Department of Electrical and Computer Engineering

A New Electronic Device for Measuring Pulse and Oxygen Concentration

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ABSTRACT

Sensor devices such as pulse oximetry are practical tools used by most healthcare professionals, and even patients. An electronic sensor device that has the capability to measure physiological signs of saturation of arterial oxygen (SpO_2) and heart beat rate of the human body has been developed in this study.

The hardware design of the sensor device consists of a microcontroller PIC18F452, an external flash memory, and a transceiver unit. The most suitable sensors of red and infra red LEDs are installed on the arms of the plastic clip and functioned with the right resistor values. The red and infra red lights are detected by the photo diode and converted to digital numbers by the Assembly Language software program embedded into the microcontroller PIC18LF452. Those digital numbers are converted to SpO_2 value in percentage level. A low power dual operational amplifier LM358 is used to amplify the current signal of the two lights, which depends on the intensity and visibility of the two lights. The output signals are displayed in 16 characters and 2 lines on Hitachi HD44870 compatible liquid crystal display (LCD). In order to display this data on personal computer (PC) monitor, the data is also transmitted via Universal Synchronous Asynchronous Receiver Transmitter (USART) ports of microcontroller to a PC. A Visual Basic 6 programming language is installed in the PC to display the wave forms, the percentage of the SpO_2 level, and the pulse rate.

Pulse oximetry has a promising future in the healthcare industry. This research enables a more efficient and economical means for managing the healthcare of the growing population.

Keywords: hardware, healthcare, sensor, heart rate, oxygen concentration, SpO_2, LEDs, microcontroller, MPLAB IDE, LCD, PC, USART

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GLOSSARY

Substances

anaesthesia	A drug, administered for medical or surgical purposes, that induces partial or total loss of sensation and may be topical, local, regional, or general, depending on the method of administration and area of the body affected.
Beer-Lambert law	The Beer-Lambert law (or Beer's law) is the linear relationship between absorbance and concentration of an absorbing species.
diastole	The normal rhythmically occurring relaxation and dilatation of the heart chambers, especially the ventricles, during which they fill with blood
haemoglobin	The oxygen-carrying substance in red blood cells
isobestic point	A spectroscopic wavelength at which the absorbance of two substances, one of which can be converted into the other, is the same.
isotropic	Identical in all directions; invariant with respect to direction
Mie's Theory	Scattering in which there is no change in the direction of motion of the scattered particles. Scattering in which the angle between the initial and final directions of motion of the scattered particles is less than 90°
Monte Carlo	Of or relating to a problem-solving technique that uses random samples and other statistical methods for finding solutions to mathematical or physical problems
Myoglobin	A single-chain, iron-containing protein found in muscle fibers, structurally similar to a single subunit of

	haemoglobin and having a higher affinity for oxygen than haemoglobin of the blood
Ohm's law	Ohm's Law defines the relationships between (P) power, (E) voltage, (I) current, and (R) resistance. One ohm is the resistance value through which one volt will maintain a current of one ampere.
organelles	A differentiated structure within a cell, such as a mitochondrion, vacuole, or chloroplast, that performs a specific function.
Rayleigh's law	A law giving the intensity of radiation emitted by a blackbody within a narrow band of wavelengths; it states that this intensity is proportional to the temperature divided by the fourth power of the wavelength; it is a good approximation to the experimentally verified Planck radiation formula only at long wavelengths.
photoplethysmogram	Plethysmographic determination in which the intensity of light reflected from the skin surface and the red cells below is measured to determine the blood volume of the respective area. There are two types, transmission and reflectance.
systole	The rhythmic contraction of the heart, especially of the ventricles, by which blood is driven through the aorta and pulmonary artery after each dilation or diastole.

Abbreviations

AC	alternating current
ADC	analogue-digital converter
AGC	automatic gain control
AUSART	addressable universal synchronous/asynchronous receiver/transmitter
BPM	beat per minute
BSN	body sensor network
CCD	a charge-coupled device
CVA	a sudden loss of consciousness resulting when the rupture or occlusion of a blood vessel leads to oxygen lack in the brain
DC	direct current
EEPROM	electrically erasable programmable read-only memory
Hb	deoxygenated haemoglobin
HbO_2	oxygenated haemoglobin
IR	infrared
LCD	liquid crystal display
LDO	low drop out
LED	light emitting diode
Op-Amps	operational amplifier
PC	personal computer

PCB	printed circuit board
PLL	phase-locked loop
PWM	pulse width modulation
RAM	random access memory
RS232	recommended standard-232
SaO_2	saturation of oxygen in arterial blood
SO_2	saturation of oxygen in blood
SpO_2	saturation of haemoglobin with oxygen as measured by pulse oximetry
USART	universal synchronous asynchronous receiver transmitter

CHAPTER 1: INTRODUCTION

1.1 World's population and health-care

According to the Department of Economic and Social Affairs of United Nations, the world population amounted to 6.7 billion in 2007. The world population is predicted to be significantly higher by 2050, rocketing to 9.9 billion [United Nations 2007, p.4]. At present, approximately 47 percent of world's population lives in urban areas. It is expected that the urban population in the developing countries will be growing rapidly in the coming decades [Newbold 2007, p.6]. As the population growth is higher, modern health system breakthroughs have become essential. The increase in the world's ageing population is the result of the declining fertility rates worldwide [Markle et al. 2007, p.209].

As a result of the increasing aging population and their susceptibility to long-lasting diseases such as heart attack and high blood pressure, the elderly health-care is one of the most important issues in the world [Callahan 1997, p.73]. Commonly, an ageing person is susceptible to stroke, causing the brain cells to die when oxygen and glucose cannot be delivered to the brain [Walker 1996]. Adequate supply of oxygen and glucose depends on rhythmic contraction of the heart pump. If there is any disorder of the heart rhythm, the resulting arrhythmia can cause or precipitate sudden fatal reduction of blood supply to vital organs. Ageing persons are more susceptible to that. When oxygen and glucose cannot be delivered to the brain, the brain tissues are deprived or deranged that leads to the death of brain tissue. That is called CVA; cerebrovascular accident [Walker 1996]. When the blood fails to provide sufficient oxygen, the muscle starts to die. Then it leads to heart attack and eventually death; an immediate medical attention is paramount for elderly people [Flaws & Sionneau 2002, p.115].

Increase in the demand for aging services is resulted by the increasing elderly population. These days, the electronic and sensor network technologies have been improved for their potential advantages, thus their use have progressively benefitted the health-care sector [Lynch 2004] - [Anliker et al., 2004]. Advance technology has allowed people to perform some procedures more quickly and more safely [Callahan1997, p.63]. Recent developments of technology are anticipated to support healthcare professionals effectively and economically in long-term care conveniences. This may reduce the cost of health-care and enlarge the worth of life of the patient while decreasing the trouble on the health-care professionals [Marques et al., 2004].

The rise of the expectations in medical care has resulted in the fact that even very old persons are now receiving treatment that was not given previously [Callahan 1997, p.63]. One significant technology which would benefit from sensor implementation is pulse oximeter. The medical applications of pulse oximeter include monitoring patients during anesthesia, intensive care, or those with conditions such as asthma [Young 2003].

This system is advantageous for health status of elderly for a number of reasons. Monitoring of oxygen delivery is vital and pulse oximetry measures arterial oxygen saturation (SpO_2) [Aoyagi 2003, p.259-266]. Another benefit of pulse oximetry is the capability to measure other critical physiological information from a single compact sensor [Crilly et al., 1997]. Pulse oximetry becomes accepted for a non-invasive method and can give immediate data of the arterial oxygen saturation in the patient's blood. Pulse oximeter is used by anesthesiologists during surgery for about an hour afterwards in the recovery room [Webster 1997, p.17].

As a consequence of small enough to be portable, of apparently having no morbidity, negligible running costs and a comparatively low capital cost compared to the old health monitoring devices, simple to use, needs no user calibration and is accurate enough for clinical use, the pulse oximetry is introduced to the health-care. For these reasons, the pulse oximeter is acknowledged as a standard monitoring device in almost every hospital critical care unit and surgical theater [Segura 2008].

1.2 Objectives

The main objectives of this research are:

- To develop a new medical sensor node for saturation of arterial oxygen, and heart beat rate monitoring.
- To develop a small size sensor device that is easy to use. This is to eliminate human error while providing more accurate readings and faster results.

- To produce a new electronic device performs with low-cost, low-power consumption, miniature and light weight.

- To produce a new electronic device that can be used on everyone. It must be suitable for use with the variety of patients.

1.3 Concepts of pulse oximetry

Pulse oximetry is well known as the most widespread non-invasive technique used to measure blood oxygen saturation and the heart beat rate (pulse). The technology of pulse oximetry is based upon the different red and infrared light absorption individualities of oxygenated haemoglobin (HbO_2) and deoxygenated haemoglobin (Hb) [Hritcu - Luca, Corciova & Ciorap 2009, p.133-6]. A red, an infrared LEDs and a photodiode are used to transmit red and infrared light source to human tissue and collect the transmitted light source respectively [Moyle 2002, p.12, 14, 21].

Light from two light emitting diodes (LEDs), one at wavelength 660 nm and the other at wavelength 940 nm (infra-red) will shine through the index finger [Thilo, Curlander & Hay 1995, p.151]. A photodiode at the opposite side of the finger resolves the intensity of the resulting red and infrared signals. Oxygenated haemoglobin HbO_2 absorbs more infrared light, while deoxygenated haemoglobin Hb absorbs more red lights [Serway, Vuille & Faughn 2009, p.730]. The absorbance of oxyhaemoglobin and deoxyhaemoglobin is the same at isosbestic point for the wavelengths of 590 and 805 nm. The oxygen saturation is determined from the comparison of the absorbances at these wavelengths and the percent saturation is derived. By measuring the light transmitted through the fingertip at two different wavelengths, one in the red and the other close to infrared range, the oxygen saturation of the arterial blood in the finger will be calculated. The oxygen saturation is then defined as the division of the concentration of oxygenated haemoglobin to the total concentration of haemoglobin [Martin 1999, p.97].

Generally, the normal saturation for a patient at sea level is 95% of SpO_2 or above. The level at which a person starts to become evidently impaired is in the region of 90% of SpO_2, and a reading close to 80% SpO_2 indicates severe hypoxia which is the insufficient levels of oxygen in either blood or tissue. Light incident to human tissue is scattered and partially transmitted, reflected and absorbed by the skin, the tissues and the blood before that incident light reaches the detector [Webster 1997, p.41]. As a result of the scattering, the incident light will unfasten the initial directionality. Light will be transmitted through the tissue which will be referred to as *transmission*, but also reflected back to the surface of incidence which is called *reflectance*. Depending on the saturation of oxygen in haemoglobin, blood changes colour as haemoglobin absorbs varying amounts of light. Oxygenated haemoglobin does not absorb much red light, but as the haemoglobin oxygen saturation drops, more and more red light is absorbed and the blood becomes darker. Conversely, at the near infrared region of light, oxygenated haemoglobin absorbs more light than reduced haemoglobin.

The absorption spectrum for HbO_2 is different from that of Hb and by using two different wavelengths of light, the oxygen saturation can be found. Measuring the time varying signal of the light leaving the tissue, the oxygen saturation is found due to a functional dependence of the ratio between the time varying signals for the two different wavelengths. Due to the fluctuations in the volume of arterial blood between the source and the detector, the absorbance of both wavelengths has a pulsatile component. The sensor is attached to the extremities of the body such as a finger or an ear flip. The reason for this is that these body parts are well per fused with blood vessels [Moyle 2002, p.140-52] and the volume fraction of blood is consequently high.

Scattering of light in tissue makes it possible to measure both in a transmission mode and in a reflectance mode configuration as mentioned in the previous paragraph. In transmission mode, the light sources and light detector are placed on the opposite sides of the finger and the light is shined through the finger. The LEDs are powered alternately so that the light of one particular wavelength will pass through the tissue, and the transmitted light will be detected by the photodiode [Crilly 1997]. This configuration is used more common due to the convenience of attachment and better signal quality [Webster 1997, p.86-91].

Pulse oximeters with reflectance probes are used to monitor SpO_2 based on the intensity of reflected light. It was shown that SpO_2 can be monitored by measuring the amount of light reflected (back scattered) from the tissue by *Brinkman* and *Zyistra* in 1949

[Webster 1997, p.87]. In reflectance probe, the light sources and light detector are placed on the same surface where light sources and light detector are integrated and therefore can be placed within one patch. In a reflectance oximeter, the incident light emitted from the LEDs diffuses through the skin the back scattered light forms a circular pattern around the LEDs. Transmittance pulse oximetry offers several significant advantages over reflectance pulse oximetry, including higher signal amplitude (and thus higher signal-to-noise ratio), more convenient access, and less pressure dependence [Parlato 2009].

1.4 Thesis outline

The objective of this thesis is to design a new and miniaturized pulse oximeter. This will be accomplished by theoretical studies of pulse oximetry and experimental analysis and consideration about limitations of design solutions.

The thesis is organized as follows:

Chapter 2 discusses the optical properties of tissue for a detailed understanding of pulse oximetry. The optical property of tissue is the basic study for assessing oximeter sensor designs. This chapter also contains a detailed understanding of pulse oximetry and the relation to the optical properties of tissue and blood are given. The review of commercial pulse oximeter Nellcor N-65 is discussed. The core electronic components of pulse oximetry are also included in this chapter.

Chapter 3 describes the design and planning of laboratorial setup for measuring the oxygen saturation by pulse oximetry. The latter part of the chapter discusses the design specification of pulse oximetry

Chapter 4 contains detailed discussions of system implementation of both hardware and software.

Chapter 5 presents the experimental results with some measurements.

Chapter 6 summarizes the studies in a conclusion.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The optical properties and light propagation of tissue are discussed in this chapter. The theory of pulse oximetry is also explained. The core electronic components of pulse oximetry are described. The discussions in this chapter is important for the designing of a pulse oximetry and the working principle of the instrument such as mathematical routines utilized and that are converted to software program. The software programming will be discussed in chapter 4.

2.2 Optical properties of tissue

Human tissues are optically inhomogeneous and light propagation within tissue always depends on scattering and absorption properties of its components: cells, cell organelles and various fiber structures [Tuchin 2007, p.3]. When light is incident on human tissue, reflection, refraction and scattering of light will occur? When light passes through tissue, it can either be absorbed or scattered. The light is diffused by the scattering of photons many times, and it leads to propagating in all directions. Scattering also enlarges the absorbance due to an increase of the light path.

The basic understanding of the absorption and scattering of light propagating in human tissue is presented in those studies. In living organisms, the fundamental building block is the cell, and tissue is made up of many cells with different functions and different sizes. Generally, tissue is in a homogeneous medium with different and randomly distributed absorbers and scatters. The presence of microscopic inhomogeneities (macromolecules, cell organelles, organized cell structure, interstitial layers, etc.) makes the tissue turbid. In a turbid medium, a photon moves in all directions and it may be scattered [Welch & Gemert 1995, p.19]. The spreading of a light beam and loss of directionality are caused by the various scattering within a turbid medium [Welch & Gemert 1995, p.31-36].

The four parameters of the basic optical properties of tissue are refractive index, absorption coefficient, scattering coefficient and phase function. Those parameters are dependent on the type of tissues as human body is made up of skeleton, bones, organs, muscle, blood vessels, nervous system, etc. Depending on perfusion and structure, tissue can be divided into different layers. The epidermis outer skin has a low perfusion, but in the dermis, the layer is just beneath the epidermis, the perfusion is high and the absorption of light by blood is also consequently high.

2.2.1 Refractive index

The refractive index of biological tissues is higher than that of air. Light is partially reflected and radiated in the tissue, while the rest part penetrates the tissue. Human tissue is composed of cells, cell organelles, and various fiber structure that are dependent of light propagation within tissue. The refractive index of those components is relative to the tissue ground substances and the polarization states of the incident light [Tuchin 2007, p.3].

2.2.2 Absorption coefficient

When the light passes through the tissue, the light is attenuated. The absorbance depends on the wavelength of the light. The absorption of light changes based on the path length and the concentration. Most of the absorption in the wavelength range of interest is from 400 to1000 nm. In the near infrared region between 650 nm and 1000 nm, the absorption of most chromospheres decreases significantly compared to that in the visible. The absorption spectra of haemoglobin and myoglobin depend on their state of oxygenation. The absorption spectra are significantly the difference between the spectra for the oxygenated and deoxygenated forms of haemoglobin. The attenuation of light at a single wavelength is described by Beer-Lambert's law [Pedrotti & Pedrotti 1993], as given in equation (2.1).

$$I(z) = I_0 \exp(\ -u_a z) \tag{2.1}$$

where I(z) is the attenuated intensity as a function of the distance z in the tissue, I_0 is the incident intensity, and μ_a is the absorption coefficient.

2.2.3 Scattering coefficient

Tissue is a high scattering medium. When light is scattered, the beam results in a loss of the direction of initial propagation as the light propagates through tissue [Prasad 2003, p.11- 49]. More light will be scattered in the forward direction than the other directions [Berne & Pecora 2000, p.24].

The attenuation of the transmitted light can be described by combining the Beer-Lambert's law for absorption and scattering, as equation (2.2)

$$I(z) = I_0 \exp(-(u_a + u_s)z) \tag{2.2}$$

where I_0 is the incident intensity, μ_a is the absorption coefficient, μ_s is the scattering coefficient, and z is the spatial coordinate.

There are two types of scattering; elastic scattering and inelastic scattering. The elastic scattering can be divided into Rayleigh scattering and Mie scattering. The concepts of Rayleigh and Mie scattering are necessary for turbid media. Rayleigh scattering states that the scattering particles are smaller than the wavelengths of the incident radiation. Rayleigh's law [Ishimaru 1991] can be derived as in equation (2.3)

$$I_s \sim \frac{1+cos^2 \theta}{\lambda^4} \tag{2.3}$$

where I_s is the scattered intensity, λ is the wavelength, and θ is the scattering angle such that $\theta = 0$ is forward scattering and $\theta = \pi$ is backscattering.

From this equation, we can observe that forward and backward scattering share the same scattering intensity on dependence of a significant wavelength. This study is not in agreement with experimental results for scattering in human tissue. It is reported that photons are scattered rather in the forward direction [Prasad 2003, p.11- 49]. Rayleigh's law of scattering is therefore not a good description of scattering in tissue.

Mie's theory states that the scattering of light by particles that are large is related to the wavelength of the light. Mie scattering is therefore valid for scattering particles comparable to the wavelength of the incident light. Mie theory finds that the scattering explains weaker dependence on wavelength (~ λ^{-x} with $0.4 \leq x \leq 0.5$) compared to Rayleigh scattering (~ λ^{-4}) and that the scattering is preferably in the forward direction [Niemz 2002, p.22]. For that reason neither Rayleigh nor Mie theories are apt to the scattering mechanism of tissue. Next, the phase function $p(\theta)$ is introduced, which describes the probability for a photon to be scattered by an angle θ and can be built-in to experimental data. A measure of anisotropy of scattering is given by the coefficient of anisotropy g, where $g = 1$. For $g = 1$ the scattering is simply forward and for $g = -1$ the scattering is only backward. While both absorption and scattering take place, it is logical to define some dimensionless parameters. In general, the phase function is normalized as in equation (2.4).

$$\frac{1}{4\pi} = \int_{4\pi} p(\theta)\mathrm{d}\omega = 1 \qquad (2.4)$$

where dω is the solid angle element in spherical coordinate i.e. $\mathrm{d}\omega = \sin(\theta)\, \mathrm{d}\theta\, \mathrm{d}\varphi$.

If the phase function is independent of θ then the scattering is isotropic i.e. equal scattering in all directions, otherwise the scattering is anisotropic. A measure of the anisotropy is given by the coefficient of anisotropy g defined as in equation (2.5)

$$g = \frac{\int_{4\pi} p(\theta)\cos(\theta)\mathrm{d}\omega}{\int_{4\pi} p(\theta)\, \mathrm{d}\omega} \qquad (2.5)$$

The scattering is forwarded for the value of g = 1, and is back warded for g = -1.

When both scattering and absorption take place, some dimensionless parameters can be defined [Niemz 2002]. The first parameter is the *optical albedo*, a, given by equation (2.6).

$$a = \frac{\mu_s}{\mu_a + \mu_s} \qquad (2.6)$$

This parameter illustrates how significant scattering is compared to absorption.

For a = 0 attenuation is completely due to absorption and for a = 1 only scattering occurs. For red and near infrared wavelengths in tissue a = 0.5 [Niemz 2002, p.25].
The second parameter is the optical depth, given by equation (2.7)

$$D = \int_0^s (u_a + u_s)\, \mathrm{d}s' \tag{2.7}$$

where ds' is a segment of the optical path and s is the total length of the optical path. The optical depth is in the range of 800 μm to 1400 μm for red and infrared wavelengths in tissue [Welch & Gemert 1995].

When considering turbid media, the normalization of the phase function is given by Equation (2.4) is modified to equation (2.8) [Niemz 2007, p.26]

$$\frac{1}{4\pi} = \int_{4\pi} p\,(\theta)\; d\omega = a \tag{2.8}$$

Henyey-Greenstein phase function [Niemz 2002, p.23] is commonly used rather than the other theoretical phase functions, which is derived by equation (2.9)

$$p(\theta) = a\,\frac{1-g^2}{(1+g^2-2g\cos(\theta))^{3/2}} \tag{2.9}$$

Regarding the transport of photons through an absorbing and scattering immensity, a mathematical description of the transport of light through tissue can be derived.

The quantity to illustrate is the radiance J(r, s) with the units of $\mathrm{Wcm}^2\ \mathrm{sr}^{-1}$, the governing differential equation is denoted as the *transport equation* [Ishimaru 1989, p.2210-2215], given by equation (2.10)

$$\frac{\mathrm{dJ\,(r,s)}}{\mathrm{ds}} = -(u_\mathrm{a} + u_s)\mathrm{J(r,s)} + \frac{u_\mathrm{s}}{4\pi} \int_{4\pi} p(\mathrm{s},\mathrm{s}')J(\mathrm{r},\mathrm{s}')\mathrm{d}\omega' \tag{2.10}$$

where r denotes coordinates, s' & s denote directions, $p(s, s')$ is the phase function.
In equation (2.10), the photon scattered from a direction s to a direction s′, for symmetric scattering about the optical axis $p(s, s') = p(\theta)$, and dω is the fundamental solid angle.

It is stated that the change of radiance in a given direction is equal to the subtraction of the absorption and scattering of photons is added to the scattering of photons from other directions into this direction. This equation is an introduction for building numeric simulations of light propagation using Monte Carlo methods. The optical properties of tissue are required to understand pulse oximetry.

2.2.4 Phase function

As human tissue is optically inhomogeneous turbid media, light is propagated and scattered in the visible range. That is commonly described by the Boltzman Transport equation as described in equation (2.10), in the form of an absorption coefficient μ_a, scattering coefficient μ_s, and scattering phase function [Tuchin 2002, p.312-313].

In soft tissues, typical values for the coefficients are $\mu_a \approx 0.5$ to 5.0 cm^{-1}, $\mu_s \approx 0.2$ to 400 cm^{-1}, and $0.8 < g < 0.99$ in the visible and near infrared range. The shape of the phase function is not vital when the diffusion approximation to the Boltzmann equation is utilized for the problem.

2.3 Pulse oximetry

The pulse oximetry is based on spectro-photometry i.e. measurement of the absorptive or extinction coefficient of a given substance at particular wavelengths. In pulse oximetry only two different wavelengths are used. The saturation of oxygen in blood, SpO_2, is defined by the concentration of oxygenated haemoglobin (HbO_2) to the ratio of the sum of oxygenated and deoxygenated (Hb) haemoglobin [Webster 1997, p.29], as in equation (2.11)

$$\mathrm{SpO_2} = \frac{\mathrm{HbO_2}}{\mathrm{HbO_2} + \mathrm{Hb}} \times 100\% \tag{2.11}$$

The saturation of arterial blood (SpO_2) is measured in a pulse oximeter only. Arterial SpO_2 is a parameter measured with oximetry and is normally expressed in percentage. The ratio of the concentration of HbO_2 to the concentration of Hb and HbO_2 is called the functional oxygen concentration, which is examined with a pulse oximeter. The ratio between HbO_2 and the total haemoglobin is called fractional oxygen saturation [West 2008, p.15 -18]. In general, pulse oximeters measure functional saturation by transmitting two wavelengths of light that are differentially absorbed by oxyhaemoglobin and de-oxyhaemoglobin, commonly referred to as SpO_2, which is understood as "arterial oxygen concentration".

Oxygen supply to tissues or organs of human body depends on haemoglobin concentration, haemoglobin oxygen saturation, and dissolved oxygen in plasma and tissue perfusion [Webster 1997, p.8]. The shortage of oxygen causes most illness and degenerative disease. A person may suffer from hypoxia when there is an insufficient delivery of oxygen to human body tissue. Oxygen insufficiency in the body tissue is a definite sign for disease which results in tissue death. An abnormally low amount of oxygen in the blood may lead to the occurrence of hypoxemia which is understood as the respiratory failure. Severe hypoxemia occurs when oxygen saturation drops below 80 percent [Mayo Clinic 2008]. Blood oxygen is measured by an arterial blood test or by an oximeter. The blood is pumped through arteries, and is pumped out from the heart into the vessels at every single heart beat. That causes the pressure increases, which results in the widening of vessels, thus making room for more blood.

The absorption of light in blood changes with path length and concentration over time because of heart beats. The increase in pressure results in the increase in absorbance. When the blood pumped from the heart is oxygenated, the concentration of oxygenated haemoglobin is maximum. During the respiratory process, the oxygenated haemoglobin is decreased and deoxygenated haemoglobin is increased [Moyle 2002, p.12].

Photoplethysmogram, the optical measurement of cardiac rhythm is caused by changes in the volume of blood vessels due to blood pressure. The cardiac cycle is formed by the term "systole" which is the stage when the ventricles of heart are contracting resulting in blood being pumped out to the lungs and the rest of the body; while the term “diastole” is the stage when the ventricles of the heart are relaxed and not contracting. The heart muscle contracts due to tiny electric "shock" spreads speedily in the heart. The heart has electrical impulses flowing through the heart cells at a speedy rate. The heart muscle contracts when these electrical impulses hit muscle cells.

There are cells called pacemaker cells specialized in producing electricity in the heart [Fish & Geddes 2009, p.223]. The electricity is running within the muscles, which is responsible for such contraction. By rapidly changing their electrical charge from positive to negative and back, these cells produce electricity. The constant absorbance such as skin, tissue, bones together with the venous blood and the non-pulsating arterial blood will be denoted as the DC level. The alternative signal, which is denoted by symbol AC, is due to a pulsate blood flow. The diastole in the cardiac cycle is corresponded by the lowerness of absorption and higherness of transmitted intensity at the minima. That point is called as T_{dia}. From this point the absorption is more speedily increased to the maxima. Because of the occurrence of a heartbeat, the transmittance is decreased to minima, T_{sys}. That factor corresponds to the systole in the cardiac cycle. The absorbance is more gradually decreased. The dichotic notch, which is known as a small disturbance in contrast to the forgoing, increases [Topol & Califf 2006]. Since the heart has four chambers, the heart beat is twice. The frequency of the main beat is considered as the pulse. Ever since more light will be scattered in the forward direction, and the transmitted signal is greater than the reflected signal. During systole, the optical path length is not the core reason of the difference in the absorbance of light. The variation would be less when the diameter is changed.

Red blood cells are biconcave disks in shape [Webster 1997, p.51]. For the duration of diastole, the major axis of red blood cell is aligned parallel to the flow of blood, but for the period of systole, the direction is shifted as their major axis is perpendicular to the direction of the blood flow to become adjusted to the pressure variation. The contemporary pulse oximeter is based on the measurement of the difference in the absorption spectrum of oxygenated haemoglobin and deoxygenated haemoglobin. The saturation of oxygen in haemoglobin is measured by using the pulsatile variation in the transmitted light to separate the arterial contribution [Aitkenhead, Smith & Rowbotham

2007, p.217]. When the haemoglobin molecule is saturated with oxygen then one has oxy- haemoglobin or HbO_2. The lack of oxygen in haemoglobin molecule is deoxy-haemoglobin (Hb). These two have different spectra. The absorbance of oxy-haemoglobin and deoxy-haemoglobin is the same (isosbestic point) for the wavelengths of 548 nm, 568 nm, 578 nm and 805 nm [Welch & Gemert 1995, p.33]. In the given range, Hb is the strongest absorber for the wavelengths lower than 805 nm, and HbO_2 is the strongest absorber for the wavelengths higher than 805 nm. It is possible to measure the saturation of oxygen from the difference absorption coefficient of Hb and HbO_2 by determining the photoplethysmograms at two different wavelengths. The development of pulse oximetry was stimulated by the differences in the absorption spectra of oxy-haemoglobin (HbO_2) and the deoxy-haemoglobin in the visible and the near infrared spectral ranges.

Light scatters mostly in forward direction rather than scattering in all directions. The difference in amount of scattering and absorption is due to the different optical properties at different layers of human tissue [Graaff 1993]. Due to the poor signal to noise ratio of reflectance pulse oximeter, its accuracy level is much lower than the accuracy level of transmittance pulse oximeter. For this reason, the transmittance pulse oximeter is much more preferred to be designed in this research.

2.3.1 Oxygen saturation from photoplethysmogram

At two different wavelengths, the saturation of oxygen is observed by calculating the ratio of two photoplethysmograms. The function of the physical measured quantities of oxygen saturation is therefore the calibration of the designed instrument based on Beer-Lambert's law which demonstrates the implementation of the important signal processing steps. It was found that the optical properties of blood were significantly different from the individual data of human tissues [Tuchin 2007, p.328-337]. Beer-Lambert's law gives therefore only an estimated calibration. As discussed, the absorbance is not only unreliable as a function of path length, but also as a function of a change in the axis of the red blood cells. It was found that human tissue was a greatly forward scattering medium [Ishimaru 1991]. The variations in time are by reason of absorption of light inside the tissue. The intensity of the absorption is high in the forward scattering.

Beer- Lambert's law states that the intensity I of light (or other electromagnetic radiation) decreases exponentially with the distance d that it enters an absorbing medium such that [Webster 1997, p.40]

$$T = I_0 \exp(-\varepsilon C d) \tag{2.12}$$

In equation (2.12) T is the intensity on the other side of the medium (the transmission), I_0 is the intensity of the incident light, and ε is the molar extinction coefficient in $mM^{-1}cm^{-1}$, C is the concentration of the absorbent substance, and d is the optical path length through the medium and $\varepsilon C = \mu_{a} + \mu_{s}$.

When ε and C are constant, the transmission (T) is only a function of the optical path length (d). Then the absorbance A is defined taking the ln of equation (2.12) as in equation (2.13) [Webster 1997, p.41]

$$A = \ln \frac{T}{I_0} = \varepsilon C d \tag{2.13}$$

When light is shone through tissue, the transmitted intensity varies between a maximum at diastole T_{dia} and a minimum at systole T_{sys}. At diastole the intensity is given by equation (2.14)

$$T_{dia} = I_0 \exp(-\varepsilon_{DC}\, C_{DC}\, d_{DC}) \exp(-(\varepsilon_{HbO_2}\, C_{HbO_2} + \varepsilon_{Hb} C_{Hb}) d_{dia}) \tag{2.14}$$

Where DC is constant, which is referred to the absorbance of skin, bones, tissue, etc. T_{dia} is the intensity of transmitted light at diastole, ε_{DC} is molar absorbance of DC component medium, C_{DC} is concentration of DC component medium, d_{DC} is the optical path length of DC component medium, ε_{HbO_2} is molar absorbance of deoxygenated haemoglobin, C_{HbO_2} is concentration of oxygenated haemoglobin, ε_{Hb} is molar absorbance of deoxygenated haemoglobin, C_{Hb} is concentration of deoxygenated haemoglobin, d_{dia} is effective path length at diastole.

At systole, the transmittance is given by equation (2.15),

$$T_{sys} = I_0 \exp(-\varepsilon_{DC} C_{DC} d_{DC}) \exp(-(\varepsilon_{HbO_2} C_{HbO_2} + \varepsilon_{Hb} C_{Hb}) d_{sys}) \tag{2.15}$$

The transmittance is measured as a function of time of two different wavelengths in pulse oximetry. The absorbance of the DC components (skin, tissue and bones), sensitivity of the photo detector, and the emitted light intensity from the light sources vary at different wavelengths.

To solve out these variations, the transmitted intensity must be normalized with respect to the maximum transmittance i.e. transmittance at diastole for each of the two wavelengths, thus equation (2.16) is formulated,

$$T_N = \frac{T}{T_{dia}} \tag{2.16}$$

where *T* is the transmitted intensity as in equation (2.12)

During one cardiac cycle the optical path length, d, changes from d_{dia} to d_{sys}.
By substituting d_{sys} with $d_{dia}+\Delta d$ in equation (2.15) and dividing with T_{dia} as described in equation (2.14) to get the normalized systolic transmittance as in equation (2.17), [Webster 1997, p.48]

$$T_{N,sys} == \exp(-(\varepsilon_{HbO_2} C_{HbO_2} + \varepsilon_{Hb} C_{Hb}) \Delta d) \tag{2.17}$$

The ratio between the normalized transmittance for red (r) light T_N,r and infrared (ir) light T_N,ir varies as a function of the absorbers present in the arterial blood (AC component). From equation (2.13), we therefore have equation (2.18) [Webster 1997, p.50]

$$R_{os} = \frac{\ln T_{N,sys,r}}{\ln T_{N,sys,ir}} = \frac{A_r}{A_{ir}} \tag{2.18}$$

Where A_r is the absorbance for the red light and A_{ir} is the absorbance for the infrared light by the AC component. When equation (2.11) is rewritten to get the arterial blood only, then equation (2.19) is formulated

$$C_{HbO2} = SaO_2 \ (C_{HbO2} + C_{Hb}) \tag{2.19}$$

Similarly, the concentration of Hb can be written as in equation (2.20):

$$C_{\mathrm{Hb}} = (1 - \mathrm{SaO_2})(\mathrm{C_{HbO2}} + \mathrm{C_{Hb}}) \tag{2.20}$$

Using the superposition principle the total normalized absorbance of HbO_2 and Hb, at one specific wavelength, equation (2.13) becomes equation (2.21),

$$A = (\varepsilon_{\mathrm{HbO2}}\, C_{\mathrm{HbO2}} + \varepsilon_{\mathrm{Hb}}\, C_{\mathrm{Hb}})\, \Delta d \tag{2.21}$$

Adding the two equations (2.19), (2.20) of the two concentrations in equations (2.21) gives (2.22),

$$A = (\varepsilon_{\mathrm{HbO2}}\, \mathrm{SaO_2}\, (C_{\mathrm{HbO2}} + C_{\mathrm{Hb}}) + \varepsilon_{\mathrm{Hb}}(1 - \mathrm{SaO_2})(C_{\mathrm{HbO2}} + C_{\mathrm{Hb}}))\, \Delta d \tag{2.22}$$

This is rearranged to equation (2.23),

$$A = (\varepsilon_{\mathrm{HbO2}}\mathrm{SaO_2} + \varepsilon_{\mathrm{Hb}}(1 - \mathrm{SaO_2}))(C_{\mathrm{HbO2}} + C_{\mathrm{Hb}})\, \Delta d \tag{2.23}$$

Equation (2.18) gives equation (2.24) as:

$$R_{\mathrm{os}} = \frac{A_{\mathrm{r}}}{A_{\mathrm{ir}}} = \frac{\varepsilon_{\mathrm{r,HbO2}}\, \mathrm{SaO_2} + \varepsilon_{\mathrm{r,Hb}}\, (1 - \mathrm{SaO_2})}{\varepsilon_{\mathrm{ir,HbO2}}\, \mathrm{SaO_2} + \varepsilon_{\mathrm{ir,Hb}}\, (1 - \mathrm{SaO_2})} \tag{2.24}$$

It is noted that Δd is canceled out. After algebraic manipulation, the equation is finalized as in equation (2.25)

$$\mathrm{SaO_2}\, (R_{\mathrm{os}}) = \frac{\varepsilon_{\mathrm{r,Hb}} - \varepsilon_{\mathrm{ir,Hb}} R_{\mathrm{os}}}{\varepsilon_{\mathrm{r,Hb}} - \varepsilon_{\mathrm{r,HbO2}} + (\varepsilon_{\mathrm{ir,HbO2}} - \varepsilon_{\mathrm{ir,Hb}}) R_{\mathrm{os}}} \tag{2.25}$$

The arterial oxygen saturation to the ratio, R_{os}, between two photoplethysmograms recorded with red light and IR light can be calculated by using equation (2.25). This framework proposes that the ratio R_{os} is ≈ 0.5 for an oxygen saturation of 100 %.

In practice, the clinical empirical formula for calculating SpO_2 is as follow.

$$S = (a - b)\, R \tag{2.26}$$

a and b are coefficients when pulse oximeter is being calibrated [Sloten et.al., 2008].

2.3.2 Review of pulse oximeter

Figure 2.1: The Nellor N-65 (OxiMax N-65) handheld pulse oximeter for spot checks or continuous monitoring in virtually any setting. The image courtesy of www.nellcor.com

Pulse oximeter sensors are implemented in either a transmittance or reflectance design. In both designs, LED light is the light source of pulse oximter. Light transmitted after travelling through tissue (e.g. finger, toe, and ear) is detected by the photo-detector which is on the opposite side. Reflectance sensors are implemented with the emitter and detector in the same plane. The amount of light reflected (back scattered) from the tissue is measured to monitor the saturation of oxygen. The intensity of back scattered light depends on both optical absorption spectrum of the blood and the structure of pigmentation of the skin [Webster 1997, p. 86-88]. Although reflected pulse oximeter has advantages that can be applied at more sites such as forearm, forehead, chest, thigh and cheeks, the accuracy of it may be poorer than transmittance pulse oximeter due to signal-to-noise ratio, smaller heart-related pulsation, and less reliable electronics analysis. The smaller fraction of the illuminated light of reflectance pulse oximeter is detected by photo-detector compared to that of transmitted pulse oximetry [Moyle 2002, p.31-32]. All pulse oximters become inaccurate when SaO_2 is $< 75\%$ [Moyle 2002 p.144]. During movement and low perfusion effect the accuracy of pulse oximeter may result in difficulties in making medical decisions.

The technology of clinically used pulse oximeters have been modified and development recently. The clinically used Nellcor N-65 pulse oximeter shown in figure (2.1) automatically adjusts the signal processing while the quality of incoming signal is degraded. The advanced signal processing in the algorithms mechanically extends the amount of data required for measuring SpO_2 and pulse rate depending on measuring conditions [N-65 Operator's Manual, p.20].

2.4 Core electronic components of pulse oximetry

One of the important issues is the choice of electronic components. The two different LEDs, photodiode and operational amplifiers have been used in this study. Normally, the AC level arising from the pulse is considerably lower than the DC level together with a noise signal predictable to be rather high compared to the AC part of the signal. The wavelength of Red LED must be in the range of the narrow emission around 600 nm since the ratio of oxygenated and deoxygenated haemoglobin has a peak at 600 nm. For the transmission mode, the conventional LEDs of 600 nm, 940 nm and 950 nm wavelength must be utilized.

The noise occurs from electrical connections, photo detector and amplifier, also from motions of the finger relative to the light sources and detector, and from the scattering nature of photons moving through the body, which is continuously varying.

The noise is generated both from electrical noise and movements of finger. The noise is also amplified by the amplifier. The short noise is generated by photodiode because of the discreteness of the incident photons, while dark current noise is produced due to total thermal agitation of the carriers. The noise due to DC photocurrent is to be eliminated by the digital filter. The noise due to the motion of finger and the scattering nature of photons has to be reduced by cautious measurements. The sample data before amplification and after amplification will be presented in Figure (4.13) and (4.14) of chapter 4. The detail of electronic components used in the developed pulse oximetry is discussed in chapter 4.

2.4.1 Sensors

Figure 2.2: Red LED (L-53LSRD)

The RED and IR LEDs as light sources and a photo detector are the critical components in pulse oximetry. A good quality of the red LED must be utilized to achieve the narrow emission around 660 nm (Appendix C.1, p.149), Gallium Aluminum Arsenide red light emitting diode L-53LSRD, a super bright red source color shown in figure (2.2) and TSAL4400, a high efficiency infrared emitting diode shown in figure (2.3) are used.

These GaAlAs emitters achieve about 100 % radiant power improvement at a similar wavelength (Appendix C.2, p.151). The forward voltage at low current and at high pulse current roughly corresponds to the low values of the standard technology. Therefore these emitters are ideally suitable as high performance replacements of standard emitters.

Figure 2.3: Infrared LED (TSAL 4400)

The silicon photodiodes have good preference of light detection equipment. Hamamatsu S 1133 -14 photodiode shown in figure (2.4) was used for the reason of having a big active area and high sensitivity which is important to get a measurable value of 1 micro-ampere (1μA) of DC signal. The quantum efficiency is the number of electrons that can be detected as a photocurrent divided by the number of the incident photons. The quantum efficiency of the S1133 - 14 photodiode is high [Appendix C.3, p.153].

In general, there are three types of photo detectors: they are photomultiplier tubes, charge coupled devices (CCD), and photodiodes. The choice of light detector in pulse oximetry is a silicon PN diode or pin diode for its good performance and accurate measurement for SpO_2. The gain and quantum efficiency are the two key numbers of a photo detector. The gain is meant by an internal amplification resulting in a higher photo current. The quantum efficiency is defined as the percentage of photo generated electrons that essentially contribute to the photo current. Photodiodes are normally fabricated in silicon since this gives a lower dark current due to a larger energy difference (≈ 3 eV) at the center of the Brillouin zone compared to Germanium (≈ 0.7 eV). One of the reasons of choosing a silicon photodiode is that it can function either under an open circuit condition or under a short circuit condition where a photodiode can be operated with zero bias or reverse bias. High magnitude of noise is resulted by high magnitude of dark current in reverse bias condition. For that reason, zero bias is selected to operate in photodiode.

Figure 2.4: S1133 -14 photodiode

In pulse oximetry, a light source is the most prominently involved being small and powerful to infiltrate more than at least one centimeter of human tissue and to robust in a miniature probe. For that reason [Moyle 2002, p.17-19], LEDs are utilized in pulse oximetry. A memory in a sensor is utilized to accumulate various coefficients for a physiological parameter such as pulse rate and blood oxygen. The studied design is reusable and it does not require an adhesive to attach to the skin.

2.4.2 Microcontroller

In this study, a high-performance, high-speed, multichannel 8-bit microcontroller is used. The functions of the microcontroller in the pulse oximetry are as follows:

- Controlling the source LEDs
- Convert the sensor output into the digital form
- Pass the data onto a suitable form
- Protocol handling

Figure 2.5: PIC18F452 microcontroller

Microchip PIC18LF452 microcontroller shown in figure (2.5) is chosen for the reason of having 8-channel 10-bit ADC (Analog to Digital Converter), Capture/Compare/PWM (Pulse Width Modulation) CCP modules, 4 Timer/Counter modules, Addressable USART (Universal Synchronous Asynchronous Receiver Transmitter module) and External Interrupt pins among many peripheral features with 32 kilobytes of Flash Program Memory, 1536 bytes of RAM (Random Access Memory) and 256 bytes of EEPROM (Electrically Erasable and Programmable Read Only Memory) built in-chip (Appendix C.5, p.158. It performs digital signal processing algorithm, detects arterial blood pulsations, detects and rejects motion artifacts, calculates SpO_2 and heart rate values, and filters and scales the real time arterial blood pulsatile waveform (plethysmogram). It also controls the graphics the LCD display.

2.5 Summary

In this chapter, the optical properties of tissue and the four parameters of the basic optical properties of tissue have been detailed. The absorption spectra of tissue have been discussed and the attenuation of light at a single wavelength has been described by Beer-Lambert's law. The complex derivations with the transport equation have been presented. It has been found that the proper choice of wavelengths is the most important issue for pulse oximetry. The theory of pulse oximetry has also been explained. The derivation of formula relating the arterial oxygen saturation with red light and infra-red light has been created based on the theory of tissue optics. The core electronic components of pulse oximetry are discussed.

CHAPTER 3: PLANNING AND DESIGN

3.1 Introduction

The previous chapter discussed the tissue optics and the concept of pulse oximetry. It has been stated that the transmitted pulse oximetry has some advantages over the reflectance pulse oximetry. In this chapter, the experimental setup of the planning and design of the transmitted pulse oximetry is discussed. The trial experiments are described in the first section. An overview of the electronics setups will be discussed in the following section.

3.2 Designs of oximetry

At the beginning of the experimental setup, several reflectance and transmittance pulse oximetry designs were considered based on the literature review. Two light sources with different wavelengths and a photo detector which is silicon photodiode are the essential components in pulse oximetry. The transmission mode pulse oximetry is considered because it is supposed to be simpler and easier compared to the reflectance mode oximetry [Webster, 1997, p.86-89].In addition, it is also the most common type of finger pulse oximeter.

It has been described in the literature that transmission mode pulse oximetry should be easier to accomplish than reflectance pulse oximetry. The instrumental system was assembled with a MPLAB platform [Microchip], the augmentations therefore could be easily accomplished. The drive current was regarded as specifically as the power consumption is a major limitation. Several conditions considered in the design setup are the different types of LEDs and photodiodes with respect to signal/noise level, photoplethysmographic signal as a function of current supply, and power usage.

The next step is shown in figure (3.6) which is the initial test board design of pulse oximetry. It is designed to test the function of RED and IR LED without operational amplifier. The changes in the data of ADC in photodiode are also tested by that board.

Figure 3.1: The light from IR LED captured on mobile phone screen.

The mobile phone camera is used to test the function of IR LED as the infrared light can be seen on the mobile phone screen as shown in figure (3.1). When RED and IR LED functioned well with the initial test board, the design of pulse oximetry is fabricated. As discussed in chapter 2, pulse oximetry builds up the principles of either transmittance light or absorbance light, therefore pulse oximeter is essentially needed to be implemented with the light emitters (LED circuitry) to emit light through the area of human tissue (finger) and a photodetector (either phototransistor or photodiode) to convert the transmitted incident light into a current. The current is provided in accordance to the amount of transmitted light detected and is converted to a voltage by the convertor.

Two different types of LEDs and silicon photodiode with reference to signal/noise level, power usage, and plethysmographic signal and the battery are used to design the system. At the beginning of the experimental design, the block diagram shown in figure (3.2) has been developed.

Figure 3.2: Block diagram of designed pulse oximetry

Both red and infrared LED, and a silicon photodiode are used to mount on a plastic clip. The photodiode which is the key input device of the pulse oximetry system senses the intensity of light emitted by each LED after the light passes through the human tissue. After capturing the DC component and AC component of the red and infrared light intensity, the photocurrent supplied by photodiode is converted to a voltage by the microcontroller. The analog signal output of voltage is very small in amplitude. Therefore the operational amplifier is utilized to amplify the output voltage. The microcontroller system turns each LED on and off alternately. The transistors in the circuit regulated the light intensity from the consequent LED. The operational amplifiers not only amplify the signals but also reduce the noise of the circuit. This is discussed in chapter 4.

The amplified signals are converted into digital format by the microcontroller. The basic mathematics of pulse oximetry is derived through an algebraic manipulation of the Beer-Lambert's Law [Yelderman & Corenman 1983, p. 328-341]. PIC18F452 microcontroller enables embedded software program and time multiplex operation of the light sources and receiver channels. The mean value is calculated and dark current is subtracted in software, and the data are transmitted via serial RS232 or wireless interface [Timm et al. 2009]. The pre-calculated data is sent to a BSN mote via USART port and then relays to the hand-held device. The blood oxygen saturation SpO_2 and the heart beat rate are displayed on an LCD or PC. The display circuitry will be discussed in details in chapter 4. The initial design instrumentation of pulse oximetry is shown in figure (3.3).

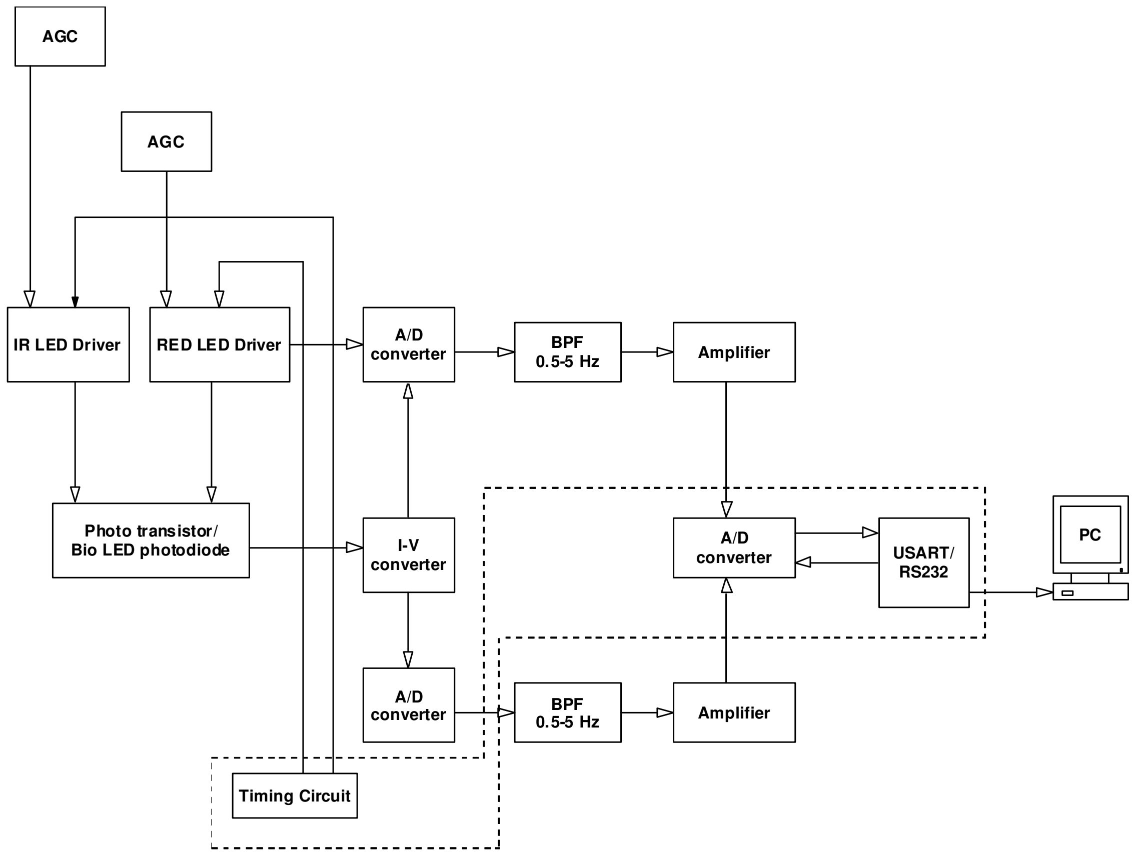


Figure 3.3: Initial design instrumentation of pulse oximetry.

The design of pulse oximetry sensor consists of both red and infrared LEDs with peak emission wavelengths of 660 nm and 940 nm correspondingly, and a silicon photodiode. When each LED is turned on, the light is emitted and passed through the human tissue. The photodiode is the most important input device of the pulse oximetry system which senses the intensity of light emitted by each LED after the light passes through the tissue. The initial circuit design of pulse oximetry is described in figure (3.4).

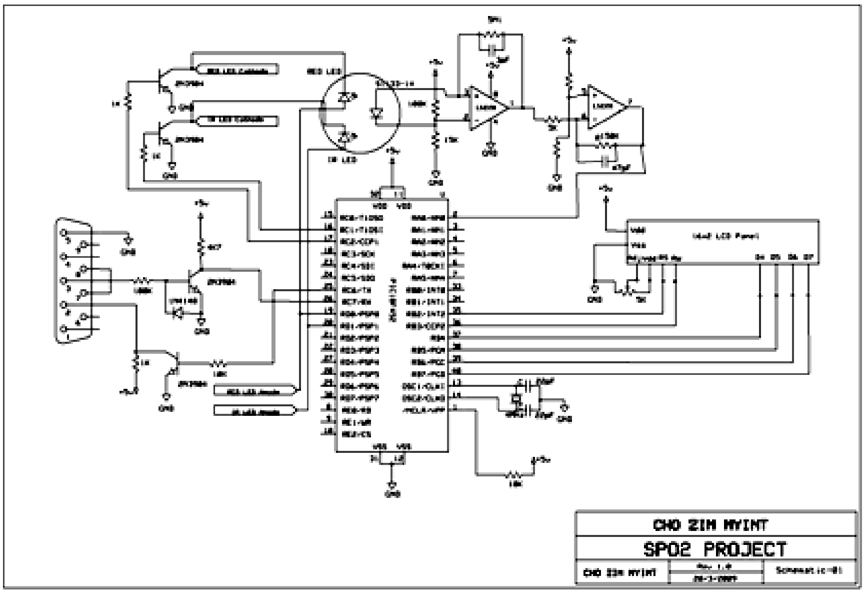


Figure 3.4: Initial schematic diagram of pulse oximetry

The current is produced by the photodiode which is linearly proportional to the intensity of light. Each LED is turned on and turned off alternately by the control of microcontroller. The light intensity emitted by the corresponding LED is adjusted by automatic gain control (AGC) circuit. The output of photodiode is sampled by the pulse oximetry and the ambient light is deducted. Switching time is meant by the time taken for an LED to switch from its ON state to its OFF state or vice versa. The initial test board to test LEDs is shown in figure (3.5). The switching time of most LEDs is 1 nanosecond. In this designed device, switching must be much faster because of the very low frequency of the arterial pulsatile waveform (~ 1Hz). Timing circuit is used to supply, approximately 50µs pulses to the red and infrared LED drivers at the repetition rate of 1 kHz. High-intensity light outputs are obtained by the infrared LED with currents of up to 1 A over a low duty cycle. The current produced by the intensity of transmittance light was taken in P-N junction in the photodiode and is converted to a voltage in the I-V converter which performed as a low-pass filter intended to remove various high frequency signals. The noise of the circuit is reduced by the low-noise operational amplifier (Op-Amps).

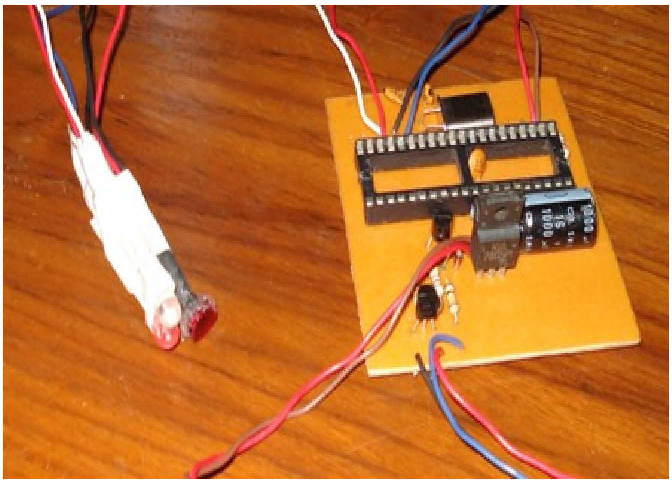


Figure 3.5: Initial test board testing LEDs

The output voltage is extremely small; it was therefore amplified. The amplification is evaluated using the standard formula for inverting amplifiers. The resulting signals are the output signals with the symbolized signal of the cardiac-synchronous information in the waveforms. Before the resulting signals are converted to digital format, it is amplified by the microcontroller. SpO_2 is calculated by dividing the logs of the rms values as in equation (3.1).

$$R = \frac{\log(I_{ac})\lambda_1}{\log(I_{ac})\lambda_2} \qquad SpO_2 \propto R \qquad (3.1)$$

where R is the ratio of pulse-to-constant proportions at different wavelengths of light λ_1 and λ_2.

The refined circuitry shown in figure (3.6) is designed.

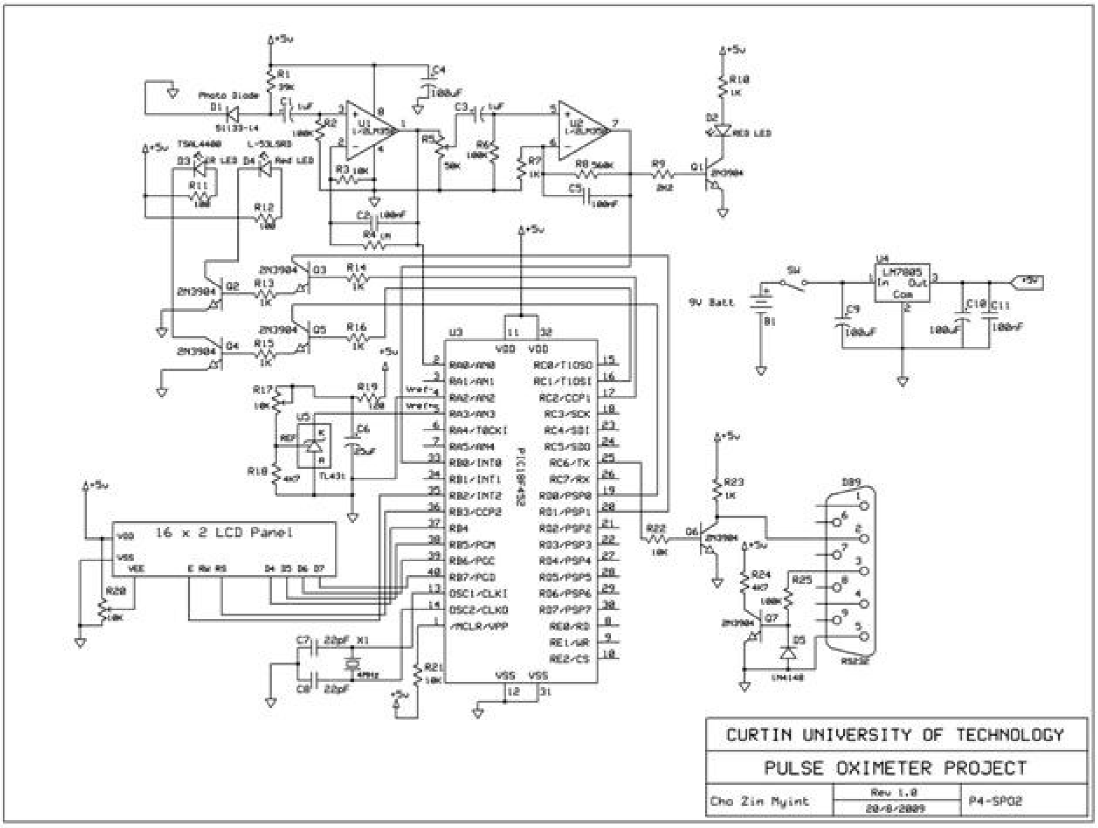


Figure 3.6: Refined circuit design of pulse oximetry

The heart beat is measured by counting the number of samples in 3 beats, since the sampling rate is 500 sps. During no motion conditions, the accuracy of the normal pulse rate is ± 3 per minute. The heart beat per minute is calculated by equation (3.2):

$$\text{Heart beats per minute } = \frac{500 \times 60}{\text{Samples Count}/\,3} \tag{3.2}$$

The pre-calculated data is sent to a BSN mote via USART port and then relayed to the hand-held device. SpO_2 level and the heart rate were displayed on an LCD. The real time samples were also sent via an RS232 to a PC. The assembly software codes are utilized to display data on LCD and the visual basic software program is used to display on personal computer (PC). For the heart beat sensing, a particular circuit was designed as shown in figure (3.7).

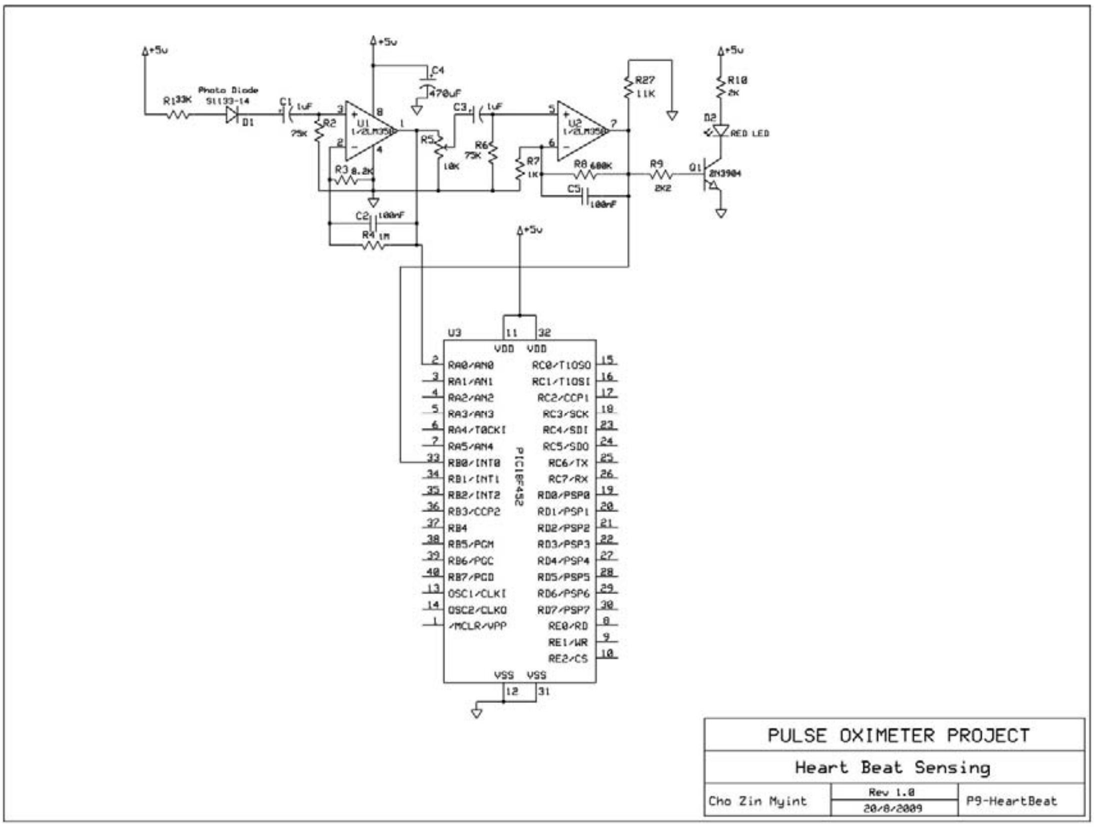


Figure 3.7: Schematic diagram of heart beat sensing circuit

When the light of each LED is incident across the finger, the peak-to-peak voltage is captured. The values are afterward converted into light intensity to determine SpO_2. The heart beat is detected at the same time with the oxygen saturation and displayed in real time on an oscilloscope.

After testing the designed system, it is realized that the power consumption is high. The power source (batteries) is needed to be changed frequently. The current flow must be reduced by replacing with higher resistor values. The values of current limiting resistors (R 11and R12) in figure (3.6) are required to be changed from 100 ohms (Ω) to 1 kilo ohms (kΩ). The signals are corrupted by noise although this system implementation is very simple to execute, the signals from this basic system are not sent properly. For this reason, a new circuitry scheme was designed and a new implementation of a refined

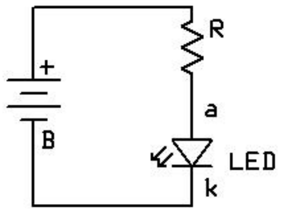


Figure 3.8: Schematic diagram of LED current limiting resistor

design was decided. The refined system or the finalized hardware design and implementation are discussed in detail in chapter 4**.**

3.3 Changes made in designing pulse oximetry

There are a number of changes made in the process of designing pulse oximetry in order to implement a further refined system. The changes are as follows:

3.3.1 LED current limiting resistors

Typical forward voltage of Red LED used in this project (L-53LSRD) shown in figure (3.8) is 1.85 V and the forward current is 30 mA. The formula $R = (V_S - V_F) / I$ is used to select a value of current limiting resistor (R) to get a maximum brightness of the LEDs without burning them, where

V_S = Supply Voltage (5 V)

V_F = Forward Voltage of LED (1.85 V)

I_F = Forward Current of LED (30 mA = 0.03 A)

Therefore, $R = (5 - 1.85) / 0.03 = 3.15/0.03 = 105\ \Omega$.

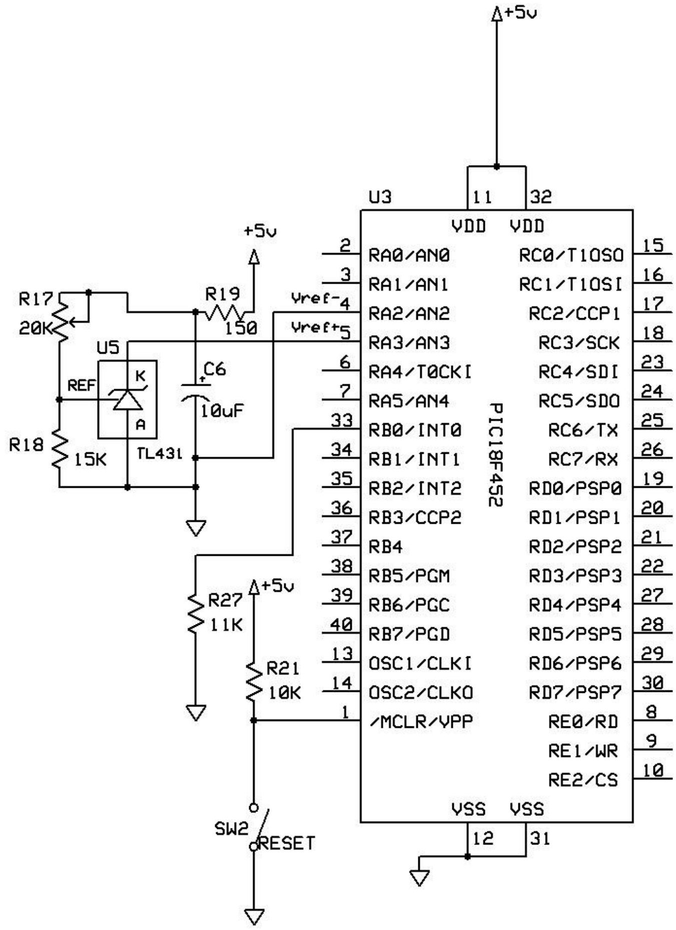


Figure 3.9: Schematic diagram of ADC module of PIC18F452

In the previous design, the resistor value of 100 Ω is used for R 11 and R12 in figure (3.6). According to the test results, there is no significant reduction of the LEDs' brightness when 1 kΩ resistors are used for R11 and R12, but the overall current consumption is considerably lower than the previous design values.

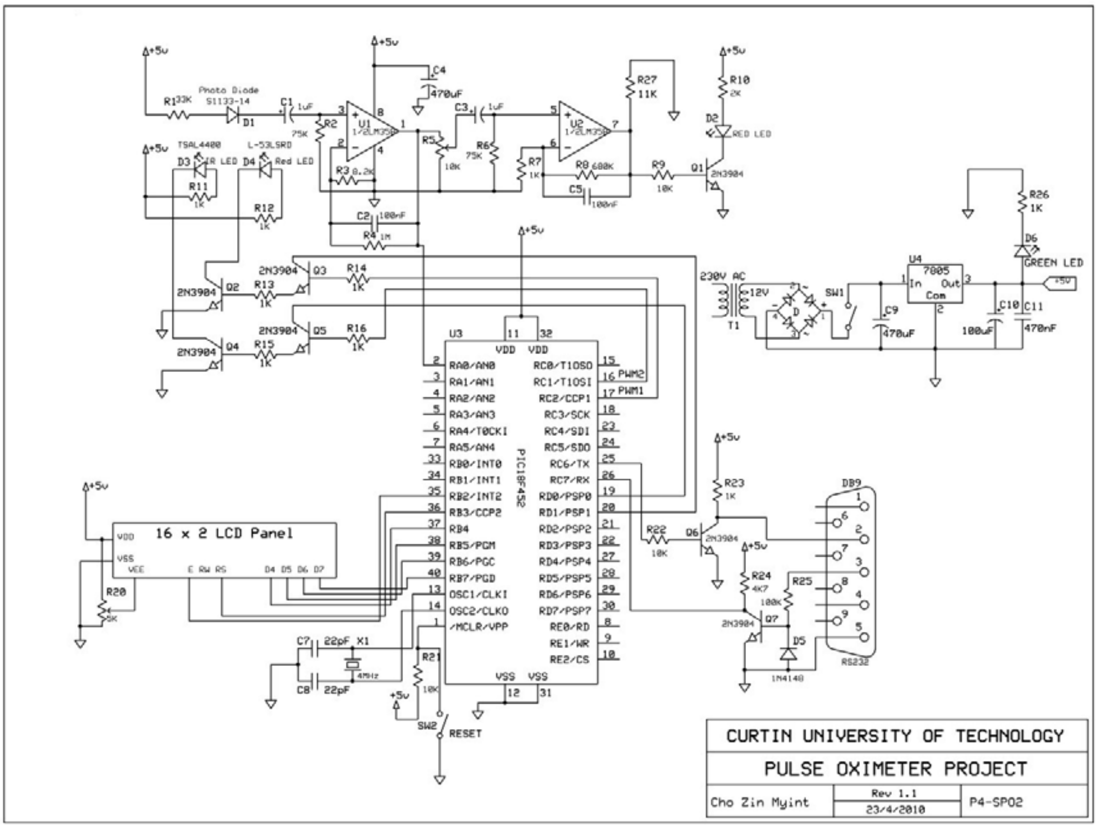


Figure 3.10: Schematic diagram of new design of pulse oximetry

3.3.2 Reference voltage (V_{ref}) for ADC conversion

The shunt regulator TL431 and its associated circuit delivering positive voltage reference ($Vref_+$) to ADC module of PIC18F452 in previous design is removed due to the reason of requiring constant adjustment to voltage reference potentiometer R17 (20 kΩ, Linear) with changing of ambient light condition in figure (3.9).

In the new design, $Vref_+$ is taken from V_{DD} (5 V Supply) and $Vref_-$ is taken from V_{SS} (Ground) which can be done by configuring in software without any physical connections in hardware as shown in figure (3.10). The advantages of this change are the reduction of the total component count, saving the board space and naturally consuming less overall current.

3.3.3. Method of sensing and calculating pulse rate

In previous design, the pulse signal is extracted from the second Op-Amp stage (pin7 of LM358) and fed to interrupt pin (pin 33, RB0, INT0) of microcontroller PIC18F452 in figure (3.7). The interrupt pin (pin 33, RB0, INT0) of microcontroller senses the rising edge of the AC signal (pulse signal) and counts the peaks and calculates the pulse rate in beats per minutes (bpm).

This calculating method of pulse rate is found to be vulnerable since interference with ambient light variation, movement of the finger and other electrical noises around the place of measurement. The pulse rate in bpm is sensed by lighting IR LED for 10 seconds in the present design. It records the changes of IR intensity received at Photodiode using ADC module and verifies the wave form in software, then calculates the pulse rate using mathematical routines in software. The details of mathematical routine of pulse rate calculation will be discussed in chapter 4.

3.3.4 Sequence of display on LCD

To achieve more user-friendly process, the sequence of displaying messages on LCD is simplified using the latest method. The sequences of display on LCD after power switch is ON are as follows:

a. "PLEASE WAIT…." – Asks the user to wait for system initialization and completion of collecting Raw Data (i.e. without finger inside the finger clip).
b. "IR–0765, RED–0743" – Shows examples of collected data. The actual numbers shown may be varied.
c. "PUT UR FINGER" – Asks the user to place the finger of the person whose SpO_2 level and Pulse Rate are to be measured.
d. "IR-0570, RED-0743" – Shows an example of collected data with finger inside the finger clip, the actual figures may vary.
e. "IRx-0080, Rx-0069" – Shows example of differences of IR and RED light intensity due to blood concentration blocked between LEDs and Photodiode Sensor. The actual figures may vary.

f. “SAMPLING” – Only IR LED is switched on for 10 seconds when collecting pulse data for BPM calculation.
g. “SPO_2-97.02%” “PULSE-0072BPM” This is an example of final readings displayed on LCD, actual figure may vary.

3.3.5 Error messages

If there are any erroneous situations arise in the process, the following error messages will be displayed on the LCD.

a. “CALIBRATION ERROR” – This message will appear when the value of the average data collected with finger inside the finger clip is more than the data without finger, which is abnormal.
b. “NO FINGER DETECT” – This message will be displayed when no finger is placed inside the finger clip after the message “PUT UR FINGER” is shown and allows the data collection process to continue.

3.4 The design specification of pulse oximetry

The design of pulse oximetry is embedded in (17 cm × 11 cm × 3 cm) portable plastic box. The length of the cable of the finger clip is 17.5 cm. The design of pulse oximetery is low-cost, low power consumption and light weight of 0.5 kilogram. The ease of use also makes the measurement convenient for the patient. The LCD of (6.5 cm× 1.5 cm) is mounted on the top of plastic box. The printed circuit board (PCB) of (4.4 cm × 8.5 cm) and the battery cabin of (5.5 cm × 2.5 cm) are placed in the plastic box. The designed pulse oximetery eliminates human error while providing accurate readings and faster results. The minimal maintenance is required so that it is able to last a minimum of five years. The probe is optimized for “spot check” rather than long term patient monitoring while it is able to use with a variety of patients.

3.5 Summary

In this chapter, the implementation of pulse oximetry designed has been discussed starting from the simplest design to a refined design. Along with the theoretical background, electrical instrumentation, the pulse oximetry device that will be capable of measuring the oxygen saturation of blood and heart beat rate is designed. The fundamental components of pulse oximetry are described and the explanation of the reason to choose the proper electronics is also included. The design specification of pulse oximetry has been described. The detailed descriptions of electronic components and the system implementation of both hardware and software will be presented in chapter 4.

CHAPTER 4: SYSTEM IMPLEMENTATION

4.1 Introduction

The initial implementation of pulse oximetry was discussed in chapter 3.The design was refined and the final design of pulse oximetry will be discussed in this chapter. The details of the implementations of both hardware and software will be described in their respective individual sections. In this chapter, all the setups for pulse oximetry measurements are investigated in details in figures. The results of the implementations will be presented in chapter 5.

4.2 Hardware implementation

Although various electronic components for the setups of design have been used, the best setups of the final work are found in this chapter. The hardware of pulse oximetry is implemented in (17cm×11cm × 3 cm) plastic box.

The pulse oximetry hardware comprises the following parts:

1. IR and Red LED driver
2. IR and Red LED light transmitter and light sensor photo diode (pin diode) assembled in an ordinary plastic clothespin converted into a finger clip.
3. Current to voltage converter / Light Source Amplifier
4. Processor (Microchip PIC18LF452 Microcontroller)
5. Display circuitry (LCD and RS232 interface with PC)
6. Power Supply

The overview architecture of the designed pulse oximetry is shown in figure (4.1). The detail of each component will be explained.

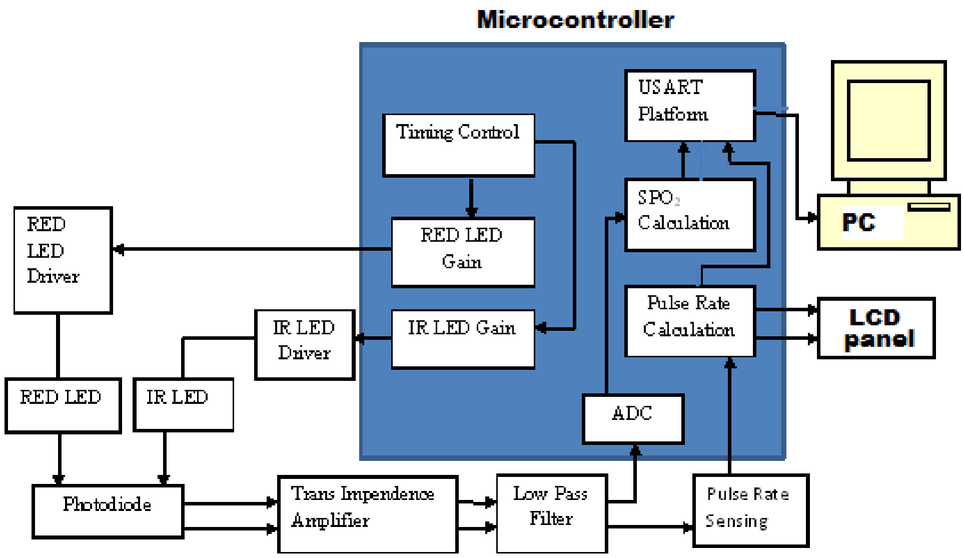


Figure 4.1: Overview architecture of the designed pulse oximetry.

4.2.1 IR and LED driver

The LEDs are powered directly by the power supply. When the switch is on, the emitted light intensity and the applied voltage following the diode characteristic in figure (4.2) is expressed by equation (4.1):

$$I(V) = I_s \exp(-\frac{eV}{k_B T}) \tag{4.1}$$

where V is the applied voltage, I_s is the reverse current of the diode, e is the electron charge, k_B is Boltzmann's constant, and T is the temperature.

The smallest forward bias current of 20 mA is operated by IR LED. According to the theory, the inverting and non-inverting inputs are maintained by the Op-Amp at the same voltage. But, the Op-Amp has nearly infinity entrance impedance resulting in zero current feedback.

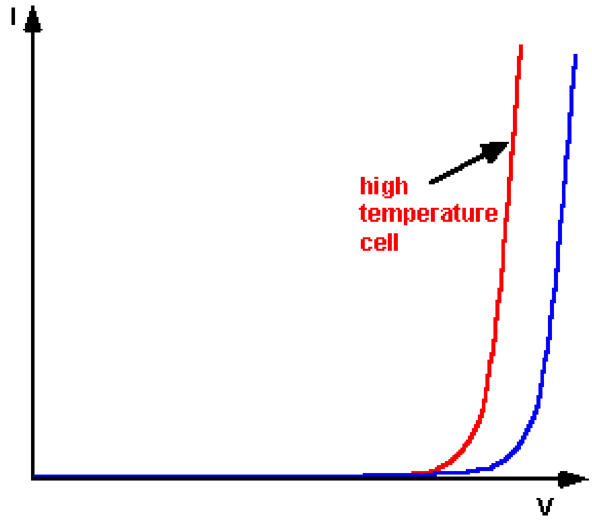


Figure 4.2: Diode law for silicon - current changes with voltage and temperature

It is clearly seen in figure (4.3) and figure (4.4) that the current through the diode is the same as the current through the resistor. According to Ohm's law, the current is given by I = V/R. This shows that the current is linearly controlled by the applied voltage. When the Op-Amp constantly adjusts to the current conditioned by the resistor, the temperature dependencies in the LED turn out to be irrelevant, then the current is unchanged; while it should be generally changed according to the Diode's law.

In figure (4.4), when LEDs are switched on, the light from the LEDs pass through the finger tissue and the photodiode detect the transmitted light at the other side of the finger. Figure (4.3) and figure (4.4) show Red and IR LED circuits involving the transmitting light through the finger tissue. A current flow through the resistor and LED is produced by 5 V power supply applied to LEDs.

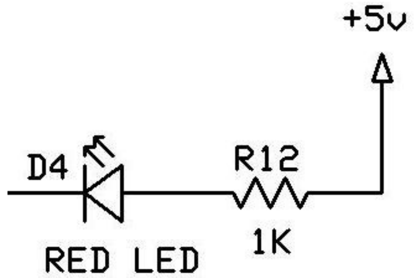


Figure 4.3: Circuit diagram of RED LED

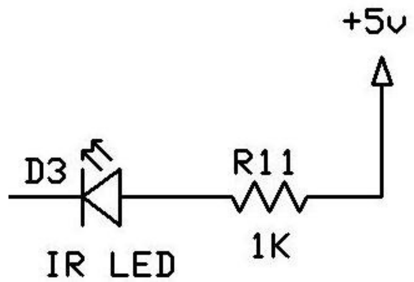


Figure 4.4: Circuit diagram of IR LED

By increasing the values of current limiting resistors (R11 and R12) from 100 Ω to 1 k Ω for IR and Red LEDs, the current through LEDs are reduced and thus the overall current consumption is then lessened. The brightness of the LEDs is not significantly reduced since it can be increased by increasing the duty cycle of pulse width modulation (PWM) in the software. Testing the 1 kΩ resistor shows no significant reduction in the brightness of the LEDs with improvement in stability of the whole process of sampling of SpO_2 and bpm results.

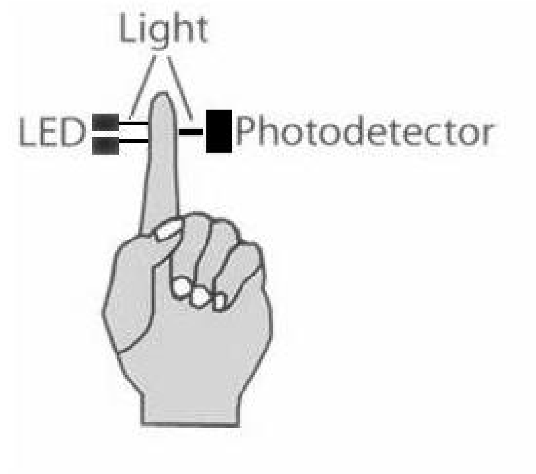


Figure 4.5: RED LED, IR LED and photodiode for the transmission probe pulse oximetry

When the light from LEDs is detected by the photodiode, the current is generated. This current flows through the resistor and a voltage is produced. Figure (4.6) describes the photodiode and current-to-voltage convertor which operate to detect the transmitted light through the finger and convert that current into a voltage. The low pass filter is implemented to maintain the frequency range between 0 – 5 Hz. It consists of 330 kΩ resistor and the 0.1 μF capacitor. The low pass filter which gives a ~ 5 Hz cut-off cancels the high frequency noise existing in the signal. The noise is also attenuated at the 60 Hz frequency range which is found due to the power line.

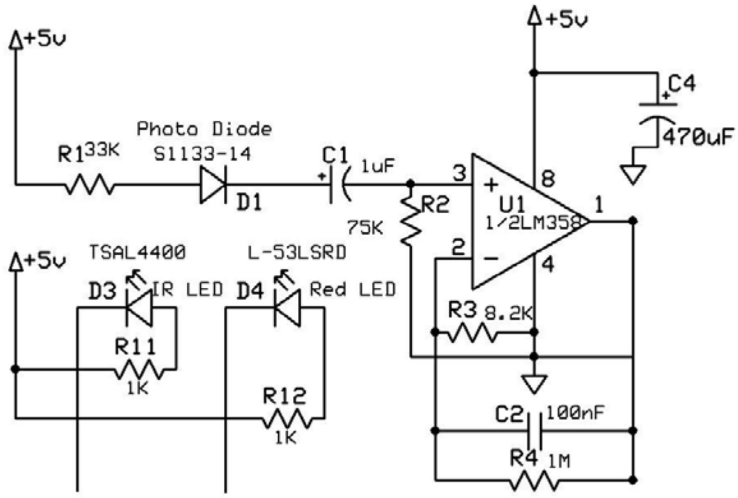


Figure 4.6: Circuit diagram of detecting photdiode and current-to-voltage converter.

Figure (4.7) shows the separate drivers that are used to drive IR and Red LED inside the finger clip. These drivers are made up of two pairs of 2N3904 NPN transistors (Q5, Q3 and Q4, Q2) which operate as switches. The pulses come from pin 19 and pin 20 of the microcontroller PIC18LF452 to the collectors of the first transistors Q5 and Q3. These signals follow from the emitter of the first transistors to the base of the second transistors Q4 and Q2. These transistors control the intensity of IR/Red LEDs by the Pulse Width Modulation PWM signals, which are generated from pins 17 and 16 where assigned as PWM1 and PWM2 respectively. IR and Red LEDs are alternately switched every 50 ms by feeding positive pulses to Q3 and Q5 via ports RD0 (pin19) and RD1 (pin20) of PIC18LF452. The PWM1 and PWM2 signals are created in the software to achieve the desired intensity of IR and Red LEDs and are compensated for the ambient light variations.

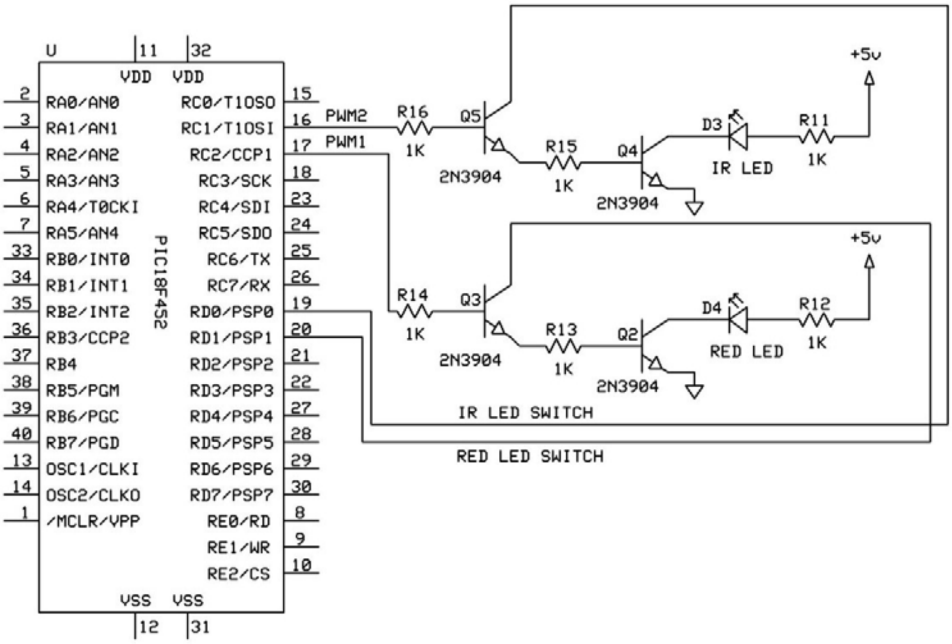


Figure 4.7: IR and RED LED Drivers and switching circuit

4.2.2 Finger clip

The architecture of finger clip is depicted in figure (4.9). The finger clip is made of an ordinary plastic clothespin and IR LED (TSAL4400) and Red LED (L-53LSRD) are resided on one appendage of the clip and are soldered on a small piece of printed circuit board PCB. The photo sensor pin diode (S1133-14) is soldered on a small piece of PCB and placed on other appendage of the clip to receive the transmitted light from IR LED and Red LED. The Red and IR LEDs are lit alternately every 50 ms (ON and OFF). There are six cables connected to the finger clip as shown in figure (4.8), and these cables are soldered to a 6-pin female header in order to connect with the main board through 6-pin male connector pins.

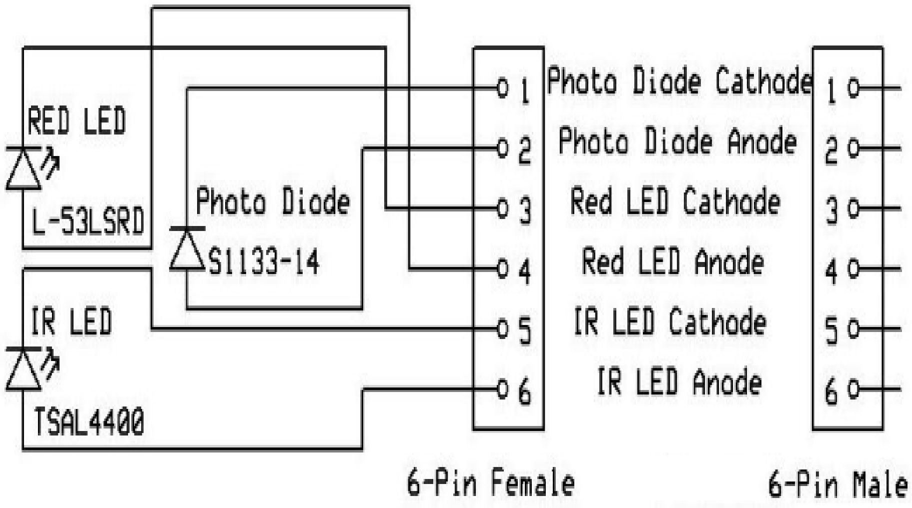


Figure 4.8: The circuitry scheme of the finger clip

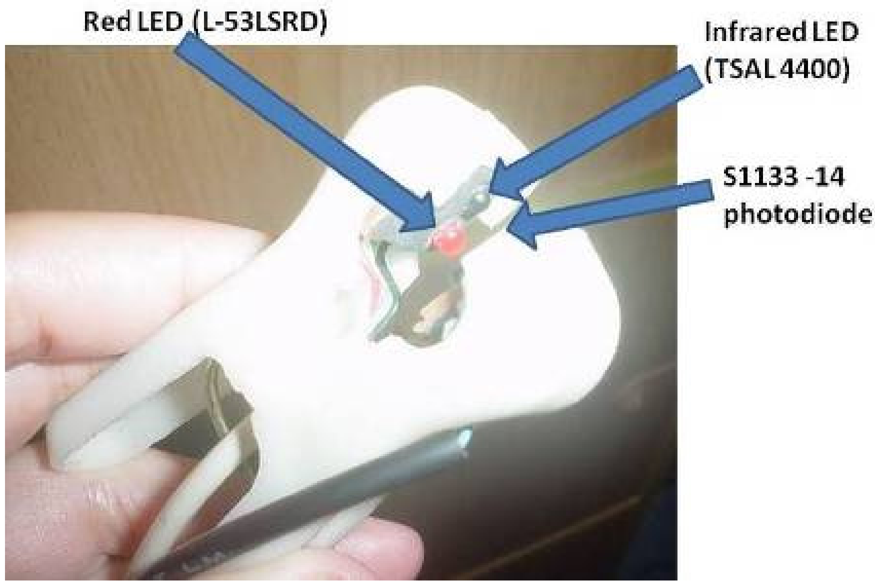


Figure 4.9: Architecture of finger clip

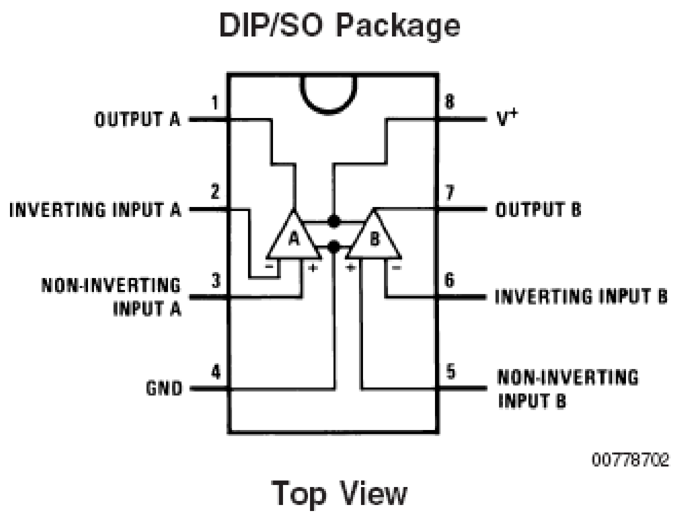


Figure 4.10: Low power dual operational amplifiers

4.2.3 Light source amplifier

Figure (4.10) explains LM358 Operational Amplifier which is the main component of the trans-impedance amplifier to amplify a very small amount of current (micro ampere) depending on the intensity of IR and visible red light. The IR and red light are sensed by the photo diode to 2 V - 3 V of analogue voltage swing which is converted to digital numbers by the built-in ADC of embedded microcontroller PIC18LF452 as shown in figure (4.11). In order to convert those digital numbers to SpO_2 level in terms of percentage, the software program is implemented in the microcontroller which operates the mathematical routines. The signals are shown in 16 character 2 lines Hitachi HD44870 compatible LCD shown in figure (4.16). At the same time these data can be transmitted via Universal Synchronous Asynchronous Receiver Transmitter (USART) ports of microcontroller to a PC. A Visual Basic 6 programming language is installed in the PC to display the wave forms, the percentage of the SpO_2 level, and the pulse rate.

A low power dual operational amplifier LM358 Op-Amp is chosen for its simplicity and routine. According to its data sheet [Appendix C.4, p.155], the operation from

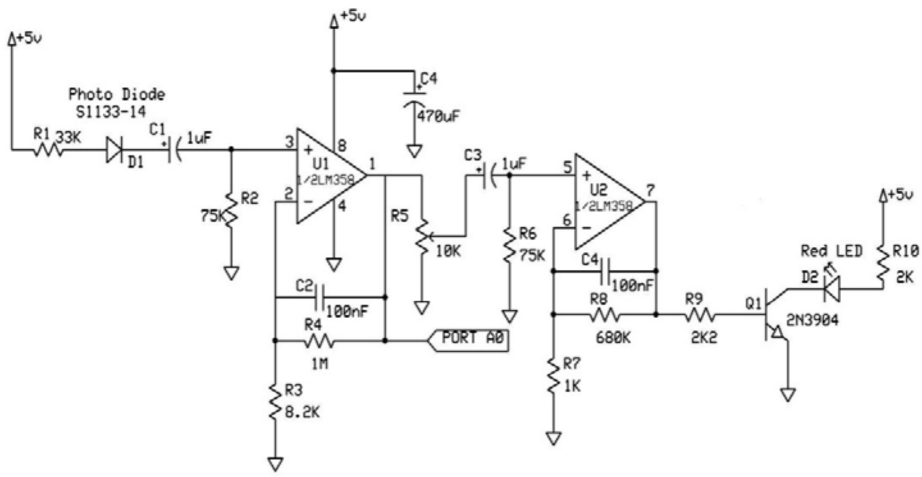


Figure 4.11: Schematic circuitry of operational amplifier LM358 Op-Amp of pulse oximetry

split power supplies is possible and also the low power supply current drain is independent of the magnitude of the power supply voltage. It consists of dual Op-Amp in a single package and it can operate at supply voltages as low as 3 V or as high as 32 V with low quiescent currents according to its data sheet. Although one feature of LM358 is the maximum of +32 V, the maximum voltage of 5 V is utilized. The single stage of this Op-Amp can achieve voltage swings of 0 VDC to common-collector voltage Vcc (pin 8) - 1.5 V [Appendix C.4, p.156].

The sample obtained before amplification is shown in figure (4.13). By operating with 5 V power supply, the currents of 3 to 4 mA pass through Red LED and IR LED each. The signal sensed by the Photo Diode D1 shown in figure (4.11) passes through a high-pass filter formed by C1 and R2 that removes slow drift to non-inverting input of first Op-Amp (pin 3). Figure (4.11) also explains that the high frequency noise is decoupled by a low-pass filter formed by C2 and R4 fed back from output of first Op-Amp (pin 1) to inverting input of first Op-Amp (pin 2). It amplifies the signal in the pass-band which is centered at 100 bpm (beats per minute), by a factor of 100.

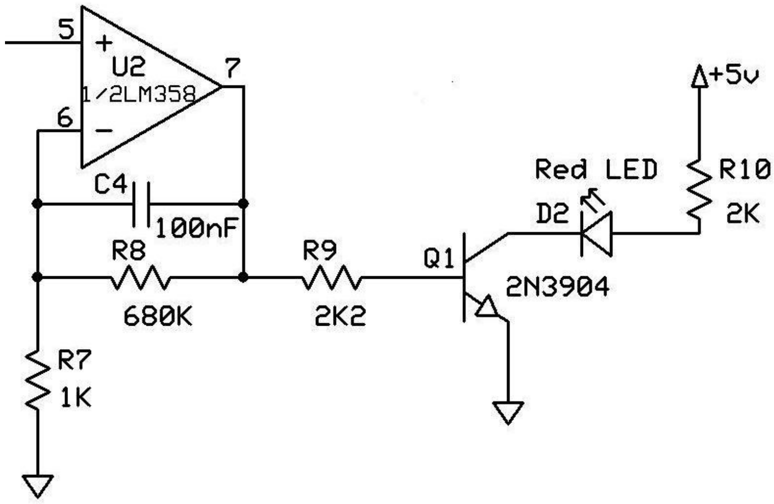


Figure 4.12: Second stage output (pin 7) and a driver circuit to light the LED

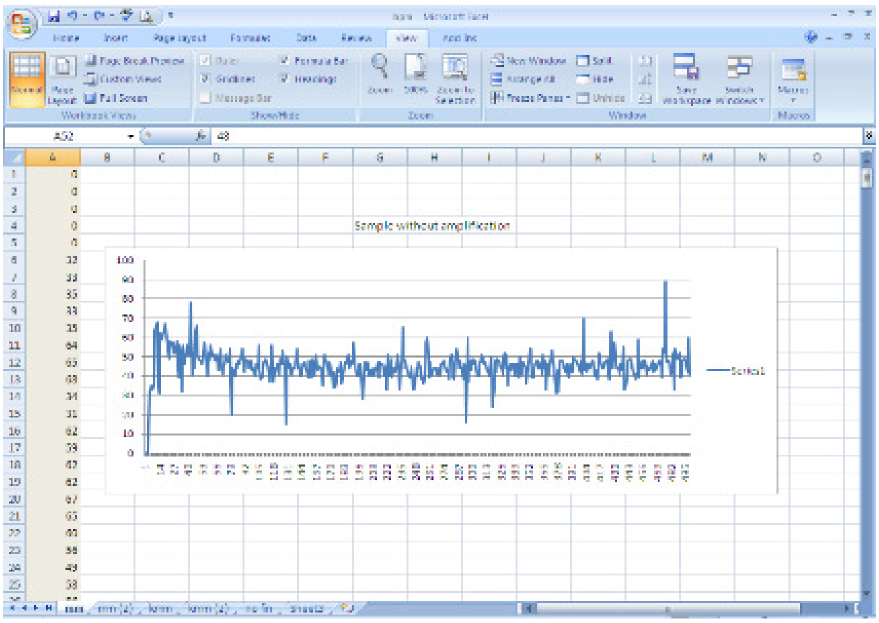


Figure 4.13: The sample obtained before amplification

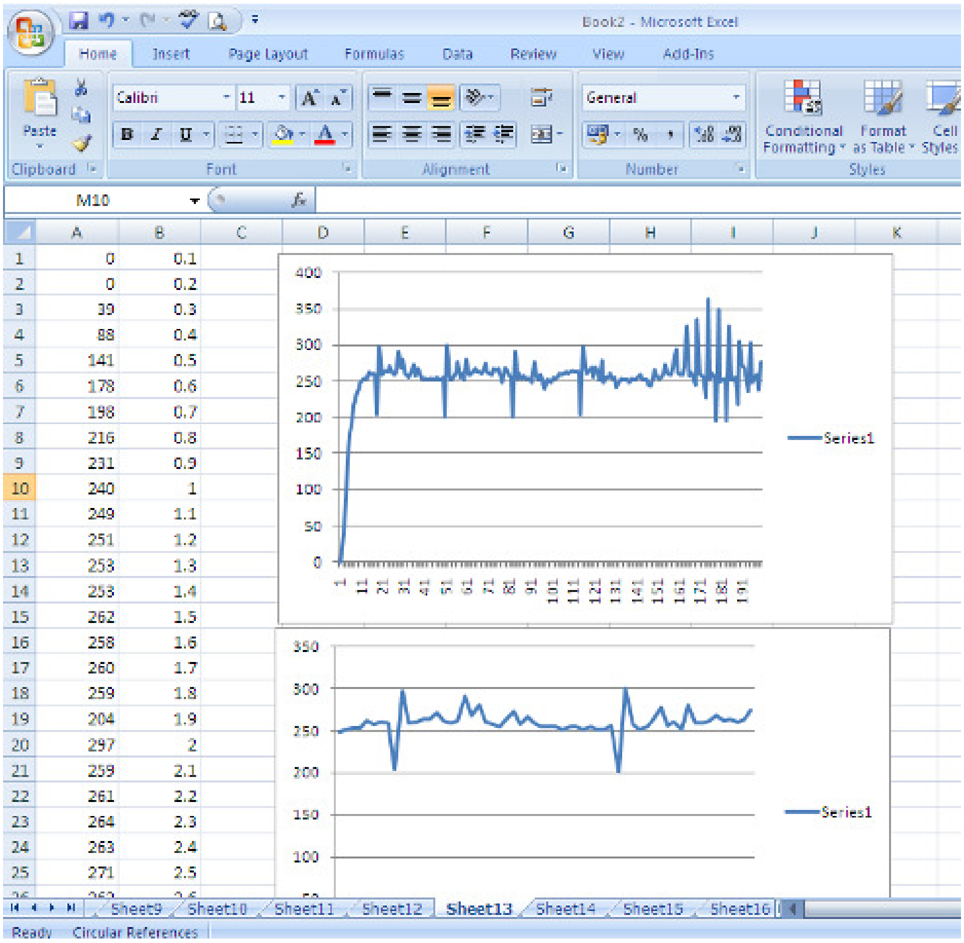


Figure 4.14: Sample obtained after amplification

The second stage of LM358 which is U2 in figure (4.11) is fabricated in the same routine as the first stage of LM358 (U1). The value of 500 is gained in the second stage. The overall gain of the two stages can be regulated with R5, 10 kΩ potentiometer The output of first Op-Amp (pin 1) in figure (4.11) generates 2.5 voltage peak with ripple which is sufficient enough to be converted by 10-bit ADC of the microcontroller PIC18LF452 through port RA0 pin 2 configured as RAN0 (Analogue Input) shown in figure (4.7). This amplified signal includes both DC and AC components representing infrared and visible red alternately. The second stage output (pin 7) is connected to a driver circuit to light the LED, indicating signal activity shown in figure (4.12). The figure (4.13) shows the sample data obtained before amplification and the sample data obtained after amplification is shown in figure (4.14).

4.2.4 Processor (microchip PIC 18LF452 microcontroller)

The heart of the pulse oximetry is the Microchip PIC18LF452-8bit microcontroller. It has DC to 40 MHz oscillator/clock input and 4MHz to 10MHz oscillator/clock input with PLL (Phase Lock Loop) feature which can speed up to 4 times of input frequency when PLL is active.

According to its data sheet [Appendix C.5, p.158], the synchronous serial port can be configured as either 3-wire Serial Peripheral Interface (SPI™) or the 2-wire Inter-Integrated Circuit (I²C™) bus and Addressable Universal Synchronous Asynchronous Receiver Transmitter (AUSART). The microcontroller was programmed to switch and control the timing and intensity of IR and Red LEDs. Figure (4.7) explains that pin 19 (RD0) and pin 20 (RD1) are used for switching and pin 17 (RC1-PWM1) and pin 16 (RC2-PWM2) of figure (4.7) are functioned for luminance changing values of period and duty cycle in the software.

The ADC function is configured so as the external voltage reference is not required by using V_{DD} (+5V) as V_{ref+} and Vss (Ground) as $Vref_{-}$ in figure (4.7) which helps the overall circuitry simpler and reduces the component count. Although all eight analog inputs (RA0/AN0 to RA7/AN7) can be used by this configuration, only RA0/AN0 (pin 2) is used since only one channel is required for analog to digital conversion in this project.

4.2.5 Display circuitry (LCD and RS232 interface with PC)

The main display to show SPO_2 concentration in percentage (%) and Pulse Rate in BPM (beats per minute) is 16 character 2 line LCD JHD162A with back light (Hitachi HD44780 compatible) driven by Port B (RB2 to RB7) pin 35 to Pin 40 of microcontroller using 4-bit data (D4-D7) to save the number of pins used shown in figure (4.15). Although LED back light is available as the reflective light, LCD's back light is disabled to save power consumption [Appendix C.6, p.161]. The LCD panel is connected to the microcontroller via 10-pinconnector. Figure (4.16) shows the percentage of SpO_2 and the heart beat rate of the author who is in good health.

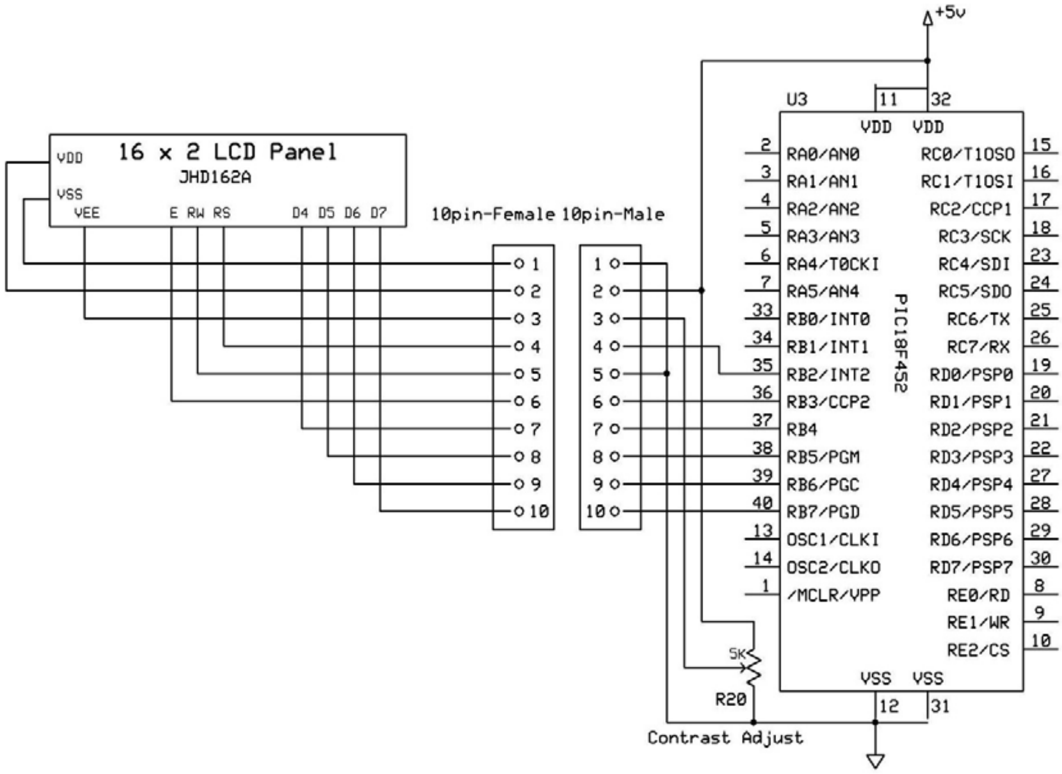


Figure 4.15: LCD Panel of pulse oximetry

Another type of display is a personal computer (PC) with serial (USART) port with appropriate software installed. The microcontroller PIC18LF452 has built-in USART hardware on board at pins 25 and 26 (RC6/TX and RC7/RX) shown in figure (4.16), that can send data to PC via RS232 interface and display information such as SpO_2 content in percent and/or pulse rate (beats per minute). As 2N3904 transistors perform the same function as RS232 chip, they are used for the interface circuit instead of RS232 chip, not only for low- cost, but it also saves the space for USART communication with PC shown in figure (4.18).

Figure 4.16: LCD display showing SpO_2 and pulse rate

4.2.6 Power supply

Figure (4.17) explains the power supply utilized in the pulse oximetry. The whole circuit is powered by regulating a +5 V, using LP2950 LDO (Low Drop-out Voltage Regulator) which can deliver up to 160-200 mA of current with constant +5 V. This is bipolar, low drop-out voltage regulators that can accommodate a wide input supply-voltage range of up to 30 V [Appendix C.7, p.163]. It can deliver up to 160-200 mA of current with constant +5V. As the overall circuit consumes about 50-60 mA, maximum current limit of 200 mA secures enough for even continuous operation. LP2950 is supplied to its input pin as low as 5.38V DC at 100 mA to produce 5 V regulated output to its LDO (Low Drop-out) capability. To prevent AC ripples and interference, it is better to use batteries delivering more than 5.38 V DC as the power source which is produced in most of the AC-DC adapters with poor filtering circuitry that can affect the accuracy of the pulse oximetry.

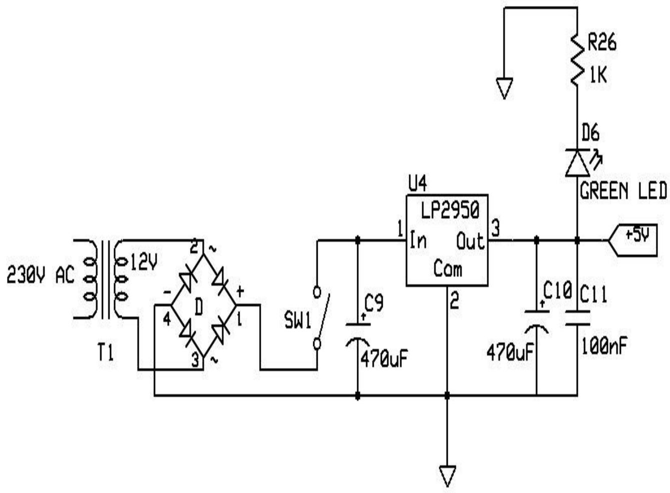


Figure 4.17: Power supply pulse oximetry

4.2.7 Transceiver (USART)

USART stands for Universal Synchronous Asynchronous Receiver Transmitter. It is also called the Serial Communications Interface or SCI. Clock and data line are used by Synchronous operation while there is no separate clock accompanying the data for Asynchronous transmission. Since there is no clock signal in asynchronous operation, one pin can be used for transmission and another pin can be used for reception. The USART is most commonly used in the asynchronous mode. The most common use of the USART in asynchronous mode is to communicate to a PC serial port using the RS-232 protocol.

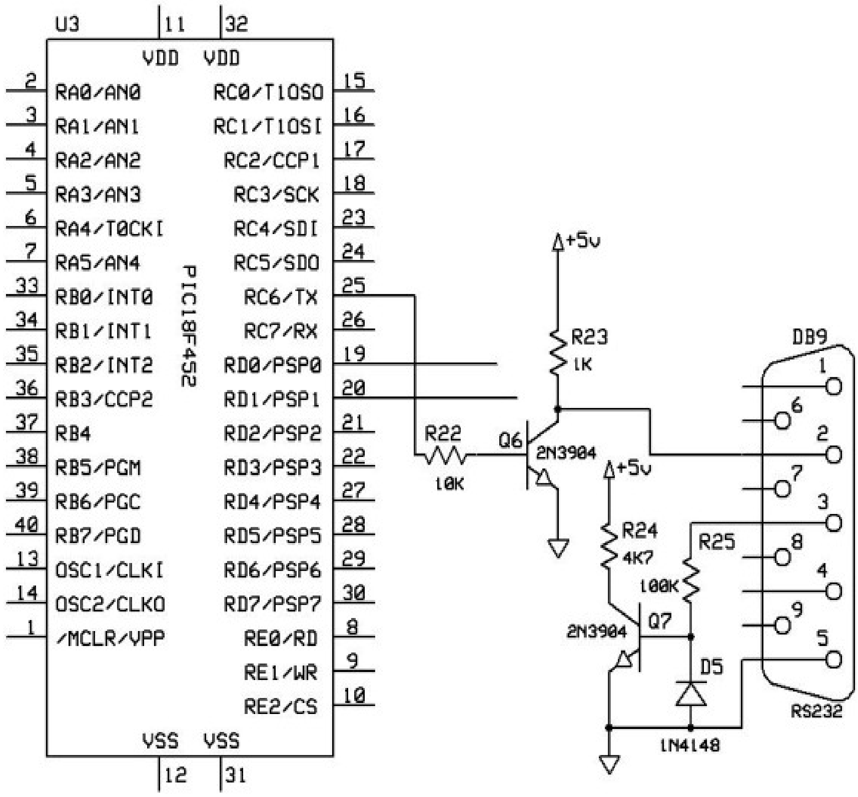


Figure 4.18: Schematic diagram of USART used in pulse oximetry

4.2.8 PCB etching

Another important procedure for the pulse oximetry design is printed circuit board (PCB) etching. Ferric Chloride solution is poured in a plastic container to etch the printed circuit board as shown in figure (4.19). The circuit board is placed into the solution and it gently swirls for about 15 to 30 minutes. When the copper is completely disappeared from the board, the board is removed from the solution and washed with water. The board is cut with a saw and the edges of it are smoothened with a metal file. Drilling the component holes is done as the next step and the board is cleaned with a PCB cleaner.

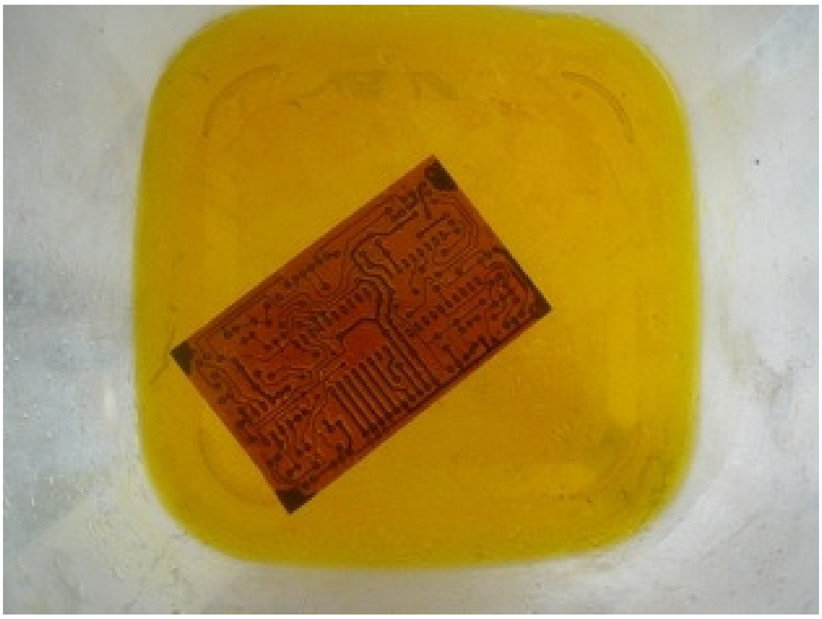


Figure 4.19: PCB (Printed Circuit Board) etching

4.3 Software implementation

The software source code for the embedded system of pulse oximetry is written in Assembly language and compiled and programmed into PIC18LF452 Microcontroller using Microchip MPLAB IDE (Integrated Development Environment) and PICkit2 programmer that is shown in figure (4.20).

MPLAB Integrated Development Environment (IDE) is available on the website of microchip “http://www.microchip.com”. The assembly codes are required to write, build and assemble the project with MPLAB's wizards, and then test the assembly code with the built-in simulator and debugger. The details of MPLAB IDE are discussed in section 4.7. The experimental set up of the pulse oximetry design is shown in figure (4.21).

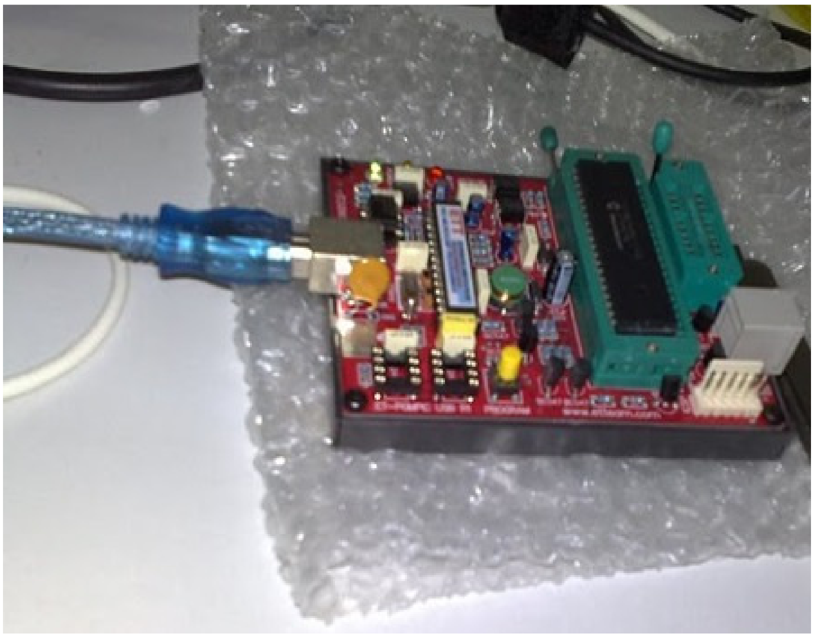


Figure 4.20: PICkit2 programmer that compiled the final source code

The projects started with IR and Red LED drivers. IR and Red LEDs are to be switched ON alternately every 50 ms (approximately 10 Hz for each LED). Then PWM feature was added to control the intensities of IR and Red LEDs, depending on ambient light condition. After programming the microcontroller, it is placed in the project board and tested the operation of IR and Red LEDs. After achieving satisfactory result, the next step proceeded.

The next stage to be tested is ADC (Analog to Digital Converter). PIC18LF452 has 10-bit ADC with 8-inputs feature. Before testing ADC, LCD source code was implemented and tested for proper display. LCD was set for 4-bit operation to save pin count and 2-line mode was chosen to display all necessary data.

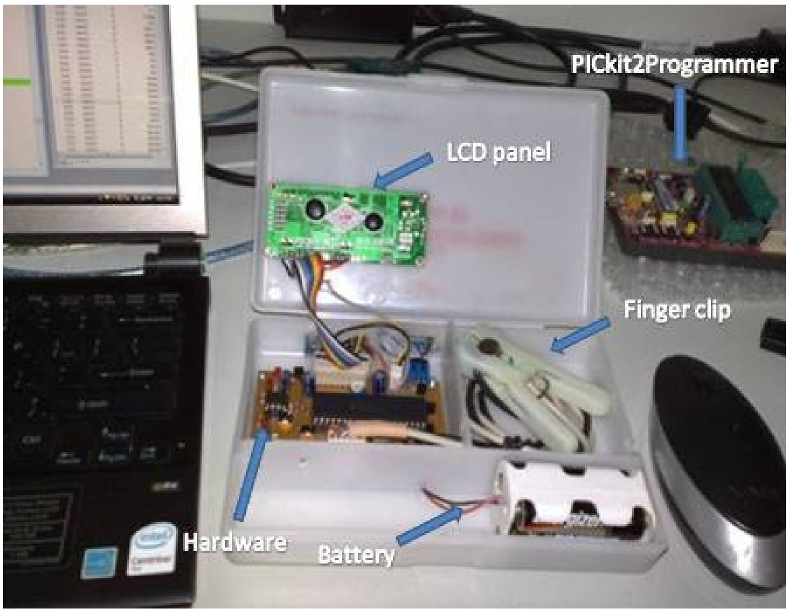


Figure 4.21: Experimental set up of the pulse oximetry design

In this project only one channel of ADC was needed and used. Pin 2 of the PIC, AN0 (Analog Input 0), is connected to first output of LM358 (pin 1) to convert into digital values of the intensity of light (Red and IR) received from the photo sensor PIN diode. V_{DD} (+5 V) was chosen as V_{ref+} (Positive Reference Voltage) and Vss (0 V) was chosen as V_{ref-} (Negative Reference Voltage). This configuration was selected in software by writing a binary number '1000 0000' in ADCON1 register.

In addition to LCD display, USART (serial communication) onboard feature of PIC18LF452 is used to enable viewing the data on PC as well. Any serial (RS232) terminal software can be used to view the data shown on LCD. A VB6 (Visual Basic 6) [Appendix B, p.147] and an RS232 program to view the readings can be found . In the software baud rate was set to 9600 and serial port should be set according to the physical or virtual port used.

There are important parts in the software program and the flow chart is depicted in this chapter for clear visualization of the process in the software. The parts are:

(1) Configuration of the Microcontroller

(2) Initialization of the Microcontroller

a. Port Initialization

b. USART Module Initialization

c. ADC Module Initialization

d. CCP (PWM) Module Initialization

e. Timer2 Module Initialization

f. LCD Initialization

(3) MAIN program.

The Assembly codes for the embedded system of pulse oximetry are total pages of 78 and only a few parts of program are displayed and explained. The related codes will be referred to Appendix A in page number 127.

4.3.1 Configuration of microcontroller

The 18F452 microcontroller has total of 1536 bytes general purpose RAM register. The codes shown in figure (4.22) are to define the RAM space (Appendix A, p.122).

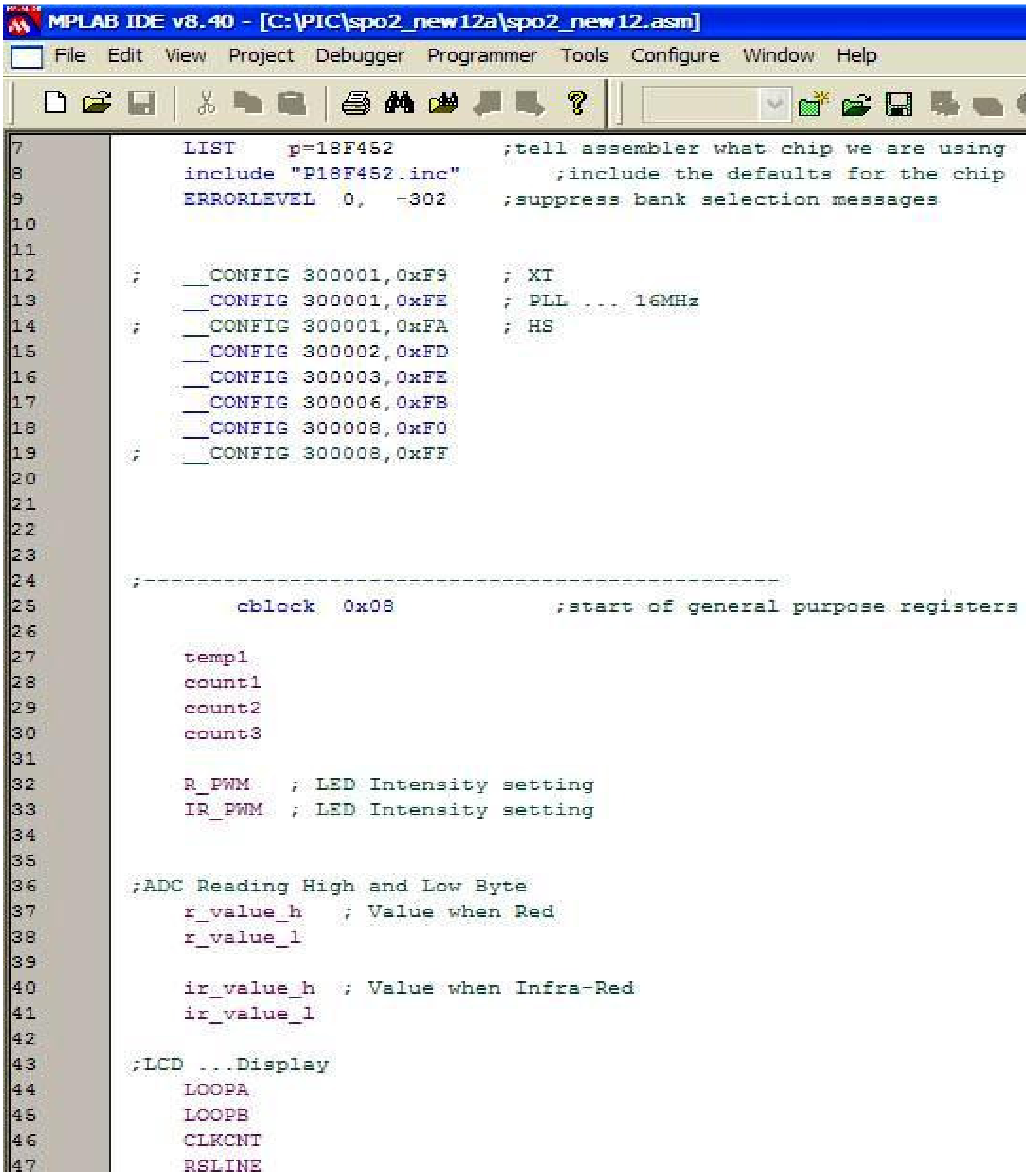


Figure 4.22: Screenshot of assembly codes to define the RAM space.

4.3.2 Initialization of microcontroller

(A) Port initialization

In 18F452 microcontroller there are 33 general purpose I/O pins group into five I/O ports. Some pins of the I/O ports are multiplexed with an alternate function from the peripheral features on the device. In general, when a peripheral is enabled, that pin may not be used as a general purpose I/O pin. PORTA pins are multiplexed with analog inputs and the analogue V_{ref+} and V_{ref}– inputs. The corresponding Data Direction register is TRIS Register. Setting a TRISA bit (= 1) will make the corresponding PORTA pin an input (i.e., put the corresponding output driver in a Hi-Impedance mode). Clearing a TRISA bit (= 0) in figure (4.23) will make the corresponding PORTA pin an output (i.e., put the contents of the output latch on the selected pin). Some peripherals override the TRIS bit to make a pin an output, while other peripherals override the TRIS bit to make a pin an input (Appendix A, p.125).

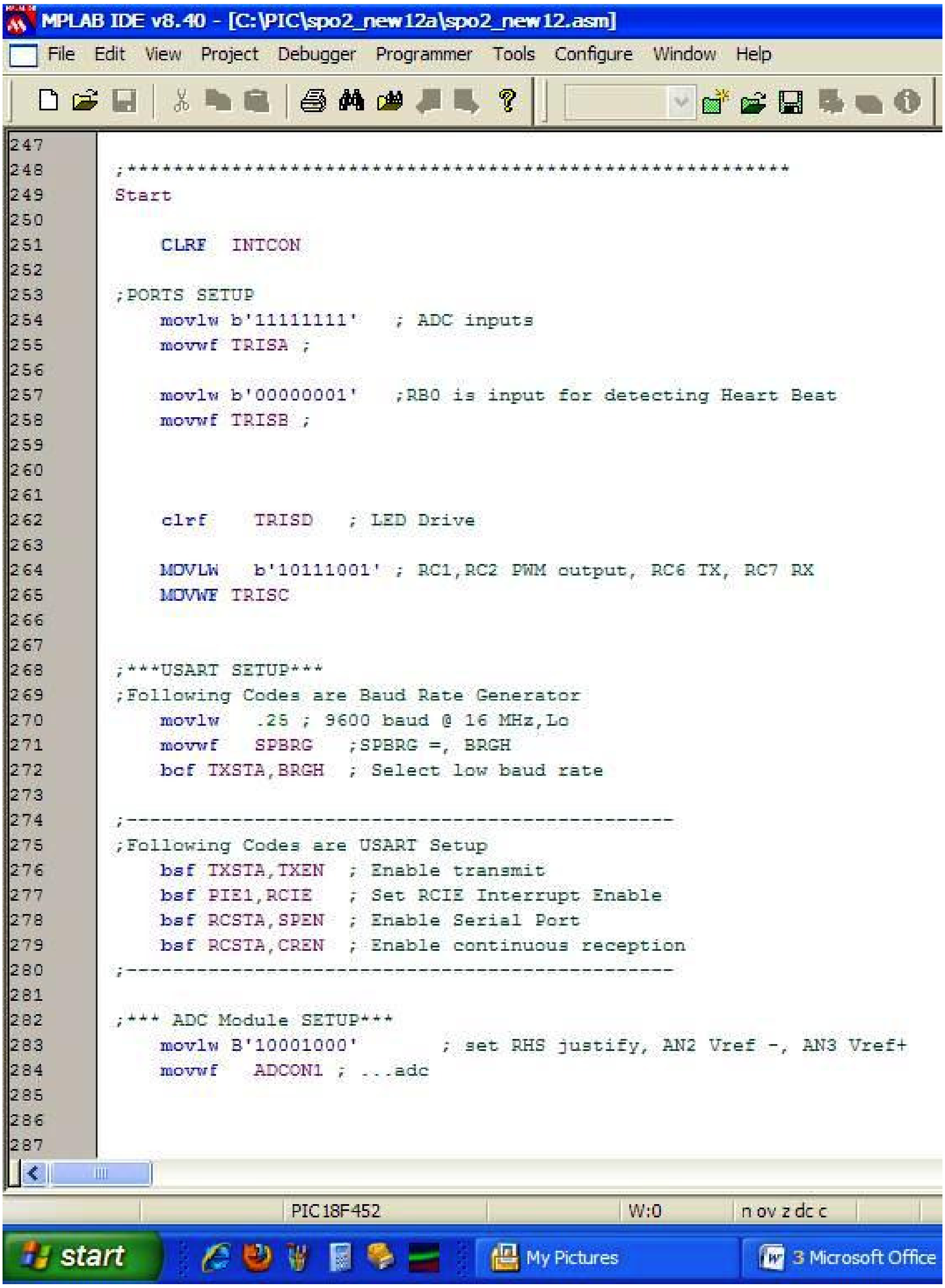


Figure 4.23: Screenshot of assembly codes to initialize the port

(B) USART module initialization

The Universal Synchronous Asynchronous Receiver Transmitter (USART) module is one of the two serial I/O modules. (USART is also known as a Serial Communications Interface or SCI.) The USART can be configured as a full duplex asynchronous system that can communicate with peripheral devices, such as CRT (Cathode Ray Tube) terminals and personal computers. The USART Baud Rate Generator (BRG) supports both the Asynchronous and Synchronous modes of the USART. It is a dedicated 8-bit baud rate generator. The SPBRG register controls the period of a free running 8-bit timer. In Asynchronous mode, bit BRGH (TXSTA<2>) also controls the baud rate. In Synchronous mode, bit BRGH is ignored. To achieve the baud rate of 9600bps on a microcontroller running at 16 MHz the nearest integer value for the SPBRG register can be calculated using the formula as follows:

Desired Baud Rate = FOSC/ (64 (X + 1))

Solving for X:

X = ((FOSC / Designed Baud Rate) / 64) –1

X = ((16000000 / 9600)/ 64) – 1

X = 25.042 = 25

Calculated Baud Rate = 16000000 / (64 (25 +1))

= 9615

Error = (Calculated Baud Rate –Desire Baud Rate) / Desired Baud Rate

= (9615 – 9600) / 9600

= 0.16 %

From this, the error in baud rate can be determined. The assembly codes for USART setup (Appendix A, p.126) are shown in figure (4.24).

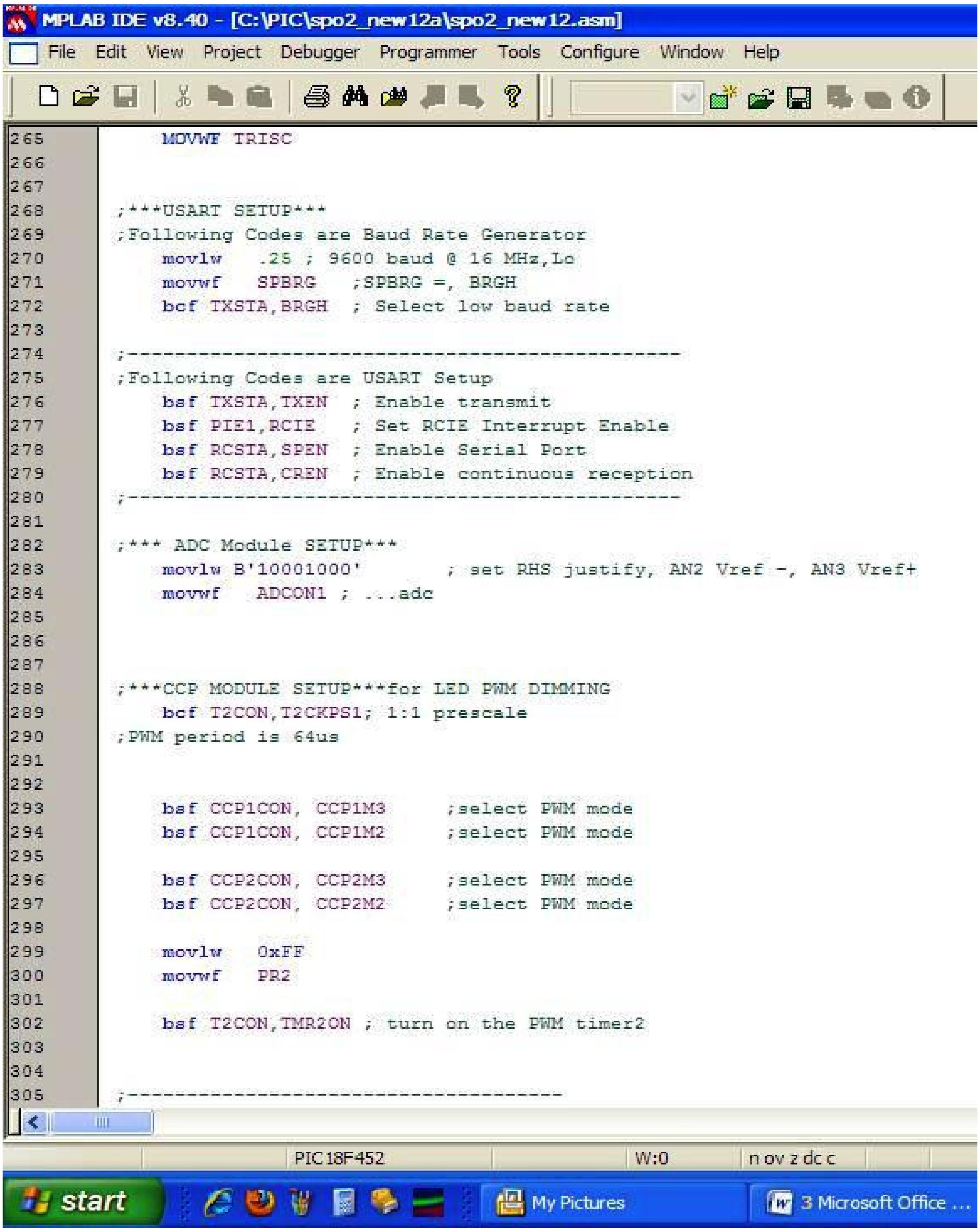


Figure 4.24: Screenshot of assembly codes to initialize the USART

(C) ADC module initialization

The Analog-to-Digital converter (ADC) module has eight inputs for the PIC18F452 devices. This module has the ADCON0 and ADCON1 register. The ADCON0 register controls the operation of the ADC module. The ADCON1 register configures the functions of the port pins. Table (4.1) describes ADCON1 Register of 18F452 Microcontroller. The ADC allows conversion of an analog input signal to a corresponding 10-bit digital number.

The analog reference voltage is software selectable to either the device's positive or negative supply voltage (Vdd and Vss), or the voltage level on the RA3/AN3/ V_{REF+} pin and RA2/AN2/V_{ref-} pin. The ADRESH and ADRESL registers contain the result of the ADC conversion. When the ADC conversion is completed, the result is loaded into the ADRESH and ADRESL registers. The result can be formatted as Right or Left and justified by setting or clearing the bit (ADFM). ADC port configuration control bits are shown in table (4.2).

Table 4.1: ADCON1 Register of 18F452 microcontroller

R/W-0	R/W-0	U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0
ADFM	ADCS2	—	—	PCFG3	PCFG2	PCFG1	PCFG0
bit 7							bit 0

Table 4.2: ADC Port Configuration Control bits

PCFG <3:0>	**AN7**	**AN6**	**AN5**	**AN4**	**AN3**	**AN2**	**AN1**	**AN0**	**V_{ref+}**	**V_{ref-}**	**C/R**
0000	A	A	A	A	A	A	A	A	V_{DD}	V_{SS}	8/0
0001	A	A	A	A	V_{ref+}	A	A	A	AN3	V_{SS}	7/1
0010	D	D	D	A	A	A	A	A	V_{DD}	V_{SS}	5/0
0011	D	D	D	A	V_{ref+}	A	A	A	AN3	V_{SS}	4/1
0100	D	D	D	D	A	D	A	A	V_{DD}	V_{SS}	3/0
0101	D	D	D	D	V_{ref+}	D	A	A	AN3	V_{SS}	2/1
011x	D	D	D	D	D	D	D	D	–	–	0/0
1000	A	A	A	A	V_{ref+}	V_{ref-}	A	A	AN3	AN2	6/2
1001	D	D	A	A	A	A	A	A	V_{DD}	V_{SS}	6/0
1010	D	D	A	A	V_{ref+}	A	A	A	AN3	V_{SS}	5/1
1011	D	D	A	A	V_{ref+}	V_{ref-}	A	A	AN3	AN2	4/2
1100	D	D	D	A	V_{ref+}	V_{ref-}	A	A	AN3	AN2	3/2
1101	D	D	D	D	V_{ref+}	V_{ref-}	A	A	AN3	AN2	2/2
1110	D	D	D	D	D	D	D	A	V_{DD}	V_{SS}	1/0
1111	D	D	D	D	V_{ref+}	V_{ref-}	D	A	AN3	AN2	1/2

The following code is used to set up the ADC module:

MOVLW B'1000000' ; set RHS justify, V_{SS}= Vref -, V_{DD} = $Vref_+$

MOVWF ADCON1 ; …adc

(D) CCP module initialization for PWM mode

To control the intensity of both IR and Red LEDs, PWM is used. In 18F452 Microcontroller, Capture/Compare/PWM (CCP) module contains a 16-bit register which can operate as a 16-bit Capture register, or as a PWM Master/Slave Duty Cycle register.

In PWM (Pulse Width Modulation) mode, the CCP1 pin produces up to a 10-bit resolution PWM output. Since the CCP1 pin and CCP2 are multiplexed with the PORTC data latch, the TRISC<2> and TRISC<1> bits must be cleared to make both CCP1 (pin 17) and CCP2 (pin 16) pins output.

```
BSF   CCP1CON, CCP1M3      ; select PWM mode

BSF   CCP1CON, CCP1M2      ; select PWM mode

BSF   CCP2CON, CCP2M3      ; select PWM mode

BSF   CCP2CON, CCP2M2      ; select PWM mode
```

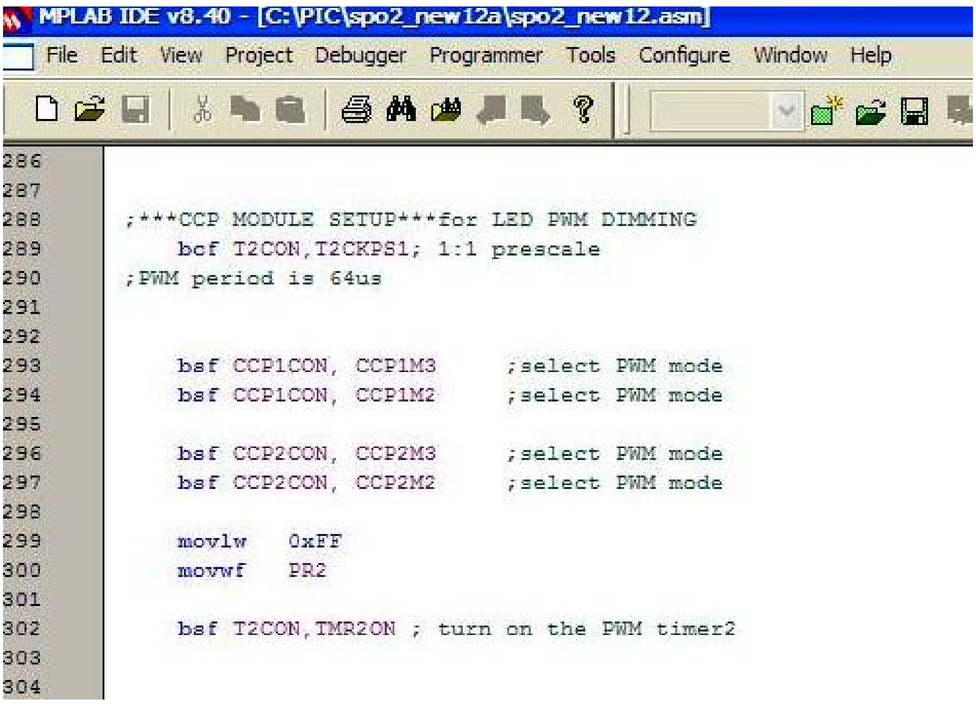


Figure.4.25: Screenshot of assembly codes of CCP Module

(E) Timer2 module initialization

Timer2 can be used as the PWM time-base for the PWM mode of the CCP module. The TMR2 register is readable and writable, and is cleared on any device RESET. The input clock (FOSC/4) has a pre-scale option of 1:1, 1:4 or 1:16, selected by control bits T2CKPS1:T2CKPS0 (T2CON<1:0>).

The PWM period is specified by writing to the Timer2 Module Period Register (PR2). The PWM period can be calculated using the following formula:

PWM period = [(PR2) + 1] • 4 • TOSC • (TMR2 pre-scale value)

PWM frequency is defined as 1 / [PWM period].

Calculation of PWM frequency

PWM period = [(PR2) + 1] • 4 • T_{OSC} • (TMR2 pre-scale value)

When PR2 = 255, T_{OSC} = 1/16000000, TMR2 pre-scale = 1

PWM period = (255+1) x 4 x 1/16000000 x 1 = 0.000064

Therefore, PWM frequency = 1/0.000064 = 15.625 kHz

The following codes shown in figure (4.25) are utilized to setup the PWM module.

```
BCF    T2CON, T2CKPS1    ; 1:1 pre-scale

MOVLW      0xFF

MOVWF      PR2

BSF    T2CON, TMR2ON     ; turn on the PWM timer2
```

(F) LCD initialization

4 bit LCD display initialization is done by calling some subroutines, delay routines and a table array as shown in figure (4.26). The following subroutines are used for LCD initialization.

The subroutines for LCD display process.

LCDIN

LCDOUT

DELAY

SENDIT

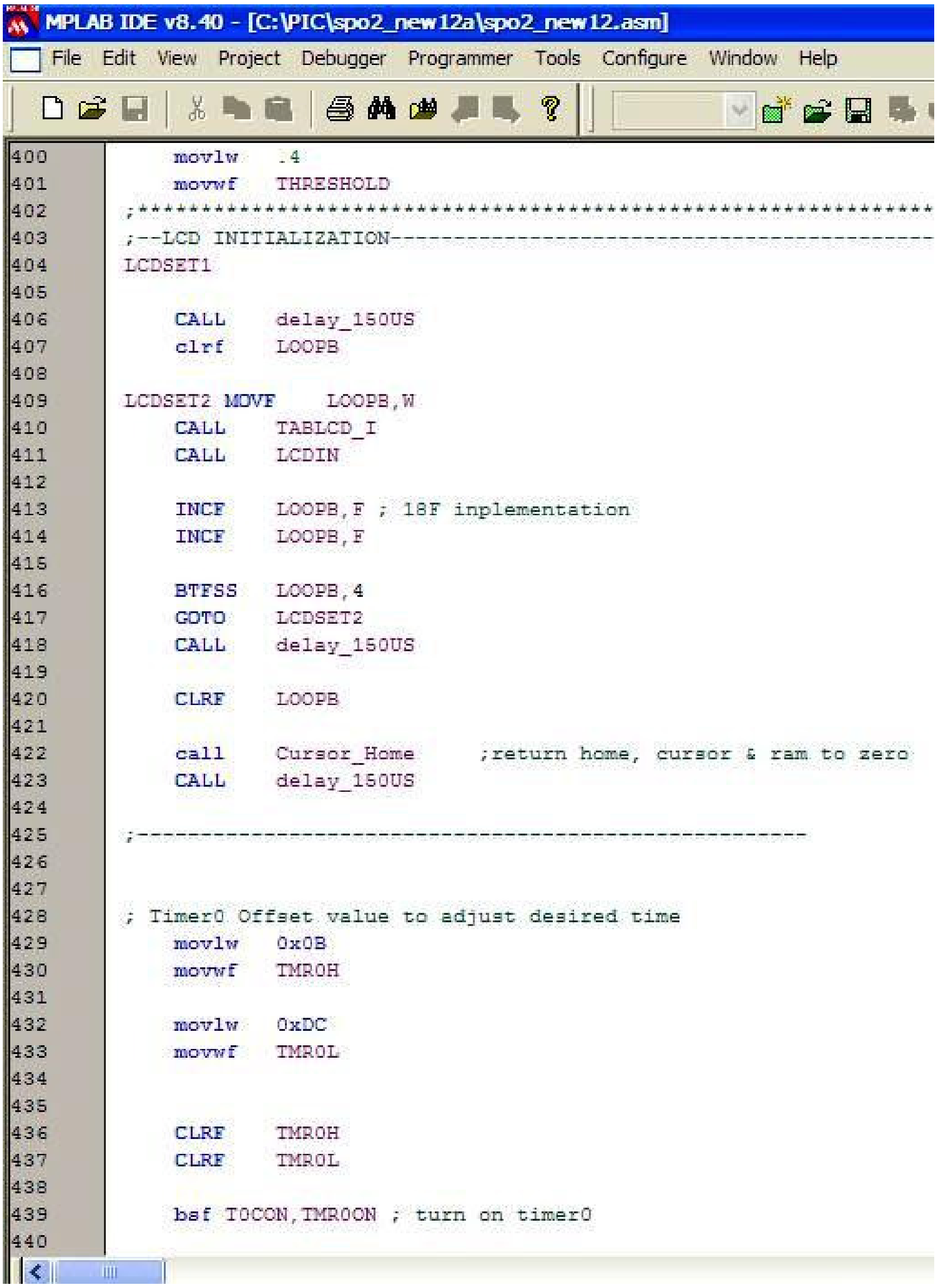


Figure.4.26: Screenshot of assembly codes to initialize LCD

4.4 Flow chart of software system of pulse oximetry

The flow chart shown in figure (4.27) describes the overall system of software analysis of the designed device to measure SpO_2 and pulse rate.

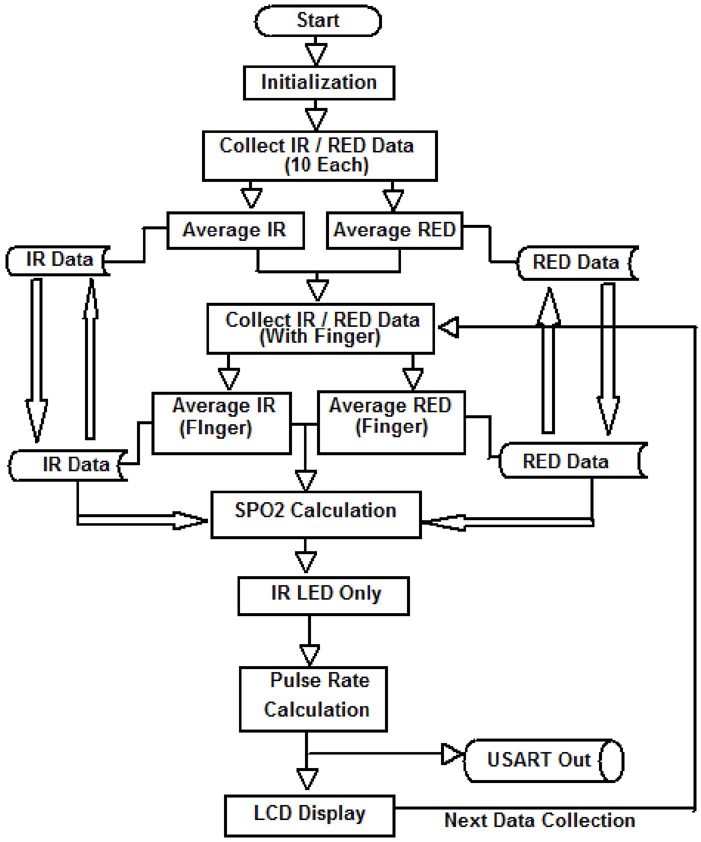


Figure 4.27: Flowchart of software analysis of pulse oximetry

4.5 Main program

4.5.1 Displaying message on LCD

After setting up required I/O ports and peripherals the main program calls some subroutine to display messages on 16x2 Line LCD Display, such as " Please Wait . . . ". The codes used for LCD display (Appendix A, p128) are shown in figure (4.28).

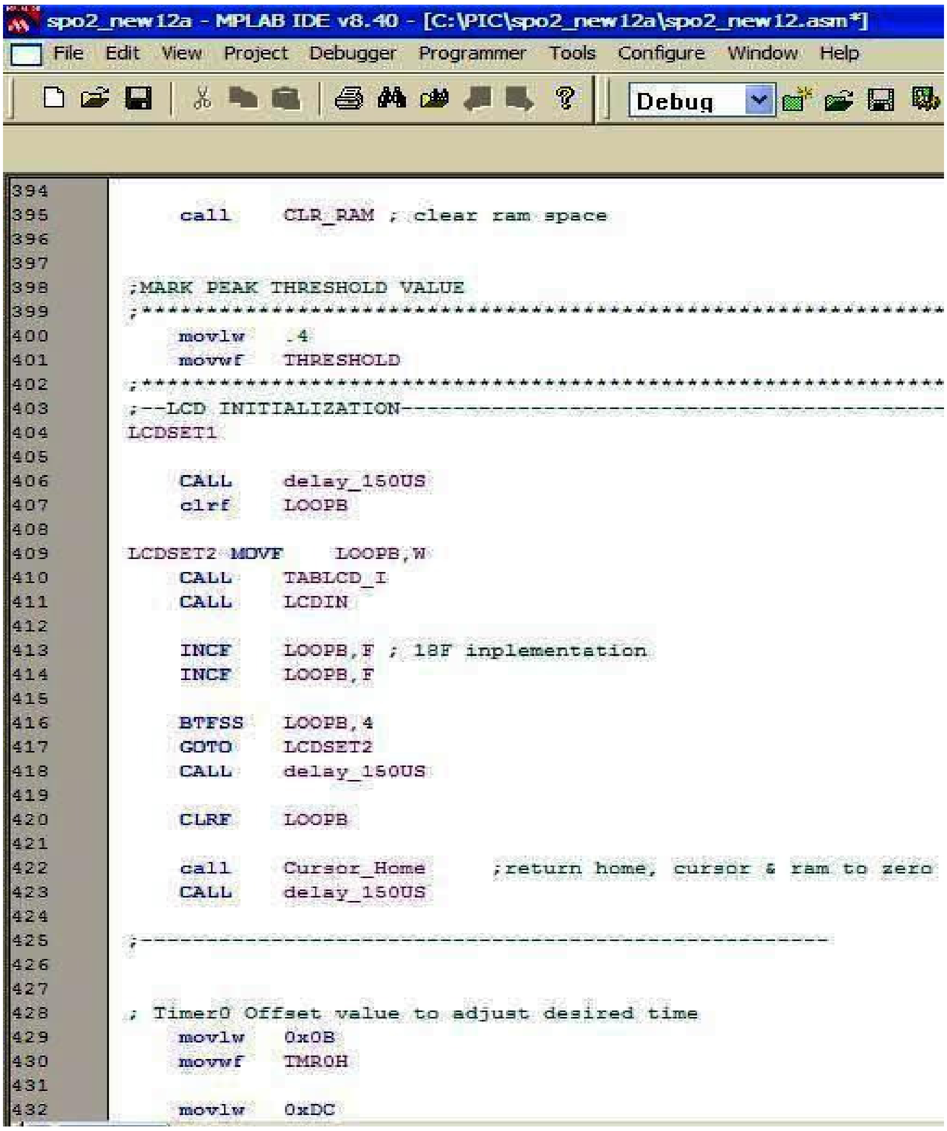


Figure 4.28: Screenshot of assembly codes used for 4 bit LCD display initialization.

4.5.2 Sensing without finger

The sample readings of IR and Red without finger inside the finger clip are collected averaging from 10 readings and saved in assigned RAM space. The voltage level at ADC Channel 0 and illuminating of IR and Red LED is sensed and carried out by the PWM module and ADC module. An average ADC value from 10 samples of 10 bit ADC value is obtained when IR LED is on. The 20 bytes of RAM and Indirect Addressing method is used. The codes shown in figure (4.29) are to achieve the Indirect

Addressing method (Appendix. A, p.129). When the main program calls the "Get Sample" subroutine, firstly mark the RAM area to save the sample values converted from ADC module.

For Red LED, the same procedure of IR LED mentioned above is executed and both samples for IR and Red level data are collected and saved in the assigned RAM areas. Indirect addressing method is used to store array of data in user memory area.

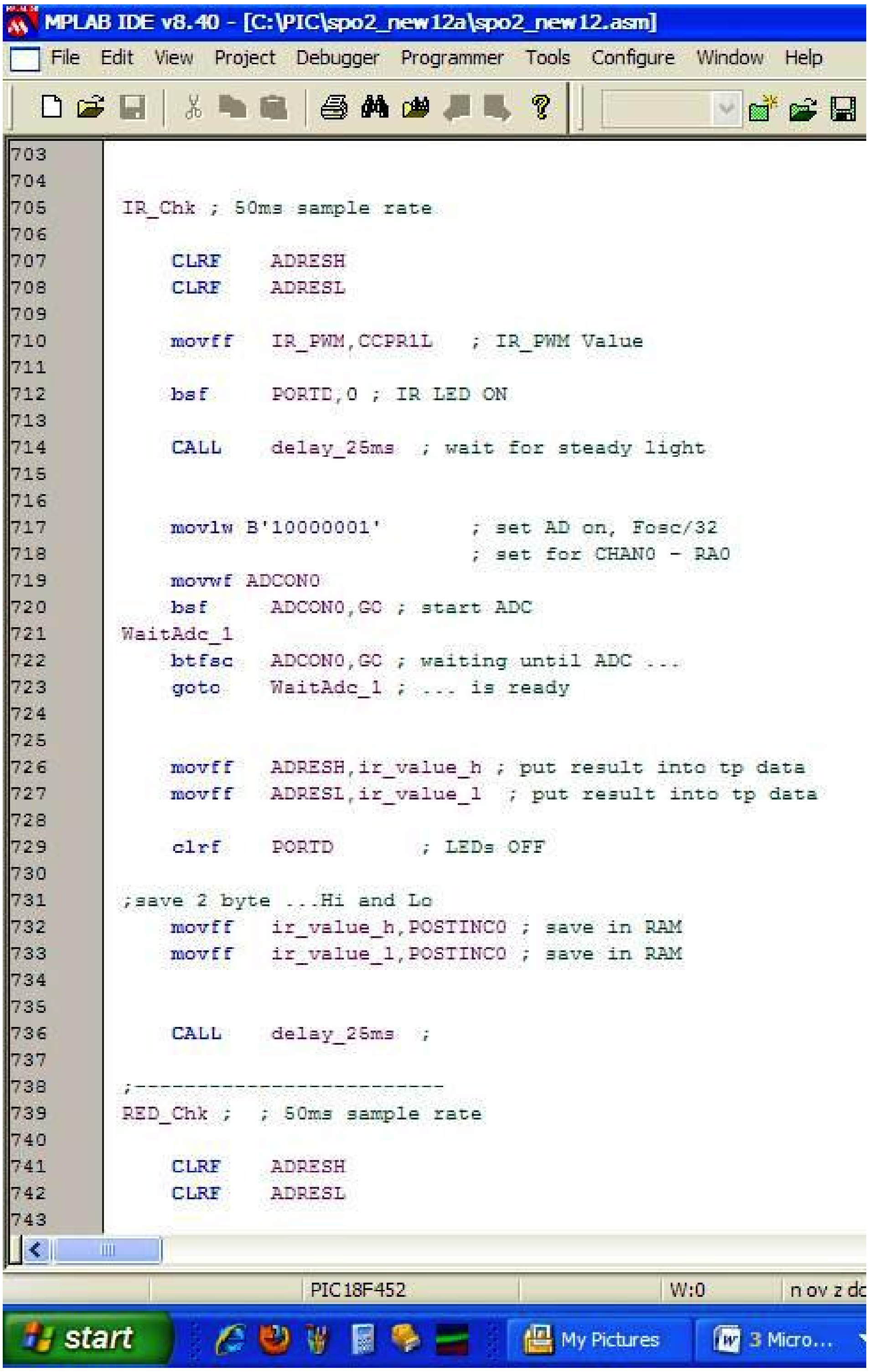
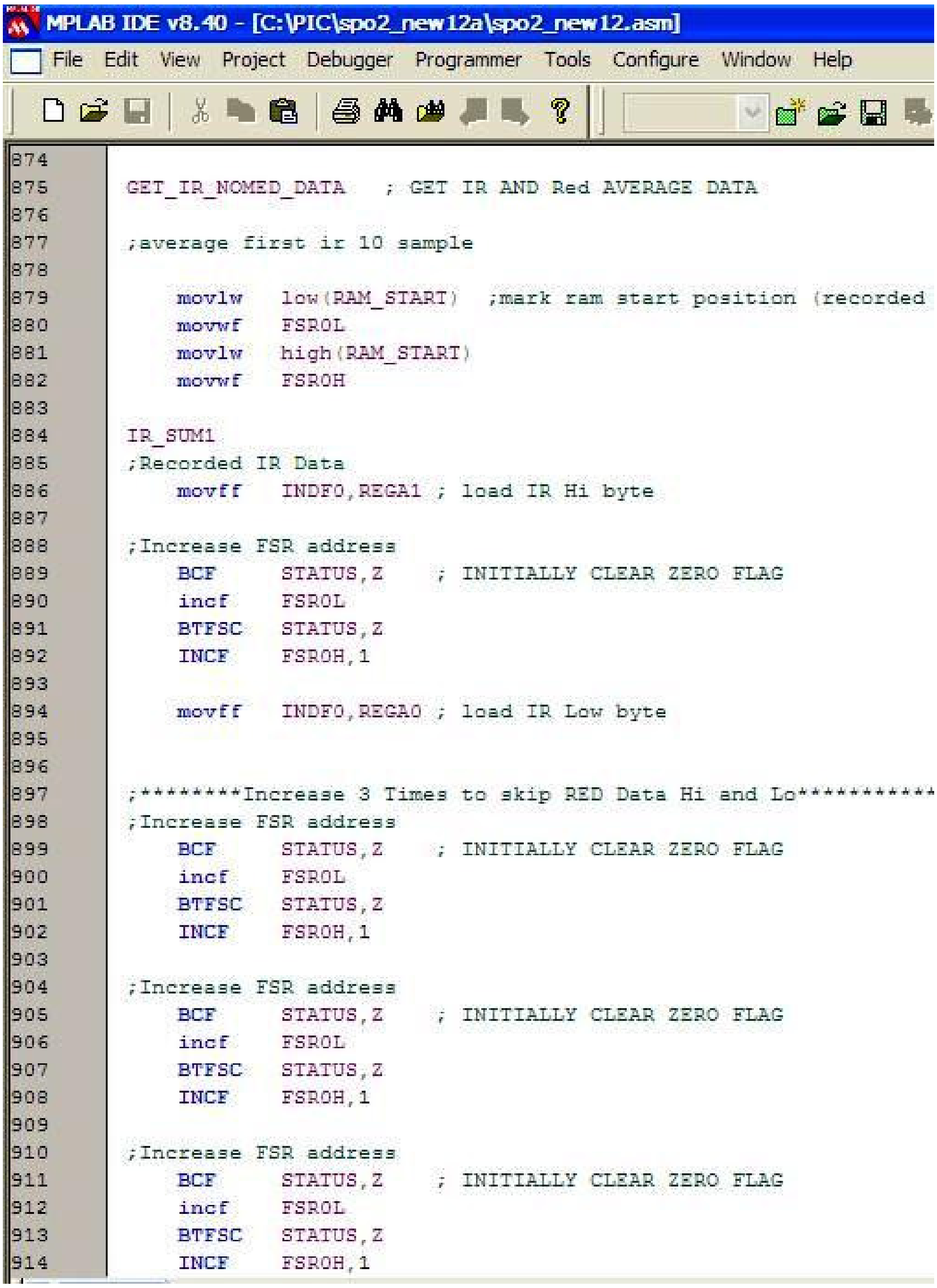


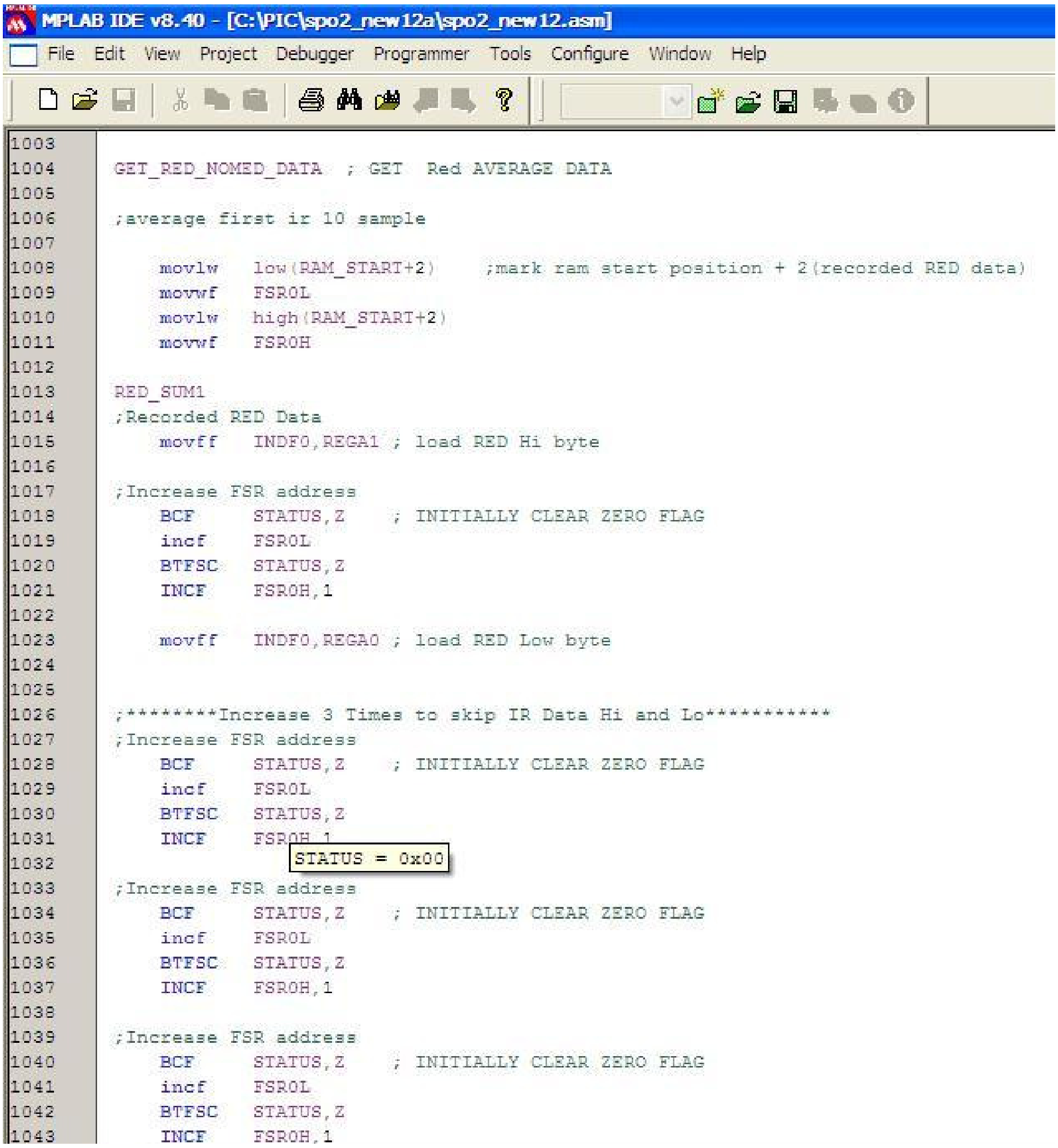
Figure 4.29: Screenshot of assembly codes to collect raw samples of infrared and red light sensed without finger




```
GET_IR_NOMED_DATA    ; GET IR AND Red AVERAGE DATA

;average first ir 10 sample

    movlw    low(RAM_START)   ;mark ram start position (recorded
    movwf    FSR0L
    movlw    high(RAM_START)
    movwf    FSR0H

IR_SUM1
;Recorded IR Data
    movff    INDF0,REGA1 ; load IR Hi byte

;Increase FSR address
    BCF      STATUS,Z     ; INITIALLY CLEAR ZERO FLAG
    incf     FSR0L
    BTFSC    STATUS,Z
    INCF     FSR0H,1

    movff    INDF0,REGA0 ; load IR Low byte


;********Increase 3 Times to skip RED Data Hi and Lo***********
;Increase FSR address
    BCF      STATUS,Z     ; INITIALLY CLEAR ZERO FLAG
    incf     FSR0L
    BTFSC    STATUS,Z
    INCF     FSR0H,1

;Increase FSR address
    BCF      STATUS,Z     ; INITIALLY CLEAR ZERO FLAG
    incf     FSR0L
    BTFSC    STATUS,Z
    INCF     FSR0H,1

;Increase FSR address
    BCF      STATUS,Z     ; INITIALLY CLEAR ZERO FLAG
    incf     FSR0L
    BTFSC    STATUS,Z
    INCF     FSR0H,1
```

Figure 4.30: Screenshot of assembly codes to obtain average sample of infra-red light sensed without finger

To illuminate IR LED at desired dimming level, predefined IR_PWM value is used. The used codes (Appendix A, p.131) are shown in figure (4.30). This value is obtained from experiment by measuring voltage at Op-Amp output pin while IR LED is on. By setting PORTD, 0 (pin 19), IR LED is selected.




```
GET_RED_NOMED_DATA  ; GET  Red AVERAGE DATA

;average first ir 10 sample

    movlw   low(RAM_START+2)     ;mark ram start position + 2(recorded RED data)
    movwf   FSR0L
    movlw   high(RAM_START+2)
    movwf   FSR0H

RED_SUM1
;Recorded RED Data
    movff   INDF0,REGA1 ; load RED Hi byte

;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1

    movff   INDF0,REGA0 ; load RED Low byte


;********Increase 3 Times to skip IR Data Hi and Lo***********
;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1
            STATUS = 0x00
;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1

;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1
```

Figure 4.31: Screenshot of assembly codes to obtain average samples of red light sensed without finger

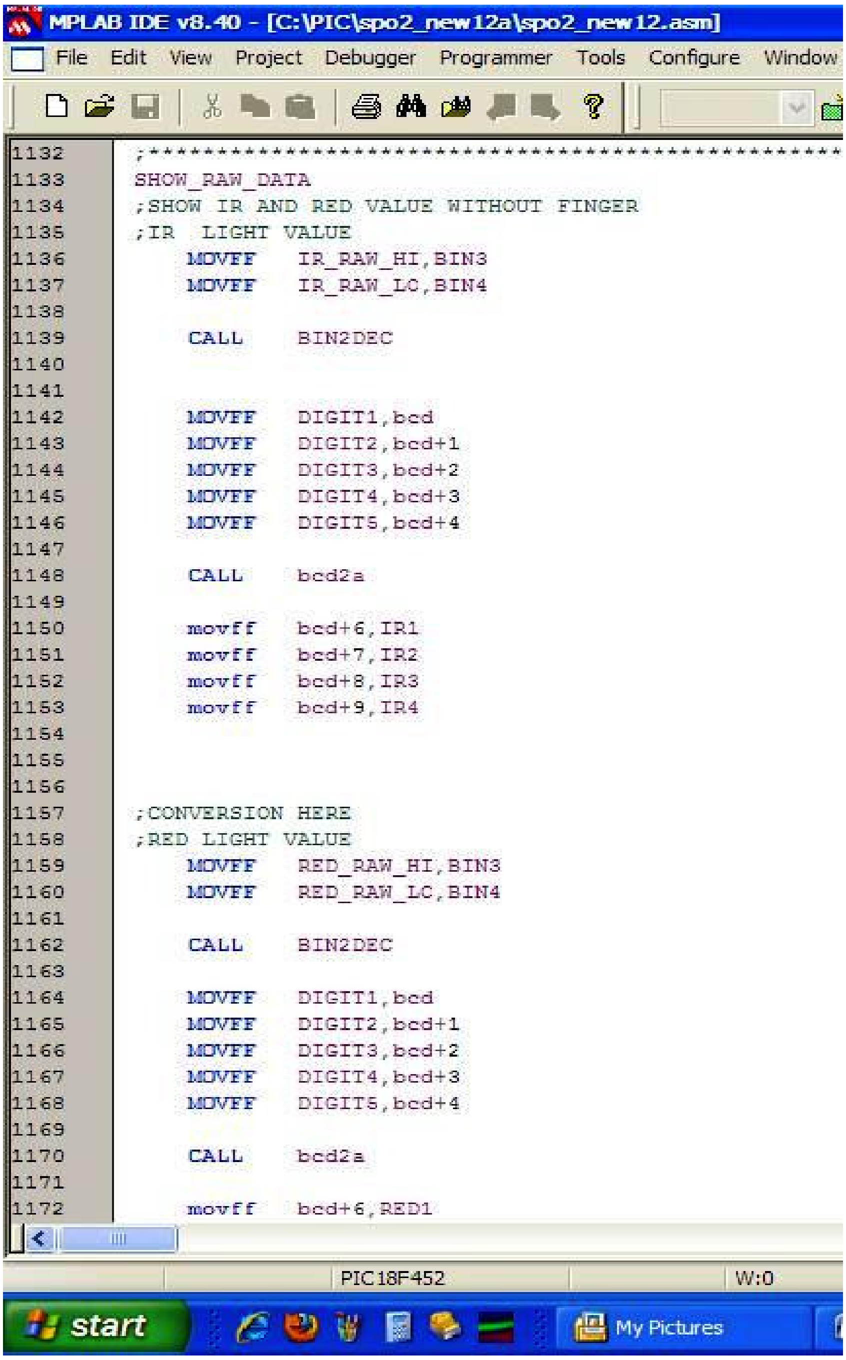


Figure 4.32: Screenshot of assembly codes to show raw data on LCD

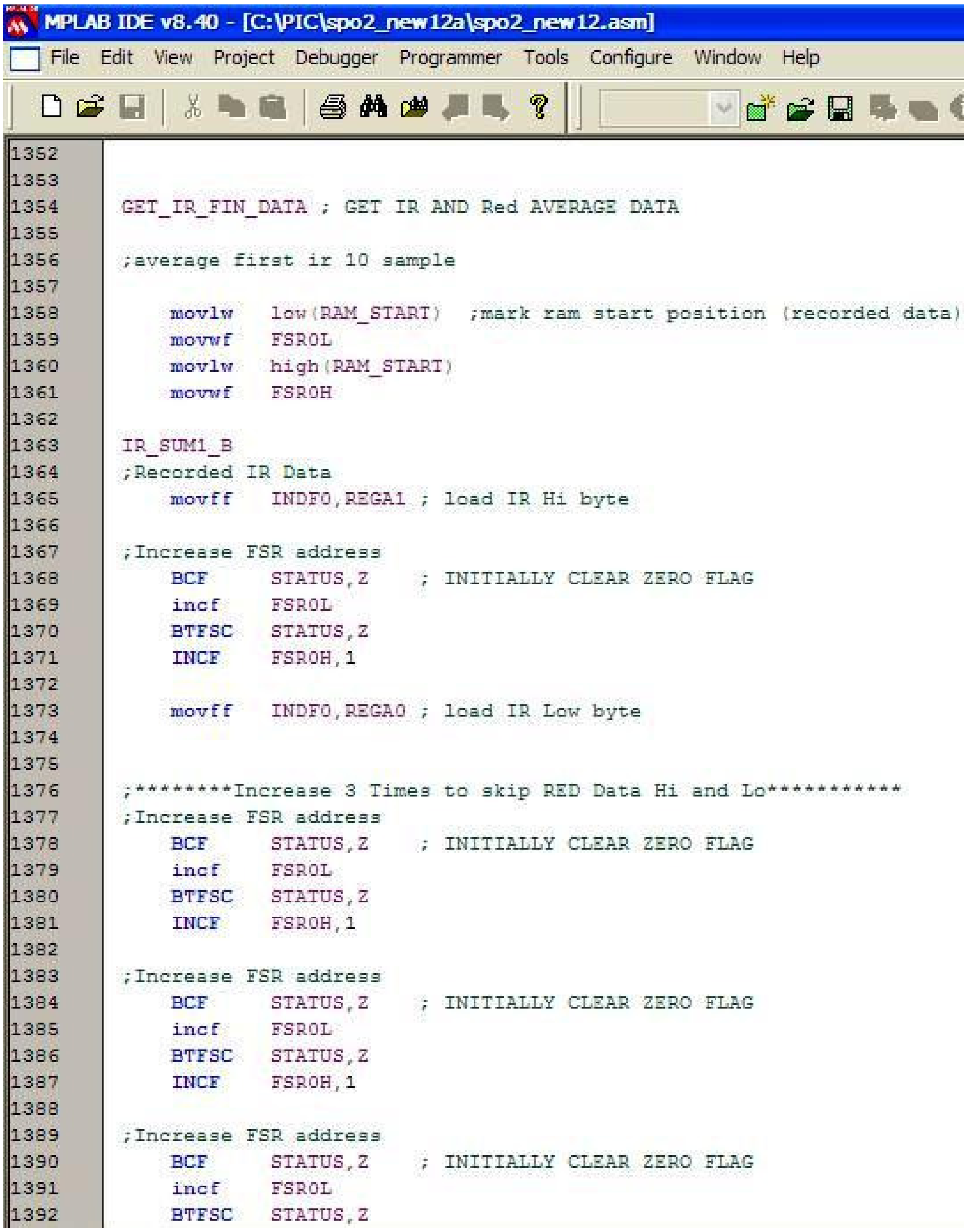
To save one sample value for IR or Red light detection, two bytes of RAM must be used. POSTINC0 is the specific instruction in 18F series to use the contents of FSR0 to address data memory value of FSR0 post-incremented (not a physical register).

```
MOVFF        IR_VALUE_H, POSTINC0    ; HI byte save in RAM
MOVFF        IR_VALUE_l, POSTINC0    ; LO byte save in RAM
```

After saving 10 sample values they are all added to make the sum value. To make the addition in assembly language, values are added repeatedly one after one. “Addba” subroutine is used to make the addition. Then, the sum value is divided by 10 to get the average for infrared light and red light. The division is made by calling the subroutine “divide”. The figure (4.31) shows the assembly codes (Appendix A, p.133) utilized to obtain the average sample of red light sensed without finger. The codes utilized to show the raw data on LCD (Appendix A, p.138) are shown in figure (4.32) then the data are shown on LCD followed by the message “SHOW_RAW_DATA”.

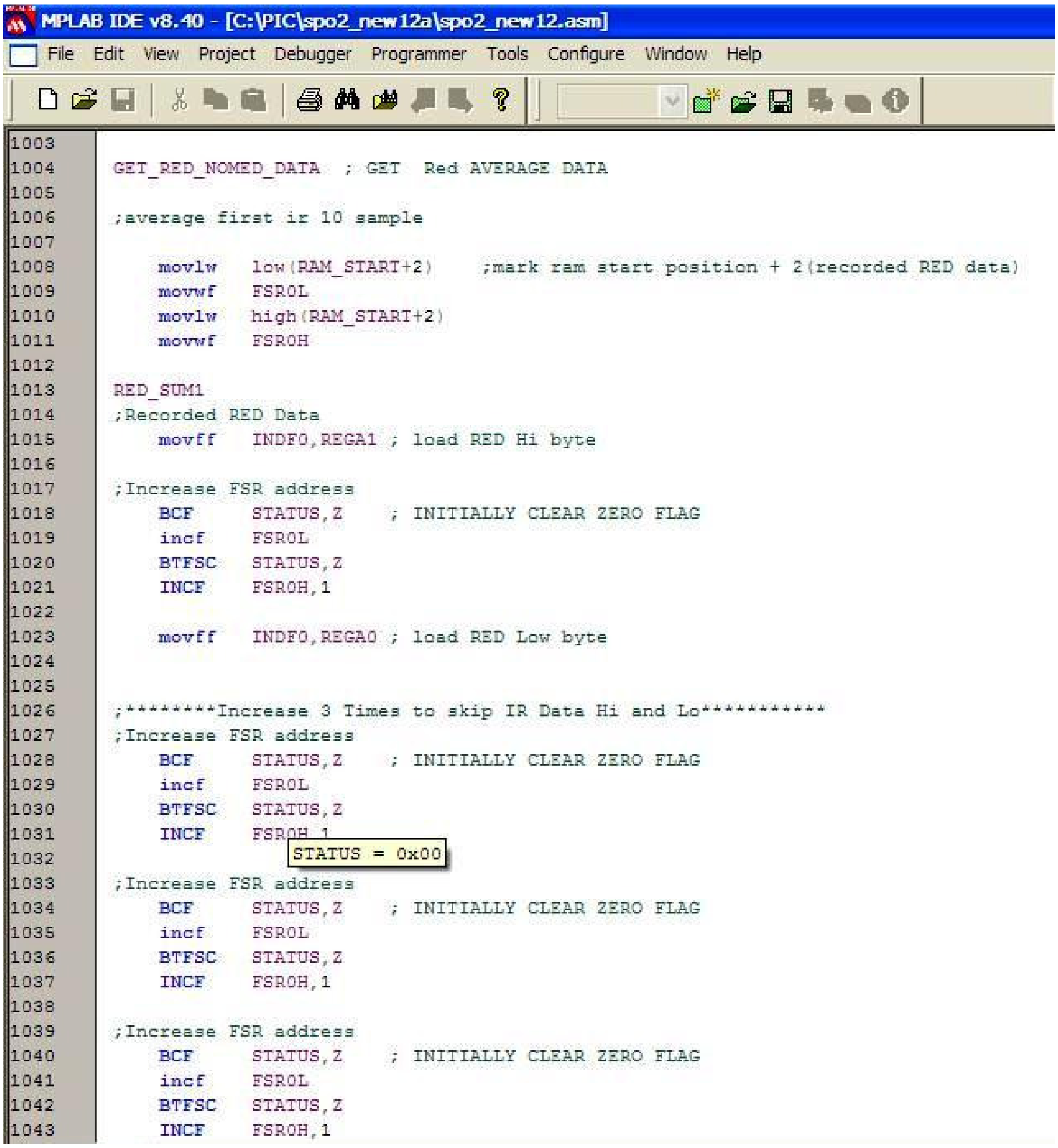
4.5.3 Sensing with finger

The readings of IR and Red inside the finger clip are collected averaging from 10 readings, then saved in assigned RAM space as the same procedure as the IR sampling method.



```
GET_IR_FIN_DATA ; GET IR AND Red AVERAGE DATA

;average first ir 10 sample

    movlw   low(RAM_START)  ;mark ram start position (recorded data)
    movwf   FSR0L
    movlw   high(RAM_START)
    movwf   FSR0H

IR_SUM1_B
;Recorded IR Data
    movff   INDF0,REGA1 ; load IR Hi byte

;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1

    movff   INDF0,REGA0 ; load IR Low byte


;********Increase 3 Times to skip RED Data Hi and Lo***********
;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1

;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1

;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
```

Figure 4.33: Screenshot of assembly codes to obtain average samples of infrared light sensed with finger




```
GET_RED_NOMED_DATA   ; GET  Red AVERAGE DATA

;average first ir 10 sample

    movlw   low(RAM_START+2)     ;mark ram start position + 2(recorded RED data)
    movwf   FSR0L
    movlw   high(RAM_START+2)
    movwf   FSR0H

RED_SUM1
;Recorded RED Data
    movff   INDF0,REGA1 ; load RED Hi byte

;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1

    movff   INDF0,REGA0 ; load RED Low byte


;********Increase 3 Times to skip IR Data Hi and Lo***********
;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1
              STATUS = 0x00
;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1

;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1
```

Figure 4.34: Screenshot of assembly codes to obtain average samples of red light sensed with finger

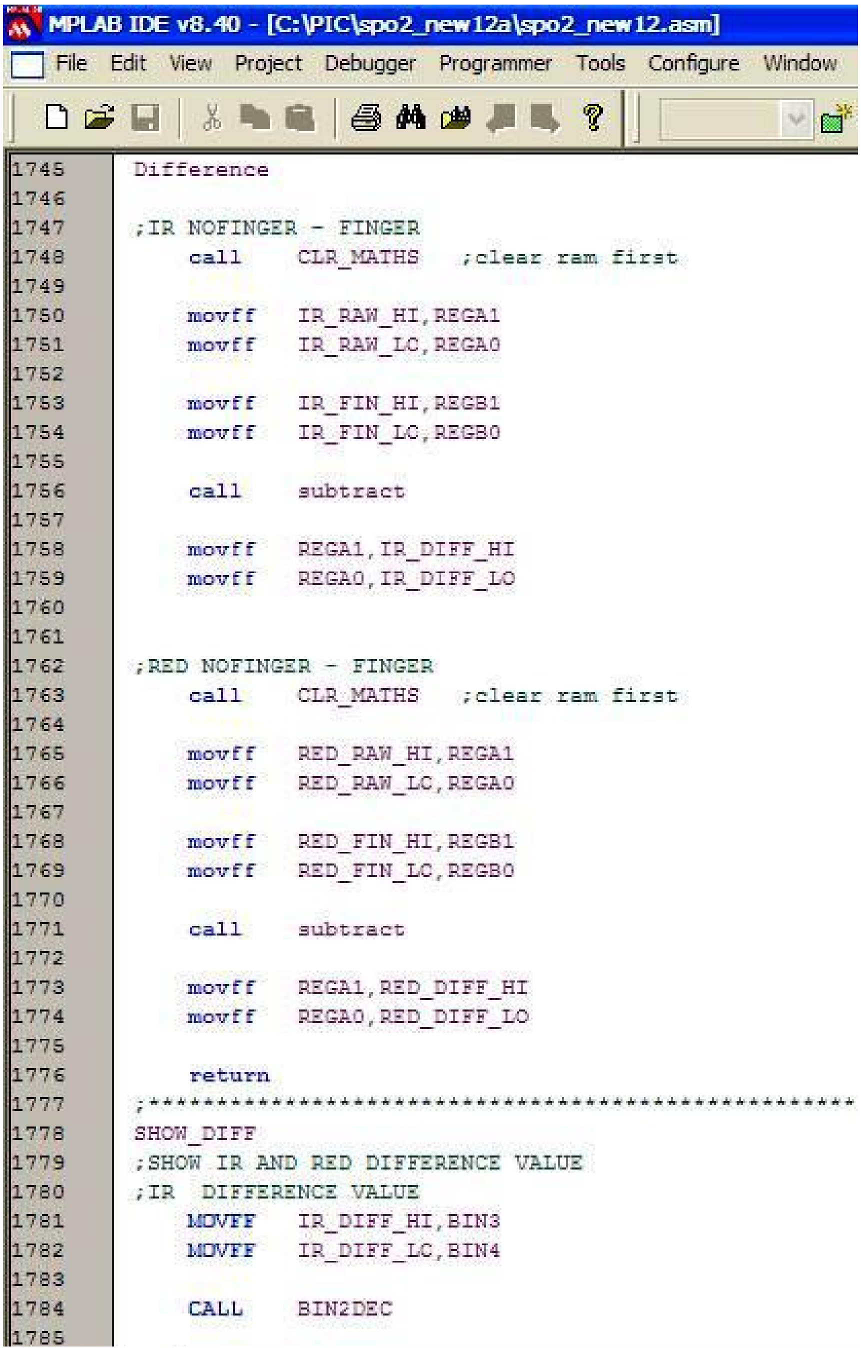


Figure 4.35: Screenshot of assembly codes for difference of the samples of red and infrared light sensed without finger and with finger

4.5.4 SpO_2 calculation

The value **R** is calculated based on the readings using mathematical functions. **R** is the difference in Red LED reading (without - with finger) / difference in IR LED reading (without - with finger). Value **R** is multiplied by coefficient **b**, then calculate (**S = a – bR**) by value **bR** is subtracted from coefficient **a** using mathematical functions. Store the value **S** in specified RAM to be shown as SpO_2 level in percentage on LCD and/or PC. The figure (4.33) shows assembly codes to obtain average samples of infrared light sensed with finger (Appendix A, p.136). The assembly codes to obtain average samples of red light sensed with finger (Appendix A, p.137) are displayed in figure (4.34). The figure (4.35) illustrates the assembly codes for difference of the samples of red and infrared light sensed without finger and with finger (Appendix A, p.138). The assembly codes (Appendix A, p.139) to find the value of (**a – bR**) are shown in figure (4.36).

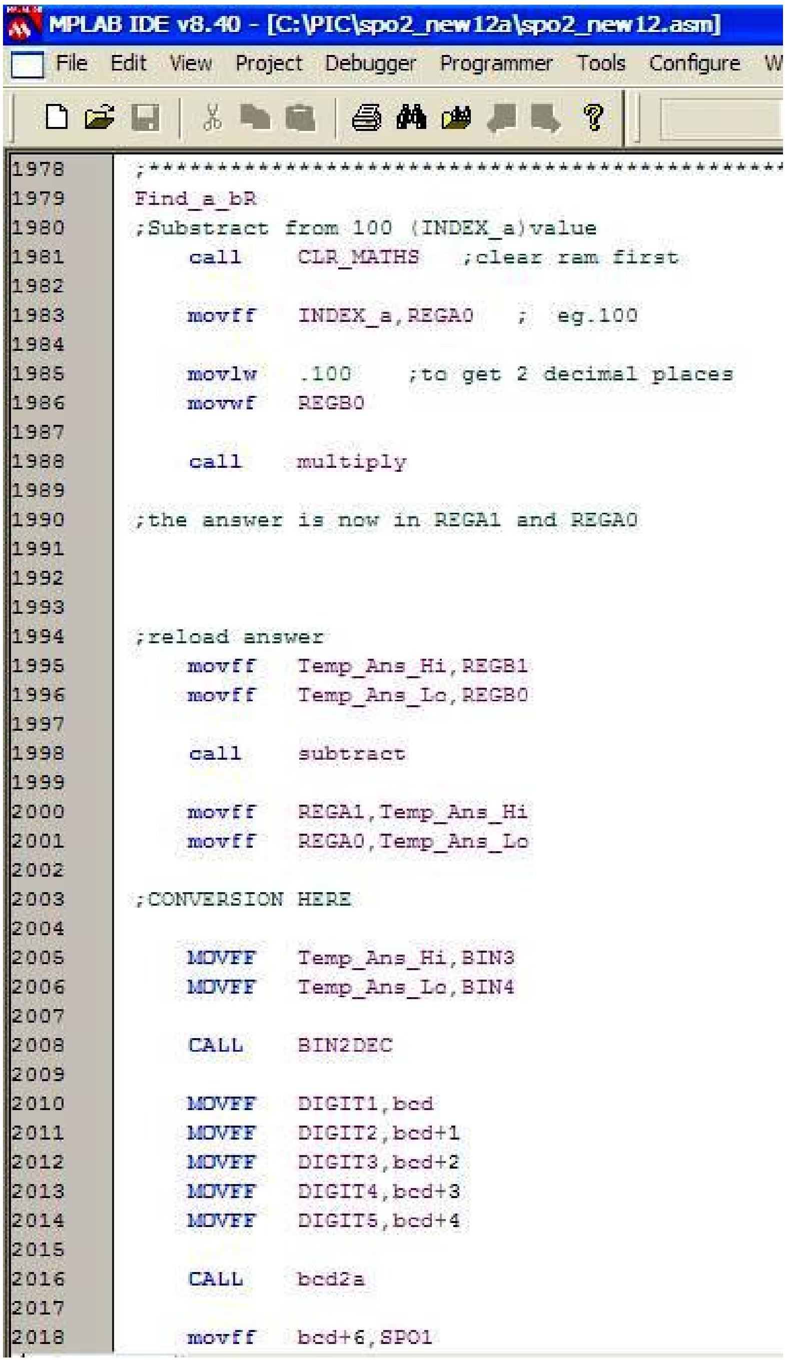
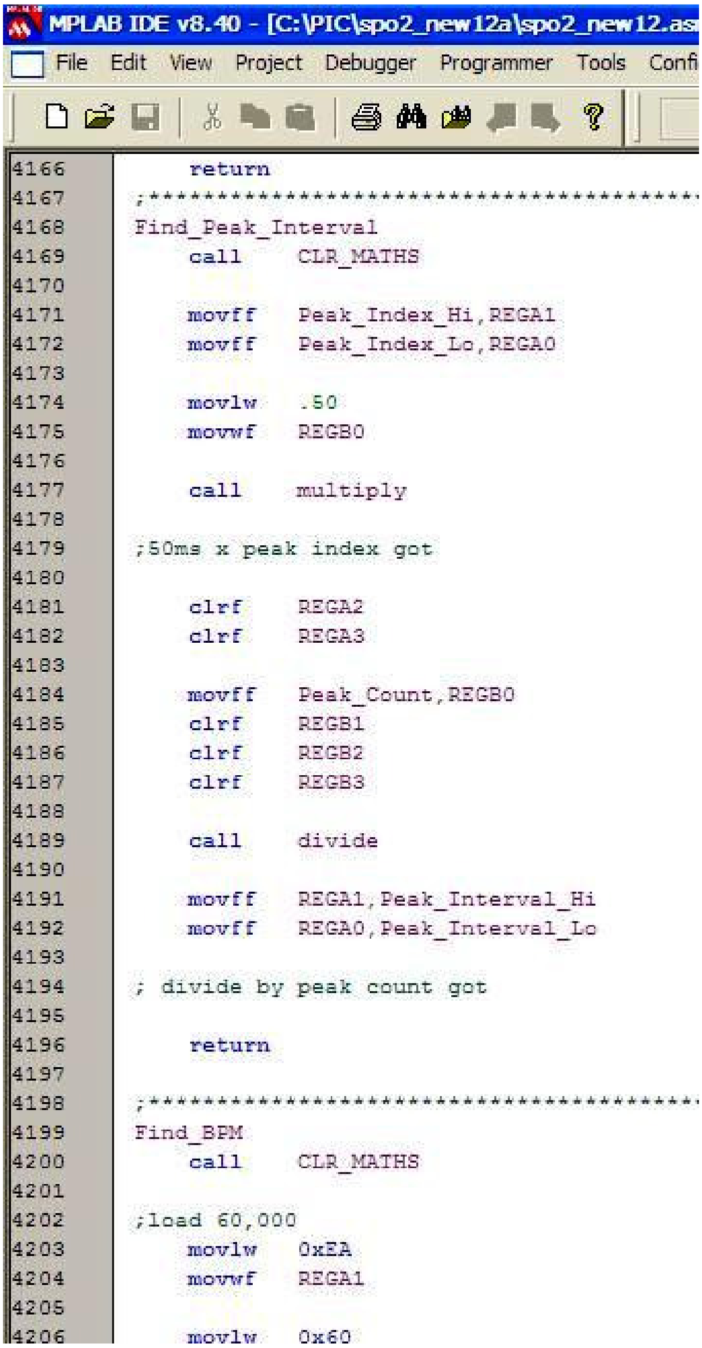


Figure 4.36: Screenshot of assembly codes to find a – bR in the routine of SpO_2 calculation

4.5.5 Pulse rate calculation




```
	return
;*******************************************
Find_Peak_Interval
	call	CLR_MATHS

	movff	Peak_Index_Hi,REGA1
	movff	Peak_Index_Lo,REGA0

	movlw	.50
	movwf	REGB0

	call	multiply

;50ms x peak index got

	clrf	REGA2
	clrf	REGA3

	movff	Peak_Count,REGB0
	clrf	REGB1
	clrf	REGB2
	clrf	REGB3

	call	divide

	movff	REGA1,Peak_Interval_Hi
	movff	REGA0,Peak_Interval_Lo

; divide by peak count got

	return

;*******************************************
Find_BPM
	call	CLR_MATHS

;load 60,000
	movlw	0xEA
	movwf	REGA1

	movlw	0x60
```

Figure 4.37: Screenshot of assembly codes utilized to obtain peak interval in the routine of pulse rate calculation

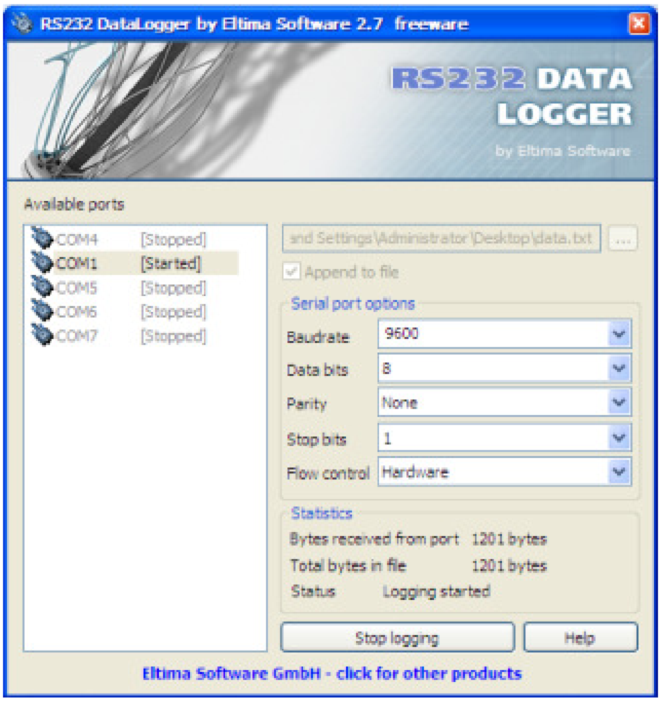
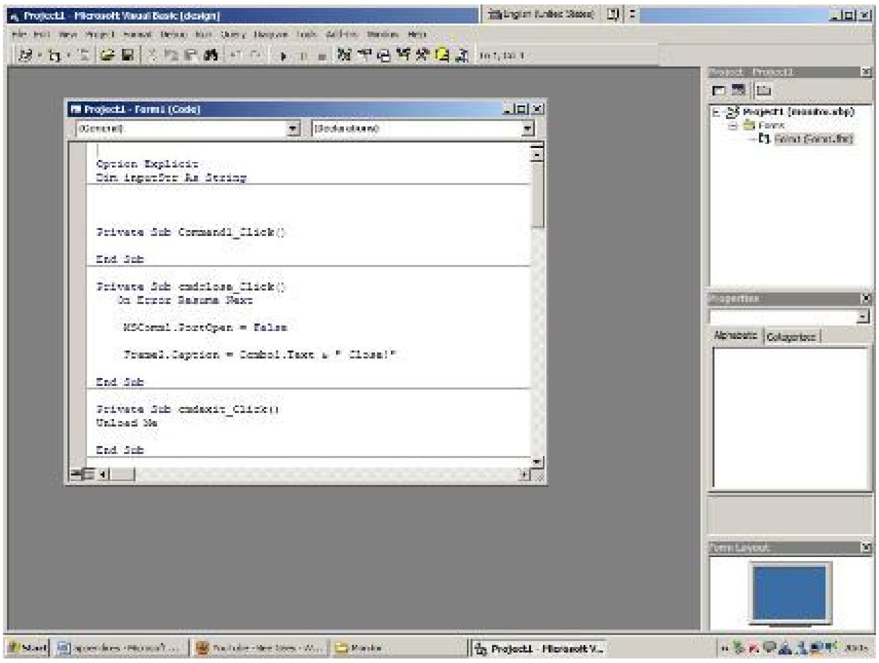


Figure 4.38: Screenshot of Eltima software utilized to transform the data sample and time to pulse

Only IR LED is lighted for 10 seconds and stored 200 samples of 10 bit ADC value in 600 bytes of assigned RAM. The samples are stored every 500 ms. The assigned RAM address starts from 0x0080 to 0x02D7 in general purpose user memory. There are 3 bytes to store a sample such as High Byte, Low Byte and Index value respectively. To measure a pulse rate, the stored samples are checked for possible peak detection algorithm. The Highest and Lowest values are taken to calculate the threshold value. The immediate rising of the values greater than threshold units marked as a peak or a pulse. The period between each peak can be calculated by multiplying of index number with 500 ms, the time between samples. Then take the average peak interval and calculate the bpm value. According to the 10 sec sample, the bpm value will be the multiplication of 6. Then the values of SpO_2 (percent) and Pulse Rate (bpm) are displayed in LCD and PC. The figure (4.36) shows assembly codes to find $a - bR$ in the routine of SpO_2 calculation (Appendix A, p.139). The assembly codes to obtain peak interval (Appendix A, p.144) are shown in figure (4.37). The Eltima software is used to transform the data sample and time to pulse as shown in figure (4.38).

4.6 USART data transmission



4.39: Screenshot of the project form of Visual Basic 6

To send the SpO_2 and Pulse Rate results to a personal computer, the USART module is used. USART is also known as a Serial Communications Interface or SCI. The USART can be configured as a full duplex asynchronous system that can communicate with peripheral devices. At the PC side, a simple Visual Basic Communication program is developed in order receives serial data at baud rate of 9600 bps. Other communication program such as Windows Hyper Terminal can also be used to display the data received in plain text format. The project form of Visual Basic 6 is shown in figure (4.39). To send data with USART module, data must be sent one byte after another. After the transmission of each byte, a delay time should be added to get the module ready for another byte transmission. The assembly codes used to send 3 bytes of data (Appendix A, p.140) is shown in figure (4.40).

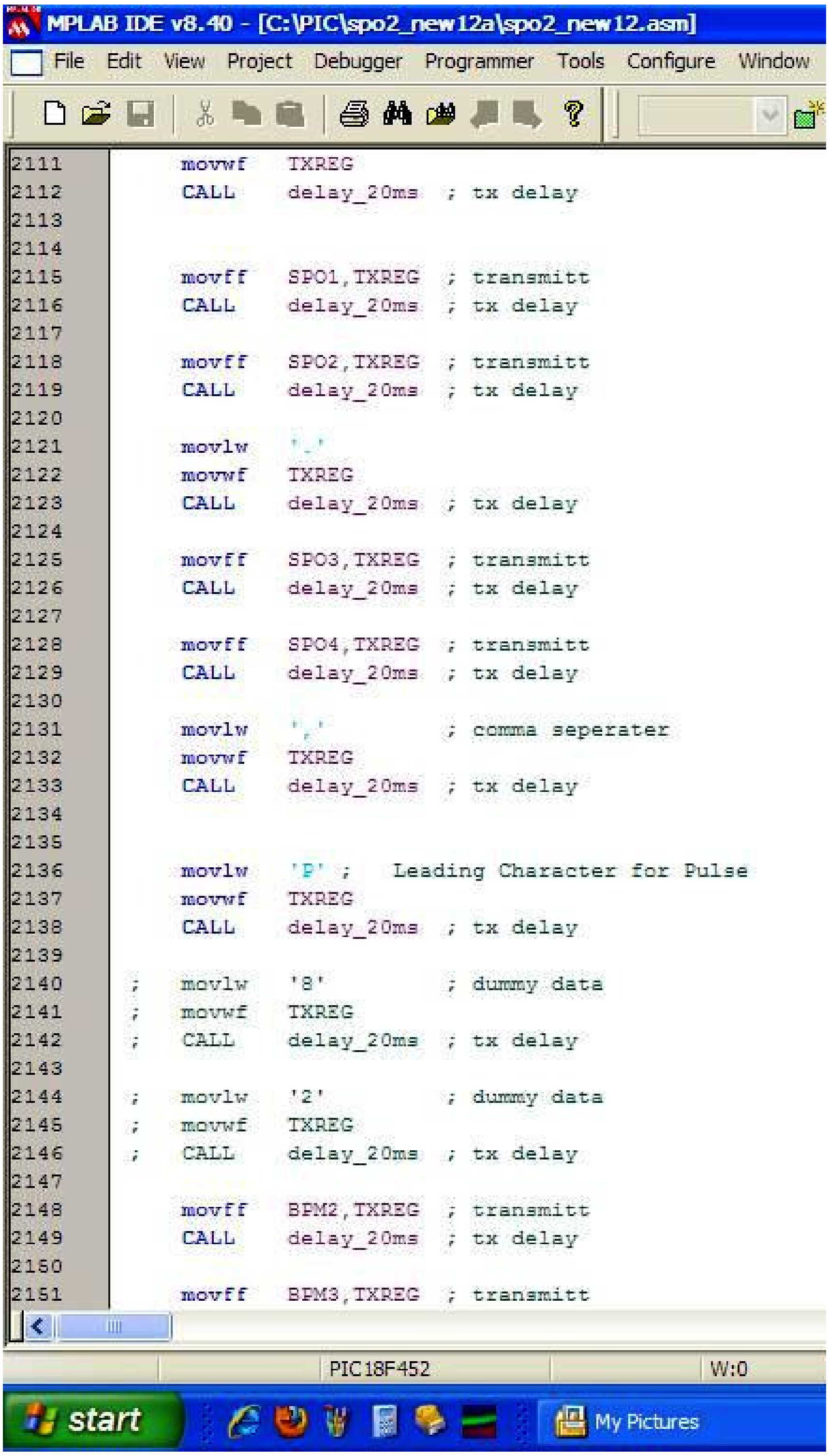


Figure 4.40: Screenshot of assembly codes to send the SPO_2 and pulse rate

4.7 MPLAB integrated development environment

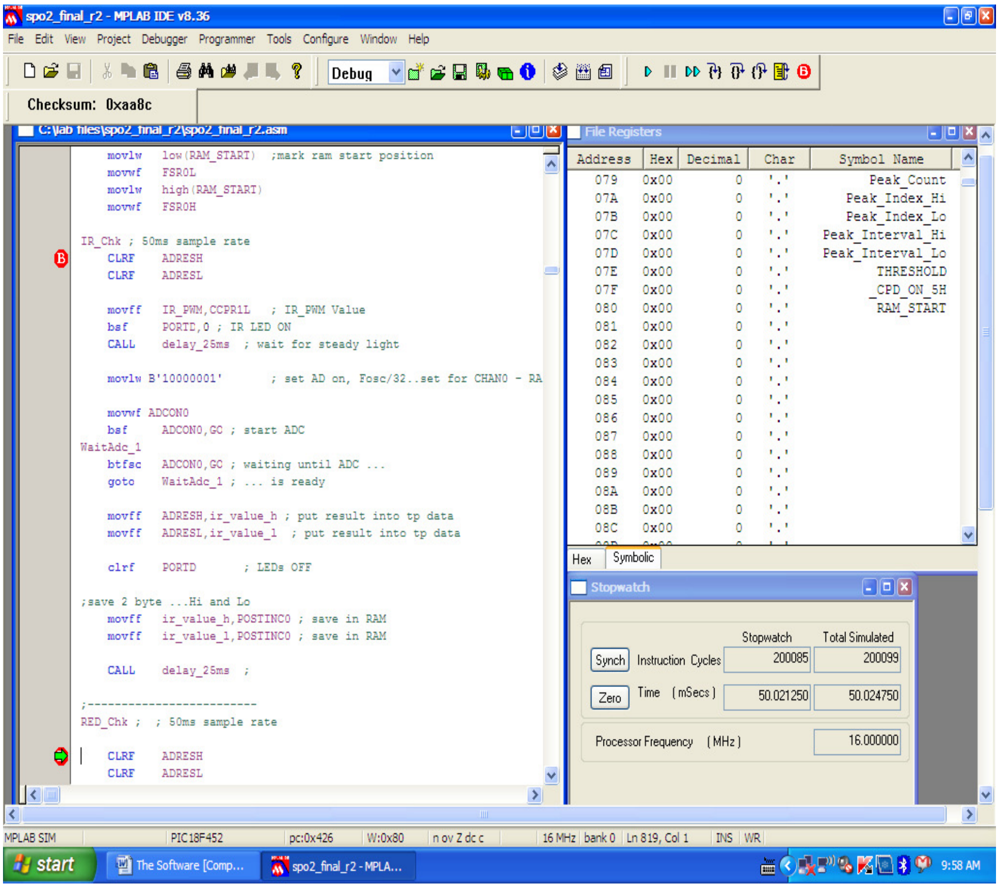


Figure 4.41: Screenshot of assembly codes for checking sample period with stopwatch in MPLAB

MPLAB Integrated Development Environment (IDE) is a free, integrated toolset for the development of embedded applications employing Microchip's PIC microcontrollers. MPLAB IDE runs as a 32-bit application on MS Windows®, is easy to use and includes a host of free software components for fast application development and super-charged debugging. MPLAB IDE is used to simulate and debug the source code, to compile the final source code to get the machine understandable HEX code and to programmer or burn it into the microcontroller chip using PICkit2 programmer. The processor clock speed is 16 MHz using 4 MHz external crystal and PLL (Phase-Locked Loop) feature of the PIC18LF452 which can speed-up the clock speed to four times of the crystal oscillator speed. MPLAB IDE also serves as a single, unified graphical user interface for additional Microchip and third party software and hardware development tools. The assembly codes for checking sample period with stopwatch are shown in figure (4.41). PWM output is checked in MPLAB logic analyzer as shown in figure (4.42).

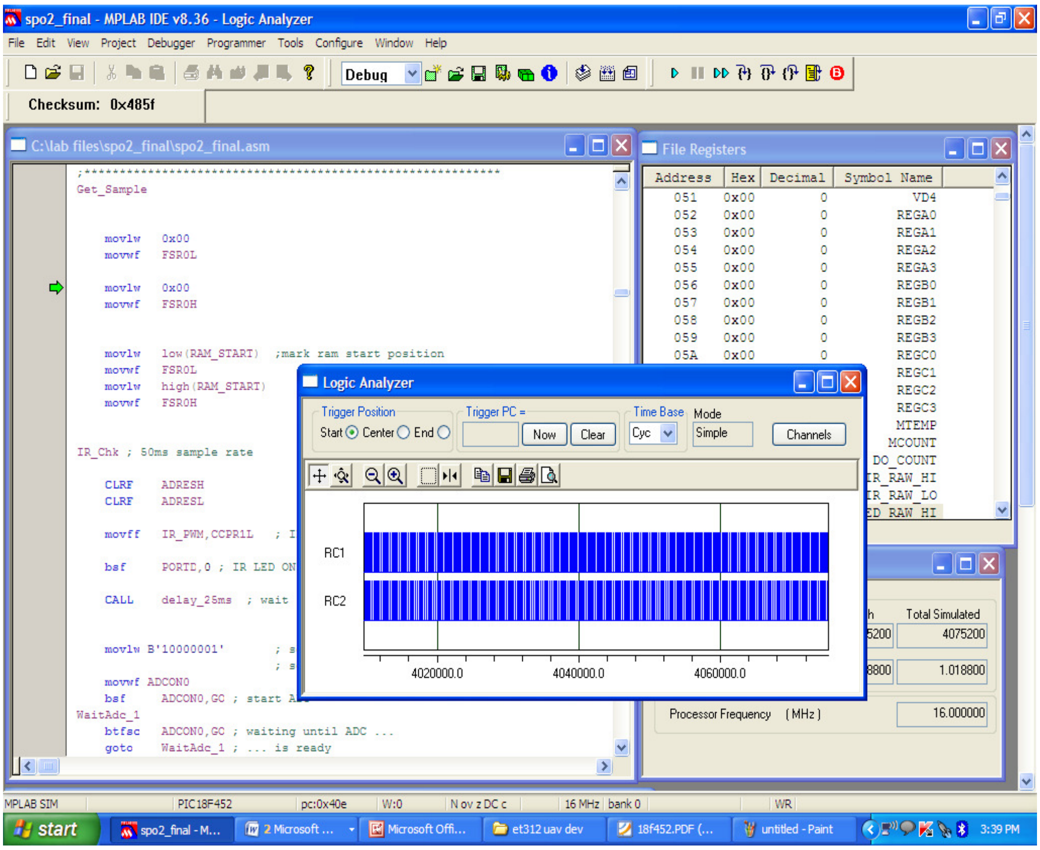


Figure 4.42: Checking PWM output signal in MPLAB logic analyzer

4.8 Summary

In this chapter, the finalized design of the hardware and software implementation has been discussed in detail. The function of IR and Red LED drivers, the implementation of the plastic clip, the choice of right resistor values, LM358 Operational Amplifier, the function of Microchip PIC18LF452 8 bit microcontroller, the function of ADC, the function of LCD display Hitachi HD44780, the function of power supply of +5 V LP2950 LDO, the reason of choosing RS232 for the transceiver unit, and PCB (printed circuit board) etching have been included in hardware implementation. The configuration of microcontroller, the initialization of microcontroller including port initialisation, USART module initialization, ADC module initialization, CCP module initialization for PWM mode, timer 2 module initialization, LCD initialization, the main program of pulse oximetry software, sensing voltage level both without finger and with finger and SpO_2 calculation and pulse rate calculation, the explanation of USART data transmission to display the readings on computer monitor, MPLAB integrated development environment and the flow chart of the entire software system are included in software implementation.

CHAPTER 5: PULSE OXIMETER MEASUREMENT

5.1 Introduction

In this chapter, the results of pulse oximetry measurements obtained from the final design are reported. A detailed discussion about each measurement is also described. The measurement was made using a transmission mode configuration with the same type of dual LED and photodiode as described in chapter 4. The reproducibility of the setup and signal processing is investigated for a single combination of LED drive current and separation between light sources of LEDs and photo detector. These components were mounted on separate PCBs and sited on opposite appendages of finger clip as described in chapter 4.

5.2 Application of the designed device

The designed device is placed in a plastic box as shown in figure (5.1). The LCD display is placed on top of the plastic box.

The procedures of measuring SpO_2 and pulse are as follows;

1. Switch the pulse oximetry on and wait for a few seconds for its calibration and check tests.
2. "PLEASE WAIT…." is displayed on LCD. The user has to wait for system initialization and completion of collecting the data without finger.
3. The collected data of intensities of Red and IR light are displayed on LCD.
4. Put your finger inside the finger clip when "PUT UR FINGER" is displayed on LCD.
5. LCD shows the collected data with finger inside the finger clip.
6. The difference of IR and Red light intensity due to blood concentration blocked between LEDs and Photodiode Sensor is displayed on LCD.
7. "SAMPLING" is displayed on LCD; that is only IR LED is switched on for 10 seconds when collecting pulse data for pulse rate calculation.
8. The final readings of SpO_2 (concentration of oxygen in the blood) in percentage and pulse in beats per minute will be displayed on LCD as shown in figure (5.8).
9. If in doubt or error occurred, press the reset button and start the procedure again.

The outside view of the plastic box is shown in figure (5.1). The steps and codes of the pulse oximeter are shown in figures (5.2) – (5.13). This probe is very similar to the probes used in the clinics. When the pulse oximetry is switched on, it takes a few seconds for its calibration and check tests.

The system is initialized and the sample readings of both Red LED and IR RED are collected. It takes a few seconds and "PLEASE WAIT…." is displayed on LCD as shown in figure (5.2). The collected data is merely raw data since the index finger of the user is not placed in the finger clip. The average ADC value from 10 samples of 10 bit is collected by using "Get Sample" software program when IR LED and Red Led are on alternately as discussed in chapter 4. When the samples are collected completely, the intensities of red and infrared lights are displayed on LCD as shown in figure (5.3). The intensities of 812 samples of infrared light and 803 samples of red light are shown.

When "PUT UR FINGER" is displayed on LCD as shown in figure (5.4), put user finger inside the clip. After passing through finger tissue, the average of 10 samples of infra-red and red lights are saved in assigned RAM space.
The collected data of 772 of infrared light and 768 of red light is displayed on LCD after crossing the finger shown in figure (5.5). In figure (5.6), the difference between the intensity of infrared and red light intensity due to blood concentration blocked between LEDs and Photodiode sensor is displayed on LCD. The only IR LED is required to switch on to calculate the pulse rate. The "Sampling" is shown on LCD while the data of IR LED is being collected as shown in figure (5.7).

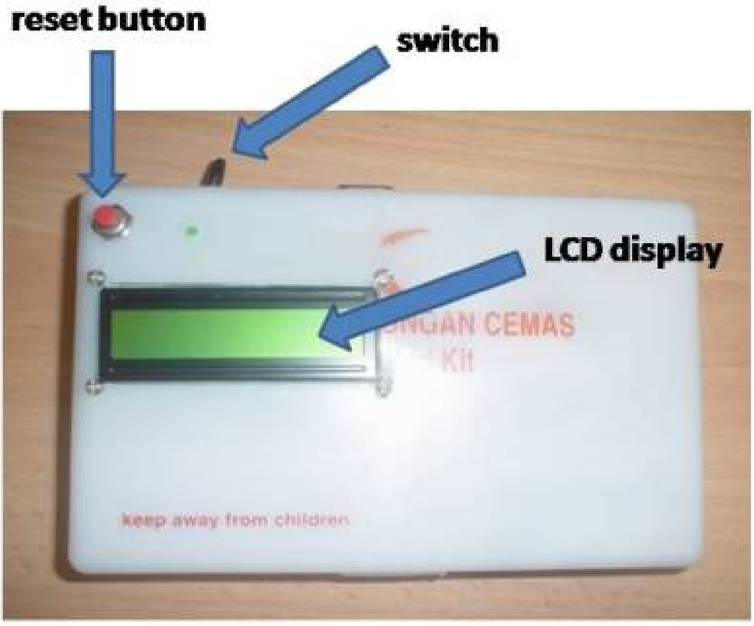


Figure 5.1: Outside view of the designed device

After calculating, the measurement of 97.63% of SpO_2 and 66 bpm of pulse rate are displayed on LCD as shown in figure (5.8). That measurement is performed on author's supervisor who is in good health. For a conscious human the oxygen saturation is 95% to 100% and pulse rate is 60 to 80 beats per minutes approximately. The measurements of pulse and SpO_2 of author's supervisor who is in good health and a non smoker while seated are shown in table (5.1). The measurements are taken twice and the results are approximately the same and acceptable.

Table 5.1 the measurements of SpO_2 and pulse of author's supervisor at a separate time.

No.	RED	IR	SpO_2(%)	Pulse Rate (bpm)	condition
1	772	768	97.63	66	sitting
2	716	716	97.33	66	sitting

Figure 5.2: LCD display shows “PLEASE WAIT….”

Figure 5.3: Intensity of red and infrared light respectively without finger

Figure 5.4: LCD display shows to put the finger inside the clip

Figure 5.5: Intensity of red and infrared light respectively with finger

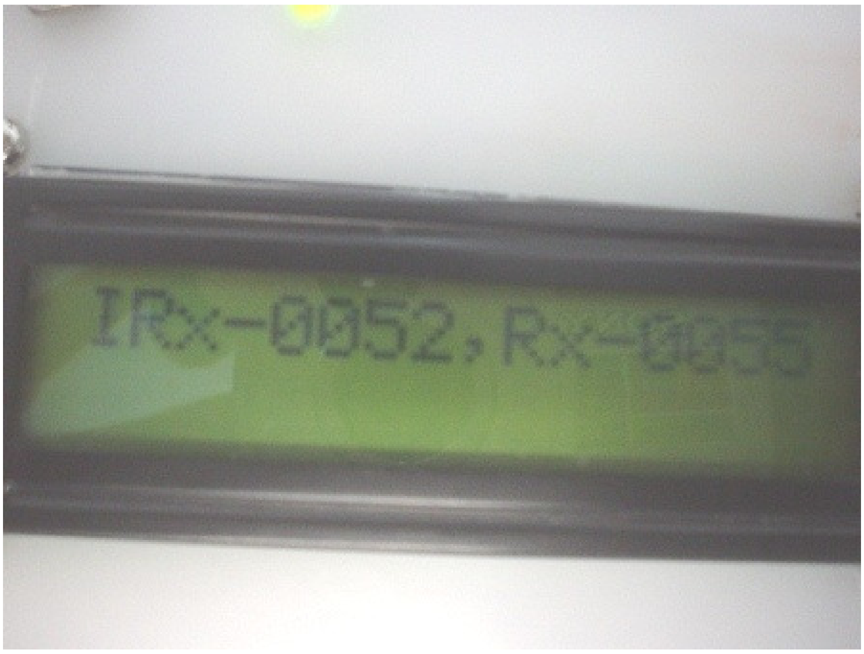


Figure 5.6: Differences of red and infrared light intensity respectively due to blood concentration

Figure 5.7: LCD displays shows “SAMPLING” when collecting pulse data for BPM calculation

Figure 5.8: Readings of blood oxygen concentration and heart beat rate of author's supervisor

5.3 Results collected under different physical conditions

The measurements are also performed on the author under different physical activities. The measurements of oxygen concentration and heart beat rate of the author are recorded. The readings under the different conditions such as resting; walking and exercising have been recorded in table (5.1).

For a healthy individual at sea level, the concentration of oxygen reading is 95% and above as stated in chapter 1. In all 3 cases shown in table (5.2), the readings are all greater than 95%. It is found that the values of SpO_2 are slightly different between resting, after walking and being exhausted. But it is clearly seen that the pulse values are different, depending on the physical activities. The intensity of 780 of infrared and 781 of red light are described on LCD while author's finger is inside the finger clip as shown in figure (5.9) after having a physical exercise such as running. The difference between the intensity of infrared and red light without finger and with finger after having physical exercise are described in figure (5.10). The pulse rate of the author after a physical exercise is shown in figure (5.11). It is obviously observed that the pulse after a physical exercise is high. When the heart rate reading is checked manually, it is approximately identical with the device measurement.

Table 5.2 the measurements of oxygen concentration and pulse of the author under different physical activities.

condition	RED intensity	IR intensity	SpO_2(%)	Pulse Rate (BPM)
resting	771	769	98.17	67
after walking	772	768	97.63	78
being exhausted	780	781	97.69	90

Figure 5.9: Intensity of infrared and red light after having physical exercise

Figure 5.10: Difference between the intensity of infrared and red light without finger and with finger after having physical exercise

Figure 5.11: Concentration of blood oxygen and pulse after having physical exercise

Figure 5.12: Incorrect readings due to movement of the finger are displayed on LCD

Some factors such as motion artifacts, exposure of measuring probe to ambient light during measurement and skin pigmentation may affect the readings. It is important that while using the designed device, the person must be seated steadily. The movement of finger may lead to incorrect readings as shown in figure (5.12). Although SpO_2 value of a healthy person (author) is acceptable as it is greater than 95%, the pulse of 48 beats per minutes is unacceptable since the pulse of a healthy individual is 60 - 80 beats per minute. It is also important that all of the sensors of pulse oximetry must contact with the finger. When the finger is not positioned correctly and Red LED does not contact with the human skin, it may result in calibration error, as shown in figure (5.13).

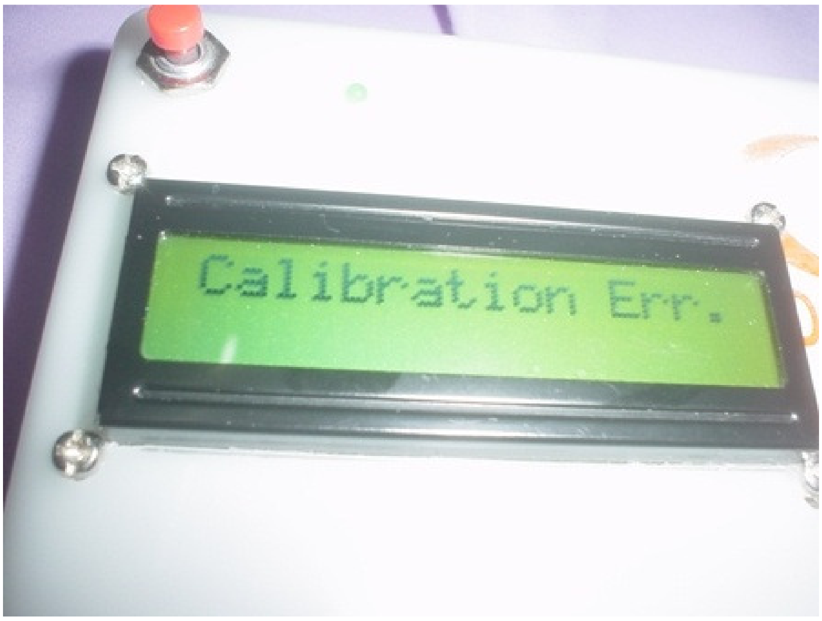


Figure 5.13: LCD display shows "Calibration Err" when the finger is not properly contacted with LEDs.

5.4 Limitations of pulse oximetry

Although the pulse oximetry is easy to use, it can produce wrong measurements in certain circumstances. The irregular heartbeats, bright overhead lighting and movement of the patient can cause inaccurate readings. Only two-wavelength spectro-photometry (660nm and 940nm) is used in this pulse oximetry, therefore they are susceptible to inaccuracies in the presence of abnormal haemoglobins. The pulse oximetry probe can be shielded with a dark material from the light source may eliminate inaccuracies. As the pulse oximetry probe is sensitive to pulsating motion, the movement of patient may affect the ability to detect a pulse that may result in inaccurate measurements. The function of pulse oximetry can be interfered by the movement of patient's finger due to shivering. Moreover, the errors can be caused due to the mal-positioning of the pulse oximetry probe that include a combination of technical and physiological problems. This can also be a particular problem with very small fingers and very large ones. If the finger clip is too large for the finger, the clip may slip and the light may not pass completely across the finger. When the finger clip is too tight on the finger , venous pulsation may occur. When the pulse oximetry detects the venous pulsation, the erroneous measurements can be obtained. The external interferences such as nail polish and skin pigmentation can interfere with inaccurate SpO_2 readings. These result in an inadequate signal for analysis. If the pulse oximetry is performed properly, the readings are typically accurate in perfect conditions.

5.5 Summary

The measurements in transmission mode pulse oximetry have been performed. The correct measurements of pulse and blood oxygen concentration have proved that the designed device could give accurate readings. The proofs of the concepts have therefore been completed by the results obtained. There are a number of limitations of pulse oximetry. The correct measurements can be obtained in perfect conditions.

CHAPTER 6: CONCLUSION AND FURTHER WORK

6.1 Conclusion

The main purpose of this research is to integrate a pulse oximetry sensor into an electronic patch and to design a simple device with low-cost, low-power consumption, small in size and portable weight. Furthermore; it contains physiological sensors, as well as data processing communication capabilities. This step has been developed and discussed.

The benefits and advantages of pulse oximetry in health care have been included. When the light signal of the two diodes (LEDs) passes through the finger tissue, the photodiode on the opposite side of the finger detects the red and infrared signals. The light transmitted through the fingertip at two different wavelengths is measured and the oxygen saturation of the arterial blood in the finger would be calculated. The two types of pulse oximetry have been presented as the reflectance and the transmittance. The advantage of transmittance pulse oximetry over the reflectance pulse oximetry includes higher signal amplitude (and thus higher signal-to-noise ratio), more convenient access, and less pressure dependence.

The light is either absorbed or scattered after passing through the human tissue. The scattering of light enlarges the absorbance due to an increase of the light path. The absorbance depends on the wavelength of light. The absorption of the light changes according to the path length and concentration; the four parameters of the basic optical properties of tissue are refractive index, absorption coefficient, scattering coefficient and phase function. The light is propagated and scattered in the visible range since human tissue is optically inhomogeneous turbid media.

The pulse oximeters measure functional saturation by transmitting two wavelengths of light that are differentially absorbed by oxyhaemoglobin and de-oxyhaemoglobin.
When the blood pumped from the heart is oxygenated, the concentration of oxygenated haemoglobin is maximum and the heart muscle contracts when the speedy electrical impulses of the heart hit muscle cells. The DC signal of electricity is formed due to the

constant absorbance such as skin, tissue, bones together with the venous blood and the non-pulsating arterial blood. The alternative signal, AC, is produced by a pulsatile blood flow. The core electronic components of pulse oximetry are of LED, IR LED, photodiode, microcontroller and power supply. In the designed pulse oximetry, LEDs are utilized for the importance of the small size and the power source of light.

The initial design and the detailed block diagram of the pulse oximetry have been explained. After testing the initial designed system, it was found that power consumption was high. The power source (batteries) was needed to be changed frequently. The resistor value of 100 ohms (Ω) has been replaced with 1 kilo ohms (KΩ) to reduce the current flow.

The method of calculating pulse rate has been changed for the accuracy of measurements. The pulse rate (bpm) is sensed by lighting IR LED for 10 seconds in the present design. The finalized design of both of the hardware implementation and software implementation has been described. The details of IR and Red LED drivers have been discussed with circuitry. The current is generated, when the light from LEDs is detected by the photodiode. That current is converted into a voltage by current-to-voltage convertor. The signal sensed by the photo diode to 2 V - 3 V of analogue voltage swing which is converted to digital numbers by the built-in ADC of embedded microcontroller PIC18LF452. The MPLAB software program is implemented in the microcontroller to convert those digital numbers to SpO_2 level in terms of percentage on LCD and/or PC.

To measure a pulse rate, only IR LED is lighted for 10 seconds and stored 200 samples of 10 bit ADC value in 600 bytes of assigned RAM. The maximum and minimum values are calculated to obtain the threshold value. The immediate rising of the values greater than threshold units marked as a peak or a pulse. The interval between each peak is calculated by multiplying of index number with 500 ms, the time between samples. The average peak interval is calculated to attain the bpm value. Eltima software is used to transform the data sample and time to pulse. Then the values of SpO_2 (percent) and Pulse Rate (bpm) are displayed on LCD and PC.

The designed device is placed in a plastic box and the LCD display is placed on top of the plastic box. The application of the pulse oximetry has been accomplished by nine steps of measurement procedures. The measurements of the oxygen concentration and heart beat rate of the author under different conditions such as resting, walking and exercising have been obtained. The readings of pulse oximetry of the author's supervisor and the measurements of oxygen concentration and heart beat rate of the author are recorded .The values under the different conditions such as resting; walking and exercising are also recorded. It is found that the values of SpO_2 are slightly different depending on the physical activities.

There are some limitations of pulse oximetry although the readings are reliable. The irregular heartbeats, bright overhead lighting and movement of the patient can cause inaccurate readings. The inaccuracies of the readings can be caused by motion artifact and the external interferences such as nail polish and skin pigmentation. The accurate readings of pulse oximetry can be obtained in perfect conditions.

6.2 Further work

The present design of the device gives the oxygen saturation reading and the pulse rate at any time on either an LCD display or a PC monitor. The device was viewed and approved by Ms. Sheryl Joy Mattu (Health Officer, Health Services and First Aid Centre, Curtin University) as it appeared to be calibrated correctly and also responded well as a pulse reader. Dr. R. D. Mattu and Dr. Lim H. J, Consultants at Columbia Hospital Miri have also viewed the monitor [Appendix C8, p.164]. If the device is intended for field trials then the finger clip should be improved before non invasive human ethics approval is applied for.

In developing the pulse oximetry, the limitations occurred in the present system implementation. For the future of remote monitoring of medical equipment, this transmittance pulse oximetry can be extended to a wireless pulse oximetry project by using one of the wireless protocols such as Zigbee.

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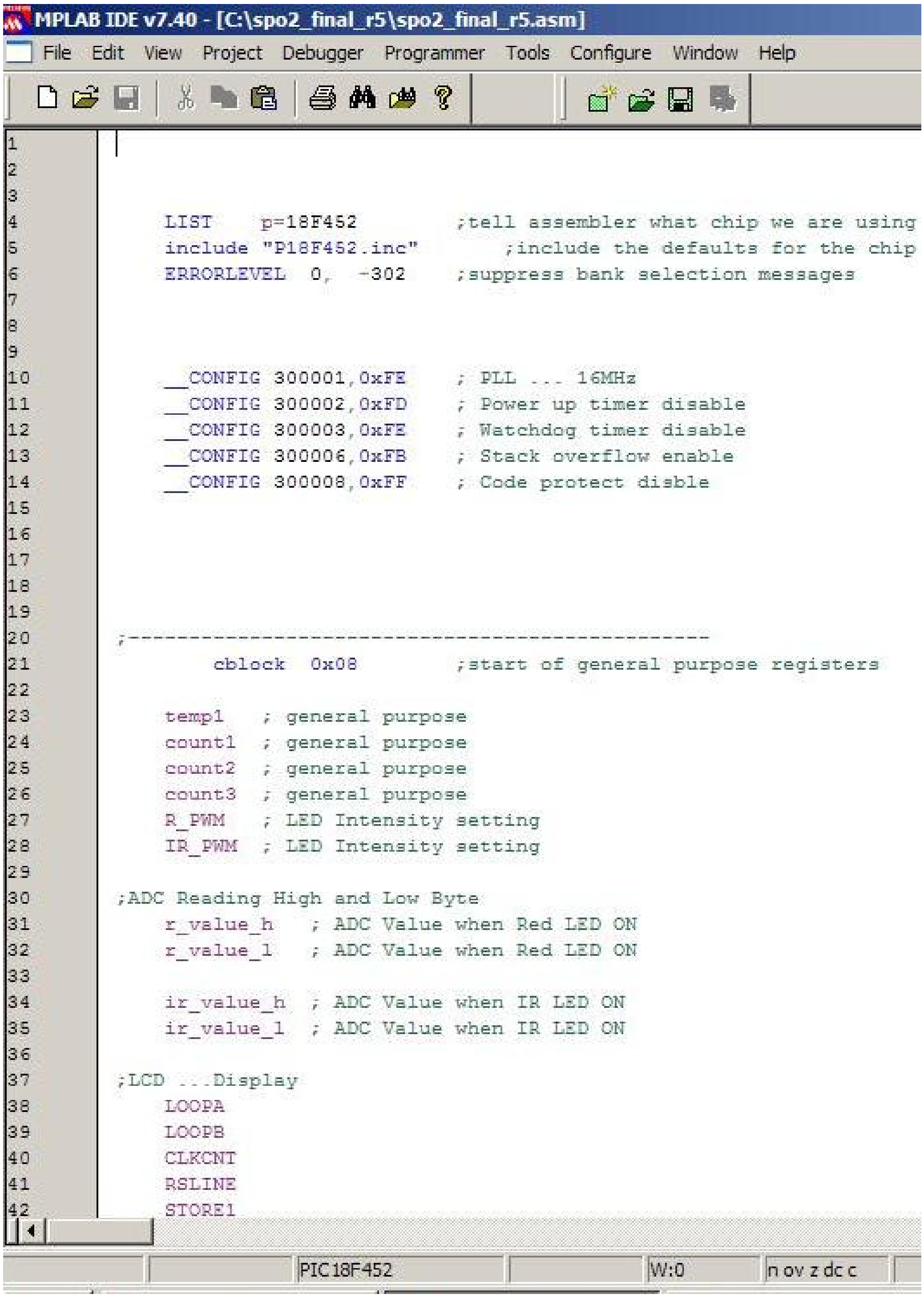
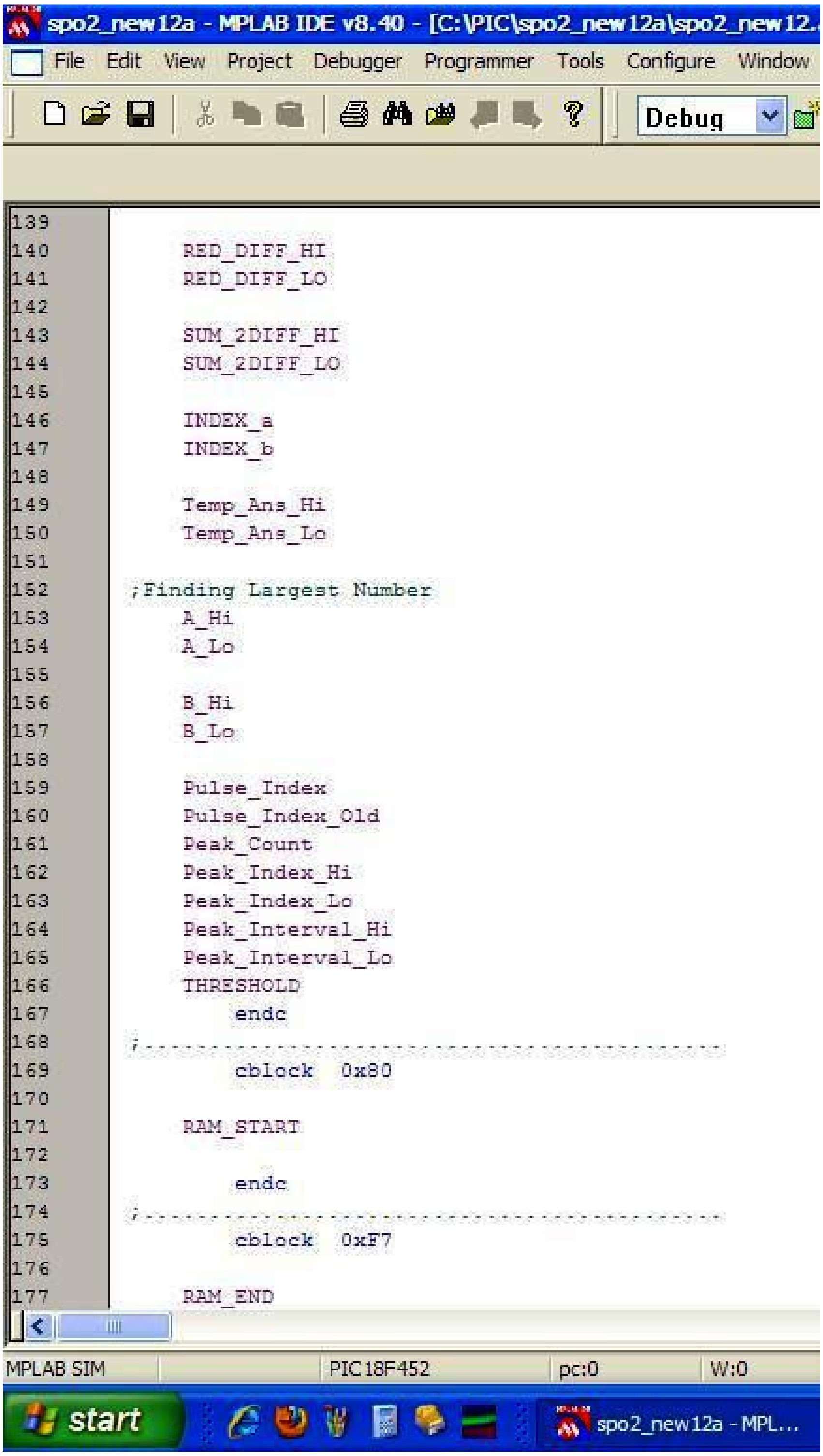
APPENDICES

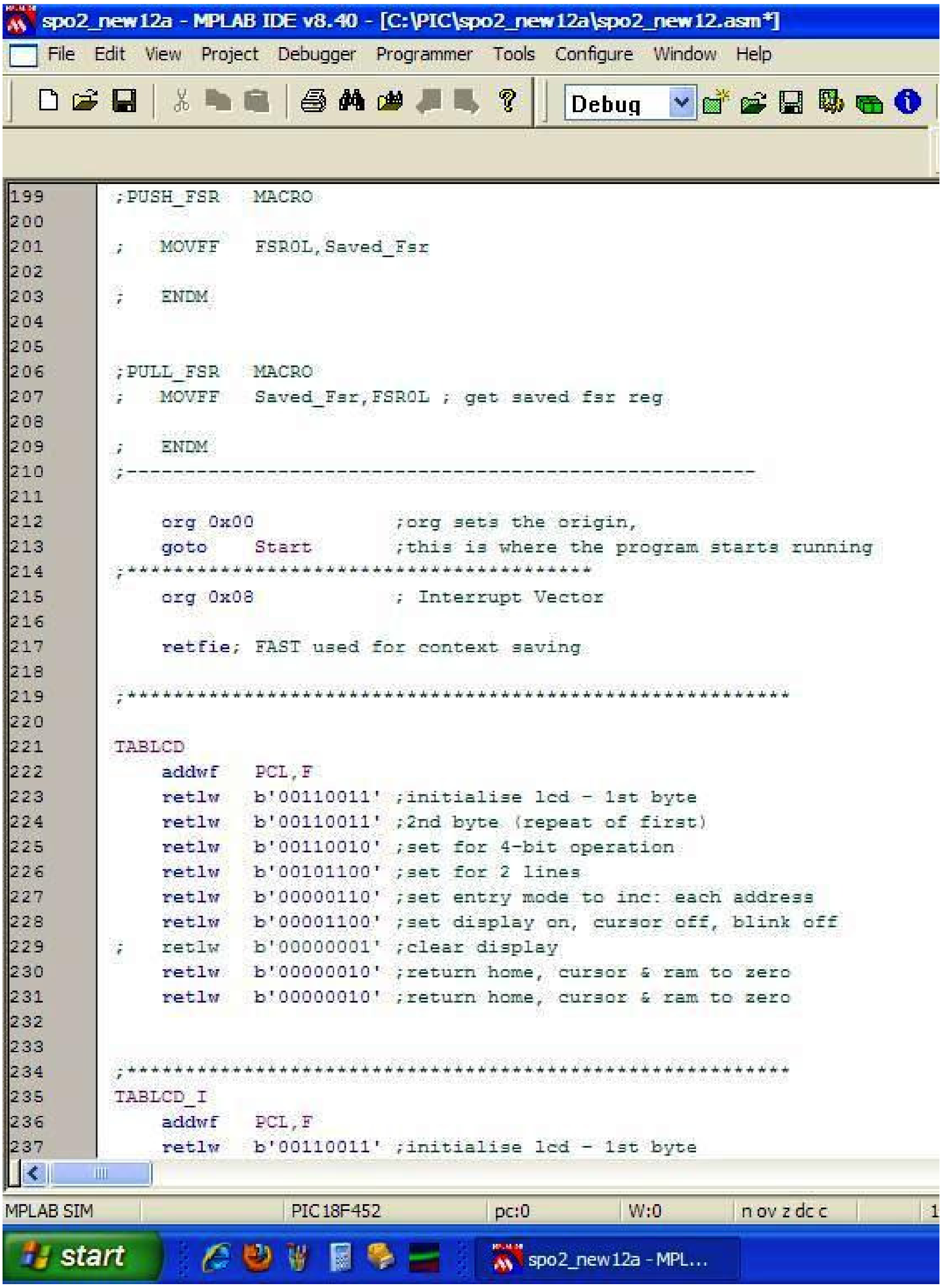
Appendix A: Source Code for the Embedded System of Pulse Oximetry (Assembly Language)

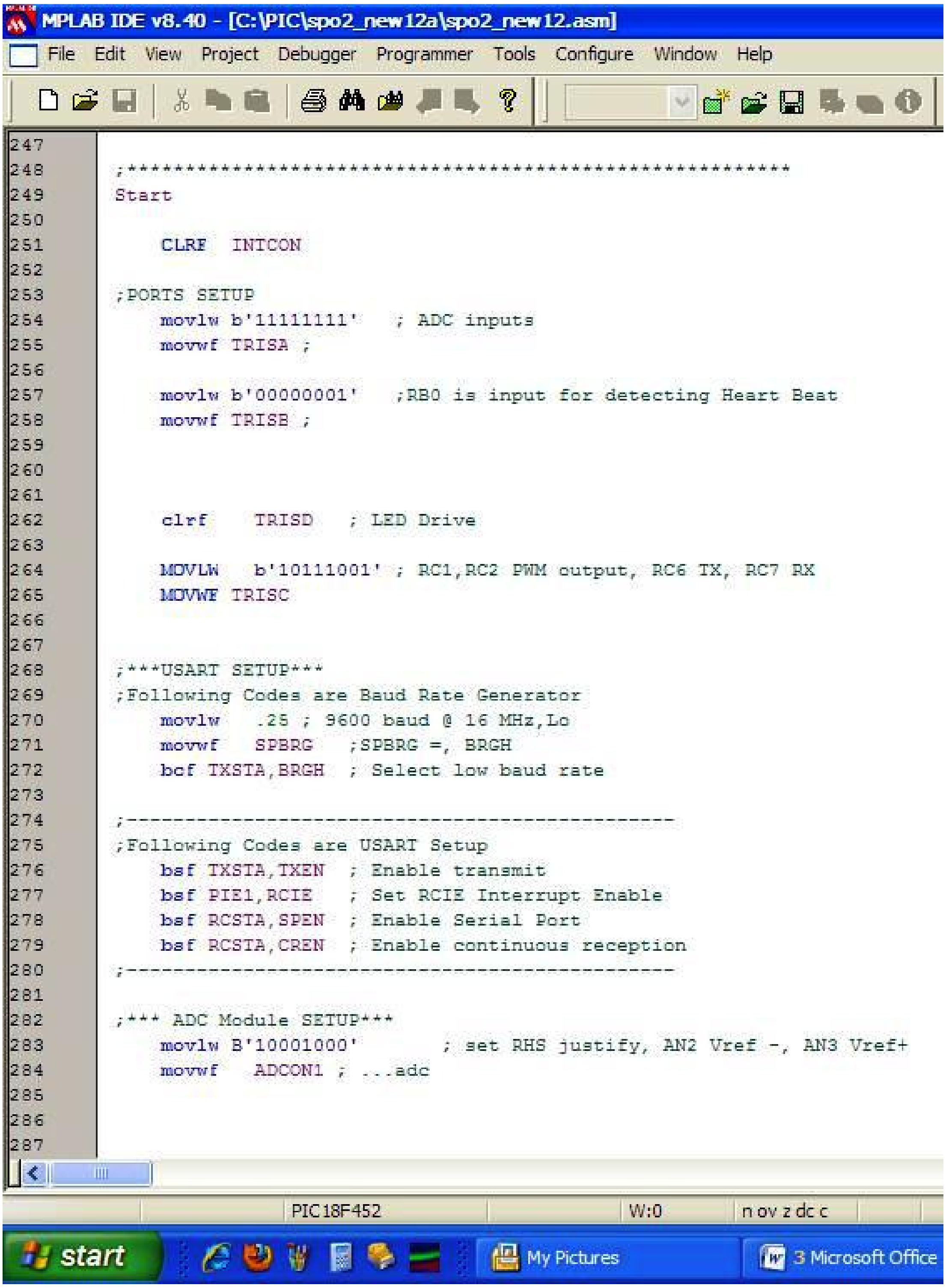
Some of assembly source code for the embedded system of pulse oximetry is as follows:

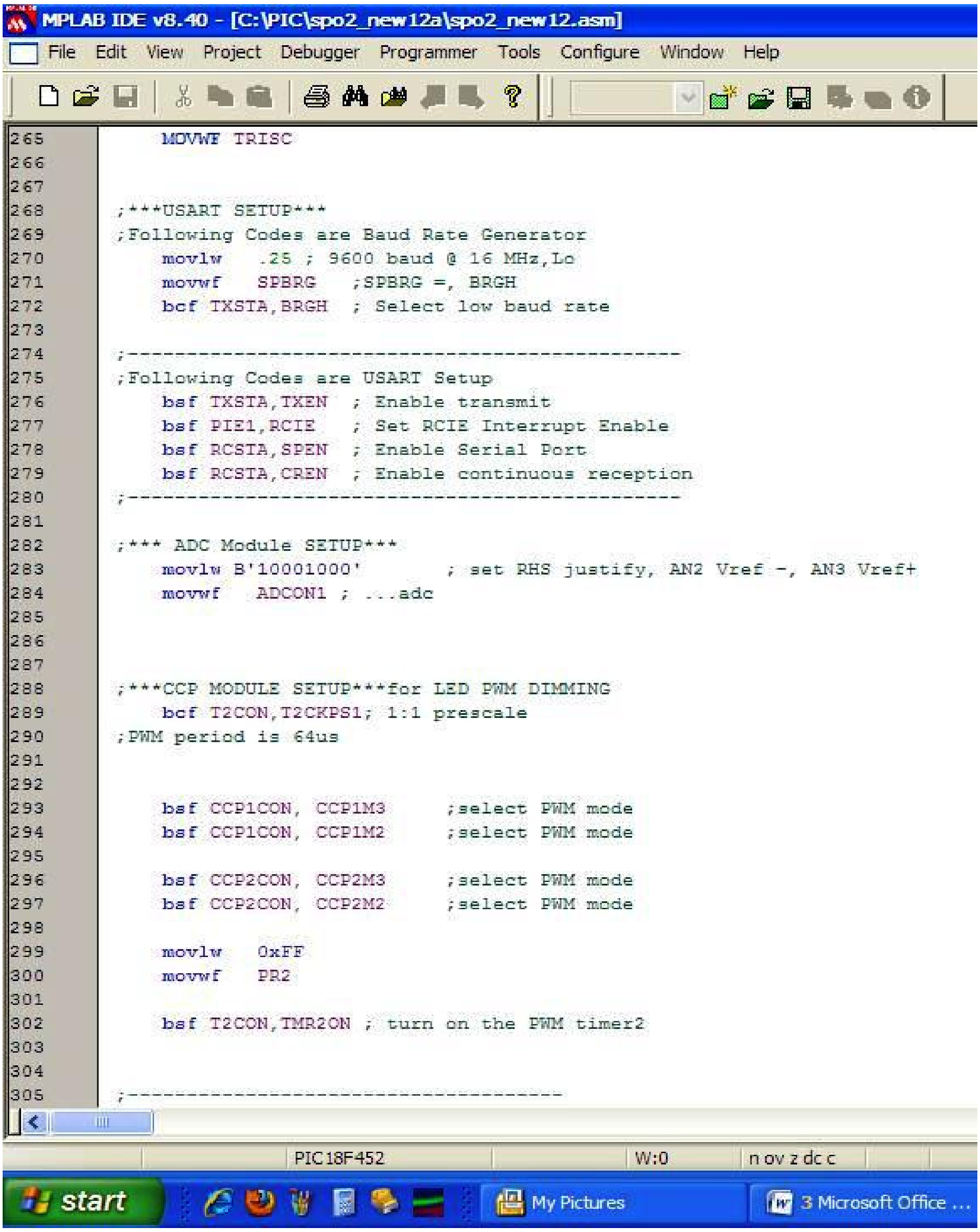



```
    LIST    p=18F452        ;tell assembler what chip we are using
    include "P18F452.inc"       ;include the defaults for the chip
    ERRORLEVEL  0,  -302    ;suppress bank selection messages



    __CONFIG 300001,0xFE    ; PLL ... 16MHz
    __CONFIG 300002,0xFD    ; Power up timer disable
    __CONFIG 300003,0xFE    ; Watchdog timer disable
    __CONFIG 300006,0xFB    ; Stack overflow enable
    __CONFIG 300008,0xFF    ; Code protect disble





;------------------------------------------------
        cblock  0x08        ;start of general purpose registers

    temp1   ; general purpose
    count1  ; general purpose
    count2  ; general purpose
    count3  ; general purpose
    R_PWM   ; LED Intensity setting
    IR_PWM  ; LED Intensity setting

;ADC Reading High and Low Byte
    r_value_h   ; ADC Value when Red LED ON
    r_value_l   ; ADC Value when Red LED ON

    ir_value_h  ; ADC Value when IR LED ON
    ir_value_l  ; ADC Value when IR LED ON

;LCD ...Display
    LOOPA
    LOOPB
    CLKCNT
    RSLINE
    STORE1
```


spo2_new12a - MPLAB IDE v8.40 - [C:\PIC\spo2_new12a\spo2_new12.
File Edit View Project Debugger Programmer Tools Configure Window
Debug
RED_DIFF_HI
RED_DIFF_LO
SUM_2DIFF_HI
SUM_2DIFF_LO
INDEX_a
INDEX_b
Temp_Ans_Hi
Temp_Ans_Lo
;Finding Largest Number
A_Hi
A_Lo
B_Hi
B_Lo
Pulse_Index
Pulse_Index_Old
Peak_Count
Peak_Index_Hi
Peak_Index_Lo
Peak_Interval_Hi
Peak_Interval_Lo
THRESHOLD
endc
;---
cblock 0x80
RAM_START
endc
;---
cblock 0xF7
RAM_END
MPLAB SIM
PIC18F452
pc:0
W:0
start
spo2_new12a - MPL...


spo2_new12a - MPLAB IDE v8.40 - [C:\PIC\spo2_new12a\spo2_new12.asm*]
File Edit View Project Debugger Programmer Tools Configure Window Help
Debug
;PUSH_FSR MACRO
; MOVFF FSR0L,Saved_Fsr
; ENDM
;PULL_FSR MACRO
; MOVFF Saved_Fsr,FSR0L ; get saved fsr reg
; ENDM
;---
org 0x00 ;org sets the origin,
goto Start ;this is where the program starts running
;***
org 0x08 ; Interrupt Vector
retfie; FAST used for context saving
;***
TABLCD
addwf PCL,F
retlw b'00110011' ;initialise lcd - 1st byte
retlw b'00110011' ;2nd byte (repeat of first)
retlw b'00110010' ;set for 4-bit operation
retlw b'00101100' ;set for 2 lines
retlw b'00000110' ;set entry mode to inc. each address
retlw b'00001100' ;set display on, cursor off, blink off
; retlw b'00000001' ;clear display
retlw b'00000010' ;return home, cursor & ram to zero
retlw b'00000010' ;return home, cursor & ram to zero
;***
TABLCD_I
addwf PCL,F
retlw b'00110011' ;initialise lcd - 1st byte
MPLAB SIM
PIC18F452
pc:0
W:0
n ov z dc c
start
spo2_new12a - MPL...


MPLAB IDE v8.40 - [C:\PIC\spo2_new12a\spo2_new12.asm]
File Edit View Project Debugger Programmer Tools Configure Window Help
;***
Start
CLRF INTCON
;PORTS SETUP
movlw b'11111111' ; ADC inputs
movwf TRISA ;
movlw b'00000001' ;RB0 is input for detecting Heart Beat
movwf TRISB ;
clrf TRISD ; LED Drive
MOVLW b'10111001' ; RC1,RC2 PWM output, RC6 TX, RC7 RX
MOVWF TRISC
;***USART SETUP***
;Following Codes are Baud Rate Generator
movlw .25 ; 9600 baud @ 16 MHz,Lo
movwf SPBRG ;SPBRG =, BRGH
bcf TXSTA,BRGH ; Select low baud rate
;---
;Following Codes are USART Setup
bsf TXSTA,TXEN ; Enable transmit
bsf PIE1,RCIE ; Set RCIE Interrupt Enable
bsf RCSTA,SPEN ; Enable Serial Port
bsf RCSTA,CREN ; Enable continuous reception
;---
;*** ADC Module SETUP***
movlw B'10001000' ; set RHS justify, AN2 Vref -, AN3 Vref+
movwf ADCON1 ; ...adc
PIC18F452
W:0
n ov z dc c
start
My Pictures
3 Microsoft Office

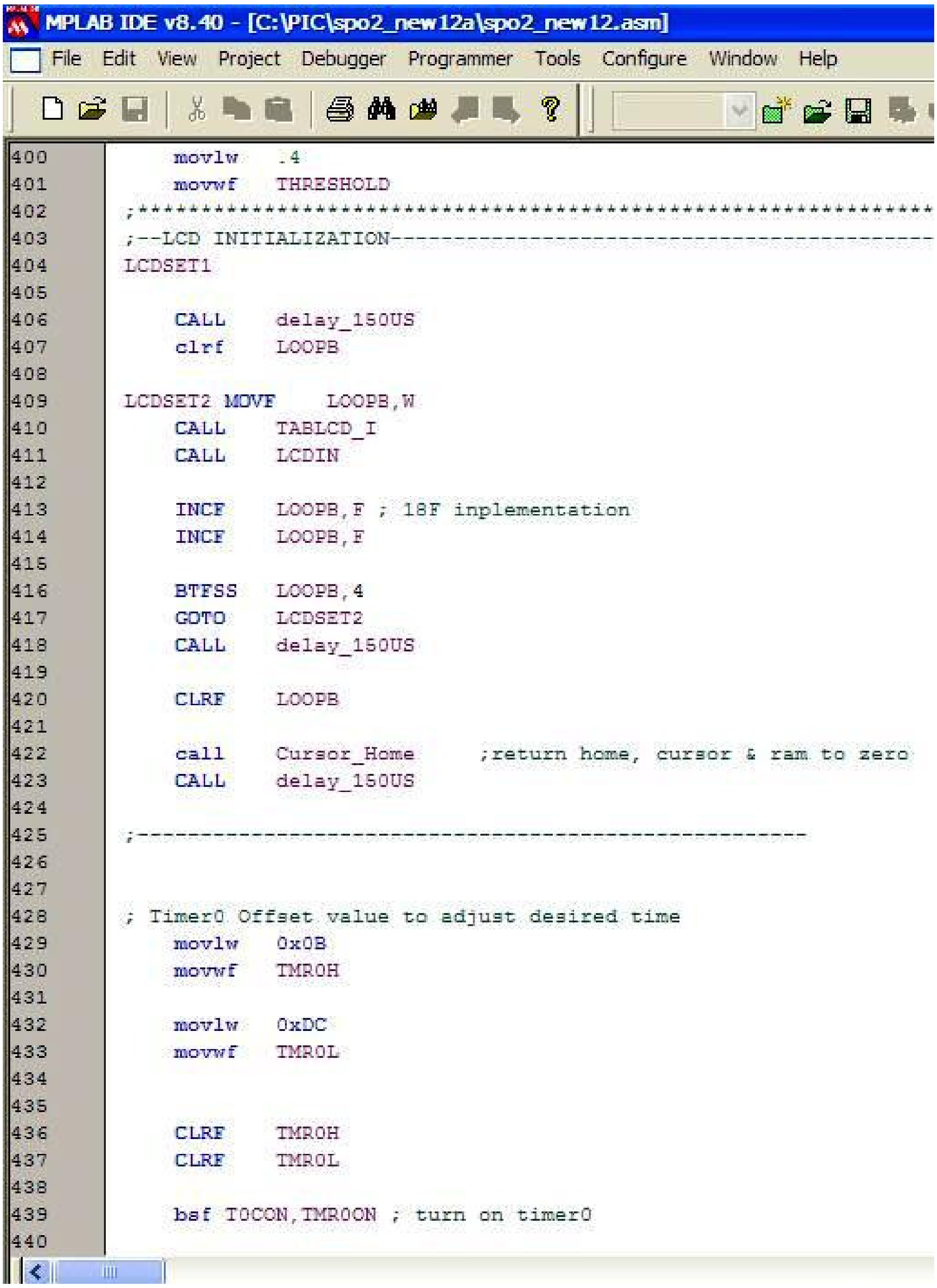

MPLAB IDE v8.40 - [C:\PIC\spo2_new12a\spo2_new12.asm]
File Edit View Project Debugger Programmer Tools Configure Window Help
MOVWF TRISC
;***USART SETUP***
;Following Codes are Baud Rate Generator
movlw .25 ; 9600 baud @ 16 MHz,Lo
movwf SPBRG ;SPBRG =, BRGH
bcf TXSTA,BRGH ; Select low baud rate
;---
;Following Codes are USART Setup
bsf TXSTA,TXEN ; Enable transmit
bsf PIE1,RCIE ; Set RCIE Interrupt Enable
bsf RCSTA,SPEN ; Enable Serial Port
bsf RCSTA,CREN ; Enable continuous reception
;---
;*** ADC Module SETUP***
movlw B'10001000' ; set RHS justify, AN2 Vref -, AN3 Vref+
movwf ADCON1 ; ...adc
;***CCP MODULE SETUP***for LED PWM DIMMING
bcf T2CON,T2CKPS1; 1:1 prescale
;PWM period is 64us
bsf CCP1CON, CCP1M3 ;select PWM mode
bsf CCP1CON, CCP1M2 ;select PWM mode
bsf CCP2CON, CCP2M3 ;select PWM mode
bsf CCP2CON, CCP2M2 ;select PWM mode
movlw 0xFF
movwf PR2
bsf T2CON,TMR2ON ; turn on the PWM timer2
;-----------------------------------
PIC18F452
W:0
n ov z dc c
start
My Pictures
3 Microsoft Office ...

MPLAB IDE v7.40 - [C:\spo2_final_r5\spo2_final_r5.asm]

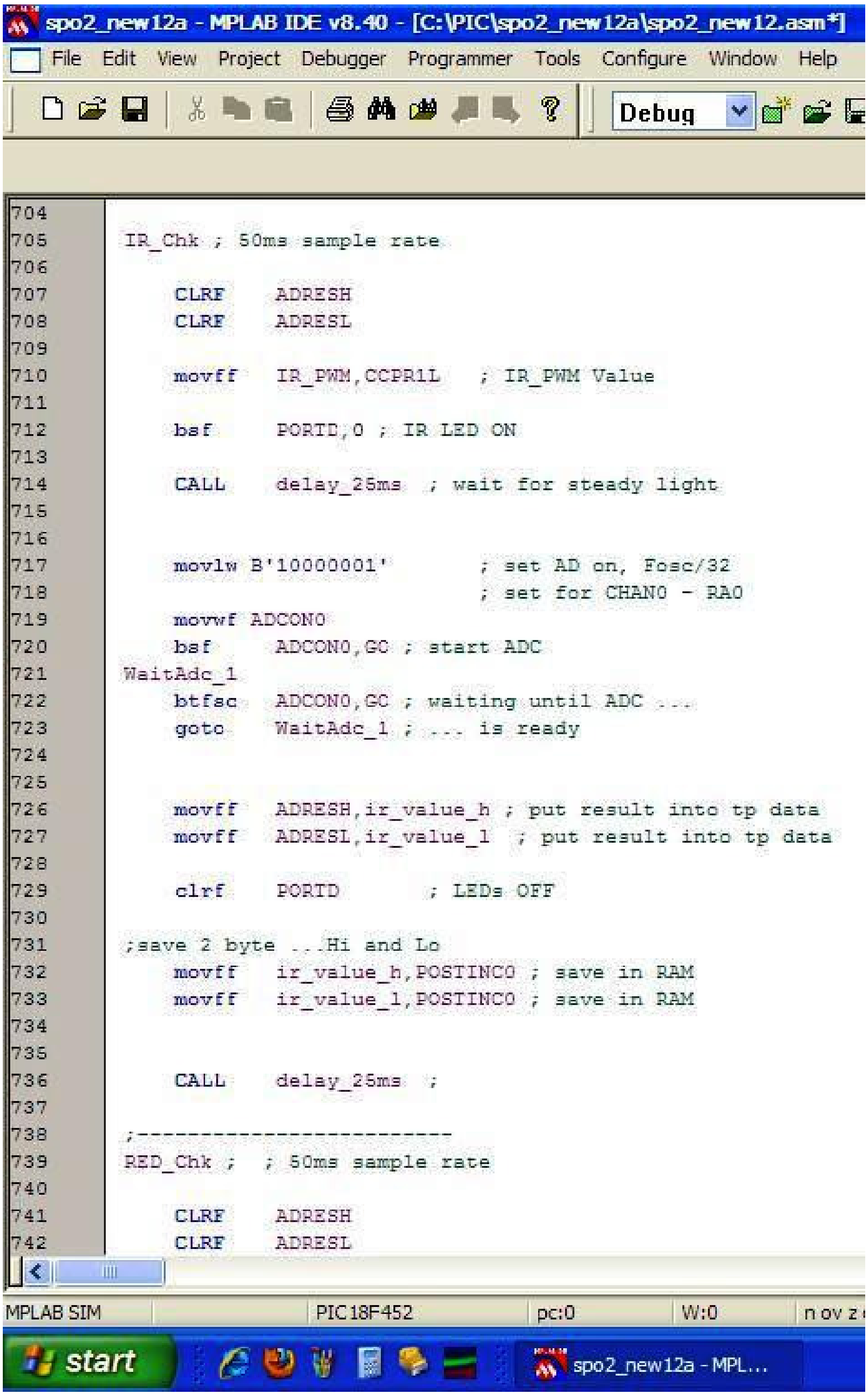
File Edit View Project Debugger Programmer Tools Configure Window Help

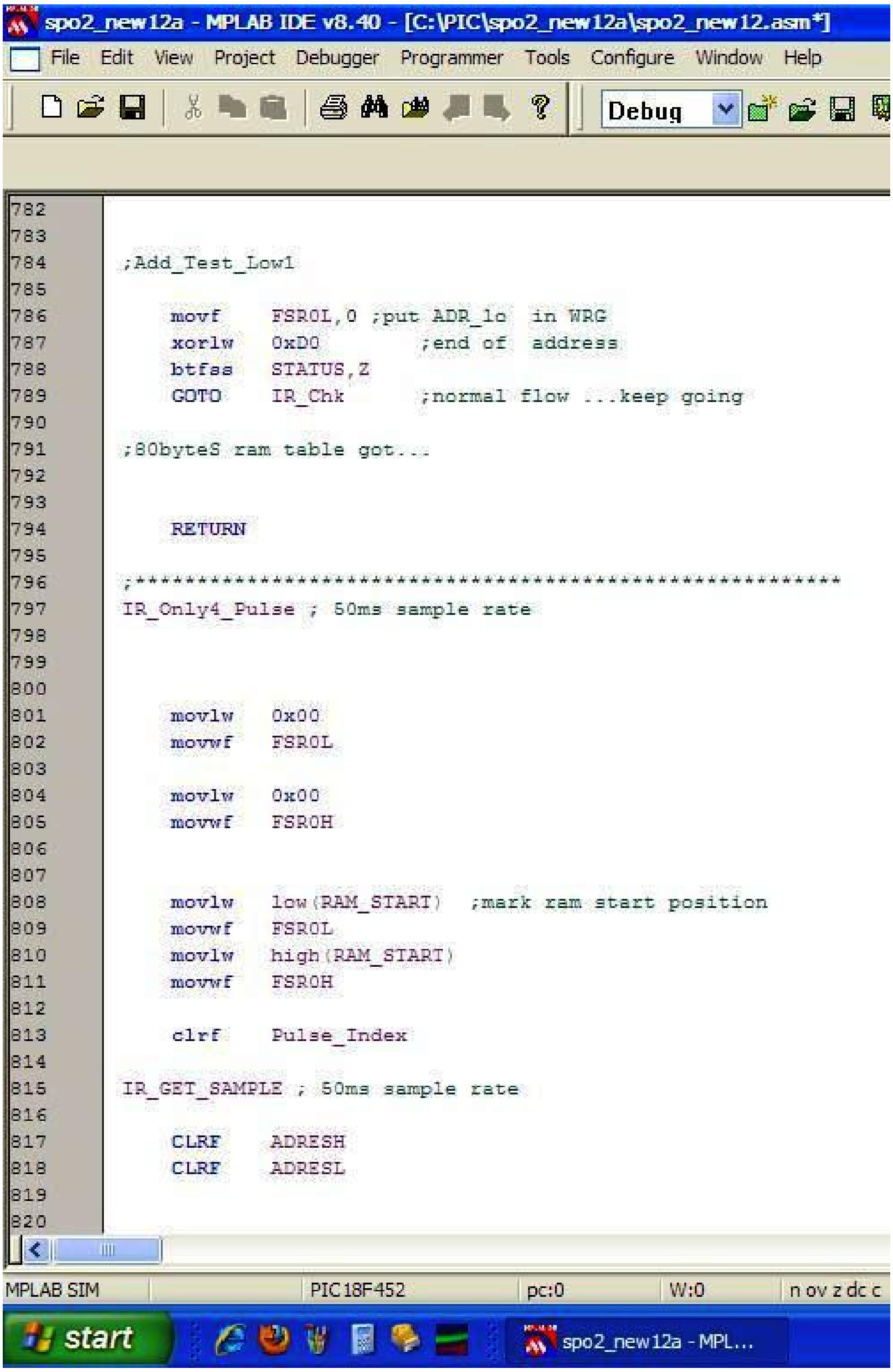
```
;--LCD INITIALIZATION-------------------------------------------------
LCDSET1
    CALL    delay_150US
    CLRF    LOOPB
LCDSET2 MOVF    LOOPB,W
    CALL    TABLCD_I
    CALL    LCDIN
    INCF    LOOPB,F ; 18F inplementation
    INCF    LOOPB,F
    BTFSS   LOOPB,4
    GOTO    LCDSET2
    CALL    delay_150US
    CLRF    LOOPB
    CALL    Cursor_Home     ;RETURN home, cursor & ram to zero
    CALL    delay_150US


;************************************************************
MAIN_ENTRY


    CALL    SHOW_WAIT

;wait 2 sec to settle the opamp
    CALL    delay_1sec  ; 1Sec delay
    CALL    delay_1sec  ; 1Sec delay

    CALL    Get_Sample  ;SAMPLES WITHOUT FINGER
    CALL    GET_IR_NOMED_DATA   ; AVERAGE IR AND RED  LIGHT DATA

    CALL    Chk_Ambient
    CALL    CORRECTION  ;SOFTWARE CORRECTION FOR AMB

    CALL    SHOW_RAW_DATA   ; debug display
    CALL    SHOW_PUT_FINGER
    CALL    Get_Sample  ;SAMPLES WITH FINGER
    CALL    GET_IR_FIN_DATA ; AVERAGE IR AND RED DATA WITH FINGER
    CALL    SHOW_WITH_FINGER    ; debug display
    CALL    Difference ;

    CALL    SHOW_DIFF   ; debug display
```

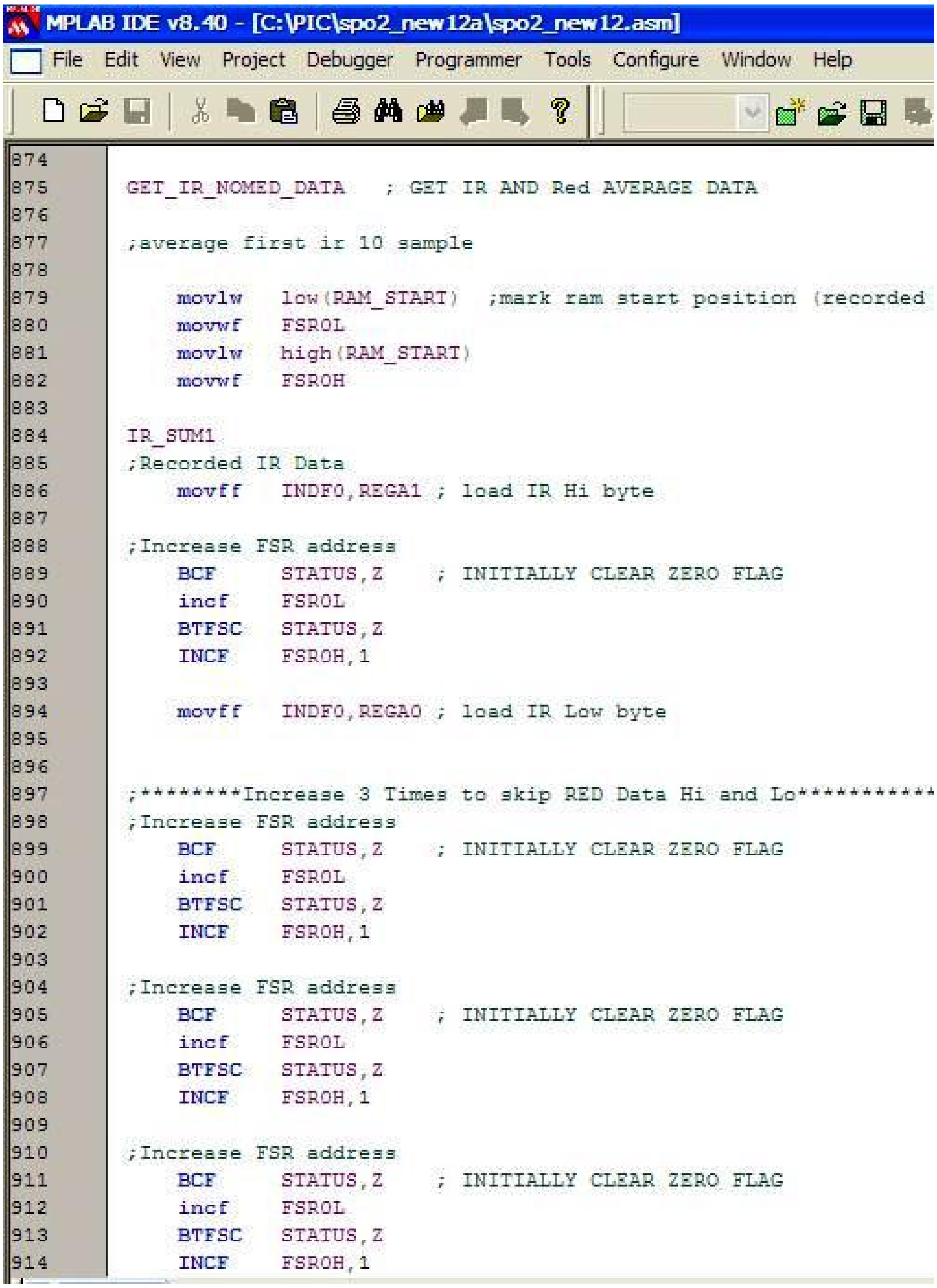
PIC18F452 W:0 n ov z dc c




```
        movlw   .4
        movwf   THRESHOLD
;*************************************************************
;--LCD INITIALIZATION----------------------------------------
LCDSET1

        CALL    delay_150US
        clrf    LOOPB

LCDSET2 MOVF    LOOPB,W
        CALL    TABLCD_I
        CALL    LCDIN

        INCF    LOOPB,F ; 18F inplementation
        INCF    LOOPB,F

        BTFSS   LOOPB,4
        GOTO    LCDSET2
        CALL    delay_150US

        CLRF    LOOPB

        call    Cursor_Home     ;return home, cursor & ram to zero
        CALL    delay_150US

;-----------------------------------------------------


; Timer0 Offset value to adjust desired time
        movlw   0x0B
        movwf   TMR0H

        movlw   0xDC
        movwf   TMR0L


        CLRF    TMR0H
        CLRF    TMR0L

        bsf T0CON,TMR0ON ; turn on timer0

```


spo2_new12a - MPLAB IDE v8.40 - [C:\PIC\spo2_new12a\spo2_new12.asm*]
File Edit View Project Debugger Programmer Tools Configure Window Help
Debug
IR_Chk ; 50ms sample rate
CLRF ADRESH
CLRF ADRESL
movff IR_PWM,CCPR1L ; IR_PWM Value
bsf PORTD,0 ; IR LED ON
CALL delay_25ms ; wait for steady light
movlw B'10000001' ; set AD on, Fosc/32
; set for CHAN0 - RA0
movwf ADCON0
bsf ADCON0,GO ; start ADC
WaitAdc_1
btfsc ADCON0,GO ; waiting until ADC ...
goto WaitAdc_1 ; ... is ready
movff ADRESH,ir_value_h ; put result into tp data
movff ADRESL,ir_value_l ; put result into tp data
clrf PORTD ; LEDs OFF
;save 2 byte ...Hi and Lo
movff ir_value_h,POSTINC0 ; save in RAM
movff ir_value_l,POSTINC0 ; save in RAM
CALL delay_25ms ;
;-------------------------
RED_Chk ; ; 50ms sample rate
CLRF ADRESH
CLRF ADRESL
MPLAB SIM
PIC18F452
pc:0
W:0
start
spo2_new12a - MPL...


spo2_new12a - MPLAB IDE v8.40 - [C:\PIC\spo2_new12a\spo2_new12.asm*]
File Edit View Project Debugger Programmer Tools Configure Window Help
Debug
;Add_Test_Low1
movf FSR0L,0 ;put ADR_lo in WRG
xorlw 0xD0 ;end of address
btfss STATUS,Z
GOTO IR_Chk ;normal flow ...keep going
;80byteS ram table got...
RETURN
;***
IR_Only4_Pulse ; 50ms sample rate
movlw 0x00
movwf FSR0L
movlw 0x00
movwf FSR0H
movlw low(RAM_START) ;mark ram start position
movwf FSR0L
movlw high(RAM_START)
movwf FSR0H
clrf Pulse_Index
IR_GET_SAMPLE ; 50ms sample rate
CLRF ADRESH
CLRF ADRESL
MPLAB SIM
PIC18F452
pc:0
W:0
n ov z dc c
start
spo2_new12a - MPL...

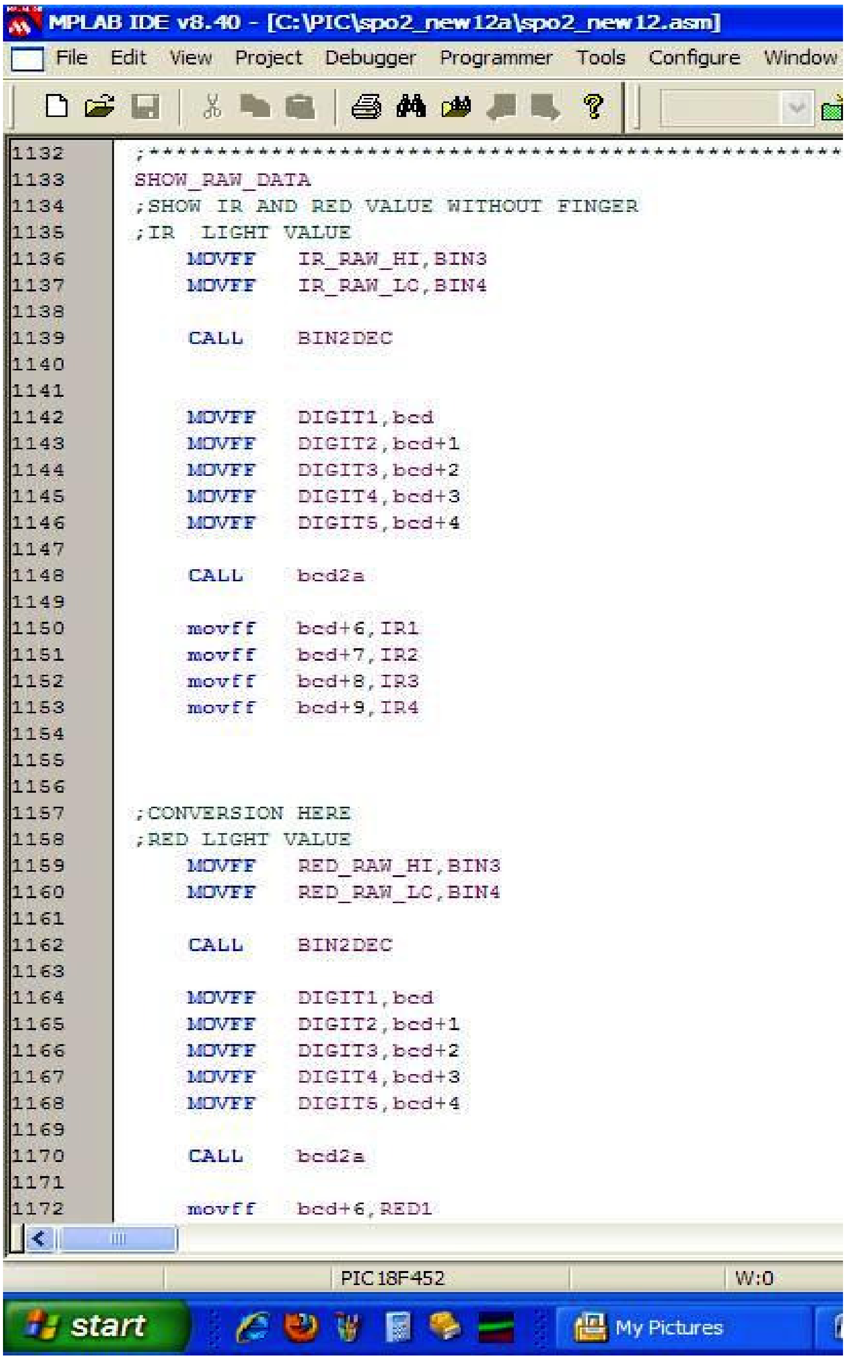


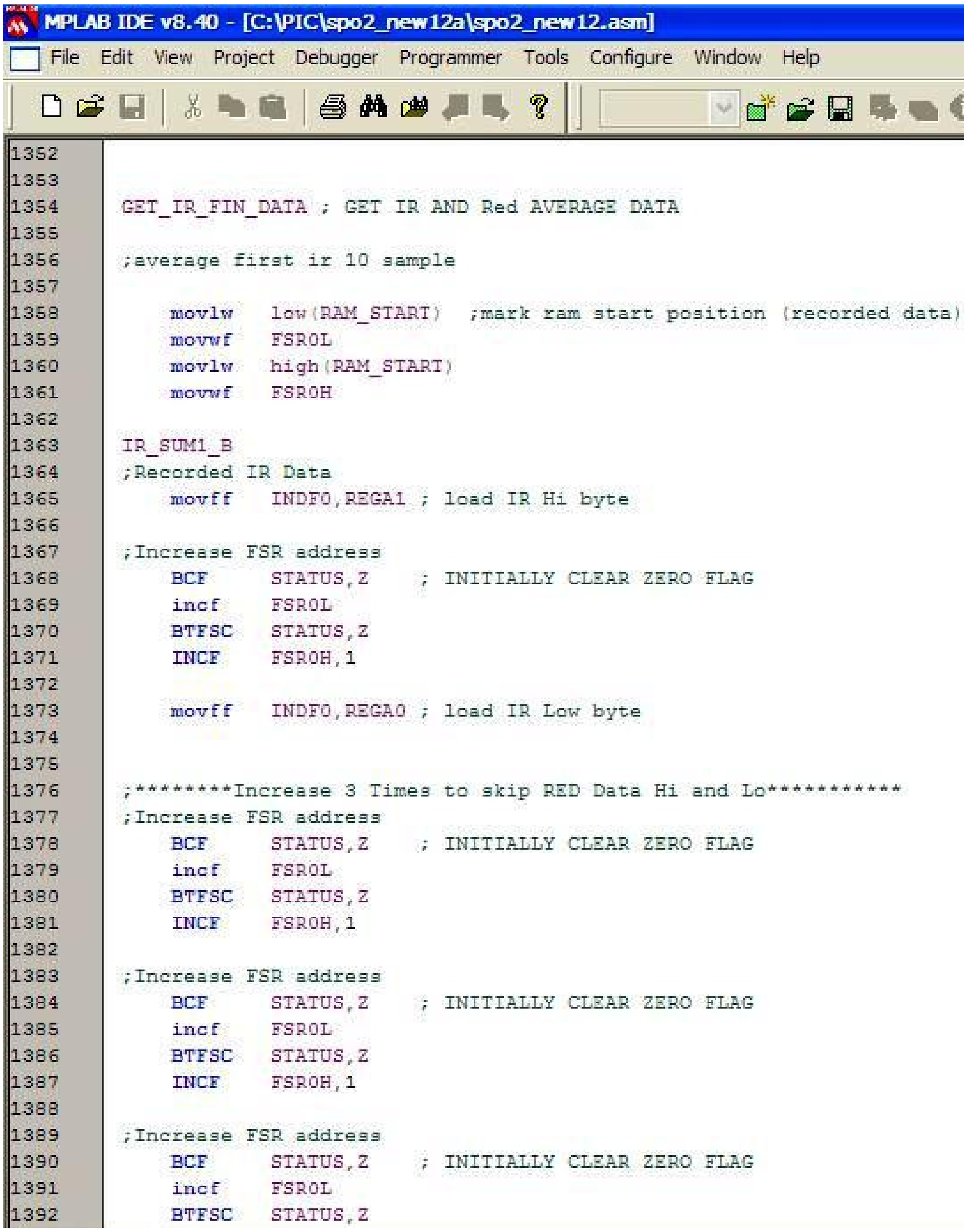

```
GET_IR_NOMED_DATA   ; GET IR AND Red AVERAGE DATA

;average first ir 10 sample

    movlw   low(RAM_START)  ;mark ram start position (recorded
    movwf   FSR0L
    movlw   high(RAM_START)
    movwf   FSR0H

IR_SUM1
;Recorded IR Data
    movff   INDF0,REGA1 ; load IR Hi byte

;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1

    movff   INDF0,REGA0 ; load IR Low byte


;********Increase 3 Times to skip RED Data Hi and Lo***********
;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1

;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1

;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1
```

MPLAB IDE v8.40 - [C:\PIC\spo2_new12a\spo2_new12.asm]

File Edit View Project Debugger Programmer Tools Configure Window Help

```

GET_RED_NOMED_DATA  ; GET  Red AVERAGE DATA

;average first ir 10 sample

    movlw   low(RAM_START+2)    ;mark ram start position + 2(recorded RED data)
    movwf   FSR0L
    movlw   high(RAM_START+2)
    movwf   FSR0H

RED_SUM1
;Recorded RED Data
    movff   INDF0,REGA1 ; load RED Hi byte

;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1

    movff   INDF0,REGA0 ; load RED Low byte


;********Increase 3 Times to skip IR Data Hi and Lo***********
;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1

;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1

;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1
```

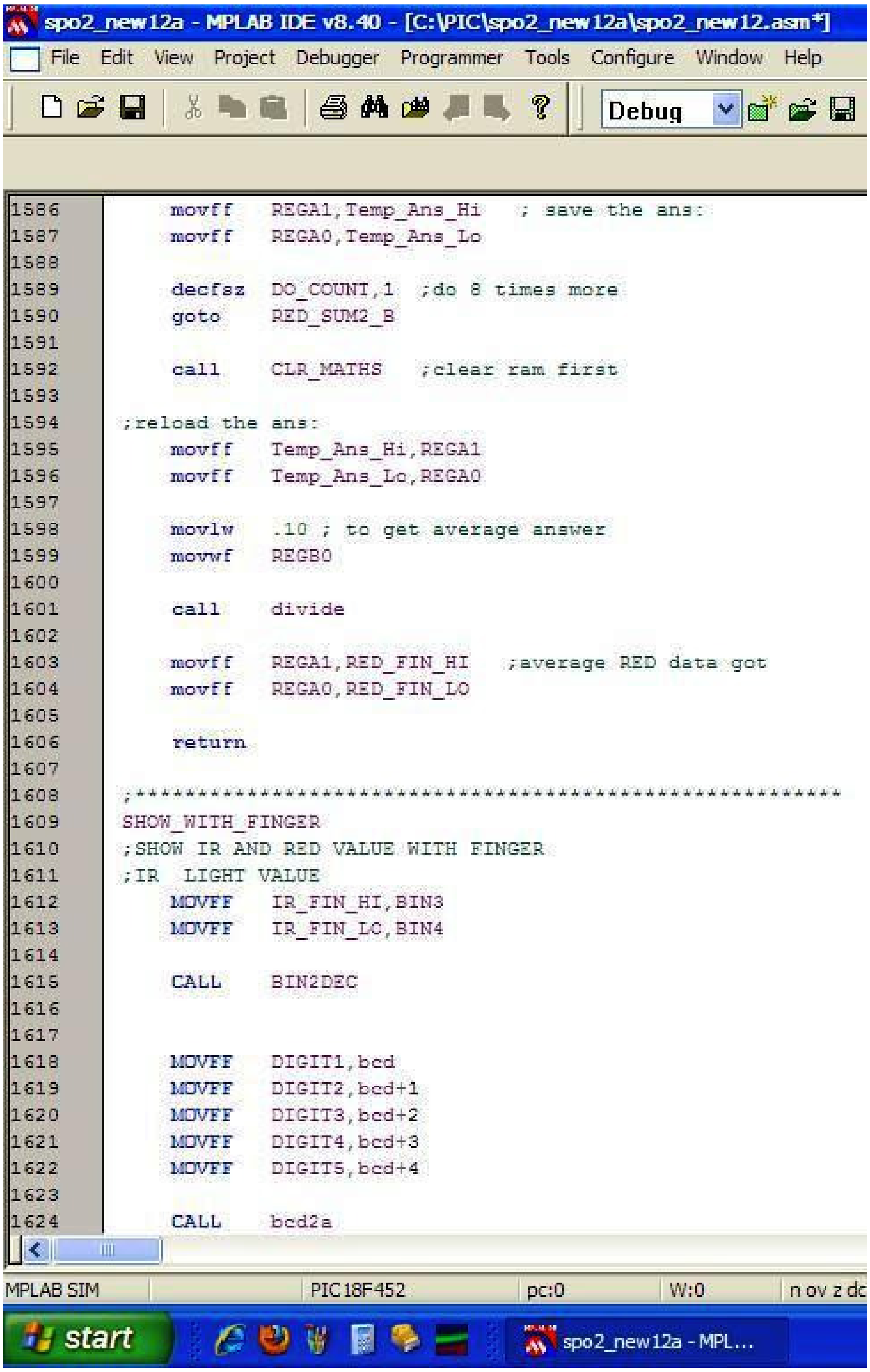

MPLAB IDE v8.40 - [C:\PIC\spo2_new12a\spo2_new12.asm]
File Edit View Project Debugger Programmer Tools Configure Window
;**
SHOW_RAW_DATA
;SHOW IR AND RED VALUE WITHOUT FINGER
;IR LIGHT VALUE
MOVFF IR_RAW_HI,BIN3
MOVFF IR_RAW_LO,BIN4
CALL BIN2DEC
MOVFF DIGIT1,bcd
MOVFF DIGIT2,bcd+1
MOVFF DIGIT3,bcd+2
MOVFF DIGIT4,bcd+3
MOVFF DIGIT5,bcd+4
CALL bcd2a
movff bcd+6,IR1
movff bcd+7,IR2
movff bcd+8,IR3
movff bcd+9,IR4
;CONVERSION HERE
;RED LIGHT VALUE
MOVFF RED_RAW_HI,BIN3
MOVFF RED_RAW_LO,BIN4
CALL BIN2DEC
MOVFF DIGIT1,bcd
MOVFF DIGIT2,bcd+1
MOVFF DIGIT3,bcd+2
MOVFF DIGIT4,bcd+3
MOVFF DIGIT5,bcd+4
CALL bcd2a
movff bcd+6,RED1
PIC18F452
W:0
start
My Pictures

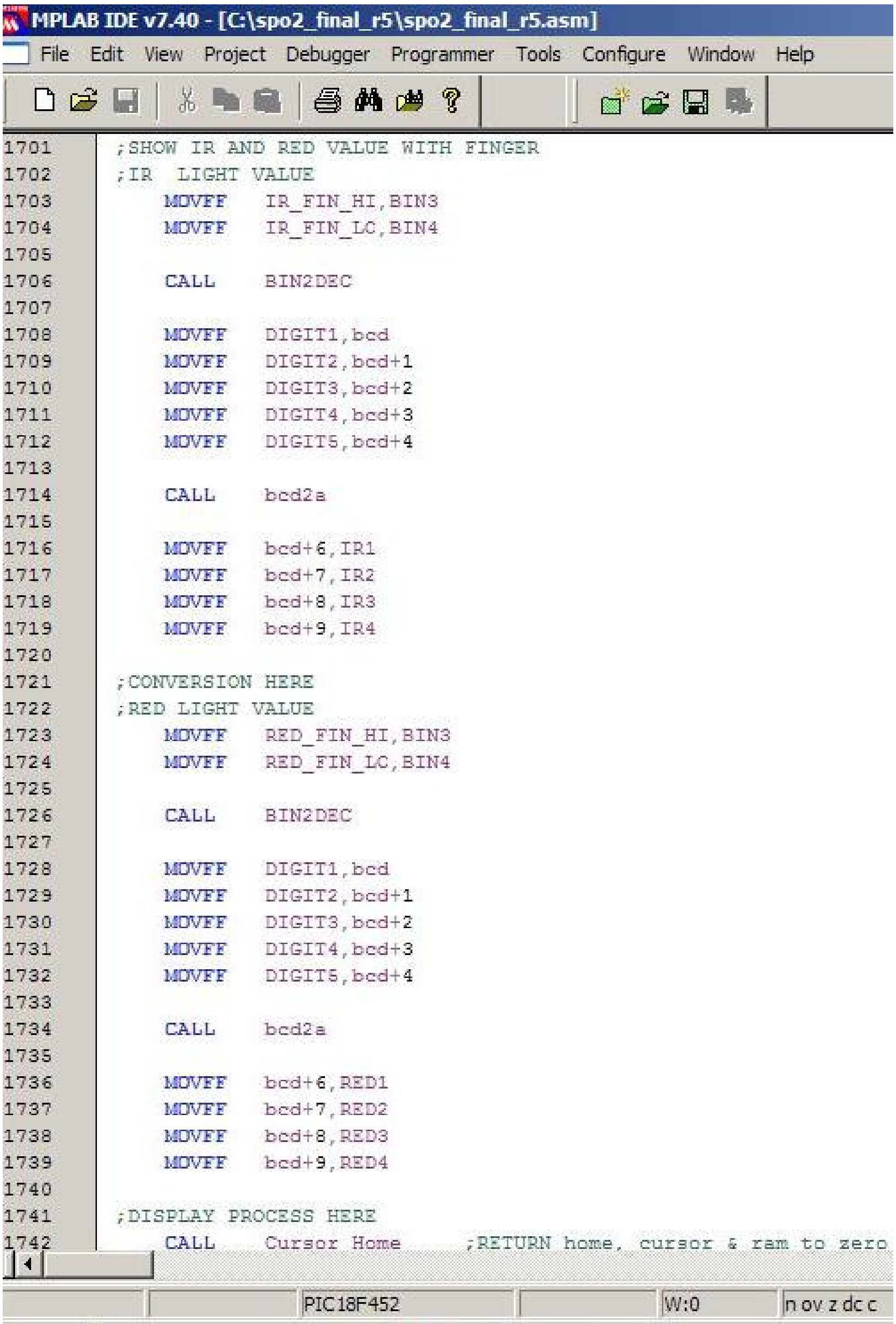


MPLAB IDE v8.40 - [C:\PIC\spo2_new12a\spo2_new12.asm]

File Edit View Project Debugger Programmer Tools Configure Window Help

```
GET_IR_FIN_DATA ; GET IR AND Red AVERAGE DATA

;average first ir 10 sample

    movlw   low(RAM_START)   ;mark ram start position (recorded data)
    movwf   FSR0L
    movlw   high(RAM_START)
    movwf   FSR0H

IR_SUM1_B
;Recorded IR Data
    movff   INDF0,REGA1 ; load IR Hi byte

;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1

    movff   INDF0,REGA0 ; load IR Low byte


;********Increase 3 Times to skip RED Data Hi and Lo***********
;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1

;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
    INCF    FSR0H,1

;Increase FSR address
    BCF     STATUS,Z    ; INITIALLY CLEAR ZERO FLAG
    incf    FSR0L
    BTFSC   STATUS,Z
```


spo2_new12a - MPLAB IDE v8.40 - [C:\PIC\spo2_new12a\spo2_new12.asm*]
File Edit View Project Debugger Programmer Tools Configure Window Help
Debug
movff REGA1,Temp_Ans_Hi ; save the ans:
movff REGA0,Temp_Ans_Lo
decfsz DO_COUNT,1 ;do 8 times more
goto RED_SUM2_B
call CLR_MATHS ;clear ram first
;reload the ans:
movff Temp_Ans_Hi,REGA1
movff Temp_Ans_Lo,REGA0
movlw .10 ; to get average answer
movwf REGB0
call divide
movff REGA1,RED_FIN_HI ;average RED data got
movff REGA0,RED_FIN_LO
return
;**
SHOW_WITH_FINGER
;SHOW IR AND RED VALUE WITH FINGER
;IR LIGHT VALUE
MOVFF IR_FIN_HI,BIN3
MOVFF IR_FIN_LO,BIN4
CALL BIN2DEC
MOVFF DIGIT1,bcd
MOVFF DIGIT2,bcd+1
MOVFF DIGIT3,bcd+2
MOVFF DIGIT4,bcd+3
MOVFF DIGIT5,bcd+4
CALL bcd2a
MPLAB SIM
PIC18F452
pc:0
W:0
n ov z dc
start
spo2_new12a - MPL...

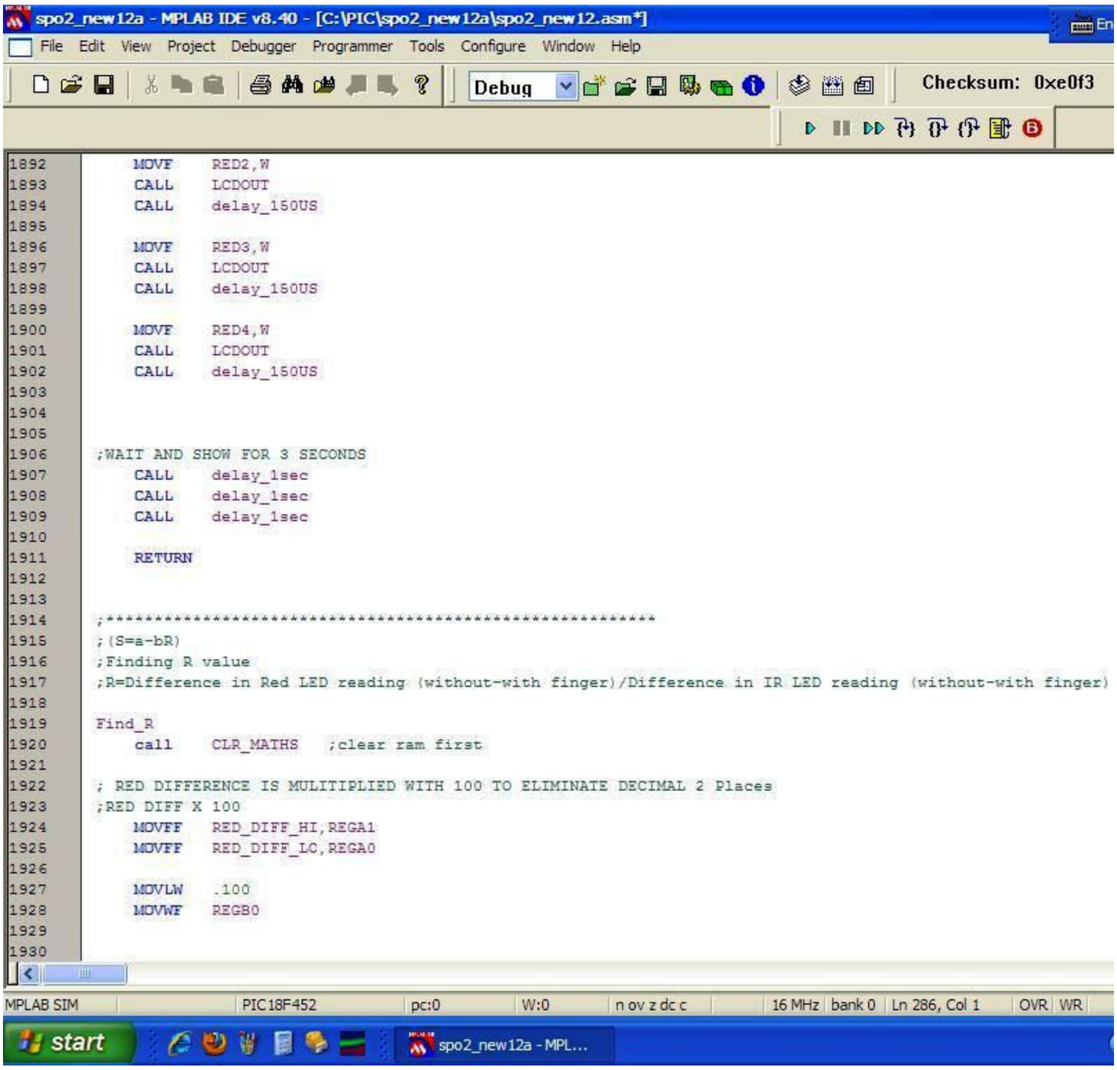



```
;SHOW IR AND RED VALUE WITH FINGER
;IR  LIGHT VALUE
    MOVFF   IR_FIN_HI,BIN3
    MOVFF   IR_FIN_LO,BIN4

    CALL    BIN2DEC

    MOVFF   DIGIT1,bcd
    MOVFF   DIGIT2,bcd+1
    MOVFF   DIGIT3,bcd+2
    MOVFF   DIGIT4,bcd+3
    MOVFF   DIGIT5,bcd+4

    CALL    bcd2a

    MOVFF   bcd+6,IR1
    MOVFF   bcd+7,IR2
    MOVFF   bcd+8,IR3
    MOVFF   bcd+9,IR4

;CONVERSION HERE
;RED LIGHT VALUE
    MOVFF   RED_FIN_HI,BIN3
    MOVFF   RED_FIN_LO,BIN4

    CALL    BIN2DEC

    MOVFF   DIGIT1,bcd
    MOVFF   DIGIT2,bcd+1
    MOVFF   DIGIT3,bcd+2
    MOVFF   DIGIT4,bcd+3
    MOVFF   DIGIT5,bcd+4

    CALL    bcd2a

    MOVFF   bcd+6,RED1
    MOVFF   bcd+7,RED2
    MOVFF   bcd+8,RED3
    MOVFF   bcd+9,RED4

;DISPLAY PROCESS HERE
    CALL    Cursor_Home     ;RETURN home, cursor & ram to zero
```

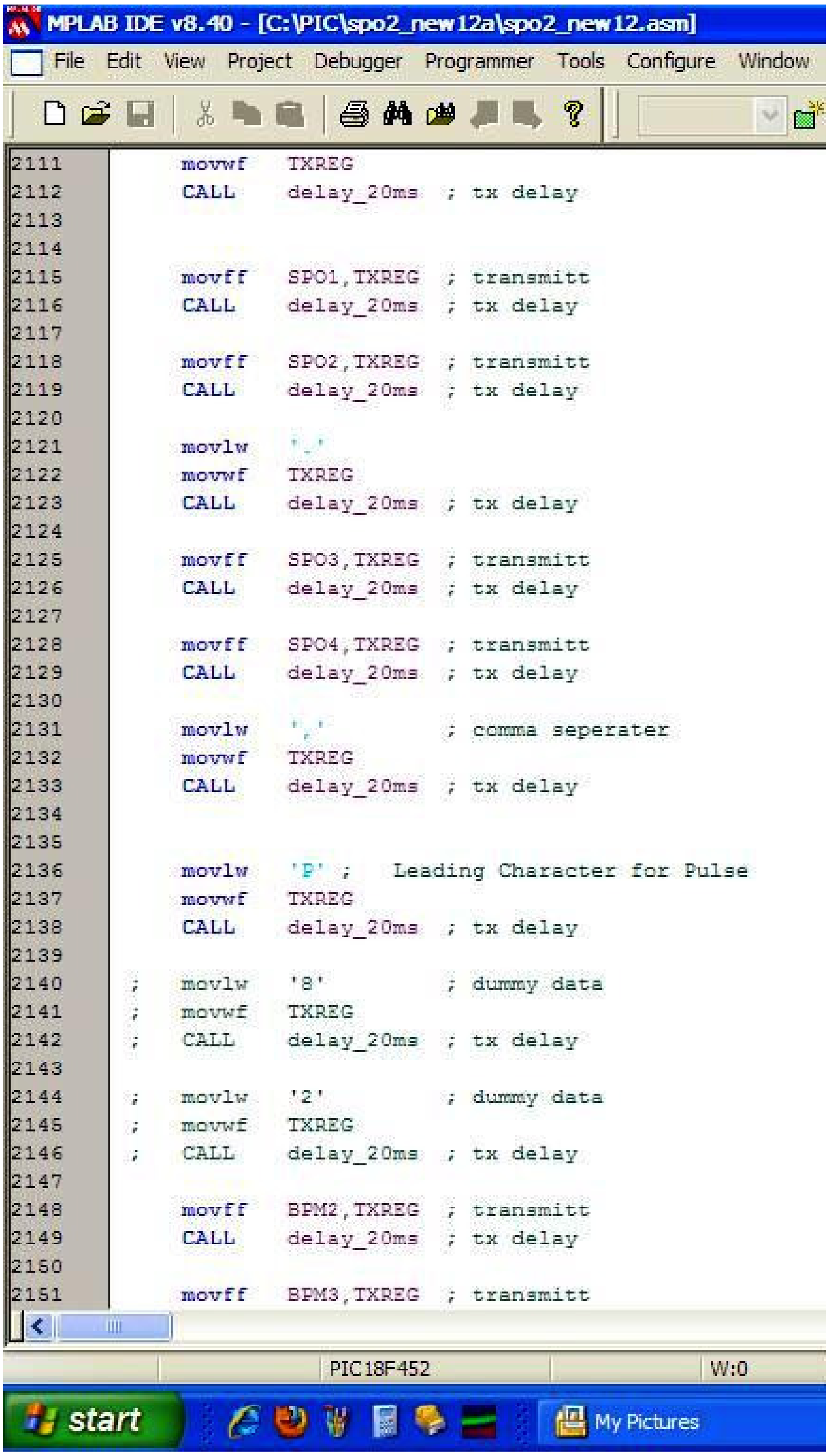
MPLAB IDE v8.40 - [C:\PIC\spo2_new12a\spo2_new12.asm]

File Edit View Project Debugger Programmer Tools Configure Window

```
Difference

;IR NOFINGER - FINGER
        call    CLR_MATHS   ;clear ram first

        movff   IR_RAW_HI,REGA1
        movff   IR_RAW_LO,REGA0

        movff   IR_FIN_HI,REGB1
        movff   IR_FIN_LO,REGB0

        call    subtract

        movff   REGA1,IR_DIFF_HI
        movff   REGA0,IR_DIFF_LO


;RED NOFINGER - FINGER
        call    CLR_MATHS   ;clear ram first

        movff   RED_RAW_HI,REGA1
        movff   RED_RAW_LO,REGA0

        movff   RED_FIN_HI,REGB1
        movff   RED_FIN_LO,REGB0

        call    subtract

        movff   REGA1,RED_DIFF_HI
        movff   REGA0,RED_DIFF_LO

        return
;*****************************************************
SHOW_DIFF
;SHOW IR AND RED DIFFERENCE VALUE
;IR  DIFFERENCE VALUE
        MOVFF   IR_DIFF_HI,BIN3
        MOVFF   IR_DIFF_LO,BIN4

        CALL    BIN2DEC
```


spo2_new12a - MPLAB IDE v8.40 - [C:\PIC\spo2_new12a\spo2_new12.asm*]
File Edit View Project Debugger Programmer Tools Configure Window Help
Debug
Checksum: 0xe0f3
MOVF RED2,W
CALL LCDOUT
CALL delay_150US
MOVF RED3,W
CALL LCDOUT
CALL delay_150US
MOVF RED4,W
CALL LCDOUT
CALL delay_150US
;WAIT AND SHOW FOR 3 SECONDS
CALL delay_1sec
CALL delay_1sec
CALL delay_1sec
RETURN
;***
;(S=a-bR)
;Finding R value
;R=Difference in Red LED reading (without-with finger)/Difference in IR LED reading (without-with finger)
Find_R
call CLR_MATHS ;clear ram first
; RED DIFFERENCE IS MULITIPLIED WITH 100 TO ELIMINATE DECIMAL 2 Places
;RED DIFF X 100
MOVFF RED_DIFF_HI,REGA1
MOVFF RED_DIFF_LO,REGA0
MOVLW .100
MOVWF REGB0
MPLAB SIM
PIC18F452
pc:0
W:0
n ov z dc c
16 MHz
bank 0
Ln 286, Col 1
OVR
WR
start
spo2_new12a - MPL...

```
	movff	INDEX_b,REGB0

	call	multiply

;bR answer got

	movff	REGA1,Temp_Ans_Hi
	movff	REGA0,Temp_Ans_Lo

	return

;*************************************************************
Find_a_bR
;Substract from 100 (INDEX_a)value
	call	CLR_MATHS	;clear ram first

	movff	INDEX_a,REGA0	;  eg.100

	movlw	.100	;to get 2 decimal places
	movwf	REGB0

	call	multiply

;the answer is now in REGA1 and REGA0



;reload answer
	movff	Temp_Ans_Hi,REGB1
	movff	Temp_Ans_Lo,REGB0

	call	subtract

	movff	REGA1,Temp_Ans_Hi
	movff	REGA0,Temp_Ans_Lo

;CONVERSION HERE

	MOVFF	Temp_Ans_Hi,BIN3
```


MPLAB IDE v8.40 - [C:\PIC\spo2_new12a\spo2_new12.asm]
File Edit View Project Debugger Programmer Tools Configure Window
movwf TXREG
CALL delay_20ms ; tx delay
movff SPO1,TXREG ; transmitt
CALL delay_20ms ; tx delay
movff SPO2,TXREG ; transmitt
CALL delay_20ms ; tx delay
movlw '.'
movwf TXREG
CALL delay_20ms ; tx delay
movff SPO3,TXREG ; transmitt
CALL delay_20ms ; tx delay
movff SPO4,TXREG ; transmitt
CALL delay_20ms ; tx delay
movlw ',' ; comma seperater
movwf TXREG
CALL delay_20ms ; tx delay
movlw 'P' ; Leading Character for Pulse
movwf TXREG
CALL delay_20ms ; tx delay
; movlw '8' ; dummy data
; movwf TXREG
; CALL delay_20ms ; tx delay
; movlw '2' ; dummy data
; movwf TXREG
; CALL delay_20ms ; tx delay
movff BPM2,TXREG ; transmitt
CALL delay_20ms ; tx delay
movff BPM3,TXREG ; transmitt
PIC18F452
W:0
start
My Pictures

MPLAB IDE v7.40 - [C:\spo2_final_r5\spo2_final_r5.asm]

```
;*** 32 BIT SIGNED SUTRACT ***
;REGA - REGB -> REGA
;Return carry set if overflow

subtract
    CALL    negateb     ;Negate REGB

    btfsc   STATUS,C
    RETURN          ;Overflow

;*** 32 BIT SIGNED ADD ***
;REGA + REGB -> REGA
;Return carry set if overflow

add MOVF    REGA3,w     ;Compare signs
    XORWF   REGB3,w
    MOVWF   MTEMP

    CALL    addba       ;Add REGB to REGA

    BCF STATUS,C
    MOVF    REGB3,w     ;If signs are same
    XORWF   REGA3,w     ;so must result sign
    BTFSS   MTEMP,7     ;else overflow
    addlw   0x80
    RETURN
;****************************************************
;Add REGB to REGA (Unsigned)
;Used by add, multiply,

addba   MOVF    REGB0,w     ;Add lo byte
    addwf   REGA0,f

    MOVF    REGB1,w     ;Add mid-lo byte
    btfsc   STATUS,C
    INCFsz  REGB1,w     ;Add carry_in to REGB
    addwf   REGA1,f     ;Add and propagate carry_out

    MOVF    REGB2,w     ;Add mid-hi byte
        btfsc   STATUS,C
    INCFsz  REGB2,w
    addwf   REGA2,f
```

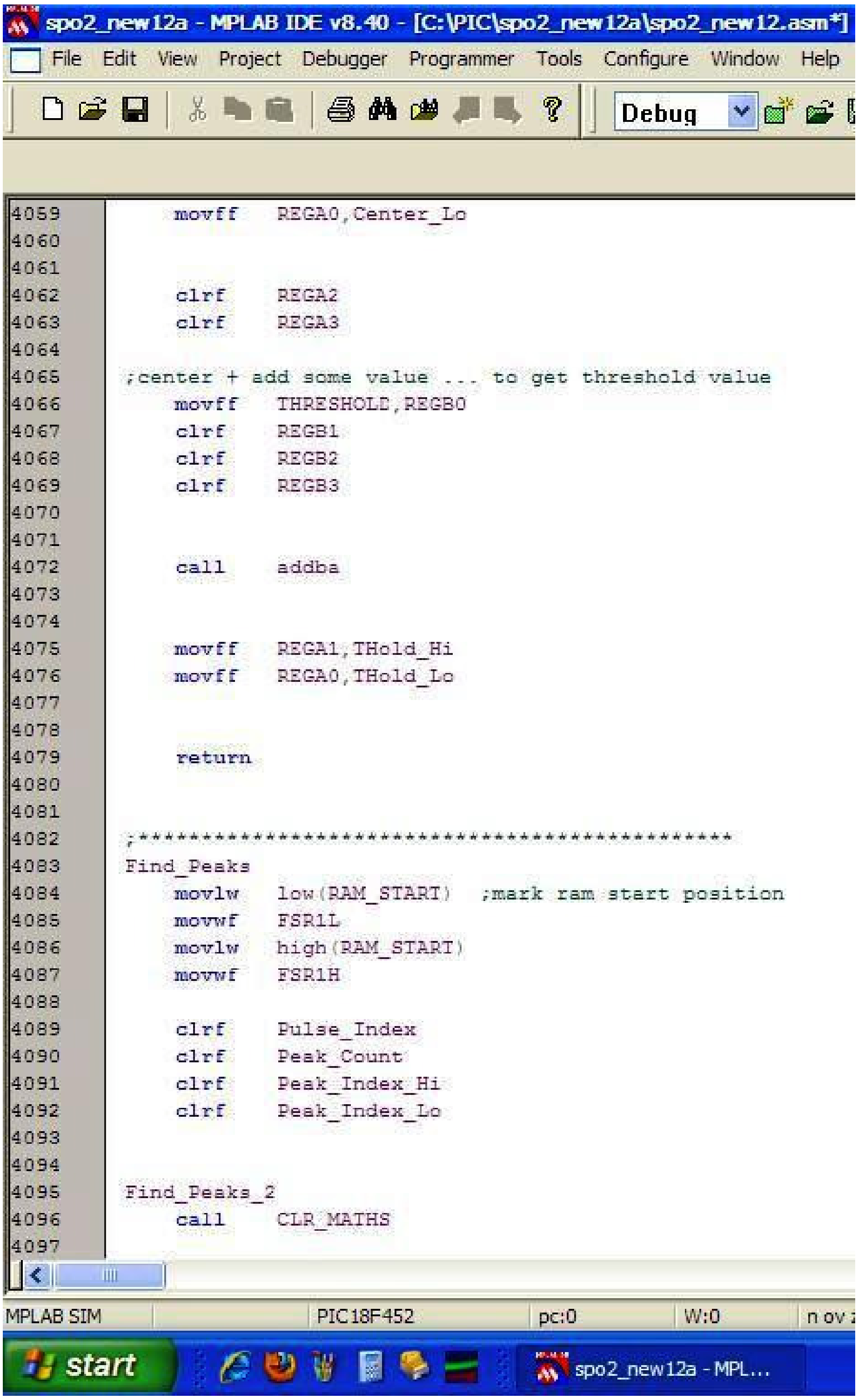
PIC18F452 W:0

MPLAB IDE v7.40 - [C:\spo2_final_r5\spo2_final_r5.asm]

File Edit View Project Debugger Programmer Tools Configure Window Help

```
;DISPLAY PROCESS HERE
SHOW_PULSE
        CALL    Cursor_Home     ;RETURN home, cursor & ram to zero
        CALL    delay_150US

        CALL    LCD21
        CALL    delay_150US

;SHOWbpm
        MOVLW   'P'
        CALL    LCDOUT
        CALL    delay_150US

        MOVLW   'U'
        CALL    LCDOUT
        CALL    delay_150US

        MOVLW   'L'
        CALL    LCDOUT
        CALL    delay_150US

        MOVLW   'S'
        CALL    LCDOUT
        CALL    delay_150US

        MOVLW   'E'
        CALL    LCDOUT
        CALL    delay_150US

        MOVLW   '-'
        CALL    LCDOUT
        CALL    delay_150US

        MOVF    BPM1,W
        CALL    LCDOUT
        CALL    delay_150US

        MOVF    BPM2,W
        CALL    LCDOUT
        CALL    delay_150US

        MOVF    BPM3,W
```

PIC18F452 W:0 n ov z dc c

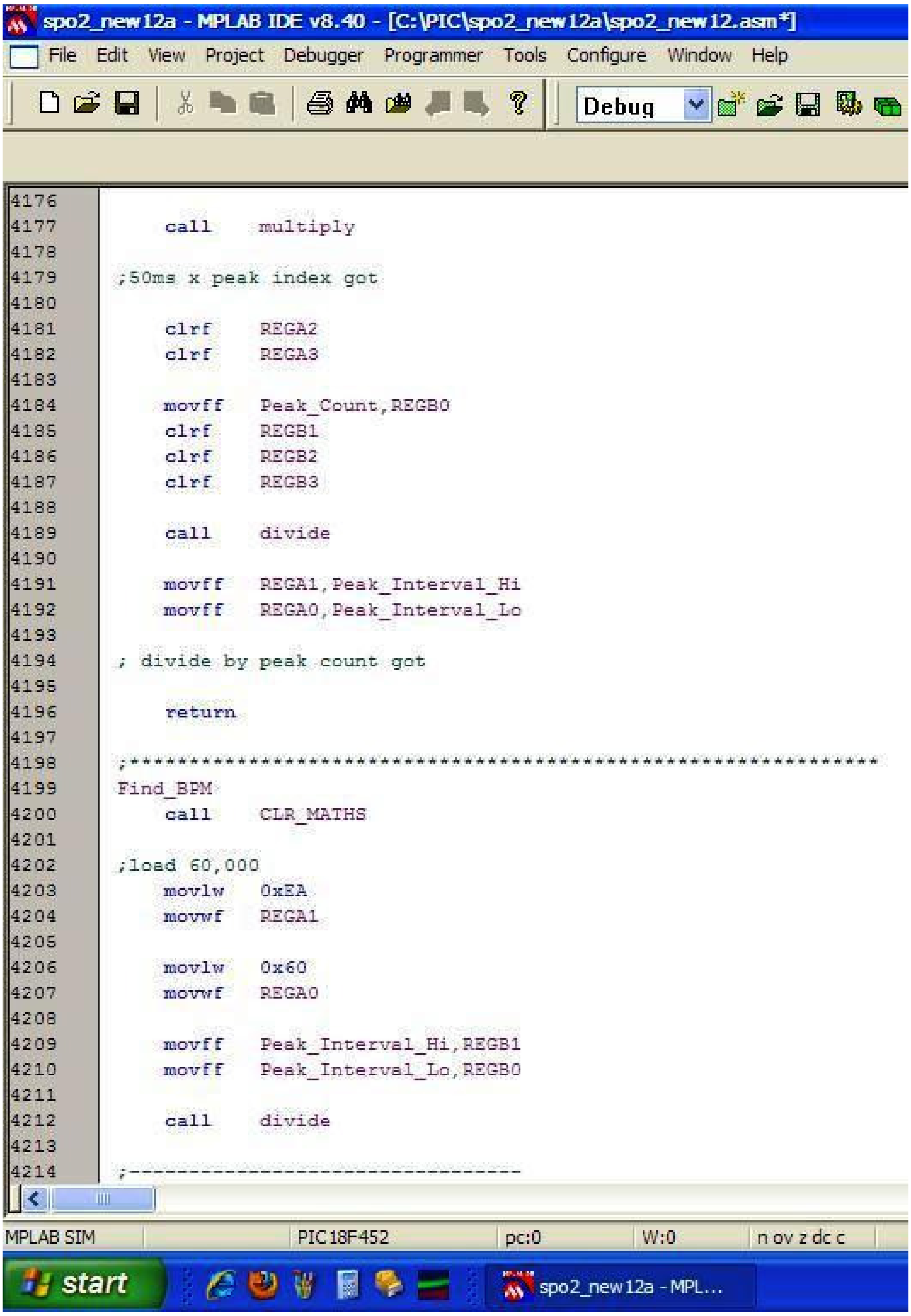



```
    movff   REGA0,Center_Lo


    clrf    REGA2
    clrf    REGA3

;center + add some value ... to get threshold value
    movff   THRESHOLD,REGB0
    clrf    REGB1
    clrf    REGB2
    clrf    REGB3


    call    addba


    movff   REGA1,THold_Hi
    movff   REGA0,THold_Lo


    return


;*************************************************
Find_Peaks
    movlw   low(RAM_START)   ;mark ram start position
    movwf   FSR1L
    movlw   high(RAM_START)
    movwf   FSR1H

    clrf    Pulse_Index
    clrf    Peak_Count
    clrf    Peak_Index_Hi
    clrf    Peak_Index_Lo


Find_Peaks_2
    call    CLR_MATHS

```

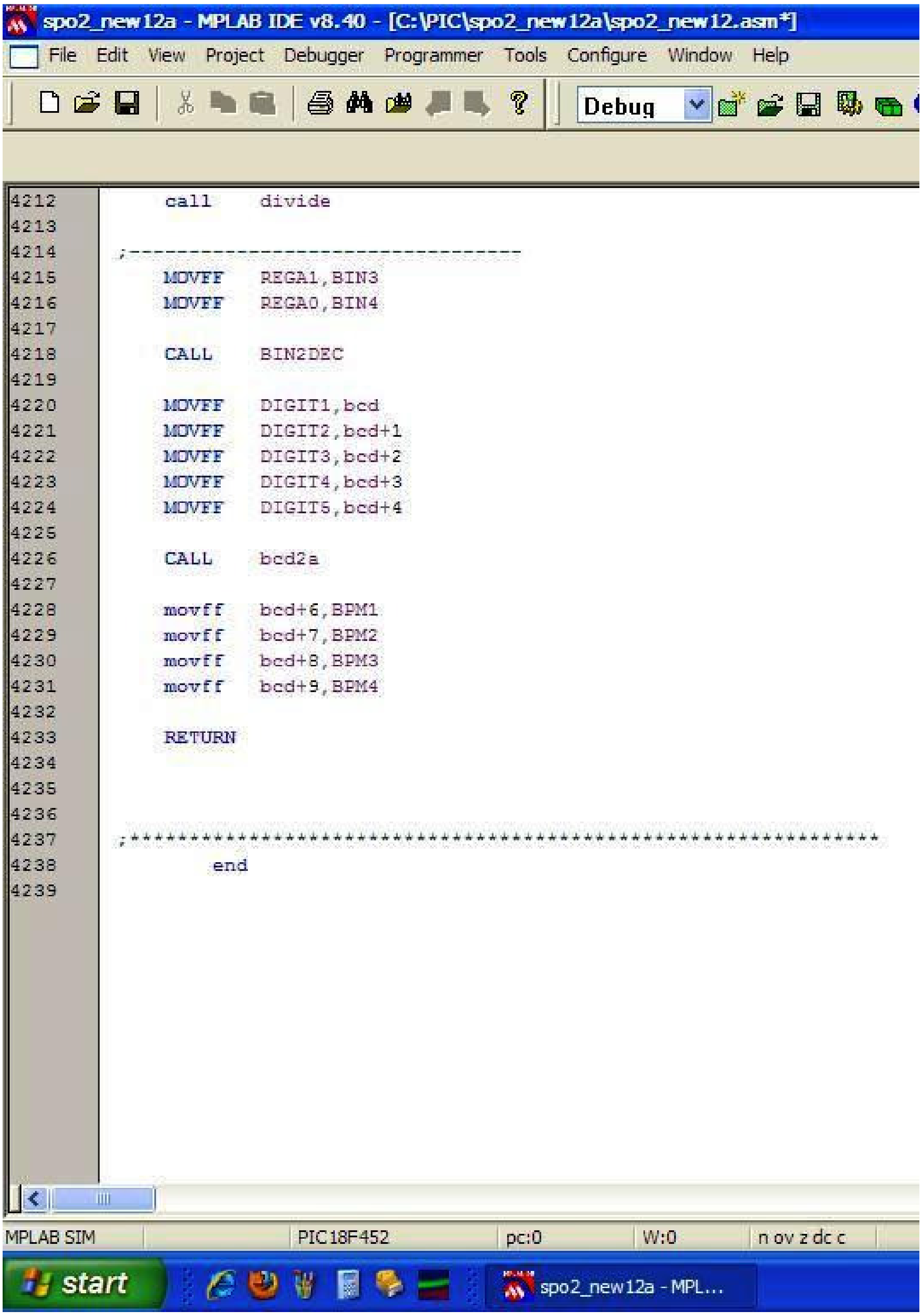
MPLAB IDE v8.40 - [C:\PIC\spo2_new12a\spo2_new12.as

File Edit View Project Debugger Programmer Tools Confi

```
        return
;*******************************************
Find_Peak_Interval
        call    CLR_MATHS

        movff   Peak_Index_Hi,REGA1
        movff   Peak_Index_Lo,REGA0

        movlw   .50
        movwf   REGB0

        call    multiply

;50ms x peak index got

        clrf    REGA2
        clrf    REGA3

        movff   Peak_Count,REGB0
        clrf    REGB1
        clrf    REGB2
        clrf    REGB3

        call    divide

        movff   REGA1,Peak_Interval_Hi
        movff   REGA0,Peak_Interval_Lo

; divide by peak count got

        return

;*******************************************
Find_BPM
        call    CLR_MATHS

;load 60,000
        movlw   0xEA
        movwf   REGA1

        movlw   0x60
```




```
    call    multiply

;50ms x peak index got

    clrf    REGA2
    clrf    REGA3

    movff   Peak_Count,REGB0
    clrf    REGB1
    clrf    REGB2
    clrf    REGB3

    call    divide

    movff   REGA1,Peak_Interval_Hi
    movff   REGA0,Peak_Interval_Lo

; divide by peak count got

    return

;*****************************************************************
Find_BPM
    call    CLR_MATHS

;load 60,000
    movlw   0xEA
    movwf   REGA1

    movlw   0x60
    movwf   REGA0

    movff   Peak_Interval_Hi,REGB1
    movff   Peak_Interval_Lo,REGB0

    call    divide

;---------------------------------
```


spo2_new12a - MPLAB IDE v8.40 - [C:\PIC\spo2_new12a\spo2_new12.asm*]
File Edit View Project Debugger Programmer Tools Configure Window Help
Debug
	call	divide

;----------------------------------
	MOVFF	REGA1,BIN3
	MOVFF	REGA0,BIN4

	CALL	BIN2DEC

	MOVFF	DIGIT1,bcd
	MOVFF	DIGIT2,bcd+1
	MOVFF	DIGIT3,bcd+2
	MOVFF	DIGIT4,bcd+3
	MOVFF	DIGIT5,bcd+4

	CALL	bcd2a

	movff	bcd+6,BPM1
	movff	bcd+7,BPM2
	movff	bcd+8,BPM3
	movff	bcd+9,BPM4

	RETURN

;**
		end
MPLAB SIM
PIC18F452
pc:0
W:0
n ov z dc c
start
spo2_new12a - MPL...

Appendix B. VB6 (Visual Basic 6) program to view the readings on computer

The source code of Visual Basic 6 to display pulse oximeter measurements on the personal computer is as follows:

```
Option Explicit
Dim inputStr As String
Private Sub cmdclose_Click()
On Error Resume Next
MSComm1.PortOpen = False
 Frame2.Caption = Combo1.Text & “Close!"
 End Sub
Private Sub cmdexit_Click()
Unload Me
End Sub
Private Sub cmdopen_Click()
On Error Resume Next
If Combo1.Text = "Com1" Then
MSComm1.CommPort = 1
End If
If Combo1.Text = "Com2" Then
MSComm1.CommPort = 2
End If
MSComm1.Settings = "9600, N, 8, 1"
MSComm1.InputMode = comInputModeText
MSComm1.PortOpen = True
Frame2.Caption = Combo1.Text & “Open!"
End Sub
Private Sub MSComm1_OnComm ()
```

```
If MSComm1.CommEvent Then
MSComm1.InputMode = comInputModeText
inputStr = MSComm1.Input
txtinput = txtinput & inputStr
Timer1.Enabled = True
End If
End Sub
Private Sub Timer1_Timer ()
txtinput = ""
End Sub
Private Sub txtinput_Change()
On Error Resume Next
If Len(txtinput) > 1 Then
txtspo2 = Mid$(txtinput, 2, 5)
txtpulse = Mid$(txtinput, 9, 3)
End If
End Sub
Private Sub txtpulse_Change()
Beep
End Sub
```

Appendix C

This appendix contains data sheets for the system components of designed pulse oximeter under study.

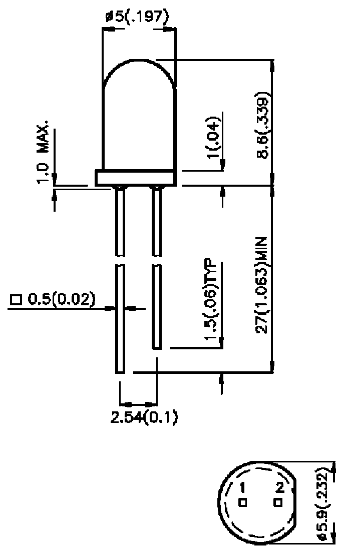
C.1 Red LED from Kingbright Inc.

The following pages display the data sheet for the Red LED of 660 nm and 940nm from Kingbright Inc.,

Features

- Ultra brightness
- Both diffused and water clear lens are available
- Outstanding material efficiency
- Reliable and rugged
- IC compatible/ low current capability

Package Dimension



1 Anode , 2 Cathodes

Note: All dimensions are in millimeters (inches)

Tolerance is ±0.25 (0.01″) unless otherwise noted.

Lead spacing is measured where the lead emerge package

Specifications are subjected to change without notice.

Electrical / Optical Characteristics at T_A=25°C

Symbol	Parameter	Device	Typ.	Max.	Units	Test Conditions
λ peak	Peak Wavelength	Super Bright Red	660		nm	IF=20mA
Δλ½	Spectical line Halfwidth	Super Bright Red	20		nm	IF=20mA
C	Capacitance	Super Bright Red	95		pF	VF= 0V; f=1MHz
V_F	Forward Voltage	Super Bright Red	1.85	2.5	V	IF=20mA
I_R	Reverse Current	All	10		µA	VR=5V

Absolute Maximum Ratings at T_A= 25° C

Parameter	Super Bright Red	Units
Power Dissipation	100	mW
DC Forward Current	30	mA
Peak Forward Current[1]	150	mA
Reverse Voltage	5	V

C.2 IR LED from Vishay Inc.

The following pages display the data sheet for the Infra red LED from Vishay Semiconductors.

Description

TSAL4400 is a high efficiency infrared emitting diode in GaAlAs on GaAs technology Molded in clear, blue - grey tinted plastic packages.
In comparison with the standard GaAs on GaAs technology these emitters achieve about 100% radiant power improvement at a similar wavelength.

The forward voltages at low current and at high pulse current roughly correspond to the low values of the standard technology. Therefore these emitters are ideally suitable as high replacements of standard emitters.

Features

- Extra high radiant power
- Low forward voltage
- Suitable for high pulse current operation
- Standard T-1 (Ø 3mm) package
- Angle of half intensity $\varphi=\pm25^{\circ}$
- Peak wavelength λ_p = 940 nm
- High reliability
- Good spectral matching to Si photodetectors

Absolute Maximum Ratings

Parameter	Test Condition	Symbol	Value	Unit
Reverse voltage		V_R	5	V
Forward Current		I_F	100	mA
Peak Forward Current	$t_p/T = 0.5$, $t_p = 100\ \mu s$	I_{FM}	200	mA
Surge Forward Current	tp= 100 µs	I_{FSM}	1.5	A
Power Dissipation		P_V	210	mW
Junction Temperature		T_J	100	°C
Operating Temperature Range		T_{amb}	−55 to + 100	°C
Storage Temperature Range		T_{stg}	−55 to + 100	°C
Soldering Temperature	t≤ 5 sec, 2mm from case	T_{sd}	260	°C
Thermal Resistance Junction/ Ambient		R_{thJA}	350	K/W

Basic Characteristics

T_{amb} =25˚C, unless otherwise specified

Parameter	Test Condition	Symbol	Min.	Typ.	Max.	Unit
Forward Voltage	I_F=100 mA, t_p =20 ms	V_F		1.4	1.6	V
	I_F=1 A, t_p = 100 µs	V_F		2.6	3	V
Temp. Coefficient of V_F	I_F=100 mA	TK_{VF}		−1.3		mV/K
Reverse Current	$V_{R\,=\,5V}$	I_R			10	µA
Junction Capacitance	V_R = 0V, f=1 MHz, E=0					
Radiant Intensity	I_F=100 mA, t_p =20 ms	I_e	16	30		mW/sr
	I_F=1 A, t_p = 100 µs	I_e	135	240		mW/sr
Radiant Power	I_F=100 mA, t_p =20 ms	φ_e		35		mW/sr
Temp. Coefficient of ϕ_e	I_F= 20mA	TKφe		−0.6		%/K
Angle of Half Intensity		φ		±25		Deg
Peak Wavelenght	I_F= 100 mA	λ_p		940		Nm
Spectral Bandwidth	I_F= 100 mA	$\Delta\lambda$				Nm
Temp. Coefficient of λ_p	I_F= 100 mA	$TK_{\lambda p}$		0.2		nm/K
Rise Time	I_F= 100 mA	t_r		800		Ns
Fall Time	I_F= 100 mA	t_f		800		Ns

C.3 Photodiode S1133 - 14 from Hammahstu

The data sheet for the photodiode S1133- 14 from Hamamatsu under the study is displayed as follows:

Features

S1133 14 : For visible near IR range

General Ratings/ Absolute Maximun Ratings

Type No.	Dimensional Outline/ Window material*	Active area size (mm)	Effective area size (mm^2)	Absolute maximum ratings		
				Reverse Voltage VR(max) (V)	Operating temperature T_{opr} (˚C)	Storage temperature T_{stg} (˚C)
S1133 14	4/R	2.4×2.8	6.6	10	−10 to +60	−20 to +70

Electrical and optical characteristics (Typ. T_A= 25˚C , unless otherwise noted.)

Spectral response range λ (nm)	Peak sensitivity wavelength λ_p (nm)	Photosensitivity S A/W		Short circuit current Isc 100 lx (µA)	Dark current ID V_R= 1V Max. (pA)	Rise time tr V_R= 0V R_L= 1kΩ (µs)	Terminal capacitance Ct V_R= 0V f=10kHz (pF)	Shunt Resistance R_{sh} V=10mV	
		λ_p	GaP LED 560 nm					Min (GΩ)	Typ. (GΩ)
320 to 1000	720	0.4	0.33	3.4	20	0.5	200	10	50

C.4 LM358 Dual Differential Input Operational Amplifier

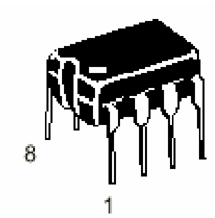
The following pages display the data sheet for LM358 dual differential operational amplifier.

This amplifier has several distinct advantages over standard operational amplifier types in single supply applications. It can operates at supply voltages as low as 3.0 Volts or as high as 32 Volts with low quiescent currents. The common mode input range includes the negative supply, thereby eliminating the necessity for external biasing components in many applications. The output voltage range also includes the negative power supply voltage.

Features

1. Short circuit protected outputs
2. True differential input stage
3. Single supply operation:3.0 V to 32 Volts
4. Low input bias currents
5. Internally compensated
6. Common mode range extends to negative supply
7. Single and split supply operation
8. ESD Clamps on the Inputs Increase Ruggedness of the Device without Affecting Operation

Pin Arrangement



DIP- 8

Odering Information

Device	Temperature Range	Package
LM358	0˚C to +70˚C	DIP-8

Absolute Maximum Ratings (TA= +25˚C, unless otherwise)

Rating	Symbol	LM358	Unit
Power Supply Voltage Single Supply Split Supplies	V_{CC} V_{CC}, V_{EE}	32 ±16	Vdc
Input Differential Voltage Range (1)	V_{IDR}	±32	Vdc
Input Common Mode Voltage Range (2)	V_{ICR}	0 to 32	Vdc
Input Forward Current (3) (VI ≤0.3 V)	I_{IF}	50	mA

Note: 1. Split power supplies

2. For supply voltage less than 32 V for LM358 the absolute maximum input voltage is equal to the supply voltage.

3. This input current will only exist when the voltage is negative at any of the input leads. Normal output states will re- establish when the input voltage returns to a voltage greater than −0.3 V.

Electrical characteristics (T_A=+25°C, VCC= 5V unless otherwise noted)

Characteristics	Symbol	LM358			Unit
		Min	Typ	Max	
Input Offset Voltage T_A=25°C A V_{CC}=5~30V,V_{IC}=V_{ICR}(min),V_O=1.4V B T_A=0°C~70°C	V_{IO}	- - -	1 4	3 7 9	mV
Average Temperature Coefficient of Input Offset Voltage T_A=0°C~70°C	ΔV_{IO} /ΔT	-	7	-	μV/°C
Input Bias Current V_O=1.4V T_A=25°C T_A=0°C~70°C	I_{IB}	- -	-20 -	-150 -500	nA
Input Common-Mode Voltage Range V_{CC}=5~30V T_A=25°C V_{CC}=5~30V T_A=0°C~70°C	V_{ICR}	0~Vcc-1.5 0~Vcc-2	- -	- -	V
Large Signal Differential Voltage Amplification T_A=25°C R_L ≧2KΩ,V_{CC}=15V, V_O=1~11V T_A=0°C~70°C	A_{VD}	25 15	100 -	- -	V/mV
Power Supply Rejection Ratio V_{CC}=5~30V T_A=25°C	PSRR	65	100	-	dB
Output Voltage- High Limit R_L≧2kΩ T_A=25°C V_{CC}=30V, R_L=2kΩ T_A=0°C~ 70°C V_{CC}=30V,R_L≧10kΩ T_A =0°C~ 70°C	V_{OH}	V_{CC}-1.5 26 27	 - 28	 - -	V
Output Source Current V_{ID}=1V,V_{CC}=15V,V_O=0 T_A=25°C T_A=0°C~70°C	I_O	-20 -10	-30 -	- -	mA
V_{ID}=-1.0V,V_{CC}=15V,V_O=0 T_A=25°C T_A=0°C~70°C		10 5	20 -	- -	
V_{ID}=-1.0V,V_O=200mV T_A=25°C		12	30	-	μA
Short Circuit output current V_{CC} at 5V,GND at –5V, V_O=0	I_{OS}	-	±40	±60	mA

C.5 PIC18F452 Microcontroller

The following pages display the data sheet for PIC18F452 Microcontroller from Microchip Technology Inc.

High Performance RISC CPU:

- C compiler optimized architecture/instruction set
  - Source code compatible with the PIC16 and PIC17 instruction sets
- Linear program memory addressing to 32 Kbytes
- Linear data memory addressing to 1.5 Kbytes

Device	On-Chip Program Memory		On-Chip RAM (bytes)	Data EEPROM (bytes)
	FLASH (bytes)	# Single Word Instructions		
PIC18F242	16K	8192	768	256
PIC18F252	32K	16384	1536	256
PIC18F442	16K	8192	768	256
PIC18F452	32K	16384	1536	256

- Up to 10 MIPs operation:
  - DC - 40 MHz osc./clock input
  - 4 MHz - 10 MHz osc./clock input with PLL active
- 16-bit wide instructions, 8-bit wide data path
- Priority levels for interrupts
- 8 x 8 Single Cycle Hardware Multiplier

Peripheral Features:

- High current sink/source 25 mA/25 mA
- Three external interrupt pins
- Timer0 module: 8-bit/16-bit timer/counter with

8-bit programmable prescaler

- Timer1 module: 16-bit timer/counter
- Timer2 module: 8-bit timer/counter with 8-bit period register (time-base for PWM)
- Timer3 module: 16-bit timer/counter
- Secondary oscillator clock option - Timer1/Timer3
- Two Capture/Compare/PWM (CCP) modules. CCP pins that can be configured as:
  - Capture input: capture is 16-bit, max. Resolution 6.25 ns (TCY/16)
  - Compare is 16-bit, max. resolution 100 ns (TCY)
  - PWM output: PWM resolution is 1- to 10-bit, max. PWM freq. @: 8-bit resolution = 156 kHz (10-bit resolution = 39 kHz)
- Master Synchronous Serial Port (MSSP) module, Two modes of operation:
  - 3-wire SPI™ (supports all 4 SPI modes)
  - I^2C™ Master and Slave mode

- Addressable USART module:
  - Supports RS-485 and RS-232
- Parallel Slave Port (PSP) module

Analog Features:

- Compatible 10-bit Analog-to-Digital Converter module (A/D) with:
  - Fast sampling rate
  - Conversion available during SLEEP
  - Linearity ≤ 1 LSb
- Programmable Low Voltage Detection (PLVD)
  - Supports interrupt on-Low Voltage Detection
- Programmable Brown-out Reset (BOR)

Special Microcontroller Features:

- 100,000 erase/write cycle Enhanced FLASH program memory typical
- 1,000,000 erase/write cycle Data EEPROM memory

• FLASH/Data EEPROM Retention: > 40 years

• Self-reprogrammable under software control

• Power-on Reset (POR), Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)

• Watchdog Timer (WDT) with its own On-Chip RC Oscillator for reliable operation

• Programmable code protection

• Power saving SLEEP mode

• Selectable oscillator options including:

- 4X Phase Lock Loop (of primary oscillator)
- Secondary Oscillator (32 kHz) clock input

• Single supply 5V In-Circuit Serial Programming™ (ICSP™) via two pins

• In-Circuit Debug (ICD) via two pins

CMOS Technology:

• Low power, high speed FLASH/EEPROM technology

• Fully static design

• Wide operating voltage range (2.0V to 5.5V)

• Industrial and Extended temperature ranges

• Low power consumption:

- < 1.6 mA typical @ 5V, 4 MHz
- 25 µA typical @ 3V, 32 kHz
- < 0.2 µA typical standby current

C.6 HD 44780U (LCD- II) from Hitachi

The following pages display the data sheet for HD 44780U (LCD- II) from Hitachi.

Description

The HD44780U dot-matrix liquid crystal display controller and driver LSI displays alphanumerics, Japanese kana characters, and symbols. It can be configured to drive a dot-matrix liquid crystal display under the control of a 4- or 8-bit microprocessor. Since all the functions such as display RAM, character generator, and liquid crystal driver, required for driving a dot-matrix liquid crystal display are internally provided on one chip, a minimal system can be interfaced with this controller/driver.

A single HD44780U can display up to one 8-character line or two 8-character lines.

The HD44780U has pin function compatibility with the HD44780S which allows the user to easily replace an LCD-II with an HD44780U. The HD44780U character generator ROM is extended to generate 208 5 × 8 dot character fonts and 32 5 ×10 dot character fonts for a total of 240 different character fonts.

The low power supply (2.7V to 5.5V) of the HD44780U is suitable for any portable battery-driven product requiring low power dissipation.

Features

- 5 × 8 and 5 ×10 dot matrix possible
- Low power operation support:
  - 2.7 to 5.5V
- Wide range of liquid crystal display driver power
  - 3.0 to 11V
- Liquid crystal drive waveform
  - A (One line frequency AC waveform)

- Correspond to high speed MPU bus interface
  - MHz (when $V_{CC} = 5V$)
- 4-bit or 8-bit MPU interface enabled
- 80 × 8-bit display RAM (80 characters max.)
- 9,920-bit character generator ROM for a total of 240 character fonts
  - 208 character fonts (5 ×8 dot)
  - 32 character fonts (5 × 10 dot)
- 64 ×8-bit character generator RAM
  - 8 character fonts (5 × 8 dot)
  - 4 character fonts (5 × 10 dot)
- 16-common × 40-segment liquid crystal display driver
- Programmable duty cycles
  - 1/8 for one line of 5 × 8 dots with cursor
  - 1/11 for one line of 5 × 10 dots with cursor
  - 1/16 for two lines of 5 × 8 dots with cursor
- Wide range of instruction functions:
  - Display clear, cursor home, display on/off, cursor on/off, display character blink, cursor shift, display shift
- Pin function compatibility with HD44780S
- Automatic reset circuit that initializes the controller/driver after power on
- Internal oscillator with external resistors
- Low power consumption

C.7 LP2950/2951 Voltage Regulator from Micrel

The following pages display the data sheet for LP2950/2951 Voltage Regulator from Micrel.

General Descriptions

The LP2950 and LP2951 are micropower voltage regulators with very low dropout voltage (typically 40mV at light loads and 380mV at 100mA), and very low quiescent current (75□A typical). The quiescent current of the LP2950/LP2951 increases only slightly in dropout, thus prolonging battery life. This feature, among others, makes the LP2950 and LP2951 ideally suited for use in battery-powered systems.

Available in a 3-Pin TO-92 package, the LP2950 is pin- compatible with the older 5V regulators. Additional system functions, such as programmable output voltage and logic- controlled shutdown, are available in the 8-pin DIP and 8-pin SOIC versions of the LP2951.

Features

- High accuracy 5V, guaranteed 100 mA output
- Extremely low quiescent current
- Low-dropout voltage
- Extremely tight load and line regulation
- Very low temperature coefficient
- Use as regulator or reference
- Needs only 1µF stability
- Current and thermal limiting

LP2951 version only

- Error flag warns of output dropout
- Logic -control electronic shutdown
- Output programmable from 1.24 to 29 V

Absolute Maximum Ratings

Power dissipation	Internally Limited
Lead Temperature (Soldering, 5 seconds)	260˚C
Storage Temperature Range	–65˚C to +150˚C
Operating Junction Temperature Range (Note 8)	
LP2950, LP2951	–40˚C to +125˚C
Input Supply Voltage	–0.3V to +30V
Feedback Input Voltage (Notes 9 and 10)	–1.5V to +30V
Shutdown Input Voltage (Note 9)	–0.3V to +30V
Error Comparator Output Voltage (Note 9)	–0.3V to +30V

ESD Rating is to be determined.

C.8 The recommendation letter of Health Officer

28th October, 2010.

TO WHOM IT MAY CONCERN

Re: Callibration of Oxymetre – Masters research project

This is to confirm that I have viewed the oxymetre device that measures oxygen concentration of the blood and also gives a pulse reading, constructed by Cho Zin Myint Master of Electrical Engineering student at Curtin University of Technology, Sarawak.

It appears to be calibrated correctly and also responds well for the pulse reading. Dr RD Mattu and Dr Lim HJ, Consultants at Columbia Asia Hospital Miri also viewed the monitor and were impressed with its functions. If Cho intends to do field trials then the finger clip should be improved before non-invasive human ethics approval is applied for.

I wish Cho all the very best in her future endeavours.

Yours sincerely,

Sheryl Joy Mattu

Sheryl Joy Mattu MIH
Health Officer |

Health Services & First Aid Centre |

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