# BLOOD PRESURE MONITORING USING PROGRAMMABLE SYSTEM ON CHIP

*Victor Obionwu, Bondini Saveli, Raisa Malcheva*
*Donetsk National Technical University, Ukraine*

*A Patient Vital Signs Monitor using PSoC has the advantage of emulating most of the required peripherals inside one chip. A single PSoC includes Flash and SRAM memory, an MCU, ADCs, PWM, filters, USB control and capacitive sensing. LCD drive is integrated in the PSoC. Only the pressure transducer and the LCD display are external to PSoC. Clearly, there is an immediate component count reduction, with most peripheral components integrated into the SOC.*

## Introduction

The phrase system on chip represents a major revolution in IC design. This revolution is enabled by the advances in process technology allowing the majority of all or most of the major components and subsystems of an electronic product onto a single chip, or integrated chipset. hence, complex functionality that previously required using heterogeneous components and interconnecting them on a PCB , are integrated within one single silicon chip. We can define an SoC as a complex integrated circuit, or integrated chipset, which combines the major functional elements or subsystems of a complete end product into a single entity. they include at least one programmable processor, and very often a combination of at least one RISC control processor and one DSP, a specialized microprocessor with an architecture optimized for the fast operational needs of digital signal processing. They also include on-chip communications structures—processor buses, peripheral buses, and perhaps a high-speed system bus. For interfacing to the external, real world.

## Blood Pressure monitoring

The non invasive method of monitoring blood pressure is widely used. It measures arterial systolic and diastolic pressures of the human body. This device can also measure heart rate. Table 1 describes various non invasive methods used in blood pressure monitors. This application note demonstrates how to use the PSoC to build an oscillometric blood pressure monitor.

## Operation Principle

The blood pressure monitor operates on the following principles.

- The cuff is worn around the upper arm and it is inflated beyond the typical systolic pressure.
- It is then deflated. The pressure starts decreasing, resulting in blood flow through the artery; this makes the
- artery to pulsate.
- The pressure measured on the device during onset of pulsations defines the systolic blood pressure.
- Then the cuff pressure is reduced further. The oscillations become increasingly

significant, until they
- reach maximum amplitude.
- The pressure at the maximum amplitude of these oscillations defines the average blood pressure.
- The oscillations start decreasing as the cuff pressure reduces. The pressure at this point defines the minimal blood pressure or diastolic blood pressure.

This method of measuring blood pressure is the oscillometric method. It is often used in automatic blood pressure monitor devices because of its excellent reliability. Figure 2 shows the variation of the artery oscillations as the cuff pressure is reduced; it also shows the systolic and diastolic points. Estimation of systolic and diastolic pressure is done using various empirical algorithms.

Table 1. Non Invasive Methods to Monitor Blood Pressure.

| Method | Non-invasive Principle |
|---|---|
| Palpatory (Riva-Rocci) | Palpable pulse when cuff pressure equals systolic pressure (SP) |
| Auscultatory | Based on sound waves generated from artery |
| Ultrasonic | Based on frequency difference between transmitted and reflected ultrasound wave when passed through arteries |
| Tonometry | When the blood vessel is partly collapsed, the surrounding pressure equals the artery pressure. Measured using an array of pressure sensors and the cuff is around the wrist |
| Oscillometric (Popular and widely used) | The intra-arterial pulsation is transmitted via cuff to transducer (example, piezo-electric). SP and DP are estimated from the amplitudes of the oscillation by using an empirical algorithm. Oscillometric method is used in almost all portable blood pressure monitors |

### Normal Approach

A typical BPM uses a differential pressure sensor measure cuff or arm pressure. As the output of this sensor lies within 30-50µV hence the output pressure signal has to be amplified using a high-gain instrumentation amplifier with a good common mode rejection ratio (CMRR). Usually the gain and CMRR has to be around 149 and100 dB respectively .The frequency of oscillatory pulses in the pressure signal lies between 0.3-11Hz with an amplitude of a few hundred microvolts. A band-pass filters with gain around 200 and cutoff frequency at 0.3-11Hz is used to extract the oscillations .A 10-bit ADC with a speed of 50 Hz is used to digitize the pressure sensor and oscillatory signal. Two timers are used to calculate the heart rate and implement safety timer functionality. A safety timer regulates the pressure kept on a subject's arm for a certain period of time. This safety timer is a part safety regulation in AAMI standards. A microcontroller core calculates the systolic and diastolic pressures values using an oscillometric Algorithm. The cuff is inflated and deflated using motors driven by PWMs.

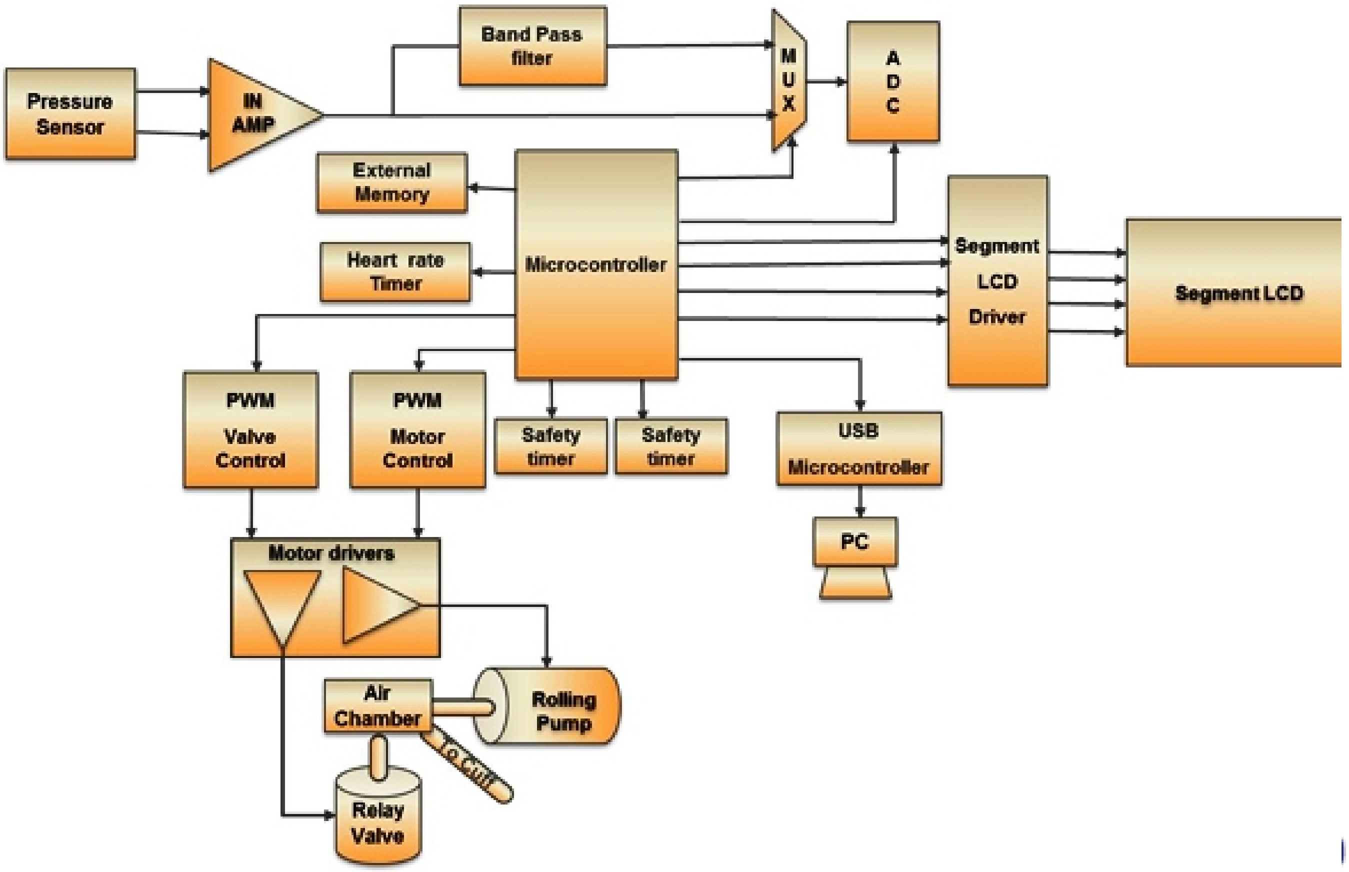

Figure 1. Blood pressure monitor in normal design approach

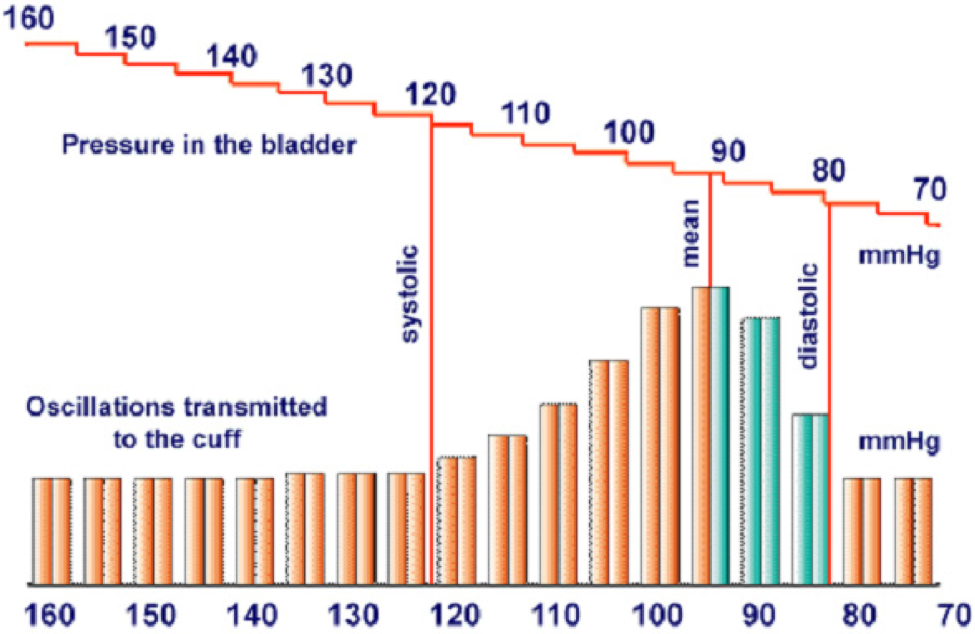

Figure 2 – Oscillometric Pulses Vs Cuff Pressure

## PSOC Design Approach

The device also uses oscillometric method to determine systolic and diastolic pressures. This system includes the following blocks:

- Pressure sensor;
- Amplifier;
- Filter;
- Multiplexer and ADC;
- Heart rate timer;
- Safety timer;
- Pneumatics;
- Display;

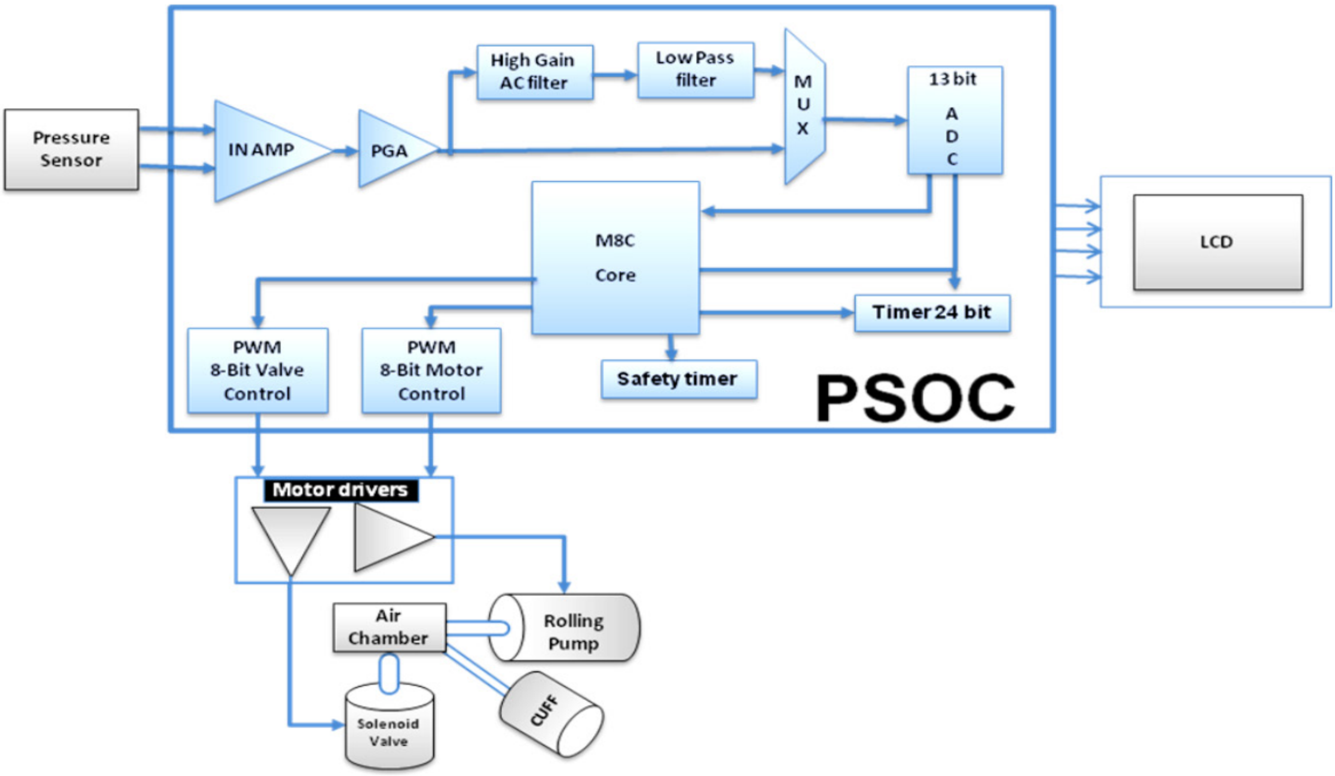

Figure 3. block diagram of the blood pressure monitor using PSoC.

## Pressure Sensor

The pressure sensor for blood pressure monitoring system should have the following characteristics:

- Measure pressures from 0 mmHG (0 Kpa) to 300 mmHg (40 Kpa);
- Gauge type, because blood pressure in relation to atmospheric pressure;

MPX2053 (piezoresistive pressure sensor from Free scale) is used in this example. It gives differential output with maximum measurable pressure range of 50 Kpa. It has a transfer characteristic of (20 mV/50 Kpa) 0.4 mv for every 1 Kpa change in pressure or 53 µV per mmHG with Vs=5V as illustrated in Figure 4.

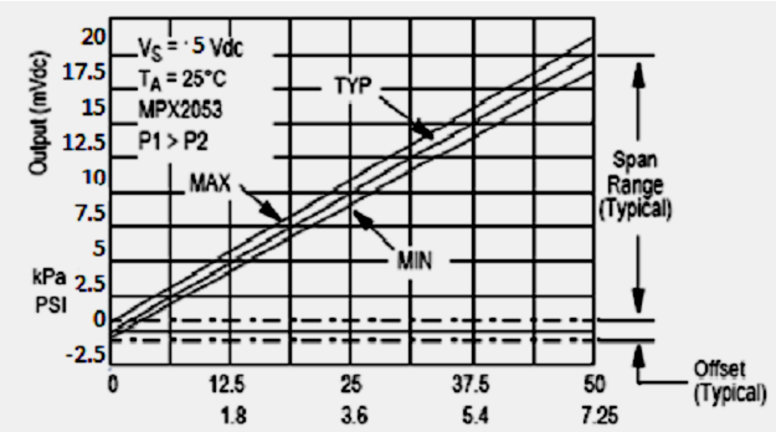

Figure 4. Transfer characteristic

### Amplifier

The sensor output is in the order of a few mega volts. Three opamp topology instrumentation amplifier is used to amplify the pressure signal. It provides a gain of 93. Gain = Diff Gain * Conversion Gain = 48 * 1.98 = 93.

### Filter

The sensor output consists of two signals: cuff pressure signal and oscillometric signal. The oscillometric signal has frequency components between 0.3 Hz to 20 Hz. Two stage filters are used to filter out the oscillometric pulses.

### First Stage

A high gain AC filter, described in the Cypress application note AN2320 is implemented in the first stage. Topology of this stage is illustrated in Figure 5

The filter's cutoff is set around 1 Hz. This filter removes all DC components and gives the AC signal a sufficient gain. The output of the first stage has unwanted high frequency components.

### Second Stage

High frequency components are removed using two pole low pass filters implemented inside PSoC. This filter is constructed using two switched capacitor blocks. The filter's cutoff is set at 50 Hz with a 0 dB gain.

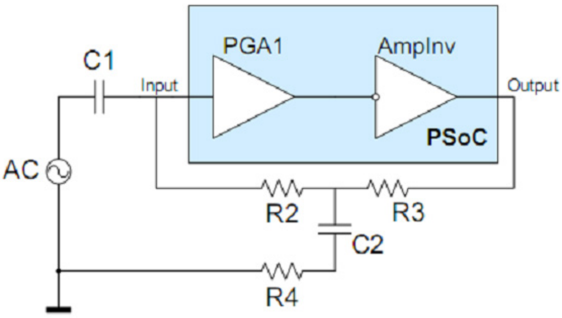

Figure 5 – High AC Gain Amplifier

DC Pressure signal and the oscillometric are multiplexed to ADC inside the PSoC. The MUX selects one of these signals to a 13-bit incremental ADC, which runs at a sampling rate of 30 samples/second. Correlated double sampling, described in the Cypress application note AN2226 is implemented to avoid offset errors. A low-pass IIR filter is implemented in software. This averages and effectively reduces the noise from the input signal. For details on modifying the filter constant and other IIR techniques, see application note AN2099 Single-Pole IIR Filters. To Infinity And Beyond!

### Heart Rate Timer

A 24-bit timer is used to calculate the heart rate. Timer is clocked using a source of frequency 62.5 kHz. The period value is set to 500000 to deliver an output of 4 seconds. Heart rate is calculated by capturing the timer period at oscillometric pulse triggers.

- Start the four second window timer;
- Capture the timer's period value when oscillometric pulses crosses the defined threshold;
- Record timer value for four such crossings;

$$Heart\ Rate(\min) = \frac{60 * Clock\ Frequency}{Ave.\ of\ 4\ Captured\ Values} \qquad (1)$$

### Safety Timer

This timer generates an interrupt every four seconds and checks if the cuff pressure is above specific threshold for that time window. (AAMI safety standards defines the maximum time limit for holding a particular pressure at arm cuff.) If the pressure in the cuff exceeds the safety pressure level then the solenoid valve is opened to deflate the cuff completely.

### Pneumatics

Pneumatics forms the main part of any blood pressure monitoring system. Pneumatics of a typical monitor has the following:

- Cuff;
- Air chamber;
- Rolling pump;
- Solenoid valve.

The cuff is worn around the upper arm; it detects the change in pressure due to pulsation of artery. Cuff is connected to pressure sensor through air chamber, which in turn connects to the solenoid valve and rolling pump. Rolling pump inflates the cuff. Solenoid valve deflates the cuff at a defined rate .Usually the deflation rate is lowered if more samples of oscillometric pulses are needed and vice versa. Figure 6 shows the pneumatics setup used to build a typical blood pressure monitor.

### Display

A 16x2 character LCD is used to display the results Using RS232 communication, the. oscillometric pulses are recorded with reference to pressure in cuff.

### Software

Blood pressure monitor software performs the following functions:

- Reads cuff pressure;
- Reads oscillation amplitude;
- Correlates cuff pressure with oscillation amplitude;
- Calculates systolic and diastolic pulses;
- Calculates heart rate.

First inflate the cuff to an optimum value (here 160 mmHg); look for pulses (oscillation signal). When the pulse is recognized and systolic is higher than 160, then pump to 180. Check for the pulse again. Continue this cycle until the pulses disappear. Then start deflating.

$$Transducer\ Voltage = \frac{Dc\ voltage\ \ from\ amplifier}{Ave.\ of\ \ 4\ CaptuTotal\ DC\ gain} \qquad (2)$$

(3)

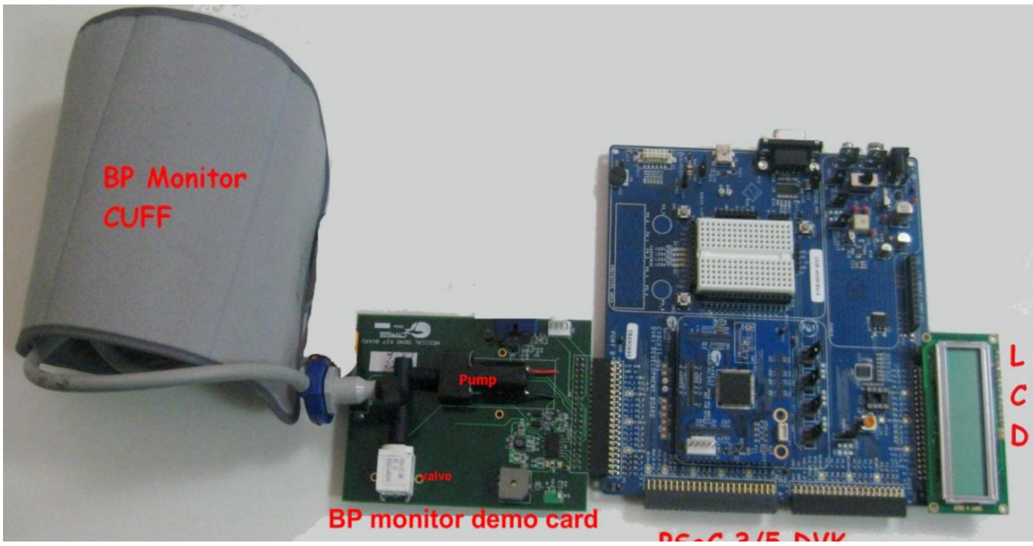

Figure 6. Pneumatics setup

$$\Pr essure\ Kpa = \frac{Transducer\ Voltage}{slope}$$

This is the transfer characteristic of sensor:

$$\Pr essure\ (Kpa) = \frac{DC\ Voltage\ \ from\ \ Amplifier \cdot slope}{Total\ \ DC\ Gain} \qquad (4)$$

$$\Pr essure(mmHg) = \Pr essure(Kpa) \cdot \frac{760\ mmHg}{101.325\ Kpa} \qquad (5)$$

When deflating the cuff, wait for systolic pulses in filtered signal. After systolic pulses are detected, accumulate four to six valid systolic pulses along with cuff pressure data. Average these pressure data to get systolic pressure. Pulse rate is calculated by capturing the time interval between oscillometric pulses in a four second time window. Diastolic pressure is calculated using a similar method.

Offset error due to sensor and the amplifier is eliminated by employing correlated double sampling method described in application note AN2226. To do this, follow these steps:

1. Short the inputs. Measure ADC output. Store as offset.
2. Connect inputs to thermocouple. Measure output. Store as signal.
3. Subtract offset from signal – in the software, short the inputs of instrumentation amplifier.

Accuracy of the pressure measurement can be increased by calibrating the setup against a standard pressure meter. Besides precision of the analog signal chain, the accuracy of the systolic and diastolic pressures depends on the algorithm used to find systolic and diastolic pulses.

## Summary

The blood pressure monitor described here is constructed using PSoC with no active external components. To increase accuracy, calibrate the system using blood pressure calibrators and simulators. Devices used for medical diagnostic applications must undergo a rigorous documentation and qualification program to meet applicable interruption medical safety efficacy standards.

## References

[1] AN58128 - PSoC® 3/5 - Blood Pressure Monitor

[2] AN2284 Sensing - Low-Cost EKG Pulsometer

[3] AN2158 Sensing - Optical PulsOmeter with PSoCThe pressure in the cuff is calculated as follows: