Solar Energy Harvesting for Wireless Sensor Nodes

Velibor Škobić, Branko Dokić, Željko Ivanović

Abstract – In this paper, we propose a system for collecting solar energy in the ambient environment. The system power supplies a module whose role is to measure the ambient temperature. For system supplying is used battery and small size of solar panel. To compensate the lost energy during the active period, measurements are performed at least every 95s. Characteristics of the used module and solar panel are shown in the paper. Simulation and practical results are also presented in this paper.

I. INTRODUCTION

In most aplications, *w*ireless sensor networks consist of a number of wireless sensor node in the network. A common task in network devices using sensors is to either obtain information about the measured values (temperature, pressure, etc..) which is afterwards processed and then forwarded through the network, or to manage small processes. ZigBee standard is just one of numorous technologies which is designed for applications of wireless sensor networks. ZigBee devices are based on low-power, small size and low cost, what makes them suitable for the realization of wireless sensor networks. They consist of a microcontroller and the transceiver with an antenna, and all these together are called ZigBee module. In order to carry out its tasks, the device consumes appropriate energy. Most applications require that the device within the network is mobile and battery powered. In this case it is necessary to replace a discharged battery with a new one. For some applications this process can be complicated while in others even impossible. In order to increase the lifespan of the batteries, there was a justifiable need for introducing alternative energy sources. The amount of energy needed to operate the device in the network is small, and that is why we are using alternative sources of energy, such as solar energy, temperature differences, vibrations, etc. [1]. From these sources we can collect enough energy to power the device within the network. Solar energy is the most common source of energy that is available throughout the day from sunlight or from the artificial light at indoor conditions. Vibrations, kinetic and mechanical energy generated by the object movement can also be converted into electrical energy and adequately stored. Thermal energy harvesting uses tempreature differences or gradients to generate electricity. Depending on what kind of energy source is available to us, we use an appropriate system for collecting energy. The system can also have a hybrid character in which the energy is collected from two or more sources [2]. In Table I values of these power sources are shown [3].

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This paper introduces a way of power ZigBee modules using solar energy in the ambient environment. Power system consists of solar panels, boost converter, battery and super capacitor. The role of modules is to measure the ambient temperature, and then forward information about the measurement through the network. The second section provides a description of the solar energy and solar panel model. In the third section proposed scheme is for power supplying ZigBee module and theoretical analysis of the module energy consumption. In the fourth section are shown results of measuring the consumption of the system for temperature measurement and comparison with a theoretical consideration.

TABLE I
POWER DENSITIES OF ENERGY HARVESTING TECHNOLOGIES [3]

Sollar cells (outdoors at noon)	$15 mW / cm^3$
Piezoelectric (shoe inserts)	$330 \mu W / cm^3$
Vibration (small microwave oven)	$116 \mu W / cm^3$
Thermoelectric ($10^o C$ gradient)	$40 \mu W / cm^3$
Acoustic noise (100dB)	$960 nW / cm^3$

II. INDOOR SOLAR HARVESTING

The most common restorable source of energy in this kind of systems is solar energy. Depending on intensivity of the lightening, we can collect apropriate amounts of energy. Solar cells are elements which convert solar into electrical energy. There are two ways for collecting the energy, directly from the sun or indoor collecting- ambient light source. The energy from outdoor conditions, collected from sunlight, is than the one collected in indoor conditions (Table II). Solar panel whose main role is to convert solar energy into electricity does not give a constant amount of energy over time. During the office hours of the day, the panel has the ability to convert energy with more success because of relatively good lighting. After ending a office hours, there is no lighting rest in the room and no ability to collect energy anymore. In applications that use this method for collecting the energy time intervals have to be considered which give the information whether the source is available or not.

TABLE II
SURFACE DENSITY OF SOLAR ENERGY [2]

	Solar panel
Indoor condition	$100\mu W / cm^2$
Outdoor condition	$10mW / cm^2$

Consumption reduction can be provided by the device the network that is not constantly active, but there is a certain time interval when the device goes to the inactive state lowering the power consumption. In its active state module communicates with the other devices in the network and its current supply is significant, about $10mA$. In an inactive state, microcontroller and the transmitter module are excluded thus reducing consumption to several μA. Smaller dimension of solar panels can not provide enough power for continuous operation of modules in an active state. Consumption in the active period must be less than the amount of energy that is collected in periods of inactive time. Collected energy is used to carry out tasks and send data through the network. The time between battery replacements depends on the amount of sent and received data through the network [4].

In Fig. 1 a block diagram of a typical wireless sensor node, which is powered by combination of energy scavenging and battery technology, is shown [5]. The system consists of sensors which can observe environment, an analog-to-digital converter (ADC) which can quantize the analog signal from the sensors, a digital signal processing (DSP) core which can analyze and encode the quantized data and a transceiver (RF) so that the node can transmit and receive information. Light energy is converted to electrical energy trough a photodiode and mechanical vibrations are converted to electrical energy by an electromehanical transducer.

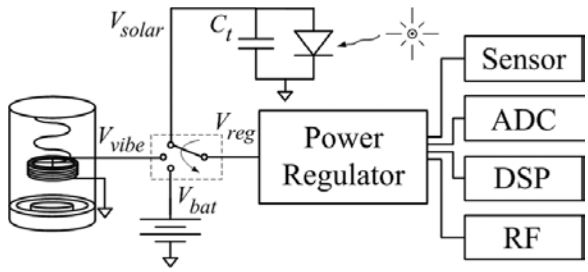

Fig. 1. Low power wireless system powered from energy scavengers and a batery. Energy sorces include solar, mehanical vibration and a battery. A multiplexer switches between the unregulated energy sources [4].

The solar panel is modeled (Fig. 2) with the electric generator I_{Light} as a function of light intensity, the diode with the inverse saturation current I_O and serial R_S and parallel R_P resistance [6].

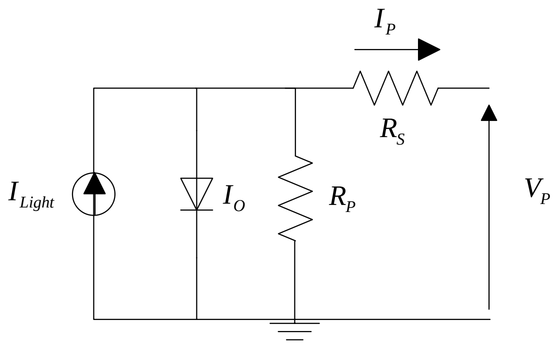

Fig. 2. Model solar cells

Dependence of output current I_P and output voltage V_P is given by the equation [6]:

$$I_P = I_{Light} - I_O(e^{\frac{V_P + I_P R_S}{k N_S T_C / q}} - 1) - \frac{V_P + I_P R_S}{R_P} \quad (1)$$

where: q is electron charge, k Boltzman constant, T_C temperature potential and N_S number of cells in series.

The maximum energy utilization from solar panels is obtained by setting the working point of the cell to the place of the maximum power point (MPP) [3]. For this purpose, various algorithms have been developed to achieve optimum operating point, i.e. maximum utilization of solar cells [7].

III. SUPLLYING ZIGBEE MODULE

The functional block diagram for proposed solution which is providing power to the ZigBee module is shown in Fig. 3. It consists of solar panels, boost converter, super-capacitors and batteries. The role of solar panels and boost converter is to power ZigBee module. In the case of no solar light, the device is battery supplied. In a case that solar panel provides more energy than it is enough to supply module, the rest of the energy it is used to charge the battery.

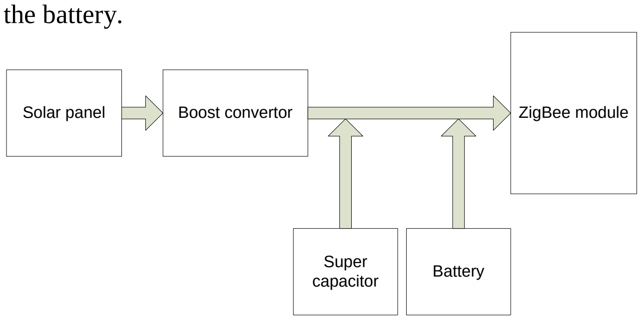

Fig. 3. Functional block diagram

The communication device mode is based on the ZigBee standard, ATMEL ATZB-24-A2 and consists of the microcontroller ATmega1281 and RF transceiver

AT86RF230. In active mode and idle mode, supply current is $I_A = 19mA$ and $I_N = 6\mu A$, respectively. Solar panel is used from the calculator "GENIE" . Solar panel is based on four cells conected in series producing voltage of 2.4V at the output of the panel. The maximum measured power of solar panels in the ambient environment is $P_{Pmax} = 20\mu W$. The capacitance of the used super capacitor is $0.1F$.

A. Calculation of power consumption

In order to calculate power consumption, it is necessary to know, besides the values of I_A and I_N, the values of power supply module. The maximum and minimum power supply voltages are $V_{M\max} = 3.6V$ and $V_{M\min} = 1.8V$, respectively. The active mode time is $T_A = 10ms$. Voltage at the capacitor before the active period is 3.3V. After the module goes in active mode, voltage on the capacitor decreases. Required amount of charge for an active period is :

$$Q = I_A \cdot T_A = 190\mu C \quad (2)$$

The capacitor voltage drops to a value in time T_A:

$$\Delta V = \frac{\Delta Q}{C} = \frac{190\mu C}{0.1F} = 1.9mV \quad (3)$$

The maximum permited voltage amount change is:

$$\Delta V_{\max} = V_{M\max} - V_{M\min} = 1.8V \quad (4)$$

Thus the number of active periods in which the module is working properly for one charging capacitor, where voltage changed from $V_{M\min}$ to $V_{M\max}$, is:

$$N = \frac{\Delta V_{\max}}{\Delta V} = 947 \quad (5)$$

Maximum size of the physical layer header of ZigBee standard is 128 bytes, with the maximum useful payload 104 bytes. Taking this into consideration we find that the maximum number of transferred data for a single charging capacitor is:

$$N_B = N \cdot N_{kar} = 947 \cdot 104 = 98488 \quad (6)$$

The output voltage of used solar cell is 2.4V and current depends on the lighting intesity. At maximum power consumption ($20\mu W$), through measurement we obtain the value of solar panel current as $I_{sol} = 8\mu A$ under indoor conditions. Thus, minimal required time needed to recharge the super capacitor is given as:

$$T_{ch} = \frac{\Delta V_{\max} \cdot C_{super-capacitor}}{I_{sol}} = \frac{1.8V \cdot 0.1F}{8\mu A} = 22500s = 6.25h \quad (7)$$

As it is calculated, during an active period of time it is spent $190\mu C$ of charge, so we have the $I_{sol}(T_A + T_N) = T_A \cdot I_A + I_N \cdot T_N$, the time that solar panel spends to compensate the charge:

$$T_N = T_A \cdot \frac{I_A - I_{sol}}{I_{sol} - I_N} = 95s \quad (8)$$

The result of simulation for the circuit in Fig. 4 is shown in Fig. 5, where the solar panel is replaced by current generator and a ZigBee module is replaced by current pulse generator with pre-calculated times of active and inactive modes and the corresponding currents.

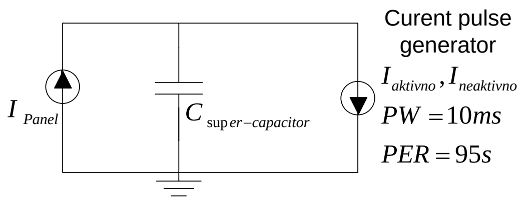

Fig. 4. Electrical circuit of supply mode

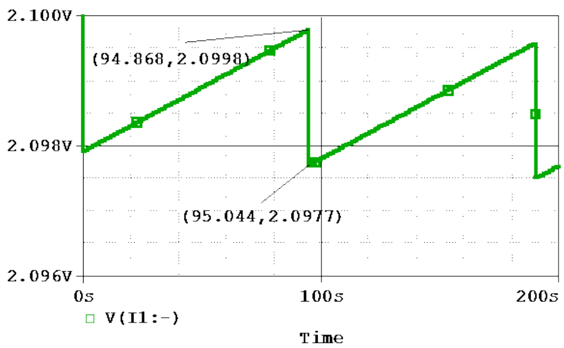

Fig. 5. The results of simulation of ZigBee module power consumption

The result shown in Fig. 6 proves theoretical analysis already given in this paper. There it is shown that 95s of the inactive working mode is enough to collect the charge lost during the active working mode. In this way we can increase the time between battery replacements, because the system supply is capable of collecting enough energy in the minimal time of 95s, for an active period of work time mode.

IV. EXPERIMENTAL MEASUREMENTS

In order to verify the preliminary examination, the prototype was implemented (Fig.6.) to measure temperature. It consists of super capacitor, module ATZB-24-A2 and circuits for measuring the temperature and voltage of power supply for module. The system for measuring temperature is implemented with using a thermistor. Thermistor is chosen to increase the speed of measuring a temperature and to reduce power consumption. From a voltage divider the voltage is assessed with using analog - digital converter (AD), in order to obtain information of the temperature. The power supply voltage module is not constant, so that the use of voltage dividers can yield information about the value of power supply voltage. If the supply voltage drops below a certain critical value, the module has the ability to send information about reducing the voltage, across the network and goes to idle mode longer time interval. Using the GPIO pins (General Purpose Input / Output) ensures that the circuit for measurement of voltage and temperature during the inactive period is turned off in order to reduce consumption of energy. After taking the information about voltage dividers, voltage information is then sent through the network. Further processing samples obtaines information about the ambient temperature. After sending data, module goes into inactive mode specific time interval.

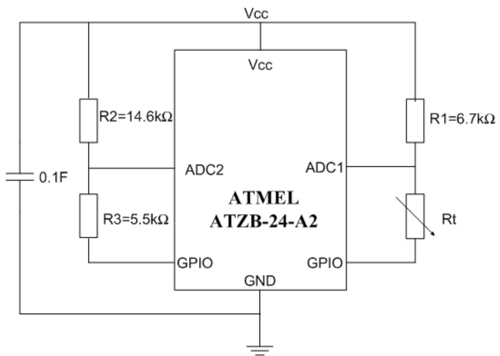

Fig. 6. Electrical cyrcut for mesuring a temperaure.

Realization of prototypes and the corresponding measurements yielded following results. The temperature was measured every 10s. Capacitor is charged to a value of 3.3V. For 170 active periods capacitor voltage fall to 2.8V. Taking into account the consumption of circuits for measuring temperature and supply voltage the expected theoretical value is 195 measurements. The result does not deviate much from theoretical considerations, taking into account the deviation values of capacitance super capacitor and the deviation of consumption circuit for measuring voltage and temperature.

V. CONCLUSION

A particular challenge in creating wireless sensor networks is the realization of power nodes in the network. In this paper it is shown that it is possible to provide adequate power for ZigBee modules using solar panels with small dimensions. The usage of this power supply type is limited to applications which do not require frequent processing and sending data. Solar energy is collected in the ambient environment that is considerably smaller than the energy available in outdoor applications. In order to exploit the maximal solar energy and more efficient energy storage it is recommended to use the boost converter.

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