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# Autonomous data logger design example

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## Abstract

***The guidelines of autonomous electronic data logger device equipped with SD flash card storage system are described. Various micro power sources are proposed for implementation of autonomous work, as well as the problem of uninterruptable power supply are discussed and designed with combination of small Solar panel and Li-ion battery. Specific power management integrated circuits are described. In context of decreasing the power consumption of data logger system, the way of usage of microcontroller's internal peripheral devices is described and software code is analyzed.***

## Keywords

Autonomous work, data logging, SD flash card

## 1. Introduction

The analysis of any process is possible when data are collected during some period, which depends on inertia of the process. It may be as small as several seconds, for example to measure fast dynamics process, such as wind pattern of moving train, or it may be even years to collect the data on wind or Solar energy potential in certain place. Of course this requires data storage with appropriate capacity that is possible to store the necessary data of the process during data collecting period.

Mostly such tasks require uninterruptable power supply, at the same time it may be unachievable to utility grid that requires additional attention to this problem.

In this paper autonomous data logger with small Solar panel and battery backup energy system has been investigated, implemented and tested.

## 2. Providing Autonomous Work

### 2.1. Choosing the energy source

The autonomous work is desirable solution for data logging because it does not requires any additional infrastructure, such as utility grid.

The solution for this autonomous data logger application may be harvesting energy from one of the "free" energy sources: Solar, Wind, Thermo or Vibration. Last two solutions are quite exotic. Nevertheless it is available to buy on the market Thermo Electricity generators and Piezoelectric energy transducers, which provides micro volts of electrical power, what is unusable for most electronics for direct connection. However with innovative energy management integrated circuits (for example LTC3108, LTC3588) it is possible to boost it till desirable 3.3 V. During system work period it may consume about 50 mA@3.3 V (165 mW), but assuming that duty cycle of the system is 1% (10 ms with 1 s period), average power is only 1.65 mW, what makes it possible to use Thermo electric and Piezoelectric transducers which provides power in a range of 10 uW...10 mW. And to make more less constant voltage, output capacitor should have enough capacity to provide little voltage drop during operation period, preserving system malfunctioning.

Wind power also is a form of "free" energy that can be harvested on open air or in tunnels, where the air flow is presenting. Another inconvenience is related with the area of windmill rotor that delivers required power. It has square ratio on delivered power versus rotor area, that is why to deliver small power the size of rotor will not be so small.

Beside that all mentioned, windmill is complicated engineering task that is costly in compare with small electronic device that is planned to do.

On that perspective the Solar panels are great looking, first of all because they are available on the market at different sizes and power at an average price of 1...2 USD per 1 W including housing. More over it is possible to buy separate parts and make custom design Solar panel that will fit certain conditions [1].

### 2.2. Choosing the required power

Solar power is unpredictable and inconstant, that requires additional energy storage element that will provide power for electronic system during night and even cloudy weeks. That requires some analysis of power consumption of electronic system.

Average energy consumption of electronic device for one sample equals to:

$$E_{sample} = P_{MCU} \cdot t_{sample} = (3 \cdot 0.05) \cdot 0.01 = 1.5\,\text{mW}$$

Then the power required by exact sample rate (SR [1/sek]) could be found as fallowing, for example for one sample per second:

$$P_{MCU@SR=1} = E_{sample} \cdot SR = 1.5 \cdot 1 = 1.5\,\text{mW}$$

If it is required that the load need to be powered during certain period of time, when the main source of energy is inaccessible, then the calculation should be made of energy storage element, which will supply the system. As an example it is proposed system with uninterruptable power supply during period of one month.

The total energy amount that will be consumed during one month is:

$$E_{month} = P_{MCU@SR=1} \cdot T_{period} =$$

$$1.5 \cdot 10^{-3} \cdot 3600 \cdot 24 \cdot 30 = 3888 \text{ J}$$

It is comparable with one 3048 coin type Li-ion rechargeable battery energy capacity (300 mA·h, 3.6 V), that can be used in the data logger's power supply [10].

$$E_{bat} = I \cdot t \cdot V = 0.3 \cdot 3600 \cdot 3.6 = 3888 \text{ J}$$

Another task is to calculate the appropriate power of "free" or renewable energy source, to be able to charge the battery and supply the system as well. Let's assume that Solar panel should have enough power ($P_{RES}$) to charge the battery during three hour in sunny day (minimal time by Constant Current Constant Voltage (CCCV) charging method for chosen battery):

$$P_{RES} = \cdot \frac{E_{bat}}{T_{charging}} = \frac{3888}{(3*3600)} = 0.36 \text{ W}$$

It was made 2 W Solar panel, which consist of four 0.5 watt (0.5 V, 1 Amp) Solar cells connected in series to provide high voltage. Cells are placed in hermetic enclosure made of Plexiglas, with external contacts.

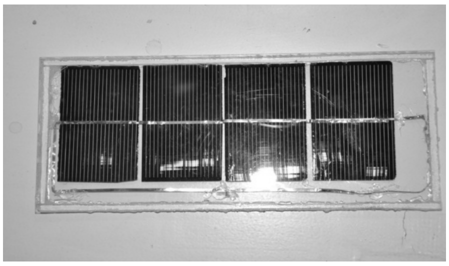

*Fig. 1. Custom design 2 W Solar panel*

**2.3. Designing the power supply scheme**

Solar panel provides variable voltage depending on Solar irradiation level and angle. It means that output voltage could vary from 0 till 2 V, what could not used directly supplying MCU and Flash card. TPS61200 IC was used as Boost controller, which is possible to harvest energy from Solar panel starting from 0.3 V and boost it till 5 volts.

The next key element of the power system is called System Power Path Management – this IC (BQ24230) provides power for the load and if input voltage does not drop, then it charges the battery. If the input voltage becomes smaller than Battery voltage then "Power good" condition disappears and system starts to supply system from the battery. This IC implements CCCV charging algorithm. Main set points of this algorithm is programmed by two resistors – charging current and termination current values [9].

Charging current (150 mA for chosen battery) is defined by impedance of resistor connected to Iset pin. Its resistance could be found by formula from [9] ($k_{Iset} = 870 \text{ A}\cdot\Omega$).

$$R_{Iset} = \cdot \frac{k_{Iset}}{I_{chrg}} = \frac{870}{0.15} = 5.8\ k\Omega \Rightarrow 5.6\ k\Omega$$

The charging termination current (which is 9 mA for chosen battery), is found by formula

($k_{Iterm} = 0.03 \text{ A}$) [9]:

$$R_{Iterm} = \cdot \frac{R_{Iset} \cdot I_{term}}{k_{Iterm}} = \frac{5600 \cdot 0.009}{0.03} =$$

$$1.68\ \text{k}\Omega \Rightarrow 1.8\ \text{k}\Omega$$

The power supply board dimensions could be very small because mentioned IC has QFN packages. Passive elements could also be chosen smaller than it was used in prototype (SMD 1206), as well as PCB could be two-side, instead of one side, like in photo (see Fig. 3). The principle circuit is shown below (see Fig. 2)

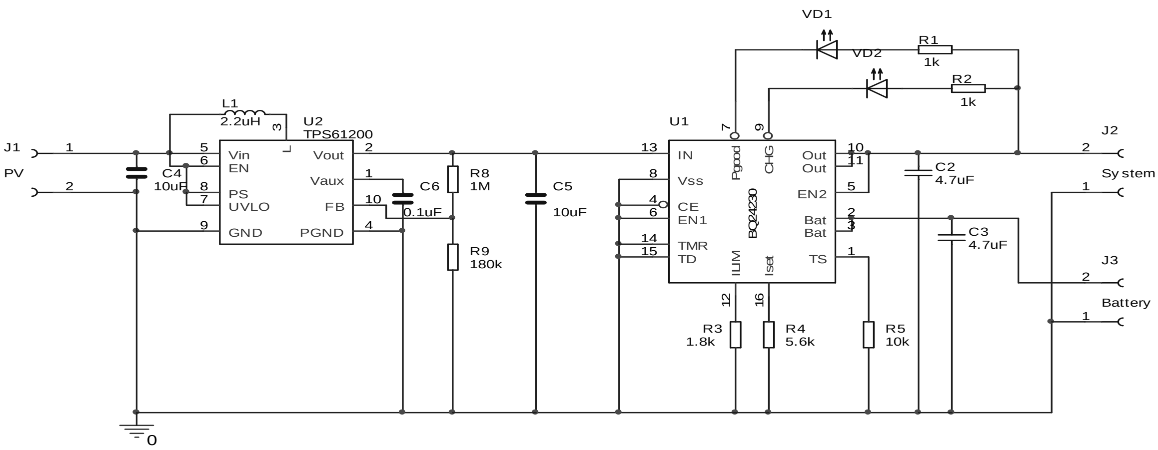


*Fig. 2. Uninterruptable power supply for autonomous data logger*

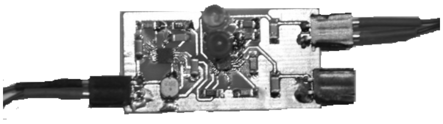

*Fig. 3. Power Supply PCB prototype*

## 3. Data logger electronic elements

### 3.1. Storage system

Flash cards are compact data storage elements, that can be easily used in data logger. There are available several basic types of Flash memory cards on the market, such as Compact Flash, Multi Media Card, Secure Digital Card. The type of particular Flash memory card defines required I/O pins for microcontroller, to establish a data communication between them.

CF cards have 50 pins connection circuit, with many service pins like in LPT port. It provides direct connection for Flash memory via 2x8bit or 1x16 bit bus. As well there are power supply pins, which consists of three power groups: VCCK kernel supply (1.65...1.95 V by internal regulator), VCC3 reference voltage (2.7...3.6 V) for flash interface, VCC5 – reference voltage (3.0...5.5 V) CF interface I/O [8].

MMC cards are connected through special card interface (containing CMD, CLK, DAT0..3) or more popular SPI interface (via MOSI, MISO, CLK, CS ), which is often build in microcontrollers. During card initialization procedure it is possible to choose the desirable interface for communication [6].

SD card has similar connection scheme – it could be initialized in SD card mode (where 4 bits at one clocking period are transmitted parallel) or in SPI mode (serial interface). This card type is available in various form factors: standard SD, mini SD and micro SD [7].

**Table 1.** Comparison of different flash card power consumption [5, 6, 7, 8]

| | Sleep | Read | Write |
|---|---|---|---|
| Compact Flash | 0.45 mA | 15 mA | 15 mA |
| Multi Media Card | 0.075 mA | 70 mA | 70 mA |
| microSD(3V @25 °C) | 0.12 mA | 40 mA | 40 mA |

For this application it was chosen microSD card because of its compactness and small energy consumption, secondly because it works via SPI interface. Additional advantage is that the card goes in standby mode automatically if no command received during 5ms, which potentially decreases power consumption.

### 3.2. Choosing microcontroller

The microcontroller peripheral set (such as RAM, EEPROM, UART modules, DMA, GPIO, ADC etc.) must match the particular application. Firstly, it should match minimal requirements which are: USART module interfacing SD card over SPI bus and at least 512 RAM (because it is required by minimal writing block size for chosen SD card) and DMA modules for minimization of power consumption due to optimized software code design, which will be described later. Secondly, application specific peripheral modules set may require additional UART module for communication with sensor over serial bus (for example optical sensor with I2C interface), ADC modules for analog data measurements etc.

For proposed prototype the MSP430F169 microcontroller were chosen, which contain 5 GPIO ports with 8 pins each, 2USART, 3 DMA modules, 12bit ADC, RAM, EEPROM [3].

This microcontroller has four sleeping modes (LPM0, LPM2, LPM3, LPM4) with various configurations of internal clocking system settings. The main clocking system may consist of three different clock sources (LFXT1CLK, XT2CLK, DCOCLK), which are independently chosen for each of three basic internal clocking signals: MCLK used by CPU, SMCLK and ACLK used by peripheral modules. The power consumption varies in a range from 320 µA (in active mode) till 0.1 µA (in LPM4 mode), which has great potential to minimize the power consumption [2].

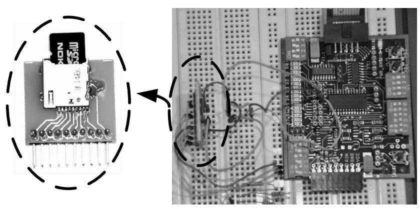

*Fig. 4. Data logger prototype*

## 4. Optimized software design

It is available in the Internet many examples of software source codes, which interfaces microcontroller with SD card, but the problem is that they don’t care on power consumption. As an example from [4], it may be analyzed the byte sending procedure:

```
unsigned char spiSendByte(const unsigned
char data)
{
  while ((IFG2&UTXIFG0) ==0); //wait while
not ready
  U0TXBUF = data; // write
  while((IFG2&URXIFG0)==0);
//wait for RX buffer (full)
  return (U0RXBUF);
}
```

It is used two loops there, during which the microcontroller checks the special register *IFG2* content on presence of *transmit complete (UTXIFG0)* or *receive complete(URXIFG0)* event notification bits. During that loops the microcontroller works in active mode with the maximal power consumption, instead waiting for interrupts, which are generated by microcontroller USART module [2].

Another way how to decrease the power consumption of microcontroller is to use Direct Memory Access (DMA) module. The idea is to realize the data transfer procedure without the use of energy consuming CPU. This module is programmable for various event handling, particularly for events generated by USART module. DMA is capable to transmit the data from some place in memory to another place. For example, this module should be used to realize captured data transfer from RAM to USART transmit buffer, while CPU remains in off state [2].

If DMA is used when microcontroller is in LPM3 mode (only ACLK is working and MCLK is set to LFXT1CLK source) it needs only 5 MCLK cycles to transmit the byte. Assuming 8 MHz LFXT1CLK source it is 0.5 µs [2].

The configuration of DMA (for 0 channel) module for this procedure is following:

```
DMACTL0 |= 0x0100b; // DMA trigger source is
set to UTXIFG0
DMA0SZ = 512; //sector size
DMA0SA=0x200h; //sector_start in RAM
DMA0DA = &U0TXBUF; //Dest.address
DMA0CTL0 = DMADT0 + DMADSTINCR_0 +
DMASRCINCR_3 + DMASRCBYTE + DMAEN + DMAIE;
// single transfer mode, no dest.address
increment, source address increment set to
+1;
```

This approach allows sending a block of captured data in LPM3 mode (when DCO generator is OFF, CPU is OFF, SMCLK clock is OFF), which will consume (per sector write operation):

$$E_{LPM3} = N_{bytes} \cdot P_{MCU\_LPM3(@3V;8MHz)} \cdot \left(T_{byte@400kHz} + T_{DMA@8MHz}\right) = 512 \cdot 3 \cdot 1 \cdot 10^{-6} \cdot 8 \cdot \left(8 \cdot \frac{1}{400 \cdot 10^{3}} + 5 \cdot \frac{1}{8 \cdot 10^{6}}\right) = 0.253\,\mu J$$

Comparing it with active microcontroller's working mode (when CPU is constantly On), the power consumption is (per sector write operation):

$$E_{AM} = N_{bytes} \cdot P_{MCU\_AM(@3V;8MHz)} \cdot \left(T_{byte@400kHz} + T_{code@8MHz}\right) == 512 \cdot 3 \cdot 320 \cdot 8 \cdot \left(8 \cdot \frac{1}{400 \cdot 10^{3}} + 17 \cdot \frac{1}{8 \cdot 10^{6}}\right) = 87\,\mu J$$

It is clearly seen the difference of power consumption in both mentioned operating modes. This means, that it is very important to use in practice special software optimization for maximal decreasing of MCU energy consumption.

## Conclusions

The proposed solution of autonomous data logger design describes several steps of system design. Firstly, the Solar energy harvesting system is proposed as the most suitable solution. Specific ICs are used to implement uninterruptable power supply which uses also Li-ion battery. The principles of choice of microcontrollers are described for efficient work and small energy consumption. As well several features of program code design are described, which uses microcontroller's internal peripheral modules, which greatly affects upon power consumption.

## Future work

For the future work it is planned to realize FAT file system on MSP430 microcontroller for enhancing the functionality of proposed prototype of autonomous data logger.

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