AN1525

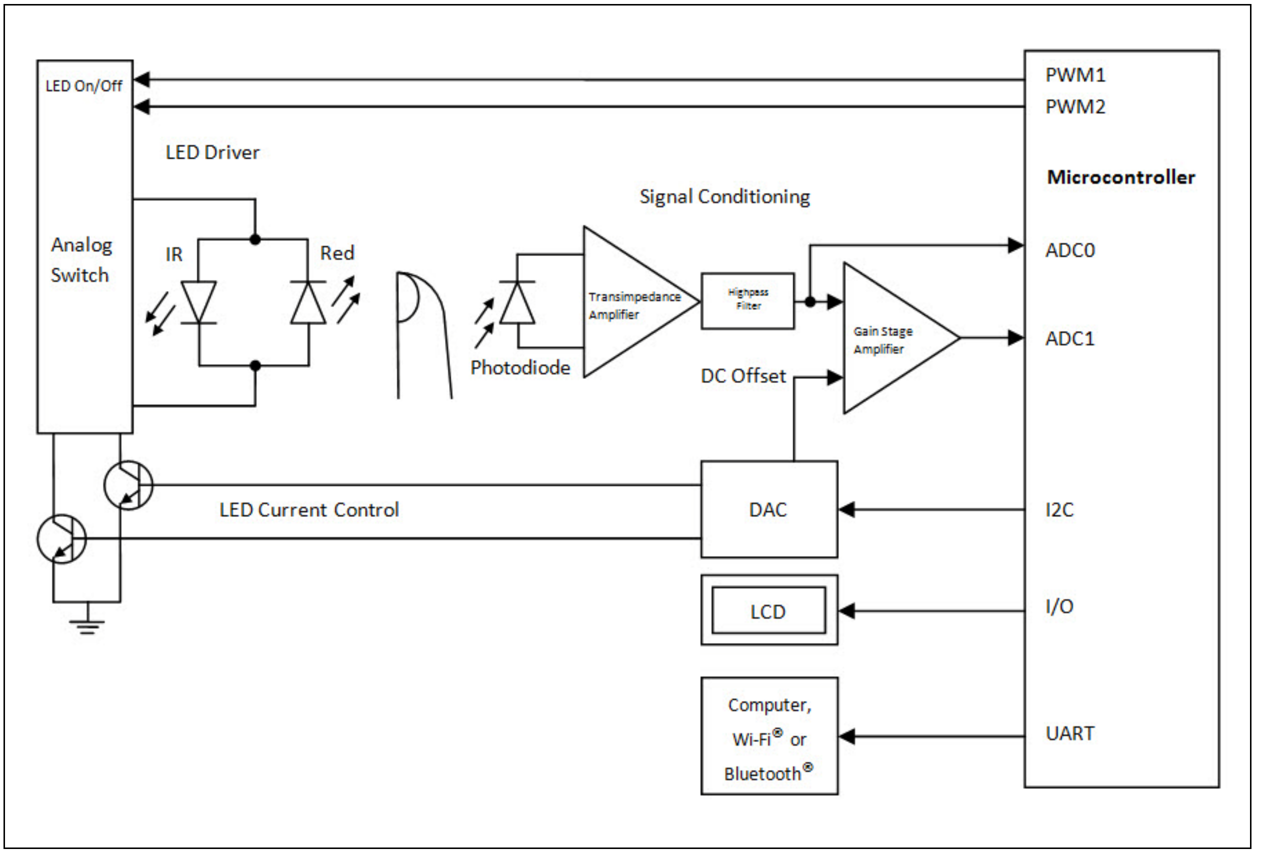
Pulse Oximeter Design Using Microchip's dsPIC® Digital Signal Controllers (DSCs) and Analog Devices

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 dsPIC® Digital Signal Controllers (DSCs) and analog devices.

FIGURE 1: FUNCTION BLOCK DIAGRAM

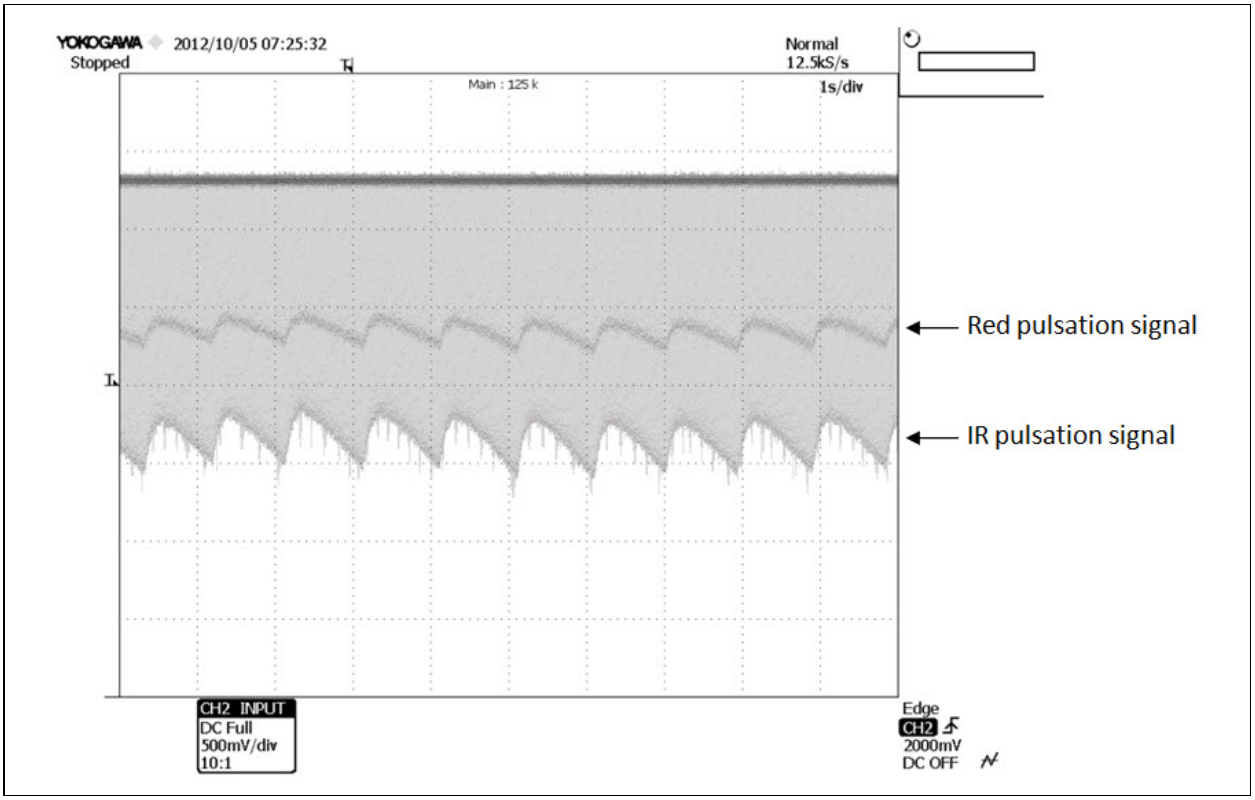


THEORY OF OPERATION

A pulse oximeter monitors the oxygen saturation (SpO_2) of a human's blood based on the red light (600-750nm wavelength) and infrared light (850-1000nm 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

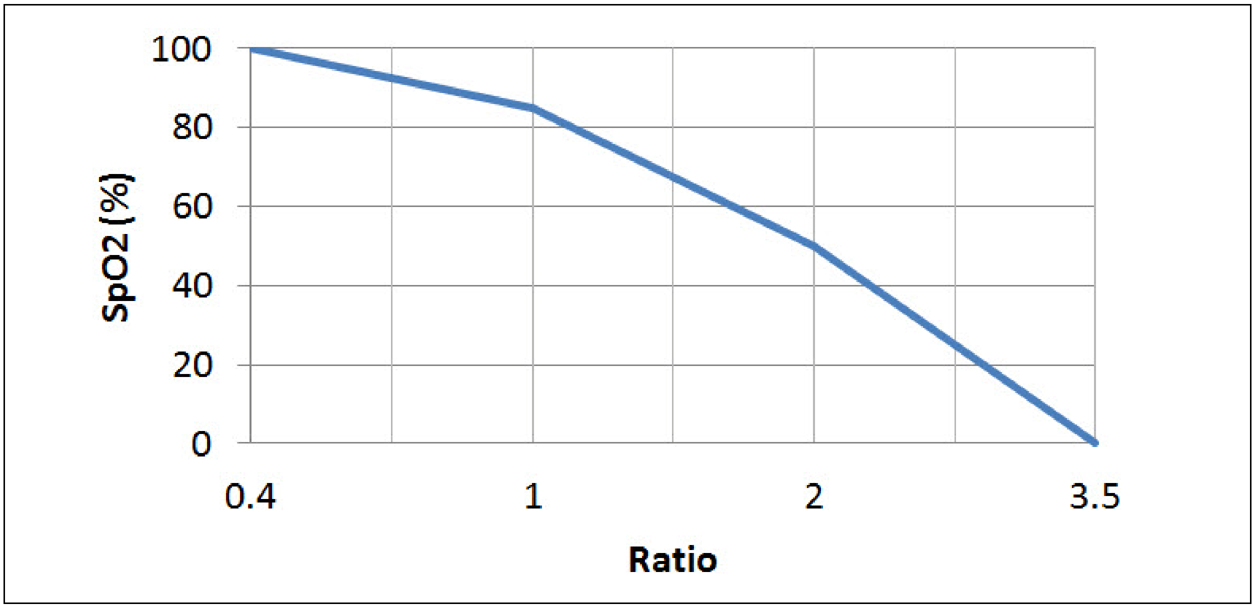


The pulse amplitudes (Vpp) of the red and infrared signals are measured and converted to Vrms to produce a Ratio value as given by the Equation 1. The SpO_2 can be determined using the Ratio value and a look-up table that is made up of empirical formulas. The pulse rate is calculated based on the Analog-to-Digital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

EQUATION 1:

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

FIGURE 3: SAMPLE CALIBRATION CURVE



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.

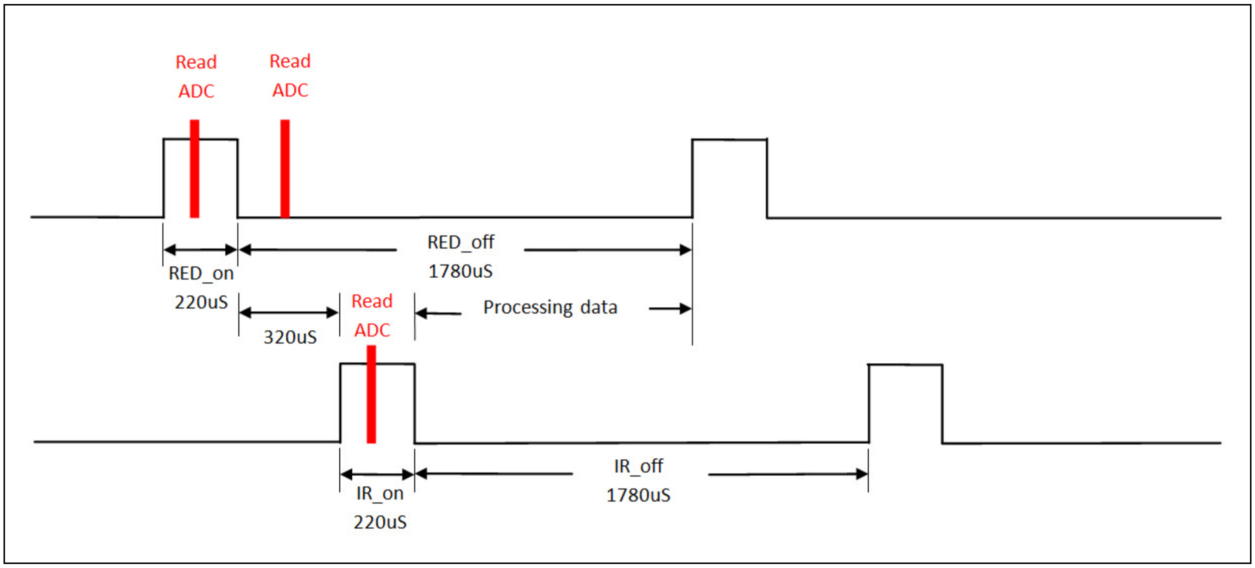
CIRCUIT DESCRIPTION

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 Analog-to-Digital Converter (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 amp 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 220mV. 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 the 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 Ripple (-dB): 0.1
Passband Frequency (Hz): 1 & 5	Stopband Ripple (-dB): 50
Stopband Frequency (Hz): 0.05 & 25	Filter Length: 513
FIR Window: Kaiser	

CONNECTIVITY

The SpO_2 and Pulse Rate data can be sent to a computer through a UART port with 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 Wi-Fi® or Bluetooth® module via UART port.

FIGURE 5: THE WAVEFORM DISPLAYING THE PULSE SIGNAL

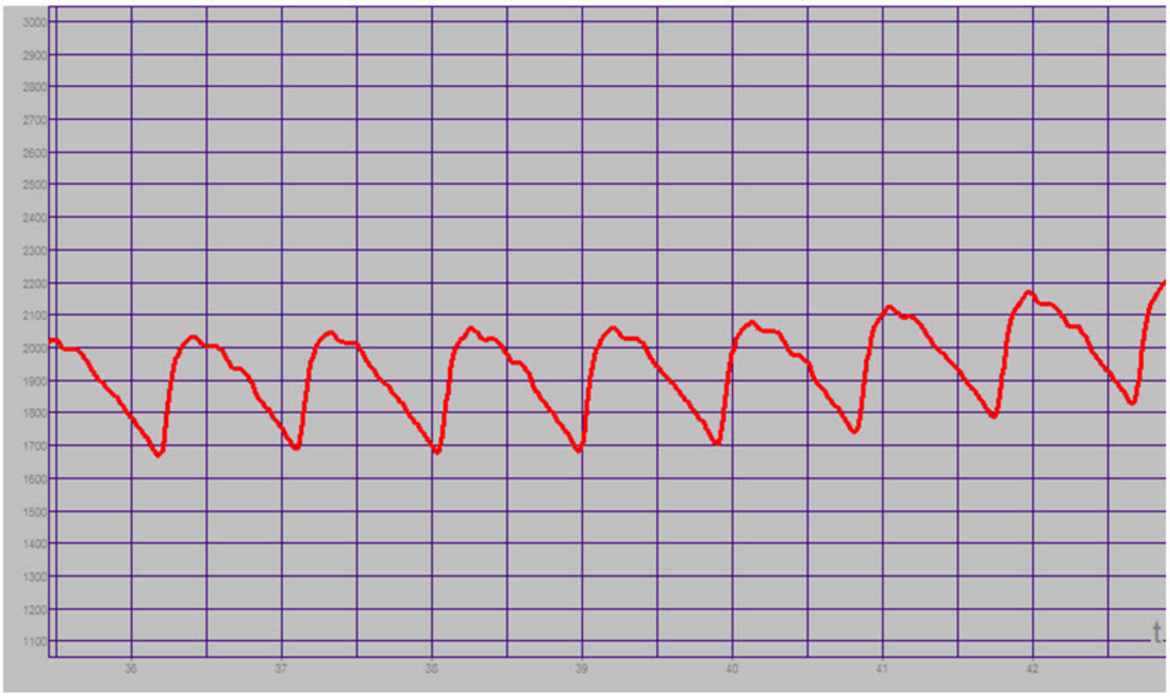
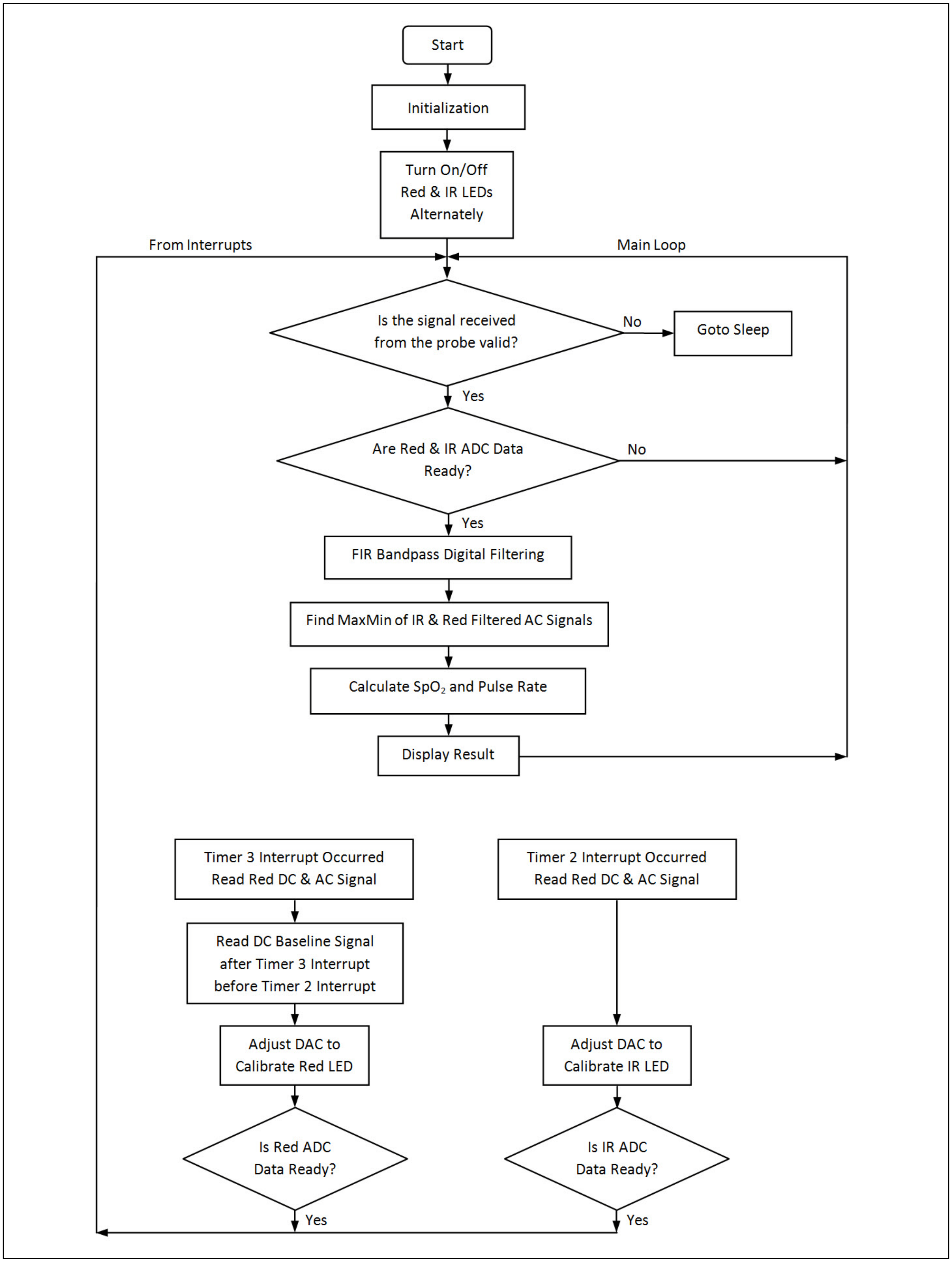


FIGURE 6: PROGRAM FLOWCHART

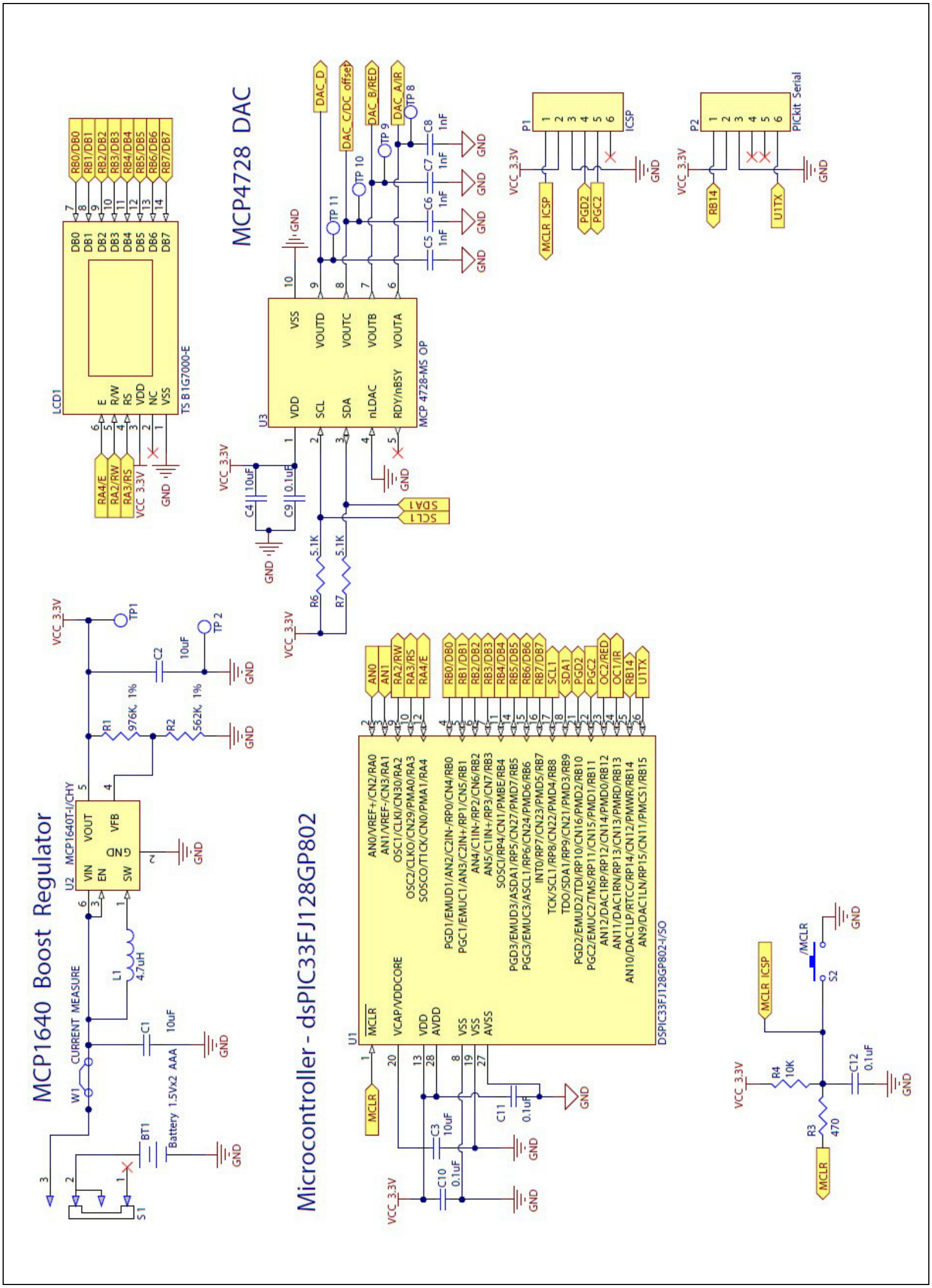


NOTES:

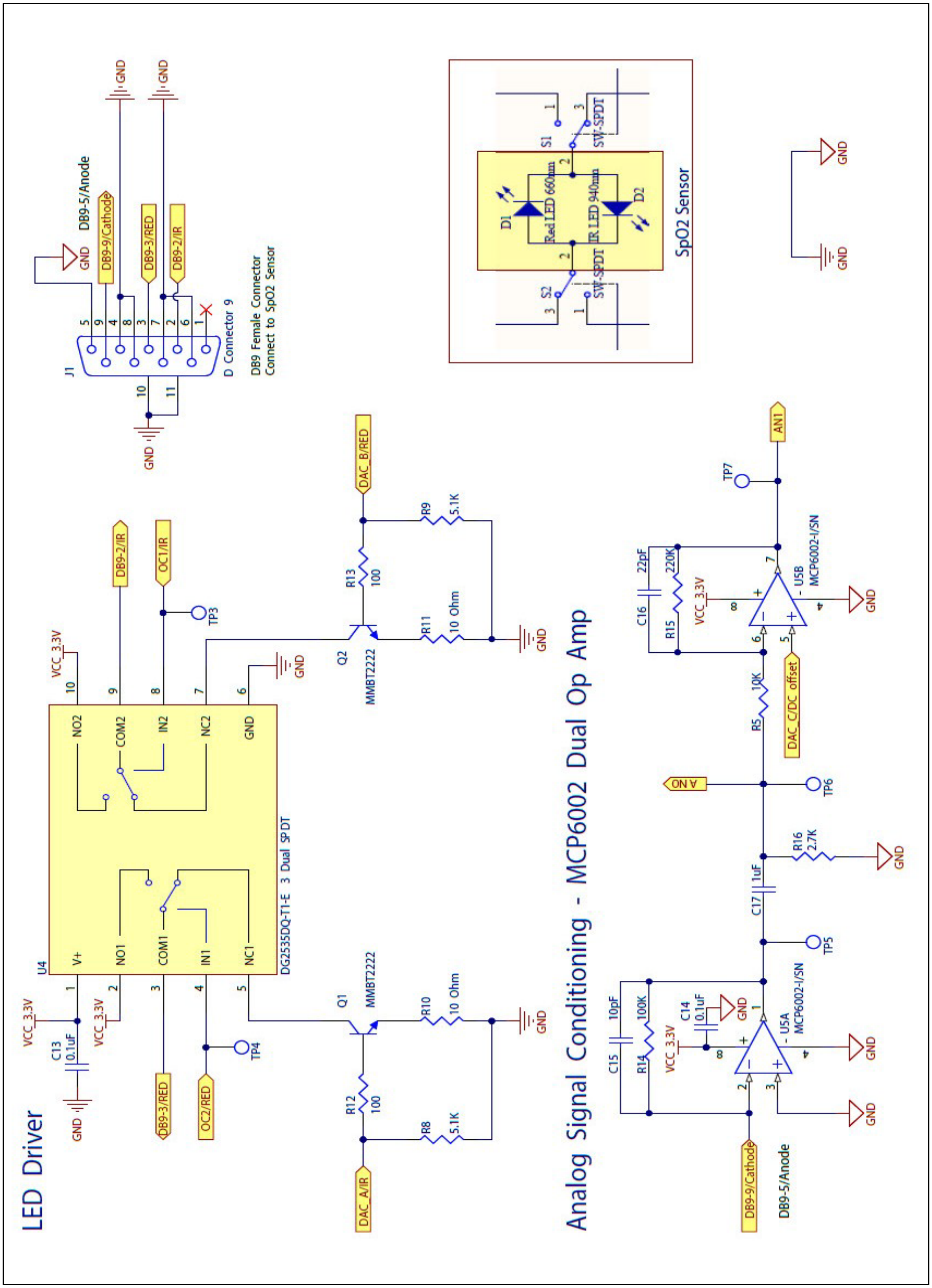
APPENDIX A: SCHEMATICS

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.

ISBN: 978-1-62077-222-5

Worldwide Sales and Service

AMERICAS

Corporate Office
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200
Fax: 480-792-7277
Technical Support:
http://www.microchip.com/support
Web Address:
www.microchip.com

Atlanta
Duluth, GA
Tel: 678-957-9614
Fax: 678-957-1455

Boston
Westborough, MA
Tel: 774-760-0087
Fax: 774-760-0088

Chicago
Itasca, IL
Tel: 630-285-0071
Fax: 630-285-0075

Cleveland
Independence, OH
Tel: 216-447-0464
Fax: 216-447-0643

Dallas
Addison, TX
Tel: 972-818-7423
Fax: 972-818-2924

Detroit
Farmington Hills, MI
Tel: 248-538-2250
Fax: 248-538-2260

Indianapolis
Noblesville, IN
Tel: 317-773-8323
Fax: 317-773-5453

Los Angeles
Mission Viejo, CA
Tel: 949-462-9523
Fax: 949-462-9608

Santa Clara
Santa Clara, CA
Tel: 408-961-6444
Fax: 408-961-6445

Toronto
Mississauga, Ontario,
Canada
Tel: 905-673-0699
Fax: 905-673-6509

ASIA/PACIFIC

Asia Pacific Office
Suites 3707-14, 37th Floor
Tower 6, The Gateway
Harbour City, Kowloon
Hong Kong
Tel: 852-2401-1200
Fax: 852-2401-3431

Australia - Sydney
Tel: 61-2-9868-6733
Fax: 61-2-9868-6755

China - Beijing
Tel: 86-10-8569-7000
Fax: 86-10-8528-2104

China - Chengdu
Tel: 86-28-8665-5511
Fax: 86-28-8665-7889

China - Chongqing
Tel: 86-23-8980-9588
Fax: 86-23-8980-9500

China - Hangzhou
Tel: 86-571-2819-3187
Fax: 86-571-2819-3189

China - Hong Kong SAR
Tel: 852-2943-5100
Fax: 852-2401-3431

China - Nanjing
Tel: 86-25-8473-2460
Fax: 86-25-8473-2470

China - Qingdao
Tel: 86-532-8502-7355
Fax: 86-532-8502-7205

China - Shanghai
Tel: 86-21-5407-5533
Fax: 86-21-5407-5066

China - Shenyang
Tel: 86-24-2334-2829
Fax: 86-24-2334-2393

China - Shenzhen
Tel: 86-755-8864-2200
Fax: 86-755-8203-1760

China - Wuhan
Tel: 86-27-5980-5300
Fax: 86-27-5980-5118

China - Xian
Tel: 86-29-8833-7252
Fax: 86-29-8833-7256

China - Xiamen
Tel: 86-592-2388138
Fax: 86-592-2388130

China - Zhuhai
Tel: 86-756-3210040
Fax: 86-756-3210049

ASIA/PACIFIC

India - Bangalore
Tel: 91-80-3090-4444
Fax: 91-80-3090-4123

India - New Delhi
Tel: 91-11-4160-8631
Fax: 91-11-4160-8632

India - Pune
Tel: 91-20-2566-1512
Fax: 91-20-2566-1513

Japan - Osaka
Tel: 81-6-6152-7160
Fax: 81-6-6152-9310

Japan - Tokyo
Tel: 81-3-6880- 3770
Fax: 81-3-6880-3771

Korea - Daegu
Tel: 82-53-744-4301
Fax: 82-53-744-4302

Korea - Seoul
Tel: 82-2-554-7200
Fax: 82-2-558-5932 or
82-2-558-5934

Malaysia - Kuala Lumpur
Tel: 60-3-6201-9857
Fax: 60-3-6201-9859

Malaysia - Penang
Tel: 60-4-227-8870
Fax: 60-4-227-4068

Philippines - Manila
Tel: 63-2-634-9065
Fax: 63-2-634-9069

Singapore
Tel: 65-6334-8870
Fax: 65-6334-8850

Taiwan - Hsin Chu
Tel: 886-3-5778-366
Fax: 886-3-5770-955

Taiwan - Kaohsiung
Tel: 886-7-213-7828
Fax: 886-7-330-9305

Taiwan - Taipei
Tel: 886-2-2508-8600
Fax: 886-2-2508-0102

Thailand - Bangkok
Tel: 66-2-694-1351
Fax: 66-2-694-1350

EUROPE

Austria - Wels
Tel: 43-7242-2244-39
Fax: 43-7242-2244-393

Denmark - Copenhagen
Tel: 45-4450-2828
Fax: 45-4485-2829

France - Paris
Tel: 33-1-69-53-63-20
Fax: 33-1-69-30-90-79

Germany - Munich
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

Italy - Milan
Tel: 39-0331-742611
Fax: 39-0331-466781

Netherlands - Drunen
Tel: 31-416-690399
Fax: 31-416-690340

Spain - Madrid
Tel: 34-91-708-08-90
Fax: 34-91-708-08-91

UK - Wokingham
Tel: 44-118-921-5869
Fax: 44-118-921-5820

11/29/12