P.O. Pro

WIRELESS REFLECTANCE PULSE OXIMETER

Design 2

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**Introduction**

The P.O. Pro will monitor the blood oxygen content of infants and small children with the use of an LED and photodiode sensor. The information will then be sent using a wireless transmitter integrated circuit device to a bedside monitor. The wireless transmitter and receiver utilize Bluetooth Technologies. The monitor device will display the blood oxygen content on a digital display as well as the pulse rate of the child. This information is then sent to a portable beeper device that the parent can carry in their pocket or attach to their belt. If the child’s blood oxygen content or pulse rate drops below normal levels for any reason, an alarm will sound on the beeper device to alert the parents of a problem. The beeper will have a two figure digital display to show the oxygen content in the blood and an LED that flashes with the child’s pulse.

1) **Wireless technology**

In order to send data from one device of the P.O. Pro to another, a wireless communication will be used. Bluetooth technology incorporates several techniques to provide effective wireless data linkages. There are a few main advantages of a wireless device using Bluetooth technologies over other standard Rf wireless devices, among these are cyclical redundancy encoding, packet re-transmission, and frequency hopping which can occur up to 1600 times per second.

ATMEL: Bluetooth /ISM 2.4-GHz Font-End IC (T7024)

**Features:**
- Single 3-V Supply Voltage
- High Power-added Efficient Power Amplifier (Pout Typically 23 dBm)
- Ramp-controlled Output Power
- Low-noise Preamplifier (NF Typically 2.1 dB)
- Biasing for External PIN Diode T/R Switch
- Current-saving Standby Mode
- Few External Components
Packages:
- PSSO20
- HP-VFQFP-N20 with Extended Performance

The Bluetooth module consists of a RF transceiver unit; base band link controller unit, a link management and host controller interface support unit (see figure1). The antenna is another component, which can either come as a standalone item or be integrated on the PCB itself. Along with the mentioned functional blocks, the module also incorporates higher-level software protocols, which control the functionality of the module itself as well as its ability to operate with other modules. The RF transceiver changes the frequency bands, channel arrangement, and transceiver characteristics. The base band link controller unit sets the packet formats, physical and logical channels, and the different modes of operation, which support the transfer of voice and data between devices. The host controller interface support unit provides an interface between the Bluetooth module and the host.

Figure1: Bluetooth module
Performance and behavior of a Bluetooth module can be affected by high temperature due to a power supply, or low temperature from the environment. At high temperatures, digital circuits will make occasional errors, while at low temperatures, they cease to function. Analog circuits, like RF amplifiers, experience degradation with extreme temperatures. The operating range of the module is dependant on the transmit power class and can range from 10 cm up to 100m. Power class 1 which has a max power of +20dBm has a max range of 100m. Power class 2 has a max power +4dBm, and power class 3 has a max power of 0dBm and max range of 10m. A power class 3 will be used for the sensor which will transmit 10 feet from the monitor.

The profile that will be used to transmit the data will be asynchronous since it is a data connection and not a voice connection. When choosing a packet, the amount of interference and bandwidth of the application must be determined. DH5 packets are best for applications with low levels of interference, DH3 packets are best for most normal types of interference, and DH1 packets are best for applications with low bandwidth (<200kB/s). Since our application is low bandwidth, DH1 packets will be used. Sensitivity is very important for Bluetooth technology. Sensitivity of Bluetooth modules is usually under optimum conditions, due to high RF noise, metallic shielding, high temperatures, and light interference degrading the sensitivity. Therefore, a module with suitable sensitivity for the application should be chosen.
Radio interference rejection of the Bluetooth module is another important specification. For co-channel interference rejection, 11dB interfere is in the same channel at 11dB below the desired signal, the adjacent channel interference rejection is 0dB when the interferer is in the adjacent channel at the same power level as the desired signal. If the supplier does not specify the specifications for the radio interference rejection, a C/I (Carrier-to-Interference) performance test may be conducted. This can be accomplished by sending co-channel or adjacent channel modulated signal in parallel with the desired signal and measuring the receiver’s BER.

Electrical design, which ranges from direct frequency modulated VCO/analog discriminator to IQ modulator/digital demodulator designs, can be implemented (See figure 3). The designs influence the electrical characteristics such as better interference rejection, longer batter life, or faster delivery.

![Figure 3: Direct frequency modulated VCO/analog discriminator block diagram](image)

It is important to know which regulatory agencies and certification bodies a supplier might have consulted to certify its Bluetooth modules. The FCC (Federal Communications Commission) and a Telecommunications Certification Body (TCB) must be consulted for the certification of modules destined for the USA. Each certification agency will have its own regulatory requirements. By evaluating all of the specifications, you will know, or at least have a better grasp of, which Bluetooth
module(s) is best adapted for your device. Assuming the modules works as specified, it needs to be integrated into each device. However, to anticipate the kinds of problems that can occur during integration, some factors should also be analyzed. These factors are noise from the power supply, power consumption, battery life, radiated or conducted interference, and antenna radiation pattern. These factors must be investigated before integrating a Bluetooth module into a device.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency band</td>
<td>2.4 GHz to 2.493 GHz</td>
<td>V1.0b: partly national assignment; max. number of channels per system: 79</td>
</tr>
<tr>
<td>Channel spacing</td>
<td>1 MHz</td>
<td></td>
</tr>
<tr>
<td>Modulation</td>
<td>Gaussian frequency shift keying (GFSK), $B \times T = 0.5$</td>
<td>Max. frequency deviation 160 kHz</td>
</tr>
<tr>
<td>Time multiplex</td>
<td>625 μs/timeslot</td>
<td>Master and slave send alternately</td>
</tr>
<tr>
<td>Frequency hopping</td>
<td>1600 hops/s</td>
<td>The frequency is changed in each timeslot (3200 hops/s during call setup, i.e. the frequency is changed in each half timeslot)</td>
</tr>
<tr>
<td>Physical packet types</td>
<td>1, 3 and 5 slots</td>
<td>Variable packet length for current packet type. Packet formats with different error correction are used depending on the application.</td>
</tr>
<tr>
<td>Power classes</td>
<td>0/+4/+20 dBm</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Key Parameters of the Bluetooth RF interface

Pre-integration factors cannot be analyzed just by reading the module datasheet or information, which the supplier provides. To optimize their analysis and anticipate the problems that could be generated during integration, we need to perform certain measurements. We first had to determine the type of interference the device and its larger environment can create. Radiated interference can come from virtually anywhere. A system working in the ISM band IEEE 802.11b, home RF devices, microwave ovens, a system working in another band (GSM, UMTS, etc.), a power supply, cell phone, digital noise of a PC, PDA, or other electronic device. Conducted interference can come from a power supply, clock circuit, or other application components. The ideal situation would be to simulate the device’s total working environment, which is very complex. More realistically we plan to place the Bluetooth module in our device and get the device to do
some “work.” The idea is to show how the device will be affected by as much electrical noise as possible consistent with its normal operation.

Another consideration when choosing a wireless device is the antenna. A high-quality radio link requires the sufficient link gain and desired pattern of radiation. Loss of gain reduces transmitter-coverage area. Alternatively, if the loss is compensated by increasing transmit power, it will reduce the Bluetooth device’s operating time and/or power efficiency. Gain is affected by losses in the circuit, including mismatch loss (for example, the antenna does not look similar to 50 $\Omega$). If the antenna is not placed close to the power amplifier (PA), losses can occur in the printed circuit board (PCB) or transmission line and connector mismatch losses leading to the antenna. Figure 4 below shows an example of the radiation pattern of the antenna proposed for our device.

![Figure 4: Radiation pattern of the antenna proposed](image-url)
2) Design of pulse oximetry instrumentation

The block diagram to be used in the construction of the P.O Pro is shown below in Figure 5.

![Figure 5: P.O. Pro block diagram circuit.](image)

The main sections of this block diagram are now described.

2.1) The Sensor

In order to make the P.O Pro practical, a light source is required that is powerful enough to penetrate more than a centimeter of tissue, yet diminutive enough to fit in a small probe. This requirement is fulfilled by the use of LED’s. One of the important factors considered in the use of LED’s is the emission spectrum of the LED. Because of the steep slope of the deoxyhemoglobin extinction curve at 660nm, it is extremely important that the red LEDs used in pulse oximeter probes emit a very narrow range of
wavelengths centered at the desired 660nm in order to minimize error in the SPO2 reading. The width of the wavelength range of the IR LED is not as important for the accuracy due to the relative flatness of both the Hb and HbO2 extinction curves at 940nm. See figure 6.

![Figure 6: Absorption spectra of Hb and HbO2.](image)

The optical sensor of the P.O pro consists of both red and infrared LED’s with peak emission wavelengths of 660 nm and 940 nm respectively, and a silicon photodiode. The photodiode is the main input device of the pulse oximeter system and should have a broad range of spectral responses that overlap the emission spectra of both the red and infrared LED’s. These devices, found in the probe, sense the intensity of light emitted by each LED after the light passes through the tissue. The photodiode produces current linearly proportional to the intensity of light striking it. A photodiode cannot distinguish between red and infrared light, but to accommodate this, the microprocessor system alternately turns each LED on and off. The pulse oximeter repeatedly samples the photodiode output while the red LED is on, while the infrared LED is on and while both
are off. By sampling with both LED’s off, the pulse oximeter is able to subtract any ambient light that may be present.

The distance between the LEDs and photodiodes is one of the major design considerations when designing a reflectance pulse oximeter sensor. The distance should be such that the plethysmograms with both maximum and minimum pulsatile components can be detected. These pulsatile components depend not only on the amount of arterial blood in the illuminated tissue, but also on the systolic blood pulse in the peripheral vascular bed. The most suitable technique to enhance the quality of the plethysmogram is to place the photodiode close to the LED. However it is important not to place the photodiode too close to the LEDs. If the photodiode is placed too close to the LEDs, the photodiode will be saturated as a result of the large DC component obtained by the multiple scattering of the incident photons by the blood free layers of the skin.

Switching time is the time required for an LED to switch from its ON state to its OFF state or vice versa. Most LEDs have a switching time in the low hundreds of nanoseconds. In the P.O Pro, this is much faster than required because of the extremely low frequency of the arterial pulsatile waveform (~ 1Hz). Like in most cases, the P.O Pro’s LED switching cycle will occur at a rate of 480 Hz, much more slowly than the maximum switching capabilities of LEDs.

The light intensity detected by the photodiode depends, not only on the intensity of the incident light, but mainly on the opacity of the skin, reflection by bones, tissue scattering, and the amount of blood in the vascular bed. The P.O Pro will generate a digital switching pulse to drive the red and infrared LED’s in the sensor alternately at a converter repetition rate of approximately 1KHz. Timing circuits are used to supply, approximately 50 µs pulses to the red and IR LED drivers at the repetition rate of 1 kHz, as shown in Figure 7 (a frequency of 1 kHz is suitable because such a frequency is well above the maximum frequency present3 in the arterial pulse). High-intensity light outputs can be obtained with the IR LED with currents of up to 1A over a low duty cycle.
Referring to Figure 8, reflected light enters the Signal Processing Circuit at photodetector D1. Current is provided in accordance to the amount of reflected light absorbed by the P-N junction in the photodetector and is converted to a voltage in the Current - Voltage Converter U1. U1 also acts as a low-pass filter intended to remove various high frequency signals, yet possesses a high enough DC that allows all frequencies from the reflected light to pass through.

The cut-off frequency for this filter is calculated using:

\[ f = \frac{1}{2\pi RC} \]
Gain is also achieved with this Converter calculated by:

\[ V_{OUT} = -I_{IN}R_f \]

It is desired that this converter be as close to the photodetectors as possible to reduce any noise. Using lower-valued resistors and low-noise Op-Amps also reduces general circuit noise. The signal output from U1 is very small; therefore it is amplified at U2. Amplification is calculated using the standard formula for inverting amplifiers, this equation being:

\[ V_{OUT} = -\frac{R_f}{R_i}V_{IN} \quad Gain = \frac{R_f}{R_i} \]

The signal is now output into an Analog Multiplier. Using a multiplier for purposes of demodulation is appropriate because multiplying two signals results in one DC signal, the desired information signal. The resulting signals thus represent the cardiac-synchronous information in the waveforms and these are further amplified before they are converted to digital format for subsequent analysis by the microprocessor.

2.2) The Monitor

It can be seen from the block diagram in Figure 5 that the output from each sample-and-hold is also passed to a low-pass filter. This is the first stage of an automatic gain control (AGC) circuit that adjusts the light intensity from the corresponding LED so that the dc level always remains at the same value (example 2V) regardless of the thickness or characteristics of the. Reasons for using an AGC circuit include: firstly, the amplitude of the ac signal (which may vary between 0.1% and 2% of the total signal) is also within a pre-defined range and this makes the amplifier that follows the band-pass filter easier to design. Secondly, the dc component of the transmitted red and IR signals can be set at the same value (2 V) in each case. Hence it can be eliminated from the formula used by the microprocessor to calculate the oxygen saturation.
Each of the main circuits concerning the monitor shown in the block diagram will now be considered.

2.2.1 Constant current source for driving LEDs

A simple potential circuit for achieving this is shown in Figure 9a in which an op-amp is combined with a bipolar transistor. In this circuit, the negative feedback forces $v_e = v_{in}$.

Thus,

$$I_e = \frac{V_{in}}{R_1}.$$

Since the collector current is almost equal to the emitter current ($I_c$ is equal to $I_e + I_b$), the LED current is therefore also given by

$$I_{LED} = \frac{V_{in}}{R_1}.$$

However, this current source is slightly imperfect because the small base current, $I_b$, may vary with $V_{ce}$. This arises because the op-amp stabilizes the emitter current
whereas the load sees the collector current. By using a FET instead of a bipolar transistor, this problem can be avoided as shown in Figure 10b. Since the FET draws no gate current, the output is sampled at the source resistance without error, eliminating the base current error of the bipolar transistor. The load current is limited by the $I_{DS(on)}$ of the MOSFET. If a bipolar power supply is available, the circuits of Figure 9 can be further simplified by omitting Vin and tying the non-inverting input of the op-amp to ground as shown in Figures 10(a) and 10(b) in both of which:

$$I_{LED} = \frac{12 \text{ V}}{R_1}.$$ 

![Alternative circuits for constant current LED driving when a bipolar power supply is available.](image)

**Figure 10:** Alternative circuits for constant current LED driving when a bipolar power supply is available.

### 2.2.2) Timing circuit

The accuracy of the timing is not of much importance; hence the timing circuit can be built around the 555-timer integrated circuit. From the data sheet for this i.c, it can easily be worked out that the circuit given in Figure 11 can be configured, for example by
setting $C = 22 \, \text{nF}$, $R_a = 56k\Omega$ and $R_b = 3.3k\Omega$, to give a 50 $\mu$s pulse approximately every millisecond, as intended

\[ T_1 = 0.7(R_a + R_b)C \]
\[ T_2 = 0.7 R_b C \]

**Figure 11:** Generating the timing pulses for pulse oximetry.

### 2.2.3) Pulsing the light output from the LEDs

The output from the LED can be pulsed by connecting an n-channel enhancement-mode MOSFET across it as shown in Figure 12. The pulses from the output pin of the 555 timer (pin 3) are taken to the gate of the transistor. The FET needs to be an enhancement-mode MOSFET for it to be turned fully off and on by the gate pulses. The MOSFET chosen for this task should also be capable of handling the maximum current flowing through the LED.

**Figure 12:** Pulsing the LED.
2.2.4) Receiver circuit

The simplest solid-state optical detector is the photodiode. Photodiode detectors normally operate with reverse bias applied to the p-n junction (photoconductive mode). When light falls on the junction region of the photodiode, an electron-hole pair is created; under the influence of the junction (or built-in) field, the hole is swept towards the p-material and the electron towards the n-material. The resulting light current is seen as a large increase in the reverse current. For the purposes of signal amplification, the photocurrent must be transformed into a voltage with moderate output impedance; this is achieved with the circuit shown in Figure 13, the op-amp being configured as a current-to-voltage converter. Because of the high junction resistance of the reverse-biased photodiode, the op-amp should be a FET type with very high input impedance. Since the negative input of the op-amp acts like a virtual ground, the output voltage of the circuit is \( v_o = -I R_L \). A very large feedback resistance may be used, values as high as several tens of M\( \Omega \) being typical in practice.

![Figure 13: Photodiode current-to-voltage converter circuit.](image)
2.2.5) Sample-and-hold circuit

In the sample mode, the output of an ideal sample-and-hold circuit is equal to the input signal at that particular instant. When switched to the hold mode, the output should remain constant at that value of the input signal that existed at the instant of switching. A simple sample-and-hold circuit is shown in Figure 14.

![Sample-and-hold circuit diagram](image)

**Figure 14**: Sample-and-hold circuit.

This circuit uses a FET switch that passes the signal through during the sample period and disconnects it during the hold period. Whatever signal was present at the time the FET is turned off is then held on the capacitor $C$. The choice of a value for $C$ is a compromise between two conflicting requirements: Leakage currents in the FET and the op-amp cause the capacitor voltage to droop during the hold period according to the equation:

\[
\frac{dV}{dt} = \frac{I_l}{C}
\]

where $I_l$ is the leakage current. Thus $C$ should be as large as possible in order to minimize droop. The resistance of the FET when turned on (typically tens of ohms) forms a low-pass filter in combination with $C$ and so $C$ should be small if high speed signals are to be followed accurately. Ready-built sample-and-hold circuits are also available as
monolithic integrated circuits that simply require the connection of an external hold capacitor.

2.2.6) Automatic gain control circuit

The output from the sample-and-hold circuit, as indicated in the general description of the block diagram, is fed to a band-pass filter which extracts the pulsatile signal prior to its further amplification and analysis. The same output is also taken to a low-pass filter with a cut-off frequency of, say, 0.1 Hz, which extracts the dc value of the transmitted signal. There are then several ways of implementing the AGC function. One of the simplest ways is to feed the dc signal to one input of a differential amplifier whose other input is a constant, reference voltage (from a zener diode, for example).

2.3) Alarm

The alarm is an inductive load needing a positive and a negative signal. Figure 14 below shows that currents to these two inputs are controlled by two different paths.

![Figure 15: A Schematic Representation of How Data Causes the Alarms to Sound](image)

Depending on the address/data information the demultiplexer generates many signals like the VRED, VIR and the volume control signal. A sample-and-hold circuit is used to hold
this signal. This signal is then passed by means of a series of power transistors to boost
the current flowing into the speaker or in this case, the alarm.

A thinner and counter chip will be used to generate a count using certain address/data
information and will temporarily save it into a buffer. This tone signal will be used to
control a FET switch which alternately will connect or disconnect the speakers negative
input to ground. The frequency of the tone signal (determined by the timer/counter chip)
will determine the pitch of the sound produced. A capacitor will be present to smooth the
sound. A diode will also be present to suppress any transients from the induced load.

3) Evaluation of Pulse Oximetry Data

The objective of this section is to describe several sources of error in pulse
oximetry that may cause risky consequences to the subjects. Recognizing the limitations
that will be described shortly and applying appropriate corrective inspections are
necessary to optimize the use of pulse oximeters.

3.1) Accuracy, Bias, Precision, and Confidence Limit

Accuracy is a measure of systemic or bias, the greater the error, the less accurate
the variable. The accuracy of a measurement is the degree to which it actually reflects
the accuracy of the measurement. The accuracy of pulse oximeter oxygen saturations can
usually be tested by comparing with the reference technique, Co-oximeter. Parameters
frequently used to represent the degree of accuracy are bias, and mean errors. Bias, in
this case defines as the mean of the differences between the pulse oximeter readings and
the CO-oximeter readings, which can be expressed as

$$\text{bias} = \frac{\sum_{i=1}^{N} x_i}{N} = \bar{x}$$

where $x_i$ is calculated by subtracting the $i$th Co-oximeter measurement from the
corresponding oximeter saturation displayed by a pulse oximeter. $N$ is the total number
of measurements. Units are percent saturations.
Precision is a measure of variation of random error, or degree of reproducibility. The dispersion of points around the mean reflects the precision of the measurement. The precision is often described statistically using the standard deviation (SD) of the differences between the pulse oximeter readings and the CO-oximeter readings of repeated measurements as in the following equation. Units are percent saturation.

\[
\text{precision} = SD = \sqrt{\frac{\sum_{i=1}^{N} (x_i - \overline{x})^2}{N-1}}
\]

Most frequently, 95% confidence limit is used, which is equal to 1.96 times SD for a normal distribution:

\[
95\% \text{ confidence limit} = 1.96 \times SD = 2 \times SD
\]

The use of bias and precision is helpful in getting a clear picture of a pulse oximeter’s performance and how this compares to other units or other studies. A unit may be very precise, so that the results are highly reproducible with a low scatter, but have a high bias so that the results are not centered on the true values. In contrast, a unit may have a very low bias, but have poor precision, with values swinging widely from side to side of the true value. In clinical practice, therefore in this project’s case, a 95% confidence limit of less than ±3% is considered acceptable for most cases.

3.2) What Do Pulse Oximeters Really Measure?

Pulse oximeters only measure a ratio of transmitted red and infrared light intensities, and relate this to reference table of empirical oxygen saturation values. In this particular project, the PO. Pro will deal with reflected instead of transmitted red and infrared light intensities. The data used for calibration processes are usually obtained from healthy adults breathing hypoxic gas mixtures. Pulse oximeters can measure neither fractional SO\(_2\) nor functional SO\(_2\).
3.3) *Accuracy versus Saturation*

Accuracy at different levels of oxygen saturation is not the same. Oxygen saturation is divided into three ranges: normal saturation, high saturation, and hypoxic condition (low saturation level).

- **High saturation (greater than 97.5%)**:
  Pulse oximeters are designed to give a saturation reading of less than or equal to 100%; this limits the potential for positive errors and makes precision calculations difficult to interpret in this high range. Even though precision calculations cannot be determined in a biased way due to the positive errors, the correct corresponding oxygen saturation is not critical in this range. As long as the oxygen saturation is over 97%, the patients are in favorable conditions and they require no urgent medical attention.

- **Normal saturation (90 to 97.5%)**:
  Most models of pulse oximeters have a reliable performance in this range, and are well calibrated in this range since it is the most commonly found condition.

- **Low saturation (less than 80%)**:
  Ethically manufacturers cannot stimulate severe hypoxia repeatedly in volunteers for calibration purposes. For this reason mainly, pulse oximeters have a high potential for errors at low saturations. The error associated with low saturations can be explained by a reduction on the signal-to-noise ratio in pulse oximetry. As saturation decreases, less red light is able to penetrate through the tissues due to a high absorbance of Hb, so the AC signal becomes weaker. To compensate for this drawback, the LED-driving current and the photodiode amplifier gain are increased to maintain the AC signal in a usual range. As the gain increases, incidental electrical and physiological noise also increase, therefore resulting in a decline in the pulse oximeter’s accuracy. In summary, pulse oximeters are poorly calibrated for saturations below 80%, and in general, accuracy and precision are worse for saturations above this percentage.

3.4) *Saturation versus Perfusion*

The P.O. Pro, like most pulse oximeters, will have the ability to recognize a weak waveform which could cause an invalid reading. An alarm will sound in case of a low perfusion alerting the user of possible problems in peripheral blood perfusion.
3.5) Saturation versus Motion Artifacts

As with most medical devices, motion artifacts contribute a significant error to pulse oximetry. The motion artifact is a major problem that is usually due to the patient’s muscle movement proximate to the oximeter probe inducing false pulses that are similar to actual pulses. The false pulses when processed can produce incorrect results. This problem is particularly significant in patients that do not remain still during monitoring, and in active infants which the P.O. Pro will be designed for. One attempt that may be performed to reduce these artifacts is by utilizing digital signal processing and averaging the SpO\(_2\) values over several seconds before they are displayed. Motion artifacts are usually recognized by false or erratic heart-rate display or by distorted plethysmographic waveforms.

3.6) Accuracy versus Optical Artifacts

All pulse oximeters are known to be affected by bright external light sources. This sensitivity will be also shared by the P.O. Pro. This occurs due to the fact that these instruments use optical means to make their measurements. As a result, in order to achieve accurate measurements, potential sources of optical interference must be controlled. Because the P.O. Pro will contain its optical components in the probe, proper probe application and use will be key factors in reducing optical interference. Optical interference occurs when bright light from an external source (ambient light) reaches the photodiode, or when light reaches the photodiode without passing through a pulsatile arteriolar bed.

The P.O. Pro will be designed to reject ambient light since the photodiode will have the capability of measuring weak signals. When the intensity of ambient light is high, such as the one from heat lamps or sunlight, the photodiode will not be able to sense light transmitted through tissue for SpO\(_2\) calculations. Protecting the photodiode from bright light will prevent this problem. One solution that has been used is covering the probe site with some opaque material, such as a surgical towel. Although this approach is generally useful, it will not be the best solution in the case of the P.O. Pro.
since it will be utilized on active children where the towel may be displaced leading to the exposure of the oximeter probe. As an alternative solution, designers of the P.O. Pro will consider an effective remedy to this problem suggested by Siegel and Gravenstein (1987) where the probe will be covered, while it is attached to a digit, with a packaging from an alcohol swab or an epoxy resin. This packaging is manufactured in a shape that makes a convenient, dark container for a digit, even one on which the flexible pulse oximeter probe that will be placed in the P.O. Pro.

3.7) *Effect of Temperature*

Exposing the body to cold temperatures may cause changes in peripheral perfusion which may cause inaccuracy. Reynolds et al (1991) illustrated that the temperature dependence of LEDs in pulse oximeter probes is unlikely to affect the obtained measured values. In other words, the effect of shifts in wavelength of the LEDs on pulse oximeter accuracy is negligible as the temperature increases from 0°C to 50°C.

During low temperature exposure, a reduction in amplitude of the ac signal takes place making the pulse oximeter to be more sensitive to motion artifacts, for instance those caused by shivering or coughing. These artifacts may lead to an incorrect value of SpO₂ by the pulse oximeter. Reynolds et al (1991) concluded that inaccuracies in pulse oximeter readings at extreme temperatures are far more likely to be caused by reductions in peripheral perfusion, rather than a result of the temperature dependence of the LEDs in the pulse oximeter probe. A decrease in a patient’s temperature does not result in a significant error increase in pulse oximeter readings.

**Conclusion**

The P.O. Pro is a wireless solution to every household allowing parents to monitor their child’s pulse rate and blood oxygen content. This design will provide this information wirelessly giving flexibility to the parents. The product displays information in a straightforward manner to ease interpretation of the information by the users. This product will be readily available to the general public at retail stores at a competitive price. The final product will consist of a sensor module, a monitor and an alarm. A
watch shaped sensor module which will be placed on the infant’s ankle will transmit data to the monitor which can be place within thirty feet from the sensor. This monitor will transmit data to the beeper like alarm that can be carried around by the caretaker provided it is within one hundred feet of the monitor. The alarm will sound if an abnormal level of oxygen or pulse rate is detected or if the battery is low. In addition to infants and toddlers being the primary target, the product is designed in such a way that it can easily be modified to other target age groups.