Remote Power Switch to Make Standby Power of Infrared Remote Controlled Product Zero

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***Abstract*—This paper proposes a novel power supply circuit that can make a standby power consumption of an infrared remote (IR) controlled product completely zero. In our proposal, the ground or power line of IR controlled product in standby mode is disconnected by a power transistor. Thus, the power consumption is zero because there is no electric current path. When the user pushes the power-on button on the IR remote controller, the strong infrared light is irradiated. The infrared photodiodes attached to the IR controlled product generates the electromotive force by receiving the infrared light. This electromotive force drives the power transistor and the disconnected ground or power line is connected. As a result, the IR controlled product in standby mode with zero power is activated without any power consumption. The activated product keeps the connection of the ground or power line, and can continue to be controlled by the same single remote controller. The experimental result demonstrates that our power circuit actually achieves the zero standby power consumption while the conventional power circuit consumes the adequate standby power to be activated by the IR remote controller. The estimation indicates that our proposal does not affect the battery life of IR remote controller although the strong infrared light has to be generated.**

***Index Terms*—energy harvesting, power, standby, remote, photodiode, infrared.**

I. Introduction

THE standby power consumption of the electronic products occupy about 6% of the total power consumption in common households annually [1]. Thus, the standby power consumption of worldwide common households may be badly affecting the environment of the earth.

To reduce the standby power, we have to disconnect the power cable of the electronic product from the power strip. If there are many cables in the power strip, we have to find out the correct cable to be disconnected. The power strip also tends to lie behind the electronic products and furnitures. We have to pick up the power-strip through the crowded things. Alternatively, the standby power can be removed by turning off the main switch of the electronic product. However, when activating the electronic products, we have to get closer to each product, turn on the main switch again, seek the remote controller, and operate the electronic product. Since these are very inconvenient job, we tends to give up easily as daily custom.

To tackle these problems, several technologies have been proposed [2]–[5].

One of the most intuitive approaches is to use the photovoltaic. In [2], the photovoltaic constantly charges an ultra-capacitor. The electronic product in the standby mode uses the power previously charged in this ultra-capacitor instead of AC commercial power. However, the large photovoltaic panel is needed and the photovoltaic cannot charge the capacitor well in the indoor space without enough illumination intensity.

Similarly, Tanizawa et al. have attempted to reduce the standby power by using an ultra-capacitor [3]. Instead of the solar photovoltaic, they charge the ultra-capacitor via AC commercial power. When the product is standby mode, the product consumes the power charged in the capacitor, instead of the AC power supply. Thus, they claim that the standby power can be zero virtually. However, this technology consumes the power beforehand charged in the capacitor, which will be consumed in the standby mode. As they say, this technology can make the standby power zero virtually, but not actually.

Fukuoka et al. have developed a system-on-a-chip (SoC) with some energy efficient features [4]. They set unused components in the SoC to a low-power mode by the sophisticated scheduling method. They also developed a real device by the LSI process technology with low-leak current. Although the power consumption can be reduced significantly, the standby power still exists. The SoC is generally used to build a micro-controller which is one of the components constructing the electronic product. The electronic products consist of many discrete components like LCD panel, speaker, hard disk, DC-DC converter, several sensors and actuators in addition to the micro-controller. To eliminate the standby power completely, not only the micro-controller but also other discrete components constructing the electronic product have to be switched off.

Druml et al. have proposed an usage of the near field communication interface (NFC) transferring the power via a magnetic field to remove the standby power of the target product [5]. The radio frequency identifier (RFID) tag system is one of the applications of the NFC. The target product is completely switched off in the standby mode. The reader emits a magnetic field to activate the target product. The antenna in the target product generates the power by receiving this magnetic field. By using the electromotive force generated by the antenna, a power supply control part in the target product connects a power switch disconnecting its own power supply rail. Thus, the target product can be activated with zero power while the standby power is zero. However, to activate the products, the user must approach the target products and attach the reader to each magnetic field directly. This burden seems to be equal to the burden of which we turn off each main switch of the products or disconnect each power plug on the power strip. Most of electrical house appliances employ the infrared remote controller to be remotely controlled. Thus, we have to use individually its own IR controller to operate the target product in addition

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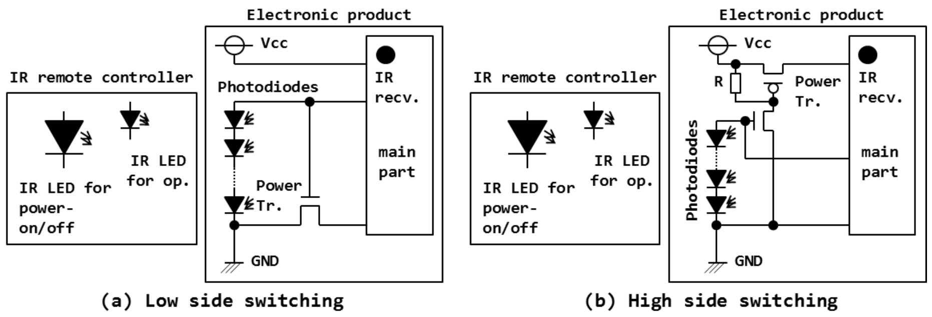

Fig. 1. Conceptual organization.

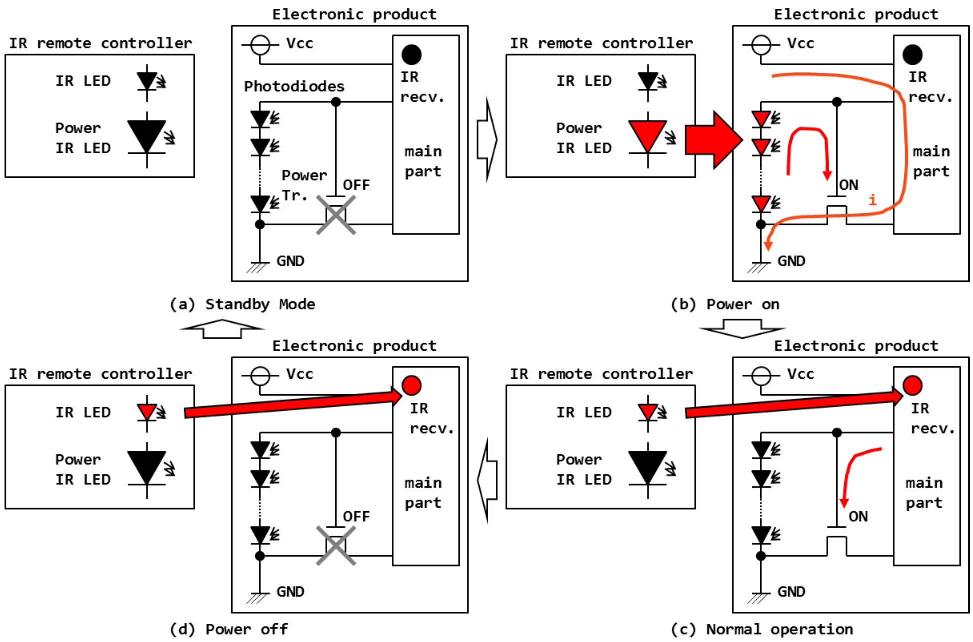

Fig. 2. Operation overview.

to the reader. This is another drawback of NFC usage.

To solve these problems mentioned above, we propose a novel power supply circuit that can make a standby power consumption of an infrared remote controlled product zero [6].

In our proposal, the ground or power line of IR controlled product in standby mode is disconnected by a power transistor. Thus, the power consumption is zero because there is no electric current path. When the user pushes the power-on button on the IR remote controller, the strong infrared light is irradiated. The infrared photodiodes attached to the IR controlled product generates the electromotive force by receiving the infrared light. This electromotive force drives the power transistor and the disconnected ground or power line is connected. As a result, the IR controlled product in standby mode with zero power is activated without any power consumption. The activated product keeps the connection of the ground or power line, and can continue to be controlled by the same single remote controller. Thus, our proposal can remove significantly the burden cutting off the standby power over many home appliances.

The rest of paper is organized as follows. Section 2 shows a conceptual organization and an overview of our power circuit operation. Section 3 explains the detail of a prototype hardware developed to perform the preliminary experiments to confirm the effectiveness of our proposal. Section 4 describes the experimental results and discusses them. Finally, Section 5 concludes our paper.

II. Zero Standby Power Supply Circuit

A. Organization

Fig.1 shows a conceptual organization of our power circuit. At first, we explain an electronic product with our proposed power circuit. A power transistor is used to connect and disconnect the ground line or power line of the electric product as shown in Fig. 1 (a) and (b) respectively. The photodiodes with a sensitivity of infrared light are used, which drive the n-ch or p-ch power transistor. When an IR controller irradiates the infrared light to the electronic product, the photodiodes generate an electromotive force and drive the power transistor bridging the ground line or power line by this force. Some photodiodes are connected sequentially to generate higher voltage than the threshold voltage of the transistor to be driven. The main part of the electronic product is equal to the conventional one. The main part is operated by the infrared light from the IR controller to a conventional IR receiver.

Next, we explain an IR controller supporting our proposal. The IR controller has an infrared power LED to achieve the power on/off, and has a conventional infrared LED to operate the electronic product. The modifications of the IR controller are very few as mentioned later.

To simplify explanation, we henceforth focus only to the low side switching shown in Fig. 1 (a).

B. Operation Overview

Fig.2 shows an operation overview of our power circuit. Fig.2 (a) dipicts the standby mode of the electronic product employs our proposal. There is no current flow because the power transistor cuts off the ground line. That is, the standby power consumption is completely zero.

As shown in Fig.2 (b), the remote controller irradiates a strong infrared light from its infrared power LED at moment, when the user of the electronic product pushes the power-on button on the IR controller. The photodiodes in the electronic product receive this irradiated infrared light and generate the electromotive force. The n-ch power transistor is driven and connects the ground line disconnected. As a result, the electronic product is activated and starts up since the current begins to flow from the power supply to the ground.

As shown in Fig.2(c), the electronic product drives the n-ch power transistor constantly instead of the photodiodes. As the user pushes a button on the IR controller to operate the electronic product, the IR controller irradiates a normal weak infrared light to the electronic product.

As shown in Fig.2(d), the electronic product finishes driving the n-ch power transistor when the user pushes the power-off button on the remote controller. The electric product receiving the power-off command turns off the n-ch power transistor. The current pass from the power to ground disappears and the electric product moves to the standby mode. Again, the standby power cunsumption becomes completely zero.

The IR controller has to generate the strong infrared light to have the photodiodes generate a large electromotive force enough to drive n-ch power transistor. The battery life of the remote controller must be worried about. However, there are the power transistors that can be driven by the small voltage threshold like 0.8V and can flow the enough current like 4A [7]. In addition, the strong infrared light is irradiated during the short term (just ms order) in a PWM fashion. Thus, the buttery life may be equal to the conventional remote controller. We will in detail estimate the battery life in the experiment section later.

III. Prototype Hardware

A. Electronic Product Operated by IR controller

To perform preliminary experiments, we have developed the prototype systems imitating a digital photo frame that can be controlled by the IR controller. One employs our proposed power circuit and another employs a conventional one. Fig.3 depicts the experimental setup.

Fig.4 shows the block diagram of the prototype system with our proposal. As you can see, there are many electrical parameters such as resistors, capacitors, and so on. Those

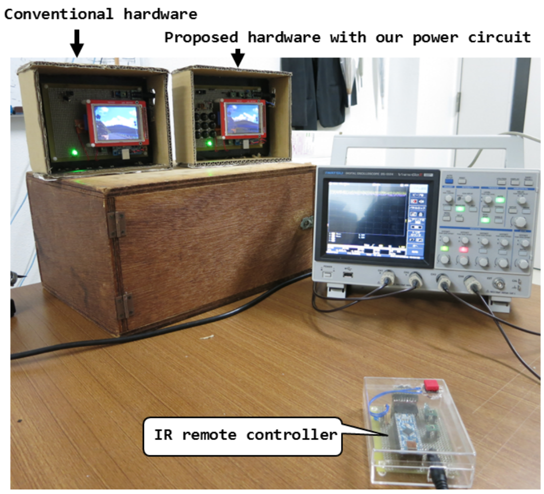

Fig. 3. Picture of experimental setup.

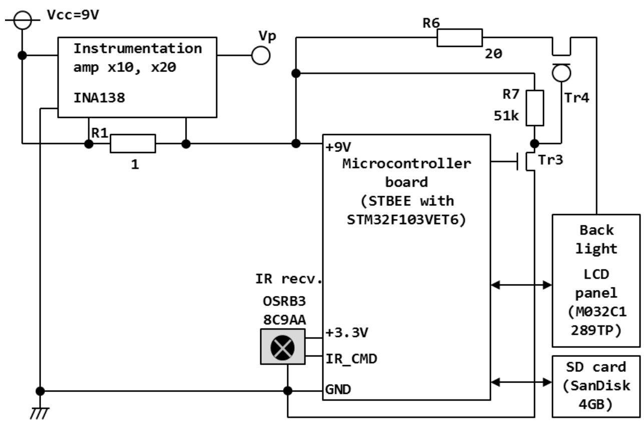

Fig. 5. Block diagram of conventional hardware.

parameters have been decided through the preliminary experiments.

We have used 9 photodiodes of HAMAMATSU S6801-01 [8] with much higher sensitivity to the infrared light domain than the visible light domain. They drive the transistor, Tr_1 in Fig.4, when receiving the infrared light irradiated by the IR controller. The Tr_1 is the n-ch CMOS power transistor bridging the ground line, which is Internal Rectifier IRML6344TRPbF [7]. Its threshold voltage is typically 0.8V and its continuous drain current is 5.0 A at absolute maximum. We know the forward voltage of S6801-01 generated in receiving the infrared light becomes about 0.7V at maximum. Thus, 9 photodiodes can generate 6.3 voltage at maximum without any load. This voltage is enough to exceed the threshold voltage of the n-ch power transistor used.

The photodiodes basically generate some current as the electromotive force. This current of the used photodiodes is typically 80uA. We have inserted the resistor of 180K (R_2) that converts the electromotive current to the voltage for driving the CMOS transistor.

A passive bandpass filter consisting of R_3, R_4, C_1, and C_2 is inserted as shown in Fig.4. This is because we have modulated the infrared light irradiated by the IR controller with a pulse to eliminate the effect of the ambient light. This passive bandpass filter removes the ambient light and passes

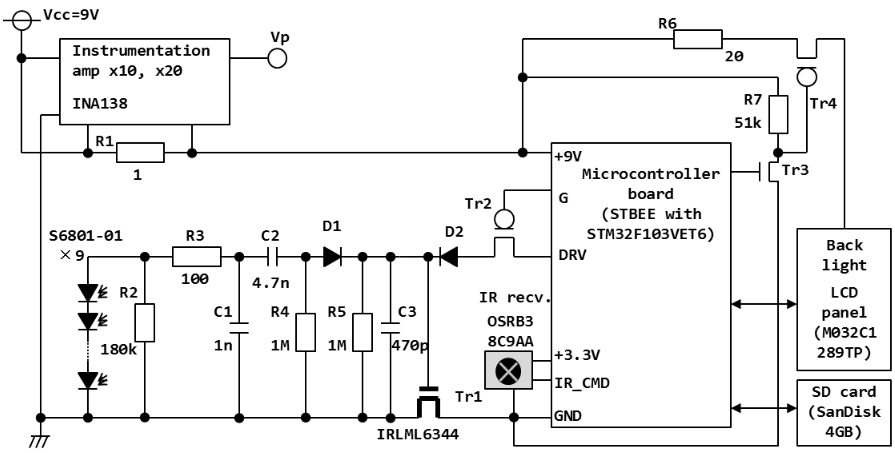

Fig. 4. Block diagram of prototype hardware with our proposal.

only the swinging infrared light indicating a command with a dedicated carrier frequency. Note that we cannot use any active filter to remove the standby power completely.

The electromotive force generated by the photodiodes drives the CMOS n-ch transistor Tr_1 through the band-pass filter and the diode D_1. Once the ground line is connected, the microcontroller of STMicro electronics STM32F103VET6 [9] begins to run. This microcontroller is mounted on Strawberry Linux STBEE board [10] with several components including DC-DC converter, oscillators and LEDs. The microcontroller activated drives the Tr_1 instead of the photodiodes via the diode D_2. However, there is one problem to avoid. When Tr_1 is cut off, the microcontroller is pulled up by the power line of 9V and its pins become high level though there is no current flow. Thus, the pin (DRV) to drive the Tr_1 becomes high even if the system is the standby mode. That is, the Tr_1 is connected constantly. To avoid this problem, we have inserted a CMOS p-ch transistor Tr_2 into the driving line of the Tr_1. In standby mode, the Tr_2 is closed by the pin G with high level. Thus, the gate of Tr_1 becomes low by being pulled to the ground via the resistor R_5. The microcontroller activated opens the Tr_2 by making the pin G low and drives the pin DRV with the high. As a result, the microcontroller does not drive Tr_1 in standby mode and opens it only after activation.

Once the microcontroller is activated, the bitmap images stored in the SD card are displayed in a slide show fashion onto the LCD panel. The used LCD panel is Aitendo M032C1289TP [11] and the used SD card is the SanDisk 4GB SD card. The transistors of 3 and 4 (Tr_3 and Tr_4) form a switch of the backlight for the LCD panel.

The microcontroller accepts the command from the IR controller by the interrupt. The interrupt is invoked from the IR receiver used, which is OptoSupply OSRB38C9AA [12]. Once the interrupt by the command sent by the IR controller is accepted, the microcontroller decodes the command. When the decoded command is to turn off the power, the microcontroller stops driving the Tr_1. As as result, the ground line is disconnected, the current flow disappears, and the zero power is achieved in the standby mode.

We have inserted an ammeter which is constructed by an instrumentation amp, Texas Instrument INA 138 [13] into the power line. The instrumentation amp measures the voltage between the 1Ω resistor bridging the power line. We have calculated the current by the measured voltage as the consumption current.

Fig.5 shows the block diagram of the system with a conventional power circuit. In standby mode, the microcontroller and LCD panel go into the standby mode with low power consumption. The switch of the backlight for the LCD panel is also turned off. However, the IR receiver has to be running to accept the command sent by the IR controller even if the system is standby mode. Also, the DC-DC converter on the microcontroller board is implicitly generating the multiple voltages for several components such as the microcontroller, IR receiver, SD card, LCD panel, and its backlight. Note that the microcontroller [1] and LCD panel staying at the standby mode consume a little power but not zero.

B. IR controller

Fig.6 shows the block diagram of the IR controller we have developed. The IR controller uses 4 infrared power-LEDs to send the power to the photodiodes on the proposed power circuit shown in Fig.4. The infrared power-LED is OSRAM SFH4725S [14]. In addition, the IR controller employs the normal infrared LED to send the commands to the prototype-electronic product shown in Fig.4.

When the user pushes the power-on switch, SW_1, the microcontroller drives the transistor connected to the infrared power-LEDs in a PWM fashion. The pulse has the high period of 400us and the low period of 800us. The pulse is generated five times. The width of the pulse, duty ratio of the pulse and number of pulses have been decided by a trial and error.

The transistor connected to the normal infrared LED is driven when the user pushes the switch, SW_2. The infrared LED blinks in a PWM fashion modulated by the pulse of 38KHz. This is the conventional method widely used in the IR communication of the commercial house appliances.

The prototype-electronic product with our power circuit is activated by the infrared light irradiated by the infrared

[1]The microcontroller used has 3 standby modes, which are the sleep mode, stop mode and standby mode [9]. To accept the interrupt from the IR receiver and make the standby power as low as possible, we have used the stop mode.

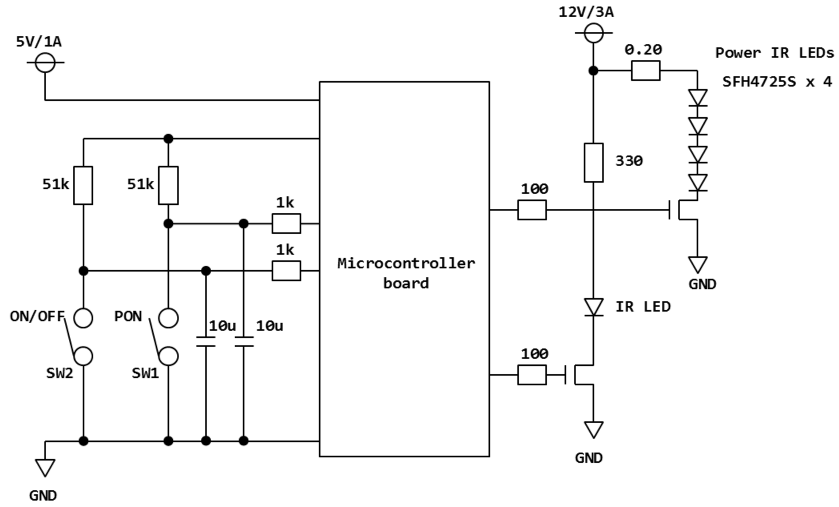

Fig. 6. Block diagram of IR controller.

power-LEDs. When the user pushes the switch, SW2, the command is sent via the normal infrared LED. Then, the prototype-electronic product turns off the power completely.

The conventional electronic product stays at the standby mode after starting up. In the standby mode, it becomes the active mode by pushing SW_2. In the active mode, it moves to the standby mode by pushing SW_2.

IV. Experiment and Discussion

A. Power-on pulse

Fig.7 shows the waveforms measured when we have pushed the power-on button on the IR controller. The distance between the IR controller and the electronic product is 1.3m. The lines of the photodiode, BPF and gate are the waveforms observed in the electronic product. The line of the infrared pulse is the waveform observed in the IR controller. The gate threshold voltages of the used power-transistor are also shown. These values indicate the maximum value, typical value and minimum value.

When the power-on button is pushed, five infrared pulses are generated to blink the infrared power-LEDs. Corresponding to these infrared pulses, the photodiode in the electronic product generates five pulses. These five pulses go through the band pass filter and the waveform of the BPF is gained. The BPF goes through the diode, D_1, and charges the capacitor, C_3 as shown in Fig.4. The waveform of the signal charged by C_3 is the gate shown in Fig.7. The gate drives the power-transistor, Tr_1, shown in Fig.4 until about 5.7ms. After 5.7ms, the microcontroller activated alternarively drives the Tr_1 instead of the photodiode. The activated electronic product performs the slide show on the LCD panel, changing the images stored in the SD card.

The waveform of the gate exceeds the minimum threshold voltage of the used power-transistor. As a result, we have confirmed that the proposed power circuit can actually activate the electronic product by using the electromotive force of the photodiode.

B. Distance Effect

The effect of distance between the IR controller and the electronic product must be worried about. This is because the power of the infrared light is attenuating more as traveling longer. Fig. 8 shows the waveforms generated by the photodiode and the waveforms of the signal gating the power-transistor. We have measured those signals, changing the distance between the IR controller and electronic product.

As shown in Fig. 8, the prototype can be activated until the distance becomes greater than 3 m. When the distance is lower than equal 3 m as shown in Fig. 8(a)–(c), the signal gating the transistor never becomes lower than the minimum gate threshold, 0.5V until the microcontroller (MPU) starts up. However, when the distance is 4 m as shown in Fig. 8(d), the gating signal becomes lower than the minimum threshold offten at the earlier period in the activating pulses before the microcontroller actually runs. Thus, the microcontroller fails to drive the transistor and never runs.

To more extend the distance between the IR controller and the electronic product, we plan to use a full wave rectification instead of the half-wave rectification by one diode, D_1, shown in Fig.4. By using a full wave rectification, the capacitor, C_3 shown in Fig.4 must be charged more. As a result, it is expected that the level of the gating signal remains high enough to make the transistor open even if the distance is rather long.

C. Power Consumption of Electronic Product

We have measured output voltages of the instrumentation amplifier, IN138, shown in 4 and 5 when we have set the conventional product and the proposed one to standby mode. Since the shunt resistor is 1Ω, the consumption current can be calculated by dividing the measured output voltage with the gain of IN138. Fig.9 shows the experimental results for the output voltages of INA138. We set the gains of IN138 to 10 times and 20 times respectively.

The conventional product consumes the consumption current of about 8 mA at average, while the proposed one consumes that of about -20 uA at average. Although we have changed the gain of INA138 to x10 and x20, the measured consumption current of the proposed product shows the same tendency. We think that the measured value of the proposed product is the offset value of which INA138 inherently has.

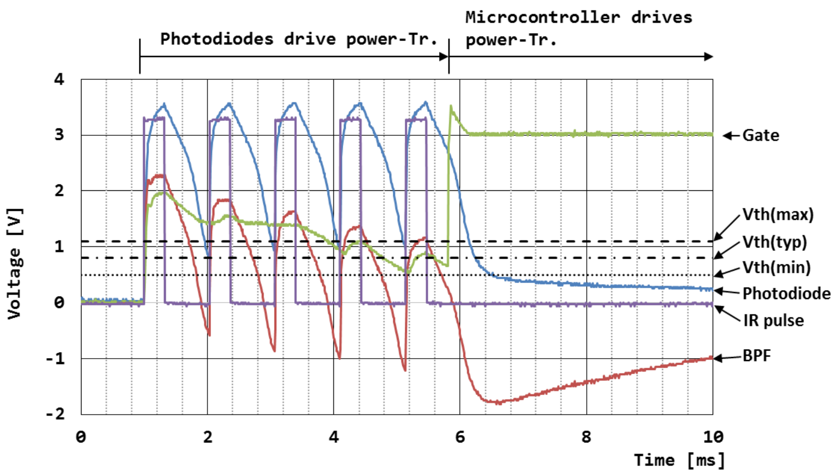

Fig. 7. Power-on pulse (distance of 1.3m between IR controller and electronic product).

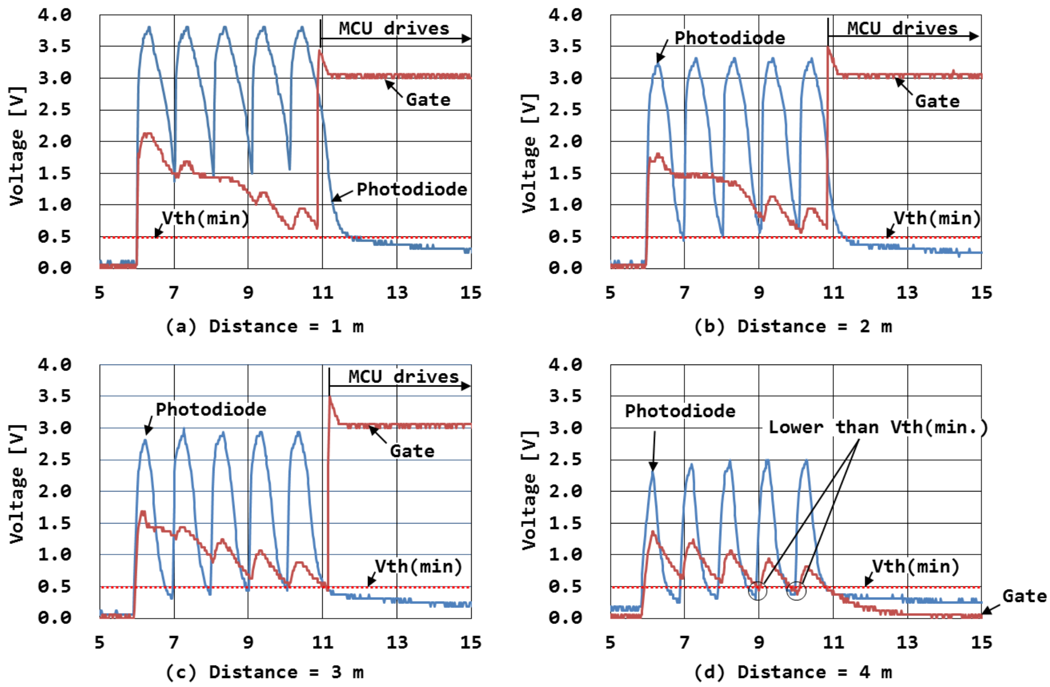

Fig. 8. Distance effect of Power-on Pulse.

That is, this fact indicates that the proposed product can reduce the standby power consumption to zero.

D. Power Consumption of IR Remote Controller

In our proposal, the IR controller has to blink some infrared power-LEDs as shown in Fig.6. The conventional IR controller does not have such infrared power-LEDs. Thus, the battery life of the IR controller may be worried about when employing our proposal. This section attempts to estimate the battery life of the IR controller.

Once the user pushes the power-on button on the IR controller, the pulse to drive the infrared power-LEDs is generated 5 times as mentioned before. We have measured the current passing through infrared power-LEDs when the pulse is generated. The result shows that the current is about 1.57 [A]. The duty ratio of the used pulse is 33%, whose high and low periods are 400 us and 800 us respectively. Thus, the average current during 5 pulses are generated becomes $1.57[A] * 0.33 = 0.52[A]$. The time period of 5 pulses is 6 ms. That is, the current of 0.52A passes through the infrared power-LEDs during 6 ms.

We assume that the N is the number of making the electronic product active from the standby mode with zero power consumption in a day. The duty ratio in a day of the power-on period of 6 ms mentioned above becomes $(6 \times 10^{-3})/(24 \times 60 \times 60/N) = 6.94 \times 10^{-8} \times N$. Thus, the total current due to the activation, I_{act}, in a day becomes $6.94 \times 10^{-8} \times N \times 0.52[A] = 3.61 \times 10^{-8} \times N[A]$.

We assume that the battery capacity is 2000mAh which is equal to the capacity of an AA alkaline battery. This is equal to 83.3mA in a day. Thus, as for the activation of the electronic product in standby mode, the battery life of the IR controller becomes $83.3mA/I_{act}[day] = 2307479/N[day] = 6321/N[year]$.

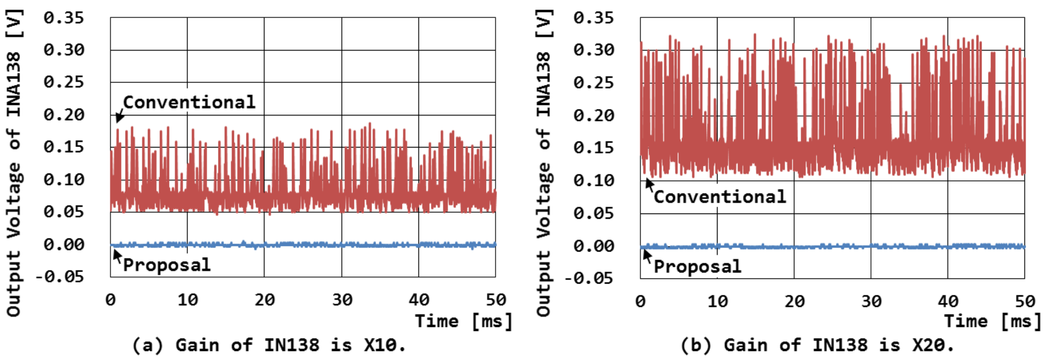

Fig. 9. Standby Power Consumption.

Making the standby power consumption zero that is equal to disconnecting the power cable from the power strip seems not to occur frequently. For example, home appliances may be completely switched off when the family travels, goes to shopping, goes to office, goes to school, sleeps at night, and so on. Generally, the makers design the home appliances so that the IR controller can keep the battery life 10 year. If the N is 10, the battery life then becomes 63 years. Thus, we think that the power consumption of the activation due to blinking the infrared power-LEDs would be neglectable.

V. Conclusion

We have proposed a novel power supply circuit that can make a standby power consumption of an infrared remote controlled product zero. It is a hybrid power supply circuit combining the energy harvesting and conventional power supply structure. The IR controlled product is activated with no-power by the power generated by infrared photodiodes receiving the infrared light from the remote controller. The activated product runs normally using the conventional power supply rail. These activation and control to the product are uniformly handled by a single remote controller.

Through the preliminary experiments on the prototype, we have confirmed that the proposed power circuit can actually activate the electronic product by using the electromotive force of the photodiode. Compared with the conventional power circuit, it has been confirmed that our proposal can reduce the standby power consumption to zero. About the battery life of the IR remote controller, our estimation indicates that our proposal does not badly affect although the strong infrared light has to be generated.

We plan to refine our power circuit to extend the distance between the IR controller and the electronic product. We are also developing a power strip employing our proposal to avoid modifying the conventional electronic products.

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