Implementation Details of an Automatic Monitoring System Used on a Vodafone Radiocommunication Base Station

F. Corrêa Alegria, *Member, IEEE,* Francisco António Martins Travassos

***Abstract*—A monitoring system has been built to record, during one month, the power consumption of different equipments and the temperature at different points inside and outside of a radiocommunication base station operated by Vodafone Portugal. The system is centered on a microcontroller and has sensors for voltage, current and temperature measurement as well as a secure digital card for data storage and a real time clock for accurate timekeeping. The data recorded is intended to be used to optimize the operation of the base station. This will be done by correlating the energy consumption and temperature with the radiocommunication traffic in order to access the efficiency of the station and propose ways to reduce operating cost.**

***Index Terms*—Automatic monitoring system, data logging, telecommunication base station, power consumption, SD card.**

I. INTRODUCTION

The Vodafone Group Plc is at this moment on a European program of reduction of costs including IT outsourcing, consolidation of databases and management of suppliers. The electric consumption of a base station of radiocommunications (BTS) (Fig. 1) is an important factor in the costs of operation of a network of mobile communications. The knowledge of the consumption in the different equipment used as a function of the traffic of calls and data as well as the analysis of the temperature at different points inside a base station will allow its optimization and can lead to a reduction of the costs of operation.

Vodafone Portugal already monitors the voice and data traffic of its base station. However, the only energy consumption indicator they have is the total energy consumption by month which is not enough for a proper study of the correlation between energy consumption and radio traffic since this varies greatly along the day and week.

Vodafone Portugal commissioned Instituto Superior Técnico to analyze the base station energy consumption and to propose changes to the BTS operation in order to reduce operating costs. In a previous publication [1] we presented an overview of the system created, listing its features, its components and giving an example of its application. Here we have added some implementation details of the system, namely connection diagrams between the electrical components used.

In section II we present the system requirements that shaped the system developed. In section III we present the implementation details of the different parts of the system. In section IV we present some results obtained with the system for illustrative purposes and finally, in section V we draw some conclusion about the work presented and future changes that can be made to increase the system's capacity and lower its cost.

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II. SYSTEM REQUIREMENTS

Inside a BTS there are several radiocommunication equipments (RBS) for second (2G) and third (3G) generation networks. This equipment needs a DC supply and thus the BTS also has a rectifier to convert the AC voltage supplied to the BTS (250 V, 50 Hz) to a DC voltage (50 V) required for the RBS. To keep the BTS working in case of power supply failure, it is equipped with a set of batteries for energy storage. It also has an air conditioning unit to keep the temperature inside the BTS low enough for proper operation of the radiocommunication equipment and batteries.

Fig. 1 – Photograph of the exterior of a base station.

To study the efficiency of the base station, we wanted to analyze the efficiency of the rectifiers, the distribution of the energy consumption among the different equipment inside the base station and to measure the individual energy consumption of each radiocommunication equipment do that it could be correlated to the voice and data traffic going through the BTS.

Another important concern was the optimization of the air conditioning unit operation. The less time it operated the less energy it would consume. It is important, however that the temperature of the batteries be kept between 25 ºC and 27 ºC so as not to diminish their lifetime.

After analyzing some typical base stations the following list of required measurements was compiled:

- The energy consumed by the entire station (tri-phase).
- The energy consumed by the rectifiers (tri-phase).
- The energy consumed by the air conditioner (tri-phase).
- The energy consumed by 3 RBS (DC).
- Temperature in several points of the base station.

Also a list of desirable features was put together consisting of the following abilities:

- Be able to store the results for posterior analysis.
- Be able to monitor the measurements made without interrupting the measuring system operation.
- Be able to install the system in a BTS without interrupting the DC power supply to the radiofrequency equipment.
- Be able to keep track of time even if the power supply of the measuring system was briefly interrupted.
- Do not occupy a large space inside the BTS.
- Be light so that it could be easily moved from BTS to BTS.
- Have a small cost.

To achieve all this measurement requirements and features and after a careful analysis of the commercial system available, it was decided to built a measurement system from scratch.

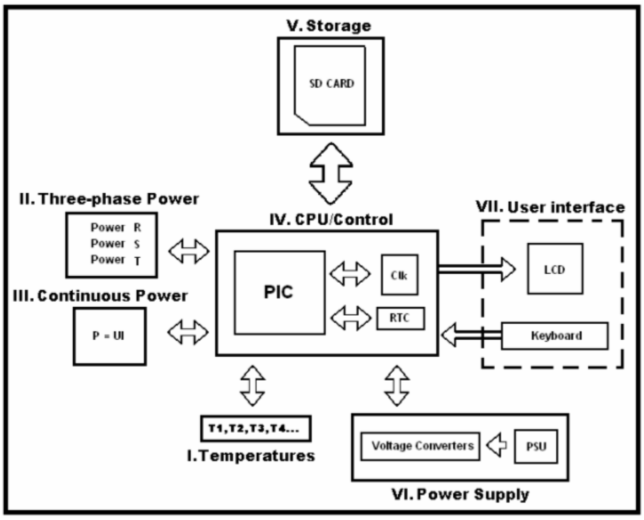

Fig. 2 – Block diagram of the measurement system.

III. System Development

The measurement system was built around a microcontroller. One from Microchip, model PIC18LF8722, was chosen since it is a low cost microcontroller which has 16 analog inputs as well has SPI and I^2C interfaces needed to communicate with a Secure Digital Card which would store the measurement results and a real time clock to keep track of time. In Fig. 2 we show a block diagram of the measurement system.

In the following we will describe in detail each part of the system, presenting connection diagrams and justifying the values of the components used.

A. Temperature Measurement

A mobile station of radio communications is not a very ample space ($19m^3$ of volume) and the heating of the air inside of the container has 2 possible sources: i) the exterior temperature; ii) the heat of the exhausted air by the fans on each RBS.

The batteries have an optimal storage temperature (24ºC-27ºC) and they are very sensitive to small changes in temperature, affecting severely its durability when the temperature is outside the specified range.

The knowledge of the temperature at different points in the station and along different hours of the day can be used to determine if there is some relation between:

- exterior temperature and inside temperature of the shelter;
- inside temperature and volume of calls;
- temperature in the exhausted air of each RBS and volume of calls;
- temperature in the batteries and in A/C´s exhausted air;
- temperature in the batteries and temperature in the exhausted air of each RBS.
- temperature in the exhausted air of each RBS and electric consumption of each RBS.

The areas strategically chosen to place 6 temperature sensors were:

- In the exhaust of each of three RBSs;
- In the exit of the air conditioner;
- By the batteries;
- Outside the station.

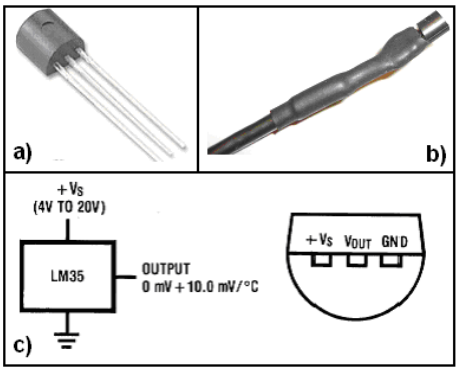

Fig. 3 –Temperature sensor LM35DZ: a) photograph; b) Sensor connected to a cable; c) Pin diagram.

To measure the temperature we chose the LM35DZ [2] from National Semiconductor (Fig. 3). It´s an accurate temperature sensor consisting of an integrated circuit that guarantees a precision of 0.5 ºC around 25ºC. Its output is linear with a sensitivity of 10mV/ºC.

The sensors were connected to a three-wire cable as shown in Fig. 3b.

In Fig. 4 the connections between the temperature sensor and the microcontroller are shown. The only difference between the 6 temperature sensors used is the analog input port of the microcontroller. Ports AN3 through AN9 were used.

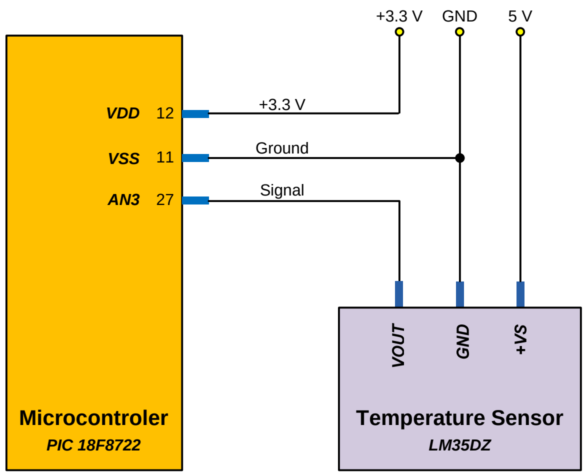

Fig. 4 – Connection diagram between the microcontroller and the temperature sensors. Only one sensor is shown. The other sensors are connected to ports AN4 through AN8 (pins 33, 24, 23, 18 and 17) of the microcontroller instead of port AN3 (pin 27).

B. *Three-phase Power Measurement*

The rectifier and the air conditioning unit work with a 230V three-phase system. The energy consumed by those systems is determined by measuring the active power drawn and integrating it through time. To measure the active power we use the three-wattmeter method which basically consists in measuring the active power in each phase separately.

The active power is, by definition, the average of the product of voltage and current:

$$P = \frac{1}{T}\int_0^T u(t)\,i(t)\,dt\ . \qquad (1)$$

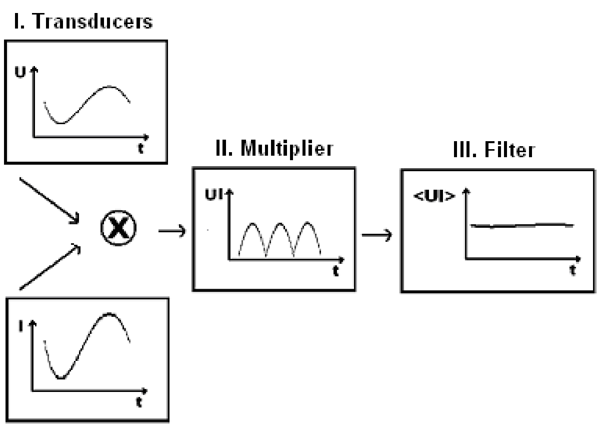

Fig. 5 – Block diagram of the active power measurement circuit.

Two Hall effect sensors are use to convert the high voltage and current into small proportional voltages which are then multiplied using an integrated multiplier. Finally the average value is obtained with the help of a properly dimensioned low pass filter implemented with discrete components (Fig. 5).

The Hall Effect transducers used to sample the voltage and current were the LV25-P [3] and the LA25-NP [4] respectively from LEM USA. The LV25-P is a Hall Effect closed cycle transducer which works with DC or AC signals up to 500 V (Fig. 6). It has galvanic isolation between the primary circuit (high voltage) and the secondary one (electronics) and a theoretical conversion factor of 2500:1000. It needs a power supply between ±12 and ±15V. It has an excellent precision and an accurate linearity.

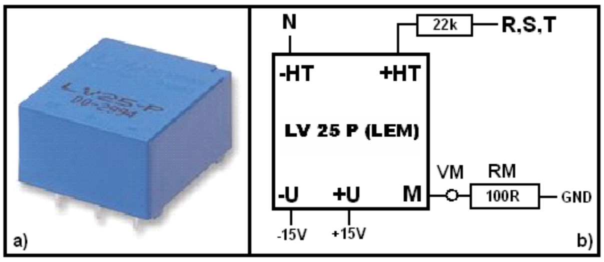

Fig. 6 – Voltage Transducer LV25-P.

The LA25-NP is also a Hall Effect closed cycle transducer which works with DC or AC signals up to 25A (Fig. 7). It also has a galvanic isolation between the primary circuit and the secondary one. The power supply is also between ±12 and ±15V. It is accurate and linear such as the LV 25 P.

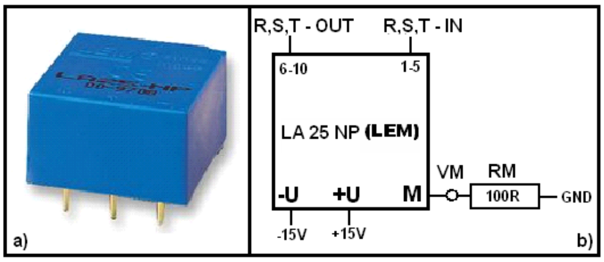

Fig. 7 – Current Transducer LA25-NP.

In Fig. 8

Fig. 8the connection of the voltage and current transducer to the system under measurement is depicted. Note that the current transducer is placed in series with the phase whose current is to be measured.

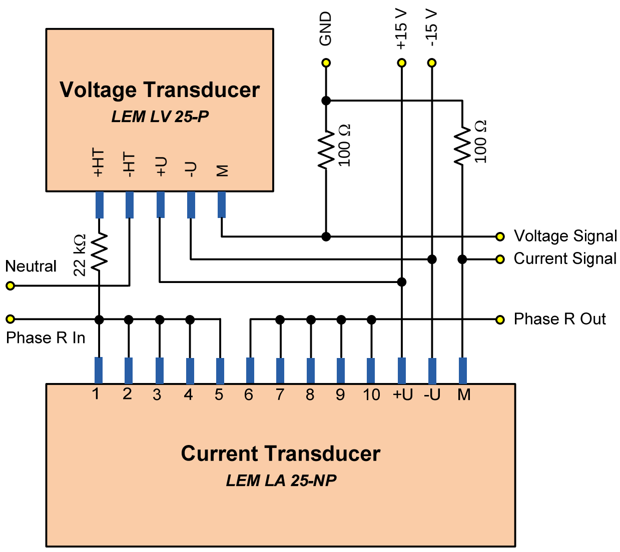

Fig. 8 – Connection diagram of the voltage an current transducers. Only one phase is shown.

The output of the current sensor is a current out of terminal "M" with a nominal value of 25 mA when the primary current has an effective value of 25 A. Other nominal values may be used if the connections between pins 1 through 10 are changed as indicated in [4]. In order to produce a voltage, a measuring resistance of 100 Ω was used which leads to a nominal voltage of 2.5 V which is inside the range of the multiplier to which it is connected.

The voltage sensor needs a resistance in series with the "+HT" terminal to produce a current which should be in the order of 10 mA [3]. Since the phase effective voltage is 230 V, a resistance of 22 kΩ was used. The sensor output is also a current out of terminal "M" (with 25 mA nominal value) which is converted to a voltage with the help of another 100 Ω resistance.

To multiply the outputs of the sensors we used the integrated circuit from Analog Devices, model AD633JRZ [5], which is a 4-quadrant multiplier (Fig. 9).

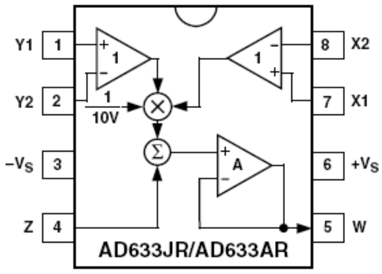

Fig. 9 – Pins of the AD633JRZ multiplier.

To realize the average value, a 1st order RC low pass filter (Fig. 10) with a cut-off frequency of approximately 1 Hz was used. A 330 kΩ resistor and a 0.47 µF capacitor were used to implement the filter.

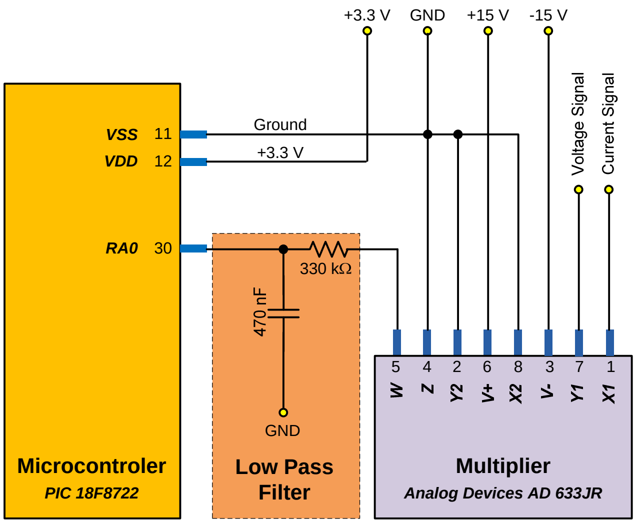

Fig. 10 – Connection diagram between the microcontroller and the multiplier and low pass filter used to determine the active power from two signals proportional to the AC voltage and AC current. Only one phase is shown. The circuits for the other two phases are connected to ports RA1 (pin 29) and RA2 (pin 28) of the microcontroller instead of port RA0 (pin 30).

Fig. 11 shows a photograph of the there-phase power measurement board.

Fig. 11 – Photograph of the three-phase power measurement board.

C. DC Power Measurement

Each RBS was powered by a DC voltage around 50 V. To measure the energy consumption we just had to measure, at each instant, the supply voltage and the current drawn. One of the pre-requisites of the system was that during installation of the measurement system the power supply to the RBS equipment was never turned off. The only solution to measure the current was to use DC current clamps. If current transducers like the ones used for the there-phase power measurement could be used the measuring system would be much cheaper. The three current clamps used represent around half of the total cost of the measurement system.

The clamps used were from Chauvin Arnoux, model PAC21 (Fig. 12). Their sensitivity is 10mV/A and the option to disable the "AUTO OFF" feature. This is an important characteristic, not found in most current clamps, since the measuring system developed had to operate continuously for at least a month during which the current claps had to remain on.

Fig. 12 – Amperimetric Clamp PAC 21 from Chauvin Arnoux.

The clamp has an input of 9 V. We used a 15V to 9V DC/DC converter with galvanic isolation, the SLW05A-09 from MeanWell to power the three current clamps.

The DC voltage was measured with the same type of transducer used to measure the AC voltages, namely the LV25-P. In this case the 22 kΩ resistor in Fig. 6b was replaced by a 5 kΩ one.

D. Microcontroller

The microcontroller (PIC) used was the 80-pin PIC18LF8722 [6] from Microchip controlled by an external 20 MHz oscillator clock. It is a low voltage microcontroller (3.3V) with 16 10-bit analog inputs. The main reason for this choice was, besides the low voltage, the two Master Synchronous Serial Port (MSSP) modules supporting 2/3/4-wire SPI™ (all 4 modes) and I^{2}C™ Master and Slave modes which was used to interact with the real time clock and the secure digital card.

The 16 available analog inputs were used as follows:

- ❖ Two three-phase power measurement modules: 6 inputs.
- ❖ Three DC power measurement module (common voltage): 4 inputs.
- ❖ Six points temperature measurement module: 6 inputs.

The PIC was programmed through an ICD2 interface whose connection to the microcontroller was a complished with a RJ 11 connector as depicted in Fig. 13.

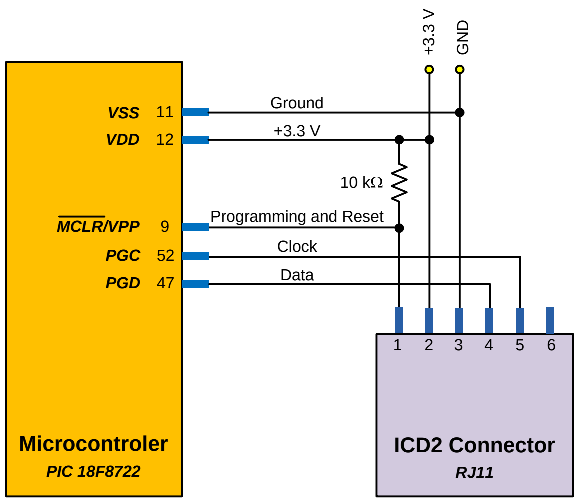

Fig. 13 – Connection diagram between the microcontroller and ICD2 debugger.

The firmware was created in Microchip's MPLab and written in C.

E. Real Time Clock

In order to maintain an accurate time and date, a real time clock (RTC) was used. It was connected to the PIC through the I^2C^{TM} protocol. The one we used was the DS3232 from Dallas Semiconductor [7] which is a 3.3 V low cost temperature-compensated crystal oscillator (TCXO) with 236 byte SRAM. The integration of the crystal resonator enhances the long-term accuracy of the device which was important in our system since it had to keep accurate timing for at least one month. The specified 2 ppm accuracy guarantees an error of less than 6 seconds during 31 days.

Additionally, the DS3232 can be connected to a battery so that it keeps track of time even if the measuring system power supply fails. Two 1.5 V AA batteries were used in series.

In this application the second Master Synchronous Serial Port of the microcontroller is used in I^2C mode to interface the microcontroller with the real time clock. In Fig. 14 a connection diagram is presented. The I^2C protocol requires only two lines – one for the data and another for the clock signal.

F. Storage

The amount of data that needed to be stored was too much for an EEPROM to be used. If we consider one measurement per second in each of the 16 10-bit analog inputs used during one month (31 days) we have 81.7 Mbytes of data to store if the data is saved in binary form (2 bytes per measurement). If we save it in ASCII form we need more than that.

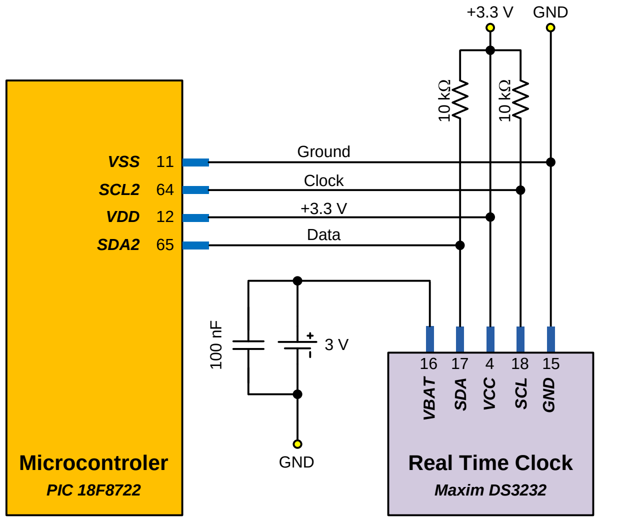

Fig. 14 – Connection diagram between the microcontroller and the real time clock.

We choose to use a Secure Digital Card (SD) [8] which is a cheap solution, has plenty of storage space and can be easily connected to a computer. The SD card communicates with the microcontroller through an SPI interface and since it is powered with 3.3 V it matches perfectly with the low voltage microcontroller used.

The SPI is a synchronous serial data link made up of four wires: one for the clock signal, one for the data in one direction, one for the data in the opposite direction and one to select the chip (multiple devices may be connected to the bus simultaneously).

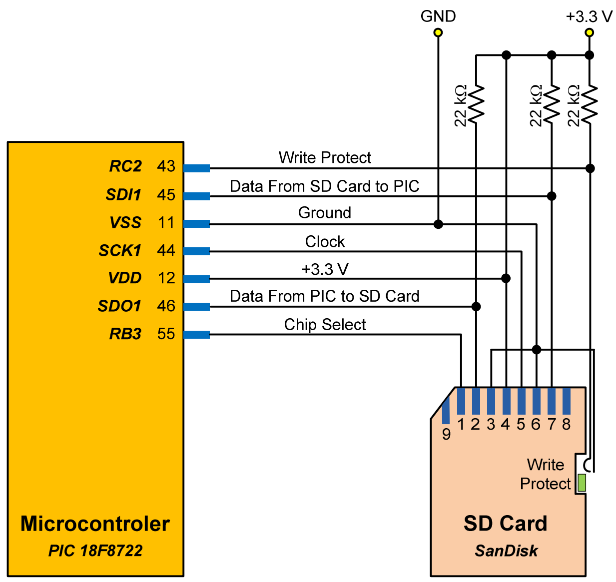

Fig. 15 – Connection diagram between the microcontroller and the SD Card.

The SD Card interface has two possible operation modes: the SD Bus Mode and the SPI Mode. The latter was used since the chosen microcontroller had an integrated SPI interface (pins 44, 45 and 46). In Fig. 15 a diagram of the electrical connections between the microcontroller and the SD Card is presented. Port RB3 (pin 55) of the microcontroller was chosen to implement the chip select functionality. One other feature used was the Write Protection which is implemented in the SD Card by a switch that causes a circuit to be closed in the SC Card slot. That circuit is a simple connection between the power supply and ground through a pull-up resistor. In our application we chose to connect the resistor to port RC2 of the microcontroller (pin 43). Any other free port could be used.

The C compiler, from Microchip, used to program the microcontroller has an SPI library of functions ready to use and which allow the read and write of data from devices connected to the SPI interface existent in the microcontroller. In addition to that library, it was necessary to develop the code to implement the FAT32 file system on the SD Card. That file system was chosen since it allows the SC Card data to be read in a personal computer or laptop running Microsoft Windows operating system.

G. Power Supply Unit / Converters

The power supply (PSU) used was the T-60C model from MeanWell which is a multiple output PSU with ± 15 V and +5V. To obtain from this PSU the microcontroller 3.3 V supply voltage, we used a 15V to 3.3 V DC/DC converter model KRB1203P-3W from Morsun.

H. User Interface

So that the user could check the operation of the measurement system and configure the measurement intervals we fited the system with a LCD panel and a 4-button keypad (Fig. 16).

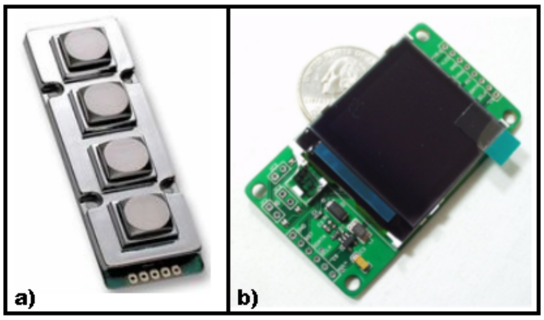

Fig. 16 – Photographs of the keypad (left) and LCD (right) used.

The connection to the LCD to the microcontroller is shown in Fig. 17.

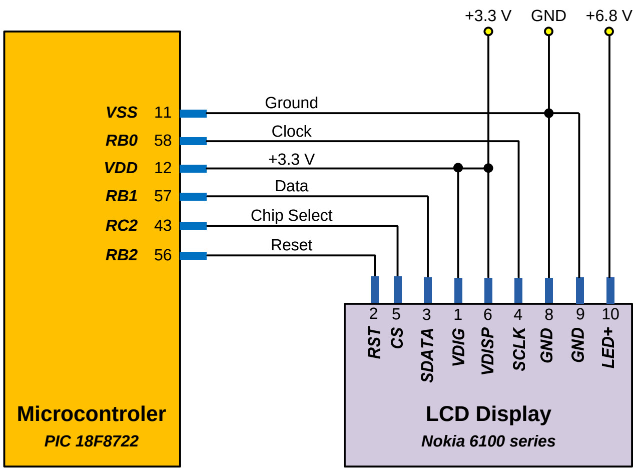

Fig. 17 – Connection diagram between the microcontroller and the LCD display.

In Fig. 18 the connections between the 4-button keypad and the microcontroller are depicted.

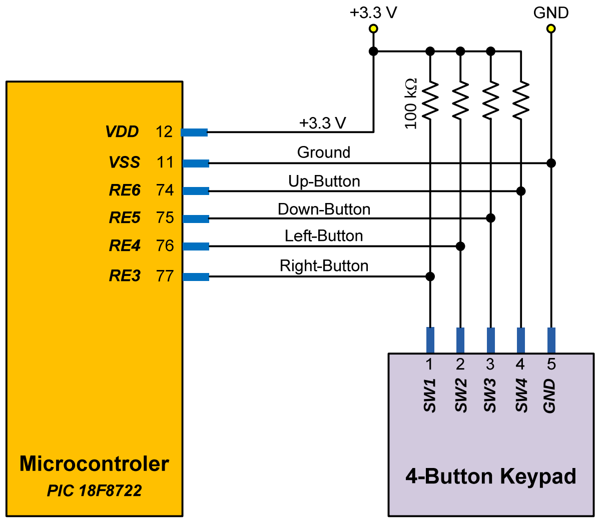

Fig. 18 – Connection diagram between the microcontroller and the 4-button keypad.

The input leakage current (I_{IL}) of the microcontroller is 1 μA and its input low voltage (V_{IH}) is 0.8 VDD [6], which in our application, where VDD = 3.3 V, leads to V_{IH} = 2.64 V. The pull-up resistor value should be such that when the buttons are in the off state, the current drawn by the microcontroller (I_{IL}) and which goes through the pull-up resistor, does not make the voltage at the microcontroller input lower than V_{IH}, otherwise the logical level will be incorrectly determined by the microcontroller. Its value can be computed using

$$R < \frac{V_{DD} - V_{IH}}{I_{IL}} = 660\ \text{k}\Omega\ . \qquad (2)$$

The higher the value of the pull-up resistor, the lower is the power consumed when the buttons are in the on state. In our application this is not critical since the system is not battery powered nor the buttons are used often. Four 100 kΩ pull-up resistors were used.

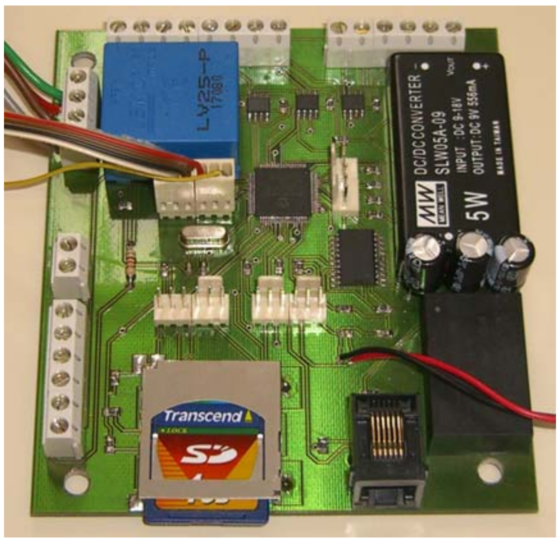

Fig. 19 – Photogram of the main printed circuit board. It contains the storage hardware (SD-Card), the PIC and RTC components, the DC/DC converters and the transducer for the DC voltage analysis from the rectifiers.

I. System Assembly

The complete measurement system was assembled into three printed circuit boards – two for three-phase power measurement (Fig. 11) and one for the rest of the modules (Fig. 19).

The three printed circuit boards, the power supply and batteries were mounted inside a plastic enclosure (Fig. 20) which was fitted with adequate connectors to plug in the current clamps, DC voltage and ground, two three-phase systems with neutral, 6 temperature probes and a RJ11 connector for microcontroller firmware update. A slot was made in the enclosure to insert and remove the SD card.

Fig. 20 – The finished measurement system.

The cost of the entire system is around 2400 € at 2007 prices. The breakdown of the costs can be seen in Table I.

Table I – Breakdown of the cost of the measurement system.

Component	Price
Temperature Measurement Module	54,47 €
Two Three-Phase AC Energy Measurement Modules	531,44 €
DC Energy Measurement Module	1288,97 €
Others	352,31 €
Storage	22,34 €
Enclosure	45 €
User Interface Components	33,6 €
Power Supply	63,67 €
TOTAL	2391,8 €

IV. Discussion of Results

During a period of 30 days the measurement system was tested inside a Vodafone´s base station in order to see the accuracy and efficiency of the components. The tested station had inside 3 different RBS: GSM900, GSM1800 and UMTS/3G.

During this period of time the data logger was storing data in the SD-Card every 2 seconds into text files. All the data was transferred to a personal computer for analysis. In Fig. 21 we show the evolution of the total energy consumption of the rectifiers and air conditioning unit during one day. We can see the increased energy consumption of the RBS equipment (rectifier output) during the day.

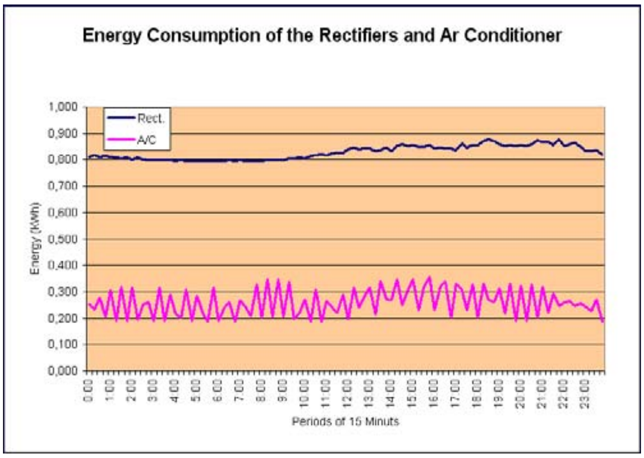

Fig. 21 – Evolution of the total energy consumption of the rectifiers (top) and air conditioning unit (bottom) during one day.

It was determined that the total energy consumed by the studied station is divided approximately in 76% for the power supplying of the RBS´s and the remainder for the cooling system. The efficiency of the rectifiers is approximately 92%. The variation of the consumption of the RBS´s between the period of the night and the period with more traffic it´s not higher than 200 Wh per 15 minute interval. The RBS that more consumes is the GSM900 while the UMTS has more constant energy consumption along the 24 hours of the day (Fig. 22).

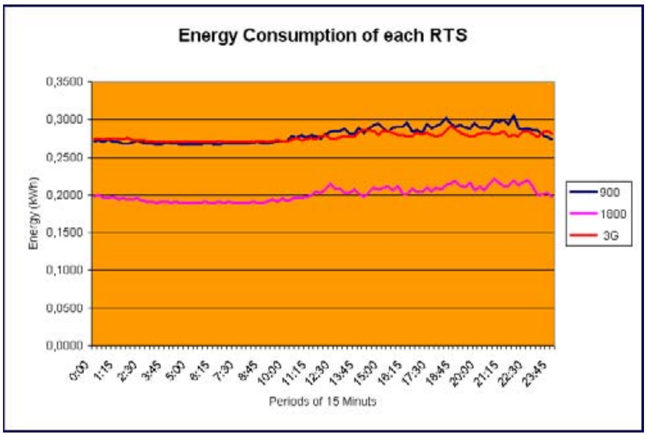

Fig. 22 – Total diary energy consumption of each RBS: GSM900 (top, dark), GSM1800 (bottom) and UMTS/3G (top, light).

From the analysis to the graphic in Fig. 23, it´s easily observed that the temperature at the batteries is almost constant. However when the temperature at the exit of the air conditioning unit (A/C) decreases, the environmental temperature also decreases but without going below 25 ºC.

V. Conclusion

The measurement system build was able to perform the required tasks. In the future a bigger LCD and different keypad should be used. If the system is to be used in an application were the DC supply can be briefly interrupted for system installation, the current clamps are not necessary and the system can be easily adapted to measure the DC current with appropriate current transducers.

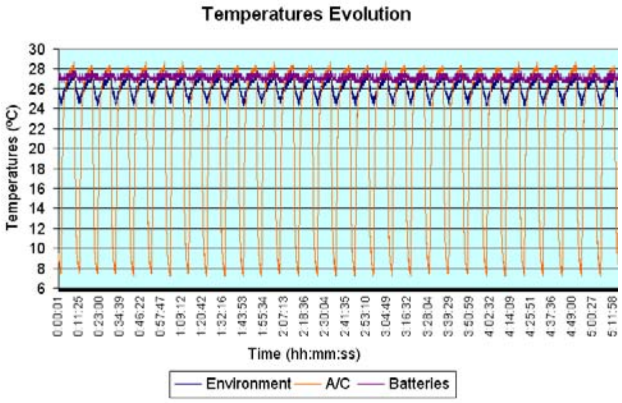

Fig. 23. Temperatures Evolution in a short period of time.

During a period of 31 days, the prototype was tested collecting data in intervals of 2 second, in a station with GSM900, GSM1800 and UMTS communication equipment (RBS). It was determined that the total energy consumed by the studied station is divided approximately in 76% for the power supplying of the RBS´s and 24% for the cooling system. The efficiency of the rectifiers is approximately 92%. The variation of the consumption of the RBS´s between the period of the night and the period with more traffic it´s not higher than 200 Wh. The RBS that more consumes is the GSM900 while the UMTS presents energy consumption practically constant during the day. An increase in energy consumption both in RBS GSM900 and GSM1800 between the low and the high traffic hour is seen. However, this variation is minimum going up to around 60 Wh in the GSM1800 and 80 Wh in the GSM900.

By analysis of the measured temperatures we see that the station is very well isolated from the exterior temperature. The temperature inside of the station varies between 25 ºC and 27 ºC although near the batteries it stays constant around 27 ºC. The temperatures in the exit of the exhaust fan of each RBS are practically constant. The RBS GSM900 and the GSM1800 have an average temperature of 31 ºC and the UMTS of 28 ºC.

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