INDOOR MICRO-LIGHT ENERGY HARVESTING SYSTEM FOR LOW POWER WIRELESS SENSOR NODE

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Abstract: Indoor micro-light energy harvesting is very challenging because of very low indoor light energy density and conversion efficiency. It is therefore important to optimize system design so an energy harvester can provide sufficient energy to the WSN in low illuminance levels. In this paper, we present a special power management system that includes maximum power point tracking (MPPT), energy storage circuit, hysteresis comparator and DC-DC boost converter. Photovoltaic cells characteristics, energy storage units, power management circuit design, and power consumption pattern of the target mote are presented. The measured prototype can successfully drive a wireless humiture sensor node load when the humiture sensor transmits signal.

Keywords: MPPT, power management circuit, DC-DC boost converter, micro-energy harvesting

INTRODUCTION

Solar energy harvesting is a comparative fledged technology for wireless sensor networks used for outdoor applications. However, for indoor applications, it is necessary to note that the efficiency of photovoltaic cells is very low because of its low light luminous intensity. Typically, the light intensity under artificial lighting conditions found in hospitals and offices is less than 10 W/m^2 as compared to 100−1000 W/m^2 under outdoor conditions. For example, a typical light energy density in a fluorescent lighting condition (500 lux) is one to two orders of magnitude lower than the outdoor light energy density. With low light intensity, the energy harvested may be too low to supply power for the wireless sensor node. Thus, the special power management circuit should cater for the large difference between photovoltaic cell and sensor node load [1-4,6].

This paper presents an indoor micro-light energy harvesting system that includes photovoltaic cell, maximum power point tracking (MPPT), energy storage, hysteresis comparator and DC-DC boost converter. By use of special power management circuit, the prototype circuit of this system can also successfully drive the wireless sensor node load. The several key design issues on designing micro-energy scavenging system are explained. The paper provides an overall block diagram of the system circuit with descriptions of each block. Finally, the measured results and conclusion are presented.

PROPOSED POWER MANAGEMENT SYSTEM DESCRIPTION

Fig. 1 shows the block diagram of the power management system. The basic design idea is to store the photovoltaic cells generated power in supercapacitor and deliver it when it is enough to

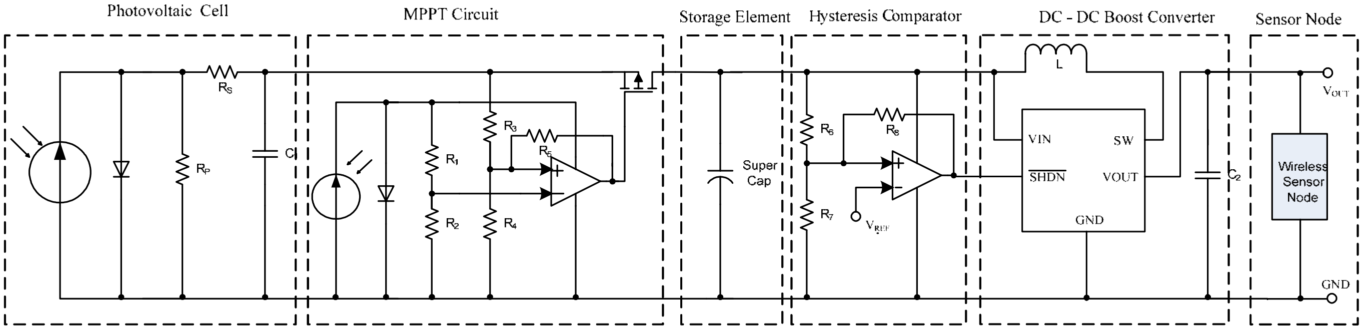
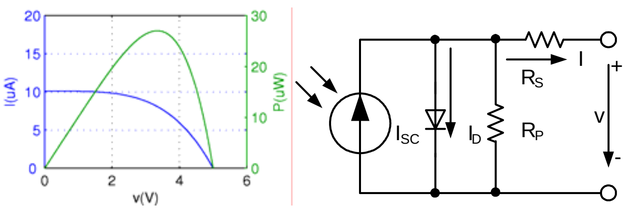


Fig.1: The block diagram of the proposed power management system.

supply the load for an established amount of time. The proposed power management system consists of photovoltaic cell, MPPT circuit, energy storage circuit, hysteresis comparator and DC-DC boost converter. The different parts of the circuit system are analyzed with detailed information.

Models of Photovoltaic Cell

Amorphous silicon photovoltaic (PV) cell has a relatively high efficiency at low light intensity levels, compared to other types of cell. This makes them particularly suited to use in low indoors light condition. Fig. 2(a) shows output characteristics of the PV cell and Fig. 2(b) shows electrical model of the PV cell respectively. At a low light intensity, the output of the PV cell behaves like a current source with a voltage limiter. Photovoltaic cells are characterized by two parameters, the open circuit voltage (V_{oc}) and the short circuit current (I_{sc}). The output current of the PV cell follows the following equation (1)[3-4,6]:



(a) (b)

Fig.2: (a) Output characteristic of the PV cell.

(b) Electrical model of PV cell.

$$I = I_{SC} - I_O\left(e^{\frac{V+R_S I}{V_t}} - 1\right) - \frac{V + R_S I}{R_P} \quad (1)$$

Where I_{SC} is the photo-generated current, I_O is the dark saturation current, R_S and R_P are the series and shunt cell resistance, and V_t is the junction terminal voltage.

MPPT Circuit

Maximum power point tracking (MPPT) refers to drawing power from energy harvesting source at a level that maximizes the power output. For DC sources such as photovoltaic cells, the maximum power point is a voltage-current combination that maximizes the power output under a given light condition and temperature. The control method for MPPT can be implemented either in hardware or software. The special MPPT circuit hardware by using the fractional open circuit voltage approach is adopted in this paper, which adopts a hysteresis voltage comparator and regulates the photovoltaic cell voltage to be a fixed fraction of its open circuit voltage. Its theoretical principle is based on the relational expression of the maximum power point (MPP) operation voltage V_{mpp} and the open circuit voltage Voc, which means $V_{mpp} = V_{oc} \cdot K$ ($0<k<1$)[7].

This MPPT circuit consists of the MPPT control unit circuit and the MOSFET switch. A hysteresis voltage comparator is used as a control unit. It generates control signals to drive the MOSFET switch by comparing the reference V_{mpp} and the main PV cell operational voltage. By adjusting the hysteresis, the threshold voltage of the comparator can be changed, thus, the sensitivity of the MPP tracking can be adjusted. The controlled MOSFET can then approach the theoretical maximum power point voltage $K \cdot V_{oc}$ by oscillating around the required voltage range. In the tracking control unit, a reference voltage is required to set V_{mpp}. A secondary PV cell is used to obtain this reference voltage. By using the same photovoltaic technology as the main PV cell, the reference PV cell has the same open circuit voltage V_{oc}. A pair of resistors is then used to divide the open circuit voltage V_{oc} to the required V_{mpp}[7].

Energy Storage Element

In order to drive low power wireless sensor nodes successfully, energy harvested from indoors PV modules which is normally of the order of 1uW, must be 'buffered' in energy storage element. The two choices available for energy storage, either batteries or ultra capacitors, can be used as energy storage devices for this system. Super capacitors are more efficient than batteries and offer higher lifetime in terms of charge-discharge cycles and smaller self discharge rate. What is more important is that super capacitors do not require a special type of charger as long as their current and voltage does not exceed the nominal value. So a proper size of super capacitor in equation (6) can be used in the system as a storage element [4].

$$C_u = \frac{(I_l + I_d)t_{dark}}{\Delta V} \quad (2)$$

Where C_u is the capacitance of the ultra capacitor, I_l is the average load current. I_d is the discharge current of the capacitor, and t_{dark} time is the time that system must survive with no light. The charge time of the capacitor from zero to maximum voltage can be calculated as follows in equation (7). E_0 is PV cell voltage and i_c is charge current. I_s is saturation current, and m, n is the specific coefficient respectively [4-5].

$$t = \frac{-CE_0 n}{m}\int_{Is}^{0}\frac{1}{i_c^2}\left(1-\left(\frac{i_c}{I_s}\right)^n\right)^{\frac{1}{m}-1}\cdot\left(\frac{i_c}{I_s}\right)^n\cdot di_c \quad (3)$$

As shown in Fig.1, switch MOSFET is series connected in circuit in order to keep from inversely discharging to photovoltaic cell.

Inverting Hysteresis Comparator

Comparator with hysteresis can be built using LT6700 single supply comparator integrated circuit chip. This circuit's output will swing to high or low using two threshold values which can be decided by three resistors R_6, R_7 and R_8.High threshold and low threshold are as follows respectively:

$$V_{THR} = V_{REF} \times R_6 \left[\left(\frac{1}{R_6} \right) + \left(\frac{1}{R_7} \right) + \left(\frac{1}{R_8} \right) \right]$$

$$V_{THF} = V_{THR} - \left(\frac{R_6 \times V_{CC}}{R_8} \right)$$

In the proposed circuit, high threshold value is set by 1.8V, and low threshold value is set by the value of 1.2V.

DC-DC Boost Converter

This DC-DC boost converter choose LT3525 chip, it is high efficiency synchronous step-up DC/DC converters with output disconnect that can start up with an input as low as 1V. It offers a compact, high efficiency alternative to super capacitor applications. Only three small external components are required. The LTC3525 is offered in fixed output voltages of 5V. Its quiescent current is an ultra low 7 uA and shutdown current is 1uA.

Wireless Humiture Sensor Node

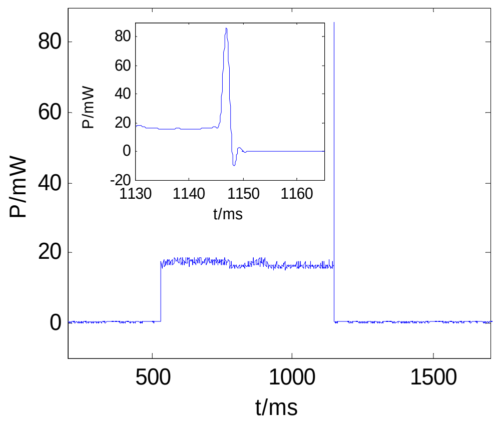


Fig. 3: Measured power dissipation curve of the wireless humiture sensor load.

A typical wireless sensor node is composed of sensor units, a data processing and controlling unit, a transceiver and a power supply. Consisting of a capacitive polymer humidity sensing element, a temperature-sensing element made by an energy gap material, a 14 bits A/D converter and a serial interface, the wireless humiture sensor adopted in the proposed system is a high-accuracy digital wireless micro-sensor [8]. This wireless humiture sensor works in the so called burst mode, transmitting and receiving information very fast in very small time slots (1ms). Most of the functional blocks of the transceiver remain in sleep or standby-mode, consuming a minimum of electrical energy. Only during the active time slots large peak current to power the electronics of the transceiver are required. The current and power of the transmitting data are 25mA and 85mW at a transmitting time of 1ms, respectively. The current and the power of receiving data are less than 6mA and 20mW at a receiving time interval of 620 ms, respectively. The measured power dissipation curve of the wireless humiture sensor load is shown in Fig.3.The power consumption in the transmitting state is the largest. This means that indoor amorphous silicon photovoltaic cell may not be sufficient to power the system, by itself, if connected directly to the load. Energy harvested indoors from PV modules and other devices must be 'buffered' in super capacitor[5-7].

RESULTS AND DISCUSSION

A photo of the proposed indoor micro-light energy harvesting system while receiving signal is shown in Fig. 4. The proposed energy harvesting system can successfully drive the wireless humiture sensor load when the humiture sensor node transmits signal. The great improvement of the proposed converter is its maximum power point tracking circuit and DC-DC boost converter. Fig. 5 shows the proposed system can successfully drive the wireless sensor load when the humiture sensor node transmits signal. Output voltage drops from 5V to 3.2V while the voltage of the wireless humiture sensor node is transmitting the data.Fig.6 shows magnified measured voltage waveform of the wireless humiture sensor node while transmitting signal load.

Fig. 4: The photo of the wireless sensor receiving node and interface window.

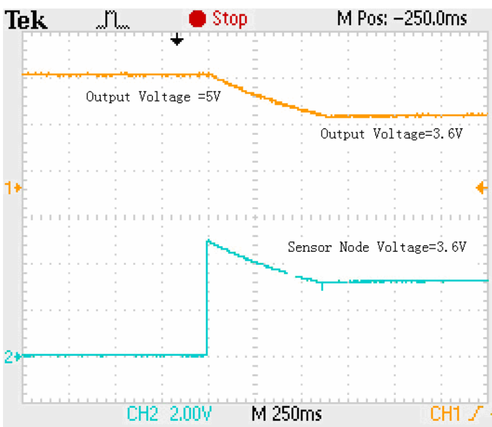


Fig. 5: Measured waveform of output voltage and the wireless humiture sensor node voltage while transmitting signal load.

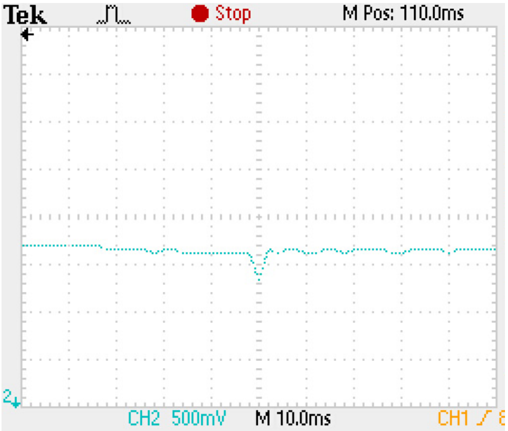


Fig. 6: Magnified measured voltage waveform of the wireless humiture sensor node while transmitting signal load.

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