Design & Implementation of a Mobile Phone Charging System Based on Solar Energy Harvesting

Qutaiba I. Ali, IEEE Member
Mosul University/ Iraq
e-mail:Dr.Qutaiba@ieee.org, Qut1974@gmail.com

Abstract— **The ability to harvest energy from the environment represents an important technology area that promises to eliminate wires and battery maintenance for many important applications and permits deploying self powered devices. This paper suggests the use of a solar energy harvester to charge mobile phone devices. In the beginning, a comprehensive overview to the energy harvesting concept and technologies is presented. Then the design procedure of our energy harvester was detailed. Our prototype solar energy harvester proves its efficiency to charge the aimed batteries under sunlight or an indoor artificial light.**

I. INTRODUCTION

Energy harvesting devices can harvest different kinds of energy, including radio frequency, solar, thermal, and vibration. In addition, a single device can harvest energy from multiple ambient energy sources[1,2].

Radio frequency (RF) devices harvest electromagnetic radiation emitted by radio devices, such as wireless radio networks. As the most commonly used frequencies are well known, the devices have an antenna and circuitry tuned to maximize energy harvesting at these frequencies. Unfortunately, typical electric field strengths are weak (unless located close to sources), which severely limits the quantity of energy that can be harvested, e.g., to approximately two orders of magnitude less than indoor solar and thermoelectric devices. Active systems attempt to overcome this limit by broadcasting RF energy, as is done currently for RFID tags used in commerce[3].

Thermoelectric [TE] devices harvest energy developed from temperature differences via the Seebeck effect, i.e., a temperature difference at the junction of two metals or semiconductors causes current to flow across the junction. The power density of TE increases with the temperature difference[1,3] increasing their attractiveness in applications such as sun/shade installations, compressors, and hot/cold/air/water/refrigerant flows.

Vibration harvesters extract energy from ambient vibrations. As power usually scales with the cube of vibration frequency and the square of vibration amplitude, these devices have the most value in applications with high-frequency, high-amplitude vibrations[3] Thus, potentially promising vibration sources could include compressors, motors, pumps, blowers, and, perhaps to a lesser extent, fans and ducts. All vibration-harvesting systems contain mechanical elements that vibrate, typically a spring-mass assembly with its natural frequency close to those of the vibration source to maximize energetic coupling between the vibration source and the harvesting system. Several different ways exist to translate the vibrating elements into electric energy, including piezoelectric, capacitive, and inductive systems[4].

Solar energy harvesting devices use photovoltaic (PV) cells to convert incident light into electricity. As such, they leverage the extensive investments made and progress achieved in increasing the efficiency and reducing the cost of PV for building- and utility-scale power. Solar devices can produce energy from both outdoor and indoor light sources, although outdoor insolation levels yield approximately two to three orders of magnitude more electricity per unit area than indoor electric light sources[3,4]. Relative to other sources, solar devices can achieve high energy densities when used in direct sun, but will not function in areas without light (e.g., highly shaded areas, ducts)[3,4]. Applications to date include contact and motion sensors for building applications,[5] as well as calculators, PDAs, and wristwatches[3].

Table 1 shows the power generation potential of several energy harvesting modalities [2]. While a wide variety of harvesting modalities are now feasible, solar energy harvesting through photo-voltaic conversion provides the highest power density, which makes it the modality of choice to power an embedded system that consumes several mW using a reasonably small harvesting module.
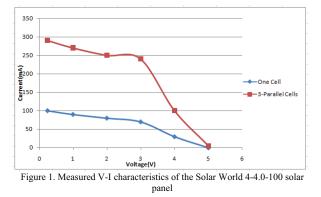
TABLE 1. POWER DENSITIES OF HARVESTING TECHNOLOGIES

Harvesting technology	Power density
Solar cells (outdoors at noon)	$15 mW/cm^2$
Piezoelectric (shoe inserts)	$330 \mu W/cm^3$
Vibration (small microwave oven)	$116 \mu W/cm^3$
Thermoelectric (10^oC gradient)	$40 \mu W/cm^3$
Acoustic noise (100dB)	$960 nW/cm^3$

This paper focus on using solar cell energy harvesting in providing an alternative power source to charge mobile phone devices. Previous works in this field can be found in [6-9]. A solar harvesting augmented high-end

embedded system was described in [6], in which a switch matrix was used to power individual system components from either the solar panel or the battery. Harvesting aware protocols have also been proposed for data routing [7], and distributed performance scaling [8], [9].

II. CHARACTERISTICS INVESTIGATION OF A SOLAR ENERGY HARVESTER

Solar cells have vastly differing characteristics from batteries. The V-I characteristics of the 4-4.0-100 solar panel, which was adopted in this work, from Solar World Inc. are shown in Figure 1. The characterization was performed on May 12, 2010 at 12.30 PM with a panel that measured 4.25" x 2.5". Solar panels are characterized by two parameters, the open circuit voltage (Voc) and the short circuit current (Isc). These form the x- and y- intercepts of the V-I curve, respectively. Several observations can be made from the figure. First, it is clear that a solar panel behaves as a voltage limited current source (as opposed to a battery which is a voltage source). Second, there exists an optimal operating point at which the power extracted from the panel is maximized. Finally, as the amount of incident solar radiation decreases (or increases), the value of Isc also decreases (or increases). However, Voc remains almost constant. Due to its current source-like behavior, it is difficult to power the target system directly from the solar panel, since the supply voltage would depend on the time varying load impedance. Hence, an energy storage element, such as a battery, must be used to store the energy harvested by the panel and provide a stable voltage to the system.

Figure 1. Measured V-I characteristics of the Solar World 4-4.0-100 solar panel

Other tests were performed to investigate the solar cell characteristics using artificial indoor light source (40 W fluorescent neon) as shown in Figures (2 & 3). It is obvious that limited power could be obtained from this light source and it is greatly affected by the distance between the light source and the solar panels.
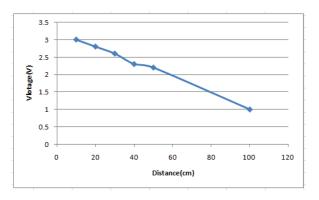

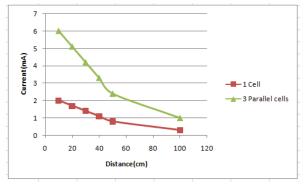Figure 2. Voltage Characteristics of an Indoor Solar Cell

Figure 3. Current Characteristics of an Indoor Solar Cell

III. ENERGY STORAGE TECHNOLOGIES

Perhaps the most complex (and crucial) design decision involves the energy storage mechanism. The two choices available for energy storage are batteries and electrochemical double layer capacitors, also known as ultracapacitors. Batteries are a relatively mature technology and have a higher energy density (more capacity for a given volume/weight) than ultracapacitors, but ultracapacitors have a higher power density than batteries and have traditionally been used to handle short duration power surges. However, they involve leakage (intrinsic and due to parasitic paths in the external circuitry), which precludes their use for long term energy storage.

Thus, the choice of battery chemistry for a harvesting system depends upon its power usage, recharging current, and the specific point on the cost-efficiency tradeoff curve that a designer chooses. Different types of rechargeable batteries are commonly used. The available type in our lab. was Nickel Cadmium (NiCd), so that, it was suggested in this paper.

IV. HARVESTING CIRCUIT DESIGN

The core of the harvesting module is the harvesting circuit, which draws power from the solar panels, manages energy storage, and routes power to the target system, see Figure(6). The most important consideration in the design of this circuit is to maximize efficiency. There are several

aspects to this. A DC-DC converter is used to provide a constant supply voltage to the embedded system. The choice of DC-DC converter depends on the operating voltage range of the particular battery used, as well as the supply voltage required by the target system. If the required supply voltage falls within the voltage range of the battery, a boost-buck converter is required, since the battery voltage will have to be increased or decreased depending on the state of the battery. However, if the supply voltage falls outside the battery's voltage range, either a boost converter or a buck converter is sufficient, which significantly improves power supply efficiency. In this work, we used Texas Instruments TPS63000 low power boost-buck DC-DC Converter because it suits our needs. This converter (see Figure(4))provides a power supply solution for products powered by either a two-cell, or three-cell alkaline, NiCd or NiMH, or one-cell Li-Ion or Li-polymer battery. Output currents can go as high as 1200 mA while using a single-cell Li-Ion or Li-Polymer Battery, and discharge it down to 2.5 V or lower. The buck-boost converter is based on a fixed frequency, pulse-width-modulation (PWM) controller using synchronous rectification to obtain maximum efficiency. At low load currents the converter enters the Power Save mode to maintain a high efficiency over a wide load current range. The Power Save mode can be disabled, forcing the converter to operate at a fixed switching frequency. The maximum average current in the switches is limited to a typical value of 1800 mA. The output voltage can be programmed by an external resistor divider, or is fixed internally on the chip[10].

Within the TPS6300X family there are fixed and adjustable output voltages available. To properly configure the fixed output voltage devices the FB pin is used to sense the output voltage. This means that it must be connected directly to VOUT. At the adjustable output voltage versions and external resistor divider is used to adjust the output voltage. The resistor divider must be connected between VOUT, FB and GND. When the output voltage is regulated properly the typical value of the voltage at the FB pin is 500 mV. The maximum recommended value for the output voltage is 5.5 V. The current through the resistive divider should be about 100 times greater than the current into the FB pin. The typical current into the FB pin is 0.01 µA, and the voltage across the resistor between FB and GND, R2, is typically 500 mV. Based on those two values, the recommended value for R2 should be lower than 500 kΩ, in order to set the divider current at 1 µA or higher. It is recommended to keep the value for this resistor in the range of 200 kΩ. From that, the value of the resistor connected between VOUT and FB, R1, depending on the needed output voltage (VO), can be calculated using Equation 1:

$$R_1 / R_2 \times \left(\frac{V_{OUT}}{V_{FB}} + 1 \right) \quad (1)$$

In our case, an output voltage of 3 V is needed, a 1.0 MΩ resistor should be chosen for R1. To improve control performance using a feedforward capacitor in parallel to R1 is

recommended. The value for the feedforward capacitor can be calculated using Equation 2.

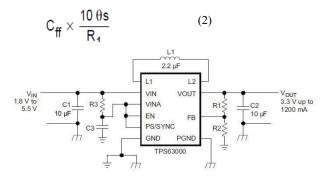$$C_{ff} \times \frac{10 \, \theta s}{R_1} \quad (2)$$

Figure 4. Application Circuit for Adjustable Output Voltage Option

To properly configure the TPS6300X devices an inductor must be connected between pin L1 and pin L2. To estimate the inductance value Equation 3 and Equation 4 can be used.

$$L_1 / \frac{V_{OUT} \times (V_{IN1} + V_{OUT})}{V_{IN1} \times f \times 0.3 \, A} \quad (3)$$

$$L_2 / \frac{V_{in2} \times (V_{OUT} + V_{IN2})}{V_{OUT} \times f \times 0.3 \, A} \quad (4)$$
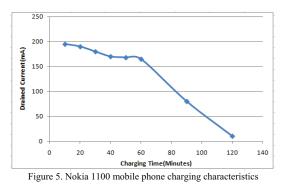
In both equations f is the nominal switching frequency. In Equation 3 the minimum inductance value, L1 for step down mode operation is calculated. VIN1 is the maximum input voltage. In Equation 4 the minimum inductance, L2, for boost mode operation is calculated. VIN2 is the minimum input voltage. The recommended minimum inductor value is either L1 or L2 whichever is higher. A suitable inductor, for generating 3V from a NiCD battery with a battery voltage range from 2.5V up to 4.2V, is 2.2 mH. In general this means that at high voltage conversion rates higher inductor values offer better performance. For the input capacitor, at least a 4.7 µF input capacitor is recommended to improve transient behavior of the regulator and EMI behavior of the total power supply circuit. For the output capacitor, an estimated value of the recommended minimum output capacitance could be obtained using Equation 5:

$$C_{OUT} + 5 \times L \times \frac{F}{H} \quad (5)$$

In order to determine our needs, the following procedure was followed:
1. A survey was made to determine the traditional phone chargers characteristics. It was found that most charging methods depends on "constant voltage" supply with a (3 to 4) DC voltage and several hundreds mA current.

2. To be more specific, Nokia 1100 mobile phone charging characteristics was investigated. Figure(5) shows the current draining cycle for this device using (3 V) constant DC supply .

Figure 5. Nokia 1100 mobile phone charging characteristics

From Figure(5) above, it is clear that we need 3V supply with (200 to 100 mA) current value to start the charging process. To enhance a previously charged battery, we need a supply with (3 V) and several tens mA current.

To increase efficiency, our design choices were guided by the goal of increasing the current supplied by the harvesting module. We used three parallel 4-4.0-100 solar panels from Solar World Inc., which have a rated *Voc* of 5.0V and *Isc* of 100mA. The maximal power point of this panel lies at 3.0V and varies slightly depending on the time of day, as evident from its V-I characteristics shown in Figure(1) .

The solar panel is connected to a battery whose terminal voltage determines the panel's operating point along its V-I curve. We ensure operation at the maximal power point through our choice of battery. Using two parallel NiCd batteries with voltage varies between 2.2V and 2.8V, which, together with a diode used to prevent reverse current flow into the solar panel, ensures that the voltage across the solar panel terminals remains close to optimal. Our charging circuit is considerably simplified, leading to increased efficiency.

To avoid problems such as decreased radio range caused by decreased battery voltage, we use a step up DC-DC converter to provide a constant 3V supply voltage to the battery which provides overcharge and undercharge protection for the batteries.
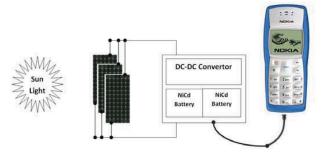

Figure 6. The Suggested Solar Energy Harvesting Circuit

V. CONCLUSIONS

This paper suggests the use of a solar energy harvester in mobile phone devices. The following remarks could be extracted from the current work:

1. It is possible to use solar energy to supply mobile phones batteries with the necessary power.
2. Under direct sunlight, it possible to charge an empty battery using the necessary number of parallel solar cells.
3. Indoor artificial light could be used to enhance the charge of the battery.
4. Our design was implemented using simple and cost effective circuit.

REFERENCES

[1] G. Park "Overview of Energy Harvesting Systems (for Low-Power Electronics)." Presentation at the First Los Alamos National Laboratory Engineering Institute Workshop: Energy Harvesting, 2005 .
[2] Ferro Solutions. "VEH-360: Evaluation Power System Specifications."
[3] J.A. Paradiso and T. Starner. 2005. "Energy scavenging for mobile and wireless electronics." *Pervasive Computing* 4(1):18–27, 2007.
[4] S. Roundy "Energy scavenging for wireless sensor nodes with a focus on vibration-to-electricity conversion." Presentation at University of California, Berkeley. http://tinyurl.com/2s8khk, 2003.
[5] EnOcean. *Perpetuum International Edition* 4(6). http://tinyurl.com/2lxbo5 (or www.enocean.com/fileadmin/redaktion/pdf/perpetuum/perpetuum_06_en.pdf), 2007.
[6] C. Park and P. Chou , "Power utility maximization for multiple-supply systems by a load-matching switch", *Proc. ACM/IEEE International Symposium on Low Power Electronics and Design*, pp. 168–173, 2004.
[7] T. Voigt, H. Ritter, and J. Schiller, "Utilizing solar power in wireless sensor networks", *Proc. IEEE Conference on Local Computer Networks*, 2003.
[8] A. Kansal and M. Srivastava, "An environmental energy harvesting framework for sensor networks", *Proc. ACM International Symposium on Low Power Electronics and Design*, pp. 481–486, 2003.
[9] A. Kansal, D. Potter, and M. Srivastava "Performance aware tasking for enrironmentally powered sensor networks", *Proc. ACM Internationl Conference on Measurement and Modeling of Computer Systems*, pp.223–234, 2004.
[10] TPS63000 Data Sheet, WWW.ti.com.