Photovoltaic Charged Supercapacitor Power Supply for On-Body Sensors

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Abstract. This paper presents a human body temperature monitoring system in which the temperature read by the sensor is analyzed by the programmed logic from a microcontroller. Two LEDs are used to signal out the patient's body temperature. The whole system is powered by button cell type supercapacitors which are charged by a mini photovoltaic panel. This system is designed and addressed to people who want or need to continuously monitor their body temperature. It is a compact and easy to use system, being integrated in a bracelet that is attached to the upper arm. The successful functioning of the designed power supply opens new directions in the on-body sensor field, where the replacement of the classical batteries can be avoided by the patient.

1. Introduction

Supercapacitors are being used in areas in which a fast energy storage is needed. The supercapacitor does not lose its properties during its charging and discharging cycles, in which it releases a very large charge of electrons which can sometimes be problematic. The areas in which supercapacitors are used are from a simple backup source for different instruments and machineries, up to ensuring the backup supply for servers in case of power failures. The power source for electronic implantable devices is one of the most difficult elements of this system’s design, and a limiting factor for their use. Recent developments on supercapacitors (SC), also called ultracapacitors or electric double-layer capacitor (EDLC), have created a new possibility for energy storage on implanted devices. The supercapacitor is very attractive for this use because it has more energy density than common capacitors, typically only one or two order of magnitude less than batteries. Having 1% or 10% of a battery energy density might be a good trade-off for having a much greater power density and expected life and much smaller charge time and toxicity, especially for implanted devices [1].

Human diagnosis devices mostly composed of low-power body sensors play an important role in the field of disease prevention and health monitoring by using a traditional battery power supply, which is the mainstream option resulting in the consequences that include frequent charging and battery replacement as well as serious environmental pollution. Therefore, people continue to explore sustainable clean energy options to replace batteries. As a new type of high-performance electrochemical energy storage device, the flexible super capacitor, which can be bent or folded, is becoming a trend. Compared with conventional batteries and ordinary super capacitors, flexible super capacitor has flexibility, cleanliness and then the effect of conjunction with clothing is close to perfect [2].
The demand for stretchable electronic devices has continuously increased in recent years. Wearable electronics have attracted considerable attention because of their good flexibility, outstanding electrical conductivity, high intensity and light weight, long cycle stability and their suitability in intelligent terminals, such as medical monitoring equipment [3].

With the continuous development of different power technologies, the body sensor network is expected to be more lightweight, unobtrusive and reliable, leading to a low-cost and ubiquitous healthcare soon. Wearable sensor devices such as epidermal sensors, implantable sensors and real-time monitoring sensors rely on intimate contact between the sensor and surface of physiology systems with high stability operating under large scale strain [4,5].

Smart meters also use supercapacitors due to their abilities to preserve energy in case of power supply and meteorological phenomena. Therefore, hybrid energy storage is a very popular method for powering loads that require very high peak power bursts and large energy stored used in applications such as electric cars, aerial vehicles, robotics, artificial prosthesis, building control, security, location tracking, health monitoring, sports and RFID [6-10].

2. System implementation

An energy loading system for the supercapacitors bench was implemented with a small sized photovoltaic panel of 44x35mm, with electrical characteristics of 4V/35mA. When choosing the photovoltaic cell, several aspects were taken into consideration. The first aspect is the capacity of energy storage and the second aspect was the size of the photovoltaic cell. The complete system is made of two supercapacitors, a photovoltaic cell, two red LEDs, an LMT86 temperature sensor and a PIC12LF1840 microcontroller.

The circuit used to test the loading of the supercapacitors with the photovoltaic panel is presented in figure 1.

The supercapacitor ensemble is one of the main parts of the system. Based on this, the usage time of the application as well as the loading time is determined, the supercapacitors being able to load very fast. The supercapacitors were chosen to generate a voltage in the range of 1.8–3.6V required for proper functioning of the system components; high capacity in order to be used for a longer period without the need of a frequent charging. Another important aspect considered was the size of the supercapacitors. For the implementation, a block of two parallel connected supercapacitors was used. The characteristics of the chosen supercapacitors are maximum capacity of 220mF and a maximum voltage of 5.5V; the size is of 10.2mm in diameter and 5.1mm in height.

To monitor the supercapacitor discharge time, a discharge monitoring system was implemented, which is illustrated in figure 2. In this system the same assembly of two parallel connected supercapacitors were used in series with loads of different values.

For the body sensor we opted for the LMT86 temperature sensor, which generates an analog voltage at its output and has the following parameters: low functioning voltage of 2.2V; maximum current of 5.4μA; the temperature domain of −50 to 150°C; high accuracy: ±0.04°C; step: -10.9mV/°C.

Figure 1. The circuit used to test the charging of the supercapacitors.

Figure 2. The circuit used to test the discharging of the supercapacitors.
The command-and-control of the system was implemented with a microcontroller. For choosing the microcontroller, the supply voltage, the consumed current in the functioning mode, the integrated ADC were taken into consideration. Therefore, the PIC12LF1840 microcontroller was chosen, with a few important parameters as: supply voltages between 1.8 and 3.6V; operating current of 30μA/MHz; ADC of 10 bits resolution and 4 channels; fixed reference voltage with three values: 1024mV, 2048mV and 4096mV, software adjustable; precise internal oscillator of 32MHz and software adjustable frequency with values between 31kHz and 32MHz.

Two red LED indicators are used to communicate the whole system state and the sensed body temperature. The LEDs specifications are the following: low power consumption; specific current $I_F = \frac{2}{\text{mA}}$; light intensity: minimal value of 1mcd and 2mcd maximum value; minimal supply voltage of 1.9V.

A first prototype was created to test the circuit functionality and it was implemented on a breadboard. The final circuit implemented on the PCB (figure 3, left) and introduced in the custom designed housing as presented in figure 3 (right). The size of the PCB was imposed by the size of the photovoltaic cell (34x38mm).

![Figure 3. The 3D view of the PCB layout (left); the final device attached to a Velcro strap (right).](image)

The PCB together with the supercapacitors and the microcontroller are inside of the housing, while the temperature sensor, the two LEDs as well as the photovoltaic cell are placed outside of the device. The photovoltaic cell is located at the top of the system and the temperature sensor is located on the Velcro bracelet.

### 3. Experimental results

First time we tested out the charging time of the supercapacitors in different illumination conditions. The results of these tests are presented in figure 4 for indoor low-lighting conditions, figure 5 in cloudy sky outdoor conditions and figure 6 for direct sunlight conditions.

![Figure 4. The charging of supercapacitors in indoor lighting conditions.](image)

![Figure 5. The charging of supercapacitors in outdoor cloudy sky conditions.](image)
Figure 6. The charging of supercapacitors in outdoor direct sunlight conditions.

Figure 7. The discharging of the supercapacitors through an 8.2kΩ load.

From the above charging characteristics can be seen that the supercapacitors charging time is very good even if the system is used inside indoor conditions when in 8min. it is fully charged. When it is exposed to outdoor conditions can be fully charged in 3min. in cloudy conditions or 1min. in direct sunlight conditions.

Using the Arduino board, the discharge of the supercapacitors was monitored. The obtained results were:

- the discharge through a load of 100Ω, from a voltage value of 3.8 V to 1.7 V take placed in a time frame of 2min and 2s;
- the discharge through a load of 8.2kΩ, from a voltage value of 3.8 V to 1.8 V happened in a time frame of 51min and 39s;
- the discharge through a load of 100kΩ, from a voltage of 3.8 V to 2.61 V happened in a time frame of 4h and 43min.

The discharging time of the supercapacitors is presented in figure 7 with a load of 8.2kΩ.

Having a low power consumption circuit which sinks a current of less than 1mA (LMT86 and LEDs) the discharging of the supercapacitors to a value of 1.8V takes around 7 hours; test which were conducted by decoupling the photovoltaic cell from the system.

For the temperature range between 35ºC and 42ºC the output voltage indicated in the datasheet of the temperature sensor is between 1723mV and 1646mV. To indicate these temperature range in an easy visual way the two red LEDs will light up by the logic programmed into the microcontroller and presented in Table 1.

| #  | Temperature [ºC] | LED 1                     | LED 2                     |
|----|------------------|----------------------------|----------------------------|
| 1  | < 37             | 1s ON and 9s OFF           | OFF                        |
| 2  | 37 – 37.5        | 1s ON and 5s OFF           | OFF                        |
| 3  | 37.5 – 38        | 1s ON and 2s OFF           | OFF                        |
| 4  | 38 – 38.5        | 1s ON and 1s OFF           | 1s ON and 5s OFF           |
| 5  | 38.5 – 39        | 1s ON and 1s OFF           | 1s ON and 2s OFF           |
| 6  | > 39             | 1s ON and 1s OFF           | ON all the time            |
For body temperatures less than 37ºC the first LED will blink once at 10s and will act as a system indicator as well. If this LED won’t blink it means that the power supply given by the supercapacitors is under the 1.8V which is the minimum operation voltage of the microcontroller. For temperatures higher than 39ºC the second LED will be in ON state all the time to indicate a critical body temperature which needs immediate action.

4. Conclusions
By the work presented in this paper we underlined the possibility to use in a successful manner the button cell type supercapacitors as power supplies for low power consumption applications as the on-body sensors. Taking advantage by the supercapacitors quick charging properties a photovoltaic system can be a very good solution in this way. In our measurements the charging of a pair of two 5.5V and 220mF supercapacitors takes between 1min. and 8min. for a full charging depending on the indoor-outdoor conditions. The proposed system to be powered up by this supercapacitor-photovoltaic solution is a body-temperature system. The designed body-sensor system can be attached to the upper arm and indicates visually by two red LEDs the body-temperature range of interest between 37ºC and 39ºC. The system was developed as a prototype by us using THT components. By proving the proper functioning of such a system, it can be redesigned with SMD components and smaller photovoltaic cell to reduce the overall size of it. This type of supercapacitor-photovoltaic power supply can be adapted to other body sensors as well.

Acknowledgments
The present work was accomplished by the support of the grant “REGRENOPOS” PN-III-P2-2.1-PED-2019-2601, founded by the Romanian Ministry of Education and Research.

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