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Designing and Testing Energy Harvesters Suitable for Renewable Power Sources

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Abstract. Energy harvesters convert waste power (heat, light and vibration) directly to electric power . Fast progress in their technology, design and areas of application (e.g. "Internet of Things") has been observed recently. Their effectiveness is steadily growing which makes their application to powering sensor networks with wireless data transfer reasonable. The main advantage is the independence from wired power sources, which is especially important for monitoring state of environmental parameters. In this paper we describe the design and realization of a gas sensor monitoring CO level (powered by TEG) and two, designed an constructed in ITE, autonomous power supply modules powered by modern photovoltaic cells.

1. Introduction

The number of various electronic devices in our environment is growing fast. It creates problems concerning energy supply and increases electromagnetic radiation pollution, especially in dangerous form of microwaves. A possible solution to this problem is to use energy which has usually been treated as a waste. It is available in great amounts, since most popular devices have relatively low energetic effectiveness – most of them show only 15% efficiency. A good example is general lighting, only a few years ago, thanks to the widespread usage of LED's, popular lamps have achieved efficiency greater than 10%. Energy harvesters are a new group of electronic devices designed to acquire and store this "waste" energy, which can be used for control and measurement equipment, wearable devices, personal communicators and many others [1-12].

Devices described in this paper acquire small amounts of power (from miliwatt range), but they collect it permanently. This allows to store energy suitable for high power devices which work for a short time but with long intervals. Designed and described harvesters are suitable for powering wide range of sensors working in measurement systems with wireless data transfer including emergency systems. As a source of power we use modern photovoltaic cells (especially Graetzel cells –DSSC, organic – OPV and amorphous silicon cells) which can work in artificial lighting conditions. As a base for calculations we have used EN 12464-1:2012 recommendations, which require 500 lux for office space lighting and 300 lux for others spaces in buildings as a minimum. In such conditions even relatively small cells are suitable for powering sensors usable in building automation such as ambient temperature sensors, light level sensors, smoke detectors, presence detectors, access control points, etc. Small power thermogenerators (TEG) are usable in many applications too. They are especially efficient for heating systems controllers, because they eliminate a need of wired grid supply systems. They are suitable for example for gas sensors and smart power meters.

2. Review of designs

Our main goal was designing and testing devices manufactured from standard electronic parts, which have application in white goods area.

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2.1. Harvester based on thermogenerator (teg)

An example of such application are devices measuring level of CO in output gases of gas boilers and ovens. They can be used in heating systems and powered by standard thermogenerator. Such device eliminates a need of standard grid supply and the oven can work autonomously. Similar device can be used in solar collectors for powering the system monitoring the amount of the generated heat. In this case hot water is the power source.

A block diagram of the device is shown in Figure 1:

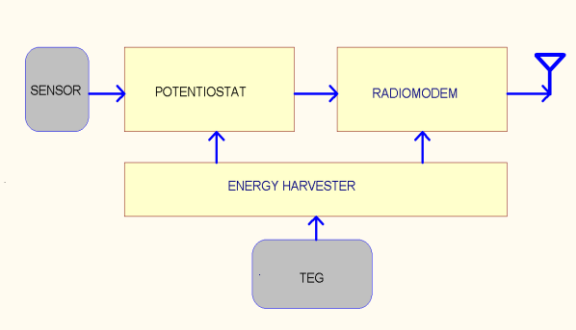


Figure 1. Block diagram of the CO detector

Level of CO is measured by electrochemical sensor manufactured by „Alphasense" company. Diagram of potentiostatic measurement module for the sensor is shown in Figure 2. It is based on micropower operational amplifiers ADA4505-2 from "Analog Devices" [13].

Detailed description of the module is available in application note CN0234 [14]. It states that the module in the "wake" mode needs 110µA, and after detecting CO presence the current grows up to 460 µA, (supply voltage level is 5V) generating an alarm signal. We can estimate power needs of a module at ca. 2.5mW. Above listed data were confirmed during measurements of the working devices.

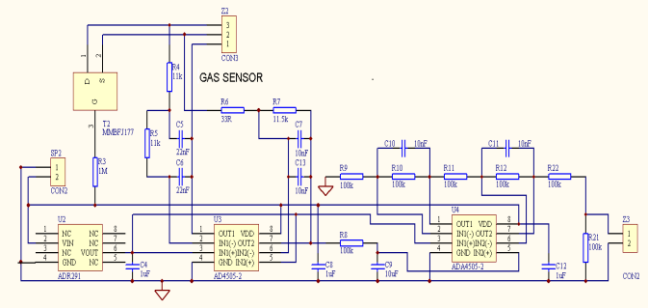


Figure 2. Potentiostat based on ADA4505-2

For its proper work the device requires a storage of small amount of power for wireless alarm. It can be estimated using the data of the radiomodem used in the device (in this case Telit LE50-433) [16]. During transmission the device requires 50mA for 0.1s. Start from the „sleep" mode requires 10mA for 5s. It implies that it needs minimum 0.1mWh of energy stored before start of the alarm procedure. Such amount of power can be stored by a 0.22F/5.5V supercapacitor.

LTC3107 [23] from „Linear" can work as a harvester, it has a very low input voltage (starts from Vin=20mV). It is a result of using a switching input via TR1 input transformer. The diagram of harvester is shown in Figure 3.

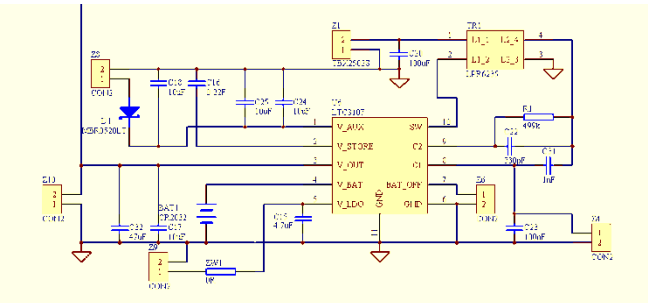


Figure 3. Harvester based on LTC3107.

Telit radiomodem works in a telemetric mode. This opens a possibility ~~to~~ of automatic activation of the radiomodem when the alarm signal is on. Before activation the radiomodem is in "sleep" mode and requires under 10μW of power. Alarm signal generates interrupt which obliges ~~a~~ the radiomodem to send a signal which specifies a source of the alarm [17].
Figure 4 shows a diagram of the radiomodem, and Figure 5 presents the complete device.

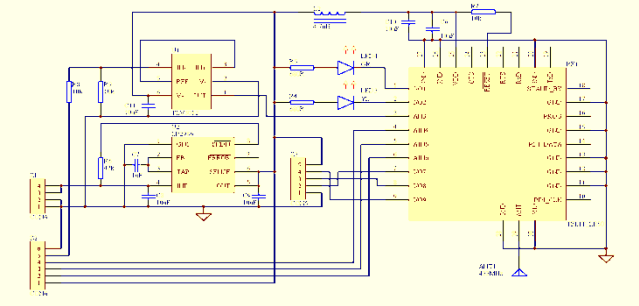


Figure 4. Radiomodem Telit LE50 433MHz

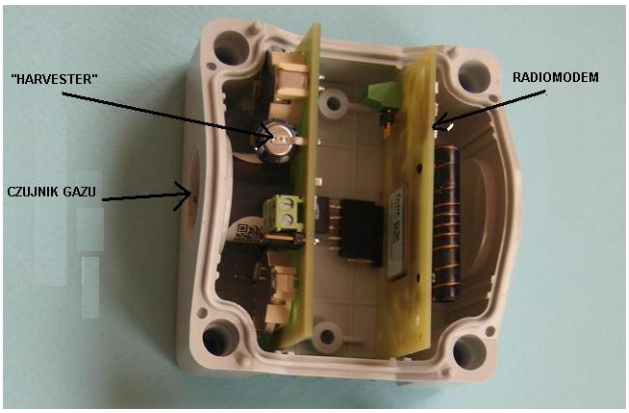


Figure 5. Complete device (enclosure without a cap)

During tests we measured thermogenerators manufactured by "Marlow" – TG-12-4 [18], "Customthermoelectric" 1261-7L31-04CL [19] and "Wellen Technology" TEG 10-46 [20]. Tests confirmed that they supplied the required power (ca. 2.5 mW) when the temperature difference between „cold" and „hot" side was greater than 25-30°C. This corresponds to the hot side temperature within 45-50°C range. Such working conditions are acceptable for practically all ovens or boilers currently present on the market. It is possible to use similar device for power generated by solar hot water collectors.

Diagram of the power generated by TEG's is shown in Figure 6.

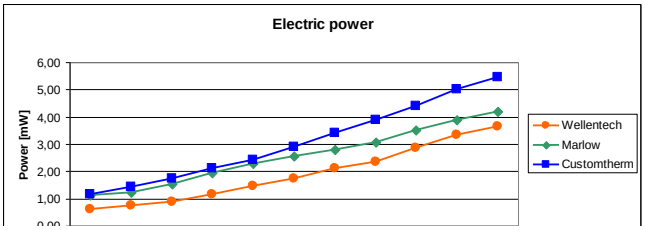


Figure 6. Power generated by TEG's.

Supercapacitors are optimal for energy storage. They have a big reliability - up to 500 000 charge/discharge cycles and a wide range of working temperatures -40/+60°C. At present we can use small-dimensions capacitors from Cooper-Bussmann with capacity 5F (Vmax= 5.5V). Amount of energy stored in such capacitors allow a device to work even if gaps in heating are long.

2.2. Devices powered by photovoltaic cells.

During tests we designed and manufactured power supplies based on IC's from „Linear Technology" (LT3105) „Texas Instruments" (bq25505) and „ST Microelectronics" (SPV1040 i SPV1050). They was DC/DC converters working with maximum power point tracking algorithm (MPPT).

Figure 7 shows example of such converter.

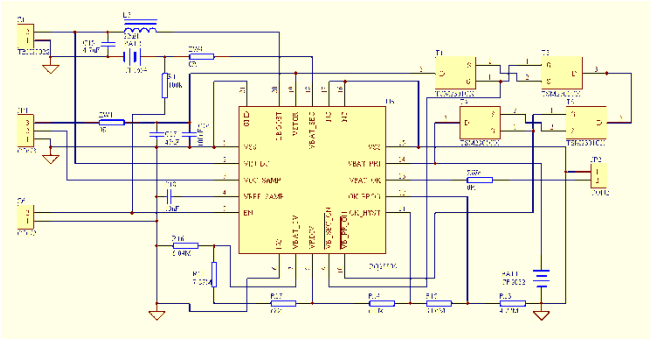


Figure 7. Power supply with MPPT based on bq25505.

It is based on chip bq25505 [15], it contains Li-Ion battery charger and power source selector (multiplexer battery / primary battery). In this design we used coin cell CP1654 from „Varta Microbatteries". Power source selector is based on P-MOS transistors (T1, T3, T4, T5). The resistor ladders R13, R14, R15 and R16, R17, R18 set control points to charging/discharging block and power source selector. Maximum regulated power is on level ca. 500mW. Maximum power point tracking is in accord with „Perturb&Observe" algorithm. MPPT block in chips SPV1040 and SPV1050 works similar.

The maximum power point in LTC3105 [24] is programed using a resistor, which sets value of the maximum power point voltage. This IC contains a regulator which aproximate the optimal amount of current draw from input photovoltaic cell.

As power sources we tested photovoltaics cells suitable for working with artificial lighting manufactured in below listed technologies:

- thinfilm (CIGS) – SP4.2-37 cell from Powerfilmsolar - USA
- amorphous silicon („Amorton") – AM-1816 cell from Panasonic - Japan
- DSSC (Graetzel cell) – from Gcell – UK
- OPV (organic photovoltaic cell) - from „InfinitePV" - Danemark

We measured cells lighted by fluorescent light with intensity from range 200-1100lux (in accord with EN 12464-1:2012). Normalized output current (μA/cm^2) is presented on figure 8.

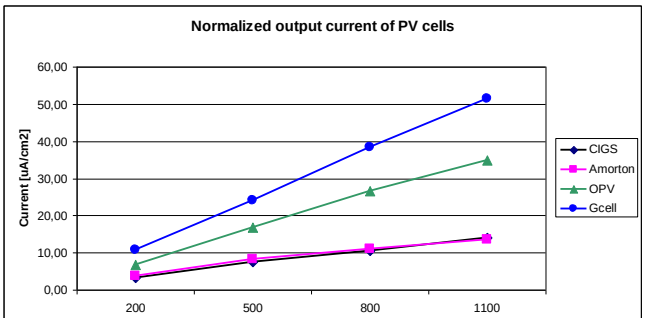


Figure 8. Normalized output current of PV cells.

Based on such tests we can select DSSC cells as optimal for working with artificial lighting. It is recommended to test perovskite and tandem OPV cells when their commercial versions will be available.

When a small dimensions cell (ie. credit card size) is required, a good alternative is to replace a MPPT controller by simple circuit named "Ideal diode". It cuts off connection between cell and battery (or supercapacitor) when cell is in the dark, preventing battery discharge by the darkened cell. In normal conditions battery is directly charged by cell, and in such conditions we spare energy needed for working internal MPPT regulator of the controller. Figure 9 presented a diagram of such simple circuit.

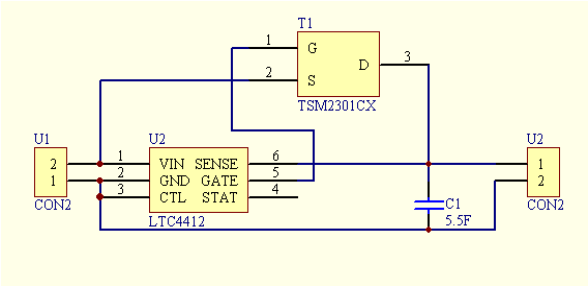


Figure 9. „Ideal diode" circuit.

Above mentioned circuit is based on LTC4412 [21] and works well in most small power applications. We recommended application of the multivibrator for long periods – ie. TPL5100 [22] – it allows periodical activation of load for a short time. It allows practically permanent charging battery of supercapacitor by attached PV cell.

3. Conclusion

When we consider as an example acredit card size GCell, exposed to 500 lux light during 12 hours, we find that harvesting a 13.5mAh charge is possible. The radiomodem for standard session requires 0.02 mAh. Rest of the charge we can use for powering a controller and input/output devices. When we use a modern CMOS devices, the amount of energy harvested is suitable for sophisticated actions. Such example shows that even small power PV cells can be reliable and efficient power source for many usable devices. It is expecially valid for standard office building where lighting is practically permanent. The same opinion is valid for thermogenerators in winter season. We suppose that harvesters will grow in number and particular application areas. They will beimportant especially for „Internet of Things" devices, because they are alternative to expensive wired supply grids or to permanent battery replacement. Very probable is further growth in usage of non silicon photovoltaic devices, because their manufacturing cost will be low and their „manufacturing energy return time" is short. Manufacturing technology is based on printing layers of polimers and cheap. Currently six european research teams are working in such area. We can estimate that as a result of such efforts, this kind of energy sources will be cheap and reliable. Very probable are efforts to design „printable" harvesters which will be manufactured in the same technology as the energy sources (photovoltaic cells).

4. References

[1] Starner T Paradiso J.A 2004 Human Generated Power for Mobile Electronics in Piguet, C. (ed) *Low Power Electronics* CRC Press **45**-1− 45-35

[2] Harry Zervos 2013 Thermoelectric Energy Harvesting 2013-2023: Devices *Applications, Opportunities PRNewswire* (New York)

[3] Chung-Yang Sue, Nan-Chyuan Tai 2012 Human powered MEMS-based energy harvest devices *Applied Energy* **93** 390–403.

[4] Shengulette J 2012 Pace is picking up for Energy Harvester's Walking Charger *Rochester Democrat and Chronicle, Gannett Co., Inc., McLean* (USA) .

[5] Paradiso J A, Starner T 2005 Energy Scavenging for Mobile and Wireless Electronics *IEEE Pervasive Computing* **4** 18-27.

[6] Saha C R, O'Donnell T, Wang N, McCloskey P 2008 Electromagnetic generator for harvesting energy from human motion *Sensors and Actuators A* **147** 248–253.

[7] Ahmed Munaz, Byung-Chul Lee, Gwiy-Sang Chung 2013 A study of an electromagnetic energy harvester using multi-polemagnet *Sensors and Actuators A* **201** 134– 140.

[8] Korla S, Leon R A, Tansel I N, Yenilmez A, Yapici A, DemetGul M 2011 Design and testing of an efficient and compact piezoelectric energy harvester *Microelectronics Journal* **42** 265–270

[9] Tkaczyk E 1997Compact and Lightweight Energy Conversion Using Electrostrictive Polymers *Proc. Prospector IX: Human-Powered Systems Technologies Space Power Inst., Auburn Univ* 313-329.

[10] Kymissis J, Kendall C, Paradiso J, Gershenfeld N 1998 Parasitic Power Harvesting in Shoes *Proc. 2nd Int'l Symp. Wearable Computers, IEEE CS Press* 132–139.

[11] Shaahank Priya, Daniel J Inman 2009 Energy harvesting Technologies *Springer* (New York).

[12] Krupenkin T, Ashley Taylor J 2011 Reverse electrowetting as a new approach to high-power energy harvesting *Nature Communications* **2** 448.

[13] Datasheet of the ADA4505-2 http://www.analog.com , access february 2015

[14] Application note CN0234 from Analog Devices, http://www.analog.com , access february 2015

[15] Datasheet of the bq25505 http://www.ti.com, access february 2015

[16] Telit_xE50-433/868_RF_Module_User_Guide_r11 http://www.telit.com access february 2015

[17] Telit_Star_Network_Protocol_Stack_User_Guide_r9 http://www.telit.com access february 2015

[18] Datasheet of the TG12-4 http://www.marlow.com , access october 2014

[19] 1261G-7L31-04CL_spec_sht http://www.customthermoelectric.com access october 2014

[20] Datasheet of the TEG 10-46 http://www.wellentech.com access october 2014

[21] Datasheet of the LTC4412 http://www.linear.com, access february 2015

[22] Datasheet of the TPL5100 http://www.ti.com, access may 2015

[23] Datasheet of the LTC3107 http://www.linear.com, access february 2015

[24] Datasheet of the LTC3105 http://www.linear.com, access february 2015