LOW POWER WIRELESS PULSE OXIMETER TERMINAL

Dan LOZNEANU*, Paul BORZA*, Gheorghe PANĂ*, Horațiu MOGA*

*"Transilvania" University, Brasov, Romania

Abstract: *The implemented solution is part of the BIOMED-TEL project and this system combines two methods that represent the basis pulse-oximetry: spectrophotometry with role in measuring the concentration of hemoglobin (the light absorption is a function that depends on the level of blood oxygenation) and optical pletismography with role in measuring the pulsatile changes in the level of arterial blood (changes that are due to the variations in the level of arterial blood in tissues and dependent on the systolic-diastolic cardiac regime). This way the pulse-oximetry is defined as being o method noninvasive of monitoring the saturation with oxygen of the hemoglobin (blood component that has the role of transporting oxygen through tissues). The product is remarcable trough it's small dimmensions, mobility offered to the patient and low power consumption that makes possible the long on-time of the device.*

Key words: *pulse-oximetry, wirelesss terminal, sensor, battery powered.*

1. INTRODUCTION

The optical proprieties of the tissues are used in biomedical applications for diagnosing, treatment and surgery. Certain processes can take place as many times as the tissue is irradiated with light, these processes being able to include reactions: photo-thermic, photo-chemical, fluorescence, reflection and optical transmittance. These processes are not dependent on energy, for example the incidental power is equal to the sum of reflectance, absorption and transmittance.

For the pulse-oximetry application, the interesting term is the one of the time dependent absorption, by blood, due to the pulse, this way generates a lack of transmittance. The oxygen saturation from blood, SO_2, is defined by the concentration of oxygenated hemoglobin (HbO_2) related to the sum of oxygenated and unoxygenated hemoglobin (HB):

$$SO_2 = \frac{C_{HbO2}}{C_{HBO2} + C_{Hb}} \qquad (1)$$

The result given by a pulse-oximeter is an estimation of the concentration of functional arterial oxygen and should be interpreted as "the concentration of arterial oxygen measured by pulse-oxymetry" or S_pO_2. In total there are three terms that denote the saturation of functional oxygen from blood:

- SO_2: the saturation of oxygen from blood;
- S_aO_2: the saturation of oxygen from the arterial blood;
- S_pO_2: the saturation of oxygen from the arterial blood measured by the pulse-oximeter.

Fig. 1 presents the optical measure of the cardiac rhythm that is also called photopletismogram, where photo denotes (shows) the fact that an optical method is used, and pletismogram refers to the fact that the variations are caused by changes in volume (here of blood vessels) due to blood pressure.

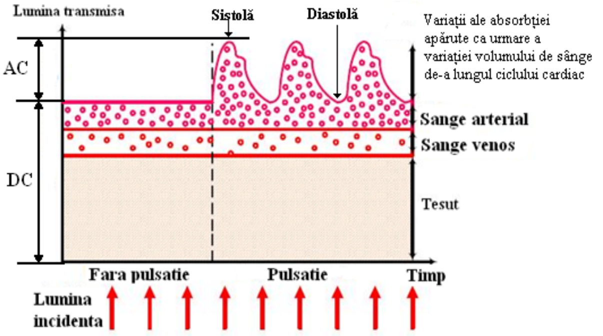

Fig. 1 Changes in the areterial volume caused by the arterial pulse

The blood as well as the skin, bones and tissue concur to the absorption. Only the arterial blood has an AC component because of the pulse. On the graphic, diastole state (the minimum) and systolic state (the maximum) can be observed together with the dicrotic notch (small plateau at the middle of the descent). The signal presented is inversed in comparison with the signal from the photo-detector, inversion made to determine a rise of the signal of the increasing pressure in blood (which is more intuitive for medical use).

2. PULSE-OXIMETER SpO_2

The bio-physical signal is captured at the level of a segment of the body (the forefinger or the earlobe) through the use of the pair LED-photodiode (optical principle). Two LEDs with two different wave lengths 660 nm (red) and 940 nm (infrared) are used due to the light absorption's different coefficients of the component elements of the hemoglobin: oxyhemoglobin (HbO_2) and the reduced hemoglobin (Hb). The LEDs work alternatively, the duration of the light pulse/ LED is of 50 µs, and the work frequency is of 1kHz (much bigger than the cardiac frequency). The resulted signal, synchronous systolic-diastolic cardiac cycle is processed through levels of conversion, amplification, gear and filtration, like this result the signal needed for the subsequent processes.

2.1. RED/INFRARED SENSOR

The central element of the pulse-oxymetrical system is the acquisition sensor. This is provided with two leds, a red one and an infra-red one and a photo-detector diode, Fig. 2**.**

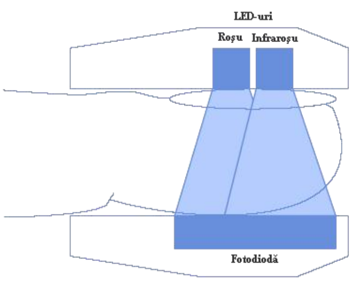

Fig. 2 Sensor with LEDs and photodiode

The sensor must be of high quality, and for this purpose a well compatible with a series of commercial pulse-oximeter was acquisitioned. It was done this way because we wish for the acquisition of a precision and quality of the bio-physical signal as high as possible.

Its purpose is to emit two different wave lengths through the tissue. The red led emits 660 nm and the infra-red one emits 940 nm. Depending on the level of blood oxygen a certain part of the light beam will be absorbed by the tissue, the rest being detected by a photo-diode.

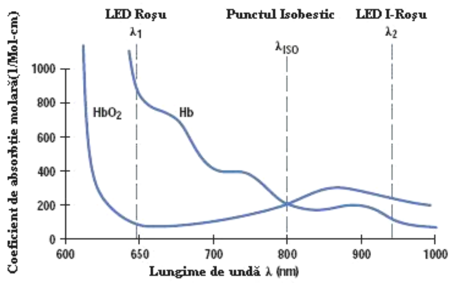

Fig. 3 Light absorbtion at different wave lenghts

2.2. METHOD

To capture the useful/practical signal a non-invasive method is used because of the use as an acquisition sensor of the signal of the well provided with two LEDs and a photo-detecting diode, elements that don't produce a violation of the integrity of the human body nor contraindications or adverse effects subsequent to their use.

The method is based on the *Beer-Lambert principle*, Fig. 4, according to which the signal detected by the photo-detector (transmitted light) is the difference between the emitted signal (incidental light) and the tissue absorber.

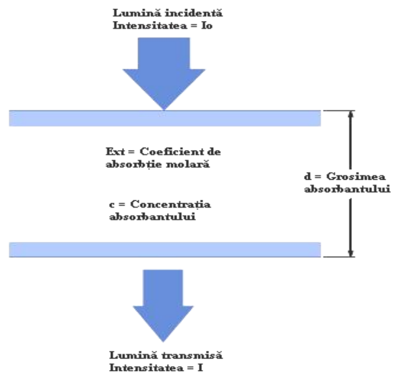

Fig. 4 The light absorbtion in tissue

The absorber holds a series of tissue intrinsic factors: the coefficient of the molar absorption, the concentration of the tissue, the thickness of the tissue.

In the project it was used a sensor (SF-1011N) that has the following characteristics:

Measurement techniques	Dual wave length
Cable length	1,0 m
Connector	Sub-D9 header
Measurement range	0-100% SpO2
Pulse range	20-250 bpm
Precision	80%-100% ± 2 digits, 70%-79% ± 3 digits, 0%-69% NA
Operating temperature	5-40 ^{0}C
Application	Adult, > 40kg, forefinger

3. PULSE OXIMETER HARDWARE

The current to voltage amplifiers have a double role: to *convert* the current detected by the photo diode in voltage and to *amplify* the detected signal. The signal detection will be made with the photo diode reverse polarised, in photoviltaic mode (Fig. 5).

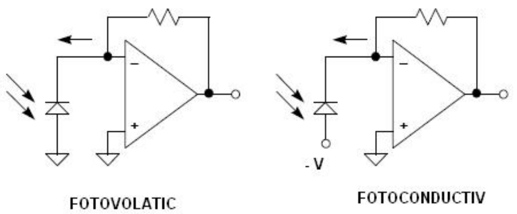

Fig. 5 Operating modes of the photodiode

This setting in comparison to the photo-conductive mode presents the advantage of linearity, Jonson noise elimination and signal precise measurement at the expense of the acquisition speed. The detected signal is of the order of tens of 10^{-9} amperes.

The operational amplifier in this level is AD8618. Compared with the operational amplifiers with bipolar transistors on input, this operational amplifier with CMOS has a few advantages: very high entry impedance, very low/small values of the voltages and offset currents, a very good value of the rejection report of the common mode and also very good slew rate and gain-bandwidth product. The detected signal will so be amplified and displayed at the exit AD8618. Due to the use of the diode as well as of the amplifier in reverse configurations, the signal phase will not be modified. The estimated current consumption is of 1.7 mA.

3.1. ANALOGUE SIGNAL FILTERS

To configure the filters some information offered to the collaborator doctors' team of this project referring to the values of cardiac pulse must be taken into account:

- Adult, healthy person: 60-100 beats per minute (BPM)
- Athlete, standing: under 60 BPM
- Athlete, in case of physical effort: 150-200 BPM
- Adult, during sleep: 40 BPM
- New-born and children: average 110 BPM

Considering all these information we have configured the central frequencies of the filters as follows: low pass filter 0.1 Hz and band pass filter 1.2 Hz (72 BPM).

The operational amplifiers of the filter are differentially powered at ±5 V. The estimated consumption is of 1mA.

3.2. LOW PASS FILTER

The low pass filter presents importance in the *separation of the direct component* of the signal (DC) from the rest of the detected signal. The continuing value will be processed the microcontroller and will be used to calibrate the value of the current through leds depending on the patient's tissue characteristics.

A second order filter, Sallen-Key, with a falling slope of 40 dB/decade will be used. The Sallen-Key topology allows a better independence of the filters performance compared to the amplifiers performance, other topologies have a lower independence. The filter with *Bessel* answer for its characteristics at pulse like signal will be configured.

The operational amplifiers of the filter are differentially powered at ±5 V. the estimated consumption is of 1 mA.

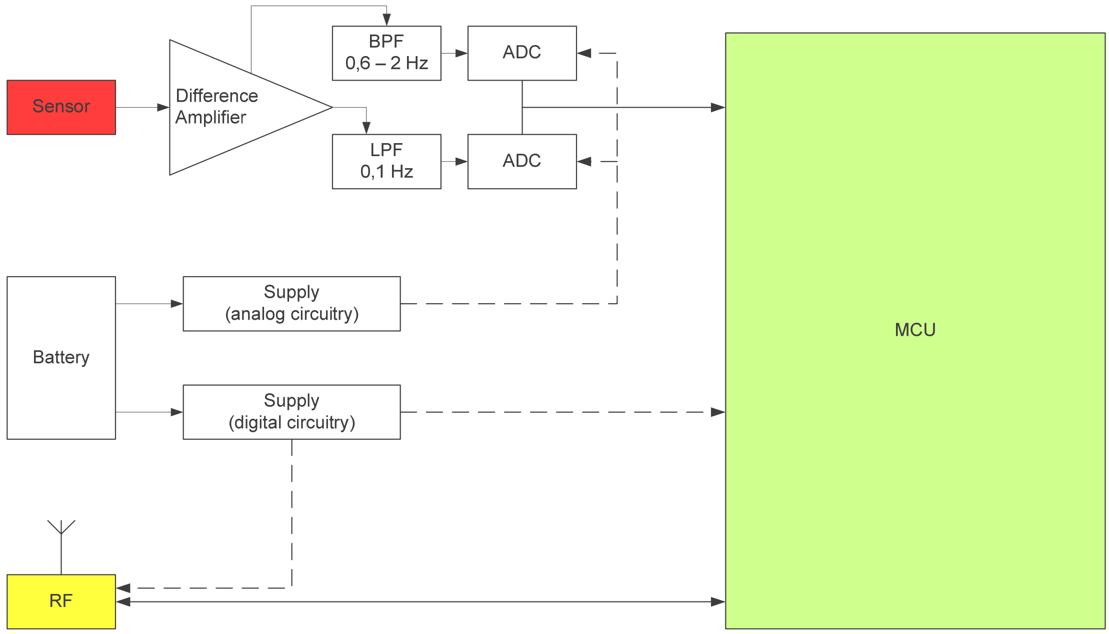

Fig. 6 Block diagram of the wireless pulse-oximeter

3.3. BAND PASS FILTER

The band pass filter has a role in the weakening of the direct component (DC) of the signal and the *separation of the pulse component* (AC) that follows the systolic-diastolic cardiac system. This value will be amplified, processed and used in the determination of the value of the blood oxygen saturation.

A fourth order filter Sallen-Key, with a falling slope of 80 dB/decade will be used. The filter with *Bessel* answer for its characteristics at pulse like signal will be configured. The reasons for choosing this type of filter were presented in the Low Pass Filter.

To configure a fourth order filter, two second order filters will be serial connected.

3.4. DIGITAL ANALOG CONVERTOR

The Digital-to-analog converter has the role of converting the analogue signals, red and infrared. The digital signals will be used further by the microcontroller and passed trough the wireless module to the data centralizer (PDA).

For this project the A/D converter AD1110 was used.

Samples / seccond	Bits
15	16
30	15
60	14
240	12

3.5. LEDS CONTROL AND CURRENT SOURCE CIRCUIT

This circuit is realized with two complementary pairs of transistors configured in H-bridge which has a double role:

- Alternate command for the LEDs;
- Constant current trough the LEDs.

The supply of the current source is made unipolar with +5 V. Current consumption of this block is 3 mA.

3.6. RADIO FREQUENCY CIRCUIT

Has the role of transmitting the data gathered from the pulse-oximeter sensor to the data centralizer of the entire system?

For this interface we have decided to use the CC1000 circuit because of its nice to have features: low power consumption, possibility of manual configuration and lack of low level stack implemented on the RF controller and high enough data transfer rate (76.8 kbps).

This circuit is supplied with 3.3 V and it uses SPI interface for data communication.

3.7. CONTROL CIRCUIT

In order to be able to keep the power consumprion of this module as low as possible we have used an Atmel microcontroller from picoPower familly, which uses only 0.5 mA.

This device has the role of handling the data taken from the ADCs and transmitt them trough the SPI interface to the wireless module, it also handles the power management of the entire system and process information comming from the centralisator of the system.

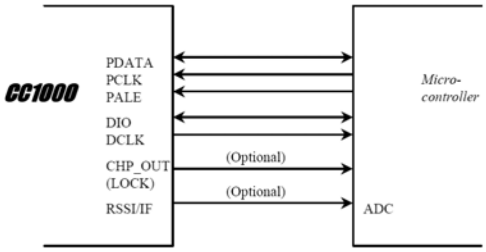

Fig. 7 Interface MCU – CC1000

3.8. THE SUPPLY CIRCUIT

The supply circuit converts the voltage from the two Li-Ion batteries.

In order to obtain the three voltages required for the entire system there were used switiching regulators, which have a greater efficiency than the linear regulators.

The two LT1615 are generating:

- +3,3V, efficiency 70-75% ;
- +5V, efficiency 75-80% ;

The LM2611A is generating:

- -5V, efficiency 75-80%.

The performace of this supply is remarcable also trough the low noise at the output of the regulators 1 mVp-p.

4. RESULTS

The results which have to be obtained on a healty person by the analog system of this pulse oximetter at sea level 94%-98% and at 1500 metters altitude are betwen 92% and 94%.

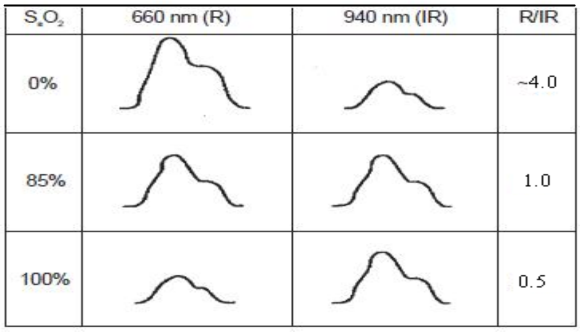

Fig. 8 Wave representation of SPO_2 measurement

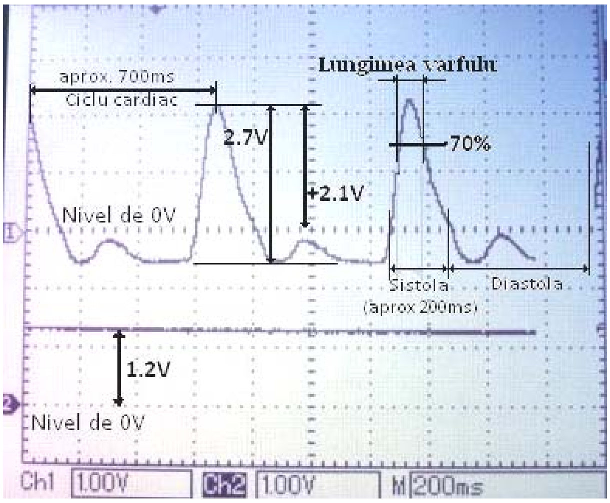

Fig. 9 Measurement of AC signal obtained with IR LED on

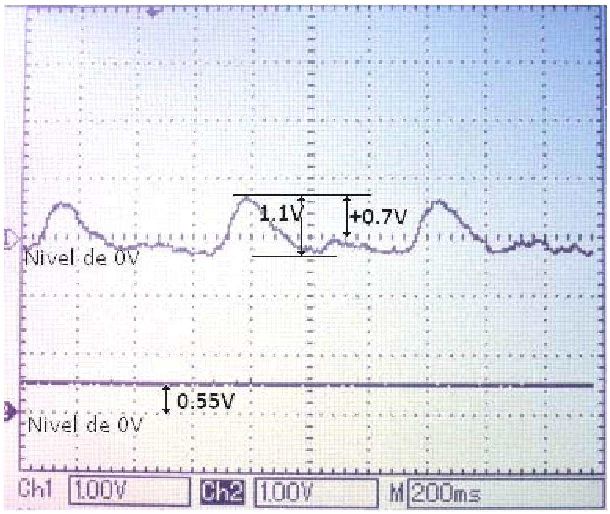

Fig. 10 Measurement of AC signal obtained with red LED on

Experimental results of measurement of SPO_2 have generated the following results:

$T_{Cardiac\text{-}cycle}$ = 700 ms

AC_IR = 2.1 V
DC_IR = 1.2V
AC_R = 0.7V
DC_R = 0.55

4. CONCLUSIONS

This puls e-oximeter is a wireless solution embedded intro the BIOMED TEL research project, which will monitor along with this biomedical parameter other important characteristics of the patient and all of them will be centralized and will be available in real time to the medic in charge. This design will provide this information wirelessly giving flexibility to the patient. The modern product displays information in a straightforward manner to ease interpretation of the information by the users.

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