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Electronic Energy Meter Suitable for Energy Efficiency Analysis

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Abstract - **This paper presents an electronic power metering system using the MCP3905 energy metering chip from Microchip® together with the microcontroller PIC16F873A for the data processing. The purpose of the system is to monitor active power consumption of domestic electric devices like air conditioners, stoves, lights, hot plates, etc. The system provides RS-232 interface for connecting to another module to logging the data into a backend or controlling the monitored device (data logger or host system). Mentioned modules can be embedded electronic devices or a simple personal computer (PC).**

Keywords – **Power Consumption, Energy meter**

I. Introduction

It is important for us to know exactly how much power consume our electronic devices. This is especially true for cooling/heating devices that operate on time-division power saving basis like air conditioners. A look over the measurements and statistics can show any problems in high cost monthly bills; also it will show the energy efficiency. Now the energy efficiency analysis is the top priority policy in European Union [4]. This paper will show you a solution for a cheap high-precision measurement system suitable to use for energy analysis. Also a PC based front-end is developed to plot statistical data from the device. This device could be a part from an energy efficiency analysis system [1]. The design uses four core components listed down:

- The MCP3905A/05L/06A devices are energy-metering ICs designed to support the IEC 2053 international metering standard specification [2]. They supply a frequency output, proportional to the average active real power, as well as a higher-frequency output proportional to the instantaneous power for meter calibration. They include two 16-bit Delta-Sigma ADC for wide range input currents. There is a DSP block built into the chip for active real-power calculation. A no-load threshold block prevents any current creep measurements.
- The PIC16F873A is a low cost, high performance RISC microcontroller operating on up to 20 MHz clock frequency [3]. Its instruction set contains 35 single-word instructions. It has 8K x 14 words of Flash Program Memory, 368 x 8 bytes of Data Memory (RAM) and 256 x 8 bytes of EEPROM Data Memory. The built-in peripherals include 3 timers (2x8 bit and 1x16 bit), two CCP modules, Synchronous Serial Port with SPI and I^2C, Parallel Slave Port, USART, etc.
- The DS1307 serial real-time clock (RTC) is a low power; full binary-coded decimal (BCD) clock/calendar plus 56 bytes of non-volatile SRAM. Address and data are transferred serially trough an I^2C bi-directional bus. The clock/calendar provides seconds, minutes, hours, weekday, date, and month and year information. The chip has built-in power-sense circuit that detects power failures and automatically switches to the backup supply.
- AC204Y is 20 characters x 4 lines LCD display with integrated controller (KS0066U). The display operates on 5V power supply. It has 8-bit wide data bus (can be used in 4-bit mode) and 3 control lines. Its instruction set contains 11 commands. Its font table contains 210 factory defined characters and 16 user definable characters.

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II. Functional Blocks and Working Principle

The device includes six functional blocks (see Fig. 1). Every block is separated on the printed circuit board (Fig 2). There is isolation between the high-voltage measurement part and the low-voltage computing unit.

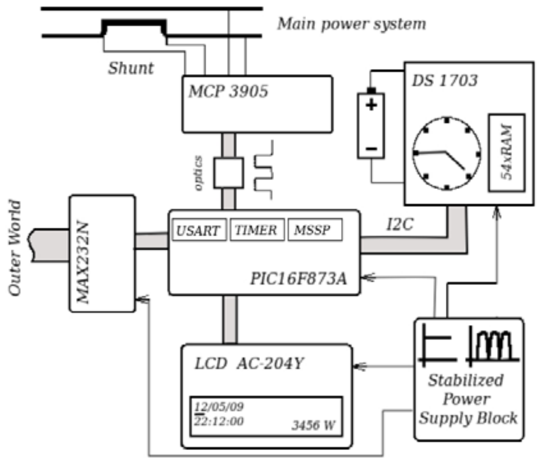

FIGURE 1 – HIGH LEVEL SCHEMATIC

Power supply block

Power supply for the digital devices on the board is taken from the main power network trough transformer, rectifier and stabilizer. The transformer is connected before the measuring part of the device to avoid measuring self-consumption (which is smaller than 1W). The transformer lowers the mains voltage to 12V. The lowered voltage is driven trough a diode bridge after which is connected an switching voltage stabilizer LM2575T-5.0. It outputs 5V for the rest of the circuit.

Measurement block

It is based on the MCP3905 chip from Microchip®. That part of the board is isolated and disconnected from the other parts of the device by transformers and optical connections. The consumption is calculated via measuring voltage and current sink from the target device. The voltage is lowered to safe range with suitable voltage divider. The current is measured by measuring voltage drop onto a shunt with fine grade precise resistance. It is calculated that so the voltage drop onto it should be in a device-safe range. These two values are driven to specified chip inputs, which are connected to an internal two-channel Sigma-Delta ADC. After conversion the values are multiplied in the hardware DSP block. The result is converted to a sequence of square pulses with proportional frequency to the active power. The range of the measurement can be defined via some configuration pins that set gain of the Channel 0 (current channel) and multiplication of the output frequency. This chip outputs two signals – one low frequency and one high frequency. In the current design the high frequency output is used. The chip has a built-in driver for controlling mechanical counters in cheaper and simpler systems.

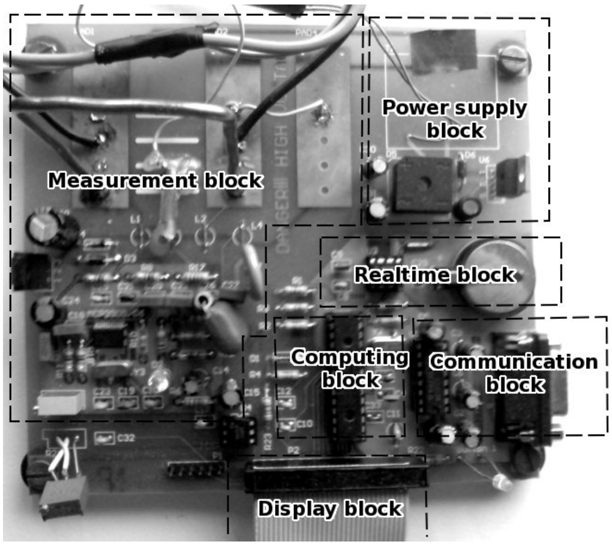

FIGURE 2 – PCB OF THE MEASUREMENT MODULE

Computing block

It is based on the PIC16F873A, which is a single-chip microcontroller from Microchip®. It does all the smart work in the device. Information that comes from the Measurement block is just frequency pulse signal. It increments one of the internal timers of the MCU and every second it gets processed. Instant power is calculated from the timer value and it increments the counters for total consumption in two rates – night and day. The MCU choose the target consumption counter according to the current system time. The counter value is stored back into the non-volatile memory and it is displayed on the LCD. The MCU also serves the USART serial communication with other systems trough a developed data exchanging protocol.

Real time block

It is based on the DS1307 single-chip clock/calendar from Dallas®. The block has its own emergency power (a 3.6V Li-Ion battery) that is used when a main power failure is detected. Uninterrupted and continuous work of the chip is needed because it is the non-volatile memory of the device. The chip provides independency of the device from any outer-board clocks that are used in the old mechanical power metering systems. The chip has square wave output pin which frequency can be software programmable. One pulse per second (1 Hz) output is selected in this design. That pin is connected to the MCU and triggers an interrupt, which forces data calculation (see Computing block).

Display block

It is based on AC204Y LCD from Ampire®. The module is working at 8-bit data, which is faster than 4-bit data rate. Most frequently used commands are: SET DDRAM ADDRESS (moving the cursor) and WRITE DATA TO DDRAM (putting a symbol on the display grid). The following indications are displayed (see Fig. 3): instant power [W] (4 digits), total power counters for day and night rate [kWh] (5 digits, 1 decimal dot, 2 digits after) and current time (MM/DD/YY HH:MM:SS). There is a spare space on the display that can be used in future (for example for the calculated price value of the used energy). The LCD module has its own backlight and fine contrast control, which make it comfortable for observation in different situations.

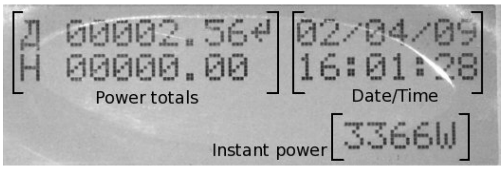

FIGURE 3 – DISPLAY INDICATIONS

Communication block

We used MAX232 as a universal receiver/transmitter and level converter for the RS232 standard. The chip is MAX232N from Maxim®. It converts ±15V (RS232) to 0-5V (digital logic USART). The transmitted data contains: power total counters, instant power counter, clock readings and some debug values. The device is always slave device, i.e. it responds to commands, but cannot start the communication on its own.

Communication sequence

When external module (host system) sends a command to the energy measurement module, the communication scenario goes like that:

1. *If no response is sent back from the device in a specific timeout, the external module retries and goes to stage 1.*
2. *If there is a response, it goes to stage 4.*
3. *If there is no response in a number of retries, the communication is failed. Must be checked for hardware malfunction.*
4. *The device responses with a status and information.*
5. *If the devices responses with an 'Unknown command or Error', the external module must retry the last command after that it goes to stage 1.*
6. *End of the communication;*

Information is transmitted in RS232 specification with the following parameters: 9600 bps, 8 data bits, 1 stop bit, no parity bits and no flow control. The data is encapsulated in packets of 8 bytes with the following structure:

Packets transmitted from the device:

- 1 byte status
- 7 bytes data and/or padding

Packets received from the device:

- 1 byte command
- 7 bytes arguments and/or padding

III. EXPERIMENTAL RESULTS

We have conducted an experiment to check the precision of the real time clock. We are comparing the DS1307 clock against an NTP-updated computer clock.

TABLE 1. CLOCK JITTER

Computer time (NTP)	DS1307 difference [s]
09:56:10 09/04/09	0
09:28:08 12/04/09	-1
09:28:07 13/04/09	-1
09:28:12 15/04/09	-2
09:28:09 16/04/09	-3
09:28:11 19/04/09	-4

Negative values in the difference shows that, the RTC is going too fast. Measurements are collected in a controlled environment with a temperature range of 18-23ºC.

On figure 4 is plotted measured data from several consumer devices that are turned on in different times (light bulb, 2-stage heater and a hot-plate).

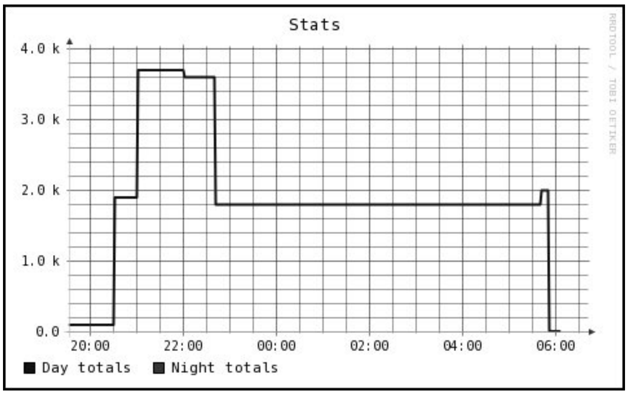

FIGURE 4 – CONSUMPTION GRAPH

The presented energy measurement module is used in a complex system for analysis of the energy efficiency of HVAC equipment. In this statistical experiment we investigate the efficiency of inverter air-conditioner, which is overrated [1].

A graph of total consumption in time is illustrated on figure 5. The investigated model was ASY-A12LCC, developed by Fujitsu-General Limited. The nominal heating power of the model is about 4,8kW and the unit was installed in a small living room (about 14 square meters) with heating requirements about 1,8kW.

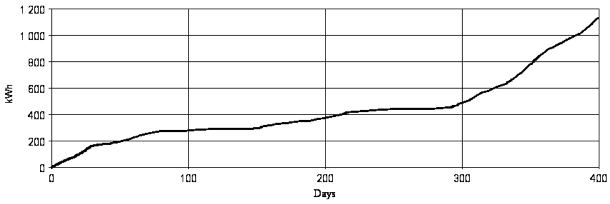

FIGURE 5 – CONSUMPTION OF DOMESTIC AIR-CONDITIONER

The graph on figure 5 starts from 24-JAN-2008. The results from the measurements show that the required electrical energy for heating is 4,9 times higher than the energy in cooling mode. The heating mode continues 6 months, while the cooling continues only 3.

The result from the measurement show that the efficiency of the inverter air-conditioner increase (measured Heating Seasonal Power Factor is 5,07) when the air conditioner works below its nominal power. The HSPF factor, listed in the specifications for this model, when it is used around 4,8kW is about 3,40.

The electronic power meter is compared with the industry ones, installed by the energy companies on their customers. In the comparison we used ACE2000 type 290, manufactured by Actaris [5]. The Itron ACE2000 type 290 meter with internal real-time clock is a compact meter offering cost-effective, complex tariff functionality with enhanced features. EVN Bulgaria EAD installs it on its customers. The comparison shows difference of 0.3% in the total measurements using a complex load.

IV. CONCLUSIONS

The presented device is a suitable solution for monitoring power usage by domestic electric devices. It has a communication capabilities and this allows the device to be used as an embedded power-metering module in complex systems. Also additional features can be built in, because most of the computing power of the MCU is idle. The precision of the RTC is enough for the purpose of the device - one second difference for 3 days means about one minute difference per year. The maximal electrical load power that can be measured is about 18kW.

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