Using an Ultrasound Module to Reduce the Standby Power Consumption of a PC Monitor

Cheng-Hung Tsai*, Ying-Wen Bai**, Kung-Shen Lin**, Li-Chia Cheng**, Roger Jia Rong Jhang*** and Ming-Bo Lin*, Senior Member, IEEE

Abstract—In this paper we present a design using an ultrasound module to reduce the standby power consumption of a personal computer (PC) monitor. Although a PC monitor enters standby status by means of the power management of the operating system (OS) after a preset idle time and awakens when the keyboard is hit or the mouse is moved, this way of entering standby status is not efficient for the monitor which still consumes 0.3–1 W of power in standby status. Our design features a socket to plug-in the PC monitor, which enters standby status more efficiently, consuming 0.008 W. This socket supplies the monitor with power when a user is detected by the ultrasound module; when the user leaves it turns the monitor off without using an idle timer, and the electric power is cut off by the solid state relay (SSR) controlled by the micro control unit (MCU) to reduce the standby power.

Keywords—ultrasound sensor; standby power; SSR; power consumption; PC monitor

I. INTRODUCTION

A typical office PC might consume 90 W when active, i.e. approximately 50 W for the base unit, 40 W for a typical liquid crystal display (LCD) screen and 0.3 to 1 W when in standby status [1]–[3]. The power management features are standard in common operating systems which are based upon an idle timer. If the PC is idle for longer than the preset timeout it may be configured to either standby or hibernate status. The OS uses a combination of user activity and CPU activity to determine when the PC is idle. The power management causes the monitor, the hard disk (HD) or the CPU to enter its low-power standby status individually after a preset idle time. By simply either hitting the keyboard or moving the mouse the computer or monitor awakens from its standby status in seconds [4]. The monitor enters standby status after a preset idle time that is not sufficiently exact. With the user leaving and the CPU still busy, the monitor cannot enter standby status, although in such a situation it should. When the CPU is idle and the user may be in the front of the monitor, then the monitor enters standby status by means of the power management function, although in that case it should not. In this paper a simple design with an ultrasound module is added to solve this problem. In the standby status of the PC the devices mentioned do not completely cut off; they continue to consume some power which is called standby power [5]–[9]. HD and CPU need standby power to keep the necessary data for awakening. The monitor does not need temporarily stored display data and could therefore be completely cut off while in standby status. Unfortunately for general PC monitors, the consumption of power is between 0.3 and 1 W when they are in standby status. The standby power is consumed in an inside ac/dc converter which serves as a power supply for the monitor, converting ac voltage to dc voltage for the monitor display. The converter even still consumes power even while the monitor does not display anything on its screen. However, this standby power should be either reduced or eliminated. In this paper a design called “PC monitor power management socket” is proposed both to reduce the standby power and to enter the standby status more exactly. When the user appears the ac power is immediately supplied by the socket to the monitor. The monitor then shows a display, and when the user leaves the ac power is cut off completely by the socket and the monitor becomes dark. The PC monitor standby power can be decreased to 8 mW by means of the socket. This socket turns the monitor on when the user is in front of the monitor and off when the user leaves, saving energy more efficiently.

The organization of this paper is as follows. Section II presents the circuit designs of the socket. Section III presents the measurement of the power consumption of this design to verify the total power saved. Section V presents the implementation prototype of the socket. In Section IV the conclusion is drawn.

II. CIRCUIT DESIGN OF THE PC MONITOR POWER MANAGEMENT SOCKET

The PC monitor still consumes standby power in standby status. The power consumption cannot be switched off completely without the converter being unplugged. If the monitor is fitted with the PC monitor power management socket, the ac source of the monitor can be switched off to reduce the standby power. Thus the main concept of this design is to cut off the ac source of the monitor when there is no user present, and to turn it on when a user appears, so as to save energy more efficiently [10]–[12]. There are three state of the socket operation defined in this paper: the cut-off state, the standby state and the display state. Fig. 1 shows the state transition of the PC monitor power management socket.

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978-1-4673-4623-8/13/$31.00 ©2013 IEEE 717
The standby state in Fig. 1 means that if the user leaves, the PC monitor is not in use, and the ac power source is completely cut off as if the unit had been unplugged to reduce the standby power consumption. The display state means that if the user is approaching, the PC monitor uses the ac power source provided by the socket as if the unit had been plugged into the ac socket. If the user stays in front of the monitor, the ac power source is provided by the socket continuously. The cut-off state means that the socket is unplugged from its power source and does not consume any electricity. Figure 2 shows the block diagram of this design. The PC monitor power management socket is made up of an MCU, an ultrasonic module, a dc voltage module and a start button module. The design also includes an ac/dc converter to provide power for the socket operation. This converter still consumes standby power which the dc voltage module is designed to reduce. The ultrasound module senses whether a user appears. When a user appears the main power SSR (MPSSR) turns on the ac power to the monitor, when the user leaves the ac power is cut off completely by the MPSSR [13] [14]. The ultracapacitor (UC) is an energy storing element that stores the dc voltage energy provided by the converter [15] [16]. The \( V_{UC} \) detector circuit detects the UC voltage to determine when to charge or stop charging the UC. The operation voltage of the socket is supported by the boost circuit that transfers the energy provided by the UC. The start button module is designed to charge the dc voltage module at initialization.

A. Ultrasound module

Our design adopts an ultrasound module to detect whether a user is approaching. An ultrasonic pulse is generated in a particular direction. If there is an object in its path, part or all of the pulse will be reflected back to the transmitter as an echo and can be detected through the receiver path. By measuring the difference in time between the pulse being transmitted and the echo being received, it determines how far away the object is. The MCU only needs to supply a short 10 \( \mu s \) pulse to the trigger input to start the ranging. The ultrasound module sends out an 8-cycle burst of ultrasound at 40 kHz and raise its echo line high. It then listens for an echo, and as soon as it detects one it lowers the echo line again. The echo line is therefore a pulse whose width is proportional to the distance to the object. The maximum detection range is 3 meters. In general, the distance between user and monitor is less than 50 cm and not affected by objects or walls that are closer to the user. The ultrasound module timing diagrams are shown in Fig. 3.

The MCU judges the received echo signal and causes the MPSSR ctrl+ pin to be high whenever the ultrasound module detects a user’s appearance within 50 cm of the monitor. Otherwise, the ctrl+ pin is low. When the ctrl+ pin is high, the MPSSR is turned on to provide ac power to the monitor. If the MPSSR is turned off, the ac power is cut off completely to reduce the standby power. For lower power consumption the ultrasound module is not always turned on and triggered to detect whether a potential user is approaching, because that user’s moves are not as fast as the electronic signal of this design. Hence the module is turned on and triggered every 1 sec by the MCU. During each sec, the MCU is in sleep mode and the ultrasound module is turned off to save power. The circuit design of the ultrasound module is shown in Fig. 4. The MCU uses the NMOS \( Q_1 \) as a switch to turn on the module.
and trigger to detect whether a user is approaching. The signals of the ultrasound module are shown in Fig. 5. The power consumption of the situations is listed in Table I.

**Figure 5. Ultrasound module circuit design.**

**Figure 6. Ultrasound module circuit signals.**

**FIGURE 5.** Ultrasound module circuit design.

**FIGURE 6.** Ultrasound module circuit signals.

**TABLE I**

<table>
<thead>
<tr>
<th>Situation</th>
<th>Power consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCU sleep mode</td>
<td>2 μW</td>
</tr>
<tr>
<td>Ultrasound module turned off</td>
<td>2 μW</td>
</tr>
<tr>
<td>MPSSR turned off</td>
<td>2 μW</td>
</tr>
<tr>
<td>MCU active mode</td>
<td>15 mW</td>
</tr>
<tr>
<td>Ultrasound module triggered and turned on</td>
<td>140 mW</td>
</tr>
<tr>
<td>MPSSR turned on (user appears)</td>
<td>140 mW</td>
</tr>
</tbody>
</table>

**B. dc voltage module**

The dc voltage module supplies the VCC to the socket design which consists of a boost circuit, a VUC detector circuit, a limiter circuit and a UC. The MCU controls the VUC detector circuit and the boost circuit to keep both VUC and VCC to the predefined voltage levels. The UC thus functions as a battery supporting the boost circuit input. The VUC detector circuit supplies the normal VUC to the boost circuit. The boost circuit outputs the regular voltage VCC which supports the MCU and the operation of other modules. The limiter circuit limits the charge current to the UC.

**1. Boost circuit**

The boost circuit uses a dc-dc converter as the boost regulator. It provides an easy-to-use power supply solution for MCU applications powered by batteries. In this design the UC supports the boost regulator’s input voltage (VUC) as a battery. Fig. 5 shows the boost circuit.

**Figure 6. Boost circuit design.**

The input voltage of a boost circuit is VUC, and the output voltage is VCC. The input voltage VUC must be kept to sufficient values between VUCmin and VUCmax to result in an output of VCC=5 V. The values of VUCmin and VUCmax are determined by the method [10]. In Fig. 6 the boost regulator is not always enabled. Making the MCU I/O output low and turning off the NMOS QE causes the boost regulator to be enabled. Subsequently the input voltage (VUC) of the boost regulator is increased from 0 V to 2.5V, and then decreased from 2.5 V to 0 V by a programmable power supply and thus measures the output voltages VCC. The result is shown in Fig. 6. The circuit operations of the MCU and the other modules require VCC=5 V in the MCU active mode. Thus by means of the measurement curves the VUCmin is determined at 1 V. The VUCmax is determined at 2.4 V because the UC breakdown voltage is 2.7 V, and charging becomes inefficient when the VUC is above 2.4 V. The boost regulator produces low voltage to support our design operation by means of a single UC. Without the boost circuit, as the design needs two UCs to support operations, we need to reduce the number of UCs.

**Figure 7. VCC in respect to VUC of boost regulator.**

When the MCU is in the sleep mode it requires a minimum of VCC=2.1 V to operate while other module circuits do not need any operation voltage VCC. Thus the boost regulator operating in the disabled mode lowers the input current consumed from the UC by using the MCU in the sleep mode. Therefore the MCU first operates in the sleep mode, then wakes up to the active mode every 1 sec to pump up the VCC to 5 V and turn on the ultrasound module to detect any user approaching. The output voltage VCC and the control signals in the MCU sleep and active modes are demonstrated in Fig. 8.

![Diagram](image-url)
2. **V_{UC} detector circuit and limiter circuit**

As mentioned earlier, the ac/dc converter still consumes power without any load on the dc output. To overcome this problem, our design includes the V_{UC} detector circuit and the limiter circuit which are shown in Fig. 9. The ac/dc converter’s dc output V_{dc} is the power source that provides the UC with a current of a sufficient charge. The limiter circuit limits the charge current from the ac/dc converter to the UC to protect the circuit.

The latching relay is set on the primary side of the ac/dc converter as a switch controlled by the MCU. It can have 2 coils, no default position and remain in its last position when the drive current stops flowing. This arrangement is useful in limiting power consumption because, once actuated, no parts of the circuit require any current flow to maintain their position. When starting, the armature closes the reset contact in Fig. 9. The latching relay provides ac power to the ac/dc converter until the UC has been charged to V_{UCmax}. After this, the MCU causes the Q_S turned on to provide energy to the set coil, and the induced magnetic field moves the armature, which closes the set contact that does not provide power to the converter, which means that the input ac power is cut off completely by the latching relay.

The UC voltage V_{UC} is connected to the analog-to-digital converter (ADC) of the MCU that digitizes an analog input signal V_{UC} to an 8-bit binary representation of the V_{UC} voltage. In this design the V_{UC} must be within the range of V_{UCmin} and V_{UCmax} for the V_{CC}=5 V. The ADC reference voltage is fixed in the MCU active mode that represents the value of the ADC accurately enough. The MCU detects the value representing the V_{UC} to judge when to charge and to stop charging the UC. The MCU detects if the V_{UC} is below V_{UCmin} and then causes the Q_R to turn on; hence the ac/dc converter charges the UC, and the V_{UC} increases. After the ac/dc converter has charged the UC, the V_{UC} reaches V_{UCmax}. Then the MCU causes the Q_S to turn on thus stopping the charge. After stopping the charge, the UC discharges for the socket operation until the V_{UC} below V_{UCmin}. Since in our design the MCU detects whether the V_{UC} is at a normal level between V_{UCmin} to V_{UCmax}, this design saves both power and cost. When the user leaves and the monitor is in the standby status, the ac/dc converter of the PC monitor power management socket consumes power only when the UC is charged. If the UC is discharged, the ac/dc converter is cut off, and the power consumption is zero. If there is a power failure and if the V_{UC} has decreased to 1.2 V, the MCU causes the armature of the latching relay to move to the reset contact, but as the UC cannot be charged, the V_{UC} keeps decreasing until the MCU shuts down. With power restoration, as the armature of the latching relay still connects to the reset contact, the UC would be auto charged to support this design.

### III. MEASURING THE POWER CONSUMPTION OF THIS DESIGN

The V_{UC} and the ac power consumption with respect to charge and discharge times are shown in Fig. 9.

#### A. ac/dc converter standby power

In this design the standby power of the ac/dc converter used in Fig. 1 is 1 W; the V_{UC} detector circuit is designed to reduce the power consumption of the converter. The power consumption of the discharge time is 0 W and that of the charge time is more than 8 W. The charge and discharge of the UC are a cycle whose time is
\[ T_{cycle} = T_{charge} + T_{discharge} \]  

The average power is denoted in \( T_{cycle} \) as \( P_{ave} \) and

\[ P_{ave} = \frac{\sum P_{charge} + \sum P_{discharge}}{T_{charge} + T_{discharge}}, \sum P_{discharge} = 0 \]  

Thus \( P_{ave} = \frac{\sum P_{charge}}{T_{cycle}} = 0.008 \text{ W}. \)  

The improvement is 99.99%.

The socket reduces the power consumption of the PC monitor in standby status. There are several monitors of different brands in an electric appliance store. Four typical products denoted as monitors A, B, C and D measure the power consumption both with and without the socket in standby status. The power consumption is shown in Table II.

### Table II

<table>
<thead>
<tr>
<th>Type</th>
<th>Size</th>
<th>Standby power without the socket</th>
<th>Standby power with the socket</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitor A</td>
<td>15”</td>
<td>1 W</td>
<td>0.008 W</td>
</tr>
<tr>
<td>Monitor B</td>
<td>17”</td>
<td>0.5 W</td>
<td>0.008 W</td>
</tr>
<tr>
<td>Monitor C</td>
<td>19”</td>
<td>0.3 W</td>
<td>0.008 W</td>
</tr>
<tr>
<td>Monitor D</td>
<td>22”</td>
<td>0.3 W</td>
<td>0.008 W</td>
</tr>
</tbody>
</table>

B. Start button module

A latching relay is factory-set to the reset state for shipment. Thus the \( V_{UC} \) detector circuit could auto charge when the PC monitor is first plugged into ac power. However, it may set again while being transported, due to vibration or shock. If it is first plugged into ac power, there is no electric power in the UC and the latching relay connects to the set contact. Therefore the UC cannot be charged, the MCU does not work, and the PC monitor is always in the cut-off state. To prevent such a situation, a start button is placed in the circuit to make sure that the relay is reset when the PC monitor is first plugged into ac power and there is no electric power in the UC at the beginning of the operation. The start button module circuit design is shown in Fig. 11. The start button circuit includes five contacts: three normal open (NO) and two normal close (NC). If the latching relay connects to the set contact and there is no electric power in the UC, the user just presses the start button. The line power is then connected to the converter by the NO1, the UC charge path is turned off by the NC2 since the \( V_{dc} \) rises to 3 V immediately, and the \( V_{dc} \) is connected to the reset coil of the relay by the NO2 at the same time. The reset coil is enabled and the relay is reset. After the button release, the circuit in Fig. 11 is the same as that in Fig. 9. The UC is being charged at the beginning of the operation. The switching time from pressing the button to the relay reset is less than 20 msecs, and the user just needs to touch the start button once at the beginning. The signals of the start button module at first charge when there is no electric power in the UC are shown in Fig. 12.

C. Implementation result

The latching relay and the MPSSR are integrated in a main PCB. The Ultrasound module is integrated in another, separate PCB. These are shown in Fig. 13.

IV. CONCLUSION

A PC monitor wastes much power in the long run, although its standby power is not great. In this paper a new circuit design with an ultrasound module, an SSR, interface circuits and a low-power microcontroller is proposed which reduces the standby power substantially. The power consumption of our design is only 8 mW, which is much less than of those without the socket. In addition the PC monitor socket enters a standby status more efficiently. In daily use the monitor is more in standby status than in display status, so this design is power saving. If the user is often in front of the monitor, the power saving is not as effective as could be expected.
REFERENCES


