PIR-sensor-based Lighting Device with Ultra-low Standby Power Consumption

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Abstract—In this paper we present a way to reduce the standby power consumption of a PIR-sensor-based lighting device. Generally although a PIR-sensor-based lighting device will turn on when motion is detected, and will turn off when the motion disappears, the device still consumes 1-3 W power when the lamp is off. In our design the device consumes 0.007 W when the light is off, and is not only easy to set up but also inexpensive. Our circuit supplies the lamp with power when motion is detected; when the motion disappears it turns the lamp off, and the electric power is shut off in order to reduce the standby power. We use an MCU which receives signals from a PIR sensor which detects any individual approaching the device. The MCU controls the SSR On/Off when used as a lighting switch for shutting off the standby power. The MCU monitoring program provides automatic detection of any individual by means of the PIR sensor. The MCU has internal modules to simplify the hardware circuit design. The circuit component count, cost and power consumption are low.

Keywords: PIR-sensor-based Lighting Device, Standby Power, PIR, SSR, Power Consumption

I. INTRODUCTION

The pyroelectric infrared (PIR) sensor-based lighting device is now in widespread use. This device with its built-in PIR sensor cuts the electricity when no user is near the PIR sensor. The PIR sensor turns the light on instantly when someone enters the room, and off after the individual exit. Thus a PIR-sensor-based lighting device saves one from fumbling for that light switch or leaving lights on for hours on end which is great for both energy saving, security and safety. And because the device only comes on when the PIR sensor is activated, no energy is wasted. The light is suitable for a number of locations, including the laundry room, attic, basement, pantry, closet, kitchen, path light, outdoor wall lantern, hallway, garage, bathroom and even children’s rooms. But the device cannot be switched off completely without being unplugged. In this paper we define three states of the PIR-sensor-based lighting. In the standby state the lighting device is connected to a power source but does not produce light. In the active state the device’s light is on when the PIR sensor is activated. The cut-off state means that the device is unplugged from its power source and does not consume any electricity. The lighting device in standby state draws power 24 hours a day. We call the power consumption, used while there is no light and the device is plugged in the power socket “standby power”. This amount is typically small, but the sum of the standby power consumption of all PIR-sensor-based lighting devices within a household becomes significant [1]-[5]. Though the lighting device in standby state is not performing its main function of lighting it is often performing some secondary function like sensing IR and ambient light that cannot be switched off unless the unit is unplugged. This secondary function requires not only a specific low DC voltage to operate but also a continuous power supplied by an AC/DC converter which has no power-off switch. The AC/DC converter as a power supply in the lighting device converts AC 120 V into low voltage DC for the secondary function operation [6]. The AC/DC converter, which is very inefficient at low DC voltage, has a power consumption between 1 and 4 W, which is many times more than the power actually used for the secondary function. Therefore, in the long run, the PIR-sensor-based lighting device consumes much power while in the standby state.

In 2000 the International Energy Agency (IEA) adopted a proposal to reduce the standby power of all electrical apparatus to less than 1 Watt within ten years [7]-[9]. Thus it is imperative to develop new techniques to reduce the power consumption in electronic circuits. A recently published survey shows that various attempts have been made to reduce such power leakage to make the adapter more efficient [10]-[13]. Another way to improve efficiency is accurate control of the apparatus by both software and microcontroller [14]-[16].

In this paper we present a design to reduce the standby power consumption of the PIR-sensor-based lighting device. The standby power consumption of our design is reduced to 7 mW [1]. We call our design “ultra-low standby power PIR-sensor-based lighting”. It is also easy to set up, inexpensive, and saves power more efficiently. Consequently it is suitable for use in most locations. In the long run the lighting saves much more power.

The organization of this paper is as follows. In Section II we present the circuit designs and a flowchart of our design. In Section III we present the measurement of the power consumption of our design to verify the total power saved. In Section IV we draw the conclusions.

II. CIRCUIT DESIGN OF THE ULTRA-LOW STANDBY POWER PIR LIGHTING

The PIR-sensor-based lighting device is turned on only when motion is detected. When motion disappears, the time when the light is switched off, and the duration of the lighting can be adjustable. The lighting device has an ambient light
sensor to detect ambient light. If the ambient light suffices, the lighting is not turned on even if any motion is detected. On the contrary, the lighting device will immediately turn on when motion is detected. Both the threshold of the ambient light and its duration time are adjustable. The adjustable duration of lighting, the sensing of ambient light and its threshold are all internal functions of the PIR lighting device.

In general, the PIR-sensor-based lighting device is plugged into AC 120 V as its power source. The internal modules in the lighting require low DC voltage to operate, and this is supplied by an AC/DC converter which as the power supply in the lighting device converts AC 120 V into low voltage DC for the operation of the internal module functions [5]. The converter is inefficient at low voltage; in the long run the lighting device consumes much power in the standby state.

This consumption of the PIR-sensor-based lighting device standby power is mainly the necessary power consumption of the AC/DC converter that supplies secondary functions in the standby state whose consumption is many times more than the power actually used by the lighting device in the standby state. To reduce the standby power, the converter is cut off. The main idea of our circuit design is that if the user is not in the vicinity of the lighting device, as it is not being used, it should be in the cut-off state, so it won’t use any unnecessary standby power. All power can be cut off completely by means of a solid state relay (SSR). Therefore we present a simple design to reduce the total amount of standby power. The block diagram of our design is shown in Fig. 1. When the user is detected by the PIR sensor module, the main power SSR for the lamp stays turned on. Conversely, if the PIR sensor module doesn’t detect the user, the main power SSR is turned off as if the lamp were unplugged. The operation voltage detector, the ultracapacitor and the ultracapacitor charge SSR are designed to reduce the AC/DC converter power consumption.

The ultracapacitor charge SSR and the main power SSR which are normally open are turned off initially. Thus at first the ultra-low standby power PIR-sensor-based lighting is plugged into an AC power source. As there is no power in the ultracapacitor, the MCU can’t work; thus both SSRs are turned off and no electricity flows into the lighting. As the lighting device can’t work, the ultracapacitor charge SSR load terminal. First, the user presses the start button in the circuit that parallels the ultracapacitor charge SSR load terminal. First, the user presses the start button to charge the ultracapacitor for 10 secs to provide the MCU start work power. After the MCU begins its work, the ultracapacitor charge SSR is turned on to charge the ultracapacitor in order to achieve sufficient normal operation voltage value, at which time the SSR is then turned off. For the first time, after the user presses the start button for 10 secs, the lighting device is plugged into the AC power source. After this, the lighting works well automatically.

The ultracapacitor thus functioning as a battery supports the whole circuit operation. If there is no motion detected, the MCU goes into the sleep state and the peripheral circuit is cut off to save power. When any motion is detected or if the operation voltage is lower than the predefined value, the MCU wakes up from its sleep state and turns the SSR on. When the operation voltage is lower than the predefined value, the ultracapacitor charge SSR is turned on to charge it until the operation voltage is raised to a normal level. If any motion is detected and the ambient light is below the threshold, the main power SSR supplies power to the lamp for the duration of the lighting. The SSR supplies the main power to the lamp until the duration of the lighting, which is adjustable.

The AC/DC converter which is very inefficient at low DC voltage, still consumes power when the primary function is provided by the power source without any load in the DC output. To overcome this problem we have designed the...
The ultracapacitor as a battery supports the secondary function of the device. The ultracapacitor voltage is the secondary function operation voltage (VCC). The AC/DC converter DC output is the power source that provides the ultracapacitor with a current of a sufficient charge when its voltage is lower than a predefined value. The ultracapacitor charge SSR is set on the primary side of the AC/DC converter as a switch controlled by the MCU. Both VOV+ voltage and VOV- voltage are connected to the MCU comparator 1 module. The MCU judges when to charge the ultracapacitor by means of the comparator 1 module output. To save power the MCU controls NMOS Q1 as a gate; when the voltage signals are needed by the comparator 1 module, the Q1 is turned on; otherwise it is turned off. The operation voltage detector module circuit works only during the ultracapacitor discharge time and only if the voltage decrement is less than 1 mV per second. Thus the MCU just turns on both the NMOS Q1 and the comparator 1 module to detect the operation voltage every 2.3 secs; that is enough to get an accurate judgment and consumes less power. The highest operation voltage for the whole circuit is 4.2 V and the lowest is 3.1 V. Between these voltages the circuit operates normally. The breakdown voltage of the ultracapacitor is 2.5V. To increase the breakdown voltage there are two ultracapacitors connected in series. We decrease the VCC from 4.2 V to 3.1 V and measure VOV+ and VOV-. The voltage relationship of the operation voltage detector circuit is shown in Fig. 4.

When VCC = 4.2 V, VOV+ = 2.27 V, VOV- = 2.73 V
VOV+ < VOV- ⇒ Comparator 1 output = 0 ⇒ Discharge
When VCC = 3.1 V, VOV+ = 1.75 V, VOV- = 1.74 V
VOV+ > VOV- ⇒ Comparator 1 output = 1 ⇒ Charge (1)

At the start, the user presses the start button on the device for 10 secs to charge the ultracapacitor and provide the necessary MCU start work power. After the MCU starts, the ultracapacitor charge SSR is turned on to charge the ultracapacitor to achieve a sufficient normal operation voltage value. The timing diagram of the socket’s first charge is shown in Fig. 5.

In our measurement the charge time for the ultracapacitor from 3.1 V to 4.3 V is 74 secs. After that the MCU uses the timer to determine the charge time and turns off the SSR. Then the lighting device consumes power from the ultracapacitor. As a result the ultracapacitor enters the discharge state and the VCC voltage decreases. When the VCC has decreased to 3.1 V, the MCU not only detects this by means of the comparator 1 module but also causes the SSR to turn on so that the AC/DC converter charges the ultracapacitor thus raising the VCC. After the converter has charged for 74 secs and the VCC has reached 4.2 V, the MCU causes the SSR to turn off, thus stopping the charge. Since the design keeps the MCU continuing to detect whether the VCC is rising to a level of 4.2 V, we save both power consumption and cost. Fig. 6 shows VCC and power consumption with respect to charge and discharge time.
In Fig. 6 the first charge time, which is 95 secs, consumes more power. This value has been derived from experimental measurements. Charging the ultracapacitor from 3.1 V to 4.3 V requires 74 secs and consumes less power than the first charge. In our design, the operation voltage detector module circuit is designed to reduce the power consumption of the AC/DC converter. The power consumption of the discharge time is 0 W and that of the charge time is more than 4 W. The charge and discharge of the ultracapacitor are a cycle whose time is \( T_{cycle} = T_{charge} + T_{discharge} \).

We denote the average power in \( T_{cycle} \) as \( P_{ave} \) and

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

thus \( P_{ave} = \frac{\sum P_{charge}}{T_{cycle}} = 0.007 \) W. (3)

The percentage of improvement is 99.3%:

\[
\frac{\text{Power consumption}}{\text{Power consumption without design}} = \frac{1 \text{ W} - 0.007 \text{ W}}{1 \text{ W}} = 99.3 \%
\]

### B. PIR sensor module circuit

The PIR sensor is used as an electronic device to measure the infrared light radiating from objects or human bodies nearby to detect whether the user is approaching or not, in order to decide whether the main power SSR should supply power to the lamp. The PIR sensor detects motion and generates a signal which is amplified and digitalized by the PIR motion detector IC. This chip takes the output of the sensor and does some processing on it to output a digital pulse from the analog sensor. The output signal is active high and is sent to the MCU external interrupt input pin (INT) to judge whether a user is approaching. The INT interrupt wakes up the MCU from the sleep state. Fig. 7 shows the PIR sensor module circuit. The circuit output signal triggers the MCU external interrupt at VCC=3.1 V and 4.2 V. The MCU then turns on the main power SSR for the duration of the lighting, which is convenient for the user. Fig. 8 shows the PIR sensor circuit module output signal at VCC=3.1 V and 4.2 V.

![PIR sensor module circuit](image)

### C. Ambient light sensor module circuit

In order to save energy, when the ambient light suffices, the lighting device is not turned on even if motion is detected. We use a photoresistor whose resistance decreases with increasing incidental light intensity to sense the light intensity. In the ambient light sensor module circuit, the \( V_{AL+} \) voltage increases the incidental light intensity and the \( V_{AL-} \) is the ambient light threshold, whose the value is adjustable by \( R_{AL2} \). Both \( V_{AL+} \) and \( V_{AL-} \) are connected to the MCU comparator 2 modules. The MCU judges whether to light the lamp by means of the comparator 2 module output. To save power the MCU controls NMOS \( Q_2 \) as a gate. When motion is detected, the \( Q_2 \) is turned on to sense ambient light; otherwise the \( Q_2 \) is turned off to save power. Fig. 9 shows the ambient light sensor module circuit.
D. Lighting duration module circuit

The lighting will be on only when motion is detected and
the ambient light is not sufficient; moreover, the duration of
the lighting is adjustable. The duration is controlled by \( V_{AIN} \) voltage that is adjustable by the user. The \( V_{AIN} \) is inputted to
the MCU analog-to-digital converter (ADC) module input
channel (AIN) to set the timer module count that determines
the lighting duration. Fig. 10 shows the lighting duration
module circuit.

![Fig. 10. Lighting duration module circuit.](image)

To save power the MCU also controls NMOS \( Q_3 \) as a gate;
when the voltage signals are needed by the ADC module the
\( Q_3 \) is turned on to determine the timer module count;
otherwise it is turned off to save power. When motion is
detected and the ambient light does not suffice, the MCU turns
on the main power SSR to light the lamp for the duration
controlled by the adjustable \( V_{AIN} \) voltage.

E. Implementation

Fig. 11 depicts our ultra-low standby power PIR-sensor-
based lighting device circuit design. We integrate the operation
voltage detector module circuit, PIR sensor module circuit,
ambient light sensor module circuit, lighting duration module
circuit and the ultracapacitor with the MCU in a board as
shown in Fig. 12.

![Fig. 11. Circuit of a ultra-low standby power PIR-sensor-based lighting
device.](image)

III. MEASURING THE POWER CONSUMPTION OF THE PIR-
SENSOR-BASED LIGHTING DEVICE

Our design, the ultra-low standby power PIR-sensor-based
lighting device, still requires power to work. Fig. 6 shows the
average power consumption is 0.007 W when no user
approaches and the lamp is not lit. Table I shows the
breakdown of the power consumption of each module in our
design when \( V_{CC}=4.2 \) V. In our design, as the operation
voltage is not a fixed value that make difficult to measure
power consumption. Thus, we fixed \( V_{CC}=4.2 \) V to measure
the power consumption.

<table>
<thead>
<tr>
<th>Module</th>
<th>Power consumption when ( V_{CC}=4.2 ) V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sleep mode</td>
</tr>
<tr>
<td>MCU</td>
<td>( 4.2 \times 0.28 ) mA</td>
</tr>
<tr>
<td>Operation voltage detector module</td>
<td>( 4.2 \times 0.58 ) mA</td>
</tr>
<tr>
<td>PIR sensor module</td>
<td>( 4.2 \times 0.05 ) mA</td>
</tr>
<tr>
<td>Ambient light sensor module</td>
<td>( 4.2 \times 0 ) mA</td>
</tr>
<tr>
<td>Lighting duration module</td>
<td>( 4.2 \times 0 ) mA</td>
</tr>
<tr>
<td>Total power</td>
<td>( 1.386 ) W</td>
</tr>
</tbody>
</table>

The power consumption of our design is lower than that of
other PIR-sensor-based lighting devices. There are several PIR-
sensor-based lighting devices of different brands in electric
appliance store. We use three typical products and measure the
power consumption, that are denoted as product A, B and C. The power consumption of our design against these products with no user approaching and the lamp not light is shown in Table II.

<table>
<thead>
<tr>
<th>Type</th>
<th>Standby power consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultra-low standby power PIR-sensor-based lighting device (Our design)</td>
<td>0.007 W</td>
</tr>
<tr>
<td>A: PIR lighting device</td>
<td>1.2 W</td>
</tr>
<tr>
<td>B: PIR lighting device</td>
<td>1.5 W</td>
</tr>
<tr>
<td>C: PIR lighting device</td>
<td>1.4 W</td>
</tr>
</tbody>
</table>

The AC/DC converter inside the PIR lighting device consumes power when the lighting device is in the standby state. In our design, as the main power SSR is used to cut off power from the AC source, the standby power for the lighting device is eliminated. Although our design still includes an AC/DC converter, it requires an even smaller amount of power than others because as our design consists of circuit included in a few common low-power consumption components, the converter is not in use during most of time. Thus its required standby power is much less than that of other PIR lighting devices.

IV. CONCLUSION

Although the standby power of a PIR-sensor-based lighting device is not great, it affects the electricity bill in the long run. In this paper we propose a new design which, by using fewer circuit components, reduces the standby power substantially. In addition, the power consumption is less than that of other PIR-sensor-based lighting devices. Our new design, the ultra-low standby PIR lighting device which consumes 0.007 W, is both easy to set up and inexpensive. Moreover, the long run our design saves much more power.

REFERENCES


