Realization of an Inexpensive Embedded Mini-Datalogger for Measuring and Controlling Photovoltaic System

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This article describes the design and the realization of an automatic recording device for measurements and controls of multiple physical parameters, in order to manage and monitor a mini central photovoltaic (PV) electricity. It is based on an 8-bit microcontroller, a PIC16F716, which is the lowest cost in the midrange portfolio from Microchip. The automatic recording device (or datalogger) measures the following parameters: the current sourced by a set of PV panels to solar batteries, the voltage across these batteries, the internal and the external temperatures, through a 4 channel multiplexed 8-bit analog–digital converter (ADC) integrated module. This datalogger is clocked with a real time clock and calendar (RTCC), which controls also the periodic measurements. These are stored in an external 8 kB flash electrically erasable/programable read-only memory (EEPROM), a 24LC64, using the I^2C protocol, which allows us to easily increase the storage capacity by adding, if necessary, in parallel, up to eight external flash EEPROM. [DOI: 10.1115/1.4029232]

Introduction

Electricity produced from PV systems has a far smaller impact on the environment than traditional methods of electrical generation. During their operation, PV cells need no fuel, give off no atmospheric or water pollutants, and require no cooling water. Unlike fossil fuel (coal, oil, and natural gas) fired power plants, PV systems do not contribute to global warming or acid rain [1,2]. Indeed, a disadvantage of PV systems is that the installation cost is still high, so their design optimization is desirable. However, such an effort requires detailed knowledge of meteorological data of the site where the system will be installed and operational results from similar systems, if available. Many data-acquisition systems have been developed in order to collect and process such data, as well as monitor the performance of PV systems under operation, in order to evaluate their performance [3–5]. In this paper, we will discuss the design of a four-input low cost prototype.

Material and Methods

The realized device is dedicated to an automatic measurement of five important parameters to be monitored in a PV solar installation, namely: the current sourced by the panels to the storage element (12 V battery), its discharge current, the battery voltage [6,7], the external temperature (inside the PV panel), and the internal temperature (inside the electronic device) [8]. These measurements are acquired periodically (one measurement per second) and immediately displayed on a 2×16 characters LCD: the first line is reserved to display the measured value of the battery voltage, its charging current (or discharge, depending on the sign displayed), the quantity of electricity (accumulated when charging the battery, or consumed). The second line is reserved to display the current time clock, and, alternately, the current date, the number of days corresponding to the current date, the time of sunrise, the time of sunset, the internal temperature, and the external temperature. A simple keyboard of three pushbuttons is used for the initial adjustment of the clock and date related to the RTCC module. The power supply is provided by a classic regulator circuit: a

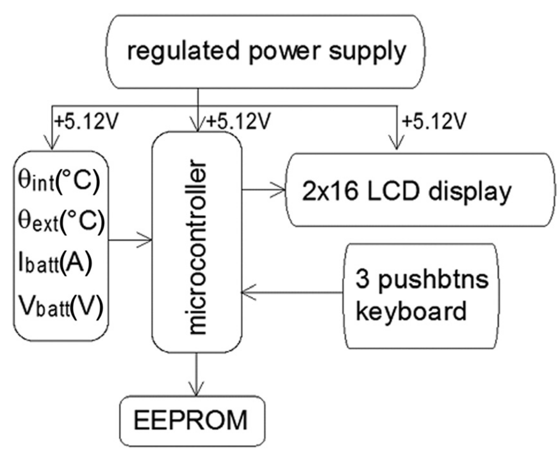

Fig. 1 Diagram of the prototype device

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78L05 to deliver a fixed voltage of 5 V (useful to power the temperature sensors LM35DZ and the LCD display) [9], but slightly modified to output 5.12 V through the addition of a Schottky diode BAT85 in the bias circuit of this regulator. This particular value has been chosen in order to obtain a sensitivity of exactly 20 mV from the 8-bit resolution of the internal ADC of the PIC16F716 microcontroller.

Hardware Description

The synoptic below (Fig. 1) shows the main modules of this design: a 8-bit microcontroller (PIC16F716), a 2×16 characters LCD display, a keyboard of three pushbuttons, the measurement circuitry for the four channels (internal temperature θ_{int}, external temperature θ_{ext}, current charge (or discharge) I_{batt}, voltage charge (or discharge) V_{batt}), the regulated power supply, and finally the external EEPROM.

The 8-bit Microcontroller (PIC16F716). This microcontroller belongs to the midrange portfolio of Microchip, which becomes a world leader in this category of programmable components. It is equipped with a reduced instruction-set computing (RISC) architecture, whose performance in speed and amount of memory gives better performances than the old complex instruction set computer (CISC) architecture (e.g., Motorola 68705 or Intel 8051). It can be powered from 2.0 V to 5.5 V, but we choose the particular voltage of 5.12 V. This choice was dictated by the imperatives of the 8-bit internal ADC of the PIC16F716. With an 8-bit resolution, there are 256 steps of measurements, and by setting a voltage of 5.12 V, we then obtain a sensitivity of $5120/256 = 20$ mV. But this sensitivity of 20 mV is insufficient to measure the sensed temperature by sensors like the LM35DZ, characterized with 10 mV/°C. Instead of looking for another PICmicro containing a 10-bit integrated ADC which would be much more expensive, we preferred to continue using this low cost PIC16F716, and passing from 8-bit resolution of the ADC to 9-bit by programming an oversampling algorithm [10]. In fact, the practice of oversampling is well suited to the measurement of slowly changing signals, as in our case, with the measurement of external and internal temperatures, the voltage and current charge or discharge. Briefly, this algorithm consists of taking M successive samples of a physical quantity, where $M = 4.K$, with K the number of additional bits (in our case, moving from 8-bit to 9-bit requires $K = 1$, so $M = 4$) then to operate a decimation which consists of computing the sum of these M samples followed by a divide by 2.K (which simply results in a right shift of K bits). However, an important precaution must be observed: this method works correctly only in the presence of a white noise with amplitude higher than the average of the quantum desired. If the noise level is insufficient, we must artificially add noise to the signal to be converted (dithering), which explains the presence of the high value carbon type resistance ($R3 = 120$ kΩ) at the output of the temperature sensor IC2. Finally, this PIC16F716 is clocked by a 4 MHz quartz oscillator (Fig. 2), resulting in a period of 1 μs per instruction (except for jump instructions which require 2 μs). The calendar clock RTCC is managed precisely with an internal 16-bit timer (TMR1) of the photonic integrated circuit (PIC).

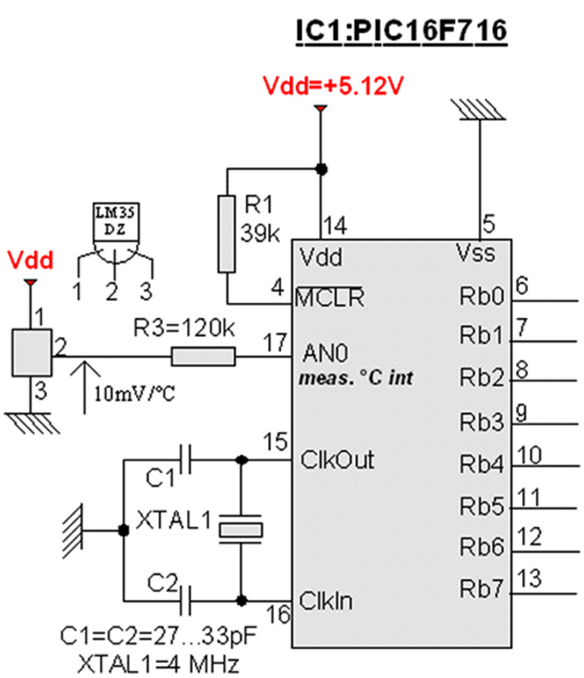

Fig. 2 The PIC16F716 circuit with its 4 MHz quartz

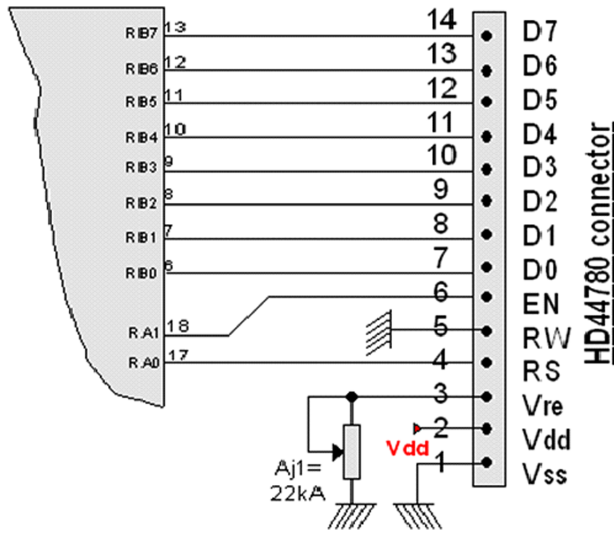

Fig. 3 LCD display module in 8-bit classic mode

The 2 × 16 Characters LCD Module. The 2×16 characters LCD module requires a minimum of 10 I/O lines (input/output) from the PIC (Fig. 3), in 8-bit mode [11], or only 6 I/O lines, in 4-bit mode. This latter method was chosen to minimize the number of I/O lines. We have further reduced the minimum to 5 I/O lines only as shown in Fig. 4.

The command line (EN: pin 6) of the LCD display is directly driven by the output RB0 (pin 6) of the PIC16F716, whereas the

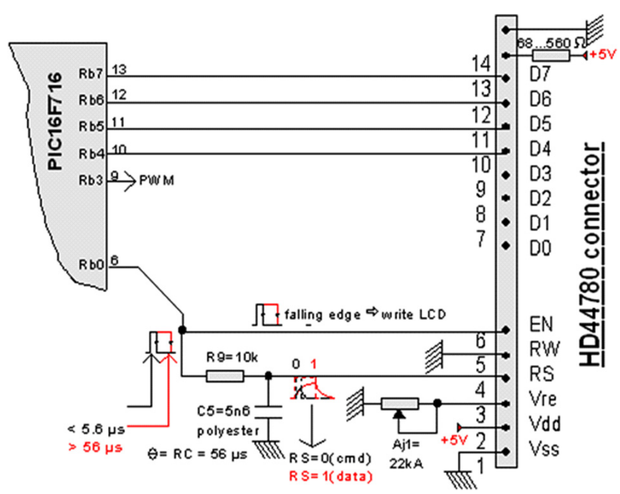

Fig. 4 2 × 16 LCD display module in 4-bit mode using only 5 I/O lines

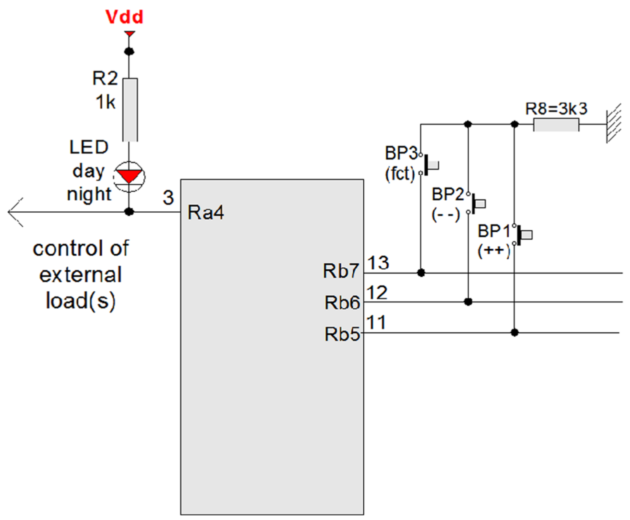

Fig. 5 The three pushbuttons keyboard and the output RA4 (day/night tasks control)

command line (RS: pin 4) of the LCD is indirectly controlled by the same output RB0, through a low pass RC filter. In fact, if the duration of the high state at the output RB0 is longer than the time constant filter (R9. C5 = 10kΩ. 5.6nF = 56 μs), then the input RS of the LCD sees a high state (this indicates that the inputs D4 to D7 of the LCD get a data nibble). If the duration of the high state at the output RB0 is less than one tenth of the time constant filter of 56 μs, then the input RS of the LCD sees a low state. (This indicates that the inputs D4 to D7 of the LCD receive a command nibble.) This does not interfere with the input EN of the LCD as it is only sensitive to the falling edge transition of the output RB0 [12].

Table 1 Recording format of a package per day

Nbr bits	Variable	Significations
9	nDay	Number of days in a year = 1, 2,., 366
6	Year	Year = 00, 01,., 99 correspond to 2000 to 2099
24	Qday	Quantity of electricity accumulated on the day
8	RhoMax	Maximum efficiency on the day
8	TintMax	Maximum internal temperature
8	TextMax	Maximum external temperature
24	Qnight	Quantity of electricity consumed at night
8	TintMin	Minimum internal temperature
8	TintMax	Minimum external temperature

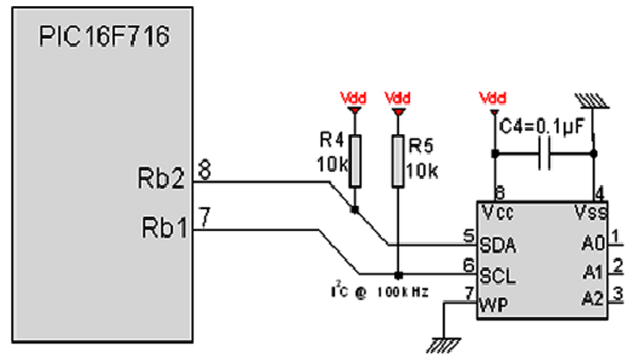

Fig. 7 Section external EEPROM

The Three Pushbuttons Keyboard

The keyboard has only three pushbuttons (Fig. 5):BP1 is used to increment, BP2 to decrement, and BP3 to go to the next function. This minimum required parts was dictated primarily for setting the clock-calendar RTCC, necessary for the imperatives of

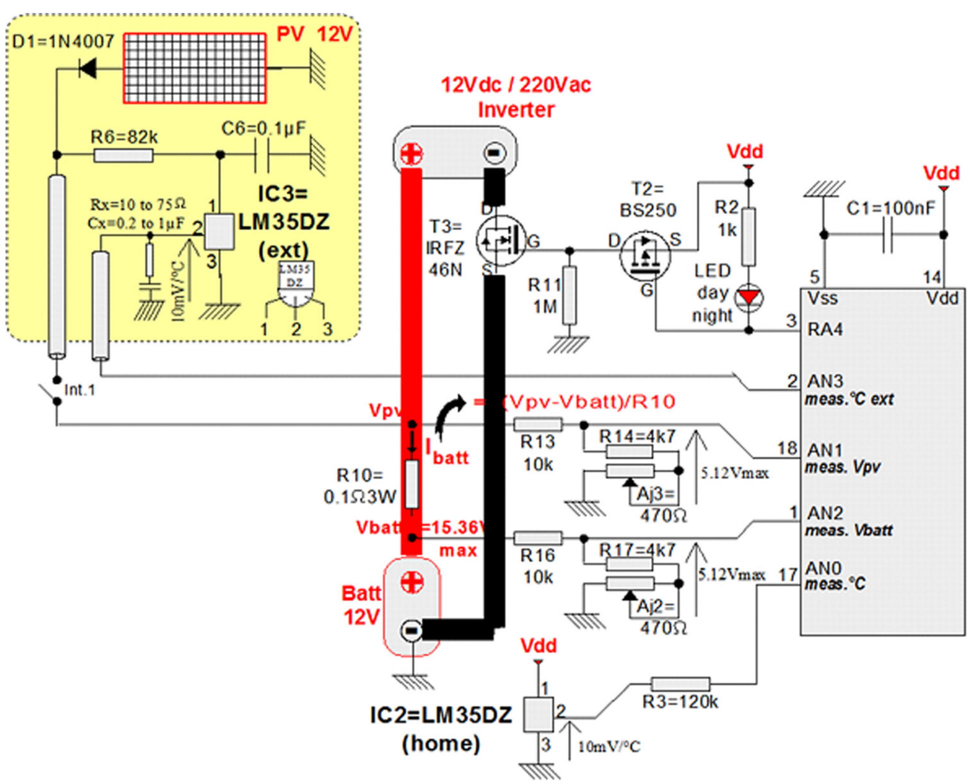

Fig. 6 The measurements circuitry for the 4 analog channels

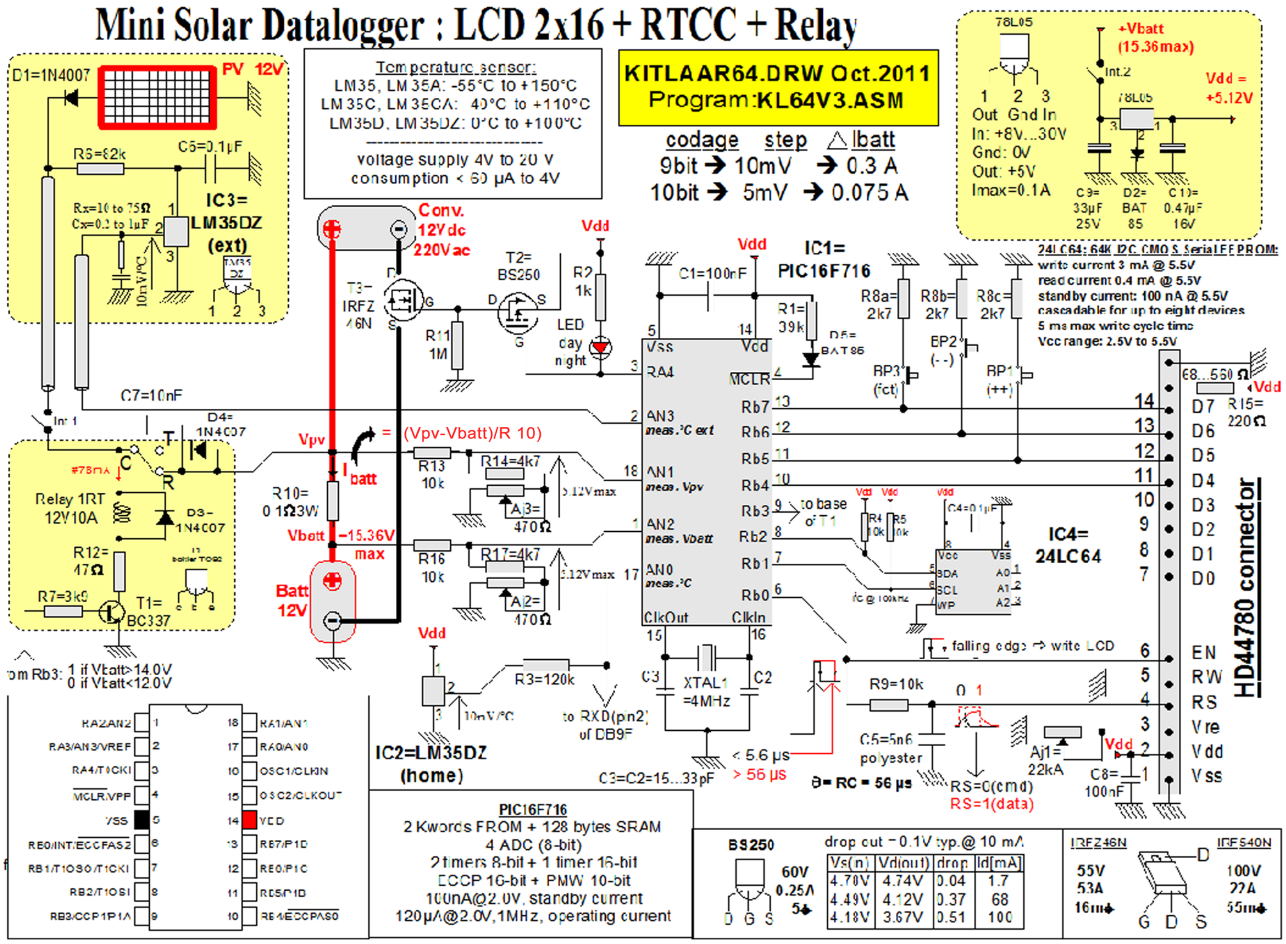

Fig. 8 Detailed and completeness of the device constructed

day/night and seasonal tasks control. The open drain Ra4 (pin 3 of the PIC16F716) was configured as an output and changes state at dawn and dusk.

The Measurement Circuitry for the Four Channels

The four analog inputs of the PIC16F716 have been chosen to measure five important physical parameters, they are respectively, the current charge intensity of the energy accumulator (12 V battery), its discharge current intensity, its voltage charge, the external temperature (inside the PV panels 12 V), and the internal temperature (inside the electronic device) [13,14]. The temperature sensor used is a LM35DZ [15] with a sensitivity of 10 mV/°C and a precision of $\pm 0.5\,^{\circ}$C. Its temperature range is from 0 °C to +100 °C (whereas the improved version, the LM35, provide a temperature range from −55 °C to +150 °C). It can be powered by a DC voltage from 4 V to 20 V. The current charge (or discharge) of the battery is measured through a voltage drop across a low value resistor (0.1 Ω) [16], in series with the positive terminal of the battery. The calculation of the maximum power dissipated by this resistor depends on the maximum current that can be delivered by the solar panels in use, and the maximum current allowed for consumer user. Finally, the charging voltage is measured with a classic voltage divider (Fig. 6) [17].

The External Memory EEPROM

An external 8 KB EEPROM (a 24LC64) has been used to store all the measurements over one year [18,19], and the format used is looked in Table 1.

A package of measures therefore requires 13 bytes per day or $13 \times 366 = 4758$ bytes over a year (leap year included). This value has dictated us to choose a 24LC64; this EEPROM contains 8192 bytes (Fig. 7). To manage this external memory, standard routines for I^2C [20] communication have been programmed into the microcontroller, in assembly code through the MPLAB IDE interface v7.52 [21]. Finally, to get this package of measures, a minimalist RS232 serial link was provided to connect this datalogger to a compatible PC [22], driven through an application developed in C++ Builder v3.0 under Windows XP.

Figure 8 shows the complete and detailed schematic diagram of the datalogger realized

Conclusion

The objective of this study is the design of a simplified multichannel solar datalogger based on a low cost 8-bit PIC microcontroller (PIC16F716). The role of this instrument is the control and the measurement of the most important physical parameters of a PV solar installation, namely, the current intensity, the voltage, and the temperature. We were particularly interested in the measurement of load current intensity through the energy accumulator (12 V battery), the voltage charging (or discharging), the external temperature (inside the PV panel), and the internal temperature (inside the device). Finally, this prototype may have a commercial advantage in term of low cost, uses few components, which can be, found easily anywhere, and provide a good reliability.

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