INTRODUCTION

Pulse oximeter is a non-invasive medical device that monitors the oxygen saturation of a patient's blood and heart rate. This application note demonstrates the implementation of a high-accuracy pulse oximeter using Microchip's analog devices and dsPIC® Digital Signal Controllers (DSCs).

FIGURE 1: FUNCTION BLOCK DIAGRAM
THEORY OF OPERATION

A pulse oximeter monitors the oxygen saturation (SpO₂) of a human's blood based on the red light (600-750 nm wavelength) and infrared light (850-1000 nm wavelength) absorption characteristics of oxygenated hemoglobin (HbO₂) and deoxygenated hemoglobin (Hb). The pulse oximeter flashes the red and infrared lights alternately through a finger to a photodiode. HbO₂ absorbs more infrared light and allows more red light to pass through. On the other hand, Hb absorbs more red light and allows more infrared light to pass through.

The photodiode receives the non-absorbed light from each LED. This signal is inverted using inverting Op-Amp and therefore the result, as shown in Figure 2, represents the light that has been absorbed by the finger.

**FIGURE 2: REAL-TIME RED AND INFRARED (IR) PULSATION SIGNALS CAPTURED BY THE OSCILLOSCOPE**

The pulse amplitudes (Vpp) of the red and infrared signals are measured and converted to Vrms to produce a Ratio value as given by **Equation 1**. The SpO₂ can be determined using the Ratio value and a look-up table that is made up of empirical formulas. The pulse rate is calculated based on the Analog-to-Digital converter (ADC) sample number and sampling rate.

**EQUATION 1:**

\[
Ratio = \frac{\text{Red}_{\text{AC} \text{ Vrms}} / \text{Red}_{\text{DC}}}{\text{IR}_{\text{AC} \text{ Vrms}} / \text{IR}_{\text{DC}}}
\]

The look-up table is an important part of the system. Look-up tables are specific to a particular oximeter design and are usually based on calibration curves derived from many measurements of a healthy subject at various SpO₂ levels. **Figure 3** shows a sample calibration curve.
CIRCUIT DESCRIPTION

The SpO₂ probe used in this example is an off-the-shelf Nellcor® compatible finger clip type of probe which integrates one red LED and one IR LED and a photodiode. The LEDs are controlled by the LED driver circuit. The red light and IR light passing through the finger are detected by the signal conditioning circuit and are then fed to a 12-bit ADC module of the microcontroller where %SpO₂ can be calculated.

LED Driver circuit

A DUAL SPDT analog switch driven by two PWM signals from the microcontrollers turns the red and infrared LEDs on and off alternately. In order to acquire the proper number of ADC samples and have enough time to process the data before the next LED turns on, the LEDs are switched on/off according to the timing diagram in Figure 4:

The LED current/intensity is controlled by a 12-bit Digital-to-Analog Converter (DAC) which is driven by the microcontroller.
Analog Signal Conditioning Circuit

There are two stages in the signal conditioning circuit. The first stage is the transimpedance amplifier and the second stage is the gain amplifier. A Highpass filter is placed between the two stages.

TRANSIMPEDEANCE AMPLIFIER

The transimpedance amplifier converts a few microamps of current generated by the photodiode to a few millivolts.

HIGHPASS FILTER

The signal received from the first stage amplifier passes through a Highpass filter which is designed to reduce the background light interference.

GAIN AMPLIFIER

The output of the Highpass filter is sent to a second stage amplifier with a gain of 22 and a DC offset of 220 mV. The values for the amplifier’s gain and DC offset are set to properly place the output signal level of the gain amplifier into the microcontroller’s ADC range.

DIGITAL FILTER DESIGN

The output of the analog signal conditioning circuit is connected to the ADC module of the dsPIC DSCs. One ADC sample is taken during each LED’s on-time period, and one ADC sample is taken during both LED’s off-time period.

Taking advantage of the powerful Digital Signal Processing (DSP) engine integrated in dsPIC DSCs, a digital FIR Bandpass Filter is implemented to filter the ADC data. The filtered data is used to calculate the pulse amplitude. Digital filter code is generated using Microchip’s Digital Filter Design Tool.

**FIR Bandpass Filter Specifications**

- Sampling Frequency (Hz): 500
- Passband Frequency (Hz): 1 and 5
- Stopband Frequency (Hz): 0.05 and 25
- FIR Window: Kaiser
- Passband Ripple (-dB): 0.1
- Stopband Ripple (-dB): 50
- Filter Length: 513

CONNECTIVITY

The SpO₂ and pulse rate data can be sent to a computer through a UART port with the PIChit™ Serial Analyzer. The serial port setting is 115200-8-N-1-N. The pulse signal can be plotted out using an application such as Microchip’s Generic Serial Data Display GUI as shown in Figure 5.

The data can also be sent to a Wi-Fi® or Bluetooth® module via UART port.

**FIGURE 5: THE WAVEFORM DISPLAYING THE PULSE SIGNAL**
FIGURE 6: PROGRAM FLOWCHART

Start

Initialization

Turn On/Off RED and IR LEDs Alternately

Is the signal received from the probe valid?

Yes

Are RED and IR ADC Data Ready?

No

Go to Sleep

Yes

FIR Bandpass Digital Filtering

Find MaxMin of IR and RED Filtered AC Signals

Calculate SPO2 and Pulse Rate

Display Result

From Interrupts

Timer 3 Interrupt Occurred
Read RED DC and AC Signal

Timer 2 Interrupt Occurred
Read IR DC and AC Signal

Read DC Baseline Signal after Timer3 Interrupt before Timer2 Interrupt

Adjust DAC to Calibrate Red LED

Is RED ADC Data Ready?

No

Yes

Adjust DAC to Calibrate IR LED

Is IR ADC Data Ready?

Yes
This appendix shows the Microchip Pulse Oximeter schematics.

Sheet 1: Microchip Pulse Oximeter Demo Board Schematic 1

APPENDIX A: SCHEMATICS
APPENDIX B:  MEDICAL DEMO
WARNINGS, RESTRICTIONS AND DISCLAIMER

This demo is intended solely for evaluation and development purposes. It is not intended for medical diagnostic use.

APPENDIX C:  REFERENCES

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip’s Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as “unbreakable.”

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip’s code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

Information contained in this publication regarding device applications and the like is provided only for your convenience and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications.

Microchip makes no representations or warranties of any kind, whether express or implied, written or oral, statutory or otherwise, related to the information, including but not limited to its condition, quality, performance, merchantability or fitness for purpose. Microchip disclaims all liability arising from this information and its use. Use of Microchip devices in life support and/or safety applications is entirely at the buyer's risk, and the buyer agrees to defend, indemnify and hold harmless Microchip from any and all damages, claims, suits, or expenses resulting from such use. No licenses are conveyed, implicitly or otherwise, under any Microchip intellectual property rights.

Trademarks

The Microchip name and logo, the Microchip logo, dsPIC, FlashFlex, flexPWR, JukeBox, KEELOO, KEELOO logo, Kleer, LANCheck, MediaLB, MOST, MOST logo, MPLAB, OptyLozyer, PIC, PICSTART, PIC® logo, RightTouch, SpyNIC, SST, SST Logo, SuperFlash and UNI/O are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

The Embedded Control Solutions Company and mTouch are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Analog-for-the-Digital Age, BodyCom, chipKIT, chipKIT logo, CodeGuard, dsPICDEM, dsPICDEM.net, ECAN, In-Circuit Serial Programming, ICSP, Inter-Chip Connectivity, KleerNet, KleerNet logo, MiWi, MPASM, MPF, MPLAB Certified logo, MPLIB, MPLINK, MultiTRAK, NetDetach, Omniscient Code Generation, PICDEM, PICDEM.net, PICkit, PICtail, RightTouch logo, REAL ICE, SQI, Serial Quad I/O, Total Endurance, TSHARC, USBCheck, VariSense, ViewSpan, WiperLock, Wireless DNA, and ZENA are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

SQTP is a service mark of Microchip Technology Incorporated in the U.S.A.

Silicon Storage Technology is a registered trademark of Microchip Technology Inc. in other countries.

GestIC is a registered trademarks of Microchip Technology Germany II GmbH & Co. KG, a subsidiary of Microchip Technology Inc., in other countries.

All other trademarks mentioned herein are property of their respective companies.

© 2013-2015, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.


QUALITY MANAGEMENT SYSTEM CERTIFIED BY DNV

ISO/TS 16949