AN1525

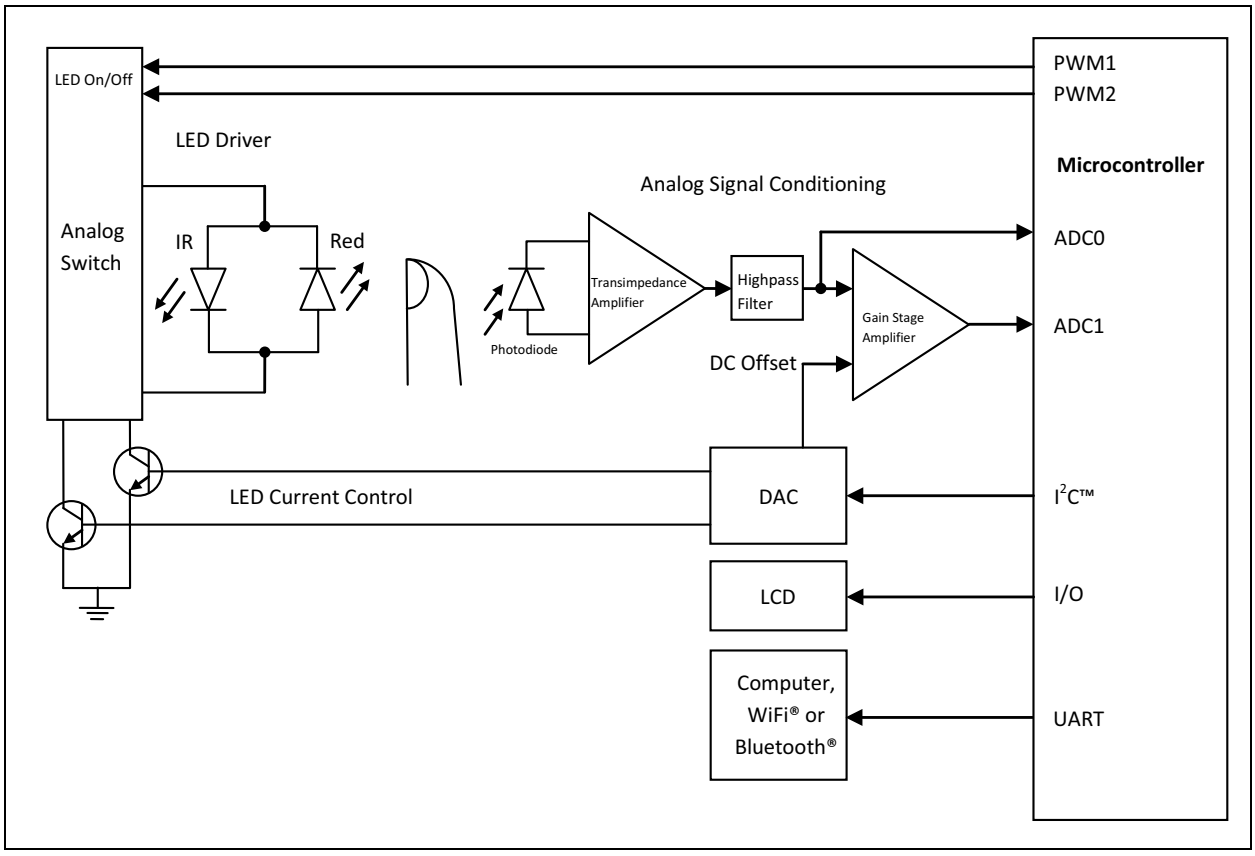
Pulse Oximeter Design Using Microchip's Analog Devices and dsPIC® Digital Signal Controllers (DSCs)

Author: *Zhang Feng*
Microchip Technology Inc.

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

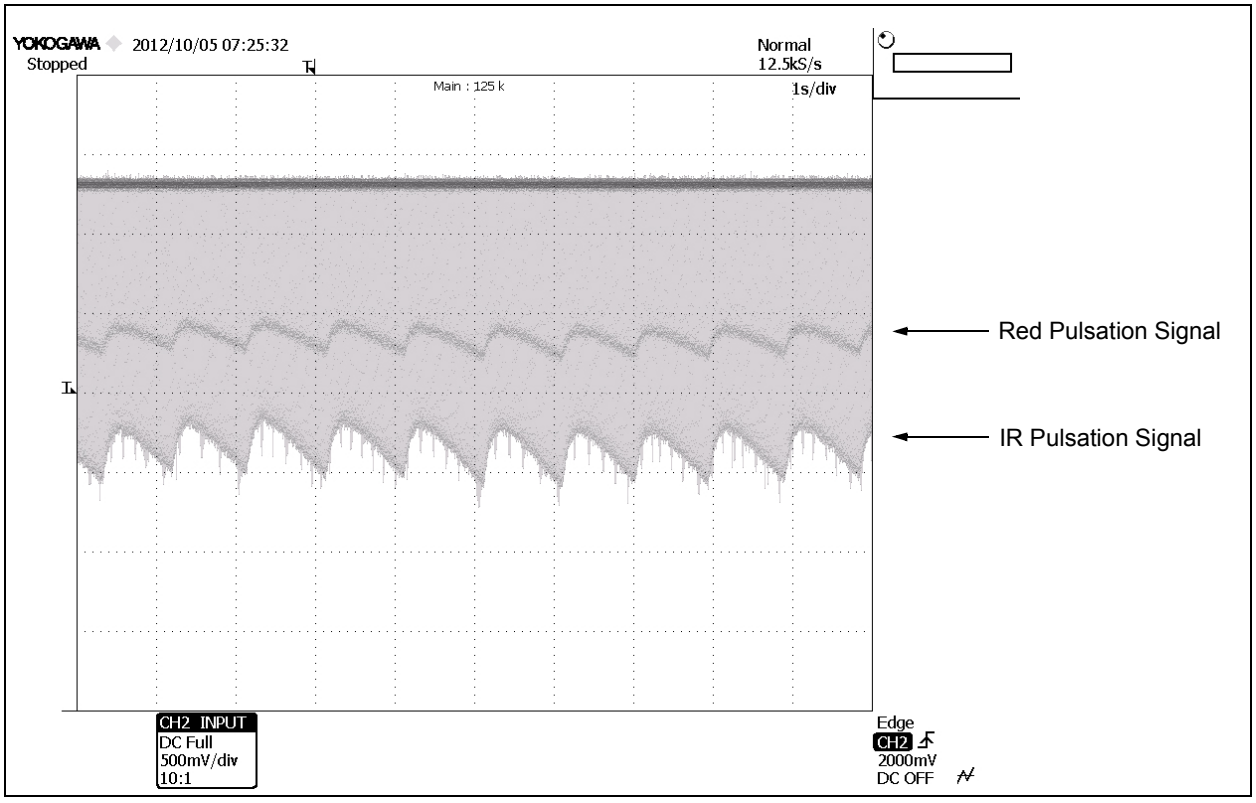


THEORY OF OPERATION

A pulse oximeter monitors the oxygen saturation (SpO_2) 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 (HbO_2) and deoxygenated hemoglobin (Hb). The pulse oximeter flashes the red and infrared lights alternately through a finger to a photodiode. HbO_2 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



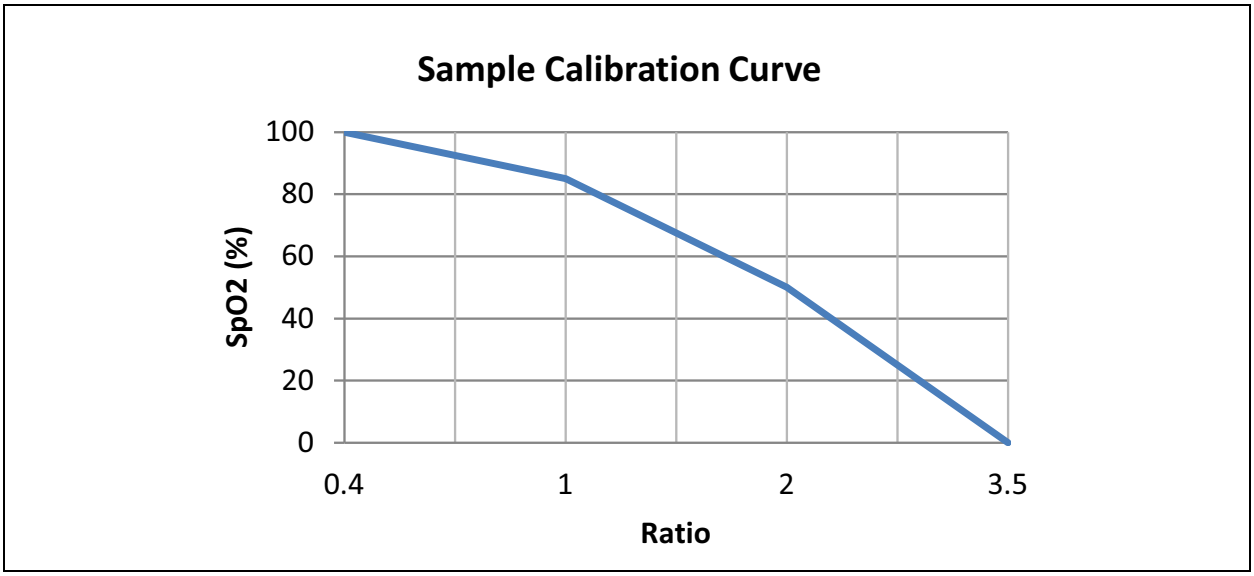
The pulse amplitudes (Vpp) of the red and infrared signals are measured and converted to Vrms to produce a Ratio value as given by Equation 1. The SpO_2 can be determined using the Ratio value and a look-up table that is made up of empirical formulas. The pulse rate is calculated based on the Analog-to-Digital converter (ADC) sample number and sampling rate.

EQUATION 1:

$$Ratio = \frac{Red\_AC\_Vrms / Red\_DC}{IR\_AC\_Vrms / IR\_DC}$$

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 SpO_2 levels. Figure 3 shows a sample calibration curve.

FIGURE 3: SAMPLE CALIBRATION CURVE



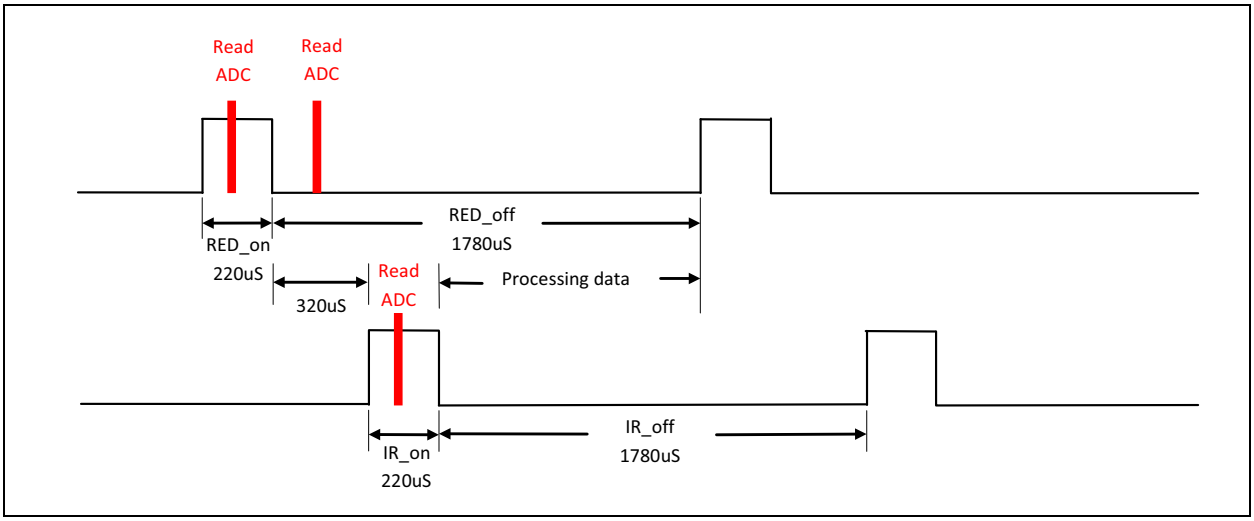
CIRCUIT DESCRIPTION

The SpO_2 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 $\%SpO_2$ 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:

FIGURE 4: TIMING DIAGRAM



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.

TRANSIMPEDANCE AMPLIFIER

The transimpedance amplifier converts a few micro amps 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 SpO_2 and pulse rate data can be sent to a computer through a UART port with the PICkit™ 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

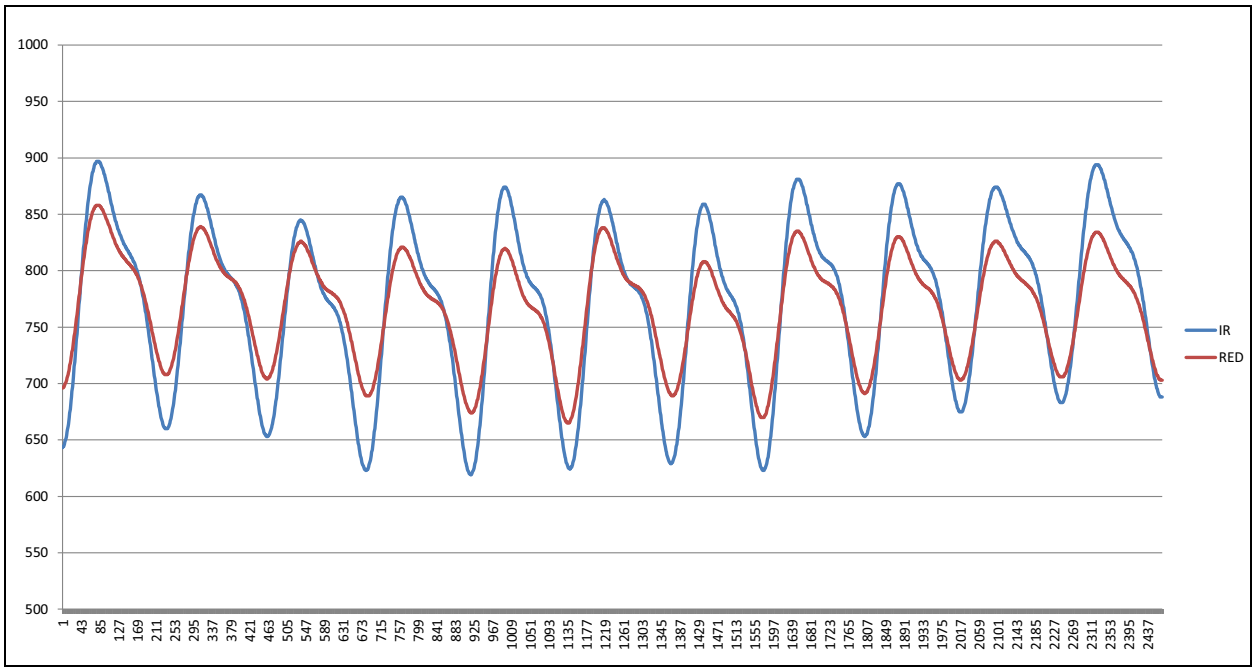
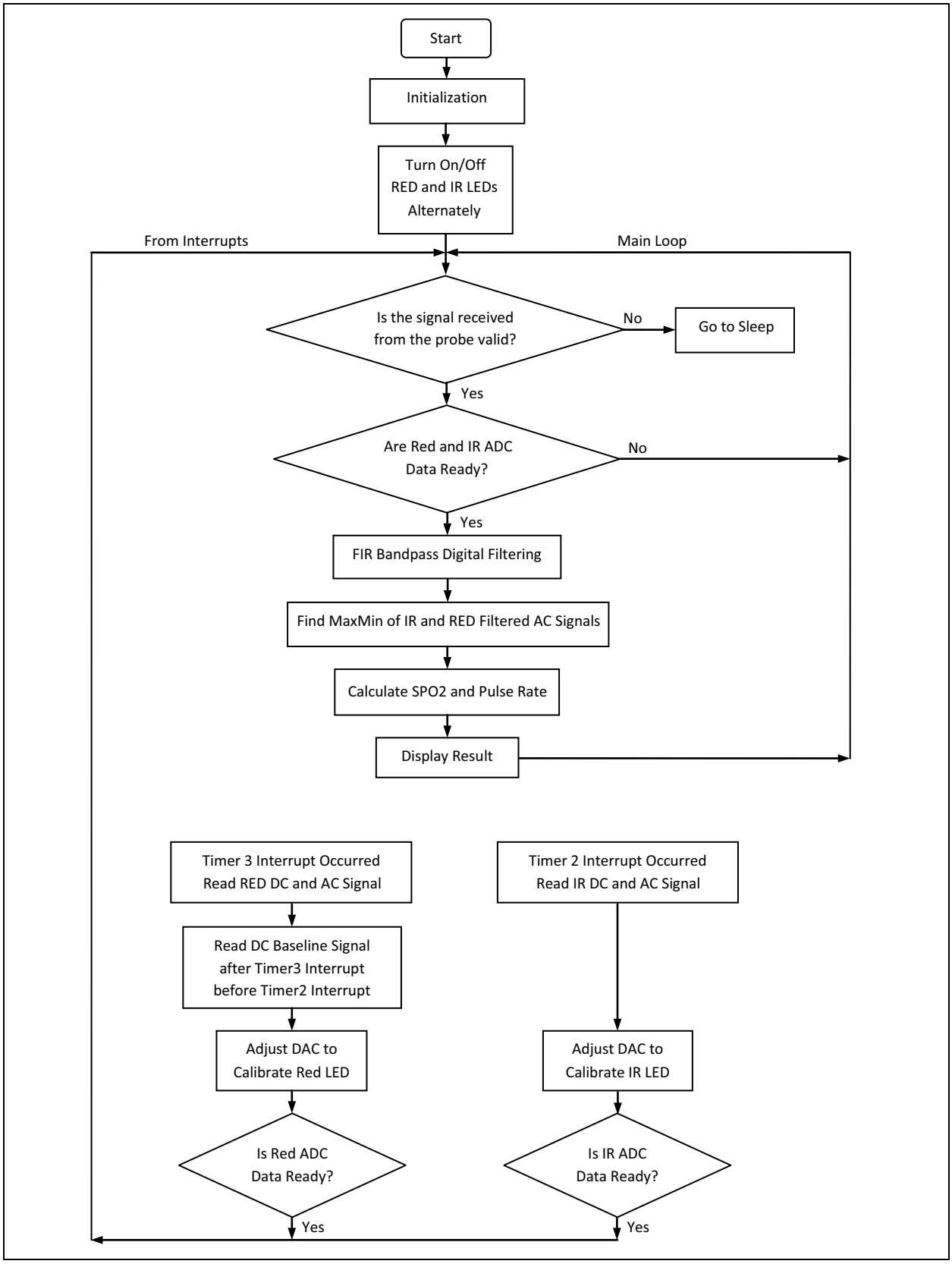


FIGURE 6: PROGRAM FLOWCHART

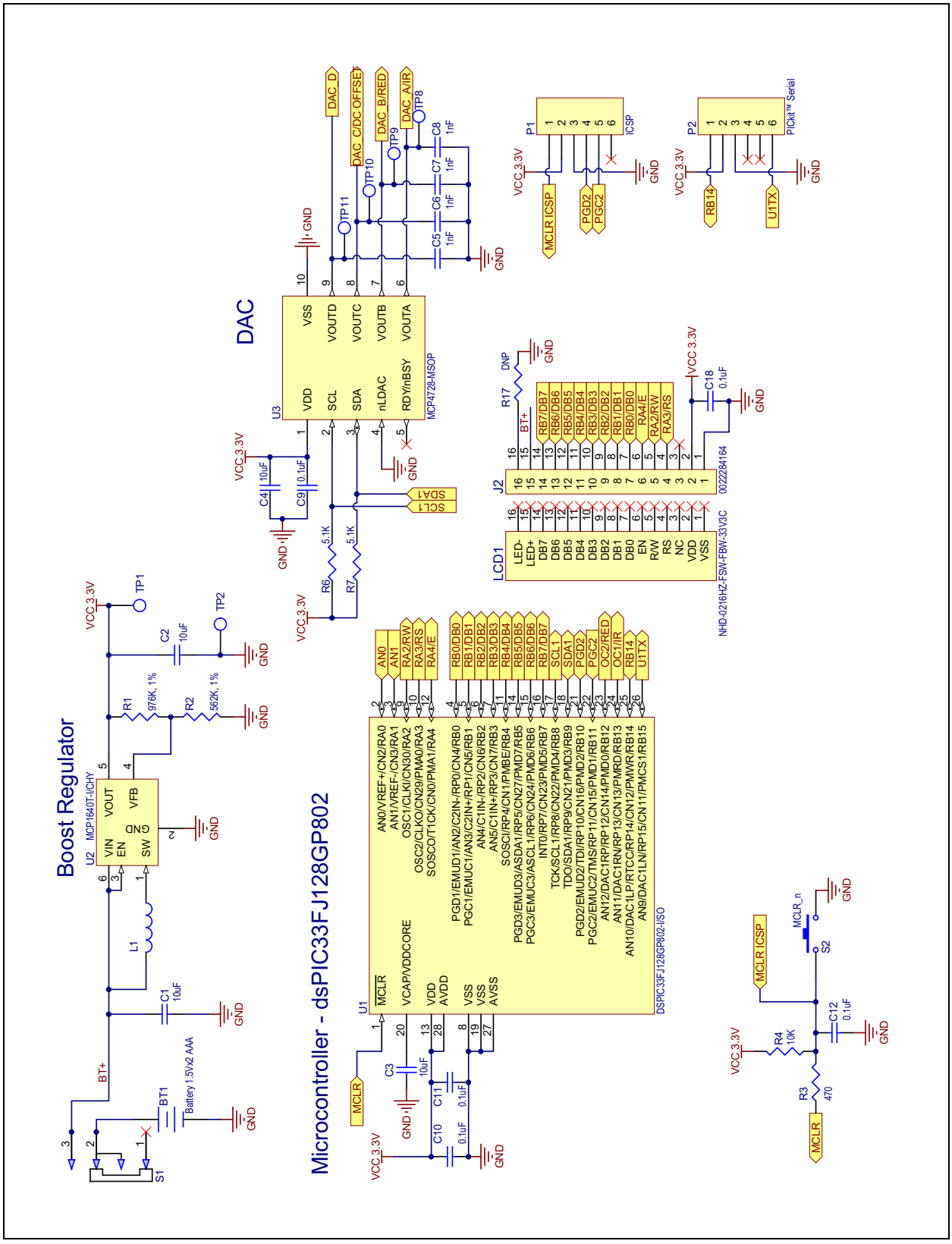


NOTES:

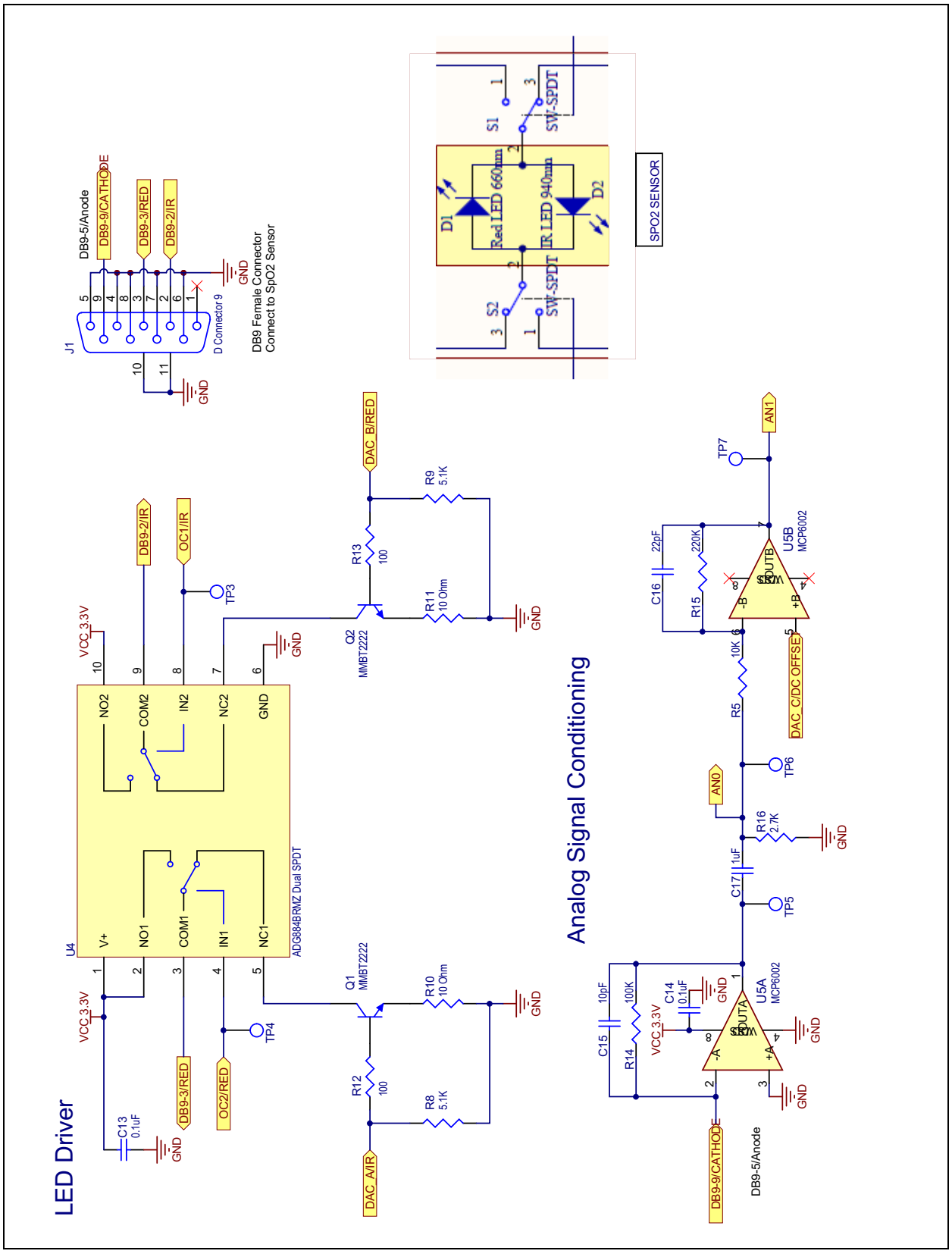
APPENDIX A: SCHEMATICS

This appendix shows the Microchip Pulse Oximeter schematics.

SHEET 1: MICROCHIP PULSE OXIMETER DEMO BOARD SCHEMATIC 1



SHEET 2: MICROCHIP PULSE OXIMETER DEMO BOARD SCHEMATIC 2



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

AN1494, “Using MCP6491 Op Amps for Photodetection Applications”, Microchip Technology Inc., DS01494, 2013.

NOTES:

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