THIS SPEC IS OBSOLETE

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Spec Title: BLOOD PRESSURE MONITOR WITH PSOC(R) - AN58128

Sunset Owner: Shruti Hanumanthaiah (SSHH)

Replaced By: None

AN58128

Blood Pressure Monitor with PSoC®

Author: Sanjeev Kumar K.
Associated Project: Yes
Associated Part Family: CY8C27xxx, CY8C28xxx, CY8C29xxx
Software Version: PSoC® Designer™ 5.3
Related Application Notes: For a complete list of the application notes, click here.

If you have a question, or need help with this application note, contact the author at kuk@cypress.com.

Blood pressure is one of the vital signs in the human body. It is measured using both invasive and non invasive techniques. This application note demonstrates how to build a non invasive blood pressure monitor using the PSoC® 1. This design does not use any external active components to buffer, amplify, and filter the signal.

Contents

Introduction

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.

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

Operation Principle

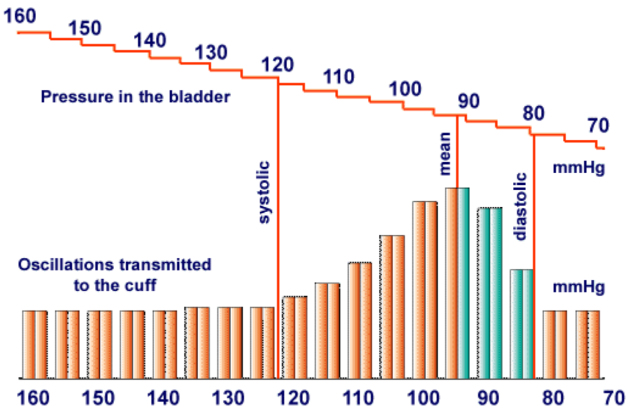
The blood pressure monitor operates on the following principles.

- 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 1 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. This application note demonstrates PSoC hardware's capability to perform blood pressure monitoring by extracting the oscillometric waveform and doesn't describe the algorithm used to extract blood pressure from the oscillometric waveform. This is primarily because all reliable algorithms are complex and deserve a separate discussion and empirical algorithms don't give a reliable value across a good number of people.

Figure 1. Oscillometric Pulses Vs Cuff Pressure

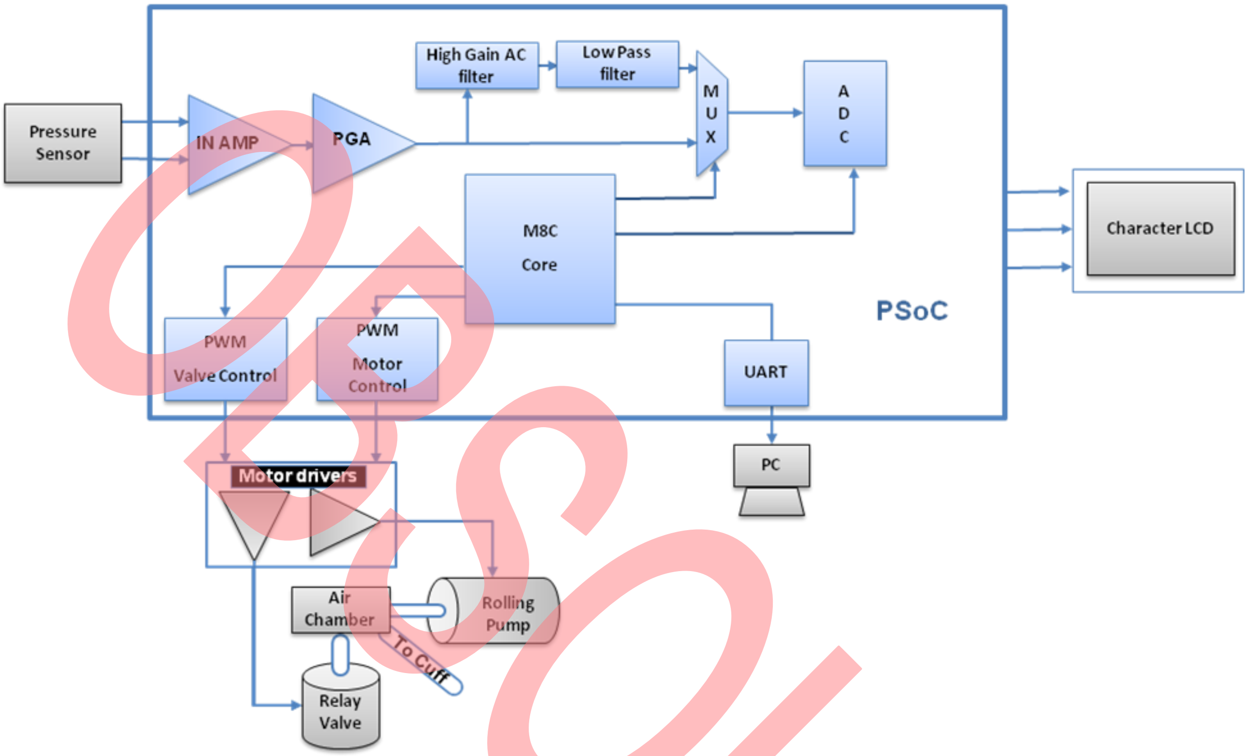


Block Diagram

Figure 2 shows the block diagram of the blood pressure monitor using PSoC. The device uses oscillometric method to determine systolic and diastolic pressures. This system includes the following blocks:

- Pressure sensor
- Amplifier
- Filter
- Multiplexer and ADC
- Pneumatics
- Display

Figure 2. Block Diagram



Implementation of these blocks in PSoC is described in the following sections.

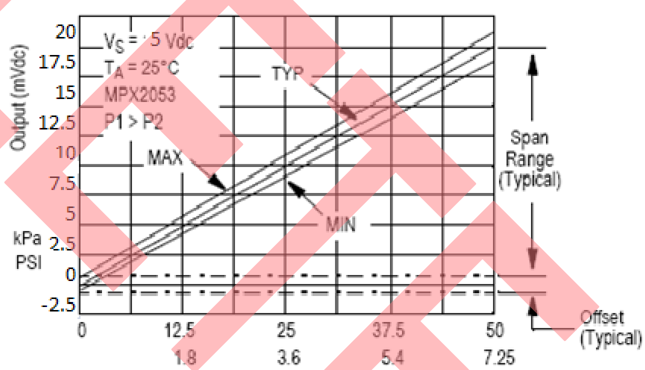
Pressure Sensor

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=5 V as illustrated in Figure 3.

Figure 3.Transfer Characteristics of Sensor



Amplifier

The sensor output is in the order of a few micro volts. Three opamp topology instrumentation amplifiers are used to amplify the pressure signal. It provides a gain of 93.

Gain = Diff Gain * Conversion Gain = 48 * 1.98 = 93

Filter

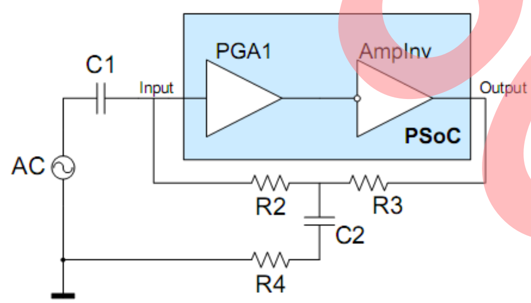
The sensor output consists of two signals: cuff pressure signal and oscillometric signal. The oscillometric signal has frequency components between 0.3 Hz to 20 Hz. Two stage filters are used to filter out the oscillometric pulses.

First Stage

A high gain AC filter is implemented in the first stage. Topology of this stage is illustrated in Figure 4.

This circuit uses only two analog I/O. An Inverting Amplifier (AMPINV) User Module is used to achieve inverted output as opposed to input. This allows the connection of output to input via the additional RC-circuit to form negative feedback-coupling. Capacitor C2 suppresses the AC component of the feedback signal. The DC component passes from output to input without any changes, which forms 100% DC negative feedback. This permits the output DC voltage to be close to analog ground, independent of the amplifier's input offset voltage.

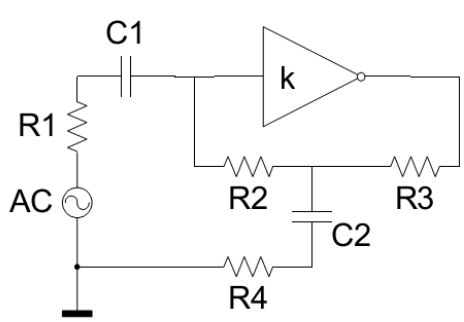
Figure 4. High AC Gain Amplifier



The circuit in Figure 4 seems to be very simple. Nevertheless, it is not easy to estimate the gain-frequency characteristic of the whole amplifier due to frequency-dependent feedback. For analysis purposes, the amplifier circuit should be slightly modified as shown in

Figure 5.

Figure 5. Amplifier Equivalent



The resistor R1 is added, taking into account the AC signal source output resistance.PGA and AMPINV coupled in series are replaced by one equivalent inverting amplifier with gain equal to k.

Using Kirchhoff's laws and simple algebra, the frequency-response function for the circuit shown in

Figure 5 can be written as follows:

$$K(p) = -\frac{a_2 p^2 + a_1 p}{b_2 p^2 + b_1 p + b_0}.k$$

$$a_2 = C_1 C_2 (R_2 R_3 + R_2 R_4 + R_3 R_4)$$

$$a_1 = C_1 (R_2 + R3) \qquad \rightarrow \text{Equation 1}$$

$$b_2 = C_1 C_2 R_3 (R_1 + R_2) + C_1 C_2 R_4 (R_1 + R_2 + R_3 + kR_1)$$

$$b_1 = C_1 (R_1 + R_2 + R_3) + C_2 R_3 + kC_1 R_1 + (1+k) C_2 R_4$$

$$b_0 = k + 1$$

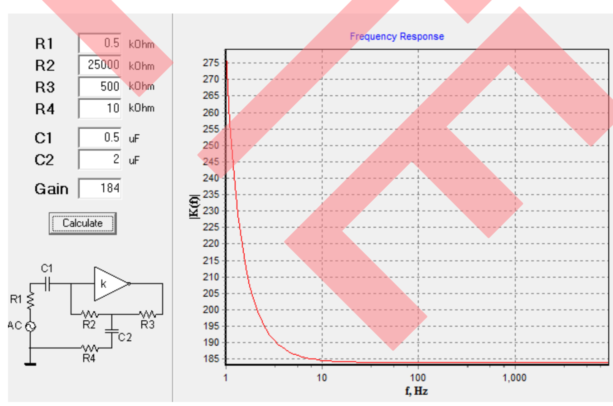
Equation (1) describes a combination of high-pass and band-pass filters with the same roll-off frequency.

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.

$$\omega_r^{\,2} = \frac{b_0}{b_2} \qquad \rightarrow \text{Equation 2}$$

The gain at higher frequencies is equal to $-k\frac{a_2}{b_2}$. The frequency response is shown in Figure 6.

Figure 6. Frequency Response



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.

Multiplexer and ADC

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!

Pneumatics

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

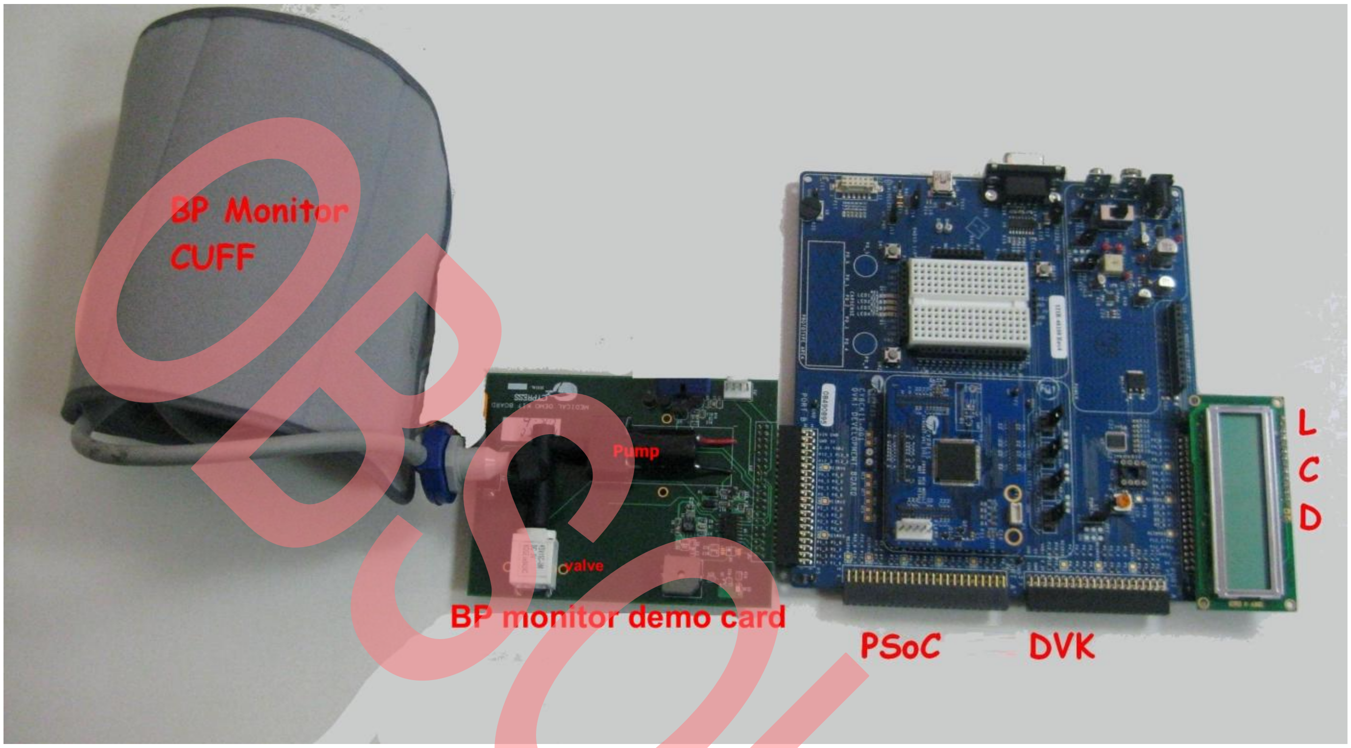
- Cuff
- Air chamber
- Rolling pump
- Solenoid valve

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 7 shows the pneumatics setup used to build a typical blood pressure monitor.

Display

Using serial UART communication, the oscillometric pulses are recorded with reference to pressure in cuff. The UART transmitter runs at a baud rate of 19200. Oscillometric pulses and pressure in cuff are recorded during deflation. Figure 8 shows the Oscillometric Pulses and Pressure Signal.

Figure 7. Blood Pressure Monitor with PSoC



Note Medical demo daughter card is built for internal cypress demo and the same is not sold in cypress web.

Figure 8. Oscillometric Pulses and Pressure Signals

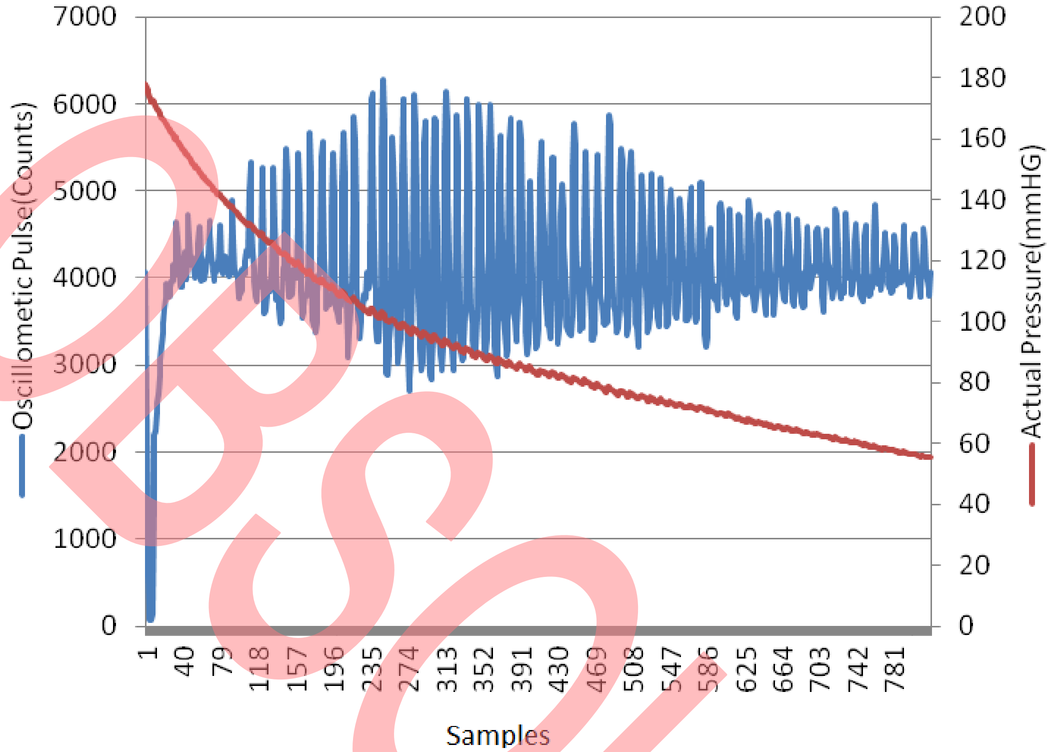
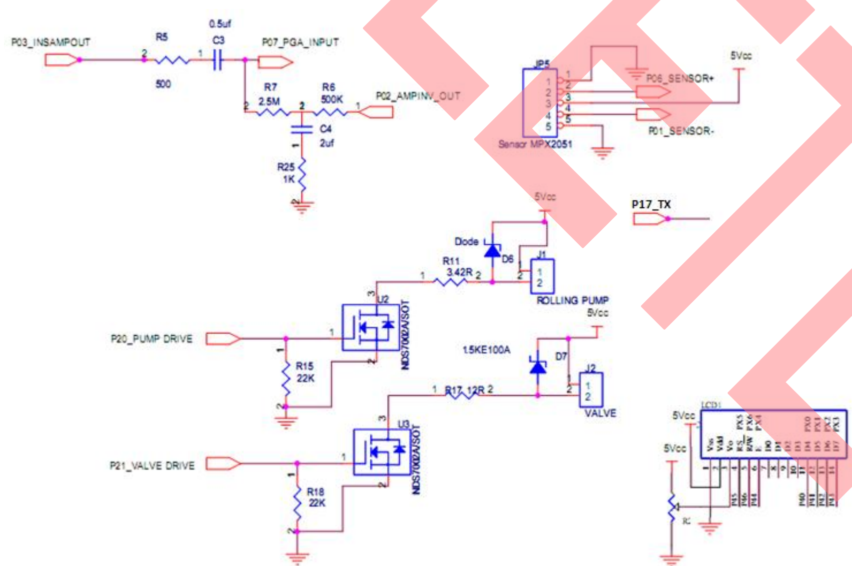


Figure 9. Device Schematic



Error! Reference source not found. shows the schematics of blood pressure monitor daughter card built to interface with Port B of CY8CKIT-001 - Development Kit (DVK) with

CY8CKIT-008. P0x, P2x refers to the ports of PSoC1 in the DVK. The rolling pump and valve used are from koge and the part numbers are KPM12A and KSV04A-3C. Table 2 provides details of each net.

Table 2. Net Details

Net name	Details
P07_PGA_INPUT	Input of high AC filter
P01_ SENSOR-	Negative input from pressure sensor
P03_I	Amplified pressure sensor output which acts as input to filter
P06_SENSOR+	Positive input from pressure sensor
P20_PUMP DRIVE	PWM output to drive pump
P21_VALVE DRIVE	PWM output to drive valve
P17_TX	UART transmitter

Working

The PWMs are set to 100% duty cycle for inflating the cuff. When the pressure inside the cuff exceeds a threshold, say 180 mmHg, the cuff is deflated. The systolic and diastolic pressures are determined based on the filtered (ADC) output.

Project Description

A project is attached with this application note. This project helps to extract the pressure and oscillometric waveform from which you can find the BP by manual inspection or using your own algorithm. The project inflates the cuff to 180 mmHG. Then deflates the cuff at a constant rate and simultaneously puts the pressure values and filtered output in counts through UART in a comma separated format so that you can directly import it to MS excel in *.csv format to plot graphs and find systolic and diastolic pressures. A reference MS Excel sheet is attached this project. The pressure in the cuff is calculated as follows.

$$\text{Transducer Voltage} = \frac{Amplified\_Transducer\_Voltage}{Total\_DC\_Gain}$$

$$\text{Slope} = \frac{20mV}{50Kpa} = 0.4\ \text{mV/Kpa}$$

This is the transfer characteristic of sensor.

$$\text{Pressure}(Kpa) = \frac{Transducer\_Voltage}{slope}$$

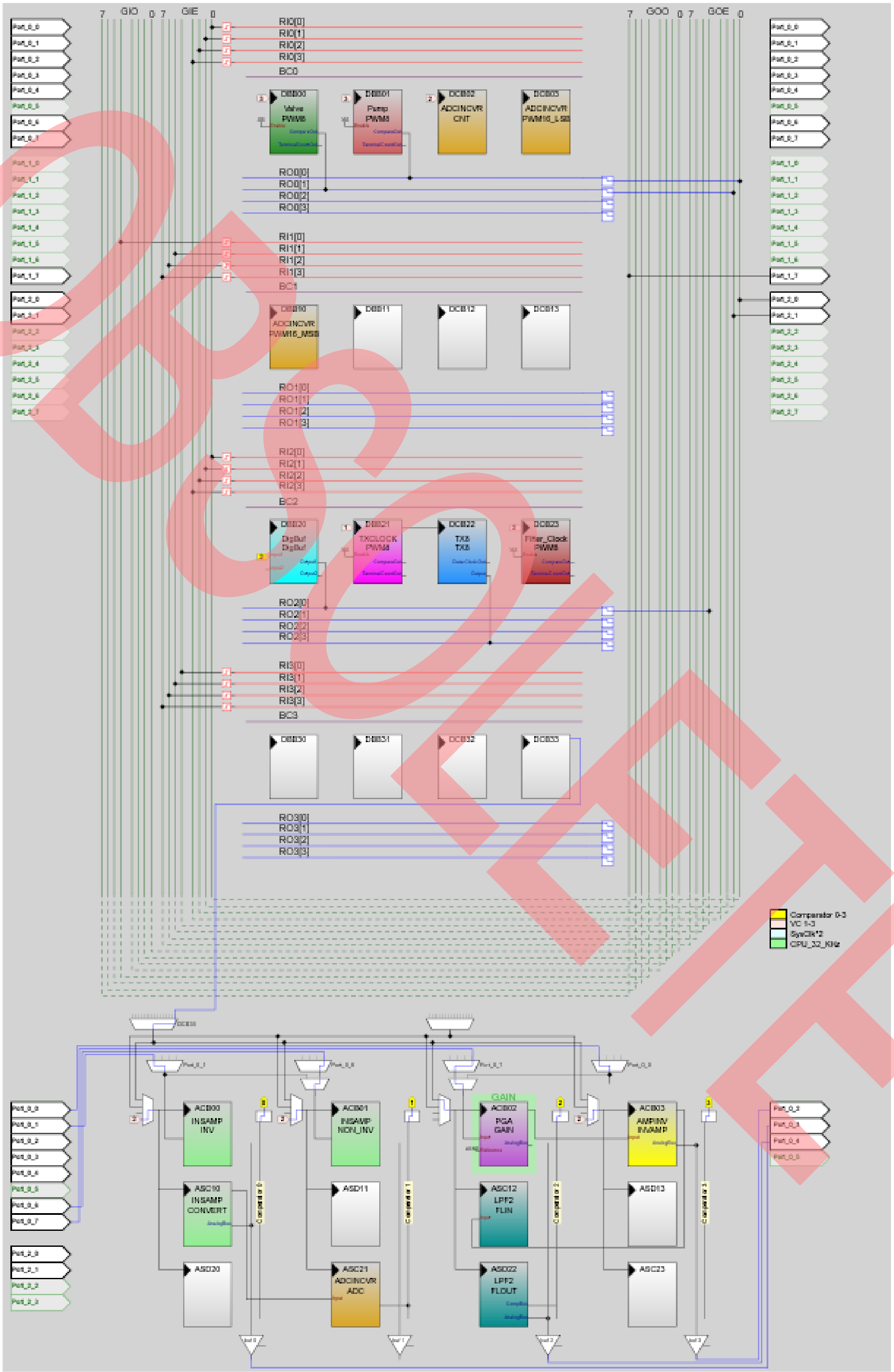
$$\text{Pressure(mmHg)} = \text{Pressure(Kpa)} * \frac{760\text{mmHg}}{101.325\ \text{Kpa}}$$

$$\text{Pressure(mmHg)} = Amplified\_Transducer\_Voltage * 201.62$$

Calibration

The captured ADC counts of pressure signal can be calibrated for the range 0-300 mmHG pressure range using a standard pressure meter. The process involves plotting the ADC counts against pressure measured in standard pressure meter in steps of 2-5 mmHG. The data can be used to derive trend line equation in form of polynomial with required order or the data can be used as a lookup table. This is will compensate errors due to gain and offset of the whole signal chain. The attached XL sheet contains the calibration data for the setup in Figure 7.

Figure 10. PSoC Internal Routing and Placement



Summary

The blood pressure monitor described in this application note is constructed using PSoC 1 with no active external components. Devices used for medical diagnostic applications must undergo a rigorous documentation and qualification program to meet applicable interruption medical safety efficacy standards.

Related Application Notes

AN2226 - PSoC® 1 - Using Correlated Double Sampling to Reduce Offset, Drift, and Low Frequency Noise

AN2099 - PSoC® 1, PSoC 3, and PSoC 5LP - Single-Pole Infinite Impulse Response (IIR) Filters

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Appendix A

Segment LCD Glass Drive and Capacitive Sensing

Portable blood pressure monitors have custom LCD glasses and a few buttons for user input. Apart from monitoring blood pressure, some parts in the PSoC family can drive LCD glasses directly without any driver and also do capacitive touch sensing. Using these parts enable a greater reduction in total bill of materials. For details about LCD drive and capacitive touch sensing refer application note AN56384.

Document History

Document Title: Blood Pressure Monitor with PSoC® - AN58128

Document Number: 001-58128

Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	2824451	KUK	1/18/10	New application note
*A	3126383	KUK	01/03/2011	Comment added to Figure 5. Project updated to Latest PSoC designer 5.1 and author profile updated.
*B	3940502	KUK	03/27/2013	Updated Software Version as “PSoC® Designer™ 5.3”. Updated Operation Principle. Updated Block Diagram (Updated Filter, removed “Safety Timer” and “Pneumatics”). Added Working. Renamed “Software” as Project Description and updated the same section. Added Calibration. Updated Summary. Updated Related Application Notes (Removed references of AN2320 as it is an obsolete document). Updated in new template. Algorithm to determine systolic and diastolic pressures have been removed.
*C	4744464	SSHH	04/27/2015	This document is obsolete.

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