting time. First, one builds up the RAID (Redundant Array of Independent Disks) to increase the throughput of the hard disk or one adds more cache memory to the hard disk [2]. But there isn't any significant improvement in shortening the loading time while the systems are booting up, due to the interface throughput limitation. Second, we may be able to shorten the loading time by using "Suspend to RAM" instead of "System off" as well [3]. All the relevant OS data could be saved into the system memory while we pretend to turn off the system, and these data could be re-loaded directly when turning on the system. As this paper proposes a low-power design for the system memory to hold both the OS and the system status, thus by using our design a machine can be instantaneously turned on.

In Section 2 we analyze the resume time and power consumption of the system while in standby state [4]. In Section 3 we use the "Suspend to RAM" state instead of the "System off" state to reduce the system booting time. In Section 4 we analyze the power consumption of each module of the whole system in the standby state. In Section 5 we reduce the standby power consumption of each module. In Section 6 we draw the conclusions.

II. SYSTEM RESUME TIME AND POWER CONSUMPTION

According to Moore's Law the CPU performance doubles every 18 months. From the first Pentium CPU to the Pentium 4, which has dual core and quad core CPUs, the core clock has increased from 66MHz to 4GHz. The CPU has improved its performance more than 30 times within 10 years, but the storage device - the hard disk drive (HDD) - has only improved its performance 1.3 times within the same period. Fig.1 shows a performance comparison between a CPU and a hard disk.
When turning on the PC, the OS and a large amount of data are loaded into the memory from the HDD. With its reading speed constrained by the HDD, the system needs a long booting time. When one turns on the machine, the Pentium 4 PC takes 40 to 90 seconds to load the OS from "System off". When we set the PC standby mode to "Suspend to Disk", the OS, applications and opened documents are collected into one file, and that file is stored in the HDD. When the system is turned on a second time, the system is reloaded from the collected file, and the resume time is about 20 to 40 seconds. When we use "Suspend to RAM" as the standby mode, which is similar to the S4 state where that collected file has been stored in the system memory, the resume or reboot time is only 3 seconds. Finally, we can also set the standby mode or states to "Power on Suspend", and the resume time will now be less than 1 second.

According to the ACPI (Advanced Configuration and Power Interface) specifications, the standby modes have five states, S0/S1/S3/S4/S5, which may be described as follows [5].

S0: "System on" is the power on state for the normal working state of the computer, which means that the OS and whatever applications are running. In this state the power consumption is at its highest.

S5: "System off" is the system shutdown state, when the power consumption is at its minimum. Only the power consumption for a few devices is needed for power on.

S1: "Power on Suspend" is the first state of a standby mode. In this state the system turns off some unnecessary peripheral devices like the monitor or the hard disk to save power. But since the CPU, system memory and interface card are still working, there is only a limited amount of power saving.

S3: "Suspend to RAM" is the third state of a standby mode. In this state the main memory is still powered, although it is almost the only component in use. In this state of the OS, all applications and the opened documents are stored in the main memory; the main memory needs to consume power to maintain these stored data.

S4: "Suspend to Disk" is the fourth state of a standby mode. In this state, all content of the main memory is saved to the hard drive, the preserving the state of the OS and all applications and opened documents. The power consumption is equal to shutdown as there is no extra power needed to maintain the machine state.

The system standby state depends on the ACPI controller and the OS. When the user sets the standby mode in the OS and the BIOS, the OS requests a standby command from the ACPI controller, and the ACPI controller generates the S3#, S5#, and POK (Power OK) signals to control the system standby state.

Fig. 2 shows the state transition in the standby mode. The system initially starts-up from S5, and when S3#, S5# and POK are logic high the system turns the power on and switches into the S0 state. When the system goes into the S1 state, S3#, S5# and POK don't change. When S3# becomes low and S5# and POK stay high in S0 mode, the system switches into and stays in S3 state till S3# changes to high. When both S3# and S5# change to low and POK stays high in the S0 state, the system switches into and stays in S4 or S5 states till S3# and S5# change to high.

The S0 and S1 states are controlled by the OS; the standby mode is also controlled by the ACPI controller, while the S4 and S5 states of the standby mode or states are controlled by the OS.

Under the current ATX (Advanced Technology eXpanding) structure, the power supply of a PC can be divided into two categories: general power and standby power [6]. Except for 5VSB, which supports the standby power under both "System on" and "System off", all other power supplies are general power and are only supplied while the system is on and not at shutdown. 5VSB is supplied to the resume system: keyboard, mouse, network, modem and more. Apart from the resuming system devices, the ACPI controller also consumes standby power to manage and regulate the power in the power on, shutdown and standby modes or states.

Fig. 3 shows CPU and 5VSB power consumption in every state during practical system operation. We have measured the power consumption in every standby state. From the initial state S5 booting, the maximum CPU power consumption ranges up to 132 watts, and the average power consumption is about 84 watts. The 5VSB power consumption averages 1.75W in S5 state, 2.5 watts in S3 state and 1.5W in S4 state.
III. SUSPEND TO RAM INSTEAD OF SYSTEM OFF

Our design uses "Suspend to RAM" instead of "System off" to avoid a long booting time by utilizing high-speed transmission of the DRAM. When the system turns the power off, the OS is kept in the DRAM waiting for the next use. In such a situation the system usually takes less than 3 seconds to resume or reboot.

When in S3 state, extra power is needed for the OS to be stored into the DRAM, and the energy cost is constantly increased. In order to comply with the "ENERGY STAR(R) Program Requirements for Computers", we need to improve the power consumption of the system standby powered components, by reducing the S3 power consumption [7]. Table I shows the comparison of the power consumption and standby resume times of the standby states of a Pentium 4 system.

<table>
<thead>
<tr>
<th>State</th>
<th>S0</th>
<th>S5</th>
<th>S1</th>
<th>S3</th>
<th>S4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resume time (sec.)</td>
<td>N/A</td>
<td>40~90</td>
<td>&lt; 1</td>
<td>3~5</td>
<td>20~40</td>
</tr>
<tr>
<td>Power consumption (watts)</td>
<td>100~200</td>
<td>1~2</td>
<td>30~180</td>
<td>2~5</td>
<td>1~2</td>
</tr>
<tr>
<td>Excellence</td>
<td>N/A</td>
<td>Saves power</td>
<td>Fastest resume</td>
<td>Fast resume</td>
<td>Saves power</td>
</tr>
<tr>
<td>Defect</td>
<td>N/A</td>
<td>Slowest resume</td>
<td>Wastes power</td>
<td>Saves power</td>
<td>Slow resume</td>
</tr>
</tbody>
</table>

The standby states in Table I show that of all the standby states, S3 has the better power consumption and faster resume time. We propose the use of the "Suspend to RAM" state instead of the "System off" and shall focus on reducing the power consumption of the S3 to less than 1 watt and on reaching a lower system resume time.

IV. ANALYSIS OF STANDBY POWER CONSUMPTION

After several energy crises and environmental and ecological disasters, power-saving green computers became a goal for the PC industry. The US Environmental Protection Agency founded a joint program entitled "ENERGY STAR(R) Program Requirements for Computers" and specified requirements for energy-efficient computers. Under the guidelines, to save energy the newly revised and distributed Version 4.1 desktop computers should consume less than 2 watts of power when turned off and less than 4 watts in standby modes. This aforementioned condition is the goal for Tier 1. Tier 2 specifications, which are expected to be in place by January 2009, will require desktop computers to consume less than 1 watt when turned off and less than 2 watts while in a standby state [8][9].

If, in order to have an instant booting system, we are going to replace the system S5 state with a system S3 state, then the power consumption in the S3 state will have to meet the requirements of the S5 state in the ENERGY STAR specifications for computers. By our measurement, the power consumption of 5VSB (5V standby) is 1.4 watts at S5, 1.5 watts at S4 and 2.4 watts at S3.

The power consumption in the S3 state is 1.4 watt higher than the requirement for the S5 state in the specifications. If we can reduce the power consumption in the S3 state to 1 watt or less, it will become better to use S3 instead of S5.

Fig. 4 shows the distribution of the system standby power supply. 5VSB is the main power source in standby states; it converts to 3VSB by means of the LDO1 (Low Drop Output) power regulator, then joins 3.3V on a MOSFET switch to become 3VDUAL. 3VDUAL is used for Super I/O, ICH, network controller and clock generator. The power source of both the USB and the PS/2 ports is 5VUSB, which is 5VSB joined to 5V on a MOSFET switch. 5VDUAL, which is also 5VSB joined to 5V on another MOSFET switch, is converted by a PWM (Pulse Width Modulation) regulator into 1.8V, thus providing the power supply for the memory modules in S3 state. By means of another LDO2 this power supply is converted into a 0.9V rail, thus providing the power for the terminator of the DIMM (Dual Inline Memory Module) [10][11].

The ACPI controller controls the modes of all MOSFET switches. When the system goes into S0 state, the entire power supply is switched to normal, and when the system switches to standby state, the power supply is switched to standby. The power supply changes according to the power state of the system.
3VDUAL is provided by 3.3V in the S0 state and by 3VSB in the S3/S4/S5 states. 5VUSB is not used in the S5 state and is provided by 5VSB in the S3 and S4 states for the function of keyboard and mouse to wake the system up. 5VDUAL is used for the power supply of the memory modules in the S3 state. The current of the memory modules when the system is in the S0 state is quite considerable; it may reach 9.4A. As the memory modules do not need to keep any data in either S4 or S5 states, there is no power provided.

When we measured the power consumption of the devices using 3VDUAL and 5VSB in S3 and S5 states, the power consumption of 3VDUAL was 676.7mW for both S3 and S5, while that of 5VSB was 355mW at S5 and 1.12W at S3.

V. IMPROVEMENT OF POWER CONSUMPTION

As ACPI controller, Super I/O and ICH are necessary power management controllers for turning on the system, we cannot disable any of them.

In Fig. 4 we add in three switches for three power regulators. There are two LDO and one PWM in a power regulator. As we are trying to reduce the power consumption of the system, the power dissipation when the LDO converts the voltage levels cannot be neglected. This reaches 348.6mW for LDO1, 234mW for LDO2 and 168mW for PWM [12].

A. Turning off the USB, PS/2 and LAN Chip Power Supply

The standby power for USB, PS/2 ports and LAN is for waking the system up. So if we are not going to wake the system up using USB, PS/2 ports or LAN, we shut them down in order to save power. The clock generator is turned on in standby state to provide a 25MHz frequency to let the network chip use the WOL (Wake on LAN) function, so we can also shut down the power of the clock generator if the network chip is disabled while in a standby state. Fig. 5 shows the 3VLAN and VCC_USB1 power control circuits where we add a MOSFET as an electronic switch to control the power supply.

![Figure 5. 3VLAN and VCC_USB1 power control circuits](image)

When the system is turned on, the ACPI controller drives 5V_DRV to high to connect 3VLAN and VCC3, as shown in Fig. 5. When we enable the WOL function and the system is in standby state, 5V_DRV drives low and 3VSBDRV drives high, and the 3VLAN power comes from 3VDUAL; when we set the WOL to disable and the system is in a standby state, both 5V_DRV and 3VSBDRV drive low and turn off the 3VLAN power; this situation is the same as in the 3VLAN control circuit in that the USB and PS/2 power is controlled by the ACPI controller and Q22 [13].

B. Changing the Regulator from LDO to PWM

The efficiency of LDO1 is only 66%, as shown in Eq. (1), which means that 34% of the power is wasted and turned into heat, and the power dissipation is increased because of the load current increase.

\[
P_{\text{eff}} = \frac{P_{\text{output}}}{P_{\text{input}}} = \frac{3.3V \times I}{5V \times I} = \frac{3.3V}{5V} = 66\% \tag{1}
\]

In the 5V to 3.3V LDO circuit, when the output current is 205mA, the LDO1 power dissipation is 348.5mW. We use a higher efficiency PWM voltage regulator to reduce the power dissipation, shown in Fig. 6.

![Figure 6. PWM power regulator](image)

In the 3VSB power circuit we use the PWM to replace the LDO voltage regulator, thus reducing the power dissipation to 80mW.

C. Turning off the LDO2 Power Supply

Fig. 7 shows the LDO2 circuit, which is used to convert 1.8V into 0.9V, to provide the power for the termination resistors of the memory modules.

![Figure 7. LDO2 regulator circuit](image)

In the S3 state, the memory controller only needs to keep the data of the internal registers and does not need to give commands to the memory modules, so the 0.9V for the termination resistors is not needed. We change pins 5, 6, 7 and 8 in Fig. 7 from 3VDUAL to VCC3 to shut down the regulator. After the termination resistors are disabled, as the 234mW for the LDO2 and the 234mW for the resistors are no longer being consumed, we save a total of 468mW of power.
D. Enlarging the Value of the Divider Resistors

Fig. 7 shows the LDO2 circuit with R197 and R194 as voltage dividers for reference voltage (VREF). The static state current is 0.9mA. We enlarge the resistor value from 1kΩ to 100kΩ. There are three identical circuits within the memory circuit, the memory controller and the separate DIMMs. We change the divider resistors from 1kΩ to 100kΩ. The four VREF circuits are reduced from 6.48mW to 64.8µW altogether.

E. Improvement of the Power LED Circuits

Power consumption is a major disadvantage of the circuit shown in Fig. 8. The power LED is using a green/yellow dual color LED which is green when system is on and yellow when the system is in a standby state. The LED color is controlled by the SUS_LED and PWR_LED pins of the ACPI controller.

The PWR_LED signal and the SUS_LED signal are Open-Drain 24mA design in the chip, and since the dual-color LED cannot be driven, an extra LED driving circuit has been added.

Fig. 9 shows the improved circuit. When the system is on, SUS_LED=LOW and PWR_LED=HIGH, Q2 on and Q1 off, 5VSB goes from R1 to D1, Q2 then on. The green LED is turned on at this moment, causing a 32mA current from 5VSB to R2, Q2 then on, wasting 160mW of power. As the same problem exists on R1 and Q1 when the yellow LED is on, we change the circuit into a Push-Pull circuit and change the bi-polar components into CMOS to reduce the power consumption.

F. Improved Power Consumption

As shown in Fig. 10, we reduce the power consumption by turning off the power supply for the keyboard, the mouse, the network chip and the clock generator, and together with the improvements we have made regarding the voltage regulator and the power state indicator we reduce the standby state power consumption of the system from 2.4 watts to 0.697 watts as in Eq. (2).

\[ P_{\text{STANDBY}} = P_{\text{TOTAL}} - P_{\text{LAN}} - P_{\text{CLK}} - P_{\text{I2C}} - P_{\text{PS/2}} - P_{\text{LED}} = 2.4 - 0.462 - 0.125 - 0.268 - 0.47 - 0.1 - 0.278 = 0.697 W \] (2)

G. Comparison with Other Products

For comparison with other products we have made a graph comparing the standby mode power consumption and the resume time of five systems in Fig. 11.

In the graphs shown in Fig. 11 we use "Striker Extreme", "P5LD2", "GA945PL-S", as well as "P965 Platinum" before and after our improvement. "Striker Extreme" is especially designed for enthusiastic users; it has lots of LEDs turned on even if the system is turned off, in order to remain spectacular to look at, and of course, the power consumption is much higher than that of the others. GA945PL-S3, on the other
hand, is more focused on price-oriented users; as it has no fancy functions, it, therefore, has a better energy performance ratio. Before the circuit improvement, as the suit under test (SUT) was a product between the two "P965 Platinum" products described above, its power consumption and the booting time could not be considered to be better than those of the others. But as the result of the improved circuit, we obtain a noticeably higher energy performance ratio.

VI. CONCLUSION

As a result of our experiments, we conclude that the system memory can be a suitable storage medium to store the OS. Using the high speed of the system memory we reload the OS in a short time to achieve the goal of an instant system turn-on, and through analyzing and probing the circuits we have reduced the circuit power dissipation, thus reducing the power consumption.

A fully utilized system can boot into the OS in 3 seconds, with a power consumption of less than 0.7 watts. Both of these two categories meet the requirements of electronic home appliances and the "ENERGY STAR(R) Program Requirements for Computers" Tier 2 energy efficiency requirements, which demand the power consumption of a PC in suspension to be below 1 watt.

REFERENCES


