THIS SPEC IS OBSOLETE

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Spec Title: PSOC(R) 3 / PSOC 5 - BLOOD PRESSURE MONITOR ANALOG FRONT END - AN62651

Sunset Owner: Praveen Sekar (PFZ)

Replaced by: None

CYPRESS PERFORM

PSoC® 3 / PSoC 5 - Blood Pressure Monitor Analog Front End

AN62651

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Associated Project: Yes
Associated Part Family: CY8C34XX,CY8C36XX,CY8C38XX
Software Version PSoC® Creator™
Prerequisites: AN58128

Application Note Abstract

AN62651 shows how a blood pressure (BP) monitor analog front end can be implemented in PSoC® 3 / PSoC 5. The flexibility of PSoC 3 / PSoC 5 enables you to implement BP monitor in two different ways, one using analog signal processing and another using digital signal processing.

Introduction

Blood Pressure (BP) is one of the vital signs of human body. There are various invasive and non-invasive techniques to measure BP. Table 1 describes various non-invasive methods used in blood pressure monitors

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

This application note describes the oscillometric method of implementing BP monitor in PSoC 3 / PSoC 5.

With CapSense® for the input touch sensing user interface, direct segment LCD drive for displaying the BP values, and on-chip EEPROM for storing historical BP values, PSoC 3 / PSoC 5 provides a complete integration of the whole functionality within a chip.

Basic Principle

The blood pressure monitor operates on the following principles.

1. The cuff is worn around the upper arm and it is inflated beyond the typical systolic pressure.
2. It is then deflated. The pressure starts decreasing, resulting in blood flow through the artery; this makes the artery to pulsate.
3. The pressure measured on the device during onset of pulsations defines the systolic blood pressure.
4. Then the cuff pressure is reduced further. The oscillations become increasingly significant, until they reach maximum amplitude.
5. The pressure at the maximum amplitude of these oscillations defines the average blood pressure.
6. 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. This is called the oscillometric waveform. As the pressure in the cuff is decreased, we see the oscillations start, grow big and then finally die down. These oscillations, as seen in the figure 1, are of very low amplitude (typically around 50uV to 150uV) and should be filtered to separate it from the slow varying cuff pressure signal and amplified to make out meaningful information. The oscillations after filtering and amplification are shown in Figure 2. After filtering and amplification, the start and end of oscillations can be found out easily.

Figure 1. Oscillometric Waveform

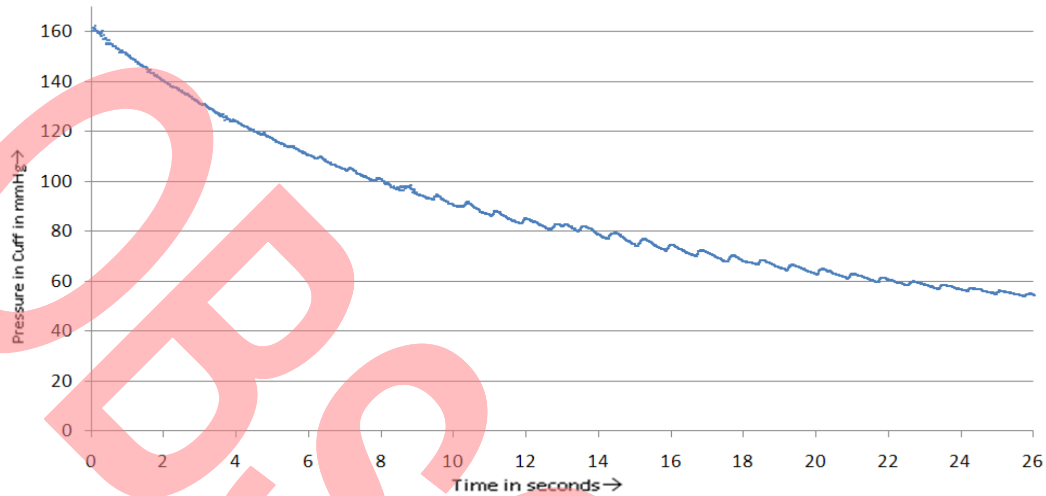


Figure 2. Filtered Oscillations

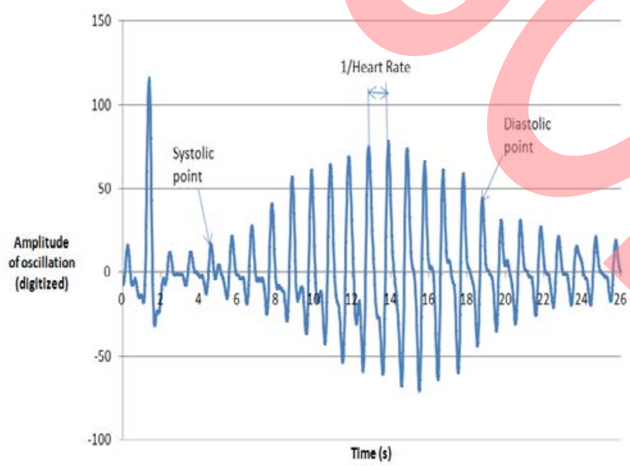


Figure 2 shows the systolic and diastolic points. The pressures corresponding to these points (time) gives the systolic and diastolic pressures. Using figure 1 and figure 2, the pressure at 4.2 s (approximate) gives the systolic pressure and the pressure at 19 s (approximate) gives the diastolic pressure.

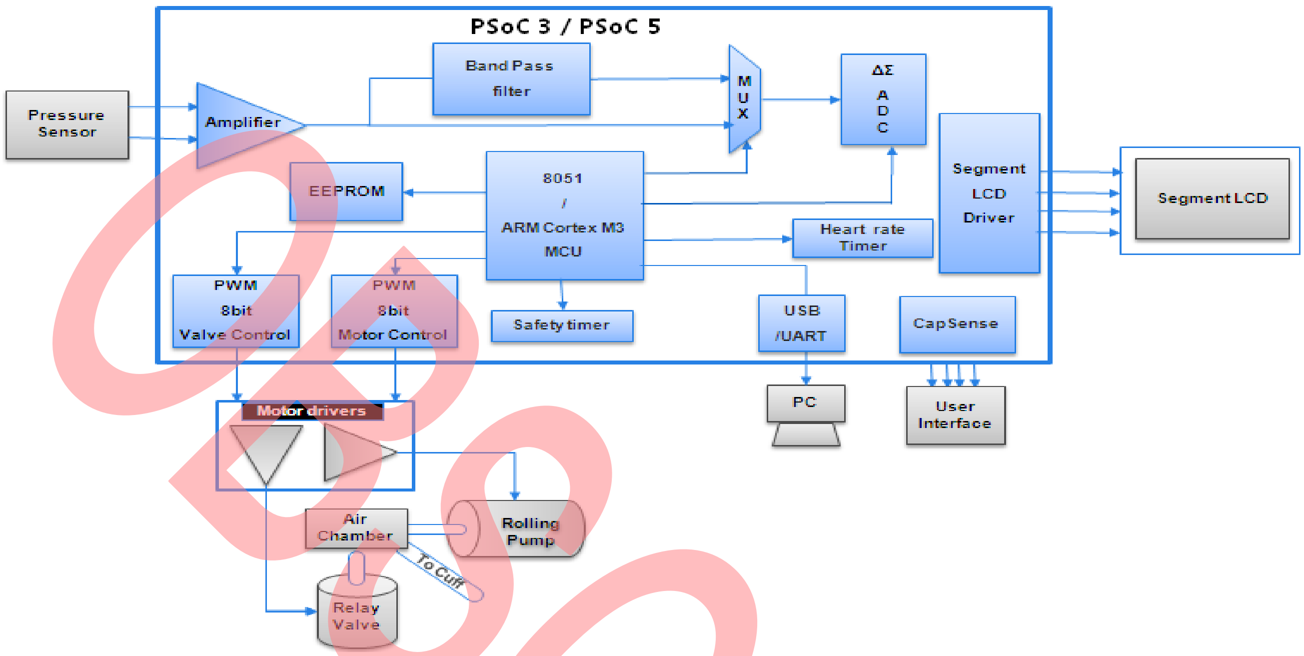
This application note demonstrates PSoC hardware's capability to perform blood pressure monitoring by extracting the oscillometric waveform and doesn't describe the algorithm used to extract blood pressure from the oscillometric waveform. This is primarily because all reliable algorithms are complex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

Hardware Requirements

- A pressure sensor to convert the pressure variations to electrical signal
- An amplifier to amplify the pressure sensor output
- A band pass filter with sufficient gain to filter slow varying AC component (cuff oscillations) and amplify it
- An analog to digital convertor to measure the pressure sensor output and the filter output
- Two pulse with modulators (PWM), one to drive the motor and another the valve to control the rate of inflation and deflation of the cuff
- A timer to measure the heart rate
- A safety timer to detect if the pressure is held high above a threshold for more than a specified duration and release the valve if so. (The Association for the Advancement of Medical Instrumentation (AAMI) standards defines the time duration beyond, which you cannot hold the cuff pressure above a specified threshold)

Figure 3 shows the block diagram for the oscillometric method based BP monitor.

Figure 3. BPM Block Diagram



Method 1: Analog Filtering

Following is the top design of the analog filtering based solution.

Figure 4. BPM using Analog Filtering Method

Internal Schematic - Page 1

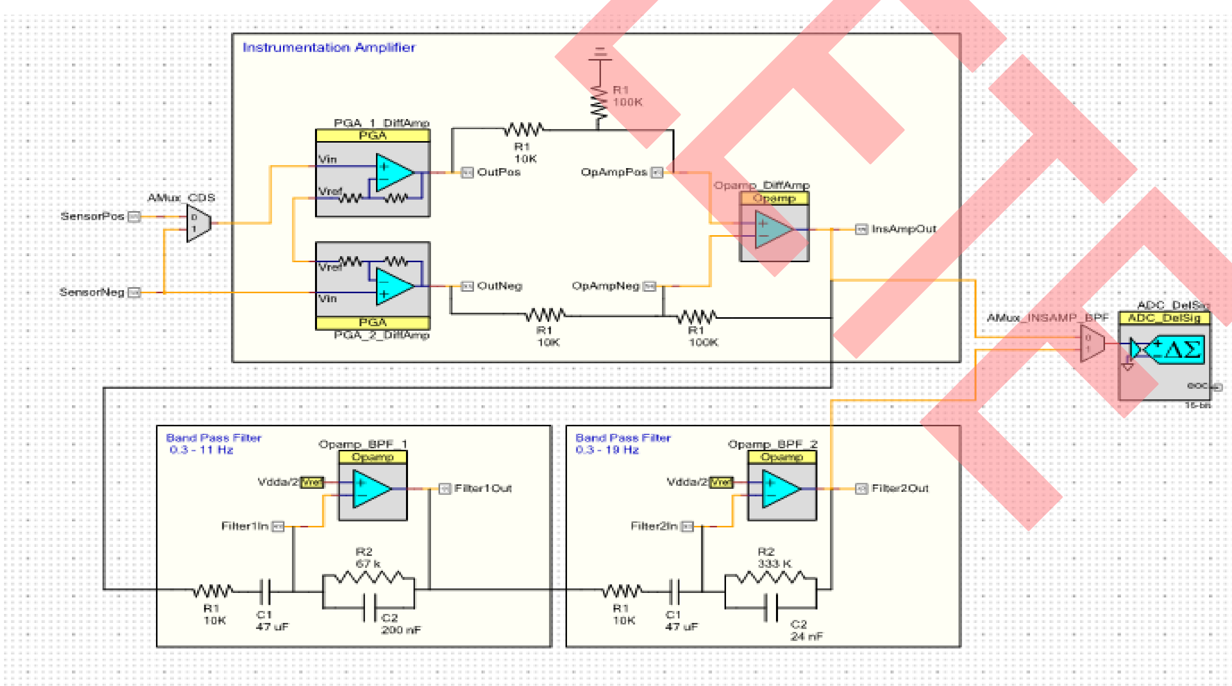
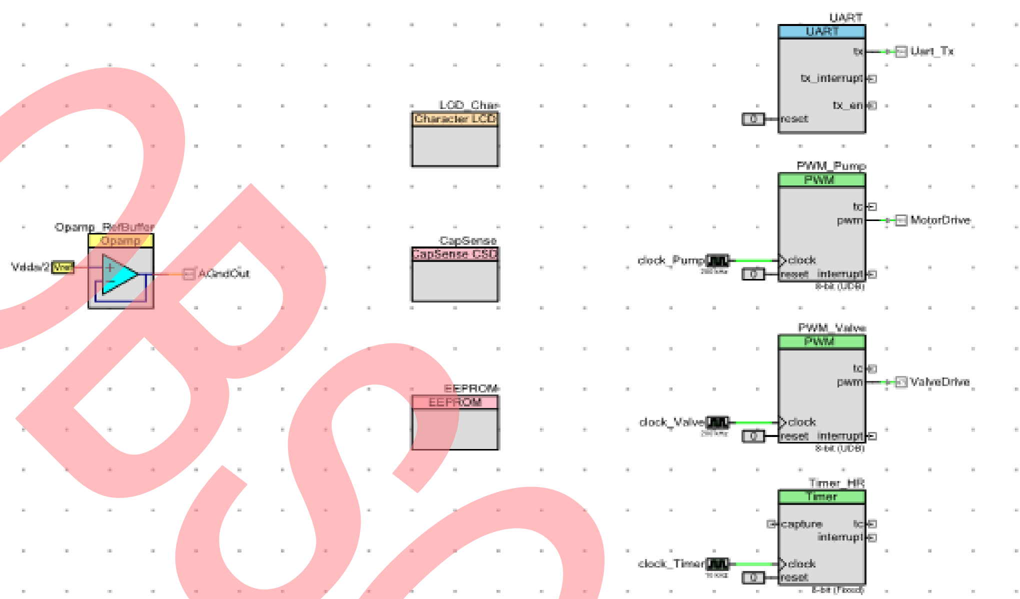


Figure 5. BPM using Analog Filtering Method

Internal Schematic - Page 2



Pressure Sensor

The pressure sensor should operate from 0 to 250 mmHg. This range is inclusive of the maximum systolic pressure that can be encountered. MPX2051 is used in this case. It is a ratio metric sensor giving differential output with a sensitivity of 0.4 mV / KPa or 53 µV / mmHg for a 5 V operation. 0 to 200 mmHg of pressure translate to 0 to 10.6 mV. It has a full scale span of approximately 375 mmHg, offset of < 1mV and a linearity of < 0.3% Full scale. Low offset and good linearity are important for good accuracy of the pressure values.

Amplifier

The amplifier should take differential signals, the pressure sensor output being differential, and gives out a single ended output so that it can be passed to the subsequent filter stage. Therefore an Instrumentation amplifier should be used. The instrumentation amplifier is constructed in a classical three opamp topology. The reference (V_{REF}) is set to $V_{DDA}/2$. This sets the output of the instrumentation amplifier. The instrumentation amplifier is set for a gain of 160 (16 in first stage and 10 in the second stage). AN60319 explains instrumentation amplifier in detail.

- Variation in pressure = 0 to 200 mmHg
- Pressure sensor sensitivity = 53 µV/mmHg
- Corresponding variation in voltage = 0 to 10.6 mV
- Voltage at instrumentation amplifier output (gain = 160) = 0 to 1.69 V

Band Pass Filter (BPF)

The filter has to amplify the voltage oscillations with typical values around 50 to 500 µV rms, rejecting the cuff pressure signal and high frequency noise. These oscillations, as mentioned earlier, are at the heart rate, which is 72 beats per minute or 1.2 Hz for an average human being. A Band pass filter with pass band of 0.3 to 11 Hz is constructed with a gain of around 200. The band pass filter is implemented in two stages to get this gain. The gain should ensure that the oscillations occupy the full ADC range. Two op-amps and external resistors and capacitors are used. These oscillations without any amplification are typically around 50 to 150 µV rms. The Band pass filter is set to gain around 200 so that the final amplitude of oscillations after gain is 1.6 to 4.8 V.

- Typical amplitude of voltage oscillations = 50 to 150 µV
- Amplitude of oscillations at instrumentation amplifier output (gain - 160) = 8 to 24 mV
- Amplitude of oscillations at BPF output (gain = 200) = 1.6 to 4.8 V

Analog to Digital Converter (ADC)

A 16-bit delta Sigma ADC in $V_{SSA} – V_{DDA}$ range is used. The resolution actually depends on the final resolution on the BP value required. Resolution required for a resolution of 1 mmHg pressure:

- A 1 mm Hg pressure variation = 53 µV change at pressure sensor output = 8.48 mV change at instrumentation amplifier output
- No of ADC bits required for 8.48 mV resolution = log 2 (5000 / 8.48) = 10 bits
- A 10-bit ADC actually suffices for 1 mmHg resolution
- The ADC input is multiplexed between the instrumentation amplifier output and the filter output every sample

Pneumatics

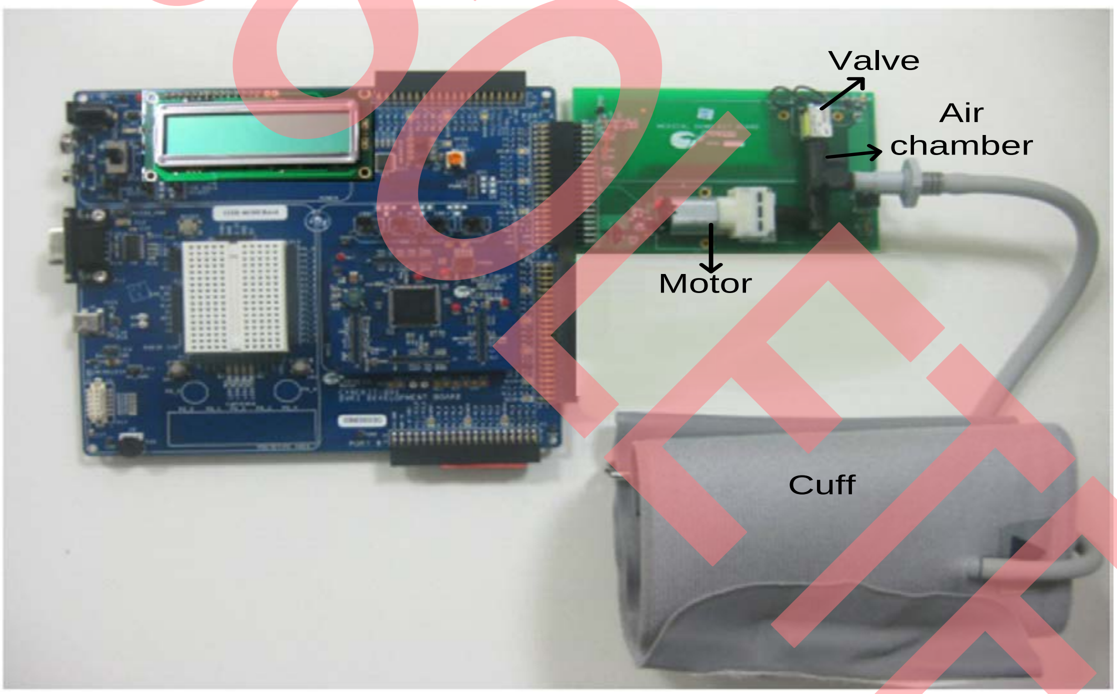
Pneumatics forms the main part of any BP monitoring system. Pneumatics of a typical monitor has the following:

- 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, typically 2 mmHg/sec. Two PWMs are used to control the motor and the valve.

The following figure shows the PSoC 3 / PSoC 5 BP monitor setup, which includes the pneumatics. The schematic and BOM of the BP monitor EBK are provided in the end.

Figure 6. Cuff and BP Monitor EBK



Working

The PWMs are set to 100% duty cycle for inflating the cuff. When the pressure inside the cuff exceeds a threshold, say 160 mmHg, the cuff is deflated. Once deflation starts, the cuff pressure and the filter output (both are readings from the ADC) should be monitored to get the systolic and diastolic pressures.

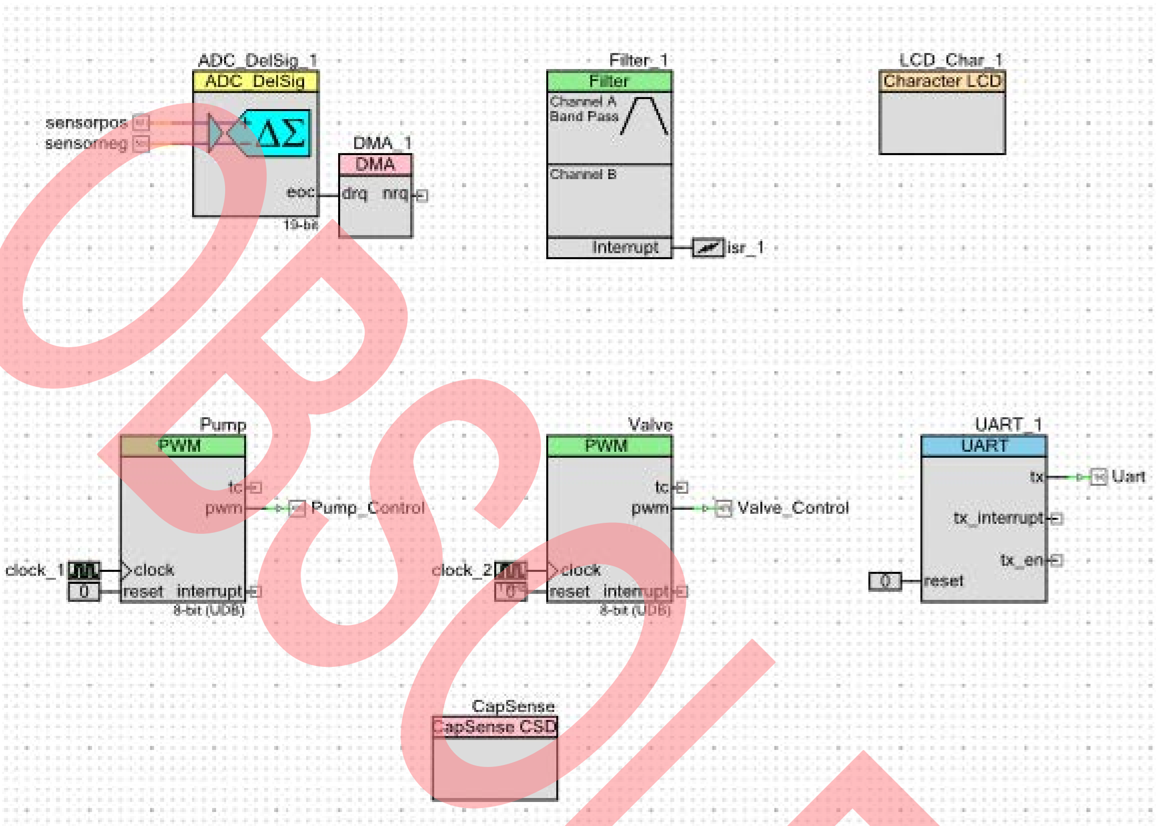
Project Description

A project based on analog signal processing is attached with this application note. This project helps extract the pressure and oscillometric waveform from which you can find the BP by manual inspection or using your own algorithm. The project puts the pressure values and filtered output 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.

Method 2: Digital Filtering

The following figure shows a top design of digital filter based BP monitor. The instrumentation amplifier, analog filter with ADC combination is replaced with just ADC with digital filter. The ADC provides all the required amplification.

Figure 7. BPM using Digital Filtering – Internal Schematic



Amplifier

The ADC, by itself, can provide a total gain of 128, eliminating the need for an external amplifier. The gain and resolution have to be selected in such a way, that a signal with sufficiently high resolution is fed to the DFB. In case of the analog solution, the BPFs provided a gain of close to 200 to have sufficiently high amplitude of oscillation. However, the DFB cannot provide gain in this case. A gain in the DFB is just equivalent to multiplying the DFB output by a constant factor which is of no use if the resolution is insufficient. So, the input to the DFB should be fed with sufficiently high resolution, so that the oscillations can be detected easily. To achieve this, a gain of 32 (8 in buffer and 4 in modulator) is given.

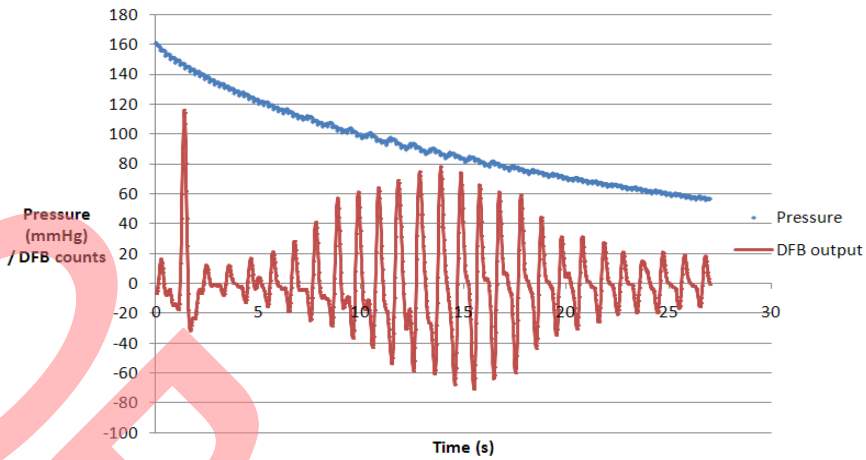
- Amplitude of cuff oscillations = 150 µV
- ADC gain = 32
- Amplitude seen by the ADC = 4.8 mV
- Resolution of a 16-bit ADC (± 1.024 V range) = 32 µV
- No of digital codes obtained by 16-bit ADC in 4.8 mV range = 150

150 levels in the oscillometric waveform output is sufficient enough for a resolution to determine the systolic and diastolic points. Figure 8 shows the filter output oscillations with counts from -70 to 80 indicating a total of 150 levels. As you see with 150 levels the oscillations are clear and systolic and diastolic pressures can be determined easily. Setting the ADC to its maximum gain (128) and resolution (20), we can have 9792 levels for one oscillation.

Filter

An FIR band pass filter is constructed with the DFB so that it passes 0.3 to 10 Hz. Figure 8 is a typical oscillometric waveform filtered with the DFB.

Figure 8. Oscillometric Wave form using Digital Filtering Method



Associated Project

A project based on digital filtering method is also attached with the application note. This does exactly the same functionality as the analog filtering project. It sends the pressure values and the filtered oscillations out through UART as a comma separated value. This can be directly saved in Microsoft Excel in .csv format from the hyper terminal. From this, the systolic and diastolic pressures can be obtained. A sample Excel sheet which plots the waveforms from which systolic pressure, diastolic pressure and heart rate are computed is also provided.

Blood Pressure Monitor EBK

The blood pressure monitor EBK that is shown in Figure 6 on page 5 is not available in Cypress website for sale and is used for internal Cypress demonstration purposes only. The schematic and BOM of the board is provided in Figure 9 and Table 2 respectively.

Figure 9. Schematic Diagram of the Board

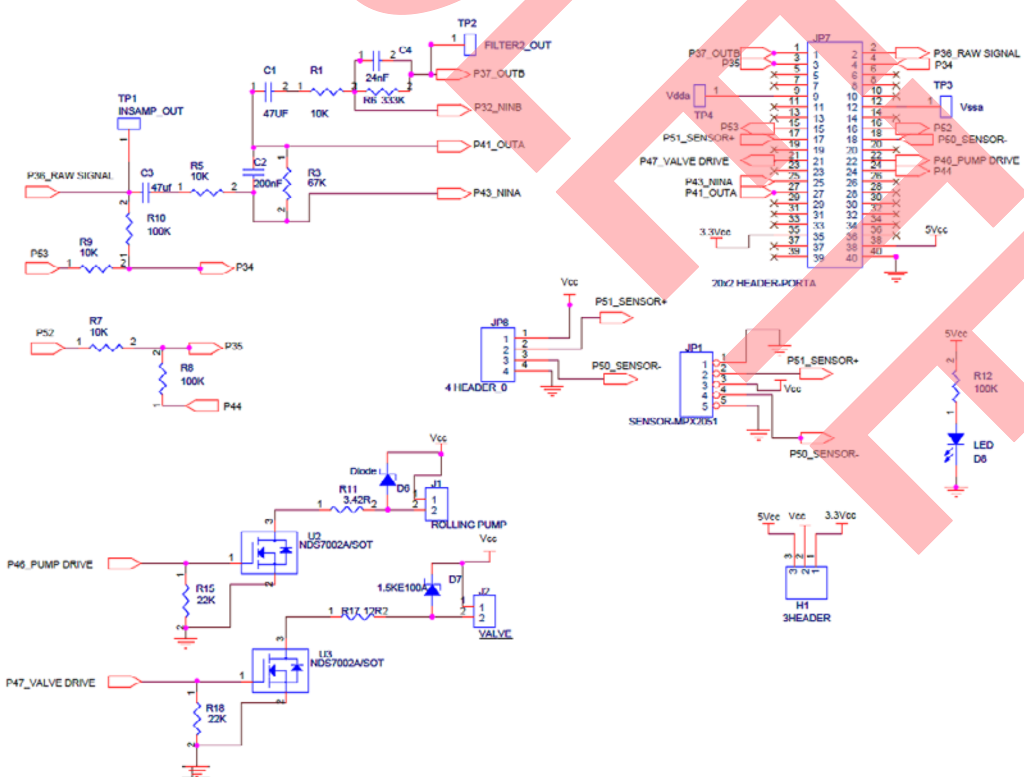


Table 2. Bill of Materials (BOM)

S.No	Quantity	Reference	Value/Part No
1	2	C1, C3	47uf
2	1	C2	200nF
3	1	C4	24nF
4	1	D6	Diode - 1.5KE100A
5	1	D7	Diode - 1.5KE100A
6	1	D8	LED
7	1	H1	3 pin HEADER
8	1	JP1	SENSOR-MPX2051
9	1	JP7	20x2 HEADER-PORTA
10	1	JP8	4HEADER
11	1	J1	ROLLING PUMP (KPM12A) Manufacturer: Koge
12	1	J2	VALVE - KSV04A-3C Manufacturer:Koge
13	4	R1,R5,R7,R9	10K
14	1	R3	67K
15	1	R6	333K
16	3	R8,R10,R12	100K
17	1	R11	3.42R
18	2	R15,R18	22K
19	1	R17	12R
20	1	TP1	Test point INSAMP_OUT
21	1	Tp2	Test point FILTER2_OUT
22	1	Tp3	Test point Vssa
23	1	Tp4	Test point Vdda
24	2	U2,U3	MOSFET NDS7002A/SOT

Summary

Two implementations of BP monitor using PSoC 3 / PSoC 5 are discussed. The application note also shows how an analog signal chain, consisting of a high gain instrumentation amplifier, ADC and analog filters, can be replaced with a simple PSoC 3 / PSoC 5 ADC with DFB signal chain.

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Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	2965540	PFZ	06/30/10	New Application Note
*A	3013599	PFZ	08/23/10	Updated Projects to Beta 5.
*B	3176753	PFZ	02/18/2011	BOM has been added Document title updated
*C	3196399	PFZ	03/15/2011	Minor text edits. Document title updated
*D	3302877	PFZ	07/06/2011	Added Non Invasive Methods to Monitor Blood Pressure (Table 1) Updated Basic Principle section Updated Associated Project section Updated Figure 9 caption.
*E	3329749	PFZ	07/27/2011	Obsolete spec.

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