International Journal of Electrical and Computer Engineering (IJECE)
Vol. 13, No. 3, June 2023, pp. 2734~2742
ISSN: 2088-8708, DOI: 10.11591/ijece.v13i3.pp2734-2742

Optimized design of an extreme low power datalogger for photovoltaic panels

Bilal Merabtane[1], Noureddine Benabadji[2]
[1]Laboratory of Plasma Physics of Conductive Materials and their Applications, Faculty of Physics, University of Science and Technology of Oran, Oran, Algeria
[2]Laboratory of Analysis and Application of Radiations, Faculty of Physics, University of Science and Technology of Oran, Oran, Algeria

Article Info

Article history:

Received Jul 15, 2022
Revised Oct 2, 2022
Accepted Dec 2, 2022

Keywords:

Data acquisition
Data processing
Extreme low power data logger
XLP PIC microcontroller
Photovoltaic system

ABSTRACT

The paper focuses on the design and implementation of a low cost and compact data logger prototype using an extreme low power (XLP) and low pin count programmable interface controllers (PIC) microcontroller using its own flash memory for the periodic data acquisition storage, while many other works focus in the Arduino Eco-system. It is planned to pick four important analog measures from the photovoltaic system, and store them directly as 10-bit numerical counts, this yields to faster data acquisition and storage (no time consuming for mathematical computation to convert each numerical count of raw data to meaningful real-world data). Avoiding the use of any kind of display and keypad, and keeping the ratio run time over sleep time as low as possible, has a maximum impact on lowering the power consumption. This prototype can be serially linked to a personal computer (PC) to view the acquisition of measurements in real time, and to retrieve all collected data through a terminal application. The experimental results are stored in comma-separated values (CSV) files to ease post data analysis with any spread sheet software, for statistical calculations and graphs drawing, in order for instance, to find the faults of the photovoltaic system and optimize its management and its performance.

Corresponding Author:

Noureddine Benabadji
Laboratory of Analysis and Application of Radiations, Faculty of Physics, University of Science and Technology of Oran
B.P.1505 El-M'nouar, 31024, Oran, Algeria
Email: benabadjinoureddine2016@gmail.com

1. INTRODUCTION

Solar energy is an unlimited, unpolluted source, and the exploitation of the sunlight does not causes any ecological damage, such as other renewable energy sources, like wind [1], tides [2], water movements in rivers [3], and geothermal heat [4], to name a few; it respects our environment by reducing the greenhouse gases emissions [5], and it is a better alternative for traditional energy sources, such as coal, oil, natural gas, and because the sun is the most dense energy source on our planet [6], solar energy is the best alternative to fossil energy [7]. The human pursuit of clean energy with the current drive toward reducing global carbon emissions has been a major global environmental, social, and economic issue in recent years [8]. It has led to the rapid development of technologies used to convert this energy, but this development has not yet achieved what is intended, which is to reduce the costs of these technologies and put renewable energy in the ranks of energy competition, due to recurring undetectable faults [9]–[11]. Therefore, there is still a lot of research to improve energy conversion efficiency especially photoelectric conversion.

The photovoltaic system is predominantly subjected to various faults that lead to its degradation and the impact of the energy produced. In general, errors observed in any system are classified into three categories: premature failure, substantial or random failure, and wear [12]. The performance of the photoelectric system is largely dependent on the location and conditions of the photovoltaic panels and the battery health [13]. Photovoltaic (PV) module temperature is one of the important factors that affect how much electricity your panel PV will produce, where the more sunshine you get, the hotter the modules get and this in turns counteracts the benefit of the sun [14]. Also, during high irradiation intensity, increased power on the input side may cause false tripping of over-current relays [15], [16]. The precise estimation of its current-voltage (I-V) and power voltage (P-V) characteristic helps diagnose faults occurring at the level of solar panels, whereas, the I-V and P-V characteristics of a PV module are affected by different factors, such as partial shading and dust [17], [18]. These have a great effect on the maximum power point, in some areas, 70% of energy loss can be caused by panel contamination [19].

High-precision measurements of PV battery systems are being carried out to gain a better understanding of the technology and support distributed renewable energy generation and smart grids [20]. The charge state in battery systems is an indicator of the operating conditions of the battery system, and is used to regulate the charge/discharge decisions and to ensure their safety and longevity [21]. As such, accurate estimation is always one of the most important tasks in battery management systems [22]. Improving the performance of a photovoltaic system and extending its life is desirable, through continuous monitoring and detailed knowledge of the system data that helps multiple diagnoses and proper decision making. For instance, thanks to embedded dataloggers, an air flight is nowadays much more secure than any other means of transport.

Dataloggers are considered as simplified tools compared to traditional data acquisition equipment system. While the main goals are still measurement, storage and data processing, the differences rise with the widespread emergence and proliferation of the microcontrollers, with ever growing performances [23]. Newly released microcontrollers, with multichannel and multi resolution analog to digital internal converter, high capacity internal flash memory, and wireless internal module, allow the design of unlimited kind of embedded systems, dedicated to various emerging scientific field [24], [25]. The trend is how to make newer prototypes with: i) more energy efficient (some recent dataloggers do not even use battery pack, but energy harvesting instead) [26]; ii) smaller devices (especially useful for medical research) [27]; iii) more analog and/or digital inputs for measurements with higher numerical resolution and sampling rate, and meeting the International Electro Technical Commission (IEC) standards specifically (IEC 60904-1) [28], [29]; and iv) higher (non-volatile) memory capacity storage.

In this article, we describe the design of a datalogger prototype dedicated to monitor a photovoltaic system through parameters like the charge/discharge process by measuring voltages and currents, and also the temperatures (PV panels and batteries), as this physical parameter affects the available power. The main specifications are an extreme low power consumption and a very small footprint device. This device is particularly suitable when we need a correct sizing in building an off-grid PV system.

2. MATERIAL AND METHOD

To meet the low power requirements [30], [31], and a small footprint device, we have chosen a low pin count microcontroller from the 8-bit XLP enhanced mid-range family of Microchip: a PIC12F1840 [32]. Four 10-bit analog channels have been used to measure periodically the following parameters: The battery voltage, current and temperature, and the PV panel temperature. These parameters are stored in the internal random-access memory (RAM) memory, as numerical count, and are also sent in real time through a serial port to a compatible personal computer (PC) running a terminal software under Windows, Linux or MacOS. After 24 h of data acquisition, we look for the quantity of electricity (acquired and consumed) in the current elapsed day, and the maxima of temperatures; these values are stored in the internal flash read-only memory (ROM) memory. To lower the power consumption (and also to reduce the final cost), we have not used a regulated voltage module. Nevertheless, precise analog measurements (with 2 mV resolution) are possible due to the stable 2.048 V internal voltage reference, activated only during the 10-bit acquisition. Also, we have not used any kind of embedded display, nor a keypad, as the initial configuration is set with a PC, then the device is detached, we no longer need to see the successive measurements, until the final check day (several months later).

2.1. Hardware description

As shown in Figure 1, what should be highlighted as the main parts of this proposed prototype are: an 8-bit microcontroller (PIC12F1840), a minimalist universal serial bus (USB) serial link, a real time clock circuit and the four analog channels measurement circuit (PV panel temperature, battery temperature, current and voltage). The microcontroller flash ROM, used to program the device, is also used to store the periodic data acquisition, instead of using an external dedicated electrically erasable programmable ROM (EEPROM). We have chosen the PIC12F1840 microcontroller, from the XLP 8-bit family of Microchip (4th generation) with low pin count (8 pins), which is characterized by a run mode current of 302 µA @ 4 MHz (Vdd=3.0 V) and a sleep mode current lower than 0.3 µA (or 30 nA for the LF grade).

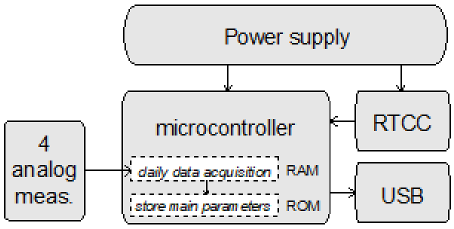
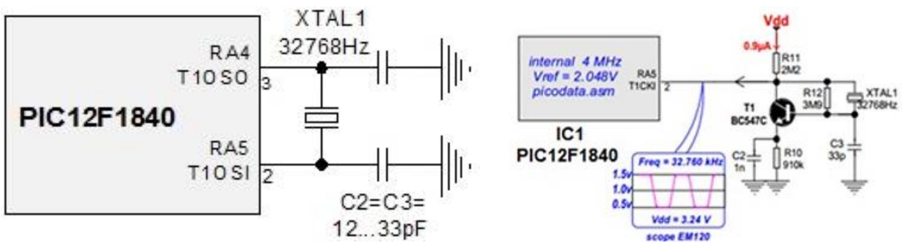


Figure 1. Bloc diagram of the datalogger

The internal oscillator module has a wide variety of clock sources and selection features that allow it to be used in a wide range of applications while maximizing performance and minimizing power consumption. Clock sources can be supplied from external crystal-based oscillators (the most accurate solution, but also the most expensive), to a simple resistor-capacitor circuit. In addition, a phase lock loop (PLL) frequency multiplier is available to both external and internal oscillator modes. The use of PLL circuits minimizes the impact of temperature and stabilizes oscillators [33]. There is also a secondary internal oscillator module which is optimized for a 32.768 kHz external clock source Figure 2(a), which is recommended to manage the real time clock and calendar (RTCC) function. In order to free the RA4 I/O pin, we used the circuit shown in Figure 2(b), as described in the reference design [34].



(a) (b)

Figure 2. PIC12F1840 circuit, with its 32768Hz quartz clock: (a) standard and (b) optimized

For the power supply as shown in Figure 3, we used a small 3 V Lithium cell coin battery (CR2032), characterized with a negligible self-discharge current, less than 0.25 µA [19]. With a 225 mAh capacity cell, a current consumption of 302 µA in run mode (during 0.4s) and 1,7 µA in sleep mode (period time=15 s), we obtain an estimated average current of 14.1 µA, and more than 1 year of autonomy [35]. When the datalogger is connected to a PC, via an USB-TTL module (wired solution) or an HC5 Bluetooth module (wireless solution), the simplified OR-wiring circuit (T3, D3, R1), inspired from [36], acts as a fast electronic relay to switch between the CR2032 battery and the 3V3 power supply provided by the USB-TTL module. If the USB/TTL cable is inserted (with a selectable output voltage of 3.3 V), the Schottky diode D3 is forward biased, with a typical drop-out voltage of 0.3 V, then the microcontroller is powered with a Vdd of 3 V, the P-mosfet transistor T3 is open, because its *Vgs* (=0.3 V) is lower than the threshold *Vgs(th)* required for conduction. In the case of a power outage, or the USB/TTL is not inserted, T3 will initially conduct the current Ids through its internal body diode, then enters a full conduction state, because its *Vgs* (=3.0 V) is much higher than the *Vgs(th)* (=0.55 V if using an extreme low-level P-mosfet like the PMN50XP).

Four analog inputs of the PIC12F1840 were dedicated to the measurement of the following important physical parameters: the charging voltage (Vpv), the discharge voltage (Vbat), the external temperature (Text) related to the 12 V photovoltaic panels, and the internal temperature (Tint) related to the 12 V batteries. The temperature sensors (two micro-power linear active thermistors, IC2 & IC3 [38]) have an extreme low quiescent current (6 µA typical), provide a temperature accuracy of +/- 0.5% @ 25 °C, and have a temperature range of -40 °C to +125 °C (with a resolution of 10 mV/°C, and a typical value of 500 mV @ 0 °C). More importantly, this family is immune to the effects of parasitic capacitance and can drive large capacitive loads. This provides printed circuit board (PCB) layout design flexibility by enabling the sensor to be remotely located from the µC (case of the external temperature sensor IC3). The decoupling capacitors (C6, C9), close to IC2 and IC3, are recommended to filter out the system noise (which compromises measurement accuracy), due to the microcontroller internal digital switching noise.

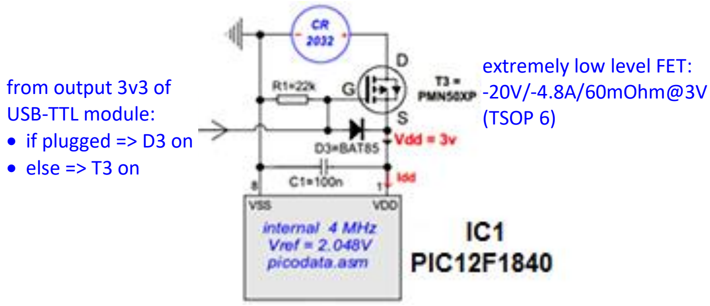


Figure 3. A simple OR-wiring circuit to supply power from the battery or the USB-TTL module

The voltage divider resistors R6, R7 and R8, R9 (1% precision, 1/4W) are inserted between the analog inputs of the microcontroller and the sources (photovoltaic panels and batteries) to fit the maximum 2 V input range (*Vm*) as we use the internal voltage reference of the programmable interface controllers (PIC) (*Vref* = 2.048 V). Capacitors C4 and C5, close to the analog input pins AN2 and AN3, are used to decrease the measurement noise. The relation expressing the voltage *Vpv* as a function of *Vm* is (1).

$$Vpv = Vm\left(\frac{R8+R9}{R9}\right) \tag{1}$$

The power resistor R15 (0.1 Ω) is used to create a small potential difference between *Vpv* and *Vbat*, to act as a simple high side current sensor. The relation expressing the intensity *Ibat* as a function of *Vpv* and *Vbat* is (2).

$$Ibat = \frac{dV}{R} = \frac{Vpv-Vbat}{R15} \tag{2}$$

Take care about the power P_{R15} dissipated (Joule effect) by this resistor R15: choose 10 W for a battery current *Ibat* <10 A.

$$P_{R15} = R15 * (Ibat)^2 \tag{3}$$

Keeping in mind the low power considerations, we choose the internal RC module as the primary system clock (4 MHz); but the secondary clock, dedicated to manage the RTCC module, must be driven with a good quality 32,768 Hz quartz [37], [38], to keep time as precise as possible. An optional TTL-USB converter module is used to configure the initial timeclock setting. This link is not required in the permanent standalone mode, thus the diode LED1, also optional, has been provided as a simple indicator of the data acquisition, giving an ultra-short blink (1 ms) each 15 s. It can be enabled through the jumper JP1, only for the periodic technical control, if necessary.

We could not use the internal UART module, as its TX and RX pins are already used (configured as analog inputs). So, we have chosen a software solution to mimic the RS232 protocol (bit-banged up to 57,600 bauds only [39]). While this is not the best solution (as it increases the processor load), it is still interesting if we want to choose freely any I/O pin for TX and RX. In this way, we could configure the I/O pin RA0 alternatively as a digital output TX (to emit the RS232 packets) and an analog input AN0 (to measure the temperature from IC2 sensor), as shown in the Figure 4, which gives full details about the datalogger schematic. Resistor R4 is mandatory, to avoid short-circuiting IC2 output with RA0 when configured as a digital output TX, and the N-mosfet transistor T2 acts as a buffer between the USB/TTL module and RA0. In the other hand, the input only pin RA3 is used as the RX pin to receive the RS232 packets. The pull-down resistor R18 is mandatory, not only to avoid a floating input (which increases the current consumption Idd, even if the PIC is put in sleep mode) but also to detect automatically if the USB/TTL cable is plugged (in this case, sleep mode is inhibited as the datalogger is connected to a PC to visualize real time data acquisition with a terminal application, like PuTTY). The Figure 5 shows an overview of the proposed datalogger, using through hole technology (THT) components in the prototyping phase, and a small plastic box (80×55×15).

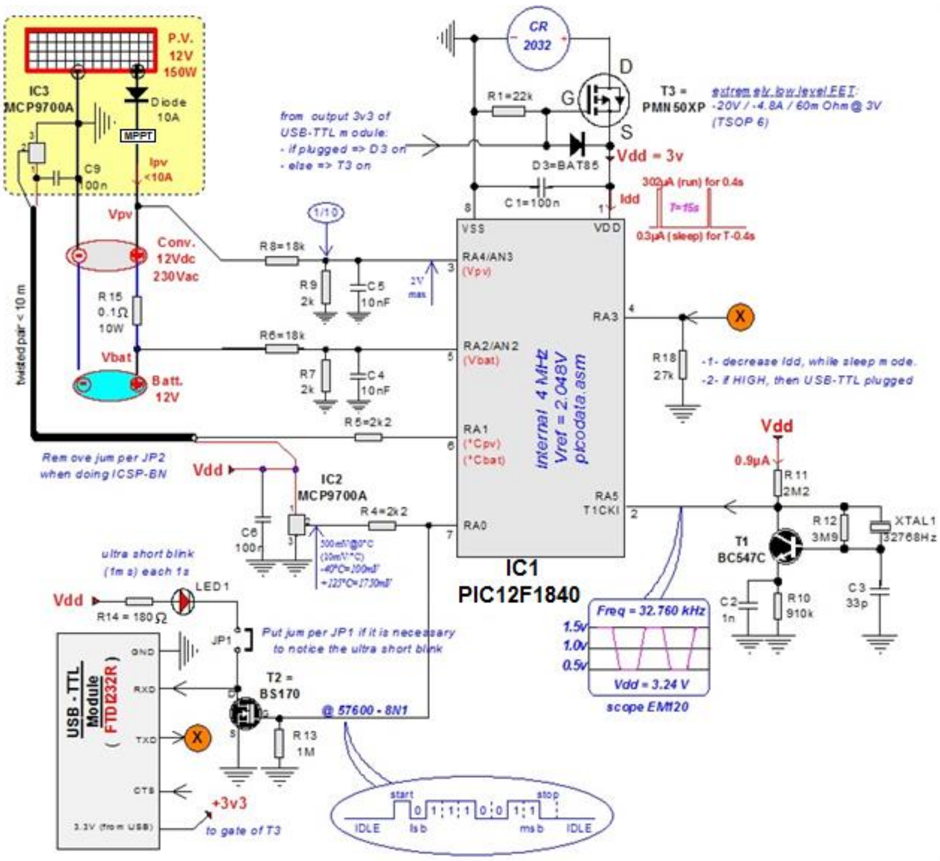


Figure 4. the schematic of the proposed datalogger

Figure 5. A prototype of the proposed datalogger

2.2. Software description

In brief, the microcontroller has been programmed in multi-files assembly code, using MPLAB v8.92 (2013) freely available [40], [41], and burned with a simple JDM2 programmer [42], with PicPgm software v1.7.8.0 (2012) also freely available [43]. Designing a very low power prototype requires a certain mindset, both for the hardware and for the firmware. Choosing the best microcontroller and high-quality components is only half of the story. In order to wipe out power draining, the following procedures have been developed for some critical situations:

a. At the initialization step, all peripherals' modules have been shut down. They will be activated, case by case, only for the duration needed.
b. In the endless main while loop as shown in Figure 6, wake the microcontroller only for the RTCC updates, sensing keystrokes, data acquisition and storage. No need for complex conversion of the numerical counts, as this task is easily done in the PC software part.
c. Tighter storage of data acquisition is preferred in RAM (which is faster and consumes less energy), except for the main cumulated parameters (stored once, each 24h, in the flash ROM).
d. Delay loops and analog conversion are processed in sleep mode, using timer interrupt (instead of polling).
e. Assembly coding has been used (against any other higher and easier language) to highly optimize the source code space, the data space and fine drive of the system frequency for each procedure, as the clock speed is one of the most important factors in power consumption.
f. The program contains two modes: off-line mode and on-line mode. In the first mode, the datalogger takes parameters every 15 seconds, and uses deep sleep in between. In the second mode, the datalogger, connected to a PC, takes parameters each second, and is useful to display, through a terminal application, the RTCC (and possibility to update, in order to reduce drift), the real time data acquisition or the whole data stored (memory dump).
g. The timer 1 interruption is enabled to manage the RTCC module, the wake from sleep mode, the periodic data acquisition, the storage and to update the RS232 messages these measurements are acquired periodically (one measurement per second) and immediately sent to a PC through the TTL-USB converter module (or an HC5 Bluetooth module) to be viewed in real time by a terminal application set at 57,600 baud, 8N1.

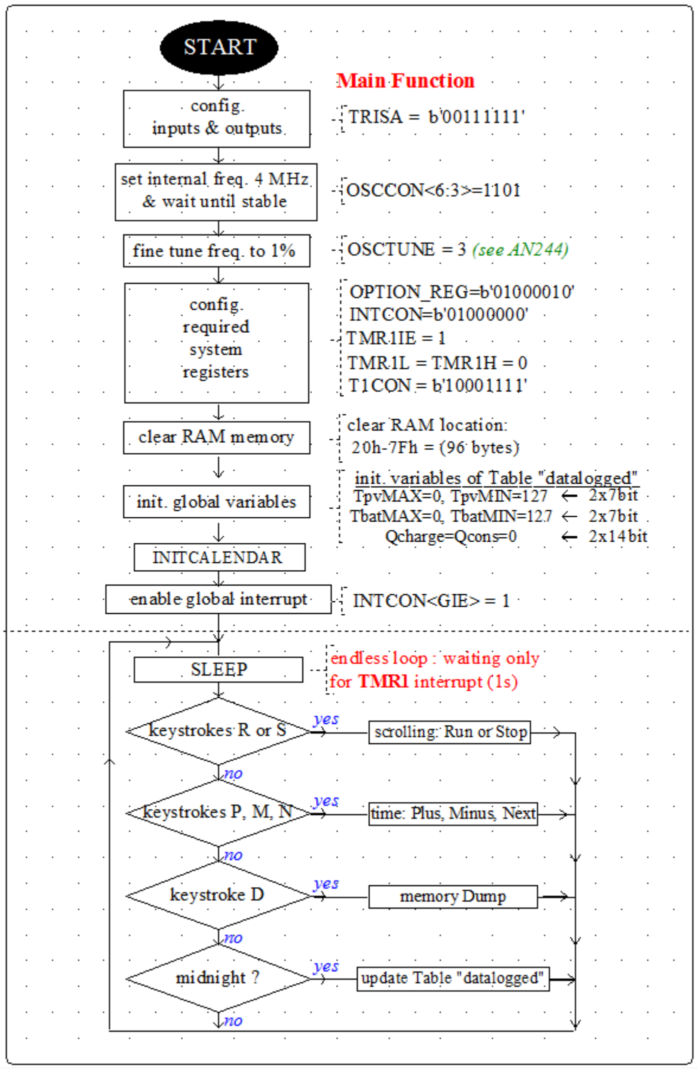


Figure 6. The program flowchart of the main function

3. RESULTS AND DISCUSSION

After 24 hours, the maximum and minimum values of the temperatures measured under the photovoltaic panels and close to the batteries are stored in flash ROM, as well as the quantity of electricity accumulated and the quantity of electricity consumed, thus 56 bits (i.e. 4 words in the flash ROM) are reserved for recording a useful data packet per 24 hours. The following data packet has been adopted:

TpvMAX TpvMIN TbatMAX TbatMIN Qacc Qcon

where:
TpvMAX : MAXIMUM temperature at the photovoltaic panels: 7 bits
TpvMIN : MINIMUM temperature at the photovoltaic panels: 7 bits
TbatMAX : MAXIMUM temperature at the batteries: 7 bits
TbatMIN : MINIMUM temperature at the batteries: 7 bits
Qaccu : Quantity of electricity accumulated in 24h: 14 bits
Qcons : Quantity of electricity consumed in 24h: 14 bits

We have reserved half of the total capacity of the PIC12F1840 flash ROM (4 kWords of 14-bit) for the daily data acquisition storage: so, with 2 kWords, we can store: 2048/4 = 512 days of data acquisition (each day requiring 4 Words of storage). Figure 7 shows a screenshot for the real time data acquisition terminal display. In the terminal application, each line is displayed with the following format:

Tpv Vbat Vpv Tbat HH: MM: SS DD/MM/YY

where *Tpv* is temperature at the photovoltaic panels level, *Vbat* is measured voltage on the battery, *Vpv* is voltage measured on photovoltaic panels, *Tbat* is temperature at the batteries level, HH: MM: SS is time (hour, minute, second), and DD/MM/YY is date (day, month, year: 00 to 99).

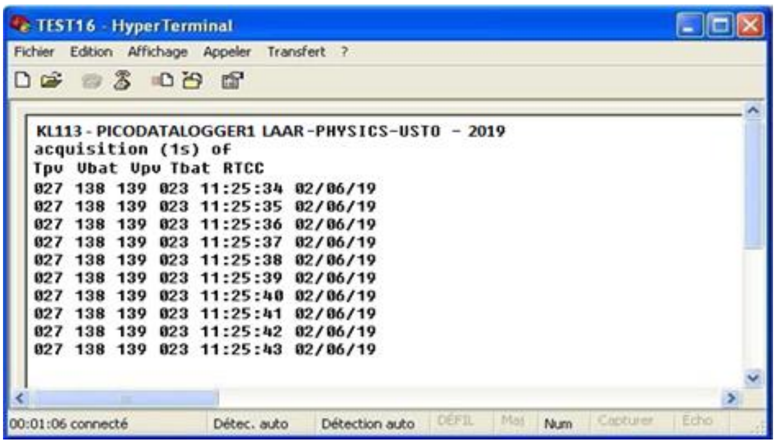


Figure 7. Real time acquisition terminal display

As we used an unknown brand 32768Hz quartz crystal, we could not track the clock drift [44], sensitive to ambient temperature, thus the RTCC circuit lacks the required precision for a long-term data acquisition device. A better choice for this task would be to choose a TCXO model, like, for instance, the DS3231 which is a low-cost, extremely accurate RTCC (2 ppm) with an integrated micro electro mechanical system (MEMS) crystal oscillator [45].

4. CONCLUSION

In this article, we have described the design of a minimalist low power, low cost and compact data logger, based on an 8-bit microcontroller, chosen from the XLP (4th generation) enhanced mid-range family of Microchip, well recommended for designing portable embedded system like dataloggers, characterized with very small current consumption, many analog channels and easily rewritable flash ROM. There is a strict minimum set of external components around this microcontroller, to keep the prototype as compact as possible (no LCD display, no pushbuttons, and no voltage regulator). In the other hand, assembler has been preferred, instead of C language (or another high-level type) to benefit of highly optimized routines (and macros) for data acquisition, tighter data storage, precise serial transfer, and flexible RTCC management. However, about the RTCC clock drift, use of a simple 32,768 Hz quartz is not recommended for long term use, as its exhibits a frequency variation of about 20 ppm (shift of 1s every 11day ½). We recommended either the use of an temperature compensated crystal oscillator (TXCO) quartz, or a dedicated RTCC IC (like the DS3231, without the external quartz, 2 ppm, and less expensive).

REFERENCES

[1] P. Jenkins, M. Elmnifi, A. Younis, and A. Emhamed, "Hybrid power generation by using solar and wind energy: Case study," *World Journal of Mechanics*, vol. 09, no. 04, pp. 81–93, 2019, doi: 10.4236/wjm.2019.94006.

[2] D. S. Coles, L. S. Blunden, and A. S. Bahaj, "Assessment of the energy extraction potential at tidal sites around the Channel Islands," *Energy*, vol. 124, pp. 171–186, Apr. 2017, doi: 10.1016/j.energy.2017.02.023.

[3] L. Gaudard, F. Avanzi, and C. De Michele, "Seasonal aspects of the energy-water nexus: The case of a run-of-the-river hydropower plant," *Applied Energy*, vol. 210, pp. 604–612, Jan. 2018, doi: 10.1016/j.apenergy.2017.02.003.

[4] D. Moya, C. Aldás, and P. Kaparaju, "Geothermal energy: Power plant technology and direct heat applications," *Renewable and Sustainable Energy Reviews*, vol. 94, pp. 889–901, Oct. 2018, doi: 10.1016/j.rser.2018.06.047.

[5] M. A. Lima *et al.*, "Renewable energy in reducing greenhouse gas emissions: Reaching the goals of the Paris agreement in Brazil," *Environmental Development*, vol. 33, Mar. 2020, doi: 10.1016/j.envdev.2020.100504.

[6] B. E. Layton, "A comparison of energy densities of prevalent energy sources in units of joules per cubic meter," *International Journal of Green Energy*, vol. 5, no. 6, pp. 438–455, Dec. 2008, doi: 10.1080/15435070802498036.

[7] O. Ellabban, H. Abu-Rub, and F. Blaabjerg, "Renewable energy resources: Current status, future prospects and their enabling technology," *Renewable and Sustainable Energy Reviews*, vol. 39, pp. 748–764, Nov. 2014, doi: 10.1016/j.rser.2014.07.113.

[8] E. Kabir, P. Kumar, S. Kumar, A. A. Adelodun, and K.-H. Kim, "Solar energy: Potential and future prospects," *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 894–900, Feb. 2018, doi: 10.1016/j.rser.2017.09.094.

[9] B. Parida, S. Iniyan, and R. Goic, "A review of solar photovoltaic technologies," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 3, pp. 1625–1636, Apr. 2011, doi: 10.1016/j.rser.2010.11.032.

[10] M. Z. M. Tumari, M. H. Suid, and M. A. Ahmad, "A modified grey wolf optimizer for improving wind plant energy production," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 18, no. 3, pp. 1123–1129, Jun. 2020, doi: 10.11591/ijeecs.v18.i3.pp1123-1129.

[11] X. Lyu, Y. Jia, and Z. Xu, "A novel control strategy for wind farm active power regulation considering wake interaction," *IEEE Transactions on Sustainable Energy*, vol. 11, no. 2, pp. 618–628, Apr. 2020, doi: 10.1109/TSTE.2019.2899087.

[12] P. Tchakoua, R. Wamkeue, M. Ouhrouche, F. Slaoui-Hasnaoui, T. Tameghe, and G. Ekemb, "Wind turbine condition monitoring: State-of-the-art review, new trends, and future challenges," *Energies*, vol. 7, no. 4, pp. 2595–2630, Apr. 2014, doi: 10.3390/en7042595.

[13] P. Manimekalai, R. Harikumar, and S. Raghavan, "An overview of batteries for photovoltaic (PV) systems," *International Journal of Computer Applications*, vol. 82, no. 12, pp. 28–32, Nov. 2013, doi: 10.5120/14170-2299.

[14] A. A. A. Al-Khazzar, "Behavior of four solar PV modules with temperature variation," *International Journal of Renewable Energy Research*, vol. 6, no. 3, pp. 1092–1099, 2016.

[15] Y. Zhao, J.-F. De Palma, J. Mosesian, R. Lyons, and B. Lehman, "Line–line fault analysis and protection challenges in solar photovoltaic arrays," *Industrial Electronics, IEEE Transactions on*, vol. 60, no. 9, pp. 3784–3795, May 2013, doi: 10.1109/TIE.2012.2205355.

[16] R. Nasrin, M. Hasanuzzaman, and N. A. Rahim, "Effect of high irradiation on photovoltaic power and energy," *International Journal of Energy Research*, vol. 42, no. 3, pp. 1115–1131, Mar. 2018, doi: 10.1002/er.3907.

[17] B. Yang *et al.*, "PV arrays reconfiguration for partial shading mitigation: Recent advances, challenges and perspectives," *Energy Conversion and Management*, vol. 247, Nov. 2021, doi: 10.1016/j.enconman.2021.114738.

[18] A. K. Gupta, T. Maity, A. H, and Y. K. Chauhan, "An electromagnetic strategy to improve the performance of PV panel under partial shading," *Computers & Electrical Engineering*, vol. 90, Mar. 2021, doi: 10.1016/j.compeleceng.2020.106896.

[19] K. L. Harrison *et al.*, "Lithium self-discharge and its prevention: Direct visualization through in situ electrochemical scanning transmission electron microscopy," *ACS Nano*, vol. 11, no. 11, pp. 11194–11205, Nov. 2017, doi: 10.1021/acsnano.7b05513.

[20] W. Chen and H. Yin, "Optimal subsidy in promoting distributed renewable energy generation based on policy benefit," *Clean Technologies and Environmental Policy*, vol. 19, no. 1, pp. 225–233, Jan. 2017, doi: 10.1007/s10098-016-1216-x.

[21] B. Bogno *et al.*, "Improvement of safety, longevity and performance of lead acid battery in off-grid PV systems," *International Journal of Hydrogen Energy*, vol. 42, no. 5, pp. 3466–3478, Feb. 2017, doi: 10.1016/j.ijhydene.2016.12.011.

[22] K.-P. Kairies *et al.*, "Real-life load profiles of PV battery systems from field measurements," *Energy Procedia*, vol. 99, pp. 401–410, Nov. 2016, doi: 10.1016/j.egypro.2016.10.130.

[23] M. M. Al-Kofahi, M. Y. Al-Shorman, and O. M. Al-Kofahi, "Toward energy efficient microcontrollers and internet-of-things systems," *Computers & Electrical Engineering*, vol. 79, Oct. 2019, doi: 10.1016/j.compeleceng.2019.106457.

[24] M. Masarrang, S. Dewi, A. Mustari, Y. Arifin, and R. Fauzi, "Design-build of photovoltaic panel data logger pressure," *ILKOM Jurnal Ilmiah*, vol. 13, no. 2, pp. 86–91, Aug. 2021, doi: 10.33096/ilkom.v13i2.692.86-91.

[25] S. S. Badhiye, P. N. Chatur, and B. V. Wakode, "Data logger system: A survey," *International Journal of Advanced Research in IT and Engineering*, pp. 24–26, 2011.

[26] R. Monthéard *et al.*, "Powering a commercial datalogger by energy harvesting from generated aeroacoustic noise," *Journal of Physics: Conference Series*, vol. 557, Nov. 2014, doi: 10.1088/1742-6596/557/1/012025.

[27] R. Stevenson, H. A. Dalton, and M. Erasmus, "Validity of micro-data loggers to determine walking activity of Turkeys and effects on Turkey gait," *Frontiers in Veterinary Science*, vol. 5, Jan. 2019, doi: 10.3389/fvets.2018.00319.

[28] M. Fuentes, M. Vivar, J. M. Burgos, J. Aguilera, and J. A. Vacas, "Design of an accurate, low-cost autonomous data logger for PV system monitoring using Arduino™ that complies with IEC standards," *Solar Energy Materials and Solar Cells*, vol. 130, pp. 529–543, Nov. 2014, doi: 10.1016/j.solmat.2014.08.008.

[29] IEC, "60904-1, photovoltaic devices, part 1: measurement of photovoltaic current–voltage characteristics," *International Electrotechnical Commission Standart, Geneva, Switzerland. Ed*, vol. 2, 2006.

[30] B. Ivey, “Low-power design guide,” *Microchip Technology Inc*, 2011.
[31] B. Ivey, “nanoWatt and nanoWatt XLPTM technologies: an introduction to microchips low-power devices,” *AN1267, Microchip*, 2009. Accessed: Mar. 26, 2009. [Online] Available: http://ww1.microchip.com/downloads/en/AppNotes/01267a.pdf
[32] M. Technology, “PIC12(L)F1840 datasheet, 8-pin flash microcontrollers with nanoWatt XLP technology,” *DS41441B*, 2011.
[33] F. Tirado-Andrés and A. Araujo, “Performance of clock sources and their influence on time synchronization in wireless sensor networks,” *International Journal of Distributed Sensor Networks*, vol. 15, no. 9, Sep. 2019, doi: 10.1177/1550147719879372.
[34] A. Woodfield, “ZL2PD programmable CMOS clock generator,” *ZL2PD Amateur Radio Website*, 2010. https://www.zl2pd.com/xtalRefOsc.html (accessed June 14, 2010).
[35] M. Technology, “XLP battery life estimator software, for nanoWatt XLP eXtreme Low Power PIC MCUs,” *Microchip Technology Inc*, 2017.
[36] B. M. Salim, “ORing low voltage sources simply and cheaply on 3.3V microcontrollers boards,” *EDN AspenCore Network*. 2020. [Online]. Available: https://www.edn.com/oring-low-voltage-sources-simply-and-cheaply-on-3-3v-microcontroller-boards/ (accessed Nov 12, 2020).
[37] L. Xu, D. Blaauw, and D. Sylvester, “Ultra-low power 32kHz crystal oscillators: Fundamentals and design techniques,” *IEEE Open Journal of the Solid-State Circuits Society*, vol. 1, pp. 79–93, 2021, doi: 10.1109/OJSSCS.2021.3113889.
[38] S. Zaliasl *et al.*, “A 3 ppm 1.5 × 0.8 mm 2 1.0 µA 32.768 kHz MEMS-based oscillator,” *IEEE Journal of Solid-State Circuits*, vol. 50, no. 1, pp. 291–302, Jan. 2015, doi: 10.1109/JSSC.2014.2360377.
[39] M. T. Tan, “Bit-banged enhanced UART for 8-bit PIC® microcontrollers,” *Microchip Application Note AN2290*, 2017.
[40] Microchip, “MPLAB® IDE: Integrated development environment,” Microchip Technology Inc., 2003. Accessed: Oct. 3, 2003. [Online] Available: https://www.microchip.com/download/tools/picmicro/devenv/51046h.pdf
[41] Microchip, “MPLAB® IDE user’s guide with MPLAB editor and MPLAB SIM simulator,” Microchip Technology Inc., 2009. Accessed: Jan. 16, 2009. [Online] Available: http://ww1.microchip.com/downloads/en/devicedoc/mplab_user_guide_51519c.pdf
[42] M. Goepogui, “PIC microcontroller programming course in C,” (in French), 2014. Accessed: Apr. 08, 2014 [Online] Available: https://www.magoe.net/magoe_cours_programmation_PIC_enC.pdf
[43] “PicPgm: a free and simple PIC development programmer software for Windows, Linux & MacOS X,” 2019. http://picpgm.picprojects.net/ (accessed August 03rd, 2017.
[44] H. Kim, X. Ma, and B. R. Hamilton, “Tracking low-precision clocks with time-varying drifts using Kalman filtering,” *IEEE/ACM Transactions on Networking*, vol. 20, no. 1, pp. 257–270, Feb. 2012, doi: 10.1109/TNET.2011.2158656.
[45] E. Vittoz, *Low-power crystal and MEMS oscillators*. Dordrecht: Springer Netherlands, 2010. doi: 10.1007/978-90-481-9395-0.

BIOGRAPHIES OF AUTHORS

Bilal Merabtane holds a Master Degree in the field of Solar Energy and Photovoltaic Systems at the University of Science and Technology Mohamed Boudiaf in Oran (Algeria). His Research areas are: electronics, embedded systems, photovoltaic systems, instrumentation. Now, he is a Senior Technician Specialized in Instrumentation at Touat Gas Group (Sonatrach). He can be contacted at email: merabtanebilal91@gmail.com.

Noureddine Benabadji my first job was a teacher at the Intitute of Telecommunications, Oran (ITO) from 1984 to 1999, where I taught the following courses: electricity, tests & measurements, electronic components, electronic circuits, logic circuits, computer hardware, microprocessors, assembler programming (8086), Algorithms and programming in C. My second job now is a teacher/researcher at the University of Sciences and Technology - Oran (U.S.T.O) where I teach C.A.D (using AutoCAD software) and doing R&D in the Laboratory of Analysis and Applications of Radiations (LAAR) where my research team has designed a local station in order to receive multispectral images from polar and geostationary satellites like NOAA and METEOSAT, and developed several image processing software (PCSATWIN, PCNOAA, MSGVIEW, COMPACTA). In the other hand, several electronic prototypes have been designed to support this local station. He can be contacted at email: benabadjinoureddine2016@gmail.com and noureddine.benabadji@univ_usto.dz.